National Aeronautics and Space Administration

FY 2024

Budget Estimates

www.nasa.gov

FY 2024 PRESIDENT'S BUDGET REQUEST SUMMARY

Budget Authority ($ in millions)	Op Plan 2022	Enacted 2023	Request 2024	Fiscal Year 2025	2026	2027	2028
NASA Total	**24,041.3**	**25,383.7**	**27,185.0**	**27,728.7**	**28,283.2**	**28,848.9**	**29,425.8**
Deep Space Exploration Systems	6,855.1	7,468.9	7,971.1	8,130.5	8,293.1	8,459.0	8,628.2
Common Exploration Systems Development	4,590.7	4,737.9	4,525.4	4,241.7	4,009.3	3,557.3	3,529.7
Artemis Campaign Development	2,007.6	2,600.3	3,234.8	3,674.4	4,068.9	4,686.2	4,879.6
Human Exp Requirements & Architecture	--	--	49.1	50.0	50.5	51.0	51.1
Mars Campaign Development	187.4	--	161.8	164.4	164.4	164.5	167.8
Exploration Research & Development	69.4	--	--	--	--	--	--
Space Operations	3,974.9	4,250.0	4,534.6	4,625.3	4,717.8	4,812.2	4,908.4
International Space Station	1,261.8	--	1,302.6	1,302.1	1,302.5	1,302.9	1,321.7
Space Transportation	1,716.9	--	1,956.7	1,990.6	2,036.2	2,068.7	2,153.4
Space and Flight Support (SFS)	889.1	--	1,047.0	1,103.0	1,076.8	1,005.4	995.4
Commercial LEO Development	102.1	--	228.4	229.6	302.3	435.2	437.8
Exploration Operations	5.0	--	--	--	--	--	--
Space Technology	1,100.0	1,200.0	1,391.6	1,419.4	1,447.8	1,476.8	1,506.3
Science	7,610.9	7,795.0	8,260.8	8,426.0	8,594.5	8,766.4	8,941.7
Earth Science	2,061.2	2,195.0	2,472.8	2,597.5	2,730.0	2,791.2	2,849.0
Planetary Science	3,120.4	3,200.0	3,383.2	3,265.8	3,246.1	3,350.8	3,389.7
Astrophysics	1,568.9	1,510.0	1,557.4	1,622.1	1,665.9	1,689.6	1,749.4
Heliophysics	777.9	805.0	750.9	837.4	847.3	827.4	844.0
Biological and Physical Sciences	82.5	85.0	96.5	103.2	105.3	107.4	109.6
Aeronautics	880.7	935.0	995.8	1,015.7	1,036.0	1,056.7	1,077.8
STEM Engagement	137.0	143.5	157.8	161.0	164.2	167.5	170.9
Safety, Security, and Mission Services	3,020.6	3,129.5	3,369.4	3,436.8	3,505.5	3,575.6	3,647.1
Mission Services & Capabilities	1,987.2	--	2,259.3	2,304.1	2,350.0	2,397.1	2,445.0
Engineering, Safety, & Operations	1,033.4	--	1,110.1	1,132.7	1,155.5	1,178.5	1,202.1
Construction and Environmental Compliance and Restoration	416.8	414.3	453.7	462.8	472.1	481.5	491.1
Construction of Facilities	342.1	--	375.9	383.4	391.1	398.7	406.6
Environmental Compliance and Restoration	74.7	--	77.8	79.4	81.0	82.8	84.5
Inspector General	45.3	47.6	50.2	51.2	52.2	53.2	54.3
NASA Total	**24,041.3**	**25,383.7**	**27,185.0**	**27,728.7**	**28,283.2**	**28,848.9**	**29,425.8**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2024 PRESIDENT'S BUDGET REQUEST SUMMARY

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The NASA Administrator has determined that, in the interest of ensuring the safe and successful execution of the early Artemis flights, managing risk effectively, and maintaining resiliency and flexibility for future missions exploration requirements, NASA has made a decision to no longer transition programs that complete their research and development phase in the Exploration Systems Development Mission Directorate to the Space Operations Mission Directorate for their operational phase.

FY 2024 President's Budget Request Summary

Budget Authority ($ in millions)	Op Plan 2022	Enacted 2023	Request 2024	2025	2026	2027	2028
			Fiscal Year				
NASA Total	**24,041.3**	**25,383.7**	**27,185.0**	**27,728.7**	**28,283.2**	**28,848.9**	**29,425.8**
Deep Space Exploration Systems	**6,855.1**	**7,468.9**	**7,971.1**	**8,130.5**	**8,293.1**	**8,459.0**	**8,628.2**
Common Exploration Systems Development	**4,590.7**	**4,737.9**	**4,525.4**	**4,241.7**	**4,009.3**	**3,557.3**	**3,529.7**
Orion Program	**1,401.7**	**1,338.7**	**1,225.0**	**1,093.7**	**1,093.7**	**1,094.2**	**1,115.1**
Crew Vehicle Development	1,388.8	1,320.3	1,212.6	1,058.7	1,058.7	1,058.5	1,062.5
Orion Program Integration and Support	12.9	--	12.5	34.9	35.0	35.7	52.7
Space Launch System	**2,600.0**	**2,600.0**	**2,506.1**	**2,483.3**	**2,322.4**	**1,917.1**	**1,969.1**
Launch Vehicle Development	2,526.9	2,361.4	2,427.2	2,365.8	2,206.7	1,804.6	1,798.8
SLS Program Integration and Support	73.1	--	78.9	117.5	115.7	112.5	170.3
Exploration Ground Systems	**589.0**	**799.2**	**794.2**	**664.7**	**593.2**	**546.0**	**445.5**
Exploration Ground Systems Development	398.1	330.6	273.2	143.5	81.8	15.6	--
EGS Program Integration and Support	190.9	--	521.0	521.2	511.4	530.4	445.5
Artemis Campaign Development	**2,007.6**	**2,600.3**	**3,234.8**	**3,674.4**	**4,068.9**	**4,686.2**	**4,879.6**
Gateway	**742.5**	**--**	**914.2**	**853.0**	**744.2**	**768.8**	**777.3**
Adv Cislunar and Surface Capabilities	**70.1**	**--**	**60.3**	**102.0**	**433.0**	**563.8**	**969.9**
Human Landing System	**1,195.0**	**1,485.6**	**1,880.5**	**2,224.7**	**2,286.7**	**2,748.3**	**2,526.6**
xEVA and Human Surface Mobility Program	**--**	**275.9**	**379.9**	**494.8**	**605.0**	**605.3**	**605.7**
Human Exp Requirements & Architecture	**--**	**--**	**49.1**	**50.0**	**50.5**	**51.0**	**51.1**
Moon & Mars Architecture	**--**	**--**	**49.1**	**50.0**	**50.5**	**51.0**	**51.1**
Mars Campaign Development	**187.4**	**--**	**161.8**	**164.4**	**164.4**	**164.5**	**167.8**
Exploration Capabilities	**187.4**	**--**	**161.8**	**164.4**	**164.4**	**164.5**	**167.8**
Exploration Research & Development	**69.4**	**--**	**--**	**--**	**--**	**--**	**--**
Human Research Program	**69.4**	**--**	**--**	**--**	**--**	**--**	**--**
Space Operations	**3,974.9**	**4,250.0**	**4,534.6**	**4,625.3**	**4,717.8**	**4,812.2**	**4,908.4**
International Space Station	**1,261.8**	**--**	**1,302.6**	**1,302.1**	**1,302.5**	**1,302.9**	**1,321.7**
International Space Station Program	**1,261.8**	**--**	**1,302.6**	**1,302.1**	**1,302.5**	**1,302.9**	**1,321.7**
ISS Systems Operations and Maintenance	982.4	--	1,036.0	1,031.1	1,031.5	1,031.9	1,050.7
ISS Research	279.4	--	266.6	271.0	271.0	271.0	271.0
Space Transportation	**1,716.9**	**--**	**1,956.7**	**1,990.6**	**2,036.2**	**2,068.7**	**2,153.4**
Crew and Cargo Program	**1,569.7**	**--**	**1,856.1**	**1,890.0**	**1,935.6**	**1,968.1**	**2,051.8**
Commercial Crew Program	**147.2**	**--**	**100.6**	**100.6**	**100.7**	**100.7**	**101.6**

FY 2024 PRESIDENT'S BUDGET REQUEST SUMMARY

Budget Authority ($ in millions)	Op Plan 2022	Enacted 2023	Request 2024	2025	2026	2027	2028
Space and Flight Support (SFS)	**889.1**	**--**	**1,047.0**	**1,103.0**	**1,076.8**	**1,005.4**	**995.4**
Space Communications and Navigation	**520.6**	**--**	**579.7**	**625.7**	**612.4**	**540.6**	**528.6**
Space Communications Networks	403.1	--	493.9	534.6	520.2	443.8	429.5
Space Communications Support	117.5	--	85.8	91.1	92.2	96.8	99.2
Human Space Flight Operations	**100.8**	**--**	**102.0**	**106.9**	**105.8**	**105.8**	**105.9**
Human Research Program	**70.6**	**--**	**153.5**	**153.5**	**153.5**	**153.5**	**153.5**
Launch Services	**102.3**	**--**	**103.8**	**108.3**	**96.6**	**96.9**	**97.2**
Rocket Propulsion Test	**47.8**	**48.2**	**48.6**	**48.9**	**48.9**	**48.9**	**49.7**
Communications Services Program	**42.0**	**--**	**59.4**	**59.7**	**59.7**	**59.7**	**60.6**
21st Century Space Launch Complex	**5.0**	**--**	**--**	**--**	**--**	**--**	**--**
Commercial LEO Development	**102.1**	**--**	**228.4**	**229.6**	**302.3**	**435.2**	**437.8**
Exploration Operations	**5.0**	**--**	**--**	**--**	**--**	**--**	**--**
Space Technology	**1,100.0**	**1,200.0**	**1,391.6**	**1,419.4**	**1,447.8**	**1,476.8**	**1,506.3**
Early Stage Innovation and Partnerships	**126.3**	**--**	**138.1**	**140.9**	**143.7**	**146.6**	**149.5**
Agency Technology and Innovation	7.4	--	--	--	--	--	--
Early Stage Innovation	99.4	--	115.6	118.0	120.3	122.7	125.1
Technology Transfer	19.5	--	22.5	23.0	23.4	23.9	24.4
Technology Maturation	**257.7**	**--**	**402.3**	**410.3**	**418.5**	**426.9**	**435.4**
Technology Demonstration	**489.0**	**--**	**551.3**	**562.3**	**573.6**	**585.1**	**596.8**
Solar Electric Propulsion (SEP)	24.2	18.5	10.8	13.7	7.7	6.4	5.5
On-Orbit Servicing, Assembly, and Manufacturing Demonstration-1 (OSAM-1)	227.0	227.0	227.0	174.5	123.0	28.7	--
Small Spacecraft, Flight Opportunities & Other Tech Demo	237.8	--	313.5	374.1	443.0	550.0	591.3
SBIR and STTR	**227.0**	**--**	**299.9**	**305.9**	**312.0**	**318.2**	**324.6**
Science	**7,610.9**	**7,795.0**	**8,260.8**	**8,426.0**	**8,594.5**	**8,766.4**	**8,941.7**
Earth Science	**2,061.2**	**2,195.0**	**2,472.8**	**2,597.5**	**2,730.0**	**2,791.2**	**2,849.0**
Earth Science Research	**541.0**	**--**	**577.9**	**590.0**	**602.2**	**618.0**	**629.5**
Earth Science Research and Analysis	375.9	--	393.5	394.2	402.9	412.6	417.4
Computing and Management	165.1	--	184.5	195.8	199.3	205.4	212.1
Earth Systematic Missions	**706.4**	**--**	**1,027.1**	**1,073.6**	**1,162.7**	**1,130.3**	**1,091.0**
NASA-ISRO Synthetic Aperture Radar (NISAR)	70.0	58.6	96.4	29.3	21.1	26.8	17.1
Sentinel-6	22.8	40.3	63.9	55.2	25.6	8.7	5.7
Plankton, Aerosols, Clouds, ocean Ecosystem (PACE)	54.9	112.8	91.4	26.3	24.8	21.2	22.3
Other Missions and Data Analysis	558.7	--	775.5	962.8	1,091.2	1,073.6	1,045.9
Earth System Explorers	**2.0**	**--**	**27.8**	**20.7**	**43.1**	**109.0**	**166.4**

FY 2024 PRESIDENT'S BUDGET REQUEST SUMMARY

Budget Authority ($ in millions)	Op Plan 2022	Enacted 2023	Request 2024	2025	2026	2027	2028
Earth System Science Pathfinder	**312.7**	**--**	**235.6**	**298.6**	**290.5**	**282.5**	**290.3**
Venture Class Missions	218.1	--	177.0	243.6	245.5	237.5	240.3
GeoCarb	39.7	20.0	--	--	--	--	--
Other Missions and Data Analysis	54.9	--	58.6	55.0	45.0	45.0	50.0
Earth Science Data Systems	**339.4**	**--**	**411.7**	**398.9**	**408.1**	**423.8**	**439.6**
Earth Science Technology	**86.1**	**--**	**105.3**	**113.5**	**117.1**	**118.4**	**120.8**
Applied Sciences	**73.5**	**--**	**87.3**	**102.3**	**106.2**	**109.3**	**111.5**
Planetary Science	**3,120.4**	**3,200.0**	**3,383.2**	**3,265.8**	**3,246.1**	**3,350.8**	**3,389.7**
Planetary Science Research	**309.0**	**--**	**307.4**	**333.3**	**352.0**	**360.2**	**386.4**
Planetary Science Research and Analysis	221.3	--	224.6	249.3	261.5	267.4	290.3
Other Missions and Data Analysis	87.8	--	82.8	84.0	90.5	92.8	96.2
Planetary Defense	**166.0**	**137.8**	**250.7**	**337.7**	**400.5**	**299.6**	**79.0**
NEO Surveyor	110.0	90.0	209.7	296.7	358.5	257.6	39.0
Other Missions and Data Analysis	56.0	--	41.0	41.0	42.0	42.0	40.0
Lunar Discovery and Exploration	**478.8**	**--**	**458.5**	**459.0**	**460.5**	**472.0**	**483.3**
VIPER	112.2	97.2	61.3	33.0	--	--	--
Other Missions and Data Analysis	366.5	--	397.2	426.0	460.5	472.0	483.3
Discovery	**331.8**	**--**	**247.5**	**386.4**	**426.0**	**579.2**	**625.9**
Psyche	163.8	109.3	57.7	34.5	34.5	37.1	15.4
DAVINCI	12.4	--	55.8	173.0	201.2	268.6	213.0
VERITAS	14.4	--	1.5	1.5	1.5	1.5	1.5
Other Missions and Data Analysis	141.1	--	132.5	177.5	188.8	272.0	396.0
New Frontiers	**283.7**	**--**	**407.5**	**447.8**	**386.1**	**367.3**	**337.5**
Dragonfly	219.1	400.1	327.7	355.5	274.8	207.7	24.8
Other Missions and Data Analysis	64.6	--	79.9	92.3	111.3	159.6	312.7
Mars Exploration	**265.0**	**--**	**268.6**	**279.2**	**311.6**	**315.3**	**367.2**
Other Missions and Data Analysis	265.0	--	268.6	279.2	311.6	315.3	367.2
Mars Sample Return	**653.2**	**822.3**	**949.3**	**700.0**	**600.0**	**612.1**	**627.6**
Outer Planets and Ocean Worlds	**484.3**	**--**	**318.4**	**121.3**	**134.8**	**178.3**	**321.9**
Jupiter Europa	472.1	345.0	303.3	100.8	80.6	77.7	84.0
Other Missions and Data Analysis	12.2	--	15.1	20.6	54.2	100.6	237.9
Radioisotope Power	**148.6**	**--**	**175.5**	**201.1**	**174.6**	**166.8**	**160.9**
Astrophysics	**1,568.9**	**1,510.0**	**1,557.4**	**1,622.1**	**1,665.9**	**1,689.6**	**1,749.4**
Astrophysics Research	**267.4**	**--**	**289.9**	**299.3**	**374.0**	**384.8**	**384.3**
Astrophysics Research and Analysis	107.4	--	113.9	114.3	122.6	129.1	132.3
Balloon Project	45.8	--	49.6	50.0	50.0	50.0	50.0
Science Activation	50.6	52.0	55.6	55.6	55.6	55.6	55.6
Other Missions and Data Analysis	63.6	--	70.8	79.4	145.8	150.2	146.4
Cosmic Origins	**364.1**	**--**	**342.5**	**358.7**	**348.2**	**428.4**	**454.0**
Hubble Space Telescope (HST)	98.3	--	93.3	98.3	98.3	98.3	98.3
James Webb Space Telescope	175.4	172.5	187.0	187.0	187.0	187.0	187.0
Other Missions and Data Analysis	90.4	--	62.2	73.3	62.9	143.1	168.7
Physics of the Cosmos	**160.0**	**--**	**202.0**	**212.7**	**204.8**	**207.8**	**216.3**

FY 2024 PRESIDENT'S BUDGET REQUEST SUMMARY

Budget Authority ($ in millions)	Op Plan 2022	Enacted 2023	Request 2024	2025	2026	2027	2028
Exoplanet Exploration	**543.0**	**--**	**463.7**	**427.1**	**419.4**	**313.0**	**196.9**
Nancy Grace Roman Space Telescope	501.6	482.2	407.3	384.0	376.5	216.6	100.5
Other Missions and Data Analysis	41.4	--	56.4	43.1	42.9	96.4	96.4
Astrophysics Explorer	**234.4**	**--**	**259.3**	**324.3**	**319.5**	**355.5**	**497.9**
Spectro-Photometer for the History of the Universe, Epoch of Reionization, and Ices Explorer	97.9	71.1	70.1	44.5	6.0	1.6	0.5
Compton Spectrometer and Imager (COSI)	23.3	--	15.0	70.3	84.6	50.6	6.3
Other Missions and Data Analysis	113.2	--	174.2	209.5	228.9	303.3	491.1
Heliophysics	**777.9**	**805.0**	**750.9**	**837.4**	**847.3**	**827.4**	**844.0**
Heliophysics Research	**218.4**	**--**	**231.3**	**240.1**	**237.2**	**238.3**	**239.3**
Heliophysics Research and Analysis	42.8	--	54.9	62.2	63.2	63.7	64.2
Sounding Rockets	69.6	--	68.1	69.2	69.2	69.2	69.2
Research Range	35.9	26.5	26.9	27.7	27.5	27.5	27.8
Other Missions and Data Analysis	70.2	--	81.3	80.9	77.2	77.8	78.0
Living with a Star	**86.1**	**147.3**	**100.0**	**119.8**	**105.2**	**104.1**	**91.8**
Other Missions and Data Analysis	86.1	--	100.0	119.8	105.2	104.1	91.8
Solar Terrestrial Probes	**229.7**	**208.0**	**194.0**	**128.8**	**82.6**	**65.3**	**55.9**
Interstellar Mapping and Acceleration Probe (IMAP)	166.3	120.8	139.8	63.9	39.5	23.9	15.3
Other Missions and Data Analysis	63.4	--	54.2	64.9	43.1	41.5	40.6
Heliophysics Explorer Program	**189.2**	**167.9**	**190.7**	**298.6**	**374.0**	**372.0**	**412.6**
HelioSwarm	3.3	--	9.5	44.3	126.8	138.2	109.0
Multi-Slit Solar Explorer	24.3	--	47.4	83.0	70.5	41.0	14.8
Other Missions and Data Analysis	161.7	--	133.8	171.3	176.7	192.8	288.8
Space Weather	**33.5**	**25.0**	**26.6**	**35.5**	**34.3**	**31.7**	**28.4**
Heliophysics Technology	**20.9**	**28.4**	**8.4**	**14.7**	**14.0**	**16.0**	**16.0**
Biological and Physical Sciences	**82.5**	**85.0**	**96.5**	**103.2**	**105.3**	**107.4**	**109.6**
Aeronautics	**880.7**	**935.0**	**995.8**	**1,015.7**	**1,036.0**	**1,056.7**	**1,077.8**
Aeronautics	**880.7**	**935.0**	**995.8**	**1,015.7**	**1,036.0**	**1,056.7**	**1,077.8**
Airspace Operations and Safety Program	**139.1**	**--**	**158.7**	**164.4**	**179.4**	**198.2**	**202.8**
Advanced Air Vehicles Program	**250.3**	**--**	**295.2**	**311.6**	**305.0**	**273.6**	**257.5**
Integrated Aviation Systems Program	**231.5**	**--**	**264.9**	**260.5**	**263.5**	**279.7**	**305.5**
Low Boom Flight Demonstrator	93.3	74.5	33.0	1.7	--	--	--
Electrified Powertrain Flight Demonstration	70.6	--	87.3	65.4	54.7	41.3	30.4
Other Projects	67.6	--	144.6	193.3	208.9	238.4	275.2
Transformative Aero Concepts Program	**142.8**	**--**	**160.0**	**161.8**	**170.3**	**184.5**	**188.5**
Aerosciences Evaluation and Test Capabilities	**117.0**	**--**	**117.0**	**117.4**	**117.7**	**120.7**	**123.5**

FY 2024 PRESIDENT'S BUDGET REQUEST SUMMARY

	Fiscal Year						
Budget Authority ($ in millions)	Op Plan 2022	Enacted 2023	Request 2024	2025	2026	2027	2028
STEM Engagement	137.0	143.5	157.8	161.0	164.2	167.5	170.9
Safety, Security, and Mission Services	3,020.6	3,129.5	3,369.4	3,436.8	3,505.5	3,575.6	3,647.1
Mission Services & Capabilities	1,987.2	--	2,259.3	2,304.1	2,350.0	2,397.1	2,445.0
Information Technology (IT)	581.4	--	681.8	696.7	709.6	722.4	736.5
Mission Enabling Services	733.8	--	802.4	818.2	834.4	851.1	868.1
Infrastructure & Technical Capabilities	672.0	--	775.1	789.2	806.0	823.6	840.4
Engineering, Safety, & Operations	1,033.4	--	1,110.1	1,132.7	1,155.5	1,178.5	1,202.1
Agency Technical Authority	190.0	--	200.1	204.1	208.2	212.3	216.6
Center Engineering, Safety, & Operations	843.4	--	910.0	928.6	947.3	966.2	985.5
Construction and Environmental Compliance and Restoration	416.8	414.3	453.7	462.8	472.1	481.5	491.1
Construction of Facilities	342.1	--	375.9	383.4	391.1	398.7	406.6
Institutional CoF	225.8	--	336.0	383.4	391.1	398.7	406.6
Exploration CoF	90.3	--	10.5	--	--	--	--
Space Operations CoF	22.5	--	29.4	--	--	--	--
Science CoF	3.5	--	--	--	--	--	--
Environmental Compliance and Restoration	74.7	--	77.8	79.4	81.0	82.8	84.5
Inspector General	45.3	47.6	50.2	51.2	52.2	53.2	54.3
NASA Total	24,041.3	25,383.7	27,185.0	27,728.7	28,283.2	28,848.9	29,425.8

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The NASA Administrator has determined that, in the interest of ensuring the safe and successful execution of the early Artemis flights, managing risk effectively, and maintaining resiliency and flexibility for future missions exploration requirements, NASA has made a decision to no longer transition programs that complete their research and development phase in the Exploration Systems Development Mission Directorate to the Space Operations Mission Directorate for their operational phase.

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

FY 2024 BUDGET REQUEST AGENCY SUMMARY

Overview

Agency Summary

MESSAGE FROM THE ADMINISTRATOR

President Biden's Fiscal Year 2024 Budget request for NASA is a reflection of the Administration's confidence in our daring missions to explore the universe for the benefit of all. NASA has set a bold vision for the future, one defined by innovation and exploration throughout the heavens. The President's Budget will help prepare NASA to make that vision a reality, through investments in human and robotic exploration throughout our solar system, Earth science, groundbreaking technology, the next generation of air travel, and educating our Nation's future explorers.

Through the Artemis campaign, NASA is partnering with the broadest exploration coalition in history. Together, we will continue to develop the technology and systems needed to live and work on the Moon in preparation for human missions to Mars. The President's Budget fully funds the Artemis II test flight which, for the first time in more than half a century, will fly astronauts around the Moon. The budget makes investments in the long-term architecture for Artemis, including funding for the Gateway lunar-orbiting outpost, surface power, and competition in the Human Landing System Program that will enable the first woman and person of color to walk on the Moon.

The missions of tomorrow will be enabled by the technology development of today. With funding for lunar robotic missions, communications on and around the Moon, Commercial Lunar Payload Services, and other key elements, NASA will deepen our understanding of the Moon, prepare for long-duration stays, and strengthen our Nation's industrial base and scientific know-how. Investment in additional exploration capabilities will enable humanity's next giant leap to Mars.

The President's Budget supports continued research on the International Space Station through 2030 with regular crewed missions to this orbiting laboratory. There, NASA astronauts will conduct critical research on the risks associated with future Mars missions – including space radiation, isolation, and distance from Earth – and groundbreaking experiments on human health that benefit life on Earth. The budget positions NASA well to continue the space station's legacy in low-Earth orbit after 2030, with investment in the development of commercial space stations. This will pave the way for continuity of sustained United States (U.S.) presence in orbit and create scientific and economic opportunities.

In 2022, NASA had the world on the edge of their seats as we revealed the first images from the James Webb Space Telescope. The President's science request will continue world-leading missions like Webb, Hubble, and Perseverance, as well as enable the next generation of great science with the Nancy Grace Roman Space Telescope, Mars Sample Return, Europa Clipper, Dragonfly, and more. In total, the budget supports over 120 NASA science missions and 10,000 U.S. scientists through more than 4,000 openly competed research awards.

One of NASA's greatest strengths is our ability to unite our partners together in pursuit of knowledge about the heavens, but also our own planet. Over the past three decades, much of what we have learned about the Earth's changing climate is built on NASA satellite observations and research. The budget will build on that legacy, enabling critical work on the next generation of observatories that will give us a 3D-holistic understanding the Earth's systems. The budget request will make NASA's Earth science data more accessible to Federal, state, and local governments, universities, researchers, and the public through investments in open science, data systems, and the Earth Information Center.

MESSAGE FROM THE ADMINISTRATOR

NASA's commitment to our climate is multi-faceted. The budget will put NASA aeronautics on a path to meet President Biden's ambitious goal of net zero emissions in the aviation industry by 2050 by accelerating research and development of aircraft technologies that are safer, faster, and greener. NASA is working to develop next-generation aircraft and engines that would make commercial airliners 25 to 30 percent more efficient, resulting in benefits to our planet, the U.S. commercial aviation sector, and passengers around the world. Through ambitious experimental programs, including the X-57 electric aircraft, X-59 low boom supersonic aircraft, and the Sustainable Flight Demonstrator, NASA is poised to revolutionize the future of air travel.

NASA has always dared to make the impossible possible. To do so, the President's Budget request will build the workforce of tomorrow by broadening student participation, expanding K-12 student engagement in STEM education, and building partnerships to magnify our reach.

The President's Budget for NASA is an investment in our Nation's future. It is an investment in U.S. innovation and competitiveness, and it is an investment in our next generation of workers. It will prepare America to compete – and succeed – in the 21st century.

Bill Nelson

NOTES ON THE BUDGET

The NASA FY 2024 President's Budget, coupled with the 2022 NASA Strategic Plan, furthers the Administration's objectives of bolstering America's international position, stimulating economic development, addressing climate change, and advocating for diversity, equity, inclusion, and accessibility. The FY 2024 Budget allocates $27.2 billion to NASA, emphasizing the Agency's unparalleled potential to promote these goals. With this funding, NASA will maintain its leadership in spearheading a new phase of space exploration, will enhance understanding of our changing planet, inspire the country and the globe, create fair and equal opportunities to work with and for NASA, and generate lucrative employment in the expanding space sector.

NASA serves as a fountainhead of national inspiration and global leadership. The Agency is fully equipped to harness its proficiency and potential to tackle the challenges and opportunities confronting our Nation. These include conducting research by utilizing crucial data from our Earth observation missions to understand climate change and natural hazards; fostering innovation and technological advancement in aviation and space; expanding significant economic sectors while fueling the growth of science, technology, engineering, and mathematics (STEM) jobs; inspiring the upcoming generation of scientists, engineers, and explorers; and promoting American leadership and international engagement through science and space exploration programs with an expanding coalition of international partners. By endorsing the exploration of the Moon, Mars, and the universe beyond, this budget reinforces America's leadership position for a new era of human and robotic exploration and discovery.

NASA's 2022 Strategic Plan encapsulates the Agency's longstanding and significant purpose through four Strategic Themes: Discover, Explore, Innovate, and Advance. These Strategic Themes guide NASA's investments toward achieving four specific goals. The first goal is to expand human knowledge through new scientific discoveries, while the second goal focuses on extending human presence to the Moon and Mars for sustainable long-term exploration, development, and utilization. The third goal is to catalyze economic growth and drive innovation to address national challenges. Finally, the fourth goal aims to enhance NASA's capabilities and operations to ensure success in current and future missions. By prioritizing these themes and goals, NASA remains committed to advancing our understanding of the universe while also contributing to economic growth and development here on Earth.

Discover

The NASA budget supports a vast array of cutting-edge space science missions, with more than 60 already in operation and 46 more presently gearing up for launch. Additionally, the Agency provides funding to over 10,000 American scientists working in universities, industry, and Government labs through over 4,000 research awards that are openly competed. The FY 2024 Budget allocates unprecedented funding for science, cementing NASA's status as a worldwide pioneer in groundbreaking discoveries.

The FY 2024 Budget designates $2.5 billion for Earth science and observations, allowing for the dissemination of comprehensive data to researchers and policymakers. Additionally, over $500 million is allotted to lessen the environmental impact of aviation. This funding encompasses prototyping initiatives for a greenhouse gas monitoring and information system, which will be included in an Earth Information Center that is adaptable to the needs of Federal, State, and local governments, as well as other users. The system will be developed in partnership with other agencies and collaborators. The budget also supports an increase in Interdisciplinary Science in anticipation of NASA-ISRO Synthetic Aperture Radar’s (NISAR's) planned launch in October 2024.

The FY 2024 Budget allocates $3.4 billion for Planetary Science to facilitate the exploration of various planetary bodies in our solar system. This includes funding for the Lunar Discovery and Exploration Program, which supports Artemis science, innovative collaborations with commercial entities, and inventive approaches for attaining both scientific and human exploration objectives. The budget also provides funding to explore new destinations in the solar system via missions such as Europa Clipper; Psyche; Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (DAVINCI); and Dragonfly. Furthermore, the budget supports forthcoming competitive mission selections within Discovery, including the Small, Innovative Missions for Planetary Exploration (SIMPLEx) opportunity, as well as the New Frontiers Program.

The budget also supports a Mars Sample Return mission in partnership with international organizations, with the aim of launching no earlier than FY 2028 and returning surface samples to Earth. Mars Sample Return costs may increase beyond the current outyear profile which would require either reduced funding for other Science activities or descoping of this mission. Additionally, the budget facilitates expanded NASA contributions to the European Space Agency's Rosalind Franklin rover, previously a joint Europe/Russia mission, which will search Mars for indications of ancient life. Lastly, the budget supports the Volatiles Investigating Polar Exploration Rover (VIPER) mission, which will explore the south pole of the Moon following its commercial lunar delivery, planned for FY 2025.

The budget provides $1.6 billion in funding for Astrophysics to further our understanding of the universe and to search for Earth-like planets. It supports the operation of the James Webb Space Telescope and the Hubble Space Telescope, as well as the development of the Nancy Grace Roman Space Telescope, which is scheduled for launch in 2027. Additionally, the budget includes funding for a competitive Explorers Program, with new selections expected every three years. The budget also supports the initial selection of the first Astrophysics Probe mission, while continuing to provide support for precursor science and technology efforts in planning and preparing for the Great Observatories Mission and Technology Maturation Program (GOMAP) recommendation outlined in the Astro2020 Decadal Survey.

Heliophysics is a field of study that focuses on the Sun and its effects on the solar system. The FY 2024 Budget of $751 million includes funding for several missions and programs related to Heliophysics research. The Interstellar Mapping and Acceleration Probe (IMAP) and the Carruthers Geocorona Observatory are two projects under the Solar Terrestrial Probes Program that will be supported by the budget. The budget will also fund a competitive Explorer Program, including the recently selected missions Multi-slit Solar Explorer (MUSE) and HelioSwarm. The budget also continues the Space Weather Program, which aims to enable the Nation to better protect technology and astronauts from space weather. The budget includes funding for the Diversity, Realize, Integrate, Venture, Educate (DRIVE) initiative, which focuses on developing technologies to enable human exploration of the Moon, Mars, and beyond. The budget also funds orbital debris investments to enable the characterization of the populations of small debris and dust in space to protect critical infrastructure and humans working in space. The budget pauses development of the Geospace Dynamics Constellation in order to fund cost growth on other missions within the Science Program.

NOTES ON THE BUDGET

Lastly, $97 million in funding for Biological and Physical Science aims to support research and experiments that will improve our understanding of how biological and physical systems function in space. The budget includes funding for a new project, Commercially-Enabled Rapid Space Science (CERISS), an initiative to develop transformative research capabilities with the commercial space industry and to dramatically increase research productivity.

Explore

NASA's exploration vision is focused on maintaining U.S. leadership in space and expanding human exploration across the solar system. The Agency plans to establish a long-term presence on the Moon, followed by missions to Mars and other destinations. This vision builds on NASA's rich history of human spaceflight and the operational experience gained from more than 20 years of continuous human presence on the International Space Station (ISS).

The Artemis Program is at the forefront of this strategy, with a series of missions aimed at landing the first woman and first person of color on the lunar surface, establishing a sustainable presence on the Moon, and preparing for a crewed mission to Mars. The Program relies on new deep space transportation systems and innovative industry capabilities, including landers and space suits, to achieve this goal.

This era of human exploration will require innovative technologies and systems that have not yet been demonstrated. These technologies will spur advancements in fields like space medicine, cryogenic storage, space power, materials science, and in-space manufacturing and assembly. Developing these capabilities will be critical to exploring new and more challenging locations, such as the lunar south pole.

Overall, NASA's exploration vision represents a significant technical enterprise in human history that will require sustained commitment and collaboration across commercial and international partners. The Agency's efforts to expand human exploration across the solar system will not only bring new knowledge and opportunities back to Earth, but also inspire future generations to pursue careers in STEM fields.

NASA's preparations for exploring the Moon, Mars, and beyond continue to be supported by the ISS. The Agency plans to leverage its mission aboard the ISS in low-Earth orbit (LEO) to identify risks to human health, develop countermeasures, and test technologies that protect astronauts. This approach will help reduce operations, maintenance, and transportation costs and provide functional robustness against operational risks due to technological, environmental, or other potential disruptions.

The FY 2024 Budget request includes funding for all necessary steps to enable a safe and seamless transition from the ISS to commercial destinations in LEO by 2030. This begins with $1.3 billion for ISS operations and research and $1.8 billion for crew and cargo transportation. NASA will continue to maintain multiple domestic and international partners for crew and cargo delivery supporting ISS operations, providing flexibility and resilience to the ISS Program. NASA is also preparing to demonstrate the capability to support a continued human presence in LEO through 2030 and beyond with no gap in U.S. presence, by supporting the development of commercially owned and operated LEO destinations with $228 million of funding in the budget. The budget request also includes

NOTES ON THE BUDGET

$180 million for the development of a U.S. deorbit vehicle that will safely deorbit the ISS once commercial destinations have been proven safe and effective.

The Commercial LEO Development Program will support the development of these new space stations, and NASA will work with the ISS National Laboratory and private companies to accelerate the growth of the commercial space industries that will use the ISS and join NASA as one of many customers in using commercial destinations in the future. This approach will help ensure a continuous American presence in LEO and create new opportunities for commercial space activities, such as research, manufacturing, and space tourism.

Overall, NASA's focus on the ISS and commercial LEO development is an important step towards building a robust economy in LEO that will create new jobs and improve life on Earth, while also expanding human exploration beyond LEO. By leveraging its experience and capabilities in LEO, NASA is preparing to establish a sustained presence on the Moon and eventually send humans to Mars and other destinations in the solar system.

The Artemis Program will send humans back to the Moon and eventually on to Mars. The Program includes the development of common exploration systems, such as the Space Launch System (SLS), Orion crew vehicle, and Exploration Ground Systems (EGS), that completed a successful flight test of Artemis I in 2022. The budget for these systems is $4.5 billion.

In addition to the common exploration systems, the budget includes $3.2 billion for the development of the Gateway lunar outpost, the lunar Human Landing System (HLS), space suits, and lunar surface systems. Gateway will provide a platform in an orbit around the Moon to sustain surface operations, with Orion providing crew transportation services. The HLS Program will begin with uncrewed and crewed demonstration missions to the lunar surface, followed by a competition for commercial services between Gateway and the lunar surface.

NASA is also expanding its interagency and international partnerships to achieve its space exploration goals. The budget includes $161 million for Mars Campaign Development, with a focus on reducing operational risk, validating operational concepts, leveraging partner capabilities, and lowering life cycle costs. The budget also includes $49 million to continue developing the detailed, integrated systems design studies needed to prepare for a human mission to Mars.

Finally, the Space and Flight Support theme of NASA's budget, which is allocated $1 billion, encompasses a range of essential services that support various missions sponsored by NASA and other stakeholders. These services include data uplinks and downlinks, which enable communication between spacecraft and ground stations, as well as unified launch service procurements that leverage NASA's collective buying power to obtain cost-effective launch services for the Government. The Space and Flight Support theme includes programs that provide logistical and technical support to NASA's various missions, such as spacecraft tracking, emergency response services, and aircraft operations. These programs are critical to ensuring the success and safety of NASA's space exploration and discovery efforts.

NOTES ON THE BUDGET

Innovate

Technological innovations funded by NASA have contributed significantly to the U.S. economy and to the well-being of society. These innovations include the development of new rockets, aerospace materials, and air traffic management tools among others. These innovations have generated significant economic growth and good-paying jobs, and improved people's lives.

NASA's Aeronautics programs focus on developing technologies that reduce fuel use and aircraft noise, ensure safe and timely travel, and keep aviation a key economic driver. The FY 2024 Budget of $996 million supports NASA's efforts in four key research areas: ultra-efficient transport, high-speed commercial flight, future airspace, and advanced air mobility. NASA's Sustainable Flight National Partnership with industry will help develop next-generation, low-carbon emitting designs that are 25 percent more fuel-efficient than today's aircraft.

NASA is playing a leading role in transforming various aspects of civil aviation, including commercial flight, low-noise supersonic flight, and advanced air mobility. Through the development of technologies for high-speed commercial flight and the X-59 Low Boom Flight Demonstrator, NASA is paving the way for quieter supersonic flight. Additionally, NASA is working on enabling a transformation in how people and goods move around communities and regions through initiatives like Advanced Air Mobility (AAM), Unmanned Aircraft Systems, and electric Vertical Takeoff and Landing (eVTOL) vehicles.

NASA is partnering with industry to mature AAM concepts and technologies for safe operations and preparing for AAM National Campaign demonstrations of new air vehicles and airspace management technologies. The Agency will conclude research of the all-electric X-57 Maxwell aircraft to inform standards development for small electric aircraft that will be common in an AAM environment.

The budget also supports the development of the next evolution of the global air traffic management system, with the aim of safely increasing operational efficiency at the vehicle, fleet, and system-wide levels while reducing fuel burn, CO_2 emissions, contrail formation, and ozone impact. NASA is expanding partnerships with universities to develop technologies that can help the industry achieve long-term climate goals while training and inspiring the future aerospace workforce. Additionally, NASA is continuing to invest in critical fundamental technologies for hypersonic flight.

The $1.39 billion budget for Space Technology is designed to develop innovative, cross-cutting technologies that will help NASA achieve its missions, boost the commercial space industry, and create jobs.

The investments made by NASA will advance the development and demonstration of transformative capabilities for space transportation and propulsion, entry, descent, and landing, sustainable resource utilization, manufacturing, and robotic mobility systems. NASA will continue to develop foundational capabilities of on-orbit servicing, assembly, and manufacturing, and take the next step in optical communications using infrared lasers to send data to and from space. NASA will continue investments in In-Situ Resource Utilization, Sustainable Power systems, lunar robotic mobility systems, research in Lunar Dust Mitigation, and small spacecraft technologies.

NOTES ON THE BUDGET

The Technology Demonstration Program conducts system-level ground-based testing to determine the feasibility of technologies and systems for use in NASA missions and for other Government agencies and the commercial space industry. The Program will launch Deep Space Optical Communications (DSOC), complete the second qualification thruster assembly for Solar Electric Propulsion, and continue development of Cryogenic Fluid Management and On-orbit Servicing, Assembly, and Manufacturing-1 (OSAM-1).

NASA will continue to develop technologies that have broad application and address multiple stakeholder needs, actively engaging with NASA centers, industry, academia, and other Federal Government agencies to help define program content. The Early Stage Innovation portfolio leads by sourcing ideas from a broad, diverse base of organizations and transferring space technology into the space economy.

NASA will explore innovation pilots to enable breakthrough technology research and development in support of U.S. competitiveness. Technological leadership is crucial to our national security, economic prosperity, and global competitiveness. An innovation-focused NASA will provide valuable breakthroughs for NASA's missions and the commercial industry, helping continue to help fuel our Nation's economic engine for decades to come.

Advance

NASA recognizes the critical importance of having a diverse and inclusive workforce in achieving its mission of advancing space exploration and scientific discovery. By embracing diversity, NASA can tap into the unique perspectives, experiences, and talents of its workforce, leading to more creative problem-solving, better decision-making, and greater innovation.

In support of this goal, NASA has implemented a range of initiatives to promote diversity, equity, and inclusion within the Agency. These include efforts to recruit and retain a diverse workforce, as well as programs to foster an inclusive and welcoming workplace culture. NASA also works to engage with underserved communities and promote STEM education and careers among underrepresented groups.

NASA's investment of $158 million in the Office of STEM Education will increase NASA's reach and impact on K-12 students and expand initiatives to attract and retain underserved and underrepresented students in engineering and other STEM fields. NASA is investing in the future of science and technology and ensuring that its workforce reflects the diversity of the Nation.

Partnering with minority-serving institutions and other higher education institutions, NASA will create unique opportunities that engage students in authentic learning experiences. These experiences will help students develop critical skills in science, technology, engineering, and mathematics, while also fostering a passion for exploration and discovery.

The funding for NASA's Safety, Security, and Mission Services (SSMS) account is critical to ensuring the success of the Agency's portfolio of missions. With a budget of $3.4 billion, SSMS provides funding for the technical and business operations required to maintain NASA centers and facilities and reduce risks to life and program objectives for all missions. SSMS also supports corporate functions, such as human capital management, finance, information technology, acquisitions, security, and stakeholder engagement. Additionally, SSMS supports the management of NASA's vast infrastructure, which includes installations in 14 states and over 5,000 buildings and structures.

The budget for SSMS also includes funding for orbital debris research and measurement technologies to better understand and address the worsening orbital debris environment. This is important for protecting the Nation's satellites and reducing risks posed by space debris.

Finally, the Construction and Environmental Compliance and Restoration (CECR) account enables NASA to manage its facilities and reduce its environmental footprint through the consolidation and replacement of old and costly facilities. CECR also funds environmental compliance and restoration projects to remediate pollutants released into the environment during prior NASA activities, with the goal of safeguarding human health and the environment, as well as preserving natural resources for future missions.

By investing in its facilities, NASA can ensure that its world-class workforce has the infrastructure necessary to carry out its missions safely and efficiently. This includes critical research facilities, launch pads, and other infrastructure that are essential to the Agency's operations. Ultimately, the funding allocated to CECR and SSMS is essential to NASA's ability to advance its mission and contribute to the ongoing exploration and scientific discovery in space.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

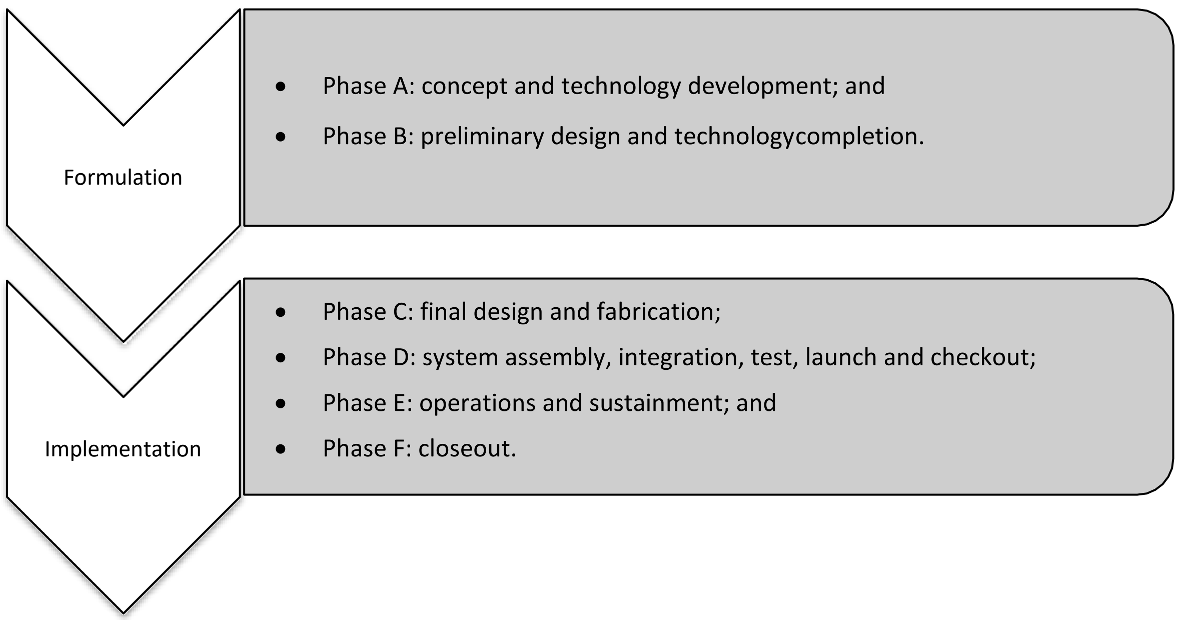
FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

EXPLANATION OF PROJECT SCHEDULE COMMITMENTS AND KEY MILESTONES

Programs and projects follow their appropriate life cycle. The life cycle is divided into phases. Transition from one phase to another requires management approval at Key Decision Points (KDPs). The phases in program and project life cycles include one or more life-cycle reviews, which are considered major milestone events.



A life-cycle review is designed to provide the program or project with an opportunity to ensure that it has completed the work of that phase and an independent assessment of a program's or project's technical and programmatic status and health. The final life-cycle review in a given life-cycle phase provides essential information for the KDP that marks the end of that life-cycle phase and transition to the next phase if successfully passed. As such, KDPs serve as gates through which programs and projects must pass to continue.

The KDP decision to authorize a program or project's transition to the next life-cycle phase is based on a number of factors, including technical maturity; continued relevance to Agency strategic goals; adequacy of cost and schedule estimates; associated probabilities of meeting those estimates (confidence levels); continued affordability with respect to the Agency's resources; maturity and the readiness to proceed to the next phase; and remaining program or project risk (safety, cost, schedule, technical, management, and programmatic). At the KDP, the key program or project cost, schedule, and content parameters that govern the remaining life-cycle activities are established.

For reference, a description of schedule commitments and milestones is listed below for projects in Formulation and Implementation. A list of common terms used in mission planning is also included.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

Formulation

NASA places significant emphasis on project Formulation to ensure adequate preparation of project concepts and plans and mitigation of high-risk aspects of the project essential to position the project for the highest probability of mission success. During Formulation, the project explores the full range of implementation options, defines an affordable project concept to meet requirements, and develops needed technologies. The activities in these phases include developing the system architecture; completing mission and preliminary system designs; acquisition planning; conducting safety, technical, cost, and schedule risk trades; developing time-phased cost and schedule estimates and documenting the basis of these estimates; and preparing the Project Plan for Implementation.

Formulation Milestone	Explanation
KDP-A	The lifecycle gate at which the decision authority determines the readiness of a program or project to transition into Phase A and authorizes Formulation of the project. Phase A is the first phase of Formulation and means that: • The project addresses a critical NASA need; • The proposed mission concept(s) is feasible; • The associated planning is sufficiently mature to begin activities defined for formulation; and • The mission can likely be achieved as conceived.
System Requirements Review (SRR)	The lifecycle review in which the decision authority evaluates whether the functional and performance requirements defined for the system are responsive to the program's requirements on the project and represent achievable capabilities
System Definition Review or Mission Definition Review	The lifecycle review in which the decision authority evaluates the credibility and responsiveness of the proposed mission/system architecture to the program requirements and constraints on the project, including available resources, and determines whether the maturity of the project's mission/system definition and associated plans are sufficient to begin the next phase, Phase B.
KDP-B	The lifecycle gate at which the decision authority determines the readiness of a program or project to transition from Phase A to Phase B. Phase B is the second phase of Formulation and means that: • The proposed mission/system architecture is credible and responsive to program requirements and constraints, including resources; • The maturity of the project's mission/system definition and associated plans is sufficient to begin Phase B; and • The mission can likely be achieved within available resources with acceptable risk.
Preliminary Design Review (PDR)	The lifecycle review in which the decision authority evaluates the completeness/consistency of the planning, technical, cost, and schedule baselines developed during Formulation. This review also assesses compliance of the preliminary design with applicable requirements and determines if the project is sufficiently mature to begin Phase C.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

Implementation

Implementation occurs when Agency management establishes baseline cost and schedule commitments for projects at KDP-C. The projects maintain the baseline commitment through the end of the mission. Projects are baselined for cost, schedule, and programmatic and technical parameters. Under Implementation, projects are able to execute approved plans development and operations.

Implementation Milestone	Explanation
KDP-C	The lifecycle gate at which the decision authority determines the readiness of a program or project to begin the first stage of development and transition to Phase C and authorizes the Implementation of the project. Phase C is first stage of development and means that: • The project's planning, technical, cost, and schedule baselines developed during Formulation are complete and consistent; • The preliminary design complies with mission requirements; • The project is sufficiently mature to begin Phase C; and • The cost and schedule are adequate to enable mission success with acceptable risk.
Critical Design Review (CDR)	The lifecycle review in which the decision authority evaluates the integrity of the project design and its ability to meet mission requirements with appropriate margins and acceptable risk within defined project constraints, including available resources. This review also determines if the design is appropriately mature to continue with the final design and fabrication phase.
System Integration Review (SIR)	The lifecycle review in which the decision authority evaluates the readiness of the project and associated supporting infrastructure to begin system assembly, integration, and test. The lifecycle review also evaluates whether the remaining project development can be completed within available resources, and determine if the project is sufficiently mature to begin Phase D.
KDP-D	The lifecycle gate at which the decision authority determines the readiness of a project to continue in Implementation and transition from Phase C to Phase D. Phase D is a second phase in Implementation; the project continues in development and means that: • The project is still on plan; • The risk is commensurate with the project's payload classification; and • The project is ready for assembly, integration, and test with acceptable risk within its Agency baseline commitment.
Launch Readiness Date (LRD)	The date at which the project and its ground, hardware, and software systems are ready for launch.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

Other Common Terms for Mission Planning

Term	Definition
Decision Authority	The individual authorized by the Agency to make important decisions on programs and projects under their authority.
Formulation Authorization Document	The document that authorizes the formulation of a program whose goals will fulfill part of the Agency's Strategic Plan and Mission Directorate strategies. This document establishes the expectations and constraints for activity in the Formulation phase.
Key Decision Point (KDP)	The lifecycle gate at which the decision authority determines the readiness of a program or project to progress to the next phase of the life cycle. The KDP also establishes the content, cost, and schedule commitments for the ensuing phase(s).
Launch Manifest	A list that NASA publishes (the "NASA Flight Planning Board launch manifest") periodically, which includes the expected launch dates for NASA missions. The launch dates in the manifest are the desired launch dates approved by the NASA Flight Planning Board and are not typically the same as the Agency Baseline Commitment schedule dates. A launch manifest is a dynamic schedule that is affected by real world operational activities conducted by NASA and multiple other entities. It reflects the results of a complex process that requires the coordination and cooperation by multiple users for the use of launch range and launch contractor assets. Moreover, the launch dates are a mixture of "confirmed" range dates for missions launching within approximately six months, and contractual/planning dates for the missions beyond six months from launch. The NASA Flight Planning Board launch manifest date is typically earlier than the Agency Baseline Commitment schedule date to allow for the operationally driven delays to the launch schedule that may be outside of the project's control.
Operational Readiness Review	The lifecycle review in which the decision authority evaluates the readiness of the project, including its ground systems, personnel, procedures, and user documentation, to operate the flight system and associated ground system(s), in compliance with defined project requirements and constraints during the operations phase.
Mission Readiness Review or Flight Readiness Review (FRR)	The lifecycle review in which the decision authority evaluates the readiness of the project, ground systems, personnel and procedures for a safe and successful launch and flight/mission.
KDP-E	The lifecycle gate at which the decision authority determines the readiness of a project to continue in Implementation and transition from Phase D to Phase E. Phase E is a third phase in Implementation and means that the project and all supporting systems are ready for safe, successful launch and early operations with acceptable risk.
Decommissioning Review	The lifecycle review in which the decision authority evaluates the readiness of the project to conduct closeout activities. The review includes final delivery of all remaining project deliverables and safe decommissioning of space flight systems and other project assets.
KDP-F	The lifecycle gate at which the decision authority determines the readiness of the project's decommissioning. Passage through this gate means the project has met its program objectives and is ready for safe decommissioning of its assets and closeout of activities. Scientific data analysis may continue after this period.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

For further details, go to:

- NASA Procedural Requirement 7102.5E NASA Space Flight Program and Project Management Requirements: https://nodis3.gsfc.nasa.gov/npg_img/N_PR_7120_005F_/N_PR_7120_005F_.pdf
- NASA Procedural Requirement NPR 7123.1C - NASA Systems Engineering Processes and Requirements: https://nodis3.gsfc.nasa.gov/npg_img/N_PR_7123_001C_/N_PR_7123_001C_.pdf
- NASA Launch Services Web site: https://www.nasa.gov/centers/kennedy/launchingrockets/index.html

DEEP SPACE EXPLORATION SYSTEMS

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Common Exploration Systems Development	4,590.7	4,737.9	**4,525.4**	4,241.7	4,009.3	3,557.3	3,529.7
Artemis Campaign Development	2,007.6	2,600.3	**3,234.8**	3,674.4	4,068.9	4,686.2	4,879.6
Human Exploration Requirements & Architecture	0.0	--	**49.1**	50.0	50.5	51.0	51.1
Mars Campaign Development	187.4	--	**161.8**	164.4	164.4	164.5	167.8
Exploration Research & Development	69.4	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**6,855.1**	**7,468.9**	**7,971.1**	**8,130.5**	**8,293.1**	**8,459.0**	**8,628.2**
Change from FY 2023 Enacted			**502.2**				
Percent change from FY 2023 Enacted			**6.7%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The NASA Administrator has determined that, in the interest of ensuring the safe and successful execution of the early Artemis flights, managing risk effectively, and maintaining resiliency and flexibility for future missions exploration requirements, NASA has made a decision to no longer transition programs that complete their research and development phase in the Exploration Systems Development Mission Directorate to the Space Operations Mission Directorate for their operational phase.

DEEP SPACE EXPLORATION SYSTEMS

DEEP SPACE EXPLORATION SYSTEMS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Common Exploration Systems Development	4,590.7	4,737.9	**4,525.4**	4,241.7	4,009.3	3,557.3	3,529.7
Artemis Campaign Development	2,007.6	2,600.3	**3,234.8**	3,674.4	4,068.9	4,686.2	4,879.6
Human Exploration Requirements & Architecture	0.0	--	**49.1**	50.0	50.5	51.0	51.1
Mars Campaign Development	187.4	--	**161.8**	164.4	164.4	164.5	167.8
Exploration Research & Development	69.4	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**6,855.1**	**7,468.9**	**7,971.1**	**8,130.5**	**8,293.1**	**8,459.0**	**8,628.2**
Change from FY 2023 Enacted			**502.2**				
Percent change from FY 2023 Enacted			**6.7%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The NASA Administrator has determined that, in the interest of ensuring the safe and successful execution of the early Artemis flights, managing risk effectively, and maintaining resiliency and flexibility for future missions exploration requirements, NASA has made a decision to no longer transition programs that complete their research and development phase in the Exploration Systems Development Mission Directorate to the Space Operations Mission Directorate for their operational phase.

The FY 2024 budget request includes $7.971 billion for the Deep Space Exploration Systems account. This funding directly supports the Artemis Campaign, which is focused on returning humans to the Moon, conducting pioneering research and technology development activities on the lunar surface, and enabling eventual missions to Mars and beyond. The Artemis missions will land the first woman and first person of color on the Moon and return them safely back to Earth. In collaboration with its commercial and international partners, NASA will create the capabilities necessary to sustainably explore high priority destinations on the lunar surface, including in-situ science and resource utilization, surface transportation, and habitation capabilities. The operational knowledge, technological advances, and scientific discoveries NASA gains from exploring the Moon in collaboration with international and commercial partners will position the Agency to take the next giant leap - safely sending astronauts to Mars.

The Exploration Systems Development Mission Directorate (ESDMD) will leverage the Science Mission Directorate's (SMD) development of smaller landers for capabilities such as navigation and precision landing of cargo and data about the lunar surface. ESDMD will also leverage technological investments to prove and verify concepts through the Space Technology Mission Directorate's (STMD) lunar exploration activities. Finally, ESDMD will leverage the Space Operations Mission Directorate's (SOMD) capabilities, such as the International Space Station and the Space Communications and Navigation program, as a technology and human system testbed and communication capability provider, respectively.

The FY 2024 President's Budget Request manifest supports an Artemis II mission in 2024, Artemis III mission in 2025, Artemis IV mission in 2028, and Artemis V mission in 2029 with subsequent flights on a yearly basis.

DEEP SPACE EXPLORATION SYSTEMS

The Deep Space Exploration Systems account consists of four themes which provide for the development of systems and capabilities needed for human exploration of deep space:

- Common Exploration Systems Development (CESD);
- Artemis Campaign Development (ACD);
- Human Exploration Requirements & Architecture (HERA); and
- Mars Campaign Development (MCD).

NASA's CESD programs are working together to build a space transportation system comprised of the Orion deep crew exploration vehicle, Space Launch System (SLS) rocket, and Exploration Ground Systems (EGS). These capabilities enable the Agency's Artemis missions, extending human presence into the solar system by transporting crews to lunar orbit and safely back to Earth in preparation for future missions to Mars.

The overarching goal of ACD is to develop the systems that will be used to land humans on the Moon, explore the lunar surface, and prepare for Mars exploration. ACD is both developing and testing prototype systems, as well as planning and developing flight missions to the Moon to develop systems and operational practices that will enable an eventual mission to Mars. The ACD theme is comprised of four programs: Advanced Cislunar and Surface Capabilities (ACSC), Gateway, Human Landing System (HLS), and Exploration Extravehicular Activity (xEVA) and Human Surface Mobility Program (EHP). ACD's work will create the exploration infrastructure in lunar orbit and on the lunar surface that astronauts will utilize during Artemis missions and that will inform future missions to Mars.

The overarching goal of HERA is to identify the exploration infrastructure required for Artemis missions that will inform future missions to Mars. It also works to ensure that lunar exploration systems are extensible to Mars exploration where technically feasible and cost-effective. HERA funds the Moon to Mars Architecture Development Office, which manages the architecture strategy activity that supports mission manifest planning and overall architecture requirements and capability identification. HERA also funds the Systems Engineering and Integration (SE&I) personnel required to support the top-level technical integration across ESDMD, SOMD, SMD, and STMD to include Artemis missions and future exploration planning.

The overarching goal of the MCD theme is to start working on long-lead technology challenges that will need to be solved for future crewed mission to Mars to succeed. Together with ACD, MCD is both developing and testing prototype technologies, and contributing to the planning and development of flight missions to lunar orbit and the lunar surface while developing systems and operations capabilities that enable an eventual mission to Mars. The Exploration Capabilities Program develops habitation systems and technologies to enable long missions on the lunar surface and in deep space and to address high priority technology gaps. MCD will begin conducting preliminary concept studies for future systems, including an eventual transit habitat that will provide living quarters and other basic life support functions for future human mission to Mars.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

For more information, go to: https://www.nasa.gov/directorates/exploration-systems-development

COMMON EXPLORATION SYSTEMS DEVELOPMENT

FY 2024 Budget

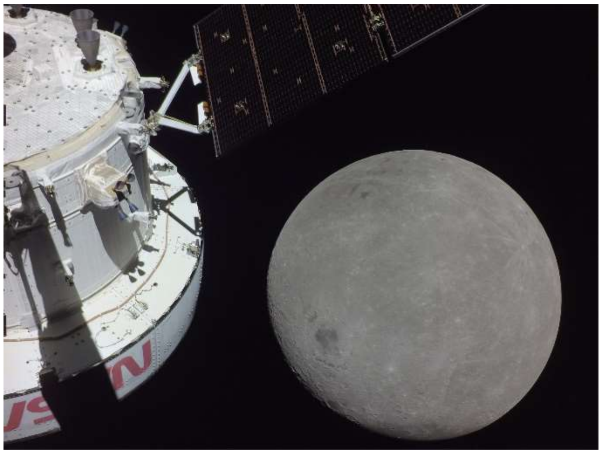
Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Orion Program	1,401.7	1,338.7	**1,225.0**	1,093.7	1,093.7	1,094.2	1,115.1
Crew Vehicle Development	1,388.8	1,320.3	**1,212.6**	1,058.7	1,058.7	1,058.5	1,062.5
Orion Program Integration and Support	12.9	--	**12.5**	34.9	35.0	35.7	52.7
Space Launch System	2,600.0	2,600.0	**2,506.1**	2,483.3	2,322.4	1,917.1	1,969.1
Launch Vehicle Development	2,526.9	2,361.4	**2,427.2**	2,365.8	2,206.7	1,804.6	1,798.8
SLS Program Integration and Support	73.1	--	**78.9**	117.5	115.7	112.5	170.3
Exploration Ground Systems	589.0	799.2	**794.2**	664.7	593.2	546.0	445.5
Exploration Ground Systems Development	398.1	330.6	**273.2**	143.5	81.8	15.6	0.0
EGS Program Integration and Support	190.9	--	**521.0**	521.2	511.4	530.4	445.5
Construction & Envrmtl Compl Restoration	90.3	--	**10.5**	0.0	0.0	0.0	0.0
Exploration CoF	90.3	--	**10.5**	0.0	0.0	0.0	0.0
Total Budget	**4,681.0**	**4,824.1**	**4,535.9**	**4,241.7**	**4,009.3**	**3,557.3**	**3,529.7**
Change from FY 2023 Enacted			**-288.1**				
Percent change from FY 2023 Enacted			**-6.0%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The NASA Administrator has determined that, in the interest of ensuring the safe and successful execution of the early Artemis flights, managing risk effectively, and maintaining resiliency and flexibility for future missions exploration requirements, NASA has made a decision to no longer transition programs that complete their research and development phase in the Exploration Systems Development Mission Directorate to the Space Operations Mission Directorate for their operational phase.

COMMON EXPLORATION SYSTEMS DEVELOPMENT



On Flight Day 5 of the Artemis I mission, Orion takes a selfie, shown above, while approaching the Moon ahead of the outbound powered flyby - a burn of Orion's main engine that gets the vehicle into lunar orbit. During this maneuver Orion came within 81 miles of the lunar surface.

NASA's Common Exploration Systems Development (CESD) programs are working together to build a space transportation system made up of the Orion crew vehicle, the Space Launch System (SLS) rocket, and the Exploration Ground Systems (EGS). CESD will enable the Agency's Artemis missions, extending human presence into the solar system by transporting crews to the Gateway or to the Moon's surface in the Human Landing System for long-term exploration and in preparation for future missions to Mars. The CESD program objectives support Agency Strategic Goal 2, which seeks to extend human presence to the Moon and on towards Mars for sustainable long-term exploration, development, and utilization.

NASA's Orion spacecraft is designed to support human exploration missions to deep space, with a crew of four, with habitation and life support on-board for missions up to 21 days. Building upon more than 50 years of spaceflight research and development, Orion's versatile design will not only carry crew to space, but also provide emergency abort capability, sustain crew during space travel, and provide safe reentry at deep space return velocities. The Orion systems are designed to operate in a contingency mode to augment life support systems in other space transport systems.

The SLS rocket is a heavy-lift launch vehicle that will launch astronauts in the Orion spacecraft on missions to cislunar space so they can return to the surface of the Moon and visit other destinations. The Block 1 configuration, which is the configuration for Artemis I, stands at 322 feet and features a lift capability of 27 metric tons to translunar injection for Moon missions with 8.8 million pounds of maximum thrust. The evolution of the architecture, currently planned for first use on Artemis IV, will include an Exploration Upper Stage (EUS), associated Universal Stage Adapter, and Payload Adapter, which provides space for SLS to launch co-manifested payloads in addition to Orion. This Block 1B configuration will be capable of delivering at least 37.3 metric tons of net payloads to Trans-Lunar Injection on crewed missions. The 37.3 metric ton total includes Orion, which weighs 27 metric tons.

The objective of EGS is to enable Kennedy Space Center (KSC) to process and launch Orion and SLS in support of the Artemis missions. To meet this objective, NASA is developing new ground systems while refurbishing and upgrading infrastructure and facilities to meet tomorrow's demands.

The Artemis Campaign is the next step in human exploration of our solar system. It is a part of NASA's Moon to Mars exploration approach, in which NASA will pursue its next giant leap, sustained human exploration of the Moon to develop the skills, systems, and operational capabilities required to enable human missions to Mars. As NASA works towards a sustainable Moon to Mars campaign, it is essential that the Agency and its contractors reduce production and operations costs for CESD systems. NASA is examining options to achieve this goal. Through a reduction in CESD program costs, the Agency can focus on the many other capabilities needed for future deep space systems and successful exploration missions.

ORION PROGRAM

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Crew Vehicle Development	1,388.8	1,320.3	**1,212.6**	1,058.7	1,058.7	1,058.5	1,062.5
Orion Program Integration and Support	12.9	--	**12.5**	34.9	35.0	35.7	52.7
Total Budget	**1,401.7**	**1,338.7**	**1,225.0**	**1,093.7**	**1,093.7**	**1,094.2**	**1,115.1**
Change from FY 2023 Enacted			**-113.7**				
Percent change from FY 2023 Enacted			**-8.5%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The NASA Administrator has determined that, in the interest of ensuring the safe and successful execution of the early Artemis flights, managing risk effectively, and maintaining resiliency and flexibility for future missions exploration requirements, NASA has made a decision to no longer transition programs that complete their research and development phase in the Exploration Systems Development Mission Directorate to the Space Operations Mission Directorate for their operational phase.

Artemis I's Orion spacecraft is shown here splashed down in the Pacific Ocean on December 11, 2022, after a 25.5-day mission around the Moon.

The Orion spacecraft will play an integral role in the Artemis Campaign, serving as an exploration vehicle that will carry crew to deep space, sustain the crew during space travel, provide emergency abort capability, and provide safe re-entry from deep space return velocities for Artemis Missions. This capsule-shaped vehicle has a familiar look, but it incorporates numerous technology advancements and innovations. The spacecraft will enable extended duration missions beyond low-Earth orbit (LEO), to the Moon, and eventually to Mars.

Orion's design, development, test (including flight tests), and evaluation will have the spacecraft ready to carry crew for the first time on Artemis II no earlier than (NET) November 2024. Development of the Orion spacecraft will be completed after the Artemis III mission, which incorporates the Rendezvous, Proximity Operations and Docking (RPOD) capability. This capability will enable Orion to work in proximity with another spacecraft, such as Gateway modules or a Human Landing System, where the intent is to dock with one another. The proposed funding levels sufficiently allow the program to support the Artemis II and Artemis III launches as soon as is technically feasible. Due to the Artemis I launch delay, NASA is re-assessing the Artemis II target launch date. The current target Launch Readiness Date (LRD) for Artemis II is NET November 2024

Orion is leveraging other capabilities, such as the Space Communications and Navigation Program's Deep Space Network to enable communication capabilities between the spacecraft and mission control. Orion will leverage the Space Launch System's (SLS) launch vehicle and Exploration Ground System (EGS)

ORION PROGRAM

capabilities to safely launch and reach its desired orbit. The capabilities provided by the Orion program enable the crews of the Artemis generation the ability to safely transport crew to deep space, which promotes new technologies and systems needed for future Mars missions.

For more information, go to: http://www.nasa.gov/orion

Program Elements

ORION PROGRAM INTEGRATION AND SUPPORT

Orion Program Integration and Support activities manage the program interfaces between the Space Launch System and the Exploration Ground Systems. This effort is critical to ensuring the Orion systems' performance meets technical and safety specifications, and supports programmatic assessments key to achieving integrated technical, cost, and schedule management. In addition, the Orion integration effort is vital to managing interfaces with other Exploration Systems Development Mission Directorate (ESDMD) activities, including strategic studies, feasibility studies, and small-scale research tasks that feed into future human exploration. Coordination and timely integration across ESDMD are aimed at mitigating the impacts of potential design overlaps, schedule disconnects and delays, and cost overruns.

CREW VEHICLE DEVELOPMENT

Orion will be capable of transporting humans to orbit around the Moon, sustaining them for longer durations beyond LEO than ever before, providing emergency abort capability, and returning them safely to Earth. See the Crew Vehicle Development section starting on the next page for additional details.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

FY 2024 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028	BTC	Total
Formulation	4,509.6	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	4,509.6
Development/Implementation	7,681.1	692.7	592.2	**290.8**	44.4	0.0	0.0	0.0	0.0	9,301.2
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2023 MPAR LCC Estimate	**12,190.7**	**692.7**	**592.2**	**290.8**	**44.4**	**0.0**	**0.0**	**0.0**	**0.0**	**13,810.8**
Total Budget	**10,209.0**	**1,388.8**	**1,320.3**	**1,212.6**	**1,058.7**	**1,058.7**	**1,058.5**	**1,062.5**	**6.7**	**18,375.8**
Change from FY 2023 Enacted				**-107.7**						
Percent change from FY 2023 Enacted				**-8.2%**						

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

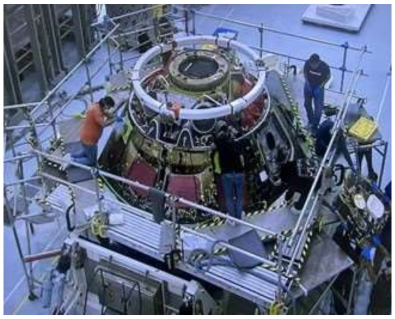
The difference between the total budget and the MPAR LCC estimate is the total budget includes content outside of Artemis II and excludes CoF; LCC only includes Artemis II content, including CoF.

The total budget prior line represents FY 2011 pre-formulation and FY 2012 - FY 2021 budgets, excluding CoF and additional expenditures from 2005-2011 under the Constellation program.

The NASA Administrator has determined that, in the interest of ensuring the safe and successful execution of the early Artemis flights, managing risk effectively, and maintaining resiliency and flexibility for future missions exploration requirements, NASA has made a decision to no longer transition programs that complete their research and development phase in the Exploration Systems Development Mission Directorate to the Space Operations Mission Directorate for their operational phase.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations



Refurbished Artemis I's Non-Core avionics are being installed on Artemis II Crew Module, shown here.

PROJECT PURPOSE

Orion is a deep space exploration vehicle that will be capable of transporting humans to orbit around the Moon, sustaining them for longer durations beyond low-Earth orbit than ever before, providing emergency abort capability, and returning them safely to Earth. Drawing from more than 60 years of human spaceflight research and development, as well as stimulating new and innovative manufacturing and production capabilities, Orion's design will meet the evolving needs of our Nation's space program.

After the successful uncrewed launch of Artemis I on November 16, 2022, NASA is focusing on the completion of Artemis II, the first crewed Space Launch System (SLS) flight, and the preparation required for Artemis III and Artemis IV. The Artemis I mission was the first integrated flight test of the Orion spacecraft, the SLS launch vehicle, and ground systems.

For more information, go to http://www.nasa.gov/orion

EXPLANATION OF MAJOR CHANGES IN FY 2024

The proposed funding levels sufficiently allow the program to support Artemis II and III launches as soon as is technically feasible. Due to the Artemis I launch delay, NASA is re-assessing the Artemis II target launch date. The current target launch date for Artemis II is no earlier than (NET) November 2024.

PROJECT PARAMETERS

Orion is the vehicle that will fly astronauts from Earth to orbits around the Moon and back again. Orion will be able to carry a crew of four astronauts to cislunar space and beyond, as well as provide habitation and life support for up to 21 days. The spacecraft's four elements are the Crew Module (CM), the Crew Module Adaptor (CMA), the European Service Module (ESM), and the Launch Abort System (LAS). Lockheed Martin is building the CM, sometimes referred to as the capsule, which provides the living space on missions for the crew. Lockheed Martin is also building the CMA, which connects the capsule to the ESM and houses electronic equipment for communications, power, and control. The European Space Agency (ESA) is designing and developing the ESM, which provides in-space power, propulsion, and other life support systems. During launch, the ESM is attached to the spacecraft adapter which joins it to the Space Launch System (SLS) launch vehicle. Once SLS has delivered the Orion spacecraft to the desired orbit, the integrated Orion spacecraft separates from the SLS launch vehicle. The mounting of the CM, CMA, ESM, and spacecraft adaptor together is referred to as the Crew and Service Module (CSM). Atop the CSM will sit the LAS, which will activate within milliseconds to propel the CM to safety away from the launch vehicle in the event of an emergency during launch or ascent to orbit. The abort system also provides a protective shell that shields the CM from dangerous atmospheric loads and heating during ascent. Once Orion is out of the Earth's atmosphere and safely on its way to orbit, the spacecraft will jettison the LAS.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Orion's first mission was Artemis I, an uncrewed flight test that demonstrated many key Orion spacecraft capabilities. The capsule successfully splashed down on December 11, 2022. The next mission, Artemis II, is a crewed test flight, with a current mission profile of transporting up to four crewmembers on a free return trajectory around the Moon. For Artemis III, the first Artemis mission to the lunar surface, the Orion spacecraft will rendezvous and dock with the Human Landing System (HLS) spacecraft. The crew and necessary equipment will transfer from the Orion spacecraft into the HLS, which will then undock, descend, and land on the lunar surface. At the conclusion of the lunar surface operations, the HLS will lift off from the lunar surface and re-dock to the Orion spacecraft where the crew will transfer back into Orion for their safe return to Earth. Although the module has a familiar visual shape, its interior and exterior capabilities far exceed any similar predecessors. The crew systems will provide a safe environment for astronauts to live and work for 21 days during missions far from Earth. Orion’s advanced heat shield will protect the crew during a high-speed reentry into Earth's atmosphere. Temperatures will exceed that experienced by any human spacecraft in more than five decades. For Artemis IV and subsequent lunar missions, Orion will dock with the Gateway in a near-rectilinear halo orbit around the Moon, giving astronauts access to more areas of the lunar surface and better communication capabilities than the Apollo program.

ACHIEVEMENTS IN FY 2022

The Launch Abort System Facility (LASF) processing of the Artemis I spacecraft concluded with Thermal Protection System (TPS) closeout tasks and final vehicle inspections in October 2021. This was followed by Artemis I Orion roll-out to the Vehicle Assembly Building (VAB) for mating of the Orion spacecraft to the SLS rocket, which was also completed in October 2021.

A series of Artemis I integrated tests across the rocket, spacecraft, and Exploration Ground System (EGS) were completed in the VAB in January 2022. Based on insights gained from the integrated stack's performance with launch operations systems, a few additional tasks were performed prior to final vehicle close-outs and Flight Termination System (FTS) testing in preparation for the culminating integrated test known as the Wet Dress Rehearsal (WDR).

Orion successfully completed its pre-Flight Readiness Review (pre-FRR) for Artemis I in January 2022. Which confirmed the program's internal readiness for launch before the integrated Artemis I FRR.

Orion completed Artemis II CMA wire harness and subsystem installations in October 2021, the final step prior to mating with the ESM, which was provided by the ESA. The ESM-2 was delivered to Kennedy Space Center (KSC) in the same month. The ESM-2 and CMA were mated to form the Service Module-2 (SM-2) in November 2021. After mating, the SM underwent clean room operations for Environmental Control and Life Support Systems (ECLSS) welding, followed by proof pressure and leak tests, which was completed in May 2022. Assembly, integration, and processing of the SM continued with Initial Power On (IPO) in August 2022 followed by functional testing.

Subsystem installations on the Artemis II CM continued throughout FY 2022. The side hatch, which the crew will use to ingress and egress the CM, was delivered in November 2021. Most of the CM hardware had been installed in FY 2022

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Avcoat installation on the Artemis II heatshield was completed in February 2022. Avcoat is the ablative heatshield material that will protect the crewed spacecraft as it experiences temperatures up to 5,000 degrees Fahrenheit during high-speed re-entry into the Earth's atmosphere.

The Artemis II LAS's Motor Adapter Truss Assembly (MATA) was delivered in June 2022. Fabrication of the LAS ogives and MATA progressed at Michoud Assembly Facility (MAF) throughout FY 2022. The ogives are protective panels that will shield the crew module from the severe vibrations and sounds it will experience during launch.

Integrated testing of software build 204 for the on-orbit portion of the Artemis II mission was performed from August 2021 to July 2022. Formal release of software build 204 occurred in April 2022. The Orion spacecraft uses a significant amount of software for commanding functions, monitoring, and transmitting data, performing fault detection and response, and other tasks. Testing of the flight software is critical to safety and mission success.

The Artemis II translational hand controllers were delivered in September 2022 for installation in the CM. It provides the capability of manual commanding simultaneous accelerations along the spacecraft axes.

The Human-In-The-Loop (HITL) cabin testing completed in December 2021. It was a critical test to support Artemis II crewed mission, ensuring that spacecraft systems meet human compatibility and safety requirements. This is part of the broader and on-going HITL testing regime.

The Artemis III pressure vessel was delivered to KSC in October 2021, followed by build-up of the CM structure. The proof pressure and leak testing of the CM pressure vessel was completed in March 2022.

Artemis III CMA aft walls were delivered to KSC in October 2021, with forward and outboard walls and other structural elements delivered in the following months in support of primary and secondary structure assembly, which was completed in September 2022.

A large number of Artemis III components were delivered to KSC in FY 2022, in support of the Artemis III CM and CMA subassembly installation schedules, including installation of secondary structures, components, harnesses, tubing, and tube welding.

The Artemis III heatshield carrier structure was completed in June 2022 and delivered to KSC to begin Avcoat installation.

Six NASA-provided auxiliary engines were shipped to the ESA prime contractor's facility in Bremen, Germany, in October 2021, and the remaining two were delivered in December 2021 for integration into ESM-3. Due to modifications to the ESM design for Artemis III and beyond, a delta Critical Design Review (dCDR) was conducted, and the initial board meeting was held in February 2022. Final closeout of the dCDR was completed in November 2022.

The Orion program began fabrication of the Artemis IV pressure vessel at MAF in February 2022. This capsule will be the first to fly on the new SLS Block 1B launch vehicle configuration. The capsule will be co-manifested with Gateway's International Habitation Module.

Orion initiated contract authorization for Artemis VI-VIII in September 2022. This will start long lead procurement for subcontracts and materials. Ordering the spacecraft in lots of three allows NASA to benefit from efficiencies that become available in the supply chain over time that optimize production and lower costs.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

WORK IN PROGRESS IN FY 2023

Artemis I was successfully launched on November 16, 2022. The Orion capsule splashed down in the Pacific Ocean off the coast of Baja, California on December 11, 2022, wrapping up its 25.5 day mission to lunar orbit and back. The mission took the Orion spacecraft beyond the Moon and demonstrated its performance capabilities during launch, transit to lunar orbit, return to Earth, re-entry, landing, and recovery.

The Orion program began post-flight analyses to assess spacecraft performance against flight test objectives. The program is recovering certain non-core avionics components from the returned spacecraft for reuse on the Artemis II mission. Those returned components will be refurbished and delivered to KSC by February 2023 for installation into the Artemis II CM. Re-use of components is planned for future missions to reduce assembly costs of subsequent Orion builds and is a key feature of the Orion Production Operation Contract (OPOC).

Artemis II's CM outfitting continues at KSC. Following installation of new and refurbished non-core avionics into the CM, the Artemis II heatshield will be installed in April 2023. Final testing and closeout of the Artemis II CM will be completed by June 2023.

Artemis II's SM functional testing and closeout will be completed in April 2023. The CM and SM will be mated to form the CSM and will undergo final installations and testing. Artemis II CSM IPO will take place in August 2023.

Delivery of the Artemis II LAS Ogive panels to KSC is planned for August 2023. Lockheed Martin will complete assembly, integration and testing of the Artemis II LAS and deliver the system to NASA in September 2023.

The Orion spacecraft uses a significant amount of software for commanding functions, monitoring systems, transmitting data, performing fault detection and response, and other tasks. Testing of the flight software is critical to safety and mission success. Formal release of software build 205 to support ascent/abort scenarios will be completed in September 2023

Orion will conduct integrated testing of ECLSS and the Orion Crew Survival System Suit (OCSS) in the Orion Life Support Integration Facility (OLIF) at the NASA Johnson Space Center (JSC) to further validate the performance of these systems in preparation for the crewed Artemis II mission. OLIF testing will take place July thru October 2023. HITL testing of Artemis II displays and controls will begin in FY 2023 and will continue into Q1 FY 2024.

Artemis III's CM assembly, integration, and testing will continue throughout FY 2023. Installations of the secondary structure, and part one of ECLSS and propulsion components will be completed by April 2023.

Key functional components of the Rendezvous, Proximity Operations, Docking (RPOD) system will be delivered throughout FY 2023. The system enables critical rendezvous, proximity operations, docking, and undocking operations.

Artemis III's CMA secondary structure installations, clean room operations, ECLSS and propulsion systems proof pressure and leak testing will be completed in January 2023. CMA wire harness and subsystem installations will follow and will be completed in May 2023. The CMA will be ready to mate with ESM-3 in late FY 2023.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Delivery of the ESM-3 to KSC is planned for first quarter of FY 2024. The Artemis III ESM and CMA will be mated to form the SM and will undergo final installation and testing for the next few subsequent months.

The Artemis IV pressure vessel welding is in progress and will be delivered to KSC in March 2023. Following delivery of the Artemis IV pressure vessel and primary structure parts to KSC, the Orion program will continue with structural assembly, proof test, and subsystem installations on the CM throughout FY 2023.

In August 2023, the Orion program will conduct a Preliminary Mission Integration Review (MIR) for Artemis IV docking system components. It is a milestone focused on ensuring all necessary mission specific requirements and objectives have been defined and are within the designed system capabilities. The review is also a check point to ensure that Orion is ready to proceed to development of mission specific products.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

Orion will complete OLIF testing of the ECLSS in preparation for Artemis II in October 2023. The program will also complete HITL testing of displays and controls in Q1 FY 2024.

The Artemis II CSM will undergo final assembly, installation, testing and closeouts in FY 2024. The CSM will be handed over to EGS for stacking and integration with the SLS launch vehicle NET Q3 FY 2024.

Environmental Test Article (ETA) testing will be performed to certify the spacecraft to abort loads for crewed missions, beginning with Artemis II. ETA testing will be completed by Q4 FY 2024.

The NASA Docking System (NDS), which provides the capability for the Orion spacecraft to dock to a Gateway or HLS element for Artemis III and later missions, will be delivered to KSC by November 2023. These key components and associated software, will support the planned IPO and subsequent testing of the CM in the Operation and Checkout (O&C) building for Artemis III in May 2024

A key high fidelity, Six-Degree-of-Freedom Test System (SDTS) of the RPOD system, complete with docking cameras and sensors, will be conducted at a Lockheed Martin facility in Denver, Colorado. These tests will demonstrate the safety-critical operation of the RPOD hardware and software in the dynamic proximity operations environment.

Final testing and closeout of the Artemis III CM will be completed in Q4 FY 2024. The CM will then be ready to mate with the Artemis SM to form the CSM.

The Artemis III SM will undergo final installations and testing, then it will be ready to mate with the CM in Q4 FY 2024.

Initial integration of the Artemis III LAS will be started in April 2024 with functional testing starting in September 2024.

Delivery of Artemis V pressure vessel parts to MAF is planned for March 2024.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2024 PB Request
System Design Review (SDR)	Aug 2007	Aug 2007
Preliminary Design Review (PDR)	N/A	Aug 2009
Key Decision Point-A (KDP-A)	Feb 2012	Feb 2012
Resynchronization Review	N/A	Jul 2012
KDP-B	Q1 FY 2013	Jan 2013
Delta PDR	Q4 FY 2013	Aug 2014
Exploration Flight Test-1 (EFT-1) Launch	Dec 2014	Dec 2014
KDP-C, Project Confirmation	FY 2015	Sep 2015
Critical Design Review (CDR)	Oct 2015	Oct 2015
Ascent Abort-2 (AA-2) Flight Test	FY 2020	Jul 2019
Artemis I Launch Readiness	FY 2018	Nov 2022
Artemis II Launch Readiness	Apr 2023	NET Nov 2024

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Development Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2015	6,768.4	70	2022	9,301.2	+37.4	Artemis II	Apr 2023	NET Nov 2024	19

The above revised baseline cost and Launch Readiness Date were approved by the Agency Program Management Council per section 103 of the NASA Authorization Act of 2005 (P.L. 109-155)

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)*	Change from Base Year Estimate ($M)
TOTAL:	**6,768.4**	**9,298.5**	**+2,530.1**
Mission Operations	281.6	412.8	+131.2
Program Management	671.5	1,097.8	+426.3
Safety and Mission Assurance	191.4	205.6	+14.2
Spacecraft and Payload	3,205.1	6,083.2	+2,878.1
Systems Engineering and Integration	539.3	746.1	+206.8
Test and Verification	460.6	619.0	+158.4
Other Direct Project Costs	1,418.9	134.0	-1,284.9

Program unallocated future expenses (UFE) was held in "Other" category in the base year estimate and realigned to other elements as the program matured.

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Crew Module	The crew module provides a safe habitat for the crew, as well as storage for consumables and research instruments, and it serves as the docking port for crew transfers.	Provider: JSC Lead Center: JSC Performing Center(s): Ames Research Center (ARC), Glenn Research Center (GRC), JSC, and LaRC Cost Share Partner(s): N/A	N/A
Service Module	The service module, the powerhouse that fuels and propels the Orion spacecraft, will support the Crew Module from launch through separation before reentry.	Provider: ESA Lead Center: GRC Performing Center(s): ARC, GRC, JSC, and LaRC Cost Share Partner(s): ESA	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Launch Abort System	The launch abort system maneuvers the Crew Module to safety in the event of an emergency during launch or climb to orbit.	Provider: JSC Lead Center: LaRC Performing Center(s): JSC, LaRC, and Marshall Space Flight Center (MSFC) Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: The Artemis II Crew Module Assembly Integration and Processing timeline are delayed, Then: The Artemis II CSM handover date to EGS will be impacted.	Teams are assessing opportunities to streamline the time from non-core avionics installation through Crew Module completion by accelerating work while the non-core avionics are refurbished, resulting in overall schedule savings.
If: Artemis III+ Orion suppliers and/or Assembly Integration and Processing work experience delays, Then: Final integration and Orion spacecraft deliveries to EGS for launch processing could be delayed.	Over the past two and a half years, production efforts have been impacted by the pandemic's direct effect on workforce as well as the workforce changes and attrition. This has been particularly noticeable in certain high skilled jobs, such as technicians. These same issues impact the Orion's international partners and supply chain flow of parts and materials into the program. To minimize impacts, Orion's integrated teams have adjusted the flow of activities and production/integration shifts to minimize delays in production and the integration critical path flow. The program will continue to reassess activity timing, opportunities to improve integration efficiency, and increased workforce in critical areas to maintain production and integration progress, but workforce and supply chain challenges remain.

Acquisition Strategy

NASA is using a contract with Lockheed Martin Corporation for Orion's design, development, test, and evaluation. The contract was awarded in 2006 and reaffirmed in 2011 as part of reformulating the Orion Crew Exploration Vehicle as the Orion Program. Orion adjusted this contract to meet NASA and the Human Exploration and Operations Mission Directorate (HEOMD), now Exploration Systems

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Development Mission Directorate (ESDMD), requirements to include the current flight test plan and the Artemis II flight readiness date. Additional Orion spacecraft have been ordered under the Orion Production and Operations Contract (OPOC) awarded in September 2019, which is an indefinite-delivery-indefinite-quantity contract that includes a commitment to order a minimum of six and the option for a maximum of twelve Orion spacecraft over the next 10 years. The first six spacecraft (Artemis III through Artemis VIII) will be acquired by cost-plus-incentive-fee orders. NASA will negotiate firm-fixed-price orders for future missions to take advantage of the anticipated spacecraft production cost decreases.

In addition, to further international cooperation, NASA has agreements with ESA for the delivery of ESMs. In 2012, NASA signed an implementing arrangement with ESA to provide service modules for the Orion spacecraft for Artemis I and later added Annexes 1 and 2 for ESA to provide the ESM for Artemis II. Annex 3 was later added, and ESA is on contract with Airbus to build ESM-3. In October 2020, NASA and ESA signed the Gateway Memorandum of Understanding, committing ESA to ESM-4 and 5. NASA and ESA signed an Implementing Arrangement covering the details of the provision of ESM-4 and ESM-5 in May 2022. Incorporating the partnership with ESA also required a contract modification with Lockheed Martin to integrate the ESA-provided service module with the Lockheed Martin portion of the spacecraft.

For the Service Module main engines, Orion has enough Orbital Maneuvering System Engines (OMS-Es) remaining from the Space Shuttle Program to fly on the ESM through Artemis VI. OMS-E will be replaced by the Orion Main Engine (OME) starting with Artemis VII. The OME contract is a single-award, indefinite-delivery-indefinite-quantity contract with firm-fixed-price orders awarded to Aerojet Rocketdyne to produce these engines.

The FY 2024 President's Budget does not mandate adjustments to contracts and agreements, and NASA expects contractors and partners to perform to their contract/agreement dates.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Orion Design Development, Test and Evaluation (DDT&E); Orion Production and Operations Contract (OPOC)	Lockheed Martin	Littleton, CO
Orion Main Engine	Aerojet Rocketdyne	Redmond, WA

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
System Requirements Review (SRR)	Standing Review Board (SRB)	Mar 2007	To evaluate the program's functional and performance requirements, ensuring proper formulation and correlation with Agency and HEOMD's strategic objectives; assess the credibility of the program's estimated budget and schedule.	Program cleared to proceed to next phase.	N/A
System Design Review (SDR)	SRB	Aug 2007	To evaluate the proposed program requirements and architecture; allocation of requirements to initial projects; assess the adequacy of project pre-formulation efforts; determine if maturity of the program's definition and plans are enough to begin implementation.	Program cleared to proceed to next phase.	N/A
Preliminary Design Review (PDR)	SRB	Sep 2009	To evaluate completeness and consistency of the program's preliminary design, including its projects meet all requirements with appropriate margins, acceptable risk, and within cost and schedule constraints; determine the program's readiness to proceed with the detailed design phase.	Program cleared to proceed to next phase.	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Resynchronization Review	SRB	Jul 2012	To realign the program's preliminary design to the current Exploration Systems Development (ESD) requirements. NASA policies allow changes to a program's management agreement in response to internal and external events. An amendment to the decision memorandum is signed at the KDP-B review held before PDR if a significant divergence occurs.	Program cleared to proceed to next phase.	N/A
Delta PDR	SRB	Aug 2014	To update the program's preliminary design; ensure completeness and consistency; determine the program's readiness to proceed with the detailed design phase.	Program cleared to proceed to next phase.	N/A
Critical Design Review (CDR)	SRB	Oct 2015	To evaluate the integrity of the program integrated design, including its projects and ground systems, its ability to meet mission requirements with appropriate margins and acceptable risk, and that it is planned within cost and schedule constraints; determine if the integrated design is appropriately mature to continue with the final design and fabrication phase for Exploration Mission (EM)-1.	Program cleared to proceed to next phase.	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
ESM CDR	SRB	Oct 2016	To evaluate the integrity of the program integrated design, including its projects and ground systems, its ability to meet mission requirements with appropriate margins and acceptable risk, and that it is planned within cost and schedule constraints; determine if the integrated design is appropriately mature to continue with the final design and fabrication phase for EM-1.	Program cleared to proceed to next phase.	N/A
Critical Integration Review (CIR) / System Integration Review (SIR)	N/A	Nov 2016	To evaluate the readiness of the program, including its projects and supporting infrastructure, to begin system Assembly, Integration, and Testing (AI&T) with acceptable risk, and within cost and schedule constraints.	Program cleared to proceed to next phase.	N/A
Artemis II CDR	Independent Assessment (IA) / Independent Review Team (IRT)	Dec 2018	To evaluate the integrity of the program integrated design, including its projects and ground systems, its ability to meet mission requirements with appropriate margins and acceptable risk, and that it is planned within cost and schedule constraints; determine if the integrated design is appropriately mature to continue with the final design and fabrication phase for EM-2.	Program cleared to proceed to next phase.	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
ESD Artemis I Independent Schedule Assessment	Schedule Assessors from Office of the Chief Financial Officer (OCFO)	Jun 2019	Programmatic assessment and analysis of Artemis I schedules across all ESD programs with an emphasis on program performance and risks.	NASA leadership was briefed on Artemis I launch date options.	N/A
Performance	Inspector General (IG)	Jul 2020	To examine the Agency's management in tracking, reporting overall cost goals of the Orion Multi-Purpose Crew Vehicle Program.	NASA'S Management of the Orion Multi-Purpose Crew Vehicle Program (IG-20-08) IG made three recommendations to increase the sustainability, accountability, and transparency of the Orion Program as it pursues the goal of landing astronauts on the Moon by 2024. These areas covered cost reporting, adjusting production schedules for future missions to align with the Artemis II mission to reduce schedule delays associated with potential rework and improving NASA's management of award fees.	N/A
Performance	Inspector General (IG)	Dec 2020	To address NASA's Aerospace Safety Advisory Panel concerns over the Agency's plans to return-to-the-Moon by 2024.	NASA's Challenges to Safely Return Humans to the Moon by 2024 (IG-21-007) IG identified returning to the Moon as a top management and performance challenge and will continue oversight of NASA's management of the Artemis Campaign and the Agency's human exploration efforts through other audits and reviews.	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	General Accountabi-lity Office (GAO)	Dec 2020	To assess the progress the programs are making towards Artemis I with respect to schedule and cost, and the extent to which the programs are positioned to support the planned Artemis flight schedule beyond Artemis I.	GAO made two recommendations to establish baselines ahead of a key design review and improve internal reporting about capability upgrades for human space exploration programs beyond Artemis I. NASA concurred with the recommendations made in this report.	N/A
ESD Enterprise Integration Review (EIR)	Independent Review Team	Jan 2021	To confirm that flight and ground hardware elements, software, support equipment, facilities, and infrastructure are ready to support assembly, integration, test, and mission operations per the planned schedule for Artemis I.	The IRT confirmed the programs are sufficiently mature to proceed for integrated operations	N/A
Docking Capability CDR	IA/IRT	Apr 2021	To evaluate the integrity of the upgrade's integrated design, including its ability to meet mission requirements with appropriate margins and acceptable risk, and that it is planned within cost and schedule constraints of the broader Orion program; determine if the integrated design is appropriately mature to continue with the final design and fabrication phase for flight on Artemis III.	The docking capability was found to be sufficiently mature to proceed to final design and fabrication; costs were analyzed as part of the Orion program Joint Cost and Schedule Confidence Level analysis and reported as part of the Orion program re-baseline.	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	IG	Apr 2021	To provide an update on the NASA 2020 Artemis Plan.	Artemis Status Update (IG-21-018) - IG will continue to monitor the Agency's efforts towards achieving 2020 Artemis Plan.	N/A
Performance	GAO	May 2021	To assess NASA's ability to accomplish the March 2019 White House direction to accelerate its plans for a lunar landing by four years to 2024.	Significant Work Remains, Underscoring Challenges to Achieving Moon Landing in 2024 (GAO-21-230) - GAO made four recommendations, including that NASA document the process for determining key programmatic and technical tools for the Artemis missions. NASA concurred with three of the recommendations, but not the fourth, which related to the costs included in a lunar rover's cost estimate.	N/A
System Integration Review (SIR)	IA/IRT	May 2021	To assess risks and plans for starting integration of all hardware into the structure to build up the flight vehicle.	The IRT reviewed and approved (technical and programmatic products) for the project to proceed to Phase D.	N/A
KDP-D	IA/IRT	Aug 2021	To assess system assembly, integration, and test; verification / certification; prelaunch activities; launch; and checkout.	The IRT reviewed and granted Orion to proceed with re-baseline cost and schedule.	N/A
Performance	Inspector General	Nov 2021	To assess the Artemis campaign's schedule and projected costs as well as how the Agency's acquisition and programmatic approaches facilitate landing astronauts on the Moon.	NASA's Management of the Artemis Missions (IG-22-003) - IG will continue to monitor acquisition and programmatic approach for Artemis Missions.	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	GAO	Mar 2022	To update NASA's progress and challenges in working towards the first three Artemis missions.	Moon Landing Plans Are Advancing but Challenges Remain (GAO-22-105533) - GAO restated its 10 previous recommendations related to improving NASA's management of its Artemis efforts and related programs. NASA generally agreed with these recommendations and plans to take steps to implement them.	N/A
Operational Readiness Review/ Flight Readiness Review (ORR/FRR) for Artemis II	IA/IRT	NET Mar 2024	To evaluate the readiness of the project to operate the flight system and associated ground system; and support systems for safe and successful launch and flight/mission.	N/A	N/A
Launch Readiness Date/Initial Operations Capability (LRD/IOC) for Artemis II	IA/IRT	NET May 2024	To assess all capabilities of the vehicle to support the readiness to launch.	N/A	N/A

SPACE LAUNCH SYSTEM

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Launch Vehicle Development	2,526.9	2,361.4	**2,427.2**	2,365.8	2,206.7	1,804.6	1,798.8
SLS Program Integration and Support	73.1	--	**78.9**	117.5	115.7	112.5	170.3
Total Budget	**2,600.0**	**2,600.0**	**2,506.1**	**2,483.3**	**2,322.4**	**1,917.1**	**1,969.1**
Change from FY 2023 Enacted			**-93.9**				
Percent change from FY 2023 Enacted			**-3.6%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Shown above, NASA's SLS rocket carrying the Orion spacecraft successfully launched on November 16, 2022, at 1:47 a.m. EST from Launch Complex 39B at NASA's Kennedy Space Center in Florida. NASA's Artemis I mission was the first integrated flight test of the Orion spacecraft, Space Launch Systems vehicle, and Exploration Ground Systems.

NASA demonstrated the launch capabilities of the Space Launch System (SLS) heavy-lift vehicle with the successful launch of Artemis I in November 2022. SLS precisely delivered the Orion spacecraft on its desired trajectory to the Moon. The SLS program will enable transportation beyond low-Earth orbit, to the Moon, and eventually to Mars.

SLS plays an integral role in the Artemis Campaign as the human-rated launch system capable of sending the crewed Orion spacecraft to the Moon. This launch system will be used in each of the Artemis missions, beginning with Artemis I, however, its capabilities will evolve into more powerful configurations (Block 1B by Artemis IV, Block 2 by Artemis IX) to address component obsolescence issues and to meet the launch capability needs of future missions. The Agency will continue to identify and implement affordability strategies to help SLS become a sustainable exploration capability used by subsequent Artemis missions. The proposed funding levels are sufficient to allow the program to support Artemis II and III launches as soon as is technically feasible. Due to the Artemis I launch delay, NASA is re-assessing the Artemis II target launch date. The current target Launch Readiness Date (LRD) for Artemis II is no earlier than NET November 2024.

SLS relies on other capabilities, such as those provided by the Space Operations Mission Directorate's Space Communications and Navigation program as its telemetry communications capability provider. SLS relies on the Exploration Ground System's capabilities to assemble and safely launch the vehicle. SLS's capabilities will enable for the safe delivery of humans and larger volumes of cargo than ever before to deep space on future Artemis missions.

For more information, go to: http://www.nasa.gov/exploration/systems/sls/index.html

SPACE LAUNCH SYSTEM

Program Elements

SLS PROGRAM INTEGRATION AND SUPPORT

SLS Program Integration and Support activities manage the program interfaces between Orion and the Exploration Ground Systems. This effort is critical to ensuring the SLS systems' performance meets technical and safety specifications, and supports programmatic assessments key to achieving integrated technical, cost, and schedule management. In addition, the SLS integration effort is vital to managing interfaces with other Exploration Systems Development Mission Directorate (ESDMD) and Space Operations Mission Directorate (SOMD) activities, including strategic studies, feasibility studies, and small-scale research tasks that feed into future human exploration. Coordination and timely integration across ESDMD and SOMD are critical and aimed at mitigating the impacts of potential design overlaps, schedule disconnects and delays, and cost overruns.

LAUNCH VEHICLE DEVELOPMENT

The Launch Vehicle Development project developed the SLS launch vehicle to enable deep space exploration and support production and sustainment for future flights. See the Launch Vehicle Development section beginning on the next page for additional details.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

FY 2024 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028	BTC	Total
Formulation	2,674.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	2,674.0
Development/Implementation	8,921.4	177.2	6.2	**0.0**	0.0	0.0	0.0	0.0	0.0	9,104.8
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2023 MPAR LCC Estimate	**11,595.4**	**177.2**	**6.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**11,778.8**
Total Budget	**0.0**	**2,526.9**	**2,361.4**	**2,427.2**	**2,365.8**	**2,206.7**	**1,804.6**	**1,798.8**	**0.0**	**15,491.4**
Change from FY 2023 Enacted				**65.8**						
Percent change from FY 2023 Enacted				**2.8%**						

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The difference between the total budget and the MPAR LCC estimate is the total budget includes content outside of Artemis I and excludes CoF; LCC only includes Artemis I content, including CoF.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

NASA's Space Launch System (SLS) rocket (shown above), carrying the Orion spacecraft, successfully launches the Artemis I flight test on Wednesday, November 16, 2022, from Launch Complex 39B at NASA's Kennedy Space Center (KSC) in Florida.

PROJECT PURPOSE

The Space Launch System (SLS) launch vehicle serves as the primary crew transportation capability for the Artemis Campaign, and when upgraded to the Block 1B variant will also carry cargo to orbit. For the first time since the Apollo program in 1972, American astronauts will explore space beyond low-Earth orbit (LEO) and return to the Moon, reinvigorating America's human exploration of the solar system.

After the successful uncrewed launch of Artemis I on November 16, 2022, NASA is focusing on the completion of Artemis II, the first crewed SLS flight, and the preparation required for Artemis III and Artemis IV. The Artemis I mission was the first integrated flight test of the Agency's deep space exploration systems: the Orion spacecraft, the SLS launch vehicle, and the ground systems.

For more information, go to: http://www.nasa.gov/exploration/systems/sls/index.html

EXPLANATION OF MAJOR CHANGES IN FY 2024

The proposed funding levels sufficiently allow the program to support Artemis II and III launches as soon as is technically feasible. Due to the Artemis I launch delay, NASA is re-assessing the Artemis II target launch date. The current target launch date for Artemis II is NET November 2024.

PROJECT PARAMETERS

The SLS launch vehicle will evolve its capabilities throughout the Artemis Campaign. The first three launches, including the Artemis I mission which successfully launched in November 2022, will feature the SLS Block 1 configuration which incorporates a human-rated Interim Cryogenic Propulsion Stage (ICPS). NASA will continue development of the SLS Block 1B configuration with the Exploration Upper Stage (EUS) for a first flight on Artemis IV. When heritage booster segments from the Space shuttle program are used up after Artemis VIII the new Booster Obsolescence and Life Extension (BOLE) boosters associated with Block 2 performance will be implemented. This block evolution approach focuses NASA and its contractors on successfully delivering and flying the SLS Block 1 launch vehicle before folding in the additional Block 1B and Block 2 developments.

The primary components of the SLS Block 1 launch vehicle include the Launch Vehicle Stage Adapter (LVSA), the ICPS, the core stage and avionics, two five-segment solid rocket boosters, and four RS-25 engines.

The SLS core stage is over 200 feet tall and is responsible for storing the cryogenic liquid hydrogen (LH2) and liquid oxygen (LOX) and all the systems that feed the stage's four RS-25 engines. The core

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

stage contains five primary subcomponents: the forward skirt, liquid oxygen tank, intertank, liquid hydrogen tank, and engine section. The engine section is the attach point for the four RS-25 engines, which combined with the boosters, produces a maximum thrust of 8.8 million pounds. On each side of the core stage, the five-segment solid rocket boosters stand 17 stories tall and burn six tons of propellant per second. The boosters connect via the intertank and engine section attach points and augment initial thrust for the first two minutes of flight. Atop the core stage sits the LVSA, which encapsulates the ICPS and connects the core stage to the Orion Stage adaptor and Orion spacecraft stack. The LVSA provides structural support for launch and separation loads and protects propulsion system electrical components.

The Launch Vehicle Development project leverages hardware designed for heritage programs, including adapted and refurbished Space Shuttle RS-25 main engines, five-segment Shuttle-derived solid rocket boosters, and an ICPS derived from the Delta Cryogenic Second Stage (DCSS). The program benefits from NASA’s over half-century of experience and knowledge of liquid oxygen and hydrogen heavy-lift launch vehicles, large solid rocket motors, and advances in technology and manufacturing practices, such as friction stir welding. The SLS launch vehicle generates a total thrust at liftoff greater than that of the Saturn V rocket used in the Apollo program.

The launch vehicle development follows a block evolution framework where the core stage will serve as the common component in all future configurations. The Block 1 configuration, which is the configuration successfully flown in Artemis I, stands at 322 feet and features a lift capability of over 27 metric tons to Trans-Lunar Injection (TLI) for Moon missions. With this performance, the SLS Block 1 configuration can send the Orion spacecraft towards the Moon. This SLS configuration allows Orion to demonstrate deep space technologies and hardware required for Earth-independent missions.

The planned evolution of the SLS architecture to the SLS Block 1B configuration will increase the size and payload to orbit capabilities. The SLS Block 1B configuration will stand 365 feet and be capable of delivering at least 37 metric tons for crew and cargo to TLI. As a result, the SLS Block 1B configuration can send Orion and up to 10.3 metric tons of additional payloads to TLI starting with the Artemis IV mission. To be able to do this, the Launch Vehicle Development team will exchange the ICPS for an EUS, as well as the LVSA for an Universal Stage Adapter (USA) and Payload Adapter (PLA) to support Co-Manifested Payloads (CPLs).

When the flight manifest depletes the heritage SRB components currently available after Artemis VIII, the SRB design for additional Block 2 performance upgrades will be accomplished primarily by producing new composite boosters in lieu of the heritage metallic casing used in the Shuttle program, increasing motor pressure, and extending Booster nozzle length through the BOLE development work happening within the program. The propellant is changing from polybutadiene acrylonitrile (PBAN) to hydroxyl-terminated polybutadiene (HTPB). This is a major change to the design that also contributes to improved performance.

ACHIEVEMENTS IN FY 2022

The SLS Program and Orion program supported the Exploration Ground System's four Wet Dress Rehearsals (WDRs) and one tanking test for the Artemis I vehicle in FY 2022. The WDRs exercised flight operations at the launch pad, for example filling tanks and chilling engines, prior to the actual

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

launch of the vehicle. The Program Pre-Flight Readiness Review (FRR) in Feb 2022 and Agency FRR in August 2022 were also conducted. These reviews assessed all processing, testing, and analyses for Artemis I and determined the vehicle was ready for flight.

In addition to Artemis I activities, the SLS Program continues manufacturing future Artemis missions. The liquid engines for Artemis II are complete and were delivered to Michoud Assembly Facility (MAF) in FY 2022 in preparation for core stage integration in FY 2023. The solid rocket booster segments for Artemis III were also completed in FY 2022 and are now in storage. Block 1B, to be implemented on Artemis IV, conducted the review period for the Critical Design Review (CDR) in FY 2022 in preparation for the CDR Board that was completed in early FY 2023.

The Booster Element Office (BEO) has also definitized the contract for the Booster Production and Operations Contract (BPOC) contract which will execute the design, manufacture, and testing of the Artemis IX solid rocket boosters with significant upgrades from the current booster design.

WORK IN PROGRESS IN FY 2023

After successful preparations throughout FY 2022, Artemis I was successfully launched on November 16, 2022. Artemis II assembly continues throughout FY 2023. The LVSA was completed in February 2023. Core Stage 2 completion and delivery to KSC is scheduled for May 2023. ICPS Delta Operations Center (DOC) activities will complete in June 2023. Final checkout and acceptance testing of the ICPS (e.g., Inertial Navigation and Control Assembly install and power-on testing) is performed at the DOC at the Cape Canaveral Space Force Station.

Each SLS element office has production activities for missions beyond Artemis II in work as well.

The Stages Production and Evolution Contract (SPEC) was definitized in December 2022. Under this contract, Boeing will produce SLS core stages for Artemis III and IV, procure critical and long-lead material for the core stages for Artemis V and VI, provide the EUS for Artemis V and VI, as well as tooling and related support and engineering services. The contract comes as Boeing optimizes manufacturing capabilities using KSC in Florida to perform some specific core stage assembly and outfitting activities beginning with the Artemis III rocket (a Memorandum of Agreement was signed in October 2022 allowing for this subset of core stage processing to occur at KSC). In tandem, teams will continue all remaining core stage manufacturing activities at the Michoud Assembly Facility in New Orleans.

The CDR Board for the Block 1B KDP-C was held November 3, 2022. Manufacturing of EUS elements will continue in FY 2023. The program will continue the build of EUS Structural Test Articles (STA) and begin manufacturing on the LH2 and LOX Tanks for flight. A Block 1B Flight Software CDR is planned for June 2023.

For Artemis I through Artemis IV, the liquid engines are heritage engines from the Space Shuttle Program. For Artemis V and beyond, the liquid engines will be built using new design and manufacturing improvements. The Liquid Engine Office will complete the build of the RS-25 certification engine and start a series of tests beginning in December 2022 to verify it for flight. The certification engine is the first engine of the re-started RS-25 assembly line. The Design Certification Review (DCR) for the new RS-25 is scheduled for first quarter FY 2023.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

KEY ACHIEVEMENTS PLANNED FOR FY 2024

The final assembly, integration and test of SLS hardware for Artemis II will occur at KSC in preparation for launch. Artemis II will be the first crewed launch of the SLS rocket and the Orion spacecraft.

In FY 2024, production will continue for Artemis III and beyond missions as well. The LVSA, OSA, and ICPS for Artemis III will be completed. The BEO complete the Artemis IV segments. BEO expects to test the first full scale BOLE test motor as part of the BPOC contract and conduct the PDR for BOLE in FY 2025. EUS will also begin the structural testing with the STA and complete the flight hardware and prepare it to ship to Stennis Space Center (SSC) for Green Run testing.

Schedule Commitments/Key Milestones

Milestone	Confirmation Baseline Date	FY 2024 PB Request
Key Decision Point-A (KDP-A)	Nov 2011	Nov 2011
Formulation Authorization	May 2012	May 2012
System Requirements Review (SRR)	May 2012	May 2012
KDP-B Agency Project Management Council (APMC)	Jul 2012	Jul 2012
Preliminary Design Review (PDR) Board	Jun 2013	Jun 2013
KDP-C APMC	Jan 2014	Jan 2014
Critical Design Review (CDR) Board	Jul 2015	Jul 2015
Design Certification Review	Sep 2017	Sep 2021
Artemis I Launch Readiness	Nov 2018	Nov 2022

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Mileston e Data	Current Year Milestone Data	Milestone Change (months)
2015	6,390.4	70%	2022	9,104.8	+29.8%	Artemis I Launch Readiness	Nov 2018	Nov 2022	48

Note: NASA continues to review past reporting, and estimates do not necessarily accurately incorporate actual expenditures to date. Additionally, cost and confidence levels do not reflect the cost impacts of currently anticipated schedule delays. The estimates are expected to increase as NASA assesses the impacts of further delays and updates reporting on expenditures. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**6,390.4**	**9,104.8**	**+2,714.4**
Stages Element	3,138.6	5,160.8	+2,022.2
Liquid Engines Office*	567.3	505.9	-61.4
Booster Element	1,090.3	1,058.2	-32.1
Spacecraft Payload Integration and Evolution (SPIE)	447.1	667.5	+220.4
Other	1,147.1	1,712.4	+565.3

**The Agency Baseline Commitment previously included fixed and shared costs with the RS-25 production restart activity (in the Liquid Engines Office), which supports Artemis I and later missions. SLS removed those costs from the estimate and significantly lowered the Artemis I Liquid Engines Office and Base Year Development Cost Estimate.*

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Booster	Responsible for development, testing, production, and support for the five-segment solid rocket motor to be used on initial capability flights.	Provider: Marshall Space Flight Center (MSFC) Lead Center: MSFC Performing Center(s): MSFC Cost Share Partner(s): N/A	N/A
Engines	Responsible for development and/or testing, production, and support for both core stage (RS-25) and upper stage liquid engines.	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC; SSC Cost Share Partner(s): N/A	N/A
Block 1B Development Office	Responsible for development, testing, and production of the initial Exploration Upper Stage, as well as development for the Autonomous Flight Safety System (AFSS).	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC/MAF; SSC Cost Share Partner(s): N/A	N/A
Stages	Responsible for development, testing, production, and support of hardware elements, including core and upper stages, liquid engine integration, and avionics integration.	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC/MAF; SSC Cost Share Partner(s): N/A	N/A
Spacecraft Payloads and Integration	Responsible for development, testing, production, and support of hardware elements for integrating the Orion spacecraft and payloads onto SLS, including the ICPS, OSA, LVSA, USA, and payload fairings.	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC, Langley Research Center (LaRC), Glenn Research Center (GRC), and KSC Cost Share Partner(s): N/A	N/A

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Project Risks

Risk Statement (Ranked in Sequential order)	Mitigation
If: SLS suppliers and/or Assembly Integration and Processing work experience delays, Then: Final integration and SLS Launch Vehicle deliveries to Exploration Ground Systems for launch processing could be delayed.	Production efforts have been impacted by the pandemic's direct effect on workforce as well as the workforce changes and attrition experienced in the years since the pandemic started. This has been particularly noticeable in certain high skilled jobs, such as technicians. These same issues impact the SLS's supply chain flow of parts and materials into the program. To minimize impacts, SLS's teams have adjusted the flow of activities and production/integration shifts to minimize delays in production and the integration critical path flow. The program will continue to reassess activity timing, opportunities to improve integration efficiency, and increased workforce in critical areas to maintain production and integration progress, but workforce and supply chain challenges remain.
If: Projected inflationary rise in prices for labor and materials is fully realized, Then: The purchasing power of the SLS Program could experience funding inefficiencies, cost, and schedule growth.	Purchasing power for the SLS Program has been affected by recent inflation experienced in all industries. Material and labor costs are projected to see a steep rise over the upcoming years if the current trend continues. The program will continue to assess the cost and schedule and look for opportunities to save money to maintain the current activities as planned.

Acquisition Strategy

NASA is using contracts with Aerojet Rocketdyne, Boeing Aerospace, Northrup Grumman Innovation Systems, Teledyne Brown Engineering Inc. and United Launch Alliance for the production and design, development, test, and evaluation of the elements that make up the SLS launch vehicle. These elements include the Core and Upper stages, Solid Rocket Boosters, the Interim Cryogenic Propulsion Stage (ICPS), the Core Stage Engines (RS-25s), the Upper Stage Engines (RL10s), Universal Stage Adaptor, and the Launch Vehicle Stage Adaptor as applicable to the various SLS Block configurations. SLS utilizes these contracts to meet the Artemis Campaign requirements for the Launch Vehicle. SLS is continuing to review options for future production contracts that will move the program to procure launch vehicles on a service basis.

The FY 2024 President's Budget does not mandate adjustments to contracts and agreements, and NASA expects contractors and partners to perform to their contract/agreement dates.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Procurement for SLS launch vehicle development meets the Agency's requirement to provide an evolvable launch vehicle within a schedule that supports various mission requirements. Procurements include use of existing assets to expedite development and further development of technologies and future competitions for advanced systems and key technology areas specific to SLS launch vehicle needs.

Element	Vendor	Location (of work performance)
Universal Stage Adaptor	Dynetics, Inc.	Huntsville, AL
Launch Vehicle Stage Adaptor	Teledyne Brown Engineering, Inc.	Huntsville, AL
Boosters	Northrop Grumman Innovation Systems	Magna, UT
Core Stage Engine	Aerojet Rocketdyne	Desoto Park, CA; SSC
ICPS	United Launch Alliance under contract to Boeing Aerospace	Huntsville, AL
Stages (Core and Upper)	Boeing Aerospace	New Orleans, LA
Upper Stage Engines	Aerojet Rocketdyne	West Palm Beach, FL

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Preliminary Design Review (PDR)	Standing Review Board (SRB)	Aug 2013	To evaluate the completeness and consistency of the planning, technical, cost, and schedule baselines developed during formulation; assess compliance of the preliminary design with applicable requirements; and determine if the project is sufficiently mature to begin Phase C.	The SRB evaluated the project and determined the project is sufficiently mature to begin Phase C and begin final design and fabrication.	N/A

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Critical Design Review (CDR)	SRB	Jul 2015	To evaluate the integrity of the project design and its ability to meet mission requirements with appropriate margins and acceptable risk within defined project constraints, including available resources. To determine if the design is appropriately mature to continue with the final design and fabrication phase.	The SRB evaluated the project and determined the project is sufficiently mature to progress to major manufacturing, assembly, and integration.	N/A
Exploration Systems Development (ESD) Artemis I Independent Schedule Assessment	Schedule Assessors from Office of the Chief Financial Officer (OCFO)	Jun 2019	Programmatic assessment and analysis of Artemis I schedules and schedule risk across all ESD programs with an emphasis on program performance and risks.	NASA leadership was briefed on Artemis I launch date options.	N/A
Performance	Inspector General (IG)	Mar 2020	To update the status of Core Stages development and examine the remaining major SLS elements and corresponding prime contracts to determine the extent to which the SLS is meeting Artemis 1 cost and schedule goals, that NASA is tracking and appropriately reporting overall cost and schedule goals, and SLS is managing cost and schedule for key contracts.	NASA's Management of Space Launch System Program Costs and Contracts (IG-20-012) NASA concurred with IG recommendations including reviewing Human Exploration and Operations Mission Directorate and program management policies, procedures, and ABC reporting processes; and improvements to contract management, cost accounting and performance monitoring.	N/A
ESD Artemis I Re-baseline	Independent Review Team (IRT)	Apr 2020	Programmatic assessment and analysis of Artemis I schedule and schedule risks of Artemis I launch date and JCL.	Established revised baseline and launch readiness date.	N/A

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	IG	Dec 2020	To address NASA's Aerospace Safety Advisory Panel concerns over the Agency's plans to return-to-the-Moon by 2024.	NASA's Challenges to Safely Return Humans to the Moon by 2024 (IG-21-007) IG identified returning to the Moon as a top management and performance challenge and will continue oversight of NASA's management of the Artemis campaign and the Agency's human exploration efforts through other audits and reviews.	N/A
Performance	General Accountabi-lity Office (GAO)	Dec 2020	To assess the progress the programs are making towards Artemis I with respect to schedule and cost, and the extent to which the programs are positioned to support the planned Artemis flight schedule beyond Artemis I.	GAO made two recommendations to establish baselines ahead of a key design review and improve internal reporting about capability upgrades for human space exploration programs beyond Artemis I. NASA concurred with the recommendations made in this report.	N/A
ESD Enterprise Integration Review (EIR)	IRT	Jan 2021	To confirm that flight and ground hardware elements, software, support equipment, facilities and infrastructure are ready to support assembly, integration, test, and mission operations per the planned schedule for Artemis I.	The IRT confirmed the programs are sufficiently mature to proceed for integrated operations.	N/A

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	IG	Apr 2021	To provide an update on the NASA 2020 Artemis Plan.	Artemis Status Update (IG-21-018) - IG will continue to monitor the Agency's efforts towards achieving 2020 Artemis Plan.	N/A
Performance	GAO	May 2021	To assess NASA's ability to accomplish the March 2019 White House direction to accelerate its plans for a lunar landing by four years to 2024.	Significant Work Remains, Underscoring Challenges to Achieving Moon Landing in 2024 (GAO-21-230) - GAO made four recommendations, including that NASA document the process for determining key programmatic and technical tools for the Artemis missions. NASA concurred with three of the recommendations, but not the fourth, which related to the costs included in a lunar rover's cost estimate.	N/A
Design Certification Review (DCR)	SLS IRT	Sep 2021	To certify the implemented design complies with applicable requirements and necessary verification activities are satisfactorily completed.	This multiple segment process certified the vehicle in preparation for the Artemis I Flight Readiness Review.	N/A
Performance	IG	Nov 2021	To assess the Artemis Campaign's schedule and projected costs as well as how the Agency's acquisition and programmatic approaches facilitate landing astronauts on the Moon.	NASA's Management of the Artemis Missions (IG-22-003) - IG will continue to monitor acquisition and programmatic approach for Artemis Missions.	N/A

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	GAO	Mar 2022	To update NASA's progress and challenges in working towards the first three Artemis missions.	Moon Landing Plans Are Advancing but Challenges Remain (GAO-22-105533) - GAO restated its 10 previous recommendations related to improving NASA's management of its Artemis efforts and related programs. NASA generally agreed with these recommendations and plans to take steps to implement them.	N/A
Performance	IG	Apr 2022	To assess NASA's life-cycle cost estimating and reporting practices and policies for major programs with multiple deliverables.	NASA's Cost Estimating and Reporting Practices for Multi-Mission Programs (IG-22-011) IG made seven recommendations. NASA agree with three of the recommendations and has stated that it is meeting the statutory requirements of Title 51 regarding the reporting of major program life cycle and development costs.	N/A
Performance	GAO	Jun 2022	This report describes the cost and schedule performance of NASA's major projects and GAO's assessment of these projects' technology development and design stability. The report also includes individual assessments of the major projects.	NASA: Assessments of Major Projects (GAO-22-105212) GAO made multiple recommendations to improve NASA's management of its major projects. NASA agreed with most of those recommendations and implemented many changes.	N/A

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Operational Readiness Review/ Flight Readiness Review (ORR/FRR) for Artemis I	Independent Assessments (IA)/IRT	Aug 2022	To evaluate the readiness of the project to operate the flight system and associated ground system; and support systems for safe and successful launch and flight/mission.	Conducted an in-depth assessment of the readiness of the Agency's Space Launch System and Orion spacecraft to support the uncrewed flight of Artemis I on its mission beyond the Moon and return to Earth	N/A
Performance	GAO	Sep 2022	To assess the extent to which NASA (1) is managing mission integration risks; (2) developed Artemis mission-level schedules; and (3) assessed the ability of the Artemis workforce to manage and oversee lunar landing missions.	NASA Lunar Programs: Improved Mission Guidance Needed as Artemis Complexity Grows (GAO-22-105323). GAO is making four recommendations, including that NASA develop Artemis mission-level schedule management guidance and develop guidance on conducting Artemis workforce scenario planning. NASA concurred with all four of the recommendations.	N/A
Launch Readiness Date/Initial Operations Capability (LRD/IOC) for Artemis I	IA/IRT	Nov 2022	To assess all capabilities of the vehicle to support the readiness to launch.	Successful launch on November 16th, 2022.	N/A

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
B1B Critical Design Review (CDR)	SRB	Nov 2022	To evaluate the integrity of the project design and its ability to meet mission requirements with appropriate margins and acceptable risk within defined project constraints, including available resources. To determine if the design is appropriately mature to continue with the final design and fabrication phase.	The SRB evaluated the project and determined the project is sufficiently mature to progress to major manufacturing, assembly, and integration.	N/A

EXPLORATION GROUND SYSTEMS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**589.0**	**799.2**	**794.2**	**664.7**	**593.2**	**546.0**	**445.5**
Change from FY 2023 Enacted			**-5.0**				
Percent change from FY 2023 Enacted			**-0.6%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

To the left is the Liquid Hydrogen (LH2) "flare stack" where vented LH2 is burned off safely while to the right NASA's Space Launch System (SLS) and Orion spacecraft lift off from Pad 39B on November 16, 2022, at NASA KSC in Florida.

The Exploration Ground Systems (EGS) program plays an integral role in the Artemis missions by enabling integration, processing, and launch of the Space Launch System (SLS) and Orion spacecraft. The EGS program, based at Kennedy Space Center (KSC), is responsible for developing and operating the systems and facilities necessary to process, integrate, transport, and launch NASA's SLS rocket, Orion spacecraft, and any co-manifested SLS payloads for Artemis missions. EGS's mission is to enable the center to handle future Artemis missions which will return astronauts to the Moon and eventually Mars.

EGS is responsible for the facility and ground support equipment at KSC to enable to enable assembly, test, and launch of SLS and Orion, along with landing and recovery activities of the Orion spacecraft flight elements in support of Artemis missions. EGS is also modernizing communication and control systems to support these activities.

After successfully supporting the uncrewed flight test of Artemis I, EGS continues to upgrade the Launch Complex-39B (LC-39B), crawler-transporters, Vehicle Assembly Building (VAB), Launch Control Center's Young-Crippen Firing Room 1, Mobile Launcher-1 (ML-1), and other ground facilities for crewed operations. EGS also continues to upgrade its infrastructure to support the SLS Block 1B launch vehicle configuration, which is the next evolution of the SLS launch vehicle, including the development of the Mobile Launcher-2 (ML-2). EGS enables the safe launch and recovery of Artemis missions.

For more information, go to: https://www.nasa.gov/exploration/systems/ground/index.html

EXPLORATION GROUND SYSTEMS

Program Elements

EGS PROGRAM INTEGRATION AND SUPPORT

EGS Program integration and support activities manage program interfaces between the SLS and Orion. This effort is critical to ensuring the ground systems' performance meets technical and safety specifications and supports the programmatic assessments key to achieving integrated technical, cost, and schedule management. In addition, the EGS integration effort is vital to managing interfaces with other Exploration Systems Development Mission Directorate (ESDMD) and Space Operations Mission Directorate (SOMD) activities, including strategic studies, feasibility studies, and small-scale research tasks that feed into future human exploration. Coordination and timely integration across ESDMD and SOMD are critical and aimed at mitigating the impacts of potential design overlaps, schedule disconnects and delays, and cost overruns.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

EGS Development is responsible for developing the necessary ground systems as well as refurbishing and upgrading infrastructure and facilities required for assembly, test, and launch of SLS and Orion. This includes LC-39B, the VAB, the MLs, other smaller facilities, and Orion landing and recovery activities. See the Exploration Ground Systems Development section beginning on the following page for additional details.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

FY 2024 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028	BTC	Total
Formulation	974.7	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	974.7
Development/Implementation	2,494.7	205.7	30.0	**0.0**	0.0	0.0	0.0	0.0	0.0	2,730.4
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2023 MPAR LCC Estimate	**3,469.4**	**205.7**	**30.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**3,705.1**
Total Budget	**3,609.3**	**398.1**	**330.6**	**273.2**	**143.5**	**81.8**	**15.6**	**0.0**	**0.0**	**4,852.1**
Change from FY 2023 Enacted				**-57.4**						
Percent change from FY 2023 Enacted				**-17.4%**						

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The difference between the total budget and the MPAR LCC estimate is the total budget includes content outside of Artemis I and excludes CoF; LCC only includes Artemis I content, including CoF.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Shown here is the fully assembled Space Launch System rocket and Orion Spacecraft in High Bay 3 of the Vehicle Assembly Building at NASA's Kennedy Space Center (KSC) in Florida.

PROJECT PURPOSE

Exploration Ground Systems (EGS) is responsible for safely launching the Space Launch System (SLS) and Orion spacecraft in support of the Artemis missions. EGS develops upgrades and maintains the necessary ground systems infrastructure and facilities required for assembly, test, and launch of SLS and Orion, along with the landing and recovery activities of Orion. This includes the pad, known as Launch Complex-39B (LC-39B), the Vehicle Assembly Building (VAB), Mobile Launchers 1 and 2 (ML-1, ML-2), and other smaller facilities to evolve from a Space Shuttle focus to supporting Artemis missions. The modernization efforts maintain flexibility for LC-39B and the VAB to accommodate other potential users and commercial partners, though no other users have been identified to date. Following the Artemis I launch of the first SLS and Orion, the ML-1, VAB, and LC-39B will undergo additional modifications to accommodate crewed flight. For more than 50 years, Kennedy Space Center (KSC) has served as our Nation’s gateway to exploring the universe. Using the knowledge and assets of NASA’s successful spacefaring past, the EGS Program is helping to build a successful future for human spaceflight.

After the successful uncrewed launch of Artemis I on November 16, 2022, NASA is now focusing on the completion of Artemis II, the first crewed SLS flight, and the preparation required for Artemis III and Artemis IV. The Artemis I mission was the first integrated flight test of the Agency’s Deep Space Exploration Systems: the Orion spacecraft, the SLS launch vehicle, and the exploration ground systems.

For more information, go to: http://go.nasa.gov/groundsystems

EXPLANATION OF MAJOR CHANGES IN FY 2024

The proposed funding levels sufficiently allow the program to support Artemis II and III launches as soon as is technically feasible. Due to the Artemis I launch delay, NASA is re-assessing the Artemis II target launch date. The current target launch date for Artemis II is no earlier than (NET) November 2024.

Additional funding since the last budget request has been added to support continued development and construction of ML-2. The additional funding is necessary to address contractor underperformance, increased material costs driven by inflation, and some government contract changes. NASA is leveraging recommendations from multiple independent reviews to stabilize and maintain ML-2 construction as it is currently the critical path to Artemis IV. ML-2 is the ground platform structure that will launch the SLS Block 1B (B1B) launch vehicle configurations into lunar orbit.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

PROJECT PARAMETERS

EGS is focusing on the equipment, management, and operations required to safely mate Orion with the SLS, move the integrated SLS/Orion stack to the launch pad, and successfully launch it into space. The work entails use of many of the facilities unique to KSC such as the 52-story VAB and LC-39B launch complex. For the Artemis missions, the EGS team is developing procedures and protocols to process the Orion spacecraft, the launch vehicle elements, and the launch abort system before assembly into an integrated vehicle. Additional ground system work required to launch astronauts into space on Artemis II includes modifying the ML-1 and crawler-transporters, preparing LC-39B at KSC, and modernizing computers, software, tracking systems, and other network communications.

The ML-1 is the ground structure used to assemble, process, and launch the SLS rocket and Orion spacecraft from LC-39B at KSC. ML-1 consists of a two-story base that is the platform for the launch vehicle and a tower equipped with several connection lines, called umbilicals, and launch accessories that will provide SLS and Orion with power, communications, coolant, fuel, and stabilization prior to launch. The tower also contains a walkway for personnel and equipment entering the crew module during launch preparations. ML-1 will support the Agency's Artemis I, II, and III launches.

ML-2 is the ground platform structure that will launch the SLS B1B launch vehicle configurations into lunar orbit. ML-2 is the primary interface between the ground launch control system and the SLS rocket and Orion spacecraft flight hardware. The ML-2 construction contract was awarded in July 2019 and is aligned to support the first launch of a B1B on Artemis IV.

Machines called crawler-transporters have carried the load of the launch vehicle and spacecraft to the launch pad for more than 50 years at KSC. Crawler-Transporter 2 (CT-2) will be used for launches of SLS and Orion.

ACHIEVEMENTS IN FY 2022

Significant Artemis I milestones were completed in FY 2022, such as the booster stack, core stage mate, Orion to SLS Integration, and the Integrated Vehicle Tests. In addition, significant development progress was made in support of future Artemis crewed missions, such as the Preliminary Design Review for the ML-2, fabrication of the ML-2 Exploration Upper Stage Umbilical and construction of the LC-39B landing area for the Emergency Egress System (EES).

The program completed Underway Recovery Test-9 (URT-9) in November 2021. The purpose of URT-9 was to certify the recovery personnel and related on-shore mission interfaces who will be responsible for Artemis I mission recovery operations. URTs like this one resulted in successful recovery of the Orion Crew Module from the Pacific Ocean into the welldeck of the U.S.S. Portland on December 11, 2022.

The Spacecraft Command and Control System (SCCS) completed software development, verification and validation activities and supported processing operations at KSC in support of the Artemis I mission. SCCS functions as the operating system in which all the ground to flight application software (GFAS) run. Without SCCS the firing room would not be able to run the applications that provide critical and timely telemetry about the vehicle during launch countdown.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

In addition to these software efforts, Launch Team Training, and the final Multi-Element Verification and Validation (MEVV) of the ground systems in support of Artemis I were also completed.

The program successfully completed major tests including the Artemis I vehicle Wet Dress Rehearsal (WDR) and Cryogenic Demonstration Testing in FY 2022 and early FY 2023 in preparation for launch. The Cryo Demonstration test met all objectives including fully fueling the vehicle, verifying new loading procedures, conducting engine kick start bleed and the pre-press test of the Core Stage. While delays were experienced due to the scrub of the first two Artemis I launch attempts and the vehicle was rolled back to the VAB due to Hurricane Ian, EGS successfully launched the first Artemis mission and conducted landing and recovery operations in early FY 2023. The program continued construction activities of the new 1.4-million-gallon Liquid Hydrogen (LH2) Sphere at LC-39B which will enable multiple launch attempts with a quicker turnaround time for future missions. The new LH2 Sphere, in addition to the current LH2 Sphere, will supply an increased capacity of LH2 for Artemis II and beyond. The larger tank will allow NASA to attempt SLS launches on three consecutive days, instead of opportunities of two out of three days, in the event of a scrub. The newer technology reduces liquid hydrogen burn-off, allowing more launch attempts before having to refill the larger tank. Construction began in 2018 and will be complete in time to support Artemis II.

The program continued the development work for the upgrades and modifications to the launch pad, VAB, and ML-1 in support of the first crewed mission, Artemis II, and future missions. The EES Conveyance Modifications Construction Contract for ML-1 and LC-39B began off-line fabrication in October 2021 and will begin on-site field installation in the fourth quarter of FY 2023. The EES system will provide crew and safety personnel emergency egress to safely exit from the launch vehicle in an emergency. Construction will be complete in time to support crewed Artemis missions.

EGS continued fabrication of the Environmental Control System (ECS) in the VAB and begin upgrades at LC-39B to support future Artemis missions and continue upgrades at the Compressor Converter Facility. Concrete pads for the Liquid Helium (LHe) vaporizers have been poured and concrete foundation for the LHe pump skids have been completed.

The program continued design of the LN2 RL-10 Chilldown system at LC-39B. The system will be used to chill down the propellants pre-launch for the RL-10 engines of the SLS B1B Exploration Upper Stage (EUS).

EGS began the construction for the VAB High Bay 3 (HB3) B1B platform modifications in FY 2022. The HB3 platforms will be utilized for processing and stacking of the EUS and Interstage, which will support future Artemis missions that utilize the SLS B1B launch vehicle configuration.

ML-2 PDR was completed in December 2021 and the team is working toward the Critical Design Review (CDR) in FY 2023. The establishment of an Agency Baseline Commitment for ML-2 will also be reviewed for final approval in 2023.

WORK IN PROGRESS IN FY 2023

Artemis I was successfully launched on November 16, 2022. The Orion capsule splashed down in the Pacific Ocean off the coast of Baja California on Sunday December 11, 2022 wrapping up its 25.5-day mission to lunar orbit and back. The mission took the Orion spacecraft beyond the Moon and

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

demonstrated its performance capabilities during launch, transit to lunar orbit, return to Earth, re-entry, landing, and recovery.

EGS will complete post flight processing and de-servicing of Orion, followed by an Artemis I Post-Flight Assessment Review (PFAR) in the spring of 2023.

EGS will utilize the period between Artemis I and Artemis II to complete critical modifications, upgrades, and testing development to the launch pad, VAB, and ML-1 required to support the first crewed launch. Launch Equipment Test Facility (LETF) will complete testing of some critical ML-2 ground support equipment, such as the vehicle support posts and Exploration Upper Stage umbilical, in preparation for turnover to the ML-2 Contractor for installation. The EES Conveyance Modifications Construction Contract for ML-1 and LC-39B will begin on-site field installation in the fourth quarter of FY 2023.

The integrated recovery team of NASA, EGS, Lockheed Martin, and the Department of Defense (DoD), along with additional contractor support, will conduct URT-10 in the Spring of 2023 off the Pacific coast of San Diego, California to ensure safe recovery of the Orion crew module for future Artemis missions. URT-10 will be the first underway recovery test to support Artemis II's crewed mission. This test will include day and night recovery testing.

In the summer of 2023 ML-2 will complete the CDR and begin the construction phase of the project. The establishment of an Agency Baseline Commitment for ML-2 will also be reviewed for final approval in 2023.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

The Artemis II Vehicle Integration and Operations, to include stacking, spacecraft offline operations, payload processing, integrated test and checkout, and a tanking test utilizing the new LH2 Sphere at launch pad 39B, will all occur in FY 2024 in preparation for the Artemis II crewed launch in early FY 2025. The program will also complete the remaining Artemis II development, verification, and validation efforts discussed above to support the Artemis II crewed launch.

The Spaceport Command and Control System and Ground and Flight Application Software upgrades will be completed in FY 2024 to support Artemis II crewed missions.

The program will also complete procurement and be making significant progress on construction of the ML-2 required for future B1B crewed missions.

Other major construction projects, such as the construction for the Liquid Nitrogen Infrastructure Update and designs for VAB HB4 upgrades will begin in FY 2024. These efforts will support future crewed Artemis missions by upgrading the Liquid Nitrogen capabilities for quicker turnarounds for scrubbed launches, building the VAB HB4 EUS stand for engine servicing and starting the VAB Payload Environmental Access Room (PEAR) for cleanroom payload processing. The integrated recovery team of NASA, EGS, Lockheed Martin, and the DoD, along with additional contractor support, will conduct URT-11 in FY 2024 off the Pacific coast of San Diego, California to ensure safe recovery of the Orion crew module for future Artemis missions.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Schedule Commitments/Key Milestones

Milestone	Confirmation Baseline Date	FY 2024 PB Request
Key Decision Point-A (KDP-A)	Feb 2012	Feb 2012
Formulation Authorization	Apr 2012	Apr 2012
Systems Requirements Review (SRR) / System Design Review (SDR)	Aug 2012	Aug 2012
KDP-B Agency Project Management Council (APMC)	Nov 2012	Nov 2012
Preliminary Design Review (PDR) Board	Mar 2014	Mar 2014
KDP-C APMC	May 2014	May 2014
Critical Design Review (CDR) Board	Dec 2015	Dec 2015
System Integration Review (SIR)	Apr 2018	Jun 2018
Operational Readiness Review / Flight Readiness Review (FRR)	Jul 2019	Jul 2019
Artemis I Launch Readiness	Nov 2018	Nov 2022
Mobile Launcher 2 PDR (Technical)	Mar 2021	Mar 2021
Mobile Launcher 2 PDR (Programmatic)	Jul 2021	Dec 2021
Mobile Launcher 2 CDR	Mar 2023	Apr 2023

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Mileston e	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2015	1,843.5	80%	2022	2,629.3	42.9%	Artemis I Launch Readiness	Nov 2018	Nov 2022	48

NASA continues to review past reporting, and estimates do not necessarily accurately incorporate actual expenditures to date. Additionally, cost and confidence levels do not reflect the cost impacts of currently anticipated schedule delays. The estimates are expected to increase as NASA assesses the impacts of further delays and updates reporting on expenditures. Estimates that include combined cost and schedule risks are denoted as joint confidence

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)*	Change from Base Year Estimate ($M)
TOTAL	**1,843.5**	**2,629.3**	**+785.8**
Mobile Launcher	213.1	501.8	+288.7
LC-39B Pad*	77.5	48.9	-28.6
VAB*	92.7	42.8	-49.9
Command, Control, and Communications	198.0	544.6	+346.6
Offline Processing and Infrastructure*	110.2	149.3	+39.1
Other	1,152.0	1341.9	+189.9

Other includes Crawler Transporter, Launch Equipment Test Facility, Integrated Operations, Program Management, Logistics, Safety and Mission Assurance (S&MA), Integrated and Offline Operations, Construction of Facility and Systems Engineering and Integration (SE&I).

**The Agency Baseline Commitment for LC-39B Pad, VAB, and Offline Processing and Infrastructure previously integrated Operations cost which support Artemis I and later missions. EGS realigned those costs from each element and moved those costs to the other element, significantly lowering those elements' Current Year Development Cost Estimate. In addition, the program removed $27 million in costs for the VAB Utility Annex from the VAB element estimate. Those costs were covered by Center Management and Operations as that work was determined to benefit all programs at KSC.*

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Project Management & Commitments

EGS balances customer requirements among SLS, Orion, and other Government and commercial users. EGS is developing ground systems infrastructure necessary to assemble, test, and launch SLS and Orion, as well as land and recover Orion flight elements.

Element	Description	Provider Details	Change from Baseline
Ground Systems Implementation (GSI)	GSI is responsible for the design, development, build, hardware/software integration, verification and validation, test, and transition to operations for Program facility systems and Ground Support Equipment (GSE).	Provider: KSC Lead Center: KSC Performing Center(s): Ames Research Center (ARC) Cost Share Partner(s): N/A	N/A
Operations and Test Management (O&TM)	O&TM is responsible for conducting overall planning and execution of both flight hardware and ground systems processing activities.	Provider: KSC Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Command, Control, Communication (C3)	C3 is responsible for development, operation, and sustainment of End-to-End Command and Control and Communications services.	Provider: KSC Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Program Management Team (PMT)	PMT includes project management, safety and mission assurance, logistics, systems engineering, utilities and facility operations, and maintenance.	Provider: KSC Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: The modifications to ML-1 are not completed in the planned 18-month window between Artemis I and Artemis II, Then: There is a possibility that the Emergency Egress System (EES) construction will not be completed in time to allow for Verification and Validation (V&V) prior to vehicle processing for Artemis II.	There is a dependency on the ML-1 being available and modifications being completed to complete the construction and activation of the EES at the Pad. The dependencies with Artemis II ML-1 modifications may prevent timely installation and testing of the EES with ML-1. Mitigation efforts being pursued include compressing the EES design schedule, compressing the construction schedule, exploring alternate implementation methods, initiating the construction earlier, and/or reducing the overall V&V schedule.
If: The modifications to the ECS ducting configuration and circuits are not completed in the planned 18-month window between Artemis I and Artemis II, Then: There is a possibility that the ECS construction will not be completed in time to allow for V&V prior to vehicle processing for Artemis II.	To support launches post Artemis I, modifications are planned to the ECS that will enable it to support both Block 1 and B1B vehicles. This will require modifications to the existing circuits; however, these circuits had to be maintained throughout the entire Artemis I launch campaign. Mitigation efforts being pursued include compressing the design schedule, improving design package flexibility, identifying design scope that can be deferred, exploring alternate implementation methods, and/or reducing the overall V&V schedule.
If: ML-2 construction experiences design and construction delays, Then: ML-2 readiness for Artemis IV could be delayed.	EGS Program management is working with the prime contractor to shore up the discipline and rigor associated with project execution. NASA leadership has also increased oversight on the ML-2 project to ensure remaining development and construction work is executed as efficiently as possible. The program has seen challenges due to the COVID-19 pandemic, particularly in the areas of market pricing on materials/services and labor inefficiencies.

Acquisition Strategy

EGS serves as its own prime contractor for development activities. EGS executes SLS and Orion ground infrastructure and processing requirements by leveraging center and programmatic contracts. For more routine work, EGS also uses pre-qualified indefinite-delivery, indefinite-quantity contractors while exercising full and open competition for larger or more specialized projects, such as facility systems construction contracts and associated GSE fabrication firm-fixed-price contracts. A fixed-price

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

contracting approach is the first choice whenever possible, as it provides maximum incentive for contractors to control costs because the contractors are subject to any losses incurred. In addition, a fixed-price contract imposes less administrative burden on the contracting parties.

The FY 2024 President's Budget does not mandate adjustments to contracts and agreements, and NASA expects contractors and partners to perform to their contract/agreement dates.

MAJOR CONTRACTS/AWARDS

EGS development activities will encompass projects of varying content and size. EGS uses the center's institutional contracts to execute the development, engineering, construction, and programmatic activities. If the project size or scope falls outside existing center capabilities, then a competitively bid firm-fixed-price contract will be used.

Element	Vendor	Location (of work performance)
ML-1 Structural and Facility Support Modification Contract	J.P. Donovan Construction, Inc.	KSC
VAB Platform Construction	Hensel Phelps Construction, Inc.	KSC
ML-2 Design Build	Bechtel National, Inc.	KSC

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Preliminary Design Review (PDR)	Standing Review Board (SRB)	Mar 2014	To evaluate completeness and consistency of program preliminary design; to determine readiness to proceed with detailed design phase.	Program cleared to proceed to next phase.	N/A
Critical Design Review (CDR)	SRB	Dec 2015	To demonstrate that program design is mature; support full-scale fabrication, assembly, integration, and test; and meet overall performance requirements within cost and schedule constraints.	Program cleared to proceed to next phase.	N/A

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
System Integration Review (SIR)	KSC Independent Review Team (IRT)	Jun 2018	To evaluate the readiness of the program, including its projects and supporting infrastructure, to begin system Assembly, Integration, and Test with acceptable risk and within cost and schedule constraints.	Program cleared to proceed to next phase.	N/A
Exploration Systems Development (ESD) Artemis I Independent Schedule Assessment	Schedule assessors from Office of the Chief Financial Officer (OCFO)	Jun 2019	Programmatic assessment and analysis of Artemis I schedules across all ESD programs with an emphasis on program performance and risks.	NASA leadership was briefed on Artemis I launch date options. OCFO staff briefed NASA leadership on Artemis I launch date options.	N/A
Performance	Inspector General (IG)	Mar 2020	To assess the Agency's development of its mobile launchers.	Audit of NASA'S Development of its Mobile Launchers (IG-20-13). The IG made four recommendations to NASA on changes needed to ensure success with developing a second mobile launcher.	N/A
Performance	IG	Mar 2020	To evaluate whether NASA's management has taken appropriate steps in developing and managing the risk of its Ground and Flight Application Software for the Artemis Campaign.	NASA's Development of Ground and Flight Application Software for the Artemis Campaign (IG-20-014). The IG made 2 recommendations to NASA as it proceeded through the remaining Artemis software development.	N/A
ESD Artemis I Re-baseline	IRT	Apr 2020	Programmatic assessment and analysis of Artemis I schedule and schedule risks of Artemis I launch date and JCL.	Established revised baseline and launch readiness date.	N/A

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	IG	Dec 2020	To address NASA's Aerospace Safety Advisory. Panel concerns over the Agency's plans to return-to-the-Moon by 2024.	NASA's Challenges to Safely Return Humans to the Moon by 2024 (IG-21-007). IG identified returning to the Moon as a top management and performance challenge and will continue oversight of NASA's management of the Artemis Campaign and the Agency's human exploration efforts through other audits and reviews.	N/A
Performance	General Accountabi-lity Office (GAO)	Dec 2020	To assess the progress the programs are making towards Artemis I with respect to schedule and cost, and the extent to which the programs are positioned to support the planned Artemis flight schedule beyond Artemis I.	GAO made two recommendations to establish baselines ahead of a key design review and improve internal reporting about capability upgrades for human space exploration programs beyond Artemis I. NASA concurred with the recommendations made in this report.	N/A
ESD Enterprise Integration Review (EIR)	IRT	Jan 2021	To confirm that flight and ground hardware elements, software, support equipment, facilities and infrastructure are ready to support assembly, integration, test, and mission operations per the planned schedule for Artemis I.	The IRT confirmed the programs are sufficiently mature to proceed for integrated operations.	N/A

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Mobile Launcher 2 PDR (Technical)	IRT	Mar 2021	To evaluate completeness and consistency of program preliminary design; to determine readiness to proceed to CDR.	Verify technical readiness for the project to initiate construction.	PDR (Progra-mmatic)
Performance	IG	Apr 2021	To provide an update on the NASA 2020 Artemis Plan.	Artemis Status Update (IG-21-018) - IG will continue to monitor the Agency's efforts towards achieving 2020 Artemis Plan.	N/A
Performance	GAO	May 2021	To assess NASA's ability to accomplish the March 2019 White House direction to accelerate its plans for a lunar landing by four years to 2024.	Significant Work Remains, Underscoring Challenges to Achieving Moon Landing in 2024 (GAO-21-230) - GAO made four recommendations, including that NASA document the process for determining key programmatic and technical tools for the Artemis missions. NASA concurred with three of the recommendations, but not the fourth, which related to the costs included in a lunar rover's cost estimate.	N/A
Performance	IG	Nov 2021	To assess the Artemis Campaign's schedule and projected costs as well as how the Agency's acquisition and programmatic approaches facilitate landing astronauts on the Moon.	NASA's Management of the Artemis missions (IG-22-003) - IG will continue to monitor acquisition and programmatic approach for Artemis missions.	N/A

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Mobile Launcher 2 PDR (Programmatic)	IRT	Dec 2021	To evaluate completeness and consistency of program preliminary design; to determine readiness to proceed to CDR.	The IRT confirmed the programs are sufficiently mature to proceed to CDR.	CDR
Performance	GAO	Mar 2022	To update NASA's progress and challenges in working towards the first three Artemis missions.	Moon Landing Plans Are Advancing but Challenges Remain (GAO-22-105533) - GAO restated its 10 previous recommendations related to improving NASA's management of its Artemis efforts and related programs. NASA generally agreed with these recommendations and plans to take steps to implement them.	N/A
Performance	IG	Jun 2022	To examine the extent to which NASA is meeting cost, schedule, and performance goals for the ML-2 contract.	NASA's Management of the Mobile Launcher 2 Contract (IG-22-012) IG made four recommendations to improve NASA's management of the ML-2 contract and contractor performance as well as to provide transparency to existing and future contracts.	N/A

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Operational Readiness Review/ Flight Readiness Review (ORR/FRR) for Artemis I	Independent Assessment (IA) / IRT	Aug 2022	To evaluate the readiness of the project to operate the flight system and associated ground system; and support systems for safe and successful launch and flight/mission.	Conducted an in-depth assessment of the readiness of the Agency's Space Launch System and Orion spacecraft to support the uncrewed flight of Artemis I on its mission beyond the Moon and return to Earth.	N/A
Performance	GAO	Sep 2022	To assess the extent to which NASA (1) is managing mission integration risks; (2) developed Artemis mission-level schedules; and (3) assessed the ability of the Artemis workforce to manage and oversee lunar landing missions.	NASA Lunar Programs: Improved Mission Guidance Needed as Artemis Complexity Grows (GAO-22-105323). GAO is making four recommendations, including that NASA develop Artemis mission-level schedule management guidance and develop guidance on conducting Artemis workforce scenario planning. NASA concurred with all four of the recommendations.	N/A
Launch Readiness Date/Initial Operations Capability (LRD/IOC) for Artemis I	IA / IRT	Nov 2022	To assess all capabilities of the vehicle to support the readiness to launch.	Successful launch on November 16th, 2022.	N/A

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Mobile Launcher 2 CDR	IA / IRT	Mar 2023	To demonstrate that program design is mature; support full-scale fabrication, assembly, integration, and test; and meet overall performance requirements within cost and schedule constraints.	N/A	N/A

ARTEMIS CAMPAIGN DEVELOPMENT

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Gateway	742.5	--	**914.2**	853.0	744.2	768.8	777.3
Adv Cislunar and Surface Capabilities	70.1	--	**60.3**	102.0	433.0	563.8	969.9
Human Landing System	1,195.0	1,485.6	**1,880.5**	2,224.7	2,286.7	2,748.3	2,526.6
xEVA and Human Surface Mobility Program	0.0	275.9	**379.9**	494.8	605.0	605.3	605.7
Total Budget	**2,007.6**	**2,600.3**	**3,234.8**	**3,674.4**	**4,068.9**	**4,686.2**	**4,879.6**
Change from FY 2023 Enacted			**634.5**				
Percent change from FY 2023 Enacted			**24.4%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Virtual Reality (pictured above) is being used to help astronauts evaluate the Crew Cabin that is being developed for Artemis missions.

The overarching goal of the Artemis Campaign Development (ACD) theme is to develop the systems that will be used to enable humans to live and operate in deep space, land humans on the Moon, explore the lunar surface, and prepare for Mars exploration. ACD comprises five programs: Gateway, Advanced Cislunar and Surface Capabilities (ACSC), the Human Landing System (HLS), and Exploration Extravehicular Activity (xEVA) and Human Surface Mobility Program (EHP). In collaboration with commercial and international partners, ACD will create the necessary exploration infrastructure in lunar orbit and on the lunar surface that astronauts will use during Artemis missions. ACD is responsible for developing and testing prototype systems, as well as planning and developing flight missions to lunar orbit and the lunar surface. In addition to expanding our lunar capabilities, these efforts will also inform and enable future missions to Mars. ACD's program objectives support the National Space Policy of 2020 and the 2021 Space Priorities Framework, as well as the Agency's Strategic Goal 2, which seeks to extend human presence to the Moon and onto Mars for sustainable, long-term exploration, development, and utilization.

ACD will leverage other capabilities, such as life support systems, within the Exploration System Development Mission Directorate for transportation of the crew to and from orbit around the Moon and technology development for future Mars systems. ACD will leverage the Science Mission Directorate's (SMD) development of smaller landers for capabilities such as navigation and precision landing of cargo, as well as for data about the lunar surface. Finally, ACD will leverage the Space Operations Mission Directorate's (SOMD) capabilities, such as the International Space Station and the Space Communications and Navigation program, as a technology and human system testbed and communication and navigation capability provider, respectively.

ACD activities utilize a variety of agreement and contract types, such as firm-fixed-price contracts, that enable NASA, private industry, academia, and international partners to share in the risks and rewards of Government investments. These shared risks incentivize technical performance and building future commercial markets with entities other than NASA interested in using the new capabilities. These programs are also utilizing the unique skills of the NASA workforce to perform risk reduction, develop life support systems, and build and manage the missions that will take humanity back to the Moon and beyond.

Utilizing partnerships and competition to drive affordability, the HLS program will leverage commercial capabilities to develop integrated lunar landing systems. Artemis III's lunar landing demonstration will consist of landing two crew members on the lunar surface via the SpaceX Starship vehicle. Once the Orion spacecraft has docked to the Starship in lunar orbit, two crew members will board the Starship to continue their journey to the surface of the Moon for nearly a week, then return to lunar orbit and rendezvous with Orion for the return to Earth. The Agency has announced plans regarding NASA's intent to purchase lunar landing services through the Sustaining Lunar Development procurement for Artemis missions in the late 2020s and is reaching out to all potential industry providers for input. NASA intends to support the development and use of multiple industry provided landing systems to maintain competition and enable redundancy in the HLS program.

The Exploration Extravehicular Activity (xEVA) and Human Surface Mobility Program (EHP) develops and manages the systems that NASA will use to explore the surface of the Moon. These surface systems, including surface suits and mobility systems, will enable exploration capabilities on the surface of the moon. Utilization of surface systems will also yield lessons learned that will be applied to the development and support of future Mars missions. EHP will execute acquisition plans for future surface systems and elements required for lunar sustainability.

The Gateway will serve as a multi-purpose outpost orbiting the Moon, providing capabilities to enable a sustained deep space presence for NASA and its partners to conduct human exploration and scientific research on and around the lunar surface. Both in early and later stages of assembly, Gateway will enable crewed missions in lunar orbit, where astronauts will prepare for lunar surface missions and future crewed missions to Mars.

ACD leads the next phase of lunar sustainability with the development activities occurring under ACSC. Future systems will provide habitation and cargo landing capabilities, including the Foundation Surface Habitat and a Lunar Cargo Lander capable of landing major surface elements, both of which are key elements required for sustainable and long-duration missions on the lunar surface. These systems have requirements that overlap with requirements likely to be established for crewed Mars missions, and so they also reduce risk and prove capabilities likely needed for future missions to Mars. ACSC is working alongside the Mars Campaign Development (MCD) to bridge some of these technological gaps.

The missions pioneered by ACD will enable the first intrepid crews of the new space age to travel safely to and from the surface of the Moon and mature the systems that can achieve sustainability on the Moon. These missions will enable new scientific discoveries and promote new technologies, research, and systems needed to sustain living in deep space for the benefit of all humankind and eventually feed into future Mars missions.

ARTEMIS CAMPAIGN DEVELOPMENT

EXPLANATION OF MAJOR CHANGES IN FY 2024

This budget increases funding for the Gateway program to support a technical re-design of the Gateway's Power & Propulsion Element (PPE). The re-design includes significant content for risk mitigation hardware and testing, mission operations, emulators and simulators, cybersecurity, data, analyses, and support to verify critical Gateway requirements.

GATEWAY

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**742.5**	**--**	**914.2**	**853.0**	**744.2**	**768.8**	**777.3**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Pictured above is the Gateway, which will serve as a multi-purpose outpost orbiting the Moon that provides essential support for long-term human return to the lunar surface and also serves as a staging point for deep space exploration.

The Gateway will serve as a multi-purpose outpost orbiting the Moon, providing capabilities to enable a sustained deep space presence for NASA and its partners to conduct human exploration and scientific research on and around the lunar surface. Both in early and later stages of assembly, Gateway will enable crewed missions to lunar orbit, where astronauts will live, work, and prepare for lunar surface missions.

In addition to serving as a destination for crewed missions and scientific research, Gateway will dock with human lander systems in route to the lunar surface. Gateway's unique near-rectilinear halo orbit (NRHO) will periodically (roughly weekly) bring Gateway within about 1,000 miles/1,500 kilometers (km) of the surface at its closest point. This orbit will allow NASA and its international and commercial collaborators to have unprecedented lunar surface access, in particular to the north and south poles of the Moon, to conduct deep space science and technology investigations and perform sustainable lunar exploration which will also inform future Mars missions.

Elements of the Gateway will be developed and deployed incrementally. The initial Gateway architecture consists of the two foundational elements: the Power & Propulsion Element (PPE) and the Habitation and Logistics Outpost (HALO). Maxar Technologies is developing and building the PPE, which will provide power, high-rate communications, attitude control, and orbital transfer capabilities for the Gateway. Northrop Grumman initially designed and is building HALO, which is where astronauts will live and conduct research while visiting Gateway. HALO will provide command and control systems for the lunar outpost and docking ports for visiting spacecraft. PPE and HALO will be integrated and launched together on a SpaceX Falcon Heavy rocket no earlier than 2025.

As astronauts prepare for missions to the lunar surface, they will need deliveries of pressurized and unpressurized cargo, science experiments, and supplies, such as sample collection materials for the lunar surface. The Gateway Deep Space Logistics (DSL) Project manages the Gateway Logistics Services (GLS) contract, which will deliver supplies and hardware to support Gateway's sustained lunar orbit operations and lunar landing missions.

International partners will provide important contributions to Gateway, including advanced external robotics via the Gateway External Robotic System (GERS) from Canada, additional habitation via the International Habitat (I-HAB) from the European Space Agency (ESA) and Japan Aerospace Exploration Agency (JAXA), a refueling capability via European Systems Providing Refueling, Infrastructure, and

Telecommunications (ESPRIT-Refueler), and potentially other enhancements such as an airlock to support science and maintenance. The Canadian Space Agency (CSA) awarded a contract to MacDonald, Dettwiler and Associates Inc. (MDA) to build the Canadarm3 for the Gateway. This capability will perform tasks without human intervention. JAXA signed an agreement and implementing arrangement providing Gateway contributions of habitation components and logistics resupply. These capabilities will support sustained Gateway operations during crewed and uncrewed time periods. ESA signed an agreement with NASA to contribute habitation and refueling modules and enhanced communications to the Gateway. These capabilities enable longer duration crewed Gateway missions.

Gateway is leveraging the legal framework, knowledge, and relationships built via the International Space Station (ISS). It will leverage other Space Operations Mission Directorate capabilities, such as the Space Communications and Navigation program as a communication capability provider. Gateway will leverage the Space Launch System's (SLS) launch vehicle and Orion capsule capabilities to transport some of its elements into cislunar orbit, starting with the I-HAB as a co-manifested payload on Artemis IV. Gateway will be humanity’s first space station in lunar orbit to support NASA’s deep space exploration plans and supports the Moon and Mars exploration initiative by providing the infrastructure necessary for sustained lunar surface exploration and provides a research platform aimed at capabilities necessary for Mars exploration.

For more information, go to: http://www.nasa.gov/gateway

EXPLANATION OF MAJOR CHANGES IN FY 2024

This budget increases funding for the Gateway program to support a technical re-design of the Gateway's PPE. The re-design includes significant content for risk mitigation hardware and testing, mission operations, emulators and simulators, cybersecurity, data, analyses, and support to verify critical Gateway requirements.

ACHIEVEMENTS IN FY 2022

The Gateway Program and constituent elements continued through formulation stages at varying levels of maturity. ESA completed their I-HAB Preliminary Design Review (PDR) Board in November 2021, and the PPE Maxar PDR Part 2 was completed in December 2021. The HALO Critical Design Review (CDR) kick-off was held in August 2022.

A Gateway Program PDR Sync Review was held in May 2022.

The GERS System Requirements Review (SRR) was held in January 2022. The ESA ESPRIT Refueler Module SRR Board was held in June 2022.

The DSL team and GLS contractor, SpaceX, continued special studies during FY 2022 in advance of the first mission Authority to Proceed (ATP).

WORK IN PROGRESS IN FY 2023

In FY 2023, the Gateway Program closed out the PDR sync review and will proceed to Key Decision Point (KDP-I). This will mark the transition from formulation to implementation for the whole tightly coupled Program. An Agency Baseline Commitment (ABC) will be established at this KDP for the Gateway Initial Capability (the configuration with just the PPE and HALO elements).

At the element level, PPE's contractor will hold a CDR and HALO will close out their CDR. A CDR determines if the design is appropriately mature to continue with the final design and fabrication phase. The PPE-HALO commercial launch vehicle is planning to hold a mission specific PDR. CSA GERS will hold a PDR in FY 2023, in addition to a CSA external robotics interfaces CDR and the ESA HALO Lunar Communications System (HLCS) CDR.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

In FY 2024, the Assembly, Integration, and Test (AI&T) phase for HALO and PPE will be underway. The HALO habitable element (manufactured by Thales Alenia Space Italia for Northrop Grumman) will be shipped and delivered to the United States. The HLCS Delivery will take place.

The GERS will complete its CDR, in preparation for delivery on a Gateway Logistics Services mission currently planned to take place in sync with the Artemis V mission.

The Gateway will continue working with ESA on the delivery of I-HAB and the ESPRIT. Planned negotiations for provisioning of the airlock will continue in FY 2024.

Program Projects

POWER & PROPULSION ELEMENT (PPE)

The PPE is a high-power, 60-kilowatt (kW) solar electric propulsion spacecraft that will provide power, high-rate communications, attitude control, orbit maintenance, and orbital transfer capabilities for the Gateway.

The PPE will be the most powerful electric propulsion spacecraft ever flown, and it will maneuver Gateway around the Moon, opening up more of the lunar surface for exploration than ever before. The PPE project leverages Space Technology Mission Directorate investments in Advanced Electric Propulsion Systems. PPE will demonstrate an advanced Solar Electric Propulsion (SEP) system, which combines 12kW and 6kW SEP thrusters.

The PPE is being developed and built by Maxar Technologies of Westminster, Colorado, and is managed out of NASA’s Glenn Research Center (GRC) in Ohio. Maxar Technologies was awarded the contract for PPE in 2019. PPE will be launched with HALO as an integrated vehicle on a SpaceX Falcon Heavy commercial rocket, and PPE will propel the co-manifested vehicle to cislunar space.

HABITATION AND LOGISTICS OUTPOST (HALO)

HALO is where astronauts will initially live and conduct research while visiting the Gateway. The pressurized living quarters will provide command and control systems for the lunar outpost, and docking ports for visiting spacecraft, such as NASA’s Orion spacecraft, lunar landers, and logistics resupply craft.

The HALO module will serve as the backbone for command and control and power distribution across Gateway and will perform other core functions, including hosting science investigations via internal and external payload accommodations and communicating with lunar surface expeditions. HALO also will enable the addition of the I-HAB habitable element to expand Gateway capabilities. HALO leverages contributions from the Gateway international partners for robust capabilities. Batteries provided by JAXA will power HALO until PPE solar arrays can be deployed and during eclipse periods. Robotic interfaces provided by CSA will host payloads and provide base points for Canadarm3 robotic operations. ESA will provide a lunar communications system to enable high-data-rate communications between the lunar surface and Gateway.

Northrop Grumman of Dulles, Virginia, was awarded a contract for HALO in June 2020. Northrop Grumman's design for HALO, developed through NASA's Next Space Technologies for Exploration Partnerships (NextSTEP) contract vehicle, is based on its Cygnus spacecraft currently being used to deliver cargo to the ISS. HALO will be launched with PPE as an integrated vehicle on a SpaceX Falcon Heavy commercial rocket.

DEEP SPACE LOGISTICS (DSL)

The DSL Project is the element of the Gateway Program charged with delivering payloads to and removing waste from the Gateway. The functional reality of human habitation in any location on Earth or in space is that it involves the consumption of resources and the generation of waste. The development of a sustainable, repeatable, and reliable supply chain is critical to the success of the Gateway.

The Logistics spacecraft will have their own power, propulsion, and navigation systems to rendezvous autonomously with the Gateway in cislunar orbit and dock at a radial port. The Logistics spacecraft will provide consumable resupply, outfitting equipment, and cargo delivery including utilization and spares. The Logistics module is designed to serve as a large pantry where supplies can be easily accessed by the crew. The design of the spacecraft will accommodate the collection, storage, and eventual disposal of waste accumulated at Gateway. The cargo and supplies delivered by the Logistics spacecraft will support habitation of the Gateway as well as provide provisions for the lunar landers during the sustained lunar exploration phase.

The Logistics flights are necessary to supply Gateway with critical cargo deliveries and sustain the crew during stays on Gateway. The GLS contract and technical capability are extensible to deliver unique payload configurations to the Gateway. As an example, the Canadian robotic arm will be supplied to Gateway via a logistics flight in 2027.

In March 2020, NASA awarded SpaceX as the provider under the Gateway Logistics Services contract to deliver cargo and other supplies to the lunar outpost. ATP has not yet been provided for the first mission.

INTERNATIONAL HABITAT (I-HAB)

The I-HAB module is a contribution from ESA and will provide additional crew habitation and workspace, as well as additional environmental systems capability. This module will also provide additional docking ports and accommodations for internal and external science experiments.

I-HAB's environmental control and life support systems will augment the life support system capabilities provided by HALO and the docked Orion, enabling longer missions at the Gateway and on the lunar surface. JAXA plans to provide several capabilities for the Gateway's I-HAB, including I-HAB's environmental control and life support system, batteries, thermal control, and imagery components, which will be integrated into the module by ESA prior to launch on the SLS Block 1B launch vehicle on Artemis IV.

ESA is under contract with Thales Alenia Space for the I-HAB module, and delivery of I-HAB to the Gateway will be via the SLS Block 1B launch vehicle with Orion providing orbital insertion and docking.

EUROPEAN SYSTEMS PROVIDING REFUELING, INFRASTRUCTURE, AND TELECOMMUNICATIONS (ESPRIT)

The ESPRIT provides additional capabilities that are realized in two components. The first HLCS will be integrated and launched with HALO and will provide high-rate communications relay between Gateway and elements on the lunar surface. The second, separate module is the ESPRIT Refueling Module, which will incorporate crew observation windows and enable refueling of the PPE.

ESA is under contract with Thales Alenia Space for the ESPRIT Refueling Module. NASA is responsible for delivering the ESPRIT Refueling Module to the Gateway.

GATEWAY EXTERNAL ROBOTICS SYSTEMS (GERS)

CSA will provide the Gateway's external robotics system, including a next-generation robotic arm, known as Canadarm3. Canadarm3 will move end-over-end to reach many parts of the Gateway's exterior, where its anchoring "hand" will plug into specially designed interfaces. CSA also will provide robotic interfaces for Gateway modules, which will enable payload installation including that of the first two scientific instruments launching on the foundational Gateway elements (PPE/HALO). Canadarm3 will be used to conduct maintenance, to berth and inspect vehicles, install science payloads, and support potential future Gateway EVAs. CSA will be responsible for end-to-end external robotics, including engineering and operations.

CSA selected MDA for both the Canadarm3 and external robotic interfaces. Delivery of Canadarm3 to Gateway is targeted to coincide with Artemis V via a Gateway Logistics Services mission.

GATEWAY AIRLOCK

The Gateway airlock module, currently a notional concept, would support both crewed spacewalks as well a science airlock to transfer scientific experiments and Gateway hardware between the pressurized cabin and the exterior of Gateway. Canadarm3 would be an integral part of the science airlock operations moving the hardware into and out of the science airlock and deploying/retrieving around Gateway.

NASA continues to discuss Airlock options with the International Partner community.

Program Schedule

The Gateway Program is in the formulation phase. Additional milestones will be identified after Gateway KDP-I.

Date	Significant Event
Q3 FY 2023	Gateway Sync Review technical closeout
Q3/4 FY 2023	Gateway KDP-I

Program Management & Commitments

In 2019, the Human Exploration and Operations Mission Directorate (now Exploration Systems Development and Space Operations Mission Directorates [ESDMD/SOMD]) Associate Administrator (AA) assigned authority for the Gateway Program to Johnson Space Center (JSC). The Program Manager reports to the Deputy Associate Administrator (DAA) for the Artemis Campaign Division (ACD) in coordination with the ESDMD AA. The Gateway program will make an ABC for the initial capability spacecraft following the PDR-informed Sync Review at KDP-I. DSL will make a separate ABC at KDP-C.

Program Element	Provider
PPE	Provider: Maxar Technologies Lead Center: GRC Performing Center(s): GRC and JSC
HALO	Provider: Northrop Grumman Lead Center: JSC Performing Center(s): JSC
DSL	Provider: SpaceX Lead Center: KSC Performing Center(s): KSC

Acquisition Strategy

Gateway's integrated acquisition strategy includes procurements and international partner contributions. NASA conducted an Acquisition Strategy Meeting (ASM) in August 2018 to determine center roles/responsibilities assignments (depicted in the previous table) and the acquisition strategy for each Gateway element. Domestic Gateway elements are procured using fixed-price, milestone-based contracts to the greatest extent possible. All major contracts have been awarded. The sections below identify the major domestic contracts.

PPE was awarded on May 23, 2019, to Maxar Technologies.

Orbital Sciences Corporation, a wholly owned subsidiary of Northrop Grumman Space, referred to as Northrop Grumman here, was selected as one of the habitation partners under the NextSTEP contract vehicle on September 3, 2015. The contract scope was authorized over five phases initially beginning with defining the architecture and concepts. The latest (Phase 5) was for final HALO production and delivery and was signed on July 8, 2021.

The Gateway Logistics Services (GLS) contract was awarded in March 2020 to SpaceX.

NASA selected SpaceX to provide a Falcon Heavy launch vehicle for the co-manifested PPE/HALO launch through a competitive Launch Service Task Order evaluation under the NASA Launch Services II contract in February 2021.

The FY 2024 President's Budget does not mandate adjustments to contracts and agreements, and NASA expects contractors and partners to perform to their contract/agreement dates.

GATEWAY

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
PPE (May 2019)	Maxar Technologies	Westminster, CO
HALO (Jun 2020)	Northrop Grumman	Dulles, VA
Gateway Logistics Services (Mar 2020)	SpaceX	Hawthorne, CA
CMV Launch Vehicle Provider (Feb 2021)	SpaceX	Hawthorne, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Gateway Formulation Synchronization Review (FSR)	Independent Review Team	Feb 2019	Equivalent to a SRR, the FSR evaluated the program's functional and performance requirements, ensuring proper formulation and correlation with Agency and mission directorate strategic objectives.	Program cleared to proceed to next phase	Gateway SDR-informed Sync Review
Gateway Program SDR-informed Sync Review	Standing Review Board (SRB)	Jun 2020 Delta - Mar 2021	To evaluate the credibility and responsiveness of the proposed program requirements / architecture to the mission directorate requirements and constraints, including available resources, and allocation of requirements to projects. To determine whether the maturity of the program's mission/system definition and associated plans are sufficient to begin preliminary design.	Approval to proceed in Formulation at KDP-0	Gateway PDR-informed Sync Review
Gateway Program PDR-Informed Sync Review	SRB	May 2022, with close-out in Dec 2022	To evaluate the completeness / consistency of the program's preliminary design, including its projects, in meeting all requirements with appropriate margins, acceptable risk, and within cost and schedule constraints, and to determine the program's readiness to proceed with the detailed design phase of the program.	TBD at KDP-I	Gateway CDR-informed Sync Review

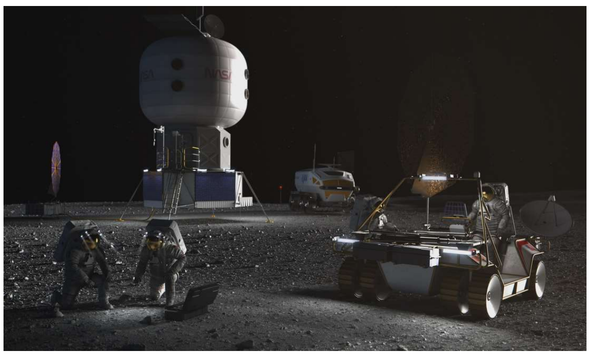
ADV CISLUNAR AND SURFACE CAPABILITIES

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	70.1	--	60.3	102.0	433.0	563.8	969.9

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



Shown here is an artist rendition of future systems including the Foundation Surface Habitat to enable long duration stays on the lunar surface.

The Advanced Cislunar and Surface Capabilities (ACSC) program manages and integrates the systems that NASA will use throughout the Artemis Campaign to access and explore the surface of the Moon.

Within ACSC, Artemis Campaign Development (ACD) Program Integration funds the team that leads the integration of the human space flight elements of the Artemis missions, starting with Artemis III. This integration team comprises the system engineering, safety, operations, and programmatic organizations that ensure the human spaceflight lunar mission are implemented successfully with contributions from the programs across the Exploration Systems Development Mission Directorate (ESDMD).

Future Systems Formulation (FSF) formulates the systems that NASA will use to sustainably explore the surface of the Moon. These systems, including cargo landing and habitation, will provide capabilities to support future Artemis missions and act as analogs for future Mars missions. FSF will utilize initial studies and pre-formulation activities to establish initial element system requirements. As these technologies and systems mature, they will be the building blocks for the capability to extend stays on the Moon.

In the near term, FSF is conducting risk-reduction studies to identify required lunar surface technologies to be utilized on the lunar surface and act as precursor systems for potential future missions. These surface systems may include a human-class cargo lunar lander and a future surface habitat.

FSF will work with the Moon and Mars Architecture (M&MA) team to oversee the Agency's habitation strategy using the Next Space Technologies for Exploration Partnerships (NextSTEP) Broad Area Announcement (BAA) process, a public-private partnership model seeking commercial development of deep space exploration capabilities to support human spaceflight missions.

In this capacity, FSF and M&MA are the primary interfaces between the external NextSTEP partners and internal stakeholders, including Space Technology Mission Directorate, the International Space Station (ISS), Orion, Space Launch System (SLS), the Human Research Program, and the Space Communications and Navigation program. Through NextSTEP contracts, NASA and industry identify and leverage commercial capability development for low-Earth orbit (LEO) that will inform the Agency's long-duration deep space habitation requirements.

ADV CISLUNAR AND SURFACE CAPABILITIES

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ACHIEVEMENTS IN FY 2022

ACSC continued to support the Solar Systems Trek software application, which combines images and other science data to simulate exploration of the solar system, including the Moon, Mars, and small-bodies (e.g., asteroids). This application can be used to inform future missions including the return to the lunar surface through the Human Lander System.

The M&MA activity initiated studies to provide context for how near-term lunar activities that will inform future missions to Mars. M&MA identified potential lunar surface systems, operations, and technology which, through the NextSTEP BAA, will help NASA and industry identify commercial capability development for LEO that intersects with the Agency's long-duration, deep space habitation requirements, along with any potential options to leverage commercial LEO advancements and promote commercial activity in LEO. The multiple phases of NextSTEP are informing NASA's conceptual future deep space, long-duration habitation capability.

Through a partnership with the Korea Aerospace Research Institute (KARI), the ShadowCam flight instrument launched on the Korea Pathfinder Lunar Orbiter (KPLO) in 2022. By collecting high-resolution images of the Moon's permanently shadowed regions (PSRs), ShadowCam will provide critical information about the distribution and accessibility of water ice and other volatiles at spatial scales required to mitigate risks and maximize the results of future exploration activities.

WORK IN PROGRESS IN FY 2023

NASA is providing ShadowCam with Deep Space Network lunar navigation and trajectory assistance.

The M&MA team will conduct risk-reduction activities to identify risks, capability gaps, and requirements to ensure mission success for ACD.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

ACSC will advance technologies to prevent the accumulation of lunar dust on surface systems and protect the crew from the hazardous effects of dust upon the return of humans to the lunar surface and subsequent long duration missions.

FSF will continue conducting risk-reduction activities to further develop key elements of the Artemis plan for the lunar surface. FSF will leverage commercial and international interest to begin pre-formulation of systems such as pressurized rovers, surface habitats, and transit concepts.

ACD Program Integration will continue managing the integration and required synergies across the Artemis Campaign Division, working closely with the Human Landing System (HLS), Gateway, Exploration Extravehicular Activity (xEVA) and Human Surface Mobility Program (EHP), and Future Systems Architecture to ensure that the Artemis Missions are successfully executed while driving human exploration of the Moon toward sustainability.

ADV CISLUNAR AND SURFACE CAPABILITIES

Program Elements

ACD PROGRAM INTEGRATION

ACD division is responsible and accountable for the Programmatic integration of the Gateway, Human Lander Systems, ACSC and Exploration Capabilities Programs. ACD leverages the ESDMD Resource Management Office (RMO) and is infused with embeds from other NASA Headquarters (HQ) offices, as well as cross-directorate teams with Common Exploration Systems Development (CESD).

ACD manages the definition, certification, and operation of the systems that establish a sustained human presence in cislunar space. ACD also maintains content in the products that define the technical and programmatic baseline at the ESDMD level. ACD supports configuration and data management for ACD activities, directs cross-program integration activities that involve ACD objectives, and manages the various technical risks that affect sustaining operations.

ACD works closely with the other NASA Mission Directorates, and ESDMD programs, and the ESDMD Architecture and Technical Integration Offices to ensure that efforts are effective and integrated.

FUTURE SYSTEMS FORMULATION

The future systems group conducts activities that will lead directly to the development of capabilities based on the surface habitat and lunar cargo lander concepts, as well as other systems required for NASA to continue to advance human exploration.

Program Schedule

Currently all systems are in pre-formulation and schedules have not been defined.

Program Management & Commitments

ESDMD manages the ACSC activities.

Program Element	Provider
ACD Integration	Provider: NASA Centers Lead Center: NASA Headquarters (HQ) Performing Center(s): Marshall Space Flight Center (MSFC), Langley Research Center (LaRC), Glenn Research Center (GRC), Goddard Space Flight Center (GSFC), Johnson Space Center (JSC), Jet Propulsion Laboratory (JPL), Kennedy Space Center (KSC), Ames Research Center (ARC), Armstrong Flight Research Center (AFRC) Cost Share Partner(s): N/A
Future Systems	Provider: TBD Lead Center: HQ Performing Center(s): MSFC, JSC, JPL, KSC, ARC Cost Share Partner(s): TBD

ADV CISLUNAR AND SURFACE CAPABILITIES

ACQUISITION STRATEGY

No acquisition planned for this program.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

None.

HUMAN LANDING SYSTEM

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**1,195.0**	**1,485.6**	**1,880.5**	**2,224.7**	**2,286.7**	**2,748.3**	**2,526.6**
Change from FY 2023 Enacted			**394.9**				
Percent change from FY 2023 Enacted			**26.6%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Pictured above, NASA is working with SpaceX Starship to ensure astronauts can safely operate the HLS Crew and Cargo elevator

The Human Landing System (HLS) Program leads development of the system to carry crews from lunar orbit to the surface of the Moon and back.

To best meet mission needs, NASA is working with U.S. industry to develop Artemis lunar landers. This allows NASA to share its knowledge and maintain oversight of safety, while companies develop, test, and iterate on designs. Through the award of the two initial landing demonstrations to SpaceX for the Artemis III and Artemis IV missions, as well as future awards for Sustainable HLS Studies and Risk Reduction, NASA is working with multiple industry partners to support development of integrated landing systems that can safely transport crew to and from the lunar surface and maintain competition in the HLS Program.

The Artemis III and IV lunar landing demonstrations will each land two crew members on the lunar surface via SpaceX's Starship. The Artemis III lunar landing demonstration will be preceded by an uncrewed demonstration mission. For all Artemis missions, the Agency's Space Launch System rocket will launch four astronauts aboard the Orion spacecraft for their multi-day journey to lunar orbit. For the Artemis III lunar return mission, two crew members will transfer to the SpaceX Starship for the final leg of their journey to the surface of the Moon. After approximately a week exploring the surface, they will board the lander for their short trip back to lunar orbit, where they will return to Orion and their colleagues before heading back to Earth. Starting on Artemis IV, both Orion and HLS will dock with Gateway in lunar orbit.

NASA teams will work closely with U.S. industry to provide insight and expertise to ensure HLS meets NASA's performance requirements and human spaceflight standards. These agreed-upon standards for engineering, safety, health, and medical support are the foundation for the safe operation of HLS.

In its work toward a regular cadence of astronaut Moon landings, the Agency is pursuing two paths for sustainable lunar lander development and demonstration. The first calls for additional work with SpaceX to upgrade the version of Starship used for the Artemis III mission so that it can meet the more demanding requirements of the Artemis IV mission. The second invites other U.S. companies to provide new lander development and demonstration missions from lunar orbit to the surface of the Moon with an initial demonstration on Artemis V. Combined, these efforts will pave the way for multiple companies to provide recurring Moon landing services for Artemis astronauts using the Gateway as the crew staging vehicle in lunar orbit. Using NASA's unique and historic experience in lunar exploration, paired with the expertise and innovation of industry partners, Sustaining Lunar Development will ensure NASA can reach the long-term goal of regular, sustainable Moon landings.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ACHIEVEMENTS IN FY 2022

With the resolution of the Government Accountability Office (GAO) protest and legal processes, NASA worked with SpaceX to update and release a revised schedule for the milestones leading up to the HLS-supported Artemis missions. SpaceX, in 2022, in collaboration with NASA, achieved all planned milestones for the initial capability and demonstration of landing on the lunar surface.

NASA announced the exercise of Option B on SpaceX's existing HLS Next Space Technologies for Exploration Partnerships 2 (NextSTEP-2) Appendix H contract. Under this award, SpaceX will further develop its Starship Human Landing System to meet NASA's sustaining lander requirements for the Artemis IV mission. With this addition, SpaceX is on contract to support a second crewed landing demonstration mission as part of NASA's Artemis IV mission.

NASA engaged in numerous product development and review activities to support the Sustaining Lunar Development. This work was informed by industry responses to a NASA Request for Information (RFI) and through the work on NextSTEP-2 Appendix N. The final call for proposals incorporated industry feedback on the draft solicitation, released in March 2022, encouraged companies to send comments to help shape a key component of the Agency's human exploration Artemis architecture. NASA also hosted a virtual industry day in April to present an overview of the solicitation and to provide companies an opportunity to ask clarifying questions and provide comments.

WORK IN PROGRESS IN FY 2023

Under the NextSTEP-2 Appendix H Option A, SpaceX will conduct both a crewed and uncrewed lunar landing demonstration as part of the Artemis III mission, marking humanity's first return to the Moon in more than 50 years. Under Option B, SpaceX will work with NASA to evolve its Artemis III Starship HLS design to meet NASA's sustainable requirements at the Moon and conduct another crewed demonstration landing on Artemis IV.

Separately, under a new draft solicitation released March 2022, NextSTEP-2 Appendix P, HLS Sustaining Lunar Development (SLD), NASA has provided requirements for new companies interested in developing and demonstrating additional astronaut Moon landers. Proposals for the sustainable lunar lander development and demonstration were due November 15, 2022 and selection for the SLD contract is planned in 2023.

These concurrent sustaining lander development efforts will meet NASA's needs for recurring, long-term access to the lunar surface, such as the ability to land four astronauts on the Moon instead of two and deliver more cargo to the surface.

HUMAN LANDING SYSTEM

KEY ACHIEVEMENTS PLANNED FOR FY 2024

NASA has provided requirements for companies interested in developing and demonstrating astronaut Moon landers. These efforts will pave the way for multiple companies to provide recurring Moon landing services beyond the Artemis III and Artemis IV missions.

Companies selected under this contract will be required to perform one uncrewed and one crewed lunar landing demonstration. NASA will certify any lander system to meet its requirements prior to the crewed demonstration mission(s).

SpaceX will perform multiple demonstrations such as a in-orbit fuel transfer and Starship test flights including one uncrewed demonstration mission prior to use of their system on the Artemis III mission.

NASA will continue working to ensure continuous human landing system services are available to support the Agency's goal of frequent and regular lunar surface missions.

Program Elements

HLS PROGRAM MANAGEMENT

Human Landing System Program Management is responsible for executing programmatic roles assigned to Marshall Space Flight Center (MSFC) by the Exploration Systems Development Mission Directorate (ESDMD). The HLS Program Office will oversee all HLS verification, validation, and certification to ensure requirements for flight readiness satisfy NASA's standards for crew safety and human rating.

HLS Program Management is responsible for the insight and oversight activities in collaboration with commercial partners associated with human landing system hardware development, integration, and flight demonstration, leading to services that can be procured by NASA. HLS performs risk reduction activities and identifies and prioritizes upgrades to the human landing systems so they can support sustainable future exploration missions. HLS will include a lander ground operations office at Kennedy Space Center (KSC), and both a crew compartment office and a lander flight operations office at Johnson Space Center (JSC). HLS will also prioritize and coordinate collaboration resources across multiple NASA centers and manage major integrated system test activities, as applicable.

HUMAN LANDING SYSTEMS

HLS will support development of the landing system that will carry astronauts to and from the lunar surface. The SpaceX design will complete an uncrewed landing demonstration followed by a crewed landing demonstration that includes astronaut exploration of the lunar surface.

HLS continues working with multiple American companies to bolster competition and commercial readiness for the procurement of sustainable transportation services to and from the lunar surface for the long-term exploration of the Moon staged at the Gateway.

HUMAN LANDING SYSTEM

SUSTAINABLE STUDIES AND RISK REDUCTION

NASA's Artemis efforts include sending a suite of new science instruments and technology demonstrations to study the Moon, and technologies to prepare for the next giant leap – sending astronauts to Mars.

Contracts established under NextSTEP-2 Appendix N Broad Agency Announcement (BAA) (Sustainable Human Landing System Studies and Risk Reduction) provide for engagement with potential commercial partners for architecture concept development and risk reduction activities.

The activity will also award and manage NextSTEP-2 Appendix P BAA (Human Landing System Sustaining Lunar Development).

Program Schedule

Date	Significant Event
Mar 2020	Selected and awarded SpaceX for initial HLS demonstration mission
Nov 2022	Selected SpaceX for Option B Sustaining Lander Development
2024	Uncrewed HLS demonstration with SpaceX Starship to the Lunar surface
Dec 2025	Crewed HLS demonstration with SpaceX Starship as part of Artemis III
Sept 2028	Artemis IV, first mission utilizing sustainable transportation services to and from the lunar surface

Program Management & Commitments

Program Element	Provider
HLS Program Management	Lead Center: MSFC Performing Center(s): Ames Research Center (ARC), Glenn Research Center (GRC), Langley Research Center (LaRC), Goddard Space Flight Center (GSFC), Stennis Space Center (SSC), JSC, KSC Cost Share Partner(s): TBD
Integrated Lander	Provider: SpaceX (Artemis III and Artemis IV) Lead Center: MSFC Performing Center(s): Ames Research Center (ARC), Glenn Research Center (GRC), Langley Research Center (LaRC), Goddard Space Flight Center (GSFC), Stennis Space Center (SSC), JSC, KSC Cost Share Partner(s): TBD

Acquisition Strategy

The HLS Program utilizes the NextSTEP BAA contract vehicle. Through this approach, NASA can award firm-fixed-price, milestone-based proposals to enable rapid development of a crewed flight demonstration of the HLS. NASA initially utilized this with the Appendix H solicitation for the initial landing development. This contract was structured with the following Contract Line Item Numbers (CLINs):

- Base CLIN - contract award through 10 months - only long-lead items supporting the first mission and various design activities are allowed during this base period. Awarded to multiple industry partners to enable competitive design.
- Option A CLIN(s) - flight and landing demonstrations of initial human landing systems. Awarded to SpaceX.
- Option B CLIN(s) - Flight and landing demonstrations of sustaining landing systems. Awarded to SpaceX.

NASA has further utilized the NextSTEP BAA with the Appendix P solicitation for sustaining landing development. This solicitation is also structured into a base CLIN for initial development and further option CLINs for flight and landing demonstrations of both sustained crew landing and cargo landing systems.

The HLS Program is currently evaluating acquisition vehicles for sustainable transportation services to and from the lunar surface for long-term exploration of the Moon starting with the Artemis VI mission.

The FY 2024 President's Budget does not mandate adjustments to contracts and agreements, and NASA expects contractors and partners to perform to their contract/agreement dates.

MAJOR CONTRACTS/AWARDS

NextSTEP-2 Appendix H BAA Option A: Selected SpaceX of Hawthorne, California firm-fixed price, milestone-based contract total award value is $2.89 billion. SpaceX is developing the Starship – a fully integrated lander that will use the SpaceX Super Heavy rocket.

NextSTEP-2 Appendix H BAA Option B: Selected SpaceX of Hawthorne, California. NASA has awarded SpaceX a $1.15 billion contract to develop an upgraded version of its Starship lunar lander and fly a second crewed mission.

NextSTEP-2 Appendix N BAA: NASA awarded a total of $146 million to five U.S. companies to mature sustainable human landing system concepts, conduct risk-reduction activities, and provide feedback on NASA’s requirements to cultivate industry capabilities for enabling a steady pace of crewed trips to the lunar surface under the Agency’s Artemis return to the Moon. Three of the awardees are part of the Nation Team led by Blue Original, as well as Lockheed Martin and Northrop Grumman.

The awards under the NextSTEP-2 Appendix broad Agency announcement are firm fixed-price, milestone-based contracts.

HUMAN LANDING SYSTEM

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Human Landing Systems Program	Standing Review Board (SRB)	Spring 2022	To evaluate the completeness/ consistency of the planning, technical, cost, and schedule baselines developed during formulation; assess compliance of the preliminary design with applicable requirements; and determine if the project is sufficiently mature for HLS Program Key Decision Point (KDP)-C	Approved to proceed to KDP-C.	KDP-C

Historical Performance

The NextSTEP-2 Appendix H: Base Period was completed on schedule in April 2021 and incurred no additional costs outside of the firm fixed priced contractual agreements. Option A and Option B continue to advance the HLS designs to maturity.

xEVA and Human Surface Mobility Program

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**0.0**	**275.9**	**379.9**	**494.8**	**605.0**	**605.3**	**605.7**
Change from FY 2023 Enacted			**104.0**				
Percent change from FY 2023 Enacted			**37.7%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Shown here, the Exploration Extravehicular Activity (xEVA) team conducts an Exploration Extravehicular Mobility Unit (xEMU) Design Verification Testing helmet light testing.

The NASA Exploration Extravehicular Activity (xEVA) and Human Surface Mobility Program (EHP) seeks to work with partners to advance the technologies associated with human mobility and lunar surface infrastructure in support of NASA's Artemis missions. The EHP vision provides safe, reliable, and effective EVA and HSM capabilities that allow astronauts to survive and work outside the confines of a spacecraft on the Moon. Artemis missions will return humans to the surface of the Moon using innovative technologies to explore more of the lunar surface than ever before. The xEVA and Human Surface Mobility Program will collaborate with commercial and international partners and establish the first long-term presence on the Moon. Then, the program will use what it learned on and around the Moon to develop surface systems that can be used by the first astronauts to land on Mars.

The EHP and partners will collaborate on developing lunar capabilities to increase the productivity of crews on the lunar surface during Artemis missions. EHP focuses on high-risk technologies for lunar surface systems that will provide mission planners with more choices, thereby increasing mission success. In pursuing these types of capabilities, NASA and potential partners will develop new and improved technologies that will provide additional options for terrestrial applications in multiple industries.

Artemis astronauts exploring the Moon's South Pole will wear new spacesuits to keep them safe and productive in this harsh lunar environment. NASA is embracing commercial collaborations to optimize spacesuit technology and inspire innovation in the space market. NASA has selected Collins Aerospace and Axiom Space to advance spacewalking capabilities in low-Earth orbit and at the Moon, by buying services that provide astronauts with next generation spacesuit and spacewalk systems to work outside the International Space Station (ISS), explore the lunar surface on Artemis missions, and prepare for human missions to Mars. The Exploration Extravehicular Activity (xEVA) System, which is required for astronauts to conduct moonwalks on the lunar surface, includes the Exploration Extravehicular Mobility Unit (xEMU) spacesuit development, vehicle interfaces to suit equipment (VISE), system servicing equipment, and specialized tools for these moonwalks.

xEVA AND HUMAN SURFACE MOBILITY PROGRAM

The Lunar Terrain Vehicle (LTV) is an unpressurized surface transportation system that will significantly extend the range of crew excursions and enable more scientific research, resource prospecting, and exploration activities to be conducted. Because Artemis missions will be targeting the lunar South Pole area, the new LTV must be able to withstand and operate in cold temperatures and unique lighting conditions. The Artemis LTV is also expected to be able to be operated remotely when astronauts are not on the surface, enabling access to diverse locations that will facilitate science discoveries, resource prospecting, and exploration. It will also be available for commercial uses when not carrying out NASA research and operations.

Procuring services from industry partners allows NASA to leverage commercial innovation and provide the best value to U.S. taxpayers while achieving its human spaceflight and exploration goals. The contract will support continued science and long-term human exploration at the Moon under Artemis, which will land the first woman and first person of color on the lunar surface

Long duration mobility is a key enabler of more productive lunar exploration. The Surface Pressurized Rover (SPR) is a pressurized surface transportation system that would be used on the Moon to expand the range of excursions even further, allowing crews to perform longer-duration research and exploration activities. In addition, this capability would allow NASA to conduct analogs of Mars surface activities to reduce risk and optimize operational concepts. When NASA sends a pressurized rover to the surface of the Moon, it will serve as astronauts' living and working space, their life support system, and their means of transportation for up to a month at a time. As part of a study agreement with NASA, the Japanese Aerospace Exploration Agency (JAXA) may provide a pressurized rover for Artemis missions.

The capabilities provided by the EHP program enable the crews of the new space age the ability to safely explore the lunar surface and mature sustainability on the Moon. The ability to explore the lunar surface will enable new scientific discoveries and promote new technologies, research, and systems needed for future Mars missions.

EXPLANATION OF MAJOR CHANGES IN FY 2024

With the awards of the xEVAS contracts to Axiom Space and Collins Aerospace, NASA has refined the funding needed for the timely ISS and Artemis suit developments to support EVA activities on the lunar surface and low-Earth orbit.

ACHIEVEMENTS IN FY 2022

In FY 2022, xEVA Project awarded the Exploration Extravehicular Activity Services (xEVAS) contract to provide spacesuit and spacewalking services to support both ISS and Artemis missions and completed Design Verification Testing (DVT) of the integrated xEMU design verification test unit. Additionally, the xEVA Project completed testing of the Spacesuit Evaporation Rejection Flight Experiment (SERFE) on the ISS, following a planned six-month dwell period to simulate planned quiescent periods between use. The results from the DVT and SERFE evaluations will be compiled along with all other Government design and test data to support a NASA-led technical review of the Government reference design with the selected xEVAS provider.

EVA and Mobility conducted risk-reduction activities and evaluated potential commercial and international collaborations to take the next step in developing the systems and technologies identified by the Moon and Mars Architecture (M&MA) program under Advanced Cislunar and Surface Capabilities

(ACSC). Through surface systems, NASA will seek to identify specific system architecture and begin formulation activities on key elements of NASA's Artemis plan.

In 2022, both LTV and the SPR transferred from M&MA to EHP.

As astronauts explore the South Pole region of the Moon during Artemis missions, they will be able to go farther and conduct more science than ever before thanks to the LTV. Instead of owning the vehicle, NASA plans to contract it as a service from industry. EHP released a draft request for proposals for the LTV Services (LTVS) contract for industry to review.

NASA continued to support JAXA-NASA feasibility studies to further refine and coordinate on requirements development, concept of operations development, and review of the JAXA concept for SPR. The team also focused on risk reduction activities to further refine the suitport concept, which is an augmentation to a traditional airlock, and develop the standard interface and documentation.

WORK IN PROGRESS IN FY 2023

EHP will continue to support the EVAS contract developing the spacesuits to allow astronauts to continue work on the ISS and return to the lunar surface.

NASA selected Axiom Space to deliver a moonwalking system for the Artemis III mission. This award – the first one under a competitive spacesuits contract – is for a task order to develop a next generation Artemis spacesuit and supporting systems, and to demonstrate their use on the lunar surface during Artemis III.

NASA has awarded a task order to Collins Aerospace to deliver a spacewalking system for use outside the ISS. With this second award for a new suit and system, NASA is beginning to replace the spacesuit used by NASA astronauts for decades during space shuttle and ISS missions. The new suit will support continued station maintenance and operations and enable a broader variation in astronaut size as NASA.

NASA is reviewing and answering questions received in response to the LTVS Draft request for proposals (RFP). EHP will release a final RFP in fiscal year 2023 and is targeting an award by the end of the year.

As NASA works to develop technologies needed to establish a long-term presence at the Moon with future Artemis missions, pressurized rovers in which humans can live and work will play an important role. SPR will continue to define requirements and identify the necessary procurements to begin development of the system that will be delivered to the lunar surface in the late 2020s.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

In addition to monitoring the major system acquisition for LTV, EHP will provide technical expertise to ensure LTV meets NASA's requirements.

Collins Aerospace will complete a critical design review and demonstrate use of the ISS suit on Earth in a simulated space environment by January 2024. NASA will have the option to extend the contract for a demonstration with Agency crew members outside the space station by April 2026.

Axiom will continue the development of next generation astronaut spacesuits to support the Artemis lunar missions. NASA will land the first woman on the Moon wearing Axiom’s xEVAS spacesuits beginning with Artemis III.

xEVA AND HUMAN SURFACE MOBILITY PROGRAM

Under the indefinite delivery and indefinite quantity of the xEVAS contract, eligible industry partners compete for task orders that will provide a full suite of capabilities for NASA's spacewalking and moonwalking needs during the period of performance through 2034.

Future task orders under the contract will consist of recurring lunar landings, the development of spacesuits for use in low-Earth orbit outside the ISS, and special studies. The Agency is currently evaluating task order options for space station spacesuits. EVA Operations will maintain EVA support to the ISS through 2028.

Program Elements

PROGRAM MANAGEMENT & EXECUTION

xEVA and Human Surface Mobility Program Management & Execution is responsible for executing programmatic roles assigned to Johnson Space Center (JSC) by the Exploration Systems Development Mission Directorate (ESDMD). The EHP Program Office will oversee all EVA, LTV, and SPR verification, validation, and certification to ensure requirements for flight readiness satisfy NASA's standards for crew safety and human rating.

EHP Program Management is also responsible for the insight and oversight activities in collaboration with commercial and international partners associated with EVA and mobility system hardware development, integration, and flight demonstration, in some cases leading to services that can be procured by NASA. EHP performs risk reduction and technology development activities to identify and prioritize upgrades to the systems so it can support sustainable future exploration missions. EHP will also prioritize and coordinate collaboration resources across multiple NASA centers and manage major integrated system test activities, as applicable

EVA DEVELOPMENT

The goal of the EVA development project is to provide a safe, reliable, and effective EVA capability that allows astronauts to survive and work outside the confines of the base spacecraft in orbit or on the lunar surface, in support of both the ISS and Artemis.

The xEMU is designed to provide astronauts with enhanced mobility to accomplish their exploration tasks on the lunar surface. It is also designed to be more comfortable when worn by male and female astronauts with a wider range of physiological characteristics.

LUNAR TERRAIN VEHICLE

The Lunar Terrain Vehicle project will provide the unpressurized vehicle required for astronauts to explore the surface of the Moon. The project will also explore capability to allow remote use of the vehicle to perform tasks on the Moon during periods where astronauts are absent from the lunar surface.

xEVA AND HUMAN SURFACE MOBILITY PROGRAM

SURFACE PRESSURIZED ROVER

The Surface Pressurized Rover project will provide the means for astronauts to explore the surface of the Moon for long durations beyond any previous capability. Specifically, the habitable volume built into the surface pressurized rover will allow for long range reconnaissance missions.

Program Schedule

The specific schedule is still in the formulation phase and needs to be informed primarily by commercial responses to planned industry engagements. During FY 2023, NASA will make significant progress on finalizing milestones, program implementation assignments, and acquisition strategy beyond the initial engagements.

Program Management & Commitments

ESDMD manages the xEVA and Human Surface Mobility Program activities.

Program Element	Provider
xEVA	Provider: Collins, Axiom Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): TBD
LTV	Provider: TBD Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): TBD
Surface Pressurized Rover	Provider: TBD Lead Center: JSC Performing Center(s): TBD Cost Share Partner(s): TBD

Acquisition Strategy

Acquisition plans for all functions/elements of xEVA and Human Surface Mobility Program will be varied and depend upon specific activities as this effort is comprised of risk-reduction activities, studies, and pre-formulation work.

The FY 2024 President's Budget does not mandate adjustments to contracts and agreements, and NASA expects contractors and partners to perform to their contract/agreement dates.

MAJOR CONTRACTS/AWARDS

NASA selected Axiom Space for the task order for developing a spacesuit to enable lunar surface activities, which has a base value of $228.5 million. A future task order will be competed for recurring spacesuit services to support subsequent Artemis missions. Axiom Space will be required to test the suits in a spacelike environment before Artemis III.

NASA has awarded a task order to Collins Aerospace to deliver a spacewalking system for use outside the International Space Station. This award – the second under NASA's xEVAS contract – is for design and development of a next-generation spacesuit and support systems. The task order has a base value of $97.2 million.

The spacesuit contracts, which will advance spacewalking capabilities in low-Earth orbit and on the Moon, is managed by the Agency's JSC in Houston

INDEPENDENT REVIEWS

The program will undergo quarterly Directorate Program Management Council reviews, and periodically, representatives from the Office of Chief Engineer, the Office of Safety and Mission Assurance, and the Office of Chief Financial Officer will assess performance during Agency-level Baseline Performance Reviews. In addition, the EHP program provides briefing reports to, and seeks feedback on planning and development activities from the NASA Advisory Council Human Exploration and Operation Committee and the Technology Committee.

HISTORICAL PERFORMANCE

None.

HUMAN EXPLORATION REQUIREMENTS & ARCHITECTURE

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Moon & Mars Architecture	0.0	--	**49.1**	50.0	50.5	51.0	51.1
Total Budget	**0.0**	**--**	**49.1**	**50.0**	**50.5**	**51.0**	**51.1**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Shown here is an artist's rendition of the United States' return to the lunar surface, utilizing systems that will act as precursors to an eventual mission to Mars.

The overarching goal of the Human Exploration Requirements & Architecture (HERA) theme is to identify the exploration infrastructure required for Artemis missions that will inform future missions to Mars. It also works to ensure that lunar exploration systems are extensible to Mars exploration where technically feasible and cost-effective to do so. These program objectives support the National Space Policy of 2020, the Space Priorities Framework of 2021, as well as the Agency's Strategic Goal 2, which seeks to extend human presence to the Moon and onto Mars for sustainable long-term exploration, development, and utilization.

HERA manages the architecture strategy activity that supports mission manifest planning and overall architecture requirements and capability identification. HERA conducts an annual Agency Architecture Concept Review to gain concurrence on the current state of architecture planning, driven by NASA's Moon to Mars Objectives, which were updated in September 2022.

HERA maintains the Systems Engineering and Integration (SE&I) expertise required to support the top-level technical integration across Exploration Systems Development Mission Directorate (ESDMD), Space Operations Mission Directorate (SOMD), Science Mission Directorate (SMD), and Space Technology Mission Directorate (STMD) to include the Artemis missions and future exploration planning.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

MOON & MARS ARCHITECTURE

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	0.0	--	49.1	50.0	50.5	51.0	51.1

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

As seen above, the Moon and Mars Architecture Program will collaborate with programs across NASA to integrate strategy and architecture for the future of human exploration.

The Moon and Mars Architecture (M&MA) Program is responsible for the integration of strategy and architecture across the Exploration Systems Development Mission Directorate (ESDMD).

In the near term, M&MA is conducting trade studies to reduce risk and identify required technologies to be utilized as part of the Artemis campaign and act as precursor systems for potential future Mars missions.

M&MA oversees the Agency's strategy across many key components of human space exploration, habitats, robotics and mobility, and landing. The habitat group serves as the central management authority for the Next Space Technologies for Exploration Partnership (NextSTEP) - Appendix A Habitation contract mechanism, a public-private partnership model seeking commercial development of deep space exploration capabilities to support human spaceflight missions. In this capacity, M&MA has served as the primary interface between the external NextSTEP partners and internal stakeholders, including the Space Technology Mission Directorate, International Space Station, Orion, Space Launch System, Human Research Program, and Space Communications and Navigation Program. The multiple phases of NextSTEP are informing NASA's notional future deep space, long-duration habitation capability.

M&MA also maintains the technical integration required to support ESDMD include the Artemis missions and future exploration planning. Technical integration includes the following activities:

- Capability integration for planning and gap analyses of capabilities required for future exploration missions;
- Science and technology utilization for coordination and planning for future exploration missions; and
- Technical integration across ESDMD programs to support requirements development and configuration control of ESDMD-level systems engineering and integration documentation.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

MOON & MARS ARCHITECTURE

ACHIEVEMENTS IN FY 2022

Not applicable. Moon and Mars Architecture is a new program in FY 2023. This content was previously funded under the Advanced Cislunar and Surface Capabilities program.

WORK IN PROGRESS IN FY 2023

The M&MA Program will initiate studies to inform how near-term lunar activities are leveraged for future Mars activities.

M&MA will identify potential lunar surface systems, operations, and technologies that will help NASA and industry identify a commercial logistics capability path to support future lunar surface activities. In addition, extensions of NextSTEP Appendix A are informing NASA's conceptual future deep space, long-duration habitation capability. The Architecture Concept Review (ACR22) provided an opportunity for the Agency to synchronize the Moon and Mars architecture, document the functional needs of the architecture, and in some cases, identify hardware elements to accomplish the functional needs.

Risk reduction and pre-formulation activities in 2023 also include the FROST-E Box, an in-space refrigeration solution for sample return, and the Multi-purpose Habitat (MPH) in partnership with the Italian Space Agency (ASI).

KEY ACHIEVEMENTS PLANNED FOR FY 2024

M&MA will conduct risk reduction activities to identify risks, capability gaps, and requirements to ensure mission success across NASA.

ACR23 will provide an updated Moon and Mars architecture with the goal of documenting additional details for missions further out into the 2030s, including elements provided by international partners and industry providers. Under the Next Space Technologies for Exploration Partnerships (NextSTEP) Habitation Systems BAA, NASA industry partners will complete critical concept risk reduction efforts advancing the readiness of inflatable soft-goods structures technologies and investigating other light-weight materials solutions for Artemis and Mars transportation habitats.

Program Elements

TECHNICAL INTEGRATION

The Deputy Associate Administrator for Technical Integration and supporting staff are responsible for ensuring the overall ESDMD strategies are reflected in program requirements. The office also leads architecture, formulation activities for future exploration mission planning, and provides technical direction for ESDMD activities (e.g., Moon, Mars).

Concepts for crewed lunar surface systems, such as habitats, rovers, and a robotic precursor to support human exploration, will be defined through these studies before being further pursued by an implementing program or office.

MOON & MARS ARCHITECTURE

ARCHITECTURE STRATEGY

Architecture Strategy activities are focused on developing the future exploration architecture to take humans from the initial Artemis lunar landing to a Mars landing. This architecture will identify needed capabilities and technologies, as well as define operational concepts that will guide the development of flight systems.

Program Schedule

No formal commitment dates.

Program Management & Commitments

ESDMD manages the M&MA activities.

Acquisition Strategy

None.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

To be determined.

Historical Performance

Not applicable as this is a newly established program in FY 2023.

MARS CAMPAIGN DEVELOPMENT

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**187.4**	**--**	**161.8**	**164.4**	**164.4**	**164.5**	**167.8**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

FY 2022 amounts reflect funding previously budgeted for Advanced Exploration Systems under the retired Exploration Research & Development theme.

As shown above, the Advanced Oxygen Generator will produce high pressure O2 for Extravehicular Activities (EVA).

The overarching goal of the Mars Campaign Development (MCD) is to start working on long-lead technology challenges that will need to be solved in order for an eventual crewed mission to Mars to succeed. MCD will address these challenges through a combination of in-house activities, industry collaborations, and international partnerships.

MCD is developing and testing prototype technologies, as well as contributing to the planning and development of flight missions to lunar orbit and the Moon to develop systems and operational practices that will enable an eventual mission to Mars. These program objectives support the National Space Policy of 2020, the Space Priorities Framework of 2021, as well as the Agency's Strategic Goal 2, which seeks to extend human presence to the Moon and onto Mars for sustainable, long-term exploration and utilization.

The Exploration Capabilities program develops habitation systems technologies to enable long-duration missions on the lunar surface and in deep space. The performance and reliability of prototype systems are demonstrated in International Space Station (ISS) flight experiments and integrated ground tests. The Exploration Capabilities program also coordinates with the Space Technology Mission Directorate to fill high priority technology gaps that are identified by the Environmental Control Life Support System (ECLSS) System Capabilities and Leadership Team (SCLT) and the Exploration Systems Mission Directorate's (ESDMD) Systems Engineering and Integration (SE&I) team.

Exploration Capabilities will infuse new technologies into the formulation of future flight programs such as surface habitats and the vehicles that will eventually transport astronauts to Mars.

MCD will begin conducting preliminary concept studies for future systems, namely an eventual transit habitat, that will be needed to provide living quarters and other basic life support functions for an eventual human mission to Mars.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

EXPLORATION CAPABILITIES

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	187.4	--	161.8	164.4	164.4	164.5	167.8

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

FY 2022 amounts reflect funding previously budgeted for Advanced Exploration Systems under the retired Exploration Research & Development theme.

Astronaut Jessica Watkins is shown here harvesting the first crop from eXposed Root On-Orbit Test System (XROOTS). Roots are intact.

Exploration Capabilities (EC) develops high-priority technologies and capabilities, which will be infused into prototype systems that will be used in future human spaceflight missions. These technologies and capabilities are developed using a combination of in-house activities and industry collaborations. EC provides technologies to enable deep space missions, including capabilities that enable sustained surface missions on the Moon and Mars. The technology capabilities and processes pioneered by EC will enable the crews of the new space age to stay safe and healthy, make scientific discoveries, and sustain new homes away from Earth for the benefit of all humankind.

To enable NASA's Artemis program and the Mars Campaign Development, EC invests in the development and demonstration of high-priority technologies and capabilities to reduce risk, lower life cycle cost, and validate operational concepts for future human missions with a focus on habitation capabilities, life support systems, and other enabling technologies. The Agency identifies and addresses potential risks by performing early validation and ground/flight testing of technologies in the Technology Readiness Level (TRL) 3 through 5 range prior to integration into planned operational systems. This approach is intended to minimize cost growth and improve affordability of future space exploration. EC focuses on advancing the technologies that will foster a sustainable presence on the Moon and Mars and enable a lasting presence utilizing reusable systems. These technologies will provide access for a diverse community of contributing collaborators and sustainability for repeatable trips to multiple destinations across the lunar surface and to Mars.

To test the technologies, capabilities, and systems required for deep space missions, EC is employing a phased approach by testing on the ground, sub-orbital platforms, in low-Earth orbit (LEO), and in cislunar space. The goal is to make exploration missions more capable, safer, and more affordable. This phased approach helps to accelerate technology development and infusion into operational systems.

EC will continue to coordinate with the Space Technology Mission Directorate on identifying and addressing knowledge gaps and delivering fundamental capabilities to provide astronauts with a place to live and work with integrated life support systems, radiation protection, food, fire-safety, avionics and software, logistics management, and systems to manage waste.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ACHIEVEMENTS IN FY 2022

In support of NASA's goal of extending human space exploration beyond LEO, EC continued development of reliable life support systems, deep space habitats, and overall capabilities reducing logistics requirements necessary to support sustainable human spaceflight missions and eliminating dependencies on frequent resupply from Earth.

EC began work on an integrated Environmental Control and Life Support System (ECLSS) ground test system at Marshall Space Flight Center (MSFC), which consists of refurbishing, upgrading, and integrating current test systems and the fabrication of new test systems. Procurements for flight-like test hardware are progressing. On April 28th, EC completed the Preliminary Design Review milestone for the Miniaturized Total Organic Carbon Analyzer (MiniTOCA) prototype. TOCA is the primary water quality monitor on International Space Station (ISS) and at its current mass cannot be accommodated by future Exploration missions needing recycled water. The MiniTOCA exploration class water quality instrument built on lessons learned for the ISS. The new design will have a reduced mass, longer operational life, and reduced maintenance need compared to the system currently in operation on the ISS and will be flight-tested in preparation for exploration.

The crew was selected for the first Crew Health and Performance Exploration Analog (CHAPEA) simulated Mars mission. Four crew members will be confined to the habitat and surrounding "sandbox", simulating the Mars surface for 387 days and performing extravehicular activity (EVA), including virtual reality on a realistic Mars landscape. The CHAPEA team completed 3D printing of the habitat, built, and installed an airlock module for the habitat, and built the sandbox with an enclosing dome where the simulated spacewalks will take place. CHAPEA held a facility readiness review on July 28.

In partnership with Sierra Space, EC successfully completed the Exposed Root On-Orbit Test System (XROOTS) ISS Tech Demo in October 2022. XROOTS demonstrated hydroponic and aeroponic techniques to grow plants without soil or other growth media. These findings will help identify alternative methods available to produce crops on a larger scale for future space missions. EC continued European Enhanced Exploration Exercise Device (E4D) development. The E4D is a multi-purpose exercise device the crew will use to maintain their fitness on long-duration missions. EC completed the critical design review (CDR) milestone in July 2022.

EC development of Radiation Protection activities include a demonstration of the Hybrid Electronic Radiation Assessor (HERA) on Artemis II. Radiation tolerant displays are being developed for Orion.

Implementation and completion of year one of a two-year initiative called Project Polaris was completed. Project Polaris aims to execute 10 distinct low-cost activities addressing the most critical gaps across multiple centers to give experience to Early Career civil servant project management teams. The activity teams are working to rapidly advance the technology base for future missions. Some recent successes include: The Joint Augmented Reality (Joint AR) Visual Informatics System completed a Heads-Up-Display (HUD) prototype with EVA glove compatible controls, which has been tested with EVA experienced Astronauts and EVA Flight Controllers; the prototype 50 meter Tall Lunar Tower activity, which will provide a self-erecting structure on the lunar surface for resources such as solar panels or communications equipment, is progressing towards a demonstration in late FY 2023; and. Autonomous Satellite Technology for Resilient Applications partnered with a small satellite provider for a ride share test to demonstrate autonomous operations of the satellite and instruments.

WORK IN PROGRESS IN FY 2023

EC habitation work will continue to deliver the fundamental capabilities and systems to provide astronauts a place to live and work in space. EC will continue upgrades to the Urine Processor Assembly (UPA) and Water Processor assembly (WPA) to increase reliability and mailability and reduce mass for exploration ECLSS water revitalization system. The system upgrades will be installed and tested on ISS. Ongoing ISS flight demonstrations of advanced CO2 removal and the environmental monitoring system, as well as ground based advanced ECLSS testing and development, will also continue. Additionally, ISS flight demonstrations for the MiniTOCA, and upgrades to the ISS oxygen generation and CO2 resource recovery systems are planned for 2025.

EC will conduct the first mission for the CHAPEA simulated Mars habitat located at Johnson Space Center (JSC) beginning in June 2023. Four crew will inhabit CHAPEA during a one-year mission. Throughout the mission, crew members will be evaluated for performance based on diet and exercise throughout the mission. Food for the crew is being produced, packaged, and stored in the JSC Food Lab for the mission. The CHAPEA mission will provide performance and risk data associated with volume and mass requirements for food for long-duration exploration missions The Food and Nutrition team will also research further water reduction in packaged foods to minimize mass and volume.

Another Food Systems effort is the Ohalo III facility that is being designed and built at Kennedy Space Center (KSC) to fly on ISS in the FY 2026 timeframe to demonstrate plant growth approaches in micro and low gravity. Two grants have been awarded through the Research Opportunities in Space Biology (ROSBio) to develop plant growth trays that will utilize the Ohalo III facility to demonstrate novel approaches to plant growth in space and provide better nutritional and psychological benefits for crew on long duration mission.

The Spacecraft Fire Safety Project will continue research into flammability in exploration environments with two flights in FY 2023. The Saffire VI experiment will launch on the NG-19 vehicle in Q2 or Q3 FY 2023 and execute in Q4 FY 2023, completing the series of six flights in microgravity and enabling validation of ground models. The LUCI (Lunar Combustion Investigation) will execute on a Flight Opportunities flight on New Shepard in mid-FY 2023 to study flammability in simulated lunar gravity. The project will also continue work on the Flammability of Materials on the Moon (FM2) experiment which is currently manifested on the CP-21 Commercial Lunar Payload Services (CLPS) flight.

EC will fly the Spacecraft Atmosphere Monitor (SAM) Technology Demonstration Unit (TDU) 2 with Trace Gas Capability to ISS. SAM2 is currently scheduled for delivery in FY 2023 and will be the first instrument capable of measuring the major constituents trace contaminants in the air.

Development of the Enhanced European Exploration Exercise Device (E4D) multi-purpose exercise equipment and its associated vibration isolation system and software will continue in partnership with ESA. This device is being developed for crew use to maintain physical fitness on long missions. Physical activity is the most effective way to counteract the adverse effects of weightlessness on the human body and is part of the daily routine for astronauts in orbit.

EC launched four CubeSats on Artemis I: BioSentinel, Near Earth Asteroid (NEA) Scout, Lunar IceCube, and Lunar Infrared Imaging (LunIR) to help answer strategic knowledge gaps associated with the Moon, asteroids, and effects of space radiation on biological systems; and develop capabilities for deep space CubeSats, enabling future missions for academia and industry. The BioSentinel project has successfully operated its spacecraft on every available pass and will complete mission operations in FY 2023.The remaining CubeSats have not been able to operate and project teams will conclude mission operations in March 2023.

Project Polaris activities are nearing close out. The teams will complete a full-scale demonstration on earth of the 50-meter robotic tower assembly. Joint AR continues integration with informatics into the heads-up display engine. Testing of the irradiated test displays to look for degradation will be conducted. ASTRA will fly on a satellite and mirror fault detection isolation and controls of the spacecraft to ground controllers. Multi-function nano sensors will be testing against KSC's launch leak detection systems to baseline performance against field designed systems.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

EC will continue development of ground and flight experiments to investigate long duration support for landing humans on the Moon and establishing a sustainable, long-term presence there. EC will focus on the key critical technologies required to enable Mars missions, using Lunar missions and infrastructure as testbeds. Testing new ECLSS component options and conducting critical demonstrations for autonomous control of integrated ECLSS will continue. Development and reliability testing of the ISS UWMS toilet will progress in preparation for future missions to Mars. The logistics reduction project will demonstrate trash compaction and processing options for make/buy decision in 2024. Space Radiation sensors will be constructed. The team will begin operations, flight data analysis and integration with Space Weather radiation analysis modeling tools for Gateway and HLS radiation shielding requirements.

EC will also continue building upon the current commercial engagement contracts to advance commercial habitation, life support, in-space refueling capabilities, or through collaboration with commercial space industry partners. The Fire Safety team will continue development of an experiment for the Commercial Lunar Payload Services (CLPS) mission CP-21 (CLPS Payloads and Research Investigations on the Surface of the Moon [PRISM]-year two, first mission) to test material combustion in lunar gravity. CHAPEA will complete its first mission, debrief, and prepare for the second mission (including crew selection). Ohalo III will continue development of its ISS facility. The Exploration Medical team will continue development and testing of exploration medical capabilities to support long term crew health needs, e.g., medical systems such as on demand generation of IV fluids and in-flight Exploration Electronic Health Record (xEHR) system on ISS use on long-duration missions and perform radiation testing of pharmaceuticals.

Program Elements

HABITATION SYSTEMS

Habitation Systems delivers the fundamental capability to provide integrated life support systems, environmental monitoring, crew health, radiation protection, fire-safety, and systems to manage food, waste, clothing, and tools that enable astronauts to carry out NASA's mission in space and on other worlds. EC focuses on developing key habitation systems to enable the crews to live and work safely in space, with an initial focus on lunar missions. Activities include life support systems, logistics reduction, food and crew health systems, and radiation measurements and protection.

Experiments to improve spacecraft fire-safety are also under way to better understand how fire spreads and how to recover from fire events in lunar gravity. These investments will progressively move from habitation subsystems to integrated systems and then be infused into deep space exploration elements and system designs.

CREW HEALTH AND PERFORMANCE

These activities include development of countermeasures such as exercise equipment to maintain crew fitness on long missions, food systems such as crop production to provide nutritious food for the crew, development of diagnostic sensors for remote medical care, and models of human physiology to predict crew fatigue and injuries when performing EVA.

EC works with the ECLSS-CHP Strategic Capabilities Leadership Team (SCLT) to follow Road Maps developed within the SCLT that show planned infusion into future exploration systems, such as Surface Hab and Mars Transit Hab. The Road Maps show clear paths of development and testing leading to adoption by future missions, aligned with Agency Program milestones, and contain both funded and unfunded work. These Road Maps assist in prioritization and assessing the impacts of development delays to Agency milestones.

ROBOTIC PRECURSORS

In addition to the four CubeSats that were launched on Artemis I, EC is developing small robotic spacecraft and remote sensing instruments to search for lunar resources.

Program Schedule

Date (FY)	Significant Event
Nov 2022	Launched 4 CubeSats on Artemis-I and began mission operations
Q2 FY 2023	Award of the ROSBio Phase B grants for nutrient delivery systems for Ohalo III and for plant spacing/volume management concepts
Q2/Q3 FY 2023	Execute LUCI experiment in simulated lunar gravity on New Shepard
Q3 FY 2023	CHAPEA begins the first of three consecutive 1-year missions in the Mars analog habitat
Q4 FY 2023	Conduct Saffire–VI fire safety experiment
FY 2024	Deliver Flammability of Materials on the Moon (FM2) to Commercial Lunar Payload Services (CLPS)
FY 2024	Demonstrate trash compaction and processing options
FY 2024	Complete: CAPSTONE operations in Near Rectilinear Halo Orbit (NRHO) to demonstrate pathfinder lunar operations for Gateway

EXPLORATION CAPABILITIES

Date (FY)	Significant Event
TBD 2024	Demonstrate autonomous control of integrated ECLSS components, incorporating prognostics

Program Management & Commitments

Exploration Systems Development Mission Directorate's Associate Administrator delegated management authority, responsibility, and accountability to the EC division at NASA Headquarters. EC Division establishes overall direction and scope, budget, and resource allocation for activities implemented by the NASA centers.

Program Element	Provider
ECLSS	Provider: NASA Centers Lead Center: Headquarters (HQ) Performing Center(s): JSC, MSFC, Ames Research Center (ARC), Glenn Research Center (GRC), Langley Research Center (LaRC), KSC, and Jet Propulsion Laboratory (JPL) Cost Share Partner(s): Bigelow Aerospace, Boeing, Lockheed Martin, Orbital ATK, Sierra Nevada, NanoRacks (NextSTEP), Dynetics, and UTC Aerospace Systems (UTAS)
Crew Health & Performance	Provider: NASA Centers Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): N/A
Core	Provider: NASA Centers Lead Center: Various NASA Centers Performing Center(s): JSC, MSFC, ARC, GRC, GSFC KSC, LARC, SSC and JPL
Robotic Precursors	Provider: NASA Centers Lead Center: HQ Performing Center(s): MSFC, JPL, ARC, GSFC Cost Share Partner(s): N/A

Acquisition Strategy

Each year, EC evaluates how the portfolio aligns with human exploration priorities and technology gaps and either terminates or realigns activities that do not demonstrate adequate progress. EC also adds new activities to the portfolio, as appropriate. EC will continue to utilize this process to identify and evaluate risk-reduction activities needed in support of lunar and future Mars missions. EC strives to maximize specialized skills within the civil service workforce, but it may also utilize contractor effort in areas where NASA can leverage external skills and knowledge in a cost-efficient manner. EC will also use the Small Business Innovation Research program to engage small businesses for risk reduction and technology maturation. EC continues the use of competitively selected external awards and industry collaborations. Upgrades to existing ISS life support systems will use existing contracts.

EXPLORATION CAPABILITIES

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Habitation Systems: Brine Water Processor	Paragon	Tucson, AZ; MSFC
Habitation Systems: Thermal Amine CO2 Scrubber	Collins Aerospace	Windsor Locks, CT
Habitation Systems: Oxygen Generation Assembly	Collins Aerospace	Windsor Locks, CT
Habitation Systems: Water Processor Assembly	Collins Aerospace	Windsor Locks, CT
NextSTEP Broad Agency Announcement Awards	Boeing, Bigelow Aerospace, Lockheed Martin, Orbital ATK, and Dynetics	JSC; MSFC; KSC

INDEPENDENT REVIEWS

EC undergoes quarterly Directorate Program Management Council reviews, and periodically, representatives from the Office of Chief Engineer, the Office of Safety and Mission Assurance, and the Office of Chief Financial Officer will assess EC performance during Agency-level Baseline Performance Reviews. In addition, EC provides briefing reports to, and seeks feedback on planning and development activities from, the NASA Advisory Council's Human Exploration and Operation Committee and Technology Committee.

SPACE OPERATIONS

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
International Space Station	1,261.8	--	**1,302.6**	1,302.1	1,302.5	1,302.9	1,321.7
Space Transportation	1,716.9	--	**1,956.7**	1,990.6	2,036.2	2,068.7	2,153.4
Space and Flight Support (SFS)	889.1	--	**1,047.0**	1,103.0	1,076.8	1,005.4	995.4
Commercial LEO Development	102.1	--	**228.4**	229.6	302.3	435.2	437.8
Exploration Operations	5.0	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**3,974.9**	**4,250.0**	**4,534.6**	**4,625.3**	**4,717.8**	**4,812.2**	**4,908.4**
Change from FY 2023 Enacted			**284.6**				
Percent change from FY 2023 Enacted			**6.7%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The NASA Administrator has determined that, in the interest of ensuring the safe and successful execution of the early Artemis flights, managing risk effectively, and maintaining resiliency and flexibility for future missions exploration requirements, NASA has made a decision to no longer transition programs that complete their research and development phase in the Exploration Systems Development Mission Directorate to the Space Operations Mission Directorate for their operational phase.

SPACE OPERATIONS

SPACE OPERATIONS

FY 2024 Budget

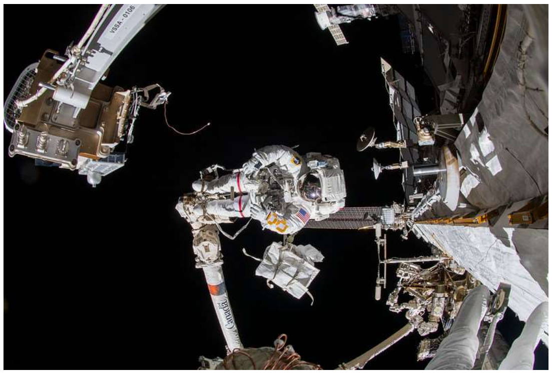
Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
International Space Station	1,261.8	--	**1,302.6**	1,302.1	1,302.5	1,302.9	1,321.7
Space Transportation	1,716.9	--	**1,956.7**	1,990.6	2,036.2	2,068.7	2,153.4
Space and Flight Support (SFS)	889.1	--	**1,047.0**	1,103.0	1,076.8	1,005.4	995.4
Commercial LEO Development	102.1	--	**228.4**	229.6	302.3	435.2	437.8
Exploration Operations	5.0	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**3,974.9**	**4,250.0**	**4,534.6**	**4,625.3**	**4,717.8**	**4,812.2**	**4,908.4**
Change from FY 2023 Enacted			**284.6**				
Percent change from FY 2023 Enacted			**6.7%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The NASA Administrator has determined that, in the interest of ensuring the safe and successful execution of the early Artemis flights, managing risk effectively, and maintaining resiliency and flexibility for future missions exploration requirements, NASA has made a decision to no longer transition programs that complete their research and development phase in the Exploration Systems Development Mission Directorate to the Space Operations Mission Directorate for their operational phase.

SPACE OPERATIONS



NASA astronaut and Expedition 66 Flight Engineer Raja Chari is pictured attached to the Canadarm2 robotic arm during a six-hour and 54-minute spacewalk to install thermal gear and electronic components on the ISS. This activity requires the support of multiple Space Operations programs: ISS provides overall support for the spacewalk; Space Transportation ensures the astronaut and all the equipment, including spacesuits, is on orbit; and Space and Flight Support provides astronaut training, safety protocols, and communication from mission control to the astronauts during the spacewalk (March 23, 2022).

The Space Operations account is dedicated to sustained human presence in low-Earth orbit (LEO), enabling future exploration and advanced operations in our solar system, and advancing scientific discoveries that benefit life on Earth. In the near term, this includes support of International Space Station (ISS) operations and research, while laying the foundation for America to develop and maintain a commercial economy in LEO. This budget request includes all the elements needed to implement a smooth transition from ISS operations to commercial operations in LEO, ensuring no gap in U.S. presence in LEO and a safe deorbit of the ISS. Space Operations is comprised of the ISS, Space Transportation (including the new ISS de-orbit vehicle), Space and Flight Support, and Commercial LEO Development themes. Collectively, these themes are developing and operating American-led space infrastructure enabled by a commercial market, enhancing space access and services to both Government and commercial entities, and researching and developing capabilities to safeguard astronaut explorers. These activities, which support existing and future space operations for both NASA and non-NASA missions, are catalysts for economic development and lay the groundwork for a commercial future in LEO in which NASA is one of many customers for commercial services. Additionally, these activities continue to return medical and environmental benefits to humanity, advance scientific knowledge, and foster new technologies that improve American lives.

The ISS is now in its most productive decade of utilization, including advancing research, providing commercial value, and fostering global partnership. ISS continues to demonstrate American leadership in global space exploration, enabling a U.S.-led multinational partnership to advance shared goals in space. As a testbed for deep space exploration, ISS is helping us learn how to keep astronauts healthy during long-duration space travel and demonstrating technologies for human and robotic exploration beyond LEO, to the Moon, and to Mars. NASA's research and development activities aboard are advancing the technologies and procedures that will be necessary to send the first woman and first person of color to the Moon and the first humans to Mars. In addition to supporting future exploration, scientific research on ISS is helping to solve health challenges for humans on Earth through medical advancements. ISS enables commercial industry, academic institutions, U.S. Government agencies, and other diverse users to access a unique research platform with unmatched capabilities for developing and demonstrating new technologies, treatments, and products for improving life on Earth.

Under the Space Transportation theme, the Crew and Cargo Program manages transportation services provided by both international partners and domestic commercial providers. Through the program, NASA has greatly strengthened U.S. competitiveness by awarding ISS cargo resupply contracts to multiple vendors, as well as continuing to advance commercial spaceflight and support American jobs.
The Commercial Crew Program (CCP) is developing and operating safe, reliable, and affordable crew transportation systems capable of carrying humans to and from the ISS and other LEO destinations. Working with industry to develop and provide human transportation services to and from space lays the

foundation for more affordable and sustainable future human space transportation. These commercial partnerships bolster American leadership in space, have ended sole reliance on foreign providers for crew transportation services, help stimulate the American aerospace industry, and allow NASA to focus on building the capabilities and expertise necessary for missions to the Moon and Mars. The Space Transportation theme also includes funding for the ISS de-orbit vehicle that will be competitively awarded to U.S. industry.

The Space and Flight Support Theme (SFS) continues to provide mission critical space communications, launch and test services, and astronaut training to support its customer missions. The Space Communications and Navigation (SCaN) Program provides communication to missions in LEO, including ISS, suborbital missions, and some lunar orbital missions, utilizing the Near Space Network. The Deep Space Network communicates with missions most distant from Earth and initially provided primary communications links to the Artemis I mission. SCaN is planning for expanded services for missions to the Moon, including lunar relay capability for missions that cannot communicate directly with Earth and enhanced position, navigation, and timing services that are less dependent on tracking stations on Earth. The Communication Services Program focuses on demonstrating the feasibility of using commercially provided satellite communications (SATCOM) services to support NASA missions. The Launch Services Program provides expertise and active launch mission management for more than 70 NASA and other Government missions in various stages of development. The Rocket Propulsion Test Program manages a wide range of facilities capable of ground testing rocket engines and components under controlled conditions. The Human Space Flight Operations Program provides the training and readiness to ensure crew health and safety and mission success. The Human Research Program is working to improve astronauts' ability to collect data, solve problems, respond to emergencies, and remain healthy during and after extended space travel.

NASA's Commercial LEO Development effort focuses on the development of a robust commercial space economy in LEO. It is stimulating development of commercially owned and operated LEO destinations from which NASA can purchase services to meet enduring LEO human spaceflight requirements. NASA’s goal is to be one of many customers of commercial LEO destination (CLD) services, purchasing only the goods and services the Agency needs, rather than owning and operating the platform(s). As commercial LEO destinations become available, and without a gap in a U.S. presence in LEO, NASA intends to implement an orderly transition from current ISS operations to the new commercial enterprise as laid out in NASA's ISS Transition Report (January 2022).

EXPLANATION OF MAJOR CHANGES IN FY 2024

The FY 2024 budget request includes funds for development of an ISS de-orbit vehicle included in the Space Transportation Theme, that will be competitively awarded to U.S. industry.

The planned transfer of work from Deep Space Exploration Systems to Space Operations will no longer begin in FY 2024.

For more information, visit: https://www.nasa.gov/directorates/space-operations-mission-directorate

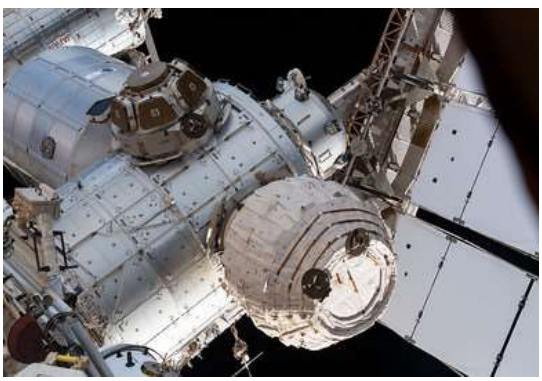
INTERNATIONAL SPACE STATION PROGRAM

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
ISS Systems Operations and Maintenance	982.4	--	**1,036.0**	1,031.1	1,031.5	1,031.9	1,050.7
ISS Research	279.4	--	**266.6**	271.0	271.0	271.0	271.0
Total Budget	**1,261.8**	**--**	**1,302.6**	**1,302.1**	**1,302.5**	**1,302.9**	**1,321.7**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



This view from a window on the International Space Station's Russian segment shows the Bigelow Expandable Activity Module (BEAM), the cupola with its seven windows shuttered, and the NanoRacks Bishop airlock. Behind the cupola is the Leonardo permanent multipurpose module. All four components are attached to the Tranquility module (August 2, 2022).

The International Space Station (ISS) is the largest and most complex space-based research facility ever constructed. ISS enables distinct research opportunities, including research supporting the Artemis human lunar exploration missions and future Mars human exploration programs. Returns from the investment in ISS are not limited to scientific discovery and technology advancement. The ISS international partnership is composed of five space agencies representing 15 nations, led by the United States. NASA's international partners include the Canadian, European, Japanese, and Russian space agencies. Engineers, scientists, and managers from around the world have directed their resources for the peaceful use of space and are now reaping the benefits to humanity. The ISS partnership uses global engagement and diplomacy to provide a cooperative foundation for the global enterprise of space exploration. The partnership allows members to collectively allocate resources and manage operational risks in a way that benefits all parties. ISS provides a high visibility opportunity for American leadership in low-Earth orbit (LEO).

ISS orbits the Earth about every 90 minutes and has been continuously occupied since 2000. November 2, 2022, marked the 22nd anniversary of human occupation aboard the ISS. The U.S. Orbital Segment (USOS) is the portion of the ISS operated by the United States and its Canadian, European, and Japanese partners. Russia exclusively operates the Russian segment. The ISS spans the area of a U.S. football field (with end zones) and weighs more than 463 tons (92,6000 pounds). Its solar arrays, which help power the vehicle, are longer than a Boeing 777's wingspan at 240 feet. The ISS has eight docking and berthing ports for visiting vehicles delivering crew and cargo. Orbiting Earth 16 times per day at a speed of 17,500 miles per hour, the ISS maintains an altitude range of 230 to 286 miles. The complex has more livable room than a conventional five-bedroom house, with two bathrooms, fitness equipment, a 360-degree bay window, and state-of-the-art scientific research facilities. In addition to external test beds,

INTERNATIONAL SPACE STATION PROGRAM

the USOS houses three major science laboratories: the United States Destiny, European Columbus, and Japanese Kibo. With the launch of the first U.S. commercial crew post-certification in November 2020, NASA increased its crew size on the USOS by one, to a total of four astronauts. On average, this doubled the total available hours of USOS crew time allocated to perform research on board the ISS each week.

This budget request funds the civil service and contractor staff, as well as the facilities and equipment, required to support U.S. obligations for the USOS and enable vehicle operations and research in the harsh conditions of space with constant, around-the-clock support. The requested funding enables four major focus areas of activity for the ISS program including: (1) serving as a key steppingstone on the pathway to deep space exploration; (2) maintaining U.S. global leadership of space exploration; (3) enabling the development and advancement of a commercial marketplace in LEO; and (4) returning benefits to humanity on Earth through space-based research, technology development, and science, technology, engineering, and mathematics (STEM) education for students of all ages.

The ISS plays an essential role in facilitating the expanding sphere of human space exploration from LEO to the Moon (via the Artemis Program) and eventually to Mars. The ISS is currently the only microgravity platform capable of long-term testing of new life support and crew health systems, advanced habitation modules, and other technologies needed to expand NASA's exploration horizons. This research and development program will continue to focus on capabilities needed to maintain a healthy and productive crew in deep space, including the Gateway and future missions to the Moon and Mars. Manifested or planned experiments and demonstrations to enable human exploration at the Gateway, lunar surface, and into deep space include: tests of improved long-duration life support technologies; advanced fire safety equipment; on-board environmental monitors; techniques to improve logistics efficiency; in-space additive manufacturing; advanced exercise and medical equipment; radiation monitoring and shielding; human-robotic operations; and autonomous crew operations. The facility enables scientists to identify and quantify risks to human health and performance and to develop and test preventative techniques and technologies to protect astronauts during extended time in space. The ISS platform and future commercial LEO destinations provide a rich environment for both basic and applied research.

NASA will maintain research and technology efforts in LEO using the ISS to enable exploration with humans to the Moon and Mars, while continuing to perform research that benefits humanity and leads to a robust ecosystem in LEO. NASA is working to implement a stepwise transition of ISS from the current model of NASA sponsorship and direct NASA funding to a model where NASA is one of many customers purchasing services from a LEO human spaceflight enterprise via the Commercial LEO Development Program. NASA will transition from current ISS operations to this new model when these commercial platforms and services become available. Following the completion of ISS operations in 2030, the ISS will be safely deorbited via a controlled reentry into an unpopulated region of the Pacific Ocean. The Crew and Cargo program is developing this de-orbit capability with U.S. industry through a competitive procurement.

NASA and its partners use this unique asset to advance STEM education efforts to inspire youth to pursue those fields. Over 10 million U.S. students have designed, launched, operated, or used data from more than 800 student experiments launched to ISS, including a 30 percent representation from underserved communities. ISS also provides a unique opportunity for STEM inspiration through direct engagement

INTERNATIONAL SPACE STATION PROGRAM

between astronauts and students. ISS inspires future generations and helps foster greater interest in STEM careers.

The ISS program aims to provide direct research benefits to the public through its operations, research, and technology development activities. As a National Laboratory, the U.S. segment of the ISS enables Government agencies, academia, and industry to utilize its unique environment and advanced facilities to perform investigations. The focus of the ISS National Laboratory (ISSNL) is to provide ISS access to academia, the commercial sector, and other Government agencies through partnerships, cost-sharing agreements, and other arrangements for research, technology development, LEO commercialization, and education. Observing from and experimenting aboard ISS provides the opportunity to learn about Earth, life, and the solar system from a very different perspective. ISS serves as an innovation laboratory for experiments that cannot be accomplished on Earth. Earth observation instruments on ISS expand our Nation's understanding of the climate and carbon cycle. It also allows other NASA mission directorates to conduct research and demonstrate technologies. This includes technology demonstrations sponsored by the Space Technology Mission Directorate and Biological and Physical Sciences and Earth Science research funded by the Science Mission Directorate. The results of the research completed on ISS can be applied to many areas of science, improving life on Earth, fueling American innovation and enhancing U.S. overall economic competitiveness, and furthering the experience and increased understanding necessary to journey to other worlds.

For more on the ISS program, visit: https://www.nasa.gov/mission_pages/station/main/index.html

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ISS SYSTEMS OPERATIONS AND MAINTENANCE

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**982.4**	**--**	**1,036.0**	**1,031.1**	**1,031.5**	**1,031.9**	**1,050.7**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

NASA astronaut Josh Cassada (center) is pictured here trying on an Extravehicular Mobility Unit (EMU), or spacesuit, with assistance from astronaut Koichi Wakata (left) of the Japan Aerospace Exploration Agency and NASA astronaut Nicole Mann (right) inside the International Space Station's Quest airlock (November 5, 2022).

The International Space Station (ISS) is a complex research facility and human outpost in low-Earth orbit (LEO) developed in a collaborative, multinational effort led by the United States with partners in Canada, Europe, Japan, and Russia. It is supported by the commercial industry via the Crew and Cargo Program and Commercial Crew Program (CCP). The facility's primary goals are to advance exploration of the solar system, enable unique scientific research, and promote commerce in space with industry partners as new commercialization concepts are explored. The ISS Systems Operations and Maintenance (O&M) project funds civil service and contractor labor as well as facilities and equipment necessary to enable vehicle operations in the harsh conditions of space with constant, around-the-clock support. The ISS systems operate in extreme temperatures, pressures, and energies that challenge engineering techniques with minimal margin for error. The risks associated with operating the ISS are significant and must be effectively managed to protect against catastrophic consequences to mission success and human life. Successful risk mitigation activities on ISS in LEO pave the way for a more successful Artemis Program and missions to Mars.

Safely operating the ISS in the severe conditions of space and ensuring the crew always have a sufficient supply of food, water, oxygen, and repair parts demands precise planning and logistics. The 463-ton vehicle requires routine maintenance and is subject to unexpected mechanical failures, given its highly complicated systems and the harshness of space. Resolving problems can be challenging and often requires the crew to make repairs in space with support from ground teams on Earth. Astronauts aboard the ISS must rely on the materials available to them on board. This requires the support team on Earth to monitor and meticulously plan for replacement parts and consumables, such as filters and gases, as well as Orbital Replacement Units (ORUs) like the Inlet De-ionizing Bed, Microbial Check Valves, and Multi-Filtration Beds, which are key components of the Regenerative Environmental Control Life Support System (Regen ECLSS). The coordination and support necessary for the ISS crew to live and

ISS SYSTEMS OPERATIONS AND MAINTENANCE

work comfortably in space requires intensive Earth-based mission operations. Ground teams continually monitor ISS performance, provide necessary vehicle commands, and communicate with the crew.

Even before the astronauts leave Earth, the ISS Systems O&M project, in conjunction with the Human Space Flight Operations program, provides the crew training to prepare them for their stay aboard the ISS. One example includes operating the Neutral Buoyancy Laboratory, an indoor underwater training facility, where astronauts, in a safe environment, can simulate specific extravehicular (EVA) activities to repair, replace, or install new instruments and operational systems. During training exercises, neutral-buoyancy diving is used to simulate the weightlessness of space operations. To achieve this effect, suited astronauts or pieces of equipment are lowered into the pool using an overhead crane and then weighted in the water by support divers so that astronauts experience minimal buoyant force and minimal rotational moment about their center of mass.

The ISS program considers all aspects of the mission when developing operations plans to meet program objectives. These include scheduling crew activities, choreographing docking and undocking of visiting crew and supply ships, evaluating supplies of consumables, managing flight plan variability, and resolving stowage issues. The ISS Systems O&M project ensures the ISS is always operational and available to perform its research mission.

A critical component of the ISS Systems O&M project is immediate emergency services and analyses conducted by mission control teams on Earth, known as vehicle and program anomaly resolution. Engineers and operators diagnose system failures and develop solutions, while program specialists respond to changing program needs and priorities through re-planning efforts. These teams ensure appropriate redundancy, training, and procedures are in place to respond to any type of failure at any time. The project requires sparing and repairing nine highly complex on-orbit systems made up of hundreds of unique ORUs. Additionally, software sustainment manages and executes millions of lines of flight code to support operation and control of the ISS.

Because the ISS is an international partnership, program decisions are not made in isolation. Rather, they require collaboration with multiple countries to ensure all technical, schedule, and resource supply considerations are taken into account. The experience NASA is gaining through integration with its ISS partners is helping the Agency to better prepare for future programs in human space exploration, such as on the Gateway or the lunar surface.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ACHIEVEMENTS IN FY 2022

The ISS Systems O&M project continued to maintain resources both on-orbit and on the ground to operate and utilize the ISS. The ISS Systems O&M project funded Mission Control Center (MCC) operations monitoring the safety of crew and integrity of ISS 24/7, while other MCC activities were funded by the programs they support. This is required to maintain success in providing all necessary

ISS SYSTEMS OPERATIONS AND MAINTENANCE

resources, including power, data, crew time, logistics, and accommodations, to support research while operating safely with a typical crew of seven astronauts, four USOS crew, and three Russian crew.

The ISS Systems O&M project supported the arrival and departure of 15 flights, both domestic and international crew and cargo missions, to the ISS. This resulted in supporting over one flight per month. Each flight required extensive planning and analyses to support on-orbit operations, as well as launching, docking, undocking, berthing, unberthing, deorbiting, packing, manifesting, hardware processing, and on-orbit configuration.

NASA ground teams continued to monitor overall vehicle health and oversee general maintenance and performance of all the ISS vehicle systems, including command and data handling, communication and tracking, crew health care, environmental control and life support, electrical power, extravehicular activities (EVAs), robotics, flight crew equipment, propulsion, structures and mechanisms, thermal control, guidance, navigation, and control. These individual teams worked together to support the crew in quick resolution of several unexpected anomalies, including continued support to identify and mitigate a small ISS atmosphere leak in the transfer tunnel of the Zvezda module, which launched to space in 2000 and forms part of the Russian region of the space station. Zvezda supports the station's life support systems (which have some backup in the U.S. orbital side of the station) and contains living quarters for two cosmonauts. The leak has been reduced by patching identified small cracks. Both Roscosmos and USOS continue to monitor the air pressure, search for root cause, and ensure that the ISS is supplied with sufficient consumables.

In FY 2022, the team supported two USOS EVAs for the new ISS Roll Out Solar Array (iROSA). The combination of the eight original arrays and the smaller, more efficient, new iROSA arrays will provide a 20 to 30 percent increase in power for space station research and operations. This upgrade ensures the ISS will be able to support the anticipated power demand of future utilization and commercialization activities while preserving for the expected increase in research and exploration technology demonstrations for Artemis and beyond.

In FY 2022, the ISS Program successfully integrated the first-ever private astronaut mission (PAM), Axiom Mission-1, during which 150 hours of activities for 27 ISS National Lab sponsored research experiments were performed. The ISS Program team also successfully supported the launching, docking, and return of the Boeing Starliner Orbital Flight Test 2 (OFT-2), which showcased the NASA Docking System (NDS) and marked the first time SpaceX Crew and Boeing Crew vehicles were docked to ISS at the same time.

The ISS Systems O&M project supported integration of the new Nauka Multi-purpose Laboratory Module (MLM) and Node modules from Roscosmos as well as the Cygnus reboost. The ISS Systems O&M project procured essential consumables and spares for the functional cargo block (FGB) to meet demand through FY 2024 and modified FGB test stands to support ISS through 2028. In support of Regenerative ECLSS, the first upgraded Oxygen Generating Assembly (OGA) Cell Stack was delivered to reduce risk of extended compression time on existing electrochemical cells, and additional key deliveries included fire cartridge units, as well as commercial major air constituent trending sensors measuring oxygen, carbon dioxide, and humidity.

ISS SYSTEMS OPERATIONS AND MAINTENANCE

There were advances in software vital to ISS on-orbit safety and day-to-day operations. The software updates included completion and transition on-orbit to software release R20. FY 2022 also saw the beginning development of software release R22 and testing of the R21 update. The program delivered 11 IT security patches to meet NASA and other Government security mandates. The ISS System O&M project completed 164 joint software tests, which include software interaction from USOS with any visiting International Partner spaceship, researchers, and crewed Private Astronaut Missions (PAM).

In the Avionics area, ISS continued external wireless connection upgrades which converted an external High Definition (HD) camera to also serve as a wireless communication link, improving the Joint Station Local Area Network (LAN) Robustness. PAM-Net, a specific virtual private network devoted to enable PAM investigations and research separate from the ISS-crew, was implemented. The Ku-Band Space to Ground Transmitter Receiver Controller (SGTRC) spare builds were completed and delivered to NASA. The Forward Link project continued, which is upgrading the encryption algorithms on ISS.

WORK IN PROGRESS IN FY 2023

Throughout the year, NASA ground teams will continue to monitor overall vehicle health and oversee general maintenance and performance of all the ISS vehicle systems. The ISS Systems O&M project will continue to manage resource requirements and changes, including vehicle traffic, cargo logistics, stowage, and crew time. The ISS Systems O&M project is expected to support at least two U.S. Commercial Crew post-certification missions, as well as the first crewed test flight of Boeing's Starliner spacecraft and the second PAM, Axiom Mission 2. In addition to the U.S Commercial Crew flights, the ISS System O&M project is planning five U.S. Commercial Resupply Services cargo flights, including the first Sierra Space Dream Chaser cargo flight, four Progress flights, and two crewed Soyuz flights.

USOS and Roscosmos work together to help the crew resolve routine and critical, urgent anomalies. An example is the December 14, 2022, discovery of an external cooling loop leak from the Roscosmos Soyuz MS-22 spacecraft docked to the Rassvet module. With integrated crews on each other's spacecraft, NASA and Roscosmos jointly discussed all decisions related to crew safety and transportation, conducting a variety of engineering reviews, and consulted with other international partners about methods for nominal and contingency safe return of the Soyuz crew. The Russian State Commission approved the launch of an uncrewed Soyuz to replace Soyuz MS-22, which will be utilized for the nominal return of the crew at the end of their mission.

The program is supporting six Russian EVAs and nine U.S. EVAs in FY 2023. Six EVAs are scheduled to be completed in Increment 68. The first four will prepare and install the 3A and 4A iROSA solar arrays. A double EVA is scheduled for late Increment 68 to prepare for the 1A iROSA solar array installation and to replace the failed P1 S-Band Antenna Sub Assembly (SASA). The final three EVAs for FY 2023 are planned in Increment 69 to install the 1A and 1B iROSA solar arrays.

ISS continues to develop and install software vital to its on-orbit safety and day-to-day operations. The planned software updates include completion and transition to on-orbit of software release R21. Over 140 joint software tests are planned, including 19 to support commercial crew/cargo flights, 26 for software transitions, and the remaining 95 tests will support payload/technology demonstration activities.

ISS SYSTEMS OPERATIONS AND MAINTENANCE

In the avionics area, the ISS Systems O&M project will procure new digital still cameras and the next generation of laptops for ISS. The project will complete analysis of S-Band sparing to ensure ISS viability to 2030. In addition, the team will transition the Forward Link project to update the ISS encryption algorithms into the testing phase. Axiom Mission 2 will be integrated and continue its use of PAM-Net.

In FY 2023, the ISS Systems O&M project is making significant progress toward the launch and installation of four additional iROSA wings as well as launch and first use of the upgraded Cycle Ergometer with Vibration Isolation & Stabilization (CEVIS) enabling cycling activities via leg or arm ergometry to provide aerobic exercise as a countermeasure to cardiovascular deconditioning on-orbit. In support of FGB, the program will implement a Thermal System gas trap and perform shell diagnostics and analysis. In support of Regenerative ECLSS, the program will deliver two OGA cell stack kits, a spare Four-Bed CO2 Scrubber blower, an improved Urine Processor Assembly purge pump, an upgraded potable water dispenser, and Anomaly Gas Analyzer (AGA) units to ISS for use during emergency fire or ammonia response.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

The ISS Program will continue to work closely with CCP and commercial crew providers to ensure any challenges with the initial missions are addressed with minimal impact to ISS operations and research. NASA plans to work with international partners to maintain a continuous ISS crew member capability by coordinating and managing resources, logistics, systems, and operational procedures. The ISS Systems O&M project will continue to manage resource requirements and changes, including vehicle traffic, cargo logistics, stowage, and crew time. In addition to providing anomaly resolution and failure investigation (as needed), they will provide real-time support for activities, such as EVAs and visiting vehicles. The ISS Systems O&M project plans to support the launch of two U.S. crew flights, six U.S. cargo flights, two PAM missions, two Russian crew flights, four Russian cargo flights, and the first Japanese cargo flight on the new H-II Transfer Vehicle (HTV)-X vehicle.

The ISS program protects for four EVAs to install hardware and/or payloads and four EVAs to address external anomalies. Until the cargo vehicle manifests are finalized, specific EVA hardware installations are under review, including the EVAs to install the iROSA Wings on the 2A and 3B power channels. Two Russian EVA is currently planned. The ISS software team is planning to transition to R22 version of ISS software and launch and deploy the Forward Link enhancement to improve security of the command links. The final HD camera will be converted to complete the external wireless upgrade. Over 150 joint tests are expected with 19 supporting software transitions, 31 for visiting vehicle flights, and 100 tests to support payload and technology demonstrations. Additionally, the program is planning the delivery and launch of the Supplemental Heat Rejection Evaporative Cooler (SHREC) designed to provide heat rejection for the U.S. Lab Internal Thermal Control System (ITCS) heat loads in the event of a concurrent loss of both External Thermal Control System (ETCS) loops and conducting planning and analysis work to support the FGB extension through 2030.

ISS SYSTEMS OPERATIONS AND MAINTENANCE

PROJECT SCHEDULE

The table below provides a schedule for FY 2023 and FY 2024 completed and planned EVAs. Only currently planned EVAs are included in the table; additional EVAs will be added as needed. The ISS conducts near-term, real-time assessments of EVA demands, along with other program objectives, to efficiently plan all required ISS activities. NASA remains postured to conduct EVAs on short notice in response to specific contingency scenarios. In addition, the ISS program balances routine maintenance EVAs against overall astronaut availability to maintain focus on utilization and research.

Date	Significant Event
Dec 2022	Two USOS EVAs
Dec 2022	Two Russian EVAs
Feb 2023	Russian EVA
Apr 2023	Two Russian EVAs
May 2023	Russian EVA
Jun 2023	Russian EVA
June 2023	Two USOS EVAs
Jul 2023	Russian EVA
Oct 2023	Russian EVA
Dec 2023	Russian EVA
TBD	USOS EVAs

Project Management & Commitments

While NASA maintains the integrator role for the entire ISS, each partner has primary authority for managing and operating the hardware and elements they provide. Within NASA, Johnson Space Center (JSC), located in Houston, TX, leads the project management of the ISS Systems O&M.

Acquisition Strategy

The current Boeing vehicle sustaining engineering contract extends through September 2024. Requirements of this contract include sustaining engineering of U.S. on-orbit segment hardware and software, technical integration across all the ISS segments, end-to-end subsystem management for most of the ISS subsystems and specialty engineering disciplines, and U.S. on-orbit segment and integrated system certification of flight readiness.

ISS SYSTEMS OPERATIONS AND MAINTENANCE

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
U.S. on-orbit segment Sustaining Engineering Contract	The Boeing Company	JSC

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	NASA Advisory Council/SOMD committee	Jan 2023	Provides independent recommendations for the NASA Administrator.	TBD	At least annually, date TBD
Other	NASA Aerospace Safety Advisory Panel	Oct 2022	Provides independent assessments of safety with recommendations to the NASA Administrator.	The Panel recommended "NASA should define an executable and appropriately budgeted deorbit plan that includes implementation on a timeline to deliver a controlled re-entry capability to the ISS as soon as practicable to be in place for the need of a controlled deorbit in event of an emergency as well as in place before the retirement of the ISS to ensure that the station is able to be de-orbited safely."	Feb 2023

ISS RESEARCH

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	279.4	--	266.6	271.0	271.0	271.0	271.0

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Shown here is expedition 67 Flight Engineer and NASA astronaut Jessica Watkins sets up cell samples for viewing in a microscope for the Immunosenescence space biology study. The investigation studies the immunological aging of cells that takes place in microgravity to learn how to keep astronauts healthy on long term missions and treat immunity conditions on Earth (July 20, 2022).

The International Space Station (ISS) is an orbiting platform that astronauts and researchers use to understand the effects of space on human health and to develop technologies to mitigate those effects that are a barrier to future human exploration missions. The unique microgravity environment enables scientific investigation of physical, chemical, and biological processes in an environment very different from Earth.

November 2, 2022, marked the 22nd anniversary of continuous human presence in space aboard ISS. In that span, the orbiting platform has evolved into a dynamic laboratory that hosts an increasing variety of Government and privately-owned science facilities, external testbeds, and observatory sites. The ISS provides the only current capability for human-assisted space-based research and is a foundation for efforts to expand commercial use of low-Earth orbit (LEO) and to enable a sustained U.S. presence in this region of space.

The ISS Research budget funds support for all research users of the ISS through NASA's multi-user systems support (MUSS). In addition, this budget line also supports the ISS National Laboratory, which is dedicated to enabling 50 percent of the ISS U.S. research capacity for non-NASA use.

In 2005, the ISS was designated as a National Laboratory by Congress. The National Lab manages the non-NASA use of the ISS. The 2010 Authorization Act subsequently required national laboratory managed experiments be guaranteed access to, and utilization of, not less than 50 percent of the U.S. research capacity allocation, including power, cold stowage, and requisite crew time onboard ISS. NASA was directed by Congress to enter into a cooperative agreement with a single purpose non-profit, non-Government organization (NGO) to manage non-NASA use of the ISS in cooperation with NASA. NASA selected the Center for the Advancement of Science in Space, Inc. (CASIS) as the operating manager of ISS National Lab activities in 2011. The ISS National Laboratory Program allows non-NASA users to conduct research and development (R&D) activities on ISS that benefit life on Earth and foster commerce in space. Non-NASA users of the ISS National Lab include other Government agencies, such as the National Science Foundation (NSF), National Institutes of Health (NIH), and the Department of

ISS RESEARCH

Defense (DoD) - as well as multiple academic institutions and commercial companies. Since 2012, more than 600 payloads have flown under the ISS National Lab allocation. For the past three fiscal years, nearly 80 percent of the ISS National Lab payloads launched represent investigations from the private sector, fostering economic growth to fuel a new innovation ecosystem in low-Earth orbit.

MUSS provides strategic, tactical, and operational support to all ISS research, whether sponsored by NASA, international partners, or the ISS National Lab. Through MUSS, the ISS Research budget supports the execution of the broader portfolio of research and technology development activities undertaken on the ISS and funded through other NASA organizations (e.g., Science Mission Directorate [SMD], Biological and Physical Sciences [BPS], Human Research Program [HRP], Exploration Systems Development Mission Directorate [ESDMD], and Space Technology Mission Directorate [STMD]). ISS external research platforms enable research recommended by the National Academies Decadal Survey and funded by NASA's SMD to provide access to Earth and space vantage points. These R&D activities enable future human exploration, pioneer scientific discovery, expand our understanding of the universe and our home planet, and benefit our economy and life on Earth. MUSS continues to support new capabilities and technologies that benefit multiple ISS users and operation of on-orbit and ground control research facilities.

Research conducted aboard ISS, supported by this budget line item through MUSS and ISS National Lab activities, have made fundamental contributions to human knowledge and have advanced scientific goals set by the National Academy of Sciences through a series of Decadal Surveys.

ISS research also supports development of technologies for potential use in exploration campaigns such as Artemis, and longer-duration missions to Mars and beyond. ISS provides a means to demonstrate technology and system readiness for use on a human occupied exploration vehicle by documenting performance in a spacecraft environment with humans-in-the-loop, piloting operational procedures and training requirements, and determining logistics requirements, safety, and interoperability concerns with respect to overall space systems infrastructure. ISS is host to multiple long-duration flight experiments and projects which include investigations in water purification, recovery, and utilization; oxygen generation and filtration systems; carbon dioxide filtration systems; crop production; and mitigation of known medical issues, all of which contribute to closing the technology and knowledge gap of future long duration space exploration missions.

ISS Research also contributes to Agency efforts to spur economic growth of LEO and to enable a sustained U.S. presence in this region of space. In Space Production Applications (InSPA) awards help companies raise the technological readiness level of their products and move them to market, propelling U.S. industry toward the development of a sustainable, scalable, and profitable non-NASA demand for services and products in low-Earth orbit. These commercialization awards provide opportunities for NASA to reduce its future costs in LEO enabling deep-space missions farther from Earth, including the Moon and Mars.

NASA's plans for expanding activities in LEO build on and apply the lessons learned from over a decade of work and experience with private companies in ISS research. For example, research facilities onboard ISS continue to evolve from primarily Government funded and operated to privately owned and operated. Since 2012, privately owned research facilities have greatly increased access, capability, and use-inspired science return from ISS-supported research. Currently, there are 24 such facilities in operation supporting more than 80 percent of ISS National Lab-sponsored payloads. In addition, 39 companies provide services as Implementation Partners, guiding researchers to build and ship flight hardware to be executed on the station. These activities validate business models and expand the numbers of entities with experience in conducting business in space.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ACHIEVEMENTS IN FY 2022

FY 2022 saw upgraded research facilities come online, new capabilities piloted, an increase in crew hours dedicated to science, and new solar panels added to increase ISS power capacity.

Facility updates included an upgraded version of Space Tango's TangoLab facility, an upgraded Nanoracks Nanode facility, and successful testing of the Nanoracks Bishop Airlock for the disposal of waste from the ISS, a new capability representing the first open-close cycle of the commercial airlock.

FY 2022 also saw an increasingly diverse portfolio of commercial, fundamental science, and technology demonstration investigations conducted. The ISS Research budget supported, either directly or through MUSS integration services, nearly 400 active investigations across all ISS partners. NASA and the ISS National Lab combined to sponsor almost 200 U.S. research investigations. These totals included 76 payloads for the ISS National Lab.

Examples of fundamental research included:

- Studies of Bose-Einstein condensates using one of ISS's newer research facilities, NASA Cold Atom Laboratory (CAL). CAL supports studies that require atom interferometry measurement capability, a first of its kind in LEO. Atom interferometry can be used to precisely measure a host of phenomena including gravity, acceleration, rotation, electric fields, magnetic fields, and chemical interactions (see: https://www.jpl.nasa.gov/missions/cold-atom-laboratory-cal).
- An NSF-funded project sponsored by the ISS National Lab studied protein aggregation to improve pharmaceutical manufacturing for patients on Earth. Protein aggregation (clustering) is a significant limitation in pharmaceutical manufacturing that reduces the quality and yield of many medicines and vaccines. This investigation developed and tested predictive models for understanding and controlling hydrodynamics (forces acting on or exerted by fluids) that can result in protein aggregation during manufacturing and purification processes.
- The ISS National Lab continued to drive upward trends for industry involvement in supply, demand, and investment related to its R&D portfolio. ISS National Lab R&D activities in FY 2022 included projects from industry, startup companies funded in collaboration with Boeing, and research entities. Industry-driven activities included:
  - Merck and Co. continued ISS National Lab-sponsored research related to its cancer immuno-oncology drug Keytruda®. Leveraging microgravity, Merck produced highly uniform, concentrated crystalline suspensions of the active pharmaceutical ingredient in Keytruda® and translated these findings to drug development processes back on the ground. Merck's latest crystallization experiment builds on this previous research, and results could lead to additional

improvements in the manufacture and storage of Keytruda®, which would both reduce costs and improve quality of life for patients on Earth.

- Two NIH-funded tissue chip experiments launched in FY 2022 could lead to new treatments for patients on Earth: a University of Florida project studying muscle loss and a University of California, San Francisco project studying immune system function in response to aging.
- Based on publicly available data, $658 million of private and public capital, as well as grant funding, was raised during FY 2022 by startups that have completed a flight project with the ISS National Lab. This included several capital-raising successes by companies that had tested technology through the ISS National Lab, ranging from public market entry by Planet to earlier-stage financial and strategic capital access by Apogeo Space (formerly GP Advanced Projects), Hedron Space, Kernal Biologics, Lynk, Lonestar, NSLComm, Optisys, SatRevolution, and several others. Since 2014, startups that completed projects sponsored by the ISS National Lab have raised more than $1.8 billion after completion of their flight. These funds were raised from public equity markets, venture/private capital, and public and private grants.

Additional examples of accomplishments in FY 2022, representing both MUSS support and ISS National Lab efforts, include:

- The eXposed Root On Orbit Test System (XROOTS) was an investigation that demonstrated hydroponic (liquid based) and aeroponic (air based) techniques to grow plants without soil or other traditional growth media. These techniques could enable production of crops on a larger scale for future space exploration, providing a diverse food supply to astronauts. Current space-based plant systems are small, and their water and nutrient delivery systems do not scale well for longer spaceflight due to issues such as mass, containment, maintenance, and sanitation. Growth system components developed for this investigation could also enhance the cultivation of plants in terrestrial settings, such as greenhouses, contributing to better food security for people on Earth.
- Nearly 50 peer-reviewed publications in FY 2022 related to ISS National Lab-sponsored research were identified—the most ever identified in a single fiscal year: 32 were related to projects awarded through NSF/CASIS joint solicitations; 18 from solicitations on tissue engineering and mechanobiology; and 15 from solicitations on transport phenomena, combustion, and fluid dynamics. Topics included research using engineered skeletal muscle to study muscle deterioration and test treatments for muscle wasting; research on cool flames that may lead to improved efficiency in combustion engines and cleaner emissions; and research on flame spread in confined spaces that could be applied to fire hazard assessment in places such as buildings, tunnels, and spacecraft. Additionally, two peer-reviewed articles detailed results from Genes in Space student-led investigations on techniques to monitor immune system and DNA changes in astronauts during spaceflight.
- Two patents related to ISS National Lab-sponsored research were granted: one to Hewlett Packard Enterprise for a novel electronic cooling system related to the Spaceborne Computer, and one to Made In Space (acquired by Redwire Space) for a sensor system for optical fiber manufacturing. A third patent was filed by the University of Alaska Anchorage related to biofuel production.
- Four products resulting from ISS National Lab-sponsored research were identified in FY 2022:
    - The latest formulation of P&G's Febreze Unstoppables Touch Fabric Spray incorporates materials based on the company’s space-based research.

  - More than 200 hours of footage captured on station was used to create the Emmy-winning virtual reality series "Space Explorers: The ISS Experience" produced by Felix & Paul Studios in association with TIME.
  - Felix & Paul Studios also used the footage to produce "Space Explorers: The Infinite," a traveling interactive exhibit in which viewers put on virtual reality headsets to experience what it is like to be an astronaut on the space station.
  - Redwire Space achieved a significant milestone for LEO commercialization with the first sale of an optical crystal produced in the Redwire Industrial Crystallization Facility onboard the ISS—one of the first times a space-produced materials product has been sold on Earth.
- The National Stem Cell Foundation collaborated with the Exomedicine Institute on a unique 3D study of neurodegeneration in the absence of gravity using cells from patients with primary progressive multiple sclerosis (PPMS) and Parkinson's disease (PD). This marks the first time that disease-specific cells from patients with PPMS and PD were studied on the ISS. Results could lead to a better understanding of the genetic makeup of these conditions.
- Lockheed Martin Corporation (in collaboration with StemRad) continued to test the performance of the AstroRad radiation shielding vest on ISS crew members. AstroRad uses a selective shielding technology to protect organs that are most sensitive to radiation exposure. This ISS National Lab-sponsored investigation is beneficial not just to protect astronauts from radiation in space but also for people on Earth whose professions involve periodic exposure to radiation.
- The ISS National Lab Space Station Explorers program gained five new education partners in FY 2022: PocketLab, Beyond School Hours, the National Center for Simulation, SETI Institute (Search for Extraterrestrial Intelligence), and the University of California, San Francisco. In FY 2022, more than 9.5 million people participated in partner programs within the Space Station Explorers community, and more than 17.5 million people used online ISS National Lab educational products.

For more information, visit: https://www.nasa.gov/mission_pages/station/research/index.html and https://www.issnationallab.org/

WORK IN PROGRESS IN FY 2023

Planned activities will continue to increase the number of commercial research facilities onboard the ISS. Those facilities will be enabling an increasingly diverse portfolio of commercial, fundamental science, and technology demonstration investigations. In the first half of FY 2023, 222 investigations are scheduled to be active, 149 of which are NASA and ISS National Lab sponsored. Of these investigations, 68 are new.

Highlights of research planned, representing both NASA and the ISS National Lab efforts include:

- The Flow Boiling and Condensation Experiment (FBCE) to develop a facility for collecting data about two-phase flow and heat transfer in microgravity. Comparisons of data from microgravity and Earth's gravity are needed to validate numerical simulation tools for designing thermal management systems (see: https://www1.grc.nasa.gov/space/iss-research/iss-fcf/fir/fbce/).
- Redwire Space will relaunch the BioFabrication Facility (BFF)—the first American bioprinter in space. Originally validated onboard the ISS in 2019, the BFF was returned to Earth for refinements

(see: https://www.nasa.gov/mission_pages/station/research/experiments/explorer/Facility.html#id=7599). Once the BFF is back on the ISS, multiple investigations are slated to leverage its capabilities, including projects to bioprint human cardiac muscle tissue and human vascular tissue, as well as a project from the DoD building on their previous investigation using the BFF to bioprint a partial human meniscus (cartilage of the knee).

- L3 Harris will launch an ISS National Lab-sponsored project to advance understanding of photonic integrated circuit (PIC) technology, toward development of the company's new satellite constellations in LEO. A better understanding of the effects of radiation on PIC performance could enable the design of PIC technology with improved radiation tolerance.
- ISS National Lab-sponsored research funded by NIH and NSF will continue to fly in FY 2023.
    - Beginning in 2016, the ISS National Lab partnered with the NSF Engineering Directorate to sponsor annual research solicitations in fundamental science. These joint NSF/CASIS annual research announcements have resulted in seven annual solicitations from 2016 to 2022 in the physical sciences topic area of transport phenomena and five annual solicitations from 2018 to 2022 in the biomedical topic area of tissue engineering and mechanobiology.
    - Also beginning in 2016, the ISS National Lab partnered with NIH's National Center for Advancing Translational Sciences (NCATS) on the Tissue Chips in Space initiative. Beginning in 2017, the ISS National Lab also began partnering with NIH's National Institute of Biomedical Imaging and Bioengineering (NIBIB) on Tissue Chips in Space. This initiative supports the use of tissue chip technology for translational research onboard the ISS to benefit human health on Earth.
- The NanoSat Atmospheric Chemistry Hyperspectral Observation System CubeSats (NACHOS) project validates a CubeSat-based hyperspectral imager (HSI) for imaging of trace gases such as NO_2 associated with fossil fuel burning and SO_2 emitted by volcanoes. This technology could lead to a constellation of many CubeSat-based HSIs, providing greater flexibility and coverage than traditional large-satellite instruments, at much lower cost.
- The Alternate Fecal Container (AFC) demonstrates using a soft-sided container to collect and store fecal deposits as part of the ISS's Universal Waste Management System (UWMS). The AFC is lighter weight and can launch in a collapsed configuration, reducing launch mass and supporting longer exploration missions.
- Houston Methodist Research Institute will launch an ISS National Lab-sponsored investigation to test a remote-controlled drug delivery implant. Such an implant could one day provide extended, adjustable medication for patients who need daily medication but lack medical access. This investigation builds upon the research team's previous ISS National Lab-sponsored investigations that studied fluid flow through nanochannels and tested an implantable nanochannel drug delivery system in a rodent model.
- Biomedical startup RevBio (previously LaunchPad Medical) will launch a follow-on investigation sponsored by the ISS National Lab to advance its bone adhesive therapeutic Tetranite®, which could help osteoporosis patients with a bone fracture to regrow bone. This research builds on a previous ISS National Lab-sponsored project from RevBio, which was awarded a grant through the Technology in

Space Prize. In the upcoming investigation, RevBio will evaluate Tetranite®'s efficiency in promoting bone regeneration and investigate how skeletal stem cells are affected by microgravity.

- The ArgUS platform, capable of hosting multiple experiments on a single payload slot in the Bartolomeo External Science and Payload Hosting Facility on the ISS, is expected to become available in FY 2023. Through the ArgUS and Bartolomeo platforms, Airbus DS Space Systems aims to reduce the cost of conducting experiments in LEO, helping to foster commercial use of LEO and support new-to-space users with limited budgets who depend on the availability of space access and infrastructure.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

NASA will continue to innovate, implementing new processes for payload development and integration that are focused on sending investigations to ISS as soon as they are ready, including renewed focus on cancer and radiation studies supporting the President's Cancer Moonshot initiative. The improved timelines offered by these processes better meet the demands of its users, resulting in quicker payload deliveries to ISS (within months in some cases). Thus, private sector users looking to leverage space-based activities to accelerate time to market for product enhancements have a rapid path from project concept to flight. This bolsters the value proposition for space-based R&D. Similarly, R&D sponsored by NASA, by private companies, or by non-NASA Government agencies can be executed within a timeline that enhances the relevance of the research projects. For these cutting-edge projects, scientific discovery and technological advancement moves quickly and will benefit by optimized timelines to flight.

Under the streamlined payload development and integration processes, the flight manifest for FY 2024 is still in development. As a result, the majority of specific investigations that will be conducted on ISS in FY 2024 have not yet been identified. However, known upcoming investigations planned to fly in FY 2024 include:

- Tissue engineering and regenerative medicine to improve human health and longevity, and flight projects supported by other Government agencies, including NSF, will explore a range of related topics from stem cell biology to cancer research to 3D printing of tissue.
- The Atmospheric Waves Experiment (AWE), planned to launch in late 2022, will attach to the exterior of the ISS. From its space station perch, AWE will focus on colorful bands of light in Earth's atmosphere, called airglow, to determine what combination of forces drive space weather in the upper atmosphere. AWE is the first dedicated NASA mission designed specifically to characterize the properties of global mesospheric gravity waves (see: https://www.nasa.gov/press-release/nasa-selects-mission-to-study-space-weather-from-space-station).
- Multiple ISS National Lab-sponsored physical science projects funded by NSF, projects selected and funded by the CASIS-Boeing Technology in Space Prize, and projects selected through the NASA Vascular Tissue Challenge.
- Multiple projects awarded through ISS National Lab research announcements in the areas of in-space production applications and technology development/demonstration, including projects to advance stem cell biology, optical fiber production, and crystal growth.

ISS RESEARCH

Project Schedule

An increment, or expedition, is a period of time for ISS operations that spans from one crew return mission to another. Three to five expeditions typically span a calendar year, and each consists of cargo ship arrivals and departures, extensive research investigations, and standard crew maintenance and logistical tasks. The table below provides a schedule for FY 2023 through FY 2025 completed and planned start dates for the upcoming increments to ISS.

Date	Significant Event
Mar 2023	Increment 69
Sep 2023	Increment 70
Mar 2024	Increment 71
Sep 2024	Increment 72
Mar 2025	Increment 73
Sep 2025	Increment 74

Project Management & Commitments

The ISS Program Office meets commitments to international partners for utilization access under the ISS Intergovernmental Agreements and follows statutory guidance in the NASA Authorization Act of 2010 in providing access to on-orbit capabilities for ISS National lab research. The ISS Program interfaces with the ISS National Lab and personnel from a wide variety of NASA organizations to integrate objectives into strategic plans and implement research.

Within NASA, mission directorates also prioritize their research investments for ISS based on exploration roadmaps for technologies needed to support NASA's exploration goals, the Human Research path to risk reduction, and recommendations from the relevant National Academies of Science decadal surveys. These are demonstrated in non-ISS budgets of HRP, some activities in STMD, and specific SMD divisions including BPS.

Element	Description	Provider Details	Change from Formulation Agreement
MUSS	MUSS activities support all research on ISS (NASA sponsored and non-NASA sponsored)	Provider: ISS program and contractors Lead Center: Johnson Space Center (JSC) Performing Center(s): Marshall Space Flight Center (MSFC), Ames Research Center (ARC), Glenn Research Center (GRC), Kennedy Space Center (KSC), Jet Propulsion Laboratory (JPL) Cost Share Partner(s): N/A	N/A

ISS RESEARCH

Element	Description	Provider Details	Change from Formulation Agreement
ISS National Lab	Manages the ISS National Laboratory through the National Laboratory Cooperative Agreement	Provider: Center for the Advancement of Science in Space, Inc. (CASIS)	N/A

Acquisition Strategy

NASA awards contracts and grants for conducting research on ISS. NASA prioritizes ISS research based on an established Agency process that prioritizes NASA's use for exploration critical research needs (human research for exploration and technology research for systems to support long-duration lunar and Mars missions) followed by research that aligns with the National Academies' Decadal Surveys that are related to science that can be done in space. NASA manages non-NASA ISS research activities through the ISS National Lab in cooperation with CASIS and that research is prioritized separately from the NASA research. Peer review is practiced in each selection and is the means to ensure a high-quality research program. Engaging leading members of the research community to assess the competitive merits of submitted proposals is essential to ensuring the productivity and quality of ISS research.

MAJOR CONTRACTS/AWARDS

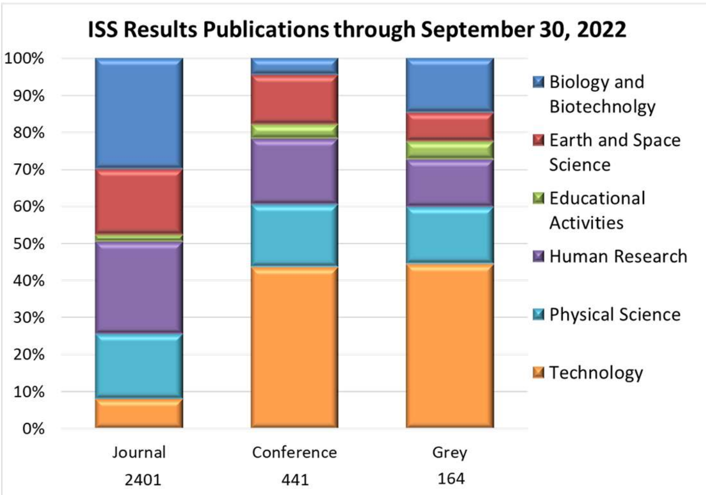
Element	Vendor	Location (of work performance)
Vehicle Sustaining Engineering Contract	The Boeing Company	Houston, TX
Huntsville Operations Support Center	COLSA Corporation	Huntsville, AL
Mission Operations and Integration (MO&I) Contract	Teledyne Brown Engineering	Huntsville, AL
ISS National Lab Management Entity	CASIS	Melbourne, FL

INDEPENDENT REVIEWS

Independent reviews for the ISS program as a whole are cited in the ISS O&M section of this document. There are no independent reviews planned that are unique to ISS research, although CASIS engages a user advisory group to provide recommendations on their activities.

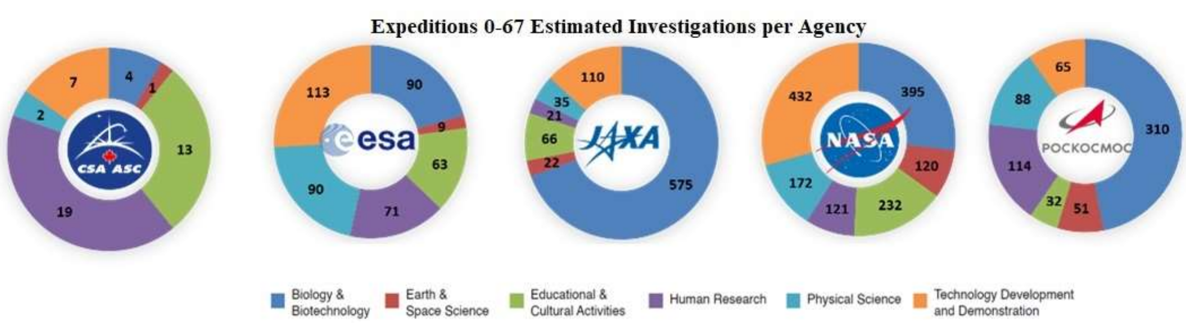
ISS RESEARCH

HISTORICAL PERFORMANCE

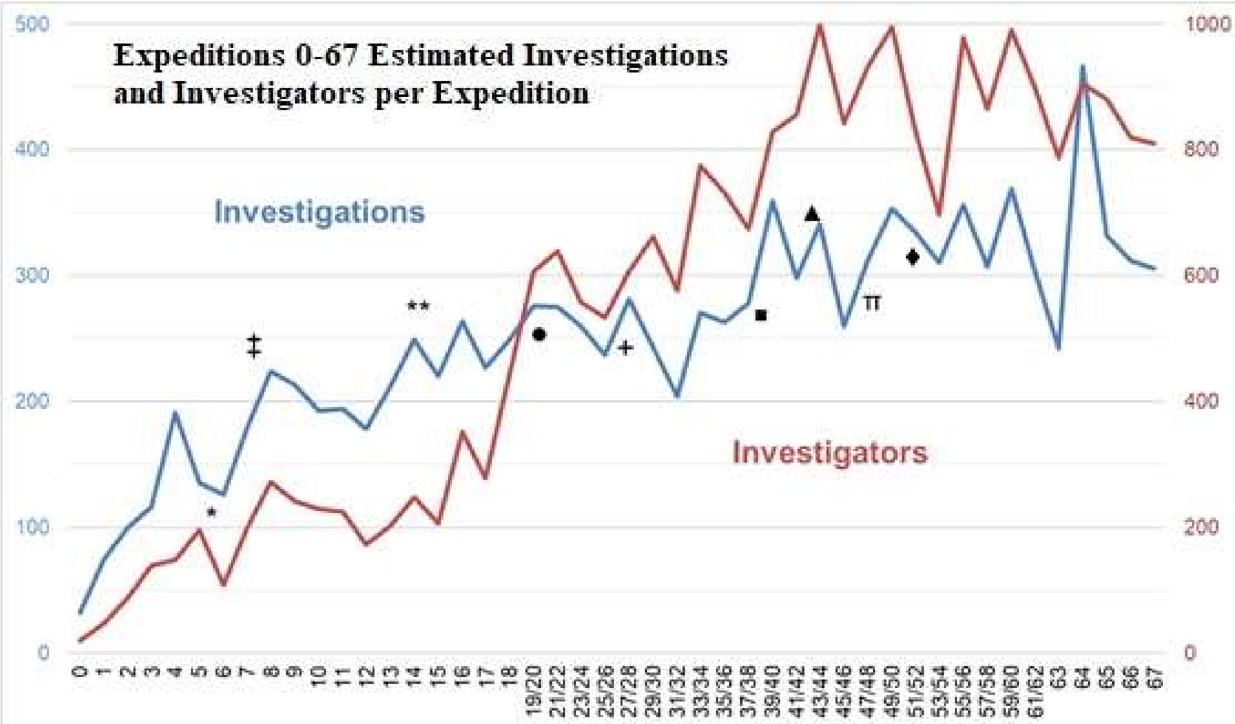


As of the start of Expedition 68, at the beginning of FY 2023, more than 4,800 investigators from over 109 countries have performed more than 3,400 investigations and technology demonstrations utilizing the ISS. As shown in the ISS Research Results Publications graph to the left, over 2,400 papers have been published in scientific journals; more than 400 conferences; and 160 grey literature publications (such as technical reports or books). FY 2022 saw more than 392 papers published, representing roughly 16 percent of the total papers published over the life of the ISS, demonstrating the growing impact of ISS research results in the scientific community as ISS research capabilities have expanded.

The graphs below highlight the amount and diversity of research conducted on the ISS. The first graph shows the number of investigations by expedition and the type of investigations by category and space agency. The data for expeditions 0 through 62 has been approved by the ISS Mission Control Board, and data for expeditions 63 through 67 includes estimates which are under review. Of particular interest on the 2nd graph is how the number of investigations by expedition has varied over history. This fluctuation is largely driven by crew and cargo transportation and number of crew members on board the ISS.



ISS RESEARCH



SPACE TRANSPORTATION

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Crew and Cargo Program	1,569.7	--	**1,856.1**	1,890.0	1,935.6	1,968.1	2,051.8
Commercial Crew Program	147.2	--	**100.6**	100.6	100.7	100.7	101.6
Total Budget	**1,716.9**	**--**	**1,956.7**	**1,990.6**	**2,036.2**	**2,068.7**	**2,153.4**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The SpaceX Dragon resupply ship, with its solar panel-covered trunk, is pictured here before undocking from the Harmony module's forward port on the ISS (August 19, 2022).

Space Transportation's objective is to transport U.S. Orbital Segment (USOS) astronauts and cargo safely to and from space, including the International Space Station (ISS). This theme includes the Commercial Crew Program (CCP) and the Crew and Cargo Program. Maintaining ISS requires a fleet of vehicles and launch locations to: transport astronauts, science experiments, critical supplies, and maintenance hardware; replenish propellant; and dispose of waste.

CCP partners with the U.S. commercial sector to develop and operate safe, reliable, and affordable crew transportation to low-Earth orbit (LEO). NASA awarded Commercial Crew Transportation Capability (CCtCap) contracts to Boeing and Space Exploration Technologies Inc. (SpaceX) in September 2014. Through its certification efforts, NASA will ensure the selected commercial transportation systems meet NASA's safety and performance requirements for transporting crew to ISS.

Within the Crew and Cargo Program, NASA purchases cargo transportation to ISS under Commercial Resupply Services (CRS) contracts with Northrop Grumman, Sierra Space (a subsidiary of Sierra Nevada Corp [SNC]), and SpaceX. NASA has transitioned from purchasing crew transportation to ISS from the Russian Roscosmos State Corporation, known as Roscosmos, to purchasing from U.S. commercial providers Boeing and SpaceX. The first commercial crew service mission was the SpaceX Crew-1 flight on November 15, 2020. The budget also supports other space transportation-related activities, such as integration work required to ensure that these visiting vehicles can safely dock or berth to ISS and the development of hardware such as the NASA docking system.

As of September 30, 2022, NASA had allocated approximately $25.4 billion towards service providers under the commercial crew and cargo programs. These funds have supported the completion of two rockets, two cargo vehicles, and one crew vehicle; the ongoing development of one other crew vehicle and one other cargo vehicle; and 42 successful cargo flights to ISS. Of that amount, NASA contributed $5.9 billion towards the development of the commercial crew and cargo systems. This is the amount NASA refers to as its "investment" in the systems. The $5.9 billion includes NASA's share of the commercial cargo development costs as well as all NASA Commercial Crew Program development costs (Commercial Crew Development [CCDev] Phases 1 and 2, the Commercial Crew Integrated Capability [CCiCap] initiative, Certification Products Contract [CPC], and CCtCap). The remaining $19.5 billion is the amount NASA has contracted for services (i.e., the transportation of cargo and crew to the ISS). This amount includes the current contract values for both CRS-1 and CRS-2 cargo contracts, as well as CCtCap crewed missions to the ISS. Within the current maximum contract value, NASA can still award another $6.1 billion under the CRS-2 contracts. Of the $25.4 billion NASA has allocated to these programs, $17.9 billion has been paid to the companies as of September 2022.

At the completion of ISS operations in 2030, the ISS will be safely de-orbited via a controlled re-entry into an unpopulated region. This budget request includes $180 million in FY 2024, building on the $10 million provided in FY 2023 appropriations to initiate development of this capability. NASA intends to pursue this capability with U.S. industry through a competitive procurement.

EXPLANATION OF MAJOR CHANGES IN FY 2024

NASA and its partners have studied deorbit requirements and determined that additional capabilities are needed to reduce risk and provide for a more robust deorbit capability. The FY 2024 budget request includes $180 million in funding for development of an ISS de-orbit vehicle.

CREW AND CARGO PROGRAM

Formulation	Development	Operations

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**1,569.7**	**--**	**1,856.1**	**1,890.0**	**1,935.6**	**1,968.1**	**2,051.8**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Northrop Grumman's Cygnus space freighter, shown here, is positioned away from ISS in the grips of the Canadarm2 robotic arm prior to its release ending a four-month stay attached to the orbiting lab's Unity module (July 28, 2022).

Maintaining the International Space Station (ISS) requires a fleet of spacecraft to sustain a constant supply line of both crew and cargo that is crucial to ISS operations and research. Deliveries not only provide science experiments, supplies, and maintenance hardware, but also rotate crewmembers, return research and equipment for repair, and dispose of waste.

The Crew and Cargo Program manages transportation services provided by both international partners and domestic commercial providers. NASA's commercial service contracts to resupply the ISS have changed the way the Agency does business in low-Earth orbit (LEO). With these contracts, NASA continues to advance commercial spaceflight while simultaneously supporting the American jobs created by this industry.

Through FY 2020, NASA purchased cargo delivery to the ISS from Northrop Grumman (formerly Orbital ATK) and Space Exploration Technologies Inc. (SpaceX) under the original Commercial Resupply Services (CRS) contracts. These vehicles provided between 2,200 and 3,750 kilograms of cargo to ISS with each mission. The cargo provided to ISS includes crew supplies, operations hardware, and numerous science research and technology demonstration investigations.

Northrop Grumman, SpaceX, and Sierra Space are working under the follow-on CRS-2 contracts with missions that began in FY 2020. Under CRS-2, Sierra Space will launch CRS missions from Cape Canaveral, FL, as SpaceX does today. Both of these providers also have or will have the capability to return science experiments to Earth. SpaceX uses its Falcon 9 rocket to launch the Dragon-2 docking cargo vehicle, while Sierra Space will use United Launch Alliance's Vulcan rocket to launch its Dream Chaser Cargo (DCC) berthing vehicle. Northrop Grumman previously launched its Cygnus

CREW AND CARGO PROGRAM

Formulation	Development	Operations

berthing cargo vehicle on the Antares rocket from the Mid-Atlantic Regional Spaceport at NASA's Wallops Flight Facility (WFF) in Virginia. Beginning in FY 2024, Northrop Grumman will launch its Cygnus spacecraft on SpaceX's Falcon 9 rocket until an upgraded version of the Antares rocket is available. Northrop Grumman provides trash disposal and may conduct additional experiments before the Cygnus spacecraft burns up in the atmosphere after leaving ISS. These capabilities enable studies of fire suppression, deployment of small satellites at altitudes above the ISS, and other activities not suited for ISS on-board operations. The Crew and Cargo Program budget supports all milestone payments for these contracted flights to provide cargo transportation for a multitude of users, including transportation for National Laboratory science research payloads.

The Commercial Orbital Transportation Services Program used a series of fixed-price, milestone-based Space Act Agreements to support the development of several companies' efforts to develop commercial cargo resupply capabilities. As a result, NASA is now able to purchase these commercial services from several providers under the Crew and Cargo Program using fixed-price contracts, which have more predictable budget requirements than cost-reimbursable contracts, and which can provide cost savings to the Federal Government compared to other types of contracts. This arrangement has resulted in a stronger U.S. space launch industry, redundancy in the cargo resupply mission area that has increased mission assurance, and robust private sector employment. NASA is leveraging the lessons learned in this program to expand science and research capabilities that these vehicles provide for CRS-2 missions. The CRS contract vehicle has been used as an example by other programs, such as Gateway and the Human Lander System.

For years after the Space Shuttle was retired in 2011, crew transportation to ISS was provided using the Russian Soyuz vehicle. However, beginning with the SpaceX commercial crew Demo-2 flight in May 2020, the United States is again launching astronauts into space and to ISS. The Commercial Crew Program (CCP) manages these activities to develop and provide domestic crew transportation to the ISS under the Commercial Crew transportation Capability (CCtCap) contracts with Boeing and SpaceX.

The Crew and Cargo Program also funds activities supporting visiting vehicles that provide transportation for the ISS, including integration activities.

At the completion of ISS operations in 2030, the ISS must be safely deorbited via a controlled reentry over an unpopulated region. Existing USOS transportation vehicles do not have sufficient propulsive capabilities (e.g., thrust) or propellant quantities to meet the deorbit needs. A much more extensive vehicle redesign or new development would be needed to meet the deorbit requirements. NASA intends to pursue this capability with U.S. industry through a competitive procurement. Based on the extent of this development, NASA estimates it would take industry 4-5 years to develop this capability once the contract is awarded.

CREW AND CARGO PROGRAM

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2024

NASA and its partners have studied deorbit requirements and determined that additional capabilities are needed to reduce risk and provide for a more robust deorbit capability. The FY 2024 budget request includes funds for development of an ISS de-orbit vehicle.

ACHIEVEMENTS IN FY 2022

Northrop Grumman completed nine mission milestones in support of six commercial resupply flights, including milestones for successful completion of one CRS-2 flight in FY 2022. SpaceX completed 15 mission milestones in support of ten commercial resupply flights, including milestones for successful completion of two CRS-2 flights in FY 2022. Northrop Grumman and SpaceX have completed all seven CRS-2 integration milestones required to demonstrate new contract capabilities and design enhancements to support science and payload research objectives. Sierra Space completed one ISS Integration milestone (GPS Navigation near ISS risk reduction test and FCC license review). One Sierra Space mission milestone was completed in FY 2022.

The program funded CCtCap contract milestones for post-certification crew missions that will be flown by Boeing and SpaceX. The program supported two SpaceX Commercial Crew missions (Crew-3 and Crew-4) and Boeing Orbital Flight Test (OFT)-2. More information on CCtCap progress can be found under the CCP portion of this document.

The program supported the first private astronaut mission (PAM) with Axiom Space of Houston (AX-1). In addition, the program supported four crewed Soyuz launches, three launches of Progress, a Russian cargo vehicle, and one Russian space station module deployment flight, not funded by NASA.

In August 2022, NASA issued a Request for Information to assess industry's capability to design, develop, manufacture, launch, and provide the on-orbit operation to enable a controlled re-entry and the safe deorbit of the ISS.

WORK IN PROGRESS IN FY 2023

NASA expects five commercial resupply flights to deliver research and logistics hardware in FY 2023. Northrop Grumman plans to launch two flights and complete 13 mission milestones in support of six CRS-2 flights. SpaceX plans to launch three flights and complete 15 mission milestones in support of eight CRS-2 flights. Sierra Space plans to complete two mission milestones in support of four CRS-2 flights. Sierra Space will also complete their final ISS integration milestone.

The program will also continue funding CCtCap contract milestones for post-certification crew missions with Boeing and SpaceX. SpaceX missions began in November 2020 after successful completion of the test flights and NASA certification. Boeing will be conducting their Crew Flight Test (CFT) in FY 2023. A launch date for NASA's Boeing Starliner-1 post certification mission will be determined following a

CREW AND CARGO PROGRAM

Formulation	Development	Operations

successful CFT and close out of the Agency's certification work. Once Boeing CCtCap development and certification is complete, both partners' space transportation systems will begin regularly flying astronauts to and from ISS. The regular flight plan will provide for two commercial crew flights per year carrying four crew each flight. More information on CCtCap progress can be found under the CCP portion of this document.

The program will support the second PAM with Axiom Space of Houston AX-2. In addition, the program will also support two Soyuz crew launches and four Progress cargo launches, not funded by NASA.

In 2023, NASA plans to release a Request for Proposal to provide the capability to design, develop, manufacture, launch, and provide the on-orbit operation to enable a controlled re-entry and the safe deorbit of the ISS. Contract award is planned for fall 2023. The deorbit vehicle will attach (via docking or berthing) to the ISS at least one year prior to the planned ISS reentry date to enable adequate time for on-orbit tests and checkouts. Although nominal ISS end of life is late 2030, the Government requires that this deorbit capability be available as soon as possible to protect for contingencies that could drive early re-entry.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

The Crew and Cargo Program will enable continued research and technology development by providing a stable crew and cargo flight plan.

NASA expects seven commercial resupply flights to deliver research and logistics hardware in FY 2024. Northrop Grumman plans to launch two commercial resupply flights and complete 10 mission milestones in support of six CRS-2 flights. SpaceX plans to launch three commercial resupply flights and complete 13 mission milestones in support of seven CRS-2 flights. Sierra Space plans to launch their first two cargo missions, Dream Chaser Cargo (DCC)-1, and DCC-2 and complete eight mission milestones in support of six CRS-2 flights. These resupply flights will be vital for delivering not only the day-to-day supplies needed, but also the experiments that will enable the astronauts to continue important research on ISS. The flights will also support the increased number of research and science investigations enabled by the additional astronauts once commercial crew is available.

The program will also continue funding CCtCap contract milestones for post-certification crew missions with Boeing and SpaceX. NASA is planning for at least two commercial crew missions annually. The program is also preparing to support a third and fourth PAM. The flight schedule also includes two Soyuz crew launches, four Progress cargo launches, and one H-II Transfer Vehicle (HTV)-X, a Japanese cargo vehicle, that are not funded by NASA.

The FY 2024 budget request includes $180 million in funding to begin work to develop a U.S. deorbit capability for ISS.

CREW AND CARGO PROGRAM

Formulation	Development	Operations

PROJECT SCHEDULE

Maintaining a regular rate of cargo delivery on a mix of NASA and international partner vehicles ensures the ISS can sustain nominal operations and maintenance, while allowing the program to respond to any anomalies that might occur. The table below shows all 34 scheduled ISS flight plans for FY 2023 and FY 2024. Of these 34 planned flights, 19 are funded by NASA. The missions not funded by NASA are noted with an asterisk (*). NASA funds SpaceX (SpX), Northrop Grumman (NG), and Sierra Space cargo missions, as well as Boeing and SpaceX crew missions. The planned spacing of the Commercial Crew and Soyuz crew rotation flights ensures a continuous crew presence on the ISS and smooth transitions between crews.

Date	Significant Event
Oct 2022	SpX Crew-5
Oct 2022	Progress 82P*
Nov 2022	NG-18
Nov 2022	SpX-26
Feb 2023	Progress 83P*
Feb 2023	SpX Crew-6
Feb 2023	Soyuz 69S*
Mar 2023	SpX-27
Apr 2023	NG-19
No Earlier Than (NET) Apr 2023	Boeing CFT
May 2023	Ax-2 (PAM)*
May 2023	Progress 84P*
Jun 2023	SpX-28
Fall 2023	SpX Crew -7
Aug 2023	Progress 85P*
Sep 2023	Soyuz 70S*
Oct 2023	PAM-3*
Oct 2023	NG-20
Dec 2023	Progress 86P*
Dec 2023	SpX-29

CREW AND CARGO PROGRAM

Formulation	Development	Operations

Date	Significant Event
Dec 2023	Sierra Space DCC-1
Jan 2024 Under Review (UR)	HTV-X1*
Spring 2024	Commercial Crew Mission
Feb 2024	Progress 87P*
Feb 2024	SpX-30
Mar 2024	Soyuz 71S*
May 2024	PAM-4
May 2024	DCC-2
Jun 2024	Progress 88P*
Jun 2024	NG-21
Jun 2024	SpX-31
Fall 2024	Commercial Crew Mission
Aug 2024	Progress 89P*
Sep 2024	Soyuz 72S*

**Missions are not funded by NASA*

Project Management & Commitments

Johnson Space Center (JSC) is responsible for management of the Crew and Cargo Program.

Element	Description	Provider Details	Change from Formulation Agreement
Crew transportation	Commercial crew transportation will be provided by Boeing and SpaceX and managed by the Commercial Crew Program.	Provider: Boeing; SpaceX Lead Centers: JSC, Kennedy Space Center (KSC) Performing Center(s): N/A Cost Share Partner(s): Canadian Space Agency (CSA), European Space Agency (ESA), and Japan Aerospace Exploration Agency (JAXA)	N/A

CREW AND CARGO PROGRAM

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
Cargo transportation	Northrop Grumman, SpaceX, and Sierra Space will provide cargo transportation to the ISS via the major contracts described below. JAXA will provide additional cargo transportation as part of the ISS partnership.	Provider: Northrop Grumman, SpaceX, Sierra Space, and JAXA Lead Center: JSC Performing Center(s): Goddard Space Flight Center (GSFC), KSC Cost Share Partner(s): CSA, ESA, and JAXA	N/A

Acquisition Strategy

The ISS Program competitively procures all ISS cargo transportation services, excluding services obtained via barter with our international partners or nominal cargo transportation provided by Soyuz. On January 14, 2016, NASA competitively awarded CRS-2 contracts to Orbital ATK (now Northrop Grumman), Sierra Space, and SpaceX, with cargo transportation services that began in November 2019. Like the preceding CRS contracts, CRS-2 contracts are milestone-based, fixed-price, indefinite-delivery-indefinite-quantity (IDIQ) contracts.

In September 2014, NASA's CCP awarded two Federal Acquisition Regulation (FAR)-based fixed-price CCtCap contracts to Boeing and SpaceX for commercial crew transportation services to ISS that began in FY 2021. CCP will continue to manage and provide technical insight on these contracts even though the Crew and Cargo Program will fund remaining milestones in FY 2024 and beyond. These crewed vehicles provide a minimum of 220 pounds of cargo as specified by the ISS Program.

Acquisition of the ISS de-orbit vehicle will be competed in FY 2023 with U.S. industry.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Crew transportation	Boeing	Houston, TX
Crew transportation	SpaceX	Hawthorne, CA
Cargo transportation	Northrop Grumman	Dulles, VA
Cargo transportation	Sierra Space	Louisville, CO

CREW AND CARGO PROGRAM

Formulation	Development	Operations

Element	Vendor	Location (of work performance)
Cargo transportation	SpaceX	Hawthorne, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	NASA Advisory Council	Jan 2023	Provides independent recommendations for the NASA Administrator	TBD	At least annually, date TBD
Other	NASA Aerospace Safety Advisory Panel	Oct 2022	Provides independent assessments of safety and recommendations to the NASA Administrator	The panel recommended "NASA define an executable and appropriately budgeted deorbit plan that includes implementation on a timeline to deliver a controlled re-entry capability to the ISS as soon as practicable to be in place for the need of a controlled deorbit in event of an emergency as well as in place before the retirement of the ISS to ensure that the station is able to be de-orbited safely."	Feb 2023

COMMERCIAL CREW PROGRAM

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**147.2**	**--**	**100.6**	**100.6**	**100.7**	**100.7**	**101.6**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Shown here, SpaceX's Falcon 9 rocket and Dragon spacecraft named Endurance lift off from Launch Pad 39A at KSC in Florida on October 5, 2022, for the Crew-5 mission to ISS.

Boeing's CST-100 Starliner crew ship, shown here, approaches the International Space Station on the company's Orbital Flight Test-2 mission before automatically docking to the Harmony module's forward port (May 20, 2022).

With technical guidance and support from NASA, the U.S. private sector is developing and operating safe, reliable, and affordable crew transportation to space, including to the International Space Station (ISS). Partnership with the commercial space industry for access to ISS and other low-Earth orbit (LEO) destinations bolsters American leadership, eliminates our reliance on foreign providers for this service, and helps stimulate the American aerospace industry. Crew transportation to ISS is currently provided using the SpaceX Crew Dragon which was certified in 2020 and the Russian Soyuz vehicle. The Boeing Starliner spacecraft is still in the development and test phase but making significant strides towards certification by NASA for crew transportation to ISS. By supporting development of U.S. human spaceflight capabilities, NASA is also contributing to the foundation of a more affordable and sustainable future for human spaceflight in LEO and beyond.

Through the Commercial Crew Program (CCP), NASA provides technical insight and financial support to industry partners as they develop and operate their crew transportation systems using milestone-based contracts and certifies them to carry astronauts to and from the ISS. Under this acquisition model, NASA defines requirements up-front and pays the partner only once contract milestones are successfully completed. This approach reduces financial risk to taxpayers and incentivizes the private sector to provide increased cost-control and decreased systems development cost.

COMMERCIAL CREW PROGRAM

As mentioned in the Crew and Cargo program section, CCP manages the Commercial Crew Transportation Capability (CCtCap) contracts and provides technical oversight for NASA missions. The CCtCap awards represented a significant milestone in U.S. human spaceflight, ending the Nation's reliance on foreign crew transportation to ISS and achieving certification of safe and cost-effective U.S. commercial crew transportation systems. In addition, this approach helped stimulate growth of new space transportation industry capabilities available to all potential customers, strengthened America’s space industrial base, and provided a catalyst for future business ventures that can capitalize on affordable, globally competitive U.S. space access. Returning these launches to American soil has significant economic benefits, with more than 1,000 suppliers working across nearly every state. A total of 14 Post Certification Missions (PCM) have been awarded to SpaceX and six PCMs to Boeing.

In FY 2020, NASA initiated the Suborbital Crew (SubC) activity under the CCP. This activity will develop a safety case assessment to enable NASA personnel to leverage suborbital human space transportation capabilities to meet Agency needs and procure commercial suborbital space transportation services for NASA Astronauts and other NASA personnel. After several years of development, the first commercial suborbital human space transportation systems have entered commercial operations. The flight profiles of these vehicles include flying to altitudes of approximately 100 kilometers, which results in periods of microgravity longer than can be created with drop towers and parabolic aircraft flights. Potential uses include human-tended microgravity research, astronaut training, and testing and qualification of spaceflight hardware. Suborbital human spaceflight has the potential to provide an effective and affordable way to meet the Agency’s needs and continue efforts to enable a robust spaceflight economy.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ACHIEVEMENTS IN FY 2022

NASA certified SpaceX's crew transportation system for carrying NASA astronauts to and from the ISS as the first human-rated commercial space system in November of 2020, a major milestone in the return of human spaceflight from the United States. Following that certification, the first PCM to the ISS with crew launched on November 15, 2020, from Kennedy Space Center’s (KSC) Launch Complex 39A in Florida. Since then, SpaceX has launched an additional four PCM missions. SpaceX Crew-2 successfully launched on April 23, 2021. After staying 199 days in orbit, the Crew-2 astronauts returned to Earth in a splashdown off the coast of Florida on November 8, 2021. Two days later, on November 10, 2021, SpaceX Crew-3 launched from KSC carrying NASA astronauts Raja Chari, Tom Marshburn, and Kayla Barron, and European Space Agency (ESA) astronaut Matthias Maurer. The Crew-3 astronauts spent approximately six months aboard the space station before returning to Earth on May 6, 2022. Before Crew-3 departed, SpaceX Crew-4 launched on April 27, 2022 carrying NASA astronauts Kjell Lindgren, Bob Hines, and Jessica Watkins, and ESA astronaut Samantha Cristoforetti.

Boeing completed several significant CCtCap milestones including the successful completion of their uncrewed test flight to ISS, Orbital Flight Test 2 (OFT-2), validating the end-to end capabilities of the Starliner crew transportation system. The Boeing Starliner launched on a United Launch Alliance Atlas V rocket on May 19, 2022, from Space Launch Complex-41 at Cape Canaveral Space Force Station in Florida. The uncrewed spacecraft successfully docked to the ISS Harmony module on May 20, 2022. While docked to ISS, NASA Flight Engineers on ISS, Kjell Lindgren and Bob Hines, conducted cargo and test operations inside the vehicle. Boeing's OFT-2 mission returned to Earth and completed its touchdown on May 25, 2022, at White Sands Space Harbor in New Mexico accomplishing all planned flight test objectives. Boeing also continued production and outfitting of the Starliner crew and service modules for the upcoming Crew Flight Test (CFT) inside the Commercial Crew and Cargo Processing Facility at KSC.

SubC continued progress towards refining the approach for a safety case and determining how NASA will assess commercial suborbital crew systems for NASA personnel safety.

WORK IN PROGRESS IN FY 2023

SpaceX Crew-5 launched on October 5, 2022, carrying NASA astronauts Nicole Mann as mission commander, and Josh Cassada as pilot, as well as mission specialists astronaut Koichi Wakata from Japan Aerospace Exploration Agency (JAXA) and cosmonaut Anna Kikina from Roscosmos. Crew-5 will spend several months aboard the ISS conducting new scientific research in areas such as cardiovascular health, bioprinting, and fluid behavior in microgravity to prepare for human exploration beyond LEO and to benefit life on Earth.

SpaceX Crew-4 astronauts returned to Earth on October 14, 2022, after spending 170 days aboard ISS. With completion of that flight, Cristoforetti has logged 369 days in space on her two flights, making her second on the all-time list for most days in space by a woman. Lindgren has logged 311 days in space over his two flights, and it was the first spaceflight for both Hines and Watkins. Crew-4 astronauts contributed to a host of science and maintenance activities and technology demonstrations.

NASA astronauts Stephen Bowen and Warren "Woody" Hoburg, as well as United Arab Emirates (UAE) astronaut Sultan Alneyadi, and Roscosmos cosmonaut Andrey Fedyaev, will soon lift off from Launch Complex 39A at KSC as part of the sixth crew rotation mission with SpaceX to the ISS, where they will perform science, technology demonstrations, and maintenance activities aboard the microgravity laboratory. Crew-6 will spend up to six months at the ISS in FY 2023 before returning to Earth. The astronauts of the Crew-5 mission will undock from the ISS and splash down off the coast of Florida several days after Crew-6's arrival.

The Crew-6 astronauts are expected to welcome NASA's Boeing CFT astronauts during their stay aboard the orbiting laboratory. Preparations are proceeding for the launch of NASA’s Boeing CFT currently planned for April 2023 as teams work to ready the hardware, crew, and mission support teams for flight. Boeing recently completed the exterior of the Starliner crew module with installation of the forward heat shield and entry cover. Formal qualification testing on the CFT version of Starliner’s flight software was also completed. NASA astronauts Barry “Butch” Wilmore and Suni Williams, CFT’s commander and pilot, respectively, and Mike Fincke, backup spacecraft test pilot, along with the Boeing team, also successfully completed the crew validation test during which the astronauts suited up and tested out the pressurized crew module to ensure seat fit, suit functionality, cabin temperature, audio system, and day of launch operations. The astronaut test pilots will fly on CFT to the ISS, where they will live and work for approximately eight days. Following a successful CFT mission, NASA will begin the final process of certifying the Starliner spacecraft and systems for crew missions to ISS. NASA and Boeing currently are working on a variety of verification efforts across several critical systems that will be used for Starliner's crew flight certification. A launch date for NASA's Boeing Starliner-1 mission will be determined following a successful CFT and close out of the Agency's certification work.

SubC will continue refining the approach to its safety case and determining how NASA will assess commercial suborbital crew systems for NASA personnel safety.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

CCP will continue to focus on mission planning and preparations for future CCP missions as well as remain actively engaged with the providers as they continue space hardware manufacturing, critical testing, and qualification and verification events.

Having multiple U.S. domestic crew launch capabilities supports uninterrupted access to ISS, incentivizes performance through competition, and reduces risk. Therefore, it is imperative that NASA achieve its goal of certifying the Boeing Starliner crew transportation system. Once Boeing CCtCap certification is complete, both partners' space transportation systems will begin regularly flying astronauts to and from ISS. CCP will transition to sustaining operations at a level needed to safely operate with two commercial providers. CCP will continue to manage the CCtCap contracts, including providing technical oversight and managing modifications and upgrades to both crew transportation systems and potentially certifying new launch vehicles or spacecraft to other LEO destinations in the future.

NASA will begin to leverage commercial suborbital crew systems to fly NASA personnel to perform microgravity research and other testing and qualification for spaceflight hardware, as well as conduct astronaut training.

Program Schedule

NASA funds SpaceX and Boeing crew missions related to U.S. Orbital Segment (USOS) crew requirements. Commercial crew flights planned for FY 2023 and FY 2024 are included in the table below.

Launch Date	Significant Event
Oct 2022	Successful launch of SpaceX (SpX) Crew-5, currently on orbit
Feb 2023	SpX Crew-6
NET Apr 2023	Boeing CFT
Fall 2023	SpX Crew-7
Spring 2024	Commercial Crew Mission
Fall 2024	Commercial Crew Mission

COMMERCIAL CREW PROGRAM

Program Management & Commitments

The Space Operations Mission Directorate (SOMD) team at NASA Headquarters performs strategic management and oversight of CCP, while KSC is responsible for day-to-day CCP management, in collaboration with the Johnson Space Center (JSC). CCP partnered with industry leaders and utilized a combination of Space Act Agreements and FAR-based fixed-price contracts to stimulate efforts to develop and demonstrate crew transportation capabilities.

Program Element	Provider
Commercial Crew Program	Providers: Boeing, SpaceX Lead Center: KSC Performing Center(s): All Cost Share Partner(s): Industry Partners (shown above)

Acquisition Strategy

CCP facilitates development of a U.S. commercial crew space transportation capability with the goal of achieving safe, reliable, and cost-effective access to and from space and ISS. Under the CCP's partnership approach, NASA engineers have insight into a company's development process and evaluate systems for overall safety, reliability, and performance. The Agency's technical expertise and resources are also accessible to partner companies. Because companies are only paid a fixed amount, they are incentivized to reduce costs and apply their most efficient and effective manufacturing and business operating techniques throughout the process. Additionally, the partners own and operate their completed transportation systems.

The current and final stage of the acquisition lifecycle began with the award of two FAR-based fixed-price CCtCap contracts in September of 2014 for development, test, evaluation, and final NASA certification of a Crew Transportation System. CCtCap contracts include demonstration of crewed ISS missions and subsequent service missions, assuming sufficient budget and technical progress. The contracts also include a Special Studies Services section for special studies, tests, or analyses, as needed by NASA to reduce program risk. NASA's FAR-based fixed-price contracts during this phase allow for compliance with NASA's existing mission and safety requirements for transporting crew to and from ISS.

NASA measures partner progress against fixed-price milestones, based on performance of agreed upon entrance and success criteria. Although the content varies by partner, milestones are designed to demonstrate progress toward completing crew transportation system development, such as risk reduction testing, design reviews, hardware development, and flight tests. The Government pays for milestones only after completion.

COMMERCIAL CREW PROGRAM

Major Contracts/Awards

Element	Vendor	Location (of work performance)
CCtCap	Boeing	Houston, TX
CCtCap	SpaceX	Hawthorne, CA

Independent Reviews

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	Aerospace Safety Advisory Panel	Oct 2022	Provide independent assessments of safety and recommendations to the NASA Administrator	No new formal recommendations or findings	Feb 2023
Other	NASA Advisory Council	Jan 2023	Provide independent recommendations for the NASA Administrator	TBD	At least annually, date TBD

SPACE COMMUNICATIONS AND NAVIGATION

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Space Communications Networks	403.1	--	**493.9**	534.6	520.2	443.8	429.5
Space Communications Support	117.5	--	**85.8**	91.1	92.2	96.8	99.2
Total Budget	**520.6**	**--**	**579.7**	**625.7**	**612.4**	**540.6**	**528.6**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

On flight day 13 (November 28, 2022), Orion reached its maximum distance from Earth during the Artemis I mission when it was 268,563 miles away from our home planet. This mission was supported by the SCaN Program. The Deep Space Network (DSN) supported a constant flow of data with Artemis I's uncrewed Orion capsule beyond low-Earth orbit after launch. This included the mission's outbound journey and return, plus all the mission's trajectory maneuvers in between, ensuring commands could be sent to the spacecraft and data could be returned to Earth. Shortly before the service module separated from the crew module, communication switched from the DSN to the Near Space Network (NSN) for the final return trajectory correction burn, spacecraft separation, re-entry through the Earth's atmosphere and splashdown. Together the DSN and NSN create a foundation for future crewed Artemis launches to the lunar surface.

NASA's Space Communications and Navigation (SCaN) capabilities provide mission-critical communications and navigation services required by all NASA human and robotic missions. These missions range from high-altitude balloons to the International Space Station (ISS) in low-Earth orbit (LEO) to Voyager 1, which is the most distant manmade object, currently more than 14 billion miles from Earth. SCaN retrieves science, spacecraft, and crew health data for all these missions, uploads commands, and sends data to individual control centers. Navigation services determine the precise location of a satellite so it can control its trajectory through space, gather valid scientific data, and avoid other spacecraft or space debris.

Without services to move data and commands between spacecraft and Earth, space assets worth tens of billions of dollars would be little more than orbital debris. SCaN provides secure, reliable, and adaptable communication services to NASA missions, as well as external customers who rely on space communications services daily. External customers include foreign governments, international partners, commercial entities (e.g., launch service providers), and non-NASA U.S. missions to which SCaN provides services on a reimbursable basis.

The Near Space Network (NSN) provides communication services to NASA users and missions using a combination of commercially-owned and Government-owned ground assets, along with relay spacecraft which allow for near real-time, low latency support, including support for human spaceflight operations. The relay component is comprised of a constellation of Government-owned Tracking and Data Relay Satellites (TDRS) and various ground terminals. This allows SCaN to offer 24/7 global telecommunication services via the NSN for telemetry, tracking, and command of LEO spacecraft.

SPACE COMMUNICATIONS AND NAVIGATION

The NSN supports an extensive and diverse customer base from suborbital to Lagrangian orbits by providing direct-to-ground data transfer from spacecraft at S-, X-, and Ka-band frequencies up to data rates of gigabits per second. The NSN supports users that require low latency global coverage through TDRS, by utilizing a mix of ground antennas owned by NASA, universities, and private companies to maximize the network's geographic coverage. Such users include the Hubble Space Telescope and ISS (for which the NSN provides constant communication), as well as vehicles from international partners and commercial interests.

SCaN's goal is to migrate the NSN completely away from Government-owned assets by leveraging the diverse space communications capabilities provided by private industry to provide new technology and capabilities for NASA missions. A key part of this migration includes commercial service demonstrations managed by the Communications Services Program.

While the NSN primarily supports missions close to the Earth, the Deep Space Network (DSN) is focused on supporting deep space missions by utilizing its global network of large antenna ground assets. Both networks support Commercial Crew providers and Artemis missions. The DSN is a keystone of NASA's exploration of the solar system. It provides reliable and high-performance telecommunications and tracking services to planetary missions. This international network supports interplanetary spacecraft missions and radio and radar astronomy observations for the exploration of the solar system and the broader universe. Current locations of the three deep space communications facilities are positioned approximately 120 degrees of longitude apart around the world. These locations are Goldstone, in California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia.

NASA uses the SCaN-provided Goldstone Solar System Radar to track and characterize near-Earth objects that pass within nine million miles of Earth and to determine their orbits for use by the Science Mission Directorate’s (SMD) Planetary Science Division in assessing the probability of possible collisions with Earth. The installation of new radar equipment, planned for completion in FY 2026, will extend the radar's capability to 42 million miles, which increases the time to develop viable solutions to avoid orbital collision for planetary defense.

Both networks require maintenance, replenishment, modernization, and capacity expansion to ensure continued operation and to meet new mission needs. Human and robotic exploration of the Moon requires communications to support video, telemedicine, and advanced instruments that locate and identify exploitable resources on the Moon (e.g., subsurface ice). SCaN is engaged in the planning of the Artemis Campaign's lunar exploration and science missions to ensure that communications and navigation capabilities meet mission needs. SCaN is planning for expanded services for missions to the Moon, including a lunar relay capability for missions that cannot communicate directly with Earth and enhanced position, navigation and timing services that are less dependent on tracking stations on Earth. SCaN will seek to maximize the use of commercial assets and services when implementing these new capabilities.

Space Communications Support provides efficient planning and integration of current and future network capabilities to meet customer mission needs while reducing costs. It provides systems engineering, architecture planning, communications data standards, technology development, testbeds for future capabilities, radio frequency spectrum management, and navigation policy.

Operating in space requires significant national and international coordination. SCaN participates in several U.S. and international organizations that coordinate compatibility and interoperability in space communications and navigation. SCaN’s standards development and management activity maintains a portfolio of international interoperability standards that enable joint space missions with other nations. SCaN also promotes new technologies and provides technical leaders and domain experts who ensure appropriate space communication standards are available to NASA missions. The research and

SPACE COMMUNICATIONS AND NAVIGATION

technology avenues within SCaN aim to predict the needs of future communications missions in a manner that will yield performance advancements and reduced costs.

Amid soaring demand for wireless broadband, such as 5G mobile services, radio frequency spectrum management has become increasingly critical to the world's spacefaring nations. SCaN coordinates nationally and internationally to protect radio frequencies critical to NASA space and science missions.

For more information, go to http://www.nasa.gov/scan

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

SPACE COMMUNICATIONS NETWORKS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**403.1**	**--**	**493.9**	**534.6**	**520.2**	**443.8**	**429.5**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The Madrid Deep Space Communications Complex (MDSCC) held an Inaugural event to mark the beginning of operations for the new 34-meter Beam-Wave Guide (BWG) antenna (DSS-53), shown above; attendees included the King of Spain, U.S. Ambassador to Spain, and senior JPL and NASA management.

Space Communications Networks provide 24/7, global, near-Earth and deep space communications capability, plus tracking and navigation services to more than 100 NASA programs and other U.S. Government, international civil space agencies, and commercial missions. This capability ensures reliable and near-continuous communication with NASA and customer spacecraft. The SCaN program continuously examines and integrates commercial capabilities, and services to meet NASA's space communications and navigation requirements.

NASA's space communications networks provide ongoing services to Agency and customer missions, averaging approximately 600 tracking passes per day. Services are provided to both to new spacecraft that are increasingly powerful, complex, and capable of acquiring an increasing amount of mission data, as well as to legacy missions such as the two Voyager spacecraft launched more than 40 years ago that are still returning valuable science data. Customer missions include James Webb Space Telescope (Webb), Parker Solar Probe (PSP), Joint Polar Satellite System (JPSS), Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight), Ice, Cloud and land Elevation Satellite (ICESat-2), Lucy, Landsat 9, Mars Perseverance, Commercial Crew, and Transiting Exoplanet Survey Satellite (TESS). NASA would not be able to deliver key science data or advance exploration goals without SCaN's network capabilities. The networks are supporting the Artemis Campaign as the Agency aims toward the goal of landing the first woman and first person of color on the Moon. Human exploration of the Moon requires communications and navigation to and from the Moon to support video, telemedicine, and advanced instruments to locate and identify exploitable resources on the Moon, such as subsurface ice.

The Near Space Network (NSN) will provide near-continuous communication services to users from ground level up to cislunar distances via commercial and Government assets. The NSN enables utilization of a reliable, robust, and cost-effective set of commercial space-to-ground communications services in which NASA is one of many customers. NSN Government assets, including the Tracking and Data Relay

SPACE COMMUNICATIONS NETWORKS

Satellites (TDRS), are maintained and operated by the Advanced Communications Capabilities for Exploration and Science Systems (ACCESS) project. NSN is the prime user interface for current and future missions to ensure compatibility, complete pre-mission planning, and provide communication services during mission operations. NSN serves as the Government interface to commercial service providers located in the United States and internationally. The Commercial Services, Innovation, and Synergies (CIS) office aids with the infusion of future commercial capabilities and services into the NSN. A key technology SCaN is currently developing to support commercialization is wideband tunable user terminals.

As a part of the NSN, NASA's TDRS are a system of Government-owned, contractor-operated communications satellites in geosynchronous orbit matched with a set of space-to-ground link terminals located at NASA's White Sands Complex (WSC) in New Mexico, Guam, and Blossom Point, MD. NASA will continue to maintain Government-owned ground stations necessary to communicate with geosynchronous, lunar, and highly elliptical Earth orbits, as well as spacecraft launched from certain suborbital launch locations, supported by the Launch Communications Segment (LCS). The LCS provides pre-launch, launch, ascent and landing communication services to various users through two modern ground stations: the Kennedy Uplink Station on site at NASA's Kennedy Space Center (KSC) and the Ponce de Leon Station 40 miles north in New Smyrna Beach, Florida. The NASA-owned ground stations are currently located at WSC, U.S. McMurdo Antarctic Station, and Wallops Flight Facility (WFF) in Wallops Island, VA.

The Deep Space Network (DSN), which has been in operation for nearly 60 years, provides reliable and high performance communication and tracking services to approximately 40 NASA and non-NASA missions beyond geosynchronous orbit (more than 22,000 miles above the Earth's surface). It is a worldwide network of 34-meter and 70-meter antennas that supports interplanetary spacecraft missions and radio and radar astronomy observations for the exploration of the solar system and the universe. The DSN currently consists of three deep-space communications facilities located approximately 120 degrees of longitude apart around the world: at Goldstone in California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia. The site separation ensures any spacecraft in deep space can always communicate with at least one DSN facility as the Earth rotates and the spacecraft continues to move along its trajectory. Additionally, NASA uses the Goldstone Solar System Radar (GSSR) capability to track and characterize near-Earth objects that pass within nine million miles of Earth. The orbits of the near-Earth objects are determined and utilized by the Science Mission Directorate's (SMD) Planetary Science Division to assess the probability of a conjunction between the object and the Earth. Investments in GSSR, such as installation of a new klystron, are underway to increase its capability for supporting planetary defense research. In FY 2020, SCaN initiated a DSN "Road to Green" activity to improve the long-term maintenance posture and network health requirements to ensure reliability and meet future Agency needs.

The ongoing DSN Aperture Enhancement Project (DAEP) is modernizing and upgrading the DSN to expand capacity, improve flexibility to support customer missions, and reduce operations and maintenance costs. The project is augmenting the capabilities of the existing 70-meter antennas by completing arrays of four 34-meter Beam Waveguide (BWG) antennas at each of the three DSN facilities: California by 2025, Spain by 2026, and Australia by 2029. The BWG antennas allow for antenna arraying and are less complicated, more flexible, and more cost-effective to maintain than the 70-meter antennas.

SPACE COMMUNICATIONS NETWORKS

Antenna arraying combines the signals received by two, three, or four 34-meter antennas to offer performance beyond that of one 34-meter antenna and up to the equivalent of a 70-meter antenna. When missions do not require all four 34-meter antennas to be arrayed, the 34-meter antennas can support multiple spacecraft individually, offering greater flexibility than a single 70-meter antenna. The new 34-meter antenna construction efforts use Construction of Facilities funds appropriated in NASA’s Construction and Environmental Compliance and Restoration account. As part of future DAEP requirements, SCaN plans to install an 80-kilowatt transmitter on one 34-meter BWG antenna per DSN facility to match the transmit capabilities of a 70-meter antenna and plans to be operational at all facilities by 2029.

SCaN will continue work on acquiring lunar communications relay services and an interoperable lunar network through commercial service procurements and international partnerships. The network is required to meet all of the communication and navigation needs for lunar missions and support mission objectives such as human landing, sustained human presence, and scientific exploration on and around the Moon. The Lunar Exploration Ground System (LEGS), a dedicated new set of 18-meter antennas, will provide additional capacity in support of Lunar Exploration and other missions while preserving DSN capacity for Mars and outer planet missions. SCaN is increasing its infrastructure to support human and robotic exploration of the Moon, including providing a lunar communications capability and enhanced position, navigation, and timing services. The Lunar Communications Relay and Navigation Systems (LCRNS) is an infrastructure that will meet NASA's mission needs, enable a sustainable, long-term approach to human and robotic exploration, and embody an extensible solution for supporting future travel to Mars and beyond.

In alignment with lunar interoperability and standardization goals, SCaN is in the process of implementing Delay Tolerant Networking (DTN) to both the NSN and DSN. DTN will provide an internet-like approach to spacecraft communications and the ability to handle greater data rates and volumes up to 1.2 Gbps. Mission implementation of DTN is planned for the International Space Station (ISS), Laser Communications Relay Demonstration (LCRD), Artemis, Lunar IceCube, Plankton Aerosol Cloud Ocean Ecosystem (PACE), Korea Pathfinder Lunar Orbiter (KPLO), Integrated LCRD LEO User Modem Amplifier and Terminal (ILLUMA-T), Optical to Orion (O2O), and Gateway.

NSN and DSN support a different set of customer requirements for spacecraft orbit, signal strength, and real-time coverage. Both networks provide services to customer missions at a proficiency greater than 99 percent. To continue providing this level of support, each network requires regular maintenance, modernization and capacity expansion, and IT security upgrades to combat the ever-growing cybersecurity threats toward U.S. assets.

The Network Integrity Project Office was created in 2018 to provide a holistic, enterprise level management of the cyber and physical security program across the SCaN portfolio. The cornerstone of the office is the ability to ingest the various Federal security mandates, assess mission risk, provide secure technical solutions and compensating controls, and mitigate the ever-evolving threats and vulnerabilities to our mission networks. The office also heavily collaborates with the NASA OCIO and external Federal agencies to leverage expertise in all facets of cyber and physical security. The operational networks and development projects security posture is continuously being assessed and evaluated to ensure that the risk tolerance compliments the needs of individual missions.

SPACE COMMUNICATIONS NETWORKS

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ACHIEVEMENTS IN FY 2022

Consistent with prior years' successes, SCaN Networks continued to provide communications, tracking, and navigation services to more than 100 NASA, U.S. Government, international civil space agencies, and commercial missions above its 95 percent proficiency target.

The NSN transitioned the Space Network Ground Segment Sustainment (SGSS) project to Network Operations. The NSN also continued developing a conceptual design approach for sustainment activities to improve system reliability and operational efficiency.

The NSN executed an implementation plan to fully commercialize the DTE communications services for LEO customers. This will better leverage evolving capabilities of the private sector while still ensuring reliable support of user communication and navigation requirements through a robust, interoperable, and comprehensive network. The NSN continued progress on the Ka-band Advancement (NIKA) effort with the successful Level 5 Test Readiness Review (L5 TRR) and Normal Operations Readiness Review (NORR) in Q2 FY 2022 and Q3 FY 2022 to meet mission launch readiness dates for NISAR and Plankton.

The DSN completed the Deep Space Station (DSS)-35 BWG antenna's emergency repair work at the Canberra Deep Space Communications Complex (CDSCC) and returned the antenna to service. Additional repairs are planned for DSS-26 at the Goldstone Deep Space Communications Complex (GDSCC) for the BWG Transmitter (TXR) Servo obsolescence which will result in downtime until Q2 FY 2023. DSN began a DSS-65 downtime maintenance period in late FY 2021 at MDSCC and returned to service in early FY 2022.

The DSN Road-to-Green initiative and activities began in FY 2022, with initial planning, procurement and implementation of key long term maintenance tasks. These tasks included antenna uplink subsystems, life and safety systems, and IT security updates. The majority of these activities are multi-year efforts.

DSN completed installation of a badge reader access control replacement system at GDSCC in Q2 FY 2022. The badge replacement system will improve physical security at the main gate and Venus, Apollo, and Mars sites. The new system will bring GDSCC security at the designated sites into compliance with Enterprise Physical Access Control system (EPACS). The first ever successful demonstration of DTN on the DSN took place between a KPLO DTN node aboard the spacecraft and DTN nodes on the ground. Additionally, the GRC High-rate Delay Tolerant Networking (HDTN) implementation cleared a major technical hurdle after completing testing at both 500 Mbps and 1000 Mbps.

At MDSCC, DAEP successfully delivered DSS-53 to operations in Q2 FY 2022, began constructing the pedestal and erecting the antenna for DSS-23 radio frequency (RF) optical, and awarded the facilities contract for DSS-23 and DSS-54 in Q1 and Q4 FY 2022, respectively. The 7-segment testing for DSS-13 was completed at JPL and shipped to GDSCC by Q3.

SPACE COMMUNICATIONS NETWORKS

The DSN and the NSN will continue network upgrades in support of human and robotic exploration of the Moon as these require extensive communications to and from the Moon including support for video, telemedicine, and advanced instruments. The DSN Lunar Exploration Upgrades (DLEU) effort provides capability upgrades to the DSN 34-meter subnet to support enhanced communications requirements for Artemis. Specifically, two antennas per complex will have Ka-band (22.5 GHz) uplinks, enabling simultaneous uplink and downlink capability, and will support 20 Mbps data rates. Downlink processing will be upgraded by using improved decoding for error-correcting code and a low latency processing capacity of 150 Mbps. These new capabilities will allow real-time video from the Moon. The DLEU upgrades for increasing lunar readiness, were completed in Goldstone and work began in Canberra.

In April 2021, preliminary requirements were defined at the LEGS System Requirements Review (SRR), and pre-Phase A tri-band antenna technical interchange meetings were conducted with potential vendors. The Preliminary Design Review (PDR) project milestone for LEGS was completed in Q4 FY 2022, which served as a technical assessment on the baseline system operational functionality.

SCaN continued collaboration with the European Space Agency (ESA) and other potential international partners to pursue cooperative efforts toward lunar communications and navigation capabilities. SCaN prepared a draft document to define interoperability standards for a cooperative lunar network and has collected inputs from international partners and private companies to gain consensus on a baseline standards document. NASA has published three subsequent updates to the lunar interoperability specification in collaboration with ESA. NASA has shared the lunar relay service requirements with ESA and others; and in collaboration with ESA, is developing a joint concept of operations for a cooperative lunar network. SCaN also completed a reference design for a lunar relay satellite concept as background for the commercial service procurement and international collaboration.

After completing successful ground-based demonstrations of a wideband multilingual RF terminal in FY 2021, SCaN initiated work on a flight demonstration to prove that interoperable SATCOM services are an achievable end and operational concept for future NASA users. The Wideband flight terminal completed the Critical Design Review (CDR).

WORK IN PROGRESS IN FY 2023

SCaN Networks will continue to provide communications, tracking, and navigation services at a 95 percent or greater proficiency rate to more than 100 entities including NASA and other U.S. Government agencies, international civil space agencies, and commercial missions.

The DSN will begin site preparations for DSS-33 at the CDSCC for DAEP and will complete pedestal construction and begin facilities installation for DSS-23 at GDSCC. The DSS-23 upgrades will support the Psyche/Deep Space Optical Communications (DSOC) mission and other optical communication opportunities. DLEU upgrades will also continue on two more antennas, DSS-24 and DSS-36, with DSS-36 completing Ka-band installation.

DSS-54 site excavation at MDSCC is scheduled to be completed in Q3 FY 2023 in support of the DAEP DSS-54 pedestal rehabilitation plan. Completing excavation by Q3 FY 2023 will facilitate antenna operational readiness by Q4 FY 2026.

SPACE COMMUNICATIONS NETWORKS

In Q4 FY 2023, construction of a solar farm is scheduled to be completed at the CDSCC through a Solar Power Purchase Agreement, allowing for generation of renewable energy. The DSN will continue to complete key Road-to-Green tasks including completion of GDSCC and CDSCC medium-priority fire and life safety systems, and procurement of antenna uplink spares.

Scheduled completion of an upgraded fencing system at the Apollo GDSCC site is planned for Q3 FY 2024. The enhanced fencing will significantly improve security measures at the GDSCC location and will complement the security improvements completed in FY 2022.

NASA released a draft RFP in December 2022 to support SCaN's commercialization goals and the Agency's lunar exploration plans with awards planned for the Spring of 2023. These awards will define the detailed milestones and validation for commercial lunar relay services. In addition to these awards, LEGS will also support lunar missions by providing a dedicated new set of antennas designed to help alleviate the user load on the current 34-meter subnet and to allow DSN to focus on deep space support. A decision to incorporate tri-band antennas into LEGS sites 2 and 3 will be made based on study results. The LEGS project successfully completed an overall Preliminary Design Review (PDR) in Q1 FY 2023 and plans to conduct an Antenna PDR and project CDR in Q4 FY 2023.

DTN demonstrations will continue between the DSN and KPLO, including the first formal in-flight test and demonstration of video transfer, which took place in Q1 FY 2023. The NSN is scheduled to complete the first DTN experiment on LCRD and continue preparing for PACE implementation, despite spacecraft launch delays.

The ACCESS Project completed the fourth and final Operational Readiness Review (ORR) for the NIKA antenna located at WFF. With completion of this ORR in Q1 FY 2023, all NIKA tri-band stations are operational. Upon completion of pre-launch integration testing scheduled to begin in Q4 FY 2023, NIKA will be ready to provide high-rate downlink services to NISAR and PACE.

The ORR for the Orion/Artemis-II Optical Ground Segment (O2OGS) at the WSC is scheduled for Q4 FY 2023. The ORR is one of the final milestones for O2OGS and successful completion of the ORR will determine if O2OGS is ready to demonstrate operational utility of laser communications on Artemis-II and prove feasibility for human space flight. This ensures that all system and support hardware, software, personnel, procedures, and user documentation accurately reflect the deployed state of the system and are in place to support launch operations of Artemis II.

The LCRD is scheduled to complete its experimental phase in Q2 FY 2023. The experimental phase will demonstrate unique capabilities of optical communications, which include bandwidth increases of 10 to 100 times more than radio frequency systems. After the experimental phase is completed, LCRD will transition to the NSN for operations.

In alignment with SCaN's goal to pioneer optical communications efforts, the Low-Cost Optical Terminal (LCOT) will establish the infrastructure for proving and demonstrating advanced optical communications. LCOT will conduct a Phase A experiment with LCRD in FY 2023.

SCaN's Wideband demonstration will complete selection of a commercial satellite small-sat bus provider and operator, a terminal integration review, and initiate final integration and testing.

SPACE COMMUNICATIONS NETWORKS

KEY ACHIEVEMENTS PLANNED FOR FY 2024

SCaN Networks will continue to provide communications, tracking, and navigation services to more than 100 NASA and other U.S. Government, international civil space agencies, and commercial missions at a 95 percent or greater proficiency rate.

The DSN will continue to complete the lunar upgrades (DLEU) with DSS-24 and DSS-34 scheduled for completion during FY 2024.

The LEGS project will conduct an Antenna CDR in Q1 FY 2024 and Signal Processing CDR in Q2 FY 2024. RF compatibility testing is also scheduled to be completed in Q3 FY 2024.

DSN sustainment and maintenance activities and Road-to-Green initiative will continue, resolving recommendations from fire safety review team and additional sparing for critical uplink systems. Obsolescence tasks for antenna subsystems will continue during FY 2024.

NIKA tri-band stations will support the NISAR and PACE missions, based on their expected launch readiness dates. The NSN DTN implementation is also scheduled to complete the first demonstration with the PACE mission.

NSN will continue commercialization efforts by onboarding and infusing commercial buyers. Lunar Relay is expected to conduct a PDR and CDR in Q2 and Q4 FY 2024, respectively.

The wideband demonstration will complete payload integration onto the bus provided by York Space Systems, launch the satellite on a SpaceX Transporter rideshare opportunity, and conduct LEO operations demonstrating interoperability between multiple service providers, including Telesat/Blackjack, Inmarsat, SES/O3b mPower, and TDRSS.

LCOT will finalize integration and testing and is scheduled to conduct a more sophisticated demonstration with O2O and LCRD in Q3 and Q4 FY 2024, respectively.

DSS-54 pedestal build and installation of mirrors will be completed by Q4 FY 2024. The DSS-23 Antenna build will be completed, and electronics will be delivered.

Project Schedule

The table below includes significant SCaN network milestones in FY 2023 and FY 2024.

Date	Significant Event
Q1 FY 2023	DSN GDSCC Apollo Fence Completion
Q1 FY 2023	DTN Demonstration of Video Transfer
Q1 FY 2023	Lunar Exploration Ground System (LEGS) PDR
Q2 FY 2023	LCRD Begins Transition to NSN
Q2 FY 2023	NSN RFP release
Q3 FY 2023	DAEP DSS-54 Excavation Completion

SPACE COMMUNICATIONS NETWORKS

Date	Significant Event
Q3 FY 2023	DSS-23 Pedestal Build Completion
Q3 FY 2023	Upgrading Fencing System at the Apollo GDSCC site
Q3 FY 2023	Lunar Relay Services Contract Award
Q4 FY 2023	Orion Artemis-II Optical Ground Segment (O2OGS) Operational Readiness Review (ORR)
Q4 FY 2023	Construction of Solar Farm at CDSCC
Q4 FY 2023	ORR for O2OGS
Q4 FY 2023	LEGS CDR
Q3 FY 2024	DSS-23 Reflector LiftAntenna Build Completion
Q4 FY 2024	DLEU Completion
Q4 FY 2024	DSS-54 Pedestal Build Completion
Q4 FY 2024	LCOT Demonstration Lunar Relay CDR
Q4 FY 2024	LCOT Demonstration

Project Management & Commitments

Element	Description	Provider Details	Change from Formulation Agreement
ACCESS (Advanced Communications Capabilities for Exploration and Science Systems)	ACCESS provides the project management and subject matter expertise required to operate, maintain, and sustain assigned Government Owned / Contractor Operated ground- and flight-based systems and assigned facilities to provide NASA, other Government agencies, and partners optimal communications and navigation mission services through its alignment to and interfaces with the NSN.	Provider: ACCESS Project Office Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): Non-NASA customers	N/A
NSN	NSN provides the project management and subject matter expertise required to provide continuous LEO communication services to users via commercial and Government assets and providers. NSN will act as the Government interface to the commercial service providers located in the U.S. and internationally.	Provider: NSN Project Office Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): Non-NASA customers	N/A

SPACE COMMUNICATIONS NETWORKS

Element	Description	Provider Details	Change from Formulation Agreement
CIS	CIS functionally will provide project management leadership and subject matter expertise required to identify opportunities, extend invitations, implement collaborative solutions, and nurture diverse relationships to leverage commercial capabilities across the space communications industry.	Provider: CIS Project Office Lead Center: GSFC Performing Center: N/A Cost Sharing Partner(s): Non-NASA customers	N/A
DSN	DSN provides communication and navigation services to customer missions in deep space.	Provider: DSN Project Office Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): Non-NASA customers	N/A

Acquisition Strategy

The major acquisitions for the operational networks are in place. NASA uses reimbursable, international, and barter agreements, as well as competitive procurements. NASA's JPL provides the management of the DSN. The Communications Services Program (CSP) is conducting pilot efforts for commercial communications services for NASA's near-Earth missions. If these pilots are completed successfully, subsequent operational services would be transitioned to operations. SCaN also issued a solicitation for Lunar communication and navigation services in direct support of Artemis.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
DSN	JPL/California Institute of Technology	Pasadena, CA
NSN	Peraton	Herndon, VA
DSN	Commonwealth Scientific and Industrial Research Organization	Canberra, Australia
DSN	Instituto Nacional de Tecnica Aeroespacial (INTA)	Madrid, Spain
Wideband	Applied Physics Laboratory	Laurel, MD

SPACE COMMUNICATIONS NETWORKS

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
SCaN	Standing Review Board	Dec 2022	Program Implementation Review with focus on interdependencies, implementation planning, and risk gaps or shortfalls.	TBD	TBD

SPACE COMMUNICATIONS SUPPORT

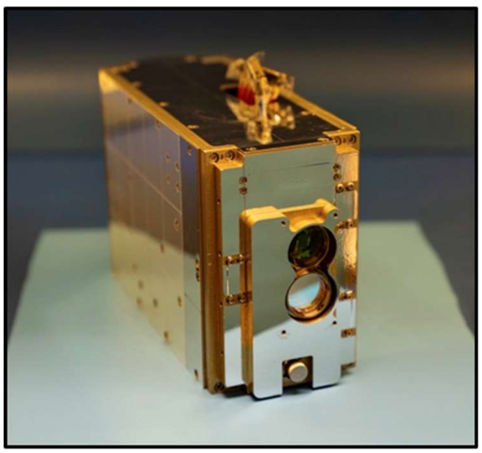
Formulation	Development	Operations

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	117.5	--	85.8	91.1	92.2	96.8	99.2

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



The TeraByte Infrared Delivery (TBIRD) payload, shown here at MIT Lincoln Labs, was hosted on a Tyvak 6U cube-sat that launched on May 25, 2022, on the SpaceX Transporter-5 rideshare. TBIRD will demonstrate a revolutionary and robust 200 Gbps direct-to-Earth downlink.

The Space Communications Support project supports NASA and the Space Communications and Navigation (SCaN) Program through planning, management, and development of advanced technologies.

Evolving space communication systems will transform future NASA mission capabilities. SCaN’s technology development efforts invest in leading-edge communications technologies that will enable, improve, and mature available spacecraft communication and navigation technologies for both ground and space-based use. Technology items are created and tested in laboratory settings before they are taken into space for further testing. Demonstrable technologies have proven themselves in laboratory tests and have begun experimentation and testing in space. Key technologies that SCaN is currently developing include cognitive networking and software-defined radios for use with commercial satellite communication (SATCOM) providers. These technologies will demonstrate use of a common radio to provide cross-service support for NASA, commercial, and Department of Defense (DoD) networks.

Another key space communications technology is optical (i.e., near-infrared laser) communications. Laser communication is highly efficient compared to radio frequency. Transmitting a 30-centimeter resolution map of the entire Martian surface (at one bit/pixel) would take current radiofrequency (RF) systems two years, while a laser communications system operating at projected capacity would be able to complete transmission in nine weeks, a nearly 12 times reduction in task time. However, any individual laser communication link is more expensive and has lower availability than an individual RF link because laser communication technology is not widely commercially available and cannot penetrate clouds. NASA's Space Technology Mission Directorate (STMD) and SCaN jointly developed the Laser Communications Relay Demonstration (LCRD) project with SCaN funding the ground operations and STMD funding the spacecraft payload. LCRD is NASA's first long-duration optical communications

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

project and is demonstrating a set of technologies that could be used on future missions. Other low-Earth orbit (LEO) optical technology demonstrations include: an optical user terminal called the Integrated LCRD LEO User Modem and Amplifier Terminal (ILLUMA-T), that will fly on the International Space Station (ISS) and communicate to the LCRD relay, demonstrating a 1.244 gigabits per second relay link in 2023; Optical-to-Orion (O2O), a terminal on the Artemis II Orion spacecraft that will provide 260 megabits per second of bandwidth, a rate not available with the current Orion communications system; and the TeraByte InfraRed Delivery (TBIRD), a CubeSat payload capable of delivering 200 gigabits per second from LEO to Earth. The TBIRD payload technology is based on 1,550 nanometer wavelength commercial components used for terrestrial fiber optic connections.

Deep Space Optical Communications (DSOC) is another critical technology being developed through a joint SCaN/STMD collaboration. DSOC will conduct optical communications from deep space, demonstrating key capabilities related to pointing accuracy and implementation of the High Photon Efficiency signaling standard. SCaN sponsors the ground network, including the five-kilowatt uplink beacon at the Jet Propulsion laboratory (JPL) Table Mountain facility and a superconducting single-photon-sensitive nanowire detector and real-time receiver at the Palomar Observatory in California. DSOC is currently on track to be integrated onto the Psyche planetary science mission, currently scheduled to launch no earlier than October 10, 2023.

SCaN continues to invest in the Deep Space Atomic Clock (DSAC) technology to mature designs for future mission use. DSAC technology allows a spacecraft to calculate its own timing and navigation data in real-time. With existing technology, a spacecraft can navigate autonomously to the top of the Martian atmosphere with uncertainty of one to two kilometers. It is expected that DSAC will enhance deep space navigation and reduce positional uncertainty to 100 meters, an improvement factor of 10 to 20 over today's capabilities, which will save fuel and enable more accurate scientific measurements. DSAC's improved long-term stability will also enhance on-board, autonomous navigation for future robotic and crewed missions, and enable investigations of fundamental physics (e.g., relativity). Further, DSAC's long-term stability will reduce network operations costs for tracking data collection by enabling one-way metric tracking. This allows a single antenna to service multiple DSAC-using spacecraft at common locations in the sky (e.g., Mars).

SCaN is researching opportunities to leverage investments, experience, and accomplishments from optical communications to build foundational capabilities needed for future spaced-based quantum communications and networking.

SCaN is an active member of multiple international organizations (e.g., Interagency Operations Advisory Group [IOAG], Consultative Committee for Space Data Systems [CCSDS]) that coordinate space communications and navigation compatibility and interoperability, as well as development of communications and data systems standards for spaceflight. SCaN serves as the NASA representative to the IOAG and CCSDS and provides the Secretariats for both entities. Space communications data standards enable world space agencies and industry to interoperate and provide communications and/or backup communications services with each other, reducing mission risk and reducing or eliminating the need to build and deploy their own space and ground assets. These standards provide significant cost

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

savings to NASA without reducing services or coverage to space missions and serve as a compatibility and interoperability guide for industry.

Electromagnetic spectrum is a valuable and limited natural resource that all NASA missions and most operations require for communications, navigation, remote sensing, and data services in the areas of Earth science, space science, human space exploration, and aeronautical research. All forms of wireless systems used by the Federal Government or by commercial entities use the electromagnetic spectrum. Therefore, spectrum use is highly regulated and must be carefully coordinated. SCaN is responsible for ensuring access to portions of the electromagnetic spectrum necessary to support NASA's mission needs including ensuring interference-free operations and bandwidth availability. The National Telecommunications and Information Administration (NTIA) within the Department of Commerce is the Federal spectrum regulator. SCaN serves as the Agency's Spectrum Manager and provides NASA representatives to advocate for NASA's requirements at domestic spectrum governing bodies including the Interdepartment Radio Advisory Committee (IRAC) within the NTIA and at international spectrum governing bodies. SCaN represents NASA's interests at multiple international technical forums, the most important of which are the World Radiocommunication Conferences (WRCs), which convene every three to four years and includes delegates from more than 150 nations. Among the purposes of these conferences is to review and revise the International Telecommunication Union's Radio Regulations, which govern international use of the electromagnetic spectrum. NASA's delegates play leading roles in several key WRC working groups and regional committees throughout the year. In both the domestic and international arenas, NASA continues to engage with the commercial sector to identify more flexibility in the use of spectrum resources that will meet mission objectives for the entire space community.

NASA spacecraft in Earth orbit can employ the U.S. Global Positioning System (GPS) and other Global Navigation Satellite System (GNSS) signals for precision positioning, navigation, and timing (PNT), allowing NASA to minimize network tracking burdens while maximizing spacecraft autonomy and improving operations. In 2019, the NASA Magnetospheric Multiscale (MMS) mission validated use of GPS signals up to half the distance from Earth to the Moon. SCaN is now leading NASA efforts on the Lunar GNSS Receiver Flight Experiment (LuGRE) on the Blue Ghost Mission-1 (Commercial Lunar Payload Services Mission 19D), scheduled for launch in 2024. The LuGRE payload includes a GPS-Galileo receiver, furnished by the Italian Space Agency (ASI), that will be used validate use of GPS and Galileo signals throughout cislunar space and on the nearside of the Moon. SCaN and the Science Mission Directorate (SMD) Earth Science Division (ESD) are collaborating with the European Space Agency (ESA) on space geodesy experiments hosted on the Lunar Pathfinder, for launch in 2025. This includes furnishing a Laser Retro-Reflector payload that, in combination with an ESA-furnished GPS-Galileo receiver payload, will enable combined GNSS radiometric and optical laser measurements to tie the Earth and Moon reference frames and improve navigation in lunar space. SCaN is also leading efforts to validate multi-GNSS use for range safety applications, including the Space Loft 15 GPS-Galileo flight experiment which launched in Q1 FY 2023. SCaN also manages NASA’s policy on GPS use, represents NASA at the U.S. PNT Executive Committee, works with the U.S. Space Force to continue improving GPS capabilities to support space users, and leads U.S. efforts at the United Nations International Committee on GNSS (ICG) to develop interoperable multi-GNSS capabilities to support space users, which resulted in the 2018 publication of the technical specifications, "The Interoperable

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

GNSS Space Service Volume," and a second edition in 2021. These specifications provide GNSS space users and space receiver manufacturers with a single resource offering a concise overview on the characteristics provided by every GNSS as their contribution to an interoperable GNSS SSV. A third edition will extend the analysis from Geosynchronous Orbit (GEO) altitude through cislunar space and up to lunar orbit. Another key SCaN activity is working with other U.S. departments and agencies in mitigating threats to the GPS spectrum and protecting GPS users from data-spoofing (GPS cybersecurity). SCaN manages two National Advisory Boards, the National Space-Based PNT Advisory Board and the National Space Council (NSpC) Users' Advisory Group (UAG). SCaN continues its role established in 2007 of providing the Executive Director and Designated Federal Officers (DFOs) to the National Space-Based PNT Advisory Board, which reports to the National Space-Based PNT Executive Committee (EXCOM), co-chaired by the Deputy Secretaries of Defense and Transportation. Since 2019, SCaN has provided the Executive Secretary and DFOs of the NSpC UAG. The UAG reports to the Executive Secretary of the NSpC, which is chaired by the Vice President of the United States.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ACHIEVEMENTS IN FY 2022

LCRD successfully launched on December 7, 2021 and began the experiment phase in June 2022. SCaN continues to operate and maintain the LCRD payload through the LCRD Mission Operations Center (LMOC) for a prime demonstration operations period of two years post launch.

The O2O payload was completed in July 2022 and integration into the spacecraft will begin no earlier than February 2023. In addition, SCaN developed a Ground Terminal (GT) as an element of the O2O Artemis II mission to prepare for operations at the Optical Communication Telescope Laboratory at the Table Mountain Observatory, which is scheduled to complete integration and testing in Q2 FY 2023. The GT will support the Orion space terminal with a minimum downlink data rate of approximately 80 megabits per second and an uplink data rate of approximately 20 megabits per second.

TBIRD, which launched on May 25, 2022, established a low-cost burst data delivery architecture and protocols by leveraging high-rate commercial off the shelf telecom equipment for a 200 gigabits per second data delivery in a CubeSat form-factor. TBIRD mission recently achieved a record for optical communications in space. The satellite downlinked 1.4 terabytes of data over laser communications links in a single pass that lasted about five minutes. TBIRD will continue to demonstrate optical high data-rate capabilities designed for small payloads (i.e., a 200 gigabits per second package that is ≤3U [three-unit]), that require reduced size, weight, and power (SWaP).

NASA completed the DSOC Operational Readiness Review (ORR). Psyche's launch is currently scheduled for early FY 2024.

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

DSAC follow-on technology maturation leveraged the progress of the Technology Readiness level (TRL)-7 DSAC technology demonstration mission and data collected from its second year of flight operation to design a commercially manufacturable version of the clock in a reduced SWaP form-factor suitable for a wide-range of space missions. SCaN continued quantum entanglement pre-formulation and technology maturation, with focused on ground-based research and development.

NASA leveraged the Navigator weak-signal tracking GPS receiver technology which developed a small form-factor, multi-GNSS receiver (e.g., GPS/Galileo) that is used in cislunar and lunar space and completed TRL-6 testing in FY 2022. This provided reliable, real-time, autonomous, onboard navigation and timing for cislunar and lunar users by leveraging the always-on GNSS assets in orbit around the Earth. The receiver will reduce the tracking burden on Earth-based networks, which are a finite resource, for cislunar and lunar users, and serve as a significant risk reduction for commercial user operations. SCaN continued leading NASA efforts in partnership with ASI and ESA, to develop a flight experiment to validate the use of combined GPS-Galileo signals to support range safety applications. Key achievements included delivery and testing of two GPS-Galileo receivers furnished by ASI and ESA, for integration on the Space Loft 15 sounding rocket which launched Q1 FY 2023.

SCaN continued leading NASA's effort, in partnership with ASI, to develop the Lunar GNSS Receiver Experiment (LuGRE) payload on Blue Ghost Mission-1, for launch in 2024. This payload will validate the use of GPS-Galileo signals at lunar distances.

SCaN's collaboration with SMD/ESD resulted in the manufacture, testing, and delivery of a laser retro-reflector array to be hosted on ESA's Lunar Pathfinder relay satellite, for launch in 2025. In combination with an ESA-furnished GPS-Galileo receiver payload, this reflector will enable combined GPS-Galileo and optical laser measurements to tie the Earth and Moon reference frames and improve navigation in lunar space.

WORK IN PROGRESS IN FY 2023

SCaN continues to operate the LCRD payload and experiments throughout the two-year experiment period, which includes an experiment to verify collection of metric tracking data from optical links.

The ILLUMA-T optical demonstration payload is scheduled to launch to ISS in FY 2023. This will demonstrate data transfer between LEO and the ground through a geosynchronous relay (LCRD). TBIRD will continue demonstrations, supported by the 1-M Optical Communications Telescope Laboratory (OCTL) at JPL's Table Mountain Facility.

The O2O payload is scheduled to complete all Ground Readiness Tests and Mission Readiness Tests by the end of Q1. The payload will launch aboard the Artemis II mission. The O2O Ground Terminal at Table Mountain will conduct an Operational Readiness Review in Q2 FY 2023 in preparation for supporting the Artemis II launch.

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

The ASI and ESA furnished GPS-Galileo receivers were integrated on the Space Loft 15 sounding rocket in October 2022, for launch in Q1 FY 2023. The LuGRE GPS-Galileo flight experiment is scheduled for delivery to Firefly Aerospace in Q2 FY 2023 for integration on the Blue Ghost Mission-1 lunar lander.

SCaN will continue to develop the third edition of the United Nations International Committee on GNSS (UNICG) technical specification, "The Interoperable GNSS Space Service Volume", that extends the analysis throughout cislunar space and up to Lunar orbit. This document is currently planned for release and publication at the ICG-17 meeting in Q4 FY 2023.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

NASA will continue the ILLUMA-T optical demonstration payload to ISS. This includes continued operations of the LCRD payload and ground station support via OCTL. ILLUMA-T will demonstrate LEO to GEO optical communications crosslink via the operational LCRD payload in GEO. DSOC will launch onboard the Psyche spacecraft and begin its demonstration period to last at least one year. DSOC will demonstrate deep-space optical communication uplink data rates of 1.6 kbps for multiple ranges between 0.25 and 1 astronomical units (AU). It will also demonstrate optical communication downlink for various data rates and distances. DSOC will enter its Phase E in FY 2024 and complete operations for technology demonstration.

The Blue Ghost-1 lunar lander, which carries the LuGRE GPS-Galileo flight experiment is scheduled for launch in FY 2024. This experiment will validate the use of GPS and Galileo signals for positioning, navigation, and timing at lunar distance.

SCaN will also be defining, developing, and demonstrating evolutionary and foundational communications and Position, Navigation, and Timing technologies to enable LunaNet and address technology gaps in the Artemis III-V and Artemis VI+ timeframes. These technologies include optimetric ranging, user-initiated services and protocols, and onboard mission autonomous navigation, guidance, and control.

Project Schedule

The table below includes significant Space Communication Support milestones in FY 2023 and FY 2024.

Date	Significant Event
Q1 FY 2023	Space Loft 15 Launch (sounding rocket with GNSS flight experiment)
Q2 FY 2023	O2O Delivery to KSC
Q2 FY 2023	ILLUMA-T Launch
Q2 FY 2023	LuGRE payload delivery to Firefly Aerospace for integration on Blue Ghost Mission-1 (CLPS Mission 19D)
Q3 FY 2023	Deep Space Optical Communications (DSOC) Operational Readiness Review

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

Date	Significant Event
Q1 FY 2024	Psyche Launch - DSOC begins demonstration
TBD FY 2024	ILLUMA-T demonstration with LCRD

Project Management & Commitments

The SCaN Program office at NASA Headquarters manages Space Communications Support functions.

Element	Description	Provider Details	Change from Formulation Agreement
Space Communications Support	Provides critical communication and navigation architecture planning, systems engineering, technology development, standards development and management, spectrum management, and policy and strategic communications for NASA.	Provider: NASA Responsible Center: HQ	N/A

Acquisition Strategy

Space Communications Support functions use multiple small, contracted efforts, most of which are support services functions.

MAJOR CONTRACTS/AWARDS

None.

HUMAN SPACE FLIGHT OPERATIONS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**100.8**	**--**	**102.0**	**106.9**	**105.8**	**105.8**	**105.9**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Shown here is a group photo of the Astronaut Candidate (ASCAN) Class of 2021, taken in JSC Mall on December 3, 2021.

The Human Space Flight Operations (HSFO) Program supports the astronaut corps, space flight readiness training, and health of crew members before, during, and after each spaceflight mission to the International Space Station (ISS) and future Artemis missions. All crews on board ISS have undergone rigorous preparation, which is critical to mission success. Within the HSFO Program, the Space Flight Crew Operations (SFCO) element provides astronaut selection and space flight readiness training and the Crew Health and Safety (CHS) element manages all aspects of NASA astronaut crew health.

To pave the way to the Moon and on to Mars, NASA is working with industry to develop the transportation, habitation, and exploration systems that will enable crewed exploration of destinations beyond Earth's orbit. NASA must also prepare the human system for living and working for extended periods in the hostile environment of space. As astronauts explore further from Earth, many different issues will arise and need investigating. Questions that should be considered are:

- What health risks will astronauts face and how are they resolved?
- What type of training will crews need to prepare for months of travel in the harsh space environment? and
- How will they deal with medical emergencies or technical anomalies when Earth is no longer within reach?

CHS, in collaboration with NASA's Office of Chief Health and Medical Officer (OCHMO) and the Human Research Program (HRP), answers these and other questions to ensure crew health, safety, and mission success. SFCO and CHS are responsible for astronaut space flight readiness training and health, while HRP funds research of human health and performance countermeasures, the human response to space, and technologies that enable safe, reliable, and productive human space exploration.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

HUMAN SPACE FLIGHT OPERATIONS

ACHIEVEMENTS IN FY 2022

SFCO directed and managed the astronaut corps and provided trained astronauts for NASA human space flight efforts, including for Expeditions 66 and 67. SFCO began training astronauts for future ISS Expeditions, the first crewed test flight of the Boeing Starliner on the Crewed Flight Test (CFT) mission, and Boeing's first Post Certification Mission (PCM)-1. The 2021 Astronaut Candidate (ASCAN) class reported for training in FY 2022 for their two-year training flow, which is progressing nominally. SFCO also began the planning process for the next ASCAN selection cycle.

SFCO continued to operate and maintain the T-38 high-performance jets in support of space flight readiness training, the Gulfstream aircraft for support of direct crew return after completion of ISS Expeditions, the Super Guppy aircraft for transporting oversized cargo for NASA's programs, and the WB-57 aircraft for high altitude imagery for NASA's human space flight and science programs.

SFCO provided support to the crew during launch, landing, and recovery operations for ISS Expeditions. SFCO also ensured the vehicle hazard safety process accounted for crew and operations safety for all NASA human space flight missions.

CHS maintained the Astronaut Occupational Health Program that includes clinical certification for 54 active NASA astronauts and health and fitness through training, flight, and post-mission recovery. CHS continued to implement all aspects of the To Research, Evaluate, Assess, and Treat (TREAT) (Astronauts Act to monitor, diagnose, and treat former NASA astronauts and enhance behavioral health and medical data collection, including the TREAT Astronauts Act Board, which assists in determining whether medical conditions are associated with spaceflight). CHS continued development of the occupational surveillance program for current and former astronauts, ensuring unique Artemis Program spaceflight exposures are considered and accounted for in future surveillance program for those astronauts.

To support ISS mission increments, CHS provided preflight training, medical and behavioral health management, physical conditioning, radiation exposure reports, and baseline occupational surveillance, as well as medical risk modeling through Probabilistic Risk Assessment tools. For NASA's Artemis, Gateway, and Lunar mission architecture and vehicles, CHS continued to provide analysis and technical expertise to support requirements and operational concept development. CHS also medically monitored and supported astronaut training activities for ISS EVAs and xEMU development. CHS provided recently selected ASCANs training in fundamentals of expeditionary skills and competencies and individual coaching on development of these competencies over the course of their training.

Data obtained under the TREAT Astronauts Act, as well as all CHS activities, continued to be added to the Information Management Platform for Data Analytics and Aggregation (IMPALA) data analysis tool to inform current and future operational programs and expectations of crew health and performance. IMPALA continued to improve NASA's access to astronaut medical data to inform programmatic decisions, and CHS maintained and updated the IMPALA Data Catalog to enhance the community's understanding of data available within IMPALA, as well as generated IMPALA data deliverables required for evaluation of human system risks to enable lunar and Mars missions. CHS continued to maintain and provide an in-house testing capability for SARS-CoV-2 (COVID-19). CHS restarted Lifetime Surveillance of Astronaut Health (LSAH) exams, which were suspended due to the

COVID-19 pandemic. LSAH exams facilitate collection of vital retired astronaut medical data for understanding long-term effects of the astronaut occupation for informing future space missions.

WORK IN PROGRESS IN FY 2023

SFCO will direct and manage the astronaut corps and provide trained astronauts for NASA human space flight efforts, including for Expedition 68 and 69 and Boeing's CFT mission. In addition, SFCO will assign astronauts to be the Artemis II crew and they will begin training for the mission. SFCO will begin the recruitment and selection process for the 2024 ASCAN class.

SFCO will continue to operate and maintain the T-38 high performance jets in support of space flight readiness training, Gulfstream aircraft for support of direct crew return after completion of ISS Expeditions and the Boeing CFT mission, transportation of oversized cargo with the Super Guppy aircraft for NASA's programs, and the WB-57 aircraft for high altitude imagery for NASA's human space flight and science programs.

SFCO will provide support to the crew during launch, landing, and recovery, and rescue operations for ISS Expeditions and the Boeing CFT mission. SFCO will support the vehicle hazard safety process to ensure crew and operations safety for all NASA human space flight missions.

CHS will maintain the Astronaut Occupational Health Program that includes clinical certification for 50 active NASA astronauts and health and fitness through training, flight, and post-mission recovery. CHS will continue to implement all aspects of the TREAT Astronauts Act to monitor, diagnose, and treat former NASA astronauts and enhance behavioral health and medical data collection, including the TREAT Astronauts Act Board, which assists in determining whether medical conditions are associated with spaceflight. CHS will continue development of occupational surveillance program for current and former astronauts, ensuring unique Artemis Program spaceflight exposures are considered and accounted for in future surveillance program for those astronauts.

To support ISS mission increments, CHS will provide preflight training, medical and behavioral health management, physical conditioning, radiation exposure reports, and baseline occupational surveillance, as well as medical risk modeling through Probabilistic Risk Assessment tools. For NASA's Artemis, Gateway, and Lunar mission architecture and vehicles, CHS will provide analysis and technical expertise to requirements and operational concept development. CHS will also medically monitor and support astronaut training activities for ISS EVAs, xEMU development, and training for three NASA astronauts for lunar surface EVAs. CHS will provide selected ASCANs training in fundamentals of expeditionary skills and competencies and individual coaching on development of these competencies over the course of their training. CHS will also provide medical and behavioral screening expertise to SFCO in support of the 2025 Astronaut Candidate selection.

Data obtained under the TREAT Astronauts Act as well as all CHS activities, will continue to be added to the IMPALA data analysis tool for informing current and future operational programs and paradigms for crew health, safety, and performance. IMPALA will continue to improve NASA's access to astronaut medical data to inform programmatic decisions, and CHS will maintain and update the IMPALA Data Catalog to enhance the community's understanding of data available within IMPALA, as well as generate IMPALA data deliverables required for the evaluation of human system risks to enable lunar and Mars missions. Pending future state of the pandemic, CHS will continue to maintain and provide an in-house testing capability for COVID-19. CHS will continue LSAH exams with the goal of obtaining a 75 percent participation rate. LSAH exams facilitate collection of vital retired astronaut medical data for understanding long-term effects of the astronaut occupation for informing future space missions.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

SFCO will direct and manage the astronaut corps and provide trained astronauts for NASA human space flight efforts, including for ISS and Artemis missions. SFCO is targeting 2025 and 2028 for the next ASCAN class selections.

SFCO will continue to operate and maintain the T-38 high performance jets in support of space flight readiness training, Gulfstream aircraft for support of direct crew return after completion of ISS Expeditions and the Boeing CFT mission, transportation of oversized cargo with the Super Guppy aircraft for NASA's programs, and the WB-57 aircraft for high altitude imagery for NASA's human space flight and science programs. Longer term, skills needed to conduct the Artemis lunar missions will require a fundamental shift in the SFCO fleet from all high-performance T-38's to a mixed training regime that focuses on delivering the benefits of the current high-performance aircraft along with vertical descent training and non-pilot mission commander training. The last two are projected to operate at a much lower cost per flight hour than the current T-38. The current T-38 fleet is projected to be retired in the 2030s as maintenance costs, spare part obsolescence, and airframe age combine to present insurmountable challenges. Because replacing the T-38 would require a budgetary expenditure in the hundreds of millions of dollars even to procure a smaller high-performance fleet, NASA is evaluating more cost-effective alternatives. Additionally, NASA is considering options to replace the one-of-a-kind Super Guppy. Until a replacement is found, NASA will continue to invest in repairs and maintenance to keep the aging aircraft flying.

SFCO will provide support to the crew during launch, landing, and recovery, and rescue operations for ISS and Artemis missions. SFCO will support the vehicle hazard safety process to ensure they account for crew and operations safety for all NASA human space flight missions.

CHS will maintain the Astronaut Occupational Health Program that includes clinical certification for 46 active NASA astronauts and health and fitness through training, flight, and post-mission recovery. CHS will continue to implement all aspects of the TREAT Astronauts Act to monitor, diagnose, and treat former NASA astronauts and enhance behavioral health and medical data collection, including the TREAT Astronauts Act Board, which assists in determining whether medical conditions are associated with spaceflight. CHS will continue occupational surveillance program for current and former astronauts, ensuring unique Artemis Program spaceflight exposures are considered and accounted for in future surveillance program for those astronauts.

To support ISS mission increments, CHS will provide preflight training, medical and behavioral health management, physical conditioning, radiation exposure reports, and baseline occupational surveillance, as well as medical risk modeling through Probabilistic Risk Assessment tools. For NASA's Artemis, Gateway, and Lunar mission architecture and vehicles, CHS will provide analysis and technical expertise to requirements and operational concept development and support these programs with Probabilistic Risk Assessment tools designed for exploration objectives. CHS will also medically monitor and support astronaut training activities for ISS EVAs, xEMU development, and training for three NASA astronauts for lunar surface EVAs. CHS will provide selected ASCANs training in fundamentals of expeditionary skills and competencies and individual coaching on development of these competencies over the course of their training. CHS will also provide medical and behavioral screening expertise to SFCO in support of the 2025 Astronaut Candidate selection.

Data obtained under the TREAT Astronauts Act as well as all CHS activities, will continue to be added to the IMPALA data analysis tool for informing current and future operational programs and paradigms for crew health, safety and performance. IMPALA will continue to improve NASA's access to astronaut medical data to inform programmatic decisions, and CHS will maintain and update the IMPALA Data Catalog to enhance the community's understanding of the data available within IMPALA, as well as generate IMPALA data deliverables required for evaluation of human system risks to enable lunar and Mars missions. CHS will support transition to operations of Informing Mission Planning via Analysis of Complex Tradespaces (IMPACT) for exploration missions and programs. Pending future state of the COVID-19 pandemic, CHS will continue to maintain and provide an in-house testing capability for COVID-19. CHS will continue LSAH exams with the goal of obtaining an 80 percent participation rate. LSAH exams facilitate collection of vital retired astronaut data for informing future space missions.

Program Elements

SPACE FLIGHT CREW OPERATIONS (SFCO)

SFCO directs and manages the astronaut corps activities, assigns flight crew, is responsible for human space flight readiness training, and maintains and operates the Johnson Space Center (JSC) aircraft fleet, including the T-38 high-performance aircraft, Gulfstream aircraft, and Super Guppy transport aircraft.

SFCO also determines the need for and selects astronaut candidates. It takes approximately two years from the decision to select a new astronaut class until the selection process is completed. Once selected, new astronauts must complete two years of training for eligibility and then 30 months of ISS training before qualifying for an ISS mission. The number of spacecraft seats U.S. astronauts will fill in the next four years of human space flight determines the manifest requirement. The manifest includes projected Commercial Crew flights to ISS, Commercial Crew test flights, and Artemis flights. Requirements for future missions, for example to Gateway and the Moon, will be planned as those missions become better defined.

Astronaut space flight readiness training activities implemented by SFCO put the crew into operational environments which share some aspects of the fast dynamics, physical stress, and risk found in spaceflight. The training develops the skills and ability to work as a team in an environment that is fast-paced, stressful, and carries potentially severe penalties for failure. The training also includes developing the skills necessary to respond in an emergency/high-stress environment and currently includes operating a high-performance aircraft.

CREW HEALTH AND SAFETY (CHS)

CHS enables healthy and productive NASA crew during all phases of spaceflight missions, implements a comprehensive NASA astronaut occupational health care program, and works to understand, prevent, and mitigate negative long-term health consequences from exposure to the spaceflight environment. Using HRP research and other findings, CHS implements enhancements to astronaut occupational health protocols to ensure crew health and safety. In this collaboration, HRP concentrates on the research aspects of crew health, whereas CHS focuses on implementing the research results and mitigation plans into occupational health protocols. As research continues on ISS, CHS is actively seeking new approaches to apply research findings to improve NASA health protocols, including collaborative opportunities with other Federal agencies and academia. Further, CHS is implementing the TREAT Astronauts Act for former NASA astronauts. This Act enables NASA to provide monitoring, diagnosis, and treatment to astronauts for spaceflight-related medical issues following retirement from NASA. In addition, NASA will be able to obtain more medical data to supplement the occupational surveillance program for former NASA astronauts and better assess the long-term effects of spaceflight on the human body to enable exploration.

CHS is also responsible for maintaining the health of active NASA astronauts during non-mission periods, focusing on three aspects of health care: preventive care, risk factor management, and long-term health monitoring. CHS integrates and coordinates information relevant to human health before, during, and after spaceflight. CHS documents and assesses all emerging health risks, such as Spaceflight Associated Neuro-ocular Syndrome, a spaceflight condition that affects astronauts eye structure and can lead to impaired vision, and the risk of venous flow changes. CHS continues to collaborate with several non-NASA organizations, including the National Academies, to inform the risk decisions associated with long-duration and exploration missions.

Program Schedule

Date	Significant Event
FY 2023	Continue the annual LSAH exams with the goal of reaching 75 percent of former astronauts.
FY 2023	Train ASCANs selected in FY 2022.

Program Management & Commitments

Program Element	Provider
SFCO	Provider: SFCO Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): N/A

HUMAN SPACE FLIGHT OPERATIONS

Program Element	Provider
CHS	Provider: CHS Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): N/A

Acquisition Strategy

The section below identifies the current contracts that support SFCO and CHS.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Aircraft Logistics, Integration, Configuration and Engineering	Yulista Tactical	Ellington Field, Houston, TX El Paso, TX
Human Health and Performance Contract	Kellogg Brown & Root	Houston, TX

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	National Council on Radiation Protection (NCRP) and Measurements	Jan 2022	To prepare a commentary that evaluates sex-specific differences in lung cancer radiation risks and assesses their use in transfer models and lifetime risk projections, with accompanying recommendations for NASA.	Report: Evaluation of Sex-Specific Differences in Lung Cancer Radiation Risks and Recommendations for Use in Transfer and Projection Models	N/A
Performance	Intercenter Aircraft Operations Panel (IAOP)	May 2022	NASA HQ assessment of the Center's aviation Program.	Findings and recommendations were made to enhance compliance with Agency guidelines.	May 2025
Performance	JSC AS9100 NQA Audit	Nov 2022	Recertification to AS9100, ensuring quality and safety in Spaceflight Hardware.	JSC was recertified to AS9100.	Nov 2024

HUMAN RESEARCH PROGRAM

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**70.6**	**--**	**153.5**	**153.5**	**153.5**	**153.5**	**153.5**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

FY 2022 funding was split between Exploration Systems Development Mission Directorate and Space Operations Mission Directorate. Total appropriated amount was $140 million.

NASA's Human Exploration Research Analog (HERA) crew member, shown here, prepares freeze-dried veggies in October 2022.

Sending astronauts into space involves a multitude of complicated systems, but perhaps the most complex is the human system – human health, human factors (i.e., how crews interact with their environment, including the spacecraft, habitat, and systems during missions), and the crew interactions. While NASA has more than 50 years of crew experience in low-Earth orbit (LEO), researchers are continuing to unravel the mysteries of how the human body responds to the harsh environment of space. The Human Research Program (HRP) is responsible for understanding and mitigating the highest risks to astronaut health and performance to ensure crews remain healthy and productive during long-duration missions beyond LEO.

As NASA prepares to conduct crewed missions via the Artemis campaign to cislunar space and the lunar surface, HRP is developing the scientific and technological capabilities to support these exploration missions. In support of the risk reduction strategy for human space exploration contained in the human research roadmap, HRP is coordinating with the National Academies, the National Council on Radiation Protection and Measurements (NCRP), and other domestic and international partners to deliver products and strategies to protect crew health and performance during and after exploration spaceflight missions. Current research on the International Space Station (ISS) in LEO and in ground-based analog laboratories is expanding NASA's capabilities to enhance crew performance and protect the health and safety of astronauts. Investigations regarding space radiation protection, deep space habitat systems, behavioral health, innovative medical technologies, advanced food and pharmaceutical systems, space suit requirements, and validated countermeasures are evolving to ensure crew health. HRP also collaborates with NASA’s Office of Chief Health and Medical Officer (OCHMO) and the Crew Health and Safety (CHS) and Spaceflight Crew Operations (SFCO) projects to research these issues and answer other questions to ensure crew health, safety, and mission success. SFCO and CHS are responsible for astronaut training, readiness, and health, while HRP funds research development on human health and performance countermeasures, knowledge, and technologies that enable safe, reliable, and productive human space exploration.

Space poses significant health risks for crewmembers, including the possibility of long-term health effects manifesting later in life from space radiation exposure, health and performance decrements developing during the mission, and decrements in capabilities immediately upon return to Earth. HRP is working with the Exploration Capabilities (EC), CHS, and Orion teams on both in-mission and post-mission countermeasures, medical treatment capabilities to maximize crew health and performance, and rehabilitation protocols to minimize residual impacts on the crew, minimize exposures, and provide radiation protection. The collaborative efforts involve defining permissible exposure limits, requirements for real-time medical response, optimized mission architectures, biomedical monitoring, and potential drug or nutritional countermeasures, as well as incorporating post-mission health surveillance to ensure that crewmembers can safely live and work in space without exceeding acceptable health risks.

In collaboration with other Federal agencies, such as the Department of Defense (DoD), the Department of Energy (DOE), the National Science Foundation (NSF), the Department of Health and Human Services (HHS), and the National Institutes of Health (NIH), HRP supports human research to increase NASA's understanding of the effects of spaceflight on human physiological systems, behavioral responses to isolation and confinement, and space radiation health effects. This knowledge enables NASA's plans for long-duration human space missions beyond LEO. In addition, as is the case with many space-based medical investigations, this research may lead to significant advancements in treating patients on Earth.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ACHIEVEMENTS IN FY 2022

HRP implemented an ISS flight research plan critical to mitigating crew health and performance risks for Artemis missions that includes: ISS Standard Measures Project to capture a core set of physiological and performance measures from crew members to accurately characterize adaptive responses to long-duration spaceflight and monitor effectiveness of countermeasures; a microbial risk assessment study to ensure crew safety and allow increased dependence on bioregenerative food systems; a study to analyze the relationship between the increased microbial virulence and reduced human immune function commonly observed during orbital spaceflight; and a technology demonstration of the rHEALTH ONE system which will establish if this technology can identify and analyze biomarkers, cells, microorganisms, and proteins in the spaceflight environment. HRP also implemented the Complement of Integrated Protocols for Human Exploration Research (CIPHER) study to characterize time courses of physiological and psychological measures on ISS missions up to one year in duration to understand the impact to human health and performance during future long-duration planetary missions.

HRP and the German Aerospace Center (DLR) implemented a bed rest study to assess the effectiveness of different countermeasures to mitigate Spaceflight Associated Neuro-ocular Syndrome (SANS) symptoms observed in prior bedrest studies using the DLR: envihab facility. During the new campaign, subjects evaluated the effectiveness of lower body negative pressure, thigh cuffs and exercise as countermeasures. Investigators compared subjects with head-down bed rest or seated only to subjects experiencing head-down bedrest in combination with countermeasures on aspects such as ocular measures, cerebral measures, cognition, neuroimaging, and structural and functional Magnetic Resonance Imaging (MRI).

HRP is committed to understanding behavioral and physiological health challenges associated with isolation and confinement, and therefore, the program continued the 45-day Human Exploration Research Analog (HERA) studies at Johnson Space Center (JSC). In addition, the Scientific International Research in Unique Terrestrial Station (SIRIUS) 21 mission provides the environment for crew members to further conduct behavioral experiments on behalf of nearly 70 different researchers from around the world, including eight studies funded by HRP over the course of an eight-month mission spent isolated in the Nezemnyy Eksperimental'nyy Kompleks (NEK) facility. NEK is located within the Institute of Biomedical Problems at the Russian Academy of Sciences in Moscow.

HRP leveraged resources through multiple research partnerships, including advanced food and nutrition studies with DoD, behavioral and physiological studies during winter over campaign at NSF polar facilities, bed rest studies at the DLR: envihab facility, and joint flight research and data sharing with international partners.

HRP engaged in research to support future Artemis missions by working closely with the Artemis Campaign, OCHMO, and Flight Operations Directorate (FOD) to understand high priority human health and performance areas where HRP can contribute research to reduce those programs' risk posture. HRP continued to refine its initial Artemis payload planning as those missions evolved. HRP continued to define its strategic research needs on the Artemis platform in collaboration with OCHMO and ESDMD/Mars Capability Division systems engineering and integration organizations. As an example of this collaboration, HRP has pivoted from solely Mars-focused research to a more immediate requirement of enabling Artemis Lunar Missions and the utilization of Artemis Missions to mitigate the Mars risks. Mars risk reduction remains a primary requirement for HRP.

Through HRP's Translational Research Institute for Space Health (TRISH) cooperative agreement, HRP continued to foster and grow commercial spaceflight's ability to support human research activities. For all commercial spaceflight opportunities that are orbital, TRISH planned a suite of experiments to set a precedent for those companies to be able to offer those experiences to their customers. Strategically, this will likely open additional subjects and platforms to help HRP accelerate its research goals.

WORK IN PROGRESS IN FY 2023

HRP is developing Informing Mission Planning via Analysis of Complex Trade spaces (IMPACT) to assist SOMD/ESDMD and OCHMO/ Health and Medical Technical Authority (HMTA) in understanding impacts of mission design and vehicle resource allocation on medical risk for long duration lunar missions via the Artemis Campaign. IMPACT is an integrated computational tool suite used by ground personnel to perform complex trade space analysis and enable decision-making about medical system design and content. It also maps potential medical systems against Model-Based Systems Engineering (MBSE) medical system requirements to enable informed trades between requirements. IMPACT supports data-driven and evidence-based decision-making throughout the entire mission life-cycle and it is a significant evolution from the current Integrated Medical Model (IMM) used for ISS/LEO medical kit decision making.

HRP intends to characterize the relationship between headward fluid (blood, interstitial, cerebrospinal) shift and structural and functional changes observed in the eye and brain of ISS astronauts, a condition referred to as SANS. Over 70 percent of ISS astronauts exhibit signs of SANS during or after ISS missions, including optic disc edema, choroidal folds and increased brain ventricle volumes. While vision is correctable to 20/20 in flight, long-term health consequences of chronic exposure to optic disc edema or enlarged brain ventricles are unknown and may be of consequence. The primary hypothesis for these morphological changes is the sustained headward fluid shift that all astronauts experience, although it is unclear why not all crew experience the same magnitude of change. Characterization of the relationship between SANS and these headward fluid shifts will help drive countermeasure development (i.e., lower body negative pressure or venoconstrictive thigh cuffs to reverse fluid shift).

HRP will conduct a ground study to characterize the limit of acceptable performance (physical and cognitive) decrements and symptom severity for mission operations when subjected to elevated inspired CO2 levels (up to 30 mmHg). Inspiring elevated partial pressures of CO2 can cause both physical and cognitive decrements. The task will qualitatively evaluate severity of symptoms, if they occur, whether symptoms require walk-back termination, and the timeline for resolution of those symptoms across a range of inspired CO2 levels. This information will be vital for vehicle and suit design for upcoming exploration missions, and these results will be used to inform a new NASA standard as well as Exploration Extravehicular Mobility Unit (xEMU) requirements for suited contingency inspired CO2 levels.

HRP will conduct a study of astronauts within two hours, and in the hours and days upon their return to Earth to evaluate functional performance. Measurable performance parameters such as the ability to perform a seated egress, recover from a fall, and other performance tasks will be used to establish a sensorimotor time constant for the recovery from observed decrements. Results of this study will identify sensorimotor changes as the result of long duration spaceflight and allow individually tailored interventions to prevent injury when ground personnel cannot assist flight crews.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

HRP will continue working with Agency stakeholders to enable early Artemis missions. The gravity transitions (e.g. Earth to Space, Space to Moon, Moon to Space, Space to Earth) of early Artemis missions can cause decreased performance due to sensorimotor issues. HRP will develop and test a portfolio of sensorimotor countermeasures to mitigate these issues while improving the astronauts' ability to pilot vehicles during contingency scenarios. In addition, this research has potential to improve their preparedness for Lunar Extra Vehicular Activities (EVA). Further, early Artemis missions use multiple vehicles operating at varied atmospheric environments, specifically different pressure and oxygen concentrations. The programmatic consequences of trading pressure and oxygen has not been well verified and validated. Given this, HRP will better characterize human performance at a variety of pressures and oxygen concentrations to provide impacts to overall mission architecture. Early Artemis missions provide an opportunity for NASA to test a variety of technology that will enable Mars missions. HRP will perform an array of technology demonstrations in multiple platforms to verify and validate HRP investments in Crew Health and Performance (CHP) capabilities. Specifically, to advance in-situ laboratory analysis and reduce the need for cold stowage of samples to be returned to Earth, HRP will demonstrate new blood analysis hardware. HRP will also demonstrate a variety of new technologies that allow NASA to operate in a progressively Earth-Independent manner which may include but not be limited to new procedures and training technologies that exhibit that our astronauts' ability to execute missions with less involvement from Mission Control.

HRP will work closely with Agency stakeholders to prepare for longer duration Artemis and Mars missions. The Mars missions will require humans to endure mission durations between 700-1000 days, considerably longer that our standard 180-day ISS missions. To prepare for this extension, HRP will continue the Complement of Integrated Protocols for Human Exploration Research (CIPHER) study. CIPHER is the first study to integrate multiple physiological and psychological measures, giving NASA the ability to assess the whole human response to time spent in space. This protocol of studies will characterize how the various systems of the body, such as the heart, muscles, bones, and eyes, adapt to long-term spaceflight and feed that information into future mission planning.

Finally, HRP will continue to leverage the development of a viable commercial human spaceflight economy. The TRISH Cooperative Agreement plans to fund multiple studies on upcoming Polaris Dawn Missions with emphasis on dynamic loads, motion sickness, pharmaceutical stability, and neuro-ocular syndrome (SANS).

Program Elements

EXPLORATION MEDICAL CAPABILITY

As NASA makes plans to extend human exploration beyond LEO, identifying and testing next generation medical care and crew health maintenance technologies is vital. Healthcare options evolve based on experience, anticipated needs, and input from flight surgeons and crew offices. During future Mars missions, crews will not be able to rely on real-time conversations with Earth-based medical experts due to communication lag-time associated with the distance between Earth and deep space. Therefore, crew and relevant systems will have to be able to facilitate autonomous medical care operations. Teams in this area draft requirements for medical equipment and clinical care, develop remote medical technologies, and assess medical requirements unique to long-duration space missions.

HUMAN HEALTH COUNTERMEASURES

Countermeasures are the procedures, medications, devices, and other strategies that offset the impacts of spaceflight stressors (e.g., low-gravity, closed environment) and help keep astronauts healthy and productive during space travel and after their return to Earth. Researchers are responsible for understanding normal physiologic effects of spaceflight and provide biomedical expertise and develop countermeasures to harmful effects on human health and performance. These experts define health and medical standards; validate human health prescriptions and exercise system requirements; develop injury and sickness prevention standards; integrate and validate physiological countermeasures; and establish criteria for NASA fitness for duty, as well as crew selection and performance standards.

HUMAN FACTORS AND BEHAVIORAL PERFORMANCE

Just as the space environment poses physical risks to crewmembers, the unique stresses and challenges of spaceflight, as well as vehicle design, can affect cognitive and mental performance. Considering external factors is essential when designing a spacecraft, habitat, or spacesuit. Human factors experts develop new equipment, procedures, and technologies designed to make the space environment more livable. Behavioral health researchers assess the impact of space travel on human behavioral health and develop interventions and countermeasures to ensure optimal health and performance. Experts in this area make extensive use of analogs, which are experimental environments created to simulate certain aspects of space travel. By duplicating space conditions, such as altered day and night cycles, heavy workloads, social isolation, and close living quarters, scientists gain insight into the impact of these circumstances on human behavior and performance. Scientists then work to develop countermeasures, equipment, and other interventions to minimize these risks.

SPACE RADIATION

As NASA expands human presence beyond the Earth's protective magnetic field, it is critical that astronauts be able to safely live and work in a space radiation environment. Space radiation researchers develop the knowledge base necessary to determine the biological effects of space radiation. This information can then be used for standards for health and habitability and the requirements for radiation protection. They also develop tools to assess and predict risks due to space radiation exposure and strategies to mitigate exposure effects. The deep space radiation environment is far different from that on Earth or in LEO. NASA and the DOE have partnered on a facility at Brookhaven National Laboratory in Upton, NY, to simulate the deep space radiation environment, which researchers use to help understand its biological effects.

RESEARCH OPERATIONS AND INTEGRATION

The ISS provides a unique testbed for HRP activities. The Research Operations and Integration (ROI) element plans, integrates, and implements HRP-approved biomedical flight experiments on ISS, as well as research studies that use ground-based spaceflight analog facilities to accomplish program objectives. These experiments and studies pertain to pre- and post-flight activities, and program objectives include coordinating flight or ground resources with our international partners, maintaining Human Research Facility (HRF) biomedical research racks on ISS and flight hardware, and developing crew training for both flight and ground investigations. Teams also operate a Telescience Support Center (TSC), which provides real-time support and data services to all HRP flight experiments. Strong interfaces with external implementing organizations, such as the ISS Research Integration office, analog coordination offices, and international partners, are critical to maintaining a robust research program. This group is also responsible for operating the HERA facility and for arranging access to other analog facilities required by HRP researchers, including NSF Antarctic facilities and international partner facilities in Germany and Russia.

MATURATION AND INTEGRATION OFFICE

The Maturation and Integration Office (MIO) has the responsibility for coordinating HRP's research and technology deliverables with its stakeholders. This office provides strategic planning for Artemis, Mars, and Commercial Spaceflight research opportunities. This office further fosters relationships with OCHMO, Artemis Campaign, and FOD to ensure HRP is addressing high priority operational research questions that can reduce risks or provide additional trade space for those organizations. As OCHMO and the Agency stand up a recognized "Crew Health and Performance System" for exploration missions, this office will integrate models and technology deliverables along with our operational spaceflight partners.

Program Schedule

Date	Significant Event
Dec 2022	Human Exploration Research Opportunity (HERO) NASA Research Announcement Omnibus Solicitations
Jan 2023	Step I Proposal
Apr 2023	Step II Proposals
Q2 2023	HERA Analog C6 egress
Q2 2022	SANS 3,4
Sep 2023	Step II Proposal Selections
Q1 2024	HERA C7 begins

Program Management & Commitments

The program office is located at JSC with support from Ames Research Center (ARC), Glenn Research Center (GRC), Langley Research Center (LaRC), and Kennedy Space Center (KSC).

The SOMD Associate Administrator delegated the authority, responsibility, and accountability of HRP management to the Human Spaceflight Capabilities Division at NASA Headquarters. Working closely with the Office of the Chief Scientist and the OCHMO, the Division establishes overall direction, scope, budget, and resource allocation for the program, which NASA centers then implement.

Program Element	Provider
Exploration Medical Capability	Provider: JSC Lead Center: JSC Performing Center(s): GRC, ARC, and LaRC Cost Share Partner(s): N/A
Human Health Countermeasures	Provider: JSC Lead Center: JSC Performing Center(s): ARC and GRC Cost Share Partner(s): N/A
Human Factors and Behavioral Performance	Provider: JSC Lead Center: JSC Performing Center(s): ARC, GRC, and KSC Cost Share Partner(s): N/A

HUMAN RESEARCH PROGRAM

Program Element	Provider
Space Radiation	Provider: JSC Lead Center: JSC Performing Center(s): LaRC Cost Share Partner(s): N/A
Research Operations and Integration	Provider: JSC Lead Center: JSC Performing Center(s): N/A Cost Share Partner(s): N/A
Maturation and Integration Office (MIO)	Provider: JSC Lead Center: JSC Performing Center(s): ARC and GRC Cost Share Partner(s): N/A

Acquisition Strategy

Based upon National Academies' recommendations, external peer reviews, and Agency human exploration plans, NASA HRP awards contracts and grants to further efforts in mitigating risks to crew health and performance by providing essential biomedical research and technologies for human space exploration. HRP uses a peer review process that engages leading members of the research community to competitively assess the merits of submitted proposals to assure a high-quality research program.

HRP plans to release the HERO umbrella NASA Research Announcement (NRA) that will request research proposals across all of its research elements throughout the year. This NRA provides opportunities for universities, other Government agencies, and industry researchers from across the Nation to develop high NASA priority ground and spaceflight experiments which directly contribute to NASA's exploration mission.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Program Management	Translational Research Institute for Space Health	Baylor College of Medicine
Research Operations and Integration	DLR	Envihab facility in Cologne, Germany
Space Radiation	U.S. Department of Energy	Brookhaven National Laboratory

HUMAN RESEARCH PROGRAM

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	National Council on Radiation Protection and Measurements (NCRP)	Jan 2022	Sex-differences in Lung Cancer Radiation Risks for use in Project Models.	Reduced uncertainties and improved information for cancer risk projections.	TBD
Quality	Peer Review Panel	Feb 2022	Peer review of NRA.	Selected grantees	TBD

LAUNCH SERVICES

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	102.3	--	103.8	108.3	96.6	96.9	97.2

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

A United Launch Alliance Atlas V 401 rocket, shown here, lifted off from Space Launch Complex 3 at Vandenberg Space Force Base in California on November 10, 2022 carrying the National Oceanic and Atmospheric Administration's (NOAA) Joint Polar Satellite System-2 (JPSS-2) and NASA's low-Earth orbit Flight Test of an Inflatable Decelerator (LOFTID) technology demonstration, marking LSP's 100th mission. Liftoff occurred at 2:25 a.m. PDT.

NASA's science and discovery missions, civil communications, geographic survey, and civil weather missions provide key services for our Nation and the world. The Launch Services Program (LSP) ensures access to space for the Nation's civil sector satellite and robotic planetary missions.

National Space Transportation Policy identifies the NASA Administrator as the launch agent for the Nation's civil sector. LSP enables the Administrator to execute this role by acquiring and managing domestic commercial launch services for assigned missions, certifying new commercial launch vehicles for readiness to fly high-value spacecraft, performing mission design and launch integration activities, and directing launch mission assurance efforts to ensure the greatest probability of launch mission success. While no space mission is routine, LSP has unique launch system expertise involving payloads containing nuclear power sources for launching one-of-a-kind science exploration missions to other planets, the Sun, or other locations in space. NASA relies on LSP to provide robust, reliable, and cost-effective launch services via commercial launch providers. NASA achieves assured access to space through a competitive mixed-fleet approach utilizing the breadth of U.S. industry capabilities. In addition, LSP provides launch-related expertise to other NASA programs, such as Commercial Resupply Services (CRS), Commercial Crew Program (CCP), and programs supporting the Artemis Campaign. LSP also provides launch advisory support to NASA payload missions using launch services through other Government agencies, the launch industry, or contributed by a foreign partner.

In addition to acquiring the commercial launch service, LSP arranges pre-launch spacecraft processing facility support and communications and telemetry during ascent for its customers. LSP offers insight into the commercial space launch industry, which has been utilized by CCP. LSP also tracks lessons learned to identify and mitigate risks for future managed launches and certifies readiness of new commercial launch

LAUNCH SERVICES

vehicles for NASA and other civil sector uncrewed spacecraft. The program also conducts engineering analyses and other technical tasks to maximize launch success for every assigned payload.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ACHIEVEMENTS IN FY 2022

LSP provided expertise and active launch mission management for over 70 NASA scientific spacecraft missions in various stages of development. LSP continuously works with the U.S. commercial launch industry to assess their designs and provide advice, which expands the selection of domestic launch vehicles available to NASA's missions and nurtures a competitive commercial launch service environment. LSP successfully launched four science missions, and one technology mission, as shown in the table below.

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
Oct 2021 Cape Canaveral Space Force Station, FL	Atlas V	Lucy	NASA SMD	NASA space probe that toured five Jupiter trojans, asteroids which share Jupiter's orbit around the Sun, orbiting either ahead of or behind the planet, and one main belt asteroid.
Nov 2021 Vandenberg Space Force Base, CA	Falcon 9 Full Thrust	Double Asteroid Redirection Test (DART)	NASA SMD	Demonstrates kinetic impactor technology impacting an asteroid to adjust its speed and path. DART was the first-ever space mission to demonstrate asteroid deflection by kinetic impactor.
Dec 2021 Kennedy Space Center, FL	Falcon 9 Full Thrust	Imaging X-ray Polarimetry Explorer (IXPE)	NASA SMD	Exploits the polarization state of light from astrophysical sources to provide insight into our understanding of X-ray production in objects (e.g., neutron stars, pulsar wind nebulae), as well as stellar and supermassive black holes.
Mar 2022 Cape Canaveral Space Force Station, FL	Atlas V	Geostationary Operational Environmental Satellite (GOES)-T	NASA SMD	GOES-T is the third of the GOES series next generation of weather satellites operated by NOAA that will extend the availability of the GOES satellite system until 2036.

LAUNCH SERVICES

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
Jun 2022 Mahia, New Zealand	Electron	Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE)	NASA STMD	A microwave oven–sized CubeSat weighing just 55 pounds will serve as the first spacecraft to test a unique, elliptical lunar orbit as part of the CAPSTONE. As a pathfinder for Gateway, a Moon-orbiting outpost that is part of NASA's Artemis program, CAPSTONE will help reduce risk for future spacecraft by validating innovative navigation technologies and verifying the dynamics of this halo-shaped orbit.

** Launch Dates shown in this table correspond to launch dates listed as Management Agreements elsewhere in this document.*

LSP acquired a new launch service for one future mission through a competitively awarded launch services task order under the NASA Launch Services (NLS) II contract. In addition, under the Venture-Class Acquisition of Dedicated and Rideshare (VADR) contract, LSP provides a broad range of commercial launch services capable of delivering payloads ranging from Class D payloads, with a modified technical oversight approach, to CubeSat missions to a variety of orbits. These Federal Aviation Administration (FAA) licensed Class D and small satellite payloads tolerate relatively high risk and serve as an ideal platform for technical and architecture innovation, contributing to NASA's science research and technology development in addition to fostering a growing U.S. commercial launch market.

In FY 2022, LSP acquired a new Class D launch service through a competitively awarded VADR launch services task order. The Nancy Grace Roman Space Telescope (RST) mission was a competitively awarded launch services task order under NLS II, as shown in the table below.

Contract Mechanism	Launch Date/Location*	Launch Vehicle	Payload	Customer	Mission Objectives
VADR	Aug 2024 Cape Canaveral Space Force Station, FL	Falcon 9	Total and Spectral Solar Irradiance Sensor 2 (TSIS-2)	NASA SMD	TSIS-2 will acquire measurements to determine the direct and indirect effects of solar radiation on the Earth system and its climate. TSIS-2 is a key component for understanding changes in Earth's radiation balance and provides two measurements critical for meeting this objective: Total Solar Irradiance (TSI) and Spectral Solar Irradiance (SSI).

LAUNCH SERVICES

Contract Mechanism	Launch Date/Location*	Launch Vehicle	Payload	Customer	Mission Objectives
NLS II	Oct 2026 Cape Canaveral Space Force Station, FL	Falcon Heavy	Nancy Grace Roman Space Telescope (RST)	NASA SMD	The Roman Space Telescope is a NASA observatory designed to settle essential questions in the areas of dark energy, exoplanets, and infrared astrophysics. The telescope has a primary mirror that is 2.4 meters (7.9 feet) in diameter and is the same size as the Hubble Space Telescope's primary mirror. The Roman Space Telescope will have two instruments, the Wide Field Instrument, and the Coronagraph Instrument.

** Launch Dates shown in this table correspond to launch dates listed as Management Agreements elsewhere in this document.*

LSP continued partnering with several universities and NASA centers to launch small research satellites through the CubeSat Launch Initiative (CSLI), which provides rideshare opportunities for small satellite payloads to fly on upcoming launches when excess capacity is available. These partnerships have provided regular educational opportunities for students in Science, Technology, Engineering, and Mathematics (STEM) disciplines, which help strengthen the Nation's future workforce. To date, CubeSats Projects have been selected from 42 states, the District of Columbia, and Puerto Rico, with 152 CubeSats missions launched and 30 manifested on NASA, National Reconnaissance Office, U.S. Space Force, and commercial missions. In FY 2022, 18 CSLI CubeSats missions were launched.

The 2022 NLS II on-ramp activity commenced in Q1 FY 2022. The Delta II Closeout/Space Launch Complex (SLC) 2 Demolition work continued at Vandenberg Space Force Base (VSFB) in California. Demolition of the Mobile Service Tower was completed in December 2020, and the SLC-2 launch pad was turned over to the Space Force who then leased the pad to Firefly. Along with the launch pad, there are 16 real properties (buildings across the greater SLC-2 complex) that need to be demolished at NASA's cost. A contract was awarded by the 30th Space Wing in September 2021 to demolish three of the 16 buildings that NASA is responsible to demolish per the cost sharing agreement signed between NASA and the United States Air Force (now the United States Space Force) in May 2019. The contract for demolishing the remaining thirteen buildings was awarded in November 2022. This will satisfy the cost sharing agreement and complete NASA's financial obligations.

WORK IN PROGRESS IN FY 2023

LSP will continue to execute the role of launch agent for the NASA Administrator on behalf of the U.S. civil sector, as described in the National Space Transportation Policy. The program will provide management of NASA Launch Services contracts, launch mission assurance, mission design, and launch integration support to scientific and technology spacecraft missions in various development phases. The TROPICS mission is one example of how LSP supports and manages launch services. On February 10, 2022, Astra Space Inc. failed to deliver the Mission One TROPICS payload to orbit. In

LAUNCH SERVICES

July 2022, Astra formally notified NASA LSP of their intention to discontinue Rocket 3.3 and move directly into development of Rocket 4.0. In August 2022, NASA decided to de-manifest the remaining TROPICS payloads from Astra's Rocket 3.3 under the VCLS Demo 2 contract, and to seek alternative launch opportunities through the VADR contract process. On November 23, 2022, the task order for the remaining two TROPICS payloads was awarded to Rocket Lab USA Inc. of Long Beach, California under the VADR contract. Rocket Lab will launch the TROPICS satellites into their operational orbits during a 60-day period (first insertion to final insertion), with first insertion targeted to launch no earlier than (NET) May 1, 2023. The current manifest for FY 2023 shows LSP will manage and conduct launch activities for two NASA missions contracted under NLS II, two VCLS Demo 2 missions, and one NASA mission under VADR, as shown in the table below.

Contract Mechanism	Launch Date/Location*	Launch Vehicle	Payload	Customer	Mission Objectives
NLS II	Nov 2022 Vandenberg Space Force Base, CA	Atlas V	Joint Polar Satellite System (JPSS)-2/ Low-Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID) (2nd)	NOAA and NASA SMD	JPSS-2 is a continuation of the JPSS series of satellites that will capture precise observations of the world's atmosphere, land, and waters, and provide data that inform seven-day forecasts and extreme weather events.
NLS II	Dec 2022 Vandenberg Space Force Base, CA	Falcon 9	Surface Water and Ocean Topography (SWOT)	NASA SMD; Centre National D'Etudes Spatiales (CNES)	SWOT will collect detailed measurements of how water bodies on Earth change over time.
VCLS Demo 2	NET Feb 2023 Under Review Vandenberg Space Force Base, CA	Firefly Black LLC Alpha	VCLS Demo 2 (Mission Two: [1] 75 kg payload, 550 km Sun Synchronous Orbit (SSO) [2] 20 kg to 550 km SSO w/ min 10-degree plane change)	NASA, one STEM school, and multiple universities	A demonstration flight to determine if new small launch vehicles can deliver NASA payloads to orbit at a fixed price.

LAUNCH SERVICES

Contract Mechanism	Launch Date/Location*	Launch Vehicle	Payload	Customer	Mission Objectives
VADR	May 2023 (two in 90 days) Wallops Flight Facility, VA	Electron	TROPICS	NASA SMD	The CubeSats, each the size of a shoebox, will provide rapid-refresh microwave measurements that can be used to determine temperature, pressure, and humidity inside hurricanes as they form and evolve. The TROPICS mission’s high-revisit imaging and sounding observations are enabled by microwave technology developed at the Massachusetts Institute of Technology’s Lincoln Laboratory. These observations will profoundly improve scientists' understanding of processes driving high-impact storms.

**FY 2023 Launch Dates shown in this table correspond to launch dates listed as Management Agreements elsewhere in this document.*

LSP will continue work towards certifying new commercial launch vehicles to launch high-value payloads, as needed, and will continue launch service acquisition activities necessary to support NASA and other approved Government missions.

Along with full end-to-end launch service management of awarded missions, LSP continues to offer advisory support, expertise, and knowledge to NASA programs and projects utilizing launch services not procured and managed by LSP. The program is currently providing these advisory and informational services to several programs and missions, including:

- Gateway;
- ISS Commercial Resupply Services;
- Commercial Crew Program; and
- NASA-Indian Space Research Organization Synthetic Aperture Radar (NISAR) mission.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

LSP will continue to execute the role of launch agent for the NASA Administrator on behalf of the U.S. civil sector, as described in the National Space Transportation Policy. LSP will work with the U.S. commercial launch industry to assess their designs and provide advice, which expands the selection of domestic launch vehicles available to NASA's missions and nurtures a competitive commercial launch

LAUNCH SERVICES

service environment. The program will provide management of NASA Launch Services contracts, launch mission assurance, mission design, and launch integration support to scientific spacecraft missions in various development phases. The current manifest for FY 2024 shows LSP will manage and conduct launch activities for three NASA missions contracted under NLS II, two NASA mission contracted under VADR, one VCLS Demo 2 mission, and one acquisition in work also under VADR.

Contract Mechanism	Launch Date/Location*	Launch Vehicle	Payload	Customer	Mission Objectives
NLS II	Oct 2023 Kennedy Space Center, FL	Falcon Heavy	Psyche	NASA SMD	Psyche is a NASA interplanetary mission to visit the main belt asteroid "16 Psyche". The spacecraft will take four years and one Mars flyby to reach the asteroid, which is comprised mostly of iron and nickel.
VCLS Demo 2	NET Oct 2023 Cape Canaveral Space Force Station, FL	Relativity Space Inc Terran 1	VCLS Demo 2 (Mission One: 30 kg payload, 500 km @ 41 deg inclination)	NASA, one STEM school, and multiple universities	A demonstration flight to determine if new small launch vehicles can deliver NASA payloads to orbit at a fixed price.
NLS II	Jan 2024 Cape Canaveral Space Force Station, FL	Falcon 9	Plankton, Aerosol, Cloud, ocean Ecosystem (PACE)	NASA SMD	PACE is a NASA Earth-observing satellite mission that will continue and advance observations of global ocean color, biogeochemistry, and ecology, as well as the carbon cycle, aerosols and clouds.
VADR (Non-awarded, Acquisition in Work)	NET Feb 2024	TBD	Polar Radiant Energy in the Far-InfraRed Experiment (PREFIRE)	NASA SMD	PREFIRE will quantify the radiative processes effected by changing temperatures in the Arctic, and will reveal new aspects of the Arctic climate by measuring the full spectrum of polar radiant energy.
NLS II	Apr 2024 Kennedy Space Center, FL	Falcon Heavy	GOES-U	NOAA and NASA SMD	GOES-U is the final satellite in the GOES-R Series next generation of weather satellites operated by NOAA that will extend the availability of the GOES satellite system until 2036.

LAUNCH SERVICES

Contract Mechanism	Launch Date/Location*	Launch Vehicle	Payload	Customer	Mission Objectives
VADR	Aug 2024 Cape Canaveral Space Force Station, FL	New Glenn	Escape and Plasma Acceleration and Dynamics Explores (ESCAPADE)	NASA SMD	The Escape and Plasma Acceleration and Dynamics Explorers (EscaPADE) are a dual-spacecraft mission to study ion and sputtered escape from Mars.
VADR	Aug 2024 Cape Canaveral Space Force Station, FL	Falcon 9	Total and Spectral Solar Irradiance Sensor 2 (TSIS-2)	NASA SMD	TSIS-2 will measure the Sun's energy input to Earth.

**FY 2024 Launch Dates shown in this table correspond to launch dates listed as Management Agreements elsewhere in this document.*

Program Management & Commitments

Program Element	Provider
Commercial Launch Vehicle (CLV) Launch Services	Provider: ULS, NGIS (formerly Orbital ATK), SpaceX, Rocket Lab USA, Virgin Orbit, Firefly Black, Relativity Space, Blue Origin, ABL Space Systems, Astra Space Inc., L2 Solutions, LLC, Phantom Space Corporation, Spaceflight, Inc. Lead Center: Kennedy Space Center (KSC) Performing Center(s): KSC Cost Share Partner(s): N/A

ACQUISITION STRATEGY

LSP's acquisition strategy was created for the original NLS contracts for procuring CLV launch services from domestic commercial launch service suppliers. To meet the needs of science and technology customers who typically spend three to seven years developing a spacecraft mission, NASA created a contractual approach providing multiple competitive launch service options to cover small-, medium-, intermediate-, and heavy-sized missions. The follow-on contract mechanism, known as NLS II, has similar contract features. These features include not-to-exceed prices, indefinite-delivery-indefinite-quantity contract terms, and competitive firm-fixed-price launch service task order-based acquisitions. The NLS II ordering period has been extended to June 30, 2025. To ensure active competition for NASA customers and encourage new launch capability development through these long-term contracts, NASA provides annual opportunities to U.S. industry to add new commercial launch service providers and/or launch vehicles to the contract.

LSP is also able to contract separately from the NLS contract mechanism if such an approach is necessary to meet a mission or customer need. For instance, the launch service for the Europa Clipper mission funded by NASA SMD was competed outside and separate from the NLS II contract due to the special

LAUNCH SERVICES

needs of that mission. In addition, VCLS awards for very small launch vehicles were conducted outside and separate from the NLS II contract to provide more flexibility to the new, small-class launch providers. In 2022, 13 companies were also selected to provide launch services under the VADR contract, which has a five-year ordering period with a maximum total value of $300 million across all Indefinite Delivery/Indefinite Quantity contracts. The acquisition also includes a special on-ramp provision to enable additional providers and incumbents to submit proposals introducing launch services for new capabilities not available or identified at the time of the initial contract award.

NASA has also made efforts to provide a complete launch service, including payload processing at the launch site. LSP uses firm-fixed-price indefinite-delivery-indefinite-quantity contracts for commercial payload processing capabilities on both the East and West coasts. The Payload Processing Facility (PPF) contracts are up for recompete. The East Coast Commercial Payload Processing Contract-4 (ECCPP-4) was awarded in April 2017 and the indefinite-delivery, indefinite-quantity (IDIQ) ordering period of performance ended in April 2022. The West Coast Commercial Payload Processing Contract-3 (WCCPP-3) solicitation was cancelled. LSP is currently awarding mission specific PPF contracts for those on the West coast.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
NASA Launch Services II-Blue	Blue Origin	Kent, WA Kennedy Space Center, FL
NASA Launch Services-II-O	Northrop Grumman Systems Corporation	Chandler, AZ
NASA Launch Services-II-S	SpaceX	Hawthorne, CA
NASA Launch Services-II-U	United Launch Services, LLC	Centennial, CO
East Coast Commercial Payload Processing	Astrotech Space Operations	Titusville, FL
West Coast Commercial Payload Processing	Astrotech Space Operations	Vandenberg Space Force Base, CA
Expendable Launch Vehicle Integrated Support (ELVIS) 3	a.i. Solutions, Inc.	Kennedy Space Center, FL Cape Canaveral Space Force Station, FL Vandenberg Space Force Base, CA
Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) Launch Services	Rocket Lab USA Inc.	Long Beach, CA
Europa Clipper Launch Services	SpaceX	Hawthorne, CA

LAUNCH SERVICES

Element	Vendor	Location (of work performance)
Venture Class Demonstration 2 (VCLS Demo 2)	Astra Space Inc.	Alameda, CA
	Relativity Space Inc.	Long Beach, CA
	Firefly Space Transport Services	Cedar Park, TX
Venture-Class Acquisitions of Dedicated and Rideshare (VADR)	ABL Space Systems	El Segundo, CA
	Astra Space Inc.	Alameda, CA
	Blue Origin Florida LLC	Merritt Island, FL
	Firefly Space Transport Services, LLC	Cedar Park, TX
	L2 Solutions LLC	Houston, TX
	Northrop Grumman Systems Corporation	Chandler, AZ
	Phantom Space Corporation	Tucson, AZ
	Relativity Space Inc.	Long Beach, CA
	Rocket Lab USA Inc.	Long Beach, CA
	Spaceflight Inc.	Seattle, WA
	SpaceX	Hawthorne, CA
	United Launch Services LLC	Centennial, CO
	Virgin Orbit LLC	Long Beach, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Program Implementation Review (PIR)	Standing Review Board (SRB)	May 2014	Life Cycle Review	The SRB found LSP is a successful program with a strong technical and management team representing NASA’s core competency, demonstrating exceptional performance with a 97.4 percent launch success record. The SRB recommended continuation of LSP operations as currently performed.	FY 2024*

**The FY 2024 milestone for LSP will be assessed by the Space Operations Mission Directorate (SOMD) Associate Administrator, and a determination will be made as to whether a PIR is required or if it can be delayed another five years. The FY 2024 milestone is also subject to change depending on LSP's manifest/launch schedule for that year.*

ROCKET PROPULSION TEST

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**47.8**	**48.2**	**48.6**	**48.9**	**48.9**	**48.9**	**49.7**
Change from FY 2023 Enacted			**0.4**				
Percent change from FY 2023 Enacted			**0.8%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Shown here is the RS-25 engine hot fire test in the Fred Haise Test Stand (A-1) at Stennis Space Center in February 2022.

Developing and testing rocket propulsion systems is foundational to spaceflight. Whether the payload is a robotic science experiment or a crewed mission, the propulsion system used to launch it must be safe and reliable. A rigorous engine test program is a critical component of any rocket propulsion development activity.

NASA's Rocket Propulsion Test (RPT) Program maintains and manages a wide range of facilities capable of ground testing rocket engines and components under controlled conditions. This test infrastructure includes facilities located across the United States, and the program provides a single-entry point for any user of NASA rocket test stands. RPT retains a skilled workforce capable of performing tests on all modern-day rockets and supporting complex rocket engine development. RPT evaluates customer test requirements and desired outcomes while minimizing test time and costs. It also streamlines facility usage and eliminates redundant capabilities by closing and consolidating NASA's rocket test facilities, as appropriate.

RPT is NASA's implementing authority for rocket propulsion testing. It approves and provides direction on test assignments, capital improvements, and facility modernization and refurbishment to reduce propulsion test costs. RPT integrates multi-site test activities, identifies and protects core capabilities, and develops advanced testing technologies.

The Agency has designated RPT as the NASA representative for the National Rocket Propulsion Test Group (NRPTG), an inter-agency collaboration with the Department of Defense (DoD), to facilitate efficient and effective use of the Federal Government's rocket propulsion test capabilities. The NRPTG is a standing group within the Range Commanders Council (RCC).

For more information, go to: https://rpt.nasa.gov/

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ROCKET PROPULSION TEST

ACHIEVEMENTS IN FY 2022

In FY 2022, RPT test facilities supported NASA, commercial, defense, and NASA International Space Partner requirements for purposes of component, engine and rocket stage level of testing. RPT delivered test capabilities to support technology advancement, capability demonstration, risk retirement, and hardware qualification and launch readiness for over 595 tests.

Testing of rocket engines and components for NASA and its collaborative commercial partners on the Artemis Program were of predominant importance in FY 2022. RPT continued to provide testing of the Aerojet Rocketdyne RS-25 engines in the A-1 Test Stand at the John C. Stennis Space Center (SSC) in Mississippi. This testing provided performance data on a variety of new engine components developed with advanced manufacturing techniques in support of the Artemis Program. Modification to the SSC B-2 Test Stand, used to test the Space Launch System (SLS) four-engine Core Stage in 2021, continued throughout the year in support of a similar integrated upper stage test of the Exploration Upper Stage (EUS) engine and plume management system. Elsewhere at SSC, in the E-Complex, diffuser testing was conducted to validate the system design planned for EUS test on the B-2 test stand. Commercial activity in other cells in the E-Complex supported a variety of commercial engine, turbo-pump, thruster, and component test requirements.

Test Stands at other NASA centers were also busy in FY 2022. At Marshall Space Flight Center (MSFC), testing supported both NASA internal and collaborative projects to advance manufacturing and development techniques through testing of engine components, including rocket nozzles. Testing was conducted in evaluation of liquid rocket engines in landers and on-orbit stages and spacecraft as well as on solid rocket motor nozzle and insulation materials. At White Sands Test Facility (WSTF), testing in support of NASA, International Partner, commercial and defense customers included hot firings, acceptance testing and qualification of thrusters and thruster system components. Testing supported developmental thrusters that advanced low temperature operations and nano-satellite propulsion. Work performed to deactivate Minuteman III Propulsion System Rocket Engine (PSRE) propulsion stages to an inert state in support of de-militarization also continued. At Glenn Research Center (GRC) Armstrong Test Facility (ATF), preparatory work for proto-qualification testing of the Sierra Nevada Dream Chaser Cargo System (DCCS) in the In-Space Propulsion Facility (ISPF) continued, as well as thermal-vacuum test support for balloon payload program elements.

WORK IN PROGRESS IN FY 2023

RPT continues to provide testing of the RS-25 engines used in powering the SLS Rocket that will return astronauts to the Moon and support the space exploration Artemis Campaign. Work will also continue at SSC, to ready the B-2 Test Stand for the integrated stage test of the Exploration Upper Stage (EUS), enabling the SLS to send large cargoes to the Moon and Mars. The interstage test article, an important element of that planned test, arrived at SSC prior to FY 2023 and it will be mounted into the test stand prior to integration of the four RL-10 EUS engines in support of the planned late 2024 hot fire.

RPT will continue testing of Rotating Detonation Rocket Engine (RDRE) designs and technology that are both easier to manufacture and provide better combustion performance. The objective of this effort and associated testing is to develop the engine technology towards a more flight like configuration to be used by U.S. industry and academic partners.

NASA is designing and manufacturing innovative and lightweight combustion chambers, nozzles, and injectors that will incorporate automated robotic deposition 3D printing technologies. These include cold spray deposition, and other methods. NASA intends to evolve these processes using weight-optimized materials to validate operability, performance, and reusability through hot fire testing.

RPT continues to provide test firings on Test Stand-406 at WSTF of the Thruster Advancement for Low-temperature Operation in Space (TALOS) engine, a game changing technology project supporting engines that have greater control over the spacecraft's movement during ascent and descent, important for lunar landing. The engine thruster is being tested in support of a Commercial Lunar Payload Services (CLPS) mission, as part of the Artemis Program.

The RPT Program is also seeing growing demand from Commercial Space, with FY 2023 looking to have a higher level of engine/component test requirements across the breadth of RPT's test regimes. Commercial companies drawing on RPT's Center capacities planned during FY 2023, currently include: Axiom Space, Boeing, Blue Origin, Launcher, Relativity Space, Rocket Lab, Sierra Nevada, Vaya Space, Venus Aerospace, Virgin Orbit, and Ursa Major.

Increased commercialization of RPT test facilities continues to expand through partnering agreements with industry to lease excess test facilities. The SLS Exploration Production and Operations Contract (EPOC) will also likely increase commercialization of some test operations. These changes introduce transitional uncertainties, but the level of impact to RPT operations will likely be limited in FY 2023.

RPT investments in FY 2023 will predominately be multi-year projects which carried forward from FY 2022, such as the High Pressure Gas Facility (HPGF) and the High Pressure Industrial Water (HPIW) control system upgrades and data acquisition system upgrades at multiple facilities.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

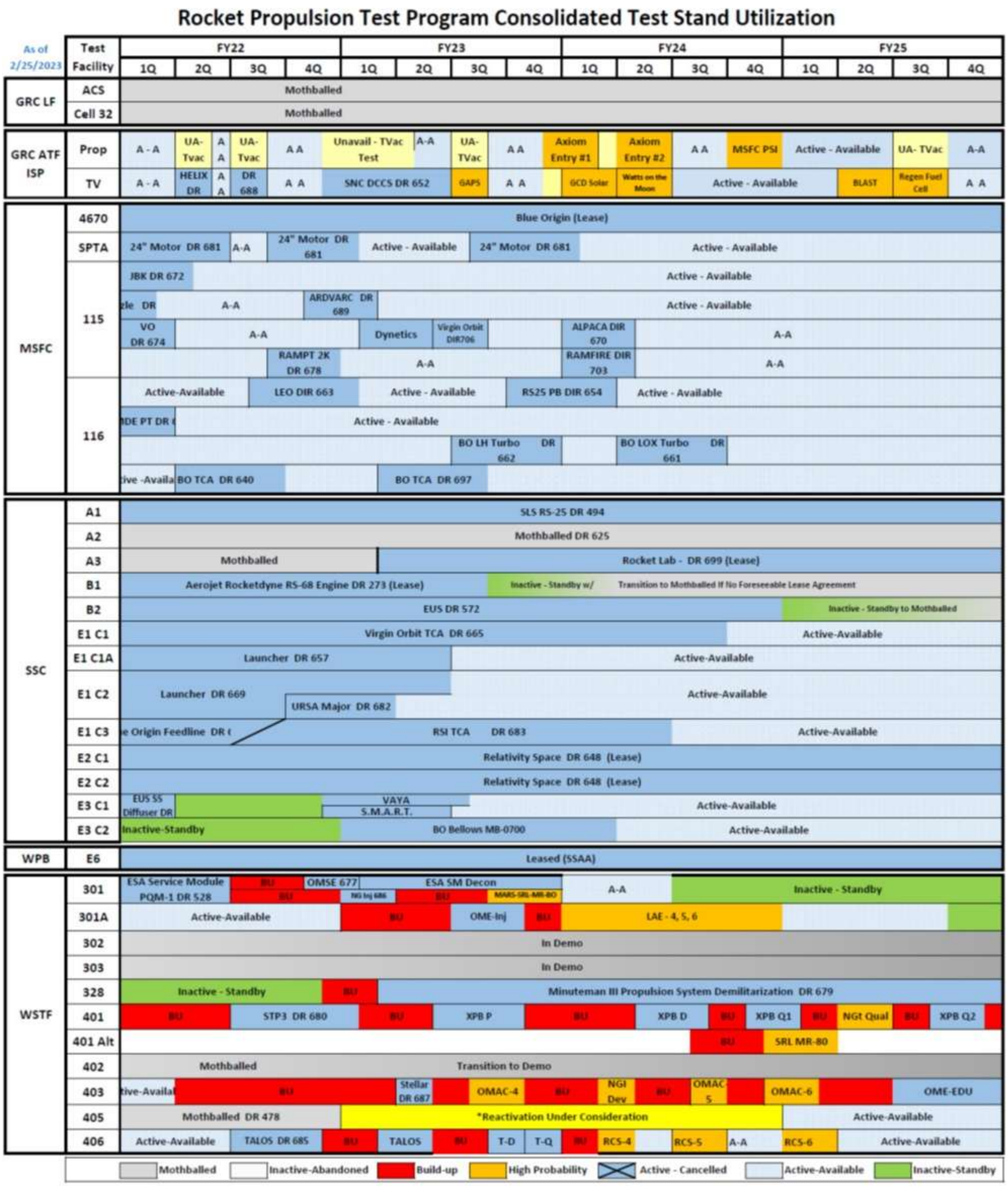
Testing to support Artemis launch and flight systems will continue to be the predominant focus of the RPT Program simply because of their relevance to the Agency, with readiness of the B-2 Test Stand for EUS Stage testing being paramount. The timing and nature of the test support needs of commercial test providers, including the Exploration Production and Operations Contract (EPOC), will be better understood in FY 2024. RPT pricing and cost recovery policies resulting from changes in sharing the cost of RPT provided test support services, and decisions on how to apply the cost of maintenance to test customers, should be in place to continue to adapt to changing requirements for test and test support infrastructure. RPT funding at SSC will likely shift toward increased investment in the E-Complex to improve the health and state of technology there as it will be key to skills retention and the provision of continuing developmental test requirements from the Agency and industry. Reassessment of the RPT test infrastructure to posture it best for Agency continuing needs will be a focused long-term planning effort.

Program Schedule

The following chart shows past, current, and planned test campaigns at SSC, MSFC, GRC, and WSTF rocket propulsion test facilities. The designations at the far left of the chart below refer to the facility, while the top of the chart shows time by quarter of fiscal and calendar year, and the key to the status of each facility appears at the bottom.

Most test stands and facilities are scheduled 18 months in advance. Defining the scope of work, selecting test stands and fuel, and estimating labor and total cost to customers is a complex process that can take 18 to 36 months. RPT is working now with internal and external customers to design testing programs for FY 2024 and beyond.

ROCKET PROPULSION TEST



ROCKET PROPULSION TEST

PROGRAM MANAGEMENT & COMMITMENTS

Program Element	Provider
RPT	Provider: RPT Lead Center: N/A Performing Center(s): SSC, JSC, GRC, MSFC, KSC, WFF Cost Share Partner(s): Various other NASA programs, DoD, and commercial partners

ACQUISITION STRATEGY

None.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

None.

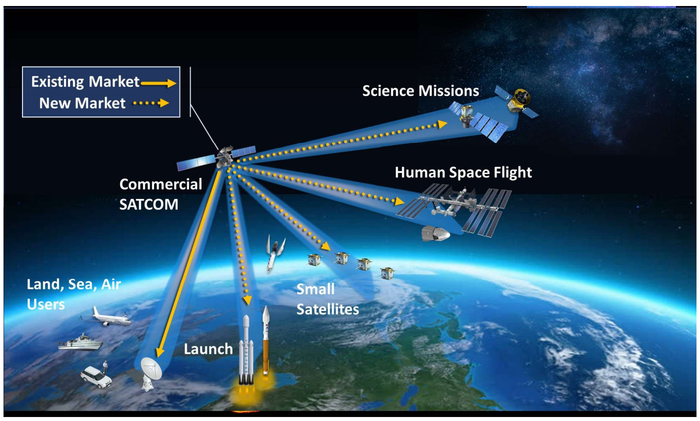
COMMUNICATIONS SERVICES PROGRAM

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	42.0	--	59.4	59.7	59.7	59.7	60.6

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



The Communications Services Program will collaborate with industry to demonstrate commercially provided data relay services for NASA space missions.

The Communications Services Program (CSP) focuses on demonstrating the feasibility of commercially provided satellite communications (SATCOM) services to NASA missions. CSP is pursuing demonstrations that will allow future NASA missions to use flight-qualified commercial communications services. Ultimately, if CSP demonstrations are successful, near-Earth users will begin transitioning from using NASA-owned networks to commercially provided services.

The CSP effort is a component of the larger NASA strategy to migrate near-Earth missions from communications and navigation services provisioned by Government-owned networks to commercial networks. This transition to commercial services, and particularly commercial SATCOM, is driven by the state of current NASA network assets, National Space Policy, and long-standing Federal procurement policies that direct the Government to make use of, rather than duplicate, commercially provided services. NASA will not replenish the Tracking and Data Relay Satellites as aging spacecraft assets are decommissioned in the 2030's. NASA will continue to support existing users but seeks to transition future space-relay users to commercial providers. This approach is consistent with Federal policies intended to increase the cost-effectiveness of Government operations and leverage investments that have already been made by the private sector.

The SCaN Program has overarching Agency responsibility to ensure operational NASA missions receive required communications and navigation support. CSP retains responsibility to execute demonstrations of commercial SATCOM services and provide assessments and recommendations for service acquisition to the Agency. SCaN will ensure that the transition to commercial services is managed in concert with the gradual phase out of the existing NASA-owned network resources.

NASA has a diverse set of users and communications needs against which commercial capabilities will be evaluated, such as launch vehicle support, visiting vehicles to the International Space Station (ISS), human space flight, and science missions in Earth orbit ranging from flagship observatories to SmallSats and CubeSats. CSP intends to leverage SATCOM capabilities developed for terrestrial users to bring flexibility and functionality of commercial service to the space domain. CSP will work with the commercial market to identify requirements and explore opportunities that are mutually beneficial to NASA and industry. NASA expects to work with multiple commercial entities to demonstrate capabilities that best fulfill NASA's requirements, while also being compatible with a larger market where NASA can be one of many customers. These agreements will be designed to bolster American industry and reduce the cost of communication services to NASA, while promoting a diverse commercial market and maximizing interoperability between Government and commercial service providers.

The CSP budget will support multiple agreements between NASA and commercial SATCOM companies to develop and demonstrate capabilities that can meet NASA's needs and begin the initial planning for acquisition of commercial SATCOM services.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ACHIEVEMENTS IN FY 2022

On April 20, 2022, NASA selected six satellite communications (SATCOM) providers to begin developing and demonstrating, near-Earth space communication services that may support future Agency missions. These selections resulted in six funded Space Act Agreements for a combined value of $278.5 million and the companies that received the awards are:

- Inmarsat Government Inc. of Reston, Virginia, for $28.6 million. Inmarsat's proposed approach demonstrates a commercial radio frequency geostationary orbiting L-band relay network for low-rate SATCOM services to spacecraft and launch vehicles for routine missions, contingency operations, launch and ascent, and early operations phase communications.
- Kuiper Government Solutions (KGS) LLC of Arlington, Virginia, for $67 million. Kuiper's proposed approach demonstrates a commercial optical low-Earth orbiting relay network for high- and- low-rate SATCOM services to spacecraft in low-Earth orbit for routine missions, contingency operations, and early operations phase communications.
- SES Government Solutions of Reston, Virginia, for $28.96 million. SES's proposed approach demonstrates commercial radio frequency geostationary orbiting C-band and medium-Earth orbiting Ka-band relay networks for high- and- low-rate SATCOM services to spacecraft in low-Earth orbit for routine missions, contingency operations, launch and ascent, and early operations phase communications.
- Space Exploration Technologies (SpaceX) of Hawthorne, California, for $69.95 million. SpaceX's proposed approach demonstrates a commercial optical low-Earth orbiting relay network for high-rate SATCOM services to spacecraft in low-Earth orbit for routine missions, contingency operations, launch and ascent, and early operations phase communications.
- Telesat U.S. Services LLC of Arlington, Virginia, for $30.65 million. Telesat's proposed approach demonstrates commercial radio frequency geostationary orbiting C-band and low-Earth orbiting

Ka-band relay networks for high- and- low-rate communications services to spacecraft in low-Earth orbit for routine missions.

- Viasat Incorporated of Carlsbad, California, for $53.3 million. Viasat's proposed approach demonstrates a commercial radio frequency geostationary orbiting Ka-band relay network for high- and low-rate communications services to spacecraft in low-Earth orbit for routine launch and missions.

NASA expects each company to match or exceed Agency contributions during the five-year development and demonstration period, totaling more than $1.5 billion of cost-share investment. NASA expects to demonstrate multiple capabilities through a diverse set of service providers over a multi-year period. Current schedules for all six partners conclude the demonstration phase in FY 2026. The intent is to develop a demonstration portfolio of commercial capabilities--applicable for different classes of NASA missions and suitable for other customers--that in aggregate will address the future NASA mission needs for reliable, robust, and cost-effective communications and navigation services.

CSP initiated monitoring of the awardees' progress based on their execution and milestone plans. Inmarsat Government, Inc. completed five milestones including ELERA Network Enhancement Preliminary Design Review. KGS completed three milestones including a Requirements Review. SES Government Solutions completed two milestones including a LEO Architecture Preliminary Design Review. SpaceX completed one milestone, the Kickoff and Concept Review. Telesat U.S. Services, LLC completed two milestones including a Mission Concept Review. Viasat Incorporated completed three milestones including a Space Vehicle Service Simulation Kickoff.

CSP completed a Formulation Systems Requirement Review (F-SRR), tailored from NASA engineering best practices to review CSP programmatic planning during the demonstration phase.

WORK IN PROGRESS IN FY 2023

CSP will initiate an Analyses of Alternatives (AoA) to explore systems engineering trades and evaluate operational approaches for provisioning future commercial services. CSP began formal engagement with the Near Space Network to include their participation in the AoA.

CSP will continue to monitor awardees' progress. Each partner has unique milestones, but FY 2023 will encompass milestones such as mission concept, system requirements, and preliminary design reviews. Inmarsat Government, Inc. is scheduled to complete four milestones including ELERA Network Enhancements Critical Design Review. KGS is scheduled to complete six milestones including a Mission Concept Review. SES Government Solutions is scheduled to complete three milestones including an Architecture Critical Design Review. SpaceX is scheduled to complete two milestones including an Optical Communications Package Technical Interchange Meeting (TIM). Telesat U.S. Services, LLC is scheduled to complete five milestones including an Architecture Critical Design Review. Viasat Incorporated is scheduled to complete four milestones including a Spaceflight Demo System Requirements Review.

CSP will continue formal engagement with the mission community and stakeholders to review progress and results of the demonstrations. Mission engagement forums will be held approximately every six months over the demonstration period.

COMMUNICATIONS SERVICES PROGRAM

KEY ACHIEVEMENT PLANNED FOR FY 2024

CSP plans to continue to monitor partner progress through the demonstration period. CSP will identify capabilities gaps, if any, using NASA use cases and through direct mission engagement. The Analyses of Alternatives (AoA) will continue into FY 2024 and be a key input for future acquisition planning. CSP will initiate planning for subsequent acquisition of services by leveraging knowledge gained during demonstrations, the AoA, and coordination with the Near Space Network.

Each partner has unique milestones, but FY 2024 will encompass milestones such as critical/interim design reviews or the launch of test network infrastructure. Inmarsat Government, Inc. is scheduled to complete six milestones including ELERA Space Relay CDR. KGS is scheduled to complete eight milestones including Launch of Kuiper Pre-Production satellites. SES Government Solutions is scheduled to complete four milestones including an Interim Design Review. SpaceX is scheduled to complete four milestones including a High-Rate Data Relay Demonstration Plan TIM. Telesat U.S. Services, LLC is scheduled to complete seven milestones including an Interim Design Review. Viasat Incorporated is scheduled to complete seven milestones including a Spaceflight Demonstration Critical Design Review.

Program Schedule

The table below includes significant Communication Services Program milestones in FY 2023 and FY 2024.

Date	Significant Event
Q2 FY 2023	Inmarsat Government Inc.; ELERA Network Enhancements Critical Design Review
Q2 FY 2023	KGS LLC; Mission Concept Review
Q2 FY 2023	SES Government Solutions; Architecture Critical Design Review
Q2 FY 2023	Viasat Incorporated; Spaceflight Demo System Requirements Review
Q2 FY 2023	CSP Analyses of Alternatives Kickoff
Q3 FY 2023	SpaceX; Optical Communications Package TIM
Q3 FY 2023	Telesat U.S. Services LLC; Architecture Critical Design Review
Q1 FY 2024	SpaceX; High-Rate Data Relay Demonstration Plan TIM
Q2 FY 2024	Viasat Incorporated; Spaceflight Demonstration Critical Design Review
Q2 FY 2024	CSP Analyses of Alternatives: Initial Results
Q3 FY 2024	KGS LLC; Launch of Kuiper Pre-Production satellites
Q4 FY 2024	Inmarsat Government Inc.; ELERA Space Relay CDR
Q4 FY 2024	SES Government Solutions; Interim Design Review
Q4 FY 2024	Telesat U.S. Services LLC; Interim Design Review

COMMUNICATIONS SERVICES PROGRAM

Program Management & Commitments

Program Element	Provider
Communications Services	Provider: CSP Project Office Lead Center: Glenn Research Center (GRC) Performing Center(s): N/A Cost Share Partner(s): N/A

Acquisition Strategy

Similar to the approach used for the Commercial Orbital Transportation System (COTS) and Commercial Crew, NASA used Space Act Agreements for the CSP demonstration awards. By using funded Space Act Agreements, CSP will stimulate industry to demonstrate end-to-end capability leading to operational service. These demonstrations will inform the future acquisition strategy for transitioning near-Earth NASA users to suitable commercially provided services. This acquisition strategy could include commercial service contracts, hosted payloads, and/or public-private partnerships to obtain commercially provided satellite communications services.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
SATCOM Demonstration	Inmarsat Government Inc.	Reston, VA
SATCOM Demonstration	KGS LLC	Arlington, VA
SATCOM Demonstration	SES Government Solutions	Reston, VA
SATCOM Demonstration	SpaceX	Hawthorne, CA
SATCOM Demonstration	Telesat U.S. Services LLC	Arlington, VA
SATCOM Demonstration	Viasat Incorporated	Carlsbad, CA

INDEPENDENT REVIEWS

In FY 2022, CSP completed a peer level F-SRR, tailored from NASA engineering best practices. Individual demonstration reviews will be held according to industry best practices and individual milestones definitized in demonstration contracts.

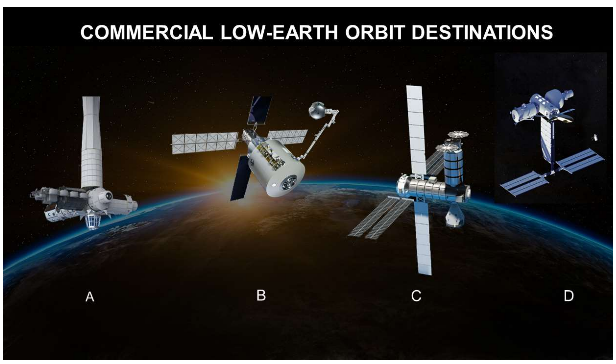
COMMERCIAL LEO DEVELOPMENT

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**102.1**	**--**	**228.4**	**229.6**	**302.3**	**435.2**	**437.8**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



Commercial LEO Destinations are shown here. CDISS: a) Axiom Space, Inc (Credits: Axiom Space, Inc). CDFF: b) Starlab, from Nanoracks, Voyager Space, and Airbus (Credits: Nanoracks / Voyager Space); c) Northrop Grumman's Commercial Space Station (Credits: Northrop Grumman); and d) Blue Origin's Orbital Reef (Credits: Blue Origin).

NASA seeks to maintain access to a low-Earth orbit (LEO) human-rated platform to continue the U.S. human presence – with both Government astronauts and private citizens – to support the utilization of space by U.S. citizens, companies, academia, and international partners, as well as to expand the American foothold in space. To successfully meet NASA's Strategic Goals and Objective 2.2 to "Develop a human spaceflight economy enabled by a commercial market", NASA established the Commercial LEO Development Program as a focused effort to ensure that there will always be a U.S. space station in LEO that meets NASA's enduring requirements, even after the International Space Station (ISS) is retired. In the course of meeting NASA's requirements, this program will also help develop a robust commercial space economy in LEO that supports good-paying jobs.

The Commercial LEO Development Program is building and executing a targeted strategy for an "economy of space commerce" that is sustainable, cost-effective, and safe. The current strategy builds on and applies the lessons learned from over a decade of partnerships with commercial companies.

NASA's Commercial LEO Development Program is supporting the development of commercially-owned and operated LEO destinations from which NASA can purchase services that meet NASA's requirements and those of other customers. As commercial LEO destinations (CLDs) become available, NASA intends to implement an orderly transition from current ISS operations to these new CLDs. The transition of LEO operations to the private sector will yield efficiencies in the long term, enabling NASA to shift resources towards other objectives. With the introduction of CLDs, NASA expects to realize efficiencies from the use of smaller, more modern and efficient platforms, and a more commercial approach to meeting the Agency's needs in LEO. In the longer term, the gradual emergence of additional customers for commercial LEO destinations will offer the opportunity for additional savings.

To achieve the Commercial LEO Development Program's goals, NASA is committed to using the ISS and its capabilities to aid in the development of U.S. industry's ability to provide the necessary platforms and services in LEO. NASA is also committed to continued Government utilization of LEO after the retirement of the ISS for basic research and development, science, and technology development. NASA's commitment to growing the future LEO economy also includes providing Government funding to private industry in the form of contracts and partnerships to ensure future capabilities can fulfill Government requirements.

NASA is pursuing several avenues to enable the LEO economy. These include offering use of an ISS berthing port to Axiom Space to deploy a new commercial element on the ISS, Commercial Destinations for ISS (CDISS); supporting development and use of Commercial Destinations Free Flyers (CDFF); and offering use of the ISS for private astronaut missions. A private astronaut mission (PAM) is a commercial mission consisting of activities conducted by private astronauts aboard the ISS or in a commercial element attached to the ISS, transported on a U.S. commercial spacecraft dedicated to this private mission.

For the ISS to support CDISS, NASA will reconfigure the ISS port, provide new ISS utilities and resources to the port, integrate the commercial elements onto ISS, and recertify new docking port locations for Commercial Resupply Services and Commercial Crew Program vehicles. These activities to support CDISS will be funded by the Commercial LEO Development Program.

NASA has also made the ISS available to private entities to enable commercial and marketing opportunities on the microgravity laboratory. Since making these opportunities available, NASA has received multiple proposals for commercial and marketing activities from both traditional aerospace companies and from novel industries, demonstrating the benefits of the space station to help catalyze and expand space exploration markets and the LEO economy.

NASA's Commercial LEO Development budget request supports and will advance the Nation's goals in LEO and for deep space exploration by furthering the development and maturity of the commercial space market. This development will enable private industry to assume roles that have been traditionally Government-only, thereby creating new opportunities for economic growth in LEO and potentially yielding long-term cost savings to the Government by leveraging industry innovation and commercial market incentives.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ACHIEVEMENTS IN FY 2022

Axiom Space continued development of the commercial segment, CDISS, that will attach to the ISS, including completing the preliminary design, which was reviewed at the Design Progress Review for the first two modules, AxH1 and AxH2. Axiom also initiated the first phase of a three-phase Critical Design Review which included systems such as avionics, structures, environmental control, and payloads. The primary structure for AxH1 and AxH2 underwent initial machining operations. Axiom also continued development tests of hardware to support flight hardware procurement and build. Axiom initiated construction for a large manufacturing and assembly facility to be used to prepare flight hardware prior to launch. In addition, Axiom continued to mature hazard reports and verification concepts to ensure successful and compliant integration with ISS.

On December 2, 2021, NASA awarded Space Act Agreements (SAAs) to three U.S. companies to develop CLDs that are launched directly to orbit (i.e., free-flyers). The agreements are part of the Agency's efforts to enable a robust, American-led commercial economy in LEO. The total estimated award amount for all three funded Space Act Agreements is $415.6 million. The companies that received awards are:

- Blue Origin of Kent, Washington, for $130 million;
- Nanoracks LLC of Houston, Texas, for $160 million; and
- Northrop Grumman Systems Corporation of Dulles, Virginia, for $125.6 million.

As mentioned above, the awards are the first in a two-phase approach to ensure a seamless transition of activity from the ISS to commercial destinations. During this first phase, NASA is partnering with the four companies mentioned above (Axiom Space, Blue Origin, Nanoracks, and Northrop Grumman) to formulate and design commercial LEO destination capabilities suitable for potential Government and private sector needs. The first phase is expected to continue through 2025.

Blue Origin and Sierra Space have partnered to develop Orbital Reef, a commercially owned and operated space station to be built in LEO, which will start operating in the second half of this decade. Orbital Reef teammates include Boeing, Redwire Space, Genesis Engineering, and Arizona State University. Orbital Reef's human-centered space architecture is designed to be a "mixed-use space business park" that provides essential infrastructure needed to support all types of human spaceflight activity in LEO and can be scaled to serve new markets. In FY 2022, Blue Origin completed their first four milestones, including their System Requirements Review (SRR) and Systems Definition Review (SDR).

Nanoracks' commercial LEO destination, in collaboration with Voyager Space is called Starlab. Starlab is targeted for launch in the latter part of this decade as a continuously crewed, commercial space station dedicated to conducting advanced research, fostering commercial industrial activity, and ensuring continued U.S. presence and leadership in LEO. Starlab is designed for four astronauts initially and will have power, volume, and a payload capability similar to the ISS. In FY 2022, Nanoracks completed their first milestone, a Kickoff Meeting. Nanoracks also completed several major trade studies for Starlab such as launch vehicle selection, environmental control systems, attachment mechanisms, and orbit altitude and inclination.

Northrop Grumman's design for a modular, commercial destination in LEO is built on decades of experience supporting NASA, defense, and commercial programs. The design leverages flight-proven elements, such as the Cygnus spacecraft that provides cargo delivery to ISS, to provide a base module for extended capabilities including science, industrial experimentation, and building of infrastructure beyond initial design. In FY 2022, Northrop Grumman completed their first three milestones, including their Concept of Operations review.

The first private astronaut mission with Axiom, Axiom Mission 1 (Ax-1), took place in April 2022 aboard ISS. Ax-1 Commander Michael López-Alegría, Pilot Larry Connor, and Mission Specialists Mark Pathy and Eytan Stibbe flew to the ISS aboard SpaceX Dragon Endeavour on a flight-proven SpaceX Falcon 9 rocket from Launch Complex 39A at NASA's Kennedy Space Center in Florida. The Axiom private astronauts completed 17 days in space at the conclusion of their mission. The spacecraft returned to Earth with more than 200 pounds of science and supplies, including NASA experiments and hardware.

In December 2021, NASA announced the selection of Axiom Space for the second private astronaut mission to the ISS, and the mission order was signed in August 2022.

COMMERCIAL LEO DEVELOPMENT

WORK IN PROGRESS IN FY 2023

NASA will complete and publish a draft Transportation, Destination, and Services Requirements Document that will define NASA's safety and services requirements for CLDs.

Progress will continue on the CDISS segments, including completion of second and third phases of the Critical Design Review for the first two commercial elements (AxH1 and AxH2), in addition to completion of the Preliminary Design Review (PDR) for the some of the other modules. Axiom plans to complete construction of their manufacturing and assembly facility and receive early flight hardware to support integration and verification activities. Axiom also plans to accept delivery of the finished primary structural assembly from their vendor to start final assembly, outfitting and verification of their first module, AxH1.

Progress will also continue on CDFF agreements. All three providers made updates to their original milestones, but the overall agreement values remained unchanged. Blue Origin is scheduled to complete three milestones including their Creep Test and Full-Scale Burst Test. The Creep Test ensures a sub-scale test article passes a short duration proof and leak tests as part of Orbital Reef's soft goods certification Program. The Full-Scale Burst Test ensures a sub-scale test article demonstrates the required factor of safety in order to complete the Orbital Reef's soft goods certification Program. Nanoracks is scheduled to complete six milestones including their Mission Concept Review, Starlab Station Systems Requirements Review (SRR), and Systems Definition Review (SDR). Northrop Grumman is scheduled to complete four milestones including their CDFF Element 1 SRR and SDR.

Axiom Private Astronaut Mission 2 (Ax-2) is planned to launch from NASA's Kennedy Space Center in Florida in the first half of 2023. Once docked to ISS, the Axiom astronauts are scheduled to spend 10 days aboard the orbiting laboratory. NASA and Axiom mission planners will coordinate in-orbit activities for the private astronauts to conduct in coordination with ISS crew members and flight controllers on the ground. The Ax-2 crew members will train for their flight with NASA, international partners, and SpaceX, which Axiom has contracted as launch provider for transportation to and from the space station, and who will familiarize the private astronauts with systems, procedures, and emergency preparedness for the space station and the Dragon spacecraft. NASA also plans to award Private Astronaut Missions 3 and 4 in FY 2023. This schedule demonstrates NASA's commitment to Private Astronaut Missions by having a regular cadence of opportunities for industry.

In addition, NASA is continuing its efforts to foster development and growth of American industry in space by announcing new opportunities to work with the Agency through the Collaborations for Commercial Space Capabilities (CCSC-2) initiative. This second invitation continues the pursuit of goals set in the U.S. National Space Policy and NASA's strategic plan that will benefit human spaceflight and the U.S. commercial LEO economy by meeting future business and Government needs through unfunded SAAs. These SAAs are designed to advance commercial space-related efforts through NASA contributions of technical expertise, assessments, lessons learned, technologies, and data. Structured sharing of NASA expertise demands minimal Government resources but fosters development of technologies crucial to development of a robust LEO economy. NASA released an Announcement for Proposals in November 2022 for the competitive selection of one or more SAAs. NASA will make awards in early 2023.

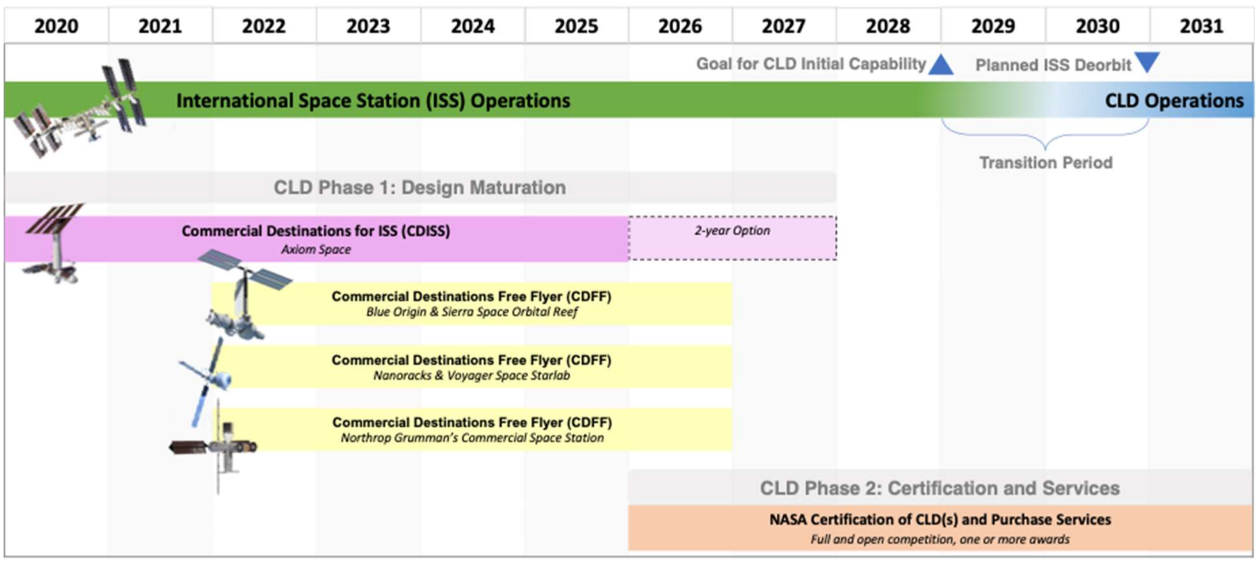
KEY ACHIEVEMENTS PLANNED FOR FY 2024

Axiom will continue its assembly, integration, and testing for AxH1 and begin that same activity for AxH2. Additionally, Axiom is planning to complete the hazard report development for the Phase 3 review of the NASA Safety Review Process associated with AxH1 and AxH2. Axiom is currently planning to launch the first element to ISS in late 2025.

Blue Origin is scheduled to complete four milestones including their PDR. Nanoracks is scheduled to complete four milestones including their Habitat Structural Test Article Preliminary Design. Northrop Grumman is scheduled to complete three milestones including their Habitation Demonstration.

Program Schedule

The following chart depicts the near-term roadmap of planned Commercial LEO Development efforts.



Program Management & Commitments

Program Element	Provider
Commercial LEO Development Program	Providers: Axiom Space, Inc.; Blue Origin; Nanoracks; Northrop Grumman Systems Corporation Lead Center: Johnson Space Center (JSC) Performing Center(s): JSC Cost Share Partner(s): Industry Partners (shown above)

Acquisition Strategy

NASA uses multiple acquisition tools for Commercial LEO Development. The established Next Space Technologies for Exploration Partnerships (NextSTEP-2) Broad Agency Announcement (BAA) contract vehicle was used for the Commercial Destinations ISS contract to initiate development of the commercial segment. Similar to the approach used for the Commercial Orbital Transportation System (COTS) and Commercial Crew, NASA used Space Act Agreements for Phase 1 of the CDFF. Federal Acquisition

Regulations (FAR)-based contracts will be utilized for CDFF Phase 2 to perform certification activities and purchase destination services. NASA is using unfunded SAAs in the CCSC-2 initiative to advance commercial space-related efforts through NASA contributions of technical expertise, assessments, lessons learned, technologies, and data. To enable private astronaut missions, NASA uses a NASA Research Announcement (NRA) to solicit private astronaut mission to the ISS.

Major Contracts/Awards

Element	Vendor	Location (of work performance)
Commercial Destination for International Space Station (CDISS)	Axiom Space, Inc.	Houston, TX
Commercial Destinations Free Flyers (CDFF)	Blue Origin	Kent, WA
Commercial Destinations Free Flyers (CDFF)	Nanoracks LLC	Houston, TX
Commercial Destinations Free Flyers (CDFF)	Northrop Grumman Systems Corporation	Dulles, VA
Private Astronaut Mission Ax-1	Axiom Space, Inc.	Houston, TX
Private Astronaut Mission Ax-2	Axiom Space, Inc.	Houston, TX
Private Astronaut Mission 3	TBD	TBD
Private Astronaut Mission 4	TBD	TBD
CCSC-2	TBD	TBD

Independent Reviews

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	NASA Advisory Council	Jan 2023	Provide independent recommendations for the NASA Administrator	TBD	At least annually, date TBD
Other	NASA Aerospace Safety Advisory Panel	Oct 2022	Provides independent assessments of safety and recommendations to the NASA Administrator	The panel provided no new formal recommendations or findings for the Commercial LEO Development Program.	At least annually, date TBD

SPACE TECHNOLOGY

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Early Stage Innovation and Partnerships	126.3	--	**138.1**	140.9	143.7	146.6	149.5
Technology Maturation	257.7	--	**402.3**	410.3	418.5	426.9	435.4
Technology Demonstration	489.0	--	**551.3**	562.3	573.6	585.1	596.8
SBIR and STTR	227.0	--	**299.9**	305.9	312.0	318.2	324.6
Total Budget	**1,100.0**	**1,200.0**	**1,391.6**	**1,419.4**	**1,447.8**	**1,476.8**	**1,506.3**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Pursuant to P.L. 115-10 Title VII Sec 702(e), this budget is formulated in such a manner to avoid duplication of projects, programs, or missions conducted by other projects, programs, or missions conducted by another office or directorate of the Administration.

SPACE TECHNOLOGY

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Early Stage Innovation and Partnerships	126.3	--	**138.1**	140.9	143.7	146.6	149.5
Technology Maturation	257.7	--	**402.3**	410.3	418.5	426.9	435.4
Technology Demonstration	489.0	--	**551.3**	562.3	573.6	585.1	596.8
SBIR and STTR	227.0	--	**299.9**	305.9	312.0	318.2	324.6
Total Budget	**1,100.0**	**1,200.0**	**1,391.6**	**1,419.4**	**1,447.8**	**1,476.8**	**1,506.3**
Change from FY 2023 Enacted			**191.6**				
Percent change from FY 2023 Enacted			**16.0%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Pursuant to P.L. 115-10 Title VII Sec 702(e), this budget is formulated in such a manner to avoid duplication of projects, programs, or missions conducted by other projects, programs, or missions conducted by another office or directorate of the Administration.

NASA's Deep Space Optical Communications (DSOC) experiment is the agency's first demonstration of optical communications beyond the Earth-Moon system. DSOC is a system that consists of a flight laser transceiver, a ground laser transmitter, and a ground laser receiver. New advanced technologies have been implemented in each of these elements.

The Space Technology Mission Directorate (STMD) is dedicated to developing transformative crosscutting technologies that enhance the capabilities and reduce the cost of missions. Through STMD, NASA invests in high-risk, high-reward activities across the technology development spectrum in collaboration with the Nation's aerospace industry, including small and large businesses, as well as academia.

NASA continues to create new ways of engaging and working with the commercial space industry as a potential user and not just a provider of new technologies. STMD embraces competition and external partnerships to develop technologies that enable the growth of commercial space companies, which will increase capabilities in space and create U.S. jobs. For example, through the use of competitively selected tipping point (TP), announcement of collaboration (ACO), and other NASA solicitations, STMD's technology investments support and stimulate a robust space economy.

STMD's projects are defined as part of the strategic framework and capabilities, through requirements determined by the Federated Team, and through selection by STMD's annual Strategic Technology Architecture Roundtable (STAR) process.

NASA also utilizes extensive university research, science, and technology expertise to advance the Agency's missions, while furthering the career development of the Nation's next generation of scientists, technologists, and explorers. STMD has over 500 academic partners supporting research and technology projects that foster interest in STEM careers and support technological advancement and economic growth.

STMD continues to seek input and recommendations from the National Academies' Space Technology Industry-Government-University Roundtable (STIGUR) and the NASA Advisory Council's Technology, Innovation, and Engineering Committee. Additionally, STMD fosters partnerships and collaborations by routinely engaging industry and academia through venues such as the Lunar Surface Innovation Consortium (LSIC), conferences, and symposiums.

The Space Technology Mission Directorate is comprised of four programs, detailed below:

Early Stage Innovation and Partnerships (ESIP)

ESIP engages innovators at universities, companies, independent labs, NASA, other government agencies and the general public to develop new and innovative high-risk/high-payoff technologies. ESIP awards early stage efforts through Space Technology Research Grants (STRG), NASA Innovative Advanced Concepts (NIAC), the Center Innovation Fund (CIF), and the Early Career Initiative (ECI) and innovation efforts through the Prizes, Challenges and Crowdsourcing Program.

Technology Maturation

STMD advances revolutionary space technologies across the critical gap that resides between early stage concepts and flight demonstration (Technology Readiness Levels [TRL] 3-6). The Technology Maturation portfolio, which includes the Game Changing Development (GCD) program, develops and demonstrates technologies needed to support other NASA mission directorates, the commercial space sector, and other government agencies (as appropriate). A portion of the Technology Maturation portfolio is dedicated to the LSII, targeting critical technologies needed for surface activities.

Technology Demonstration

NASA's Technology Demonstration portfolio funds the flight and/or ground demonstration of relatively mature technologies at a system level. Technology Demonstration encompasses the Technology Demonstration Missions (TDM), Flight Opportunities (FO), and Small Spacecraft Technologies (SST). TDM seeks to mature laboratory-proven technologies to flight-ready status (TRL 5-7). FO rapidly demonstrates promising technologies for space exploration, discovery, and the expansion of space commerce through suborbital testing with industry flight providers (TRL 4-6). SST expands the ability to quickly execute unique missions at a much lower cost than previously possible, through small spacecraft development and demonstration (TRL 3-7).

Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR)

The SBIR/STTR programs leverage the Nation's innovative small business community to support early stage research and mid-TRL technology development performed by small businesses through competitively awarded contracts that enable NASA's missions. These programs provide the small business sector with an opportunity to develop technology for NASA and to commercialize that technology to spur economic growth and address national needs in the aerospace industry as well as other sectors. Annual solicitations maintain commitment to an integrated Agency-wide program that supports both commercial interests and NASA mission needs, while addressing innovation initiatives aligned with Administration priorities.

EXPLANATION OF MAJOR CHANGES IN FY 2024

The Agency Technology and Innovation activity and its associated Office of the Chief Technologist was proposed to transfer to the Office of Technology, Policy, and Strategy under the Safety, Security, and Mission Services appropriation in the FY 2023 operating plan. As a result, STMD is not formulating its FY 2024 budget.

This budget proposal supports space nuclear technologies (Fission Surface Power, Nuclear Thermal Propulsion, and Nuclear Electric Propulsion) at an increase of approximately $75 million from the FY 2023 President's Budget Request, which will support propulsion development as well as designing, building, and testing the first ever space fission power system for deployment to and demonstration on the lunar surface.

RECENT ACHIEVEMENTS

In FY 2022, STMD pursued ground tests, launches, in-space demonstrations, collaborations, and more, including:

- Laser Communications Relay Demonstration (LCRD) began its two year experiment to refine the performance of optical communications between the ground and spacecraft(s).
- Low-Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID) completed a successful in-orbit demonstration of the inflatable decelerator which will inform future designs for inflatable heat shields for heavier payloads.
- Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) launched and began operations to validate innovative navigation technologies and to verify the dynamics of a unique, near-rectilinear halo orbit.
- Several awards totaling to approximately $84 million were made to advance key lunar capabilities: Fission Surface Power (FSP), High Performance Spaceflight Computing (HPSC) and Vertical Solar Array Technologies (VSAT).
- In addition to announcing the second annual TechRise challenge, 57 teams, representing more than 600 students from 37 U.S. states and territories, were selected to design, build, and launch experiments on suborbital flights as a result of the 2021 TechRise Challenge. The second annual TechRise challenge was also announced.
- Watts on the Moon Challenge opened Phase II which will award up to $4.5 million to public solvers with the best prototype for storing and distributing power on the Moon.
- Lunar Surface Innovation Consortium (LSIC) participation grew to over 700 organizations from all 50 states and 46 countries to foster lunar technology development.
- Technology Transfer transferred technologies and software to industry and entrepreneurs, executing 164 licensing agreements and 4,772 software usage agreements.

SPACE TECHNOLOGY

WORK IN PROGRESS IN FY 2023

- Planned award for Announcement of Collaboration Opportunities and Tipping Point selections to occur in spring of 2023.
- Nuclear Propulsion announced a non-reimbursable partnership with the Defense Advanced Research Projects Agency (DARPA) for the Demonstration Rocket for Agile Cislunar Operations (DRACO) Program to develop and demonstrate advanced nuclear thermal propulsion technology.
- Cryogenic Fluid Management (CFM) plans the SpaceX Tipping Point selection launch for 2023.
- PRIME-1, Deployable Hopper TP, Nokia 4G/LTE Proximity Communications TP working to complete delivery to Intuitive Machines and Lunar Outpost with plans to launch no earlier than calendar year 2023, dependent on the schedule of Intuitive Machines-2.
- High Performance Spaceflight Computing (HPSC) is developing a space flight computing system on a chip for use on NASA missions to improve computational performance, energy management, and fault tolerance. HPSC offers a multi-core flight computing architecture with the potential of 100 times the computational capacity of current flight processors for the same amount of power, with provisions for extensibility and interoperability. HPSC has completed the preliminary design review.
- In-Situ Resource Utilization (ISRU) Pilot Excavator will complete the preliminary design review, a full-system excavation ground demonstration, and reduce operational risk by testing lunar soil flow in simulated lunar gravity on a Blue Origin demonstration flight.
- On-Orbit Servicing, Assembly, and Manufacturing Demonstration-1 (OSAM-1) will continue critical hardware work with the robot subsystem. STMD anticipates delivery of the Spacecraft Bus and Space Infrastructure Dexterous Robot to Goddard Space Flight Center (GSFC). Planned Systems Integration Review (SIR) and the space vehicle integration and testing activities will commence at GSFC.
- Solar Electric Propulsion began qualification testing of the component-level Advanced Electric Propulsion System (AEPS). The first qualification thruster assembly (QM-1) will be completed no earlier than March 2023. The project Key Decision Point-D (KDP-D) is planned for May 2023.
- Lunar Flashlight launched and plans to use near-infrared lasers to shine light into permanently shadowed craters at the lunar south pole, while the onboard spectrometer measures surface reflection and composition to map water ice deposits and volatiles.
- Resulting from the 2022 TechRise Challenge, 60 winning teams were selected which represents over 500 students from 38 U.S. states and territories that will design, build, and launch experiments on suborbital flights.
- Deep Space Food Challenge plans selection of Phase 2 winners in April 2023, which includes prizes of up to $1 million to support the development of food production technologies that may provide future lunar crews with safe, nutritious food while in lunar orbit or on the lunar surface.
- Cube Quest Challenge entered its next phase of the competition with the launch of Artemis I on November 16, 2022, with a prize pot of $3 million available for completing various tasks while in orbit.

SPACE TECHNOLOGY

SPACE TECHNOLOGY FY 2024 INVESTMENT STRATEGY

NASA aims to enable American global leadership in Space Technology through:

- Investing in transformative crosscutting technologies that build a strong U.S. aerospace industry, create good paying jobs, and support national security;
- Bringing innovative technologies to flight and infusing them into commercial industry and government systems;
- Developing global lunar utilization infrastructure for sustained operations on the lunar surface;
- Creating partnerships with industry to establish commercial space capabilities;
- Supporting high-growth businesses of the future through small business research;
- Empowering a broad community of innovators through emphasis on early-stage investments; and
- Making targeted investments in climate change and clean energy.

PLANNED FY 2024 PROGRAM ACCOMPLISHMENTS:

The below planned accomplishments are not all inclusive of the overall program plans. For further details, please refer to the respective sections.

EARLY STAGE INNOVATION AND PARTNERSHIPS

- Early Career Initiative plans to increase the number of annual early career development awards with a goal of funding seven projects annually to nurture and develop NASA's civil servant innovators alongside industry and academic partners.
- NASA Innovation Advanced Concepts (NIAC) plans to continue to nurture visionary ideas that could transform future NASA missions by increasing the number of Phase I and II early concept awards and maintaining the number of Phase III awards.
- Space Technology Research Grants (STRG) plans to expand investments in graduate fellowships, early career faculty, research institutions, and teams pursuing lunar surface innovations utilizing a cohort of research institutions across the country. Important applied research awards will also near completion, including two Space Technology Research Institute's 2018 awards for Smart Deep Space Habitats, which are expected to generate transdisciplinary, cross-sector technologies for advanced environmental control and life support systems developments.

TECHNOLOGY MATURATION

- GCD has several near-term lunar technology demonstrations aboard Commercial Lunar Payload Services (CLPS) lunar landers. Through partnerships with NASA Science Mission Directorate (SMD), utilizing CLPS missions, STMD is planning to deliver several payloads and experiments to the Lunar surface and is contingent on the CLPS launch schedule:
    - Polar Resources Ice-Mining Experiment (PRIME-1) will drill into regolith to determine if water is present on the lunar surface.
    - Deployable Lunar Hopper will demonstrate the ability to gain access to extreme environments, such as the bottom of craters, not reachable by rovers or other technologies.

  - Nokia 4G/LTE Proximity Communications will be a first-time demonstration of a 4G/LTE communications system on the lunar surface.
  - Electrodynamic Dust Shield (EDS) will demonstrate dust removal from multiple surfaces, including glass shields and thermal radiators.
  - Stereo Camera for Lunar Plume Surface Studies (SCALPSS) will provide important data about the crater formed by the rocket plume of the lander as it makes its final descent and landing on the Moon's surface.
  - Cooperative Autonomous Distributed Robotic Exploration (CADRE) will demonstrate collaborative autonomous exploration on the lunar surface by navigating, communicating, computing, perceiving, and decision-making without human interaction.
- Crosscutting technologies to support NASA mission directorates, other government agencies, and industry needs (e.g., Advanced Spaceflight Computing, Advanced manufacturing, and Autonomous Systems and Robotics) will continue into FY 2024 and beyond, focusing on projects such as chip fabrication and qualification of HPSC, which will potentially provide 100 times the computational capacity of current flight processors for the same amount of power.
- In collaboration with industry, academia, and other government agencies, GCD will continue developing essential LSII capabilities required for humans and systems to successfully live and operate on the lunar and other planetary body surfaces. Examples are the Moon-to-Mars Planetary Autonomous Construction Technology (MMPACT) and In-Situ Resource Utilization (ISRU) Pilot Excavator, which will continue maturing key technologies leading up to potential CLPS flights in the mid-2020s. Combined, these technology development efforts enable a sustainable habitation on the lunar surface.
- Continue LSIC and sustain increased partnerships and collaborations with industry, academia, and other government agencies.

TECHNOLOGY DEMONSTRATION

- Cryogenic Fluid Management (CFM): the Eta Space Tipping Point selection launch is planned for 2024. CFM is essential for establishing a sustainable presence on the Moon and enabling crewed missions to Mars.
- Solar Electric Propulsion (SEP): the second qualification thruster assembly (QM-2) will be completed no earlier than May 2024. The Qualification System Acceptance Review 1 (QSAR-1) is planned for the fourth quarter of FY 2024.
- OSAM-1: Key Decision Point-D (KDP-D) will be held no earlier than October 2023. Integration and testing will be ongoing at GSFC.
- Flight Opportunities and Small Spacecraft Technology will continue to increase the pace of space exploration and discovery by leveraging small spacecraft and responsive launch capabilities to rapidly expand U.S. capabilities at dramatically lower costs while supporting American global competitiveness and leadership in space. In FY 2024, Flight Opportunities anticipates testing over 60 payloads and Small Spacecraft anticipates the launch of nine spacecraft.

SMALL BUSINESS INNOVATIVE RESEARCH (SBIR)/SMALL BUSINESS TECHNOLOGY TRANSFER (STTR)

- Intends to award over 460 new awards, grants, and contracts to small businesses, as well as incubating and maturing NASA commercial partnerships post-Phase II activities, such as sequential Phase II awards.
- For Phase II, NASA is planning to raise the maximum total value of an STTR award from $750,000 to $850,000 over a 24-month period of performance for Phase II awards made from the FY 2022 solicitation, which will be awarded in FY 2024.
- Continue efforts to encourage participation of underrepresented groups across the Nation to expand inclusive innovation.

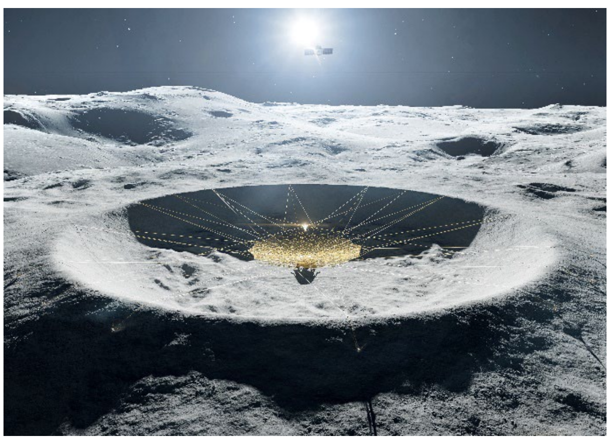
EARLY STAGE INNOVATION AND PARTNERSHIPS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Agency Technology and Innovation	7.4	--	**0.0**	0.0	0.0	0.0	0.0
Early Stage Innovation	99.4	--	**115.6**	118.0	120.3	122.7	125.1
Technology Transfer	19.5	--	**22.5**	23.0	23.4	23.9	24.4
Total Budget	**126.3**	**--**	**138.1**	**140.9**	**143.7**	**146.6**	**149.5**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



Shown here is the Lunar Crater Radio Telescope (LCRT) which is a NIAC project originally selected as a 2020 Phase I early concept study and selected to continue and mature as a 2021-22 Phase II study. LCRT's concept combines wire mesh deployment systems with advanced robotics, while leveraging the Moon's naturally occurring craters to build a radio telescope.

Early Stage Innovation and Partnerships empowers a community of innovators in aerospace research and transformative technology ventures to enable NASA’s mission and invigorate the Nation's economic future.

Early Stage Innovation supports concept studies, applied research, and early technology development that germinate revolutionary ideas, expand innovation, and transform future capabilities. Open innovation capabilities support NASA’s research and development (R&D) objectives and leverage the Agency’s connection with the American and global public to support NASA's objectives. By leveraging the creativity and technical capabilities of innovators across the Nation from academia, established industry, new businesses, NASA centers, and individual members of the public, the Agency gains new ideas and alternative approaches to solving NASA’s difficult and far-reaching space technology challenges. Recent emphasis has been placed on identifying emerging concepts and technologies that support topics, such as lunar surface requirements and orbital debris. NASA awards early stage efforts through Space Technology Research Grants, NASA Innovative Advanced Concepts, the Center Innovation Fund, and the Early Career Initiative and innovation efforts through the Prizes, Challenges and Crowdsourcing Program

Within Technology Transfer, NASA promotes the commercialization of technologies that emerge from NASA’s R&D activities to promote economic development through commercial expansion in space and tangible Earth applications.

EARLY STAGE INNOVATION AND PARTNERSHIPS

The Early Stage Innovation and Partnerships portfolio includes the following program elements:

Space Technology Research Grants (STRG)

STRG conducts a series of annual and biennial competitive solicitations targeting strategic technology gaps that engage the entire spectrum of academic researchers, from graduate students to early career and senior faculty members. STRG emphasizes technology that can make space activities more effective, affordable, and sustainable. In the process, close collaborations between U.S. universities and NASA centers are established and nurtured.

- The NASA Space Technology Graduate Research Opportunities (NSTGRO) solicitation seeks to sponsor graduate researchers who show significant potential to contribute to NASA's goal of creating innovative new space technologies for the Nation's exploration, science, and economic future.
- The topics featured in the Early Career Faculty (ECF), Early Stage Innovations (ESI), Lunar Surface Technology Research (LuSTR), and Space Technology Research Institutes (STRI) solicitations are of high priority to NASA and the aerospace community and focus on areas where academia is ideally suited to provide significant contributions.
    - ECF is uniquely focused on supporting outstanding faculty researchers early in their careers as they conduct space technology research.
    - ESI efforts are slightly larger efforts that are university-led but allow for teaming within academia as well as some external entities including industry.
    - LuSTR are university-led efforts addressing high priority lunar surface challenges that encourages larger teaming.
    - STRIs are university-led, integrated, multidisciplinary teams that requires a diverse, multidisciplinary, multi-institutional team which focuses on a high-priority early-stage space technology research for several years.

NASA Innovative Advanced Concepts (NIAC)

- NIAC executes annual solicitations seeking exciting and unexplored, but technically credible, new concepts that could one day "change the possible" in space and aeronautics. These efforts improve the Nation's leadership in key research areas, enable long-term capabilities and spawn disruptive innovations that make space exploration more effective, affordable, and sustainable.
- Phase I and continuation Phase II solicitations are open to NASA centers, other Government agencies, universities, industry, and individual entrepreneurs. NASA implemented Phase III studies to complement its portfolio of Phase I and Phase II concepts for the first time in FY 2019. Phase III studies are designed to continue maturation of Phase II transformative ideas, allowing NASA to strategically transition the most promising NIAC concepts to other NASA programs, other Government agencies, or commercial partners.

Center Innovation Fund (CIF)

CIF provides annual seed funding to each NASA center and NASA's Jet Propulsion Laboratory to stimulate aerospace creativity and workforce innovation to transform future missions and advance national aerospace capabilities. CIF activities are competitively proposed by the centers and selected by NASA HQ to explore alternative approaches or develop enhanced capabilities that will advance NASA mission capabilities. Partnerships with academia, private industry, individual innovators, as well as among NASA centers and Government agencies, are highly encouraged.

EARLY STAGE INNOVATION AND PARTNERSHIPS

Early Career Initiative (ECI)

The ECI provides the opportunity for NASA early career civil servants to propose and work on two-year technology projects with industry and academic partners, engage in hands-on technology development opportunities, and learn different approaches to project management. To maximize the effectiveness of the early career projects, each team is mentored by more senior center personnel and NASA STMD subject matter experts. Several ECI projects have targeted technology demonstrations or flight opportunities that support lunar surface operations, providing NASA civil servant innovators the opportunity to have their technologies demonstrated on the lunar surface. Designed to invigorate NASA's technology base and champion innovative management processes, ECI successfully partners NASA early career leaders with external world-class innovators to deliver transformative national space capabilities.

Prizes, Challenges, and Crowdsourcing

NASA recognizes the value of incentivizing new technology advancement and problem solving through open innovation approaches, including the use of prize competitions, challenges, and crowdsourcing open to the public. Government and non-government organizations have demonstrated the value of competitions for their ability to tap into new sources of talent they have not typically reached.

STMD's Prizes, Challenges, and Crowdsourcing Program utilizes the NASA Tournament Lab to enlist crowdsourcing to tackle challenges faced in its space and aeronautics research and development programs. The NASA Tournament Lab, which is managed by the Center of Excellence for Collaborative Innovation (CoECI), offers a wide variety of open innovation platforms that engage the crowdsourcing community in challenges to create the most innovative, efficient, and optimized solutions. CoECI also supports NASA@WORK, an internal crowdsourcing and challenge platform designed to improve the ability of NASA employees to connect with others within the Agency to solve technical and non-technical problems.

Centennial Challenges offer incentive prizes to generate revolutionary solutions to support advanced NASA technology needs and, where appropriate, partners with other organizations to maximize return on investment. NASA has launched three challenges that will address lunar excavation, manufacturing, construction, lunar power needs, and nutrition needs of astronauts.

Early Stage Innovation and Commerce (ESIC)

The Early Stage Innovation and Partnerships (ESIP) portfolio was initiated in FY 2021 to help drive impact, innovation, and transitions in STMD's early stage and commercialization work with FY 2022 being the first resourced year. The portfolio seeks to increase impact through strategic coordination between the Early Stage Innovation, Technology Transfer and SBIR/STTR programs, as well as collaboration with higher TRL programs in STMD and across NASA.

ESIC addresses the ESIP portfolio joint priorities and implements innovative pilots to advance technology driven economic growth through engagement, evidence-based implementation, and addressing barriers to promote inclusivity as a key component to ensuring American global leadership in space technology. ESIC addresses several ESIP/STMD gaps complementing other existing programs, including increasing the emphasis on and impact of inclusive innovation and participation by underrepresented and underserved communities across ESIP programs, increasing the rate of transition from university labs to market by actively supporting entrepreneurship in university-based research, and building capability for evidence-driven evaluation and technology transition. ESIC will provide the ability for ESIP programs to jointly explore innovative methods to increase the impact of NASA early stage technology development, including, for example, testing the potential of non-profit partnerships to leverage philanthropic capital to advance space technology research.

TECHNOLOGY TRANSFER

Technology Transfer provides Agency-level management and oversight of NASA-developed and NASA-owned intellectual property and manages the transfer of these technologies to external entities. Activities include active collection and assessment of all NASA inventions, strategic management and marketing of intellectual property, negotiation and management of licenses, software releases, development of technology transfer-focused partnerships, and the tracking and reporting of metrics related to these activities (e.g., numbers of new inventions, patents, licenses, cooperative research and development agreements, or software use agreements).

T2X, NASA's Technology Transfer Expansion initiative, accelerates commercialization of NASA patented technologies through outreach, strategic partnerships, and entrepreneurial projects that expand NASA's presence, create an entrepreneurial workforce, and increase national economic impact. Focused in regions across the Nation where there is evidence of highly concentrated resources to support and catalyze high-tech sustainable startup ecosystems, T2X engages in innovative entrepreneurial ecosystem activities and with institutions of higher education to increase licensing and commercialization success.

EXPLANATION OF MAJOR CHANGES IN FY 2024

The Agency Technology and Innovation activity and its associated Office of the Chief Technologist was proposed for transfer to the Office of Technology, Policy and Strategy under the Safety, Security, and Mission Services appropriation in the FY 2023 proposed operating plan to Congress. As a result, STMD is not including it in its FY 2024 Budget Request.

ACHIEVEMENTS IN FY 2022

- In February 2022, NIAC selected 12 Phase I studies and five Phase II studies, worth $175,000 and $600,000 respectively, representing visionary concepts with the potential to "change the possible" in aerospace with a focus on transformational capabilities. Examples of new studies include a method of planetary defense that allows for extremely short mitigation time scales, a digital manufacturing stream for astronaut-specific spacesuits, and a bioinspired ray (an inflatable structure combined with bioinspired propulsion) for exploring the atmosphere of Venus. NIAC also selected a Phase III study in May 2022 to advance diffractive solar sailing, worth $2 million over two years.
- ECI continued to provide opportunities to NASA early career civil servants to lead two-year technology projects with partners from industry, academia, and other Federal agencies. In FY 2022, the ECI Program selected and initiated four projects, each at a different NASA center and each worth $2.5 million over two years. For example, one of these early career projects is developing a novel capacitive approach to gauge the mass of cryogenic fluids inside tanks in microgravity – a deceptively difficult challenge and significant technology gap with nuclear propulsion applications. The CIF continued to promote innovation and stimulate creativity across the Agency by initiating over 130 studies, encompassing every NASA center, some costing as little as $20,000. Addressing nearly all NASA taxonomy areas, the variety of innovative CIF projects include new power and propulsion technologies, advanced lunar and planetary science instruments, and advanced exploration

capabilities for NASA missions, reaching from the lunar surface to the deepest regions of the solar system.

- STRG continued to fund researchers across academia to examine the feasibility of theories and approaches that are critical to making science, space travel, and exploration more effective, affordable, and sustainable. In FY 2022, STRG funded 49 new NASA Space Technology Research Graduate Research Opportunities (NSTGRO) awards, six ECF awards, eight ESI awards, and three LuSTR awards. These activities cover a range of topics including cold-tolerant electronics for lunar exploration, lightweight heat rejection radiators for space nuclear power systems, green hypergolic propellants for small spacecraft, and advanced modeling of dense atmospheric observing systems with major applications to climate change research.
- PCC completed Phase 1 of the Break the Ice and Deep Space Food competitions, each with a prize purse of $500,000. Break the Ice incentivizes new approaches for lunar excavation and movement of icy regolith. Deep Space Food solicits novel ideas for food production systems for long term space missions. Furthermore, PCC announced a continuation of these challenges to further develop their technologies with a $2 million prize purse for Break the Ice Phase 2 and $1 million prize purse for Deep Space Food. Additionally, the program announced Phase 2 of the Watts on the Moon competition with a prize purse worth up to $4.5 million to design and build prototype solutions under lunar conditions. Lastly, the NASA Tournament Lab (NTL) funded and supported the development of 11 crowdsourcing projects via PCC's annual Crowdsourcing Contenders solicitation for crowdsourcing project proposals from the NASA workforce. Selected projects include topics such as equitable hybrid workforce environment, wind tunnel technology, and research challenges in the extended/virtual reality domain. These were in addition to the 69 crowdsourcing projects administered by the NTL that were funded by other organizations, demonstrating the value of this centralized open innovation resource.
- Technology Transfer established new ground in its formation of regional partnerships and support for high tech startups. In FY 2022, Tech Transfer licensed over 170 patents, 11 copyrights, fulfilled 4,900 new software usage agreements, filed 99 new patent applications with the U.S. Patent and Trademark Office, and recorded 1,594 new inventions. Tech Transfer has also focused on In-Reach opportunities using a combination of hybrid, in-person, and virtual events to reach innovators. There have been 108 events held, reaching over 4,000 innovators. The Program continues to modernize the Technology Transfer System (NTTS) to streamline Technology Transfer related activities. The NTTS won NASA's prestigious Government Invention of the Year in 2022 for having been adopted by numerous other Federal agencies.
- NASA started to build the foundation to address common challenges for Early Stage programs with portfolio-wide investments in inclusive innovation, evidence building, and lab to market transition efforts. In alignment with ESIP's strategic framework, STMD developed an Inclusive Innovation Roadmap to guide ESIP implementation efforts in FY 2023 and beyond; began to develop evaluation plans in support of NASA's Learning Agenda in alignment with the Evidence Act; and worked with the Science Mission Directorate to release a new I-Corps solicitation to encourage the transition of STMD funded academic research to market.

WORK IN PROGRESS IN FY 2023

- NIAC selected 14 new Phase I awards in January 2023, each worth $175,000, with innovative concepts such as a new class of bimodal nuclear thermal and/or electric propulsion with a wave rotor topping cycle enabling fast transit to Mars, radioisotope thermo-radiative cell-powered generators, and a lunar south pole oxygen pipeline. The program will also select additional Phase II and III awards in FY 2023. These solicitations are open to private commercial industry, nonprofits, in-house NASA talent, academia, and innovative individuals across the Nation.

- ECI awarded five new projects to early career civil servants while the CIF program provided seed funding to over 110 studies and projects across every NASA center to nurture and advance existing technologies and infuse them into NASA missions. The technologies and topics chosen for advancement under ECI include carbon utilization for lunar and atmospheric systems, advancing high-efficiency rotating detonation rocket engines, and aerocapture systems for ice giant missions. ECI and CIF projects continue to demonstrate transition success; for example, the FY 2021 ECI project, titled Metallic Environmentally Resistant Coating Rapid Innovation Initiative, is scheduled to fly a long-duration space environment materials test on the International Space Station in FY 2023.
- STRG began seven new ECF activities with university faculty across the Nation, as well as 10 ESI initiatives. The awarded topics include lithium-ion battery testing during extreme lunar temperature transitions, lightweight elastic solar sails, and high-temperature lightweight radiator panels with applications to nuclear power and propulsion systems. Moreover, in addition to the over 320 projects and activities overseen by STRG, the program intends to select additional NSTGRO university fellowships, LuSTR lunar projects, and two major biennial university-led STRI projects, which are typically upwards of $10 million over five years.
- The Cube Quest Challenge entered its next phase of the competition with the launch of Artemis I on November 16, 2022, with a prize pot of $3 million available for completing various tasks while in orbit. The Deep Space Food challenge to build and demonstrate prototypes for in-space food production, with up to $1 million in prizes available, will close in March 2023. PCC plans to issue additional prizes and challenges in topics areas including mitigating small orbital debris, addressing climate change, and continuing to engage the workforce through the Crowdsourcing Contenders solicitation to fund a new set of crowdsourcing projects to meet Agency needs.
- Technology Transfer plans to increase the reach of NASA's T2X efforts through strategic engagements with regional ecosystems and underserved communities. T2X plans to offer commercialization boot camps that will build the entrepreneurial capacity of the NASA workforce and increase Technology Transfer University (T2U) relationships, including a focus on minority serving institution engagements.
- ESIC will continue to address common challenges for Early Stage programs with portfolio-wide investments in inclusive innovation, evidence building, and lab to market/transition efforts. In alignment with ESIP's strategic framework, STMD will expand coordinated outreach to underrepresented communities to increase participation across ESIP programs, address barriers to entry for all innovators, and establish learning agenda and program evaluation tools to be applied across STMD. In FY 2023, STMD made its first awards under the rolling I-Corps pilot solicitation conducted in partnership with NASA SMD, the first of which was from a minority serving institution.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

- The NIAC program will continue to nurture visionary ideas that could transform future NASA missions by increasing the number of Phase I and II early concept awards by approximately $2 million overall and maintaining the number of Phase III awards.

EARLY STAGE INNOVATION AND PARTNERSHIPS

- STMD's ECI program plans to begin to increase the number of annual early career development awards in FY 2024 by approximately $2.7 million, with a goal of funding seven projects annually to nurture and develop NASA's civil servant innovators alongside industry and academic partners. Furthermore, the CIF program intends to increase new seed funding by approximately $1 million for NASA centers to further enhance and enable future Agency capabilities through the innovative technologies developed by the highly skilled NASA workforce.
- STRG's plans to expand investments by approximately $5 million for graduate fellowships, early career faculty, research institutions and teams pursuing lunar surface innovations in FY 2024 in an increasingly inclusive cohort of research institutions across the country. Important applied research awards will also near completion, including STRG's two Space Technology Research Institute's 2018 awards for Smart Deep Space Habitats currently scheduled to end in the summer of 2024, which are expected to generate transdisciplinary, cross-sector technologies for advanced environmental control and life support systems developments.
- PCC will continue to support the following Centennial Challenges: Watts on the Moon, Break the Ice Lunar, and Deep Space Food. PCC will formulate new prize concepts to address Administration and Agency priorities such as climate change and identified strategic technology gaps.
- The Technology Transfer program will continue to perform its core functions, which includes protecting NASA's intellectual property; promoting commercialization of NASA inventions; ensuring NASA-developed software is available to industries, academia, entrepreneurs, and the general public; and documenting and spreading awareness of NASA Spinoff success stories. In addition, the Technology Transfer program will expand T2X beyond the initial three pilot centers to increase licensing and commercialization successes while engaging local and regional partners and will increase T2U agreements, with an emphasis on minority serving institutions and historically black college and universities.
- ESIC will coordinate with the programs to assemble a diversified portfolio of early-stage technology investments that are ambitious and strategy-informed. Consistent with the Inclusive Innovation Roadmap, ESIC will build and nurture diverse communities across the portfolio's R&D cycle. For example, such as building networks and providing capacity building support and planning grants to underrepresented groups. ESIC will implement an evaluation on transition strategies consistent with the FY 2024 Agency Evaluation Plan in the NASA Learning Agenda. To advance technology transition, ESIC will also support seedling investments and/or studies to bridge between low-Technology Readiness Levels (TRL) and mid-TRL programs. STMD will continue to make awards under the rolling I-Corps pilot solicitation conducted in partnership with NASA SMD.

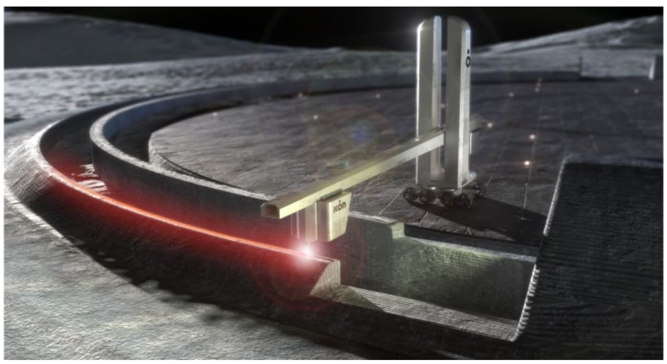
TECHNOLOGY MATURATION

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**257.7**	**--**	**402.3**	**410.3**	**418.5**	**426.9**	**435.4**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



ICON is illustrating the autonomous on demand 3D printing of a notional large scale structure on the lunar surface using in-situ regolith-based materials developed under the Technology Maturation MMPACT project.

NASA advances revolutionary space technologies from proof-of-concept to demonstration, maturing transformational and foundational technologies that primarily reside between early stage research and flight demonstration. The Technology Maturation portfolio provides transformative and crosscutting technologies that contribute to U.S. leadership in space technology and support NASA missions, including human and robotic exploration of the Moon, Mars, and beyond. Technology Maturation is committed to supporting advancements in clean energy by collaborating with industry in research and development projects for fuel cells.

Technology Maturation includes a broad array of crosscutting technology applications that fulfill multiple stakeholder needs, including NASA's mission directorates, commercial industry, and other Government agencies. Example technologies include autonomous landing and hazard avoidance, advanced materials, and in-space manufacturing and assembly. These types of technologies could benefit human and robotic exploration and spur economic growth in the space industry. NASA's Industry & Commerce Innovation Opportunity project will provide open topic calls for industry to identify and propose activities that will further enable commercial development of key technologies, which will support creating good paying jobs in a growing U.S. space industry.

Industry partnerships are an important mechanism used by NASA for Technology Maturation projects. Such agreements enable NASA and the private sector industry to share in the risk and benefit of common technology development interests and investments. These shared risks and benefits include incentivizing technical performance, enabling the commercial space economy, and sharing financial interests in the development of capabilities that support both NASA and other stakeholder needs. These industry partnerships are primarily developed through NASA's Tipping Point (TP) and Announcement of Collaboration Opportunity (ACO) solicitations.

The Lunar Surface Innovation Initiative (LSII) is also a component under Technology Maturation. Through LSII, STMD collaborates and partners with industry, academia, and other government agencies to develop cross-cutting technologies that provide key lunar surface capabilities and feed forward to Mars and beyond. Since its inception in 2019, LSII has engaged over 750 organizations across 50 states, the

District of Columbia (D.C.), Guam, Puerto Rico, and 48 countries to advance the technologies needed to explore the lunar surface and stimulate economic development.

EXPLANATION OF MAJOR CHANGES IN FY 2024

This budget includes an increase of $5 million, which will support low-to-mid technology readiness level work that engages industry innovators to identify concepts and approaches to address orbital debris.

PROGRAM ELEMENTS

Technology Maturation Budget Estimated by Focus Area

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Space Transportation	18.4	--	36.7	32.0	30.0	30.0	30.0
Entry, Descent and Landing	29.2	--	37.1	21.7	17.9	14.2	14.0
Sustainable Exploration	94.3	--	154.8	188.2	197.8	197.7	197.7
Transformative Mission and Discoveries	89.7	--	67.7	56.7	55.0	62.0	64.0
Industry & Commerce Inn Oppt (ACO/TP)	0.0	--	75.3	80.6	86.3	91.0	97.2
Space Tech Management and Integration	26.1	--	30.8	31.2	31.6	32.1	32.6
Total Budget	**257.7**	**--**	**402.3**	**410.3**	**418.5**	**426.9**	**435.4**

**Sums may not add to Total Budget due to rounding.*

PROJECT OVERVIEWS

Technology Maturation has a broad portfolio of approximately 100 projects and tasks, with majority of these activities including partnerships and collaborations with industry, academia, and/or other Government agencies. The portfolio includes a combination of mid-technology readiness levels (TRL) ground-based and flight demonstration developments.

SPACE TRANSPORTATION

NASA is making progress to advance technologies that support rapid and efficient in-space transportation that reduce transit times. Propulsion investments focus on higher thrust and efficiency, including alternatives to traditional chemical propulsion systems for deep space exploration spacecraft systems, and advancement of additive manufacturing (AM) techniques. Specific investments include:

- Thruster for the Advancement of Low-temperature Operation in Space (TALOS), which is a new class of thruster that uses propellants that can operate in space for extended periods without freezing. This capability lowers overall spacecraft mass and power needs and reduces mission costs since special heaters are not needed to keep the propellants from freezing. Through a partnership with NASA, Frontier Aerospace Corporation will provide a flight set of five axial thrusters for the Astrobotic Peregrine Lunar Lander Mission One.

- Refractory Alloy Additive Manufacturing Build Optimization (RAAMBO) and Optimized and Repeatable Components in Additive Manufacturing (ORCA), which will advance additive manufacturing using refractory alloys. This will provide high payoff optimized performance technologies and enables materials in additive manufacturing for combustion chambers, injectors, nozzles, and turbomachinery, and general industry material characterization needs.
- Composite Technologies for Exploration - Thermoplastic Development for Exploration Applications (CTE-TDEA) is advancing thermoplastic composite capabilities by developing structural joining solution methods for aerospace structures (e.g., lunar landers, on-orbit assembly of large-scale structures, and launch vehicle applications).

ENTRY, DESCENT, AND LANDING

For NASA to land increased mass more accurately on planetary bodies and to improve capabilities to return spacecraft from low-Earth orbit (LEO) and deep space, the Agency is working to develop capable Entry, Descent, and Landing (EDL) systems, materials, and computer modeling capabilities. NASA investments are focused on: precision landing and hazard avoidance; design, analysis, and testing of advanced materials for thermal protection; and EDL architectures for future exploration vehicles and planetary entry missions. An example EDL investment is the Stereo Camera for Lunar Plume-Surface Studies (SCALPSS). SCALPSS is composed of tiny cameras placed around the base of the commercial lunar lander that monitor crater formation from the precise moment a lander's hot engine plume begins to interact with the Moon's surface. This data will be used by future lunar lander vehicle designs. SCALPSS is a collaboration with NASA's Science Mission Directorate (SMD).

SUSTAINABLE EXPLORATION

NASA is also working on capabilities for sustainable living and working farther from Earth to support routine crewed operations beyond LEO. Technologies demonstrated will enable humans to live and operate on the Moon and eventually on Mars. Additionally, these capabilities provide the ability to reach challenging sites and resources on the Moon and Mars to survive and operate through the lunar night. Descriptions of these capabilities are listed below.

Crosscutting Sustainable Living

NASA will advance synthetic biology, in-space manufacturing, and intra-vehicle robotics in order to enable and sustain human presence in space. Key projects within this portfolio include the following:

- Synthetic Biology will demonstrate producing high-value bio-nutrients on demand to support long duration missions where nutrients degrade over time. This technology will enable the availability of nutrient-rich foods to maintain astronaut health. The complementary bio-manufacturing effort will demonstrate the production of mission products, such as food components, pharmaceuticals, polymers, and fuels from in-situ resource utilization derived growth media.
- In-Space Manufacturing provides a solution towards sustainable, flexible missions (both in-transit and on-surface) through on-demand fabrication, repair, and recycling capabilities for critical systems, habitats, and mission logistics and maintenance. These additive manufacturing capabilities provide tangible cost savings by reducing launch mass, as well as significant risk reduction by decreasing dependence on spares and/or over-designing systems for reliability.

Lunar Surface Innovation Initiative (LSII)

Through LSII, NASA will develop the essential capabilities required for humans and systems to successfully live and operate in multiple environments on the lunar and other planetary body surfaces. These technologies will result in the capability to extract and utilize local resources, generate surface power and store energy, access and navigate a variety of terrains, autonomously excavate lunar surface materials for manufacturing and construction, and mitigate lunar dust. Also included in LSII is the Lunar Surface Innovation Consortium (LSIC), which is facilitated by Johns Hopkins Applied Physics Laboratory and supports a nationwide alliance of universities, industry, non-profits, NASA, and other government agencies with a vested interest in establishing a sustained presence on the Moon. Key activities and elements of this initiative are described below.

In-Situ Resource Utilization (ISRU)

ISRU will develop and demonstrate technologies to use the Moon's resources to produce water, fuel, and other supplies. Following development and maturation of ISRU technologies at the component, subsystem, and scaled system levels, this effort will demonstrate the ability to produce propellants, other mission consumables, products, and infrastructure from regolith and atmospheric resources at a variety of destinations.

- Polar Resources Ice Mining Experiment-1 (PRIME-1) will be the first ISRU demonstration on the Moon. The project includes a flight-ready instrumentation package that will robotically sample and analyze for ice from below the surface. PRIME-1 is a critical instrument suite that will be integrated on the Intuitive Machines commercial lunar lander to land at the lunar South Pole to assess the volatiles and determine water content. PRIME-1 will help provide the knowledge necessary to find critical resources to produce propellant, water, and oxygen for lunar missions.
- The ISRU sub-scale plant will be a demonstration of a culmination of several critical LSII technologies (e.g., power capabilities, mining and processing of oxygen and water, excavation, mineral beneficiation, and regolith processing).

Sustainable Surface Power

NASA is making critical advancements in power generation and energy storage that will provide the capability for continuous power throughout day and night operations on the lunar surface. Solar array technology under development can generate energy in extreme environments, including low-light intensity and low temperature. In addition, NASA is developing and demonstrating a primary fuel cell system to support operations with long discharge times, including applications on rovers, powering of habitats, powering in-situ resource utilization systems, and for general energy storage.

- Vertical Solar Array Technology (VSAT) will develop lightweight solar arrays capable of autonomous 10-meter vertical deployment on uneven terrain through three contracts with industry (Astrobotic Technology, Honeybee Robotics, and Lockheed Martin). This technology will enable near continuous capture of sunlight by the solar arrays at the lunar South Pole region.
- LSIC held a power beaming workshop with broad participation from industry, academia, and other Government agencies to investigate the latest technological advancements on low-temperature power, energy storage, and generation of power at extremely low temperatures.

Dust Mitigation

- Lunar dust is one of the principal issues that NASA must address before returning to the surface of the Moon. It has the potential to affect every lunar architecture system. NASA will develop and demonstrate technologies and concepts to mitigate lunar dust hazards, which will enable affordable, sustained operations both on the lunar surface and with transfers to and from the Lunar Gateway or other orbital platforms. Electrodynamic Dust Shield (EDS) is an active dust mitigation technology demonstration that uses electric fields to move dust from surfaces and to prevent accumulation on surfaces. Potential applications include thermal radiators, spacesuit fabrics, visors, camera lenses, solar panels, and many other technologies. An EDS flight demonstration is scheduled for a Commercial Lunar Payload Services mission in 2023.

Excavation and Construction

NASA will develop and demonstrate technologies that enable affordable, autonomous manufacturing and construction (e.g., landing pad, berm, or shielding) using lunar surface materials. Critical to NASA's ISRU subscale demo plant is the ability to excavate regolith under lunar environmental conditions, which include lunar dust, extreme temperatures, and minimal gravity.

- Moon-to-Mars Planetary Autonomous Construction Technology (MMPACT) will utilize lunar in-situ materials for the on-demand construction of large-scale infrastructure elements such as habitats, berms, landing pads, and blast shields. These structures will provide protection of crewmembers, hardware, and electronics while on the surface of an extraterrestrial body to enable sustained surface exploration. Partners include: ICON, Space Exploration Architecture, the Department of Defense (DoD) Innovation Unit, and the United States Air Force.
- ISRU Pilot Excavator (IPE) will demonstrate Regolith Advanced Surface Systems Operations Robot excavator capable of supplying raw materials to an ISRU pilot plant, first in a ground demonstration followed by a lunar surface demonstration.

Extreme Environments

NASA advances rovers, manipulators, and other systems that can operate throughout the full range of lunar surface conditions, including lunar noon (up to 150 degrees Celsius), lunar night (down to negative 180 degrees Celsius), multiple day/night cycles, and permanently shadowed regions (down to negative 240 degrees Celsius).

- Motors for Dusty and Extremely Cold Environments (MDECE) is developing magnetically-geared actuator that can operate continuously and unheated for a long duration in extremely cold environments. The actuator is intended for use on rover wheels, powered robotic arms, antennas, solar arrays, and other space mechanisms.

DISCOVER AND EXPLORE

Extreme Access

NASA demonstrates technologies that enable humans or robotic systems, particularly autonomous systems, to efficiently access, navigate, and explore previously inaccessible lunar or planetary surface or subsurface areas.

- Cooperative Autonomous Distributed Robotic Exploration (CADRE) will evolve technology developed by the Pop Up Flat Folding Exploration Robot project and demonstrate collaborative autonomous exploration on the lunar surface by navigating, communicating, computing, perceiving, and decision-making without human interaction.

- Inspired by terrestrial technology, Nokia, through a TP contract, will deploy the first LTE/4G communication system on the lunar surface. The system aims to support lunar surface communications at greater distances and increased speeds.
- Intuitive Machines, through a TP contract, will develop a small, deployable hopper lander that will access lunar craters and enable high-resolution surveying of the lunar surface over a short distance.
- High-TRL Light Detection and Ranging (LiDAR) will develop a vision mapping system that will enable rovers to venture beyond benign planetary and lunar surfaces into dark, high-contrast, confined, or low-texture (i.e., extreme) environments. The main electronics box will be utilized on the Dragonfly mission, and potentially future lunar surface missions.

Servicing, Assembly, Manufacturing, and Crosscutting

- STMD will initiate planning on technology development for remediation of active space debris needed by the U.S. space industry.
- Super-lightweight Aerospace Composites (SAC) will scale up the manufacturing and use of high-strength carbon nanotube (CNT) composite materials leading to significant mass savings in rocket and spacecraft structures such as entry, descent, and landing systems; hypersonic vehicles; and propulsion systems.
- Precision Assembled Space Structure (PASS) will develop and validate critical technologies, such as autonomous assembled structures and high-precision joints for effective and efficient on-orbit assembly of large structures, such as next generation science telescope. The project collaborates with DoD and SMD.

Avionics, Communication, and Navigation

- High Performance Spaceflight Computing (HPSC) is intended to develop a next-generation flight computing system that can improve in-space computing performance to 100 times the computational capacity of current flight processors for the same amount of power.
- Distributed Spacecraft Autonomy (DSA) will develop technology for autonomous decision-making for multi-spacecraft missions which will significantly increase the effectiveness of missions by operating them as a collective rather than individually. The technology will be demonstrated on the Starling mission led out of Small Spacecraft Technologies.

INDUSTRY AND COMMERCE INNOVATION OPPORTUNITY

NASA stimulates the commercial space industry through collaborative partnerships that foster the technology development required for future NASA, commercial, and Government sector capabilities and missions. STMD employs a novel, merit-based competition model to ensure that NASA maintains a crosscutting portfolio that spans a range of technical disciplines and market readiness levels.

ACHIEVEMENTS IN FY 2022

STMD achieved multiple milestones in lunar surface power and construction: on-orbit servicing, assembly, and manufacturing; avionics; communication; and navigation projects, contributing to the maturation of industry-developed space technologies for the Moon and beyond.

- The VSAT solar array conceptual design study concluded. The project selected and awarded three contracts to Astrobotic Technology, Honeybee Robotics, and Lockheed Martin to move forward with the detail design, fabrication, and testing.
- MMPACT matured the lunar simulant materials and technology necessary for construction operations by successfully melting, sintering, casting, and printing lunar simulant samples.
- SAC continued development and testing of scaled-up composite processes that yielded structures which demonstrated increased tensile strength and extreme environmental properties above the current state-of-the-art composite materials for advanced manufacturing.
- CADRE completed the hardware and software design of the core autonomy software with surface navigation and communication subsystems and built six rover prototypes. The project also demonstrated cooperative multi-agent autonomy, including multi-rover formation and exploration drives with the prototypes (while processing of shared data) in a ground demonstration.
- HPSC completed radiation tolerance testing and evaluation of the results of the industry partner design studies and awarded a contract to Microchip to develop and produce a radiation tolerant chip with an order of magnitude increase in processing capability.
- PRIME-1, Nokia LTE/4G Communications TP, and Intuitive Machines Deployable Hopper TP completed delivery of the lunar surface flight units to Intuitive Machines.

WORK IN PROGRESS IN FY 2023

- Technology Maturation is executing approximately 25 TPs and ACOs across multiple capability areas. The next selection of awards is anticipated to occur in spring 2023.
- STMD will continue developing high-priority manufacturing, space transportation, and landing technologies to support industry and NASA, including:
  - RAAMBO, which will begin initial development, trials, and simulations of refractory alloys for additive manufacturing. The project will advance powder and process development, define printing parameters, characterize heat treatment properties, and determine inspection methods.
  - CTE-TDEA, which will demonstrate high-reliability thermoplastics joining processes for future applications as well as complete material characterization and develop a material database.
  - TALOS, which completed acceptance testing of seven novel Axial thrusters. Six flight thrusters will be delivered to Astrobotic for the Peregrine-1 flight to the Moon. Additionally, TALOS delivered 12 attitude control system (ACS) flight thrusters to Astrobotic in February 2023.
- Utilize NASA's CLPS program to deliver payloads and experiments to the Lunar surface:
  - SCALPSS and EDS will complete final flight hardware assembly, integration, and testing for delivery to the CLPS provider Firefly Aerospace, currently schedule for launch in 2024.
  - The CLPS provider, Intuitive Machines-2, will deliver PRIME-1, Deployable Lunar Hopper TP, and 4G/LTE Proximity Communications TP demonstrations to the Lunar surface no earlier than calendar year 2023.
  - CADRE will complete fabrication and integration testing of the development models and flight units of rover, base station, and developers, including testing and verifying that the hardware and software meet flight requirements. The project will deliver the CADRE system for integration

into the Intuitive Machines Nova-C lander as part of a CLPS mission, which is planned for launch in 2024.

- Develop surface excavation and construction technologies to promote sustainable habitation on the Lunar surface:
  - MMPACT will continue to evaluate lunar simulant in order to down-select materials. The team will focus development on the prototype hardware to test in simulated lunar environment conditions.
  - ISRU Pilot Excavator will complete the preliminary design review, a full-system excavation ground demonstration, and reduce operational risk by testing lunar soil flow in simulated lunar gravity on a Blue Origin demonstration flight. IPE will continue to collaborate with Caterpillar to develop a multi-year university STEM challenge to stimulate a pipeline of future engineers. Caterpillar will contribute the novel, cutting-edge automated simulation tools to model the hardware in the relevant environment, such as the lunar surface.
  - VSAT vendors will continue development of a deployable solar array and complete the systems design and fabrication of the prototypes.
  - Motors for Dusty and Extremely Cold Environments will build and test a proof of concept actuator and will hold a critical design review preceding fabrication of the final design.
- Develop crosscutting technologies to support science, human space exploration, other Government agencies, and industry needs (e.g., advanced spaceflight computing, advanced manufacturing, and autonomous systems and robotics):
  - In Space Manufacturing will complete microfurnace prototype testing with modifications to reduce power draw to meet the International Space Station power budget requirements.
  - Synthetic Biology demonstrated the generation-2 BioNutrient production packs on the ISS in November 2022 which will be activated by astronauts and returned to Earth for assessment against ground controls in 2023.
  - High TRL LiDAR will complete the design, analysis, and production of the engineering test unit light detection and radiation system.
  - HPSC completed the preliminary design review and will continue to work the design of the HPSC system on a chip. HPSC will demonstrate the completion of the top-level integration of the design and verify the full design database before sending it to the foundry for manufacturing.
  - SAC will incorporate lessons learned from CNT composite fabrication process development and then scale the process to accelerate composite production for CNT structural applications.
  - PASS will develop automated multi-agent robot coordination planning and operations.
  - DSA will complete the planned on-orbit experiments and report out on the capability development.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

STMD plans to focus technology developments on CLPS payloads and experiments, surface excavation and construction, and Moon-to-Mars Planetary Autonomous Construction Technology:

- STMD will continue developing high-priority manufacturing, space transportation, and landing technologies to support industry and NASA including:
    - RAAMBO and ORCA, which will complete testing of turbomachinery as well as gather characterization data of the additive manufacturing alloys; and
    - CTE-TDEA, which will demonstrate a thermoplastics concept structure joint element for a relevant exploration mission application through design, analysis, fabrication, and test.
- CLPS payloads and experiments:
    - EDS will support payload launch and landing activities and mission operations, which includes performing the flight demonstration, data collection, and analysis;
    - CADRE launch and landing will begin the start of the project operations phase on the lunar surface of collecting sub-surface measurements using ground penetrating radar in order to produce detailed local maps and while demonstrating multi-agent autonomy; and
    - Continue ISRU Subscale Demo integration and requirements development for payloads and launch vehicle.
- Surface excavation and construction:
    - ISRU Pilot Excavator will complete the critical design review and qualification testing on the prototype unit. The project will launch a multi-year university challenge that will give students the chance to develop autonomy code and simulations using Caterpillar software with the IPE as the subject case study;
    - MMPACT will continue development of landing pad and habitat architectural designs while developing an engineering unit for a future lunar demonstration. The project will also conduct a preliminary design review of the future demonstration mission;
    - VSAT vendors will compete testing of the components and system prototypes in a simulated lunar environment, which will mature the VSAT system to TRL 6; and
    - MDECE will complete fabrication of the actuator and demonstrate TRL 6 advancement through testing in a simulated lunar environment.
- Develop crosscutting technologies:
    - Review and analyze existing technologies and develop a plan for active space debris remediation technologies;
    - High TRL LiDAR will complete testing to define operation parameters of the engineering test unit and conduct a technology readiness assessment;
    - HPSC will complete its critical design review and begin qualification testing on prototype chips; and
    - PASS will complete a 20-meter autonomous assembly ground demonstration.

ACQUISITION STRATEGY

STMD embraces competition and external partnerships to develop technologies that enable the growth of commercial space companies, both as potential users and providers, which will increase our capabilities in space and create U.S. jobs. These technologies are competitively selected through TP, ACO, and other NASA solicitations.

These critical technology projects are defined as part of the strategic framework and capabilities, through requirements determined by the Federated Team, and through selection by STMD's annual Strategic Technology Architecture Roundtable (STAR) process.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
High Performance Spaceflight Computing (HPSC)	Microchip Technology Inc.	Chandler, AZ
Vertical Solar Array Technology (VSAT)	Astrobotic Technology Honeybee Robotics Lockheed Martin	Pittsburgh, PA Brooklyn, NY Littleton, CO

TECHNOLOGY DEMONSTRATION

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Solar Electric Propulsion (SEP)	24.2	18.5	**10.8**	13.7	7.7	6.4	5.5
On-Orbit Servicing, Assembly, and Manufacturing Demonstration-1 (OSAM-1)	227.0	227.0	**227.0**	174.5	123.0	28.7	0.0
Small Spacecraft, Flight Opportunities & Other Tech Demo	237.8	--	**313.5**	374.1	443.0	550.0	591.3
Total Budget	**489.0**	**--**	**551.3**	**562.3**	**573.6**	**585.1**	**596.8**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The Low-Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID) launched as a secondary payload on the United Launch Alliance Atlas V rocket on November 10, 2022 and successfully completed its flight demonstration.

The Technology Demonstration portfolio includes the Technology Demonstration Missions (TDM), Flight Opportunities, and Small Spacecraft Technology programs.

The TDM program matures crosscutting system-level technologies through demonstration in operational environments. The program does this through both ground-based testing and space flight demonstrations. Ground-based testing is performed to advance technologies from component validation in a relevant environment to system model or prototype demonstration in a relevant or operational environment. Space flight demonstrations further advance system level technologies, also in a relevant environment, with the goal to transition these new capabilities to operational use by NASA missions, industry, and other Government agencies.

The TDM portfolio technology investments include high-power solar electric propulsion; Cryogenic Fluid Management (CFM); sustainable lunar surface power; space nuclear propulsion; advanced communications and navigation; and in-space servicing, assembly, and manufacturing.

Commercial sector collaborations continue to be used to share the risk and financial interest and better leverage Government investments. For example, through NASA's Tipping Point Technologies solicitation and selection process, CFM, as well as in-space servicing, assembly, and manufacturing technologies, will be matured through in-space demonstrations with the goal of implementing these technologies into operational missions. In partnership with industry, CFM will develop and test numerous cryogenic storage, transfer, and mass gauging technologies to enable more efficient usage of cryogenic fluids. This could contribute to several applications including lander systems, In-Situ Resource Utilization technologies, in-space chemical propulsion systems, and nuclear thermal propulsion.

The Flight Opportunities and Small Spacecraft programs rapidly develop and demonstrate technologies through partnerships with U.S. industry for suborbital flight testing and small spacecraft missions. These programs leverage agile spacecraft platforms and responsive launch capabilities to increase the pace of space exploration, scientific discovery, and the expansion of space commerce. These emerging capabilities have the potential to enable new mission architectures, enhance conventional missions, and promote development and deployment on faster timelines. The programs partner with U.S. industry and academia to target technology gaps that market forces would not otherwise fill. The two programs address the advancement of technologies that support national efforts in cislunar space, breakthrough observing capabilities for Earth and beyond, and other capabilities that ensure national leadership in space and help the commercial space industry grow.

EXPLANATION OF MAJOR CHANGES IN FY 2024

This budget proposal supports space nuclear technologies (Fission Surface Power, Nuclear Thermal Propulsion and Nuclear Electric Propulsion) at an increase of approximately $75 million from the FY 2023 President's Budget Request, which will support propulsion development as well as designing, building, and testing the first ever space fission power system for deployment to and demonstration on the lunar surface.

SOLAR ELECTRIC PROPULSION (SEP)

Formulation	**Development**	Operations

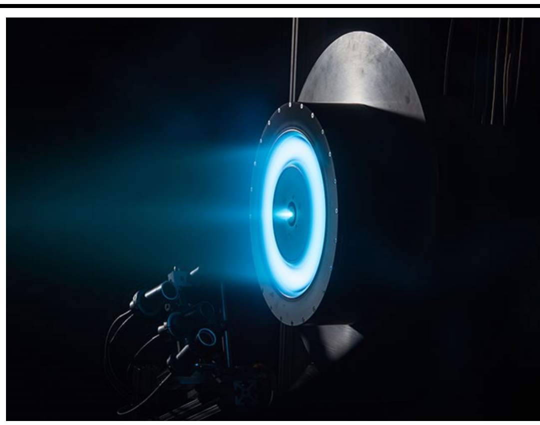
FY 2024 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028	BTC	Total
Formulation	179.2	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	179.2
Development/Implementation	100.0	30.1	21.7	**16.5**	14.3	7.7	6.4	5.5	1.1	203.2
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2023 MPAR LCC Estimate	**279.2**	**30.1**	**21.7**	**16.5**	**14.3**	**7.7**	**6.4**	**5.5**	**1.1**	**382.4**
Total Budget	**272.4**	**24.2**	**18.5**	**10.8**	**13.7**	**7.7**	**6.4**	**5.5**	**1.1**	**360.2**
Change from FY 2023 Enacted				**-7.7**						
Percent change from FY 2023 Enacted				**-41.6%**						

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The 2023 MPAR LCC Estimate reflects the Fiscal Year 2023 Quarter 1 Financial Report, which is current as of December 2022. The requested budget authority is the project's current budget requirements.



Solar Electric Propulsion technology development unit hall thruster is shown here in testing. The project will be qualifying a 12-kilowatt thruster that will be demonstrated on the Lunar Gateway Power and Propulsion Element.

PROJECT PURPOSE

NASA will continue the development of Solar Electric Propulsion (SEP) with progressively higher-power, longer-life thrusters. Led by NASA's Glenn Research Center (GRC), the first operational demonstration of this 12-kilowatt (kW) thruster will be on the Exploration Systems operational architectural system, the Power and Propulsion Element (PPE) to place Gateway into its highly elliptical lunar orbit. This demonstration and operational mission will provide NASA with experience in electric propulsion around the Moon, while demonstrating operational approaches and interfacing with visiting crew and robotic vehicles. SEP will also enable more efficient orbit transfer of spacecraft and accommodate the increasing power demands for government and commercial satellites.

Demonstrating the SEP thrusters in an operational environment will support the growing demand for increased electric propulsion performance for commercial satellites and will also support future exploration missions. The SEP thrusters will be integrated with previous NASA advancements in

SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

deployable solar array structures. These arrays, provided by PPE, have half of the mass and one-third of the packaging volume compared to state-of-the-art solar arrays, and have already been incorporated into commercial satellite product lines, which enable greater payload mass.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

PROJECT PARAMETERS

The goal is to qualify a 12-kW solar electric propulsion thruster to be used as the primary propulsion for a spaceflight demonstration during an operational mission. Objectives include:

- Qualify high-power SEP thruster technology for use in relevant space environments through demonstration of continuous long-term operation of the system sufficient to characterize and predict the performance and lifetime of the system; and
- Qualify electric propulsion thruster for extended operations in deep space.

ACHIEVEMENTS IN FY 2022

The SEP project completed the Advanced Electric Propulsion System (AEPS) thruster Critical Design Review (CDR) in March 2022. The project rebaselined in March 2022. The majority of the AEPS development testing was completed. The manufacturing and assembly of the Qualification Module-1 (QM-1) thruster was initiated. The Plasma Diagnostic Package was discontinued, and a decommissioning review was held in June 2022.

WORK IN PROGRESS IN FY 2023

AEPS component-level qualification testing began. QM-1 will be complete no later than April 2023. The project Key Decision Point D (KDP-D) is planned for May 2023.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

The completion of the second qualification thruster assembly (QM-2) is planned for the third quarter of FY 2024. The Qualification System Acceptance Review 1 (QSAR-1) is planned for the fourth quarter of FY 2024.

SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2024 PB Request
Formulation Authorization	Mar 2015 (as part of Asteroid Redirect Robotic Mission [ARRM])	Mar 2015 (as part of ARRM)
KDP-A	Mar 2015 (as part of ARRM)	Mar 2015 (as part of ARRM)
Preliminary Design Review	Aug 2017	Aug 2017
KDP-C	Oct 2019	Oct 2019
Delta KDP-C	-	May 2021
CDR	Mar 2022	Mar 2022
New Baseline	Mar 2022	Mar 2022
Advanced Electric Propulsion System Life Qualification Test Report	Oct 2028	Oct 2028

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2022	203.2	70%	2023	203.2	0	Electric Propulsion Thruster Life Qual Test Report	Oct 2028	Oct 2028	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**203.2**	**203.2**	**0.0**
Science/Technology	159.7	164.9	+5.2
Other Direct Project Costs	43.5	38.3	-5.2

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Project Management	Manages Aerojet Rocketdyne contract, thruster development life testing and qualification testing	Lead Center: GRC Performing Center(s): GRC Cost Share Partner(s): N/A	N/A
Thruster Development	Thruster development and life qualification testing support	Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Thruster Design	Thruster design and qualification	Provider: Aerojet Rocketdyne Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

Acquisition Strategy

All major acquisitions are in place.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Advanced Electric Propulsion System Contract	Aerojet Rocketdyne	Redmond, WA

SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
QSAR-1	SRB	July 2024	Assess/approve environmental test results for Qualification Module-1	TBD	QSAR-2
QSAR-2	SRB	Dec 2025	Assess/accept preliminary life test data for Qualification Module-2	TBD	N/A

ON-ORBIT SERVICING, ASSEMBLY, AND MANUFACTURING DEMONSTRATION-1 (OSAM-1)

Formulation	Development	Operations

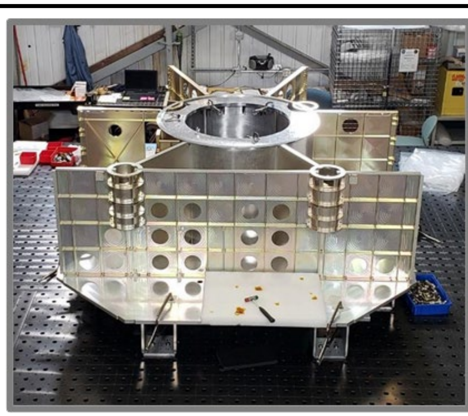
FY 2024 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028	BTC	Total
Formulation	740.6	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	740.6
Development/Implementation	299.3	227.0	227.0	**227.0**	174.5	83.8	5.4	0.0	0.0	1,244.0
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	39.2	23.3	0.0	0.0	62.5
2023 MPAR LCC Estimate	**1,040.0**	**227.0**	**227.0**	**227.0**	**174.5**	**123.0**	**28.7**	**0.0**	**0.0**	**2,047.1**
Total Budget	**1,040.0**	**227.0**	**227.0**	**227.0**	**174.5**	**123.0**	**28.7**	**0.0**	**0.0**	**2,047.1**
Change from FY 2023 Enacted				**0.0**						
Percent change from FY 2023 Enacted				**0.0%**						

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The 2023 MPAR LCC Estimate reflects the Fiscal Year 2023 Quarter 1 Financial Report, which is current as of December 2022. The requested budget authority is the project's current budget requirements.



Shown here: OSAM-1 commenced servicing payload structure assembly.

PROJECT PURPOSE

On-Orbit Servicing, Assembly, and Manufacturing Demonstration-1 (OSAM-1) is a full-scale technology demonstration featuring an on-orbit refueling mission of a U.S. government satellite in low-Earth orbit (LEO), followed by an assembly and manufacturing demonstration. The SPace Infrastructure DExterous Robot (SPIDER), which is part of this demonstration, aims to advance technologies needed for an in-space robotic manufacturing and assembly capability.

The technologies developed and demonstrated by OSAM-1 have direct applicability to future space endeavors by potentially providing technologies for space hardware capture, refueling and fluid transfer capabilities, the ability to relocate a space asset, conducting planned maintenance of client spacecraft, and the capability to assemble and manufacture structures. As part of its autonomous operations demonstration, NASA will assemble multiple antenna elements into one large antenna reflector using SPIDER. This revolutionary process allows satellites, telescopes, and other systems to use larger and more powerful components that

ON-ORBIT SERVICING, ASSEMBLY, AND MANUFACTURING DEMONSTRATION-1 (OSAM-1)

Formulation	Development	Operations

would not fit into a standard rocket fairing when assembled on the ground or without complex folding mechanisms. SPIDER is a payload developed under a NASA Space Technology Mission Directorate (STMD) Tipping Point procurement. The OSAM-1 technologies could enable entirely new architectures and space infrastructure for a wide range of government and commercial missions. The project is actively transferring technologies to the U.S. commercial sector in an effort to jump-start new product lines and services for commercial aerospace. Examples of OSAM-1 technology transferred include the gripper tool used to grapple satellites and the client berthing system.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

PROJECT PARAMETERS

OSAM-1 will demonstrate satellite servicing capabilities and in-space assembly and manufacturing capabilities. Objectives include:

- Autonomous, real-time relative navigation system, including sensors, algorithms, and processors allow the spacecraft to inspect and rendezvous safely with its client;
- Servicing avionics will control the spacecraft rendezvous and robotic tasks;
- Autonomous capture of client satellite;
- Dexterous robotic arms provide maneuverable arms for executing servicing assignments using telerobotics, including software;
- Advanced tool drive system and tools subsystem are multifunction tools for executing the servicing tasks;
- Propellant transfer system delivers measured amounts of fuel to the client at the right temperature, pressure, and rate;
- Relocation of client satellite;
- On-orbit assembly of an antenna; and
- On-orbit manufacture of a thermally stable and structural precision beam.

ACHIEVEMENTS IN FY 2022

OSAM-1 successfully completed the mission critical design review (CDR) in February 2022. Mechanical and electrical integration of the servicing payload and the spacecraft commenced. The project rebaselined in April 2022 as a result of both the COVID-19 pandemic and other non-COVID-19 impacts, which affected the project cost and schedule baseline commitments.

ON-ORBIT SERVICING, ASSEMBLY, AND MANUFACTURING DEMONSTRATION-1 (OSAM-1)

Formulation	Development	Operations

WORK IN PROGRESS IN FY 2023

In FY 2023, critical hardware work will continue with the robot subsystem. The spacecraft bus and SPIDER will be delivered to Goddard Space Flight Center (GSFC). The project will hold its systems integration review (SIR) and the space vehicle integration and testing activities will commence at GSFC.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

The project's Key Decision Point-D (KDP-D) will be held no earlier than (NET) October 2023. Integration and testing will be ongoing at GSFC.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2024 PB Request
KDP-C	May 2020	May 2020
CDR	Sep 2021	Feb 2022
New Baseline*	Apr 2022	Apr 2022
SIR	Jan 2024	NET Sep 2023
KDP-D	Feb 2024	NET Oct 2023
Operational Readiness Review (ORR)	Oct 2026	NET Dec 2025
KDP-E	Dec 2026	NET Feb 2026
Launch Readiness Review	Dec 2026	NET Feb 2026
Launch	Dec 2026	Feb 2026 - Dec 2026

**OSAM-1 was rebaselined in April 2022 as a result of the COVID-19 pandemic and other non-COVID-19 impacts that affected the project cost and schedule baseline commitments.*

ON-ORBIT SERVICING, ASSEMBLY, AND MANUFACTURING DEMONSTRATION-1 (OSAM-1)

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2022	1,244.0	~88%	2023	1,244.0	0%	Launch	Dec 2026	Dec 2026	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**1,244.0**	**1,244.0**	**-**
Spacecraft	58.7	59.4	+0.7
Payloads	484.8	534.2	+49.4
Systems I&T	114.5	106.8	-7.7
Launch Vehicle	103.5	103.5*	-
Ground Systems	44.9	46.2	+1.3
Science/Technology	0.2	0.2	-
Other Direct Project Costs	437.4	393.7	- 43.7

**Based on estimates provided at confirmation (KDP-C); estimate will be revised after contract award, expected in summer 2023.*

ON-ORBIT SERVICING, ASSEMBLY, AND MANUFACTURING DEMONSTRATION-1 (OSAM-1)

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Propellant Transfer Subsystem	Develop, test, and build of propellant transfer system.	Provider: N/A Lead Center: Kennedy Space Center (KSC) Performing Center(s): KSC, GSFC Cost Share Partner(s): N/A	N/A
Spacecraft Bus	Build and deliver a spacecraft bus to carry the payload.	Provider: Maxar Technologies Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Program Management	Project management, payload development and delivery, and mission integration.	Provider: N/A Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
SPIDER	Build and deliver the SPIDER payload.	Provider: Maxar Technologies Lead Center: GSFC Performing Center(s): GSFC, Langley Research Center (LARC) Cost Share Partner(s): N/A	N/A

Acquisition Strategy

Element/Component	Acquisition Method	Developer
Servicing Payload Robot Arm	In-house development	GSFC with Maxar Technologies as major sub
Rendezvous and Proximity Ops Cameras	NASA Competition	Neptec Design Group
LIDAR	In-house development	N/A
Vision Sensor Subsystem Cameras	NASA Competition	Malin Space Science Systems
Propellant Transfer System	Competition/Justification for Other than Full and Open Competition	Valve Tech, FHM Aerospace, Vacuum and Air Components Company of America, Hoffer

ON-ORBIT SERVICING, ASSEMBLY, AND MANUFACTURING DEMONSTRATION-1 (OSAM-1)

Formulation	Development	Operations

Element/Component	Acquisition Method	Developer
Motors Arm, next generation Tool Drive, Pan/Tilt Unit (camera), Motorized Zoom Lenses	Omnibus Multidiscipline Engineering Services contract	CDA InterCorp, Triumph, Honeybee Robotics
SPIDER	Competitively selected via STMD Tipping Point solicitation	Maxar Technologies

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Build and delivery of spacecraft bus	Maxar Technologies	Palo Alto, CA
Build and delivery of SPIDER payload	Maxar Technologies	Palo Alto, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Mission Concept Review	N/A	Apr 2016	Affirm mission need, examine proposed mission objectives, and validate the concept for meeting those objectives.	Passed	SRR
System Requirements Review (SRR)	Standing Review Board (SRB)	Oct 2016	Examine the functional and performance requirements and the preliminary project plan. Ensure the requirements and selected concept will satisfy the mission.	Passed	PDR
JCL	Tecolote	Nov 2017	Determine realistic 50/70 percent confidence level on reference budget and schedule.	N/A	PDR
Preliminary Design Review (PDR)	SRB	Nov 2017	Demonstrate the preliminary design meets all system requirements with acceptable risk and within cost and schedule constraints.	Passed	CDR

ON-ORBIT SERVICING, ASSEMBLY, AND MANUFACTURING DEMONSTRATION-1 (OSAM-1)

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
CDR	SRB	Feb 2022	Demonstrate the maturity of the design is appropriate to support proceeding with full-scale fabrication, assembly, integration, and test.	Passed	SIR
SIR	SRB	NET Sep 2023	Evaluate the readiness of the program to begin system Integration and Test with acceptable risk and within cost and schedule constraints.	TBD	ORR
ORR	SRB	NET Dec 2025	Evaluate the readiness of the program to operate the flight system and associated ground systems in compliance with program requirements and constraints during the operations phase.	TBD	N/A

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Flight Opportunities & Small Spacecraft	67.0	--	**84.0**	85.7	87.4	89.2	91.0
TDM Cryogenic Fluid Management (CFM)	60.1	--	**90.9**	99.0	99.0	99.0	99.0
TDM Space Nuclear Technologies Portfolio	66.8	--	**119.5**	170.8	240.1	344.9	350.4
TDM LeO Flight Test of an Inflatable Dec	16.6	--	**0.0**	0.0	0.0	0.0	0.0
TDM Mars Oxygen ISRU Experiment (MOXIE)	1.7	--	**0.0**	0.0	0.0	0.0	0.0
TDM OSAM-2 (Archinaut)	10.4	--	**3.3**	0.0	0.0	0.0	0.0
TDM Deep Space Optical Comm (DSOC)	5.4	--	**3.5**	2.7	0.1	0.0	0.0
TDM Laser Comm Relay Demo (LCRD)	4.2	--	**0.0**	0.0	0.0	0.0	0.0
Tech Demo Selected ACO/TP	0.5	--	**0.0**	0.0	0.0	0.0	0.0
Tech Demo Management and Integration	5.2	--	**12.4**	15.9	16.4	16.9	50.9
Total Budget	**237.8**	**--**	**313.5**	**374.1**	**443.0**	**550.0**	**591.3**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Shown here are the four Starling 6U spacecraft undergoing solar array deployment testing during integration at NASA Ames Research Center. The Starling launch is currently slated for mid-to-late 2023.

FLIGHT OPPORTUNITIES (FO) AND SMALL SPACECRAFT TECHNOLOGY (SST)

This portfolio increases the pace of space exploration, discovery, and the expansion of space commerce through the rapid identification, development, and testing of capabilities that exploit agile spacecraft platforms and responsive launch capabilities from industry providers. It pursues risk-tolerant technology development and rapid access to space test conditions, both suborbital and orbital, to de-risk technologies for future applications. FO and SST engage in collaborations with U.S. commercial industry and academia to support American global competitiveness and leadership in space.

Through flight tests of payloads with commercial flight providers, FO matures the capabilities needed for NASA missions and commercial applications, while strategically investing in the growth of the U.S. commercial spaceflight industry. The annual flight test activity varies based on commercial suborbital vehicle flight rates but has averaged 59 payloads per year. These tests take technologies from ground-based laboratories into relevant flight environments to increase technology readiness and validate feasibility, while reducing the costs and technical risks of future missions.

SST aims to enable execution of missions at much lower cost than previously possible and substantially reduces the time required for development of spacecraft. In addition, the program enables new mission architectures and expands the reach of small spacecraft to new destinations and different environments such as the Moon.

Space-Based Manufacturing, Commercial Research, and Space Commerce

One area of focus for FO has been testing space-based manufacturing technologies that address both future NASA needs and opportunities for commercial industry. Capabilities for in-space manufacturing, as well as technologies that further commercial in-space biological and physical research capabilities, can not only assist NASA with plans for the next wave of human exploration beyond Earth, but are also enabling for companies exploring innovative products that can only be discovered or produced in microgravity.

Industry Collaborations and Space Test Capability Enhancements

In addition to purchasing flights, FO also invests directly in U.S. commercial spaceflight capabilities. The program partners with commercial flight providers on the development of new space test capabilities and aims to provide researchers with access to additional emerging commercial space test offerings. Similarly, SST not only leverages commercial small spacecraft capabilities to test technologies for NASA missions but also seeks to expand the capabilities of the U.S. small spacecraft industry. Focus areas include:

- Expanding Collaboration with Industry and Commercial Partnerships
    - FO seeks to expand collaborations with the U.S. commercial spaceflight industry to advance space test capabilities through industry partnerships. In collaboration with the SST Program, FO is interested in providing cost-effective access to a continuum of relevant test environments and commercial capabilities using suborbital vehicles and orbital platforms. This includes hosting of suborbital payloads on recoverable orbital rocket stages and hosting of small payloads on commercial spacecraft.
    - SST seeks to expand collaboration through commercial partnerships. The Small Spacecraft Technology Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) mission is not only a precursor for lunar exploration but is also intended to lay the groundwork for future commercial support of missions beyond Earth. As a NASA-sponsored but commercially owned and operated spacecraft, CAPSTONE represents an innovative approach to deep space missions. The Pathfinder Technology Demonstrator 3 (PTD-3) mission that helped demonstrate record breaking optical communications speeds uses a commercial spacecraft and commercial operations. The upcoming Starling mission will not only demonstrate distributed mission capabilities and autonomous reactive operations for NASA missions but is also partnered with industry to develop technologies and protocols that can help constellations of spacecraft from different operators safely cohabitate similar orbits.
- Supporting Vehicle Capability Enhancements
    - Through contracts, Space Act Agreements, and purchase of payload space, Flight Opportunities continues its support of capability enhancements for select commercial suborbital flight vehicles. These new capabilities are expected to expand the options available to program awardees for flight testing.

- Continuing collaboration with other NASA mission directorates and offices
  - For scientific research payloads, the program recently collaborated with NASA's Science Mission Directorate (SMD) to include the use of commercial flight providers contracted through FO as an option for testing suborbital science payloads under the 2022 Research Opportunities in Space and Earth Science solicitations. Flight Opportunities is also collaborating with NASA's Suborbital Crew office to develop a process for NASA personnel to fly on vehicles such as Blue Origin's New Shepard and Virgin Galactic's SpaceShipTwo. These types of opportunities for cross-directorate collaboration are planned to continue.

Continued Access to Flight Testing for Accademia and Early Career Workforce

The NASA TechRise Student Challenge is a hands-on competition, which received over 500 applications in 2022 from 39 states and territories and invites students in grades 6-12 to submit ideas for experiments related to areas including climate research, remote-sensing, and space exploration to fly aboard a high-altitude balloon. The winning teams received $1,500 to build their payloads and will also be awarded an assigned spot on a NASA-sponsored commercial suborbital flight.

NASA's University SmallSat Technology Partnership (USTP) initiative supports university-based technologies with the potential to advance the small spacecraft industry. USTP aims to enhance the capabilities of SmallSats as a platform for innovative research and technology demonstrations, contributing to the Nation's lunar and deep space exploration objectives and high-priority science. To accomplish this, USTP facilitates collaborations between accredited U.S. colleges and universities and NASA centers across the country.

In addition to the activities above, FO and SST lead STMD's participation in the NASA CubeSat Launch Initiative, which provides access to space for CubeSats built by U.S. universities, high schools, middle schools, non-profit organizations, and NASA's early-career workforce.

FO and SST Demonstration Missions of Opportunity

Traditional multi-year budgeting and acquisition cycles do not readily address challenges related to the fast pace of space technology innovation, changing geopolitical and market environments, and the typical 24-month development target for small missions. As such, FO and SST make use of a flights-of-opportunity and missions-of-opportunity-based approach that improves the ability to work with the entrepreneurial space industry and increases the agility and effectiveness of portfolio. For FY 2024, the portfolio intends to target the following areas:

- Advancing commercial microsatellite and orbital maneuvering vehicle systems for continued expansion of small risk-tolerant missions further beyond Earth and for advanced near-Earth applications. Such systems can support cislunar operations, science, planetary defense, and orbital debris mitigation.
- Enabling lunar utilization infrastructure via commercial flight-testing opportunities (especially suborbital) for lunar communication, positioning, navigation, and timing capabilities as well as in-situ resource utilization and advanced manufacturing.

In FY 2024 and beyond, FO and SST plan to continue to increase the pace of space exploration and discovery by leveraging small spacecraft and responsive launch capabilities to rapidly expand U.S. capabilities at dramatically lower costs, while supporting American global competitiveness and leadership in space.

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

ACHIEVEMENTS IN FY 2022

- FO conducted 97 flight tests of payloads across 28 suborbital flights with commercial flight providers.
- As part of NASA's In Space Production Applications (InSPA) project, Space Fibers 3 and Orbital Fiber Optic Production Module transitioned to the International Space Station as part of SpaceX Commercial Resupply Services mission CRS-25, arriving July 16, 2022. The orbital demonstrations on station are intended to enable InSPA to assess results and inform future hardware improvements and steps toward potential optical fiber manufacturing in space in the coming years.
- FO NASA TechLeap Prize is intended to increase the speed with which impactful technologies can be identified and tested on suborbital flights. The TechLeap Prize will also increase access to flight tests for small and entrepreneurial organizations.
  - The Nighttime Precision Landing Challenge No. 1 launched on February 15, 2022, and three winners were selected on June 23, 2022.
  - Flight tests for the three Autonomous Observation Challenge No. 1 winners occurred in July and August 2022.
- SST launched four spacecraft into low-Earth orbit and one spacecraft to the Moon, including:
  - CAPSTONE, which launched June 28, 2022, and arrived in a near-rectilinear halo orbit (NRHO) on November 13, 2022. As a precursor for the Artemis Campaign, CAPSTONE will help reduce risk for future spacecraft by validating innovative navigation technologies and verifying the dynamics of the NRHO that is planned for use by future lunar missions. For more information, go to: https://www.nasa.gov/directorates/spacetech/small_spacecraft/capstone
  - Lunar Flashlight, which launched in November 2022 and will precede human explorers to the Moon to prospect for water resources that can be extracted to support sustainable exploration and commercial lunar activity. The CubeSat will use near-infrared lasers to shine light into permanently shadowed craters at the lunar south pole, while the onboard spectrometer measures surface reflection and composition to map water ice deposits and volatiles. For more information, go to: https://www.nasa.gov/directorates/spacetech/small_spacecraft/What_is_Lunar_Flashlight
  - PTD-3 is carrying the TeraByte InfraRed (TBIRD) laser communications system and launched on May 25, 2022. TBIRD is targeting a 200 gigabits per second (Gbps) optical downlink using modified terrestrial fiberoptic components. As of January 2023, the system had demonstrated a record setting downlink in excess of 100 Gbps, transferring over 1.4 terabytes of information from the PTD-3 CubeSat in low-Earth orbit to the ground in under 5 minutes. For more information, go to: https://www.nasa.gov/directorates/spacetech/small_spacecraft/Pathfinder_Technology_Demonstrator/

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

WORK IN PROGRESS IN FY 2023

- FO TechLeap Prize:
    - Suborbital flight tests for the Nighttime Precision Landing Challenge No. 1 winners are planned for spring 2023.
    - Reflights to further advance the technologies for the three Autonomous Observation Challenge No. 1 winners are planned for mid-2023.
- FO announced the second NASA TechRise Student Challenge, and winning teams from across the U.S. were announced in January 2023. Flights are currently scheduled for summer 2023.
- SST has 17 Earth-orbiting spacecraft being readied for launch through the end of FY 2024, including:
    - Starling is an orbital flight test that will deploy a formation of four CubeSats to test multiple distributed mission technologies. Distributed systems of small spacecraft can responsively provide cost-effective multi-point science data collection, communications, monitoring, and in-space inspection infrastructure. An extended mission in work for Starling will develop and demonstrate both the technology and operational protocols for autonomous maneuvering coordination between spacecraft constellations from different operators. These new protocols will help mitigate future orbital debris concerns from commercial mega constellations. The Starling launch is currently slated for mid- to late-2023 based on launch vehicle scheduling. For more information, go to: https://www.nasa.gov/directorates/spacetech/small_spacecraft/starling/

KEY ACHIEVEMENTS PLANNED FOR FY 2024

In 2024, Small Spacecraft anticipates launch of nine small spacecraft that are currently in development. These include demonstration of the Courier CubeSat scale solar electric propulsion public-private partnership with ExoTerra, two Pathfinder Technology Demonstrator missions with Terran Orbital, and the Aerospace Corporation led DiskSat demonstration in partnership with the United States Space Force. While Flight Opportunities suborbital testing cadence varies based on commercial vehicle flight rates, the program projects that over 60 payloads will be tested in 2024. Flight Opportunities also anticipates completion of several current vehicle capability partnerships in 2024, including initial use of new rocket powered decent and landing test bed capabilities in development with Astrobotic Technology.

In FY 2024, the Flight Opportunities and Small Spacecraft Technology portfolio will continue to de-risk technologies for future exploration, science, commercial, academic, and OGA missions. The programs will also continue to initiate and execute collaborations with the commercial suborbital and spaceflight industry to advance U.S. space test capabilities. These efforts will include:

- TechLeap Prize opportunities;
- TechRise student challenges;
- TechFlight awards;
- University SmallSat Technology Partnerships; and
- Flights and Missions of Opportunity.

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

OTHER TECH DEMO

Cryogenic Fluid Management (CFM)

CFM is an enabling technology that holds the potential to support a human presence on a planetary surface as well as long-duration spaceflight by optimizing the preservation of chemical propellants. Improved cryogenic fluid management helps enable in-space transportation systems, such as human lander systems, lunar and, eventually, Mars surface operations, including in-situ resource utilization. Missions that involve durations ranging from months to multiple years are far beyond the current state-of-the-art capabilities for in-space cryogenic fluid management. The CFM portfolio's goal is to advance and demonstrate technologies enabling autonomous transfer and storage of cryogenic propellants, capable of scaling to tens of metric tons, with negligible losses for long duration in space and on the lunar surface.

As part of the 2020 Tipping Point solicitation process, NASA selected four companies for milestone-based firm-fixed price contracts to demonstrate cryogenic fluid technologies in the areas of passive thermal control, tank pressure control, active cooling, and tank-to-tank propellant transfer. The four Tipping Point contracts were awarded between April and September 2021 and are expected to launch between FY 2023 and FY 2025.

Additionally, as part of the CFM portfolio, NASA has contracts to advance cryocoolers, a technology critical to long duration storage of cryogens, as well as a variety of in-house work related to the storage, transfer, and mass gauging of cryogenic fluids.

Fission Surface Power (FSP)

As a part of the Space Nuclear Technologies portfolio, FSP is developing a small, lightweight fission power system that will enable long-duration lunar surface operations and is extensible for use on Mars. The goal is to demonstrate an integrated fission power system on the lunar surface to verify the engineering function, power performance, and operational reliability of the capability. Following a successful demonstration, this power technology could form a key capability for long-duration human surface missions on the Moon and eventually Mars. The technology could enable mission operations in harsh environments, such as permanently shadowed craters and the 14-day lunar night away from the poles, and satisfy mission needs for continuous solar-independent power operations. This work is being conducted in collaboration with the Department of Energy to optimize the use of common technology found in terrestrial fission power systems. NASA will explore technology synergies for Nuclear Electric Propulsion and potential collaborations with the United States Space Force.

In FY 2023, NASA will finish the industry-led Phase I designs for an integrated lunar fission power system which is considered foundational to the Agency’s ability to formulate a strategy leading to the design, build, and test of the first ever space fission power system for deployment to and demonstration on the lunar surface. Additional investments will be made to advance fission fuels and reactor materials needed to address the unique engineering requirements of space fission power systems. NASA will also continue industry engagements on the design of integrated power systems and advanced Brayton energy conversion systems to gain alignment with industry concepts and the potential for power growth.

Nuclear Propulsion

NASA will continue to advance solutions to existing technology gaps necessary for the design of safe and reliable propulsion systems. These gaps include advancing high-temperature reactor fuel, materials, and designs, as well as methods for managing cryogenic propellants. In 2023, NASA and the Defense Advanced Research Projects Agency (DARPA) announced a collaboration to demonstrate a nuclear thermal rocket engine in space. NASA and DARPA will partner on the Demonstration Rocket for Agile Cislunar Operations, or DRACO, Program.

Both agencies established an agreement that defines roles and responsibilities in a jointly managed flight demonstration project where NASA will have the responsibility to fund and manage the development, design, and test of the nuclear thermal propulsion engine. DARPA will have the responsibility to fund and manage development and design of the flight vehicle, assembly, integration and testing of the integrated system, launch of the demonstrator, and flight operations. Overlapping collaboration opportunities under the proposed NASA-DARPA flight demonstration include cryogenic fluid management technologies, advanced fission fuels, and reactor materials. NASA plans to continue current industry-led reactor designs, which can be used to enhance the overall performance of the reactor and engine.

On-Orbit Servicing, Assembly, and Manufacturing Demonstration-2 (OSAM-2/Archinaut)

In partnership with the commercial space industry, NASA is developing and will demonstrate technologies required to manufacture, assemble, and aggregate large and/or complex systems in space utilizing robotic and additive manufacturing technology.

Made In Space (now Redwire) was awarded a contract in July 2019 to develop a flight demonstration payload of their Phase I ground demonstration technology. Once deployed and positioned in orbit, a small spacecraft will 3D-print two beams. The first beam will extend nearly 33-feet from one side of the spacecraft while deploying a solar array surrogate. The second beam will extend nearly 20-feet from the opposite side of the spacecraft. This disruptive capability could transform the traditional spacecraft-manufacturing model by enabling in-space creation of large spacecraft systems. No longer will developing, building, and qualifying a spacecraft focus so heavily on an integrated system that must survive launch loads and environments. OSAM-2/Archinaut could reduce costs while increasing capabilities for both NASA and commercial space applications.

Deep Space Optical Communication (DSOC)

Deep Space Optical Communication technologies are considered essential for future human missions to Mars and have a wide range of applications for planetary science missions including those to Mars and the Jovian systems, as well as other deep space distance exploration missions. The DSOC project, led by JPL, will develop key technologies for the demonstration of a deep space optical flight transceiver and ground receiver that will provide greater than 10 times the data rate of a state-of-the-art deep space radio frequency system (Ka-band). This capability will enable advanced instruments, live high-definition video, and telepresence that allow for deep space human exploration of the solar system.

NASA successfully completed and reduced significant risks on DSOC technologies, including a low-mass spacecraft disturbance isolation assembly, a flight qualified photon counting detector array, a high-efficiency flight laser amplifier, and a high-efficiency photon counting detector array for the ground-based receiver. Combined, these components and subsystems make up the DSOC system, which will demonstrate the high-bandwidth flight laser optical communication terminal on the SMD's Psyche mission. DSOC was delivered on time in June 2021 and integrated onto Psyche in FY 2022 and is planned to launch on Psyche in FY 2024.

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

Recent and Planned Achievements

- Fission Surface Power: NASA awarded three 12-month, Phase I contracts on June 21, 2022, to industry for initial FSP system designs. The selected companies are Lockheed Martin, Westinghouse, and Intuitive Machines/X-Energy (IX). In FY 2023, NASA will finish the industry-led Phase I designs for an integrated lunar fission power system.
- Nuclear Propulsion: The industry-led Phase 1 reactor designs were completed, and nuclear thermal propulsion engine fuel sub-element testing was conducted in FY 2022. Works in progress in FY 2023 include the extension of the industry-led reactor designs to demonstrate manufacturability and operational feasibility and initiating NASA-DARPA flight demonstration project partnership. Key achievements planned for FY 2024 include advancing the design of a fission reactor for an integrated propulsion system that can be demonstrated in cislunar space.
- CFM Tipping Point:
  - SpaceX Test Configuration Design Review was held in April 2022 and successfully completed a ground demo test in June 2022. Launch is planned for FY 2023.
  - Eta Space held the Preliminary Design Review in February 2022, its Critical Design Review (CDR) part one in August 2022, and Mission Design Review in November 2022. Launch is planned for FY 2024.
  - Lockheed Martin held a Technology Maturation Review (TMR) 1 in December 2021, TMR 2 in March 2022, TMR 3 in June 2022, and TMR 4 in October 2022. Launch is planned for FY 2025.
  - ULA held its System Requirements Review in March 2022 and Program Status Reviews in April 2022 and September 2022. Launch is planned for FY 2026.
- LOFTID completed Assembly, Integration and Test activities and was delivered to Vandenberg Space Force Base on August 14, 2022. The project launched on November 10, 2022, as a rideshare with the Joint Polar Satellite System-2 spacecraft on the Atlas V. The project completed its flight demonstration with a successful atmospheric reentry, and reentry vehicle and ejectable data module ocean recovery.
- MOXIE continues oxygen production runs on Mars (12 to date).
- OSAM-2/Archinaut completed a CDR in December 2021.
- DSOC was completed and integrated onto Psyche and will launch with Psyche no earlier than October 2023.
- Laser Communications Relay Demonstration launched on STPSat-6 for the U.S. Space Force STP-3 mission on December 7, 2021 and initiated the two-year demo operations in May 2022.

Acquisition Strategy

These critical technology projects are defined as part of the strategic framework and capabilities, and through requirements determined by the Federated Board and through STMD's Strategic Technology Architecture Roundtable process. In addition, Space Technology embraces competition and external partnerships; as such, some of the technologies are selected through annual Tipping Point, Announcement of Collaboration Opportunity, and other NASA solicitations.

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
OSAM-2/Archinaut	Redwire	Jacksonville, FL

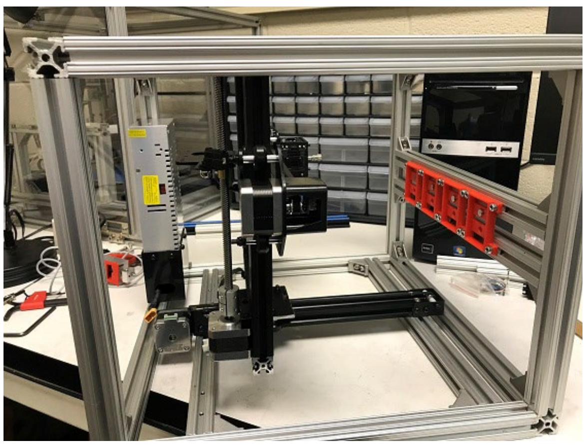
SBIR AND STTR

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	227.0	--	299.9	305.9	312.0	318.2	324.6

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



Morningbird Media partnered with HBCU Alabama A&M University (AAMU) on the development of the Electronic Alchemy eForge, a 3D electronics printer (shown here) to help NASA support long-duration missions. The work of the AAMU researchers and the Morningbird Media team led to the development of six new materials with electronic properties, which have all been submitted for patents.

NASA's Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs leverage the Nation's innovative small business community to fund research and development in support of NASA's mission in space technology, human exploration, science, and aeronautics. These programs will also support NASA's Artemis Program objectives by identifying and accelerating relevant technologies throughout all phases (Phase I, II and Post Phase II). Post Phase II awards may involve matching funding from investors and encouraging the advancement of innovations and commercialization of technologies developed through Phase I and Phase II. These programs provide the small business sector with an opportunity to develop and commercialize technology for NASA to spur economic growth. NASA's SBIR/STTR programs will expand efforts to increase participation by women, socially or economically disadvantaged businesses, historically black colleges and universities (HBCU), and minority serving institutions (MSI), while also emphasizing entrepreneurial engagement.

The Agency actively works to facilitate the transition of NASA-funded SBIR and STTR technologies into missions, projects, and commercial applications. SBIR/STTR funded research and technologies have made important contributions to the Agency's mission, such as:

- Rover Slip Estimation and Traction Control for Optimal Mobility in Lunar Environments, which provides improved robotic and manned rover wheeled locomotion on the Moon and is supporting the Volatiles Investigating Polar Exploration Rover (VIPER) mission.
- Roll-Out Solar Arrays technology, which greatly improves on traditional solar panels compactness, weight, and affordability without compromising on strength and is being tested on the International Space Station and the Double Asteroid Redirection Test (DART) spacecraft.
- In collaboration with the Small Spacecraft Technology (SST) program, the Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) project

utilized both a SBIR Phase III contract mechanism funded by SST and a Phase IIE cofounded by SBIR and SST. CAPSTONE was built on numerous prior SBIR/STTR Phase I and II investments that helped develop many of the underlying technologies for this lunar exploration precursor mission.

The SBIR and STTR program elements are as follows:

SBIR

The SBIR program was established by statute in 1982 and was most recently reauthorized in 2022 to increase research and development opportunities for small businesses. The program stimulates U.S. technological innovation, employs small businesses to meet Federal research and development needs, increases the ability for small businesses to commercialize innovations they derive from Federal research and development, and encourages and facilitates participation by socially disadvantaged businesses. The SBIR program budget is based on a level of at least 3.2 percent of NASA's extramural research and development budget. The maximum value for an SBIR Phase I contract is $150,000 for a period of performance of six months. NASA raised the maximum total value of an SBIR award from $750,000 to $850,000 over a 24-month period of performance for Phase II awards made from the FY 2022 solicitation, which will be awarded in FY 2023. NASA also supports several Post Phase II vehicles:

- Phase II-E is a contract opportunity on Phase II awards that provides incentives for cost sharing with non-SBIR investors to extend the research and development efforts of the current Phase II contract.
- Civilian Commercialization Readiness Pilot Program (CCRPP) contracts with non-SBIR investors with incentives for cost sharing to extend the research and development efforts of previous Phase II contracts with strong customer pull for technology maturation and commercialization.
- Phase II sequential contracts help accelerate the technology readiness level (TRL) of technologies to a point that other investors will then advance the technology or to rapidly advance the TRL of a technology to enable NASA programs.
- I-Corps training grants to enable small businesses to commercialize their innovations through an Interagency Agreement with the National Science Foundation.

STTR

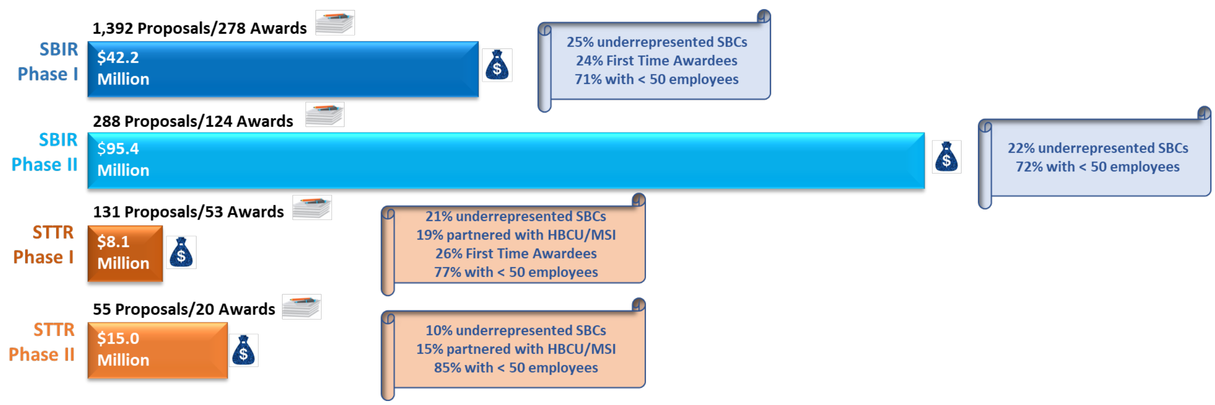
The STTR program was established by statute in 1992 and reauthorized in 2022 to award contracts to small businesses for cooperative research and development with a non-profit research institution, such as a university. NASA's STTR program facilitates the transfer of technology developed by a research institution through the entrepreneurship of a small business, resulting in technology to meet NASA's core competency needs in support of its mission programs. Modeled after the SBIR program, STTR is funded based on 0.45 percent of the NASA extramural research and development budget. The maximum value for an STTR Phase I contract is $150,000 for a period of performance of 13 months. For Phase II, NASA is planning to raise the maximum total value of an STTR award from $750,000 to $850,000 over a 24-month period of performance for Phase II awards made from the FY 2022 solicitation, which will be awarded in FY 2024. Phase II E, CCRPP, Phase II sequential contracts, and I-Corps are also available to STTR participants.

SBIR AND STTR

EXPLANATION OF MAJOR CHANGES IN FY 2024

NASA's SBIR/STTR programs will continue to expand efforts to increase participation by women, socially or economically disadvantaged businesses, HBCUs, and MSIs, while also emphasizing entrepreneurial engagement. For example, the program office released a new Intern Diversity Supplement, which will fund internships for placement of diverse interns with Phase II companies in FY 2024 and increase participation from HBCUs by coordinating with NASA's Minority University Research and Education Project (MUREP).

ACHIEVEMENTS IN FY 2022



- STMD collaborated across NASA mission directorates, centers, and industry to identify subtopics for the FY 2022 Solicitation, which was released in January 2022 and supports Artemis, climate change, and clean energy solutions, including five awards on nontraditional airspace operations and aerial wildfire response. Additionally, the Phase II Sequential Program made two wildfire related technology awards: an unmanned aerial vehicle (UAV) airborne sensor instrument for measurements near wildfires and thermal mapping and a measurement system for UAVs or small satellites to enhance wildfire studies.
- For the first time in ten years, NASA increased award amounts for SBIR Phase I from $125,000 to $150,000, which further supports industry in meeting NASA technology needs.
- Implemented techniques to further accelerate award timelines and improve the approachability to entrepreneurial aerospace companies and underrepresented communities.
- Encouraged participation of underrepresented groups, such as Minority Serving Research Institutions, through planning grants with MUREP.
- Hosted a Climate Technology Roundtable with non-profits and private industry representatives around topics that could benefit early stage investments. Such topics included carbon removal/sequestration and climate data modeling and sensors.

WORK IN PROGRESS IN FY 2023

- The program office will continue to expand efforts to encourage participation of underrepresented groups. The program office released a new Intern Diversity Supplement, which will fund internships for placement of diverse interns with Phase II companies in FY 2024 and increase participation from HBCUs by coordinating with MUREP on their road-tours.

- Selected 12 firms for award under the pilot solicitation SBIR Ignite, which focused on commercially viable technology ideas with an emphasis on entrepreneurial engagement to encourage commercialization and economic impact.
- For the first time in ten years, NASA will increase the award amounts for SBIR Phase II's from $750,000 to $850,000, which further supports industry in meeting NASA technology needs.
- Continue outreach approach to engage innovators in locations and regions across the country by holding smaller focused webinars with targeted audiences and focused timing.
- In accordance with the new 2022 reauthorization language, NASA will implement a new due diligence program to prevent foreign influence or abuse.
- Continue to pilot opportunities to accelerate efforts in deep space exploration, climate, and clean energy technology development.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

- SBIR and STTR will continue efforts to encourage participation of underrepresented groups across the Nation to expand inclusive innovation.
- SBIR and STTR intends to award over 460 new awards, grants, and contracts to small businesses, as well as incubating and maturing NASA commercial partnerships through post Phase II activities such as sequential Phase II awards.
- Program will pilot ways to reduce barriers to entry and streamline the small business experience throughout the program phases, including strategies to encourage transition to NASA, government, and/or commercial use beyond SBIR/STTR awards.

Program Management & Commitments

Program Element	Provider
SBIR and STTR	Provider: Various Small Businesses and their research partners Lead Center: NASA HQ; Level 2: Ames Research Center (ARC) Performing Center(s): All centers play a project management and implementation role. Cost Share Partner(s): SBIR/STTR Phase II-E matches cost share funding with SBIR and STTR up to $375,000 of non-SBIR and non-STTR investment(s) from a NASA project, NASA contractor, other government agency, or third-party commercial investor to extend an existing Phase II project to perform additional research. SBIR/STTR CCRPP matches cost share funding up to $2,500,000 of non-SBIR and non-STTR investment(s) from a NASA project, NASA contractor, other government agency, or third-party commercial investor to continue a former Phase II project to perform additional research for strong customer pull for the technology maturation, commercialization, and ultimately utilization versus incremental development.

SBIR AND STTR

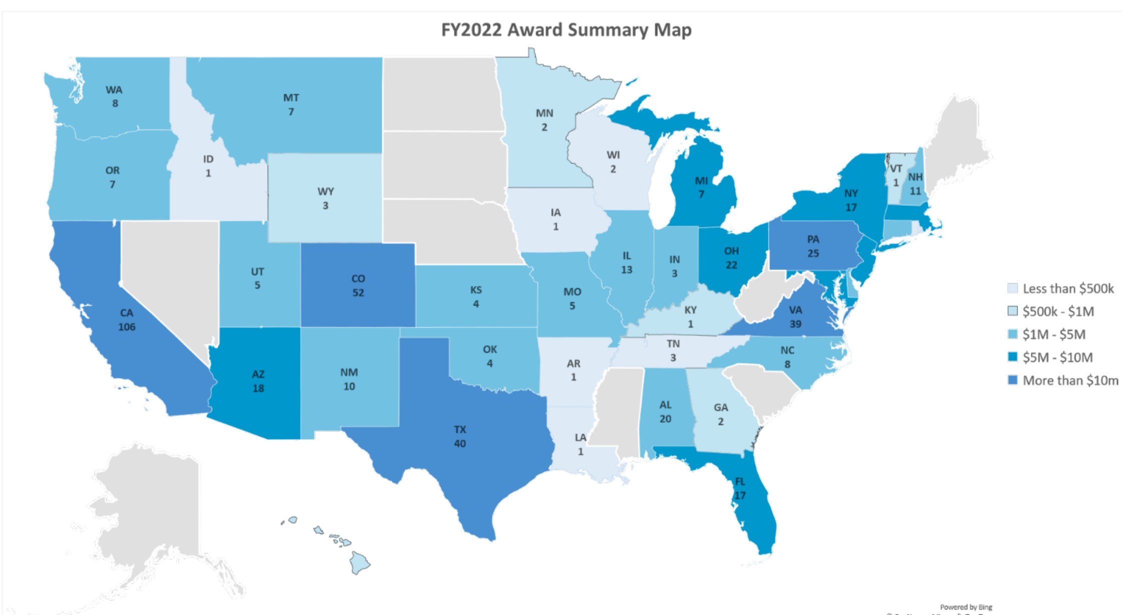
Acquisition Strategy

NASA issues annual SBIR and STTR program solicitations, setting forth a substantial number of topic areas open to qualified small businesses. There are three phases for SBIR and STTR funding awards. Phase I awards give small businesses the opportunity to establish the scientific, technical, and commercial merit of the proposed innovation in alignment with NASA interests. The most promising Phase I projects are selected for Phase II awards through a competitive selection process based on scientific and technical merit, expected value to NASA, and commercialization potential. Phase II awards focus on the development, demonstration, and delivery of the proposed innovation. SBIR Ignite is a new experiment in Phase I and II awards seeking to fund ideas that are relevant in the commercial market with a proposal process more closely aligned with what firms would see through a venture financing process. Phase II Sequentials, Phase II-E, and CCRPP support advancement of innovations developed under Phase II. Phase III supports the commercialization of innovative technologies, products, and services that result from a Phase I or Phase II contract. Commercialization includes further development of technologies and getting feedback to discover infusion opportunities into NASA programs, other government agencies, or the private sector. Phase III contracts receive funding from sources other than the SBIR and STTR programs and may be awarded without further competition.

SBIR and STTR program management work collaboratively with NASA center Chief Technologists (for STTR) and the mission directorates (for SBIR) during the acquisition process. This collaboration, from topic development through proposal review and ranking, supports the final selection of proposals of high value to NASA. Mission directorates and center program personnel interact with SBIR and STTR award winners to maximize alignment and implementation of the SBIR and STTR products with NASA's future missions and systems.

Award Distribution

The map below represents the FY 2022 SBIR and STTR investments through Phase I, Phase II, Phase II-E, Sequential, and CCRPP awards.



SCIENCE

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Earth Science	2,061.2	2,195.0	**2,472.8**	2,597.5	2,730.0	2,791.2	2,849.0
Planetary Science	3,120.4	3,200.0	**3,383.2**	3,265.8	3,246.1	3,350.8	3,389.7
Astrophysics	1,568.9	1,510.0	**1,557.4**	1,622.1	1,665.9	1,689.6	1,749.4
Heliophysics	777.9	805.0	**750.9**	837.4	847.3	827.4	844.0
Biological and Physical Sciences	82.5	85.0	**96.5**	103.2	105.3	107.4	109.6
Total Budget	**7,610.9**	**7,795.0**	**8,260.8**	**8,426.0**	**8,594.5**	**8,766.4**	**8,941.7**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

SCIENCE

FY 2024 Budget

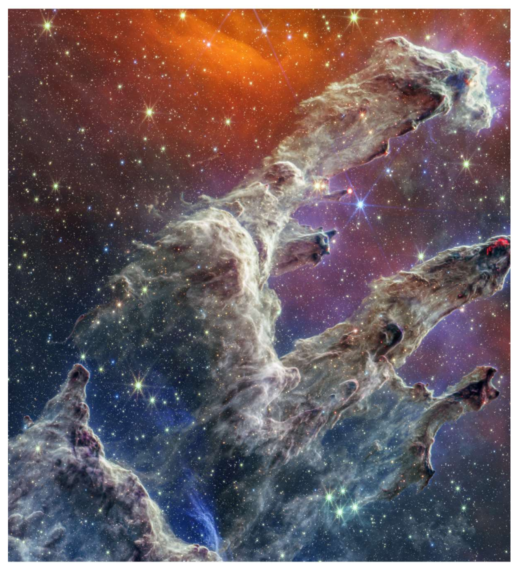
Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Earth Science	2,061.2	2,195.0	**2,472.8**	2,597.5	2,730.0	2,791.2	2,849.0
Planetary Science	3,120.4	3,200.0	**3,383.2**	3,265.8	3,246.1	3,350.8	3,389.7
Astrophysics	1,568.9	1,510.0	**1,557.4**	1,622.1	1,665.9	1,689.6	1,749.4
Heliophysics	777.9	805.0	**750.9**	837.4	847.3	827.4	844.0
Biological and Physical Sciences	82.5	85.0	**96.5**	103.2	105.3	107.4	109.6
Total Budget	**7,610.9**	**7,795.0**	**8,260.8**	**8,426.0**	**8,594.5**	**8,766.4**	**8,941.7**
Change from FY 2023 Enacted			**465.8**				
Percent change from FY 2023 Enacted			**6.0%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Since NASA's inception, scientific discovery about our Earth, the Sun, the solar system, and the universe beyond has been an enduring purpose of the Agency. NASA's Science Mission Directorate (SMD) conducts scientific exploration enabled by space-based observatories which observe the Earth, perform fundamental research, visit other bodies in the solar system, and gaze out into the galaxy and beyond. NASA's scientific exploration will also inform human exploration of the Moon, Mars, and the solar system, providing valuable scientific data for such human missions. The goal of NASA's science programs is to expand human knowledge through new scientific discoveries, focused on three objectives:

- Understand the Earth system and its climate;
- Understand the Sun, solar system, and universe; and
- Ensure NASA's science data are accessible to all and produce practical benefits to society.



By combining images of the iconic Pillars of Creation, shown here, from two cameras aboard NASA's James Webb Space Telescope, the universe has been framed in its infrared glory. Webb's near-infrared image was fused with its mid-infrared image, setting this star-forming region ablaze with new details.

NASA also strives to drive discovery by studying biological and physical phenomena in space. SMD utilizes technological advances and new partnership opportunities, including public-private partnerships that leverage commercial investments to further NASA's science objectives.

NASA's science programs also help protect and improve life on Earth through fundamental research that enables innovative and practical applications for decision-makers, including disaster response, natural resource management, and planetary defense. The Agency continues to focus on improving its operations and launching its science missions on schedule and on budget. NASA's discoveries continue to rewrite textbooks, inspire learners of all ages, and demonstrate U.S. leadership worldwide.

The Science Mission Directorate (SMD) uses the recommendations of the National Academies' decadal surveys as important inputs in planning and prioritizing the future of its science programs. For almost 60 years, decadal surveys have proven vital in establishing a broad consensus within the national science community on the state of science, the highest priority science questions we can address, and actions we can take to answer those questions. SMD uses these recommendations to prioritize future flight missions (including space observatories and probes) as well as technology development and proposals for theoretical and suborbital supporting research. In 2022, the Agency received a new decadal survey for Planetary Science titled "Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023 - 2032." NASA expects to receive decadal surveys for Biological and Physical Sciences (2023) and Heliophysics (2024) in the coming years. In determining the content of the Science portfolio, NASA also considers national priorities and policies, budgets, existing technological capabilities, partnership opportunities, and other programmatic factors.

EXPLANATION OF MAJOR CHANGES IN FY 2024

The budget provides $8.3 billion for Science, including funds for the James Webb Space Telescope, the Mars Sample Return (MSR) mission, and implementation of the Earth System Observatory. Within Earth Science, the budget initiates four Earth System Observatory missions: Surface Biology and Geology, Atmospheric Observing System - Sky, Atmospheric Observing System - Storm, and Mass Change. These missions will provide key information to guide efforts related to climate change, natural hazard mitigation, fighting forest fires, and improving agricultural processes. In addition, the budget supports the initiation of the Landsat Next mission, which will ensure continuity of the longest space-based record of Earth's land surface and will provide new capabilities for the next generation of Landsat users. The budget is consistent with NASA's decision in 2022 to cancel development of the GeoCarb mission. In addition, the budget proposes increased investments within Applied Sciences to expand efforts to build capacity for understanding and using NASA Earth observations, and to accelerate applications development work with users in the agriculture sector.

Within Planetary Science, additional funds are requested to support development of the MSR mission and to begin design of the Mars Sample Receiving facility. MSR is a partnership with the European Space Agency (ESA) to bring the first samples of Mars material back to Earth for detailed study, including samples already collected and cached by the Mars Perseverance rover. NASA will reassess the Mars Sample Return architecture this year, and will consider potential descopes such as the elimination of one of the mission's two helicopters, in order to improve the cost posture of the mission. In addition, the budget supports NASA contributions towards the ESA ExoMars Rover mission. The budget also includes additional funding to support launch of the Near-Earth Object Surveyor (NEO Surveyor) in 2028. Consistent with NASA's announcement in 2022, the budget supports a one-year delay of the Psyche mission launch, now expected in October 2023. The Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy (VERITAS) mission has been delayed by at least three years, pending the resolution of workforce issues at Jet Propulsion Laboratory and future budget developments. Within the Lunar Discovery and Exploration Program, the budget requests additional funding to support a one-year launch delay of the Volatiles Investigating Polar Exploration Rover (VIPER) lunar rover from 2023 to 2024, and funding for Artemis instruments to develop handheld and deployable instruments for crew beyond Artemis III. As an initial response to the 2022 Planetary Science Decadal survey, additional funding is requested for Planetary Science Research and Analysis to increase the amount of competed science awarded each year.

Within Astrophysics, the budget requests funding for closeout of the Stratospheric Observatory for Infrared Astronomy (SOFIA) mission, which will allow for responsible dispositioning of assets and data archiving after the conclusion of mission operations in September 2022. The budget also supports the extension of operations for missions such as Hubble, Fermi, Chandra, and the Transiting Exoplanet Survey Satellite (TESS) per the recommendations of the 2022 Senior Review.

Within Heliophysics, the budget proposes to pause the Geospace Dynamics Constellation mission, given other priorities within the Science portfolio which also have high budgetary requirements during this same period. The budget includes funding for two recently selected Explorer missions, Multi-slit Solar Explorer (MUSE) and HelioSwarm, which will help improve our understanding of the dynamics of the Sun, the Sun-Earth connection, and the constantly changing space environment.

Within Biological and Physical Sciences, the request includes funding for a new project, Commercially-Enabled Rapid Space Science (CERISS), an initiative to develop transformative research capabilities with commercial space industry and to dramatically increase research productivity.

ACHIEVEMENTS IN FY 2022

SCIENCE RESULTS

NASA investments continue to generate productive science and meaningful results. In Planetary Science, analysis of data obtained during the weeks after the successful impact of the Double Asteroid Redirection Test (DART) spacecraft with the asteroid Dimorphos on September 26, 2022 showed the spacecraft's kinetic impact successfully altered the asteroid’s orbit. This marked humanity’s first time purposely changing the motion of a celestial object and the first full-scale demonstration of asteroid deflection technology.

Researchers used Mars Science Laboratory mission data to identify the Glen Torridon region in Gale crater as an area abundant in clay minerals. Clay minerals are known on Earth for their high organic preservation potential and can be key indicators of past habitable environments. To evaluate the organic preservation potential of this region, the team used the Sample Analysis at Mars (SAM) instrument onboard the Curiosity rover to collect and characterize seven rock samples. The SAM investigation indicated the presence of various organic compounds, including the first observation on Mars of sulfur-containing and ring-structured organics and the highest abundance of sulfur organics observed to date. This investigation revealed that while some of the sulfur-bearing organics are likely Martian, a portion may also be related to the presence of chemical reagents carried in SAM, making attribution to a definitive source challenging. Nevertheless, these new SAM results confirmed that ancient organic matter is preserved in the clay mineral bearing sediments of Glen Torridon. Its origin—either meteoritic, abiotic (not derived from living organisms), or biotic—has yet to be established.

Researchers examined landslide sensitivity and response to precipitation changes in wet and dry climates at the sites of 39 landslides that occurred in California between 2015 and 2020 using open-access Interferometric Synthetic Aperture Radar (InSAR) data. They found that despite the large differences in hydroclimate, these landslides exhibited surprisingly similar behaviors and hydrologic sensitivity, characterized by faster than average velocities during wetter than average years, as well as slower than average velocities in drier than average years (once the impact of the drought diminished). The authors noted that their findings further confirm landslide sensitivity to climate change under diverse hydroclimate conditions and highlighted the need to establish a long-term series of landslide behaviors that can help to better predict future landslide activity.

Data from the EMIT mission aboard the ISS identified more than 50 “super-emitters” of methane in facilities, equipment, and other infrastructure (e.g., fossil-fuel, waste, or agriculture sectors) in Central Asia, the Middle East, and the Southwestern United States.

The James Webb Space Telescope (Webb) unambiguously detected, for the first time, carbon dioxide (CO2) in the atmosphere of an exoplanet. The exoplanet, WASP 39-b, is what is known as a ‘hot Jupiter’ type exoplanet because its size is like Jupiter and it orbits its host star so closely that its temperature is about 1,600 degrees Fahrenheit. Webb observed this system for about eight hours and confirmed the presence of CO2, which was previously only suggested during much longer observations with the Spitzer Space Telescope. Since the exoplanet atmosphere has so much CO2, it was either enriched by collisions with comets and asteroids in that system, or the planet formed much farther out in the system and then migrated inward via gravitational interactions with other exoplanets orbiting that star. Since Webb saw this in such a short observation period, many more interesting exoplanet atmosphere discoveries will be forthcoming.

The January 15, 2022 eruption of the Hunga Tonga-Hunga Ha'apai volcano revealed strong coupling between extreme events on Earth’s surface and ionospheric disturbances at the edge of space. The eruption generated shock waves, sonic booms, tsunami waves, and a variety of atmospheric gravity waves extending from the troposphere to the ionosphere that circled the globe several times. For the following 12 hours, heat released from water and hot ash in the plume remained the largest source of atmospheric gravity waves worldwide. The remarkable coupling during this event was captured by combining observations from atmospheric and heliospheric satellites.

The Cold Atom Laboratory aboard the ISS produced the first dual-species atom interferometer and Bose-Einstein condensates in space and improved the atom interferometer contrast by a factor of two. These are key steps in testing current theories of gravity, studying novel states of quantum matter and complex quantum systems, and developing sensors, in ways not possible on Earth.

NASA highlights these and many other scientific results in the pages that follow.

COST AND SCHEDULE PERFORMANCE

This budget reports recent cost increases and/or schedule delays beyond Agency commitments on the Psyche, NASA-ISRO Synthetic Aperture Radar (NISAR), JUpiter ICy moons Explorer (JUICE), and VIPER missions. In 2011, NASA implemented a requirement for most missions entering development to budget at the 70 percent joint cost and schedule confidence level. NASA has launched 24 Science missions subject to this requirement, with a total net budget overrun of 3.9 percent (including Webb). Thirteen of these 24 missions launched on or ahead of NASA's original commitment date.

In the last 12 months, NASA successfully completed or launched two missions: EMIT and the Surface Water and Ocean Topography (SWOT) mission. EMIT launched in July 2022, one month earlier than planned and exceeded planned development costs by 32 percent. SWOT launched in December 2022, nine months later than planned. Final development costs for SWOT will not be available until the conclusion of on-orbit commissioning, currently planned for June 2023.

WORK IN PROGRESS IN FY 2023

NASA Science includes over 100 missions, many of which involve collaboration with international partners or other U.S. agencies. Over 45 missions are currently in formulation or development. In Q1 FY 2023, NASA launched the SWOT mission. NASA or its partners will also launch Time-Resolved

Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS), Tropospheric Emissions: Monitoring of Pollution (TEMPO), Lunar Trailblazer, X-Ray Imaging and Spectroscopy Mission (XRISM), JUICE, and Euclid during FY 2023. Operations of more than 60 other Science missions also continue, including the James Webb Space Telescope, Mars Perseverance Rover, and Parker Solar Probe. In September 2023, NASA's first asteroid sample return spacecraft, OSIRIS-Rex, will return to Earth and deliver a sample of asteroid Bennu, completing a seven-year mission of research and discovery. In 2023, NASA expects the first deliveries of NASA science payloads to the lunar surface under the Commercial Lunar Payload Services (CLPS) initiative. CLPS is opening competition to U.S. commercial providers of space transportation services, with the strategic goal of supporting affordable commercial operations on and near the Moon, consistent with the National Space Transportation Policy and Commercial Space Act. In FY 2023, NASA has already approved three Earth System Observatory (ESO) missions and the Landsat Next project to begin formulation. The fourth ESO mission will also begin formulation in FY 2023. NASA will convene a second Independent Review Board (IRB) to provide an independent assessment of the maturity of the Mars Sample Return Program architecture and preliminary designs, along with achievability of proposed planetary launch dates and the associated cost. This review is planned to be completed prior to the preliminary design review.

The budget will continue to fund more than 4,000 competitively selected research awards for scientists located at universities, independent research centers, industry, NASA field centers, and other Government agencies. NASA Science will continue the use of Dual-Anonymous Peer Review in competitive research solicitations to ensure that the review of proposals is performed in an equitable and fair manner. NASA's Bridge Program will facilitate three-way agreements between minority-serving institutions/students, research intensive universities, and NASA centers to aid minority-serving institutions in applying for and managing NASA research grants and to give students access to NASA scientists, engineers, and facilities. In October 2022, NASA held the first Bridge Program Workshop to introduce the initiative to the scientific community and to solicit feedback on implementation models. NASA plans to release the first Bridge Program solicitation in FY 2023.

NASA has declared 2023 as a "Year of Open Science" to celebrate the benefits and successes of open science and to inspire more scientists to adopt open science practices. NASA's Year of Open Science is part of the five-year Transform to Open Science (TOPS) initiative and the Open Source Science Initiative (OSSI). TOPS is an ambitious plan to accelerate open science practices and major scientific discoveries by increasing understanding and adoption of open science practices and broadening participation by historically excluded communities. In 2023, TOPS will release an introductory open science curriculum, engage with historically underrepresented groups, and develop incentives for open science practices. The success of this Year of Open Science will be driven by collaborations with individuals, teams, and organizations who are ready to transform the culture of scientific research into one that celebrates openness and inclusion.

During FY 2023, NASA will make initial selections from the 2022 Heliophysics Small Explorer Announcement of Opportunity (AO) and will release a draft simplified AO for the Dynamical Neutral Atmosphere-Ionosphere Coupling (DYNAMIC) mission. NASA will release a draft AO for public comment for the New Frontiers 5 mission opportunity and will release the first Astrophysics Probe-class mission AO. NASA will make selections from the Payloads and Research Investigations on the Surface of the Moon (PRISM)-3 call and will release new solicitations for Artemis III Deployed Instruments, Lunar Terrain Vehicle Instruments, and PRISM-4. BPS will review commercial space companies' responses to the first CERISS Request for Information (RFI) and will issue a second RFI to the scientific community to identify which areas of research would most benefit from in situ analysis and sample preparation. NASA expects to receive the next Biological and Physical Sciences Decadal Survey from the National Academies, which will guide BPS research for the 2023 to 2032 decade.

Within Earth Science, NASA will initiate the Earth Information Center, which will deliver critical Earth Science data directly into the hands of people in ways they can use immediately. NASA will make selections from the Earth Venture Instrument-6 AO and will release the fourth Earth Venture Suborbital AO. NASA will also release the first Earth Explorers AO in FY 2023 to provide competitive opportunities for medium-sized instruments and missions that address specific science and applications needs as identified in the most recent Earth Science and Applications Decadal Survey. For the Wildfires initiative, Earth Science will conduct outreach and site visits, organize and host a series of stakeholder engagement workshops, create partnerships to deliver substantial improvements in wildfire management, and work closely with the wildfire community, the Aeronautics Research Mission Directorate, and Space Technology Mission Directorate. NASA will enhance collection of Greenhouse Gas (GHG) data from aircraft and instruments and expand existing activities including the legacy Carbon Monitoring System, competed research, and support for GHG measurement networks.

NASA continues to be actively engaged in the development and utilization of SmallSats/CubeSats as a part of a balanced program of discovery. NASA will use SmallSats/CubeSats to perform technology demonstrations, train and develop the future workforce, and enable unique science observations. In FY 2023, NASA will launch the four remaining CubeSats of the TROPICS mission, which will make measurements over the tropical latitudes to observe the lifecycle of tropical cyclones. NASA selected the current TROPICS launch provider as part of the Agency's Venture-class Acquisition of Dedicated and Rideshare (VADR) launch services contract. In FY 2023, development will continue on other SmallSat/CubeSat missions, including Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS), Polarimeter to Unify the Corona and Heliosphere (PUNCH), Escape and Plasma Acceleration and Dynamics Explorers (ESCAPADE), Polar Radiant Energy in the Far-InfraRed Experiment (PREFIRE), Total and Spectral Solar Irradiance Sensor – 2 (TSIS-2), and Investigation of Convective Updrafts (INCUS).

KEY ACHIEVEMENTS PLANNED FOR FY 2024

In FY 2024, NASA plans to launch Psyche, NISAR, Plankton, Aerosol, Cloud, ocean Ecosystem (PACE); Climate Absolute Radiance and Refractivity Observatory (CLARREO) Pathfinder; Atmospheric Waves Experiment (AWE); and PREFIRE. NASA will release the final New Frontiers AO for this cycle. Within the Lunar Discovery and Exploration Program, additional Commercial Lunar Payload Services deliveries will occur, which will deliver new lunar science payloads to the surface of the Moon. NASA will complete step two selections from the Astrophysics MIDEX and Mission of Opportunity (MO) solicitation and from the 2022 Heliophysics Explorer Program SMEX and MO solicitation. NASA will release the second Earth Venture Continuity AO and will also make Earth Venture Suborbital selections and step one selections from the first Earth Explorers AO.

In FY 2024, NASA will conduct a mission confirmation review for the Mars Sample Return mission. Europa Clipper will complete the integration and testing of all flight hardware and will conduct its Operational Readiness Review (ORR). The spacecraft will then ship to Kennedy Space Center to prepare for launch in October 2024.

The four Earth System Observatory missions initiated in FY 2023 will continue formulation: Surface Biology and Geology; Atmosphere Observing System - Sky; Atmosphere Observing System - Storm; and Mass Change. BPS will deliver hardware to the ISS for the second investigation in the Zero Boil-Off Tank investigation series, which will study the effect of non-condensable gases in the propellant storage tank. NASA expects to receive the next Heliophysics Decadal Survey from the National Academies, which will guide Heliophysics mission planning for the 2024 to 2033 decade.

Themes

EARTH SCIENCE

NASA's unique capabilities as a space and science Agency ultimately enable decisionmakers everywhere to address the most pressing challenges posed by our rapidly changing planet. NASA develops innovations in instrument, flight, data, and mission technology to improve capability, resolution, and frequency of our remote sensing and in-situ Earth observations. NASA missions use the vantage point of space to observe our planet and continuously improve our scientific understanding of Earth's interconnected systems, from Earth's core to its atmosphere. Missions include continuity measurements made for decades, and advances in observations to advance understanding of the Earth system. NASA selects and funds innovative research enabling the Nation's scientific community to build an ever-improving understanding of global-scale changes, connecting causes to effects.

That understanding allows us to develop models that better predict changes in our climate and understand how a difference in one part of the system drives differences in others. For example, the warming climate drives intensification in the water cycle (from drought to intense precipitation), which drives changes to living systems (from agriculture to wildlands) and the carbon cycle. From that predictive capability we can deliver new solutions and applications to help policymakers, natural resource managers, and others make informed decisions. This capability also enables other agencies to provide informed services such as forecasting and decision support systems and helps to advance National capabilities to predict climate, weather, and natural hazards.

In January 2018, the National Academies released the second Decadal Survey for Earth Science and Applications from Space, which provided recommendations for 2018 to 2027. The primary recommendations are underlined below, followed by current status:

- <u>Complete the program of record, including maintaining the Venture Class Program and completing missions currently in formulation and development</u>. This budget supports this recommendation.
- <u>Establish a "Continuity" strand as an addition to the existing Venture Class Program to provide opportunities for the demonstration of low-cost sustained observations</u>. This budget supports this recommendation within Venture Class missions. The first Earth Venture Continuity (EVC) mission, Libera, was selected in February 2020 and will maintain the 40-year data record of the balance between the solar radiation entering Earth's atmosphere and the amount absorbed, reflected, and emitted. The second EVC solicitation is planned for release in FY 2024.
- <u>Implement cost-capped medium- and large-size missions/observing systems to address the five "Designated" observables (Aerosols; Clouds, Convection, and Precipitation; Mass Change; Surface Biology and Geology; and Surface Deformation and Change)</u>. The budget supports this recommendation by initiating the formulation phase of four Earth System Observatory (ESO) missions in FY 2023: Surface Biology and Geology; Atmosphere Observing System - Sky; Atmosphere Observing System - Storm; and Mass Change. The fifth ESO mission, Surface Deformation and Change, will remain in the pre-formulation study phase until FY 2026, but the observable can be met by the NISAR mission when it launches in FY 2024.
- <u>Establish a new competed "Explorer" flight line to provide opportunities for cost-capped medium-size Principal Investigator (PI)-led instruments and missions</u>. This budget supports the Earth Explorer Program, and the release of the first Earth System Explorer mission solicitation in FY 2023.

- Establish an "Incubator Program" to mature specific technologies for important – but presently immature – measurements. This budget continues to support this recommendation with the Decadal Incubation Project within the Earth Science Technology Program, which includes projects addressing all 20 observables highlighted in the Decadal Survey.

NASA seeks input from the Committee on Earth Science and Applications from Space to ensure that our proposed programs maximize scientific productivity within the general framework established by the National Academies. In addition, two advisory committees, the Earth Science Advisory Committee and the Applied Sciences Advisory Committee, provide continuous review of NASA management of Earth Science activities under the NASA Advisory Committee structure.

In addition to addressing the recommendations described above, this budget supports translating Earth science into actionable data and information via investments in Applied Sciences, which will support applications and user engagement related to disaster response, wildfires, environmental justice, energy, and agriculture. NASA will work jointly with the Environmental Protection Agency (EPA) and other agencies to integrate greenhouse gas data from a variety of sources with a goal of making data more accessible to Federal, State, and local governments, as well as other users. Visualization of the information and partnerships in a comprehensive Earth system framework will be enabled by open science and cutting-edge data science techniques. NASA will continue development of the Earth Information Center, a physical and virtual space that provides easily accessible, readily usable, and scalable Earth information – enabling global understanding of the Earth system.

PLANETARY SCIENCE

To answer questions about the solar system and the origins of life, NASA sends robotic space probes to the Moon, other planets and their moons, asteroids and comets, and the icy bodies beyond Neptune. In October 2020, the New Frontiers OSIRIS-Rex spacecraft successfully stored and stowed the Bennu asteroid sample collection and is now headed back to Earth with those samples, scheduled for return in September 2023. In January 2023, the Mars Rover 2020, also known as Perseverance, successfully dropped ten Martian rock and soil samples, forming a cache depot, for the future Mars Sample Return mission which is currently in formulation. NASA is operating spacecraft at Mars, Jupiter, and the Moon, and is preparing to deliver new instruments to the lunar surface in 2023 and 2024, launch the Psyche mission to a unique metal-rich asteroid orbiting the Sun in early FY 2024, and launch the Europa Clipper mission in early FY 2025. The primary recommendations of the National Academies' Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032 are underlined below, followed by current status:

- Continue support for missions in operation and development. This budget supports all missions currently in development, prime operations, and extended operations at the time of the Senior Review. NASA is delaying, by at least three years, the Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy (VERITAS) mission, which is in early formulation and has not been confirmed.

- Continue the Mars Sample Return (MSR) campaign as currently planned. MSR has yet to be confirmed and during formulation is working to mature the fidelity of cost estimates and conducting launch date schedule assessments prior to the Agency commitment at KDP-C.

- Increase R&A funding to 10 percent of the annual PSD budget by mid-decade ($1.25 billion increase). In this budget, the percentage for research is at just over 7.5 percent in 2024 and just under 10 percent by 2028.

- Initiate the Uranus Orbiter and Probe Flagship mission in FY 2024. This budget includes a Planetary Decadal Future funding line beginning in FY 2025 to begin formulation studies of a future flagship mission. The Decadal also specifically states that the Uranus mission schedule is flexible and should be adjusted to meet other higher priority recommendations.
- Initiate five new Discovery missions at recommended cost cap. The budget request supports one new Discovery mission with the next planned AO to be released no earlier than 2025. NASA plans to select only one mission to address the increased cost of this priority science.
- Initiate one New Frontiers 5 and two New Frontiers 6 selections at recommended cost cap. This budget supports the New Frontiers 5 AO release in early FY 2024.
- Provide robust plutonium production to meet the needs of the decade. This budget supports the required ramp up in constant rate production in the Radioisotope Power System Program.
- Continue support for the Lunar (LDEP) Program with mid-decade start of Endurance-A. This budget supports a comprehensive LDEP Program with regular CLPS deliveries, lunar research, and science instruments for robotic landers, rovers, and use by astronauts. Science Definition studies of the Endurance-A mission concept begin during FY 2024.
- Restore Mars Exploration Program (MEP) to pre-MSR funding level with late decade start of Mars Life Explorer. MEP funding levels over the past decade have ranged from 20 percent to 30 percent of the Planetary budget. The combined budget for MSR and MEP is just over 35 percent of the Planetary budget request for FY 2024. This budget supports continuation of all operating and extended Mars missions, studies and early funding for a Sample Receiving Project for Mars Sample Return, and increased support for the ESA Rosalind Franklin ExoMars mission, launching in FY 2028.
- Maintain support for Planetary Defense with NEO Surveyor and a new NEO characterization mission. This budget supports a June 2028 NEO Surveyor launch readiness date.
- Initiate the Enceladus Orbilander in FY 2029. This mission is beyond the current budget planning horizon and will be considered once plans for a Uranus mission are under way.

NASA asks the Planetary Science Advisory Committee for input to ensure that proposed programs maximize scientific productivity within the general framework established by the National Academies.

ASTROPHYSICS

We stand on the threshold of new endeavors that will transform not only our understanding of the universe and the processes and physical paradigms that govern it, but also humanity's place in it. Progress in understanding pathways to habitable worlds, opening new windows on the dynamic universe, and unveiling the drivers of galaxy growth require the essential vantage point of space. Building on the revolutionary advances in our observations of exoplanets, we now seek to identify and characterize Earth-like exoplanets orbiting Sun-like stars, with the ultimate goal of obtaining imaging and spectroscopy of potentially habitable worlds.

We aim to exploit the new observational tools of gravitational waves and particles, along with temporal monitoring of the sky across the electromagnetic spectrum and wide-area surveys to probe the most energetic processes in the universe and also address the nature of dark matter, dark energy, and cosmological inflation. By linking observations and modeling of the stars, galaxies, and the gas and energetic processes that couple their formation, evolution, and destinies, we can revolutionize our understanding of the origins and evolution of galaxies, from the nature of the tenuous cosmic webs of gas that feed them, to the nature of how this gas condenses and drives the formation of stars.

The National Academies released the new decadal survey in 2021, "Pathways to Discovery in Astronomy and Astrophysics for the 2020s." It recommends a coordinated program of research, technology development, ground-based facilities, and space-based missions for implementation, as well as addressing inclusion, diversity, and training necessary to maintain the health of the astrophysics profession. The primary recommendations are underlined below, followed by current status:

- Foundations of the Profession: Addressing inclusion, diversity, and training within the Astrophysics profession. The budget continues investment in the SMD Bridge Program to strengthen partnerships with minority-serving institutions to broaden participation in NASA's science research programs and initiates an Astrophysics mission design summer school to help train new PIs. Initially piloted in the Astrophysics Theory Program, the Research Program includes further expansion of the ROSES Inclusion Plan Pilot with incorporation into selection decisions in 2023. Continuation of the NASA Hubble Fellowship Program will encourage development of scientific leaders who advance diversity and inclusive excellence, in accordance with the external NASA Hubble Fellowship Program Review.
- Research Foundation: Improvements to research and analysis and data centers. NASA will continue to release data on proposal success rates at all American Astronomical Society (AAS) Town Halls and Astrophysics Advisory Committee meetings. Increases in Research and Analysis, as recommended by the Decadal Survey, are included in the budget.
- Balancing the Operating Portfolio. The Decadal Survey committee found that SOFIA's low science productivity could not justify its high operating costs. Consistent with the recommendation, science operations ceased at the end of FY 2022. The budget supports an orderly closeout of SOFIA beginning in FY 2023. The budget supports other operating missions, including the James Webb Space Telescope and the Balloon Program.
- Technological Foundation: Improvements to technology development programs and the balloon Program. The budget includes the Strategic Astrophysics Technology Program, which matures technologies for identified future Great Observatories and identified future Probe missions. The budget supports the SPHEREx and COSI missions, as well as the next MIDEX and SMEX. The budget supports an external review of the Balloon Program.
- Time Domain Astrophysics and Multi-Messenger Program: Realize and sustain the suite of electromagnetic capabilities required to study transient and time-variable phenomena, and to follow-up multi-messenger events. NASA is developing actions to address the Time Domain Astrophysics and Multi Messenger (TDAMM) recommendations of the 2020 Decadal Survey. The budget supports the operation and development of missions that address TDAMM priorities including Swift, Fermi, TESS, UltraSat, COSI, and Roman. In addition to flight missions, the budget supports multi-mission, interagency, and international coordination in the areas of data archives, data standards, transient alerts networks, and community research opportunities.
- Astrophysics Probe class missions. The budget supports the release of an AO for the first Astrophysics Probe in mid-FY 2023 and the selection of two to three proposals for competitive Phase A mission concept studies.
- Great Observatories. NASA's priority is ensuring mission success for the Roman Space Telescope. The budget includes enabling science and technology investments for the Habitable Worlds Observatory by re-vectoring the Strategic Astrophysics Technology Program investments to

technologies responsive to Decadal Survey priorities until it is possible to transition to a dedicated investment program.

NASA asks the Astrophysics Advisory Committee for input to ensure that proposed programs maximize scientific productivity within the general framework established by the National Academies.

HELIOPHYSICS

The Sun, a typical small star midway through its life, governs our solar system. The Sun wields its influence through its gravity, radiation, solar wind, and magnetic fields, all of which interact with the Earth and its space environment. These processes are crucial for our understanding of the universe, and they relate directly to our ability to live in space as they produce space weather, which can affect technological infrastructure and human activities in space. Using a fleet of sensors on various spacecraft in Earth orbit and throughout the heliosphere, NASA seeks to understand the fundamental processes of how and why the Sun varies in many ways, how Earth and our solar system respond to the Sun, how the Sun and the solar system interact with the interstellar medium, and how human activities are affected by these processes. The science of heliophysics, including space weather, enables the predictions necessary to safeguard life and society on Earth and the outward journeys of human and robotic explorers.

The primary recommendations of the National Academies' 2013 Decadal Survey for Heliophysics are underlined below, followed by current status:

- Maintain and complete the current program. The Decadal Survey assumed launch of Van Allen Probes by 2012, Interface Region Imaging Spectrograph (IRIS) by 2013, Magnetospheric Multiscale (MMS) by 2014, Solar Orbiter Collaboration (SOC) by 2017, Parker Solar Probe by 2018, and continued current funding of the research program. Van Allen, IRIS, MMS, Parker Solar Probe, and the ESA-led Solar Orbiter Collaboration all have launched successfully. The Global Scale Observations of the Limb and Disk (GOLD), Ionospheric Connection Explorer (ICON), and the Space Environment Testbed missions also have launched successfully and are in primary operations or have achieved mission success criteria. Support for 20 operating missions and associated research has also continued.
- Implement the DRIVE (Diversify, Realize, Integrate, Venture, Educate) initiative, including the incorporation of smaller spacecraft and an increase in the competed research program from 10 percent to about 15 percent of the budget request. This budget supports competed research funding equivalent to approximately 15 percent of the division budget in FY 2024 and invests in the SMD-wide CubeSat/SmallSat initiative. DRIVE Science Centers address grand challenge goals that are both ambitious and focused enough to be achievable within the lifetime of the center - in other words, problems poised and ready for major advances. DRIVE has been fully implemented and is now considered part of the Heliophysics Research and Analysis (R&A) Program. In FY 2022 NASA selected three DRIVE Science Centers.
- Accelerate and expand the Heliophysics Explorer Program, resulting in an increase to the cadence of competed missions to one launch every two to three years. NASA has maintained an Explorer launch cadence of every two to three years and the budget supports this cadence going forward. NASA launched IRIS in 2013, Global-Scale Observations of the Limb and Disk (GOLD) in 2018, and ICON in October 2019. The proposed out-year budgets, if realized, would enable launch of Atmospheric Waves Experiment (AWE) mission of opportunity in FY 2023, Polarimeter to Unify the Corona and Heliosphere (PUNCH) as early as FY 2025, and Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS) no earlier than 2026. MUSE and HelioSwarm will launch in 2027 and 2028, respectively. NASA released a SMEX AO in FY 2022 and will release a MIDEX AO

in 2025. The increased cadence of Explorers has contributed to an overall resurgence in the NASA Heliophysics Flight Program and system observatory.

- Restructure Solar Terrestrial Probes (STP) as a moderate-scale, principal investigator-led flight program, and implement three mid-scale missions with an eventual recommended four-year cadence. This budget supports launch of the PI-led IMAP mission in 2025. NASA selected the Carruthers Geocorona Observatory (formerly known as Global Lyman-alpha Imager of the Dynamic Exosphere [GLIDE]) from the most recent STP MO AO, which will fly as a rideshare with IMAP. The budget proposes no funding for the DYNAMIC mission due to the need to fund higher priorities within the Science program.
- Implement a large Living with a Star (LWS) mission to study Global Dynamic Coupling with a launch in 2024. The budget proposes to postpone the Geospace Dynamics Constellation mission given other priorities within the Science portfolio, including Mars Sample Return, which also have high budgetary requirements during this same time period.

The Decadal Survey also made recommendations related to space weather applications, addressed collectively to the relevant Government agencies. NASA has implemented the HERMES (Heliophysics Environmental and Radiation Measurement Experiment Suite) space weather instrument designed to operate on the Gateway and maintains funding for space weather applications research. NASA will continue collaborating with other agencies to improve space weather observation and forecasting capabilities.

NASA asks the Heliophysics Advisory Committee for input to ensure that proposed programs maximize scientific productivity within the general framework established by the National Academies.

BIOLOGICAL AND PHYSICAL SCIENCES

NASA's mission is to lead the world in performing fundamental biological and physical sciences research that contributes to transformational discoveries, improves life on Earth and in space, and enables sustained deep-space human exploration. We achieve this by pioneering research to understand how spaceflight affects living and physical systems in space and to prepare for future human exploration missions far from Earth. The experiments NASA conducts on the ISS and other platforms examine how astronauts, plants, animals, and physical systems respond to the extreme conditions of space, including microgravity, ionizing radiation, and altered atmosphere.

NASA examines processes of metabolism, reproduction, and development and studies how organisms repair cellular damage and protect themselves from infection and disease in the conditions of deep space. In addition to providing useful information on how living organisms respond and adapt to spaceflight, the discoveries NASA makes in space have enormous implications for life on Earth.

NASA also conducts research to understand the fundamental laws of the universe, including quantum science, as well as determine how physical systems react in spaceflight environments. This research provides basic scientific knowledge and results leading to societal benefit, including contributions to the fundamental understanding of underlying space exploration technologies such as power generation, storage, and fuel transfer; space propulsion; life support systems; and environmental monitoring and control. NASA research also contributes to scientific discoveries in novel areas, such as the fifth state of matter, known as Bose-Einstein Condensates, material sciences, and soft matter. This physical sciences research has led to improved space systems and new products on Earth.

The Decadal Survey on Biological and Physical Sciences Research in Space 2023-2032 will review the state of knowledge in the current and emerging areas of space-related biological and physical sciences research. It will generate consensus recommendations for a comprehensive vision and strategy for a decade of transformative science at the frontiers of biological and physical sciences research in space. The study report will help NASA define and align research in these areas to uniquely advance scientific knowledge, meet human and robotic exploration mission needs, and provide terrestrial benefits.

EARTH SCIENCE

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Earth Science Research	541.0	--	**577.9**	590.0	602.2	618.0	629.5
Earth Systematic Missions	706.4	--	**1,027.1**	1,073.6	1,162.7	1,130.3	1,091.0
Earth System Explorers	2.0	--	**27.8**	20.7	43.1	109.0	166.4
Earth System Science Pathfinder	312.7	--	**235.6**	298.6	290.5	282.5	290.3
Earth Science Data Systems	339.4	--	**411.7**	398.9	408.1	423.8	439.6
Earth Science Technology	86.1	--	**105.3**	113.5	117.1	118.4	120.8
Applied Sciences	73.5	--	**87.3**	102.3	106.2	109.3	111.5
Total Budget	**2,061.2**	**2,195.0**	**2,472.8**	**2,597.5**	**2,730.0**	**2,791.2**	**2,849.0**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Earth Science

EARTH SCIENCE RESEARCH

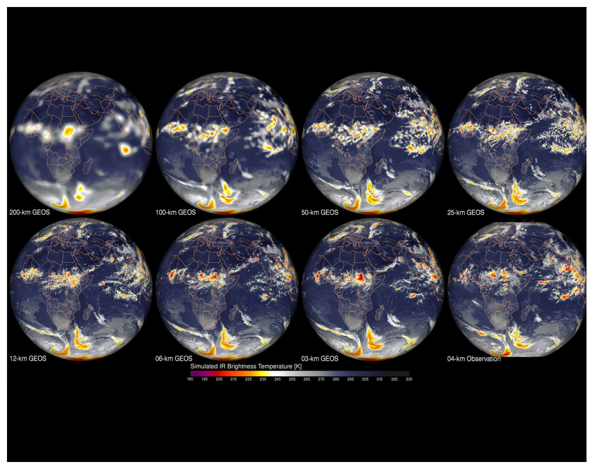
FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Earth Science Research and Analysis	375.9	--	**393.5**	394.2	402.9	412.6	417.4
Computing and Management	165.1	--	**184.5**	195.8	199.3	205.4	212.1
Total Budget	**541.0**	**--**	**577.9**	**590.0**	**602.2**	**618.0**	**629.5**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

NASA's Earth Science Research program develops a scientific understanding of Earth and its response to natural or human-induced changes. Earth is a system, like the human body, comprised of diverse components interacting in complex ways. Understanding Earth's atmosphere, crust, water, ice, and life as a single, connected system is necessary to improve our predictions of climate, weather, and natural hazards. The Earth Science Research program addresses complex, interdisciplinary Earth science problems in pursuit of a comprehensive understanding of the Earth system. This strategy involves six interdisciplinary and interrelated science focus areas, including:



Cloud-top temperatures and structure from infrared brightness simulated by the NASA Global Earth Observing System (GEOS) model, at resolutions from 200km to 3km, compared to observations. As the model resolution increases, the simulation becomes increasingly realistic and in agreement with observations. The GEOS Earth system model above is used to produce experimental forecasts of weather, atmospheric composition, short-term climate change to investigate and develop forecasting science, and model-observations syntheses of the current state of the Earth system.

- Water and Energy Cycle: quantifying the key reservoirs and fluxes in the global water cycle, assessing water cycle change, and assessing water quality.
- Weather and Atmospheric Dynamics: enabling improved predictive capability for weather and extreme weather events.
- Earth Surface and Interior: characterizing the dynamics of the Earth's surface and interior and forming the scientific basis for the assessment and mitigation of natural hazards and response to rare and extreme events.
- Climate Variability and Change: understanding the roles of ocean, atmosphere, land, and ice in the climate system and improving our ability to predict future changes.
- Atmospheric Composition: understanding and improving our predictive capability for changes in the ozone layer, Earth's radiation budget, and air quality associated with changes in atmospheric composition.

EARTH SCIENCE RESEARCH

- Carbon Cycle and Ecosystems: quantifying, understanding, and predicting changes in Earth's ecosystems and biogeochemical cycles, including the global carbon cycle, land cover, and biodiversity.

NASA's Earth Science Research program pioneers the use of both space-borne and aircraft measurements in all these areas. The Earth Science Research program is critical to the advancement of the interagency United States Global Change Research Program (USGCRP), established in 1989 and mandated in the Global Change Research Act of 1990 to develop and coordinate "a comprehensive and integrated U.S. research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change." The Earth Science Research program also makes extensive contributions to international science programs, such as the World Climate Research Program, and greenhouse gas (GHG) measurement and calibration efforts.

EXPLANATION OF MAJOR CHANGES IN FY 2024

The Budget supports an increase in Interdisciplinary Science in anticipation of NASA-ISRO Synthetic Aperture Radar's (NISAR) planned launch in October 2024. It also reflects adjustments to the Earth Science Directed Research and Technology (DR&T) to offset increases in Directorate Support which funds NASA's Science Mission Directorate's institutional and crosscutting activities. The increase in Directorate Support, supports improved benefits and pay for Fellows in NASA's Postdoctoral Fellowship program as well as ramping up NASA's Science Mission Directorate's website modernization activities.

ACHIEVEMENTS IN FY 2022

NASA-funded researchers implemented a network that links environmental satellite-derived data (e.g., Landsat-derived land cover) to biodiversity observations collected from trail cameras. Using the synthesis of both satellite and in-situ detection methods, this network provides environmental context that facilitates inference, prediction, and forecasting of ecological conditions to improve ecological monitoring and management. In addition, these trail camera observations have led to new understanding of environmental impacts on biodiversity loss.

Another research study applied Global Ecosystem Dynamics Investigation (GEDI) data along with environmental and biogeographical variables to explain global patterns in tree species richness. They found that forest structure information from GEDI explained 66 percent of the variation in global tree species richness in natural forests without a history of recent disturbance. Understanding and predicting variations in tree species diversity is important because of the ecosystem services it provides, such as productivity and carbon sequestration.

Recent analysis shows that rapidly urbanizing regions of sub-Saharan Africa, South America, Mesoamerica, and Southeast Asia, will result in major biodiversity loss. This analysis utilized the Coupled Model Intercomparison Project and the Land-Use Harmonization 2 project. Under current trends, researchers project unmitigated urbanization will directly threaten up to 855 species by 2050. Coastal ecosystems are witnessing similar impacts driven by changing climate.

Using Landsat imagery, researchers found that as of 2016, sea level rise in the Florida Big Bend region has led to an annual forest loss of 10 km2. This is an 800 percent increase from 2003 rates.

EARTH SCIENCE RESEARCH

Also using Landsat imagery, a different study showed that heavy management of the hydrological system in the Central Valley of California during early fall and late spring significantly reduces available habitat for migratory shorebirds. Increased understanding acquired from this type of research provides a means of mitigating negative human impacts.

A study created a landslide susceptibility map along the China Pakistan Economic Corridor (CPEC) route using 13 landslide causative factors. These included interpolated Integrated Multi-satellitE Retrievals for GPM (IMERG) rainfall data, elevation, slope, physical characteristics of rock in the area, drainage intensity, Normalized Difference Water Index (NDWI), structural fault, land use, earthquake hazard, Normalized Difference Vegetation Index (NDVI), and soil type. Researchers weighted the causative factors according to their potential for developing a landslide event. Results indicate that soil type (17 percent), slope (16 percent), rainfall (16 percent), and NDWI (11 percent) are more prominent conditioning factors for landslides. The results indicated that about 38 percent of the study area falls under the categories of high and very high susceptibility.

Researchers identified how fluid injection and oil and gas extraction caused induced seismicity in Texas. They used the Interferometric synthetic aperture radar (InSAR) to monitor three study sites and found inflation related to injection at site one, slight subsidence and earthquakes related to extraction at site two, and significant subsidence and earthquakes at the third site related to a combination of groundwater and oil/gas extraction. Although there were several factors influencing the third site, all earthquakes seemed to correspond to the occurrence of fluid injection.

In FY 2022, researchers coordinating with National Oceanic and Atmospheric Agency (NOAA), JPL, and the U.S. Coast Guard completed the Santa Barbera Oil Slick experiment. This experiment used NASA's Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) to observe natural seeps near the Santa Barbara shoreline in coordination with the in-situ teams as well as satellite imagery. Researchers used UAVSAR imagery to validate oil slick characterization algorithms and prepare for disaster response to oil spills and major storms.

The Global Learning and Observation to Benefit the Environment (GLOBE) project continues to build on long-standing investments in infrastructure to promote learning about the environment. This year, the GLOBE team initiated the development of an evaluation strategy with the goal of informing ongoing operations, and to serve as an evidence base for the value of the project. In FY 2022, GLOBE continued to support student-based research. The GLOBE International Virtual Science Symposium received 220 entries from student teams in 24 countries. Several countries held in-person or virtual GLOBE student research events, including Switzerland, Thailand, and Nigeria. Additionally, the Latin America and Caribbean Region and the Near East and North Africa region held multi-country student research events. In the U.S., continuing school-based travel restrictions led the program to shift from six in-person regional symposia to seven in-person local research symposia, which enabled 212 students to present a total of 68 projects. GLOBE also made major progress in revamping app-based data entry for the program, which will lower barriers to entry for new students, educators, and citizen scientists and enable stronger participation from existing GLOBE domestic and international partners. Additionally, GLOBE-trained participants can now enter data for all atmosphere and hydrosphere protocols directly in the GLOBE Observer app that has an improved user interface and enhanced functionality to support educators compared to the previously used GLOBE Mobile Data Entry App.

The Space Geodesy project continued the development, deployment, and operation of a modern network that includes the co-located next-generation Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Global Navigation Satellite System (GNSS), and Doppler Orbitography and

EARTH SCIENCE RESEARCH

Radiopositioning Integrated by Satellite (DORIS) stations. NASA also delivered an engineering model of its Laser Retroreflector Arrays (LRA) for GPS-III to the U.S. Space Force and completed building the first two flight-ready units for verification testing. The GPS-LRA will provide an independent tool for improved positioning, navigation, and timing. NASA's new domestic VLBI antennas expanded intensive observing sessions with the global network, and the National Earth Orientation Service for Earth Orientation Parameter is now using the associated data operationally for its daily products. Space Geodesy also began production of five-minute interval, multi-GNSS (including GPS and the European Galileo system) satellite orbit and timing products, improving the accuracy over prior GPS-only products.

Both Scientific Computing (SC) and High-End Computing Capability (HECC) projects expanded computing and storage at their centers. The expansions will allow NASA to create machine learning or physics-based Earth system model projections that address the needs for relevant societal climate resilience and mitigation decisions typically at city scales (i.e., high-resolution). These will also allow increased fidelity in simulating launch and space flight vehicles' propulsion systems. HECC made significant improvements in both storage and computing and implemented innovative approaches to using the public cloud for science. HECC is working with multiple scientific and engineering teams to develop workflows that take advantage of the rapid turnaround and tools available in the cloud to reduce the time to solution. The Aitken supercomputer, housed in an energy-efficient module is now NASA's fastest computer and has replaced Pleiades as the Agency workhorse. The file systems now provide over 70 petabytes of storage with the addition of innovative tiered storage. HECC worked with another government agency and two private industry partners to host the second winter classic invitational student cluster competition for 12 teams from six Historical Black Colleges and Universities (HBCUs) and four Hispanic Serving Institutions (HSIs). The students worked with HECC mentors to learn how to optimize codes to run in complex supercomputing environments. A computing architecture study began to inform recommendations for the computing services required to support the future science and engineering efforts.

SC completed a computing architecture study for the evolution of computing services to support future science and engineering efforts. SC supported Earth Information Systems projects in the deployment of in-the-cloud computational environment and the porting of the NASA Global Earth Observing Systems (GEOS) atmospheric model to graphical processing unit (GPU) based computing systems.

WORK IN PROGRESS IN FY 2023

In FY 2023, NASA will put in place new awards solicited in Research Opportunities in Space and Earth Science (ROSES) 2022. These will emphasize ties to the core focus areas of the Earth System Observatory (ESO), which are: aerosols; cloud convection and precipitation; mass change; surface biology and geology; surface deformation; and change. NASA released the ROSES 2023 solicitation in February of 2023.

NASA will continue to fund interdisciplinary research to leverage NASA's unique scientific research capabilities to provide wildland fire managers with information to make better fire management decisions. In FY 2023, NASA will continue to engage with stakeholders at partner agencies to better understand their wildfire management needs.

NASA's SnowEx investigation continues to collect snow data in forested regions with both airborne multi-sensor and in situ validation observations. This is a multi-year airborne and ground campaign to collect observations to enable studies for snow satellite mission designs. SnowEx has three goals; to develop and test algorithms for measurements of Snow Water Equivalent, the depth of water that would

EARTH SCIENCE RESEARCH

cover the ground if snow was in a liquid state, in forested and non-forested areas; to develop and test energy balance models and snow distribution models of beneath-canopy snowpack; and to explore how best to combine sensing technologies with modeling and data assimilation methods to produce the most accurate products.

The Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas (AEROMMA) is a NOAA-NASA joint field campaign aimed at addressing the emerging research needs in urban air quality, marine emissions, climate feedbacks, and atmospheric interactions at the marine-urban interface. It also includes future satellites capable of monitoring atmospheric composition over North America. AEROMMA will bring together airborne, ground, and satellite observing systems, and state-of-the-art air quality and climate models, to investigate these research topics. In coordination with AEROMMA, will be the NASA Synergistic TEMPO Air Quality Science (STAQS) campaign. The STAQS campaign seeks to integrate NASA's Tropospheric Emissions: Monitoring of Pollution (TEMPO) satellite observations with traditional air quality monitoring to improve understanding of air quality science and increase societal benefit. Researchers will target two primary domains in Los Angeles and New York City and several secondary domains across North America with ground and airborne based measurements from the NASA G-V and G-III research aircraft.

GLOBE will focus on four key themes: strengthening program operations, ensuring educational relevancy, expanding GLOBE Earth science research, and supporting U.S. partners. In FY 2023, GLOBE will strengthen the Data and Information System operations with additional technical enhancements, such as improving tools for educators, and accelerate the speed and depth of a website update. GLOBE will continue to support evaluation efforts focused on educational outcomes. This work will build on initial investments in FY 2022 and help develop an overall evaluation framework.

The Space Geodesy Program will install the gimbal and telescope for the Ny-Ålesund SLR system, commencing major hardware deployment at the site. Work towards deployment of the Brazil VLBI antenna will proceed with completion of the Critical Design Review. The United States Space Force will receive the first four GPS-LRA flights for integration with the GPS-III space vehicles. Space Geodesy will begin producing new monthly updates to its ITRF 2020 solution, a first-of-its-kind improvement to maintain ITRF quality between reprocessing of full solutions, with benefits to multiple science objectives that rely on precise positioning.

SC and HECC projects will continue the current path to expand computing and storage at NASA centers. HECC will make a large investment in General Purpose Graphics Processing Units (GPGPU) quadrupling the GPGPU capability providing a platform to develop codes for the Department of Energy systems and to facilitate advancements in artificial intelligence and machine learning. SC will expand on-premise use of GPUs for Artificial Intelligence (AI)/Machine Learning (ML) science and atmospheric modeling. The centers will further their research providing innovative approaches between on-premise computing centers and cloud capabilities that utilize the strengths of both environments. SC is continuing the support of Earth Information System projects in the deployment of cloud computational environment and the porting of NASA GEOS atmospheric model to GPU based computing systems. SC and HECC are engaging in supercomputing workforce development discussions with minority serving institutions (MSIs) and HBCUs.

In FY 2023, NASA will support domestic airborne observations of GHG, upgrade existing GHG-measuring airborne instruments, as well as provide additional observations to support the developing GHG center. NASA will augment the Total Carbon Column Observing Network (TCCON) which makes surface-based Carbon Dioxide (CO_2) measurements and provides calibration/validation information for current GHG-measuring satellites. Additional ROSES selections for the Carbon Monitoring System (CMS) will provide enhanced data products on fluxes and stocks of carbon. NASA will support research at NASA centers and partner institutions on hot spot detection, multiscale modeling approaches (including enhancements to the GHG-component of the Earth Information System), consensus GHG products, support for research to operations and operations to research (R2O) as well as improving trust in remote sensing observations. NASA will continue international coordination support with the World Meteorological Organization's Integrated Global Greenhouse Gas Information System (IG3IS) activities of the World Climate Research Program, and Future Earth.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

In early FY 2024, NASA will conduct its first biodiversity field program incorporating airborne imaging spectroscopy, lidar, and field observations across South Africa's Greater Cape Floristic Region (GCFR) including surrounding coastal and marine environments. The GCFR contains two Global Biodiversity Hotspots with the richest temperate flora and the third-highest marine endemism in the world. The field campaign includes collecting new hyperspectral data ranging from UV to thermal wavelengths acquired by PRISM, AVIRIS-NG, and HyTES spectrometers combined with the LVIS laser altimeter aboard the NASA G-III and G-V aircraft.

In FY 2024, NASA will execute an airborne remote sensing wildland technology demonstration field campaign over a combination of western prescribed and wildland. This field campaign will deploy existing sensing instruments, and test new capabilities where possible, to map fuel loading, fuel structure, and fuel moisture status to update fire vulnerability and risk management maps in the areas of the western United States where this data is most needed. The second goal of this field campaign is to provide a comprehensive dataset suitable for evaluating and maturing predictive models of fire behavior and fire weather. NASA will develop these new capabilities (products, sensors, models, information systems) with partner agency stakeholders to facilitate the transition of these tools and improve wildfire management practices in the United States.

The Arctic Radiation-Cloud-Aerosol-Surface Interaction Experiment (ARCSIX) investigation will quantify the contribution of surface properties, clouds, aerosol particles, and precipitation to the Arctic summer surface radiation budget and sea ice melt during the early melt season (May through mid-July). ARCSIX will achieve this by flying two aircraft in coordination, one collecting in situ aerosol particle, cloud, atmospheric and surface properties along with radiation below, above, and inside a cloud layer, while the other will serve as a bridge to satellite observations by surveying with heritage and novel remote sensing instruments from above.

The Airborne and Satellite Investigation of Asian Air Quality (ASIA-AQ) campaign will aim to contribute to science-based satellite validation and modeling efforts central to priorities of NASA and international partners under the Committee on Earth Observation Satellite Atmospheric Composition Virtual Constellation (CEOS AC-VC) collaboration on air quality observations from space. NASA will deploy two aircraft to sample air quality over selected Asian cities using a strategy like Korea-United States Air Quality (KORUS-AQ) with repetitive sampling to include profiling over the city and surrounding area multiple times per day.

The Space Geodesy Program plans to complete verification of the new SLR system in Maryland, before deployment and installation of remaining components at Ny-Ålesund. The McDonald Geodetic observatory in Texas will install a new SLR gimbal and telescope, beginning hardware deployment towards future operations at that site. Space Geodesy will also complete the new VLBI antenna in Brazil,

EARTH SCIENCE RESEARCH

while continuing work and planning for upgrades at other sites. Upon completion of the upgrades, NASA expects improved accuracy for precision orbit determination for missions such as Ice, Cloud and land Elevation Satellite (ICESat-2) and Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) data products. The upgrades will continue to increase the accuracy of low-degree gravity field estimates for tracking processes such as those provided by Sentinel-6 Michael Freilich including ice sheet mass change, estimates of sea level rise rate and its acceleration. The upgrades will also improve the quality of Earth Orientation Parameters for spacecraft navigation and measurement of the angular momentum balance among the solid Earth, ocean, and atmosphere.

SC and HECC will continue the path to expand on-premise computing and storage at NASA centers. HECC will build a on-premise data module to support the supercomputer usage. Both computing centers will continue to expand cloud usage to support open science. NASA plans to mature the research in moving NASA computational tasks between on-premise and cloud capabilities. Based on the result of the computing architecture study completed in FY 2023, SC and HECC will start architecture evolution projects. SC will begin procurements based on the architecture evolution project completed in FY 2023. SC will leverage cloud usage to support both open science and High Performing Computing (HPC) as on-premise utilization demands. SC will continue to expand on-premise use of GPUs for AI/ML science and atmospheric modeling.

In FY 2024, NASA will begin international campaigns to take airborne observations of GHG and provide additional observations to support the developing GHG center. NASA will augment surface-based GHG measurement networks to provide updated instrumentation for GHG-measuring devices that provide important boundary conditions for inverse models, with a likely emphasis on the Advance Global Atmospheric Gas Experiment (AGAGE) network. NASA will continue funding for additional work for the Carbon Monitoring System (CMS) selected from ROSES 2023. NASA will continue international coordination support with the World Meteorological Organization’s Integrated Global Greenhouse Gas Information System (IG3IS), activities of the World Climate Research Program, and Future Earth.

Program Elements

GLOBAL MODELING AND ASSIMILATION OFFICE

The Global Modeling and Assimilation Office creates global climate and Earth system component models using data from Earth science satellites and aircraft. Investigators can use these products worldwide to further their research.

AIRBORNE SCIENCE

The Airborne Science project is responsible for providing aircraft systems to further science and advance the use of satellite data. NASA uses these assets worldwide in campaigns to investigate extreme weather events, observe Earth system processes, obtain data for Earth science modeling activities, and calibrate instruments flying aboard Earth science spacecraft. NASA Airborne Science platforms support mission definition and development activities. These activities include:

- Conducting instrument development flights;
- Gathering ice sheet observations as gap fillers between missions;

EARTH SCIENCE RESEARCH

- Serving as technology test beds for Instrument Incubator Program missions;
- Serving as the observation platforms for research campaigns, such as those competitively selected under the suborbital portion of Earth Venture; and
- Calibrating and validating space-based measurements and retrieval algorithms.

OZONE TRENDS SCIENCE

The Ozone Trends Science project produces a consistent, calibrated ozone record used for trend analyses and other studies.

INTERDISCIPLINARY SCIENCE

Interdisciplinary Science includes science investigations as well as calibration and validation activities that ensure the utility of space-based measurements. In addition, this project supports focused fieldwork (e.g., airborne campaigns) and specific facility instruments which fieldwork depends on.

EARTH SCIENCE RESEARCH AND ANALYSIS

Earth Science Research and Analysis is the core of the research program and funds the analysis and interpretation of data from NASA's satellites. This project funds the scientific activity needed to establish a rigorous foundation for the satellites' data and their use in computational models.

EARLY CAREER RESEARCH

The Early Career Research project (formally named Fellowships and New Investigators) supports graduate and early career research in the areas of Earth system research, applied science, data systems, and technology.

SPACE GEODESY

Geodesy is the science of measuring Earth's shape, gravity, orientation, and rotation and how these properties change over time. The Space Geodesy Project (SGP) encompasses the development, operation, and maintenance of a global network of space geodetic technique instruments, a data transport and collection system, data analysis, and the public dissemination of data products required to maintain a stable terrestrial reference system. SGP provides the data and analysis essential for fully realizing the measurement potential of the current and coming generation of Earth-observing spacecraft.

EARTH SCIENCE DIRECTED RESEARCH AND TECHNOLOGY

The Earth Science Directed Research and Technology project funds the civil service staff who work on emerging Earth Science flight projects, instruments, and research.

EARTH SCIENCE RESEARCH

GLOBAL LEARNING AND OBSERVATIONS TO BENEFIT THE ENVIRONMENT

Global Learning and Observations to Benefit the Environment (GLOBE) is a worldwide, hands-on primary and secondary school-based project that promotes collaboration among students, teachers, and scientists to conduct inquiry-based investigations about our environment. The program centers on the study of dynamics of Earth's environment, focused on atmosphere, hydrosphere, pedosphere (i.e., soil), and biosphere. Students take measurements, analyze data, and participate in research in collaboration with scientists. NASA initiated a citizen science component, called GLOBE Observer, in 2016 that makes four protocols available for use by anyone in a GLOBE country. NASA sponsors the GLOBE project and partners with the National Science Foundation, the National Oceanic and Atmospheric Administration, and the United States Department of State.

SCIENTIFIC COMPUTING

The Scientific Computing project funds NASA's Earth Science Discover supercomputing system, high-end storage, network, software engineering, and user interface projects, including climate assessment modeling and data analysis. Scientific Computing supports Earth system science modeling activities based on data collected by Earth science spacecraft. The system is separate from the High-End Computing Capability program at NASA Ames Research Center, so it can be close to the satellite data archives at GSFC. The proximity to the data and the focus on satellite data assimilation makes the Discover cluster unique in its ability to analyze large volumes of satellite data quickly. The system currently has approximately 127,000 central processing unit cores and 415,000 graphical processing unit cores.

HIGH-END COMPUTING CAPABILITY

HECC supports the Endeavour, Pleiades, Electra, and Aitken supercomputer systems and the associated network connectivity, data storage, data analysis, visualization, and application software support. It serves the supercomputing needs of all NASA mission directorates and NASA-supported principal investigators at universities. The funding supports the operation, maintenance, upgrade, and expansion of NASA's supercomputing capability. These four supercomputer systems, with approximately 675,000 central processing unit cores and 1.2 million graphical processing unit cores, support NASA's aeronautics, human exploration, and science missions. For example, the systems perform first-of-a-kind simulations helping engineers reduce risk from acoustic vibrations generated by Orion's Launch Abort System motor. The systems also run simulations created with unprecedented resolution, helping scientists understand how galaxies co-evolve with extensive reservoirs of gas around them.

DIRECTORATE SUPPORT

The Directorate Support project funds the NASA Science Mission Directorate's institutional and crosscutting activities including National Academies studies, proposal peer review processes, printing and graphics, information technology, the NASA Postdoctoral Fellowship program, working group support, independent mission assessments, procurement support for the award and administration of all grants, and other administrative tasks.

EARTH SCIENCE RESEARCH

Program Schedule

Date	Significant Event
Q1 FY 2023	ROSES-2022 selection within six to nine months of receipt of proposals
Q2 FY 2023	ROSES-2023 solicitation release
Q1 FY 2024	ROSES-2023 selection within six to nine months of receipt of proposals
Q2 FY 2024	ROSES-2024 solicitation release
Q1 FY 2025	ROSES-2024 selection within six to nine months of receipt of proposals
Q2 FY 2025	ROSES-2025 solicitation release
Q1 FY 2026	ROSES-2025 selection within six to nine months of receipt of proposals
Q2 FY 2026	ROSES-2026 solicitation release
Q1 FY 2027	ROSES-2026 selection within six to nine months of receipt of proposals
Q2 FY 2027	ROSES-2027 solicitation release
Q1 FY 2028	ROSES-2027 selection within six to nine months of receipt of proposals
Q2 FY 2028	ROSES-2028 solicitation release

Program Management & Commitments

Program Element	Provider
Global Modeling and Assimilation Office	Provider: Various Lead Center: HQ Performing Center(s): GSFC Cost Share Partner(s): N/A
Airborne Science	Provider: Various Lead Center: HQ Performing Center(s): AFRC, ARC, WFF, JSC, LaRC Cost Share Partner(s): N/A
Scientific Computing	Provider: GSFC Lead Center: HQ Performing Center(s): GSFC Cost Share Partner(s): N/A

EARTH SCIENCE RESEARCH

Program Element	Provider
Ozone Trends Science	Provider: Various Lead Center: HQ Performing Center(s): LaRC, GSFC Cost Share Partner(s): USGCRP and Subcommittee on Ocean Science and Technology (SOST) agencies
Interdisciplinary Science	Provider: Various Lead Center: HQ Performing Center(s): HQ, JPL, GSFC, ARC, AFRC, GRC, LaRC, MSFC, JSC Cost Share Partner(s): USGCRP and SOST agencies
Earth Science Research and Analysis	Provider: Various Lead Center: HQ Performing Center(s): All NASA Centers Cost Share Partner(s): USGCRP and SOST agencies
High-End Computing Capability	Provider: ARC Lead Center: HQ Performing Center(s): ARC Cost Share Partner(s): N/A
Directorate Support	Provider: Various Lead Center: HQ Performing Center(s): All NASA Centers Cost Share Partner(s): N/A
Early Career Research	Provider: Various Lead Center: HQ Performing Center(s): All NASA Centers Cost Share Partner(s): N/A
Space Geodesy	Provider: Various Lead Center: GSFC Performing Center(s): GSFC, JPL Cost Share Partners: N/A
Global Learning and Observations to Benefit the Environment	Provider: University Corporation for Atmospheric Research Lead Center: HQ Performing Center(s): HQ, GSFC Cost Share Partner(s): N/A

EARTH SCIENCE RESEARCH

Acquisition Strategy

NASA implements the Earth Science Research program via competitively selected research awards. NASA releases research solicitations each year in the ROSES NASA Research Announcements. All proposals in response to NASA ROSES are peer reviewed and selected based on defined criteria. The program competitively awards funds to investigators from academia, the private sector, NASA centers, and other Government agencies.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Earth Science Advisory Committee	October 2022	Annual review to assess progress against Earth Science performance goals and overarching strategic objective.	Expectations for the research program fully met.	2023; annually
Performance	Earth Science Advisory Committee	TBD	Annual review to assess progress against Earth Science performance goals and overarching strategic objective.	TBD	2024; annually

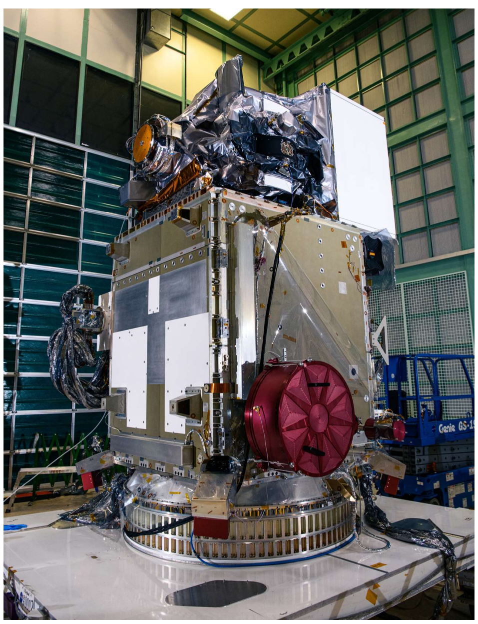
EARTH SYSTEMATIC MISSIONS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
NASA-ISRO SAR	70.0	58.6	**96.4**	29.3	21.1	26.8	17.1
Sentinel-6	22.8	40.3	**63.9**	55.2	25.6	8.7	5.7
PACE	54.9	112.8	**91.4**	26.3	24.8	21.2	22.3
Other Missions and Data Analysis	558.7	--	**775.5**	962.8	1,091.2	1,073.6	1,045.9
Total Budget	**706.4**	**--**	**1,027.1**	**1,073.6**	**1,162.7**	**1,130.3**	**1,091.0**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



This image shows the fully integrated Plankton, Aerosols, Clouds, ocean Ecosystem (PACE) observatory with Ocean Color Instrument and Star Tracker for planned launch in Mav 2024.

The Earth Systematic Missions (ESM) program includes a broad range of multi-disciplinary science investigations aimed at understanding the Earth system and its response to natural and human-induced forces and changes. Understanding these forces will help determine how to predict future changes and mitigate or adapt to these changes.

NASA's understanding of the Earth's systems – land, ice, oceans, and atmosphere – starts with the Earth Systematic Missions (ESM). This constellation of Earth-orbiting satellites collects observations that drive NASA's understanding of Earth systems. That scientific understanding shapes the predictive models, data products and science applications needed to mitigate, adapt to, and respond to the real-world impacts of climate change.

ESM includes the next generation of remote-sensing satellite missions, the Earth System Observatory (ESO), to address the high-priority Earth observation needs of the research and applications communities, as identified by the National Academies of Science's 2017 Decadal Survey.

Each ESO mission will deliver higher-resolution observations with greater frequency. By integrating multiple missions into a single observatory, NASA will achieve an unprecedented, holistic view of Earth – significantly advancing our ability to measure, predict and respond to climate change and natural hazards.

Interagency and international partnerships are central elements of the ESM program. More than half of the projects in formulation or development under ESM have an international or interagency contribution, and several on-orbit missions provide data products in near real-time for use by the United States and international meteorological agencies and disaster responders.

EARTH SYSTEMATIC MISSIONS

The ESM program develops Earth-observing satellite missions, manages the operation of these missions once on-orbit, and produces data products to support the research and applications communities.

EXPLANATION OF MAJOR CHANGES IN FY 2024

NASA approved a replanned cost and schedule for the NISAR mission in August 2022 and increased the budget to reflect these updated estimates. NASA approved a delay to the NASA-ISRO Synthetic Aperture Radar (NISAR) Launch Readiness Date (LRD) by 13 months to October 2024. The new development cost estimate exceeds the Agency Baseline Commitment established at KDP-C by more than 30 percent, requiring re-baseline of NISAR. For more information, refer to the NISAR section of this document.

This budget initiates three Earth System Observatory missions: Surface Biology and Geology (SBG), Atmosphere Observing System (AOS) Storm, and AOS Sky, which have all entered the formulation phase in early 2023. The fourth ESO mission, Mass Change (MC), is nearing the decision point for transition to formulation with KDP-A planned in March 2023. The anticipated launch dates for these missions are delayed slightly from previously planned dates.

This budget also initiates the Landsat Next mission, a constellation of land imaging satellites to be launched no earlier than November 2030. This new mission will ensure consistency and continuity of key land imaging measurements with enhancements that will increase the utility of the data for science and applications.

NASA added a contribution to the ESA Sentinel 6C mission and removed planned contributions to the ESA Copernicus Imaging Microwave Radiometer (CIMR) mission within the Sustained Climate Observations Future Missions. Sentinel 6C is an additional Advanced Microwave Radiometer (AMR) hosted on an ESA-provided satellite to extend the continuity of sea surface altimetry beyond the Sentinel-6 (Michael Freilich and B) satellites.

In May 2022, NASA confirmed the Total and Spectral Solar Irradiance Sensor (TSIS)-2 mission to proceed into development for final design and fabrication activities. This budget includes an updated budget profile supporting a planned launch in May 2025.

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

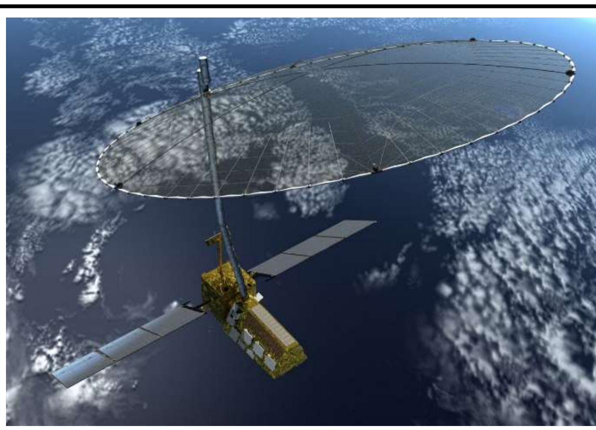
FY 2024 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028	BTC	Total
Formulation	117.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	117.0
Development/Implementation	707.8	61.5	80.2	**71.5**	0.0	0.0	0.0	0.0	0.0	921.1
Operations/Close-out	0.0	0.0	0.0	**21.7**	25.4	21.1	11.6	0.1	0.0	79.9
2023 MPAR LCC Estimate	**824.8**	**61.5**	**80.2**	**93.3**	**25.4**	**21.1**	**11.6**	**0.1**	**0.0**	**1,118.0**
Total Budget	**850.3**	**70.0**	**58.6**	**96.4**	**29.3**	**21.1**	**26.8**	**17.1**	**0.0**	**1,169.5**
Change from FY 2023 Enacted				**37.8**						
Percent change from FY 2023 Enacted				**64.5%**						

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The 2023 MPAR LCC Estimate reflects the most recent estimates based on current project data as of February 2023. The requested budget authority is the project's current budget requirement which has seen programmatic changes and are anticipated in the Quarter 2 Financial Report.



The NISAR satellite (depicted here) is a joint mission between NASA and the Indian Space Research Organization (ISRO) and will be the first radar imaging satellite to use dual frequencies. NISAR will observe and take measurements of some of the planet's most complex processes, including ecosystem disturbances, ice-sheet collapse, and natural hazards.

PROJECT PURPOSE

The NASA-ISRO Synthetic Aperture Radar (NISAR) mission will provide an unprecedented, detailed view of the Earth using advanced radar imaging and a dual frequency (L-band and S-band) Synthetic Aperture Radar (SAR). NISAR will be NASA's first dual frequency radar imaging satellite and will observe and measure some of the Earth’s most complex processes, including ecosystem disturbances, ice sheet collapse, and natural hazards (e.g., earthquakes, tsunamis, volcanoes, and landslides). The mission will reveal information about the evolution and state of Earth’s crust, broaden scientific understanding of our planet's changing processes and their effect on Earth's climate, and aid future resource and hazard management.

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

Both the 2007 and 2017 Earth Science Decadal Surveys endorsed the NISAR science objectives. NISAR is a collaborative mission with the Indian Space Research Organization (ISRO).

EXPLANATION OF MAJOR CHANGES IN FY 2024

Technical challenges encountered during System Integration and Test activities severely impacted the NISAR project. The technical challenges occurred in both the testing of the (Jet Propulsion Laboratory) JPL provided L-SAR and in the ISRO provided S-SAR. In August 2022, NASA reviewed and approved an updated development budget and established an updated Launch Readiness Date for the NISAR mission. The replan added 13 months to the Launce Readiness Date (LRD) (from September 2023 to October 2024); the development budget increased by $146.8 million to $1,118 million. The updated development cost breached the KDP-C commitment by more than 30 percent. NASA transmitted a notification of the breach to Congress on September 19, 2022.

PROJECT PARAMETERS

NISAR consists of a dual frequency (L-band and S-band) SAR. NASA will provide the L-band SAR (L-SAR), the engineering payload, the payload integration, and payload operations. ISRO will provide S-band SAR (S-SAR), the spacecraft bus, the launch vehicle, observatory integration and testing, and spacecraft operations. NISAMRAR has a prime mission of three years.

NISAR will implement enhanced data acquisition and data downlink capability as well as a global soil moisture product for agricultural, forest, and modeling efforts, as recommended by the interagency Satellite Needs Working Group (SNWG) process (a function of the United States Group on Earth Observations). The SNWG identified multiple other agencies that would benefit from NISAR systematically collecting data over North America in Quad-pol 40-megahertz mode, thus requiring additional data acquisition and downlink capability. NASA will track the cost of these additional capabilities outside of the Agency Baseline Commitment for cost, as approval of the scope enhancements took place after mission confirmation.

ACHIEVEMENTS IN FY 2022

The NISAR project continued System Integration and Test activities (SIT-2 and 3) including environmental tests during FY 2022. The ISRO provided S-SAR had an electro-magnetic interference issue that surfaced after the NISAR project integrated it with the NASA provided L-SAR and tested it for simultaneous operation. A NASA-ISRO joint review board reviewed the root cause analyses and mitigation approach. The NISAR project implemented the jointly-developed mitigation plan with a change in S-SAR controller box that ISRO delivered. This entire process impacted the SIT schedule severely and added additional cost to the NASA development phase. NASA conducted a programmatic review of NISAR in March 2022 to assess the impact and recommended path forward. The JPL NISAR project team completed a thorough schedule update in coordination with the ISRO team from lessons learned during the SIT-2 and three activities, to forecast the SIT-4 activities that will happen at the ISRO facilities after NASA sends the integrated payload to India in February 2023. In August 2022, NASA

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

approved additional funding for the development phase of NISAR, increasing the development cost and establishing a new LRD of October 2024. The updated development cost breached the KDP-C commitment by more than 30 percent. NASA sent notification of the breach to Congress on September 19, 2022.

WORK IN PROGRESS IN FY 2023

The project will continue System Integration and Test (SIT-3) activities at JPL during the first half of FY 2023. This includes environmental tests and science operation mode testing at various levels, antenna and boom assembly tests in stowed position, deployment activities, and fully integrating the payload assembly. The project expects to pack and deliver the fully integrated and tested payload to ISRO in Q2 of FY 2023 along with ground support test equipment to continue the SIT-4 activities. During SIT-4 the NASA and ISRO teams will integrate the fully tested payload with the ISRO-provided spacecraft bus. The NASA team will support the SIT-4 activities in India during Q3 and Q4 of FY 2023 per the jointly-developed SIT-4 plan. The SIT-4 activities will continue through integration with the launch vehicle provided by ISRO to prepare for launch in FY 2024.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

The project will continue SIT-4 activities at ISRO and will support launch by ISRO in Q4 of FY 2024.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2024 PB Request
Key Decision Point (KDP-C)	Aug 2016	Aug 2016
Critical Design Reviews (CDR)	Oct 2018	Oct 2018
Key Decision Point (KDP-D)	Dec 2019	Mar 2021
Payload Delivery to ISRO	Feb 2021	Mar 2023
Launch Readiness Date (LRD)	Sep 2022	Oct 2024

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Chang e (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2017	661.0	70%	2022	921.1	+39%	LRD	Sep 2022	Oct 2024	+25

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**661.0**	**921.1**	**+260.1**
Aircraft/Spacecraft	77.1	143.6	+66.5
Payloads	211.1	369.6	+158.5
Systems I&T	23.0	104.8	+81.8
Launch Vehicle	0.6	0.2	-0.4
Ground Systems	72.6	97.1	+24.5
Science/Technology	28.2	35.4	+7.2
Other Direct Project Costs	248.4	170.4	-78.0

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

Project Management & Commitments

The Earth Systematic Missions program at NASA Goddard Space Flight Center (GSFC) has program management responsibility for NISAR. NASA assigned project management responsibility to JPL. NISAR is a partnership between NASA and ISRO.

Element	Description	Provider Details	Change from Baseline
L-SAR	Radar imaging payload	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
S-SAR	Radar imaging payload	Provider: ISRO Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ISRO	N/A
Spacecraft	Provides platform for the payload	Provider: ISRO Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ISRO	N/A
Launch Vehicle	Geosynchronous Satellite Launch Vehicle (GSLV); delivers observatory to orbit	Provider: ISRO Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ISRO	N/A

Project Risks

Risk Statement	Mitigation
If: The Reflector Deployment operations is not successful, Then: The observatory will not function as planned.	The project will exercise and test the critical functionality during system integration and test activities and ensure the risk is retired before launch.
If: The Boom Deployment operation is not successful, Then: The observatory will not function as planned.	The project will exercise and test the critical functionality during system integration and test activities and ensure the risk is retired before launch.

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

Acquisition Strategy

The design and build of L-SAR radar is an in-house build at JPL with competed subcontracts.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Solid State Recorder	Airbus	Germany
Reflector Antenna	Astro Aerospace	California

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Strategic Review Board (SRB)	Dec 2014	Systems Requirement Review (SRR) / Mission Design Review (MDR)	Successful	Jun 2016
Performance	SRB	Jun 2016	Preliminary Design Review (PDR)	Successful	Oct 2018
Performance	SRB	Oct 2018	Critical Design Reviews (CDR)	Successful	Oct 2020
Performance	SRB	Oct 2020	System Integration Review (SIR)	Successful	Jan 2024
Performance	SRB	Jan 2024	Operational Readiness Review (ORR)	TBD	N/A

SENTINEL-6

Formulation	Development	Operations

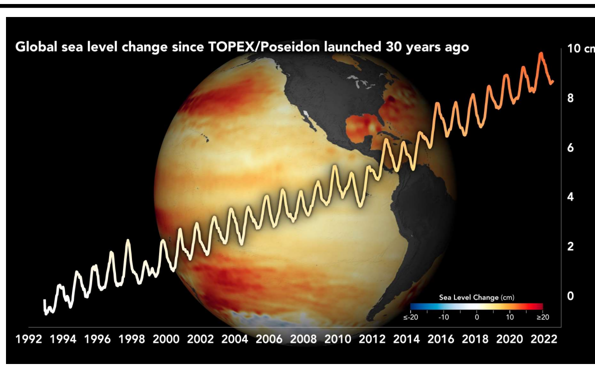
FY 2024 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028	BTC	Total
Formulation	15.5	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	15.5
Development/Implementation	222.2	13.6	34.1	**60.4**	49.0	23.1	0.0	0.0	0.0	402.3
Operations/Close-out	0.0	9.2	6.2	**3.5**	6.2	2.5	8.7	5.7	25.0	67.0
2023 MPAR LCC Estimate	**237.6**	**22.8**	**40.3**	**63.9**	**55.2**	**25.6**	**8.7**	**5.7**	**25.0**	**484.7**
Total Budget	**238.1**	**22.8**	**40.3**	**63.9**	**55.2**	**25.6**	**8.7**	**5.7**	**25.0**	**485.2**
Change from FY 2023 Enacted				**23.6**						
Percent change from FY 2023 Enacted				**58.6%**						

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The 2023 MPAR LCC Estimate reflects the most recent estimates based on current project data as of February 2023. The requested budget authority is the project's current budget requirement which has seen programmatic changes and are anticipated in the Quarter 2 Financial Report.



This image shows the 30-year rise in sea level from NASA sea level mission observations from Topography Experiment (TOPEX)/Poseidon though Sentinel-6 Michael Freilich. Globally, sea levels have gone up by 10 centimeters (cm) since the early 1990s due to human interference with the climate.

PROJECT PURPOSE

The Sentinel-6 mission will provide continuity of ocean topography measurements beyond the Topography Experiment (TOPEX)/Poseidon (launched in 1992), Jason-1 (2001), Ocean Surface Topography Mission/Jason-2 (2008), and Jason-3 (2016) missions. The Sentinel-6 mission consists of two satellites, Sentinel-6 Michael Freilich and Sentinel-6B, that will launch approximately five years apart (2021 for Sentinel-6 Michael Freilich and 2026 for Sentinel-6B) to extend measurement continuity for at least another decade. This mission will serve both the operational user community and the scientific community by enabling the continuation of multi-decadal ocean topography measurements for ocean circulation and climate studies.

SENTINEL-6

Formulation	Development	Operations

As a secondary mission objective, Sentinel-6 will characterize atmospheric temperature and humidity profiles by measuring bending angles of Global Navigation Satellite System (GNSS) signals occulted by the Earth's atmosphere. The project will process these measurement products on Earth within a few hours of acquisition on-board the satellite and make them available for incorporation into National Weather Service models to support weather forecasting capabilities.

Sentinel-6 is a collaborative mission with the National Oceanic and Atmospheric Administration (NOAA), the European Space Agency (ESA), and the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT).

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

PROJECT PARAMETERS

NASA will provide the launch vehicle and launch services as well as a set of three instruments for each of the Sentinel-6 spacecraft. These two sets of instruments are Advanced Microwave Radiometer-Climate Quality (AMR-C), the GNSS-Radio Occultation (GNSS-RO) receiver, and the Laser Reflector Array (LRA). Additionally, NASA will provide support for instrument integration and testing on the satellites, mission operations support for the NASA-developed instruments, an operational AMR-C science data processor for EUMETSAT, near real-time and offline data processing for GNSS-RO data, and mission data product archiving and distribution. The Sentinel-6 Michael Freilich and Sentinel-6B observatories each have a five-and-a-half-year prime mission.

ACHIEVEMENTS IN FY 2022

Sentinel-6 Michael Freilich continued to produce high-accuracy research-quality science data products. The Sentinel-6 validation team met twice during FY 2022, once in Oct 2021 to assess the quality of near real-time data, and once in July 2022 to assess the quality of high-resolution data from Sentinel-6. The data products assessed by the team were deemed to be of high-quality and met all the science and operational objectives. NASA released this mission data to the public on time and as scheduled. The Ocean Surface Topography Science Team also met in March of 2022 to assess the overall quality of Sentinel-6 Michael Freilich data in comparison to its predecessor mission, Jason-3. The Sentinel-6 data again met all necessary requirements and following this meeting the Committee on Earth Observation Satellites (CEOS) Ocean Surface Topography Virtual Constellation partners met and declared Sentinel-6 Michael Freilich to be the new reference mission.

NASA completed the development of the Sentinel-6B satellite in June 2022. NASA completed integration of the Sentinel-6B (S6-B) satellite completed all functional, performance, and environmental testing. The S6-B satellite is currently in storage in preparation for a launch by early 2026.

SENTINEL-6

Formulation	Development	Operations

WORK IN PROGRESS IN FY 2023

NASA has selected SpaceX to provide launch services for the Sentinel-6B mission. This launch vehicle selection reduces the risk of differing launch environments from the Sentinel-6 Michael Freilich satellite, since it will launch on the same vehicle, the SpaceX Falcon 9 rocket. The project will have sufficient time for any additional analysis and testing of the S6-B satellite in time to support an early 2026 launch.

In early Nov 2022, the Ocean Surface Topography Science Team held its first in person meeting since the start of the pandemic. There will be further assessment of the Sentinel-6 data, along with presentation of new science results

KEY ACHIEVEMENTS PLANNED FOR FY 2024

Sentinel-6 expects to produce high-accuracy research-quality science data products from the Michael Freilich satellite. The project will refresh ground systems to maintain consistent and reliable mission operations, perform further health checks of the stored S6-B satellite, and conduct detailed planning for taking the S6-B satellite out of storage and prepare additional testing in advance of a launch by early 2026.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2024 PB Request
Key Decision Point (KDP-C)	Apr 2017	Apr 2017
CDR	Oct 2017	Oct 2017
Sentinel-6 Michael Freilich U.S. Payload delivery to ESA	Mar 2020	Mar 2020
Sentinel-6B U.S. Payload delivery to ESA	Oct 2020	Oct 2020
Launch (Sentinel-6 Michael Freilich)	Nov 2021	Nov 2020
Start Phase E (Sentinel-6 Michael Freilich)	Feb 2022	Feb 2021
End Prime Mission (Sentinel-6 Michael Freilich)	Aug 2027	Aug 2026
Launch (Sentinel-6B)	Nov 2026	Nov 2026
Start Phase E (Sentinel-6B)	Feb 2027	Feb 2027
End Prime Mission (Sentinel-6B)	Aug 2032	Aug 2032

SENTINEL-6

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2017	465.9	>70%	2023	402.3	-14%	LRD of Sentinel-6 Michael Freilich	Nov 2021	Nov 2020	-12
N/A	N/A	N/A	N/A	N/A	N/A	LRD of Sentinel-6B	Nov 2026	Nov 2026	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**465.9**	**402.3**	**-63.6**
Aircraft/Spacecraft	0	0	0
Payloads	65.8	77.2	+11.4
Systems I&T	8.8	6.2	-2.6
Launch Vehicle	280.7	248.1	-32.6
Ground Systems	9.7	14.0	+4.3
Science/Technology	4.4	20.2	+15.8
Other Direct Project Costs	96.5	36.6	-59.9

SENTINEL-6

Formulation	Development	Operations

Project Management & Commitments

The Earth Systematic Missions Program at the Jet Propulsion Laboratory (JPL) has program management responsibility for Sentinel-6. NASA also assigned project management responsibility to JPL. Sentinel-6 is a partnership with NOAA, ESA, and EUMETSAT.

Element	Description	Provider Details	Change from Baseline
AMR-C	Provides high spatial resolution wet tropospheric path delay corrections for the ESA-supplied Ku/C-Band Altimeter	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
GNSS-RO	Supports secondary mission objectives for weather modeling and forecasting	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
LRA	Provides orbit determination	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Ku/C-Band Altimeter	Measures Jason-heritage ocean surface topography at nadir	Provider: ESA Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS)	Provides orbit determination	Provider: ESA Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Spacecraft Bus	Provides instrument platform	Provider: ESA Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Launch Vehicle	Delivers spacecraft to orbit	Provider: NASA Lead Center: JPL Performing Center(s): Kennedy Space Center (KSC) Cost Share Partner(s): N/A	N/A

SENTINEL-6

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: The launch environments for the Sentinel-6B spacecraft are different than for Sentinel-6 Michael Freilich due to changes in the selected launch vehicle, Then: The project will need to do additional testing or analysis to ensure compatibility of the spacecraft with the launch vehicle.	NASA has prepared requirements for the qualification test levels used for the Sentinel-6 Michael Freilich spacecraft as a spacecraft-specific requirement during the Sentinel-6B launch service acquisition process. In late 2022, the SpaceX Falcon-9 was selected as the launch vehicle for Sentinel-6B. Sentinel-6 Michael Freilich launched on the same vehicle. NASA anticipates retiring this risk following coordination with the mission partners.

Acquisition Strategy

Sentinel-6 leverages Jason heritage by using JPL legacy instrument designs (e.g., AMR-C, GNSS-RO, and LRA) and an in-house build with a combination of sole source and competitive procurements. NASA selected SpaceX to provide a Falcon 9 launch vehicle through a competitive Launch Service Task Order evaluation under the NASA Launch Services II contract.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
GNSS-RO Electronics	MOOG	Golden, CO
AMR-C Antenna	Northrop Grumman Innovation Systems	San Diego, CA
LRA	ITE	Laurel, MD
Launch Services (S-6 Michael Freilich and S-6B)	SpaceX	Los Angeles, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Oct 2017	Critical Design Reviews (CDR)	Successful	Apr 2019
Performance	SRB	Apr 2019	Project System Integration Review (P-SIR)	Successful	Sep 2021

SENTINEL-6

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Sep 2020	Sentinel-6 Michael Freilich ORR	Successful	Aug 2026
Performance	SRB	Aug 2025	Sentinel-6B ORR	TBD	N/A

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	Development	Operations

FY 2024 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028	BTC	Total
Formulation	260.3	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	260.3
Development/Implementation	385.0	54.9	112.8	**68.5**	0.0	0.0	0.0	0.0	0.0	621.2
Operations/Close-out	0.0	0.0	0.0	**22.9**	26.3	24.8	8.5	0.0	0.0	82.5
2023 MPAR LCC Estimate	**645.3**	**54.9**	**112.8**	**91.4**	**26.3**	**24.8**	**8.5**	**0.0**	**0.0**	**964.0**
Total Budget	**645.3**	**54.9**	**112.8**	**91.4**	**26.3**	**24.8**	**21.2**	**22.3**	**0.0**	**998.9**
Change from FY 2023 Enacted				**-21.4**						
Percent change from FY 2023 Enacted				**-19.0%**						

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The 2023 MPAR LCC Estimate reflects the most recent estimates based on current project data as of February 2023. The requested budget authority is the project's current budget requirement which has seen programmatic changes and are anticipated in the Quarter 2 Financial Report.

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	Development	Operations

Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) (depicted here) will advance the assessment of ocean health by measuring the distribution of phytoplankton, tiny plants and algae that sustain the marine food web. It will also continue systematic records of key atmospheric variables associated with air quality and Earth's climate.

PROJECT PURPOSE

The Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission will improve our understanding of how the ocean and atmosphere exchange carbon dioxide. In addition, it will reveal how aerosols might fuel phytoplankton growth in the surface ocean. PACE's unprecedented spectral coverage will provide the first-ever global measurements designed to identify phytoplankton community composition. This will significantly improve our ability to understand Earth's changing marine ecosystems, manage natural resources (e.g., fisheries), and identify harmful algal blooms.

PACE's primary sensor, the Ocean Color Instrument (OCI), is a highly advanced optical spectrometer that will measure properties of light over portions of the electromagnetic spectrum extending key ocean color data records. The interaction of sunlight with substances or particles in seawater such as chlorophyll, a green pigment found in most phytoplankton species, determine the color of the ocean. By monitoring global phytoplankton distribution and abundance with unprecedented detail, through measurement of ocean color, OCI will help us improve our understanding of the complex systems that drive ocean ecology.

PACE includes two contributed polarimeters to measure how the oscillation of sunlight within a geometric plane - known as its polarization - changes by passing through clouds, aerosols, and the ocean. Measuring polarization states of ultraviolet (UV)-to-shortwave light at various angles provides detailed information on the atmosphere and ocean (e.g., particle size and composition).

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

PROJECT PARAMETERS

The NASA Goddard Space Flight Center (GSFC) is responsible for the design and fabrication of the spacecraft, development of the OCI, and development of the mission operations center. GSFC will collect, process, archive, and distribute PACE data. OCI will consist of a cross-track rotating telescope,

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	Development	Operations

thermal radiators, along with half-angle mirror and solar calibration mechanisms. OCI's tilt mechanism will help avoid sun glint and single science detector design will inhibit image striping. Its signal-to-noise ratios will rival or exceed previous ocean color instruments. OCI will have two-day global coverage at a 60-degree instrument view angle.

The Hyper-angular Rainbow Polarimeter 2 (HARP-2) is a wide-swath imaging polarimeter capable of characterizing atmospheric aerosols for the purposes of sensor atmospheric correction and atmospheric science. The Spectro-Polarimeter for Exploration (SPEXOne) provides atmospheric aerosol and cloud data at high temporal and spatial resolution.

PACE will launch in 2024 with a minimum mission duration of three years. Nominal spacecraft altitude is 676.5 kilometers (420 miles) with an inclination of 98-degrees.

ACHIEVEMENTS IN FY 2022

The PACE team continued to make significant progress in FY 2022. The OCI team completed their first full system-level Comprehensive Performance Test (CPT) in May 2022 and integration in July 2022. SPEXOne successfully completed acceptance and integration readiness reviews. In November 2022, the project delivered the Flight Tilt System and HARP2 for integration and testing (I&T), and OCI completed thermal vacuum testing.

WORK IN PROGRESS IN FY 2023

PACE Observatory I&T began in October 2022 with the delivery of the OCI instrument. The team completed the Systems Integration Review (SIR) in early November 2022 and Pre-Environmental Review (PER) in December 2022. The team proceeded to Key Decision Point D for approval to enter the System Assembly, Integration and Test phase in February 2023.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

The PACE team expects to hold the Pre-Ship Review (PSR) in October 2023 and to ship to the launch site shortly thereafter. The project will complete the ground system end to end test in December 2023. PACE will launch from Kennedy Space Center on a Space X Falcon 9 NET May 2024.

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2024 PB Request
KDP-B	Jul 2017	Jul 2017
KDP-C	Aug 2019	Aug 2019
KDP-D	Aug 2021	Feb 2023
Launch Readiness Date	Jan 2024	May 2024
End Prime Mission	Apr 2027	Aug 2027

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2020	558.0	>70%	2023	621.2	+11%	LRD	Jan 2024	May 2024	+4

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**558.0**	**621.2**	**+63.2**
Aircraft/Spacecraft	103.6	136.3	+32.7
Payloads	79.2	189.2	+110.0
Systems I&T	18.8	27.1	+8.3
Launch Vehicle	105.0	80.4	-24.6
Ground Systems	19.3	28.8	+9.5
Science/Technology	50.0	59.1	+9.1
Other Direct Project Costs	182.1	100.3	-81.8

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Polarimeter (HARP-2) - Contribution	Measures how the oscillation of sunlight changes by passing through clouds, aerosols, and the ocean.	Provider: University of Maryland Baltimore County (UMBC) Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): UMBC	N/A
Polarimeter (SPEXOne) - Contribution	Measures how the oscillation of sunlight changes by passing through clouds, aerosols, and the ocean.	Provider: Netherlands Institute for Space Research (SRON) Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): SRON	N/A
Ocean Color Instrument	Highly advanced optical spectrometer that will measure properties of light over portions of the electromagnetic spectrum.	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Spacecraft	Provides a platform for instruments.	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Launch Vehicle	Provides launch services for the PACE Observatory.	Provider: SpaceX Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Mission Operations and Ground system	Provides software and system with capabilities for command and control, mission scheduling, long-term trending, and flight dynamics analysis. Collects, processes, archives, and distributes PACE data.	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: PACE Reaction Wheel Assembly (RWA) Assembly and Test continues to have schedule delivery challenges, Then: Observatory Integration and Test will be delayed.	Project has added significant staffing and resources to mitigate RWA schedule erosion. The first two RWA(s) of four have started environmental testing. Project is evaluating possible modification to observatory environmental test flow.

Acquisition Strategy

GSFC will build the spacecraft and OCI instrument in-house. UMBC will contribute the HARP-2 polarimeter. The Netherlands Institute for Space Research will contribute the SPEXOne polarimeter. The PACE Project worked with the NASA LSP to award the launch services contract to SpaceX in February 2020.

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Launch Vehicle	SpaceX	Hawthorne, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Mar 2019	Preliminary Design Review (PDR)	Successful	Jan 2020
Performance	SRB	Jan 2020	Critical Design Review (CDR)	Successful	Aug 2022
Performance	SRB	Nov 2022	Systems Integration Review (SIR)	Successful	Sep 2023
Performance	SRB	Sep 2023	Operations Readiness Review (ORR)	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Atmosphere Observing System-Sky	3.3	--	**138.9**	169.3	192.9	159.1	141.6
Atmosphere Observing System-Storm	3.3	--	**43.7**	79.8	124.5	110.4	131.2
Landsat Next	0.0	--	**95.7**	166.6	182.4	180.4	211.7
Mass Change	0.0	--	**35.5**	37.0	73.6	69.1	46.2
Surface Biology and Geology	12.7	--	**68.9**	126.1	168.3	166.8	105.4
Sustained Climate Observations Future Mi	33.4	--	**20.7**	42.7	39.4	44.0	44.7
Earth Systematic Missions (ESM) Research	25.6	--	**26.0**	37.5	39.9	39.9	39.9
Surface Water and Ocean Topography Mission (SWOT)	27.8	--	**16.2**	16.2	15.1	13.2	9.4
Ocean Surface Topography Science Team (OSTST)	5.9	--	**6.2**	6.2	6.3	6.5	6.6
Earth Observations Systems (EOS)	10.5	--	**10.7**	10.7	10.7	10.7	10.7
Landsat 9	8.6	--	**3.0**	3.0	3.1	3.1	0.0
Sage III	4.6	--	**4.8**	4.8	4.8	4.8	4.9
Radiation Budget Instrument (RBI)	0.4	--	**0.0**	0.0	0.0	0.0	0.0
Sustainable Land Imaging	19.8	--	**11.0**	11.0	11.0	11.0	11.0
Earth from ISS	1.7	--	**1.5**	0.9	0.0	0.0	0.0
Total Solar Irradiance Sensor-2 (TSIS-2)	36.5	--	**48.4**	22.3	6.4	6.0	4.0
Earth Radiation Budget Science	14.8	--	**15.8**	15.9	16.9	17.0	17.3
Ozone Mapping and Profiler Suite (OMPS)	0.4	--	**5.2**	1.5	1.4	1.4	1.4
Total Solar Irradiance Sensor-1 (TSIS-1)	3.6	--	**5.3**	4.9	4.9	4.9	4.9
CLARREO Pathfinder	18.5	--	**15.5**	5.7	2.8	2.8	2.8
Earth System Observatory Future Missions	89.7	--	**5.4**	4.0	15.6	52.5	79.4
Earth Science Program Management	65.3	--	**64.9**	68.5	67.0	68.0	68.4
Precipitation Science Team	6.5	--	**6.8**	6.8	7.0	7.1	7.3
Ocean Winds Science Team	3.1	--	**3.3**	3.3	3.3	3.4	3.5
Land Cover Science Project Office	1.3	--	**1.4**	1.4	1.4	1.5	1.5
Ocean Salinity Science Team	7.6	--	**8.0**	8.0	8.2	8.4	8.5
Soil Moisture Active and Passive (SMAP)	6.5	--	**13.4**	13.8	13.7	14.0	14.2
Deep Space Climate Observatory	1.7	--	**1.7**	1.7	1.7	1.7	1.7
Global Precipitation Measurement (GPM)	24.4	--	**25.6**	23.1	23.3	23.2	23.7
Suomi National Polar-Orbiting Partnership (Suomi NPP)	3.8	--	**4.0**	4.0	4.1	4.2	4.3
Terra	30.3	--	**9.0**	9.0	0.0	0.0	0.0
Aqua	30.6	--	**11.7**	11.7	0.0	0.0	0.0
Aura	20.9	--	**8.3**	8.0	3.4	0.0	0.0
ICESat-2	24.5	--	**26.6**	26.0	26.3	26.8	27.5
GRACE Follow-On	11.1	--	**12.5**	11.5	12.0	12.0	12.2
Total Budget	**558.7**	**--**	**775.5**	**962.8**	**1,091.2**	**1,073.6**	**1,045.9**

OTHER MISSIONS AND DATA ANALYSIS

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Earth Systematic Missions Other Missions and Data Analysis includes operating missions and their science teams and competed research projects. Mission science teams define the scientific and applications requirements for their missions and generate algorithms used to process the data into useful data products. The research projects execute competitively selected investigations related to specific mission measurements.

Also included are Sustainable Land Imaging activities, as well as smaller instruments and missions in formulation and development, such as the Ozone Mapping and Profiler Suite Limb Sounder and Total and Solar Irradiance Sensor-2.

Mission Planning and Other Projects

EARTH SYSTEMATIC MISSIONS (ESM) RESEARCH

ESM Research funds various science teams for the Earth Systematic missions. These science teams are composed of competitively selected individual investigators who analyze data from the missions to address related science questions.

Recent Achievements

Researchers performed a Greenland ice sheet-wide glacier classification based on seasonal velocity patterns derived from three years of Sentinel-1 radar data. The researchers primarily focused their classification system on two distinctive seasonal ice velocity patterns, with the first showing time periods of acceleration and deceleration during the melt season, and the second type displaying a longer period of deceleration from higher ice velocities in the winter and spring. They found that while glaciers meeting each of these different classification types vary from year to year, glaciers that experience periods of acceleration and deceleration during the melt season are more common in northern Greenland while glaciers displaying a longer period of deceleration from higher ice velocities in the winter and spring are more common in southern Greenland. These results show the highly variable impact of meltwater on glacier flow and subglacial drainage systems of Greenland's outlet glaciers.

Researchers examined landslide sensitivity and response to precipitation changes in wet and dry climates at 39 landslides that occurred in California between 2015 and 2020 using open-access InSAR data. They found that despite the large differences in hydroclimate, these landslides exhibited surprisingly similar behaviors and hydrologic sensitivity, characterized by faster than average velocities during wetter than average years, as well as slower than average velocities in drier than average years, once the impact of the drought diminished. The authors note that their findings further confirm landslide sensitivity to climate change under diverse hydroclimate conditions and highlight the need to establish a long time series of landslide behaviors that can help to better predict future landslide activity.

Scientists described a new NASA–Air Force Precipitation Analysis (NAFPA) that combines precipitation estimates from numerical models, rain gauges, and satellites to produce global three-hour maps of precipitation on a grid with about 10-kilometer (km) resolution. While the Air Force system employs

OTHER MISSIONS AND DATA ANALYSIS

several legacy satellite products, they are shifting to NASA's Integrated Multi-satellitE Retrievals for GPM (IMERG) Early Run products as the primary source due to limitations in the legacy products. Scientists evaluated multiple years of test runs over the continental United States, Africa, and monsoonal Asia against best-available gauge analyses and compared to a range of other observational and numerical model global precipitation products, including the IMERG Late and Final Run products. For most metrics in these regions NAFPA performed better than most of the near-real-time products and was competitive with the post-real-time products. Operational implementation is underway to provide precipitation information, including input to an operational Air Force land data assimilation system.

OCEAN SURFACE TOPOGRAPHY SCIENCE TEAM (OSTST)

OSTST uses scientific data from the Ocean Surface Topography Mission and Jason radar altimetry satellites. Together with data from international altimetry satellites such as the European Space Agency's (ESA) Sentinel-3a, OSTST can measure global sea surface height. Data from tide gauges and a handful of calibration stations such as the Harvest oil platform help validate the satellite data.

Recent Achievements

OSTST is the official science team for all 'reference' satellite altimetry missions, including the Jason-series (1,2,3) of U.S.-European satellites, and the recently launched Sentinel-6 Michael Freilich satellite. OSTST carefully studies the accuracy of the data from these missions, helping the agencies make sure it remains error free over the life of the missions. In March 2022, the OSTST met to assess the quality of data from the Sentinel-6 Michael Freilich satellite mission during its tandem flight with Jason-3. The team concluded that the mission met all science requirements and the international Committee on Earth Observing Satellites declared Sentinel-6 Michael Freilich to be the reference altimetry mission, meaning it is the gold standard to which all other altimeter missions should be compared. In August 2022, Sentinel-6 Michael Freilich extended the global, high-precision record of sea level change to 30 full years. Spanning the life of five different satellites, this record now stands as one of the most important measures of human interference with the climate, and its accuracy and consistency is one of the most important long-term accomplishments of the OSTST.

In addition to overseeing the ongoing integrity of the climate record, the OSTST continues to produce a wide range of scientific results on climate and ocean circulation. In January of 2022, Sentinel-6 Michael Freilich and Jason-3 observed the tsunami generated by the massive volcanic eruption in Tonga. While altimeter observations are not frequent enough to be useful for early tsunami warnings, observations of the tsunami signal help scientist better understand how these damaging waves generate and propagate thousands of miles across the open ocean. The ocean absorbs over 90 percent of the heat trapped by human interference with the climate, driving sea levels higher as warming water expands.

Recent work by the OSTST shows that the Earth's rate of warming increased in recent decades, and that in most ocean regions the warming is becoming clearer against the background of natural cycles. In addition, scientists use ocean altimetry records to improve our understanding of sea level rise, including the ongoing acceleration in the rate of rise, and to explain changes in the ocean circulation in all global oceans, including the Arctic. Data from Sentinel-6 Michael Freilich is ingested and served entirely through cloud services, making it the first NASA product to provide all data services through the cloud. All data products from the mission are now available to the public through NASA's Physical Oceanography Distributed Active Archive Center (PODAAC) cloud services.

OTHER MISSIONS AND DATA ANALYSIS

EARTH OBSERVATION SYSTEMS (EOS) RESEARCH

EOS Research funds science for the EOS missions, currently Terra, Aqua, Aura, and ICESat-2 missions. The project competitively selects individual investigators to undertake research projects that analyze data from specific missions. Overall, most selected activities focus on science data analyses; however, some funded activities continue algorithm improvement and validation for the EOS mission instrument data products.

Recent Achievements

A research team developed a plume rise model based on data from approximately 4.6 million smoke plumes occurring within the western United States and western Canada during the months of August and September between 2003-2020. Researchers validated the model results by comparisons with the Multi-angle Imaging SpectroRadiometer (MISR) observational plume heights database. The findings indicate that current trends towards enhanced wildfire activity correspond to elevated wildfire plume-top heights and aerosol injection aloft for most mountainous ecoregions across the western United States. These results suggest a causal link between climate change and the increase in wildfire plume top heights and enhanced injection of aerosols above and within the boundary layer, leading to a growing risk of air quality degradation downwind of the fires.

Researchers found evidence in Ozone Mapping and Profiler Suite (OMPS) Limb Profiler ozone and aerosol measurements to support the hypothesis that two extraordinary events (the Australian wildfires of early 2020 and the eruption of La Soufriere in 2021) influenced the 2020 and 2021 Antarctic ozone holes. They argue that both ozone holes were associated with changes in Southern Hemisphere surface climate consistent with the established climate impacts of Antarctic ozone depletion. Together, the results provide suggestive evidence that injections of both wildfire smoke and volcanic emissions into the stratosphere can lead to hemispheric-scale changes in surface climate.

NASA funded researchers combined 36 years of movement, genetic, and demographic data to show that polar bears in Southeast Greenland are distinct from bears living elsewhere along the island's eastern coast. Instead of traveling large distances to hunt on sea ice, polar bears in Southeast Greenland are relatively stationary; they live and hunt solely in the region's glacial fjords at the interface of glacier ice and sea ice/mélange. The unique population has been isolated from similar polar bears in the Arctic for long enough that they have become genetically distinct. The team used Moderate Resolution Imaging Spectroradiometer (MODIS) data, as well as in situ data to document the conditions in the fjords and the offshore sea ice environment. They found that southeastern polar bears are cut off from sea ice for two-thirds of the year, and instead rely on the broken up and floating ice mixture in these glacial fjords to hunt. Based on these observations and conclusions, the team surmises that the way southeastern polar bears have adapted could be an indication of how other polar bear populations may adapt to survive as global warming persists.

SUSTAINABLE LAND IMAGING (SLI)

The SLI project enables the development of a multi-decade, space-borne system that will provide U.S. users with high-quality global land-imaging measurements. These measurements will be compatible with the existing Landsat record and will address near and long-term issues of continuity risk. They will also evolve flexibly and responsibly through investment and introduction of new sensor and system technologies. Under the SLI framework, NASA will maintain responsibility for developing, launching, and initial checkout of space systems. The U.S. Geological Survey (USGS) will be responsible for

OTHER MISSIONS AND DATA ANALYSIS

collecting and documenting user needs, developing the associated ground systems, and operating the on-orbit spacecraft. USGS will also collect, calibrate, archive, process, and distribute SLI system data to users.

Through the implementation of SLI technology activities, NASA will enable new SLI measurement technologies, capabilities, and architectures. The Sustainable Land Imaging-Technology (SLI-T) program element aims to: demonstrate improved, innovative, full-instrument concepts for potential infusion into the architecture and design of the next generation of Landsat missions. SLI-T develops technologies at the component and/or breadboard-level that have long-term potential to improve future land imaging instruments and systems significantly through substantial architecture changes. NASA will solicit instrument and subsystem development activities in coordination with the Landsat science community.

Additional SLI activities support efforts to minimize costs and maximize the overall utility for U.S. users by responsibly engaging with international partners to ensure access to high-quality data and fusion of those measurements with those from the U.S. Landsat missions. NASA and USGS conducted pre-launch cross-calibration investigations with the European developers of the Sentinel-2A/B land imaging system, ensuring uniform calibration of both Landsat 8 and Sentinel-2A/B instruments to the same standards. The USGS, supported by NASA and other agencies, is serving as the primary United States Government point of contact to ensure access to and archiving of Sentinel-2 data products for U.S. research and operational users.

Recent Achievements

Under the SLI program, NASA is working with USGS to define a commercial imagery pathfinder for Sustainable Land Imaging. This pathfinder will explore the development of data products making use of high spatial resolution and high revisit commercial visible - Near infrared (VNIR) imagery that can augment the Landsat data archive and provide additional value in meeting user needs.

Seven existing grants in the SLI-T portfolio continued to make progress in FY 2022. The grants support technology development activities aimed specifically at demonstrating improved, innovative, full-instrument concepts for potential infusion into the design of missions beyond Landsat Next. Development and technical maturation at the component and/or breadboard-level have long-term potential to significantly improve future land imaging instruments and systems through substantial architecture changes. NASA funded one of the Earth Science and Technology Office (ESTO) Instrument Incubator Program (IIP) grants for a flight demonstration of an uncooled long wavelength infrared bolometer-based imager, which launched on January 3, 2023, as a hosted payload.

LANDSAT NEXT

The Landsat Next mission is the successor mission to Landsat 8 and 9. USGS and NASA have collected Landsat imagery since 1972, resulting in the longest continuously acquired collection of space-based terrestrial observations. The Earth observation capabilities offered by previous Landsat missions have ensured consistency and continuity of measurements but with incremental improvements that increased the utility of the data for science and applications.

The Landsat Next concept consists of a Superspectral Coincident Visible and Short Wave Infrared plus Thermal Infrared (TIR) architecture. The Superspectral architecture provides increased spectral coverage, with simultaneous measurements in 26 bands, compared to the 11 bands of Landsat 8 and 9. These additional bands enable new user applications, including assessments of water quality, mineral mapping, snow hydrology, and soil conservation. The new architecture also increases the spatial resolution over

OTHER MISSIONS AND DATA ANALYSIS

Landsat 8 and 9 by a factor of two, providing more detailed insight into land use and yielding spatial resolution comparable to the Sentinel-2 Multispectral Instrument (MSI).

Landsat Next is being designed as a constellation of three identical satellites in 18 day repeat orbits. The spacecraft are phased in orbit to yield a Landsat Next system revisit of six days.

This architecture emphasizes the key priorities of existing Landsat users: improved temporal frequency of multispectral observations, higher spatial resolution, and additional spectral information for existing and emerging applications.

The proposed plan for Landsat Next reflects the results of a close collaboration between NASA and USGS in developing program strategy and architecture, identification of user needs, and defining mission requirements. NASA will maintain responsibility for developing, launching, and checking-out space systems. The USGS will be responsible for developing the associated ground systems, operating the on-orbit spacecraft, and collecting, archiving, processing, and distributing SLI system data to users. NASA will be responsible for management of mission operations from launch through the completion of on-orbit checkout, at which point Landsat Next will transition to the USGS.

Recent Achievements

Landsat Next completed pre-Phase A activities in 2022, culminating in a successful Mission Concept Review (MCR) in March 2022 for a triplet constellation architecture. NASA approved Landsat Next to enter Phase A of formulation to complete concept and technology development in November 2022. Landsat Next launch readiness date is no earlier than November 2030.

CLARREO PATHFINDER (CPF)

CPF will measure sunlight reflected by the Earth and Moon and improve the accuracy of these measurements by five to ten times compared to current best sensors. Higher accuracy means greater certainty in the measurements, which will make it possible to detect Earth's subtle climate change trends decades sooner than otherwise possible.

Recent Achievements

The project is continuing flight hardware development, integration, and test of different subassemblies. The project is on course for launch to the International Space Station in August 2024. The project continues to work on interface design details and meeting launch requirements.

TOTAL SOLAR IRRADIANCE SENSOR-2 (TSIS-2)

The TSIS-2 instruments will maintain and extend the 41-year measurement record of total solar irradiance and spectral solar irradiance beyond 2023 provided by TSIS-1 and earlier missions. Researchers have used the solar irradiance data to understand how the solar energy affects the Earth system over an 11-year cycle and longer time scale. NASA is implementing TSIS-2 by leveraging the available spare parts from the TSIS-1 mission to the greatest degree possible. NASA will implement TSIS-2 as a Class D payload and as a free flyer. The TSIS-2 launch readiness date is May 2025 and the mission will operate for no less than three years.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

NASA confirmed TSIS-2 to enter the development phase in May 2022 and the mission began final design and fabrication activities. The spacecraft developer presented a critical design of the spacecraft to reviewers and received approval to move to fabrication of the detailed design. The instrument vendor completed both instruments and started all required testing. The NASA Launch Services Program awarded the TSIS-2 launch vehicle services contract to SpaceX through the Venture-Class Acquisition of Dedicated and Rideshare (VADR) contract in August 2022.

EARTH RADIATION BUDGET SCIENCE (ERBS)

The ERBS project produces climate data records of Earth's radiation budget and the associated cloud, aerosol, and surface properties. The project utilizes data from the multiple radiation budget instruments in orbit and ancillary measurements to produce integrated, self-consistent data products over the entire suite of radiation budget instruments. The data products utilize coincident imager measurements and Clouds and the Earth's Radiant Energy System (CERES) instrument broadband radiative fluxes from Terra, Aqua, Suomi National Polar-orbiting Partnership, NOAA-20, and operational geostationary satellite observations. In total, scientists have used 30 instruments on 24 spacecraft thus far to produce an accurate and temporally consistent description of the radiation budget, not only at the top of the atmosphere but also at the surface and within the atmosphere. The ERBS project is the only project worldwide whose prime objective is to produce global, climate-quality ERB data from dedicated ERB satellite instruments.

Recent Achievements

In FY 2022, the ERBS team developed a software tool and graphical user interface for planning CERES instrument special operations. Members of the ERBS Data Management Team migrated several of the CERES near-real time product generation executives into a partially automated production framework and completed proof-of-concept runs of current code in the cloud to improve run-time efficiency. The ERBS team developed a new production code for determining instantaneous surface radiative fluxes and tested and validated machine learning algorithms for improved near-real time surface fluxes. The ERBS team developed and implemented new automated procedures for identifying and flagging scan anomalies in geostationary imager data and completed numerous algorithm improvements to use in a future reprocessing of all CERES data products.

OZONE MAPPING AND PROFILER SUITE LIMB SOUNDER (OMPS-L)

The advanced OMPS tracks the health of the ozone layer and measures the concentration of ozone in the Earth's atmosphere. OMPS is a three-part instrument, a nadir mapper that maps global ozone with about 50-km ground-resolution, a nadir profiler that will measure the vertical distribution of ozone in the stratosphere, a limb profiler that will measure ozone in the lower stratosphere, and troposphere with high vertical resolution. The entire OMPS suite currently operates on the Suomi NPP spacecraft. To ensure data continuity, NASA provided a copy of this suite for NOAA's Joint Polar Satellite System-2 (JPSS-2) mission, which launched in November 2022. NASA is responsible for providing the OMPS-Limb profiler for integration on the OMPS instrument. The project budget also supports OMPS-Limb profilers for JPSS-3 and JPSS-4.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

In FY 2022, the OMPS team successfully completed installation of the JPSS-2 OMPS onto the spacecraft and launched November 2022. Completion of the JPSS-3 OMPS occurred, inclusive of the Limb instrument, and the entire suite is in storage awaiting delivery to the spacecraft. The JPSS-4 OMPS Limb is nearing completion with delivery expected to the integrated sensor suite in FY 2023.

EARTH SYSTEM OBSERVATORY FUTURE MISSIONS

In January 2018, the National Academies released a new Earth Science Decadal Survey, entitled "Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space." In addition to recommending that NASA complete the missions that were already in formulation and development, this Decadal Survey recommended an observing program that prioritized observables to address key science and applications objectives for the coming decade. These include the following high priority "designated observables" (DOs): Aerosols; Clouds, Convection, and Precipitation (ACCP); Mass Change (MC); Surface Biology and Geology (SBG); and Surface Deformation and Change (SDC). See the project sections below for more details on SBG, Atmospheric Observing System (AOS), and MC.

In October 2018, NASA initiated studies to develop concepts for missions/observing systems to address the five DO priorities. The ACCP priority is addressed by the Atmospheric Observing System. The other observables MC, SBG, and SDC are addressed by missions of the same name. These missions/observing systems will constitute a new Earth System Observatory (ESO) with implementation as cost-constrained projects. The AOS missions, SBG, and MC will enter formulation in FY 2023. However, SDC will remain in pre-formulation until FY 2026. The Earth-focused DOs will provide key information to guide efforts related to climate change, natural hazard mitigation, fighting forest fires, and improving agricultural processes.

Recent Achievements

In FY 2022, the SDC study team completed a new ionospheric model based on Global Navigation Satellite System ionospheric estimates to better characterize the impact of the ionosphere. The team also conducted an RFI for industry engagement and insight into their interests and capabilities in SDC and completed an inter-spacecraft time-transfer study to characterize requirements for distributed synthetic aperture radar spacecraft.

SURFACE BIOLOGY & GEOLOGY (SBG)

The SBG element of the ESO will revolutionize scientific understanding of climate change, agriculture, species’ terrestrial and marine habitats, the surface water cycle, and the distribution of surface natural resources. SBG will answer open questions about the fluxes of carbon, water, nutrients, and energy within and between ecosystems, the atmosphere, the ocean, and the Earth.

SBG consists of a VSWIR hyperspectral platform and a thermal infrared (TIR) platform. These elements will take measurements from separate spacecraft. The VSWIR element will be in a morning sun synchronous orbit and the TIR element will be in an early afternoon sun synchronous orbit. NASA will provide the instrument, spacecraft, and launch vehicle for VSWIR. The Italian Space Agency (ASI) will provide the spacecraft and launch vehicle for the NASA TIR instrument. The TIR and VSWIR delivery and launch readiness dates support a minimum one-year overlap of TIR and VSWIR observations. The target launch dates are CY 2027 for the TIR payload and CY 2028 for the VSWIR payload.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

Surface Biology & Geology (SBG) completed Mission Concept Review in June 2022. The project held its KDP-A in November 2022 and entered the formulation phase.

ATMOSPHERE OBSERVING SYSTEM (AOS)-STORM

AOS is a distributed science mission with science products dependent on observations provided by multiple platforms. Leveraging multiple orbit planes optimizes sub-orbital components and complementary instrumentation, key measurements, and enables new discoveries of Earth's climate. The AOS distributed science mission is comprised of the AOS-Storm and AOS-Sky projects, which together addresses key focus areas of ESO science: aerosols, clouds, convection, precipitation, and their interactions.

The Atmosphere Observing System (AOS)-Storm project advances measurements of convection through observations of storm dynamics from an inclined orbit that offers more frequent sampling over different times of the day. These observations will increase our understanding of all stages of storm development to enable more accurate predictions of convective rainfall and severe weather. Additionally, AOS-Storm will measure the structure of dust and smoke aerosols within the atmosphere on sub-daily timescales. AOS-Storm will provide the first ever time-varying measurements of coincident cloud, precipitation, and aerosol profiles. These measurements will enable improved weather and air quality forecasting, and freshwater resource management. NASA is targeting a launch for AOS-Storm in FY 2029.

Recent Achievements

NASA completed Mission Concept Review in May 2022 for the Atmosphere Observing System (AOS), including AOS-Storm, followed by KDP-A in January 2023.

ATMOSPHERE OBSERVING SYSTEM (AOS)-SKY

AOS is a distributed science mission with science products dependent on observations provided by multiple platforms. Leveraging multiple orbit planes optimizes sub-orbital components and complementary instrumentation, key measurements, and enables new discoveries of Earth's climate. The AOS distributed science mission is comprised of the AOS-Storm and AOS-Sky projects, which together addresses key focus areas of ESO science: aerosols, clouds, convection, precipitation, and their interactions.

The AOS-Sky project will utilize cutting-edge, diverse measurements and synergistic approaches to observe aerosol, cloud and climate processes from a polar orbit that provides access from the tropics to the poles. These global observations of tiny particles known as "aerosols" and cloud and precipitation transformations are key to understanding linkages between energy and water cycles on Earth. AOS-Sky will deliver key data to improve climate modeling, weather forecasts, and air quality predictions by providing unmatched insight into vertical structure of our atmosphere. AOS-Sky will provide the first ever global observation of convective vertical motions, and the first ever global vertical profiles of aerosol properties. Measurements from AOS-Sky will enable enhancements to disaster monitoring and response and can inform policy such as the health impacts of particles. NASA is targeting a launch for AOS-Sky in FY 2031.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

NASA completed Mission Concept Review in May 2022 for the Atmosphere Observing System (AOS), including AOS-Sky, followed by KDP-A in January 2023.

MASS CHANGE (MC)

The MC mission will extend and improve upon the precision measurements of the Earth's gravity field and its changes in time arising from mass distribution and mass transport within the Earth System due to climatic, tectonic, or anthropogenic forces. MC will advance the goals of the ESO by providing continuity of the more than 20-year record of monthly measurements of Earth's mass redistribution established by the Gravity Recovery and Climate Experiment (GRACE) and GRACE-Follow On (GRACE-FO) missions. This data is valuable for drought assessment and forecasting, associated planning for agriculture water use, as well as supporting natural disaster responses, understanding the drivers of sea level rise, Earth's energy imbalance, and ice mass loss from the world's ice sheets.

MC is a partnership between NASA and German Aerospace Center (DLR) that includes a satellite-to-satellite tracking gravitometer instrument to address science and application areas in climate variability and change, global hydrological cycle and water resources, and Earth surface and interior. NASA is targeting a launch in FY 2028.

Recent Achievements

MC completed Mission Concept Review in June 2022, advancing towards KDP-A scheduled in March 2023.

SUSTAINED CLIMATE OBSERVATIONS FUTURE MISSIONS

Sustained climate observations provide ongoing records of the changing climate and Earth system that support climate change prediction and implementations of adaptation and mitigation measures. NASA will work with international and commercial stakeholders to identify opportunities for achieving these observations through effective and cost-efficient collaborations. The first two NASA contributions to European Space Agency climate monitoring missions are: The Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL) and Sentinel-6C. The CRISTAL mission will address and measure sea ice thickness, snow depth, surface elevation of glaciers and ice caps, and global ocean topography as a continuum up to the polar seas. Sentinel-6C will extend partnership with ESA beyond the current Sentinel-6 (Michael Freilich and B) satellites. Sentinel-6C extends the Sentinel-6 series of sea level observations with an additional Advanced Microwave Radiometer (MR) hosted on an ESA provided satellite.

Recent Achievements

CRISTAL completed the initial two-year study of a contribution of two fully operational versions of the Sentinel-6 radiometer with high- and low-frequency capabilities in February 2022. NASA plans to deliver the instrument to ESA in 2025.

ESA is in the very early stages of defining the implementation plan to implement the Sentinel-6C satellite. NASA plans to continue a joint study with ESA to mature plans and estimates.

OTHER MISSIONS AND DATA ANALYSIS

EARTH SCIENCE PROGRAM MANAGEMENT

The Earth Science Program Management budget supports critical flight project management functions executed by the ESM program offices at NASA Goddard Space Flight Center (GSFC) and the Jet Propulsion Laboratory (JPL). This budget supports:

- The GSFC conjunction assessment risk analysis function, which determines maneuvers required to avoid potential collisions between spacecraft and to avoid debris;
- The technical and management support for the international Committee on Earth Observation Satellites, which coordinates civil space-borne observations of Earth. Participating agencies strive to enhance international coordination and data exchange and to optimize societal benefit;
- Senior Review Board teams, who conduct independent reviews of the various flight projects in Earth Science;
- Earth Science division communications and public engagement activities; and
- Management and infrastructure for the Earth Information Center (EIC).

Recent Achievements

Leveraging modern information systems developed for broad incorporation of Earth science datasets, NASA plans to conduct a pilot study of delivery of greenhouse gas information to support greenhouse gas data users internal and external to government. Expansion of capability to distribute data and develop new approaches to interconnected knowledge provides new opportunity to partner with other Federal agencies, state, local and tribal governments to ensure that climate information is available to support the services they provide.

In FY 2022, NASA completed a design study for the first physical location of the EIC to optimize space and impact in the NASA Headquarters East Lobby. NASA developed the EIC specifications and initiated procurement for a hyperwall display and immersive experience materials for the EIC. Content development is on-going, leveraging expertise across all NASA centers. NASA is developing an Interagency Agreement with the Smithsonian Institution for additional outreach and display at the National Museum of Natural History (NMNH).

In FY 2023, NASA plans to: install the Hyperwall display, an immersive experience taking visitors inside NASA data, and an Earth Pulse light display in the East Lobby of NASA Headquarters and install an analogous Hyperwall display at the NMNH; additionally, NASA will conduct focus groups for content test and evaluation at the NMNH to improve audience understanding of NASA Earth imagery and information.

PRECIPITATION SCIENCE TEAM

The Precipitation Science Team carries out investigations of precipitation using measurements from, but not limited to, the Tropical Rainfall Measuring Mission (TRMM) mission, which ended in 2015, the Global Precipitation Measurement (GPM) mission, which launched in February 2014, and GPM mission constellation partner spacecraft. GPM mission constellation partners include NOAA, Department of Defense, Centre National d'Études Spatiales (CNES), Japan Aerospace Exploration Agency (JAXA), and Exploitation of Meteorological Satellites (EUMETSAT). This program supports scientific investigations in three research categories:

- Development, evaluation, and validation of TRMM and GPM retrieval algorithms;

OTHER MISSIONS AND DATA ANALYSIS

- Development of methodologies for improved application of satellite measurements; and
- Use of satellite and ground measurements for physical process studies to gain a better understanding of the global water cycle, climate, and weather and concomitant improvements in numerical models on cloud resolving to climate scales.

Recent Achievements

The Precipitation Science Team continued to develop and validate spaceborne precipitation measurements. These efforts further increase understanding of the underlying physical processes of precipitation as well as the broader links to Earth system science and impacts on society. In FY 2022, a new three-year cycle of the Precipitation Science Team began with the selection of 36 projects, consisting of both previous and new investigators from within NASA and the external scientific community.

These funds also continue to support the development of gridded global satellite projects and ground validation measurements at NASA centers. NASA conducts periodic reassessments of these projects to ensure that the associated work plans align with the evolving scientific priorities associated with these products. This culminated in the release of a new version of the Integrated Multi-satellitE Retrievals for GPM (IMERG) product.

OCEAN WINDS SCIENCE TEAM (OWST)

The OWST uses scientific data received from the QuikSCAT satellite, RapidScat instrument, and other international missions, which measure ocean surface winds by sensing ripples caused by winds at the ocean's surface. From this data, scientists can compute wind speed and direction thus acquiring global observations of surface wind velocity each day. Wind data from ships and buoys serve to calibrate the satellite data.

Recent Achievements

OWST team members are actively participating in the ongoing NASA Earth Venture Suborbital-3 (EVS-3) Sub-Mesoscale Ocean Dynamics Experiment (S-MODE) mission that collects simultaneous wind and currents measurements from a NASA airborne platform to characterize air-sea interactions on small spatial scales. The OWST also continued to examine new mechanisms of air-sea interaction, such as explanations of variability in coastal upwelling and marine heat waves and wind-induced ocean mixing. The improved mixing might enable improved forecasting of tropical hurricanes and cyclones, and ongoing work on intercalibration will improve forecaster confidence in remotely sensed winds. Recent improvements in ocean wind climate data records, including better handling of rain contamination, facilitated applications in near-coastal regions and enabled better intercalibration studies. OWST also explores conceptually novel approaches to measure winds from space in preparation to the upcoming NASA Earth Explorer mission opportunity recommended by the National Academies of Sciences.

LAND COVER PROJECT SCIENCE OFFICE (LCPSO)

The LCPSO maintains over 40 years of calibration records for the Landsat 1 through Landsat 8 series of satellites. The office also provides community software tools to make it easier for users to work with this data. In collaboration with USGS, LCPSO supports cross-calibration of the Landsat record with other international sensors, provision of preprocessed data sets for land-cover change analysis and facilitates use of international data sets for improved land cover monitoring.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

The LCPSO continued scientific support of the Harmonized Landsat Sentinel-2 (HLS) product in close collaboration with NASA Marshall's IMPACT Team and the Land Processes Distributed Active Archive Center (LP DAAC). This product combines observations from the U.S. Landsat and European Union Sentinel-2 satellite series into a single data set, fulfilling a priority of the 2016, 2018, and 2020 interagency U.S. Group on Earth Observations Satellite Needs Working Group (SNWG) survey process. HLS data support additional SNWG products, including surface water extent and near real-time forest disturbance mapping. Global HLS products are now available with an average 1.7-day latency and provide an intermediate 2.9-day temporal frequency at the equator. Including Landsat-9, the revisit frequency increases towards the poles. The HLS team processes new data as they come in (forward processing) from the satellite constellations and historical data (backward processing) from the Landsat-8 and the Sentinel-2 archives. The HLS time series now includes the historical global Landsat-8 (April 2013 to present) archive. In addition, the LCPSO is prepared to generate HLS products from the pre-2020 historical Sentinel-2 Level-1 Collection data (November 2015 to present), as ESA will make the reprocessed version of L1C data available in future months. The Global Observation for Forest Cover and Land Dynamics (GOFC-GOLD) organized more than nine virtual meetings during the last year and posted reports on the GOFC-GOLD website. The LCSPO is continuing coordination with the Land-Cover and Land-Use Change (LCLUC) PI's, metadata preparation, and data distribution through the LCLUC website.

OCEAN SALINITY SCIENCE TEAM (OSST)

The OSST supports the development and construction of surface salinity products from L-Band microwave radiometers such as Aquarius, Soil Moisture Active and Passive (SMAP), and data sets of opportunity such as ESA's Soil Moisture and Ocean Salinity (SMOS) mission. The team also seeks to understand upper-ocean processes that impact variability of surface salinity to improve interpretation of the space-based salinity products. The team is working on a SMAP salinity product that is consistent with the Aquarius salinity product, which ended in June 2015.

Recent Achievements

A new release of NASA SMAP Sea Surface Salinity (SSS) product with improved algorithm and mitigation of contamination of salinity signals by sea ice and icebergs facilitated the application of the salinity science investigation in the polar ocean. NOAA is using this product, together with the near real-time SMAP SSS product, for development of operational ocean analysis and forecasts. NASA OSST also developed open-source software for SMAP SSS retrieval that is currently under evaluation by the community before the public release of the software. This effort represents one of the early examples of NASA open science accomplishments.

NASA OSST initiated an Arctic Ocean salinity campaign Salinity and Stratification at the Sea Ice Edge (SASSIE) to explore the potential of salinity in predicting sea ice dynamics. The ongoing campaign includes in-situ and airborne observing elements. In particular, the airborne experiment is using an innovative technology based on broad-band, multi-frequency radiometer aiming improve the capability of polar-ocean salinity remote sensing in future satellite missions. OSST science investigations have demonstrated the importance of salinity observations for understanding ocean-hurricane interactions on synoptic time scales and for reducing the uncertainty in estimating climate sensitivity for climate change time scales.

OTHER MISSIONS AND DATA ANALYSIS

Operating Missions

ICE, CLOUD, AND LAND ELEVATION SATELLITE (ICESAT-2)

The ICESat-2 mission measures global elevation to provide an important multi-year record needed to determine sea ice thickness and ice sheet mass change. It also provides topography and vegetation data around the globe. These additional data products support estimates of biomass and carbon in aboveground vegetation in conjunction with related missions, measurements of ocean topography, inland water body elevation such as lakes and rivers, and cloud properties. The ICESat-2 observatory has one instrument, the Advanced Topographic Laser Altimeter System (ATLAS), which measures the round-trip time of laser light from the observatory to Earth and back as the basis for the mission's elevation measurements. Launched on September 15, 2018, ICESat-2 was in prime mission operations through December 2021. NASA conducted an out-of-cycle review in early 2022 for ICESat-2 and extended the project operations through FY 2023. ICESat-2 will propose to the 2023 Senior Review for mission extension for FY 2024-2026.

Recent Achievements

The ICESat-2 observatory and ATLAS instrument continue to operate nominally. To date, over 5,278 users have downloaded over 25.8 million data files spanning 19 data products. Over the Arctic Ocean, ICESat-2 measured continued loss of sea ice during the fall and winter months, with an airborne calibration and validation campaign conducted in July 2022 to improve ICESat-2 measurements of Arctic Sea ice change during summer melt. In conjunction with the European Space Agency's CryoSat-2 mission, the Cryo2 Ice campaign completed an orbital alignment with ICESat-2 that is allowing for cross-cutting measurements of ice change from the two satellites. In addition, analysis shows that the green laser light of ICESat-2 can penetrate up to 15 meters (nearly 50 feet) of water, enabling shallow water bathymetry measurements from space. Mapping of global surface water bodies from ICESat-2 provided a new baseline to track human modifications to the global hydrological cycle and shown that human-managed reservoirs currently account for the largest variability in water storage across the Earth. To date, more than 236 peer-reviewed publications in the scientific literature have used ICESat-2 data. As the ICESat-2 data volume continues to grow, the ICESat-2 project has developed tools for cloud-based data access and analysis.

GRAVITY RECOVERY AND CLIMATE EXPERIMENT FOLLOW-ON (GRACE-FO)

The GRACE-FO mission provides continuity of month-to-month mass change observations and high-resolution global models of Earth's gravity field, as in the original GRACE mission (launched in 2002). The GRACE-FO mission allows scientists to gain new insights into the dynamic processes of Earth's water cycle, including variations in water storage over land, the mass of glaciers and ice sheets, and sea level and ocean currents. GRACE-FO also maps large earthquakes and tectonic processes. Data from the mission, in combination with other existing sources of data, greatly improves scientific understanding of how Earth's water cycle evolves. GRACE-FO data is vital to ensuring there is a minimal gap in mass change measurements following the decommissioning of the original GRACE mission in 2017. GRACE-FO is a partnership with the German Research Centre for Geosciences (GFZ). Launched on May 22, 2018, GRACE-FO will remain in prime mission operations through May 2023.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

As of October 2022, the mission added 49 monthly Global Mass Change datasets to the more than 16 years of monthly mass change maps archived by GRACE. The combined data record now consists of 212 monthly global mass change maps, spanning over two decades. The data produced by GRACE-FO feeds into several climate indicators of NASA's Vital Signs of the Planet website as well as into the U.S. Drought Monitor to generate seasonal forecasts of groundwater and soil moisture for the contiguous U.S. In FY 2022, the GRACE-FO project team embarked on an extensive data calibration effort and reprocessed the mission's entire data (2018-2022). This resulted in an improvement in the science data quality, and enables more accurate mass change estimates (e.g., over the Antarctic ice sheet).

In addition to the mass change observations, GRACE-FO also delivers approximately 500 daily near real-time profiles of atmospheric temperature and humidity (via GPS radio occultation measurements). Routine use of this data improves the accuracy of predictions of operational weather forecast models.

SOIL MOISTURE ACTIVE AND PASSIVE (SMAP)

The SMAP mission, launched in January 2015, provides a capability for global mapping of soil moisture with unprecedented accuracy, resolution, and coverage. The SMAP measurement system consists of a radiometer (passive) instrument and a synthetic aperture radar (active) instrument operating with multiple polarizations in the L-band range. Although the active radar instrument failed in July 2015, the radiometer is operating nominally, and continues to provide global mapping of soil moisture with accuracy, resolution, and coverage that exceeds the capability of other on-orbit systems. The SMAP project team has developed a blended data product that combines SMAP radiometer measurements with the European Copernicus Program's Sentinel-1 active radar measurements. This operational product provides soil moisture information with higher spatial resolution whenever the two systems have coincident measurements.

The 2020 Senior Review for Operating Missions approved extended mission operations for SMAP through FY 2023. NASA will conduct the next Senior Review in the Spring of 2023 to determine mission extensions for FY 2024 through FY 2026.

Recent Achievements

In FY 2022, SMAP made significant improvements to its soil moisture and vegetation water content products. The SMAP data products are available for public access in near real-time. Usage of the data in applications leads to societal benefits as well as scientific studies that advance our understanding of Earth System science.

Several U.S. Federal and state agencies use SMAP data to meet or improve operational requirements. These include support of weather prediction such as in the U.S. Air Force's 557th Weather Wing. The United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) uses the SMAP derived soil moisture data in the Crop Condition and Soil Moisture Analytics (Crop-CASMA) application to monitor crops across the United States and assess food security globally. Maps showing the changes in soil moisture are available to the multi-agency National Drought Mitigation Center (NDMC) which forms the weekly Drought Monitor by combining information on persistent soil water storage deficit. The research community uses SMAP data intensively to understand the effects on water stress on plants and discover processes that affect regional water availability. In FY 2022, over 300 studies using SMAP data appeared in peer-reviewed scientific journals.

OTHER MISSIONS AND DATA ANALYSIS

GLOBAL PRECIPITATION MEASUREMENT (GPM)

The GPM mission, launched in February 2014, advances the measurement of global precipitation through the combined use of active and passive remote-sensing techniques. Tracking storms as they move within the tropics and higher latitudes, GPM provides a three-dimensional view of their structural and microphysical properties and provides estimates of storm rainfall accumulations for major storm events. The GPM Microwave Imager (GMI) measures energy from different types of precipitation within clouds to estimate heavy to light rain and to detect falling snow. The Dual-frequency Precipitation Radar (DPR) provides three-dimensional information about precipitation particles, including their size distributions and associated rainfall rates, derived from reflected energy at two radar wavelengths at different heights within the cloud system. GPM is a joint mission with JAXA.

The 2020 Senior Review for Operating Missions approved extended mission operations for GPM through FY 2023. NASA will conduct the next Senior Review in the Spring of 2023 to determine mission extensions for FY 2024 through FY 2026.

Recent Achievements

GPM continued satellite operations, data processing and delivery, and science activities. The project continued to work with industry and the International Space Station (ISS) to coordinate close approaches between the GPM core observatory and other spacecraft. The project continued development and implementation of a new satellite control algorithm for use in the event of multiple reaction wheel failures, with the first of two flight software patches expected by the end of 2022. The Precipitation Processing System (PPS) has reprocessed the entire suite of core mission data products back to 1987. Particularly, the new version of the radar precipitation retrievals takes advantage of the dual-frequency coverage across the entire width of the radar swath that began in May 2018, allowing for more accurate precipitation estimates.

The GPM Ground Validation (GV) group continues to partner with the Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) field campaign that studies snowstorms along the eastern seaboard of the United States, which flew its second field program in winter of 2022 and is working toward a third campaign in winter of 2023. GPM GV instruments deployed are part of IMPACTS. The GPM Applications team focused on engagement and outreach activities, including leading the 2021American Geophysical Union workshop “Applying Earth Observation to Extreme Weather Events in Support of Humanitarian Aid and Sustainable Development”, initiating a GPM Mentorship Program, and developing GPM-based outreach for use at events such as the 2022 Joint Base Andrews Air and Space Expo and the 2022 Smithsonian Folklife Festival.

SUOMI NATIONAL POLAR-ORBITING PARTNERSHIP (SUOMI NPP)

The Suomi NPP mission is a partnership between NASA and NOAA launched in October 2011. The five instruments on Suomi NPP provide visible and infrared multi-spectral global imagery, atmospheric temperature and moisture profiles, total ozone and stratospheric ozone profiles, and measurements of Earth’s radiation balance. In addition to a wide range of applications studies, the NASA science focus areas served by Suomi NPP include atmospheric composition, climate variability and change, carbon cycle, ecosystems, water and energy cycles, and weather. Several primary Suomi-NPP products have demonstrated their capabilities to provide critical continuity and near-real-time data, extending the EOS observation long time-series in monitoring changes in land, ocean, and atmosphere as well as Earth’s

OTHER MISSIONS AND DATA ANALYSIS

radiation budget. NASA built and launched Suomi NPP. NOAA operates the spacecraft and instruments. NASA and NOAA continue to collaborate to ensure meeting the shared objectives of both agencies.

Suomi NPP is currently in extended operations; a Joint Steering Group meeting with NOAA will be held in early 2023 to discuss plans for the project's future.

Recent Achievements

In FY 2022, the NASA Suomi NPP team continued to add to the existing data records from Earth Observing System missions, enabling scientists to build multi-satellite, multidecadal (greater than 30 years) time series with high accuracy and long-term stability suitable for studies of Earth systems science. These datasets play a critical role in detecting changing trends in Earth’s atmosphere, land, and ocean. In addition, the Suomi NPP team continued to provide timely support during disaster events. For example, the Visible Infrared Imaging Radiometer Suite (VIIRS) products offered near real-time information of smoke loading, fire counts, and locations during the wildfire events over California as well as other western states in 2022. OMPS Sulfur Dioxide (SO2) and aerosol index as well as Cross-track Infrared Sounder (CrIS) SO2 products also provided important data in tracking the volcanic plumes during the explosive eruption of the Hunga Tonga–Hunga Haʻapai volcano in 2022. Detection of large amounts of volcanic ash and water vapor occurred in the upper troposphere and stratosphere by the OMPS Limb Profiler (LP) following the eruption, which may have long-term implications in modulating climate and stratospheric ozone. Ocean observations from VIIRS on Suomi NPP continue to provide critical data for detecting and tracking the evolution of sargassum, a brown macroalgae found in the Atlantic and Gulf of Mexico. Sargassum can have major environmental and economic impact on coastal communities and sea life.

TERRA

Terra, launched in December 1999, is one of the EOS flagship missions. It enables a wide range of interdisciplinary studies of atmospheric composition, carbon cycle, ecosystems, biogeochemistry, climate variability and change, water and energy cycles, and weather. The Terra mission has provided more than 20 years of continuous data collection, including fundamental observations of the Earth’s climate system, high-impact events, and adding value to other satellite missions and field campaigns. The spacecraft platform and five sensors are all fully functional, with the exception of the shortwave infrared bands in the Advanced Space-borne Thermal Emission and Reflection Radiometer instrument. Terra is a joint mission with Japan and Canada.

Terra is currently in extended operations. Terra’s fuel is limited so it is now drifting outside of the tightly controlled orbit it has maintained for over twenty years. In early FY 2023, NASA completed an assessment of additional science that could be enabled by observations made during the period of orbital drift and as a result of that assessment invited Terra to propose to the 2023 Senior Review for mission extension beyond FY 2023.

Recent Achievements

In FY 2022, the Terra mission entered its 23rd year of operations. Multiple Federal and International agencies used Terra's land and atmospheric products for volcanic ash monitoring, weather forecasting, forest fire monitoring, carbon management, and global crop assessment. Together, Terra’s five instruments continued to play a key role in understanding fire location and intensity, burn areas and revegetation, and injection and transport of aerosols, and carbon monoxide in the atmosphere. Combining aerosol and carbon monoxide data from multiple Terra instruments as well as from other missions have

OTHER MISSIONS AND DATA ANALYSIS

shown that reductions in carbon monoxide have linkage to environmental regulations and clean-burning technologies. Terra provided key data in 2022 to land managers to help understand the impacts from wildfires. Direct broadcast and near-real-time data products from Terra sensors were especially critical for predictions of local air quality and smoke transport as well as fire management. The weather prediction models use near real-time products to provide added data for tropical storms and hurricanes.

AQUA

Aqua, launched in May 2002, is one of the EOS flagship missions. Aqua improves our understanding of Earth's water cycle and the intricacies of the climate system by monitoring atmospheric, land, ocean, and ice variables. It was the first satellite launched into what has become the afternoon constellation of satellites, known as the A-Train. Four of Aqua's Earth observing instruments – the Atmospheric Infrared Sounder (AIRS), the Advanced Microwave Sounding Unit (AMSU), Clouds and the Earth's Radiant Energy System (CERES), and the Moderate Resolution Imaging Spectroradiometer (MODIS) – continue to collect valuable data about the Earth's atmosphere, oceans, land, ice, and overall energy budget. The science community widely uses these data and in practical applications ranging from improved weather forecasting to monitoring forest fires, crop yields, volcanic ash plumes, and ice-infested waters. Aqua is a joint mission with Japan and Brazil.

Aqua is currently in extended operations. Aqua's fuel is limited so it is now drifting outside of the tightly controlled orbit it has maintained for over twenty years. In early FY 2023, NASA completed an assessment of additional science that could be enabled by observations made during the period of orbital drift and as a result of that assessment invited Aqua to propose to the 2023 Senior Review for mission extension beyond FY 2023.

Recent Achievements

In FY 2022, Aqua commemorated its 20th anniversary since launch with a journal article summarizing the history and accomplishments of the mission. The project created important new data products, including a Global Water Reservoir product suite containing MODIS data and offering a new capability for monitoring reservoir storage and evaporation simultaneously, a MODIS cloud properties dataset that enables inter-satellite evaluations as part of an international cloud intercomparison project, and a long-term atmospheric sounding record incorporating AIRS and AMSU data along with data from two other satellites. During FY 2022 researchers used CERES data to connect increased shortwave flux in the northern hemisphere subtropics with reduced aerosol amounts, suggesting altered atmospheric circulation and/or accelerated global warming. Researchers also used MODIS ocean data to connect a widespread increase in phytoplankton blooms to the massive 2019-2020 Australian wildfires, which supplied nutrients to the oceans. Lastly, researchers used AIRS data to monitor atmospheric gravity waves created by the January 2022 Hunga Tonga–Hunga Ha'apai volcanic eruption, revealing highly unusual patterns stretching over much of the globe.

Throughout FY 2022, Aqua data and imagery monitored major environmental events around the world, from the eruption of the Canary Islands' Cumbre Vieja volcano on October 1, 2021, to Hurricane Ian making landfall in Florida on September 28, 2022. Aqua also monitored severe flooding in South Sudan, Iran, Australia, and Bangladesh, as well as in the Red River Valley of Minnesota and North Dakota in May and in Death Valley, California in August. Aqua monitored tropical cyclone Batsirai battering Madagascar in February and this year's first category 5 cyclone, Typhoon Hinnamnor, as it approached Taiwan in early September. Aqua monitored major fires including these in the United States: California's Alisal Fire in October; Colorado's Marshall Fire in December and January; fires in Texas, Oklahoma, and

OTHER MISSIONS AND DATA ANALYSIS

Arkansas in March, in New Mexico in April and May, and in Alaska in June; the Oak Fire that threatened Yosemite National Park in July; and California's McKinney Fire in August.

AURA

Aura, launched in July 2004, is one of the EOS flagship missions. Aura advances the understanding of changes in the Earth's radiation balance, air quality, and the ozone layer that result from changes in atmospheric composition, climate variability, and weather by measuring atmospheric chemical composition, tropospheric/stratospheric exchange of energy and chemicals, chemistry-climate interactions, and air quality. Aura is also part of the A-Train. Two of Aura's four instruments are operational: the Microwave Limb Sounder (MLS) and the Ozone Monitoring Instrument (OMI). Additional measurements include clouds, aerosols, solar spectral irradiance, and water vapor. Aura is a joint mission with the Netherlands, Finland, and the United Kingdom.

Aura is currently in extended operations. Aura's fuel is limited so it is now drifting outside of the tightly controlled orbit it has maintained for approximately nineteen years. In early FY 2023, NASA completed an assessment of additional science that could be enabled by observations made during the period of orbital drift and as a result of that assessment invited Aura to propose to the 2023 Senior Review for mission extension beyond FY 2023.

Recent Achievements

More than 18 years into its mission, Aura continued to provide data for scientific research and societal benefit in FY 2022. Aura's OMI observed the changes in air pollution around the world after the spread of COVID-19 in FY 2020. OMI measurements of nitrogen dioxide, a pollutant released during the combustion of fossil fuels, showed a gradual recovery in pollutant emissions in late FY 2021 into FY 2022. Given that fossil fuels drive most world economies, OMI data helped to assess the impact of the pandemic on economic activity around the world, including in countries without reliable economic data. Air quality and health researchers also used the nitrogen dioxide data as a proxy of the effectiveness of lockdown efforts to contain or slow the pandemic in given areas. Climate scientists used the nitrogen dioxide measurements as a proxy for co-emitted carbon dioxide, a potent greenhouse gas, and sulfur dioxide measurements to quantify sporadic volcanic emissions effects on the stratospheric sulfate aerosol layer, ozone, and radiation.

Aura's Microwave Limb Sounder (MLS) instrument has once again observed phenomena never seen before in the stratosphere, either in the 18-year MLS record or in records from prior sensors as far back as the 1970s. Specifically, the mid-January 2022 eruption of the Hunga Tonga-Hunga-Ha'apai volcano resulted in the lofting of aerosols and volcanic trace gases to unprecedented altitudes in the stratosphere. Aura MLS observed direct injection of water vapor over a wide vertical range, extending as high as 53 km (into the mesosphere). The amount of water vapor injected was also unprecedented, even though MLS, OMI, and other sensors show that the amount of sulfur dioxide injected was less than that from other notable volcanoes in the Aura record. The enhanced water vapor has spread throughout most of the Southern Hemisphere stratosphere (excluding the Antarctic "polar vortex" region) and into the Northern Hemisphere and will likely endure over several years. This eruption could impact climate not through surface cooling due to sulfate aerosols, but rather through surface warming due to the radiative forcing from the estimated 10 percent increase in stratospheric water vapor. This event underscores the continuing capacity for the stratosphere to exhibit unexpected and/or previously unwitnessed behavior, having significant potential implications for climate and/or ozone layer stability.

OTHER MISSIONS AND DATA ANALYSIS

STRATOSPHERIC AEROSOL AND GAS EXPERIMENT III (SAGE-III)

SAGE-III, launched in February 2017, operates on the ISS, and provides global, long-term measurements of key components of Earth's atmosphere. The most important of these are the vertical distribution of aerosols and ozone from the upper troposphere through the stratosphere. In addition, SAGE-III provides unique measurements of temperature in the stratosphere and mesosphere and profiles of trace gases, such as water vapor and nitrogen dioxide, which play significant roles in atmospheric radiative and chemical processes. These measurements are vital inputs to the global scientific community for improved understanding of climate and human-induced ozone trends.

The 2020 Senior Review for Operating Missions approved extended mission operations for SAGE-III through FY 2023. NASA will conduct the next Senior Review in the Spring of 2023 to determine mission extensions for FY 2024 through FY 2026.

Recent Achievements

In 2022 science products showed the continued global decline in stratospheric aerosol injected by a moderate volcanic eruption (Raikoke 2019) and extreme Australian bushfires (early 2020). The tremendous eruption of the Hunga Tonga- Hunga Ha´apai undersea caldera in January 2022 interrupted this decline. The volcanic aerosol increase has been moderate, but the increase in stratospheric water vapor was orders of magnitude larger than ever recorded by the SAGE series of sensors spanning the last 40 years. The time evolution of the stratospheric aerosol is important in understanding what natural occurrences might have offset expected greenhouse gas induced temperature changes.

The project released to the public an additional 12 months of SAGE-III data products for a total of 63 months from the mission thus far. To inform current and future experiments hosted externally on the ISS that are interested in the on-orbit contamination environment, the mission made available to the NASA community, via the Materials and Processes Technical Information System (MAPTIS), five-years of data from the Contamination Monitoring Package (CMP) sub-system that records the external contamination environment at the location of SAGE-III payload on the ISS.

EARTH FROM THE INTERNATIONAL SPACE STATION (ISS)

NASA's ISS program sponsored the development of several Earth science instruments for the ISS. The Earth from ISS project ensures the appropriate processing of data and its availability to the Earth science research community from the data collected by these instruments. This project invests in algorithm development, data production and distribution, as well as data analysis and modeling for the currently planned ISS Earth science payloads.

The ISS Lightning Imaging Sensor (LIS) makes space-based global lightning observations, using the backup flight spare for the instrument that operated for 17 years on the Tropical Rainfall Measuring Mission. LIS provides a great opportunity to not only extend the TRMM record of tropical lightning measurements, but also to expand coverage to the higher latitudes missed by the previous mission. LIS observations continue to support the global scientific research community, across a wide range of disciplines that include weather and extreme storms, climate studies, atmospheric chemistry, and lightning physics. Researchers use LIS to help calibrate and validate the observations from the new Geostationary Lightning Mapper operating on NOAA's GOES geostationary weather satellites.

OTHER MISSIONS AND DATA ANALYSIS

The 2020 Senior Review for Operating Missions approved extended mission operations for LIS through FY 2023. NASA will conduct the next Senior Review in the Spring of 2023 to determine mission extensions for FY 2024 through FY 2026.

Recent Achievements

LIS successfully completed five years on orbit in FY 2022. Publication of additional scientific results occurred in major research journals, including a comparison of LIS observations of lightning with lidar observations of clouds. As part of the 5th Space Test Program – Houston (STP-H5) payload, LIS relocated on the ISS to make room for another NASA Earth Science mission. In the new location, LIS has successfully demonstrated similar performance (e.g., lightning detection efficiency, as well as geolocation and timing accuracy) compared to its previous location.

TOTAL SOLAR IRRADIANCE SENSOR-1 (TSIS-1)

Launched in December 2017, TSIS-1 is currently in its prime mission phase through May 2023, providing absolute measurements of total solar irradiance (TSI) and spectral solar irradiance (SSI) important for accurate scientific models of climate change and solar variability. NASA will conduct the next Senior Review in the Spring of 2023 to determine mission extensions for FY 2024 through FY 2026. TSIS-1 is comprised of two instruments, the Total Irradiance Monitor (TIM) and the Spectral Irradiance Monitor (SIM), which are the most accurate solar irradiance instruments in the world, allowing scientists to better understand solar variability at both short and long-time scales. The Laboratory for Atmospheric and Space Physics (LASP) built a highly sensitive thermal pointing system that the project uses to accommodate the instruments on the ISS.

Recent Achievements

The TSIS-1 TIM and SIM instruments on the ISS are currently the only instruments to track both daily TSI and SSI variations with climate-quality accuracy and precision. In FY 2022, the TIM extended the TSI record to 43 years and observed a gradual increase of solar irradiances during Solar Cycle 25. The long-term TSI record is very important in climate studies and the Intergovernmental Panel on Climate Change (IPCC) assessment continues use it. Earth climate variability depends critically on a balance of energy at the top of atmosphere (TOA), and TSIS-1 measures the solar energy input to Earth. Recent studies suggest a significant energy imbalance at TOA, showing that Earth is taking in more energy than radiating out. The TSIS-1 SIM continued to acquire the SSI data over the broad spectral range that started since Solar Radiation and Climate Experiment (SORCE, 2003-2020) and extended the SSI record to 19 years, showing much improved accuracy in the visible (VIS) and near infrared (NIR) wavelengths. The Committee on Earth Observation Satellites (CEOS) Working Group on Calibration and Validation (WGCV) endorsed the solar spectrum established as the new spectral irradiance reference. Measuring the incoming solar energy at different spectral wavelengths provides critical elements for understanding how the Earth's atmosphere and surface absorb that energy.

DEEP SPACE CLIMATE OBSERVATORY (DSCOVR)

DSCOVR, launched in February 2015, is a multi-agency (NOAA, United States Air Force, and NASA) mission with the primary goal of making unique space weather measurements from the Lagrange point L1. Lagrange point L1 is on the direct line between Earth and the Sun and provides about a 45-minute early warning for adverse space weather events. NASA provided the two Earth-observing instruments, the

OTHER MISSIONS AND DATA ANALYSIS

Earth Poly-Chromatic Imaging Camera (EPIC) and the National Institute of Standards and Technology Advanced Radiometer (NISTAR), to the DSCOVR satellite. NASA-processed EPIC and NISTAR data has been publicly available since June 2015 and includes color images of the full sunlit disk of the Earth; maps of ozone, clouds, aerosols, and vegetation; and measurements of sulfur dioxide from volcanic eruptions.

The 2020 Senior Review for Operating Missions approved extended mission operations for the DSCOVR NASA-provided instruments through FY 2023. NASA will conduct the next Senior Review in the Spring of 2023 to determine mission extensions for FY 2024 through FY 2026.

Recent Achievements

The DSCOVR project continued the development of the ocean product to provide global coverage of bioproductivity related to ocean chlorophyll and its time dependence in the Earth's oceans. The project refined and reprocessed the total column ozone product with an improved algorithm that has permitted better estimates of changes in tropospheric ozone and continued processing the appearance of cloud glints due to ice crystals. Additionally, the project continued to work on the detection of volcanic eruptions with improved sensitivity that uniquely allows the tracking of volcanic ash and SO2 plumes on an hourly basis for the entire Earth with one satellite. The DSCOVR data products are now incorporated into the validation plan for the upcoming Earth Venture Tropospheric Emissions: Monitoring of Pollution (TEMPO) mission since DSCOVR EPIC is the only satellite that can compare with the hourly data expected from TEMPO over North America and its coastal regions.

LANDSAT 9

The Landsat data series, initiated in 1972, is the longest continuous record of changes in Earth's surface as seen from space and the only U.S. satellite system designed and operated to make repeated observations of the global land surface at moderate resolution. Landsat data is available at no cost to users, providing a unique resource for people who work in agriculture, geology, forestry, regional planning, education, mapping, and climate research.

The Landsat 9 mission successfully launched from Vandenberg Space Force Base on September 27, 2021. Landsat 9 extends the record of multi-spectral, moderate resolution Landsat quality data and meets operational and scientific requirements for observing land use and land change. Landsat 9 is a collaboration between NASA and the USGS and is a cornerstone of our Nation's multi-satellite, multi-decadal, Sustainable Land Imaging (SLI) effort. SLI is a NASA-Department of the Interior (DOI)/USGS partnership to develop, launch, and operate a spaceborne system and provide researchers and users with high quality, global, continuous land imaging measurements that are compatible with the existing 49-year Landsat record and will evolve through investing in and introducing new sensor and system technologies.

Landsat 9 is currently in prime mission operations through December 2026.

Recent Achievements

In January 2022, Landsat 9 successfully completed commissioning activities. During early operations, the project discovered read/write errors in the Solid-State Recorder (SSR), which appeared to relate to Single Event upset radiation events (SEFIs). A manual work-around by the project allowed recovery of the SSR. However, the project decided to implement a hybrid transition approach to full operations while the project studied the anomaly. NASA conducted an Instrument Handover Review in February 2022 and

OTHER MISSIONS AND DATA ANALYSIS

initiated full science operations after transferring ownership of the OLI-2 and TIRS-2 instruments to USGS.

The NASA Landsat 9 project and the spacecraft prime contractor and SSR vendor continued to work on a flight software update to mitigate the SSR SEFI events and minimize any data loss. The project completed and uploaded the flight software in July 2022. Following successful on-orbit testing and data collection with the new flight software, the Landsat 9 Spacecraft ownership and mission operations transferred to USGS following the Mission Transition and Handover Review (MTHR) on August 11, 2022. NASA will continue to support Landsat 9 data calibration, validation, and characterization throughout the life of the mission.

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

The Surface Water and Ocean Topography (SWOT) mission will improve our understanding of the world's oceans and terrestrial surface waters. The mission will make high-resolution measurements of ocean circulation, its kinetic energy, and its dissipation, through broad swath altimetry. These measurements will improve ocean circulation models and predictions of weather and climate. The mission will also revolutionize knowledge of the surface water inventory on the continents by making precise measurements of water levels in millions of lakes and water bodies and the discharge of all major rivers. This will allow for deeper understanding of the natural water cycle and potentially better water management.

The 2007 and 2017 National Academies decadal surveys endorsed SWOT. The mission will complement the Jason oceanography missions, as well as other NASA missions currently in operation and development to measure the global water cycle: Sentinel-6, Global Precipitation Measurement, Soil Moisture Active Passive, and Gravity Recovery and Climate Experiment Follow-On.

SWOT is a collaborative mission with the Centre National d'Études Spatiales (CNES), Canadian Space Agency (CSA), and United Kingdom Space Agency (UKSA).

Recent Achievements

The SWOT mission launched successfully on December 16, 2022, from Vandenberg Space Force Base in California. The mission is conducting on-orbit commissioning activities which will continue through June 2023. Science data collection will begin in July 2023.

EARTH SYSTEM EXPLORERS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	2.0	--	27.8	20.7	43.1	109.0	166.4

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

NASA's Earth System Explorers Program provides competitive opportunities for medium-sized instruments and missions that address specific science and applications needs identified in the 2017 National Academies' report "Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space."

NASA's Earth System Explorers will continue the tradition of the first U.S. satellite Explorer 1 (illustrated above), launched in 1958.

These Principal Investigator (PI)-led projects will employ innovative, streamlined, and efficient management approaches to constrain design, development, and operations costs. Distinct from Earth Venture instruments and missions, Earth System Explorers will focus on one or more of the seven identified targeted observables, important to our understanding of Earth system science:

- Atmospheric winds;
- Greenhouse gases;
- Ice elevation;
- Ocean surface winds and currents;
- Ozone and trace gases;
- Snow depth and snow water equivalent; and
- Terrestrial ecosystem structure.

EXPLANATION OF MAJOR CHANGES IN FY 2024

NASA plans to release an Announcement of Opportunity (AO) for Earth System Explorers in the third quarter of FY 2023, a delay of one year to allow time to establish a program office at Goddard Space Flight Center (GSFC). NASA plans to release an AO every two years and make two selections from each release with staggered launch dates. NASA has adjusted the program budget to reflect the new schedule and expected selection cadence.

EARTH SYSTEM EXPLORERS

ACHIEVEMENTS IN FY 2022

NASA established a program office for Earth System Explorers and released the Community Announcement (CA) in the first quarter of FY 2023 declaring its intention to issue an AO for the Earth System Explorers Program.

WORK IN PROGRESS IN FY 2023

NASA released the draft AO in the first quarter of FY 2023 and plans to release the final AO in the third quarter of FY 2023. The AO will solicit proposals for new PI-led missions investigating one or more of the 2017 Decadal Survey Earth System Explorer Targeted Observables.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

NASA expects to receive proposal responses 90 days after the AO release. NASA plans to make selections for competitive Phase A studies in the second quarter of FY 2024. Missions selected through this AO will be the first in the Earth System Explorers Program.

Program Elements

EARTH SYSTEM EXPLORERS' FUTURE MISSIONS

Earth System Explorers Future Mission funding supports the selection of new missions through AO solicitations every two years, which will support the goal of launching three missions within a decade. This funding supports proposals selected during Step 1 of the proposal process with conducting Phase A formulation studies. Selected proposals will move to Step 2 for full mission implementation.

EARTH SYSTEM EXPLORERS PROGRAM MANAGEMENT

Earth System Explorers Program Management provides funding for the Earth System Explorers Program Office, development of AO solicitations, and the technical, management, and cost evaluations of proposals received in response to the AO solicitations. It also supports the management of missions conducting formulation studies and missions in implementation (per the two-step selection process).

Program Schedule

Date	Significant Event
Q1 FY 2022	Community Announcement release
Q3 FY 2023	AO Release
Q2 FY 2024	Selection of candidates to move into Step 1 within nine months of receipt of proposals
Q3 FY 2025	Select proposals for Step 2

EARTH SYSTEM EXPLORERS

Program Management & Commitments

Program Element	Provider
Earth System Explorers Program Management	Provider: GSFC Lead Center: GSFC Performing Center(s): TBD Cost Share Partner(s): TBD

Acquisition Strategy

NASA will issue AO solicitations for Earth System Explorers every two years to support the goal of launching three missions within a decade. NASA will select all Earth System Explorers through full and open competition using a two-step proposal process.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

None.

EARTH SYSTEM SCIENCE PATHFINDER

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Venture Class Missions	218.1	--	**177.0**	243.6	245.5	237.5	240.3
GeoCarb	39.7	20.0	**0.0**	0.0	0.0	0.0	0.0
Other Missions and Data Analysis	54.9	--	**58.6**	55.0	45.0	45.0	50.0
Total Budget	**312.7**	**--**	**235.6**	**298.6**	**290.5**	**282.5**	**290.3**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Shown here, TEMPO is the first space-based instrument to monitor air pollutants hourly across the North American continent during daytime. The instrument (attached at the top of the spacecraft) will operate as a hosted payload on the Intelsat 40e satellite from its geostationary orbit.

The Earth System Science Pathfinder (ESSP) program provides regular opportunities for competitively selected low-cost and targeted Earth science investigations that accommodate new and emerging scientific priorities and measurement capabilities. Principal Investigators lead these focused projects that contribute to studies of the atmosphere, oceans, land surface, polar ice regions, or solid Earth.

ESSP projects include space missions, remote sensing instruments for space-based missions of opportunity, and extended duration airborne-science missions. The ESSP program also supports the conduct of science research utilizing data from these missions. ESSP projects may involve partnerships with other U.S. agencies and/or international organizations. This portfolio of missions and investigations provides opportunity for investment in innovative Earth science that enhances NASA’s capability for better understanding the current state of the Earth system.

EXPLANATION OF MAJOR CHANGES IN FY 2024

This budget assumes termination of the GeoCarb mission given significant cost growth for both the instrument and access-to-space. Please see the Venture Class Missions section for more information.

Libera held a successful Key Decision Point-C (KDP-C) and entered the development phase in April 2022. This budget includes an updated budget profile for Libera, supporting a planned launch in December 2028. NASA has adjusted the budget profile for Multi-Angle Imager for Aerosols (MAIA to incorporate the final access-to-space solution, reflecting a hosted

EARTH SYSTEM SCIENCE PATHFINDER

payload solution with a launch readiness date of November 2027. The budget request includes funding for extended mission operations for Cyclone Global Navigation Satellite System (CYGNSS), Earth Surface Mineral Dust Source Investigation (EMIT), Tropospheric Emissions: Monitoring of Pollution (TEMPO), Ecosystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS), Global Ecosystem Dynamics Investigation (GEDI), and Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) (assuming launch of remaining TROPICS satellites in FY 2023).

This budget includes the realignment of the ESSP program office budget from European Service Module (ESM) Program Management to Earth Venture Management to support critical flight project management functions and Senior Review Board teams, who conduct independent reviews of the ESSP flight projects.

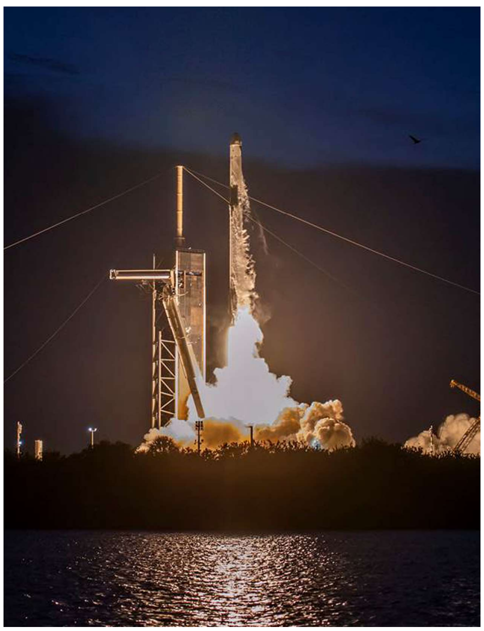
VENTURE CLASS MISSIONS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**218.1**	**--**	**177.0**	**243.6**	**245.5**	**237.5**	**240.3**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



Earth Surface Mineral Dust Source InvesTigation (EMIT) instrument, selected under EVI-4 solicitation, is shown here during launch by SpaceX-25 resupply mission to the International Space Station on July 14, 2022.

NASA's Earth Venture Class Missions provide frequent flight opportunities for high-quality, low-cost Earth science investigations that can be developed and flown in five years or less. NASA selects the investigations through open competitions to ensure broad community involvement and encourages innovative approaches. Successful investigations enhance our capability to understand the current state of the Earth system and enable continual improvement in the prediction of future changes. Solicitations include both space-borne and airborne/suborbital opportunities.

NASA established Venture Class Missions in response to recommendations in the 2007 National Academies' report, "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond." The 2017 National Academies' report, "Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space," also endorsed the Venture Class Missions.

All Earth Venture-class missions and instruments are cost and schedule constrained and openly competed. Adherence to cost caps and schedule constraints is critical to the success of the Earth Venture program to ensure availability of funding for frequent solicitations and programmatic flexibility and responsiveness. Earth Venture missions are undertaken to complement the directed elements of NASA's Earth Science program, enabling more frequent launch opportunities and demonstration of innovative ideas and higher-risk technologies outside of Earth Systematic class missions.

Earth Venture Class Missions include four components:

- Earth Venture Instruments (EVI) are missions of opportunity hosted on space-borne platforms. NASA releases EVI solicitations every three years at a cost cap of approximately $112 million in FY 2023.
- Earth Venture Suborbital (EVS) investigations are sustained suborbital-science investigations. NASA releases EVS solicitations every four years and selects multiple investigations within each call, individually cost-capped at no more than $30 million.

VENTURE CLASS MISSIONS

- Earth Venture Continuity (EVC) will fly on-orbit demonstrations of affordable measurement approaches for maintaining the long-term record of important Earth science measurements. NASA will release EVC solicitations every three years at a cost cap of approximately $173 million in FY 2023.
- Earth Venture Missions (EVM) are small space-based missions. NASA releases EVM solicitations every four years at a cost cap of approximately $193 million in FY 2023.

The cadence of solicitations for EVI and EVC investigations will alternate every 18 months, releasing each respective solicitation approximately every three years. The cadence of EVS and EVM solicitation is independent of other Earth Venture solicitations.

EXPLANATION OF MAJOR CHANGES IN FY 2024

This budget request reflects NASA's decision in 2022 to cancel and close out the Geostationary Carbon Observatory (GeoCarb) mission, which would have provided greenhouse gas observations from geosynchronous orbit over the Americas... Moving forward, NASA will target the first Earth System Explorers mission for GHG observation, procure data from new commercial providers, extend the Orbiting Carbon Observatory-3 (OCO-3) mission on the International Space Station (ISS), take advantage of emerging capability for methane observation utilizing the Earth Surface Mineral Dust Source (EMIT) on ISS, and fully utilize GHG data from international partners.

NASA finalized a new access-to-space solution for Multi-Angle Imager for Aerosols (MAIA) in January 2023 for partnership with, and contributions from, the Italian Space Agency (ASI). With this new collaboration, NASA established a new lifecycle cost less than $250 million; hence MAIA will not transition to a major project as anticipated in the FY 2023 President's Budget Request.

Libera held a successful Key Decision Point-C (KDP-C) and entered the development phase in April 2022. This budget includes an updated budget profile for Libera supporting a planned launch in December 2028.

The budget request includes funding for extended mission operations for CYGNSS, EMIT, TEMPO, ECOSTRESS, GEDI, and TROPICS (assuming launch of remaining TROPICS satellites in FY 2023).

This budget includes the realignment of the ESSP program office budget from ESM Program Management to Earth Venture Management to support critical flight project management functions and Senior Review Board teams, who conduct independent reviews of the ESSP flight projects.

Program Element

VENTURE CLASS FUTURE MISSIONS

Earth Venture Class Future Mission funding supports the selection of new missions through Announcement of Opportunity (AO) solicitations at intervals of every four years for EVS and EVM; EVI and EVC will alternate every 18 months, each of which will be released approximately every three years. NASA released the solicitation for EVI-6 in April 2022.

VENTURE CLASS MISSIONS

CYCLONE GLOBAL NAVIGATION SATELLITE SYSTEM (CYGNSS) (EVM-1, SELECTED IN 2012)

CYGNSS data enables scientists to probe from space key air-sea interaction processes that take place near the inner core of storms and play large roles in the genesis and intensification of hurricanes. The CYGNSS measurements provide information to the hurricane forecast community and seek to improve models to predict the strength of hurricanes as they develop. CYGNSS also makes measurements over land that scientists use to image flood inundation, wetland extent, and surface soil moisture.

CYGNSS's eight micro-satellite observatories receive both direct and reflected signals from Global Positioning System (GPS) satellites. The direct GPS signals pinpoint CYGNSS observatory positions and track fluctuations in GPS power, while the reflected signals are indicative of ocean surface roughness. Scientists use both measurements to derive the critical measurement of wind speed over ocean and water properties over land. CYGNSS launched in December 2016 and entered its extended mission phase in March 2019. The 2020 Senior Review for Operating Missions approved extended mission operations for CYGNSS through FY 2023. NASA will conduct the next Senior Review in the Spring of 2023 to determine mission extensions for FY 2024 through FY 2026.

Recent Achievements

NASA released a new and improved version of the CYGNSS ocean surface wind speed data product. The new product incorporates ancillary information about long wave swell conditions, with improved performance most noticeable at the higher, storm-force, wind speeds. Continuing work on numerical hurricane prediction using CYGNSS winds demonstrates that use of the new product further improves forecasts of hurricane track and intensity.

Over land, the CYGNSS soil moisture product underwent an extensive independent performance assessment and, as a result, the intermittent data production elevated from a research-grade effort to one produced on a daily cadence by the project's Science Operations Center. The product is now available as a temporary gap-filler at tropical and sub-tropical latitudes while the NASA Soil Moisture Active Passive (SMAP) mission was off-line in August through October 2022.

To further support soil moisture product development and validation, the New Zealand Space Agency and Air New Zealand are collaborating with NASA and the CYGNSS project by allowing the project to install an automated, continuously operating remote sensing instrument on one of their domestic commercial aircraft. After extensive safety certifications and engineering tests, the aircraft returned to regular commercial service in September 2022 and is now generating dense daily observations of surface conditions coincident with CYGNSS overpasses. This collaboration is expected to continue indefinitely.

Planned Future Achievements

The CYGNSS project will continue to improve its ocean surface wind product to deliver "user friendly" data to the user community The first area of improvement is a gridded and merged version which includes features of the existing product that perform best in low wind and high wind conditions and reported on a cadence consistent with operational hurricane numerical prediction models. The intent is to make ingestion of CYGNSS winds into the models as straightforward as possible. The second is an improved version of the error covariance characterization of the reported winds. Numerical weather prediction models consider the errors associated with the measurement they use, and improved error characterization helps to use them more effectively. The primary CYGNSS data product over land, soil moisture, will continue to be the focus of retrieval algorithm development, with development support and validation provided by the New Zealand airborne observations. Other over-land retrievals, particularly flood inundation mapping and river flow rate and surface slope, are also in development and will transition to become formal science data products when their retrieval algorithms are sufficiently mature, and validation is complete for the performance.

TROPOSPHERIC EMISSIONS: MONITORING OF POLLUTION (TEMPO) (EVI-1, SELECTED IN 2012)

The TEMPO instrument will measure atmospheric pollution covering most of North America. A commercial communications satellite will host the instrument and launch in 2023. On an hourly basis, TEMPO will measure atmospheric pollution spanning from Mexico to Canada, and from the Atlantic Ocean to the Pacific Ocean. TEMPO will provide measurements that include the key elements of air pollution chemistry (e.g., ozone, nitrogen dioxide) in the lowest part of the atmosphere. Measurements from geostationary orbit will capture the inherent high variability in the daily cycle of emissions and chemistry. Measuring across both time and space will create a revolutionary dataset that provides understanding and improves prediction of air quality and climate forcing.

Maxar Technologies of Westminster, Colorado will provide satellite integration, launch, and data transmission services for TEMPO.

Recent Achievements

TEMPO successfully completed the mechanical and electrical integration of the TEMPO instrument on to the Intelsat-40e commercial satellite in March 2022. The TEMPO team successfully completed mission operations rehearsals in May and June 2022. TEMPO completed the Post-Integration Functional Test, also known as the Reference Performance Test, in July 2022, marking the end of the instrument integration phase and the start of spacecraft level testing. The project also completed the Spacecraft level thermal vacuum testing (TVAC) in August 2022 and September 2022.

Planned Future Achievements

In FY 2023, the TEMPO team will hold the Operational Readiness Review (ORR) and the Key Decision Point-E (KDP-E) to confirm the project is ready to conduct mission operations. The Pre-Ship Review (PSR) and shipment to the launch site will occur in March 2023, with launch planned for April 2023.

ECOSYSTEM SPACEBORNE THERMAL RADIOMETER EXPERIMENT ON SPACE STATION (ECOSTRESS) (EVI-2, SELECTED IN 2014)

ECOSTRESS launched in June 2018 to help scientists observe changes in global vegetation from the ISS. The sensors give scientists new ways to see how changes in climate or land use affect forests and ecosystems. ECOSTRESS uses a high-resolution thermal infrared radiometer to measure plant evapotranspiration and the loss of water from growing leaves and evaporation from the soil. This data reveals how ecosystems change with climate and provide a critical link between the water cycle and effectiveness of plant growth, both naturally and agriculturally. ECOSTRESS began extended operations in August of 2019 and proposed to the 2020 Senior Review for extension through September 2023. NASA conducted an out-of-cycle Senior Review in December 2022 and approved ECOSTRESS to continue operations through September 2026 to align with the 2026 Senior Review. Reservation of ECOSTRESS site accommodations on ISS is extended through September 2028.

VENTURE CLASS MISSIONS

Recent Achievements

ECOSTRESS collected over 300,000 scenes (images that are 400km by 400 km in size) and achieved an acquisition rate that is more than double the proposed acquisition rate. Prior work in Los Angeles is extending to several megacities around the world. The data is also used to support wildfire applications, including identifying stressed vegetation prior to a fire that is most likely to burn, as well as monitoring active fire and providing that information to firefighters.

Planned Future Achievements

The project will continue extended operations through 2026. NASA will select an expanded science team to use the ECOSTRESS data for a variety of studies in agriculture, forestry, geology, and the environment. NASA and other partners will use ECOSTRESS data to simulate data for three future spaceborne missions: Surface Biology and Geology (SBG), Landsat Next, and Trishna, a French space agency (CNES)/ Indian Space Research Organisation (ISRO) mission. The planned release of a new collection of the ECOSTRESS data products is in early 2023.

GLOBAL ECOSYSTEM DYNAMICS INVESTIGATION (GEDI) LIDAR (EVI-2, SELECTED IN 2014)

GEDI is a geodetic-class laser ranging system that provides three-dimensional measurements of the Earth's forests from the ISS. GEDI measures the height of the Earth's temperate and tropical forests and their vertical structure. This data will help scientists determine, for the first time, how much carbon forests store as biomass, and the net impact of deforestation and subsequent regrowth on atmospheric carbon dioxide that results from human-influenced activities and climate variations. GEDI is the first mission optimized for vegetation measurements from space and provides the first global and transparently available data set that various U.S. agencies can use at relevant scales for policy and land management.

Launched in December 2018, GEDI completed its prime mission in April 2021. NASA conducted an out-of-cycle Senior Review in December 2022 and approved GEDI to continue operations through September 2026 to align with the 2026 Senior Review. GEDI will be temporarily stowed for about 18 months on an ISS storage site, while another mission operates at its location. Once reinstalled at its current location, NASA has requested site accommodations for GEDI though the end of life of the ISS. The ISS Program is still performing Accommodation assessments in response to this request.

Recent Achievements

GEDI has delivered nearly 15 billion surface returns, pulses of laser light emitted from GEDI to the Earth and reflected by the ground, vegetation, and any clouds back to GEDI's telescope, averaging 90 million surface returns each mission week. Despite unexpected challenges from ISS operations, GEDI has achieved 10-meter horizontal geolocation accuracy, further increasing the utility of its data. Scientists have used GEDI data to make the most complete maps to date for forest height, canopy cover, bare Earth topography, and GEDI's key product, aboveground biomass. The biomass products, at 25 meters and 1 km resolutions, provide the baseline carbon inventory for the United States and the 120 other countries that GEDI observes. The biomass products supplement existing national forest inventories and, in many cases, provide the only inventories available for some countries. These GEDI data products can quantify the impact of fires, deforestation, and other disturbances on national forest inventories and atmospheric carbon dioxide concentrations.

VENTURE CLASS MISSIONS

Initial analyses from GEDI show almost 25 percent more carbon on the land surface than estimated from existing national forest inventories as reported to the Food and Agriculture Organization (FAO) of the United Nations. Scientists used GEDI data along with the USFS Forest Inventory and Analysis (FIA) plot network (comprising over 300,000 in situ plots) to create higher accuracy and finer resolution estimates of the carbon content of U.S. forests. Scientists used GEDI estimates of global canopy heights to initialize a global carbon model that estimates current carbon stocks and future carbon sequestration and emission. GEDI data are also being used for forest conservation initiatives. Arecent analysis used GEDI data to determine that a total of 26 percent of Earth's forest biomass is stored in global protected areas, and that approximately19 picograms would have been lost without protection, equivalent to approximately one year of global fossil fuel emissions.

GEDI data was the basis for a forest structural integrity index which distinguished high integrity tropical rainforests, which in turn were strong predictors of significantly reduced mammal, bird, reptile, and amphibian species extinction risk and population trends. The United Nations Development Program used these findings to inform global environmental agreements, particularly the United Nations Convention on Biological Diversity (CBD) on the vital need for ambitious targets aimed at preserving the integrity of hyper-diverse tropical rainforest ecosystems.

Future Achievements

GEDI will continue to produce its core data sets during the extended mission, achieving higher accuracy and increased spatial resolution. This is especially true for the bare Earth topographic map that GEDI produces with its unique ability to see the ground beneath dense forests as no other sensor can, in addition to inland water bodies, rivers and land ice. GEDI will create new data products, including: a canopy structural complexity index that should be extraordinarily useful for habit and biodiversity studies; data products that blend observations from the ICESat-2 mission and GEDI; fusion of its data with those from TanDEM-X that goes beyond height to 3D canopy structure; and ecosystem modeling that predicts annual land surface carbon sources and sinks. GEDI will continue to work closely with the USFS toward the use of GEDI data for forest inventory analysis, wildfire prediction, habitat management, and national carbon accounting, among other activities. GEDI will collaborate with FAO to use GEDI data to augment or gap-fill inventory data for national reporting, starting in West Africa.

EARTH VENTURE MANAGEMENT

Earth Venture Management supports the development of AO solicitations and the technical, management, and cost evaluations of proposals received in response to the solicitations. The budget supports critical flight project management functions executed by the ESSP program office, and Senior Review Board teams, who conduct independent reviews of the ESSP flight projects. Additionally, this project supports the airborne assets that the EVS investigations rely on for their airborne campaigns, as well as large aircraft procurements.

Recent Achievements

SMD released a request for proposal in May 2022 for a Large Aircraft Science Platform Acquisition to replace the aging DC-8 aircraft. After careful analysis and review of the aircraft types proposed, the Science Mission Directorate selected a B777-200ER aircraft. NASA finalized the purchase agreement in November 2022.

VENTURE CLASS MISSIONS

Planned Future Achievements

The recently purchased large science aircraft is currently undergoing re-activation activities with an estimated delivery date in FY 2023. Science modifications will begin in FY 2023 with an anticipated ready for science date in FY 2025.

MULTI-ANGLE IMAGER FOR AEROSOLS (MAIA) (EVI-3, SELECTED IN 2016)

The MAIA investigation will use a spaceborne multi-angle imager to remotely determine aerosol characteristics and assess linkages between different airborne particulate matter (PM) types and human health (including adverse birth outcomes, cardiovascular and respiratory disease, and premature death). This project will measure concentrations of fine and coarse particles, sulfate, nitrate, organic and elemental carbon, and mineral dust particles in major urban areas around the globe at one-kilometer spatial resolution. The MAIA science team will use established epidemiological methodologies to associate human exposure to particulate matter with adverse health outcomes.

MAIA's primary spaceborne instrument consists of a specialized digital camera mounted on a 2-axis gimbal on a low-Earth orbit spacecraft, which will collect multi-angle spectropolarimetric imagery over a globally distributed set of major metropolitan areas. It will use this data in conjunction with surface-based pollution monitors and atmospheric models to map PM concentrations and types and to conduct epidemiological studies. Surface-based PM monitoring equipment deployments, overseen by the MAIA project, include instruments that collect particles on filters for subsequent chemical and gravimetric analyses; aethalometers, which measure black carbon concentrations; low-cost PM sensors to extend spatial coverage in selected areas; and aerosol sunphotometers. MAIA's Instrument Operations and Science Data Systems will be located at Jet Propulsion Laboratory (JPL). The baseline (prime) mission is three years.

The Italian Space Agency (ASI) will contribute a PLATiNO satellite to host the MAIA instrument. As an additional part of the partnership, ASI is also providing a launch vehicle for access to space along with part of the ground services to support MAIA during operations.

Recent Achievements

In FY 2022, the project successfully completed all development and integration work for the instrument. In parallel, NASA completed the deployment of the surface-based PM monitoring equipment in collaboration with the Department of State, which is already providing valuable information to both the science team as well as external stakeholders. The team participated in a multi-day workshop to highlight the opportunity to enhance the scientific cooperation between the United States and Italy in space using the MAIA mission. Additionally, the team helped facilitate the NASA Airathon, which was a challenge that had over 1,200 submissions from over 1,000 domestic and international participants to make use of available satellite data that have the potential to provide local, daily air quality information.

In FY 2023, NASA completed testing of the entire instrument and then placed the instrument into storage while the satellite development continues. New development and integration activities will continue to ensure combability between the new host satellite and the instrument.

NASA finalized a new access-to-space solution for MAIA in January 2023 that is a partnership with and includes contributions from ASI. With this new collaboration, NASA established a new lifecycle cost and schedule for a hosted payload solution with a launch readiness date of November 2025.

VENTURE CLASS MISSIONS

Planned Future Achievements

NASA plans to deliver the MAIA instrument to ASI in FY 2024 for integration onto the satellite where it will also undergo testing to ensure the system can withstand the launch and space environments.

TIME-RESOLVED OBSERVATIONS OF PRECIPITATION STRUCTURE AND STORM INTENSITY WITH A CONSTELLATION OF SMALLSATS (TROPICS) (EVI-3, SELECTED IN 2016)

TROPICS will make measurements over the tropical latitudes to observe the thermodynamics and precipitation structures of Tropical Cyclones (TCs) over much of the storm systems' lifecycles. TROPICS will take measurements of the temperature within the atmosphere, spatially and vertically resolved, as well as humidity, cloud ice, precipitation horizontal structure, and instantaneous surface rain rates. These measurements and the increased temporal resolution provided by the CubeSat constellation will enable better understanding of the TC lifecycles and the environmental factors that affect the intensification of TCs.

The TROPICS mission consists of six CubeSats, which will each have a cross-track scanning multiband passive microwave radiometer in a 1U payload (1U, a CubeSat unit, is equivalent to a 4-inch cubic box).

Recent Achievements

In FY 2022, TROPIC's commercial launch provider was unsuccessful in the first launch, resulting in the loss of the first pair of CubeSats. The investigation into the failure continues and the provider indicated that they would not resume launches prior to the Atlantic Hurricane Season in 2023. Recognizing the urgent science need to allow researchers to study tropical cyclones through more frequent observations, NASA selected a new launch provider, Rocket Lab USA, Inc., through the new Venture Class Acquisition of Dedicated and Rideshare (VADR) contract. This selection of Rocket Lab includes two separate launches to deploy the remaining four TROPICS Constellation CubeSats in FY 2023, enabling observations during the Atlantic Hurricane Season.

The TROPICS Pathfinder, a qualification unit launched in FY 2021, demonstrated the effectiveness of the end-to-end system identical to constellation in FY 2022 and continues its risk reduction mission. Additionally, the TROPICS Pathfinder provided high quality images and data products of storms of interest such as Category 4 Hurricanes Ian and Fiona that damaged Puerto Rico in the Atlantic and Category 5 Super Typhoon Hinnamnor that impacted South Korea in the Pacific. In addition, the TROPICS Pathfinder conducted a National Oceanic and Atmospheric Administration (NOAA)-funded Low Latency Data Experiment demonstrating the ability to provide an amazingly quick average latency of 55 minutes from observation until delivering the data to NOAA operators, as compared to the nominal latency of approximately four hours.

Planned Future Achievements

The TROPICS Pathfinder will continue its risk reduction mission in FY 2023. The TROPICS team continues to incorporate lessons learned from the Pathfinder mission into the planned operations for the TROPICS Constellation. The new vendor will launch the four TROPICS Constellation CubeSats to a 30-degree inclination orbit in pairs on-board two separate launch vehicles in FY 2023.

VENTURE CLASS MISSIONS

EARTH VENTURE SUBORBITAL-3 (EVS-3; SELECTED IN 2018)

In 2020, NASA initiated five investigations spanning a range of pressing research areas such as intense East Coast snowfall events and the impact of small-scale ocean currents on global climate. These investigations are:

- Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) studies the formation of snow bands in East Coast winter storms. Better understanding of the mechanisms of snow band formation and the factors that influence the location of the most intense snowfall will help improve forecasts of these extreme weather events.
- Aerosol Cloud Meteorology Interactions over the Western Atlantic Experiment (ACTIVATE) identifies how aerosol particles change cloud properties in ways that affect Earth's climate system. The investigation will focus on marine boundary layer clouds over the western North Atlantic Ocean that have a critical role in Earth's energy balance.
- Delta-X investigates the natural processes that maintain and build land in major river deltas threatened by rising seas. The project will improve models that predict loss of coastal land from sea level rise by improving estimates of how deltas add land—a process that involves trapping sediments and creating organic soils as plants grow.
- Dynamics and Chemistry of the Summer Stratosphere (DCOTSS) explores how strong summertime convective storms over North America can change the chemistry of the stratosphere. These storms regularly penetrate deep into the lower stratosphere, carrying pollutants that can change the chemical composition of this atmospheric layer, including ozone levels.
- Sub-Mesoscale Ocean Dynamics and Vertical Transport (S-MODE) examines the potentially large influence that small-scale ocean eddies have on the exchange of heat between the ocean and the atmosphere. The project will collect a benchmark data set of climate and biological variables in the upper ocean that influence this exchange.

Recent Achievements

The ACTIVATE investigation completed its fifth and sixth deployments in FY 2022. This concluded the deployment portion of the investigation. During the six deployments, ACTIVATE flew nearly 600 flight hours on each aircraft, NASA HU-25A and NASA UC-12, for a total of 179 science research flights.

The Delta-X investigation completed the deployment phase on September 25, 2021, with the low discharge campaign. For this campaign, AVRIS-NG completed eight science flights for a total of 42.7 hours; Airborne Surface Water and Ocean Topography (AirSWOT) completed 12 science flights for a total of 85.4 hours and UAVSAR completed seven science flight for a total of 35.6 hours.

The DCOTSS investigation completed its second and final deployment in July 2022. Overall, the investigation completed a total of 23 science flights and launched 56 balloons from Texas, Kansas, Colorado, and North Dakota.

The IMPACTS investigation completed its second deployment flown out of NASA Wallops Flight Facility (NASA P3) and Pope Airfield (NASA ER-2) from November 2021 through February 2022. The team conducted a successful Midterm Review on August 30, 2022.

The S-MODE investigation completed its pilot campaign in November 2021. During the pilot campaign, the investigation flew two aircraft, the NASA B200 and the Twin Otter International (TOI). The B200 flew 12 science flights for approximately 54 hours, while the twin otter flew 10 science flights for approximately 66 hours. The science team on the research cruise, the Oceanus, collected 1,396 profiles of upper-ocean temperature, salinity, oxygen, and chlorophyll fluorescence.

Planned Future Achievements

S-MODE is planning for its Intensive Operating Periods (IOP) in April 2023 through May 2023. For these IOPs, S-MODE will fly three aircraft (NASA B200, NOI Twin otter, and NASA G-III) and will deploy a research ship as well as autonomous ocean vehicles.

IMPACTS is planning its third and final deployment in Q2 FY 2023 on the NASA P-3 based out of NASA Wallops Flight Facility and on the NASA ER-2 based out of Dobbins Air Force Base.

Following the completion of the deployment phases for ACTIVATE, Delta-X, and DCOTSS, these investigations will focus on data analysis, archiving, open data workshops, and science team meetings.

EARTH SURFACE MINERAL DUST SOURCE INVESTIGATION (EMIT) (EVI-4; SELECTED IN 2018)

EMIT uses a sensor mounted to the exterior of the ISS to determine the mineral composition of natural sources that produce dust aerosols around the world. Scientists do not currently have a global inventory of the natural mineral sources of dust, and as a result, the global impacts of dust on weather, atmospheric circulation, and other aspects of Earth's environment are not well established.

EMIT's hyperspectral instrument measures the different wavelengths of light emitted by minerals on the surface of deserts and other dust sources to determine their composition. By measuring in detail which minerals make up the dust, EMIT helps answer the critical question of whether mineral-based dust has a cooling or warming effect on the atmosphere. EMIT's modeling component uses the data collected to advance the understanding of the role of atmospheric dust in Earth's climate and better predict how it can change in the future. EMIT began its prime mission in October 2022 to obtain one year of global dust observations. At the end of its prime mission, the EMIT team will propose to an out-of-cycle Senior Review for mission extension through September 2026 to align with the 2026 Senior Review. Due to the valuable methane imaging results, NASA has requested EMIT site accommodations through the end of life of ISS. The ISS Program is still performing accommodations assessments in response to this request.

Recent Achievements

The project team delivered the EMIT instrument to NASA's Kennedy Space Center (KSC) in March 2022. After functional checkout, NASA stored the instrument at KSC before handing it over to Space-X in May 2022 for integration in the Dragon Trunk for Space X-25 Cargo Resupply mission to the International Space Station (ISS). EMIT launched via SpaceX-25 on July 14, 2022, from Cape Canaveral, Florida. The Dragon Trunk docked with the ISS and EMIT, followed by robotic installation at External Logistics Character-1 (ELC-1) (designated berth on ISS) on July 24, 2022. EMIT successfully completed Post-Launch Assessment Review (PLAR) on September 29, 2022, and has transitioned to the operations phase.

The already collected EMIT data identified more than 50 “super-emitters” of methane in facilities, equipment, and other infrastructure which include the fossil-fuel, waste, or agriculture sectors that emit methane at high rates – in Central Asia, the Middle East, and the Southwestern United States. EMIT demonstrated this crucial capability to detect methane which is a potent greenhouse gas. EMIT is

VENTURE CLASS MISSIONS

performing above and beyond meeting the science requirement. Researchers and the public will use the instrument's data once it is available at the NASA Land Processes Distributed Active Archive Center (DAAC), and in a prototype for future greenhouse gas information distribution. EMIT is designed to map the prevalence of key minerals in the planet's dust-producing deserts, information that will advance our understanding of airborne dust's effects on climate.

Planned Future Achievements

EMIT will continue collecting data under the prime mission period until October 2023 and then continue under extended operations for both dust and greenhouse gas emission detection.

POLAR RADIANT ENERGY IN THE FAR INFRARED EXPERIMENT (PREFIRE) (EVI-4; SELECTED IN 2018)

PREFIRE will fly miniaturized thermal spectrometers on a pair of small CubeSat satellites to measure far-infrared emissions and how they change throughout the day and over seasons. These CubeSats will orbit Earth's poles to probe a little-studied portion of the radiant energy emitted by Earth for clues about Arctic warming, sea-ice loss, and ice-sheet melting. These observations will allow scientists to assess how changes in thermal infrared emissions at the top of Earth's atmosphere are related to changes in cloud cover and surface conditions below, such as the amount of sea ice and meltwater on the surface of ice.

Recent Achievements

The PREFIRE project successfully received all flight instrument components from the vendors and assembled both flight instruments at JPL. The team is calibrating and testing the instruments in preparation for CubeSat integration in FY 2023. The project held a successful systems integration review and pre-ship review in October 2022.

Planned Future Achievements

The PREFIRE project will deliver the instruments to the CubeSat vendor for integration. The project plans to hold its Operational Readiness Review in August 2023.The planned launch date for the CubeSats is August 2024.

GEOSYNCHRONOUS LITTORAL IMAGING AND MONITORING RADIOMETER (GLIMR) (EVI-5; SELECTED IN 2019)

GLIMR will provide unique observations of ocean biology, chemistry, and ecology in the Gulf of Mexico, portions of the southeastern United States coastline, and the Amazon River plume – where the waters of the Amazon River enter the Atlantic Ocean. It will closely monitor the health of the oceans and assess risks for coastal communities to protect our environment.

NASA will integrate GLIMR on a NASA-selected platform and launch into a geosynchronous orbit, where it will monitor a wide area centered on the Gulf of Mexico for up to 15 hours a day. From this vantage point, the hyperspectral ocean color radiometer will measure the reflectance of sunlight from optically complex coastal waters in narrow wavebands. GLIMR will gather observations of a given area each day in a way that would not be possible from a satellite in a low-Earth orbit. These observations are a critical capability in studying phenomena such as the lifecycle of coastal phytoplankton blooms and oil spills. GLIMR is a competitively selected, cost-capped, Principal Investigator-led Earth Venture

VENTURE CLASS MISSIONS

Instrument (EVI) development, with a cost cap of $107.9M for the instrument and science investigation. The access to space solution for GLIMR is the responsibility of NASA and has not yet been determined. As an EVI development, GLIMR is a higher-risk innovative project intended to achieve cutting-edge science through strictly cost-capped implementation.

Recent Achievements

The GLIMR team successfully completed the Preliminary Design Review (PDR) and an Independent Baseline Review (IBR) in June 2022.

Planned Future Achievements

GLIMR plans to hold its KDP-C review in March 2023 and Critical Design Review (CDR) later in FY 2023.

LIBERA (EVC-1; SELECTED IN 2020)

Libera is NASA's first mission selected under the Earth Venture Continuity (EVC) element. The project, named for the daughter of Ceres in ancient Roman mythology, provides continuity of the Clouds and the Earth's Radiant Energy System (CERES) Earth Radiation Budget (ERB) observations. Its primary goal is to extend the ERB record seamlessly, which is essential for recognizing changes to Earth's climate system and for constraining future predictions. The project will deliver the Libera instrument by November 2025 to NOAA for hosting on the JPSS-3 satellite.

Recent Achievements

Libera successfully completed the Preliminary Design Review (PDR) in February 2022. Libera entered the implementation phase following a successful KDP-C in April 2022.

Planned Future Achievements

Libera is planning a Critical Design Review (CDR) in June 2023.

INVESTIGATION OF CONVECTIVE UPDRAFTS (INCUS) (EVM-3, SELECTED IN 2021)

INCUS will study the behavior of tropical storms and thunderstorms, including their impacts on weather and climate models, by directly addressing why convective storms, heavy precipitation, and clouds occur and exactly when and where they form. The investigation will address objectives laid out in the 2017 Earth Science Decadal Survey and fills an important niche to help understand extreme weather and its impact on climate models – all of which serve to provide crucial information needed to mitigate weather and climate effects on our communities. INCUS means anvil in Latin and is a reference to the anvil shaped cumulonimbus thunderstorm clouds it will study.

Recent Achievements

NASA selected INCUS in November 2021 through the Agency's Earth Venture Mission-3 (EVM-3) solicitation. In FY 2022, NASA finalized the contract with the Principal Investigator's institution and recruited personnel to staff both the scientific and engineering efforts. The project is advancing preliminary trade studies to optimize the capabilities, decrease risk and inform the plan. Additionally, the project has started material procurement activities to mitigate supply chain risks.

VENTURE CLASS MISSIONS

Planned Future Achievements

INCUS will conduct a System Requirements Review and Mission Definition Review in FY 2023 that allow the project to enter the preliminary design and technology completion phase. Additionally, INCUS will complete prototyping of key technical equipment to mature the full design. INCUS is also planning the Mission Preliminary Design Review in late FY 2023.

Program Schedule

Date	Significant Event
FY 2023	MAIA instrument delivery
FY 2023	TROPICS launch readiness
FY 2024	EVC-2 (Continuity Measurement) solicitation released
FY 2023	TEMPO launch readiness
FY 2023	PREFIRE CubeSat delivery
FY 2023	PREFIRE launch readiness
FY 2023	EVS-4 (suborbital) solicitation released
FY 2025	EVI-7 (instrument) solicitation released
FY 2025	EVM-4 (mission) solicitation released
FY 2026	EVC-3 (Continuity Measurement) solicitation released
FY 2026	MAIA launch readiness
FY 2026	Libera instrument delivery
FY 2026	GLIMR instrument delivery
FY 2027	EVS-5 (suborbital) solicitation released
FY 2027	GLIMR launch readiness

Program Management & Commitments

The Earth System Science Pathfinder (ESSP) program at Langley Research Center (LaRC) manages the Venture Class projects. The “Provider” in the following table lists the Principal Investigator (PI) institution for each project.

Program Element	Provider
EVS-3: IMPACTS	Provider: University of Washington Lead Center: LaRC Performing Center(s): ARC, AFRC, GSFC Cost Share Partner(s): N/A

VENTURE CLASS MISSIONS

Program Element	Provider
EVS-3: ACTIVATE	Provider: University of Arizona Lead Center: LaRC Performing Center(s): LaRC Cost Share Partner(s): N/A
EVS-3: DCOTSS	Provider: Texas A&M University Lead Center: LaRC Performing Center(s): AFRC, ARC, GSFC Cost Share Partner(s): N/A
EVS-3: S-MODE	Provider: Woods Hole Oceanographic Institute Lead Center: LaRC Performing Center(s): JPL, JSC Cost Share Partner(s): N/A
EVS-3: Delta-X	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A
EVM-1: CYGNSS	Provider: University of Michigan Lead Center: LaRC Performing Center(s): N/A Cost Share Partner(s): N/A
EVM-3 INCUS	Provider: Colorado State University Lead Center: LaRC Performing Center(s): JPL Cost Share Partner(s): N/A
EVI-1: TEMPO	Provider: Smithsonian Astrophysical Observatory Lead Center: LaRC Performing Center(s): LaRC, GSFC Cost Share Partner(s): N/A
EVI-2: ECOSTRESS	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): USDA
EVI-2: GEDI	Provider: University of Maryland Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A

VENTURE CLASS MISSIONS

Program Element	Provider
EVI-3: TROPICS	Provider: MIT Lincoln Laboratory Lead Center: LaRC Performing Center(s): GSFC Cost Share Partner(s): N/A
EVI-3: MAIA	Provider: JPL Lead Center: LaRC Performing Center(s): JPL Cost Share Partner(s): Italian Space Agency (ASI)
EVI-4: EMIT	Provider: JPL Lead Center: JPL Performing Center(s): GSFC, JPL Cost Share Partner(s): N/A
EVI-4: PREFIRE	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A
EVI-5: GLIMR	Provider: University of New Hampshire Lead Center: LaRC Performing Center(s): LaRC, GSFC Cost Share Partner(s): N/A
EVC-1 LIBERA	Provider: University of Colorado Laboratory for Atmospheric and Space Physics Lead Center: LaRC Performing Center(s): LaRC Cost Share Partner(s): N/A

Acquisition Strategy

NASA will issue Venture Class solicitations at intervals of every four years for EVS and EVM, and every three years for EVI and EVC, alternating every 18 months. NASA will select all Venture Class missions through full and open competition.

VENTURE CLASS MISSIONS

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
CYGNSS	PI Institution: University of Michigan Instrument Provider: Southwest Research Institute Launch Vehicle Provider: NASA	PI: Ann Arbor, MI Instrument: San Antonio, TX Launch Vehicle: Cape Canaveral, FL
TEMPO	PI Institution: Smithsonian Astrophysical Observatory Instrument Provider: Ball Aerospace & Technologies Corp. Host Services Provider: Maxar Technologies	PI: Cambridge, MA Instrument: Boulder, CO Host Services: Westminster, CO
GLIMR	PI Institution: University of New Hampshire Instrument provider: Raytheon Host Services Provider: TBD	PI: Durham, New Hampshire Instrument: El Segundo, CA Host Services: TBD
Libera	PI Institution: University of Colorado Laboratory for Atmospheric and Space Physics Instrument provider: LASP Host Services Provider: NOAA (JPSS-3)	PI: Boulder, CO Instrument: Boulder, CO Host Services: TBD

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Q1 FY 2023	INCUS SRR/MDR	Passed	Q4 FY 2024
Performance	SRB	Q2 FY 2023	TEMPO ORR	TBD	N/A
Performance	SRB	Q4 FY 2023	Libera CDR	TBD	Q2 FY 2025
Performance	SRB	Q4 FY 2023	PREFIRE ORR	TBD	N/A
Performance	SRB	Q4 FY 2023	INCUS PDR	TBD	Q3 FY 2024
Performance	SRB	Q1 FY 2024	GLIMR CDR	TBD	Q1 FY 2025
Performance	SRB	Q3 FY 2024	INCUS CDR	TBD	Q1 FY 2025
Performance	SRB	Q1 FY 2025	INCUS SIR	TBD	Q3 FY 2026
Performance	SRB	Q1 FY 2025	GLIMR SIR	TBD	N/A
Performance	SRB	Q2 FY 2025	Libera SIR	TBD	N/A
Performance	SRB	Q3 FY 2026	INCUS ORR	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
ESSP Missions Research	17.8	--	**25.3**	26.8	27.1	27.1	32.1
Orbiting Carbon Observatory-3	7.6	--	**7.2**	7.2	7.2	7.2	7.2
OCO-2	11.4	--	**10.7**	10.7	10.7	10.7	10.7
CloudSat	11.2	--	**9.2**	5.1	0.0	0.0	0.0
Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)	6.9	--	**6.2**	5.3	0.0	0.0	0.0
Total Budget	**54.9**	**--**	**58.6**	**55.0**	**45.0**	**45.0**	**50.0**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Earth System Science Pathfinder (ESSP) Other Missions and Data Analysis projects include operating missions and mission-specific research. These innovative missions will enhance understanding of the current state of the Earth system and enable continual improvement in the prediction of future changes.

Mission Planning and Other Projects

ESSP MISSIONS RESEARCH

ESSP Missions Research provides funds for the science teams supporting ESSP operating missions, and Principal Investigator-led Earth Venture-Instrument, operating onboard the International Space Station (ISS). The science teams are comprised of competitively selected individual investigators who analyze data from the missions to address relevant science questions.

Recent Achievements

A NASA-funded study analyzed a week-long intense rainfall and extensive flooding in March 2021 in the eastern part of Australia, which followed extreme drought during the 2019-2020 bushfire summer. Understanding how much water storage changes in response to these climate extremes is critical for developing timely water management strategies. To quantify prompt water storage changes associated with the 2021 March flooding, the study processed the low-latency (1-3 days), high-precision intersatellite laser ranging measurements from the Gravity Recovery and Climate Experiment (GRACE) Follow-On spacecraft and determined instantaneous gravity changes along spacecraft orbital passes. Such new data processing detected an abrupt surge of water storage approaching 60–70 trillion liters (km3 of water) over a week in the region, which concurrently caused land subsidence of approximately 5 millimeters (mm) measured by a network of ground Global Positioning System (GPS) stations. This was the highest speed of ground water recharge ever recorded in the region over the last two decades. Compared to the condition in February 2020, the amount of recharged water was similar, but the recharge speed was much faster in March 2021. While these two events together replenished the region up to ~80 percent of the maximum storage over the last two decades, the wet antecedent condition of soils in

OTHER MISSIONS AND DATA ANALYSIS

2021 was distinctly different from the dry conditions in 2020 and led to generating extensive runoff and flooding in 2021.

Researchers developed a "top-down" carbon budget of carbon dioxide (CO2) emissions and removals for countries to support the Global Stocktake of the Paris Agreement (GST). Researchers used an ensemble of top-down estimates of the net surface-atmosphere CO2 flux produced by the Orbiting Carbon Observatory-2 (OCO-2) science team, in combination with fossil fuel emissions and lateral carbon fluxes (due to wood trade, crop trade, and rivers) from bottom-up models to create the CO2 budgets. Accounting for both anthropogenic emissions and changes in natural carbon storage, the products will help inform inventory development and identify strategies to produce operational top-down carbon cycle products that can quantify the impact of emission reduction activities. Another study used the multi-year archive of the OCO-2 and the Orbiting Carbon Observatory-3 (OCO-3) platforms to retrieve large fossil fuel CO2 emissions over the entire globe. The emission retrievals are based on a simple emission retrieval scheme and researchers compared them to results from a global gridded and hourly inventory. Researchers found that emission retrievals from both OCO missions explain more than one third of the inventory variance at the corresponding cells and hours. More importantly, researchers can make robust calculations of emission trends and changes but only as the length of the data record grows.

A study focused on the endangered delta smelt in the San Francisco Estuary and Sacramento–San Joaquin River Delta (Bay Delta) by investigating the relationship between open water surface and subsurface conditions from spaceborne thermal measurements (ECOSTRESS and Landsat-8) and in situ sensor data from the California Data Exchange Center to produce estimates of spatially continuous bulk temperature. Results showed that ECOSTRESS and Landsat-8 surface temperature measurements are well-correlated with bulk water temperatures. ECOSTRESS surface temperatures were also warmer than bulk temperatures in the midday period and cooler in the morning and evening periods. Researchers also found that across the Bay Delta, including open waters and pelagic bays, temperature conditions causing stress and mortality for the Delta Smelt were persistent throughout the day during summer months.

Operating Missions

OCO-3

OCO-3, which launched in May 2019, is a complete stand-alone payload, built using the spare OCO-2 flight instrument, with additional elements added to accommodate installation and operation on the ISS. The OCO-3 instrument consists of three high-resolution grating spectrometers that collect space-based measurements of atmospheric carbon dioxide with the precision, resolution, and coverage needed to assess the spatial and temporal variability of carbon dioxide over an annual cycle.

OCO-3 started extended operations in September 2022. NASA conducted an out-of-cycle Senior Review in December 2022 and approved OCO-3 to continue operations through its next Senior Review in 2026. OCO-3 will be temporarily stowed for about six months on an ISS storage site, while another mission operates at its location. Once reinstalled at its current location, NASA has requested OCO-3 site accommodations though the end of life of the ISS.

Recent Achievements

OCO-3 has a unique pointing mechanism that allows it to make dense CO2 data collections over 50-mile by 50-mile regions within two minutes. OCO-3 is currently the only mission capable of collecting such

OTHER MISSIONS AND DATA ANALYSIS

dense, localized data over urban areas, power plants, volcanoes, and other sites of interest. Over the past year these regional data collections have started to demonstrate their usefulness in advancing our knowledge of fossil fuel emissions and our understanding of the complexity of carbon dioxide variations at regional, urban and facility scales – scales that are relevant to decision-making and policy implementation. Based on recommendations from the science team, the project is now developing and preparing to test a new, improved OCO-3 data processing algorithm that will utilize some of the features implemented in the latest OCO-2 data processing algorithm. In addition, the OCO-3 mission also continues to provide a solar-induced chlorophyll fluorescence (SIF) data product. SIF is a measurement of photosynthesis activity, and an indicator of plant health. These data products are now serving the needs of scientists and researchers, as well as those in the science applications community.

OCO-2

OCO-2 launched in July 2014 and collects precise CO2 measurements across the globe every day from its vantage point in low-Earth orbit. Data scientists are gaining greater insight into how much CO2 the Earth emits by natural sources and human activities, and the natural process for removing CO2 from the atmosphere. This information may help decision-makers manage CO2 emissions and reduce the human impact on the environment.

The OCO-2 instrument has collected almost one million daily soundings globally since September 2014. OCO-2 is currently in extended mission operations. The 2020 Senior Review for Operating Missions approved extended mission operations for OCO-2 through FY 2023. NASA will conduct the next Senior Review in the Spring of 2023 to determine mission extensions for FY 2024 through FY 2026.

Recent Achievements

OCO-2 data have been used to estimate national carbon dioxide budgets in support of the Global Stocktake, a process designed to evaluate collective progress in achieving nationally-determined goals for mitigation of climate change under the Paris Agreement. In FY 2022, peer-reviewed journals published over 85 studies using OCO-2 Solar Induced chlorophyll Fluorescence (SIF) and CO2 data. The project supported two targeted Applied Sciences training courses in FY 2022: an introductory course on the OCO-2 data products and their relevance for climate. The continued nominal performance and operations of the spacecraft and instrument facilitated the long-term record of CO2 observations. Based on recommendations from the science team, the project has implemented an improved OCO-2 data processing algorithm and has released a new dataset for public distribution. The project continues to work closely with the OCO-3 project and the science community at large to maximize the scientific value of what is becoming a crucial climate data record of a fundamental driver of climate change.

CLOUDSAT

CloudSat, launched in April 2006, measures cloud characteristics to increase understanding of the role of clouds in Earth's radiation budget. This mission provides estimates of the percentage of Earth's clouds that produce rain, provides vertically-resolved estimates of how much water and ice are in Earth's clouds, and estimates how efficiently the atmosphere produces rain from clouds. CloudSat collects information about the vertical structure of clouds and aerosols that other Earth-observing satellites do not collect. This data improves models and provides a better understanding of the human impact on the atmosphere.

OTHER MISSIONS AND DATA ANALYSIS

CloudSat is currently in extended operations. The 2020 Senior Review for Operating Missions approved extended mission operations for CloudSat through FY 2023. Based on predicted spacecraft longevity, CloudSat will begin decommissioning activities in early FY 2024.

Recent Achievements

In the past year, CloudSat data enabled significant advances in understanding why severe storms are more intense over the ocean than over land. National Oceanic and Atmospheric Administration (NOAA) Enterprise Cloud Algorithms uses CloudSat to tune development of new operational cloud data products. Efforts continue to use CloudSat data as a verification dataset for the Geostationary Operational Environmental Satellite (GOES) sensors.

The CloudSat Project continues to exploit synergies with other NASA missions. For example, CloudSat data combined with information from Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) and OCO-2 resulted in the first-ever spaceborne direct measurements of cloud thickness of low altitude clouds and fog. CloudSat also collaborates with NASA's Global Precipitation Measurement (GPM) mission to routinely produce a data product of coincident GPM and CloudSat satellite overpasses that improves estimates of rainfall and snowfall around the globe, now spanning the time from the GPM launch to the present.

The heights of clouds in the atmosphere, unique information provided by CloudSat, is important for a variety of weather applications, including aviation weather forecasting. CloudSat provided essential training data used to support improvement of satellite data under the NOAA Joint Polar Satellite System (JPSS) Proving Ground Aviation Initiative. This led to new and improved satellite-based 3D cloud data used to produce cloud vertical cross-sections along selected flight routes over Alaska.

Another important application of CloudSat is the study of tropical cyclone (TC) intensification. Predicting TC intensification continues to be a major challenge. The effects of radiation interactions with the ice contained in the clouds in TC storms are important factors in intensification, and CloudSat measurements have led to a clearer understanding of TC intensification, with early results showing positive impacts on forecasts.

Research and applications use of CloudSat data has resulted in more than 3,500 peer-reviewed publication citations to-date.

CLOUD-AEROSOL LIDAR AND INFRARED PATHFINDER SATELLITE OBSERVATION (CALIPSO)

The CALIPSO mission, launched in April 2006, provides the first comprehensive three-dimensional measurement record of aerosols, helping to better understand how aerosols form, evolve, and transport over the globe. The mission provides data on the vertical structure of clouds, and the geographic and vertical distribution of aerosols, and further detects sub-visible clouds in the upper troposphere. CALIPSO also indirectly estimates the contribution of clouds and aerosols to atmospheric temperature.

CALIPSO is currently in extended operations. The 2020 Senior Review for Operating Missions approved extended mission operations for CALIPSO through FY 2023. In late FY 2023, the spacecraft's orbital drift will reach a point where it can no longer generate enough power to continue to operate the instrument. At that time, the mission will begin decommissioning activities for the spacecraft and instrument.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

CALIPSO continues to provide unique vertical profile observations of clouds and atmospheric particle (aerosol) layers over the globe. During FY 2022, the mission released an updated Level 1 lidar product, featuring improved calibrations. An updated Polar Stratospheric Cloud (PSC) product provided unique information on the occurrence and properties of PSCs, which play a key role in ozone loss in the polar stratosphere. Combined with other observations and chemical modeling, these observations have advanced our knowledge of the processes responsible for the formation of the annual polar ozone hole.

The team matured several major improvements to the CALIPSO data products to address specific needs of the scientific community, as part of the feature in data product releases in 2023. In addition, the team supported the formation of an international working group to foster collaboration between members of different aerosol disciplines. The working group currently includes six steering committee members from four countries and 200+ participants from 22 countries.

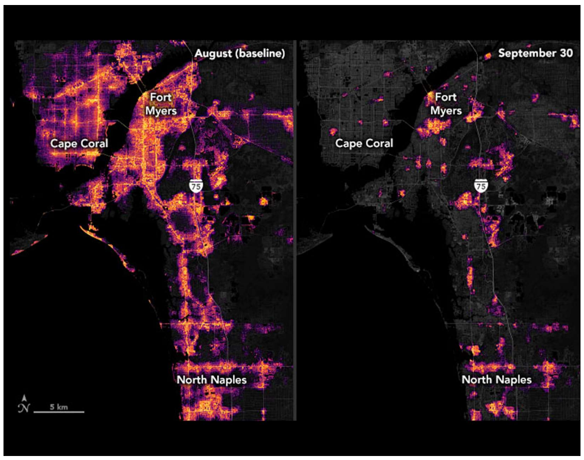
EARTH SCIENCE DATA SYSTEMS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**339.4**	**--**	**411.7**	**398.9**	**408.1**	**423.8**	**439.6**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



NASA's Black Marble Project processed data from the Visible Infrared Imaging Radiometer Suite (VIIRS) on the NOAA–NASA Suomi NPP satellite and from the Landsat 8 and 9 satellites to produce views (shown here) of lost electric power and light for millions of residential and business customers as they appeared on September 30, 2022, following Hurricane Ian.

The Earth Science Data Systems (ESDS) Program oversees the lifecycle of Earth science data with the principal goal of maximizing the scientific return from NASA's missions and experiments for research and applied scientists, decision-makers, and the Nation.

ESDS acquires, processes, preserves, and distributes observational Earth science data from spacecraft, aircraft, and in-situ sensors to support Earth Science research focus areas. The ESDS Program primarily accomplishes this via the Earth Observing System Data and Information System (EOSDIS), which has been in operation since 1994.

EOSDIS has continuously evolved to take advantage of improved technology to meet the increasing demands of data providers and users. Following the addition of data from several new missions, NASA expects the EOSDIS data archives to approximately triple in size between 2022 and 2025, growing from its current size of 75 petabytes (PB) to approximately 250 PB in 2025.

EOSDIS has a history of actively evolving its capabilities through communication with users, rapid adoption of new technologies, and by supporting competitive research elements within the Data System Evolution (DSE) component of the program. These activities ensure effective prioritization of investments to more efficiently manage user needs, while simultaneously identifying new technologies to improve the preservation of and access to the diverse data NASA collects.

Other critical components of the ESDS Program include the Commercial SmallSat Data Acquisition (CSDA) Project, which is responsible for identifying, evaluating, and acquiring data from commercial sources that support NASA's Earth science research and application goals.

NASA's Open Science activities, designed to support reproducibility, transparency, inclusivity, and accessibility of the scientific process, are at the forefront of NASA's recent efforts to build a more efficient and fair scientific infrastructure and culture. The Open Source Science Project is responsible for coordinating and implementing open science capabilities for all of the Science Mission Directorate (SMD) and is home to the Transform to OPen Science (TOPS) initiative.

EARTH SCIENCE DATA SYSTEMS

EXPLANATION OF MAJOR CHANGES IN FY 2024

This budget request includes an additional $10 million in FY 2024 for the Open Source Science Project to implement centralized data and computing tools and systems to address common data needs across all science divisions. These core data and computing services will lower operational costs for divisions and lower barriers to enhancing the openness and transparency of the scientific process. Core data and computing services will also enable more straightforward adoption of new techniques and technology by SMD. The Budget provides $65 million for the Commercial SmallSat Data Acquisition program, increasing funding by 30 percent since 2022. NASA has adjusted the outyear budget profile for Commercial SmallSat Data Acquisition to reflect a smoother ramp up in funding for the program.

ACHIEVEMENTS IN FY 2022

The EOSDIS archives grew to over 75 petabytes (PB) in FY 2022 and distributed nearly two billion data products to more than five million users around the world. The project conducted data stewardship to over 15,300 unique data products from more than 150 instruments. It also released over 400 new datasets from new and continuing missions totaling 34 PB for public access that is available in Earthdata Cloud, a commercial cloud application. The program allowed users to search over 55,000 data collections in the Common Metadata Repository, with 98 percent of queries completed in less than one second. The common metadata repository has grown to manage over one billion files of sensor data from Earth science missions. The planned growth of the data ingest rate and overall archive volume in support of new NASA missions poses challenges for the archiving, distribution, and analysis of EOSDIS' data holdings. To address these challenges, the ESDS Program initiated a mission processing study to identify and assess data system architectures that can meet mission science processing objectives, enable data system efficiencies, promote the adoption of open science practices in line with NASA and Federal policies, and seek broad opportunities that actively support Earth system science.

In FY 2022, the Earthdata Login (EDL) system achieved a milestone with one million accounts. EDL started in 2008 and provides a single mechanism for user registration and profile management for all EOSDIS system components (e.g., Distributed Active Archive Centers (DAACs), Tools, Services). NASA has scaled it continuously to keep pace with the increasing needs of EOSDIS and its data, tools, and services.

The NASA Sentinel Gateway continued to serve data from the European Space Agency (ESA) partnership, delivering 41 terabytes (TB) of data per week from ESA to the DAACs. The total archive of Sentinel data is now over 17.7 PB. During FY 2022, NASA distributed over 12 million data files (more than 52 PB) from ESA's Sentinel 1-A/B, 3A/B, and 5-P missions in support of NASA science activities. ESDS supported over 750 unique near-real-time datasets in the Land, Atmosphere Near real-time Capability for EOS (LANCE) system. LANCE produces over 42 TB of data per week within three hours of satellite acquisition. ESDS completed a data latency study for the Earth System Observatory (ESO) to investigate potential avenues for common downlink strategies.

EARTH SCIENCE DATA SYSTEMS

Open Source Science (OSS)

OSS launched the Transform to OPen Science (TOPS) initiative, whose goal is to broaden participation in science, increase accessibility to knowledge, and embrace new technologies.

Additionally, OSS funded Science Discovery Engine (SDE) team completed prototype development in September 2022. The initial version of the SDE includes over one million documents representing data and information from all five of the NASA SMD divisions (i.e., Astrophysics, Biological and Physical Sciences, Earth Science, Heliophysics, and Planetary Science).

OSS is also supporting a selected proposal from the Smithsonian Institution to expand the Astrophysics Data System to facilitate the discovery of publications and data in the fields of Earth and space science to the same extent as it currently serves the field of astrophysics.

MEaSUREs

The ice shelves that drain the Antarctic Ice Sheet to the surrounding oceans are critical to controlling the flow of glacier ice and thus are a key physical component of modulating sea level rise from Antarctic ice contributions. However, the availability of continent-wide data showing the growth and retreat cycles of ice shelves has not been widespread until recently. A MEaSUREs project generated Antarctic-wide spatially continuous coastlines showing annual ice shelf front positions from 1997 to 2021 using several optical-band, thermal-band, and radar satellite sensors, combined with observations of ice flow. The team showed that over the time series studied, the Antarctic Ice Sheet experienced an overall loss of roughly 37,000 square kilometers of ice shelf area and that the Ice Sheet will not be able to fully replace the lost area before the next onset of major iceberg calving events, which they project to occur within the next 10 to 20 years. Additionally, they modeled the impacts of Antarctica’s recent coastline changes in the absence of processes such as grounding-line movement or changes in grounded-ice geometry. The team also determined that iceberg calving and ice shelf thinning have reduced the buttressing impact of ice shelves since 2007, which implies that further ice shelf retreat could potentially produce heightened sea level rise in the future.

WORK IN PROGRESS IN FY 2023

Several new missions will deliver data in FY 2023, including EMIT on ISS, JPSS-2, SWOT, and TEMPO. ESDS is focusing on open-source, cloud-native software to provide user services on data, including the ability to subset and subsample. The program develops and enables cloud-optimized formats and standardized tools that work across data stored in the Earthdata Cloud. Additionally, the program continues to migrate high-value datasets into the Earthdata Cloud in priority order.

With the announcement of the Earth System Observatory (ESO), the ESDS Program engaged early with the missions to identify and assess potential architectures that can meet the ESO mission science processing objectives, enable data system efficiencies, promote open science principles, and seek opportunities that support Earth system science. ESDS is engaging these missions via the ESO Mission Data Processing Study, which concludes in FY 2023.

The CSDA Project is implementing long-term data preservation processes for commercial data acquired by NASA. The Earth Observing System Data and Information System (EOSDIS) core services will ingest, archive, catalog, and distribute the purchased commercial data and make it discoverable using standard search interfaces.

EARTH SCIENCE DATA SYSTEMS

FY 2023 ESDS will dedicate support to the archive and distribution of data products created to respond to needs expressed in the 2016 and 2018 (first and second) Satellite Needs Working Group (SNWG) cycles. NASA will commence a limited number of new data production projects resulting from the 2020 (third) SNWG cycle. ESDS will simultaneously continue to support NASA's role of leading the coordinated assessment of, and proposing solutions to, surveys submitted as part of the 2022 (fourth) SNWG cycle.

In FY 2023, OSS will complete a Data and Computing Architecture study to investigate how a coordinated commercial cloud-High End Computing (HEC) infrastructure can meet the data and computing needs of SMD, enable efficiencies, and support SMD’s transition to Open-Source Science. As part of the OSS-funded TOPS initiative, NASA is designating 2023 as the Year of Open Science. This activity encompasses a community initiative to spark change and inspire open science engagement through events and activities.

NASA will release a solicitation for Transform to Open Science Training (TOPST) that will minimize or reduce barriers of entry, increase outreach and open science training for underserved communities, and engage in a Dual Anonymous Peer Review process to help us ensure fairness in the selection process. The TOPST element will advance Open Science literacy through the development of a discipline-specific curriculum, the implementation of summer schools, and the implementation of virtual cohorts.

NASA will establish the Core Data and Computing Services Program in FY 2023 within Open Source Science. This activity will coordinate and oversee existing and new data and computing capabilities that are reusable by all SMD divisions. To support the development of Core Data and Computing Services, OSS will continue the SMD Data and Computing Architecture Study into FY 2023 to evaluate architecture options for scientific data and computing elements of core services infrastructure and produce recommendations for a hybrid on-premises/cloud data and computing infrastructure for SMD.

ESDS will also support the Earth Information Center (EIC) with an initial focus on prototyping capabilities for a greenhouse gas monitoring and information system that will integrate data from a variety of sources with the goal of making data more accessible and usable to Federal, State, and local governments, researchers, the public, and other users. NASA will implement these efforts in coordination with other agencies and partners.

MEaSUREs held a peer review panel in November 2022 and plans to hold two panels in the spring of 2023. MEaSUREs expects to make new selections in 2023 and establish new cooperative agreements for the new projects.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

In FY 2024, ESDS will expand its capabilities to support data from new missions, including PREFIRE, CLARREO-PR, PACE, and TSIS-2. FY 2024 will also see the launch of NISAR, which will produce over 27 PB of data per year of synthetic aperture radar data. Additionally, several suborbital missions will provide data from the continuing EVS Program. NASA will add all data to the ESDS archives and make it available to the public in line with NASA and Federal policies. The Common Metadata Repository will expand and become more flexible in FY 2024 and ESDS will continue to see its adoption by other agencies.

Based on community feedback, the CSDA Project will transition from its current annual selection process to a rolling request for proposals (RFP) to continue the project objectives of identifying, evaluating, and acquiring data from commercial sources to support NASA’s Earth science research and applications activities.

EARTH SCIENCE DATA SYSTEMS

NASA will complete the SNWG Cycle 4 CSDA assessment of data request needs. The SNWG assessments will inform the CSDA Project to provide commercial data access utilizing the tiered End User License Agreement (EULA) approach. ESDS will also continue to implement SNWG data production activities begun in FY 2023 and to release new data product solutions responding to the needs expressed in the 2020 SNWG cycle.

ESDS will continue the maturation of the EIC and support the expansion of greenhouse gas data system activities by incorporating new data and information products, providing new tools and services, engaging with stakeholders, and providing help desk support for those products, which will be made available to the public.

Program Elements

EARTH SCIENCE DATA AND INFORMATION SYSTEM (ESDIS)

The ESDIS Project manages the geographically distributed science systems of EOSDIS including the DAACs; Science Investigator-led Processing Systems (SIPS); the Land, Atmosphere Near real-time Capability for the Earth Observing System (LANCE); and core systems. Together, these systems support the processing of satellite data and seamless interdisciplinary access to EOSDIS data, including data products, data services, and data handling tools for a broad range of user communities that include scientists, Government agencies, commercial users, and the public.

- SIPS generate high-quality science products from Terra, Aqua, Aura, S-NPP, and JPSS missions at facilities under the direct control of the instrument principal investigators and team leaders. Products produced at SIPS undergo extensive quality assurance before the program transfers them to DAACs for archiving and distribution to users.
- DAACs archive, document, and distribute data and provide user support for NASA's past and current Earth-observing satellites; Sentinel 1, 3, 5P, and 6 satellites; airborne investigations; and field measurement programs. Acting in concert, the DAACs provide reliable, robust services to users whose needs may cross the traditional boundaries of a science discipline, while continuing to support the unique needs of users within specific science discipline communities. The DAAC facilities, hosted at NASA or other institutions, each specialize in a science discipline (e.g., atmosphere, calibrated radiance, solar radiance, cryosphere, human dimensions, land, or ocean science).
- LANCE generates and provides access to near real-time products from the Atmospheric Infrared Sounder, Advanced Microwave Scanning Radiometer 2, Microwave Limb Sounder, Moderate Resolution Imaging Spectroradiometer, Measurement of Pollution in the Troposphere, Ozone Monitoring Instrument, Ozone Mapping Profiler Suite, and Visible Infrared Imaging Radiometer Suite (VIIRS) (VIIRS-Land and VIIRS Atmosphere) instruments. Data is provided within three hours of observation. The data supports NASA applications users who are interested in monitoring and analyzing a wide variety of natural and man-made phenomena.

The EOSDIS system supports several core systems to provide a common entry point to discover, access, and visualize data from the distributed DAACs and SIPS. The program developed core systems to reduce duplication and improve user access to EOSDIS data, including:

EARTH SCIENCE DATA SYSTEMS

- Common Metadata Repository (CMR) is a high-performance, high-quality, continuously evolving metadata system that catalogs all data and service metadata records for EOSDIS and is the authoritative management system for all EOSDIS metadata.
- Global Imagery Browse Services (GIBS) provides visual representations of NASA Earth science data at full resolution in a free, open, and interoperable manner. Through responsive and highly available web services, it enables interactive exploration of data to support a wide range of applications, including scientific research, applied sciences, natural hazard monitoring, and outreach. GIBS provides much of the LANCE near real-time imagery, as well as present-day and historical imagery.
- NASA-compliant General Application Platform is a cloud-based platform that provides a scalable and flexible application platform solution that offers the cost benefits of hardware consolidation with the safety and security of application sandboxing and resource management.
- Cumulus is a cloud optimized software package for performing Earth science data ingest, archive, and distribution capabilities to support all EOSDIS missions.
- Earth Observing System Networks provide effective access to EOSDIS. They depend on end-to-end network connectivity between users and geographically distributed DAACs. The NASA Earthdata website integrates information from across EOSDIS. Earthdata is the entry point for EOSDIS data, articles, documentation, and collaboration. It leverages CMR to provide comprehensive search capabilities. Earthdata offers new and experienced users an organized view of EOSDIS resources and the latest events.
- The NASA Sentinel Gateway transfers data from a dedicated interface to the European Commission's Copernicus Programme Sentinel 1, 3, and 5P satellite ground system. The Sentinel Gateway transfers data from the Sentinel satellites to DAACs for archival and distribution to users.
- For more information, see https://earthdata.nasa.gov.

DATA SYSTEM EVOLUTION (DSE)

The Data System Evolution Project funds research opportunities, interagency initiatives, and promotion of data and service interoperability through the development and implementation of standards. DSE is composed of two competitive components: Advancing Collaborative Connections for Earth System Science (ACCESS), and Citizen Science for Earth Systems Program (CSESP). DSE also supports the Interagency Implementation and Advanced Concepts Team (IMPACT) activity and the development of long-term data records needed by NASA scientists and the Satellite Needs Working Group (SNWG) Management Office, which manages and coordinates the formulation, implementation, operation, and status reporting of solutions from all funded cycles. The SNWG office also serves as a data liaison between the ESDIS Project and external Federal agencies.

- ACCESS supports the evolution of ESDIS by investing in technology to enhance the analysis, delivery, and preservation of Earth science data. NASA solicits proposals in this competitive program element every two years. The intent is to identify and develop promising technology prototypes into operational tools to infuse into the EOSDIS.
- CSESP consists of two elements: the collection and analysis of data by citizen scientists across all Earth Science focus areas, and technological development and production of low-cost sensors for

EARTH SCIENCE DATA SYSTEMS

measurement and monitoring. NASA solicits proposals in this competitive program element every three years.

- IMPACT works with other Government agencies to increase the use of NASA Earth observations. This team assesses, independently evaluates, and makes recommendations to improve EOSDIS services and processes; manages archiving of airborne science observations; and develops proof of concept data system capabilities. IMPACT works closely with the SNWG to design and implement a systematic plan to assist other agencies in incorporating NASA Earth observation data into their workflows.

NASA will design and begin to implement a common system to host greenhouse gas monitoring measurements from a variety of data sources.

DSE activities also support the widespread use of NASA Earth science observations through the development and implementation of standards, through collaborations with other space agencies, and by leading activities to improve the discoverability of NASA data.

OPEN SOURCE SCIENCE

The Open Source Science (OSS) Project implements open-source science principles to accelerate scientific discovery and expand access to scientific knowledge produced by NASA. The major elements of the strategy are:

- Develop and implement capabilities to enable open science;
- Engage the SMD science community in the evolution of data systems; and
- Harness the community and form strategic partnerships for innovation.

OSS aims to expand the reproducibility, transparency, inclusivity, and accessibility of the scientific process, and in doing so, accelerate discovery by facilitating openness from project initiation through implementation. OSS is a cross-divisional effort, with ESDS leading several foundational activities.

NASA will use new investments for Open Source Science targeted toward developing an SMD-wide open science ecosystem. The ecosystem will invest in and scale existing divisional capabilities for cross-SMD use and develop new capabilities through targeted funding.

OSS includes several foundational activities needed for the open science ecosystem and advancing data science. These activities include:

- Developing a SMD-wide data catalog to support cross-divisional discovery of scientific data;
- Provisioning cross-divisional discovery tools for scientific publications that link directly to the data;
- Improving access to the tools and data needed to empower scientists;
- Investing in the maintenance of critical open source software, toolkits, and libraries used by NASA scientists and developers;
- Capacity building to transform the NASA scientific community to use Open Science principles to accelerate discovery;
- An SMD Artificial Intelligence/Machine Learning study and demonstration team and using data science prizes and challenges to leverage the skills and expertise of the community to develop innovative solutions; and

EARTH SCIENCE DATA SYSTEMS

- SMD Core Data and Computing Services to assimilate existing and new data and computing capabilities into a modular and secure architecture so that they are reusable by all SMD Divisions.

COMMERCIAL SMALLSAT DATA ACQUISITION

The Commercial SmallSat Data Acquisition (CSDA) Project identifies, evaluates, and acquires data from commercial sources to support NASA's Earth science research and applications activities. This provides a cost-effective means to augment and/or complement the suite of Earth observations acquired by NASA and other U.S. Government agencies, as well as those acquired by international partners and made available to NASA and its stakeholders. The project places an emphasis on data acquired by satellite constellations, affording the means of complementing NASA acquired data with higher resolutions, increased temporal frequency or other novel capabilities in support of existing Earth science and application activities.

NASA-funded researchers examine and analyze the data set(s) to determine the utility of the commercial data products. The evaluation phase takes approximately 12 to 18 months. NASA may enter into a longer-term agreement for continued access to data pending a favorable evaluation. CSDA provides an opportunity for vendors with new or significantly enhanced capabilities to have their data evaluated by NASA for longer-term procurement.

MAKING EARTH SYSTEM DATA RECORDS FOR USE IN RESEARCH ENVIRONMENTS (MEASURES)

The overall objective of MEaSUREs is to provide Earth science higher-level data products and services driven by NASA’s Earth science goals. These data products, called Earth Science Data Records, are critical for understanding Earth System processes; assessing variability, long-term trends, and changes in the Earth System; and providing input and validation means to modeling efforts. MEaSUREs is a competitive program element solicited every five years.

MEaSUREs emphasizes linking together multiple satellites into a constellation, developing the means of utilizing a multitude of data sources to form a coherent time series, and facilitating the use of NASA’s extensive data in the development of comprehensive Earth system models. In addition, MEaSUREs activities include infusion or deployment of applicable science tools that contribute to data product quality improvement, consistency, merging or fusion, or understanding.

PROGRAM SCHEDULE

The ESDS Program solicits research opportunities approximately every three years for ACCESS and every five years for MEaSUREs. The ESDIS Project continuously delivers software to improve functionality and improve efficiency. The OSS Project will solicit opportunities each year to support its objectives. The CSDA Project provides on-ramp opportunities for new vendors every 18 to 24 months.

Date	Significant Event
Q1 FY 2023	ROSES ACCESS Solicitation Released
Q1 FY 2023	CSDA Program RFI Released

EARTH SCIENCE DATA SYSTEMS

Date	Significant Event
Q2 FY 2023	ROSES OSS Solicitation Released
Q2 FY 2023	OSS Year of Open Science
Q1 FY 2024	CSDA Program RFI Released
Q2 FY 2024	ROSES CSESP Solicitation Released
Q2 FY 2024	ROSES OSS Solicitation Released
Q1 FY 2025	ROSES ACCESS Solicitation Released
Q1 FY 2025	CSDA Program RFI Released
Q2 FY 2025	ROSES OSS Solicitation Released
Q1 FY 2026	ROSES CSESP Solicitation Released
Q1 FY 2026	CSDA Program RFI Released
Q2 FY 2026	ROSES OSS Solicitation Released
Q1 FY 2027	CSDA Program RFI Released
Q2 FY 2027	ROSES MEaSUREs Solicitation Released
Q1 FY 2028	CSDA Program RFI Released
Q2 FY 2028	ROSES MEaSUREs Solicitation Released

Program Management & Commitments

The Earth Systematic Missions Program at Goddard Space Flight Center (GSFC) provides program management for the ESDIS Project. NASA Headquarters manages the Commercial SmallSat Data Acquisition, DSE, and MEaSUREs projects.

Program Element	Provider
EOSDIS core system	Provider: Various Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A
Alaska Synthetic Aperture Radar Facility Distributed Active Archive Center [DAAC] (Fairbanks, AK)	Provider: University of Alaska Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A

EARTH SCIENCE DATA SYSTEMS

Program Element	Provider
Atmospheric Science Data Center (Hampton, VA)	Provider: Langley Research Center (LaRC) Lead Center: LaRC Performing Center(s): LaRC Cost Share Partner(s): N/A
Goddard Earth Science Data and Information System Center (Greenbelt, MD)	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A
Land Processes Data Center (Sioux Falls, SD)	Provider: U.S. Geological Service (USGS) Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A
National Snow and Ice Data Center (NSIDS; Boulder, CO)	Provider: University of Colorado Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A
Oak Ridge National Laboratory DAAC (Oak Ridge, TN)	Provider: Oak Ridge National Laboratory Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A
Physical Oceanography DAAC (Pasadena, CA)	Provider: Jet Propulsion Laboratory (JPL) Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A
Socio-economic Data and Applications Center [SEDAC] (Palisades, NY)	Provider: Columbia University Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A
Crustal Dynamics Data Information System (Greenbelt, MD)	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A
Global Hydrology Research Center (Huntsville, AL)	Provider: University of Alabama Lead Center: Marshall Space Flight Center (MSFC) Performing Center(s): MSFC Cost Share Partner(s): N/A

EARTH SCIENCE DATA SYSTEMS

Program Element	Provider
Interagency Implementation and Advance Concepts Team (Huntsville, AL)	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC Cost Share Partner(s): N/A

Acquisition Strategy

Research opportunities within DSE are available through NASA's ROSES announcements. NASA competitively selects ESDIS support contracts through full and open competition.

NASA initiates Commercial SmallSat data acquisitions via SAM.gov. After a favorable evaluation, if deemed of sufficient value, the Agency purchases them for broader sustained use. The program will select contract types on a vendor-by-vendor basis, selecting those best suited to provide long-term access to data.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
EOSDIS Evolution & Development	Raytheon	Riverdale, MD
National Snow and Ice Data Center (NSIDC)	University of Colorado	Boulder, CO
Alaska SAR Facility	University of Alaska	Fairbanks, AK
SEDAC	Columbia University	Palisades, NY
Commercial SmallSat Data	BlackSky Technology Inc	Herndon, VA
Commercial SmallSat Data	Airbus Defense and Space Inc.	Herndon, VA
Commercial SmallSat Data	Teledyne Brown Engineering	Huntsville, AL
Commercial SmallSat Data	Maxar Technologies	Westminster, CO
Commercial SmallSat Data	Planet Labs	San Francisco, CA

INDEPENDENT REVIEWS

The American Customer Satisfaction Index (ACSI) measures customer satisfaction with the NASA Earth Observing System Data and Information System (EOSDIS) at a national level for each Distributed Active Archive Center (DAAC) on an annual basis. NASA EOSDIS scored an 81 on the ACSI survey in 2021, which represented an increase of two points from the prior year. This is the highest score NASA EOSDIS has received in the last 18 years and continues the trend of high scores / performance. It also identifies the key areas that NASA can leverage across the DAACs to continuously improve its service to its customers.

EARTH SCIENCE DATA SYSTEMS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	American Customer Satisfaction Index	2022	Survey current EOSDIS users to assess satisfaction with current services	Pending Release	2023
Performance	Earth Science Advisory Committee (ESAC)	2022	Annual review to assess progress against Earth Science performance goals and overarching strategic objective	Expectations for the research program were fully met	2023

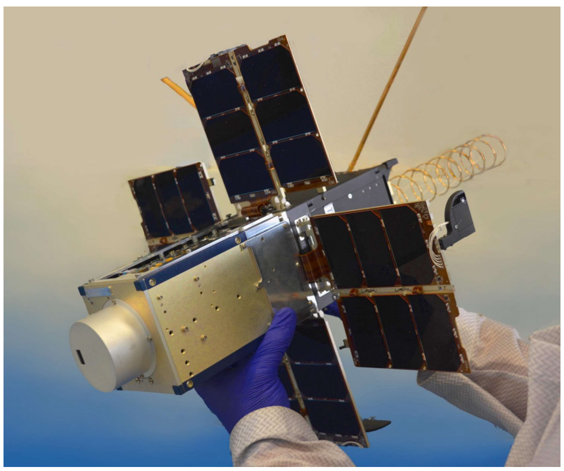
EARTH SCIENCE TECHNOLOGY

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**86.1**	**--**	**105.3**	**113.5**	**117.1**	**118.4**	**120.8**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



Shown above. one of the twin NanoSat Atmospheric Chemistry Hyperspectral Observation System 3-unit CubeSats (NACHOS-1 and NACHOS-2) being readied for launch. NACHOS-1 was launched on 02/19/2022 and subsequently deployed from an International Space Station supply vessel (Cygnus NG-17) on 06/29/2022. NACHOS-2 was launched directly into Earth's orbit on 07/02/2022 via the USSF STP-S28A VOX LauncherOne. The NACHOS CubeSats are validating a compact hyperspectral imager that, if successful, it will be the smallest, highest resolution space-based instrument dedicated to monitoring atmospheric trace gases like sulfur dioxide (SO2) and nitrogen dioxide, paving the way for future Earth-observing systems that will not only help predict volcanic eruptions, but also monitor air quality around specific cities, neighborhoods, and even individual power plants.

Advanced technology plays a major role in enabling Earth science research and applications. The Earth Science Technology Program enables previously infeasible science investigations, improves existing measurement capabilities, and reduces the cost, risk, and/or development times for Earth science instruments and information systems.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ACHIEVEMENTS IN FY 2022

The Earth Science Technology Program (ESTP) portfolio executed 174 active projects in FY 2022. Within the portfolio, 43 percent advanced at least one Technology Readiness Level (TRL) during FY 2022 and at least 10 projects advanced more than one TRL. Historically, student participation in ESTP projects has been substantial, with a cumulative total of at least 1,068 students from 162 institutions participating in the program. In FY 2022, 119 students from 37 institutions participated in the program.

The ESTP infused at least 10 projects into science measurements, airborne campaigns, data systems, or other follow-on activities during the year. For example, in November 2021, NASA selected a new Earth science mission – Investigation of Convective Updrafts (INCUS) – through the Earth Venture Mission-3 (EVM-3) solicitation. More than a decade of ESTP technology investments made the mission that consists of three SmallSats flying in formation to study the behavior of tropical storms and thunderstorms possible including:

EARTH SCIENCE TECHNOLOGY

- The RainCube (Radar in a CubeSat) project (InVEST-15) combined miniaturization, pulse compression, and a deployable antenna design, which were all successfully demonstrated on orbit and are utilized by INCUS.
- RainCube, in turn, was enabled by the Ka-Band Highly-Constrained Deployable Antenna project (ACT-13), which designed, prototyped, and developed compact 1- and 2-meter mesh antennas and feed horns for use by precipitation radars on CubeSats/SmallSats.
- The TEMPEST-D (Temporal Experiment for Storms and Tropical Systems) project (EVI-2014) developed and demonstrated a new, low-cost, compact microwave radiometer. One of the three INCUS SmallSats will host a TEMPEST-D-like radiometer.

In another example of technology infusion, the NASA-ISRO Synthetic Aperture Radar (NISAR) adopted a Smart Tasking tool (AIST-19) for its urgent response request handling system and incorporated it into the mission with some adaptations that conform to specific requirements. The technology architecture will use available triggers from major U.S. Federal agencies – such as USGS and Forest Service – to automatically task the satellite to observe unfolding events like wildfires, volcanoes, or earthquakes. The planned LRD for NISAR is October 2024.

Finally, the Libera instrument, which will fly on NOAA’s operational Joint Polar Satellite System-3 (JPSS-3) satellite, will use an uncooled microbolometer detector technology developed by the Black Array of Broadband Absolute Radiometers (BABAR) project (ACT-17) to make radiation budget measurements of Earth, continuing the record of measurements made by the CERES instruments.

The ESTP also successfully launched three technology demonstration CubeSats into low Earth orbit in FY 2022: the twin NanoSat Atmospheric Chemistry Hyperspectral Observation System CubeSats (NACHOS-1 and NACHOS-2), and the Compact Total Irradiance Monitor (CTIM) flight demonstration. All three demonstrations are underway and completing their validation requirements.

WORK IN PROGRESS IN FY 2023

With guidance from the 2017 Earth Science Decadal Survey and longer-term technology development strategies, ESTP plans to continue ongoing technology projects and fund several new cohorts of projects. Awards will continue to reflect the full breadth of NASA Earth science needs, while also focusing on the NASA Wildland FireSense and Earth Information Center (EIC) efforts.

ESTP's "Technology Development for Support of Wildfire Science, Management, and Disaster Mitigation" element, which is part of the NASA Wildland FireSense effort, released a solicitation in late-FY 2022 and expects to make awards in mid-FY 2023. The FY 2023 solicitation will include the leveraging of existing commercial capabilities, particularly in the area of low-cost, scalable, infrared sensing. and the Advanced Component Technology (ACT) program element released solicitations in mid-FY 2022 and expect to award new projects in early FY 2023.

In FY 2023, ESTP also plans to solicit proposals for the Instrument Incubator Program (IIP) element, the Advanced Information Systems Technology (AIST) program element, and the Sustainable Land Imaging-Technology (SLI-T) program element. NASA expects to make awards for these program elements in late FY 2023 or early FY 2024.

ESTP has several space validation activities for FY 2023 to accelerate technology developments and demonstrations supporting a variety of Earth observations. ESTP expects three CubeSat/SmallSat

EARTH SCIENCE TECHNOLOGY

developments to advance to launch in FY 2023: the Multi-Band Uncooled Radiometric Imager (MURI) SmallSat; the Hyperspectral Thermal Imager (HyTI) 6-unit CubeSat; and the SigNals-Of-Opportunity P-band Investigation (SNOOPI) 6-unit CubeSat.

ESTP will also continue a digital twin Earth prototype framework leveraging several AIST projects. The digital twin Earth prototype will mirror a localized Earth science system of an urban area and utilize the combination of data analytics, machine learning, and state-of-the-art models to conduct "what if" investigations that can result in actionable predictions and relate natural and physical events to urban development and human activities.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

In FY 2024, ESTP technology development will continue to reflect the full breadth of NASA Earth science needs, while incorporating requirements from the Earth Science Decadal Survey as well as the NASA Wildland FireSense, Greenhouse Gas (GHG), and Earth Information Center (EIC) efforts. ESTP plans to select new awards under the Instrument Incubator Program (IIP), the Advanced Information Systems Technology (AIST) program, and the FireSense Technology program elements. NASA also plans to release a competitive solicitation under the Decadal Survey Incubation (DSI) and In-Space Validation of Earth Science Technologies (InVEST) program elements.

Program Elements

ADVANCED TECHNOLOGY INITIATIVES (ATI)

This project enables development of critical component and subsystem technologies for instruments and platforms, mostly in support of the Earth Science Decadal Survey, through the Advanced Component Technology (ACT) element. Current awards focus on areas such as space-qualified laser transmitters, passive optical technologies, and microwave and calibration technologies. Other awards support measurements of solar radiance, ozone, aerosols, and atmospheric gas columns for air quality and ocean color, and for coastal ecosystem health and climate emissions.

The InVEST activity selects new technologies to validate in space prior to use in a science mission. This is necessary because the space environment imposes stringent conditions on components and systems, some of which cannot be tested on the ground or in airborne systems. Validation of Earth science technologies in space will further reduce the risk of new technologies in future Earth Science missions.

Technology Development for support of Wildfire Science, Management, and Disaster Mitigation (FireSense Technology), will seek new, innovative Earth system observation capabilities to predict and manage wildfires and their impacts. The FireSense Technology element receives support from NASA's Applied Sciences and Research and Analysis elements, the Aeronautics Research Mission Directorate (ARMD), and the Small Business Innovative Research (SBIR) program. FireSense Technology will work closely with interagency partners such as NOAA, the U.S. Forestry Service, the California Department of Forestry and Fire Protection, the National Interagency Fire Center, and others. In doing so, FireSense Technology will leverage NASA resources to improve the end-to-end management of wildfires in the United States and around the world. Over the next five to six years, FireSense Technology will execute a series of airborne field campaigns to test novel technologies for reducing impact of wildfires. These technologies will make use of broad capabilities in instrument and information technology, along with new observing platforms in space, in the air, and on the ground.

INSTRUMENT INCUBATOR

This project develops instruments, instrument concepts, and measurement techniques at the system level, including laboratory breadboards and operational prototypes that often lead to ground or airborne demonstrations. These instrument prototypes support multiple measurements including carbon dioxide, carbon monoxide, ocean color, and solar spectrum (from ultraviolet to infrared) for Earth science. Instrument Incubator supports the development of instrument design and prototyping through laboratory and/or airborne demonstrations for innovative measurement techniques that have the highest potential to meet the measurement capability requirements of the NASA Earth science community in both the optical and the microwave spectrum.

DECADAL INCUBATION

NASA created this project in response to the recommendation of the 2017 Earth Science Decadal Survey. It focuses on maturing observing systems, instruments, technologies, and measurement concepts to address high priority science for the next decade (2027-2037) in two targeted observable areas. These observable areas are the Planetary Boundary Layer and Surface Topography and Vegetation. Anticipated developments in this project include various observation and information system technologies, modeling/system design, analysis activities, and small-scale pilot demonstrations in support of the two observable areas. NASA currently funds 35 awards made from the DSI-21 solicitation.

ADVANCED INFORMATION SYSTEMS TECHNOLOGY (AIST)

This project develops end-to-end information technologies that enable new Earth observation measurements and information products. The technologies help process, archive, access, visualize, communicate, and understand Earth science data. Currently, AIST activities focus on three primary areas of need to support future Earth system science measurements:

- Analytic Collaborative Framework (ACF): ACF technology projects aim to harmonize tools, data, and computing environments to meet the needs of Earth science investigations of physical processes and natural phenomena. These investigations integrate new or previously unlinked datasets, tools, models, and a variety of computing resources together into a common platform to address previously intractable scientific questions. Additionally, these projects generalize custom or unique tools to make them accessible and useful to a broader community.
- New Observing Strategies (NOS): NOS projects dynamically coordinate and collaborate observations across multiple platforms (space, air, ground) to acquire a more complete picture of Earth Science phenomena. NOS can be described as a federated Observing System, a generalized SensorWeb, or more generally as an "Internet-of-Space (IoS)" concept in which each node can be an individual sensor, a group of sensors, a constellation of satellites (e.g., Earth System Observatory concept), a model or integrated models, or even database(s) or any other source of relevant information, that have varying degrees of coordination to achieve a common science objective.

EARTH SCIENCE TECHNOLOGY

- Earth System Digital Twin (ESDT): An ESDT is an interactive and integrated multidomain, multiscale, digital replica of the state and temporal evolution of Earth systems. The ESDT thrust will develop capabilities toward the development of future digital twins of the Earth or of subcomponents of the Earth, as well as toward the development of an overarching framework that will continuously evolve and connect the various components developed by Research and Analysis, Applied Sciences, Data Systems, and Computational Capabilities from other Earth Science Programs.

Program Schedule

Date	Significant Event
Q1 FY 2023	ROSES-2022 selection no earlier than six months of receipt of proposals
Q2 FY 2023	ROSES-2023 solicitation
Q1 FY 2024	ROSES-2023 selection no earlier than six months of receipt of proposals
Q2 FY 2024	ROSES-2024 solicitation
Q1 FY 2025	ROSES-2024 selection no earlier than six months of receipt of proposals
Q2 FY 2025	ROSES-2025 solicitation
Q1 FY 2026	ROSES-2025 selection no earlier than six months of receipt of proposals
Q2 FY 2026	ROSES-2026 solicitation
Q1 FY 2027	ROSES-2026 selection no earlier than six months of receipt of proposals
Q2 FY 2027	ROSES-2027 solicitation
Q1 FY 2028	ROSES-2027 selection no earlier than six months of receipt of proposals
Q2 FY 2028	ROSES-2028 solicitation

Program Management & Commitments

Program Element	Provider
Instrument Incubator	Provider: Various Lead Center: HQ Performing Center(s): GSFC, JPL, LaRC, MSFC, AFRC Cost Share Partner(s): N/A
Advanced Information Systems	Provider: Various Lead Center: HQ Performing Center(s): GSFC, JPL, LaRC, MSFC, ARC, JSC Cost Share Partner(s): N/A

EARTH SCIENCE TECHNOLOGY

Program Element	Provider
Advanced Technology Initiatives	Provider: Various Lead Center: HQ Performing Center(s): GSFC, JPL, LaRC Cost Share Partner(s): N/A
Decadal Incubation	Provider: Various Lead Center: HQ Performing Center(s): GSFC, LaRC, JPL Cost Share Partner(s): N/A

Acquisition Strategy

NASA primarily procures tasks through full and open competition, such as through the ROSES announcements. The solicitation of technology investments is competitive and selected from NASA centers, industry, and academia as well as other Government agencies, Federally Funded Research and Development Centers, and nonprofit organizations.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	National Academies of Science, Committee on Earth Science, and Applications from Space (CESAS)	Nov 2021	Provide results of the Earth Science Technology Program and outline program's ongoing response to 2017 Decadal Survey	CESAS was pleased with the status of the program	Nov 2023

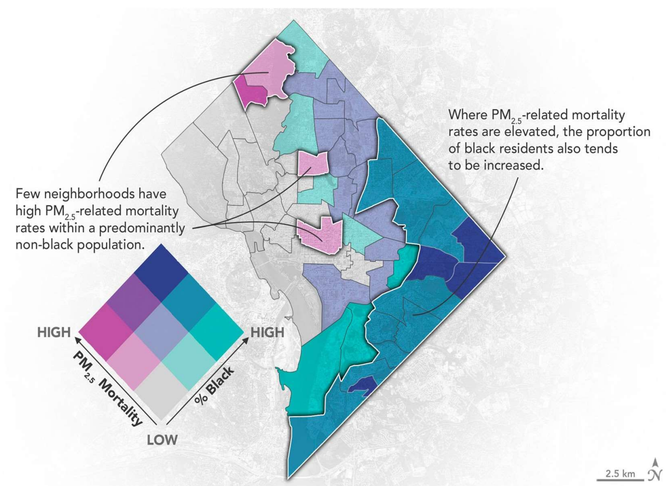
APPLIED SCIENCES

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**73.5**	**--**	**87.3**	**102.3**	**106.2**	**109.3**	**111.5**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



The Health and Air Quality program element of Applied Sciences supported a grant at George Washington University to study levels of fine particle pollution (PM2.5) across Washington, DC. The resulting map (above) shows that exposure to PM2.5 and rates of certain health problems were highest in the areas of the city that have historically higher percentages of people of color and more people with lower socioeconomic backgrounds.

The Applied Sciences program leverages NASA Earth Science satellite measurements and new scientific knowledge to enable innovative and practical uses by public and private sector organizations. It supports near-term uses of Earth science knowledge, discovers and demonstrates new applications, facilitates adoption of applications, and builds capabilities.

Applied Sciences projects improve decision-making activities to help the United States better manage its resources, improve quality of life, and strengthen the economy. NASA develops Earth science applications in collaboration with end-users in public, academic, and private organizations.

The program supports activities in thematic Earth science applications areas, in capacity building with uses of Earth observations, and in planning for future NASA missions.

Examples of these applications include:

- The U.S. Department of Agriculture uses NASA soil moisture data to support its monthly global crop production estimates;
- The U.S. Forest Service uses wildfire detection data and progression predictions to improve determination of fire boundaries and to expedite the restoration of key ecosystems;
- The Centers for Disease Control and Prevention's Environmental Public Health Tracking Network includes county-level ultraviolet (UV) exposure information;
- State and local governments use satellite-based water quality data to assess algal bloom magnitude, frequency, duration, and extent to map indicators and threats to human health from harmful algal blooms;

APPLIED SCIENCES

- Disaster-response organizations use data from multiple Earth observing satellites to identify damaged areas following disasters such as hurricanes, floods, and wildfires;
- Tourism industries, coastal resource managers, and others use satellite data to identify the amount and location of Sargassum seaweed in the Atlantic and the Gulf of Mexico to mitigate Sargassum beaching events that cause serious problems for the environment, human health, and economy;
- Local governments use satellite-based land-surface temperature data, emissivity data, and imagery to identify populations most vulnerable to extreme heat and guide service efforts; and
- The Navajo Nation uses satellite observations as part of a Drought Severity Evaluation Tool to target interventions and allocate drought relief funding more efficiently and equitably.

The program sustains the use of these products in the decision-making process of user organizations. The program encourages potential users to envision and anticipate possible applications from upcoming satellite missions and to provide input to mission development teams to increase the societal benefits of NASA missions.

For more information, go to: https://appliedsciences.nasa.gov/

EXPLANATION OF MAJOR CHANGES IN FY 2024

This budget request includes an additional $4 million in FY 2024 to enhance capacity building activities, including a new Health & Air Quality theme in SERVIR, expanded Applied Remote Sensing Training (ARSET) trainings, and increased participants and projects in DEVELOP. The request includes an additional $2 million supporting climate smart agriculture, including in collaboration with the Department of Agriculture and others in the agriculture sector.

ACHIEVEMENTS IN FY 2022

Multiple elements of the Applied Sciences program supported interagency activities related to the war in Ukraine. NASA Harvest supported United States Agency for International Development (USAID) requests for winter wheat mapping, crop condition assessments, and crop yield forecasts to understand food security implications. The Disasters project developed Damage Proxy Maps of Kharkiv, Ukraine, showing damaged buildings and infrastructure. Informing Mission Planning via Analysis of Complex Tradespaces (IMPACT) International and the Cultural Heritage Monitoring Lab utilized these maps to support their humanitarian efforts. A Health and Air Quality project, which progressed to ARL 8 with the release of the Vibrio Prediction Hub and cholera risk map viewer, contributed to ongoing monitoring of cholera risk in Ukraine. As projected risk maps estimated an increase in cholera risk across port cities in eastern Ukraine, the team worked with project partners to develop the anticipatory decision-making framework for potential interventions.

Community Action within Capacity Building initiated 39 environmental justice science projects to assess potential applications, feasibility, and to integrate socioeconomic data and Earth observations to inform environmental justice issues that impact underserved communities, consistent with the Administration's environmental justice and equity goals.

The Capacity Building project continued to build greater knowledge of remote sensing in the United States and around the globe. The SERVIR program (managed jointly with the United States Agency for International Development) worked with its global network to conduct 64 projects and 94 trainings that

APPLIED SCIENCES

reached over 2,300 individuals from 54 countries. The Applied Remote Sensing Training Program (ARSET) conducted 17 trainings. These trainings netted a reach of 13,900 instances of participation from 155 countries, 51 United States and territories, and more than 4,600 organizations. Over 2,000 organizations were new to the ARSET program in FY 2022. The DEVELOP Program, a workforce development effort that partners early career professionals with user organizations to apply Earth science data, conducted 69 feasibility projects and engaged 315 young professionals.

The Disasters project targeted over 300 partner organizations to strengthen relationships for reducing disaster risk, build resilience and to support disaster preparedness, response, and recovery. NASA activated Disaster Assistance Response and Resilience Teams, drawing on five NASA centers and 10 ROSES teams, to support four scenario exercises and 32 activations (nine domestic, 23 international) to help exposed and vulnerable communities. In FY 2022, the NASA Disasters Mapping Portal posted 1,116 data products related to events including tropical cyclones, volcanoes, flooding, and wildfires. These activities increased situational awareness for key partners including the Federal Emergency Management Agency (FEMA), USAID Bureau of Humanitarian Affairs, The World Food Programme, World Central Kitchen, and The International Federation of Red Cross and Red Crescent Societies.

On April 13, 2022, Applied Sciences released the Earth Science Applications Guidebook. The web-based resource synthesizes best practices and practical guidance in working with user communities and developing applications to inform decision making. It includes interactive and multimedia content, with use cases narrated by Principal Investigators. The Guidebook targets a broad audience across technical levels from young professionals to seasoned researchers interested in working with organizations to use Earth science information for societal benefits.

WORK IN PROGRESS IN FY 2023

With the Capacity Building project, Community Action will conduct 39 environmental justice science projects with the goal of assessing the potential applications of and feasibility to use and to integrate socioeconomic data and Earth observations. These efforts will inform solutions related to environmental justice issues directly impacting underserved communities, consistent with the Administration's environmental justice and equity goals. Twenty activities by the third SERVIR Applied Sciences team will complete their projects in early FY 2023. Their activities address challenges in food security, weather and climate, land cover, disasters, water resources, and uses of Earth observations for international development. NASA selected the fourth SERVIR Applied Sciences team which will begin work in mid-FY 2023. SERVIR will continue start up activities for a sixth hub in Central America deepening the program impact and scaling services within the region and building on the NASA Earth partnership with the Central American Integration System (SICA) in concert with USAID.

ARSET plans to conduct 17 training sessions. Learning materials will be available in English and Spanish, with some sessions delivered in both languages. DEVELOP will conduct 35-40 activities with 140-150 participants working at 12 locations. Under the Disaster Support project, Applied Sciences will initiate a Disaster Response Coordination System that leverages the full disaster-related capabilities across NASA Centers with a central Response Coordination Office based at a NASA Center.

NASA will initiate its first consortium focused on domestic agriculture, NASA A Climate Resilient Ecosystem Approach (ACRES). The NASA Harvest Consortium will continue to manage a program of activities focused on Earth science applications and applied research for international activities. This will include work performed at the country-level outside of the United States, and global agriculture systems that transcend geopolitical boundaries.

APPLIED SCIENCES

The Western Water Applications Office (WWAO) is continuing their work to characterize the Earth observation needs and developing partnerships required to support freshwater challenges in the Western United States. This includes a major emphasis on supporting the transition of NASA applied research into sustainable solutions.

In FY 2023, Applied Sciences will support the development of near-term use cases to prototype the developing greenhouse gas (GHG) center and contribute to the development of a more systematic approach for identifying and working with interagency partners to prioritize and implement additional use cases to support local, state, regional and national GHG monitoring and mitigation efforts. Applied Sciences will also reach out and coordinate with stakeholders, private and public, who will use and sustain successful GHG data products, and contribute to the center through the sharing of existing, and development of enhanced or new, products to better address identified user needs. In addition, in FY 2023, Applied Sciences will contribute to the Earth Information Center, leveraging projects and partnerships to help quickly build EIC capabilities.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

Within the Capacity Building project, FY 2024 will be the first full year of operations for the SERVIR Central America hub. Additional FY 2024 resources will support efforts to scope a new SERVIR Health and Air Quality thematic area, expand ARSET trainings, and increase participants and projects in DEVELOP.

The Applications project will expand the Agriculture element's capabilities to rapidly assess impacts of natural and human-caused shocks to the global food system and markets, making Earth Science information more responsive to agricultural markets and policy. Additional FY 2024 resources will support climate smart agriculture, including in collaboration with the Department of Agriculture and others in the agriculture sector.

Additionally, Applications will expand the Energy element's tools and support for sustainable infrastructure and renewable energy sectors. The Energy program will enhance its solar and meteorological information and tools to broaden support for large building retrofits and management, community solar systems, regional, state, and national policies, and more. These efforts connect NASA Earth Science to support of national and global sustainability goals and enabling emission reductions and monitoring to help achieve the U.S. goal of net-zero GHG emissions by 2050.

Program Elements

CAPACITY BUILDING

The Capacity Building project enhances United States and developing countries’ capacity (e.g., human, scientific, technological, institutional, and resource capabilities) to make decisions informed by Earth science data and models. Capacity Building develops skills in current and future workforce and creates opportunities in under-served areas to broaden the benefits of Earth observations. This project supports training, information product development, internships, data access tools, short-term application test activities, user engagement, and partnership development. This project has four primary elements:

APPLIED SCIENCES

- SERVIR: A joint venture with USAID that supports developing countries to improve their environmental management and resilience to climate change through uses of Earth observations in development decision-making
- ARSET: A professional-level training program for accessing and using Earth observations data through computer-based webinars and hands-on courses for all types of organizations
- DEVELOP: A national training and development program for individuals to gain experience applying Earth observations through 10-week interdisciplinary activities to address community needs
- Community Action: Activities focused on advancing equity and environmental justice, strengthening skills of Indigenous groups to use Earth observations for land management decisions and actions, and prizes and challenges to reach new communities with new ideas to address Earth science applications needs

MISSION AND APPLIED RESEARCH

The Mission and Applied Research project enables involvement by applications-oriented users in the planning and development of Earth Science satellite missions. It enables end-user engagement to identify applications early in and throughout the mission life cycle, and integrates end-user needs in design and development, enabling user feedback and broadening advocacy. Mission and Applied Research organizes community workshops to identify priority needs as well as studies to inform design trade-offs and identify ways to increase the applications value of missions. This project advises flight projects on activities to develop the applications dimension of a mission in development to help broaden benefits and maximize the return from the investment in the mission.

DISASTER SUPPORT

The Disaster Support project enables the development of innovative applications using NASA satellite mission data in concert with novel approaches to understanding disaster exposure and vulnerability. The project sponsors the use and integration of Earth observations in the decisions and actions of disaster-management and disaster financing organizations, including pursuit of feasibility studies and needs assessments, in-depth engagements, and workshops. The project also sponsors a Disaster Response Coordination System that coordinates across NASA centers to improve a preparatory-based approach to enhance value and usability of NASA Earth Science products in support of domestic and international disaster response across a wide range of disaster types including floods, fires, earthquakes, volcanoes, and landslides. Furthermore, this project pursues strategic partnerships with disaster groups that can carry forward NASA-developed information and tools to support the disaster management communities they serve. The project will begin to place greater focus on disaster risk reduction and building resilience to complex and cascading disasters.

APPLICATIONS

The Applications project sponsors the integration of Earth observations in the decisions and actions of community organizations. There are formal applications program elements in Agriculture, Climate and Resilience, Ecological Forecasting, Energy, Health and Air Quality, Water Resources, and Wildland Fires.

APPLIED SCIENCES

The applications program elements support feasibility studies, in-depth activities, applied science teams, consortia, workshops, and needs assessments. Each applications program element participates in major conferences and events that their partners attend to meet and engage managers and users.

- Agriculture: The agriculture applications program element promotes the use of Earth observations for the functioning and resilience of food systems. The area supports multi-organizational consortia to enhance domestic productivity, international food security, and improved agricultural practices, especially for economic progress and humanitarian pursuits.
- Climate: The climate application program element supports uses of Earth science information to inform climate-relevant policy analyses and understanding resilience and climate risks. This area will conduct work through solicitation efforts for applied research and applications development. Additionally, this area will seek to build resilience in the private sector (commercial and non-profit) to climate shocks and stressors.
- Ecological Forecasting: The ecological forecasting applications program element promotes the use of Earth observations and models to analyze and forecast changes that affect ecosystems and to develop effective resource management strategies. Primary user communities are natural resource managers (both land and marine) and those involved in conservation and sustainable ecosystem management.
- Energy: The major component of the energy application program element is the Prediction of Worldwide Energy Resources (POWER) tool. POWER is a web-based platform that provides solar and meteorological data sets to support the renewable energy, building design, and energy efficiency industries.
- Health and Air Quality: The health and air quality application program element promote the use of Earth observations data and models in the implementation of air quality standards, policy, and regulations for economic and human welfare (particularly involving environmental health and infectious diseases). This program element addresses issues of toxic and pathogenic exposure and health-related hazards and their effects for risk characterization and mitigation.
- Water Resources: The water resources applications program element supports the use of Earth observations in water resources management related to water demand, supply, and quality. The program element includes five functional themes: drought, streamflow and flood forecasting, evapotranspiration and irrigation, water quality, and climate effects on water resources.
- Wildland Fires: The Wildland Fires applications program element supports applications across pre-active, and post-fire phases. Initial focus will be on tools, collaborations, and modeling on fuel-load and fire-risk. This program element will pursue joining community consortia for agility in scope and duration of projects. Additionally, Wildland Fires will enable use of NASA Earth science information by users in the wildland fires community. It will work collaboratively with other elements of the NASA Earth Science Division to conduct outreach and site visits, organize and host a series of stakeholder engagement workshops, and create collaborations to: 1) create a shared vision to establish and strengthen the wildfire management system; 2) better understand current science and technological barriers in wildfire risk management; 3) co-develop and build capacity to better utilize wildfire management solutions that leverage the best-available science understanding, technology monitoring and observation, assessment and prediction; and 4) expand applications, including solutions that are proven scalable and sustainable, to the broadest range of wildfire stakeholders, partners and actors.

APPLIED SCIENCES

In addition to these activities, the Applications project supports the following initiatives:

- NASA Harvest Consortium: The program sponsors a multi-organizational consortium to advance the use of Earth observations for enhanced food security and improved agricultural practices. NASA Harvest focuses on Earth science applications and applied research for international activities, such as work performed at the country level outside of the United States, and global agriculture systems that transcend geopolitical boundaries.
- Group on Earth Observations (GEO) Work Programme: Applied Sciences supports specific elements in the GEO Work Programme to further U.S. and NASA interests internationally, leveraging resources of other countries and organizations. This initiative specifically fosters a broader involvement of domestic organizations in a national approach to GEO and the Work Programme, increasing opportunities for these organizations.
- The Valuation of Applications Benefits Linked to Earth Science (VALUABLES): VALUABLES supports the development of analytic techniques to quantify the benefits, in social and economic terms, from uses of Earth observations to improve decisions.
- The Western Water Applications Office (WWAO): WWAO is a targeted initiative to contribute Earth observations to help solve important and pressing water-resource problems faced by the western United States. WWAO involves several NASA centers to engage public and private sector stakeholders in the western water management community for innovative ways to apply Earth observations in managing water supply and accommodating a growing demand.

Program Schedule

Date	Significant Event
Q1 FY 2023	ROSES-2022 selections within six to nine months of receipt of proposals
Q2 FY 2023	ROSES-2023 solicitation release
Q1 FY 2024	ROSES-2023 selections within six to nine months of receipt of proposals
Q2 FY 2024	ROSES-2024 solicitation release
Q1 FY 2025	ROSES-2024 selections within six to nine months of receipt of proposals
Q2 FY 2025	ROSES-2025 solicitation release
Q1 FY 2026	ROSES-2025 selections within six to nine months of receipt of proposals
Q2 FY 2026	ROSES-2026 solicitation release
Q1 FY 2027	ROSES-2027 selections within six to nine months of receipt of proposals
Q2 FY 2027	ROSES-2027 solicitation release
Q1 FY 2028	ROSES-2028 selections within six to nine months of receipt of proposals
Q2 FY 2028	ROSES-2028 solicitation release

APPLIED SCIENCES

Program Management and Commitments

Program Element	Provider
Applications	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC Cost Share Partner(s): U.S. Forest Service, National Park Service (NPS), U.S. Department of Agriculture (USDA), National Oceanic and Atmospheric Administration (NOAA), U.S. Geological Survey (USGS), U.S. Fish and Wildlife Service, Environmental Protection Agency (EPA), Bureau of Land Management, Centers for Disease Control and Prevention
Capacity Building	Provider: Various Lead Center: LaRC, MSFC, GSFC Performing Center(s): ARC, GSFC, JPL, MSFC, LaRC Cost Share Partner(s): USGS, Groundwork USA, USDA, University of Georgia, NOAA, Idaho State University, Boston University, USAID, EPS, NOAA, NWS
Disaster Support	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC Cost Share Partner(s): Department of Homeland Security (DHS), NOAA, USDA, USGS, USAID, USACE, National Guard
Mission and Applied Research	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC Cost Share Partner(s): USDA, CNES, ISRO, Joint Research Centre (JRC), European Space Agency

Acquisition Strategy

NASA bases the Earth Science Applied Science acquisitions on full and open competition. Grants are peer reviewed and selected based on NASA research announcements and other related announcements.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Relevance	Applied Sciences Advisory Committee	Dec 2021	Review strategy and implementation	Provided recommendations regarding opportunities for beneficial engagement with other ESD programs	June 2023

PLANETARY SCIENCE

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Planetary Science Research	309.0	--	**307.4**	333.3	352.0	360.2	386.4
Planetary Defense	166.0	137.8	**250.7**	337.7	400.5	299.6	79.0
Lunar Discovery and Exploration	478.8	--	**458.5**	459.0	460.5	472.0	483.3
Discovery	331.8	--	**247.5**	386.4	426.0	579.2	625.9
New Frontiers	283.7	--	**407.5**	447.8	386.1	367.3	337.5
Mars Exploration	265.0	--	**268.6**	279.2	311.6	315.3	367.2
Mars Sample Return	653.2	822.3	**949.3**	700.0	600.0	612.1	627.6
Outer Planets and Ocean Worlds	484.3	--	**318.4**	121.3	134.8	178.3	321.9
Radioisotope Power	148.6	--	**175.5**	201.1	174.6	166.8	160.9
Total Budget	**3,120.4**	**3,200.0**	**3,383.2**	**3,265.8**	**3,246.1**	**3,350.8**	**3,389.7**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Planetary Science

PLANETARY SCIENCE

PLANETARY SCIENCE RESEARCH

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Planetary Science Research and Analysis	221.3	--	**224.6**	249.3	261.5	267.4	290.3
Other Missions and Data Analysis	87.8	--	**82.8**	84.0	90.5	92.8	96.2
Total Budget	**309.0**	**--**	**307.4**	**333.3**	**352.0**	**360.2**	**386.4**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The Planetary Science Research Program provides the scientific foundation for data returned from NASA missions exploring the solar system. It is also NASA's primary interface with university faculty and graduate students in this field and with the research community in general. The program develops analytical and theoretical tools, as well as laboratory data, to support analyses of flight mission data. These capabilities allow Planetary Science to answer specific questions about, and increase the understanding of, the origin and evolution of the solar system. The research program achieves this by supporting research grants solicited annually and subjected to a competitive peer review before selection and award. The Planetary Science Research Program focuses on five key research goals:

Researchers discovered possible wave ripples preserved in rocks, shown here, imaged by the Curiosity rover indicating that there may have been times when an ancient lake within Gale crater was not covered by ice.

- Advance the understanding of how the chemical and physical processes in our solar system operate, interact, and evolve;
- Explore and observe the objects in the solar system to understand how they formed and evolve;
- Explore and find locations where life could have existed or could exist today;
- Improve our understanding of the origin and evolution of life on Earth to guide our search for life elsewhere; and
- Identify and characterize objects in the solar system that pose threats to Earth or offer resources for human exploration.

EXPLANATION OF MAJOR CHANGES IN FY 2024

This budget increases the Planetary Research and Analysis (R&A) project budget through the budget window. This increase responds to the Planetary Science & Astrobiology Decadal Survey's recommendation that the research budget increase to 10 percent of the total Planetary Science budget. The percentage is at just over 7.5 percent in FY 2024 and just under 10 percent by FY 2028. The budget also includes an increase in Planetary Data System (PDS) to improve accessibility and usability of those systems.

PLANETARY SCIENCE RESEARCH

ACHIEVEMENTS IN FY 2022

During FY 2022, the Research and Analysis (R&A) portfolio funded over 250 new research grants across the United States, with approximately 1,600 active grants total. Core elements of the R&A Program, such as Solar System Workings, Emerging Worlds, Habitable Worlds (HW), Exobiology, and Yearly Opportunities in Research for Planetary Defense directly address the five key research goals listed above.

A major new element within the R&A portfolio in FY 2022 was the Planetary Science Enabling Facilities (PSEF). This program element started in response to a study carried out by the National Academies (Strategic Investments in Instrumentation and Facilities for Extraterrestrial Sample Curation and Analysis, 2019), and includes provisions for broad community access to such facilities and an emphasis on collaboration with and involvement of diverse groups of researchers. The team selected a total of 10 facilities for funding such as the Reflectance Experiment Laboratory at Brown University in Providence RI; the KiloElectron-Volt Irradiation Facility for Space Science at the University of Virginia in Charlottesville, VA; the Facility for Astromaterials Research at NASA Johnson Space Center in Houston, TX; and the Planetary Aeolian Laboratory at NASA Ames Research Center in Mountain View, CA.

Volatiles in the Moon's permanently shaded regions provide a record of the history of volatiles in the Earth-Moon system. The Lunar Crater Observation and Sensing Satellite (LCROSS) impact plume contained water and carbon, nitrogen, and sulfur-bearing molecules, but connecting them to sources is challenging. In this R&A study, scientists determined the mixture of sources by using elemental ratios and approximating how processes fractionate these ratios. This model rules out any contribution of volcanic gas to the volatiles sampled, suggesting that any volcanic volatiles present in permanently shaded regions must be buried deeper. Based on these results, this study concluded that the source of these volatiles was cometary, suggesting comets were the dominant impactors which will have important implications for future exploration.

Organic molecules are essential to all life as we know it. Clay minerals are known on Earth for their high organic preservation potential and can be key indicators of past habitable environments. Using Mars Science Laboratory mission data, researchers identified the Martian Glen Torridon region in Gale crater as an area abundant in clay minerals. To evaluate the organic preservation potential of this region, the team used the Sample Analysis at Mars (SAM) instrument onboard the Curiosity rover to collect and characterize seven rock samples. The SAM investigation indicated the presence of various organic compounds, including the first observation on Mars of sulfur-containing and ring-structured organics and the highest abundance of sulfur organics observed to date. This investigation revealed that while some of the sulfur-bearing organics are likely Martian, a portion may also be related to the presence of chemical reagents carried in SAM, making attribution to a definitive source challenging. Nevertheless, these new SAM results confirm that ancient organic matter is preserved in the clay mineral bearing sediments of Glen Torridon. Its origin—either meteoritic, abiotic (not derived from living organisms), or biotic—has yet to be established.

Large potentially hazardous asteroids can cause a global catastrophe in the event of a planetary collision. Thus, rapid assessment of such an object's physical characteristics is crucial for determining its potential risk scale. In a 2020 to 2021 study, NASA conducted a mock planetary defense exercise and treated the near-Earth asteroid 99942, Apophis, as a newly discovered object during its close approach. The Near-Earth Object Wide-field Infrared Survey Explorer (NEOWISE) detected the object. Researchers analyzed the data collected by the two active bands (3.4 and 4.6 micrometer) using thermal and thermophysical modeling. The results provide insight into the geometry of the object and allowed a more

PLANETARY SCIENCE RESEARCH

accurate assessment of the potential hazard of the asteroid. This will help improve the assessment of the risk posed by future potentially hazardous asteroids.

Planetary R&A also supports the Planetary Science & Astrobiology Decadal Survey. The National Academies published the final report (Origins, Worlds, and Life, A Decadal Strategy for Planetary Science and Astrobiology 2023-2032, [OWL]) in April 2022, and the Planetary Science Division provided an initial response to the National Academies in August 2022.

WORK IN PROGRESS IN FY 2023

FY 2023 plans in the core elements of the R&A Program are found below. These core elements support competed grants to address the five major research goals of the Planetary Science Division. The data analysis program elements will continue ensuring excellent scientific return from NASA's investments in missions. Participating scientist activities will continue, including an investment in the Martian Moons eXploration (MMX) mission, a Japanese mission to survey the moons of Mars (Deimos and Phobos) on which NASA is collaborating. The R&A project will continue investing in technology development for future mission capabilities.

FY 2023 core elements plans include:

- The Solar System Workings element expects to fund approximately 40 new research activities including atmospheric, climatological, dynamical, geologic, geophysical, and geochemical processes of the various bodies in the solar system using techniques ranging from laboratory experiments to analysis of observational data to theoretical modeling;
- The Emerging Worlds element, focused on the formation of the solar system, expects to fund approximately 30 new research awards that may address individual topics ranging from the earliest stages of solar system formation to the final events that led to the solar system as we know it today;
- The Habitable Worlds element expects to fund approximately 10 new research awards focusing on topics relating to the presence of water and/or exotic solvents, sources of energy for life, the presence of organics and their reactivity, and water body physics and chemistry as they pertain to habitability and habitability over time, as well as space weather signatures that may be indicative of impacts to planetary habitability;
- The Exobiology element will support research into the potential for life beyond Earth and expects to fund approximately 25 new investigations in five major sub-themes: Prebiotic Chemistry, Early Evolution of Life and the Biosphere, Evolution of Advanced Life, Large Scale Environmental Change and Macro-Evolution, and Biosignatures and Life Elsewhere; and
- The Near-Earth Object Observations element supports research investigations that address this theme through the Yearly Opportunities in Research for Planetary Defense solicitation. NASA expects approximately 10 new selections, including both large-scale observing programs designed for the detection and tracking of near-Earth objects, and smaller research programs aimed at characterizing the physical properties of such bodies.

FY 2023 will also see new community-accessible facilities funded through the PSEF Program element. As these newly-funded facilities become operational, they will be a boon for the scientific community, increasing access to unique scientific capabilities. This will be particularly valuable for scientific studies

PLANETARY SCIENCE RESEARCH

of extraterrestrial samples, such as those returned by Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer (OSIRIS-REx) in FY 2023.

Discussions regarding the recent Decadal Survey will continue in FY 2023. As part of these discussions, the R&A Program will evaluate how the current program reflects the scientific priorities identified by the Decadal Survey. The Advanced Multi-Mission Operations System (AMMOS) command encryption, developed recently for cis lunar spacecraft, will expand its capability towards eventual use for other deep space missions. This capability is available for all NASA missions and will be the standard for all Jet Propulsion Laboratory (JPL) SMD missions requiring command encryption in the future. It was developed as a collaboration with the Katherine Johnson Independent Verification and Validation facility in West Virginia. In addition, the AMMOS team will begin a collaboration with the Carnegie Mellon Software Engineering Institute to develop a framework which will be employed on all current and future open-source offerings.

In FY 2023, Planetary Data System (PDS) will participate in the Year of Open Science, including the Alpha and Beta releases of the centralized PDS web presence, designed to improve usability and accessibility of the PDS.

In the Astromaterial Curation project, final preparation for return of OSIRIS-REx asteroid samples will culminate in FY 2023 in preparation for the spacecraft return to Earth on September 24, 2023. With International Standards Organization 5 (ISO5) sample cleanroom construction and certification complete and lab outfitting initiated, operational activities will include sample recovery planning and rehearsals at the Utah Test and Training Range. The project will continue to conduct rehearsals for sample receiving and conduct the Touch and Go Sample Acquisition Mechanism head disassembly. NASA will conduct an operational readiness review for the sample curation lab once final outfitting of the cleanrooms is complete. The Astromaterial Curation team will continue to optimize future science by ensuring proper preparation and sample handling for the Mars Sample Return (MSR) and Artemis missions. Furthermore, rehearsals and various curation activities in support of OSIRIS-REx sample return will continue in FY 2023.

In FY 2023 the Robotics Alliance Project will continue efforts to increase interest in engineering, technology, science, and mathematics disciplines among youth in the United States to create an inspired, experienced, technical workforce for the aerospace community. Robotics Alliance will focus on exposing students to challenging applications of engineering and science, including supporting national robotic competitions in which high school students' team with engineering and technical professionals from Government, industry, and universities to gain hands-on experience and mentoring. The project will expand to include competitions focusing on Unmanned Aerial Vehicles, embedding robotics efforts with younger students, and implementing a robotics intern project with underserved communities.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

In pursuit of fundamental science that guides planetary exploration, the Planetary Science Research Program will continue to select highly rated R&A proposals that support planetary missions and goals. As described above, the individual program elements within the R&A portfolio directly address the major scientific themes identified for Planetary Science and these program elements will continue in the coming year. Planetary science will also continue archiving and distributing relevant mission data to the science community and the public in a timely manner.

PLANETARY SCIENCE RESEARCH

In FY 2024, the R&A Program will also continue evaluation of the individual program elements to ensure alignment with the priorities identified by the next Decadal Survey.

The AMMOS Ground Data System in the Cloud, developed initially for SmallSats and deployed on the Amazon Web Services Cloud, will scale up its capability to more complex missions.

In addition to creating a centralized web presence for the PDS, the team will implement a cloud migration strategy to bring the archive into a more modern type of data sharing. The PDS has nearly completed conversion to a more complete data standard (e.g., PDS4) and expects 90 percent completion by FY 2025. The completion of migrating legacy datasets into this updated standard should improve usability and accessibility of the archive for all users

Astromaterial Curation is set to receive the OSIRIS-REx samples in September 2024 and will focus a large portion of their efforts on preliminary examination and characterization of these samples and developing the catalogue to make these samples publicly available to the larger scientific community in FY 2024. Furthermore, the Curation project will continue to work with Columbia University to ensure data from the OSIRIS-REx mission as well as analysis of various astromaterials is included in the Astromaterials database, Astromat, to be publicly accessible and searchable., The Curation project will continue to support future MSR, MMX, and Artemis efforts while maintaining the integrity and availability of their current collections.

In the Robotics Alliance project, NASA organizers will increase participation of students from underserved and underrepresented communities in challenging applications of engineering and science, including national robotic competitions.

Program Elements

PLANETARY SCIENCE RESEARCH AND ANALYSIS (R&A)

Planetary Science R&A enhances the scientific return from on-going and completed spaceflight missions and provides the foundation for the formulation of new scientific questions and strategies for answering those questions. R&A develops new theories and instrumentation concepts that enable the next generation of spaceflight missions. R&A funds research tasks in areas such as astrobiology and cosmochemistry; the origins and evolution of planetary systems; the observation and characterization of extra-solar planets (i.e., exoplanets); and the atmospheres, geology, and chemistry of the solar system's bodies other than the Earth or the Sun.

Program Schedule

The Planetary Science Research Program solicits proposals as part of the Science Mission Directorate's annual Research Opportunities in Space and Earth Sciences (ROSES) research calls. The program issues solicitations every year. A Senior Review process assesses all missions in the extended operations phase every three years and all data archives every five years.

PLANETARY SCIENCE RESEARCH

Date	Significant Event
Q1 FY 2023	ROSES-2022 selection within six to nine months of receipt of proposals
Feb 2023	ROSES-2023 NRA solicitation release
Q1 FY 2024	ROSES-2023 NRA selection within six to nine months of receipt of proposals
Feb 2024	ROSES-2024 NRA solicitation release
Q1 FY 2025	ROSES 2024 NRA selection within six to nine months of receipt of proposals
Feb 2025	ROSES-2025 NRA solicitation release
Mar-Apr 2025	Senior Review Operating Missions
Q1 FY 2026	ROSES-2025 NRA selection within six to nine months of receipt of proposals
Q4 FY 2026	Senior Review Data Archives Discipline Nodes
Q3 FY 2027	Senior Review Data Archives Support Nodes

Program Management & Commitments

Program Element	Provider
R&A	Provider: NASA Lead Center: Headquarters Performing Center(s): Ames Research Center, Glenn Research Center, Goddard Space Flight Center, Jet Propulsion Laboratory, Johnson Space Center, Langley Research Center, Marshall Space Flight Center Cost Share Partner(s): N/A

Acquisition Strategy

The R&A budget will fund competitively selected activities from the ROSES omnibus research announcement.

PLANETARY SCIENCE RESEARCH

INDEPENDENT REVIEWS

The Advanced Multi-Mission Operations System (AMMOS) will have two independent reviews in 2024 of their multi-mission strategy. These reviews verify long-term value to planetary missions and spin-off value to other space domain users.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Planetary Science Advisory Committee (PAC)	2022	Annual review to assess progress against Planetary Science performance goals and overarching strategic objective.	TBD	2023

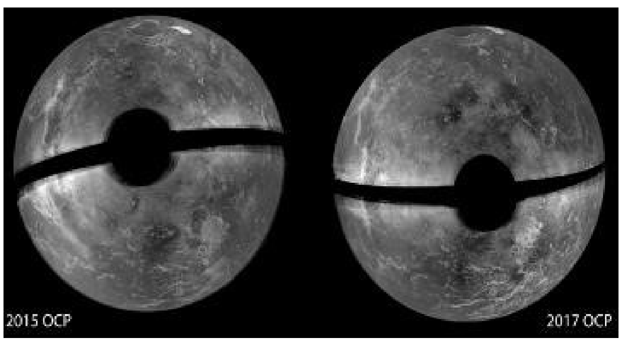
OTHER MISSIONS AND DATA ANALYSIS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Advanced Multi-Mission Operation System	40.5	--	**38.0**	38.0	38.0	37.7	38.2
Planetary Data System	27.3	--	**28.4**	28.6	33.5	35.7	38.6
Astromaterial Curation	16.0	--	**12.4**	12.4	14.0	14.4	14.2
Robotics Alliance	4.0	--	**4.0**	5.0	5.0	5.0	5.1
Total Budget	**87.8**	**--**	**82.8**	**84.0**	**90.5**	**92.8**	**96.2**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



Arecibo telescope images of Opposite-sense Circular maps of Venus from 2015 and 2017, shown here, are now archived in the Planetary Data System (PDS). The dark horizontal band is due to limits placed on echoes within 450 km of the Doppler equator.

Other Missions and Data Analysis includes activities and infrastructure that support NASA Planetary Science Research and missions, such as the Advanced Multi-Mission Operation System, Planetary Data System, and Astromaterial Curation.

Mission Planning and Other Projects

ADVANCED MULTI-MISSION OPERATION SYSTEM (AMMOS)

Advanced Multi-Mission Operation Systems (AMMOS) is a system of reusable software tools and services comprising a mission ground operations and ground data system used across multiple NASA missions. AMMOS provides multi-mission operations, navigation, design, and training tools and services for Planetary Science flight missions, as well as other Science Mission Directorate missions, and invests in improved communications and navigation technologies. The AMMOS project will continue to provide and develop multi-mission software tools for spacecraft navigation, command, control, assessment, mission planning, and data archiving. Utilizing the AMMOS common tools and services lowers individual mission costs and risks by providing a mature base for mission operations systems at significantly reduced development times. AMMOS also provides support to our international space agency partners on an as-needed basis. This support typically pertains to navigation assistance and scheduling of NASA’s Deep Space Network (DSN) assets.

AMMOS currently provides multi-mission operations tools and services to 88 missions, and includes support to Planetary Science, Heliophysics, Earth Science, and Astrophysics missions within NASA and critical operations services to 14 international missions. AMMOS continues to provide critical NASA support to international missions from the Canadian Space Agency (CNES), the German Aerospace

OTHER MISSIONS AND DATA ANALYSIS

Center (DLR), the European Space Agency (ESA), the Indian Space Research Organization (ISRO), the Japan Aerospace Exploration Agency (JAXA), the Korea Aerospace Research Institute (KARI), and United Arab Emirates Space Agency.

Operating missions enabled by AMMOS include the Mars 2020 Perseverance rover, Parker Solar Probe, Chandrayaan-2, InSight, Origins Spectral Interpretation Resource Identification and Security-Regolith Explorer (OSIRIS-REx), Mars Atmosphere and Volatile EvolutioN (MAVEN), Chandra X-ray Observatory, Lucy, the Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment, and the Korean Pathfinder Lunar Orbiter, among many others. Missions currently in development, enabled by AMMOS, include Europa Clipper, Volatiles Investigating Polar Exploration Rover, Janus, Psyche, Lunar Trailblazer, NASA CubeSats Near-Earth Asteroid (NEA) Scout and Lunar Flashlight, and nanosatellites Lunar IceCube and ArgoMoon, among others.

Recent Achievements

AMMOS utilized the CryptoLib software library developed by NASA IV&V to develop and deliver command encryption for all SMD missions. The AMMOS and IV&V teams both contributed to CryptoLib as part of implementing command encryption. AMMOS is reaching out and utilizing existing NASA investments and improving upon them with the help of other NASA centers to meet their combined needs. The Sun Radio Interferometer Space Experiment (SunRISE) mission, Lunar Trailblazer and Goddard Space Flight Center's (GSFC’s) Virtual Multi-Mission Operations Center have most recently adopted command encryption.

The Multimission Resource Scheduling Service (MRSS) team successfully negotiated their most complex mission yet, Artemis I, during its recent launch attempts. MRSS completed five contingency schedules, each of them four weeks in duration, totaling 20 weeks of contingency schedules the team negotiated at once with approximately 60 DSN users. The nominal per launch is one contingency schedule, six-weeks in duration across the mission. MRSS continues these complex negotiations for the updated Artemis I launch.

The AMMOS team demonstrated the ability to process, in real-time, spacecraft telemetry in the cloud (from the CubeSat Lunar IceCube) while leveraging ground data system capabilities provided by AMMOS. This successful demonstration is a major milestone enabling Delay Tolerant Networking demand access operations in space and allowing spacecraft to request support from the ground when needed, rather than at pre-scheduled times. Demand access is being prototyped by JPL’s Interplanetary Network Directorate and AMMOS to support Deep Space Exploration using constellations and fleets of spacecraft/smallsats.

The AMMOS Multi-Mission Geographic Information System (MMGIS) product is a web-based mapping and spatial database product that supports two-dimensional and three-dimensional interaction on planetary bodies. There was a significant increase in flight projects' mission operations and science teams adopting and using the database in FY 2022. MMGIS provides an easy-to-use user interface to enable mission operations and science team members to view contextual and interactive maps to make strategic decisions. The project largely fueled the growth through making MMGIS available as an open-source software product and incorporating mission-developed features into the core software suite. The project leveraged MMGIS to support public engagement for the Mars Program because it is easy to use and creates an interactive Martian surface experience. The ease of adoption is evident through the diversity of missions selecting and using MMGIS, including Mars Science Lab, Mars Rover 2020, the lunar Volatiles Investigating Polar Exploration Rover mission, ESA’s Rosalind Franklin Rover (ExoMars) mission, and the Earth Surface Mineral Dust Source Investigation (EMIT) mission.

OTHER MISSIONS AND DATA ANALYSIS

PLANETARY DATA SYSTEM (PDS)

The PDS is an online data archive that furthers NASA's Planetary Science goals by efficiently collecting, archiving, and making accessible digital data produced by, or relevant to, NASA's planetary missions, research programs, and data analysis. This curated archive includes raw and fully calibrated orbital and surface observations from hundreds of NASA missions and instruments exploring the solar system planets, asteroids, and small bodies. The PDS archives now span more than 50 years of NASA-funded research. PDS holdings are expanding to include ground-based observations of Near-Earth objects (NEOs). The PDS archives are publicly available through the PDS website. NASA is incorporating new PDS enhancements including a plan for unifying the PDS website, which is intended to make data easier to find and access, adopting a cloud computing strategy that will increase access to super-computing time and continuing to create training modules for finding and using PDS data.

Recent Achievements

The PDS received and released data from 20 active planetary missions since October 2021 and continues to release enhanced legacy data. The PDS website has served over 1.5 million unique visitors, domestic and international, who downloaded nearly 150,000 files and over 2,500 tools. The PDS currently contains approximately two petabytes of data from over 70 missions and works with a variety of data providers, including NASA mission teams and Commercial Lunar Payload Service (CLPS) payload providers. The PDS recently completed a programmatic review of the Support Nodes, which resulted in contract renewals. Some added objectives include creating a unified web presence to enhance user experience; and plans for cloud computing and migration of specific datasets to the cloud storage.

The PDS also continued to support data providers from over 300 NASA research program investigations, including archive support for data from ground-based observations, laboratory analyses, field observations, the production of other higher order data sets, and the restoration of old datasets. Migration of data from PDS3 to PDS4 standards continued, laying the cornerstone for the future user's enhanced and modern interaction with the PDS. As a result of these activities, the PDS archive grew in volume by approximately 300 terabytes to total approximately 2.3 petabytes.

ASTROMATERIAL CURATION

The Astromaterials Acquisition and Curation Office at Johnson Space Center (JSC) curates extraterrestrial material under NASA control. Curation is an integral part of sample return missions. Activities conducted by the Curation office include: (1) research into advanced curation techniques to support future missions; (2) sample return mission planning; (3) archiving of witness, engineering, and reference materials related to sample return missions; (4) recovery and transport of returned materials; (5) initial characterization of new samples; (6) preparation and allocation of samples for research; and (7) providing clean and secure storage for the benefit of current and future generations.

Materials currently curated include: Antarctic meteorites; cosmic dust; samples collected from the Moon; samples of the solar wind; samples from comet 81P/Wild; dust collected in interstellar space; particles from asteroid Itokawa; material from asteroid Ryugu; cosmic dust collected in Earth's stratosphere; microparticle-impacted flight hardware; witness materials (small foils and plates placed in spacecraft assembly cleanrooms to collect molecules and particles); and coupons (representative pieces of materials used in construction of spacecraft). Curated materials come from several past, present, and future sample-return missions, including Apollo, Long Duration Exposure Facility, Genesis, Stardust, OSIRIS-REx, and Mars Rover 2020. Planning and research efforts are currently underway to develop the

OTHER MISSIONS AND DATA ANALYSIS

technologies and procedures for proper curation of samples from current and future missions to the Moon, such as Artemis; asteroids, such as OSIRIS-REx; Mars, such as the Mars Sample Return (MSR) campaign; and Mars' moon, Phobos, such as Martian Moons eXploration (MMX). NASA plans to receive MMX samples under international agreements with JAXA. New laboratory space still needs to be outfitted, but construction is complete and preparation to receive the OSIRIS-REx samples, as well as conducting advanced cleaning and curation research, is underway.

Recent Achievements

The project maintains nine existing collections of astromaterials in pristine condition for scientific research within 23 cleanrooms at JSC and White Sands Test Facility. In 2022, the team announced the availability of 147 newly classified Antarctic Meteorites, an extracted gas sample from Apollo sample 73001, several new Cosmic Dust samples, and NASA's portion of the Hayabusa2 samples in two issues of the Astromaterials Newsletter.

Construction for new cleanrooms for the MMX mission, MSR sample contamination hardware, and cold sample processing is underway as part of the B31 Annex design and build at JSC. The Curation project conducted numerous laboratory readiness reviews in FY 2022 to ensure labs are safe and technically ready to receive samples. Outfitting the newly renovated labs was also a major focus. The team certified the new Hayabusa2 cleanroom at the end of FY 2021 and outfitted the lab in FY 2022 to curate approximately 0.5 grams of asteroid Ryugu regolith materials that JAXA transferred to NASA in late November 2021. The Curation project also received and commissioned a new benchtop X-Ray Fluorescence instrument for use in sample preliminary examination and characterization. In combination with the scanning laser Raman microscope and X-Ray Computed Tomography instrument, the project made unprecedented steps forward in their ability to conduct non-destructive characterization of astromaterials, which is crucial in building high quality sample catalogs for NASA's astromaterials collections. Furthermore, the Curation team conducted and participated in many rehearsals in FY 2022 to prepare for the OSIRIS-REx sample delivery in September 2024, and they will participate in more rehearsals and activities in FY 2023.

The Curation project continues to optimize future science by ensuring proper sample handling for the MSR and Artemis missions. These projects added curation experts to their internal teams. Curation is also leading a set of facility design studies for the sample return facility that will receive MSR samples. The Curation project provided their expertise and support to JAXA's MMX mission, which will launch in 2024. Specifically, the team cleaned some of the critical hardware components of the Pneumatic Sampler instrument that will fly on the JAXA spacecraft.

Finally, the Curation project is working directly with Columbia University to develop methods for archiving the data produced through the analysis of astromaterials by missions and other researchers so the data can be publicly accessible and searchable. The goal is to link the astromaterials database to curation catalogs and databases in support of open science initiatives.

ROBOTICS ALLIANCE PROJECT

The Robotics Alliance Project (RAP) increases interest in engineering, technology, science, and mathematics disciplines among youth in the United States to create an inspired, experienced, and technical workforce for the aerospace community. Annual activities and events expose students to challenging applications of engineering and science, including national robotic competitions in which

OTHER MISSIONS AND DATA ANALYSIS

high school students' team with engineering and technical professionals from Government, industry, and universities to gain hands-on experience and mentoring.

Recent Achievements

In FY 2022, the Robotics Alliance project sponsored approximately 308 U.S.-based teams (approximately 11,000 students) in the For the Inspiration and Recognition of Science and Technology (FIRST) Robotics Competition; 50 VEX Robotics Competition teams (approximately 500 students); and sponsored and/or supported 21 FIRST Robotics Competition events (affecting approximately 55,000 students). As the partner programs recovered from all-remote operations due to the COVID-19 pandemic, and resumed in-person competition events, the NASA support for these programs re-focused on more intensive support for a deliberately selected set of teams. In the upcoming year the RAP will add competition programs focusing on Unmanned Aerial Vehicles, embedding robotics efforts with younger students, and implementing a robotics intern project with underserved communities.

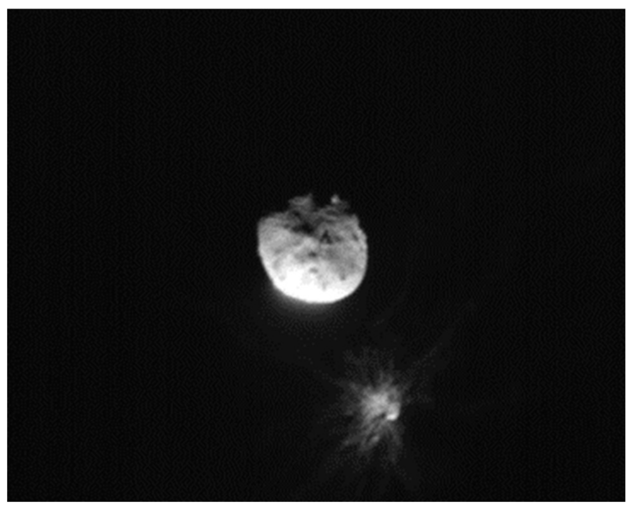
PLANETARY DEFENSE

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
NEO Surveyor	110.0	90.0	**209.7**	296.7	358.5	257.6	39.0
Other Missions and Data Analysis	56.0	--	**41.0**	41.0	42.0	42.0	40.0
Total Budget	**166.0**	**137.8**	**250.7**	**337.7**	**400.5**	**299.6**	**79.0**
Change from FY 2023 Enacted			**112.9**				
Percent change from FY 2023 Enacted			**81.9%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



The DART ride-along LICIACube spacecraft, contributed to the mission by the Italian Space Agency, captured the image shown here just before its approach to the Didymos asteroid and just after DART intentionally impacted the moonlet Dimorphos on September 26, 2022. Didymos (center), Dimorphos (lower right), and the ejecta plume coming off of Dimorphos after DART impact are clearly visible.

NASA's Planetary Defense Program focuses on projects that detect and provide follow-up observations for precision orbit determination and physical characterization of asteroids and comets with the potential to impact Earth, and test technologies and techniques that may protect Earth.

Planetary defense involves:

- Finding and tracking near-Earth objects (NEOs) that pose a hazard of impacting Earth;
- Ensuring the early detection of potentially hazardous objects (PHOs), asteroids, and comets, whose orbit are predicted to bring them within about five million miles of Earth's orbit; and of a size large enough to reach Earth's surface, with a focus on objects 140 meters or greater in size that can cause significant damage at regional scales;
- Characterizing those objects to determine their orbit trajectory, size, shape, mass, composition, rotation dynamics, and other parameters so experts can determine the severity of the potential impact event, warn of its timing and potential effects, and determine the means to mitigate the impact; and
- Planning and testing of measures to deflect or disrupt an object that’s on an impact course with Earth, or to mitigate the effects of an impact that cannot be prevented.

The Planetary Defense Coordination Office (PDCO) manages the Planetary Defense Program. PDCO administers the Near-Earth Object Observations (NEOO) project, which funds, and coordinates

PLANETARY DEFENSE

efforts to find, track, and characterize any asteroid or comet that could become an impact hazard to Earth. Scientists conduct these NEO observation efforts at observatories supported by NASA on the ground and in space, as well as with partnerships for data from assets of the National Science Foundation and space situational awareness facilities of the United States Space Force.

In addition to finding, tracking, and characterizing NEOs, NASA also researches techniques for deflecting or disrupting, if possible, PHOs that are determined to be on an impact course with Earth to provide options for Government response to any detected impact threat. If deflection or disruption of the PHO is not possible due to insufficient time available before impact, the PDCO is responsible for providing expert input to other Government agencies, such as the Federal Emergency Management Agency, for emergency response operations. The PDCO participates in implementing the United States National Near-Earth Object Strategy and Action Plan.

EXPLANATION OF MAJOR CHANGES IN FY 2024

The budget proposes an updated profile for the NEO Surveyor mission to support a June 2028 launch readiness date, consistent with the budget approved at the mission confirmation review in November 2022.

NEAR EARTH OBJECTS SURVEYOR

Formulation	Development	Operations

FY 2024 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028	BTC	Total
Formulation	73.6	91.4	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	165.0
Development/Implementation	0.0	18.6	90.0	**209.7**	296.7	385.5	255.1	0.0	0.0	1,255.6
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	2.5	39.0	160.0	201.5
2023 MPAR LCC Estimate	**73.6**	**110.0**	**90.0**	**209.7**	**296.7**	**385.5**	**257.6**	**39.0**	**160.0**	**1,622.1**
Total Budget	**73.6**	**110.0**	**90.0**	**209.7**	**296.7**	**358.5**	**257.6**	**39.0**	**160.0**	**1,595.1**
Change from FY 2023 Enacted				**119.7**						
Percent change from FY 2023 Enacted				**133.0%**						

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The NEO Surveyor spacecraft, shown above, will detect, track, and characterize asteroids and comets moving across the sky against the stationary stars in the background.

PROJECT PURPOSE

The Near-Earth Object Surveyor (NEO Surveyor) addresses NASA's objective to find, track, and characterize the asteroids and comets that could potentially impact Earth and cause significant damage. NEO Surveyor consists of ground and space-based segments that constitute a system searching the sky for significant potential impact hazards. The segments include continued flight operations of the Near-Earth Object Wide-Field Infrared Survey Explorer (NEOWISE) until NASA ends the mission, the NEO Surveyor flight project, and the associated ground node data processing and analysis.

The NEO Surveyor will make significant progress toward the objective given to NASA in Public Law 109-155 Sec. 321, the George E. Brown, Jr. Near-Earth Object Survey Act, which requires detecting, tracking, cataloging at least 90 percent of NEOs equal to or larger than 140 meters in size, and characterizing a representative subset.

The mission is responsive to the findings and recommendations for planetary defense by: the National Academy of Sciences report, Defending Planet Earth: Near-Earth Object Surveys & Hazard Mitigation Strategies (2010); the objectives of the National Near-Earth Object Preparedness Strategy and Action Plan (2018); the National Academies of Sciences, Engineering, and Medicine study on Finding Hazardous Asteroids Using Infrared and Visible Wavelength Telescopes (2019); and the Academies' most recent Planetary Science and Astrobiology Decadal Survey 2023-2032 (2022).

NEAR EARTH OBJECTS SURVEYOR

Formulation	Development	Operations

NEO Surveyor will find potentially hazardous objects because of its optimized sensitivity and observation cadence. The mission's primary goals are to: (1) identify impact hazards to the Earth posed by NEOs by performing a comprehensive survey of the NEO population; (2) obtain detailed physical characterization data for individual objects that are likely to pose an impact hazard; and (3) advance the understanding of potential impact energies of potentially hazardous NEOs through characterizing physical properties, including object size, to inform potential mitigation strategies.

EXPLANATION OF MAJOR CHANGES IN FY 2024

The budget proposes an updated profile for the NEO Surveyor mission to support a June 2028 launch readiness date, consistent with the budget approved at the mission confirmation review in November 2022.

PROJECT PARAMETERS

NEO Surveyor consists of a single scientific instrument: a 50-centimeter (nearly 20 inch) diameter telescope that operates in two heat-sensing infrared wavelengths. It will be capable of detecting bright asteroids and dark asteroids - the most difficult type to find.

The NEO Surveyor Observatory will travel in a large-amplitude halo orbit around Sun-Earth Lagrange point 1 (L1). The L1 orbit has the advantages of a flexible launch date and a stable, cold thermal environment that supports passive cooling, and enables high data rates needed to downlink full-frame images for asteroid detection and recovery using ground processing and analysis.

After launch, NEO Surveyor will carry out a five-year baseline survey to find at least two-thirds of the undetected NEOs larger than 140 meters (460 feet). These are the potentially hazardous objects large enough to cause major regional damage in the event of an Earth impact. By using two heat-sensitive infrared imaging channels, NEO Surveyor can make accurate measurements of NEO position and sizes to gain valuable information about their composition, shapes, rotational states, and orbits.

ACHIEVEMENTS IN FY 2022

The project completed the spacecraft and instrument preliminary design phase with a successful Preliminary Design Review in September 2022.

WORK IN PROGRESS IN FY 2023

NEO Surveyor conducted its Key Decision Point C review on November 29, 2022. NASA confirmed the project to begin the development phase. The project will begin detailed design; procurement of key items, including instrument and test equipment; and instrument fabrication through the rest of FY 2023.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

The project will procure spacecraft components and begin integration of the infrared instrument and telescope components.

NEAR EARTH OBJECTS SURVEYOR

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2024 PB Request
KDP-C	Nov 2022	Nov 2022
CDR	Feb 2025	Feb 2025
KDP-D	Aug 2026	Aug 2026
LRD	Jun 2028	Jun 2028
EOM	Sep 2033	Sep 2033

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2023	1,228.6	86	2023	1,228.6	0	LRD	Jun 2028	Jun 2028	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

NEAR EARTH OBJECTS SURVEYOR

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**1,228.6**	**1,228.6**	**0.0**
Aircraft/Spacecraft	338.0	338.0	0.0
Payloads	221.7	221.7	0.0
Systems I&T	4.1	4.1	0.0
Launch Vehicle	134.0	134.0	0.0
Ground Systems	25.2	25.2	0.0
Science/Technology	71.7	71.7	0.0
Other Direct Project Costs	433.9	433.9	0.0

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
NEO Surveyor Director and Investigation Team	NEO Surveyor science and operations leadership	Provider: University of Arizona Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Flight System Management	Project management, systems engineering, safety and mission assurance, and system integration	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
NEO Surveyor Spacecraft	Spacecraft bus with all flight subsystem capabilities	Provider: Ball Aerospace, Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Telescope	50 centimeter aperture telescope (waveguide and reflectors)	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A

NEAR EARTH OBJECTS SURVEYOR

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Camera Assembly Enclosure	Houses the Sensor Chip Assemblies (SCA), Sensor Chip Electronics (SCE), and focal plane modules	Provider: Space Dynamics Laboratory Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Sensor Chip Assemblies (SCA) and Sensor Chip Electronics (SCE)	Digital image sensor and electronics. Two 16 megapixel mercury cadmium telluride focal plane modules	Provider: Teledyne Scientific & Imaging Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Mission Operations	NEO Surveyor Spacecraft operations at existing facility with DSN connectivity and existing cybersecurity authorization capability	Provider: Laboratory for Atmospheric Physics (LASP), UC Boulder Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	Yes, trade study performed and LASP selected
NEOS Survey Data System (SDS)	Process, analyze, archive, and distribute NEO Surveyor instrument data.	Provider: Caltech IPAC Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Launch Vehicle	Launch vehicle and all launch services to deliver mission to orbit	Provider: TBD Lead Center: KSC Performing Center(s): KSC Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: Teledyne does not deliver a sufficient number of Sensor Chip Assemblies (SCAs) meeting flight requirements by schedule need dates due to production challenges, Then: There will be an impact to schedule/cost or technical margins.	The project began early SCA design work and completed flight pathfinder SCAs to develop and validate the build process, along with formally documenting the detector selection process. Margin assessment is ongoing to better understand threshold acceptance quality criteria. The team will produce additional SCAs to mitigate poor quality lots.

NEAR EARTH OBJECTS SURVEYOR

Formulation	Development	Operations

Risk Statement	Mitigation
If: Planned tests and model validation campaign is insufficient to produce a fully validated flight model due to the complexity of the individual tests and the difficulty of stitching test results together to emulate an end-to-end test, Then: The project will need additional cost and time to augment model or replan test sequence.	The project completed early risk reduction prototype activities and will develop a detailed test plan campaign, followed by a review of the test campaign focusing on test implementation, model validation, and detailed modeling of the test configuration. After these activities, the project will conduct a test readiness review prior to the testing, and during testing evaluate success criteria after each test result.
If: The Spacecraft team, which was reduced in FY 2023, is not able to retain, bring back and acquire new workforce that has necessary skill sets or can come up to speed in time, Then: When Spacecraft development resumes in October 2023 after the instrument development has matured and moved into fabrication and assembly, the spacecraft development catch up to the instrument design changes and/or the inability of the spacecraft team to be up to speed by the end of December 2023 will hinder progress toward launch, increase overall technical risk, may result in increased costs later in Phase C/D, and potentially delay the launch date.	The project has worked to retain key Ball Spacecraft leadership in management, systems engineering and mission assurance at low levels in FY 2023 and will continue the Sunshade Solar Thermal Shield development and mature Spacecraft areas with the least amount of heritage. Additionally, the project plans to minimize interface design changes and strategically plan for spacecraft ramp back up after FY 2023.

Acquisition Strategy

Jet Propulsion Laboratory (JPL) will initiate subcontracts for the major flight and ground support components. NASA contracted directly with the University of Arizona (UA) for the survey director, investigation team and associated efforts, and focal planes. UA will initiate subcontracts for the components of the focal plane and deliver those to the flight project. NASA contracted directly with Caltech/IPAC for the SDS.

NEAR EARTH OBJECTS SURVEYOR

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Survey director, investigation team, and focal planes	University of Arizona	Tucson, AZ
Instrument CEA, CEU, and instrument I&T	Space Dynamics Laboratory (SDL)	Logan, UT
Instrument components, spacecraft bus, and observatory I&T	Ball Aerospace	Boulder, CO
Mission Operations	Laboratory for Atmospheric and Space Physics (LASP)	Boulder, CO

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	Oct 2020	SRB Status Review to assess SRR-MDR results, progress/ resolution of SRR actions, changes since the SRR, and to assess readiness for Phase B	Successful	PDR
Performance	SRB	Sep 2022	PDR	Successful	CDR
Performance	SRB	Feb 2025	CDR	TBD	SIR
Performance	SRB	Jul 2026	SIR	TBD	ORR

OTHER MISSIONS AND DATA ANALYSIS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Double Asteroid Redirection Test	13.8	--	**0.0**	0.0	0.0	0.0	0.0
Near Earth Object Observations	42.2	--	**41.0**	41.0	42.0	42.0	40.0
Total Budget	**56.0**	**--**	**41.0**	**41.0**	**42.0**	**42.0**	**40.0**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The expanding plume immediately following the September 26, 2022 impact of DART with Dimorphos, the moon of asteroid Didymos, is shown above. The ATLAS NEO survey telescope just commissioned in South Africa earlier in the year captured this view of DART's impact Credit: University of Hawaii/South African Astronomical Observatory

Mission Planning and Other Projects

NEAR-EARTH OBJECT OBSERVATIONS (NEOO)

The NEOO project funds work that uses ground and space-based assets to search for Near-Earth Objects (NEOs) that have potential to collide with Earth and characterizes them to assess if any could do significant damage at the surface of our planet. NEOs range in size from a few meters to approximately 34 kilometers. Known NEOs of one kilometer (km) or larger in size are close to 900 in number, while those between 140 meters to one kilometer in size are close to 11,500 in number. NASA estimates that there are still over 14,000 NEOs left to find in this size range.

The NEOO project supports a network of activities including search and characterization observatories and the data processing and analysis required to understand the orbits and nature of the near-Earth population of small bodies. In accordance with the findings and recommendations of the National Academies studies on the NEO hazard in 2010, the National Academies of Sciences, Engineering, and Medicine study on Finding Hazardous Asteroids Using Infrared and Visible Wavelength Telescopes (2019), and the National Academies' most recent Planetary Science and Astrobiology Decadal Survey 2023-2032 (2022), NASA continues to:

- Analyze the small body data collected by the reactivated Wide-field Infrared Survey Explorer (WISE) mission, now called NEOWISE, and support increased follow-up and analysis of these data;
- Increase collection of NEO detection and characterization data by the Catalina Sky Survey, the Panoramic Survey Telescope and Rapid Reporting System (Pan-STARRS), and the United States Space Force’s (USSF) Space Surveillance Telescope;

OTHER MISSIONS AND DATA ANALYSIS

- Support the operation of the four small telescope wide field survey sites called the Asteroid Terrestrial-impact Last Alert System (ATLAS), designed to detect smaller asteroids as they approach the Earth and warn of any imminent impact, two of which will now operate at southern hemisphere sites;
- Support the continued and enhanced operation of planetary radar capabilities at NASA’s Goldstone Deep Space Network facility and support the processing and archiving of radar data from the decommissioned 305-meter telescope at the National Science Foundation’s Arecibo Observatory;
- Utilize NASA's Infrared Telescope Facility for targeted measurement of physical characteristics of NEOs;
- Support NEO research teams at multiple universities and space science institutes to observe and characterize the nature of asteroids and comets which can closely approach Earth; and
- Investigate both ground and space-based concepts for increasing capacity to detect, track, and characterize NEOs of all sizes.

Since NASA’s NEO search efforts started in 1998, NEOO research has found over 96 percent of the estimated population of these objects that are one kilometer and larger, and just over 41 percent of all those larger than 140 meters in size. NEOs discovered and characterized by the project may also be viable targets for future robotic and human exploration, and possible eventual candidates for asteroid resource utilization operations.

The Infrared Telescope Facility (IRTF) is NASA’s infrared-optimized three-meter telescope site at an altitude of 13,600 feet on the extinct volcano Mauna Kea on the Big Island of Hawai’i. The NEOO project funds IRTF operations and IRTF is a primary NASA planetary defense asset for NEO physical characterization. IRTF continues its mission of strategic support of NASA flight missions and science goals in both planetary science and astrophysics while being on-call for rapid response observations of NEO targets of opportunity and potential threats.

The NEOWISE mission uses the WISE spacecraft, a 40-centimeter (16-inch) diameter infrared telescope in Earth orbit that continues an all-sky astronomical survey with its two detectors, which remain in non-cryogenic operations. NEOWISE capabilities and vantage point enable contribution to NEO discovery and, more significantly, understanding the physical properties of large numbers of NEOs, comets, main-belt asteroids, and other minor planets.

Recent Achievements

The NEOWISE spacecraft orbit has been moving away from the ideal Sun synchronous orbit alignment since the end of prime operations in 2010. In FY 2022, it completed its ninth year of operations since reactivation and engineers will continue to closely monitor the temperature on the spacecraft. Excessive heat would effectively blind the infrared detectors, terminating the useful life of the spacecraft. NEOWISE has no orbital maintenance thrust capability, therefore it cannot compensate for this natural orbital movement.

The USSF Space Surveillance Telescope in Australia, a collaboration with the Royal Australian Air Force, began operational capability in 2022. The Lincoln Near-Earth Asteroid Research team initiated the data processing pipeline for detecting and retrieving asteroid positions from the data.

OTHER MISSIONS AND DATA ANALYSIS

The Asteroid Terrestrial-impact Last Alert System (ATLAS) team completed development of the two new ATLAS observatory stations in South Africa and Chile, commissioned the sites, and started southern hemisphere NEO survey operations.

WORK IN PROGRESS FY 2023

The Minor Planet Center is the internationally recognized repository for small body position measurements and the NEOO Program supports it as a sub-node of NASA's Planetary Data System. The center is modernizing and updating its services to accommodate an increasing volume of observations from current and future surveys such as the specific needs for NEO Surveyor's unique vantage point and reporting. NEOWISE survey operations will end in June 2023. If an additional extension is not deemed advantageous, NASA will decommission the spacecraft and complete data archiving by November 2023. NASA continues to coordinate with USSF on transferring Space Surveillance Telescope (SST) data from Australia to the United States for researchers to use for asteroid detection and tracking. NASA will also participate in an interagency study to assess how to meet future deep-space radar needs.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

NASA will continue to support a network of search and characterization observatories and the data processing and analysis required to understand the near-Earth population of small bodies and detect any threats for impacting Earth.

Operating Missions

DOUBLE ASTEROID REDIRECTION TEST (DART)

DART is the first planetary defense mission demonstrating the kinetic impact technique to change the motion of an asteroid in space. The target asteroid for DART is the binary asteroid system Didymos. The Didymos system consists of the primary asteroid, Didymos A, which is about 780 meters (one half mile) across, and a “moonlet,” Dimorphos. The DART spacecraft demonstrated the kinetic impact deflection method by deliberately crashing into Dimorphos at a speed of approximately 14,000 miles per hour, with the aid of an onboard camera and sophisticated autonomous navigation software. The collision reduced the period of the orbit of the moonlet around the main body by about 32 minutes, enough to easily measure from telescopes on Earth. By targeting the small moonlet in a binary system, the DART mission made this demonstration possible without causing any detectable change to the orbit of the system about the Sun. The DART mission results will demonstrate the effectiveness of the kinetic impact technique for deflecting a hazardous asteroid. NASA will use the mission to improve our understanding of the physics involved and our readiness to respond to an actual asteroid impact threat.

NASA’s DART spacecraft launched on November 24, 2021, and impacted Dimorphos on September 26, 2022, when the Didymos system was within 11 million kilometers of Earth. This enabled ground and near-Earth space-based telescope observations of the ejecta caused by the impact, and subsequent observations of the change to the orbital period.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

The DART spacecraft impacted Dimorphos on September 26, 2022, resulting in world-wide news coverage of the successful kinetic impact demonstration and clear observation of the effects, and changes caused to the moonlet's orbital period. Additional data collection and analysis will continue through FY 2023.

WORK IN PROGRESS IN FY 2023

In the final year of the DART project, the investigation team will complete telescopic observations of the Didymos asteroid system. They will characterize the overall change in orbit of the moonlet caused by the impact, conduct post-impact data analysis and modelling of the effects, and prepare the final close-out report to document the mission's success.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

None. All project activities and close-out will be complete at the end of FY 2023.

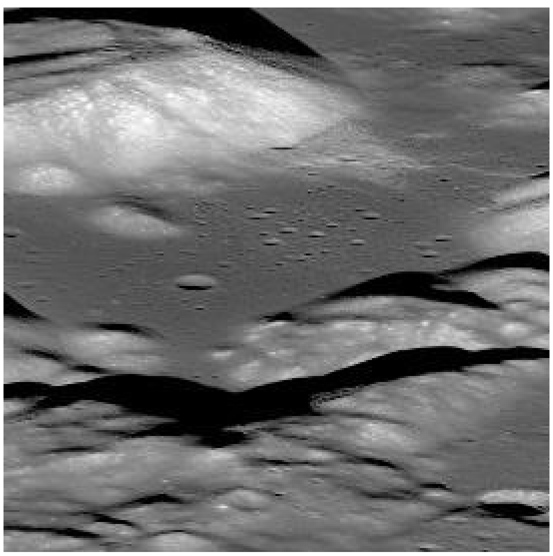
LUNAR DISCOVERY AND EXPLORATION

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
VIPER	112.2	97.2	**61.3**	33.0	0.0	0.0	0.0
Other Missions and Data Analysis	366.5	--	**397.2**	426.0	460.5	472.0	483.3
Total Budget	**478.8**	**--**	**458.5**	**459.0**	**460.5**	**472.0**	**483.3**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



The Apollo 17 landing site, imaged by the Lunar Reconnaissance Orbiter (LRO) Narrow Angle Camera, was the final expedition to the Moon by humans in the 20th century, 50 years ago. The view shown here highlights the diversity of the region as data from LRO is helping NASA prepare for the next era of lunar exploration by both crew and robotic explorers and enabling us to identify safe and scientifically important areas to explore.

NASA's exploration strategy will provide an innovative and sustainable approach to scientific and human exploration, with commercial and international collaborators to enable human expansion across the solar system and bring new knowledge and opportunities back to Earth. The Agency will achieve these accomplishments with emerging commercial capabilities and innovative approaches to achieving human and science exploration goals, including the return of humans to the Moon.

The Lunar Discovery and Exploration Program (LDEP) in the Science Mission Directorate is a key component of the Agency's exploration strategy. LDEP establishes commercial contracts for lunar payload delivery and other related services through the Commercial Lunar Payload Services (CLPS) initiative; continues operations of the Lunar Reconnaissance Orbiter (LRO); and developing SmallSats, instruments, and other payloads that serve lunar science, long-term exploration, and utilization needs. LDEP will provide innovative investigations to enhance lunar exploration and science by developing technical capabilities and increased commercialization for an expanded range of lunar services. NASA is prioritizing capabilities that support lunar resource analysis and prospecting to inform future human space flight objectives. For example, LDEP will focus on instrumentation to advance knowledge and technologies for the use of local resources, such as lunar water ice. Working with the science and human exploration communities, our international partners, and U.S. industry, NASA will refine the goals and objectives for a robust and sustainable lunar exploration and science program.

In collaboration with private industry and the scientific community, the program is developing lunar surface payloads (and supporting orbital payloads) along with cost-effective ways to deliver and provide

LUNAR DISCOVERY AND EXPLORATION

services for these payloads. These payloads and services address the Nation's lunar exploration, science, and technology demonstration goals. The recent National Academies of Sciences Decadal Survey (Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032) emphasized the need to continue supporting commercial innovation and collaboration initiatives in order to accomplish lunar (and beyond) exploration and science initiatives.

NASA purchases commercial transportation/delivery services to the Moon for NASA instruments and technology demonstration payloads. These transportation or delivery services include needed "utilities" from the commercial systems, such as power, communications, thermal control, during launch integration, launch, cruise phase, and in most cases, operations at the lunar destination. In other cases, these services culminate in deployment of a NASA asset such as a rover to fulfill its own mission. In addition, NASA will pursue the purchase of science or engineering data provided by contractor systems, as well as the possibility of returning payloads and/or samples to the Earth. LDEP also makes these commercial lunar services available to other NASA mission directorates.

EXPLANATION OF MAJOR CHANGES IN FY 2024

NASA has established two new projects within this program: the Payloads and Research Investigations on the Surface of the Moon-3 (PRISM-3) project with selections in FY 2023, awards in FY 2024 and delivery to the Moon in FY 2028; and the Artemis Instruments project, which includes developing Artemis crew-deployed and handheld instruments, as well as instruments for the Lunar Terrain Vehicle.

This budget accelerates the Lunar Trailblazer launch from a 2025 rideshare on the Interstellar Mapping and Acceleration Probe mission to a rideshare on the launch of Intuitive Machines' IM-2 mission in November 2023.

NASA directed the CLPS provider Astrobotic to perform additional risk reduction testing on their Griffin lander, consequently delaying the Volatiles Investigating Polar Exploration Rover (VIPER) delivery to the lunar surface from November 2023 to November 2024. This change increased the lifecycle cost of VIPER by $63.9 million to date.

ACHIEVEMENTS IN FY 2022

In FY 2022, NASA competitively selected two more robotic lunar surface payloads through the PRISM-2 solicitation, the Lunar Vulkan Imaging and Spectroscopy Explorer investigation and the Lunar Explorer Instrument for space biology Applications suite. Delivery to the Moon will be occur between 2026 and 2027 via CLPS-provided landing services.

The VIPER rover completed its critical design review.

The DALI solicitation was in February 2022 with final proposals submitted in June 2022.

Lunar Trailblazer completed its System Integration Review in May 2022 and the team started work toward the new 2023 launch date.

LRO remained in extended operations and continued to offer LRO landing site characterization capabilities to international and commercial stakeholders upon request.

LUNAR DISCOVERY AND EXPLORATION

WORK IN PROGRESS IN FY 2023

Two LDEP CLPS deliveries will take place in FY 2023; CLPS contractors will deliver a total of 15 LDEP-developed payloads and two STMD technology demonstrations to two locations on the lunar surface. CLPS contractors continue to work on four additional existing delivery task orders for two deliveries in FY 2024 and two deliveries in FY 2025. NASA will continue to competitively select additional robotic lunar surface science payloads through the PRISM solicitation and expects to continue its two-per year minimum cadence of delivery awards. The next CLPS delivery award will include payloads in partnerships with the European Space Agency (ESA) and the U.S. Department of Energy. ESA's Lunar Pathfinder will be the first CLPS delivery into a lunar orbit.

VIPER will enter Phase D, which is the beginning of system assembly, integration, and testing.

NASA will deliver and integrate Lunar Trailblazer with its rideshare Intuitive Machines and launch in November 2023.

NASA will complete and deliver 24 of 25 lunar instrument selections from NASA Research Announcements for the Lunar Surface Instrument and Technology Payloads (LSITP) and NASA Provided Lunar Payloads (NPLP) solicitations.

NASA will complete DALI selections and awards, PRISM-3 selections and awards, and the PRISM-4 solicitation.

NASA will release a competitive solicitation for Artemis III in-situ/deployed science instruments deployed with crew on the lunar surface, as well as instruments that will ride with or on NASA's Lunar Terrain Vehicle (LTV). The Exploration Systems Development Mission Directorate is developing LTV for the Artemis Program. LTV is a human-rated, unpressurized (unenclosed) rover that will help astronauts explore and conduct experiments on the lunar surface. NASA anticipates two LTV instrument awards in FY 2023 and development to begin in FY 2024 for delivery to the lunar surface in FY 2028. The LTV will operate on the lunar surface for a minimum of 10 years.

LRO will continue in extended operations.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

CLPS will deliver the STMD Polar Resources Ice Mining Experiment-1 to the lunar south pole region via Intuitive Machines NOVA-C lander in the first quarter of FY 2024. Two additional CLPS deliveries to the lunar surface are on track to occur in mid-2024 and will include STMD's Electrostatic Dust Shield experiment, and the Space Operations Mission Directorate's Lunar Global Navigation Satellite System Receiver Experiment. The first PRISM suite of payload, Lunar Vertex, is set to land in April 2024, alongside the STMD Cooperative Autonomous Distributed Robotic Exploration rover and two international payloads. The remaining PRISM-1 suites of payloads will also be complete and delivered to the vendor for integration onto the lander.

Lunar Trailblazer will be in its operations phase.

CLPS contractors will continue to work existing lunar instrument deliveries targeting FY 2025 launches. The VIPER team will integrate VIPER with Astrobotic in August of 2024 and then ship to Kennedy Space Center in preparation for launch in November 2024. NASA will release the PRISM-5 solicitation, and Artemis III and LTV instruments will begin development.

LUNAR DISCOVERY AND EXPLORATION

LRO operations will continue in support of scientific research and future science and exploration mission planning.

Program Schedule

Date	Significant Event
Q1 FY 2023	Deliver NASA-funded LSITP payloads for integration into CLPS deliveries to the lunar surface
Q3 FY 2023	Scheduled delivery of payloads by Intuitive Machines through CLPS*
Q2 FY 2023	Scheduled delivery of payloads by Astrobotic through CLPS*
Q1 FY 2023	Receive PRISM-3 solicitation proposals from the community
Q4 FY 2023	Artemis In-situ/Deployed Instruments Selections and Awards
Q4 FY 2023	LTV Instruments Selections and Awards
Q1 FY 2024	Scheduled delivery of PRIME-1 drill and mass spectrometer to southern lunar pole region by Intuitive Machines*
Q3 FY 2024	Deliver VIPER to Astrobotic for delivery to lunar south polar region
Q3 FY 2024	Scheduled delivery of payloads to Reiner Gamma by Intuitive Machines through CLPS*
Q3 FY 2024	Scheduled delivery of payloads to Crisium Basin by Firefly Aerospace through CLPS*

**NASA does not manage the launch vehicle portion of the CLPS effort and does not ultimately control final launch schedules of the selected providers that will deliver NASA and other provider-provided payloads. NASA will work with the CLPS vendors to ensure timely and successful launch and delivery of all science and technology payloads.*

Program Management & Commitments

Science Mission Directorate's Planetary Science Division and Ames Research Center (ARC) manage the VIPER mission. The Planetary Science Division and Johnson Space Center (JSC) manage the CLPS initiative.

The Planetary Mission Program Office located at Marshall Space Flight Center (MSFC) is responsible for managing the LRO and Lunar Trailblazer missions, as well as Lunar Surface Instrument and Technology Payloads (LSITP) and PRISM instruments.

Program Element	Provider
Lunar Reconnaissance Orbiter	Provider: Goddard Space Flight Center (GSFC) Lead Center: GSFC Performing Center(s): GSFC, Jet Propulsion Laboratory (JPL) Cost Share Partner(s): N/A

LUNAR DISCOVERY AND EXPLORATION

Program Element	Provider
Lunar Instruments	Provider: Various Lead Center: Headquarters (HQ) Performing Center(s): N/A Cost Share Partner(s): N/A
Commercial Lunar Payload Services	Provider: Various Lead Center: JSC Performing Center(s): N/A Cost Share Partner(s): N/A
VIPER	Provider: ARC Lead Center: ARC Performing Center(s): ARC, JSC, Kennedy Space Center (KSC) Cost Share Partner(s): N/A
DALI	Provider: Various Lead Center: HQ Performing Center(s): ARC, Glenn Research Center (GRC), GSFC Cost Share Partner(s): N/A
PRISM-1	Provider: JPL, Applied Physics Lab (APL) Lead Center: MSFC Performing Center(s): JPL Cost Share Partner(s): N/A
Lunar Trailblazer	Provider: California Institute of Technology Lead Center: HQ Performing Center(s): JPL Cost Share Partner(s): N/A
Lunar Management	Provider: HQ, MSFC Lead Center: HQ, MSFC Performing Center(s): MSFC Cost Share Partner(s): N/A
PRISM-2	Provider: ARC, University of Central Florida Lead Center: MSFC Performing Center(s): ARC Cost Share Partner(s): N/A
PRISM-3	Provider: TBD Lead Center: HQ Performing Center(s): TBD Cost Share Partner(s): N/A

LUNAR DISCOVERY AND EXPLORATION

Program Element	Provider
Artemis Instruments	Provider: TBD Lead Center: TBD Performing Center(s): TBD Cost Share Partner(s): N/A
Lunar Science	Provider: Various Lead Center: HQ Performing Center(s): Various Cost Share Partner(s): N/A

Acquisition Strategy

LDEP uses flexible contract mechanisms, such as indefinite-delivery-infinite-quantity (IDIQ) contracts, to enable the flexible and rapid procurement of commercial transportation services to deliver NASA scientific, exploration, and technology development payloads to the surface of the Moon, and potentially to lunar orbit. NASA may expand lunar service requirements to include more capabilities, such as mobility or sample return.

In parallel, NASA uses its established solicitation mechanisms, such as the Research Opportunities in Space and Earth Science (ROSES), NASA Research Announcements (NRA) and the Stand-Alone Missions of Opportunity Notice (SALMON) Announcement of Opportunity processes, to select and develop exploration, scientific, and technology development payloads for delivery to the Moon. In some cases, NASA may direct a NASA center to develop a lunar capability or surface payload when it is in the Government's best interest, such as when that capability supports multiple NASA applications or when a commercial entity or international stakeholder identifies a near-term opportunity for a lunar surface mission on a timeframe that does not support competitive selection. However, to the maximum extent possible, NASA will leverage competitive solicitations for science instrument procurement and commercial services.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Commercial Lunar Payload Services (2)*	Astrobotic Technology	Pittsburgh, PA
Commercial Lunar Payload Services (3)*	Intuitive Machines	Houston, TX
Commercial Lunar Payload Services	Firefly Aerospace	Cedar Park, TX
Lunar Trailblazer	California Institute of Technology	Pasadena, CA
Commercial Lunar Payload Services	Masten Space Systems	Mojave, CA
Commercial Lunar Payload Services	Draper	Boston, MA

** (#) denotes number of contract awards for landing services made to that vendor.*

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

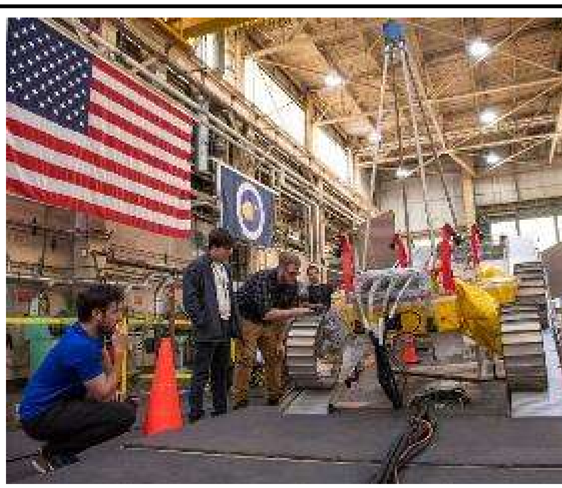
FY 2024 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028	BTC	Total
Formulation	80.1	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	80.1
Development/Implementation	113.6	112.2	97.2	**61.3**	15.9	0.0	0.0	0.0	0.0	400.1
Operations/Close-out	0.0	0.0	0.0	**0.0**	17.2	0.0	0.0	0.0	0.0	17.2
2023 MPAR LCC Estimate	**193.7**	**112.2**	**97.2**	**61.3**	**33.0**	**0.0**	**0.0**	**0.0**	**0.0**	**497.4**
Total Budget	**193.7**	**112.2**	**97.2**	**61.3**	**33.0**	**0.0**	**0.0**	**0.0**	**0.0**	**497.4**
Change from FY 2023 Enacted				**-35.9**						
Percent change from FY 2023 Enacted				**-36.9%**						

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The 2023 MPAR LCC Estimate reflects the most recent estimates based on current project data as of February 2023. The requested budget authority is the project's current budget requirement which has seen programmatic changes and are anticipated in the Quarter 2 Financial Report.



VIPER rolling off the Astrobotic Griffin lander structural test model, shown here, conducting joint egress tests at Glenn Research Center.

PROJECT PURPOSE

The Volatiles Investigating Polar Exploration Rover (VIPER) is a robotic lunar rover that will explore the relatively nearby, but extreme environment of the Moon, in search of water ice and other potential volatile resources. The suite of instruments will also address high priority science questions by providing information about the origin and distribution of water on the Moon and across the solar system. NASA will use the data the rover collects to determine where the Moon's water ice is most likely to be found and easiest to access, making VIPER the first-ever resource mapping mission on another celestial body. NASA can then use these maps to aid in the decision process for future lunar human space exploration, and beyond. The first water maps of the Moon will mark a critical step forward in NASA's Artemis Program to establish a sustainable human presence on the surface of the Moon.

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2024

In July 2022, NASA modified the Astrobotic contract to include additional ground testing on Astrobotic's Griffin lunar lander, which will deliver VIPER to the lunar surface through Commercial Lunar Payload Services (CLPS). The purpose of the additional tests is to reduce overall risk to the VIPER delivery to the Moon, but results in a one-year launch delay from November 2023 until November 2024. This change increased the lifecycle cost of VIPER by an estimated $63.9 million. Final VIPER costs are currently under review and will be finalized at the Key Decision Point D, the transition to delivery of components, testing, assembly, and integration leading to launch.

PROJECT PARAMETERS

VIPER will operate for approximately 100 Earth-days to cover three cycles of lunar day/night near the western edge of Nobile Crater in the lunar South Pole region, with a scheduled FY 2025 arrival. VIPER is a remotely commanded, golf-cart sized rover delivered onto the Moon's surface via CLPS provided services. The CLPS delivery task order awardee will provide all services required to deliver NASA equipment to the Moon's surface, such as the launch, lander system, and lander operations. The CLPS initiative funds all costs associated with the delivery task order.

VIPER will explore the Nobile Crater area and will venture into some of the semi-permanent and permanently shadowed regions of the Lunar South Pole to survey different ice-stability regions to detect and assess volatiles distributions and concentrations. To achieve its scientific goals, the rover will carry four instruments including a one-meter drill. Collectively, the instrument set will detect and analyze various lunar soil environments at a range of different depths and temperatures.

The VIPER drill, The Regolith and Ice Drill for Exploring New Terrain (TRIDENT), will excavate using the auger/percussion approach, which utilizes a hammering action in conjunction with a rotary motion, to extract down to a depth of 1-meter and deliver lunar regolith in small (10 centimeter) segments for vertical profiling.

The Neutron Spectrometer System (NSS) instrument will prospect for and map the distribution of hydrogen-rich materials while roving. NSS will be located on the front of the rover to have an unobstructed view of the lunar surface.

The Near InfraRed Volatiles Spectrometer System (NIRVSS) instrument will operate during roving or while drilling. The instrument will look for near real-time changes in the properties of the materials exposed. Using different wavelengths of light to illuminate the surface, the team will use NIRVSS to provide an additional means of surveying the surface and immediate excavation site for water and other volatiles, providing surface and regolith mineral context.

The Mass Spectrometer observing lunar operations (MSolo) instrument will operate during roving or while drilling. MSolo will identify low-molecular weight volatiles on the surface or from subsurface excavations. Working in concert with the NIRVSS instrument, the instruments will analyze volatiles from the materials delivered by the drill bit from a depth of up to one meter.

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

ACHIEVEMENTS IN FY 2022

The VIPER project successfully completed its Critical Design Review (CDR) in October 2021. The team continued progress on fabrication and subsystem testing, and began preparing hardware for eventual assembly, integration, and testing. Eight new scientists joined the VIPER team in December 2021 to enhance and expand the existing team. The rover team successfully completed a joint Astrobotic/Griffin and VIPER/rover egress testing at the Simulated Lunar Operations (SLOPE) Laboratory at NASA's Glenn Research Center in June 2022. The latest rover engineering unit, the Moon Gravitation Representative Unit 3 also completed motor/controller roving tests at the SLOPE facility to better characterize driving capabilities and performance.

WORK IN PROGRESS IN FY 2023

The VIPER System Integration Review took place in December 2022. In May 2023, VIPER will conduct its KDP-D review. Successful completion will mark the mission's transition into the system assembly, integration, and test phase of development. Mission Operations Center engineering and operational simulations continue in FY 2023.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

VIPER will conduct its Pre-Ship Review (PSR) in the summer of 2024 and then ship the completed rover to the CLPS provider. After integration with the Griffin lander, it will arrive at Kennedy Space Center (KSC) and prepare for launch.

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2024 PB Request
KDP-C	Feb 2021	Mar 2021
CDR	Nov 2021	Oct 2021
SIR	May 2022	Dec 2022
PSR/Ship to CLPS Provider	Jul 2023	Aug 2024
Launch Readiness	Nov 2023	Nov 2024
Initial Operational Capability	Nov 2023	Nov 2024

Development Cost and Schedule

The confidence level developed for VIPER confirmation is the result of a combination of analysis between an independent cost estimate and an independent schedule estimate.

Base Year	Base Year Develop-ment Cost Estimate ($M)	CL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2021	336.2	70	2022	400.1	+19	IOC	Nov 2023	Nov 2024	+12

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

Development Cost Details

The CLPS project funds all costs associated with launch and landing. Launch vehicle costs reported here are for VIPER integration requirements.

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**336.2**	**400.1**	**+63.9**
Rover	92.2	161.3	+69.1
Payloads	22.8	26.6	+3.8
Systems I&T	15.7	18.0	+2.3
Launch Vehicle	1.8	1.8	0
Ground Systems	37.1	40.6	+3.5
Science/Technology	7.2	7.5	+0.30
Other Direct Project Costs	159.4	144.3	-15.1

Project Management & Commitments

Ames Research Center (ARC) manages the VIPER mission and provides systems engineering, project science, real-time rover surface operations, and flight software.

Element	Description	Provider Details	Change from Baseline
Project Office and Mission Management including Science, System Engineering, Safety and Mission Assurance	Overall mission planning and project management functions.	Provider: NASA Lead Center: ARC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Rover	A mobility and power platform hosting the VIPER instrument set, communication system, navigation, and other vehicular sub-systems for use to traverse the lunar surface.	Provider: NASA Lead Center: ARC Performing Center(s): JSC Cost Share Partner(s): N/A	N/A

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	**Development**	Operations

Element	Description	Provider Details	Change from Baseline
TRIDENT	A percussion drilling instrument with force, displacement, and thermal sensors.	Provider: Honeybee Robotics Lead Center: ARC Performing Center(s): KSC Cost Share Partner(s): N/A	N/A
NSS	Neutron Spectrometer instrument	Provider: NASA Lead Center: ARC Performing Center(s): ARC Cost Share Partner(s): N/A	N/A
NIRVSS	Near infrared spectrometer instrument	Provider: NASA Lead Center: ARC Performing Center(s): ARC Cost Share Partner(s): N/A	N/A
MSolo	Mass spectrometer instrument	Provider: NASA Lead Center: ARC Performing Center(s): KSC Cost Share Partner(s): N/A	N/A
Lander and Launch Vehicle	CLPS-provided lander and launch vehicle (not included in VIPER baseline)	Provider: Astrobotic Lead Center: JSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: VIPER needs to make unexpected design changes to enable payload accommodation with the CLPS vendor, Then: this could increase its life cycle cost and schedule.	The VIPER project, CLPS office staff, and Astrobotic are in regular contact to develop interface requirements while maximizing system success. VIPER has secured additional mass allocation on the Astrobotic vehicle which will help mitigate any risk of mass growth on the VIPER mission.
If: supply chain and technical staff shortages continue to cause delays at vendors and NASA centers, Then: this could increase the VIPER life cycle cost and delay the mission.	The VIPER project leads are in regular contact with vendors for timely updates and to work priorities for deliveries.
If: mass margin standing is not improved by SIR/KDP-D, Then: it could delay the mission or increase the cost.	Project mass lead and rover leads continue to work the issue to reduce mass. Removing high mass density energy storage is a possible option.

Acquisition Strategy

NASA is designing, developing, building, integrating, and testing most of the elements of VIPER at NASA centers. The VIPER rover at Johnson Space Center (JSC), the NSS and NIRVSS instruments at ARC, and MSolo at KSC are all NASA in-house developments. The TRIDENT drill was competed and awarded to Honeybee Robotics.

NASA awarded a CLPS delivery task order contract to Astrobotic Technology Inc. of Pittsburgh, Pennsylvania to deliver VIPER to the Moon in late 2024. The current contract value is $320.4 million. In a CLPS delivery task order, the company provides all services required to deliver NASA equipment to the Moon's surface such as the launch, lander system, and lander operations. The CLPS initiative funds all costs associated with the delivery task order.

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

The VIPER Review Team (VRT) is an independent review team tasked to complete key life cycle reviews for VIPER, as well as to engage the project team with more frequent, less formal, and more mentoring interactions.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	VRT	Oct 2021	Critical Design Review	Passed	SIR
Performance	VRT	Dec 2022	Systems Integration Review	Pending	ORR
Performance	VRT	Aug 2024	Operational Readiness Review	TBD	

OTHER MISSIONS AND DATA ANALYSIS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Artemis Instruments	0.0	--	**30.5**	31.3	29.5	31.0	33.0
PRISM-3	0.0	--	**25.0**	30.0	5.0	0.0	0.0
Payloads and RI on Surface of the Moon-2	0.0	--	**20.4**	6.2	5.8	0.0	0.0
Development and Advancement of Lunar Instrumentation (DALI)	13.2	--	**10.0**	20.0	15.0	15.0	15.3
Lunar Trailblazer	22.8	--	**4.3**	2.4	0.0	0.0	0.0
Payloads and RI on Surface of Moon-1	25.5	--	**9.1**	0.0	0.0	0.0	0.0
Lunar Future	0.9	--	**3.9**	4.8	19.7	36.6	37.9
Lunar Instruments	24.1	--	**24.3**	57.3	80.3	83.8	85.0
Commercial Lunar Payload Services	244.3	--	**223.5**	224.1	254.4	254.5	259.5
Lunar Intl Mission Collaborations	0.0	--	**2.4**	0.5	0.5	0.5	0.5
Lunar Management	11.3	--	**5.2**	5.4	5.5	5.7	5.6
Lunar Reconnaissance Orbiter (LRO)	22.1	22.1	**22.1**	22.1	22.1	22.1	22.2
Lunar Science	2.2	--	**16.3**	21.7	22.5	22.8	24.3
Total Budget	**366.5**	**--**	**397.2**	**426.0**	**460.5**	**472.0**	**483.3**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The NASA-developed NPLP Surface and Exosphere Alterations by Landers payload being prepared for integration onto a commercial lunar lander, shown here.

Mission Planning and Other Projects

Other Missions and Data Analysis includes mission planning, small missions in development, instrument and technology development, operating missions, international collaborations, management activities, and funding for future instrument and mission selections.

DEVELOPMENT AND ADVANCEMENT OF LUNAR INSTRUMENTATION (DALI)

DALI focuses on advancing the development of spacecraft-based instruments that show promise for use in future lunar missions, including expected commercial ventures. DALI activities develop and demonstrate lunar science instruments to the point where principal investigators may propose their use in response to future announcements of flight opportunity without additional extensive technology development. DALI focuses on instruments with technology readiness levels (TRLs) four through six. NASA will make DALI selections on a biannual basis after the FY 2023 selection.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

NASA released the DALI 2022 NASA Research Announcement (NRA) in February 2022 and made five selections. NASA released DALI 2023 in February 2023 and will make up to five more selections. To date, NASA has awarded 25 technology development efforts.

LUNAR TRAILBLAZER

NASA selected a SmallSat called Lunar Trailblazer from a Small Innovative Missions for Planetary Exploration (SIMPLEx) call. Trailblazer will spend one year orbiting the Moon at an altitude of 100 kilometers to generate a high-resolution map, at 100 meters per pixel, that charts the form, abundance, and distribution of water while also collecting information about the environments where that water exists, including within shadowed craters. Lunar Trailblazer will carry two instruments: a shortwave imaging spectrometer to search for the signature of water, either in the form of ice or bound to minerals; and a multispectral thermal imager to map the temperature, physical properties, and composition of regions where the spectrometer detects water. These data will fill in gaps of our understanding of the distribution and composition of lunar volatiles and contribute to mission planning for future human exploration.

Recent Achievements

Lunar Trailblazer completed the final design phase and passed its System Integration Review (SIR) in May 2022. The two science instruments are nearing completion of assembly, testing and delivery and the mission is preparing for the start of assembly, test, launch and operations activities. Lunar Trailblazer changed its rideshare in FY 2022 and is now on a rideshare on the launch of a lunar lander mission, Intuitive Machines IM-2, which will launch in November 2023.

PAYLOADS AND RESEARCH INVESTIGATIONS ON THE SURFACE OF THE MOON (PRISM) - 1

The PRISM instrument selections will continue to help NASA develop science-driven payloads for manifesting on future CLPS deliveries and on international flight opportunities. PRISM calls are for investigations utilizing suites of instruments manifested on CLPS deliveries. The PRISM-1 selections will launch to two high science-value locations with deliveries to the lunar surface expected as early as April 2024: the Reiner Gamma albedo swirl on the lunar nearside, and the Schrödinger Basin on the lunar far side. This innovative approach for soliciting science investigations and technology demonstration payloads for future deliveries by CLPS providers will enable decadal-caliber science at the Moon and support the Artemis campaign.

Recent Achievements

NASA made PRISM-1 selections in June of 2021. Lunar Vertex is on the CLPS manifest awarded to Intuitive Machines. Lunar surface delivery of these payloads will be no earlier than April 2024. Lunar Vertex is a combination of stationary lander payloads and a rover that will make detailed measurements of the magnetic field, plasma environment, and regolith properties. The lander and rover data will augment observations collected in orbit. Combined, the observations will help show how these mysterious lunar swirls form and evolve, how they connect to local magnetic fields in the same regions, and how these features impact space weathering effects on the lunar surface.

OTHER MISSIONS AND DATA ANALYSIS

The Farside Seismic Suite (FSS) and the Lunar Interior Temperature and Materials Suite (LITMS) were both manifested on CLPS and awarded to Draper. Draper will deliver Artemis science investigations to the far side of the Moon in 2025. The FSS will return NASA's first lunar seismic data from the far side of the Moon. This new data could help scientists better understand tectonic activity on this region of the Moon, reveal how often the small meteorites impact the lunar far side, and provide new information on the internal structure of the Moon. The instrument consists of the two most sensitive seismometers ever built for spaceflight.

The Lunar Interior Temperature and Materials Suite (LITMS) is a suite of two instruments: the Lunar Instrumentation for Thermal Exploration with Rapidity, a subsurface heat-flow probe and pneumatic drill; and the Lunar Telluric Currents, an electric field instrument. This payload suite aims to investigate the heat flow and subsurface electrical conductivity structure of the lunar interior in Schrödinger Basin. The combination of these measurements will help resolve thermal and compositional structure of the surface of the Moon.

PRISM-2

PRISM calls are for investigations utilizing suites of instruments manifested on CLPS deliveries. CLPS will deliver the PRISM-2 selections to the lunar south pole and the Gruithuisen Domes. The solicitation focuses on environmental monitoring at the south polar region, which will support Artemis crewed missions. The Gruithuisen Domes delivery is to a region of silicic late-stage volcanism and will help us understand the volcanic history of the Moon.

Recent Achievements

NASA selected two new science instrument suites in July 2022.

The Lunar Vulkan Imaging and Spectroscopy Explorer (Lunar-VISE) investigation consists of a suite of five instruments, two mounted on a stationary lander and three mounted on a mobile rover provided as a service by the CLPS vendor. Lunar-VISE's scientists will study how these domes formed and evolved over time.

The second selected investigation, the Lunar Explorer Instrument for space biology Applications (LEIA) science suite, is a small CubeSat-based device. LEIA will provide biological research on the Moon by delivering the yeast Saccharomyces cerevisiae to the lunar surface and studying its response to radiation and lunar gravity. These studies could help scientists answer a decades-old question of how partial gravity and deep space radiation influence biological processes selected

PRISM-3

The PRISM-3 solicitation has allowed proposers to select their own landing sites, justified by the proposed science investigation and associated instrument suites at a landing site within plus or minus 75 degrees of the lunar equator. Delivery to the lunar surface will be by a CLPS provider in 2027.

Recent Achievements

NASA received 21 Step-2 proposals in December 2022 and will make final selections in May 2023.

OTHER MISSIONS AND DATA ANALYSIS

LUNAR FUTURE

Lunar Future supports future activities, studies, instruments, and missions with a strategic focus that will help NASA achieve human and science exploration goals, including the return of humans to the Moon. In 2022, the Planetary Science and Astrobiology Decadal Survey identified potential new strategic missions to accomplish on the Moon. NASA will perform studies to address these new strategic missions as defined in the Decadal alongside other strategic goals for science on the lunar surface and in the Moon's vicinity.

Recent Achievements

The Apollo Next Generation Sample Analysis (ANGSA) research selections from FY 2019 through FY 2022 are complete. Funding for future ANGSA selections is in the Lunar Science research line. The ANGSA initiative continued to provide new perspectives on: (1) the sources, formation, and evolution of lunar volatile reservoirs; (2) characteristics, triggers, and chronology of processes shaping the Moon; and (3) the magmatic, volatile, thermal, and impact history of the Moon based on new lunar lithologies. The results of this initiative are providing a fundamental reference point for the Artemis campaign and future lunar exploration.

LUNAR INSTRUMENTS

NASA is developing instruments and technology payloads to manifest on CLPS deliveries, Artemis crewed missions, and international lunar lander missions. These instruments come from U.S. academia, industry, and from NASA centers. NASA has manifested NPLP and LSITP instruments on CLPS deliveries to launch starting as early as Q2 FY 2023 through FY 2025. The Lunar Surface Electromagnetics Experiment (LuSEE) Night is a new instrument, building on the smaller LuSEE instrument originally selected as an LSITP payload. LuSEE Night will make the first measurement of the Dark Ages signal from the lunar surface. The pathfinder measurements enabled by LuSEE-Night will be extremely valuable to characterize the lunar far side environment and represent a significant step in understanding the Dark Ages phase of the universe. LuSEE Night is a partnership between NASA and U.S. Department of Energy (DOE).

Lunar Advanced Filter Observing Radiometer for Geologic Exploration (LAFORGE) is also a new lunar instrument development. LAFORGE is a U.S. instrument that will be on a Canadian Space Agency (CSA) rover and will serve as an imaging infrared radiometer to better create temperature maps in cold, permanently shadowed regions of the Moon.

This project also includes funding for future PRISM selections.

Recent Achievements

NASA is nearing completion of development and delivery of payloads awarded in February and May of 2019. The 12 internally developed NPLP payloads are complete and delivered to CLPS providers for integration into their delivery systems. The 12 academic- and industry- developed LSITP payloads are almost all complete and either delivered in place or delivered the vendors for their planned CLPS deliveries to the surface of the Moon. For example, the Heimdall instrument is complete and delivered in place and the RadPC instrument is complete and at Firefly Aerospace for integration onto the lander. NASA completed all LuSEE-Night payload agreements and started work in November 2022. NASA selected the LAFORGE instrument in November 2022.

OTHER MISSIONS AND DATA ANALYSIS

COMMERCIAL LUNAR PAYLOAD SERVICES (CLPS)

CLPS is opening competition to U.S. commercial providers of space transportation services, with the strategic goal of supporting affordable commercial operations on and near the Moon, consistent with the National Space Transportation Policy and Commercial Space Act. CLPS consists of a multi-vendor catalog, a 10-year indefinite-delivery-indefinite-quantity contract. NASA manages this effort through task order competitions for specific lunar surface transportation services of payloads with NASA being one of several customers. NASA also collaborates with international partners on CLPS by manifesting international payloads on CLPS landers in exchange for rights to the data and placement of U.S. scientists on the international science teams.

Recent Achievements

CLPS now has seven commercial deliveries actively in work that will occur between FY 2023 and FY 2025. These commercial missions are also delivering payloads provided by customers other than NASA. See the list of commercial service company awardees in the Major Contract/Awards table of the Lunar Discovery and Exploration Program section of this document. NASA is partnering with the European Space Agency (ESA) to fly two payloads via CLPS to the lunar surface and one payload via CLPS to lunar orbit: a large Lunar Retroreflector for Earth-based laser ranging; a volatiles characterization payload to fly to the lunar south polar region; and Lunar Pathfinder, a communications relay. In July 2022, NASA awarded a new contract to deliver Artemis science investigations to the Moon in 2025. The payloads are to be delivered to the far side of the Moon at Schrodinger Basin and include FSS, LITMS, and LuSEE.

LUNAR INTERNATIONAL MISSION COLLABORATION

In developing collaborations with our international partners, NASA funds U.S. participating science investigators and provides international collaborators with lunar landing site characterization data, as well as navigation and data relay services, in exchange for U.S. participation. Participation includes establishing U.S. scientists on the international instrument team, access to data returned from the mission, and assurance that participating scientists will publicly archive returned data in a manner consistent with NASA policies. NASA is also providing science instruments to fly on international missions. NASA is contributing a Laser Retroreflector Array (LRA) to the Indian Space Research Organization's (ISRO) Chandrayaan-3 mission and a LRA to the Japan Aerospace Exploration's (JAXA) smart landing technology demonstration mission. NASA is planning to contribute a Neutron Spectrometer to the JAXA LuPEX rover, which is a partnership between JAXA and ISRO. NASA will also support extended operations for the NASA ShadowCam instrument on the Korean Lunar Pathfinder (KPLO).

Recent Achievements

Both LRAs were shipped to the ISRO and JAXA missions, integrated into the spacecraft, and are expected to land on the Moon in 2023. NASA's Exploration Systems Development Mission Directorate built ShadowCam, delivered it to KPLO, and is funding current instrument operations; however, starting in FY 2024, management and extended operations will be funded in this project.

LUNAR MANAGEMENT

The Planetary Missions Program Office (PMPO) at the Marshall Space Flight Center manages Planetary Science flight projects that are not part of the Mars Exploration Program, including elements of the LDEP

OTHER MISSIONS AND DATA ANALYSIS

portfolio, such as the contracts selected through LSITP for lunar delivery by CLPS landers, PRISM awards, Artemis Instruments awards, Lunar Terrain Vehicle (LTV) instruments, LuSEE Night, LAFORGE, LRO, and the Lunar Trailblazer mission. PMPO provides programmatic, technical, and business management of these LDEP activities. Lunar Management also includes support for review boards and external technical support as needed and future mission studies.

LUNAR SCIENCE

NASA is maximizing the lunar science achieved in this era of lunar exploration through science planning support for Artemis architecture formulation, including science support for tool development and astronaut geology training. This project also supports Artemis-specific curation activities to prepare for the return of new lunar samples, including samples containing volatiles and those requiring cold curation. It also supports surface operations development, including analog activities to help NASA define and develop a real-time science support room structure and science team integration. In addition, targeted research and analysis funding will prepare and enable the lunar community to take maximum advantage of data and samples from Artemis and CLPS.

Recent Achievements

NASA has created an internal NASA Artemis science team, that advises on overall Artemis campaign strategy. In Q2 FY 2023, NASA released a call for an external geology-focused science team that will work with the internal science team on each Artemis mission. Selected PIs for instruments on a specific Artemis mission will be part of the overall Artemis Science Team. They will deliver timely input on a range of science issues in response to questions from Artemis on topics from allowable materials for tools and containers, to camera specifications, and cold curation requirements.

ARTEMIS INSTRUMENTS

Artemis Instruments will specifically support science on the upcoming Artemis missions, beginning with Artemis III, which is currently scheduled for launch in FY 2025. These instruments will consist of surface-deployed instruments coupled to a central power/communications station, analogous to Apollo lunar surface experiments, or designed as a stand-alone instrument suite independent of lander/vehicle support. Some of these planned instruments are extra-vehicular activity astronaut handheld instruments to enhance geological fieldwork/operations. Mobile instruments will be deployed with the LTV, or the Pressurized Rover, both provided by the ESDMD Program Extravehicular Activity (EVA) and Human Surface Mobility (HSM) Program (EHP).

NASA plans to release the Artemis Deployed Instruments solicitation by early spring of 2023 with selections by the end of FY 2023 for the first crewed landing. These instruments selections are based on their ability to be scientifically relevant at any of the current 13 lunar surface destinations identified for Artemis III and ability to be ready for the Artemis III launch timeframe of late 2025.

The LTV instruments deployed on the LTV are for both crewed and uncrewed operations. NASA plans to launch the LTV in time for Artemis V in 2028. The final call for instruments on LTV is in Q3 FY 2023 with selections by Q1 FY 2024.

OTHER MISSIONS AND DATA ANALYSIS

Operating Missions

LUNAR RECONNAISSANCE ORBITER (LRO)

The LRO mission continues to conduct priority science investigations and acquire valuable data sets that provide critical support for commercial lunar deliveries under the CLPS project, as well as for human exploration. LRO has contributed to a new understanding of the Moon and its evolution, which provides a foundation for understanding all other objects in our solar system, as well as solar systems beyond our own. LRO's investigations include a focus on lunar volatiles like ice and water and answer questions like what the volatiles are, where they come from, how they move about on the lunar surface, and where they collect. LRO has also been characterizing the thermal history of the Moon by identifying unusual volcanic features that may be geologically young, as well as tectonic features that reflect the continued gravitational pull from the Earth. Such features are targets for all seven instruments as the mission works to use multiple datasets to investigate the Moon. Scientists use the instrument suite on LRO to characterize the rate at which volatiles move across the surface, the development of the regolith on different terrains, and the location and composition of unusual rock types on the surface.

LRO will continue supporting characterization of the lunar surface, which ultimately enables and reduces risk associated with commercial and human exploration initiatives. Through 2024, LRO will continue characterizing areas on the Moon that may contain volatiles at or near the surface and will characterize landing sites in support of the upcoming U.S. commercial lunar lander missions. LRO is also providing data products in support of current and future Artemis missions.

Recent Achievements

LRO, now in its 13th year of operation, has provided over 1.3 petabytes of lunar data to the planetary data system, which comprises over two-thirds of all planetary data ever acquired. LRO continued to acquire data to support upcoming CLPS missions and has supported STMD and industry communications and navigation experiments in support of Artemis and commercial lunar infrastructure. LRO components are past their original design, but the LRO team continues to develop operational workarounds to accommodate the aging systems and the fuel, which is estimated to last into 2027.

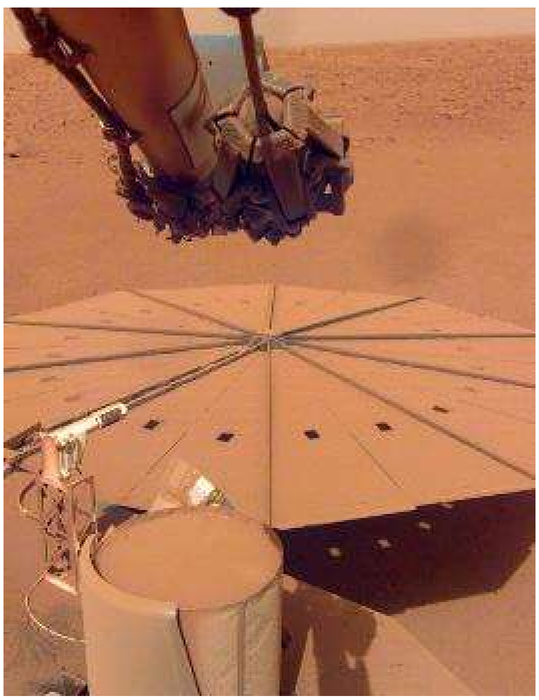
DISCOVERY

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Psyche	163.8	109.3	**57.7**	34.5	34.5	37.1	15.4
DAVINCI	12.4	--	**55.8**	173.0	201.2	268.6	213.0
VERITAS	14.4	--	**1.5**	1.5	1.5	1.5	1.5
Other Missions and Data Analysis	141.1	--	**132.5**	177.5	188.8	272.0	396.0
Total Budget	**331.8**	**--**	**247.5**	**386.4**	**426.0**	**579.2**	**625.9**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



NASA's InSight Mars lander captured this image of one of its dust-covered solar panels on April 24, 2022, the 1,211th Martian day, or sol, of the mission.

NASA's Discovery program supports competitively selected, investigator-led planetary science missions to explore the planets, their moons, and small bodies such as comets and asteroids. With a lower mission cost cap than most of NASA's other planetary missions, Discovery provides scientists the opportunity to propose innovative ways to unlock the mysteries of the solar system.

Lucy is the only Discovery mission in prime operations. Missions in formulation and development include Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (DAVINCI), Venus Emissivity, Radio Science, InSAR, Topography and Spectroscopy (VERITAS), and Psyche.

The Discovery Program also supports the development of instruments that NASA contributes to foreign-led missions, such as the Start from a ROtating FIeld mass spectrOmeter (STROFIO) instrument on the BepiColombo mission. NASA has a partnership with the Japan Aerospace Exploration Agency (JAXA) for two contributions to its Martian Moons eXploration (MMX) mission, including the Mars-moon Exploration with Gamma rays and Neutrons (MEGANE) instrument and a pneumatic sampler (P-Sampler). NASA is contributing the Venus Synthetic Aperture Radar (VenSAR) instrument to the European Space Agency's (ESA) EnVision mission.

The Discovery 2019 Announcement of Opportunity (AO) had a cost-cap of $500 million, excluding launch vehicle and mission operation costs. Launches have been separated by an average of about 43 months since the launch of the Gravity Recovery and Interior Laboratory mission in 2011 through the latest planned launch of DAVINCI in FY 2030. The Discovery Program also supports research based on

DISCOVERY

completed Discovery missions, develops technology for potential missions to investigate planetary science priorities including Venus, and solicits SmallSat missions through the Small Innovative Missions for Planetary Exploration (SIMPLEx) effort.

EXPLANATION OF MAJOR CHANGES IN FY 2024

The budget request supports increased funding in FY 2024 for the Psyche mission given the NASA decision to delay the launch readiness date to October 2023. Section 103 of the NASA Authorization Act of 2005 (P.L. 109-155) requires that NASA give notification to Congress that a major program is likely to exceed its baseline schedule milestone by more than six months or its baseline program development estimate cost by 15 percent. NASA notified Congress of this breach in September, 2022. (See the Psyche section of this document for more details.) The impact to the Psyche Life Cycle Cost is under review.

An Independent Review Board, chartered to investigate the causes of the Psyche delay, concluded that workforce shortages at Jet Propulsion Laboratory (JPL) contributed to the Psyche schedule issues. NASA has therefore deemed it prudent to rebalance work at JPL to ensure that sufficient workforce is available to support high-priority missions in development and formulation, including Psyche, Europa Clipper, and Mars Sample Return. NASA is delaying, by at least three years, the Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy (VERITAS) mission, which is in early formulation and has not been confirmed.

No funding is requested for the Janus mission, a SIMPLEx mission originally planned as a rideshare on the Psyche mission. The updated Psyche launch period is not favorable to achieving the science requirements of the Janus mission. The preliminary analysis showed the Janus spacecraft would be too close to the Sun within five months from launch to survive, therefore NASA has removed Janus from the Psyche launch manifest.

Given other priorities within the Discovery Program, NASA reduced the future Planetary SmallSat budget, which will now support one SIMPLEx selection (with an increased cost cap of $85 million) to fly concurrently with the DAVINCI mission in 2030. NASA plans to release the next Discovery AO in FY 2025. This budget also assumes the conclusion of the InSight mission as available solar power is inadequate to support continued operations; NASA declared the mission successfully completed in December 2022.

ACHIEVEMENTS IN FY 2022

The Lucy mission successfully launched on October 16, 2021. Despite one of the solar arrays not unfurling completely, the mission remains on track and the project commissioned the science instruments.

NASA delivered Psyche to the launch site in April 2022, but late delivery of flight software and test equipment required the mission team to begin assessing options for a 2023 launch.

Janus continued spacecraft assembly and test in preparation for delivery and integration to their designated rideshare.

InSight measured the largest marsquake ever recorded and collected data from meteroid impacts.

DAVINCI and EnVision/VenSAR entered formulation and started science optimization and risk reduction activities.

DISCOVERY

WORK IN PROGRESS IN FY 2023

LunaH-Map deployed from NASA's Space Launch System (SLS) Artemis I mission, which launched on November 16, 2022. NASA intended for the spacecraft to enter lunar orbit to map water-ice at the lunar South Pole. Unfortunately, on November 17, 2022, the team attempted to power on the propulsion system but after many ignition attempts the system did not achieve thrust prior to the spacecraft's planned lunar flyby on November 21st. During FY 2023 the team is continuing attempts to activate the thruster and either return to lunar orbit or identify a new target, if possible.

Psyche is continuing work on the guidance, navigation, and control flight software and other project areas such as operational readiness in preparation for launch in October 2023.

MEGANE will deliver the flight unit to JAXA after final assembly and testing.

Scientists are optimizing the STROFIO instrument on the JAXA BepiColombo spacecraft, currently enroute to Mercury, before its planned orbit insertion in 2025.

Well into an extended mission, the InSight Mars lander lost power as dust accumulated on its solar panels and the mission ceased operations in December 2022.

DAVINCI and EnVision/VenSAR continue in formulation pursuing science optimization and conducting risk reduction activities. Only VERITAS science team activities continue in FY 2023. The DAVINCI mission is performing trade studies on descent sphere size and the Venus Tunable Laser Spectrometer capabilities. EnVision/VenSAR is refining instrument requirements and determining regions of interest on Venus.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

Psyche will launch in October 2023 and will enter operations at the start of its cruise phase one month later. Psyche will begin testing on the Deep Space Optical Communication technical demonstration onboard the mission. Lucy will prepare for its first asteroid encounter, which will occur in FY 2025. NASA will release a draft AO for SIMPLEx in FY 2024 and prepare for the Discovery AO release in 2025.

Date	Significant Event
Oct 2023	Psyche Launch
FY 2024	Release SIMPLEx AO
FY 2025	Lucy first encounter with asteroid
FY 2025	Release Discovery AO

Program Management & Planned Cadence

The Discovery Program is a multiple-project program, with responsibility for implementation assigned to the Planetary Missions Program Office, located at the Marshall Space Flight Center (MSFC).

The present launch cadence, calculated from 2011 through 2030, is about 43 months, with variations in the meantime between launches from nine to 80 months. This budget supports a DAVINCI launch

DISCOVERY

in 2030, approximately 84 months after the launch of Psyche. The mission selected under the Discovery 2025 AO would launch in the 2032 and 2033 timeframe, less than 36-months after DAVINCI.

Acquisition Strategy

NASA competitively selects new Discovery missions, releasing AOs when available funding allows.

INDEPENDENT REVIEWS

NASA will schedule the Discovery Program's next Program Implementation Review (PIR) when recommended by the primary stakeholders.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
PIR	Standing Review Board (SRB)	Aug 2016	Review implementation of program	Passed	TBD

PSYCHE

Formulation	Development	Operations

FY 2024 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028	BTC	Total
Formulation	143.7	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	143.7
Development/Implementation	512.4	163.8	109.3	**28.3**	0.0	0.0	0.0	0.0	0.0	813.8
Operations/Close-out	0.0	0.0	0.0	**29.4**	34.5	34.5	37.1	15.4	0.0	150.9
2023 MPAR LCC Estimate	**656.1**	**163.8**	**109.3**	**57.7**	**34.5**	**34.5**	**37.1**	**15.4**	**0.0**	**1,108.4**
Total Budget	**656.1**	**163.8**	**109.3**	**57.7**	**34.5**	**34.5**	**37.1**	**15.4**	**0.0**	**1,108.4**
Change from FY 2023 Enacted				**-51.6**						
Percent change from FY 2023 Enacted				**-47.2%**						

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The 2023 MPAR LCC Estimate reflects the most recent estimates based on current project data as of February 2023. The requested budget authority is the project's current budget requirement which has seen programmatic changes and are anticipated in the Quarter 2 Financial Report.

PROJECT PURPOSE

The Psyche mission will explore one of the most intriguing targets in the main asteroid belt: a giant metal asteroid known as 16 Psyche. This asteroid measures approximately 140 miles in diameter and, unlike most other asteroids that are rocky or icy bodies, is likely comprised mostly of metallic iron and nickel, similar to Earth's core. Scientists theorize that Psyche may be the exposed core of an early planet that could have been as large as Mars but lost its rocky outer layers due to a number of violent collisions billions of years ago. The mission will help scientists understand how planets and other bodies separated into their layers, including cores, mantles, and crusts, early in their histories.

NASA selected the Psyche mission in December 2016 from the Discovery Program's 2014 Announcement of Opportunity (AO).

Work to prepare NASA's Psyche spacecraft, shown here, for launch is underway at Astrotech Space Operations Facility near Kennedy Space Center in Florida on December 8, 2022.

PSYCHE

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2024

In June 2022, NASA determined that Psyche would not be able to make its nominal launch window in August 2022 or the contingency window in October 2022. The Psyche team concluded that the Guidance, Navigation and Control flight software verification could not be completed in time to support a 2022 launch opportunity without adding significant risk to mission success. Psyche began a replanning effort to look at future launch opportunities and, in parallel, NASA stood up an Independent Review Board to investigate the causes of the delay. Per Section 103 of the NASA Authorization Act of 2005 (P.L. 109-155), NASA notified Congress on September 27, 2022, that Psyche was going to exceed its baseline schedule milestone by more than six months. NASA conducted a Termination/Continuation review in October 2022 and approved the mission to proceed with a new launch date of October 2023. NASA concluded that Psyche is a project with significant scientific merit, which will contribute greatly to knowledge of a unique class of metallic asteroids and add to understanding of the solar system, and that Jet Propulsion Laboratory (JPL) has established an executable plan for corrective action and mission success. The impact to the Psyche Life Cycle Cost is currently under review.

PROJECT PARAMETERS

NASA plans to launch the mission in October 2023 for arrival at 16 Psyche in 2029, where the spacecraft will spend more than two years in four different orbits. Each orbit will be at different distances from the asteroid, allowing the team to study its shape and magnetic field, topography and spectral characteristics, gravitational field, and elemental compositions. Each orbit will provide knowledge needed to guide one or more future orbits, and operators have ample time to update the models, plans, and sequences.

Psyche's instrument payload includes a multispectral imager, a gamma ray and neutron spectrometer, and a magnetometer. Psyche will use an X-band radio telecommunications system to measure 16 Psyche's gravity field.

Psyche will also carry the flight terminal for the Deep Space Optical Communications (DSOC) technology demonstration, a project funded by the Space Technology Mission Directorate (STMD) and the Exploration Systems Development Mission Directorate (ESDMD) to help mature the use of lasers to communicate with spacecraft beyond low-Earth orbit (LEO).

ACHIEVEMENTS IN FY 2022

The Psyche team safely transported the spacecraft from JPL to Kennedy Space Center (KSC) in May 2022. After the team determined they could not meet the contingency launch window, Psyche was moved from KSC to nearby Astrotech in October 2022 to prepare for additional assembly, test, and launch operations (ATLO) activities.

WORK IN PROGRESS IN FY 2023

Psyche will complete ATLO and deliver the spacecraft from Astrotech to the KSC launch site in late spring or early summer 2023. The project will also complete its Operations Readiness Review (ORR) and

PSYCHE

Formulation	Development	Operations

the Key Decision Point-E (KDP-E) review in late summer 2023. The spacecraft will launch in October 2023.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

Psyche will launch in October 2023 and begin the cruise portion of the mission.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2024 PB Request
KDP-C	Jun 2019	May 2019
CDR	Apr 2020	May 2020
System Integration Review (SIR)	Dec 2020	Dec 2020
KDP-D	Jan 2021	Jan 2021
Operations Readiness Review (ORR)	May 2022	July 2023
Launch	Aug 2022	Oct 2023
Phase E Start	Oct 2022	Nov 2023

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2020	681.9	70	2023	813.8	+19.3	Launch Readiness Date (LRD)	Aug 2022	Oct 2023	+14

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

PSYCHE

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**681.9**	**813.8**	**+131.9**
Aircraft/Spacecraft	199.9	360.3	+160.4
Payloads	49.6	87.5	+37.9
Systems I&T	19.2	36.3	+17.1
Launch Vehicle	154.3	130.7	-23.6
Ground Systems	16.1	28.6	+12.5
Science/Technology	9.3	13.2	+3.9
Other Direct Project Costs	233.5	157.2	-76.3

Project Management & Commitments

The Principal Investigator is from Arizona State University (ASU) and leads the management of the mission. The JPL serves as the development center for the Psyche mission and provides systems engineering, mission assurance, spacecraft design, build, test, mission and science operations, navigation, and ground data systems.

Element	Description	Provider Details	Change from Baseline
Solar Electric Propulsion Chassis	Spacecraft bus and propulsion system	Provider: Maxar Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Psyche Multispectral Imager	Provides high-resolution images using filters to discriminate between 16 Psyche's metallic and silicate constituents	Provider: ASU Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

PSYCHE

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Magnetometer	Detects and measures the remnant magnetic field of 16 Psyche	Provider: University of California, Los Angeles (UCLA) Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	Removed from the mission
Magnetometer	Detects and measures the remnant magnetic field of 16 Psyche	Provider: Technical University of Denmark (DTU) Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	Replacement magnetometer
Gamma Ray and Neutron Spectrometer	Detects, measures, and maps 16 Psyche's elemental composition	Provider: APL Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Gravity Science	Utilizes the X-band radio telecommunications system to measure 16 Psyche's gravity field	Provider: Massachusetts Institute of Technology (MIT) Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Launch Vehicle	Launch vehicle and launch services	Provider: Space Exploration Technologies Corp. (SpaceX) Lead Center: Kennedy Space Center (KSC) Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Deep Space Optical Communications (DSOC)	DSOC will mature the use of lasers to communicate with spacecraft beyond low-Earth orbit	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): NASA SOMD/STMD	N/A

PSYCHE

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: The project continues to see attrition commensurate with recent JPL and industry experience and/ or another COVID wave occurs, Then: Project margin on the updated schedule will degrade.	The project is fully staffed with some resiliency and cross-training. Project margin will absorb some delays, but the JPL institution is committed to supporting and providing necessary personnel resources. Per the Psyche Independent Review Board recommendation, the project has also established a 'succession plan' for critical personnel.
If: There are any late hardware deliveries to the Verification and Validation (V&V) process, Then: The launch schedule could be threatened	The vast majority of hardware related V&V and first-touch is complete (e.g., focus on FP, behaviors) The project hardware complement has been deemed use-as-is and is on track for the October 2023 launch.
If: Guidance Navigation and Control (GNC) delays continue, Then: It will delay transition of key personnel to work operational tools and procedures and/or transition to other NASA missions.	The project strategically delayed non-launch critical functionality specifically to maintain resources for operational support. The project has a schedule that closes with a two-month delay on the four months of GNC baseline work. Operational readiness is now embedded into the overall integrated plan, with a sizeable number of dedicated engineers, and new operations chief engineer.

Acquisition Strategy

NASA selected the Psyche mission through a competitive Discovery 2014 AO and a down-selection in FY 2017. All major acquisitions are in place. The major elements of the mission and spacecraft are as proposed in the AO. NASA competitively selected the launch vehicle through the NASA Launch Services Program.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Spacecraft	Maxar	Palo Alto, CA
PI, Co-Is, Imager, Science Data Center	Arizona State University	Tempe, AZ
Launch Vehicle	SpaceX	Hawthorne, CA

PSYCHE

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	Mar 2019	PDR	Successful	CDR
Performance	SRB	May 2020	CDR	Successful	SIR
Performance	SRB	Dec 2020	SIR	Successful	ORR
Performance	SRB	May 2022	ORR (Hardware)	Successful	ORR for 2023 LRD
Performance	IRB	Jan 2023	Independent Review	Successful	N/A
Performance	SRB	Jul 2023	ORR for 2023 LRD	TBD	N/A

DEEP ATMOSPHERIC VENUS INVESTIGATION OF NOBLE GASES, CHEMISTRY & IMAGING

Formulation	Development	Operations

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**12.4**	**--**	**55.8**	**173.0**	**201.2**	**268.6**	**213.0**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

PROJECT PURPOSE

The DAVINCI mission will provide a definitive, new understanding of Venus to help reveal the extent of potential habitability in our inner solar system. The DAVINCI mission addresses three overall goals:

- Understand the origin and evolution of the Venus atmosphere;
- Understand the atmospheric composition and its interaction with the surface; and
- Provide insights into the properties of the tesserae surface features which are highly deformed, high elevation features.

DAVINCI consists of a deep atmosphere "probe" (descent sphere), depicted above, with five internal instruments that measure the detailed chemistry, environment, and dynamics of the atmosphere from the upper clouds to the surface of Venus over a region of mountainous terrain called "Alpha Regio".

The first goal is important to comparative planetology questions within our solar system by answering how and why Venus, Mars, and Earth are different; and by answering questions on how Venus compares to Earth-sized exoplanets. The second goal will help address questions about the interactions of Venus's atmosphere and surface features, such as the presence of an early ocean or the rate of volcanic activity. Four instruments in the Descent Sphere "probe" will address the mission's first two goals, as they will make measurements of the current composition of Venus's atmosphere while the probe moves through the atmosphere to the surface of the planet. The third goal will help address questions about tesserae features such as how they formed and how they compare with other features on Venus. Two imagers, one on the probe itself and another on the main spacecraft will help answer these questions.

EXPLANATION OF MAJOR CHANGES IN FY 2024

The request provides additional funding for DAVINCI, consistent with updated estimates for a launch no later than FY 2030.

DEEP ATMOSPHERIC VENUS INVESTIGATION OF NOBLE GASES, CHEMISTRY & IMAGING

Formulation	Development	Operations

PROJECT PRELIMINARY PARAMETERS

The mission consists of a spacecraft and a probe. The spacecraft will track motions of the clouds and map surface composition by measuring heat emission from Venus' surface that escapes to space through the massive atmosphere. The probe will descend through the atmosphere, sampling its chemistry as well as the temperature, pressure, and winds. The probe will also take the first high-resolution images of Alpha Regio, an ancient highland twice the size of Texas with rugged mountains, looking for evidence that past crustal water influenced surface materials.

Launch is planned for no-later-than FY 2030, with two flybys of Venus prior to the probe's descent. The flybys are the initial phase of the remote-sensing mission to study the atmospheric circulation and map the surface composition. Approximately two years later, the spacecraft will release the probe to conduct its investigation of the atmosphere during a descent that will last about an hour before landing at Alpha Regio. The planned mission data return is about 65 gigabits, with up to 500 descent images, hundreds of trace gas spectra, millions of UV spectra, and thousands of near-infrared nightside images. The total mission duration is two years and one month.

NASA also selected the Compact Ultraviolet to Visible Imaging Spectrometer (CUVIS) Technology Demonstration Opportunity (TDO) as part of DAVINCI. It will demonstrate the technology readiness of freeform optics for collecting high-resolution measurements of spectra and artificial intelligence for onboard data processing. Scientists will use the observations collected by CUVIS to identify the unknown UV-absorber in the atmosphere of Venus, which absorbs half of the incoming solar energy.

ACHIEVEMENTS IN FY 2022

The project team continued science optimization risk reduction activities to buy down risk in targeted areas and increase mission robustness. The team also completed several trade studies over the past year to optimize Spacecraft and Descent Sphere performance.

WORK IN PROGRESS IN FY 2023

The project team continues to place emphasis on preparing for the May 2023 mission requirements review followed by element system requirement reviews that will evaluate the requirements defined for the mission, including instruments and subsystems.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

The DAVINCI team will conduct the mission instruments Preliminary Design Reviews (PDRs) in FY 2024 in preparation for the mission PDR planned for FY 2025.

ESTIMATED PROJECT SCHEDULE

The DAVINCI schedule is currently under evaluation. The dates shown below are preliminary and subject to change.

DEEP ATMOSPHERIC VENUS INVESTIGATION OF NOBLE GASES, CHEMISTRY & IMAGING

Formulation	Development	Operations

Milestone	Formulation Authorization Document	FY 2023 PB Request
Formulation Authorization	N/A	Jun 2021
PDR	N/A	Jun 2025
KDP-C	N/A	Aug 2025
CDR	N/A	Mar 2027
SIR	N/A	Feb 2028
KDP-D	N/A	Mar 2028
KDP-E	N/A	Apr 2029
Launch	N/A	Nov 2029

Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

Life cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows a non-advocate review and/or preliminary design review.

KDP-B Date	Estimated Life Cycle Cost Range ($B)	Key Milestone	Key Milestone Estimated Date Range
Jun 2021	1.2 - 1.6	LRD	Jun 2029 - Nov 2029

Project Management & Commitments

The Principal Investigator for DAVINCI is from Goddard Space Flight Center (GSFC). GSFC also manages the mission and will provide systems engineering, safety and mission assurance, project scientists, flight dynamics, payload management, and mission system management.

DEEP ATMOSPHERIC VENUS INVESTIGATION OF NOBLE GASES, CHEMISTRY & IMAGING

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
DAVINCI Spacecraft	Spacecraft delivers the descent sphere and hosts two instruments. Spacecraft's most important role is to deliver the descent sphere and then relay its data back to Earth.	Provider: Lockheed Martin Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Descent Sphere	One-meter diameter probe that falls through Venus' atmosphere making continuous measurements to the planet's surface.	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Venus Atmospheric Structure Investigation (VASI) Instrument	Descent sphere instrument to characterize the structure and dynamics of Venus atmosphere (approximately every 15 minutes from 67 km to surface)	Provider: Johns Hopkins University (JHU) /Applied Physics Laboratory (APL) Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Venus Mass Spectrometer (VMS)	Descent sphere instrument to survey the planet's noble gases and their isotopes, as well as trace gases	Provider: GSFC Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Venus Descent Imager (VenDI)	Descent sphere instrument (broadband and narrowband NIR) to image Venus from approximately 38 km down to the surface to define topography and composition	Provider: Malin Space Science Systems Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Venus Tunable Laser Spectrometer (VTLS)	Descent sphere instrument to discriminate chemical processes in upper clouds and near surface environment (10 ingests), including the deuterium/hydrogen ratio	Provider: Jet Propulsion Laboratory (JPL) Lead Center: GSFC Performing Center(s): JPL Cost Share Partner(s): N/A	N/A

DEEP ATMOSPHERIC VENUS INVESTIGATION OF NOBLE GASES, CHEMISTRY & IMAGING

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
Venus Imaging System for Observational Reconnaissance (VISOR)	Spacecraft instrument to image full disk upper atmosphere in UV (movies) and 1 μm nightside emissivity (highlands)	Provider: Malin Space Science Systems Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Venus Oxygen Fugacity (VfOx)	Descent sphere instrument (solid-state sensor) to measure O2 partial pressure in lower atmosphere, student collaboration	Provider: JHU/APL Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
CUVIS	Spacecraft technology demonstration instrument (UV spectrometer) to determine chemistry of upper clouds and mystery absorber	Provider: GSFC Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Launch Vehicle	Launch vehicle and all launch services	Provider: TBD Lead Center: Kennedy Space Center (KSC) Performing Center(s): KSC Cost Share Partner(s): N/A	N/A

Project Risks

The DAVINCI Project team has not yet established baseline project risks.

Acquisition Strategy

NASA competitively selected the DAVINCI mission through a Discovery 2019 Announcement of Opportunity (AO). The major elements of the mission and spacecraft are as proposed for the AO, including the prime contract with Lockheed Martin. NASA will competitively select the launch vehicle through the NASA Launch Services Program.

DEEP ATMOSPHERIC VENUS INVESTIGATION OF NOBLE GASES, CHEMISTRY & IMAGING

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Spacecraft	Lockheed Martin	Denver, CO
Navigation analysis	KinetX	Tempe, AZ
VMS instrument electronics	University of Michigan	Ann Arbor, MI
Venus Test Chamber development	National Technical Systems, Inc	Huntsville, AL
VASI instrument development	JHU/APL	Laurel, MD

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Jun 2025	PDR	TBD	CDR
Performance	SRB	Mar 2027	CDR	TBD	SIR
Performance	SRB	Feb 2028	SIR	TBD	ORR
Performance	SRB	TBD	ORR	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
EnVision	17.8	--	**33.1**	47.1	43.9	46.6	28.7
Janus	16.3	--	**0.0**	0.0	0.0	0.0	0.0
Venus Technology	6.6	--	**7.0**	3.2	1.7	1.0	1.0
InSight	11.4	--	**0.0**	0.0	0.0	0.0	0.0
Lucy	44.6	--	**24.8**	25.9	23.8	34.8	34.0
Strofio	1.0	--	**1.0**	1.8	1.2	2.3	2.4
International Mission Contributions (IMC)	8.4	--	**6.8**	8.5	10.3	10.2	8.6
Planetary Management	18.3	--	**41.2**	41.2	38.5	40.0	43.0
Discovery Future	4.5	--	**5.3**	28.3	21.8	82.4	257.2
Discovery Research	7.8	--	**9.2**	10.1	12.1	13.1	13.4
Planetary SmallSats	1.6	--	**0.1**	7.5	31.4	40.0	6.1
Mars-moon Exploration with GAmma rays and NEutrons (MEGANE)	2.9	--	**4.1**	3.8	4.2	1.6	1.7
Total Budget	**141.1**	**--**	**132.5**	**177.5**	**188.8**	**272.0**	**396.0**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The joint European-Japanese BepiColombo mission captured this view of Mercury on June 23, 2022, as the spacecraft flew past the planet for its second of six gravity assist maneuvers at Mercury.

Discovery Other Missions and Data Analysis funds research and analysis; management activities; operations of active missions; small projects and international collaborations; and future mission selections.

Mission Planning and Other Projects

JANUS

Based on an assessment of the updated Psyche launch date, NASA determined that this launch period is not favorable to achieving the science requirements of the Janus mission. The preliminary analysis showed the Janus spacecraft would be too close to the Sun within five months from launch to survive, and the Janus mission was de-manifested from Psyche. Due to the inadequacy of science prospects, project cost cap overruns, and the inability to meet requirements with its Enpulsion thrusters, the risk to mission success is too high to continue.

OTHER MISSIONS AND DATA ANALYSIS

VENUS TECHNOLOGY

High temperatures and pressures (500 degrees Celsius and 90 bars) on the surface of Venus, and an acidic atmosphere, present unique challenges to robotic missions. The Venus Technology Project focuses on developing and advancing technologies that future missions will use to explore Venus and other worlds. Venus Technology includes the Hot Operating Temperature Technology (HOTTech) activity, which supports development of technologies for the robotic exploration of high-temperature environments (e.g., the Venus surface, Mercury, or the deep atmosphere of the gas giant planets); and the Glenn Extreme Environment Rig (GEER), a pressure vessel capable of simulating the temperature, pressure and atmospheric gas mix of Venus and other extreme environments in the solar system and beyond.

Recent Achievements

GEER successfully restarted after closing during the COVID pandemic. In its first run, GEER exposed over 300 rock samples to simulate Venus's surface conditions for 60 days. The DAVINCI and EnVision missions will use these samples to interpret spectral data collected by their missions to determine Venus surface rock types and geology.

The Venus Technology Project partnered with NASA's Established Program to Stimulate Competitive Research (EPSCoR) to produce prototype concepts for a seismometer that can operate in the ambient Venus surface.

INTERNATIONAL MISSION CONTRIBUTIONS (IMC)

There are more scientifically interesting destinations across the solar system than any one country's program can undertake. NASA works closely with other space agencies to find opportunities to participate in each other's missions. These opportunities complement NASA-led planetary missions and expand the opportunities for the U.S. planetary science community to address scientific priorities identified in the Decadal Survey. Under the International Mission Contributions, NASA funds instruments and scientific investigators and provides navigation and data relay services in exchange for participation in mission science. International missions currently supported include: the Japanese Aerospace Agency's (JAXA) Hayabusa2, Akatsuki (Venus Climate Orbiter), and Martian Moons eXploration (MMX) missions; and the Korea Pathfinder Lunar Orbiter (KPLO).

The Pneumatic Sampler (P-Sampler) is also an element in IMC and is a technology demonstration instrument in development by Honeybee Robotics as a second NASA contribution to JAXA's MMX mission. The P-Sampler will complement the JAXA-developed primary surface sampler system by demonstrating the collection of surface and near-surface material on the Martian moon (Phobos) by using compressed gas jets. The MMX mission will fly on a JAXA H3 rocket in September 2024.

Recent Achievements

The NASA-supported Akatsuki Participating Program element resulted in several scientific publications, the successful archival of all the Akatsuki data in the Planetary Data system for further access by the U.S. science community, and coding of new atmospheric modeling, which will aid future Venus missions. The Akatsuki spacecraft will continue to operate through 2025.

KPLO launched successfully from Kennedy Space Center on August 5, 2022 and is following a ballistic lunar trajectory. The spacecraft entered lunar orbit in mid-December 2022 for a one-year nominal

OTHER MISSIONS AND DATA ANALYSIS

mission. Nine NASA-funded KPLO participating scientists are working with the KPLO Science Team on the orbital mission and data returned from the five scientific payloads.

The P-Sampler flight unit is complete and proceeding with environmental testing. Honeybee Robotics shipped the technology demonstration flight unit to JAXA in February 2023. NASA solicited proposals for the participating scientist program element and NASA is reviewing the submitted proposals for FY 2023 selections.

The Hayabusa2 (H2) participating scientist program element effort is almost complete. The team is archiving significant amount of H2 data in the NASA Planetary Data System and producing a variety of publications on the findings and discoveries made on samples returned from asteroid Ryugu.

ENVISION

EnVision is a European Space Agency (ESA)-led mission to Venus for which NASA is providing a mission-enabling radar instrument. EnVision will launch in 2032 and provide a holistic view of the planet from its inner core to its upper atmosphere to determine how and why Venus evolved so differently from the Earth.

NASA is contributing the Venus Synthetic Aperture Radar (VenSAR), which builds on decades of experience in planetary radar development at NASA, including the Magellan radar mapping mission that launched to Venus in 1989. VenSAR will provide regional and targeted surface imaging, topography from altimetry stereo imaging, surface properties from polarimetry, and radiometry and change detection from repeat imaging and comparison to Magellan. NASA will also support EnVision through contributions of the following: time on its Deep Space Network to support critical events, a ground system for VenSAR radar processing, and expertise to assist in planning for spacecraft aerobraking.

Recent Achievements

VenSAR continues Phase A formulation studies, which include potentially moving instrument development forward to align with the latest ESA launch date of November 2031.

NASA established the VenSAR science team to help guide the radar instrument development. Twelve U.S. and two international scientists are on the team and four of them are also on the EnVision Science Study Team (SST). NASA and ESA established a joint EnVision SST to develop the mission profile for ESA's next mission key decision point.

NASA and ESA also established the Venus Science coordination group to support coordinating with other Venus missions and maximize their scientific returns. The group's primary goal is to identify new, unanticipated scientific approaches and outcomes based on synergies among the missions and suggest studies to enhance overall scientific return.

VERITAS

The Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy (VERITAS) mission, if reinstated, would map Venus’ surface to determine the planet’s geologic history and understand why it developed so differently than Earth. Orbiting Venus with a synthetic aperture radar, VERITAS would chart surface elevations over nearly the entire planet to create 3D reconstructions of topography and confirm whether processes such as plate tectonics and volcanism are still active on Venus. VERITAS

OTHER MISSIONS AND DATA ANALYSIS

would also map infrared emissions from Venus' surface to map its rock type, which is largely unknown, and determine whether active volcanoes are releasing water vapor into the atmosphere.

NASA selected VERITAS as a Discovery mission in June 2021 from the 2019 Discovery Announcement of Opportunity (AO). The mission concept involves international partnerships for hardware and science with German Aerospace Center (DLR), French Space Agency (CNES), and Italian Space Agency (ASI).

Recent Achievements

In November 2022, NASA announced a launch delay of at least three years to VERITAS due to Jet Propulsion Laboratory (JPL) workforce issues raised in the Psyche Independent Review Board findings. NASA will continue to support the VERITAS science team.

PLANETARY MANAGEMENT

The Planetary Missions Program Office (PMPO) at Marshall Space Flight Center manages nearly all Planetary Science flight projects that are not part of the Mars Exploration Program, including the competed Discovery and New Frontiers missions, the directed Solar System Exploration Program, and the Planetary Defense Coordination Office flight missions. The PMPO includes support for the day-to-day efforts of the mission managers and business office, as well as independent review boards and external technical support (as needed) for the projects. This project also funds the Science Office for Mission Assessments at Langley Research Center to support the competed mission selection process, including the development of Announcements of Opportunity (AO) and the formation and operations of independent review panels to evaluate mission proposals.

DISCOVERY FUTURE

Discovery Future funds specific promising technology investments to enable future missions, mission concept development during step one of the AO down-select process, and funding for future Discovery mission selections.

Recent Achievements

NASA Entry Systems Modeling teams used observations of JAXA's Hayabusa2 sample capsule re-entry to inform heat shield requirements and determined that a thinner, lighter shield can be used for Mars Sample Return.

NASA's Global Reference Atmospheric Model (GRAM) team released updates of the Venus and Titan GRAMs to support atmospheric modeling required for the DAVINCI, EnVision, and Dragonfly missions.

The NASA history office began planning for the Discovery@30 conference in October 2023 where participants will discuss the lessons learned and impacts of competed missions on the Nation. The office collected oral histories from a wide range of scientists and engineers involved in Discovery missions and will release a history book about the Discovery Program in 2023.

DISCOVERY RESEARCH

Discovery Research funds analysis of archived data from Discovery missions and supports participating scientists. Discovery Research gives the broad research community an opportunity to access samples and

OTHER MISSIONS AND DATA ANALYSIS

data and allows research to continue for many years after mission completion. NASA solicits planetary research proposals from the U.S. planetary science community and evaluates them for selection through competitive peer review. Discovery Research also funds the analysis of samples returned to the Earth by the Stardust and Genesis missions, as well as the development of new analysis techniques for samples returned by future missions.

The Discovery Data Analysis Program element (DDAP) has provided support for continued analysis of spacecraft data from the Near-Earth Asteroid Rendezvous (NEAR)-Shoemaker, Stardust, Stardust-New Exploration of Tempel, Genesis, Deep Impact, Extrasolar Planet Observation and Characterization (EPOCh) and Deep Impact eXtended Investigation (DIXI), Mercury Surface, Space Environment, Geochemistry and Ranging (MESSENGER), Dawn, and Kepler missions. The supported projects conduct new scientific inquiries and regularly obtain new and unexpected scientific results, using data sets to go beyond the work conducted by the original mission teams. The Rosetta Data Analysis Program element (RDAP) has provided additional support targeted for analysis of data from Rosetta, an ESA-led mission with NASA participation, to explore and land on Comet 67P/Churyumov-Gerasimenko.

Recent Achievements

The project awarded nine new research awards in 2022. They focus on data from NASA's MESSENGER mission to Mercury, Dawn mission data from Ceres, and ESA's Rosetta Mission to Comet 67P/Churyumov-Gerasimenko. The researchers utilize diverse methods to achieve new results in planetary science, including machine learning and other numerical and theoretical approaches, image interpretation, and polar field studies. The team had some outstanding results from existing awards. For Mercury, one team mapped thrust-related landforms through faults that intersect impact crater rims and found that contractional tectonics may be occurring. Researchers used Deep Impact mission images to produce the first three-dimensional model of a comet. New Rosetta results showed that Jupiter-family comets such as 67P share compositional similarities with Saturn and the ice giants, but not Jupiter. Another study showed that ultraviolet irradiation of hydrogen sulfide ice may create sulfur polymers (S2, S3, S4) found on 67P. The team also supported the post-pandemic restart of experiments in the ice physics laboratory at JPL. One group is determining why the ice on 67P encountered by Rosetta's Philae lander is so hard and whether recrystallized ices or organic cements play a role. Another is showing how enigmatic gullies and other features on Ceres and Vesta form due to the unique properties of brine-freezing after impacts to these bodies.

PLANETARY SMALLSATS

NASA established the Small Innovative Missions for Planetary Exploration (SIMPLEx) Program element to develop and operate targeted science investigations that exploit the unique attributes of small spacecraft to conduct compelling science. These small satellite missions take advantage of available launch capacity on larger missions to reduce the overall costs of launching multiple missions, provide a means to mature technologies for future missions, and serve as additional opportunities to provide flight experience to the workforce. NASA selected three missions from the prior SIMPLEx AO: EscaPADE (in development within the Heliophysics division), Lunar Trailblazer (in development within the LDEP Program) and JANUS, which has recently been demanifested from the Psyche launch (see Janus section above). The project plans to release the next SIMPLEx draft AO in FY 2024.

OTHER MISSIONS AND DATA ANALYSIS

MEGANE

The Mars-moon Exploration with Gamma rays and Neutrons (MEGANE, also Japanese for "eyeglasses") instrument is a gamma-ray and neutron spectrometer currently in development by the Johns Hopkins University Applied Physics Laboratory, as a contribution to the JAXA Martian Moons eXploration (MMX) mission. Planned for launch in 2024, MMX will operate near the Martian moons Phobos and Deimos for approximately three years and return a sample from Phobos to Earth in 2029. MEGANE will measure the bulk composition of the near-surface materials on Phobos to constrain theories for the origin of the moons. It will also map the near-surface materials on Phobos to enable the study of surface processes and support MMX sample site selection.

Recent Achievements

MEGANE will enter Phase D in early 2023 and prepare for spacecraft integration and testing for launch readiness. The team is working through a series of functional and environmental tests and is in the final stages of assembling and testing the flight unit to deliver it to JAXA in summer 2023.

Operating Missions

LUCY

NASA’s Lucy mission launched in October 2021 to explore a diverse population of small bodies known as the Jupiter Trojan asteroids. The Trojans are remnants of our early solar system, now trapped on stable orbits associated with Jupiter. The two “swarms” lead and follow Jupiter in its orbit around the Sun and are almost as numerous as the objects in the Main Asteroid Belt. Over its 12-year primary mission, Lucy will explore a record-breaking number of asteroids, flying by one main belt asteroid and seven Trojan asteroids on a tour that sets another first by being the first mission to traverse from the inner to outer solar system and back as it moves from the leading to trailing swarm.

Solar system formation models suggest that the Trojans are remnants of the same primordial material that formed the outer planets, and thus serve as time capsules from the birth of our solar system over four billion years ago. These primitive bodies hold vital clues to deciphering the history of our solar system and may even tell us about the kinds of organic materials supplied to the early Earth. The Lucy mission is named after the Lucy fossil skeleton of a pre-human ancestor discovered in Ethiopia in 1974. Just as the Lucy fossil provided unique insights into humanity’s evolution, the Lucy mission promises to revolutionize our knowledge of planetary origins.

Lucy's objectives are to determine the properties and history of the Trojan asteroids by mapping their surface geology, measuring their color and composition, and determining their mass and density, as well as searching for satellites and/or rings that might exist.

Recent Achievements

Following a successful launch on October 16, 2021, the spacecraft deployed and unfurled its two large solar arrays. One of the arrays completed its deployment and latched into its taut, secure configuration; but the other did not, remaining partially deployed and unlatched. Engineers conducted an extensive troubleshooting campaign to understand the causes of the anomaly and the risks of either attempting to complete deployment or using the array in the unlatched state. As a result of these studies, the team executed a series of re-deployment attempts (RDAs), taking advantage of redundant motor construction,

OTHER MISSIONS AND DATA ANALYSIS

to try to pull the array further open using twice the amount of torque than was available in the initial deployment. The RDAs brought the array closer to a fully deployed state, increasing the tension in the flexible components and improving the overall strength and stability, but it still did not latch. Engineers and mission leadership are confident, based on analysis and modeling, that the full mission is executable with the array in an unlatched state. Ground testing of flight-like components and modeling will continue in order to determine if additional RDAs stand a good chance of further tensioning the array or latching it.

In the meantime, the science instruments are all commissioned and performing within specifications. The Lucy team used the high-resolution panoramic camera, Lucy Long Range Reconnaissance Imager (L'LORRI), to capture images of the Earth and Moon together as the Moon entered the Earth's shadow during the lunar eclipse on May 15 and May 16, 2002. L'LORRI was also used to observe the binary asteroid Didymos at the time of the DART mission's impact. All of the science instruments successfully executed calibration and test observations of the Earth and Moon during the first Earth gravity assist on October 16, 2022. The first Earth gravity assist puts the spacecraft into an approximately two-year orbit around the Sun in preparation for the second Earth gravity assist in 2024, which will propel Lucy out to its first encounters in the Trojan asteroid swarms.

INSIGHT

InSight is a robotic lander studying the deep interior and other aspects of Mars by measuring its seismic activity and making other measurements from the planet's surface. Launched on May 5, 2018, InSight landed on the surface of Mars at Elysium Planitia on November 26, 2018. NASA approved InSight for a two-year extended mission (EM) in December of 2020 and its second extended mission began in January 2023. Unfortunately, the solar power continued to degrade, and NASA declared the mission completed in December 2022. The mission contributed to understanding the formation of rocky planets, including Earth, by investigating the crust and core of Mars, especially seismic activity generated by tectonic activity. One of the science payload's main instruments, the Seismic Experiment for Interior Structure (SEIS), made precise measurements of quakes and other activity relevant to determining the planet's internal structure.

A second instrument, the Heat Flow and Physical Properties Package (HP3), also known as the Mole, was a heat probe developed and built by the German Aerospace Center (DLR) and designed to burrow into the Martian surface to take the planet’s internal temperature, providing details about the interior heat engine that drives the Mars’ evolution and geology. InSight deployed the probe onto the Martian surface in February of 2019. Unfortunately, this probe was unable to burrow deeply enough into the Martian regolith to meet the heat flow measurement objective, penetrating only 40 cm. The team had to abandon their efforts. It is widely believed that the soil’s unexpected tendency to clump deprived the spike-like mole of the friction it needed to hammer itself to a sufficient depth. The instrument continued to provide measurements of the ground temperature, thermal inertia, and thermal conductivity of the upper half-meter of the Martian soil. InSight also hosted the Rotation and Interior Structure Experiment (RISE) instrument which used InSight's communications (X-band transmission via a low gain antenna directly to DSN) system to provide precise measurements of planetary rotation. The wobble provided insight into the size and composition of Mars' core. Finally, InSight also had wind, temperature, air pressure, and magnetic sensors.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

During FY 2022, Insight researchers detected more than 350 new marsquakes, for a total of more than 850 since the beginning of the mission, including the largest marsquake seen during the entire mission and two confirmed large meteoroid impacts. Using refined location techniques, researchers have now identified nearly 40 marsquake epicenters, with about two-thirds of them located in the Cerberus Fossae region. Scientists used InSight seismic data, including the first observations of surface waves and compressional waves traveling through the core, to refine the thickness of the crust and its global character, the size and density of the core, and layering in the deep mantle. The RISE experiment utilized high-precision tracking data to provide additional constraints on the radius and density of the core. Science teams used multiple observations from InSight instruments to assemble a comprehensive description of the surface geology and stratigraphy of the InSight landing site, providing important constraints on the geologic history of the widespread Hesperian-aged plains on Mars.

Dust has accumulated on InSight's solar panels since the start of operations, progressively reducing available power and ultimately limiting the collection of seismic data. As of December 2022, there was insufficient power to continue any operations and the mission was declared completed. On the chance that an atmospheric event clears enough dust from the panels to allow communications, NASA will continue to monitor for signals from the spacecraft.

STROFIO

Start from a Rotating Field mass spectrOmeter (STROFIO) is a unique mass spectrometer that is part of the suite of instruments flown onboard the joint ESA and JAXA BepiColombo spacecraft, launched on October 20, 2018 and planned to enter Mercury orbit and begin observations in 2025. STROFIO will study and characterize the chemical composition and dynamics of Mercury's thin atmosphere (exosphere). Eight NASA-funded scientists serve as interdisciplinary scientists, guest investigators, or instrument co-investigators on the BepiColombo Science Team. These investigators collaborate with the BepiColombo team on a variety of projects that will improve understanding of both Mercury and Venus, as well their surrounding space environments.

Recent Achievements

BepiColombo is currently in its cruise phase. It has now completed two of six Mercury flyby maneuvers before its planned Mercury orbit insertion in December 2025. The optimization of the STROFIO instrument continues while the spacecraft travels to Mercury. A NASA-funded guest investigator is leading an effort that will bring together data from multiple BepiColombo instruments, including STROFIO, the development of mathematical methods, and the use of existing datasets from NASA's prior MESSENGER mission to study, in three dimensions, the distribution of sodium in Mercury's thin atmosphere.

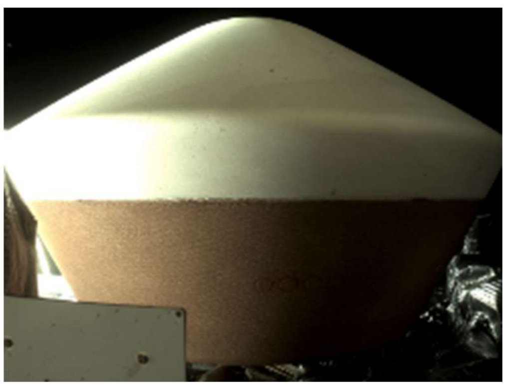
NEW FRONTIERS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Dragonfly	219.1	400.1	**327.7**	355.5	274.8	207.7	24.8
Other Missions and Data Analysis	64.6	--	**79.9**	92.3	111.3	159.6	312.7
Total Budget	**283.7**	**--**	**407.5**	**447.8**	**386.1**	**367.3**	**337.5**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



This image from October 28, 2022, shows NASA's OSIRIS-REx Sample Return Capsule (SRC) after stowing the sample collected from asteroid Bennu. The SRC will return the sample to Earth on September 24, 2023.

New Frontiers Program is a science program of medium-class spacecraft missions that performs high-quality Principal Investigator-led focused scientific investigations. Initiated in 2003, the New Frontiers Program pursues planetary science missions of moderate scope and high scientific priority and value. The program emphasizes competed and peer-reviewed missions accomplished under the leadership of the scientific research community and aligned with the scientific goals of the Planetary Science Decadal Survey.

Since its inception, the program has successfully launched three missions, one to study Pluto (New Horizons), a second to study Jupiter (Juno), and a third to return samples from the Bennu asteroid (Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer [OSIRIS-Rex]). A fourth mission to study the surface of Saturn's moon, Titan, is currently in formulation (Dragonfly).

The program also supports continued research and data analysis from its missions. The annual call for proposals competitively awards research grants based primarily upon their scientific merit. These grants not only broaden participation in the missions, but also deepen our understanding of the science objectives of each mission, produce new discoveries, and train the next generation of scientists.

The New Frontiers 4 Announcement of Opportunity (AO) had a mission cost cap of $850 million, excluding launch vehicle and mission operations costs.

EXPLANATION OF MAJOR CHANGES IN FY 2024

The FY 2024 Dragonfly budget request supports an updated budget profile for a launch readiness date of no earlier than June 2027. NASA has accelerated the New Frontiers 5 AO from 2025 to no earlier than November 2023 to reduce the time between AOs.

NEW FRONTIERS

The New Horizon extended mission will end in 2024. NASA invited the New Horizons team to prepare and submit a Senior Review proposal focused on heliophysics science to extend the mission beyond 2024 and as part of the plan to transition management of the mission to the Heliophysics Division.

The OSIRIS-REx mission will complete its prime operations in FY 2024 and will then enter an extended mission phase under a new project entitled Apophis Explorer. Using the OSIRIS-REx spacecraft, Apophis Explorer will visit the near-Earth asteroid Apophis after its close flyby of Earth in 2029.

ACHIEVEMENTS IN FY 2022

The New Horizons mission continued to downlink data and collect light curve measurements of distant Kuiper Belt objects and characterize the environment of this distant portion of the solar system. NASA approved New Horizons for a second, multi-disciplinary mission extension for two years, through FY 2024, and directed the project to propose for a transition to management under NASA's Heliophysics Division in FY 2025. New Horizons is over 50 times further from the Sun than Earth and is in a unique position to investigate the heliosphere. The New Horizons science team published in over 65 journals, magazines, and newspapers in 2021.

Juno performed nine flybys of Jupiter during FY 2022, including observations of Jupiter's moon Europa in September 2022. These flybys resulted in new measurements of the planet at higher resolution, providing detailed information about Jupiter’s interior structure, internal magnetic field, magnetosphere, and atmosphere (including its polar cyclones and auroras). During its extended mission phase, Juno will continue taking new measurements at higher northern latitudes and observations of Jupiter's moon Io. New details from these additional orbits will build upon the current understanding of the Jovian system resulting from previous NASA missions, such as Voyager, Galileo, and Cassini.

OSIRIS-REx remains in the Earth Return cruise phase of the mission. During this phase, the science team is preparing for the sample analysis stage, which will occur after the Sample Return Capsule (SRC) lands in a Utah desert in September 2023.

Dragonfly continued preliminary design, technology completion, and risk reduction activities throughout FY 2022.

WORK IN PROGRESS IN FY 2023

NASA continues to prepare for the New Frontiers 5 mission competition and released a draft AO for public comment in January 2023. NASA plans for a series of follow-on community announcements in order to continue helping proposers prepare for the final AO release in November 2023.

In addition to continued Jupiter encounters, the Juno mission will begin an observation campaign of Io, the most volcanically active body in the solar system. The spacecraft will conduct close flybys and distant observations of Io's volcanoes.

OSIRIS-REx will return to Earth with samples of the asteroid Bennu on September 24, 2023. The team is working to ensure that the spacecraft and ground support are prepared for this return.

Dragonfly will complete its preliminary design review and, pending successful confirmation by NASA, begin final design and fabrication of the hardware.

NEW FRONTIERS

KEY ACHIEVEMENTS PLANNED FOR FY 2024

NASA will release the final New Frontiers AO in early FY 2024 and plan for proposal reviews to extend into FY 2025.

New Horizons will conclude its extended mission phase at the end of FY 2024. During this extended mission, FY 2023 through FY 2024, New Horizons will investigate the ice giants from a unique perspective, collect astrophysics data related to cosmic background radiation, and help fill key knowledge gaps into superthermal ions in the outer heliosphere and interstellar medium.

The Juno mission will continue its approved extended mission, which continues to study Jupiter and some of its moons that are important in existing scientific studies.

After the entry, descent, and landing of OSIRIS-Rex's SRC, the sample material from the asteroid Bennu will be prepared for distribution and analysis, beginning a new phase of scientific research into these primitive bodies.

Dragonfly will continue its final design in preparation for the mission Critical Design Review (CDR), expected to occur no earlier than March 2024.

PROGRAM SCHEDULE

Date	Significant Event
Q1 FY 2024	Release of New Frontiers 5 AO solicitation
Q2 FY 2024	Proposals due
Q1 FY 2027	Select fifth New Frontiers mission

PROGRAM MANAGEMENT & PLANNED CADENCE

The New Frontiers Program is a multi-project program, with responsibility for implementation assigned to the Planetary Missions Program Office, located at Marshall Space Flight Center (MSFC).

The first three New Frontiers AOs have been released on an average cadence of every six-and-a-half years, and the delay in the Dragonfly launch date has extended the average launch cadence of all four missions in the program to seven years. The AO release and launch for the fifth mission will match this cadence.

ACQUISITION STRATEGY

NASA competitively selects New Frontiers missions, releasing AOs when available funding allows.

INDEPENDENT REVIEWS

NASA will schedule the New Frontier's next Program Implementation Review (PIR) when recommended by the primary stakeholders.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	MSFC	2016	PIR	Successful	TBD

DRAGONFLY

Formulation	Development	Operations

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**219.1**	**400.1**	**327.7**	**355.5**	**274.8**	**207.7**	**24.8**
Change from FY 2023 Enacted			**-72.4**				
Percent change from FY 2023 Enacted			**-18.1%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Shown here is a pair of Dragonfly's co-axial rotors and motors during testing inside the Langley Research Center's (LaRC) transonic dynamics tunnel. The large chamber enables the full-scale Dragonfly rotors to be tested under Titan-representative aerodynamic conditions for different Dragonfly flight modes: hover, descent, and climb.

PROJECT PURPOSE

Dragonfly is a mission to study Titan, the largest moon of Saturn, using a rotorcraft carrying an advanced set of instruments to characterize the surface, atmosphere, and interior from different locations. Titan is a unique world that potentially harbors an interior ocean. Its surface, layered with organic snow on an icy crust possibly shaped by wind and fluvial processes, is important to study because it may be like early Earth, where carbon and nitrogen interacted with water and energy to form life. Through measurements at diverse locations across Titan, Dragonfly will characterize the habitability of Titan's environment; investigate how far pre-biotic chemistry has progressed; and search for chemical signatures indicative of water-based and/or hydrocarbon-based life.

EXPLANATION OF MAJOR CHANGES IN FY 2024

NASA updated the budget profile to reflect updated estimates for a launch readiness date of June 2027.

PROJECT PRELIMINARY PARAMETERS

Dragonfly will launch no earlier than 2027. Upon landing on Titan, Dragonfly will fly to dozens of locations looking for prebiotic chemical processes on Titan, analogous to processes on early Earth. Dragonfly, which has eight rotors and flies like a large drone, marks the first time NASA will fly a multi-rotor vehicle designed to collect science data on another planetary body. It will take advantage of Titan’s dense atmosphere (four times denser than Earth’s) and low-gravity (one seventh that on Earth) to become the first vehicle ever to fly its entire science payload to multiple sites for repeatable and targeted

Formulation	Development	Operations

access to surface materials. It is a scientifically diverse mission that includes an assortment of instruments: the Dragonfly Camera Suite (DragonCam), which is a set of microscopic and panoramic cameras to image Titan's terrain and scout for scientifically interesting landing sites; the Dragonfly Gamma-Ray and Neutron Spectrometer (DraGNS), which consists of a deuterium-tritium Pulsed Neutron Generator and a set of a gamma-ray and neutron spectrometers to identify the surface composition under the lander; the Dragonfly Mass Spectrometer (DraMS), which is an advanced mass spectrometer to identify chemical components in surface and atmospheric samples, especially those relevant to biological processes; and the Dragonfly Geophysics and Meteorology Package (DraGMet), which is a suite of meteorological sensors including a seismometer.

Titan is an analog to the very early Earth and can provide clues to how life may have begun on our planet. During its nearly three-year baseline mission, Dragonfly will explore diverse environments from organic dunes to the floor of an impact crater where liquid water and complex organic materials, key to life, once existed together, possibly for tens of thousands of years. Its instruments will study how far prebiotic chemistry has progressed. They also will investigate the moon's atmospheric and surface properties and its potential subsurface ocean and liquid reservoirs. Instruments will search for chemical signatures suggestive of past or extant life. A multi-mission radioisotope thermoelectric generator will power the Dragonfly rotorcraft.

ACHIEVEMENTS IN FY 2022

Dragonfly successfully completed subsystem and instrument-level preliminary design reviews (PDR) in preparation for the mission-level PDR, which occurred in March 2023. The Dragonfly team conducted all planned graduation flights of the integrated test platform half-scale drone to support PDR. These short to long scout and leapfrog flights were fully autonomous, including take-off and landing. In addition, the project completed the remaining Technology Readiness Level (TRL) reviews, and all items are at TRL-6, which means the project demonstrated the prototypes in a relevant environment.

WORK IN PROGRESS IN FY 2023

Dragonfly will complete its mission-level PDR and complete a confirmation review prior to entering the final design and fabrication phase.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

In FY 2024, Dragonfly will continue to mature its system design and prepare for the mission critical design review (CDR) - the point in a project's development where the system design is complete - which is expected to occur no earlier than March 2024.

ESTIMATED PROJECT SCHEDULE

Dragonfly's project schedule is based on a notional June 2027 launch readiness date.

DRAGONFLY

Formulation	Development	Operations

Milestone	Formulation Authorization Document	FY 2024 PB Request
PDR	N/A	Feb 2023
Key Decision Point-C (KDP-C)	N/A	Spring 2023
KDP-D	N/A	Spring 2026
KDP-E	N/A	Spring 2027
Launch	N/A	Jun 2027

Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

Life cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows the PDR.

KDP-B Date	Estimated Life Cycle Cost Range ($B)	Key Milestone	Key Milestone Estimated Date Range
Jun 2019	2.1 - 2.5	Launch	Jun 2027

Project Management & Commitments

The Principal Investigator is from the Johns Hopkins University Applied Physics Laboratory (APL). APL has project management responsibility for Dragonfly.

Element	Description	Provider Details	Change from Formulation Agreement
Dragonfly Mass Spectrometer	Provides detailed analysis of organic chemistry	Provider: Goddard Space Flight Center (GSFC) Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Dragonfly Gamma-Ray and Neutron Spectrometer	Determines bulk near-surface composition and layering	Provider: APL Lead Center: Marshall Space Flight Center (MSFC) Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Dragonfly Geophysics and Meteorology Package	Measures atmospheric conditions, seismicity, and surface/subsurface properties	Provider: APL Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

DRAGONFLY

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
Dragonfly Camera Suite	Documents landforms and processes; provides context for samples; and performs aerial imaging to scout landing sites	Provider: Malin Space Science Systems Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Drill for Acquisition of Complex Organics Sampling System	Provides pneumatic transfer system and sample acquisition drill	Provider: Honeybee Robotics Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Multi-Mission Radioisotope Thermoelectric Generator	Provides power to the Dragonfly lander	Provider: Department of Energy Lead Center: Glenn Research Center (GRC) Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Cruise Stage	Propulsion stage to get Dragonfly to Titan	Provider: Lockheed Martin Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Entry, Descent, and Landing Assembly	Includes aeroshell, parachutes, and support equipment	Provider: Lockheed Martin Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Dragonfly Lander	Flight system to carry and support the science instruments	Provider: APL Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

DRAGONFLY

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: Dragonfly is not able to secure a test campaign window in the Transonic Dynamics Tunnel (TDT) by mission CDR as planned, Then: Dragonfly Mobility will not have reliable data to demonstrate flight performance for mission CDR, causing a schedule slip.	The project continues to work with NASA Langley Research Center and Headquarters personnel to schedule the Dragonfly test to a timeframe in 2023 that would mitigate the risk, which is contingent upon the TDT remaining at full operations. Identifying any potential impacts to subsystem CDR readiness is part of this assessment.
If: The Dragonfly lander mass grows beyond the capabilities of the current mobility drive train, Then: The mission requirements for range and vertical profiling will not be met within the current concept of operations and mission duration.	The lander's integrated mechanical-thermal-mobility structure continues to evolve, and the project continues to work on a preliminary design. This includes working on a single-string lander approach and a survey/implementation of mass reduction opportunities.
If: Industry supply chain delays persist or worsen, Then: Significant project-level schedule delays will occur.	The project is continuing to assess immediate procurement needs and when possible, accommodating delays by ordering parts/materials/components further in advance. In addition, the project is reviewing parts and materials to potentially identify substitute items with shorter lead times as well as examining designing out those with the longest lead times.

Acquisition Strategy

NASA competitively selected the mission through the New Frontiers 4 Announcement of Opportunity (AO), and the final down selection was in June 2019. The major elements of the mission and spacecraft are as proposed to the AO.

DRAGONFLY

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
PI; Science Co-Is; Mission Management; Lander Development; DraGMet; DraGNS; System I&T; Science Operations; and Mission Operations	APL	Laurel, MD
Cruise Stage; Entry, Descent, and Landing (EDL) Assembly; and I&T Support	Lockheed Martin	Denver, CO

INDEPENDENT REVIEWS

All dates are preliminary and subject to change.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	Feb 2023	PDR	TBD	Critical Design Review (CDR)
Performance	SRB	Mar 2024	CDR	TBD	System Integration Review (SIR)
Performance	SRB	Apr 2026	SIR	TBD	Operational Readiness Review (ORR)
Performance	SRB	Mar 2027	ORR	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Apophis Explorer	0.0	--	**14.5**	15.8	19.9	22.1	31.0
New Frontiers Future Missions	0.5	--	**0.0**	35.6	74.0	128.0	272.0
New Frontiers Research	10.4	--	**10.5**	9.3	9.3	9.5	9.7
Origins Spectral Interpretation Resource	12.5	--	**16.8**	5.4	0.0	0.0	0.0
New Horizons	9.5	--	**9.7**	0.0	0.0	0.0	0.0
Juno	31.8	--	**28.4**	26.2	8.1	0.0	0.0
Total Budget	**64.6**	**--**	**79.9**	**92.3**	**111.3**	**159.6**	**312.7**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Observations from Juno's pass of the Jovian moon Europa, shown here, in September 2022 provided the first close-up of this ocean world in over 20 years, since the Galileo mission, resulting in remarkable imagery and unique science. Europa and Ganymede are targets of two upcoming missions by NASA (Europa Clipper) and ESA (Jupiter Icy Moons Explorer). Credit: Caltech/SwRI/MSSS

New Frontiers Other Missions and Data Analysis includes support for three operating missions: New Horizons; Juno; and Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx), analysis of data from these missions, and preparation for future missions.

Mission Planning and Other Projects

NEW FRONTIERS FUTURE MISSIONS

New Frontiers Future Missions supports technology development for future missions and provides the funding required for the next Announcement of Opportunity (AO). NASA will accelerate the next AO from 2025 and release it no earlier than November 2023.

NEW FRONTIERS RESEARCH

New Frontiers Research funds analysis of archived data from New Frontiers missions, as well as participating scientists and selected members of the research community, who augment and enhance the science teams of New Frontiers missions. New Frontiers Research provides the research community access to data and samples, enabling research to continue for many years after mission completion. Participating scientists bring new ideas to mission teams and frequently provide a pathway for early career investigators to gain experience with planetary missions. This program supports efforts to maximize science return from each of the missions. NASA solicits planetary research proposals from the U.S. planetary science community and evaluates them for selection through competitive peer review. NASA will select new research in FY 2023 using the New Horizons mission data returned from the Pluto system and beyond, Juno mission data returned from Jupiter, and OSIRIS-REx mission data returned from the asteroid Bennu.

NASA will make selections early in 2024 from the New Frontiers Data Analysis program proposals solicited for funding in FY 2023.

Recent Achievements

The New Frontiers Data Analysis program element competitively selected and awarded seven new science investigations. These included studies to explore the origin of complex organic material in the Pluto-Charon system seen by the New Horizons mission, to understand the nature of the Jupiter's cloud layers observed by NASA's Juno mission, and to explore the unexpected ejection of rocks from the surface of asteroid Bennu, as observed by NASA's OSIRIS-REx mission.

The Juno participating scientist program element competitively awarded 10 new investigations. The principal investigators of new studies will join the Juno team to conduct their experiments as it flies its extended mission through the Jovian system.

The OSIRIS-REx participating scientist program element competitively awarded eight new investigators to join the OSIRIS-REx team to perform laboratory analysis of samples from the asteroid Bennu, which the spacecraft will return to Earth with September 2023.

Operating Missions

NEW HORIZONS

New Horizons is the first scientific investigation to obtain close observations of Pluto and its moons, Charon, Nix, Hydra, Kerberos, and Styx. Scientists discovered the last four moons after the spacecraft launch in January 2006. It successfully encountered Pluto on July 14, 2015 and completed downloading of the primary science observations of the plutonian system in October 2016. The mission is currently in extended operations through September 2024. NASA invited the New Horizons team to prepare and submit a Senior Review proposal focused on heliophysics science to extend the mission beyond 2024 and as part of the plan to transition management of the mission to the Heliophysics Division.

In January 2019, New Horizons visited the Kuiper Belt Object (KBO) Arrokoth, 2014 MU69, found eight years after launch using the Hubble Space Telescope. Arrokoth is in a region approximately two billion miles beyond Pluto's orbit and is the most unaltered piece of early solar system ever explored by a spacecraft. Research thus far indicates it likely formed through a gentle, low speed merger of two objects that spiraled towards each other as they orbited one another. Scientists aim to find answers to basic questions about the surface properties, geology, interior makeup, and atmospheres of these bodies, and their relationship to solar system formation.

Recent Achievements

New Horizons is approximately 54 astronomical units from the Sun, which is more than 5 billion miles, making it one of few missions with such a large suite of instruments to reach this enormous distance from our home planet. From June 2022 through March 2023, the New Horizons spacecraft will stay in hibernation to save spacecraft consumables, yet it will continue to collect data on its space environment and explore this never before visited area of our solar system. The project continues to gather data on the plasma environment of the Kuiper Belt and to obtain light curves of distant KBOs. The New Horizon's mission team recently installed a new, more sensitive filter at the Japanese Subaru telescope in Hawai'i to further support the ground-based search to find additional KBOs. The team has integrated machine learning techniques into their search processing pipelines to improve the quality and speed of the KBO search.

Mission team findings published on Pluto's moon, Charon's, red cap and possibly Pluto ice volcanoes have provided even greater insight into processes that have shaped the Pluto heart-shaped basin, Sputnik Planitia. The New Horizons science team increased their annual publication rate from approximately 25 per year to over 65 publications in 2021.

JUNO

Juno has transformed our view of Jupiter, the most massive planet in the solar system, through significant discoveries about its atmospheric dynamics and composition, interior structure, origin, and evolution. Juno launched on August 5, 2011 and entered Jupiter's orbit on July 4, 2016. The project recently celebrated its 11th launch anniversary, and the spacecraft is in its seventh year of operations in the Jovian system. Juno’s state-of-the-art instruments gather information from deep in Jupiter’s atmosphere, enabling scientists to unveil the planet's properties beneath its top cloud layer. Juno began its extended mission phase in August 2021 and continues investigations through September 2025, including close passes of Jupiter’s north polar cyclones; flybys of the moons Ganymede, Europa, and Io; and the first examination of the faint rings encircling the planet.

Recent Achievements

Juno has completed 45 of 76 planned orbits around Jupiter, which currently last 38 (previously 43) days since the close flyby of Jupiter's moon Europa in September 2022. Following a close flyby of Jupiter's moon Io in December 2023, the spacecraft will transition to its final 33-day orbit configuration.

During FY 2022 science operations, Juno continued sampling Jupiter’s full range of latitudes and longitudes during polar orbits and captured details no other mission has captured before, including those from the Jovian moons Ganymede and Europa. Key objectives of the close Europa flyby (at approximately 350 km altitude) enabled new observations with JunoCam and the Stellar Reference Unit (SRU) of the icy surface. Observations of Europa's unlit (leading) hemisphere provided high-resolution images at 1 km per pixel with the SRU. Detailed images of the sunlit (trailing) hemisphere from JunoCam revealed more features of the Annwn Regio and a global shot of the trailing side. Finally, scientists are continuing to analyze Microwave Radiometer observations which scanned the upper approximately10 km of Europa's ice shell to characterize variations in thickness and identify regions of subsurface water. Juno’s unique polar views and close-ups of Jupiter and its moons are building upon observations by NASA’s previous explorers, Voyager, Galileo, and New Horizons.

Data from the Ganymede flyby in July 2021 will result in 26 scientific papers, including 23 papers in Geophysical Research Letters and Journal of Geophysical Research, and three papers in the journal Science.

OSIRIS-REX

OSIRIS-REx is the first U.S. mission to bring a sample from an asteroid back to Earth. The OSIRIS-REx spacecraft traveled to Bennu (asteroid 101955), a near-Earth carbonaceous asteroid formerly designated

1999 RQ36, studied the asteroid in detail, and is bringing a sample (at least 60 grams or 2.1 ounces) back to Earth. Analysis of this sample by current and future generations of scientists will yield insight into planet formation and address questions yet to be formed. The data collected at Bennu will aid in further understanding asteroids that could collide with Earth. In addition, the mission will measure the Yarkovsky effect on a potentially hazardous asteroid and determine the asteroid properties that contribute to this effect. The Yarkovsky effect is a small force on an asteroid caused by the Sun as the asteroid absorbs sunlight and re-emits that energy into space as heat.

OSIRIS-REx launched on September 8, 2016 and arrived at Bennu on December 3, 2018. The mission globally mapped the surface from distances of less than half a mile to about three miles. The spacecraft cameras and instruments photographed the asteroid and measured its surface topography, composition, and thermal emissions. Radio science provided mass and gravity field maps. This information helped the mission team select the most promising locations to collect a sample of pristine asteroid material. On October 20, 2020, the OSIRIS-REx spacecraft successfully descended to the surface of Bennu, contacted the surface, collected a sample, and backed away. Following analysis of the sampling head, NASA determined that the spacecraft had likely collected an adequate amount of material and then stowed the sample for secure return to Earth. The spacecraft then conducted a post sampling reconnaissance pass over the sample site, and successfully executed the Asteroid Departure Maneuver, placing the spacecraft on an Earth return trajectory. To deliver the sample to Earth, OSIRIS-REx has a capsule similar to the one that returned the sample of Comet 81P/Wild on the Stardust spacecraft.

Recent Achievements

OSIRIS-REx will be on its return cruise through most of FY 2023. On September 24, 2023, the capsule containing pieces of Bennu will separate from the rest of the spacecraft and enter Earth’s atmosphere, where it will parachute to the Utah Test and Training Range in Utah's West Desert and be retrieved for curation and study. The team has already performed several curation and sample return analysis rehearsals to implement once the sample arrives on Earth.

OSIRIS-REx underwent its Planetary Mission Senior Review process in the spring of 2022, including an extended mission proposal to visit the near-Earth asteroid Apophis after its close Earth flyby in 2029. NASA officially extended OSIRIS-REx in April 2022 with a new name, Apophis Explorer, to reflect the extended mission’s new goals. It will explore Apophis, an asteroid roughly 1,200 feet (370 meters) in diameter that will come within 20,000 miles (32,000 kilometers) of Earth. Apophis Explorer will enter orbit around Apophis soon after the asteroid’s Earth flyby in 2029. After providing a wealth of information on a carbonaceous asteroid during its exploration of Bennu, the new project will provide an unprecedented close-up look at a stony S-type asteroid. During 15 months of orbital operations, Apophis Explorer will study changes in the asteroid caused by its close flyby of Earth, determine the mass and structure of Apophis, and perform high-resolution global spectral mapping to determine the composition of the asteroid and identify any volatiles on its surface. The mission will also search for signatures of mass shedding, whether due to the tidal encounter with Earth or an episodic process like that observed at Bennu. At the end of orbital operations, the spacecraft will fire its gas thrusters to dislodge and study the dust and small rocks on and below the surface of Apophis.

MARS EXPLORATION

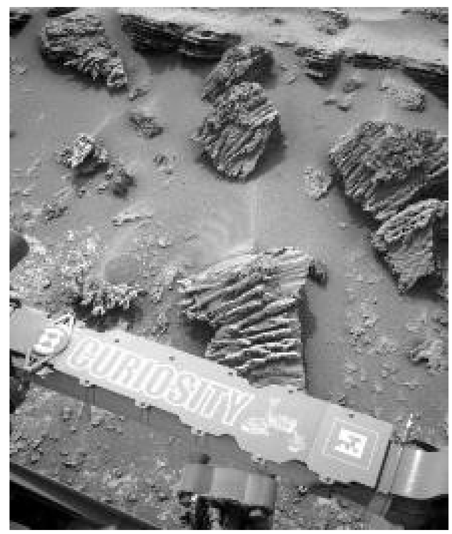
FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Other Missions and Data Analysis	265.0	--	**268.6**	279.2	311.6	315.3	367.2
Total Budget	**265.0**	**--**	**268.6**	**279.2**	**311.6**	**315.3**	**367.2**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The Mars Exploration Program seeks to understand when Mars may have had habitable conditions for microbial life, whether Mars has supported microbial life in the past or today, and the extent to which Mars could be a habitable world for humans in the future. As the most Earth-like planet in the solar system, Mars has a landmass approximately equivalent to the Earth's, as well as ancient remnants of many of the same geological features (e.g., such as riverbeds, river deltas, and volcanoes). Mars also has many of the same "systems" that characterize Earth (e.g., air, water, ice, and geology) and interact to produce the Martian environment. Mars also has fundamental differences from Earth including the lack of a global magnetic field and chaotic changes in the orientation of its spin axis over tens of millions of years, which have affected its environment.



This image is from the Mars Curiosity Left Navigation Camera and was taken on Sol 3639. The rocks in this image have interesting layering and the features in these rocks may have been formed by physical or chemical processes and hint at a changing landscape in Gale Crater. Positioning the rover to safely take measurements with its robotic arm required expert maneuvering from rover drivers. Credits: NASA/JPL-Caltech.

Individual orbital and landed robotic missions have progressively built on the discoveries of each mission, all collectively guided by four broad, overarching goals for Mars Exploration:

- Determine if life ever arose on Mars;
- Characterize the climate of Mars;
- Characterize the geology of Mars; and
- Prepare for human exploration.

Today, our robotic scientific missions are paving the way for a future in which humans and robots will together explore Mars and the solar system.

EXPLANATION OF MAJOR CHANGES IN FY 2024

This budget assumes the Mars Odyssey spacecraft will run out of fuel by 2025. NASA will reassess the fuel status periodically and adjust the budget, if necessary, in future years. The Mars Rover 2020 prime mission ended in January 2023 and this budget supports an increase for extended operations.

MARS EXPLORATION

NASA has significantly expanded support for the ESA Rosalind Franklin ExoMars Rover mission, which was formerly a partnership between ESA and Russia. In addition to the Mars Organic Molecule Analyzer (MOMA) contribution, NASA contributions may include radioisotope heater units, a launch service, and throttled landing engine elements, which will replace the Roscosmos launch and portions of the rover lander.

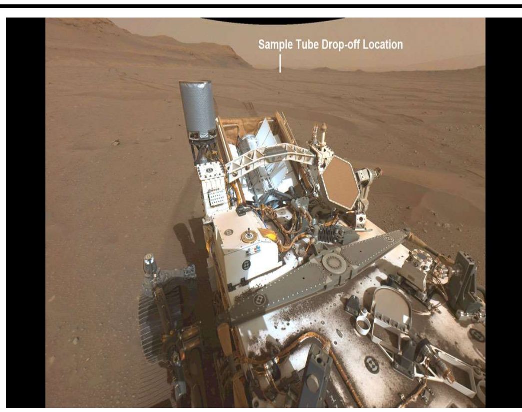
OTHER MISSIONS AND DATA ANALYSIS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Mars Organic Molecule Analyzer (MOMA)	3.4	--	**0.2**	0.0	0.0	0.0	0.0
Mars Rover 2020	109.6	--	**85.0**	80.5	82.0	82.5	83.0
Trace Gas Orbiter - ExoMars	2.0	--	**2.0**	2.0	2.0	2.0	2.0
Mars Program Management	11.8	--	**6.9**	13.2	15.3	13.3	13.5
Mars Future Missions	6.9	--	**49.9**	68.5	108.4	118.8	177.4
Mars Mission Operations	6.7	--	**5.5**	5.5	5.6	5.4	5.4
Mars Research and Analysis	15.1	--	**15.7**	15.7	15.7	15.7	15.7
Mars Technology	9.1	--	**3.0**	3.0	3.0	3.0	3.0
2011 Mars Science Lab	43.3	--	**40.5**	35.0	30.0	25.0	20.0
Mars Reconnaissance Orbiter 2005 (MRO)	24.4	--	**25.6**	25.4	25.4	25.4	25.0
Mars Odyssey 2001	10.6	--	**11.0**	6.2	0.0	0.0	0.0
Mars Express	0.0	--	**0.3**	0.3	0.3	0.3	0.3
Mars Atmosphere & Volatile EvolutioN	22.0	--	**23.0**	24.0	24.0	24.0	22.0
Total Budget	**265.0**	**--**	**268.6**	**279.2**	**311.6**	**315.3**	**367.2**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



This annotated image from NASA’s Perseverance Mars rover shows its wheel tracks in Jezero Crater and a distant view of the first potential location it could deposit a group of sample tubes for possible future return to Earth. The image was taken on August 29, 2022, by Perseverance’s navigation camera. Credit: NASA/JPL-Caltech.

Other Missions and Data Analysis includes mission planning and management, small missions in development, research and technology activities, funding for future Mars missions, and Mars operating missions. The operating projects include Mars Science Laboratory (MSL), Mars Reconnaissance Orbiter 2005 (MRO), Mars Odyssey 2001, Mars Express, Mars Atmosphere and Volatile Evolution (MAVEN), and Mars Rover 2020.

Mission Planning and Other Projects

MARS ORGANIC MOLECULE ANALYZER (MOMA)

The Rosalind Franklin ExoMars Rover mission is the second of the European Space Agency (ESA) ExoMars missions and will carry the "Rosalind Franklin" rover to

OTHER MISSIONS AND DATA ANALYSIS

the surface of Mars. MOMA is the core astrobiology instrument on the rover, and it addresses the top ExoMars science goal of seeking signs of past or present life on Mars. NASA provided the MOMA-Mass Spectrometer (MOMA-MS), a subsystem of MOMA. It is primarily a dual-source mass spectrometer, including laser desorption capability, used to detect a wide-range of organic molecules in Martian samples. Organic structure and distribution can be indicators of past or present life. ESA moved the launch date from 2022 to 2028. The delay was based on the decision to exclude the use of any Russian mission components and, therefore, reconfigure the mission and redesign associated hardware.

Recent Achievements

NASA conducted final integration of the MOMA instrument into the Rosalind Franklin rover and supported systems-level testing of the rover in preparation for launch operations. Following those activities, ESA postponed the launch of the Rosalind Franklin mission to 2028.

MARS PROGRAM MANAGEMENT

Mars Program Management provides for the broad-based implementation and programmatic management of the Mars Exploration Program. Mars Program Management also supports independent review panels, planetary protection studies, advanced mission and program architecture studies, program science, and telecommunications coordination and integration.

MARS FUTURE MISSIONS

Mars Future Missions supports the planning and design studies for a future sample facility for samples returned from the Mars Sample Return Program as well as NASA contributions to the ESA Rosalind Franklin ExoMars mission. For the sample return project, NASA requires a Biosafety Level-4 (BSL-4) rated facility and studies now underway will guide the decision on what form the facility will take. NASA is exploring various options, including the possibility of utilizing existing Government facilities. NASA and ESA are currently working to define NASA contributions to provide replacements for some of the previous Roscosmos mission elements on the Rosalind Franklin ExoMars mission, including radioisotope heater units, a launch service, and throttled landing engine elements.

MARS MISSION OPERATIONS

Mars Mission Operations provides management and leadership for the development and operation of Mars multi-mission systems for operations. Mars Mission Operations supports and provides common operational systems and capabilities at a lower cost and risk than having each Mars project produce systems individually.

MARS RESEARCH AND ANALYSIS (R&A)

Mars R&A provides funding for research and analysis of Mars mission data to understand how geologic, climatic, and other processes have worked to shape Mars and its environment over time, as well as how they interact today. The project has invested in Mars data analysis capabilities to analyze archived data collected from Mars missions, as well as critical products that provide data and analyses for the safe arrival, aero-maneuver, entry, descent, and landing on Mars.

OTHER MISSIONS AND DATA ANALYSIS

Data analysis through Mars R&A enables a much broader and objective analysis of the data and samples. It also allows research to continue for many years after mission completion. These research projects increase our scientific understanding of Mars' past and present environments and disseminate the results through the scientific publications. By using data collected by spacecraft, researchers can make scientific discoveries and test hypotheses about the Martian environment.

Recent Achievements

Recently published papers have provided significant new information on a multitude of research areas. Examples include:

- Analysis of images and spectroscopy measurements from several Mars missions provided new insight into the possibility of explosive volcanic deposits in the Elysium Planitia region.
- A paper using Mars R&A data demonstrated that individual dust storms can boost planetary hydrogen loss by a factor of five-to-ten. The significance of the storms and resulting hydrogen loss is that similar regional storms occur in most Martian years and these storms may be responsible for a large fraction of Martian water loss and represent an important driver of Mars atmospheric evolution.
- A small ice deposits study found that the ice deposit in Burroughs Crater contains particularly clear evidence that changes over the past 4 million years in the planet's orbit and axial tilt strongly control Martian climate.

MARS TECHNOLOGY

Mars Technology focuses on technological investments that lay the groundwork for successful future Mars missions, such as: entry, descent, and landing capabilities; science helicopter capability (scale-up from Ingenuity to support science instruments); Mars ascent vehicle components; sample handling and processing technologies; and surface-to-orbit communications improvements.

Recent Achievements

Some FY 2022 achievements include progress developing key technologies needed for handling samples returned from Mars within double-walled isolation cabinets. These cabinets will ensure safety of the samples and researchers performing analysis on these samples. The technology team is testing components of a new low-cost landing system. The system uses a deployable, subsonic drag skirt and a crushable energy absorption device to reduce descent velocity and absorb the impact of landing on Mars without the cost of a traditional parachute. The team is also testing a power tool with the capability to drill into the Martian subsurface up to 100 meters. The drill will sit on the surface and obtain power by compressed carbon dioxide from the Martian atmosphere.

Prior investments in Mars technology resulted in the hugely successful Mars Helicopter technology demonstration. The Ingenuity helicopter technology demonstration goal was to take five flights in 30 Martian days. Ingenuity transitioned from a pure technology demonstration to operations and has now survived more than 533 Martian days and completed over 30 successful flights. Ingenuity is performing scouting missions for Perseverance that significantly optimize the exploration of Jezero crater and create valuable time savings in performing Mars science.

OTHER MISSIONS AND DATA ANALYSIS

Operating Missions

MARS ROVER 2020

NASA's Mars 2020 Perseverance rover advanced one of the top scientific priorities detailed in the National Research Council's Planetary Science and Astrobiology Decadal Survey 2023-2032, initiating the first leg of a round trip to Mars to return samples to Earth for further study. Perseverance is characterizing the planet's geology and past climate, searching for signs of ancient microbial life on Mars, collecting and storing carefully selected rock and sediment samples, and testing new technologies to benefit future robotic missions and paving the way for human exploration of Mars. Subsequent NASA missions, in cooperation with ESA, would send spacecraft to Mars to retrieve the sealed samples collected by Perseverance from the surface of Mars and return them to Earth for in-depth analysis.

The Perseverance rover is carrying a competitively selected science and technology payload of seven instruments. Five of the instruments provide the clearest possible measurements for seeking possible signs of ancient life (potential "biosignatures") on Mars over its 4.6-billion-year history. The remaining two instruments assess environmental hazards and resources for future human exploration. Perseverance also ferried a helicopter named Ingenuity, the first aircraft to achieve powered, controlled flight on another planet. The Mars Rover 2020 mission incorporates new capabilities developed through investments by NASA's Space Technology Mission Directorate and Deep Space Exploration Systems Mission Directorate and payload contributions from international partners.

Recent Achievements

The Perseverance rover completed its initial science campaign, known to the science team as the crater floor campaign, within Jezero Crater. The campaign enabled the team to determine that rocks in the initial landing area and surrounding terrain are composed of extrusive basaltic lavas. These eight rock core samples collected are igneous in origin and when returned to Earth will help scientists determine the absolute age of the rocks in the area and a maximum date on the age of the delta deposits that sit atop them. These rocks also show signs of a minimal amount of alteration by the action of liquid water. Better understanding the nature of this alteration will help scientists determine the amount of water present during that process and possibly the chemistry of the fluids responsible. Researchers detailed results of the crater floor campaign in a set of scientific papers published in the journals Science and Science Advances. Additional papers involving other instruments onboard Perseverance, such as weather investigations, In-Situ Resource Utilization (ISRU) technology demonstration, and microphones, have appeared in other widely read journals.

After wrapping up the crater floor campaign, Perseverance drove 4.8 kilometers toward the crater's ancient river delta deposits. During the drive, the rover team set new speed records for traversing across the Martian surface by maximizing the auto navigation software developed for the mission. The team also set a new Martian record for the longest distance covered during a single sol, or Martian day. Upon reaching the delta deposits, the science team began the delta front campaign. This campaign explored the easternmost portion of the ancient river delta and investigated the complex layering of the sedimentary rocks that resulted from the deposition of sands, muds, and larger blocks of material by the river into the ancient crater-hosted lake. Analyses with the on-board instruments have shown the presence of organic molecules in a number of the rocks. The science team is currently working to determine the implications of the presence of the organic molecules in these rocks. The rover collected seven additional rock core samples and two regolith samples during this initial exploration of the delta.

OTHER MISSIONS AND DATA ANALYSIS

At the conclusion of the delta front campaign, the rover will have collected a total of 15 rock cores, two regolith samples, one atmospheric sample, and used three of its witness tubes, which are used to determine the amount of terrestrial contamination introduced during sample collection. The science team, in coordination with the Mars Sample Return Program, has successfully guided Perseverance to drop ten Martian samples (rock, regolith and atmosphere), forming a cache on the surface at the "Three Forks" location in Jezero Crater for potential retrieval by the future Mars Sample Return mission. Perseverance collected rock core and regolith samples in pairs so that this initial cache consists of one of each of the paired samples, with the remaining sample-pair left on board the rover for later caching with future samples.

Additionally, the Ingenuity helicopter continued in its extended operations demonstration phase, providing scouting support to the Perseverance mission.

TRACE GAS ORBITER - EXOMARS

The first mission in the ESA ExoMars Program is the 2016 ExoMars Trace Gas Orbiter (TGO), which launched in March 2016 and began its science and relay operations phase in March 2018 with the observations of a global dust storm. For this mission, NASA contributed two Electra ultra-high frequency (UHF) telecommunication radios, identical to those used successfully on NASA's MRO and MAVEN. The Electra radio acts as a communications relay and navigation aid for surface assets and supports navigation, command, and data-return needs for Martian landers and rovers. Furthermore, two instruments, the Colour and Stereo Surface Imaging Systems (CaSSIS) and the Nadir and Occultation for MArs Discovery (NOMAD) have provided significant contributions from U.S. co-investigators.

Recent Achievements

The NOMAD high-resolution spectrometer has permitted one of the most sensitive searches for organics in the atmosphere to date. Scientists, including U.S. co-investigators, recently discovered a new species of organics and designed a three-dimensional view of the water cycle and its isotopes on Mars using the NOMAD. This three-dimensional view is critical to determining present and past habitability on Mars.

The CaSSIS camera, with significant participation from U.S. co-investigators, continues its imaging of the surface and has now made more than 33,000 images, including more than 3,000 stereo observations. The stereo observations synthesize three-dimensional landscape models of the surface of Mars, while CaSSIS color distinguishes surface materials at high-resolution.

The ExoMars Trace Gas Orbiter, using the NASA-contributed Electra radio, continues relaying over 55 percent of the science data and images from NASA's Curiosity rover, InSight lander, and Perseverance rover. This highly successful international collaboration has proven key to achieving the mission objectives of Perseverance:

- Helping enable the collection of rock samples on the surface of Mars as part of the Mars Sample Return campaign;
- Aiding command and telemetry data transfers with the Ingenuity helicopter; and
- Returning a vast number of images to engage with and excite the public.

OTHER MISSIONS AND DATA ANALYSIS

2011 MARS SCIENCE LAB (MSL)

MSL and its Curiosity rover, which successfully landed in August 2012, completed its prime mission exploration activities in 2014. Now in extended mission, the Curiosity rover is exploring and quantitatively assessing regions on Mars as potential past habitats for life and has determined that Mars, at least at one point in time, was able to support microbial life. The Curiosity rover is collecting Martian soil and rock samples and analyzing them for organic compounds and environmental conditions that could have supported microbial life, and measuring the Martian atmosphere, the radiation environment, and the weather. MSL is the first planetary mission to use guided entry landing techniques, steering itself toward the Martian surface. This landing method enabled the rover to target, and successfully land, in an area less than 12 miles in diameter, about one-sixth the size of previous landing zones on Mars. This landing system is the basis of the system architecture for the Mars 2020 mission and enabled the targeting of the more challenging terrain in Jezero crater.

Curiosity is the first planetary rover to make use of a nuclear power source, which gave the rover the ability to travel up to 12 miles during the two-year primary mission.

Recent Achievements

In its 10 years on the surface of Mars, Curiosity has traveled over 18 miles (29 kilometers) and climbed over 2,000 feet (620 meters) in elevation exploring the lower reaches of Mount Sharp, the prime science target of the mission. Curiosity is now in its fourth extended mission period. Over the course of this extended mission, the rover is closely investigating the "sulfate-bearing unit" and increasingly younger geological layers as it continues its ascent through the Marker Band Valley and Gediz Vallis Channel of Mount Sharp. Each unit represents a distinct ancient environment, or change in environment, and each has the potential for groundbreaking advances in understanding Mars' ancient climate. Research suggests that the "sulfate-bearing unit" appeared during a time when Mars was drying out, providing a record of when the planet was becoming the cold-dry Mars of today. Curiosity recently drilled its 36th core in the sulfate-bearing unit on Mount Sharp and it may indicate a regional or global change from a wetter to a drier climate. Science results over the life of the mission include over 500 peer-reviewed publications from the mission team and over 300 peer-reviewed publications from the broader science community. In FY 2022, the Curiosity team selected a new participating scientist class and published a special issue on results from the campaign in Glen Torridon with an analysis of data on 13-Carbon, total organic carbon, and the impact of local terrain on the radiation environment.

Overall, the rover is healthy and operating nominally during this mission extension. The rover team is closely monitoring the condition of the wheels, which have driven well beyond their expected design distance. To date, five grousers have broken on the left middle wheel and a single grouser has broken on the right middle wheel. This level of wear is consistent with wear trending and system predictions. Given the current distance driven and wheel condition, the estimated life expectancy for the total wheel is 26 miles (42 kilometers) and sufficient for the full extended mission.

MARS RECONNAISSANCE ORBITER 2005 (MRO)

MRO, currently in its sixth extended operations phase, carries the highest resolution camera orbiting another planet, the High-Resolution Imaging Science Experiment (HiRISE). This capability yields a more detailed view of the geology and structure of Mars and is critical in identifying obstacles that could jeopardize the safety of future landers and rovers. A second camera, the Context Camera (CTX), acquires medium-resolution images that provide a broader geological context for the more detailed observations

OTHER MISSIONS AND DATA ANALYSIS

from higher-resolution instruments; it has covered most of the planet and searches for new phenomena, such as new impact craters, revealing subsurface ice. MRO also carries a radar sounder to find subsurface water ice, which is an important consideration in selecting scientifically worthy landing sites for future exploration.

MRO carries a high-resolution imaging spectrometer, the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM), which could map minerals at unprecedented spatial resolution. However, in FY 2022, the CRISM instrument ceased operations as its cryocoolers could no longer maintain the low temperatures required by its detectors for mineral mapping. A wide-angle camera, the Mars Color Imager (MARCI), continues to provide daily global weather maps, and the Mars Climate Sounder (MCS) maps the vertical distribution of temperature, dust, and water vapor ice around the globe. MRO will extend HiRISE operations and reveal new images of mineral deposits and the three-dimensional structure and content of the polar ice and subsurface ice; characterize the episodic nature of great dust storms; and expand coverage and quantification of active surface change on Mars today.

MRO characterized the landing sites for the Mars 2020 Rover and the ESA ExoMars Rover.

As it explores Mars, MRO also serves as a major element of an “interplanetary Internet,” as a relay communications orbiter relaying commands to and data from the MSL Curiosity and Mars 2020 Perseverance rovers and the InSight lander to Earth. In FY 2022, MRO continued to characterize phenomena on the surface of Mars, such as dust storms and the Recurring Slope Lineae (RSL). The RSL are linear features that form and grow during warm seasons and fade and often completely disappear during colder seasons but recur over multiple Martian years.

Recent Achievements

FY 2022 marked the final year of MRO's fifth extended mission. As in recent Martian years, the MARCI weather camera and MCS atmospheric sounder observed three regional dust storms (last observed in September 2022). However, MRO also detected one well before the usual southern spring and summer "great dust storm" season. Collaborative research proves that in any given Martian year, these regional dust storms more than double the water vapor lost to space, compared to the non-storm seasons.

MRO and InSight linked specific impact craters to some of the strongest seismic signals initially detected by InSight, which improved knowledge of the crustal internal structure traversed by the impact-generated seismic and acoustic waves.

Increased HiRISE observations suggest that tracks on RSL are due to dry sand or dust flows triggered by seasonal dust activity and not due to water. The extent of modern surface change has been surprising and MRO data indicates that in addition to the dust activity, wind and carbon dioxide frost/ice also reshape today's Martian surface.

Final CRISM operations in FY 2022 produced improved mineral maps by reprocessing existing data. These maps are now providing new observation targets for HiRISE. CRISM completed production of a 180 meter/pixel multi-spectral map that enables much-improved mineral detection. For example, the CRISM map shows crystalline ferric minerals are widespread in multiple environments and indicates crustal hydrous minerals may contain the equivalent of a global layer of water 100-300 meters thick (.06 to 0.2 miles). CRISM also completed data collection for a new, nonpolar, spectral map showing mineralogical variations across the surface of Mars.

The MRO Shallow Radar (SHARAD) provided new data on layered deposits at both the south and north poles by using denser radar coverage and greatly improved three-dimensional imagery. Using its Context

OTHER MISSIONS AND DATA ANALYSIS

Camera, SHARAD also mapped sedimentary deposits (alluvial fans) at the poles, which indicated that water activity continued well past the Noachian period of valley networks (as early as approximately two and up to approximately 3.7 billion years ago).

MARS ODYSSEY 2001

Mars Odyssey, currently in its ninth extended mission operations phase, continues in orbit to explore Mars with its powerful set of instruments, and provides a key element of the communications infrastructure for landed assets. During its unique early-morning pass, Odyssey's Thermal Emission Imaging System (THEMIS) observes frost, clouds, and fogs that no other orbiter can see. It sends information to Earth about Martian geology, climate, and mineralogy. Odyssey measurements enable scientists to create maps of minerals and identify regions with near-surface water associated with hydrated minerals or ice. Observations that measure the surface temperature provide spectacular images mapped onto Martian topography. Mars Odyssey will continue critical, long-term longitudinal studies of the Martian climate. Odyssey's unique late-afternoon pass allows rover planners to assess a full day of data before preparing and sending new commands. Odyssey has served as an essential link in communications between Earth and NASA's surface assets on Mars for nearly two decades. It has provided crucial relay support for the InSight lander during its entire mission since its landing in November 2018 and continues daily contacts with NASA's rovers.

Recent Achievements

Odyssey team scientists continued to study the details of Martian weather and climate, revealing current cycles of water and dust, and mapping terrains that once were potentially hospitable to life. Over the past year, Odyssey team members published 10 peer-reviewed journal articles, and the broader science community produced 38 peer-reviewed journal articles that feature Odyssey data in their analyses.

A global analysis of THEMIS image data of fluvial landforms found that the Martian climate underwent a transition from "warm and wet" to "cold and wet" around 3.5 billion years ago. THEMIS recently used its infrared capabilities to map unusual concentrations of silica-rich minerals, invisible to spectrometers measuring shorter wavelengths. THEMIS data has been key in recent studies of ground ice on Mars, including mapping shallow ice for in situ use, detecting exposed fresh ice in gullies, and the role of ice in the emplacement of impact ejecta. Odyssey is performing ongoing coordinated atmospheric observations with instruments on the United Arab Emirates' Hope orbiter, with excellent coordinated coverage during the recent dust storm season.

As part of the Mars space weather alert network, Odyssey continues to play an important monitoring radiation by using its neutron spectrometers to track solar coronal mass ejections and providing warning about hazardous solar outbursts, which could impact the operations of another spacecraft. As part of the gamma ray burst interplanetary network, Odyssey data helps astronomers determine the exact location of gamma ray bursts in our galaxy and beyond so Earth-based telescopes can carry out follow-up observations.

Odyssey has provided reliable relay support since 2004 and continues to support NASA's three surface missions. The Odyssey orbit provides relay contacts with passes in the early morning and late afternoon each Mars day, which are essential for surface missions to maximize their operational efficiency. With Odyssey and InSight using the same UHF radio they are uniquely compatible. The bulk of InSight relay contacts (more than 50 percent over the past 12 months) were via Odyssey, which mitigates contention

OTHER MISSIONS AND DATA ANALYSIS

for Curiosity and Perseverance contacts with the other orbiters. The Odyssey spacecraft is expected to run out of fuel by 2025, but NASA will reassess the fuel status periodically and adjust plans accordingly.

MARS EXPRESS

Mars Express is currently in its eighth extended mission operations phase, which runs through October 2024. Mars Express is an ESA mission that provides an understanding of Mars as a "coupled" system: from the ionosphere and atmosphere down to the surface and sub-surface. This mission addresses the climatic and geological evolution of Mars as well as the potential for life on the planet. NASA contributed components for the Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) and Analyzer of Space Plasmas and Energetic Atoms (ASPERA) instruments aboard Mars Express and participates in the scientific analysis of mission data.

Recent Achievements

The Mars Express MARSIS instrument continued investigations with both subsurface soundings and upper atmosphere/ionosphere observations. Due to the prioritization of other Mars science investigations, NASA directed that the science collaboration with the Mars Express mission conclude at the end of FY 2021. The current budget supports the Deep Space Network costs to continue communications support for the ESA-operated instruments.

MARS ATMOSPHERE AND VOLATILE EVOLUTION (MAVEN)

MAVEN, now in its fifth extended mission, launched in 2013 and successfully completed its primary mission in November 2015. MAVEN is the first mission devoted to studying Mars' upper atmosphere, with the most comprehensive measurements ever taken to address key scientific questions regarding the loss of the Mars atmosphere, liquid water, and habitability. The instrumentation suite allows scientists to observe the upper atmosphere, ionosphere, solar energetic drivers, and magnetic fields, to determine how Mars' atmosphere evolved through time. These measurements of how the Martian atmosphere responds to the Sun's radiation and intense solar storms are critical for understanding the history of water on Mars. While geological and geomorphic evidence shows that oceans of water once existed on Mars, we now know through MAVEN that much of that water slowly evaporated as the atmosphere eroded over time. Thus, the mission is answering long-standing questions regarding the loss of the Mars atmosphere, liquid water, and habitability. Scientists are also using MAVEN data to determine the role that loss of volatile compounds (e.g., carbon dioxide, water) from the Mars atmosphere to space has played through time, and the importance of this loss in changing the Mars atmosphere and climate through time.

As with all Mars Exploration Program orbiters, MAVEN carries an Electra radio for communications with rovers and landers on the Martian surface. MAVEN has carried out relay activities and began transmitting much higher volumes since 2019 after the spacecraft adjusted its orbit to serve as a more efficient relay.

Recent Achievements

MAVEN recently completed eight years in orbit about Mars. The steep rise in solar activity over the past year (as we approach solar maximum in 2025) has allowed MAVEN scientists to gain important insights into how the Martian atmosphere responds to extreme conditions. One important response is the discrete aurora produced on the nightside of the planet. Auroral activity increases dramatically during space weather events, and more auroras occur after sunset than before sunrise. This implies that magnetic

OTHER MISSIONS AND DATA ANALYSIS

reconnection of Mars' crustal magnetic fields is an important means of capturing energy from the Sun and solar storms and releasing it abruptly into the atmosphere. MAVEN has discovered and observed the three types of auroras that exist at Mars.

In addition to observing space weather effects on the Martian atmosphere, MAVEN scientists have also demonstrated a definitive link between dust storm activity, gravity waves, and increased water escape with multi-spacecraft observations from MAVEN, TGO, and MRO. Additionally, MAVEN has generated the first maps of wind circulation in the upper atmosphere of a planet other than Earth. This past year, MAVEN also provided first measurements of thermal ion temperatures since the Viking landers in 1976.

In FY 2022, over 70 peer-reviewed articles were published used MAVEN data, covering a wide range of topics, ranging from the structure of the atmosphere and ionosphere, the effects of dust on thermospheric winds, horizontal variations in the neutral composition of the upper atmosphere, the seasonal variation of the atmosphere, and the structure and dynamics of Mars' magnetosphere. These are all critical for understanding the Martian atmosphere as we continue exploring the red planet both robotically and in the future with human exploration.

MAVEN and the United Arab Emirates' Mars Mission Hope Probe established a scientific collaboration to exchange data between the two orbiters since they explore different aspects of Mars atmosphere and combining data adds significant value to both missions and scientists performing the analysis.

In April 2022, MAVEN transitioned to a Star Tracker based guidance mode called All-Stellar, increasing the longevity of the mission into the 2030s to assist Mars Sample Return and other landers in the future. In FY 2022, MAVEN supported more than 375 overflights for the Mars Rover 2020 and MSL missions as a relay return orbiter. The total volume of data transmitted for the two orbiters was over 286 gigabytes.

MARS SAMPLE RETURN

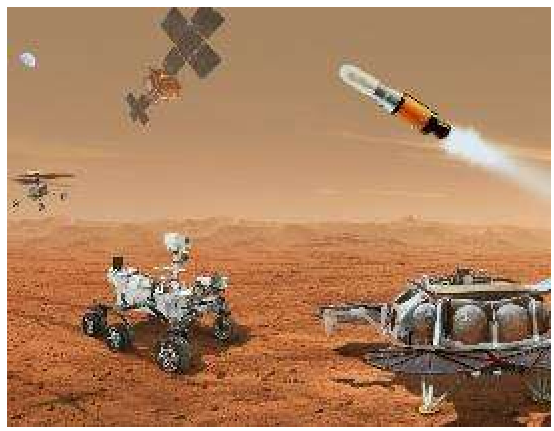
FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**653.2**	**822.3**	**949.3**	**700.0**	**600.0**	**612.1**	**627.6**
Change from FY 2023 Enacted			**127.0**				
Percent change from FY 2023 Enacted			**15.4%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The Mars Sample Return (MSR) Program will bring scientifically-selected samples from Mars to Earth to accomplish a solar system exploration goal that has been a priority since 1980 and included in the last three Planetary Decadal Surveys. The scientific driver of sample return is exploration of an ancient river-delta thought to present the best location for collecting samples that will reveal the early evolution of Mars, including the potential for life. MSR is a joint campaign with the European Space Agency (ESA). The campaign includes the MSR Program, Mars 2020 Perseverance, and sample handling once back on Earth. Perseverance completed creation of an initial surface cache of scientifically selected samples on the surface of Mars in January 2023, which are now ready for retrieval and return to Earth for investigation.



Shown above is an artist rendition of the current MSR Campaign elements, which are designed to retrieve the rock and soil samples Perseverance has collected and stored in sealed tubes. The samples will be available to the world's best laboratories for analysis to pursue answers to important science questions about planetary evolution, including the potential for extraterrestrial life.

The MSR Program consists of two coordinated flight-elements:

- NASA's Sample Retrieval Lander (SRL); and
- ESA's Earth Return Orbiter (ERO) with NASA's Capture, Containment, and Return System (CCRS) payload.

As the first step in the campaign, the Mars Rover 2020 Perseverance will continue to sample further scientifically compelling features on the Martian surface. The ERO will carry NASA’s CCRS, which includes the Earth Entry System (EES), and launch as early as 2027 and arrive at Mars as early as 2030. NASA's SRL will launch as early as 2028. The current concept for the SRL includes the Mars Ascent Vehicle (MAV), two Sample Recovery Helicopters (SRH), and ESA’s Sample Transfer Arm (STA). However, given continued cost growth and other challenges, NASA will reassess the Mars Sample Return architecture this year, which could include descoping components of the program such as one of the backup sample recovery helicopters. The MSR Program will return the scientifically selected samples as early as 2033, making them available for analysis by the most advanced instrumentation on Earth.

MARS SAMPLE RETURN

The MSR Program will deploy new capabilities developed through investments made by NASA and leverage significant contributions from international partners. Sample return will advance human exploration of Mars by demonstrating the first round-trip to another planet, providing samples to identify engineering or health hazards, and furthering our understanding of planetary protection challenges. Additionally, the SRL will utilize advanced precision-landing technology, such as the terrain relative navigation successfully used in the Mars Rover 2020 Perseverance rover landing. This technology applies directly to safely landing robotic precursors, human missions, and equipment near each other and in situ resources on the Martian surface.

EXPLANATION OF MAJOR CHANGES IN FY 2024

The budget supports increased requirements in FY 2024 to ensure the project continues to make progress towards confirmation and support the earliest feasible launch date. Mars Sample Return costs are expected to increase beyond what is shown in the outyear profile in this budget. To address this budget challenge, NASA will have to either reduce funding for other activities within the Science Program or descope elements of the Mars Sample Return mission. NASA will reassess the Mars Sample Return architecture this year and will consider potential descopes such as the elimination of one of the mission's two helicopters, in order to improve the cost posture of the mission. NASA is implementing measures to ensure program estimates-to-complete are thoroughly reviewed, including a second program Independent Review Board. This will position the Agency to make informed decisions about any architectural descopes prior to the Confirmation Review which might be necessary to mitigate program cost growth.

ACHIEVEMENTS IN FY 2022

In FY 2022, NASA revised the mission architecture, successfully completed the system requirements review (mission definition review), and completed the program Key Decision Point-B gate review. NASA descoped the ESA Sample Fetch Rover from the previous architecture and now the Perseverance rover will bring the scientifically selected samples to the lander with the MAV for return to Earth. NASA will leverage the successful Mars Rover 2020 Ingenuity helicopter technology demonstration to develop a helicopter component to serve as backup in the event of any issues that might prevent Perseverance from returning the samples to the MAV.

The MSR team also completed the technology development, engineering prototyping, heritage hardware and software assessments, and other risk-mitigation activities identified in the project formulation agreement and entered the preliminary design and technology completion phase (Phase B).

WORK IN PROGRESS IN FY 2023

NASA will reassess the Mars Sample Return architecture this year and will consider potential descopes such as the elimination of one of the mission's two helicopters, in order to improve the cost posture of the mission. NASA is convening a second Independent Review Board (IRB) to provide an independent assessment of the maturity of the program's architecture and preliminary designs, along with achievability of proposed planetary launch dates, and the associated cost. This review is planned to be completed prior to the Preliminary Design Review (PDR). Agency confirmation is subsequently delayed until early FY 2024 to allow for completion of this independent program review.

MARS SAMPLE RETURN

The program will complete the preliminary design phase, which includes a flight element level PDR and culminates in a program-level PDR.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

Agency confirmation is currently planned for FY 2024. Assuming the mission architecture is confirmed, the mission will enter the final design and fabrication phase for all components, including the CCRS, SRL, SRH, and MAV. Major milestones include completing engineering model development and initiating flight model fabrication; and conducting the Sample Recovery Helicopter PDR and Critical Design Review (CDR), as well as CDRs for the Capture, Containment, and Return System (CCRS) and Sample Retrieval Lander (SRL).

Program Elements

MARS SAMPLE RETURN (MSR)

MSR will consist of two separate launches: a NASA launch of the SRL and an ESA launch of the ESA Earth Return Orbiter (ERO) carrying the NASA CCRS. The goal of the program is to bring selected samples collected by Mars 2020 Perseverance to Earth.

The current concept for the SRL, which will be reassessed by NASA in FY 2023, includes the Mars Ascent Vehicle (MAV), two Sample Recovery Helicopters (SRH), and ESA's Sample Transfer Arm (STA). The SRL will land near and rendezvous with the Perseverance rover. The STA, operated by NASA, will transfer the sample tubes from the Perseverance rover and place them into the orbiting sample container in the MAV. In the event that the Perseverance rover is unable to deliver the samples directly to the SRL, the SRH will provide a backup capability to retrieve sample tubes cached on the surface of Mars by the Perseverance rover. The MAV is the first rocket that NASA will launch from the surface of another planet. It will launch the orbiting sample container from Mars and place it in a stable orbit approximately 400 km above the surface, where the CCRS/ERO will capture it. The MAV is a two-stage launch vehicle that utilizes two separate solid rocket motors for propulsion. Prior to its own launch from Mars, the MAV must survive Earth launch, a cruise phase to Mars, atmospheric entry and over 400 sols (Martian days), or 411 Earth days, of time on the Martian surface. The SRL launch readiness date is no earlier than 2028.

Launched by ESA, the ERO carrying the CCRS will rendezvous with and capture the orbiting sample container to "break the chain" of contact with the Martian material to satisfy planetary protection requirements and ensure no risk to Earth's biosphere. The CCRS's robotic transfer arm will place the orbiting sample into the Earth Entry Vehicle (EEV). The ERO will deliver the EEV to an Earth entry trajectory, and the EEV will execute a ballistic entry and land at a selected U.S. landing site. The ERO launch readiness date is no earlier than 2027.

MARS SAMPLE RETURN

Program Schedule

All dates past the Key Decision Point-B are tentative pending further review.

Date	Significant Event
Apr 2022	System Requirements Review
Sep 2022	Key Decision Point-B
NET Jun 2023	Preliminary Design Review
NET Q1 FY 2024	Key Decision Point-C
NET Jun 2024	Critical Design Review
NET Jan 2026	Key Decision Point-D
NET Oct 2027	ERO/CCRS Launch
NET Jun 2028	Sample Retrieval Lander (SRL) - MAV/STA Launch

Program Management & Commitments

The MSR Program Director at NASA Headquarters has overall responsibility for the MSR Program and reports directly to the Science Mission Directorate (SMD) Associate Administrator. The program director is responsible for planning and implementing the program consistent with top-level policies, requirements, and funding. The Jet Propulsion Laboratory (JPL) is the lead center for the MSR Program. The JPL MSR Program Manager is responsible for executing the program and reports to the SMD MSR Program Director.

The MSR System Engineering and Integration (SE&I) team, which includes ESA membership, will oversee the development and control of program requirements, planetary protection, and sample integrity. The MSR Program is responsible for sample integrity upon collection of the sample cache through landing on Earth and containment at the landing site. The MSR Program Office will also interface with the Mars Exploration Program during the Mars Rover 2020 Perseverance rover surface operation phase to coordinate depot caching. The future NASA Sample Receiving Project, funded in the Mars Exploration Program, will coordinate handoff of the samples upon their safe arrival on Earth.

Program Element	Provider
Sample Retrieval Lander (SRL-MAV/STA/SRH)	Provider: JPL Lead Center: JPL Performing Center(s): MSFC, LaRC, ARC, KSC, JPL Cost Share Partner(s): ESA
Capture, Containment, and Return System (CCRS) - Launched on Earth Return Orbiter (ERO)	Provider: GSFC Lead Center: GSFC Performing Center(s): JPL, LaRC, ARC, GSFC Cost Share Partner(s): ESA

MARS SAMPLE RETURN

Acquisition Strategy

NASA conducted a delta-Acquisition Strategy Meeting (ASM) in May 2021 and updated center roles/responsibilities assignments (depicted in the previous table). NASA plans to award several competitive long-lead SRL and CCRS contracts.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
MAV Propulsion System	Northrop Grumman Systems Corp.	Elkton, MD
Aeroshell	Lockheed Martin	Denver, CO
Cruise Stage	Lockheed Martin	Denver, CO
MAV Integrated System	Lockheed Martin	Huntsville, AL

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	2022	Program SRR	Successful	PDR
Performance	SRB	2023	Program PDR	TBD	CDR
Performance	SRB	2024	Program CDR	TBD	SIR
Performance	SRB	2026	Program SIR	TBD	ORR
Performance	SRB	2028	Program ORR	TBD	N/A

OUTER PLANETS AND OCEAN WORLDS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Jupiter Europa	472.1	345.0	**303.3**	100.8	80.6	77.7	84.0
Other Missions and Data Analysis	12.2	--	**15.1**	20.6	54.2	100.6	237.9
Total Budget	**484.3**	**--**	**318.4**	**121.3**	**134.8**	**178.3**	**321.9**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Surface features of Jupiter's icy moon (Europa) are revealed in an image obtained by Juno's Stellar Reference Unit (SRU) during the spacecraft's flyby on September 29, 2022. Credits: NASA/JPL-Caltech/SwRI.

The Outer Planets and Ocean Worlds Program enables the exploration of worlds in our solar system possessing vast expanses of liquid water. These liquid reservoirs provide insight into some of the most fundamental questions about life and the evolution of the solar system. The exploration of ocean worlds has high relevance and potential in the search for extant life and its habitable environments beyond Earth, one of NASA's strategic objectives.

NASA missions have revealed a surprising number of ocean worlds in our solar system, while at the same time providing enticing, though limited, details about these unexpected oceans. Underneath its icy crust, Jupiter's moon (Europa) contains a global liquid water ocean holding twice as much water as all of Earth's oceans. Recent observations suggest active water plumes erupt from the surface of Europa. Scientists detected a similar, though smaller, global ocean on Enceladus, a small moon orbiting Saturn, which also emanates active plumes. Other moons (e.g., Ganymede, Titan, and perhaps Callisto) and possibly even Pluto possess oceans deep beneath their surfaces. Unlike Europa and Enceladus, whose oceans have a rocky bottom; these oceans are sandwiched between ice layers. Titan also possesses huge lakes of liquid methane on its surface, the only place beyond Earth known to have lakes exposed to an atmosphere. Titan's lakes and atmosphere can reveal much about the exotic chemistry that ultimately led to life on Earth.

Astrobiology research, along with the exploration of Earth's oceans, has demonstrated the pervasiveness of life given the proper conditions and environment. Research and spacecraft measurements have increased our confidence that these ocean worlds possess at least some of the conditions necessary for extant life: long-lived oceans providing liquid water and a stable habitat; hydrothermal activity and other chemical sources providing energy; and the basic elements along with organics providing the necessary materials. In fact, Europa and Enceladus may possess all these conditions necessary for life. Thus, ocean worlds are the most likely places to search for currently habitable environments in the solar system and the life forms that could exist in those environments.

The Outer Planets and Ocean Worlds Program enables science investigations spanning the diversity of worlds hosting large liquid bodies in the outer solar system. The unexpected discoveries of the first ocean worlds provided by large strategic missions, such as Galileo and Cassini, have enabled the definition of more focused scientific questions. These missions enable investigation of these more focused scientific questions than smaller and less complex missions in the New Frontiers and Discovery programs can pursue.

EXPLANATION OF MAJOR CHANGES IN FY 2024

In accordance with Consolidated Appropriations Act, 2023, (P.L. 117-328), Title V, Sec. 518, NASA is providing notification to Congress that the NASA contribution to ESA’s JUICE Mission exceeded the development cost of the mission by more than 10 percent. Project cost increases were due to changes in delivery dates; technical issues arising from Electrical, Electronic, and Electromechanical (EEE) parts rework; COVID-19 related labor inefficiencies; and the need to maintain an appropriate level of project reserves.

EUROPA CLIPPER

Formulation	Development	Operations

FY 2024 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028	BTC	Total
Formulation	1,219.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	1,219.0
Development/Implementation	1,376.7	472.1	345.0	**303.3**	11.9	0.0	0.0	0.0	0.0	2,509.0
Operations/Close-out	0.0	0.0	0.0	**0.0**	88.9	80.6	77.7	84.0	940.9	1,272.0
2023 MPAR LCC Estimate	**2,595.7**	**472.1**	**345.0**	**303.3**	**100.8**	**80.6**	**77.7**	**84.0**	**940.9**	**5,000.0**
Total Budget	**2,595.7**	**472.1**	**345.0**	**303.3**	**100.8**	**80.6**	**77.7**	**84.0**	**940.9**	**5,000.0**
Change from FY 2023 Enacted				**-41.7**						
Percent change from FY 2023 Enacted				**-12.1%**						

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The 2023 MPAR LCC Estimate reflects the most recent estimates based on current project data as of February 2023. The requested budget authority is the project's current budget requirement which has seen programmatic changes and are anticipated in the Quarter 2 Financial Report.

The propulsion module of the Europa Clipper spacecraft has shipped from the Applied Physics Lab in Laurel, MD, to the Jet Propulsion Laboratory (JPL) in Pasadena, CA. The propulsion module is the core of the Clipper spacecraft. At JPL, engineers are completing the assembly of the entire spacecraft by integrating other subsystems to the propulsion module.

PROJECT PURPOSE

Jupiter's moon Europa has the largest known ocean in the solar system and is one of the most likely places to find life beyond our Earth. NASA developed concepts to explore Europa and determine if it is habitable based on characteristics of its vast oceans (twice the size of all the Earth's oceans combined); the ice surface-ocean interface; the chemical compositions of the intriguing, irregular brown surface areas; and the current geologic activity providing energy to the system.

NASA formulated the Europa Clipper mission in response to the planetary science Decadal Survey (Vision and Voyages for Planetary Science in the Decade 2013-2022), which identified a strategic mission to Europa as the second-highest priority for planetary science flagship missions.

EUROPA CLIPPER

Formulation	Development	Operations

NASA's Europa Clipper spacecraft will conduct a detailed survey of Europa to determine whether the icy moon harbors conditions suitable for life. The spacecraft, in orbit around Jupiter, will make 45 to 50 close passes over Europa, shifting its flight path for each flyby to soar over a different location so that it eventually scans nearly the entire moon. After each flyby, the spacecraft will send its data back to Earth.

Because radiation trapped in Jupiter's magnetic field bathes Europa, a thick-walled vault will enclose Europa Clipper's electronics, a technique successfully used for the first time by NASA's Juno spacecraft. The vault walls — made up of titanium and aluminum — will act as a radiation shield against most of the high-energy atomic particles, dramatically slowing down the damaging effect that radiation has on the spacecraft's electronics.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

PROJECT PARAMETERS

This mission will leverage the competitively selected payload of investigations to characterize the ice shell and any subsurface water, including their heterogeneity, ocean properties, and the nature of the surface-ice ocean exchange. It will also seek to understand the habitability of Europa's ocean through composition and chemistry of the surface and exosphere; understand the formation of surface features, including sites of recent or current activity; and identify and characterize high science interest locations. This will be the first NASA mission explicitly designed to explore an ocean world.

Europa Clipper's science payload consists of ten instruments grouped as follows:

- Cameras and spectrometers will create high-resolution images and composition maps of the moon's surface and thin atmosphere;
- An ice-penetrating radar, a magnetometer, plasma sensors, and a gravity investigation will reveal the moon's ocean and deep interior;
- The spacecraft's thermal camera will pinpoint warmer ice and might reveal recent eruptions of water or bodies of liquid water buried near the surface; and
- A dust analyzer and a mass spectrometer will study the chemistry of particles and gases ejected from the surface and subsurface of the moon.

Europa Clipper will launch on a SpaceX Falcon Heavy launch vehicle, utilizing a Mars-Earth Gravity Assist (MEGA) trajectory in October 2024. The Europa Clipper mission will spend four years in orbit around Jupiter, conducting its scientific observations by completing approximately 50 close fly-bys of Europa.

EUROPA CLIPPER

Formulation	Development	Operations

ACHIEVEMENTS IN FY 2022

At the conclusion of the final design phase, the project completed its System Integration Review (SIR) in November 2021. The project completed the project replan in the second quarter of FY 2022 and the Europa Clipper main spacecraft module arrived at the Jet Propulsion Lab in the spring of 2022. NASA conducted the Key Decision Point-D (KDP-D) review, and the spacecraft entered the Assembly Test and Launch Operations (ATLO) phase. The Clipper team delivered and integrated six of the ten science instruments onto the spacecraft by the end of the fiscal year.

WORK IN PROGRESS IN FY 2023

The project will accept delivery of the remaining pieces of flight hardware, including the final four instruments in FY 2023. The project will initiate environmental and operational testing for the entire spacecraft (except for the solar arrays) in preparation for launch in October 2024.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

The project will complete integration and test of flight hardware into the final configuration and complete the assembly and test. The Operational Readiness Review (ORR) and KDP-E will take place in July 2024. The spacecraft will then ship to Kennedy Space Center to begin launch operations, culminating in an October 2024 launch.

SCHEDULE COMMITMENTS/KEY MILESTONES

At confirmation, the project established a Launch Readiness Date (LRD) of September 2025 to fully accommodate all possible launch vehicles available to the mission. NASA selected the SpaceX Falcon Heavy launch vehicle for Europa Clipper in FY 2021 and established a target LRD of October 2024.

Milestone	Confirmation Baseline Date	FY 2024 PB Request
KDP-C	Aug 2019	Aug 2019
CDR	May 2020	Dec 2020
SIR	Mar 2021	Nov 2021
KDP-D	Apr 2021	Feb 2022
ORR	May 2023	July 2024
Launch Readiness Date	Sep 2025	Oct 2024
Phase E Start	Nov 2025	Nov 2024

EUROPA CLIPPER

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2020	2,412.8	69	2023	2,509.0	+4	LRD	Sep 2025	Oct 2024	-11

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**2,412.8**	**2,509.0**	**+96.2**
Aircraft/Spacecraft	818.7	1,130.1	+311.4
Payloads	168.7	474.9	+306.2
Systems I&T	63.2	62.5	-0.7
Launch Vehicle	432.0	202.0	-230.0
Ground Systems	104.8	160.7	+55.9
Science/Technology	24.8	33.8	+9.0
Other Direct Project Costs	800.6	445.0	-355.6

EUROPA CLIPPER

Formulation	Development	Operations

Project Management & Commitments

The Jet Propulsion Laboratory is responsible for project management.

Element	Description	Provider Details	Change from Baseline
Spacecraft	Spacecraft Bus with all flight subsystem capabilities	Provider: JPL Lead Center: JPL Performing Center(s): JPL, APL, GSFC, MSFC, JSC, KSC Cost Share Partner(s): N/A	N/A
Launch Vehicle	Falcon Heavy rocket	Provider: SpaceX Lead Center: KSC Performing Center(s): KSC Cost Share Partner(s): N/A	Previously Space Launch System (SLS)
Europa Ultraviolet Spectrograph (UVS) Instrument	Ultraviolet Spectrograph	Provider: SwRI Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
MAss SPectrometer for Planetary EXploration/Europa (MASPEX)	Time-of-Flight Mass Spectrometer	Provider: SwRI Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Europa Imaging System (EIS)	Narrow angle and wide-angle cameras	Provider: APL Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
SUrface Dust Analyzer (SUDA)	Dust Analyzer; Mass Spectrometer	Provider: LASP - CU Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Europa Thermal Emission Imaging System (E-THEMIS)	Thermal Imager	Provider: ASU Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

EUROPA CLIPPER

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Interior Characterization of Europa Using Magnetometry (ICEMAG)	Magnetometer	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	Terminated
Europa Clipper Magnetometer (ECM)	Magnetometer	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	Facility instrument to replace ICEMAG functionality
Plasma Instrument for Magnetic Sounding (PIMS)	Plasma Instrument - Faraday Cups	Provider: APL Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Mapping Imaging Spectrometer for Europa (MISE)	Infrared Spectrometer	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON)	Sounding Radar	Provider: Univ. of Texas Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: Clipper is not able to add necessary staff due to contention with other projects, Then: Delays to key activities supporting ATLO and launch readiness will result in a Clipper launch slip.	ATLO plan requires additional team members to support double shift activities starting in January 2023. The project is working to identify additions to the ATLO team. JPL leadership is tracking open staff needs weekly and adjudicating when projects are in contention for needed individuals. Working with JPL Guidance, Navigation, and Control (GNC) section to identify candidates and bring them on to project. Continuing to look for additional help to mitigate remaining risks to system GNC activities.

EUROPA CLIPPER

Formulation	Development	Operations

Risk Statement	Mitigation
If: A subsystem, instrument, software, or Ground Support Equipment (GSE) is late, or if a significant problem occurs during ATLO integration, or tests take longer than planned, Then: it could consume all the flight project practices margin and impact the ATLO schedule.	Consume margin (as needed); descope some system tests, book Saturdays (as needed); double shift once at KSC so it will not need to ship as early; and integrate Solar Arrays at KSC to increase test time at JPL. Where possible, deliver hardware prior to ATLO need date to allow flexibility in replanning of ATLO activities in "real time". Use thermal and mass models of instruments to allow environmental test to proceed. Execute only incompressible test list items as a minimum to gain back schedule.
If: The Europa Compute Element (Avionics Subsystem critical path) delivery is not on time relative to the current ATLO delivery schedule, it could delay I&T during the ATLO rework window, Then: This could result in a delayed I&T during the ATLO rework window.	Engineering Model delivered to ATLO. Include a Field Programmable Gate Array (FPGA) update window in the schedule. Assign a window for assembly of a second set of boards and build bottom side of boards now to allow time for FPGA maturation/possible slip. The Flight System Manager holding margin prior to Vault re-work window.

Acquisition Strategy

The Europa Clipper spacecraft is a JPL "in-house" build with each subsystem completing an internal make/buy assessment, with competed industry contracts where appropriate. JPL is collaborating with the Applied Physics Laboratory (APL) for development, leveraging each other's strengths as well as those of other NASA centers. As a result, APL is responsible for the propulsion module and the telecom subsystem, and GSFC will provide the propulsion subsystem. The Europa Clipper payload is comprised of nine investigations, each competitively selected via a Science Mission Directorate Announcement of Opportunity.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Telecom and Propulsion Subsystems	APL	Laurel, MD
EIS instrument	APL	Laurel, MD
PIMS instrument	APL	Laurel, MD
REASON instrument	University of Texas University of Iowa	Austin, TX Iowa City, IA

EUROPA CLIPPER

Formulation	Development	Operations

Element	Vendor	Location (of work performance)
MISE instrument	APL	Laurel, MD
SUDA instrument	LASP - University of Colorado	Boulder, CO
MASPEX instrument	SWRI	San Antonio, TX
UVS instrument	SWRI	San Antonio, TX
E-THEMIS instrument	ASU Ball Aerospace Raytheon Vision Systems	Tempe, AZ Boulder, CO Goleta, CA
Solar arrays	Airbus Defence and Space	Leiden, The Netherlands Ottobrun, Germany
Launch vehicle	SpaceX	Hawthorne, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Jan 2017	Europa SRR and MDR	Successful	PDR
Performance	SRB	Aug 2018	PDR	Successful	Delta-PDR
Performance	SRB	Jun 2019	Delta-PDR	Successful	CDR
Performance	SRB	Dec 2020	CDR	Successful	SIR
Performance	SRB	Nov 2021	SIR	Successful	ORR
Performance	SRB	May 2024	ORR	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
JUICE - Jupiter Icy Moons Explorer	0.6	--	**2.4**	2.2	2.8	2.8	2.9
Outer Planets Research	8.5	--	**12.7**	15.4	15.4	15.4	15.5
Planetary Decadal Future	0.0	--	**0.0**	3.0	36.0	82.4	219.4
Icy Satellites Surface Technology	3.2	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**12.2**	**--**	**15.1**	**20.6**	**54.2**	**100.6**	**237.9**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Other Missions and Data Analysis includes NASA's contribution to the European Space Agency (ESA) JUpiter ICy Moons Explorer (JUICE) mission and Outer Planets Research.

Mission Planning and Other Projects

JUPITER ICY MOONS EXPLORER (JUICE)

NASA is collaborating on this ESA-led mission to Ganymede and the Jupiter system. Together the Europa Clipper and JUICE missions provide an opportunity for comparative investigation of three of the ocean worlds in the Jupiter system: Europa, Ganymede, and Callisto. Researchers believe all three worlds possess liquid water oceans at varying depths beneath their surfaces. ESA plans to launch the mission in 2023 for arrival at Jupiter as early as 2030. The NASA contribution consists of three separate pieces of hardware: one full instrument, the Ultraviolet Spectrograph (UVS); two sensors for the Swedish National Space Agency Particle Environment Package suite of instruments (PEP-Hi); and the transmitter and receiver hardware for the Radar for Icy Moons Exploration (RIME) instrument.

In accordance with Consolidated Appropriations Act, 2023, (P.L. 117-328), Title V, Sec. 518, NASA is providing notification to Congress that the NASA contribution to ESA’s JUICE Mission exceeded the development cost of the mission by more than 10 percent. Project cost increases were due to changes in delivery dates; technical issues arising from Electrical, Electronic, and Electromechanical (EEE) parts rework; COVID-19 related labor inefficiencies; and the need to maintain an appropriate level of project reserves.

Recent Achievements

The team delivered all instruments to ESA for integration onto the spacecraft.

OTHER MISSIONS AND DATA ANALYSIS

OUTER PLANETS RESEARCH

Outer Planets Research increases the scientific return of current and past NASA outer planets missions and paves the way for future missions (e.g., refining landing sites on Titan, characterizing the ice shell on Europa and Enceladus).

Recent Achievements

Scientists have hypothesized that there are pockets of liquid water embedded within the ice crust of Europa. These subsurface lakes, similar to those found in Antarctica on Earth, could be the source of water plumes that have been tantalizingly glimpsed erupting on the surface. The lakes might also cause other features on Europa, such as the Chaos regions. The current research indicates that if such lakes are present, they are very near the surface, likely within the top four kilometers. At this shallow depth, the lakes will be directly detectable by multiple instruments on the Europa Clipper mission. This adds significant scientific and public excitement to the mission.

PLANETARY DECADAL FUTURE

The recent Planetary Science Decadal Survey recommended a mission to an Ice Giant planet (Uranus or Neptune) as the highest priority flagship mission to begin this decade. NASA intends to begin formulation studies in FY 2025 to define the science objectives and explore potential mission architectures. NASA will use the results of these studies to inform future decisions and planning.

RADIOISOTOPE POWER

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	148.6	--	175.5	201.1	174.6	166.8	160.9

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The image above is a 1/10th scale 3D rendition of the Dragonfly spacecraft with the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) on the dual quadcopter (the MMRTG is pictured in white at the back of the quadcopter).

Planetary Science missions demand advances in technology to enable successful trips to distant solar system destinations with harsh environments, and to enable missions with highly challenging trajectories and operations. To meet these needs, Planetary Science supports the development of advanced multi-mission capabilities through technology investments in key spacecraft systems, such as radioisotope power. Exploring the solar system requires radioisotope power when solar power is impractical or unavailable. The Radioisotope Power Systems (RPS) Program includes technology maturation and system development to improve efficiency and performance and works in partnership with the U.S. Department of Energy (DOE) to ensure continuing plutonium-238 (Pu-238) production and operations infrastructure. The program also supports nuclear launch approval activities.

EXPLANATION OF MAJOR CHANGES IN FY 2024

This budget cancels the Dynamic Radioisotope Power Systems activities scheduled to begin in FY 2024 in order to support other high-priority activities within Planetary Science.

ACHIEVEMENTS IN FY 2022

NASA's RPS Program supported utilizing RPS on missions by coordinating the possible use of RPS on the next New Frontiers mission, and new missions recommended by the National Research Council’s Planetary Science and Astrobiology Decadal Survey 2023-2032 (e.g., Uranus Orbiter and Probe). RPS continued to work on emerging requirements for RPS on Artemis for human exploration.

Key accomplishments for the RPS Program support of missions included: successfully completing the environmental assessment for Dragonfly and the finding of "No Significant Impact"; finalizing the nuclear launch authorization plan for the mission; and starting fabrication of housings for the Dragonfly Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) (F4). The RPS Program also served as a liaison between DOE and the Dragonfly mission on MMRTG system integration and provided services to enable the baselined MMRTG power system.

RADIOISOTOPE POWER

NASA started evaluating emerging commercial development and use of RPS capabilities for heat and power, including possible international contributions to source material, and supporting development of interagency standards and processes for commercial development and use of RPS. NASA established development contracts with Aerojet Rocketdyne for both Dynamic Radioisotope Power Systems (DRPS) and the Next Generation Radioisotope Thermoelectric Generator (RTG) (Next-Gen RTG). NASA began working with DOE to prepare for the potential restart of LWRHU production required to support Dragonfly and other potential missions that will need the heat.

WORK IN PROGRESS IN FY 2023

The RPS Program will evaluate if an initial unit of the Next-Gen RTG (Mod 0), based on the General-Purpose Heat Source (GPHS)-RTG existing hardware, is flight ready for a future mission, and continue to develop the capability to manufacture new units of the same design (Mod 1). NASA will continue work to develop the Vulcan multi-mission databook and the Programmatic Environmental Assessment (PEA) for the GPHS. The development of a GPHS PEA will streamline the process to obtain environmental assessments for individual missions, which will simplify the National Environmental Policy Act (NEPA) compliance process and can shorten the schedule to obtain NEPA compliance on future missions utilizing RPS power systems. The RPS Program will support the response to the Planetary Decadal Survey in 2023, which emphasized use of RPS, management of the Pu-238 supply, and the importance of developing advanced, high-efficiency RPS systems. NASA will evaluate RPS requirements for the Uranus Orbiter and Probe mission prioritized by the Decadal Survey. NASA will consider the use of Light Weight Radioisotope Heater Units (LWRHUs) for Artemis human exploration applications and other emerging missions. The RPS Program will continue to evaluate the need to restructure and adapt to emerging opportunities for RPS development and use.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

NASA plans to support DOE production of LWRHUs. The Next-Gen RTG team will deliver its Mod 0 unit and conduct a Preliminary Design Review (PDR) for the Mod 1 system.

Program Elements

RADIOISOTOPE POWER SYSTEM (RPS)

The RPS Project will continue to ensure the availability of RPS for the exploration of the solar system in environments where conventional solar or chemical power generation is impractical or impossible. NASA will achieve this goal by working with DOE to provide fueled RPS to missions and to support mission design and integration activities. The budget proposes to cancel DRPS activities and redirect funding to more urgent high priority needs in Planetary Science. The DRPS project was intended to support technology maturation of high-efficiency dynamic power convertor technologies for future radioisotope power systems. RPS will continue energy conversion research and development to advance state-of-the-art performance in heat to electrical energy conversion.

RADIOISOTOPE POWER

DOE OPERATIONS AND ANALYSIS

NASA funds the DOE national laboratory personnel and infrastructure required to maintain the capability to develop and fuel radioisotope power systems for deep space missions. DOE resumed domestic production of Pu-238 for the first time since the 1980s. They are now using a constant rate production (CRP) approach. NASA funds the effort and the DOE Oak Ridge National Laboratory leads the effort and irradiates targets at its High Flux Isotope Reactor. The DOE Idaho National Laboratory (INL) supplies Neptunium-237 and irradiates targets at the Advanced Test Reactor, required to meet Pu-238 production rates. DOE continues to increase annual production, producing approximately 700 grams per year. Over the next several years, refining and automating the process will help ramp production up to a full operational capability of 1.5 kilograms per year by 2026. DOE Los Alamos National Laboratory (LANL) manages the existing Pu-238 inventories and manufactures fuel, resulting in continual annual fueled clad manufacturing by LANL and delivery to INL at a CRP rate of 10 to 15 clads per year. INL integrates the fueled clads with generator systems and manages the transportation and launch operations activities in support of NASA missions.

Program Management & Commitments

Glenn Research Center (GRC) manages the Radioisotope Power Systems (RPS) Program.

Program Element	Provider
RPS	Provider: GRC Lead Center: GRC Performing Center(s): GRC, JPL, GSFC, KSC, DOE Cost Share Partner(s): N/A
DOE Operations and Analysis	Provider: DOE Lead Center: GRC Performing Center(s): GRC Cost Share Partner(s): N/A

Acquisition Strategy

DOE provides radioisotope power systems and production operations on a reimbursable basis. Maturity of the technologies determines the timeline for the acquisition of technologies and new systems. NASA or DOE laboratory-competed acquisitions help mature technology before system development begins. NASA-led DOE laboratory acquisitions procure unfueled designs and flight-qualified hardware when initiating a system development.

The program acquires content via existing Agency contracts with JPL and APL. The program will use in-house or competitive procurements as needed.

ASTROPHYSICS

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Astrophysics Research	267.4	--	**289.9**	299.3	374.0	384.8	384.3
Cosmic Origins	364.1	--	**342.5**	358.7	348.2	428.4	454.0
Physics of the Cosmos	160.0	--	**202.0**	212.7	204.8	207.8	216.3
Exoplanet Exploration	543.0	--	**463.7**	427.1	419.4	313.0	196.9
Astrophysics Explorer	234.4	--	**259.3**	324.3	319.5	355.5	497.9
Total Budget	**1,568.9**	**1,510.0**	**1,557.4**	**1,622.1**	**1,665.9**	**1,689.6**	**1,749.4**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Astrophysics

ASTROPHYSICS RESEARCH

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Astrophysics Research and Analysis	107.4	--	**113.9**	114.3	122.6	129.1	132.3
Balloon Project	45.8	--	**49.6**	50.0	50.0	50.0	50.0
Science Activation	50.6	52.0	**55.6**	55.6	55.6	55.6	55.6
Other Missions and Data Analysis	63.6	--	**70.8**	79.4	145.8	150.2	146.4
Total Budget	**267.4**	**--**	**289.9**	**299.3**	**374.0**	**384.8**	**384.3**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Shown here are preparations for launch of engineering balloon test flight from Ft. Sumner, New Mexico in August 2022.

The Astrophysics Research Program studies a wide range of astronomical observations from the births of the first stars, black holes, and distant galaxies in the cosmic history, to the nature of planets orbiting other stars in our Milky Way galaxy. High-altitude balloon and sounding rocket flights are used to test new types of instruments which study the nature of energetic particles.

The program provides basic research awards for scientists to test their theories and to understand how they can best use data from NASA missions to gain new knowledge from the universe. Awardees analyze the data from Astrophysics missions to understand astronomical events, such as the explosion of a star, or the fingerprints of early cosmic history in the microwave background. Competitively awarded science investigations in Astrophysics Research can also include funding for data analysis and techniques, theory and computation, laboratory astrophysics, and capital equipment purchases. The program also develops innovative technologies for future missions, including detectors and electronics, optics, gratings, and coatings.

EXPLANATION OF MAJOR CHANGES IN FY 2024

Additional funds are provided to cover higher helium and other operating costs within the Balloon Project. NASA moved funding from the Senior Review line to operating mission budgets in other Astrophysics programs to support extended mission operations.

ACHIEVEMENTS IN FY 2022

In FY 2022, NASA evaluated 804 proposals submitted to the Astrophysics Research Program using subject-matter experts as peer reviewers and made diverse selections for investigators, institution types,

ASTROPHYSICS RESEARCH

and geography over a broad range of science investigations. Over half of all Principal Investigators (PIs) are new PIs who have not been previously funded by the research programs. In addition, NASA evaluated 3,436 proposals submitted to the General Observer and General Investigator programs of NASA's nine currently operating Astrophysics missions and provided funding to the broad scientific community for new observations, archival, and theory investigations. In response to Decadal survey recommendations addressing diversity and inclusion within the Astrophysics community, NASA implemented codes of conduct for all panel reviews; is now requiring the submission of Inclusion Plans in six Research Opportunities in Space and Earth Sciences (ROSES) elements; and has also implemented Dual Anonymous Peer Review for most Astrophysics research solicitations. NASA facilitated a community planning workshop to begin implementation of the Bridge Program element.

In FY 2022, NASA launched seven Astrophysics Sounding Rocket payloads, including three payloads from a new commercial launch site (Equatorial Launch Australia [ELA]). NASA launched the Suborbital Imaging Spectrograph for Transition Region Irradiance from Nearby Exoplanet host starts (SISTINE), a spectroscopic far-UV mission studying the spectral energy distribution of low-mass star systems November 8, 2021 from White Sands Missile Range. The Diffused X-ray emission from the Local galaxy (DXL), launched on January 9, 2022 from Wallops Island, is studying the Solar Wind Charge Exchange and Local Hot Bubble X-ray emissions which are believed to be major contributors to the diffused X-ray background. The X-ray Quantum Calorimeter (XQC) mission, launched from ELA on June 6, 2022, is collecting high resolution spectroscopy of the diffuse X-ray background in the 0.1 to 3 keV range. On July 6, 2022 NASA launched the SISTINE mission again, now from ELA observing a celestial target only accessible from the southern hemisphere. The Dual-channel Extreme Ultraviolet Continuum Experiment (DEUCE), launched from ELA on July 11, 2022, is testing if B-Stars are viable candidates for providing the ionizing radiation to the intergalactic medium. These three sounding-rocket launches from ELA in the southern hemisphere are a return of the NASA Sounding Rocket Program to Australia after more than 25 years. The Micro-X mission, launched from White Sands Missile Range on August 21, 2022, demonstrated the use of transition edge sensors for x-ray observations. The tREXS mission, launched from White Sands Missile Range, NM, on September 26, 2022, is a spectroscopic x-ray instrument designed to detect key X-ray emission lines.

NASA conducted three balloon campaigns in FY 2022 in New Zealand, Sweden, and Ft. Sumner, New Mexico and successfully launched eight balloons from Sweden and Ft. Sumner. However, unfavorable weather prevented balloon launch operations in New Zealand. NASA cancelled the Antarctica balloon campaign due to COVID-19 concerns and restrictions.

A team of scientists is addressing the critical need to develop high-sensitivity, kilopixel-format detector arrays that operate over the entire far-infrared (FIR) spectrum. The project is an important step towards maturation of technologies for eventual space flight and would support the Astro2020 Decadal Survey's recommendation that NASA compete a Probe-class FIR mission and conduct the technology development for a future flagship-class FIR mission. In FY 2022, the team developed the first-ever triply-hybridized FIR detector array, enabling the push towards greater integration and higher pixel counts needed for the unprecedented sensitivities and mapping speeds that will enable FIR science.

In cross-divisional exoplanet research, researchers discovered two rocky planets in the Luyten Half-Second Catalogue (LHS) 1,678-star system using data from the Transiting Exoplanet Survey Satellite (TESS). The star is an M-dwarf that is cooler and redder than the Sun, having about 35 percent the mass of the Sun. The innermost planet has a radius 70 percent of that of the Earth and orbits in 0.86 Earth days, while the second planet has a radius 98 percent that of the Earth and orbits in 3.69 Earth days. A third as-yet unconfirmed Earth-sized planet may exist in this system in a 4.97 Earth day orbit. Researchers

ASTROPHYSICS RESEARCH

discovered a new type of supernova, 2018zd, using Hubble and Spitzer data, which has shown strong evidence of being triggered by “electron capture,” which scientists suspect to occur for stars between eight and 10 times the mass of the Sun. These stars are too massive to expire as white dwarf stars, but too small to undergo standard core-collapse supernova explosions. This discovery will provide scientists with a deeper understanding of the diversity of stellar death.

Hubble Space Telescope and the Subaru Telescope have imaged a possible forming gas giant. These images of the protoplanetary disk around the star AB Aurigae show substantial structure in the disk, such as spiral arms and clumps. One of these clumps, located 93 astronomical units from the star, may be a forming giant planet. The discovery may be evidence that some gas giant planets may form by disk fragmentation rather than dust coagulation, as is the prevailing paradigm for planet formation.

The Science Activation project, which comprises 54 teams of which half focus on underrepresented learners and communities, generated 23 million learner interactions in more than 110 countries (22 million in the United States alone), held 55,550 volunteer events since the program began (2,500 during the pandemic), leveraged 497 partnerships within the collaborative network, published 93 formal publications capturing evidence-based approaches, provided 350 science centers and museums with hands-on toolkits that were also available digitally in English and Spanish to all users, and supported more than 745 subject matter experts in interactions with learners across the five science disciplines.

WORK IN PROGRESS IN FY 2023

Astrophysics plans to launch the CubeSat BurstCube, to detect sudden gamma-ray bursts that occur when neutron stars collide.

NASA scheduled two Astrophysics Sounding Rockets for launch in FY 2023, both will launch from the White Sands Missile Range. The first sounding rocket is the Cosmic Infrared Background Experiment (CIBER-2) is measuring the cosmic near-infrared extragalactic background light. The second mission is the Off-Axis Far-UV Off Rowland-circle Telescope for Imaging and Spectroscopy (OAxFORTIS).

NASA is planning three balloon campaigns in FY 2023 in Antarctica, New Zealand, and Ft. Sumner, New Mexico.

Science Activation will support the 2023 Eclipse by optimizing the three eclipse focused teams selected last year. In FY 2023, Science Activation is leading the public outreach of the solar eclipse for the learners in the U.S. Science Activation continues to support competitive selections that broaden participation for learners in new and augmented collaborations for rural, indigenous, and other underserved areas and plans to use lessons learned from past celestial and other milestone events to engage these communities. In FY 2023, new Science Activation processes will ensure cohesion across the collective set of over 50 awards and stronger linkage between objectives and measures of success using agreed upon program objectives. In addition, NASA will highlight and report new citizen science efforts beyond the current 29 projects. The citizen science efforts have scaled to include over 410 citizen scientists that have co-authored peer-reviewed publications through 2022.

In FY 2023 and FY 2024, the Bridge Program element anticipates at least two opportunities for Bridge teams to propose for funding. Anticipated funding is approximately $5 million per year to be distributed to Bridge teams in several cost categories: Small, Medium, Large, or Key program. Key program proposals must propose to build a consortium of partner institutions whose goals include increasing the research capacity across multiple participating institutions. For all cost categories, funding duration can range from one to five years.

ASTROPHYSICS RESEARCH

KEY ACHIEVEMENTS PLANNED FOR FY 2024

NASA will continue a competed Astrophysics Research Program with emphasis on detector, instrument, optics, and key supporting technologies for use as payloads in future missions. Theoretical work will provide the foundation to develop science requirements for new missions. Data analysis will multiply the science yield from NASA's astrophysics missions.

The Balloon project plans to support an Antarctica campaign, and a Ft. Sumner, New Mexico campaign.

NASA plans to launch two CubeSats: Supernova Remnants and Proxies for ReIonization Testbed Experiment (SPRITE) to observe UV spectra of star forming regions in numerous nearby galaxies and to trace the history of star formation; and BlackCat to discover transient x-ray sources.

NASA has two Sounding Rocket launches currently planned for FY 2024. INtegral-Field Ultraviolet Spectroscopic Experiment (INFUSE) will launch from White Sands Missile Range. This sounding rocket-borne instrument is a new class of far-UV (100-180 nm) integral-field spectrograph. INFUSE will map the shocked interfaces between expanding supernovae and the ambient interstellar medium (ISM) at arcsecond scales to study how the energetic deaths of massive stars shape the evolution of the host galaxy. NASA plans to launch Off-Plane Grating Rocket Experiment from Poker Flats in Alaska. The purpose of the Off-Plane Grating Rocket Experiment (OGRE) mission is to observe Capella in the soft X-ray spectrum and to flight test the instrument concept of the Off-Plane Grating Spectrometer for use on future X-ray missions.

In FY 2024, Science Activation is leading the public outreach of the solar eclipse for the learners in the U.S. Science Activation will support the 2024 Eclipse by optimizing the three eclipse focused teams selected last year. The National Academies will also be conducting a program assessment on Science Activation which will help shape the direction of Science Activation for the next 10 years.

Program Elements

RESEARCH AND ANALYSIS

This project supports basic research, solicited through NASA's annual ROSES announcements. NASA solicits investigations relevant to Astrophysics over the entire range of photon energies, gravitational waves, and particles of cosmic origin. Scientists and technologists from a mix of disciplines review proposals and provide findings that underlie NASA's merit-based selections.

This project also solicits technology development for detectors and instruments for potential use on future space flight missions, and science and technology investigations using sounding rockets, high-altitude balloons, and similar platforms. A new type of scientific instrument often flies first on a stratospheric balloon mission or on a sounding rocket flight, which takes it briefly outside Earth's atmosphere. Instruments for balloons and sounding rockets are less expensive than orbital missions and experimenters can build them quickly to respond to unexpected opportunities, such as a newly discovered supernova. The experimenter usually retrieves the equipment after the flight so that they can test, improve, and fly the new instruments again. Suborbital flights are important for training the next generation of scientists and engineers to maintain U.S. leadership in science, technology, engineering, and math. The project also supports small experiments flown on the International Space Station, laboratory astrophysics, and limited ground-based observations.

ASTROPHYSICS RESEARCH

The Astrophysics Theory element solicits basic theory investigations needed to interpret data from NASA's space astrophysics missions and develops the scientific basis for future missions. Astrophysics Theory topics include the formation of stars and planets, supernova explosions and gamma-ray bursts, the birth of galaxies, dark matter, dark energy, and the cosmic microwave background.

The Exoplanet Research element solicits observations to detect and characterize planets around other stars and to understand their origins.

The Nancy Grace Roman Technology Fellowship develops early career researchers, who could lead future flight instruments and missions. Initially, NASA identifies promising early career researchers and supports their investigations. NASA then selects a subset of fellows for additional funding to start a laboratory or develop a research group at the Fellow's institution.

The SMD Bridge Program element is designed to boost diversity, equity, inclusion, and accessibility within the NASA workforce and within the U.S. science and engineering community. The SMD Bridge Program element will increase engagement and partnering between Minority-Serving Institutions, such as Historically Black Colleges and Universities (HBCUs); Tribal Colleges and Universities (TCUs); Primarily Undergraduate Institutions (PUIs); Primarily Black Institutions (PBIs); Hispanic Serving Institutions (HSIs); and Community Colleges, highly research-intensive universities, and NASA centers or facilities. The focus of the program will be on paid research and engineering studentships at participating institutions to transition science and engineering students from undergraduate studies into graduate schools and employment at NASA or related STEM careers.

BALLOON PROJECT

The Balloon Project offers inexpensive, high-altitude flight opportunities for scientists to conduct research and test new technologies before space flight application. Balloon experiments cover a wide range of disciplines in astrophysics, solar physics, heliospheric physics, and Earth upper-atmosphere chemistry as well as selected planetary science, such as comet observations. Observations from balloons have detected echoes of the Big Bang and probed the earliest galaxies. The Balloon Project continues to increase balloon size and enhance capabilities, including an accurate pointing system to allow high-quality astronomical imaging and a super-pressure balloon that maintains the balloon's integrity at a high altitude to allow much longer flights at mid-latitudes that include nighttime viewing of astronomical objects.

SCIENCE ACTIVATION

The Science Activation project delivers SMD's unique science content and expertise into the learning environment for learners of all ages. Through 2025, a cooperative network of 51 competitively selected teams from across the Nation will connect NASA science experts, real content, and authentic experiences with community leaders to conduct science in ways that activate minds and promote deeper understanding of our world and beyond. Awardees of cooperative agreements work collaboratively with each other, with internal NASA organizations, and with local and national partners to achieve a multiplier effect utilizing NASA investments. All awards include independent evaluators that assess the individual project's measures of success as well as a portfolio-level independent evaluator. Researchers have published 93 papers through 2022.

ASTROPHYSICS RESEARCH

Science Activation improved connections between subject matter experts (SMEs) and community-based networks in all 50 states and U.S. territories. SMEs working on missions and the latest discoveries can now receive targeted funding to work with awardees and audiences.

Broadening participation, including underserved audiences, continues to be a priority objective. Over one-half of the Science Activation portfolio focuses on broadening participation among underrepresented communities, including Native American nations, undergraduate students participating from HBCUs; neurodiverse learners at the high school level; people who are blind or have low vision; and community college students. Funding also provides opportunities for indigenous learners in the Southwest, Appalachia, upper Northwest, and Alaska.

Program Schedule

The program issues solicitations every year. A Senior Review process assesses all missions in the extended operations phase every three years and all data archives every three or four years.

Date	Significant Event
Q1 FY 2023	ROSES-2022 selection within six to nine months of receipt of proposals
Feb 2023	ROSES-2023 NRA solicitation release
Q1 FY 2024	ROSES-2023 selection within six to nine months of receipt of proposals
Feb 2024	ROSES-2024 NRA solicitation release
Mar 2024	Astrophysics Archives Programmatic Review
Q1 FY 2025	ROSES-2024 selection within six to nine months of receipt of proposals
Feb 2025	ROSES-2025 NRA solicitation release
Mar 2025	Senior Review of Operating Missions
Q1 FY 2026	ROSES-2025 selection within six to nine months of receipt of proposals
Feb 2026	ROSES-2026 NRA solicitation release
Mar 2026	Senior Review of Operating Missions
Q1 FY 2027	ROSES-2026 selection within six to nine months of receipt of proposals
Feb 2027	ROSES-2026 NRA solicitation release

ASTROPHYSICS RESEARCH

Program Management & Commitments

Program Element	Provider
Research and Analysis Project	Provider: All NASA Centers Lead Center: NASA Headquarters (HQ) Performing Center(s): All Cost Share Partner(s): None
Balloon Project	Provider: Wallops Flight Facility (WFF) Lead Center: WFF Performing Center(s): WFF Cost Share Partner(s): None
Science Activation	Provider: All NASA Centers Lead Center: Headquarters (HQ) Performing Center(s): All Cost Share Partner(s): Office of STEM Engagement (OSTEM)

Acquisition Strategy

NASA issues solicitations for competed research awards each February through ROSES. Panels of subject-matter expert scientists conduct peer reviews on all proposals. A Senior Review panel reviews all missions in the extended operations phase every three years, and all data archives every three or four years.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Operation of the Columbia Scientific Balloon Facility (CSBF)	NASA selected Peraton as the CSBF balloon support contractor	Antarctica; Fort Sumner, NM; New Zealand; Sweden; Palestine, TX

ASTROPHYSICS RESEARCH

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Astrophysics Advisory Committee	2022	Review to assess program against strategic objectives of Astrophysics science	Successful	2023
Quality	Senior Review of Operating Missions	2022	Review of Astrophysics operating missions	The Senior Review Committee recommended all Astrophysics operational missions continue operations through FY 2025, except for SOFIA	2025
Quality	Astrophysics Archives Programmatic Review	May 2023	Review of Astrophysics data archives	TBD	TBD
Performance	Astrophysics Advisory Committee	2023	Review to assess program against strategic objectives of Astrophysics science	TBD	2024

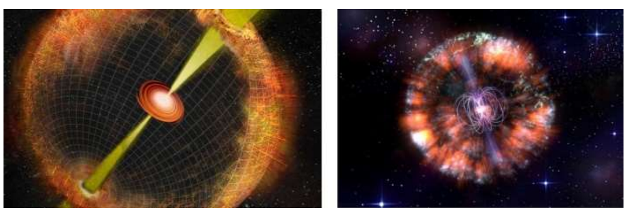
OTHER MISSIONS AND DATA ANALYSIS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Contract Administration, Audit & QA Svcs	10.9	--	**16.6**	16.6	16.6	16.6	16.6
Astrophysics Senior Review	0.0	--	**0.0**	10.6	71.2	75.4	71.6
Astrophysics Data Program	22.6	--	**23.8**	23.8	24.3	24.5	24.5
Astrophysics Data Curation and Archival	30.2	--	**30.4**	28.4	33.7	33.7	33.7
Total Budget	**63.6**	**--**	**70.8**	**79.4**	**145.8**	**150.2**	**146.4**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



Shown on the left, a baby black hole at the center of supernova remnant beams energy towards Earth. In this scenario, the directed energy beam is powered by the accretion of a disk of matter falling back onto the event horizon of a newborn baby black hole. The scenario shown on the right also has a directed energetic beam, but this time powered by the magnetic energy of a highly magnetized neutron star, or magnetar, left behind by the supernova. Astronomers are on the hunt for more such events to see if they can figure out if either scenario is correct.

Astrophysics Research Other Missions and Data Analysis includes the Astrophysics senior review project, the data program including data curation and archival, support for contract audits and contract quality assurance for the Science Mission Directorate, and Astrophysics directed research and technology.

Mission Planning and Other Projects

DIRECTED RESEARCH AND TECHNOLOGY

This project funds the civil service staff that will work on emerging Astrophysics projects, instruments, and research.

CONTRACT ADMINISTRATION, AUDIT, AND QUALITY ASSURANCE SERVICES

This project provides critical safety and mission product inspections, as well as contract audit services from the Defense Contract Management Agency and Defense Contract Audit Agency, respectively. It also provides for contract assurance audits, assessments, and surveillance by the NASA Contract Assurance Services Program.

ASTROPHYSICS SENIOR REVIEW

Every three years, the Astrophysics division conducts a Senior Review to perform evaluations of missions that have successfully completed, or are about to complete, their prime mission operation phase. The Senior Review findings help NASA prioritize which missions will receive funding for extended

OTHER MISSIONS AND DATA ANALYSIS

operations. The 2022 Senior Review found that NASA's fleet of operating astrophysics missions constitute a "portfolio of extraordinary power" and recommended that NASA continue their operations. The next Senior Review will take place in spring 2025. Funding in this line will be allocated to mission extensions recommended by the next Senior Review.

ASTROPHYSICS DATA ANALYSIS PROGRAM (ADAP)

ADAP solicits research that emphasizes the analysis of NASA space astrophysics data archived in the public domain at one of NASA’s Astrophysics Data Centers. NASA's archival astronomical data holdings continue to grow with the ongoing successful operation of the Agency's portfolio of Astrophysics flight missions. Those missions range from modest Explorer-class like the Nuclear Spectroscopic Telescope Array (NuSTAR) and the Transiting Exoplanet Survey (TESS) to the great observatories Hubble and Chandra. In addition, in FY 2023, data from the long-awaited James Webb Space Telescope (Webb), launched in December 2021, will be available to ADAP proposers for the first time. Investigations funded under the ADAP ensure that the Agency's Astrophysics data holdings continue to be the subject of vigorous scientific research, thereby maximizing the scientific return on NASA mission investments.

The ADAP portfolio includes focused investigations that involve the analysis of archival data from a single mission, as well as broader investigations that combine data from multiple missions and span a wide wavelength range. Such multi-mission, multi-wavelength studies are a unique and exciting aspect of the program. The combinations of data collected by different missions operating in different regions of the spectrum often yield scientific insights that are unobtainable through analysis of the individual data sets alone.

Recent Achievements

During FY 2022, ADAP supported more than 150 science investigations at academic institutions, NASA centers, and other Federal laboratories across the country. Much of that funding goes to support early-career scientists—undergraduate and graduate student researchers as well as postdoctoral associates—that represent the next generation of astronomers and astrophysicists.

The scientists funded under ADAP are studying our universe at all scales--from its largest structures and earliest moments to the here-and-now. In just the past year, ADAP-funded scientists have provided new insights into the production of dust and heavy elements by core-collapse supernovae from the first generation of supermassive stars formed after the Big Bang, and how that dust helped shape the subsequent evolution of the universe. Recent ADAP research has also advanced our understanding of how the supermassive black holes found in the center of most galaxies drive the evolution of the galaxy's interstellar gas and dust and regulates the process of star formation. Finally, closer to home, ADAP-sponsored research has continued to explore the enigmatic nature of M-dwarf stars, the most abundant type of star in our galaxy and host to several of the closest exoplanetary systems to the Earth. That work has shown that the energetic flares and coronal mass ejections that are common in M-dwarfs, particularly when they are young, represent a significant threat to the habitability of any planets in orbit about them.

ASTROPHYSICS DATA CURATION AND ARCHIVAL RESEARCH (ADCAR)

Astrophysics Data Centers constitute an ensemble of archives receiving processed data from individual missions and making them accessible to the scientific community. After the completion of a mission, the

OTHER MISSIONS AND DATA ANALYSIS

relevant, active, multi-mission archive takes over all data archiving activities. ADCAR covers the activities of the Astrophysics Data Centers and the NASA Astronomical Virtual Observatories (NAVO).

Recent Achievements

In FY 2022, the Astrophysics Data System (ADS), one of the Astrophysics Data Centers, started to expand its database to cover publications in Heliophysics and Planetary Science, in support of NASA's Open Science efforts. NASA plans an expansion to cover publications in Earth Sciences and in Biological and Physical Sciences in FY 2023 and beyond. The ADS data holdings have increased to 16.6 million records and 154 million citations, an increase of 4.5 percent and 8.5 percent year-over-year, respectively.

In FY 2022, the Barbara A. Mikulski Archive for Space Telescopes (MAST), in partnership with the Transiting Exoplanet Survey Satellite (TESS) project, launched a science platform where any astronomer can use the cloud and integrated community software to find exoplanets and explore time-domain astronomy at speed. MAST moved the large GALEX data set to the cloud and developed open, high-speed data transfer systems built for astronomical images. To serve novices in data science, MAST developed Hello Universe, a new suite of data sets and notebooks that provide machine learning tools for astronomy. In July 2022, MAST successfully launched the James Webb Space Telescope Archive, which served more data in its first three days than for any previous mission.

In FY 2022, the High Energy Astrophysics Science Archive Research Center (HEASARC) saw the opening of the HEASARC data archive for NASA's Imaging X-ray Polarimetry Explorer (IXPE) mission, the U.S. release of the Spectrum-Roentgen-Gamma/ extended ROentgen Survey with an Imaging Telescope Array (SRG/eROSITA) source catalog and early release data, and the release of a new multimessenger transient alert service using modern open-source, reliable and secure astronomical alert distribution technologies. HEASARC served 1.4 billion data files totaling 500 TB (15 percent increase over FY 2021), and roughly 24 million catalog queries (260 percent increase).

In FY 2022, the Infrared Science Archive (IRSA) released new data from the Stratospheric Observatory for Infrared Astronomy (SOFIA), the Infrared Telescope Facility (IRTF), and the NEOWISE Reactivation mission, and from enhanced processing efforts contributed by the community. IRSA responded to an average of 5.4 million queries per month for its publicly accessible data, and IRSA data appeared in approximately 140 refereed astrophysics journal articles per month. IRSA also significantly improved its data discovery and exploration tools.

The NASA/Infrared Processing and Analysis Center Extragalactic Database (NED) serves already-published data for 1.1 billion distinct extragalactic objects. In FY 2022, NED responded to more than 117 million data queries and 612 peer-reviewed articles referenced NED. In support of Open Science, NED led the publication "Best Practices for Data Publication in the Astronomical Literature," which is now featured in instructions for authors at major astronomy journals.

In FY 2022, the NASA Astronomical Virtual Observatories (NAVO) implemented prototype enhancements of virtual observatory protocols to address the coming era of big data and improve archive interoperability. NAVO members have taken leadership roles in the International Astronomical Union and the International Virtual Observatory Alliance, to promote and work toward increased interoperability across astronomy and astrophysics archives. NAVO members have led the effort for three releases of Python Virtual Observatory (PyVO), the most popular VO access software library, with a successful series of community workshops. The latest release improves the user-friendliness of the data discovery functions.

COSMIC ORIGINS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Hubble Space Telescope (HST)	98.3	--	**93.3**	98.3	98.3	98.3	98.3
James Webb Space Telescope	175.4	172.5	**187.0**	187.0	187.0	187.0	187.0
Other Missions and Data Analysis	90.4	--	**62.2**	73.3	62.9	143.1	168.7
Total Budget	**364.1**	**--**	**342.5**	**358.7**	**348.2**	**428.4**	**454.0**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Shown here is an image of the Cartwheel Galaxy from the James Webb Space Telescope. This galaxy's appearance resulted from a collision with another galaxy. Its light arose from hundreds of billions of stars that are each individually too faint to see.

"How did we get here?" This simple but fundamental question drives the broad science objectives of NASA's Cosmic Origins program. The search for answers raises underlying questions and topic areas, such as: How and when did the first stars and galaxies form? When did the universe first create the elements critical for life? How did galaxies evolve from the very first systems to the types we observe "in the here and now," such as the Milky Way in which we live? How do stars and planetary systems form and change over time?

Observatories collect data at different wavelengths to fully address these questions. Currently operating facilities in the Cosmic Origins program are the James Webb Space Telescope and the Hubble Space Telescope.

EXPLANATION OF MAJOR CHANGES IN FY 2024

Following the recommendation of the Astro2020 Decadal Survey "Pathways to Discovery in Astronomy and Astrophysics for the 2020s," this budget funds the closeout of the Stratospheric Observatory for Infrared Astronomy (SOFIA) mission. Activities funded by closeout include dispositioning the fleet of 747 parts, demolishing the Mirror Coating Facility, decommissioning of the Flight Simulator, and exiting the Building 703 hangar. In FY 2024, the project will also complete the administration of SOFIA Guest Observer grants.

HUBBLE SPACE TELESCOPE OPERATIONS

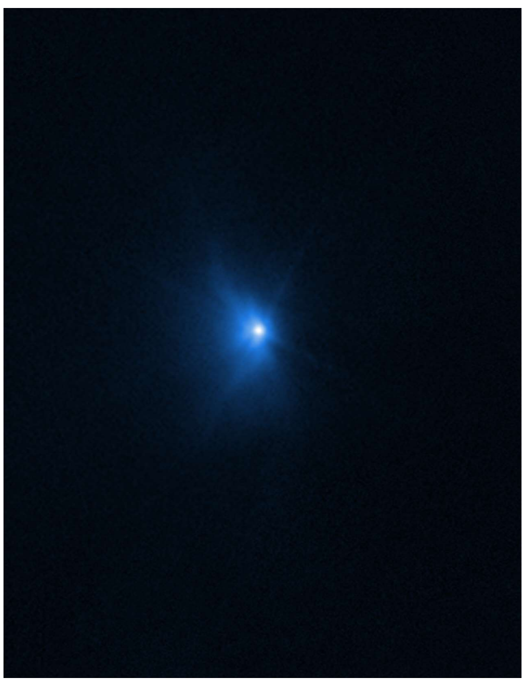
Formulation	Development	Operations

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	98.3	--	93.3	98.3	98.3	98.3	98.3

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



This animated GIF combines three of the images NASA's Hubble Space Telescope captured after NASA's Double Asteroid Redirection Test (DART) intentionally impacted Dimorphos, a moonlet asteroid in the double asteroid system of Didymos.

One of NASA's most successful and long-lasting science missions, the Hubble Space Telescope (Hubble) has beamed over 1 million images back to Earth, helping resolve many of the great mysteries of astronomy. The telescope helped scientists determine the age of the universe, the identity of quasars, and the existence of dark energy. Hubble launched in 1990 and is currently in an extended operations phase. The fifth servicing mission in 2009, the last visit by a Space Shuttle crew, added new batteries, gyroscopes, and instruments to extend Hubble's life even further into the future.

April 24, 2022 marked the start of Hubble's 32^{nd} year in orbit. The observatory is currently in its most scientifically productive period.

EXPLANATION OF MAJOR CHANGES IN FY 2024

This budget reflects use of available funds from prior years, resulting in fewer resources requested in FY 2024. NASA does not expect this adjustment to affect science generated from the mission.

ACHIEVEMENTS IN FY 2022

Hubble currently has three functional gyros with no backups and has demonstrated the ability to conduct science operations with a single gyro. These three gyros are allowing overlap with Webb science operations. In June 2021, Hubble experienced a failure of Science Instrument Command and Data Handling (SI C&DH) Unit, which caused science operations to temporarily cease. The project swapped

HUBBLE SPACE TELESCOPE OPERATIONS

Formulation	Development	Operations

several spacecraft systems including the SI C&DH to a redundant side (A side, from B side) in order to resume normal operations. The project is currently studying options should the A side SI C&DH fail. It appears possible to continue collecting science data in an 'instrument blind mode,' where data would directly telemeter to ground without passing through the SI C&DH.

NASA announced the Cycle 30 selections in July 2022. Motivated by a consistent underrepresentation of female Principal Investigators (PIs) in selected proposals, Hubble initiated a dual-anonymous peer review starting in 2018 with Cycle 26 and has now completed five rounds of this program. Statistics continue to show a near tripling of the number of PIs who are leading their first Hubble investigation, and the disparity between male and female PIs has narrowed, with the average difference between male and female PI's selection rates dropping from five percent to one percent since dual-anonymous peers reviews were instituted.

NASA's Hubble Space Telescope has established an extraordinary new benchmark: detecting the light of a star that existed within the first billion years after the universe's birth in the Big Bang – the farthest individual star ever seen to date. The newly detected star is so far away that its light has taken 12.9 billion years to reach Earth, appearing to us as it did when the universe was only seven percent of its current age, at redshift 6.2. The smallest objects previously seen at such a great distance are clusters of stars, embedded inside early galaxies. Normally at these distances, entire galaxies look like small smudges, with the light from millions of stars blending together. The galaxy hosting this star has been magnified and distorted by gravitational lensing into a long crescent named the Sunrise Arc. After studying the galaxy in detail, researchers determined that one feature is an extremely magnified star named Earendel, which means morning star in Old English. The discovery holds promise for opening up an uncharted era of very early star formation.

WORK IN PROGRESS IN FY 2023

NASA and SpaceX have signed a Space Act Agreement to study the possibility that a commercial enterprise could boost the orbit and possibly refurbish Hubble. This six-month study, to be completed in 2023, is being done on a no exchange of funds basis and is meant as a generic test of commercial enterprises boosting any NASA science satellite. The current estimated altitude of Hubble is approximately 535 kilometers. Hubble's orbit is slowly decaying, and if lower than 500 kilometers, without a boost, the Hubble orbit will decay to the point that science operations will not be possible by the mid-2030s.

In FY 2023 and beyond, NASA will support mission operations, systems engineering, software maintenance, ground systems support, guest-observer science grants, and the NASA Hubble Fellowship Program. Hubble continues mission life-extension initiatives, such as optimizing the use of gyroscopes and extending the lifetime of Hubble's instruments. NASA will select observations for Cycle 31 in mid FY 2023.

HUBBLE SPACE TELESCOPE OPERATIONS

Formulation	Development	Operations

KEY ACHIEVEMENTS PLANNED FOR FY 2024

NASA will release Cycle 32 call for proposals in early 2024. The Space Telescope Science Institute (STScI), which manages Hubble's science program, will select Cycle 32 science observations. Like other recent competitions for Hubble observing time, NASA expects requested observational orbits to outnumber the available orbits by six to one, indicating that Hubble remains one of the world's preeminent astronomical observatories.

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

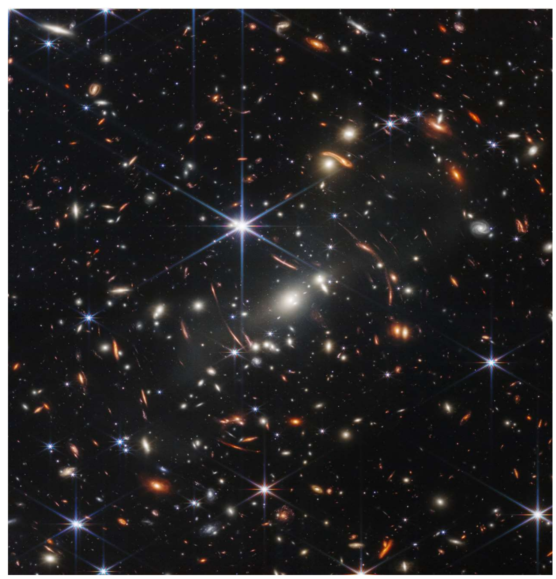
FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
James Webb Space Telescope	143.7	--	**127.0**	127.0	127.0	127.0	127.0
Webb Science	31.7	172.5	**60.0**	60.0	60.0	60.0	60.0
Total Budget	**175.4**	**172.5**	**187.0**	**187.0**	**187.0**	**187.0**	**187.0**
Change from FY 2023 Budget Request			**14.5**				
Percent change from FY 2023 Budget Request			**8.4%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The James Webb Space Telescope (Webb) is a large, space-based astronomical observatory. The mission is in many ways a successor to the Hubble Space Telescope (Hubble), extending Hubble's discoveries by looking into the infrared spectrum. Webb observes the highly red-shifted early universe and studies objects like protostars and protoplanetary disks, which strongly emit infrared light where dust obscures shorter wavelengths. With more light-collecting area than Hubble and near- to mid-infrared optimized instruments, Webb observes objects farther away and further back in time.



The James Webb Space Telescope (Webb) has produced the deepest and sharpest infrared images of our universe. Webb's First Deep Field image, shown here, was of galaxy cluster SMACS 0723 which includes the faintest objects ever to be observed in the infrared.

The four main science goals are to:

- Search for the first galaxies or luminous objects formed after the Big Bang;
- Determine how galaxies evolved from their formation until now;
- Observe the formation of stars from the first stages to the formation of planetary systems; and
- Measure the physical and chemical properties of planetary systems and investigate the potential for life in those systems.

While Hubble greatly improved knowledge about distant objects, its infrared coverage is limited. Light from distant galaxies is red-shifted out of the visible part of the spectrum and into the infrared by the expansion of the universe. Webb explores the poorly understood epoch when the first luminous objects in the universe came into being after the Big Bang.

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ACHIEVEMENTS IN FY 2022

In FY 2022, NASA transported Webb to the launch site in Kourou, French Guiana where it made final preparations for spacecraft fueling. The launch campaign commenced with integration of the observatory to the launch vehicle and subsequent preparation activities of the launch vehicle. Webb successfully launched in December 2021 and traveled to its orbit in Lagrange Point 2. NASA completed a six-month commissioning phase, first on the spacecraft, then the telescope, and finally on the instruments. Once successfully commissioned, the observatory initiated routine science operations.

Webb unambiguously detected, for the first time, carbon dioxide (CO_2) in the atmosphere of an exoplanet. The exoplanet, WASP 39-b, is known as a 'hot Jupiter' type exoplanet because it is like Jupiter in size and orbits its host star so closely that temperatures are about 1,600 degrees Fahrenheit. Webb observed this system for about eight hours and confirmed the presence of CO_2, which was previously only suggested during much longer observations with the Spitzer Space Telescope. Since the exoplanet atmosphere has so much CO_2, it was either enriched in heavy elements by a bombardment of comets and asteroids in that system, or the planet formed much farther out in the system and migrated inward via gravitational interactions with other exoplanets orbiting that star. Since Webb captured this in such a short observation period, many more interesting exoplanet atmosphere discoveries will be forthcoming.

WORK IN PROGRESS IN FY 2023

In FY 2023, Webb will conduct routine operations for Cycle 1 of the Early Release Observations, Early Release Science, Guaranteed Time Observations, and General Observer science programs.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

In FY 2024, NASA will support mission operations, systems engineering, software maintenance, ground systems support, and general observer science grants. The 3rd Cycle of observing proposals will also be solicited. In the most recently completed solicitation, Cycle 2, more proposals were received than any other NASA observatory ever. NASA anticipates this will be the case for Cycle 3 as well. It will be the first time that proposers can utilize recently publicized Cycle 1 data, enabling the best-informed planning, regarding the on-orbit performance capabilities, to date.

Mission Elements

JAMES WEBB SPACE TELESCOPE

Webb is an infrared-optimized observatory that conducts imaging and spectrographic observations in the 0.6 to 28 micrometer wavelength range. Webb is roughly 100 times more capable than Hubble because its

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

mirror is seven times larger. It spends about twice as much time observing targets since the Earth is not in the way. Webb's detectors cover larger regions of the sky and are always on. Its multi-object spectroscopic capabilities greatly expand the number of spectra per field.

The 6.5 meter primary mirror consists of 18 actively controlled segments. A multilayer sunshield the size of a tennis court passively cools the mirror, telescope optics, and instruments to about 40 Kelvin. Webb launched in 2021 from Kourou, French Guiana on an Ariane 5 rocket contributed by the European Space Agency (ESA). Webb is currently operating in deep space about 1 million miles from Earth.

Webb's instruments include the Near-Infrared Camera (NIRCam), Near-Infrared Spectrograph (NIRSpec), Mid-Infrared Instrument (MIRI), and the Fine Guidance Sensor/Near-Infrared Imager and Slitless Spectrograph.

The operating telescope project supports the telescope operations and science team.

WEBB SCIENCE

The Webb Science project funds research enabled by Webb observations and data. Observation time on Webb is allocated in a competitive process each year in cycles of awards. To ensure that the science community quickly learns to use its instruments and capabilities, Webb has made early awards during the first five months of Webb operations (Director's Discretionary-Early Release Science [DD-ERS]) prior to the first full cycle of research awards. DD-ERS research ranges from observations of the Jovian system to studying galaxies in the distant universe. The general observer program elements from Cycle 1 will be interweaved with the DD-ERS program. The project made Cycle 1 awards in April 2021.

OTHER MISSIONS AND DATA ANALYSIS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Stratospheric Observ for Infrared Astron	75.0	30.0	**20.0**	18.7	0.0	0.0	0.0
Astrophysics Strategic Mission Prog Mgmt	6.2	--	**9.6**	8.4	9.2	8.9	9.8
Cosmic Origins SR&T	7.9	--	**29.6**	43.2	50.7	131.2	155.9
Cosmic Origins Future Missions	1.3	--	**3.0**	3.0	3.0	3.0	3.0
Total Budget	**90.4**	**--**	**62.2**	**73.3**	**62.9**	**143.1**	**168.7**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

This landscape of “mountains” and “valleys” speckled with glittering stars is the edge of a young nearby star-forming region, called NGC 3324, in the Carina Nebula. Captured in infrared light by NASA’s new James Webb Space Telescope, this image reveals for the first time previously invisible areas of star birth.

Cosmic Origins Other Missions and Data Analysis funds program management, supporting research and technology, and early studies of potential future Cosmic Origins missions.

Mission Planning and Other Projects

ASTROPHYSICS STRATEGIC MISSION PROGRAM MANAGEMENT

Astrophysics Strategic Mission Program Office (ASMPO) provides streamlined Agency oversight and insight into all of NASA’s strategic astrophysics missions, consistently applying management lessons learned and best practices to increase the likelihood of mission success. The overall objective of the ASMPO is to provide a continuous flow of revolutionary scientific discoveries through a portfolio of ambitious missions spanning the full range of NASA’s broad astrophysics goals to discover how the universe works, explore how it began and evolved, and search for life on planets around other stars. ASMPO provides programmatic, technical, business management, and program science leadership for all strategic Astrophysics missions. This support continues throughout the definition, design, development, launch, and operations phases, and facilitates science investigations derived from those missions. It also provides the funding for Astrophysics Headquarters civil servants.

OTHER MISSIONS AND DATA ANALYSIS

COSMIC ORIGINS STRATEGIC RESEARCH AND TECHNOLOGY

Cosmic Origins (COR) Strategic Research and Technology (SR&T) supports program-specific research and advanced technology development efforts, such as the Strategic Astrophysics Technology solicitation. In addition, funding supports the study of future NASA space observatories, including technology development to support recommendations of the Astrophysics Decadal Survey.

This budget request supports the continuation of the Mirror Technology Development industry solicitation initiated in 2019. Two large teams of aerospace companies lead this on-going effort to increase performance, shorten schedule, and reduce risk and cost of future large space optics. The focus is exclusively on technology maturation and elimination of some technology gaps identified during the study of the four large mission concepts submitted to the Astro2020 Decadal Survey Review.

This budget continues support of precursor science and technology efforts in planning and preparing for the Great Observatories Mission and Technology Maturation Program (GOMAP) recommendation contained in the Astro2020 Decadal Survey "Pathways to Discovery in Astronomy and Astrophysics for the 2020s." SR&T funding support for GOMAP ramps up in the outyears of the budget window.

SR&T also provides support for the multi-disciplinary observations of the New Horizons extended mission. New Horizon's cameras will map the very faint cosmic background in visible and ultraviolet light, making important observations of the local interstellar medium that are not possible from Earth.

Recent Achievements

During 2022, NASA, academic, and industry technologists worked on and matured strategic COR technologies. These efforts have contributed to the overall NASA Astrophysics technology development, which has led to over 170 technology infusions into space, suborbital, ground missions, and concepts. The COR SR&T project supported oversight of the Segmented Mirror Technology Program to reduce risk and enable the ultra-stable large space telescopes needed for future flagship observatories. The technology management activities also enhanced and expanded a publicly accessible database of astrophysics technology projects and sponsored the Strategic Astrophysics Technology (SAT) principal investigators annual presentation week remotely. COR technologists have identified potential technologies that could enable implementation of decadal survey recommendations. The Astrophysics Technology Management Program published the 2022 Astrophysics Biennial Technology Report (ABTR), prioritized with ExEP technologists and others, and published Astrophysics Technology Gaps following the publication of the 2020 Decadal Survey. It also released a revised PCOS/COR Technology Management Plan (TMP).

STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY (SOFIA)

The SOFIA mission ended its five-year prime mission phase in October 2019 and ended its extended operations phase in September 2022. SOFIA completed 730 science flights and generated over 13 terabytes of raw science data.

FY 2023 closeout activities include archiving of science data, flight software, observatory engineering data, and image guides; and the decommissioning of more than 100,000 property items. The SOFIA team will decommission the following science instruments and make recommendations for potential scientific uses: FLITECAM, EXES, HAWC+, HIRMES, and FORCAST. NASA will decommission the German instruments, FIFI-LS, GREAT, and the Shack-Hartmann Test Instrument, according to direction provided by the German partner. The project will also decommission IT equipment after data archiving is

OTHER MISSIONS AND DATA ANALYSIS

complete, plan for disposition of the telescope assembly and spares, and dispose of ground support equipment that is at the end of service life.

In FY 2024, the SOFIA project will continue closeout work, including continuing the disposition of the fleet of 747 parts, decommissioning of the Flight Simulator and Mirror Coating Facility, and return of the Building 703 hangar. Even though the plane has been dispositioned at Pima Air Museum, the logistical work in closing the program, dispositioning material and property, and creating the legacy archive is significant.

COSMIC ORIGINS FUTURE MISSIONS

Cosmic Origins Future Missions funding supports studies of future mission concepts.

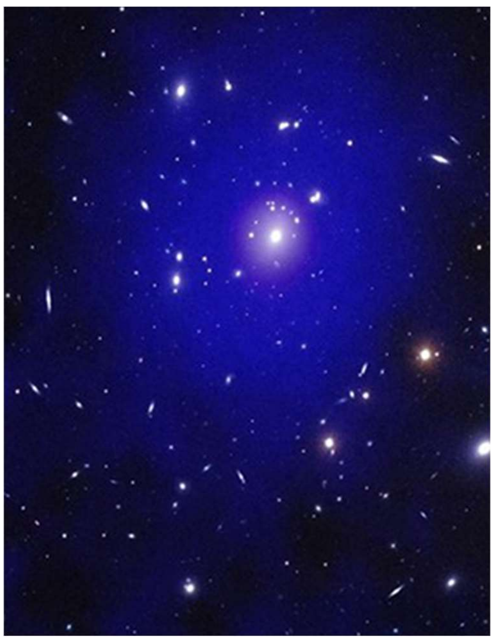
PHYSICS OF THE COSMOS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Other Missions and Data Analysis	160.0	--	**202.0**	212.7	204.8	207.8	216.3
Total Budget	**160.0**	**--**	**202.0**	**212.7**	**204.8**	**207.8**	**216.3**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



Chandra deep observations, shown here, of the merging galaxy cluster Abell 98 find the missing matter in the universe. Astronomers have examined the Chandra data of this merging cluster and detected the Warm Hot Intergalactic Medium connecting as a bridge the two merging clusters. This medium is made of normal matter and formed in the early Universe, but a third of it is yet to be found. Scientists have argued that the Warm Hot Intergalactic Medium could reside in the space between galaxies and cluster of galaxies, therefore this discovery confirms such predictions.

The universe enables scientists to study the most profound questions at the intersection of physics and astronomy. How do matter, energy, space, and time behave under extreme gravity? What is the nature of dark energy and dark matter? How did the universe grow from the Big Bang to its present size? The Physics of the Cosmos (PhysCOS) Program incorporates cosmology, high-energy astrophysics, and fundamental physics projects that address central questions about the nature of complex astrophysical phenomena, such as black holes, neutron stars, dark matter and dark energy, cosmic microwave background, and gravitational waves.

The operating missions within the PhysCOS Program continue to provide answers to these fundamental questions and more.

PhysCOS includes a vigorous program to develop the technologies necessary for the next generation of space missions to address the science questions of this program.

EXPLANATION OF MAJOR CHANGES IN FY 2024

The budget supports the continuation of extended operations for the Fermi and X-ray Multi-Mirror Mission (XMM) missions through FY 2025, as recommended by the 2022 Senior Review.

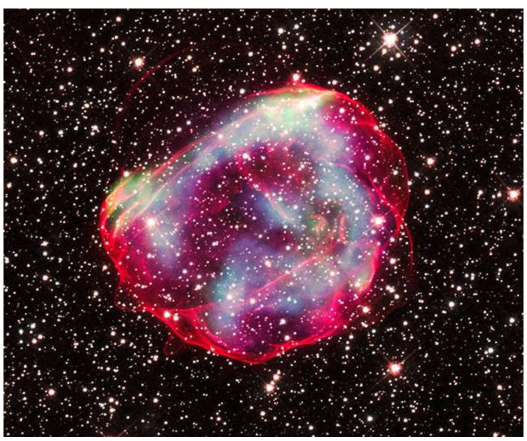
OTHER MISSIONS AND DATA ANALYSIS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Physics of the Cosmos SR&T	50.2	--	**92.1**	104.4	113.6	115.9	124.1
Euclid	8.9	--	**9.3**	9.9	9.7	9.1	8.5
PCOS/COR Technology Office Management	10.9	--	**10.8**	8.0	8.3	8.8	8.9
Physics of the Cosmos Future Missions	0.0	--	**3.0**	2.7	2.7	2.7	2.7
Fermi Gamma-ray Space Telescope	13.9	--	**14.2**	14.2	0.0	0.0	0.0
Chandra X-Ray Observatory	72.1	--	**68.7**	69.6	70.5	71.3	72.2
XMM	4.0	--	**4.0**	4.0	0.0	0.0	0.0
Total Budget	**160.0**	**--**	**202.0**	**212.7**	**204.8**	**207.8**	**216.3**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



Shown here are Chandra observations (green, blue, and purple) of the supernova remnant SNR 0519-69.0 showing the debris from the thermonuclear explosion of a white dwarf star. Optical data from the Hubble Space Telescope shows the perimeter of the remnant in red and stars around the remnant in white. Researchers use this type of supernova, called a Type Ia, for studies of thermonuclear explosions and also for measuring distances to galaxies across billions of light-years.

Other Missions and Data Analysis supports Physics of the Cosmos (PhysCOS) Supporting Research and Technology, the PhysCOS/COR Technology Management Office, PhysCOS Future Missions, and operating missions including Euclid, Fermi, Chandra, and X-ray Multi-Mirror Mission (XMM).

Mission Planning and Other Projects

PHYSCOS SUPPORTING RESEARCH AND TECHNOLOGY

PhysCOS Supporting Research and Technology leads strategic technology development efforts to prepare for the next generation of PhysCOS space missions, including program-specific research and advanced technology development efforts, such as the Strategic Astrophysics Technology (SAT) program element.

This budget supports the NASA contribution to the European Space Agency's (ESA) Advanced Telescope for High Energy Astrophysics (ATHENA) mission, an X-ray observatory dedicated to high-resolution spectroscopy, and ESA's Laser Interferometer Space Antenna (LISA) mission, a space-based gravitational wave observatory. This project supports the technology development and formulation activities necessary to contribute to the ESA missions.

OTHER MISSIONS AND DATA ANALYSIS

This budget also supports research and technology development in response to the Astro2020 Decadal Survey "Pathways to Discovery in Astronomy and Astrophysics for the 2020s" recommendation for a Time Domain Astronomy program.

Recent Achievements

NASA continues to make progress on ATHENA, with a slow-down directed in FY 2024 due to the current ESA reformulation process, which is assessing different architectures and a revised launch readiness date. A reformulated mission will also likely mandate a different approach to NASA contributions.

NASA shipped the completed laser for the LISA mission to ESA in July 2021 for one year of performance testing. The test was terminated due to a power issue with the laser. NASA is fixing the problem and plans to reship the laser to continue testing. NASA continues the hardware testing for the charge management device to prepare for Technical Readiness Level-6 development. The telescope structural thermal model development is on schedule. NASA has developed the engineering model mirrors and is proceeding with further testing.

EUCLID

NASA is collaborating on Euclid, an ESA mission, selected as part of ESA's Cosmic Visions program in June 2012 and scheduled for launch in late 2023 or 2024. Euclid seeks to investigate the accelerated expansion of the universe, the so-called "dark energy," using a Visible Instrument and a Near Infrared Spectrometer and Photometer instrument, as well as ground-based data. The Euclid Consortium, comprised of over 1,200 scientists and engineers from over 50 institutes in Europe, the United States, and Canada, is responsible for development of the two instruments and the science data centers. NASA contributes flight detector subsystems for the Near Infrared Spectrometer and Photometer instrument and a NASA Euclid Science Center that forms part of the Euclid Science Ground System. In exchange, NASA receives membership in the Euclid Science Team and Consortium and competed science opportunities for U.S. investigators.

Recent Achievements

The Euclid NASA Science Center at Infrared Processing and Analysis Center (IPAC) is responsible for developing data analysis software, processing data, and supporting U.S. researchers using Euclid data. In preparation for Euclid launch in 2023, the Center participated in extensive real-time testing of the distributed Euclid Science Ground System to demonstrate the Center can process data at the rate needed during on-orbit operations and that the software is capable of meeting science requirements for the mission's Performance Verification phase. In addition, the Center updated its analysis software to improve both calibration accuracy and processing speed.

The NASA Euclid data archive, operated as part of the NASA/IPAC Infrared Science Archive, will focus on the needs of the U.S. research community, complementing ESA's Euclid archive. In FY 2022, the Center and the Archive worked together on the design of features to support U.S. investigators. The Center also held the first meeting of its user panel to gather input from the community on support priorities.

The NASA science team members continued to provide key, critical roles in preparing for the Euclid science survey data, providing a robust method to calibrate Euclid's photometric redshift survey, and

OTHER MISSIONS AND DATA ANALYSIS

identifying optimum observation strategies. These efforts will lead to system performance that exceeds the baseline plan for the spectroscopic survey.

PHYSCOS/COR TECHNOLOGY OFFICE MANAGEMENT

The PhysCOS/COR Technology Office provides programmatic, technical, and business management for all technology development and special studies in support of the PhysCOS and Cosmic Origins (COR) Programs activities. It also is engaged and supports the science leadership and coordination with a larger science community.

Recent Achievements

The program office has completed several studies such as future communication needs study, and precursor science and time domain astronomy workshops. The program office has continued to engage the science community in developing NASA strategy and plans for implementing decadal survey recommendations.

PHYSCOS FUTURE MISSIONS

PhysCOS Future Missions funding supports concept studies of future missions.

Operating Missions

FERMI

The Fermi Gamma-ray Space Telescope (Fermi) explores extreme environments in the universe, from black holes on all scales, to ultra-dense neutron stars spinning hundreds of times per second, to expand knowledge of their high-energy properties. Fermi observations are answering long-standing questions across a broad range of topics, including solar flares, the origin of cosmic rays, and the nature of dark matter. NASA's Fermi mission launched in June 2008, developed in collaboration with the United States Department of Energy, along with important contributions from academic institutions and partners in France, Germany, Italy, Japan, Sweden, and the United States. Fermi entered extended mission operations in August 2013. The 2022 Senior Review of Operating Missions recommended continuing Fermi operations through FY 2025.

Recent Achievements

The analysis of 12 years of observations from Fermi-Large Area Telescope confirmed the existence of an efficient particle acceleration in the Kepler supernova remnant, one of the youngest in our galaxy. The researchers have found that the gamma-ray emission is most likely produced by the interaction of accelerated ions with the surrounding medium but depending on the amplitude of the magnetic field, several scenarios are plausible.

On October 9, 2022, Fermi was among the first NASA missions to detect an unusually bright and long-lasting pulse of high-energy radiation coming from the most luminous gamma-ray burst (GRB) known. GRBs are the most powerful class of explosions in the universe and are produced during the collapse of a massive star that eventually gives birth to a black hole. While the instrument team published a catalog

OTHER MISSIONS AND DATA ANALYSIS

detailing the spectral analysis of over 10 years and 2,200 GRBs detected by the Fermi Gamma-Ray Burst Monitor (GBM) in 2021. This event is particularly interesting because of its brightness, longevity (Fermi's Large Area Telescope [LAT] detected the burst for more than 10 hours), and its proximity to Earth. The event triggered multiwavelength follow ups.

CHANDRA

Launched in 1999, Chandra is transforming our view of the universe with its high-quality X-ray images, providing unique insights into violent events and extreme conditions such as explosions of stars, collisions of galaxies, and matter around black holes. Chandra enables observations of clusters of galaxies that provide direct evidence of the existence of dark matter and greatly strengthens the case for the existence of dark energy. Observations of the remains of exploded stars, or supernovas, have advanced our understanding of the behavior of matter and energy under extreme conditions. Chandra has also discovered and studied thousands of supermassive black holes in the centers of distant galaxies. The 2022 Senior Review of Operating Missions recommended continuing Chandra operations through FY 2025.

Recent Achievements

Studies of local or nearby supernova remnants (SNRs) have been the focus of Chandra observations for many years, but it is often difficult to understand the timeline of the star's explosion. The combined analysis of Chandra and Hubble Space Telescope observations of the supernova remnant, SNR 0519-69.0, allowed astronomers to wind back the clock and determine how long ago the star in this system exploded and learn about the environment the supernova occurred in. While the analysis of the Hubble data alone implies that the light from the explosion would have reached Earth about 670 years ago, Chandra data provided clues that the material has slowed down since the initial explosion, crashing into dense gas surrounding the remnant and indicating that the explosion happened more recently than 670 years ago and putting strong constraints on this source timeline.

Recent observations in the gamma-ray band with Fermi have found bubbles extending approximately 10 kilo-parsecs above and below the galactic plane, which may be evidence of galactic nuclear feedback. Chandra and XMM-Newton observations of these regions raise questions about the relationships between these structures at different scales. High-spatial-resolution Chandra data have revealed well-delineated "chimneys" extending from the Galactic center towards, and merging with, the Fermi bubbles at 150 parsec scales, suggesting that energy is transported from star-forming winds and/or supernova explosions into the bubbles. On approximately 15 parsec scales, Chandra resolves bipolar lobes extending into the chimneys. These studies in our own Galactic center are extremely important to understand feedback processes in more distant galaxies. Chandra, along with the Laser Interferometer Gravitational-wave Observatory (LIGO) and Virgo observatory, detected and performed the first observations of gravitational waves from a pair of spiraling neutron stars, opening a new branch of astrophysics.

X-RAY MULTI-MIRROR MISSION (XMM)

XMM is an ESA-led mission with substantial NASA contributions. The telescope launched in December 1999 and provides unique data for studies of the fundamental processes of black holes and neutron stars. XMM studies the evolution of chemical elements in galaxy clusters and the distribution of dark matter in galaxy clusters and elliptical galaxies. The 2022 Senior Review of Operating Missions recommended continuing U.S. science operations through FY 2025.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

XMM has helped discover the magnetic flip of a monster black hole. Combining radio, optical, and UV data with X-ray data from the Neil Gehrels Swift observatory and XMM, scientists find that a rare outburst from a galaxy 236 million light-years away may have been sparked by a spontaneous reversal of the magnetic field surrounding its central black hole. Most big galaxies host a supermassive black hole weighing millions to billions of times the Sun's mass. Near the black hole, X-rays are produced. An unexpected disappearance and reappearance of X-ray emission suggests a magnetic reversal, where the north pole becomes south and vice versa. Such a reversal relates this object to our Earth, where its magnetic field flips on average a few times every million years, and our Sun, which switches its north and south poles roughly every 11 years.

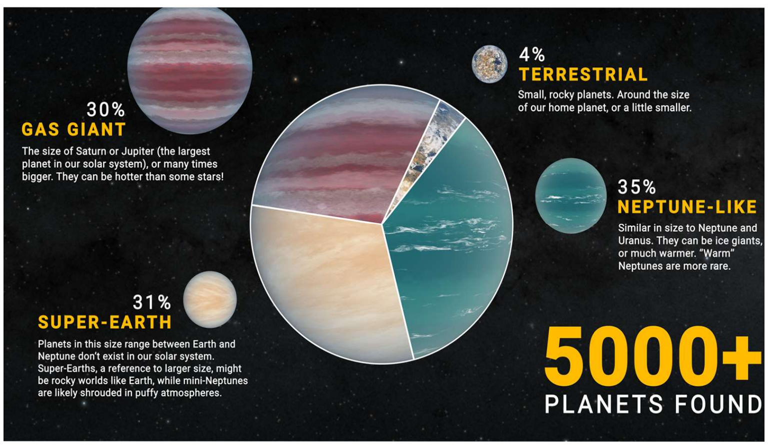
EXOPLANET EXPLORATION

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Nancy Grace Roman Space Telescope	501.6	482.2	**407.3**	384.0	376.5	216.6	100.5
Other Missions and Data Analysis	41.4	--	**56.4**	43.1	42.9	96.4	96.4
Total Budget	**543.0**	**--**	**463.7**	**427.1**	**419.4**	**313.0**	**196.9**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



The more than 5,000 exoplanets confirmed in our galaxy so far include a variety of types, as depicted here. Some are similar to planets in our solar system, while others are vastly different. Among these are a mysterious variety known as "super-Earths" because they are larger than our world and possibly rocky.

Humankind is gaining insight into timeless questions: Are we alone? Is Earth unique, or are planets like ours common? One of the most exciting new fields of research within the NASA Astrophysics portfolio is the search for planets, particularly Earth-like planets, around other stars.

Since the discovery of the first exoplanets in the 1990s, astronomers have confirmed over 5,100 planets orbiting most types of stars in our galaxy. At first, most of the planets discovered were so-called "Hot Jupiters"— gas giants similar in size to the planet Jupiter but orbiting much closer to their parent stars. However, analysis of the complete Kepler data set shows that smaller planets, with sizes between Earth and Neptune, are more common, but without counterpart in our solar system. Rocky planets in the habitable zone of their parent stars also appear to be common. The Transiting Exoplanet Survey Satellite (TESS) mission is now discovering many more small planets orbiting bright stars.

NASA's Exoplanet Exploration Program is advancing along a path of discovery leading to a point where scientists can directly study the atmospheres and surface features of habitable, rocky planets like Earth around other stars in the solar neighborhood. In the future, NASA aims to develop systems that will allow scientists to take the pivotal step from identifying an exoplanet as Earth-sized to determining whether it is truly Earth-like, and possibly even detecting if it bears the fingerprints of life. Such an ambitious goal would require overcoming significant technological challenges. An important component of the Exoplanet Exploration effort is a robust technology development program with the goal of enabling a future direct detection and characterization mission.

EXOPLANET EXPLORATION

EXPLANATION OF MAJOR CHANGES IN FY 2024

The budget includes additional funds within Supporting Research and Technology (SR&T) to test the Coronagraph Instrument's (CGI) enhanced configurations and observations modes to reduce risk for the future great observatories recommended by the Astro2020 Decadal Survey. These enhanced configurations are not necessary for the basic technology demonstration of the coronagraph; however, the risk to future implementations would be reduced considerably.

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

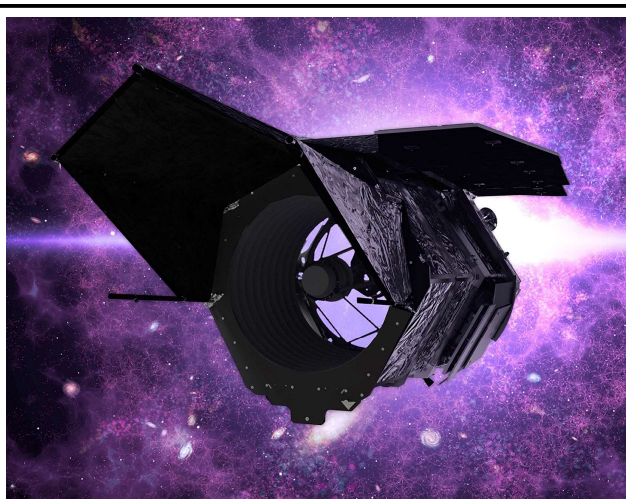
FY 2024 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028	BTC	Total
Formulation	633.8	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	633.8
Development/Implementation	1,032.8	501.6	447.3	**407.3**	384.0	367.9	129.1	0.0	0.0	3,270.0
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	8.6	87.5	100.5	215.5	412.2
2023 MPAR LCC Estimate	**1,666.6**	**501.6**	**447.3**	**407.3**	**384.0**	**376.5**	**216.6**	**100.5**	**215.5**	**4,316.0**
Total Budget	**1,666.6**	**501.6**	**482.2**	**407.3**	**384.0**	**376.5**	**216.6**	**100.5**	**215.5**	**4,350.9**
Change from FY 2023 Enacted				**-74.9**						
Percent change from FY 2023 Enacted				**-15.5%**						

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The 2023 MPAR LCC Estimate reflects the most recent estimates based on current project data as of February 2023. The requested budget authority is the project's current budget requirement which has seen programmatic changes and are anticipated in the Quarter 2 Financial Report.



The Nancy Grace Roman Space Telescope, depicted here, is a NASA observatory designed to tackle essential questions in the areas of dark energy, exoplanets, and infrared astrophysics.

PROJECT PURPOSE

The Nancy Grace Roman Space Telescope (Roman) will investigate long-standing astronomical mysteries, such as the force behind the universe's accelerating expansion, and search for distant planets beyond our solar system. Roman will unravel the secrets of dark energy and dark matter, search for and image exoplanets, and explore many topics in infrared astrophysics. This newest NASA observatory addresses the top priority large mission of the 2010 Decadal Survey in Astronomy and Astrophysics.

Roman carries two instruments. The Wide Field Instrument will accomplish the mission's primary science observations over large areas of the sky. The Coronagraph Instrument technology demonstration instrument matures

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

components and systems for imaging and spectroscopy of individual nearby exoplanets. NASA has scheduled Roman's launch for May 2027 so that Roman mission's operations overlap with those of the James Webb Space Telescope to provide synergistic science capabilities. Roman ushers in a new era of big data for astrophysics, producing an archive averaging over 10 terabytes of data per day of operations during its first five years of operations.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

PROJECT PARAMETERS

The Nancy Grace Roman Space Telescope is a NASA observatory designed to investigate essential questions in the areas of dark energy, exoplanets, and infrared astrophysics. To address these questions, the telescope has a large, 7.9-foot (2.4-meter) diameter primary mirror, since a larger surface area gathers more light and produces sharper images. Roman's mirror is the same size as the Hubble Space Telescope's primary mirror, and it is less than one-fourth the weight weighing only 410 pounds (186 kilograms), thanks to major improvements in technology. To make Roman's sensitive measurements possible, the telescope observes from a vantage point orbiting about 930,000 miles (1.5 million kilometers) away from Earth in the direction away from the Sun. Near this location, called the second Sun-Earth Lagrange point (L2), the observatory is thermally stable, views more of the sky for longer periods of time, and can prevent stray light from the Sun, Moon, and Earth more easily.

The telescope provides a field of view that is 200 times greater than the Hubble Space Telescope's infrared instrument, allowing it to capture more of the sky with less observing time. The Roman Wide Field Instrument is a 300-megapixel infrared camera and spectrometer built to provide revolutionary surveys of unprecedented size, sharpness, and depth to address key topics in cosmology, exoplanets, and infrared astrophysics. The camera features eight filters for different wavelengths of infrared light suited to studying varied astronomical objects, plus two spectroscopic elements to measure distances and study other physical characteristics of galaxies and supernovae across the universe.

In addition to the Wide Field Instrument, Roman will advance exoplanet observations by carrying the first active coronagraph into space. The Coronagraph Instrument, built as a technology demonstration, combines multiple technologies and operation modes to block the light from the host star and allow high-contrast imaging of faint exoplanets orbiting it. This capability is critical for next-generation telescopes capable of analyzing the atmospheres of Earth-like planets around other stars.

The Nancy Grace Roman Space Telescope is planned for a primary mission lifetime of five years, with enough propellant for a five-plus-year extended mission.

ACHIEVEMENTS IN FY 2022

Having completed the design work, the Roman project is building and exercising the engineering development and test units, and fabricating, testing, and assembling flight hardware. The project has

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

delivered, tested, and certified all 18 sensor chip assemblies for the Wide Field Instrument, the most critical components of the camera, along with six flight spare sensor chip assemblies. The project is testing the flight Mosaic Plate Assembly and its associated high performance readout electronics are undergoing testing. The Wide Field Instrument received the optical bench from the manufacturer and started integration in preparation for testing. The optical bench houses the large element wheel and optical filters, along with essential electronics, and brings together the detectors and onboard calibration system.

The subassemblies in the Optical Telescope Assembly have all completed fabrication and are undergoing integration and testing. The Primary Mirror Assembly has completed environmental testing to ensure that it will meet the strict optical quality requirements for the observatory. The Secondary Mirror Optical Assembly is complete; the Secondary Mirror Support Tubes are complete; the Tertiary Optics Module Assembly is in alignment; and the Aft Optics Structure is complete. Additionally, the project has fabricated many components of the instrument carrier and spacecraft bus that provide structural, communications, power, and thermal services to the observatory. In addition to the test units and flight hardware, the project is building ground support equipment and software that will be critical for successful testing and operations.

In FY 2022, the Coronagraph Instrument team had all flight hardware in hand and moved from subassemblies to full assembly integration. The team completed the Optical Bench Structure Assembly, and the Cryo-Thermal Subsystem and Electronic Heat Transport System Pallet. The project successfully tested the Deformable Mirrors, Fast Steering Mirror, Focus Control Mirror, and the Precision Alignment Mechanisms. The project completed fabrication on two cameras, one for low order wavefront sensing and one for exoplanet measurement. The project also completed fabrication of all electronics and completed integration and alignment of optical components onto the Optical Bench Structure Assembly, except for some Precision Alignment Mechanisms and the cameras.

Finally, NASA contracted with SpaceX to provide a Falcon Heavy launch vehicle for Roman.

WORK IN PROGRESS IN FY 2023

In FY 2023, NASA will focus on continued assembly, integration, and testing for all aspects of Roman. NASA anticipates completing integration of all Wide Field Instrument subsystems including the Relative Calibration System and Focal Plane System and NASA will prepare the full instrument for environmental test. NASA will complete the Optical Telescope Assembly electronics, and the full Integrated Optics, and put the assembly into validation and testing. NASA will continue assembly and testing of the Instrument Carrier and Spacecraft. The Optical Telescope Assembly and Instrument Carrier expect to hold their System Integration Reviews (SIRs) in Q3 FY 2023 in preparation for system level assembly, test, and verification.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

NASA will complete the later stages of system-level testing of flight hardware in FY 2024. The project expects to take delivery of the Integrated Optics Assembly, the Wide Field Instrument, the Instrument Carrier, and the Coronagraph. NASA will complete the spacecraft bus in FY 2024 and will take delivery

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

of the Outer Barrel Assembly (OBA) to support observatory Integration and Test (I&T). NASA expects delivery of the Launch Loads Vibration Isolation System (LLVIS) and will complete the Integrated Payload Assembly (IPA) integration by the end of FY 2024.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2024 PB Request
Key Decision Point-C (KDP-C)	Feb 2020	Feb 2020
Critical Design Review	Jul 2021	Sep 2021
SIR	Jul 2023	Jan 2025
Flight Readiness Review	Jun 2026	Jan 2027
Launch	Oct 2026	May 2027
Begin Phase E	Jan 2027	Aug 2027
End Prime Mission	Jan 2032	Aug 2032

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2021	2,898	>70	2023	3,270	+13	LRD	Oct 2026	May 2027	+7

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as Joint Confidence Level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**2,898.1**	**3,270.0**	**+371.9**
Aircraft/Spacecraft	278.1	382.9	+104.8
Payloads	661.6	744.1	+82.5
Systems I&T	183.2	301.2	+118.0
Launch Vehicle	238.6	261.1	+22.5
Ground Systems	217.6	289.9	+72.3
Science/Technology	79.4	118.3	+38.9
Other Direct Project Costs	1,239.6	1,172.5	-67.1

Project Management & Commitments

NASA Headquarters is responsible for the overall management of Roman and the Coronagraph Instrument (CGI). Goddard Space Flight Center (GSFC) has project management responsibility for Roman. Jet Propulsion Laboratory (JPL) has project management responsibility for CGI.

Element	Description	Provider Details	Change from Baseline
Project Management and Systems Engineering	Management of all technical and programmatic aspects of mission development and system engineering of each element and the integrated system	Provider: NASA Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Mission Science Management	Management of all project science activities from formulation through development and operations	Provider: NASA Lead Center: GSFC Performing Center(s): GSFC and partners Cost Share Partner(s): N/A	N/A

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Wide Field Instrument	Overall instrument management; in-house development of the Focal Plane System, Grism, Prism, and all subsystems other than the Ball-managed Wide Field Instrument Opto-Mechanical Assembly (WOMA)	Provider: NASA, Ball Aerospace Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Instrument Carrier	Structural Support for the Optical Telescope Assembly, Wide Field Instrument, and Coronagraph Instrument	Provider: NASA, Northrup Grumman Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Spacecraft	Main bus for Roman; providing power, electrical, thermal, and propulsion systems	Provider: NASA Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Coronagraph Instrument	Management of all technical and programmatic aspects of instrument development and system engineering of the technology demonstration for space-based exoplanet characterization	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Star Tracker, Flight Battery	Optical device that measures the positions of stars using photocells or a camera; rechargeable power source	Provider: European Space Agency (ESA) Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Electron-Multiplying Charge-Coupled Device Detectors	Devices for digital imaging under low-light conditions	Provider: ESA Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Super-polished optics and Off Axis Parabolas	Optical elements to collimate and direct light within the Coronagraph Instrument	Provider: French Space Agency (CNES)/LAM Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): CNES	N/A

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Precision Alignment Mechanisms	Mechanisms to direct light within the Coronagraph Instrument with 1-2 arcsecond pointing accuracy	Provider: Max Planck Institute for Astronomy (MPIA) Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): MPIA	N/A
Polarization Optics	Optical elements to select the polarization state of light within the Coronagraph Instrument	Provider: Japan Aerospace Exploration Agency (JAXA) Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): JAXA	N/A
Use of Ground Station	Daily use of a ground station in Japan and data transport to the Science Operations Center (SOC)	Provider: JAXA Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): JAXA	N/A
Launch Vehicle	Launch services for Roman on required trajectory for L2 operational orbit	Provider: SpaceX Lead Center: Kennedy Space Center (KSC) Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Mission Operations	Management of on-orbit operations	Provider: NASA Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Ground Control System and Science Operations and Control Center	Science Operations Center responsible for processing, analysis, and archiving of data from the observatory	Provider: Space Telescope Science Institute (STScI) Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Coronagraph Ground Control System and Science Operations and Control Center	Science Center responsible for processing and analysis of coronagraph data for infrared astronomy	Provider: Infrared Processing and Analysis Center (IPAC) Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: Staffing shortfalls at L3 Harris and delays in the Instrument Carrier structure manufacturing at Northrup Grumman deplete funded schedule margin, Then: The mission schedule could be impacted if early consumption of funded schedule margin leaves too little for issues later in the flow.	Roman's integration and testing replan will accommodate a later than planned Instrument Carrier build schedule at Northrup Grumman and shorten Instrument Carrier integration and testing schedule at GSFC. Additional Roman management oversight of L3 Harris is anticipated to result in a more efficient workflow, reducing potential impacts.
If: The project cannot modify the High-Capacity Centrifuge (HCC) in time to support the Instrument Carrier test need date; and the HCC test does not impart adequate loading to provide full qualification of the Instrument Carrier, spacecraft, primary structure, and the Outer Barrel Assembly, Then: There is a possibility the Instrument Carrier, spacecraft primary structure, and Outer Barrel Assembly will need additional static load test cases, resulting in additional cost/schedule to execute additional testing.	The HCC team will focus on defining the capability of the existing HCC with limited modifications such as adding extensions to the platform beams sufficient to support the entire base plate. The project will perform analysis on the feasibility of the baseline test plan and will revise, if necessary.

Acquisition Strategy

The project has awarded all major contracts.

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Optical Telescope Assembly	L3 Harris	Rochester, NY
Wide Field Instrument Opto-Mechanical Assembly (WOMA)	Ball Aerospace	Boulder, CO
Sensor Chip Assemblies	Teledyne	Camarillo, CA
	Hawaii Aerospace	Honolulu, HI
Science Operations Center Support	AURA/Space Telescope Science Institute	Baltimore, MD
Science Center Support	IPAC/Caltech	Pasadena, CA
Launch Vehicle	SpaceX	Hawthorne, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	Feb 2018	SRR/MDR: Evaluate whether Roman requirements are properly formulated to meet mission objectives and to assess the credibility of Roman's estimated budget and schedule	Proposed mission/system architecture is credible and responsive to mission requirements and constraints including resources	Oct 2019
Performance	SRB	Oct 2019	PDR: Evaluate the completeness / consistency of the Roman preliminary design in meeting all requirements with appropriate margins, acceptable risk, and within cost and schedule constraints; and to determine readiness to proceed with the detailed design phase	Roman's planning, technical, cost and schedule baselines developed during Formulation are complete	Sep 2021

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Sep 2021	CDR: Demonstrate maturity of the Roman design is appropriate to meet requirements and support proceeding with full-scale fabrication and assembly	Roman's detailed design is expected to meet requirements with adequate margins at an acceptable level of risk and there is high confidence in the baseline to allow the project to proceed with fabrication, assembly, integration, and test	Jan 2025
Performance	SRB	Jan 2025	SIR: Determine Roman readiness to proceed to system integration and test phase	TBD	Jan 2027
Performance	SRB	Jan 2027	FRR: Evaluate the readiness of the project to operate and perform the mission	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Exoplanet Exploration SR&T	23.2	--	**37.3**	24.2	23.9	32.4	32.4
Exoplanet Exploration Technoloy Off Mgmt	9.2	--	**8.6**	8.5	8.5	8.6	8.6
Exoplanet Exploration Future Missions	1.2	--	**3.0**	2.8	2.8	47.6	50.6
Keck Operations	7.7	--	**7.4**	7.6	7.7	7.8	4.9
Total Budget	**41.4**	**--**	**56.4**	**43.1**	**42.9**	**96.4**	**96.4**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Mission Planning and Other Projects

Exoplanet Exploration Other Missions and Data Analysis includes funding for Exoplanet Exploration Supporting Research and Technology, Exoplanet Exploration Technology Office Management, Keck Operations, and funding for future mission selections.

EXOPLANET EXPLORATION STRATEGIC RESEARCH AND TECHNOLOGY

Exoplanet Exploration Strategic Research and Technology supports program-specific strategic research and technology development activities that both serve the needs of the U.S. exoplanet science community today and forge a path for ever more ambitious missions of exoplanet discovery in the future. In support of these goals, the project supports the NASA Exoplanet Science Institute (NExScI) and the NASA Exoplanet Archive, which together provide coordination and support for the latest cutting-edge scientific research activities of the U.S. exoplanet community. Similarly, the project maintains and operates an array of highly specialized testbeds and related facilities that are available to the community and support the development of advanced technologies and instrument concepts for exoplanet exploration.

NASA currently supports a portfolio of competitively selected exoplanet science and technology development projects involving researchers from across the Nation. The selected projects focus on confirming the exoplanet discoveries of NASA's Kepler/K2 and Transiting Exoplanet Survey Satellite (TESS) missions and vetting potential targets for further observation and characterization with NASA's James Webb Space Telescope (Webb) and Roman Space Telescope. The portfolio of selected technology is also laying the scientific and technological foundation for the top priority large mission recommended by the 2020 Decadal Survey of Astronomy and Astrophysics: a future Great Observatory that will detect and characterize potentially habitable, Earth-sized planets orbiting Sun-like stars in the solar neighborhood and search for signs that they might harbor life.

NASA also supports a range of exoplanet science investigations through its investments in the Keck Observatory in Hawaii and the Wisconsin-Indiana-Yale-National Optical Astronomy Observatory (WIYN) Telescope in Arizona. Those science investigations include ground-based, follow-up observing

OTHER MISSIONS AND DATA ANALYSIS

programs that support NASA's TESS mission and programs that support the operational planning and design of future missions.

Recent Achievements

In March 2022, the field of exoplanet science achieved an amazing milestone when it surpassed 5,000 confirmed exoplanets at the NASA Exoplanet Archive. This large population of planets, discovered using a variety of detection techniques from the ground and from space, is enabling population studies into planet formation, evolution, and migration processes on an unprecedented scale, and providing exciting new targets for Webb to characterize.

In July 2022, the NASA Exoplanet Science Institute held its annual Sagan Summer Workshop. The workshop is held every summer to help train new and upcoming researchers in the discovery and characterization of exoplanets. The topic this year was "Exoplanet Science in the Gaia Era" and was attend by more than 1,200 people both virtually and in-person in Pasadena, CA. This was the first workshop held in-person since 2019 and featured presentations by experts in the field of exoplanets, including hands-on sessions to teach young researchers how to work with data relevant to exoplanets. Next summer, the Sagan Summer Workshop will focus on new results and data on exoplanets from NASA's James Webb Space Telescope.

EXOPLANET EXPLORATION TECHNOLOGY OFFICE MANAGEMENT

Exoplanet Exploration Technology Office Management provides scientific and technical leadership and business management for the Program's portfolio of technology development projects. It coordinates, supports, and tracks the progress of the program's numerous technology development tasks. It also manages shared testbed infrastructure for the use of the community of exoplanet technologists, actively engages science community stakeholders, and provides effective public and professional communication of exoplanet science discovery and enabling technologies.

Recent Achievements

The Exoplanet Exploration Technology Office updated the Astrophysics Division's Technology Gap List to reflect the recommendations of the National Academies' Astro2020 Decadal Survey, in collaboration with the other NASA Astrophysics Division program offices, and with broad community participation. The prioritized Technology Gap List communicates to the community the technical capabilities that must be developed to achieve NASA's strategic goals in astrophysics and helps NASA to guide technology investments effectively.

EXOPLANET EXPLORATION FUTURE MISSIONS

Exoplanet Exploration Future Missions funding supports the execution of the exoplanet mission science and technology definition teams and, ultimately, the formulation, development, and implementation of a future Exoplanet Exploration flight mission.

OTHER MISSIONS AND DATA ANALYSIS

Operating Missions

KECK OPERATIONS

Keck Operations is the NASA portion of the Keck Observatory partnership. NASA is a partner for one-sixth of the observing nights on the two 10-meter telescopes of the W.M. Keck Observatory (WMKO), the largest optical telescope pair in the world. NASA uses its share of observing time in support of its Astrophysics and Planetary Science programs. The project allocates observing time for NASA astrophysics science goals, as well as for solar system objects and direct space mission support. Supported missions in recent years include Kepler, TESS, Euclid, Webb, and the Roman Space Telescope for Astrophysics; Parker Solar Probe for Heliophysics; and Juno, New Horizons, and Cassini for Planetary Science. All observing time proposal requests are competitive with peer-review and selection managed by the NASA Exoplanet Science Institute. The Keck Observatory Archive (KOA), managed by the NASA Exoplanet Science Institute, ingests and curates existing and new data from the Keck Observatory.

Recent Achievements

The large number of proposals submitted continues to demonstrate strong demand for NASA observing nights with an oversubscription rate for both telescopes around four to one. During the 2023A observing semester that runs from February through July 2023, scientists at institutions around the United States submitted requests for 107 observing nights in total for both telescopes.

The Keck Observatory achieved successful first light in early November 2022 of the Keck Planet Finder (KPF) instrument. Extreme precision radial velocity data from KPF is important to characterize targets to assemble input catalogs for NASA operating and upcoming great observatories. The combined use of ground- and space-based data will maximize the utility and efficiency of NASA space missions.

The data services initiative to enhance operational efficiency and easier and open access to fully processed data from Keck instruments continued in 2022. All secured observations plus real time data ingestion are now available for all 12 instruments in KOA covering nearly 30 years of “Keck Sky.” Currently the astronomical community uses the KOA data with approximately 15 to 20 percent of WMKO publications citing the archive as the source of their data. Key strategic mission support programs for operating and future NASA space missions account for about 35 percent of all the NASA competed time to the U.S. community.

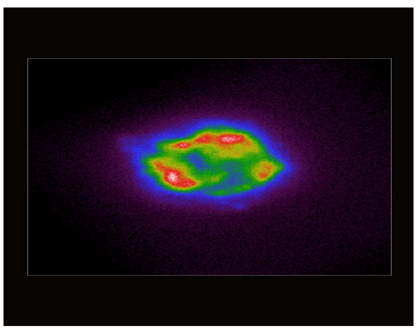
ASTROPHYSICS EXPLORER

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
SPHEREx	97.9	71.1	**70.1**	44.5	6.0	1.6	0.5
Compton Spectrometer and Imager (COSI)	23.3	--	**15.0**	70.3	84.6	50.6	6.3
Other Missions and Data Analysis	113.2	--	**174.2**	209.5	228.9	303.3	491.1
Total Budget	**234.4**	**--**	**259.3**	**324.3**	**319.5**	**355.5**	**497.9**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



This image from NASA's Imaging X-ray Polarimetry Explorer maps the intensity of X-rays coming from the observatory's first target, the supernova remnant Cassiopeia A. Colors ranging from cool purple and blue to red and hot white correspond with the increasing brightness of the X-rays. The image was created using X-ray data collected by IXPE January 11 through 18.

The Astrophysics Explorer Program provides frequent flight opportunities for world-class astrophysics investigations using innovative and streamlined management approaches for spacecraft development and operations. The program is highly responsive to new knowledge, new technology, and updated scientific priorities by launching smaller missions formulated and executed in a relatively short development cycle. NASA selects new missions based on an open competition of concepts solicited from the scientific community. The program emphasizes the accomplishments of missions under the control of the scientific research community within constrained mission life-cycle costs.

The most recent Astrophysics Medium-Class Explorer (MIDEX) missions cost up to $451 million in total, including launch services. Small Explorer (SMEX) missions cost up to $294 million including launch services. Pioneer missions cost up to $20 million, excluding the launch. The most recent Explorer Missions of Opportunity (MO) have a total NASA cost of under $100 million, including the launch. NASA intends to solicit proposals for MOs in conjunction with each Announcement of Opportunity (AO) issued for MIDEX and SMEX investigations.

EXPLANATION OF MAJOR CHANGES IN FY 2024

The Explorer budget supports the continuation of extended operations for the Transiting Exoplanet Survey Satellite (TESS), Neutron Star Interior Composition ExploreR (NICER), Swift, and Nuclear Spectroscopic Telescope Array (NuSTAR) missions through FY 2025, as recommended by the 2022 Senior Review. The Explorer budget includes the Astrophysics Probes Future Missions as a new project. NASA has delayed elements within the Explorer Program to support higher priority missions within space science. NASA has delayed the Compton Spectrometer and Imager (COSI) mission launch readiness date from 2026 to 2027 and adjusted the budget profile accordingly. The budget delays the next Explorer AO for SMEX and MO missions by one year from March 2024 to March 2025.

ASTROPHYSICS EXPLORER

ACHIEVEMENTS IN FY 2022

NASA selected COSI in October 2021 to proceed to the preliminary design and technology completion phase (Phase B) as a SMEX mission.

NASA successfully launched Imaging X-ray Polarimetry Explorer (IXPE) in December 2021.

SPHEREx successfully completed its mission Critical Design Review (CDR) in January 2022.

NASA down-selected two MIDEX missions to continue with competitive Phase A studies in August 2022: Ultraviolet Explorer (UVEX) and Survey and Time-domain Astrophysical Research eXplorer (STAR-X). NASA also selected two MO missions to continue with competitive Phase A studies in August 2022: Moon Burst Energetics All-sky Monitor (MoonBEAM) and Large Area Burst Polarimeter (LEAP). These four missions are relevant to the decadal recommendations in the area of Time Domain and Multi Messenger follow up (TDAMM).

WORK IN PROGRESS IN FY 2023

CASE successfully completed its Key Decision Point-C (KDP-C) review in January 2023.

X-ray Imaging and Spectroscopy Mission (XRISM) is scheduled to launch in FY 2023 and will transition to Phase E mission operations.

COSI completed its Systems Requirements Review in January 2023. NASA expects the project to complete its CDR in late FY 2023.

NASA will release the Astrophysics Probe Announcement of Opportunity (AO) no earlier than July 2023.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

SPHEREx will complete its KDP-D review in December 2023. Galactic/Extragalactic UltraLong-Duration Balloon Spectroscopic Terahertz Observatory (GUSTO) will launch from Antarctica in December 2023. COSI will complete its KDP-C review in January 2024 and transition to the development phase.

Program Schedule

Date	Significant Event
Dec 2022	CASE KDP-C
Jan 2023	Pioneers Notices of Intent
Mar 2023	Pioneers proposals due
FY 2023	XRISM LRD
NET Jul 2023	Astrophysics Probe Announcement of Opportunity
Summer 2023	Pioneers selection

ASTROPHYSICS EXPLORER

Date	Significant Event
Dec 2023	SPHEREx KDP-D
Dec 2023	GUSTO LRD
Jan 2024	COSI KDP-C
NET 2024	Select Probe proposals for competitive Phase A studies
NET Mar 2024	Down-select one MIDEX and Explorer MO mission for implementation
Apr 2025	SPHEREx LRD
NET 2025	Down-select one Probe mission for implementation
Mar 2025	SMEX and MO Announcement of Opportunity
Mar 2026	Select SMEX and Explorer MO proposals for competitive Phase A mission concept studies
Aug 2027	MIDEX and MO Announcement of Opportunity
2027	COSI LRD
Sep 2028	Down-select one SMEX and one Explorer MO for implementation

Program Management & Planned Cadence

The Astrophysics and Heliophysics Explorer Programs are both coordinated sets of uncoupled missions, where each mission is independent and has unique science. The programs share a common program office at NASA Goddard Space Flight Center (GSFC) and a common management structure. The Explorer Program Manager resides at GSFC, reporting functionally to the Center Director and programmatically through the Astrophysics and Heliophysics Division Directors to the Associate Administrator for Science Mission Directorate (SMD).

This budget supports approximately a three- to four-year mission cadence, or four AO solicitations every decade.

Acquisition Strategy

NASA selects all Explorer missions through competitive AOs.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	2019	Program Independent Review: Assess performance of program	Successful	2024

SPECTRO-PHOTOMETER FOR THE HISTORY OF THE UNIVERSE, EPOCH OF REIONIZATION, AND ICES EXPLORER

Formulation	Development	Operations

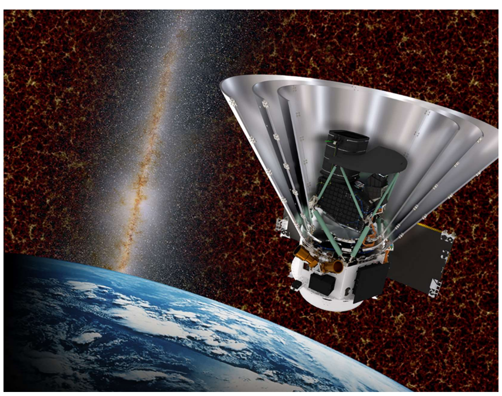
FY 2024 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028	BTC	Total
Formulation	64.2	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	64.2
Development/Implementation	95.6	97.9	71.1	**70.1**	33.0	0.0	0.0	0.0	0.0	367.8
Operations/Close-out	0.0	0.0	0.0	**0.0**	11.4	6.0	1.6	0.5	0.0	19.5
2023 MPAR LCC Estimate	**159.8**	**97.9**	**71.1**	**70.1**	**44.5**	**6.0**	**1.6**	**0.5**	**0.0**	**451.4**
Total Budget	**159.8**	**97.9**	**71.1**	**70.1**	**44.5**	**6.0**	**1.6**	**0.5**	**0.0**	**451.4**
Change from FY 2023 Enacted				**-1.0**						
Percent change from FY 2023 Enacted				**-1.4%**						

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The 2023 MPAR LCC Estimate reflects the most recent estimates based on current project data as of February 2023. The requested budget authority is the project's current budget requirement which has seen programmatic changes and are anticipated in the Quarter 2 Financial Report.



NASA's SPHEREx infrared astrophysics mission (shown here in this artist's conception cut-away image to indicate the payload and telescope subsystem) will study the quantum physics of the Big Bang, the subsequent formation of galaxies, and the large-scale interstellar distribution of ices and water. Credit: NASA/JPL-Caltech.

PROJECT PURPOSE

The Spectro-Photometer for the History of the Universe, Epoch of Reionization, and Ices Explorer (SPHEREx) Mission will serve as a powerful tool for understanding how our universe evolved and how common the ingredients for life are in our galaxy's planetary systems. SPHEREx will be NASA's first all-sky spectral astronomy survey mission and will investigate the quantum physics of the Big Bang theory of the origin of the Universe. The mission will chart the origin and history of galaxy formation, from light produced by the first galaxies that ended the cosmic dark ages, to the present day. Astronomers will use the mission to gather data on hundreds of millions of galaxies and stars. SPHEREx will also survey water and organic molecules in interstellar ices.

SPECTRO-PHOTOMETER FOR THE HISTORY OF THE UNIVERSE, EPOCH OF REIONIZATION, AND ICES EXPLORER

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

PROJECT PARAMETERS

SPHEREx is a medium Explorer-class astrophysics mission planned to launch in 2025. It is a three-axis stabilized spacecraft that NASA will launch into a sun-synchronous Earth orbit with an altitude of approximately 650 kilometers for a baseline two-year science mission. SPHEREx will survey the sky in near-infrared light. SPHEREx will probe the origin of the Universe through a large-volume galaxy redshift survey and provide a rich public spectral archive for diverse investigations. The payload consists of the thermal subsystem, optical subsystem, and instrument control electronics. The Korea Astronomy and Space Science Institute (KASI) will contribute the non-flight cryogenic test chamber. SPHEREx will launch on a SpaceX Falcon 9.

ACHIEVEMENTS IN FY 2022

The SPHEREx project completed its Critical Design Review (CDR) in January 2022. The SPHEREx project received the flight payload detectors. KASI delivered the non-flight cryogenic payload test chamber to Caltech in the Summer of 2022.

WORK IN PROGRESS IN FY 2023

The project will continue fabrication and assembly of most flight subsystems for both the payload and spacecraft bus in FY 2023.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

The project will complete the fabrication and assembly of flight subsystems of both the payload and spacecraft bus in preparation for the Systems Integration Review in November 2023. The project will hold the Key Decision Point-D (KDP-D) review in January 2024 and will begin its integration and testing phase of development.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2024 PB Request
KDP-C	Dec 2020	Dec 2020
CDR	Sep 2021	Jan 2022

SPECTRO-PHOTOMETER FOR THE HISTORY OF THE UNIVERSE, EPOCH OF REIONIZATION, AND ICES EXPLORER

Formulation	Development	Operations

Milestone	Confirmation Baseline Date	FY 2024 PB Request
System Integration Review	Mar 2023	Nov 2023
KDP-D	May 2023	Jan 2024
Launch Readiness Date (LRD)	Apr 2025	Apr 2025
Phase E start	May 2025	May 2025

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2021	367.8	>70%	2023	367.8	0%	LRD	April 2025	April 2025	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time was developed. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**367.8**	**367.8**	**0.0**
Aircraft/Spacecraft	54.9	65.2	+10.3
Payloads	45.8	87.2	+41.4
Systems I&T	11.9	15.5	+3.6
Launch Vehicle	112.4	98.8	-13.6
Ground Systems	12.0	14.4	+2.4
Science/Technology	21.0	25.9	+4.9

SPECTRO-PHOTOMETER FOR THE HISTORY OF THE UNIVERSE, EPOCH OF REIONIZATION, AND ICES EXPLORER

Formulation	Development	Operations

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
Other Direct Project Costs	109.8	60.8	-49.0

Project Management & Commitments

The Jet Propulsion Laboratory (JPL) provides project management for the mission. The SPHEREx Principal Investigator resides at the California Institute of Technology (Caltech). JPL manages the overall SPHEREx mission and will provide systems engineering, mission assurance, payload thermal and mechanical mission system, and the operations science team.

Element	Description	Provider Details	Change from Baseline
Payload Thermal Subsystem	The thermal subsystem consists of the photon shields, focal plan radiator, telescope support structure, and V-groove radiators	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): None	N/A
Payload Optical Subsystem	The optical subsystem consists of the baffle and focal plane assemblies	Provider: Caltech Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	N/A
Payload Electronics Subsystem	The electronics subsystem consists of the payload flight software and instrument control electronics	Provider: Caltech Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	N/A
Spacecraft	Spacecraft Bus	Provider: Ball Aerospace Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	N/A
Telescope	20cm wide-field off-axis all-aluminum telescope	Provider: Ball Aerospace Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	N/A

SPECTRO-PHOTOMETER FOR THE HISTORY OF THE UNIVERSE, EPOCH OF REIONIZATION, AND ICES EXPLORER

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Focal Plane Assemblies	The two focal plane assemblies are separated by a dichroic filter to deliver full short and long wavelength coverage	Provider: JPL Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	N/A
Detectors	Each of six detector arrays has its own linear variable filters	Provider: Teledyne Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	N/A
Test Chamber	The non-flight cryogenic test chamber will support two test modes: optical mode with an optical window, and dark mode with a cryogenic integrating sphere	Provider: Korea Astronomy and Space Science Institute (KASI) Lead Center: JPL Performing Center(s): None Cost Share Partner(s): KASI	N/A
Launch Vehicle	Launch vehicle and related launch services	Provider: SpaceX Lead Center: KSC/Vandenberg Air Force Base (VAFB) Performing Center(s): None Cost Share Partner(s): None	N/A

Project Risks

Risk Statement	Mitigation
If: The telescope delivery is delayed, Then: The overall payload subsystem schedule will be impacted.	Major manufacturing activities for the telescope are almost complete. The SPHEREx project will maintain oversight of the telescope and utilize existing schedule reserves as required.
If: The photon shield thermal subsystem delivery is delayed, Then: The overall observatory integration schedule will be impacted.	Manufacturing activities for the photon shield are currently on schedule. The SPHEREx project will maintain oversight of the photon shield schedule and utilize existing schedule reserves as required.

SPECTRO-PHOTOMETER FOR THE HISTORY OF THE UNIVERSE, EPOCH OF REIONIZATION, AND ICES EXPLORER

Formulation	Development	Operations

Major Contracts/Awards

Element	Vendor	Location (of work performance)
Observatory integration, spacecraft bus	Ball Aerospace	Boulder, CO
Payload detectors	Teledyne	Thousand Oaks, California
Payload telescope	Ball Aerospace	Boulder, CO
Launch Vehicle	SpaceX	Hawthorne, CA
PI, CO-Is, Mission Payload	California Institute of Technology	Pasadena, CA

Independent Reviews

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Oct 2020	PDR	Successful	Jan 2022
Performance	SRB	Jan 2022	Mission CDR	Successful	Nov 2023
Performance	SRB	Nov 2023	SIR	TBD	Sep 2024
Performance	SRB	Sept 2024	ORR	TBD	N/A

COMPTON SPECTROMETER AND IMAGER

Formulation	Development	Operations

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**23.3**	**--**	**15.0**	**70.3**	**84.6**	**50.6**	**6.3**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

NASA's COSI gamma-ray astrophysics mission will study both the origin and destruction of matter in our Milky Way galaxy, and antimatter electrons (positrons) coming from the center of the Milky Way galaxy.

PROJECT PURPOSE

The Compton Spectrometer and Imager (COSI) mission will revolutionize our understanding of creation and destruction of matter in the Milky Way Galaxy and beyond. COSI will study gamma rays from radioactive atoms produced when massive stars exploded to map where chemical elements were formed in the Milky Way. The mission will also probe the mysterious origin of our galaxy's positrons, also known as antielectrons – subatomic particles that have the same mass as an electron but a positive charge. The COSI mission benefits from years of technology development with scientific balloon flights.

EXPLANATION OF MAJOR CHANGES IN FY 2024

NASA has delayed the COSI launch readiness date from FY 2026 to FY 2027 to support higher priority missions within space science.

PROJECT PRELIMINARY PARAMETERS

COSI is a small Explorer-class gamma-ray Astrophysics mission planned to launch in 2027. It is a three-axis-stabilized spacecraft that NASA will launch into a low-Earth orbit with an orbital inclination of less than five degrees for a baseline two-year science mission. COSI is a wide-field survey gamma-ray detector designed to perform imaging, spectroscopy, and polarimetry of astrophysical gamma-ray sources from a single space platform. The science payload consists of a Compton telescope with 16 cryogenically cooled germanium detectors (GeDs). The GeDs are surrounded by bismuth germanate scintillators that shield the GeDs from high-energy photon and particle background.

COMPTON SPECTROMETER AND IMAGER

Formulation	Development	Operations

COSI will obtain coverage of gamma-ray photons from the entire sky in the 0.2-5 MeV energy range. COSI will have polarization sensitivity for the study of gamma-ray bursts (GRBs) and accreting black holes. COSI will localize GRBs and will rapidly report the positions of short GRBs, which are primarily caused by merging neutron stars. COSI will also obtain coverage of the regions of the sky where high-energy neutrinos originate.

ACHIEVEMENTS IN FY 2022

NASA selected COSI to proceed to Phase B in October 2021. The project has continued to make progress in its the preliminary design and technology completion phase.

WORK IN PROGRESS IN FY 2023

COSI completed its Systems Requirements Review (SRR) in January 2023. The project will complete technology development and risk-reduction activities in preparation for Preliminary Design Review (PDR).

KEY ACHIEVEMENTS PLANNED FOR FY 2024

COSI will conduct its PDR in October 2023. The project will hold its Key Decision Point (KDP)-C review in January 2024 and enter its final design and fabrication phase.

ESTIMATED PROJECT SCHEDULE

Milestone	Formulation Authorization Document	FY 2024 PB Request
SRR	October 2022	January 2023
PDR	April 2023	October 2023
KDP-C	July 2023	January 2024
Critical Design Review (CDR)	April 2024	October 2024
Launch	2026	2027

COMPTON SPECTROMETER AND IMAGER

Formulation	Development	Operations

Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

Life cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows a non-advocate review and/or preliminary design review.

KDP-B Date	Estimated Life Cycle Cost Range ($M)	Key Milestone	Key Milestone Estimated Date Range
Sep 2022	267- 294	LRD	Q3 FY 2027- Q1 FY 2028

Project Management & Commitments

University of California at Berkeley (UCB) is the location of the COSI Principal Investigator and the COSI Project Office. Goddard Space Flight Center (GSFC) is the Technical Authority for the COSI mission and provides overall program management for all Explorers missions.

Element	Description	Provider Details	Change from Formulation Agreement
Payload integration	Integration and test of all payload subsystems	Provider: Space Dynamics Laboratory Lead Center: N/A Performing Center(s): none Cost Share Partner(s): none	N/A
Payload	Payload detector readout system, anticoincidence shields	Provider: Naval Research Laboratory Lead Center: N/A Performing Center(s): none Cost Share Partner(s): none	N/A
Payload	Payload cryostat, radiators heat removal system	Provider: GSFC Lead Center: N/A Performing Center(s): none Cost Share Partner(s): none	N/A
Spacecraft	Spacecraft bus	Provider: Northrop Grumman Space systems Lead Center: N/A Performing Center(s): none Cost Share Partner(s): none	N/A

COMPTON SPECTROMETER AND IMAGER

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
Observatory integration	Integration of payload and spacecraft bus, testing of combined payload and bus.	Provider: Northrop Grumman Space Systems Lead Center: N/A Performing Center(s): none Cost Share Partner(s): none	N/A

Project Risks

Risk Statement	Mitigation
If: The payload detector development schedule is delayed, Then: overall payload integration schedule will be impacted.	Phase B planning is ongoing to finalize detector preliminary design as quickly as possible to reduce risk.

Acquisition Strategy

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Observatory Integration, Spacecraft bus	Northrop Grumman Space Systems	Dulles, Virginia
Payload integration	Space Dynamics Laboratory	North Logan, Utah
Payload detector readout system, anticoincidence shields	Naval Research Laboratory	Washington, DC

COMPTON SPECTROMETER AND IMAGER

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Jan 2023	SRR	TBD	Oct 2023
Performance	SRB	Oct 2023	PDR	TBD	Oct 2024
Performance	SRB	Oct 2024	CDR	TBD	Dec 2025
Performance	SRB	Dec 2025	SIR	TBD	2026
Performance	SRB	2026	ORR	TBD	N/A

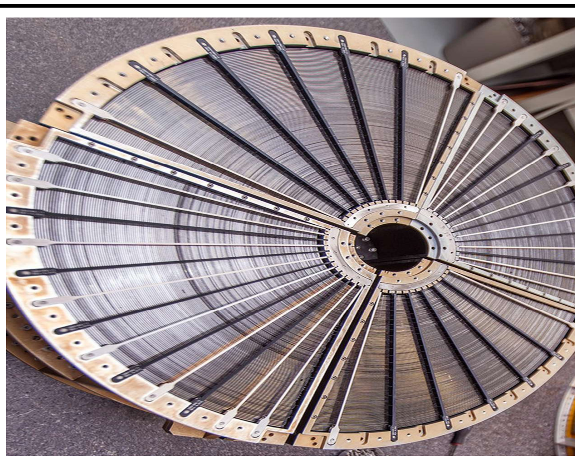
OTHER MISSIONS AND DATA ANALYSIS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Astrophysics Probes Future Missions	0.0	--	**7.5**	7.5	16.1	70.0	200.0
Pioneers	24.2	--	**28.0**	32.1	35.0	40.2	40.2
Contribution to ARIEL Spectroscopy of Exoplanets (CASE)	5.1	--	**7.8**	4.0	2.2	2.9	3.2
Astrophysics Explorer Future Missions	7.8	--	**44.9**	87.1	134.4	171.5	232.0
Astrophysics Explorer Program Management	17.1	--	**21.9**	18.2	23.6	16.0	15.7
Neutron Star Interior Composition Explorer (NICER)	4.4	--	**4.5**	4.5	0.0	0.0	0.0
Neil Gehrels Swift Observatory	5.8	--	**6.0**	6.0	0.0	0.0	0.0
Nuclear Spectroscopic Telescope Array	9.1	--	**9.3**	9.6	0.0	0.0	0.0
Transiting Exoplanet Survey Satellite	14.1	--	**14.0**	13.5	0.0	0.0	0.0
Galactic/Extragalactic ULDB Spectroscopic Terahertz Observatory (GUSTO)	5.0	--	**1.1**	0.0	0.0	0.0	0.0
Imaging X-Ray Polarimetry Explorer	8.6	--	**9.1**	8.5	1.7	0.0	0.0
X-Ray Imaging and Spectroscopy Mission	11.8	--	**20.0**	18.5	15.9	2.7	0.0
Total Budget	**113.2**	**--**	**174.2**	**209.5**	**228.9**	**303.3**	**491.1**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



The X-ray Imaging and Spectroscopy Mission (XRISM) is a JAXA/NASA collaborative mission, with ESA participation, with the objective to investigate X-ray celestial objects in the Universe with high-throughput, high-resolution spectroscopy. Full X-ray Mirror Assembly (XMA) setup with primary and secondary mirrors, all quadrants, and all foils installed.

Mission Planning and Other Projects

Astrophysics Explorer Other Missions and Data Analysis includes funding for small missions in formulation and development (CASE, SPHEREx, GUSTO, XRISM, COSI), Pioneers, operating missions (IXPE, TESS, NICER, NuSTAR, Neil Gehrels Swift Observatory), and funding for future mission selections and program management functions.

ASTROPHYSICS PIONEERS

Astrophysics Pioneers investigations will provide high-impact science with low cost via the use of new and inexpensive SmallSat and CubeSat technologies, new Ultra-Long Duration stratospheric balloon payloads, and ISS payloads.

OTHER MISSIONS AND DATA ANALYSIS

The Astrophysics Pioneers program element will solicit proposals for astrophysics suborbital and modest orbital science investigations that are greater in cost and scope than what is possible within the Astrophysics Research and Analysis (APRA) program element, but smaller in cost and scope than those allowed in the Astrophysics Explorer Mission of Opportunity (MO) element. This class of small missions fills the gap between existing ROSES investigations and MO investigations. Each investigation is managed by a Principal Investigator and is cost capped at $20 million; NASA encourages new and early career researchers to participate. In 2021, NASA announced the selection of the first four Pioneers projects. First time principal investigators lead all four investigations:

- Payload for Ultrahigh Energy Observation (PUEO), a long duration balloon instrument for particle astrophysics at the highest energies;
- Pandora, a SmallSat for multiwavelength characterization of exoplanets and their host stars;
- Aspera, a SmallSat to measure the intergalactic medium inflow/outflow from galaxies; and
- StarBurst, a SmallSat all-sky monitor for high energy gamma rays from events such as the merger of neutron stars -- events that can be synchronized with the detection of simultaneous gravity waves at facilities such as the ground-based Laser Interferometer Gravitational-wave Observatory (LIGO).

Recent Achievements

NASA recently awarded a new Pioneers Mission: Trans-Iron Galactic Element Recorder for the International Space Station (TIGERISS), designed for deployment from the International Space Station to measure ultra-heavy galactic cosmic rays. The PUEO, Pandora, Aspera, and StarBurst missions continue to work towards subsequent preliminary and critical design reviews. NASA continues to solicit Pioneers annually. NASA expects to make its next selection in the summer of 2023.

CONTRIBUTION TO ARIEL (ATMOSPHERIC REMOTE-SENSING INFRARED EXOPLANET LARGE-SURVEY MISSION) SPECTROSCOPY OF EXOPLANETS (CASE)

ARIEL is a joint ESA/NASA mission planned for launch in late 2029 that will observe hundreds of warm transiting gas giants, Neptune-sized planets, and super-Earths. The mission responds to high-priority science from the Astro2020 Decadal Survey by addressing the question: "What are the characteristics of planetary systems orbiting other stars and do they harbor life?”

ARIEL’s main science goals include measuring the composition and structure of planetary atmospheres, determining the vertical and horizontal temperature structure, and identifying chemical processes at work. A mission designed and optimized for transiting exoplanet spectroscopy will address a key gap in NASA’s exoplanet exploration mission portfolio. CASE will fill that gap and ensure the full participation of the U.S. community in ESA’s ARIEL mission. The CASE project hardware contribution to ARIEL is a pair of heritage sensor chip assemblies, cold front-end electronics, and cryogenic flex cables together with packaging and thermal management capability. CASE is currently in its development phase and is working with the European ARIEL consortium partners in implementing the NASA/CASE hardware contributions.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

The CASE project successfully completed its Preliminary Design Review (PDR) in September 2022 and is working in building engineering models of the focal plane module and enclosure which will house the focal plane electronics. The project conducted a successful Key Decision Point-C (KDP-C) in December 2022.

GALACTIC/EXTRAGALACTIC ULTRALONG-DURATION BALLOON SPECTROSCOPIC TERAHERTZ OBSERVATORY (GUSTO)

In March 2017, NASA's Astrophysics Explorer Program selected the GUSTO balloon payload as a Mission of Opportunity. GUSTO will launch on a high-altitude stratospheric zero-pressure balloon from McMurdo, Antarctica, in December 2023 for approximately 75 days. GUSTO's telescope, with its terahertz heterodyne array receivers, will provide the spectral and spatial resolution needed to study the interstellar medium. The GUSTO mission will provide the first complete study of all phases of the stellar life cycle, from the formation of molecular clouds, through star birth and evolution, to the formation of gas clouds and the restart of the cycle, addressing crucial NASA science questions such as "How did the universe originate and evolve to produce the galaxies, stars and planets we see today?" During flight, the GUSTO payload will conduct its scientific observation while tracking the prevailing stratospheric winds at the float altitude of 33.5 kilometers.

Recent Achievements

GUSTO experienced anomalies with the payload, which resulted in a launch delay from December 2022 to December 2023. The project continued rework on the payload's instrument optics and successfully completed their instrument level thermal vacuum testing at the Columbia Scientific Balloon Facility. The project will complete assembly and testing of the payload and will begin observatory integration when the payload is delivered to the Applied Physics Laboratory in spring of 2023.

THE X-RAY IMAGING AND SPECTROSCOPY MISSION (XRISM)

The X-ray Imaging and Spectroscopy Mission (XRISM), previously named XARM, is a joint NASA and JAXA mission that will recover the soft X-ray spectroscopic capability lost with the Hitomi mission that ended in March 2016. JAXA is planning to launch XRISM in FY 2023. The key scientific objective of XRISM is to investigate celestial X-ray objects in the Universe with unprecedented high-resolution X-ray spectroscopy. XRISM will provide breakthrough science in a number of areas, including structure and formation of the Universe, the evolution of clusters of galaxies, and the transport and circulation of energy in the cosmos. NASA is developing the Resolve Soft X-ray Spectrometer and many of its subsystems and the X-ray mirror assemblies for the observatory. NASA is also responsible for the Science Data Center, which is developing the analysis software for all instruments, the data processing pipeline, as well as support of Guest Observers (GO).

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

NASA and JAXA personnel completed a series of comprehensive performance and thermal cycling tests, and NASA completed integration of the Resolve instrument onto the spacecraft during in August 2022.

ASTROPHYSICS EXPLORER FUTURE MISSIONS

Astrophysics Explorer Future Missions funding supports future Astrophysics Explorer missions, and Missions of Opportunity, through concept studies and selections. The goal is to release four Announcement of Opportunity (AO) solicitations within a decade. The next AO is expected in March 2025. The Explorer Future funding also supports the Ultraviolet Transient Astronomy Satellite (ULTRASAT) mission. ULTRASAT is a Time Domain and Multi Messenger (TDAMM) mission to study the high energy transient events from the geostationary orbit. NASA is partnering with the Israel Space Agency to provide a commercial rideshare launch in 2025. NASA's role also includes Science Team membership and participation with data analyses.

Recent Achievements

NASA down-selected two MIDEX missions to continue with competitive Phase A studies in August 2022: Ultraviolet Explorer (UVEX) and Survey and Time-domain Astrophysical Research eXplorer (STAR-X). NASA also selected two MO missions to continue with competitive Phase A studies in August 2022: Moon Burst Energetics All-sky Monitor (MoonBEAM) and Large Area Burst Polarimeter (LEAP). These four missions are relevant to the decadal recommendations in the area of Time Domain and Multi Messenger follow up (TDAMM).

ASTROPHYSICS PROBE FUTURE MISSIONS

NASA will release an Announcement of Opportunity (AO) for an Astrophysics Probe mission no earlier than July 2023 as recommended by the Astro2020 Decadal Survey "Pathways to Discovery in Astronomy Astrophysics for the 2020s." The first Astrophysics Probe will be one of two mission themes recommended by the Decadal Survey: either a far infrared imaging or spectroscopy probe or an X-ray probe. The Astrophysics Probe missions will be PI-led and selected using NASA's AO acquisition process.

NASA issued a draft Announcement of Opportunity for the first Astrophysics Probe mission in August 2022 for community comment.

ASTROPHYSICS EXPLORER PROGRAM MANAGEMENT

Astrophysics Explorer program management provides programmatic, technical, and business management of ongoing missions in formulation and development.

OTHER MISSIONS AND DATA ANALYSIS

Operating Missions

NEUTRON STAR INTERIOR COMPOSITION EXPLORER (NICER)

The NICER instrument launched on June 3, 2017, to an external logistics carrier on the International Space Station (ISS) for an 18-month prime mission. Its main goal is spectroscopic X-ray observations of neutron stars with high-time resolution, to measure their masses and radii precisely and thus to test models of how matter behaves at extreme densities. NICER's operational flexibility enables it to play the role of X-ray sensor for coordinated campaigns spanning the electromagnetic spectrum with telescopes around the world and in space (including the James Webb Space Telescope) targeting a variety of cosmic phenomena. The 2022 Senior Review of Operating Missions approved extended mission operations through FY 2025 to include additional cycles of the NICER Guest Observer program element. NASA will conduct the next Senior Review in the spring of 2025.

Recent Achievements

The NICER team completed development and implementation of the Orbiting High-energy Monitor Alert Network (OHMAN) that connects NICER with the JAXA's Monitor of All-sky X-ray Image (MAXI) payload. OHMAN provides an automated mechanism for prompt triggering of NICER observations toward new sources of X-ray emission discovered by MAXI. The new combined capability represents a realization of the ISS-as-laboratory concept, in which distinct instruments not originally designed to work together are linked through ISS infrastructure to create a new tool and enables novel science. In early operations, OHMAN has resulted in rapid-response localization and study of previously unknown transients including black-hole binaries and the most powerful and most nearby gamma-ray burst yet discovered.

NICER was instrumental in identifying the most luminous and distant "tidal disruption event" (TDE), the shredding of a star as it passes too close to a supermassive black hole, known as AT2022cmc. To date, NICER has enabled the discovery of three new magnetars - the most powerful magnets in the universe, with exceptionally high magnetic field strengths trillions of times that of the Earth - and made unprecedented measurements for many more. A notable success was the first demonstration of crustal motion on a neutron star after the sudden and extremely energetic rearrangement of its strong magnetic field — such "reconnection" events, whether on our Sun or (more powerfully) on distant magnetars, can measurably affect the Earth's atmosphere, including disruptions to telecommunications and electrical power grids in the most extreme cases.

NICER increased from two to 10 the number of black holes with orbiting companion stars that exhibit "reverberation," or short timescale light echoes in X-rays. This phenomenon is a uniquely powerful probe of accretion (the flow of matter from the companion star onto the black hole) and the structures that it gives rise to: disks, jets, winds, and coronae of hot gas. Reverberation mapping reveals physical features in these systems far smaller than any imaging telescope could ever detect, and analysis of NICER black-hole data with a newly developed "Reverb Machine" software suite is revolutionizing our understanding of how accretion processes and structures evolve during highly energetic episodic outbursts in black-hole binaries. As a result of the research success stemming from NICER, the NICER team was awarded the 2022 Rossi Prize by the High Energy Astrophysics Division of the American Astronomical Society "for the development of the Neutron Star Interior Composition Explorer (NICER) and the revolutionary insights it is providing about the extreme environments of neutron stars and black holes, including the first precise and reliable measurement of a pulsar's mass and radius from detailed modeling of its pulsed

OTHER MISSIONS AND DATA ANALYSIS

waveform." The Rossi Prize is awarded annually in honor of Bruno Rossi and represents the most distinguished award in high-energy astrophysics.

NEIL GEHRELS SWIFT OBSERVATORY

The Neil Gehrels Swift Observatory (Swift) remains NASA's premier mission for prompt and accurate localization of gamma-ray bursts and rapid response X-ray and Ultraviolet follow-up observations of transient sources requested by the astronomical community. Swift is a multi-wavelength space-based observatory uniquely equipped to make rapid-response observations to fast-breaking events. The observatory measures the position, brightness, and physical properties of gamma-ray bursts, and is revolutionary in allowing scientists to solve the mystery of their origin in the formation of stellar-mass black holes. The observatory continues to target gamma-ray burst science, while also using its capabilities to increase our understanding of the entire transient universe, ranging in distance from the solar system to high-redshift quasars, and in time from the present to the epoch of reionization. Swift is a MIDEX class mission that launched in 2004 and is currently in extended mission operations. The 2022 Senior Review of Operating Missions approved extended mission operations through FY 2025. NASA will conduct the next Senior Review in the spring of 2025.

Recent Achievements

The 2022 Senior Review panel deemed Swift as the top ranked satellite among the operating missions (i.e., other than Hubble and Chandra). In January 2022, Swift suffered from a failure of an on-board reaction wheel (one of six). The team rapidly returned the spacecraft to full science operations, enabling the mission to continue meeting all original mission requirements after nearly 18 years of operation. Science highlights from the last year include the discovery of a long Gamma-Ray Burst (GRB) associated with the merger of two neutron stars, violating the traditional taxonomy of GRBs (long GRBs equals massive star progenitor; short GRBs equals neutron star merger progenitor), as well as the discovery of the brightest GRB ever observed (GRB221009A). The team is actively preparing for the next observing run of the ground-based gravitational wave detector network, planned to commence in April 2023. Swift will conduct sensitive searches for X-ray and UV counterparts to gravitational-wave detections, continuing its history of breakthrough discoveries in multi-messenger astronomy.

NUCLEAR SPECTROSCOPIC TELESCOPE ARRAY (NUSTAR)

Launched in June 2012, NuSTAR completed its prime mission in July 2014 and is now in extended mission operations. NuSTAR enables scientists to locate supermassive black holes in other galaxies, study extreme accretion onto neutron stars, locate and examine the remnants of collapsed stars in our Galaxy and the nearby universe, and observe any new supernovae in the local group of galaxies. NuSTAR's key science products are sensitive X-ray maps of the celestial sky at a higher energy band than any other focusing X-ray satellite. NuSTAR offers opportunities for a broad range of science investigations, ranging from probing cosmic ray origins and studying the extreme physics around collapsed stars to mapping microflares on the surface of the Sun. NuSTAR performs key follow-up observations of sources found by NASA's Chandra, Spitzer, and Wide-field Infrared Survey Explorer (WISE) satellites. The NuSTAR mission implemented a Guest Observer program in 2015. NuSTAR is now conducting the observations selected under Cycle 8 of the Guest Observer program. The project coordinates some NuSTAR observations with other missions, including Swift, Chandra, INTEGRAL, XMM-Newton, and NICER. Such coordinated observations take advantage of NuSTAR's unique access

OTHER MISSIONS AND DATA ANALYSIS

to high-energy X-rays with synergistic lower-energy X-ray capabilities of these other missions, such as NICER's exquisite X-ray timing, Chandra's high spatial resolution imaging, and Swift's agility for rapidly slewing across the sky to monitor variable sources. The 2022 Senior Review of Operating Missions approved extended mission operations through FY 2025. NASA will conduct the next Senior Review in spring of 2025.

Recent Achievements

NASA's NuSTAR reached the milestone of 10 years in orbit in June 2022. NuSTAR held an international conference in June 2022 that celebrated the decade of achievements, exploring the range of science that NuSTAR is conducting, with discussions focused on topics including Jupiter, Galactic binary systems, extreme transients, ultraluminous X-ray sources (ULXs), the census of obscured black holes in the local universe, black hole physics, and future high-energy facilities.

NuSTAR recently coordinated observations with NASA's Juno mission, which is orbiting Jupiter. Volcanoes on Jupiter's moon Io, shower the planet with ions, which produce light as they interact with the powerful magnetic fields along Jupiter's poles. These auroras were already known to produce ultraviolet and low-energy X-ray light, but the expected high-energy light was not detected by NASA's Ulysses mission which flew by Jupiter in 1992. NuSTAR, working at slightly lower energies, detected the high-energy X-rays that eluded Ulysses 30 years ago. Analyzing the data, which also included low-energy X-rays from the XMM-Newton satellite, astronomers were able to produce a self-consistent model for this powerful phenomenon. Ultimately, understanding Jupiter's aurora will help astronomers understand objects outside our solar system, such as exploding stars and the disks of hot gas accelerated by the gravity of massive black holes.

The Jupiter study relied on coordinated observations by multiple observatories, and such coordination has now become very routine for NuSTAR. The proportion of NuSTAR observations that are performed simultaneously with one, and often more than one observatory, are now over 50 percent. Besides coordination with ground- and space-based telescopes such as the Keck telescopes in Hawaii, NASA's Chandra X-ray Observatory, and NASA's Neil Gehrels Swift Observatory, NuSTAR also began coordinated observations with NASA's two newest astrophysics observatories in 2022: the James Webb Space Telescope and the International X-ray Polarimetry Explorer.

Over the next three years, NuSTAR will augment its planning and scheduling systems to enable an increase in the number of observations of unexpected astronomical events, like exploding stars, or high-energy flares from the regions around black holes, as well as the increasing number of coordinated observations.

TRANSITING EXOPLANET SURVEY SATELLITE (TESS)

The TESS mission launched on April 18, 2018. TESS is performing an all-sky survey to search for planets transiting nearby stars. By finding planets smaller than Neptune that transit stars bright enough to enable follow-up, TESS discoveries are prime targets to learn about the composition and atmospheric properties of planets beyond the solar system. TESS monitors the sky with four wide-field visible-light cameras to detect periodic drops in brightness caused by planets passing in front of their stars. TESS also obtains full-frame images of the entire field-of-view (24 x 96 degrees) at a cadence of 10 minutes and for a subset of preselected targets and collects data at a higher time-resolution of one image every 20 seconds.

TESS is designed to survey over 85 percent of the sky (an area of sky 400 times larger than covered by Kepler) to search for planets around nearby stars (within approximately 200 parsecs). TESS stars are

OTHER MISSIONS AND DATA ANALYSIS

typically 30-100 times brighter than those surveyed by the Kepler satellite. Planets detected around these stars are far easier to characterize with follow-up observations, resulting in refined measurements of planet masses, sizes, densities, and atmospheric properties. The 2022 Senior Review of Operating Missions approved extended mission operations through FY 2025. NASA will conduct the next Senior Review in the spring of 2025.

Recent Achievements

During its first extended mission, TESS discovered approximately 40 new small (less than 2.5 times the radius of Earth) exoplanets. TESS discovered 1,392 new planet candidates, bringing the total to about 5,900 planet candidates. Research publications based on TESS data exceeded 1,000 peer-review publications. The rate of new publications using TESS data is accelerating and is trending to double by the end of FY 2023.

TESS began its second extended mission with a new observing cadence of 200 seconds for its full-frame images to enable a broader range of science investigations than was possible before. In FY 2023, TESS will finish the second survey of the northern ecliptic hemisphere, then will begin a third survey of the southern ecliptic hemisphere. The 200 second full-frame image observing cadence and repeated coverage of the sky will yield many new exoplanets and other discoveries such as supernovae, black holes, pulsating stars, asteroids, and comets. The science community will observe 25 TESS-discovered exoplanets in the first year of James Webb Space Telescope's science observations. Webb will search for evidence of water, carbon dioxide, methane, and other molecules in these planets' atmospheres.

THE IMAGING X-RAY POLARIMETRY EXPLORER (IXPE)

NASA selected IXPE, a Small Explorer-class (SMEX) mission, in January 2017. Due to the hundred-fold improvement in the sensitivity of X-ray polarimeters during the past two decades, IXPE will enable astrophysicists to open an important new field of investigation into some of the most extremely unusual objects found in the universe. IXPE will examine polarized X-ray emissions from both galactic and extragalactic X-ray sources, such as active galactic nuclei, quasars, pulsars, pulsar wind nebulae, magnetars, accreting X-ray binaries, supernova remnants, and the Galactic Center. These observations will allow the investigation of general relativistic and quantum effects in the extreme environment associated with these sources and will significantly improve our understanding of fundamental physics. IXPE launched in December 2021 into a low-Earth orbit at a low inclination angle for a two-year mission.

Recent Achievements

IXPE completed its Key Decision Point-E review and successfully launched in December 2021. IXPE passed its Post-Launch Assessment Review signifying successful commissioning and the beginning of its operational phase.

In its first nine months of science operations, IXPE performed a total of 38 observations of 30 sources, obtaining secure (>99.99 percent confidence) polarization detections in 14 sources. Before IXPE, there had been only one source with a secure X-ray polarization detection---namely, the Crab nebula 4.5 decades ago. IXPE detected sources include accreting neutron stars and black holes, magnetars, pulsar wind nebulae, a supernova remnant, and active galactic nuclei. The IXPE Science Team comprises over 150 astrophysicists from 13 countries.

IXPE continues to refine its operations. The transition to GPS-based orbit determination will eliminate reliance on Space Track for ephemeris products and provide daily products for conjunction assessment

OTHER MISSIONS AND DATA ANALYSIS

risk analysis. The IXPE Science Operations Center is updating calibration approach/process using new Laboratory for Atmospheric and Space Physics software tools. IXPE will release a call for proposals through the Research Opportunities in Space and Earth Sciences (ROSES) and perform observations per its Long-Term Plan and of approved Targets of Opportunity.

HELIOPHYSICS

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Heliophysics Research	218.4	--	**231.3**	240.1	237.2	238.3	239.3
Living with a Star	86.1	147.3	**100.0**	119.8	105.2	104.1	91.8
Solar Terrestrial Probes	229.7	208.0	**194.0**	128.8	82.6	65.3	55.9
Heliophysics Explorer Program	189.2	167.9	**190.7**	298.6	374.0	372.0	412.6
Space Weather	33.5	25.0	**26.6**	35.5	34.3	31.7	28.4
Heliophysics Technology	20.9	28.4	**8.4**	14.7	14.0	16.0	16.0
Total Budget	**777.9**	**805.0**	**750.9**	**837.4**	**847.3**	**827.4**	**844.0**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Heliophysics

HELIOPHYSICS RESEARCH

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Heliophysics Research and Analysis	42.8	--	**54.9**	62.2	63.2	63.7	64.2
Sounding Rockets	69.6	--	**68.1**	69.2	69.2	69.2	69.2
Research Range	35.9	26.5	**26.9**	27.7	27.5	27.5	27.8
Other Missions and Data Analysis	70.2	--	**81.3**	80.9	77.2	77.8	78.0
Total Budget	**218.4**	**--**	**231.3**	**240.1**	**237.2**	**238.3**	**239.3**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The Sun, a typical medium star midway through its life, governs the solar system. The Sun wields its influence through its gravity, radiation, solar wind, and magnetic fields, all of which spread out through the heliosphere, interacting with other planets, the Earth, and its space environments to produce space weather, which can affect human technological infrastructure and activities. Heliophysics seeks to understand the Sun, heliosphere, and planetary space environments as a single connected system to answer these fundamental questions:

- How and why does the Sun vary?
- How do Earth and the heliosphere respond to the Sun's changes?
- How do the Sun and the solar system interact with the interstellar medium?
- How do these processes affect human activities?

Shown above, a long exposure shot of the two ACES II rocket trajectories as they launched from Andøya Space in Andenes, Norway on Nov 20, 2022. This NASA-funded rocket mission is headed to space to measure the global electric circuit underlying the northern lights.

The Heliophysics Research Program supports a wide variety of activities in support of these questions including:

- Investigations of the Sun, including processes taking place throughout the solar interior and atmosphere and the evolution and cyclic activity of the Sun;
- Investigations of the origin and behavior of the solar wind, energetic particles, and magnetic fields in the heliosphere and their interaction with Earth and other planets, as well as with the interstellar medium;
- Investigations of the physics of magnetospheres, including fundamental interactions of plasmas and particles with fields and waves, and coupling to the solar wind and ionospheres; and

HELIOPHYSICS RESEARCH

- Investigations of the physics of the terrestrial mesosphere, thermosphere, ionosphere, including the coupling of these phenomena to the lower atmosphere and magnetosphere.

EXPLANATION OF MAJOR CHANGES IN FY 2024

An increase in the Research and Analysis (R&A) budget will expand the participation of citizen scientists during the "Heliophysics Big Year" involving multiple natural solar events. The increase also supports the introduction of an Artificial Intelligence/Machine Learning (AI/ML) support structure in Heliophysics to provide capability and capacity to research scientists for data processing and scientific advancements.

ACHIEVEMENTS IN FY 2022

The January 15, 2022 epic eruption of the Hunga Tonga-Hunga Ha'apai volcano revealed strong coupling between extreme events on Earth’s surface and ionospheric disturbances at the edge of space. The eruption generated shock waves, sonic booms, tsunami waves, and a variety of atmospheric gravity waves extending from the troposphere to the ionosphere that circled the globe several times. For the next 12 hours, heat released from water and hot ash in the plume remained the largest source of atmospheric gravity waves worldwide. The remarkable coupling during this event was captured by combining observations from atmospheric and heliospheric satellites. A unique disturbance pattern appeared in the equatorial ionosphere approximately 14,000 km away from the epicenter twisting the equatorial ionization peaks, which normally run parallel on either side of the magnetic equator, into an “X” pattern.

Important advances were made last year in our understanding of magnetic reconnection, a fundamental physical process that explosively releases energy stored in magnetic fields. NASA’s Magnetospheric Multiscale (MMS) mission helped to solve a 60-year-old mystery that explains how rapidly reconnection occurs. MMS unique multi-spacecraft configuration provides critical observations that help us understand the reconnection phenomenon and its impact on spacecraft and astronaut health. Meanwhile, the Interface Region Spectrograph Imager (IRIS) observed the pattern of emission produced during flares, which is consistent with a recent model of how the reconnection energy release begins.

Switchbacks are kinks in the solar wind magnetic field that may be associated with substantial acceleration of plasma and enhanced turbulent energy transfer. In situ measurements from Parker Solar Probe recently revealed that switchbacks are much more prevalent closer to the Sun. Furthermore, imaging observations from Solar Orbiter indicate that switchbacks may be formed by interchange reconnection between the coronal loops of solar active regions and adjacent open-field regions. This discovery is important for understanding the origin of slow solar wind.

NASA Heliophysics Division (HPD) selected and funded 118 research projects through the Research Opportunities in Space and Earth Science (ROSES) 2021 and 2022 program elements.

Evaluation of proposals submitted to the new Space Weather Center of Excellence program element and the Heliophysics AI/ML Ready Data program element is underway.

- Phase two of the Heliophysics Diversify, Realize, Integrate, Venture, Educate (DRIVE) initiative as part of the integrated research program element is underway. Additional efficiency in our R&A program elements allowed for the selection of three DRIVE Science Centers, rather than the expected two:
  - DRIVE Science Center 1: Consequences Of Fields and Flows in the Interior and Exterior of the Sun (COFFIES). COFFIES establishes a collaborative science community to develop

comprehensive models of solar dynamics that will substantially improve the physical understanding of the ways internal plasma flows affect the origin and evolution of magnetic activity cycles of the Sun and stars like it.

- DRIVE Science Center 2: Center for Geospace Storms (CGS): CGS's vision is to transform the understanding and predictability of space weather. This center will pursue innovation, empowerment, and discovery to improve space weather modeling and research.
- DRIVE Science Center 3: Solar wind with Hydrogen Ion charge Exchange and Large-Scale Dynamics (SHIELD) whose purpose is to understand the nature and structure of the heliosphere.

The FY 2022 sounding rockets manifest featured 16 NASA missions and two reimbursable missions launching from various locations. All were successful, including three inaugural launches from the Arnhem Space Center, Australia. The Grand Challenge Initiative - Cusp campaign at the Andoya Rocket Range, Norway concluded with the successful launch of the Cusp Region Experiment 2 (C-REX-2) mission.

NASA supported the formulation and development of ten CubeSats. Science will continue to collaborate with the Exploration Systems Mission Directorate to enable the CubeSat mission to Understand Solar Particles over Earth's Poles on the first flight using the Space Launch System, Artemis I. Other CubeSat launches included:

- Plasma Enhancements in the Ionosphere-Thermosphere Satellite (PetitSat);
- Scintillation Prediction Observations Research Task (SPORT);
- The Relativistic Electron Atmospheric Loss (REAL);
- CubeSat Inner Radiation Belt Experiment (CIRBE);
- Low-Latitude Ionosphere/ Thermosphere Enhancements In Density (LLITED);
- CUbesat Radio Interferometry Experiment (CURIE);
- Atmosphere Effects of Precipitation through Energetic X-rays CubeSat mission (AEPEX);
- Auroral Emission Radio Observer (AERO); and
- Vector Interferometry Space Technology using AERO (VISTA).

WORK IN PROGRESS IN FY 2023

In FY 2023, NASA will select new awards solicited in ROSES 2021 and 2022, including continued research within Heliophysics' four main areas of inquiry - solar studies, magnetospheric studies, solar wind studies, and investigations of the uppermost regions of the Earth's atmosphere and how they interact with the space environment.

In FY 2023, NASA will begin to prepare for the 2024 solar eclipse via an Eclipse 2024 element within Research & Analysis (R&A). This element supports development of new research or enhancement of existing research, applied to the 2024 total solar eclipse visible from the northern hemisphere on April 8, 2024. This total solar eclipse will be visible from North America and is the last total eclipse viewable from North America until August 2045. NASA is seeking proposals that would utilize the unique opportunity presented by the solar eclipse to study any relevant heliophysics research topic, such as a topic focused on the Sun or on the Ionosphere-Thermosphere-Mesosphere system.

The Heliophysics Data Environment Enhancements (H-DEE) program element encompasses data environment needs throughout Heliophysics, including Solar, Heliospheric, Magnetosphere, and

HELIOPHYSICS RESEARCH

Ionosphere/Thermosphere/Mesosphere. The Heliophysics Research Program preferentially seeks to fund those efforts that directly impact NASA missions or interpretation of their data. However, the program also includes projects involving data from other United States agencies or institutions judged to be highly beneficial to NASA Heliophysics research, if not available in a suitable form from their hosts institution. In line with these goals, the Agency has reduced the scope of H-DEE to encompass only data-improvement tasks, and created a new element, Heliophysics Tools and Methods to specifically fund tool development for the Heliophysics digital resource library.

The current sounding rockets mission manifest features 22 missions in FY 2023 from various locations in the United States and Norway.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

In FY 2024, NASA will select new awards solicited in ROSES 2022 and 2023, including continued research within Heliophysics' four main areas of inquiry - solar studies, magnetospheric studies, solar wind studies, and investigations of the uppermost regions of the Earth's atmosphere and how they interact with the space environment.

In FY 2024, NASA will conclude its preparations for the 2024 solar eclipse via an Eclipse 2024 program element within R&A and support solar eclipse activities.

The new Heliophysics Citizen Science Investigations (H-CSI) program element will support the growing portfolio of citizen science opportunities through medium-scale citizen science projects. H-CSI will expand participation of citizen scientists in NASA heliophysics research, bringing unprecedented statistical power and new insights not realistically achievable by other means to the study of multiple natural heliophysics events in the quickly approaching September 2023 - December 2024 time interval. This approximately one-year time interval, designated the Heliophysics Big Year, encompasses two solar eclipses across North America in 2023 and 2024 and the arrival of solar cycle maximum. “Big Year” is a term borrowed from birding that denotes a year during which birders achieve a maximum number of bird sightings; likewise, the Heliophysics Big Year provides an opportunity to observe multiple solar and geospace phenomena.

In FY 2024, NASA will continue to develop and refine the AI/ML capabilities available to the Heliophysics community for data processing of mission science information. These tools will help researchers process larger data sets than currently possible with existing tools and identify trends within the data.

The current sounding rockets mission manifest features 16 missions in FY 2024 from various locations in the United States and Kwajalein Atoll.

Program Elements

RESEARCH RANGE

The Research Range project provides operations support, maintenance, and engineering for the Wallops Flight Facility (WFF) launch range in support of suborbital, orbital, and aircraft missions conducted on behalf of NASA and the Department of Defense (DoD). The project also supports NASA technology missions, autonomous aerial vehicle flights, and commercial launch and flight projects.

HELIOPHYSICS RESEARCH

The range instrumentation includes meteorological, telemetry, radar, command, launch and range control centers, and optical systems. Research Range mobile assets provide range services at other ranges and remote locations around the world.

SOUNDING ROCKETS

NASA's Sounding Rockets project provides suborbital launch vehicles, payload development, and field operations support to NASA suborbital missions within the Science Mission Directorate. The approximately 20 suborbital missions flown annually by the project provide researchers with unparalleled opportunities to build, test, and fly new instrument and sensor design concepts while simultaneously conducting world class scientific research. The project conducts operations from fixed launch sites such as Wallops Test Range in Virginia, Poker Flat Research Range in Alaska, White Sands Missile Range in New Mexico, and foreign sites such as Andoya Rocket Range in Norway and Esrange in Sweden.

With the capability to fly higher than many low-Earth orbiting satellites and the ability to launch on demand, sounding rockets often offer the only means to study specific scientific phenomena of interest to many researchers. Unlike instruments on board most orbital spacecraft or in ground-based observatories, sounding rockets can place instruments directly into regions where and when the science is occurring to enable direct, in-situ measurements. The mobile nature of the project enables researchers to conduct missions from strategic vantage points worldwide. To study solar and astrophysics phenomena, telescopes and spectrometers fly on sounding rockets to collect unique science data and test prototype instruments for future satellite missions.

HELIOPHYSICS RESEARCH AND ANALYSIS

The Heliophysics R&A project supports basic research, solicited through NASA’s annual ROSES announcements. It supports investigations in all research areas of Heliophysics: Sun, heliosphere, magnetosphere, ionosphere, and upper atmosphere. Investigations emphasize the understanding of fundamental processes and interconnections across the traditional science disciplines, on a broad range of spatial and temporal scales. The project also supports investigations focused on processes that create space weather events, and investigations to enable a capability for predicting future space weather events.

Heliophysics supporting research and theory, modeling, and simulation are essential in fully utilizing Heliophysics mission research data collected between the outer edge of the Earth’s atmosphere and the interaction of the Sun and solar wind with the local galactic environment (currently explored by Voyager). The DRIVE science center element supports large principal-investigator proposed team efforts, which require a critical mass of interdisciplinary expertise, to make significant progress in understanding complex physical processes with broad importance. DRIVE centers employ a variety of fundamental research techniques (e.g., theory, numerical simulation, and modeling), analysis, and interpretation of space data.

HELIOPHYSICS RESEARCH

Program Schedule

NASA implements the Heliophysics Research Program via a competitive selection process. NASA releases research solicitations each year through the ROSES NASA Research Announcements (NRA).

Date	Significant Event
Q1 FY 2023	ROSES-2022 selection within six to nine months of receipt of proposals
Q2 FY 2023	ROSES-2023 solicitation
Q1 FY 2024	ROSES-2023 selection within six to nine months of receipt of proposals
Q2 FY 2024	ROSES-2024 solicitation
Q1 FY 2025	ROSES-2024 selection within six to nine months of receipt of proposals
Q2 FY 2025	ROSES-2025 solicitation
Q1 FY 2026	ROSES-2025 selection within six to nine months of receipt of proposals
Q2 FY 2026	ROSES-2026 solicitation

Program Management & Commitments

Program Element	Provider
Research and Analysis	Provider: Headquarters (HQ) Lead Center: HQ Performing Centers: Goddard Space Flight Center (GSFC), Marshall Space Flight Center (MSFC), Jet Propulsion Laboratory (JPL), Langley Research Center (LaRC), Johnson Space Center (JSC), Ames Research (ARC) Cost Share Partners: None
Sounding Rockets	Provider: GSFC Lead Center: HQ Performing Center: GSFC Cost Share Partners: None
Research Range	Provider: GSFC Lead Center: HQ Performing Center: GSFC/Wallops Flight Facility (WFF) Cost Share Partners: None

HELIOPHYSICS RESEARCH

Acquisition Strategy

NASA issues solicitations for competed research awards each February in the ROSES NRAs. To the widest extent possible, NASA fully and openly competes all new acquisitions. Proposals are peer-reviewed and selected from the annual ROSES announcement. Universities, Government research laboratories, and industry, throughout the United States, participate in research projects.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Sounding Rocket Operations	Orbital ATK	Dulles, VA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Relevance	Heliophysics Advisory Committee	2022	To review progress towards Heliophysics objectives in the NASA Strategic Plan	The Advisory Committee Report rated all areas green.	2023
Relevance	Heliophysics Advisory Committee	2023	To review progress towards Heliophysics objectives in the NASA Strategic Plan	To be determined	2024
Quality	Mission Senior Review Panel	2023	A comparative evaluation of Heliophysics operating missions	To be determined	2026
Relevance	Heliophysics Advisory Committee	2024	To review progress towards Heliophysics objectives in the NASA Strategic Plan	To be determined	2025

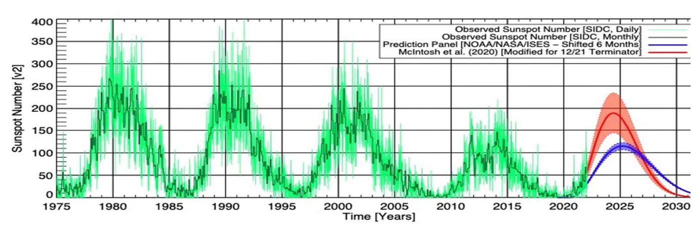
OTHER MISSIONS AND DATA ANALYSIS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Science Planning and Research Support	7.1	--	**7.1**	7.1	7.1	7.1	7.1
CubeSat	5.0	--	**8.7**	9.4	9.0	9.0	9.0
Solar Data Center	1.2	--	**2.6**	1.2	1.2	1.2	1.2
Data & Modeling Services	3.2	--	**5.2**	2.5	2.5	2.5	2.5
Space Physics Data Archive	2.9	--	**3.7**	2.3	2.3	2.3	2.3
Guest Investigator Program	22.1	--	**23.7**	25.7	24.5	24.5	24.5
Community Coordinated Modeling Center	4.9	--	**5.2**	5.9	5.6	5.6	5.6
Space Science Mission Ops Services	13.0	--	**13.8**	14.7	14.9	14.9	15.4
Voyager	5.6	--	**6.5**	7.0	7.2	7.8	7.6
Solar and Heliospheric Observatory (SOHO)	2.4	--	**2.2**	2.2	0.1	0.0	0.0
Wind	2.2	--	**2.2**	2.3	2.3	2.3	2.3
Geotail	0.6	--	**0.4**	0.5	0.5	0.5	0.5
Total Budget	**70.2**	**--**	**81.3**	**80.9**	**77.2**	**77.8**	**78.0**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



This chart shows the original predicted number of sunspots, represented as the blue line. The green lines show the observed sunspots, which are trending toward the McIntosh et al. study, represented by the red line– which predicts a higher number of sunspots.

NASA accumulates, archives, and distributes data collected by the Heliophysics System Observatory, a fleet of operating spacecraft. Combining the measurements from all these observing platforms enables interdisciplinary, connected systems science across the vast spatial scales of our solar system. This collective asset enables the data, expertise, and research results to contribute directly to fundamental research on solar and space plasma physics and to the national goal of real-time space weather prediction.

NASA teams support day-to-day mission operations for NASA spacecraft and data analysis to advance the state of space science and space weather modeling. NASA conducts science community-based projects to evaluate research models containing space weather information that is of value to industry and Government agencies. Heliophysics data centers archive and distribute the science data from operating missions in the Living With a Star (LWS), Solar Terrestrial Probes (STP) Research, and Explorer Programs.

OTHER MISSIONS AND DATA ANALYSIS

Mission Planning and Other Projects

SCIENCE PLANNING AND RESEARCH SUPPORT

This project supports NASA scientists' participation in proposal peer review panels, decadal surveys, and National Academies' studies.

CUBESAT

CubeSats are small spacecraft, built to a standardized form-factor of size and mass, which can launch as secondary or ride-share payloads. With lower development costs per investigation and rapid development cycles, CubeSats can provide frequent science and technology flight opportunities. This approach is like the traditional NASA suborbital programs that use sounding rockets, balloons, and aircraft, but extends the range of opportunities. CubeSats have significant potential to leverage exploratory and systematic science observations at minimal additional cost.

The Heliophysics CubeSat project continues to work on the cross-discipline investigations already underway. In response to the capabilities demonstrated by CubeSat investigations in the initial pathfinder stage, the CubeSat project expanded in 2019 to take advantage of new science achievable via investigations in the $2 million to $10 million range. The Heliophysics CubeSat project has one project on orbit with an additional 21 waiting for flight, and 11 planned for launch in 2023. The project added an additional two projects in FY 2021, and an additional three projects in FY 2022. The larger investigations will enable the development of remote sensing investigations with more sophisticated CubeSats, as well as small constellations of in-situ CubeSat investigations.

Recent Achievements

The Daily Atmospheric Ionospheric Limb Imager (DAILI) CubeSat deployed from the International Space Station in January 2022 and the Miniature X-ray Solar Spectrometer (MinXSS-3) payload launched in February 2022 on the Indian Space Research Organization's Polar Space Launch Vehicle from Satish Dhawan Space Centre, India. DAILI attempted to improve the accuracy of operational models for both the neutral density and the ionosphere and will help further the study of wave propagation and transport processes in the lower thermosphere. DAILI re-entered Earth's atmosphere in June 2022. Researchers will use MinXSS-3 to better understand the energy distribution of solar flare soft x-ray emissions and their impact on the Earth's Ionosphere, Thermosphere, and Mesosphere. Electron Loss and Fields Investigation with a Spatio-Temporal Ambiguity Resolving option (ELFIN) completed their science operations and deorbited in September 2022 after four years of on orbit data collection measuring precipitated electron variation across space and time. Scintillation Observations and Response of the Ionosphere to Electrodynamics also deorbited in September 2022 after more than two and a half years on orbit studying the complex challenges in discovering the wave-like plasma perturbations in the ionosphere. The CubeSat project continued to support the formulation and development of the eleven CubeSats planned for launch in 2023.

SOLAR DATA CENTER

The Solar Data Center (SDAC) provides mission and instrument expertise to enable high-quality analysis of solar physics mission data. It provides leadership for community-based, distributed development

OTHER MISSIONS AND DATA ANALYSIS

efforts to facilitate identification of and access to solar physics data, including ground-based coordinated observations via the Virtual Solar Observatory, a research tool that allows scientists to search for solar and heliospheric physics data. The SDAC also provides a repository for software used to analyze these data.

Recent Achievements

The SDAC continues to support the ever-growing storage and archival needs of the Virtual Solar Observatory. Recently, SDAC expanded its back-up and archiving capability with additional hardware procurements and support personnel. Additionally, SDAC is participating in a SMD-wide pilot to make more science and mission data available in the cloud. SDAC supported this by transferring over one petabyte of Solar Dynamics Observatory data and making it cloud accessible. SDAC also completed a project with the Google Summer of Code to create a Python viewer of the Helioviewer tool.

DATA AND MODELING SERVICES

The Data and Modeling Services project supports missions in extended operations and missions planned for decommissioning, by preparing their data holdings for long-term archival curation. This project also provides for the creation of higher-level data products, which are of significant use to the science community and not funded during the prime mission. Higher-level data products are data that combine results of multiple missions and/or instruments.

Recent Achievements

The Heliophysics Data and Modeling project continues strengthening data usability and accessibility through development of the HelioCloud. HelioCloud makes high-value Heliophysics data available in a publicly accessible cloud environment. HelioCloud provides a community heliophysics cloud computing resource that gives scientists fundamentally new and easily used computing capabilities that employ datasets of unprecedented size and complexity to advance the field of heliophysics science. It will facilitate computing of raw mission data into usable information and accelerate collaboration between users. Recently, the HelioCloud system supported 150 simultaneous users at the Python in Heliophysics Community (PyHC) Summer School which taught techniques to manipulate the data using the Python programming language. The Data and Modeling project also leads efforts to integrate and enhance PyHC tools, providing more analytic capabilities to the research community.

SPACE PHYSICS DATA ARCHIVE

The Space Physics Data Archive (SPDA) ensures long-term data preservation and online access to non-solar heliophysics science data. It operates key infrastructure components for the Heliophysics Data Environment, including inventory and web service interfaces to systems and data. It also provides unique enabling science data services.

The Heliophysics data archives are growing at an exponential rate. All science disciplines have seen a surge of data holdings over the last decade. As such, conventional storage and retrieval has become impractical. This era of Big Data requires the effective curation and preservation of critical data products. NASA will move beyond a traditional repository and toward a functional, collaborative data library. Over the next several years, NASA will transform the Heliophysics archives, consisting of the SPDA and SDAC, into a digital resource library.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

The SPDA has added more than 470 data sets from current and historic missions, along with sounding rocket, balloon, and ground instrument datasets. To support these missions, Space Physics Data Facility (SPDF) maintains an automated data ingest pipeline for more than 75 missions. In addition to data ingest, legacy mission datasets must be reprocessed and often placed into the proper formats. SPDA develops the Common Data Format (CDF) to ensure data usability and accessibility to the science and research community. The SPDA team continued populating and updating several databases of solar wind conditions and geomagnetic activity indices; deep space merged magnetic field, plasma, proton fluxes and ephemerides data; and spacecraft orbit information. The SPDA facilitated the analysis of multi-instrument and multi-mission datasets by providing powerful services to include the Satellite Situation Center web database of Heliophysics spacecraft orbits, and the Space Physics Environment Data Analysis Software to standardize retrieval of data from repositories.

GUEST INVESTIGATOR PROGRAM

The Guest Investigator Program maximizes the output of currently operating Heliophysics missions by supporting competitive research investigations, which use data from multiple spacecraft. The Heliophysics division strongly encourages investigations that address global system science since Heliophysics, by nature, is the investigation of a large-scale and complex connected system.

Recent Achievements

The Heliophysics Guest Investigator scientific review panels continued to utilize the Dual Anonymous Peer Review (DAPR) process for its second year. The DAPR process means that reviewers on scientific panels do not explicitly know the names or affiliation of the proposed research efforts when reviewing and evaluating proposals. Thus, the merits of proposed work are the primary focus of the review panel's evaluation. In the second year of DAPR implementation results have shown that the submission rates were consistent with the acceptance rates for both women and early career scientists. This demonstrates that DAPR has neither a noticeable positive nor negative impact to the review process. Community response to the DAPR process has been overwhelmingly positive and NASA has compiled the third year of implementation data in 2022 which will be analyzed for trends.

A recent research effort provides a better understanding of the local particle acceleration in the diamagnetic cavities (i.e., large regions of depressed magnetic field at the magnetopause boundary) and their escape into the magnetohydrodynamic (MHD) or deeper into the magnetosphere. Global magnetohydrodynamic simulations with Grid Agnostic MHD for Extended Research Applications (GAMERA) have shown that particles can gain above 10 kiloelectronvolt (keV) inside the cavity and subsequently leak into the MHD or onto dipolar field lines where they execute different types of bounce motion. GAMERA is simulation tool that allows source modeling in gamma astronomy.

COMMUNITY COORDINATED MODELING CENTER

The Community Coordinated Modeling Center (CCMC) is a multi-Agency partnership that enables and performs the research and development for next-generation heliophysics and space weather models. The project provides the United States and international research community access to simulations that enable “runs on demand,” using models to study space weather events in near-real time. This allows the

OTHER MISSIONS AND DATA ANALYSIS

comparison of observational data and model parameters during or shortly after solar activity, thereby improving accuracy of the models.

Recent Achievements

The CCMC continues to develop and expand forecasting methods scoreboards, for community-wide pre-event ensemble forecasts. Recent efforts supported include (1) the NASA/Space Radiation Analysis Group on Integrated Solar Energetic Proton (ISEP) project which identifies and evaluates new models, develops tailored ISEP Alert/Warning Scoreboard Software, and implements these capabilities within the NASA Moon-to-Mars Office, (2) the National Oceanic and Atmospheric Administration (NOAA)/Space Weather Prediction Center (SWPC) to establish a capability in a cloud environment to collaborate and more effectively transition research models and scoreboard tools to NOAA/SWPC Testbed and Operations.

SPACE SCIENCE MISSION OPERATIONS SERVICES

Space Science Mission Operations (SSMO) Services manages the on-orbit operations of GSFC Space Science missions. Services include consistent processes and infrastructure for missions operated at various institutions. SSMO currently manages the following Heliophysics missions: Advanced Composition Explorer (ACE); Aeronomy of Ice in the Mesosphere (AIM); Geotail; Interstellar Boundary Explorer (IBEX); Ionospheric Connection Explorer (ICON); Interface Region Imaging Spectrograph (IRIS); Magnetospheric Multiscale Mission (MMS); Parker Solar Probe; Solar Dynamics Observatory (SDO); Solar and Heliospheric Observatory (SOHO); Solar Terrestrial Relations Observatory (STEREO); Time History of Events and Macroscale Interactions during Substorms (THEMIS); Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED); and Wind. SSMO Services also sustains an operational multi-mission infrastructure for current and future missions.

Recent Achievements

SSMO continued its support and enhancement for operational heliophysics missions managed at GSFC. In addition to project management responsibilities, SSMO manages investments in operational software and hardware that continues to yield significant benefits for NASA's operational missions. Notable achievements include a refresh of the virtualized Multi-Mission Operations Center operational hardware which provides a stable and efficient operations platform for NASA missions in flight. Key benefits include consolidated and centralized processing; common tools, networking, interfaces, policies, and workforce; and standardized services including information technology security implementations, such as the suite of federally mandated continuous diagnostics and monitoring tools that provide improved awareness and adaptability to the changing IT security landscape at greater efficiency and lower cost. SSMO made significant progress in the delivery and adoption of cloud-based operations analysis and situational awareness tools. Other areas of achievement include further advancement of flight dynamics capabilities, middleware-based ground system components, and collision avoidance techniques.

OTHER MISSIONS AND DATA ANALYSIS

Operating Missions

VOYAGER

The Voyager Interstellar Mission is exploring the interaction of the heliosphere and the local interstellar medium. Voyager 1, launched in 1977, is making the first in-situ observations of the region outside the heliosphere from about 158 astronomical units (AU), or 158 times Earth's distance from the Sun, and is traveling at a speed of 3.6 AU per year, or 38,000 miles per hour. Voyager 2 is about 132 AU from the Sun and traveling at a speed of about 34,000 miles per hour, or 3.2 AU per year. Voyager 2 crossed the heliopause, the theoretical boundary where the Sun's solar wind is stopped by the interstellar medium, on November 5, 2018. Its twin, Voyager 1, crossed the heliopause on August 25, 2012, and continues to sail outward through the local interstellar medium. Both spacecraft have sufficient power to operate all instruments until the late 2020s; after this time, the project will turn off the instrument heaters and then the instruments one at a time to extend the useful life of the spacecraft to about 2030. Voyager is currently in extended operations.

Recent Achievements

Using critical in situ Voyager data in global simulations, SHIELD (Solar wind with Hydrogen Ion charge Exchange and Large-Scale Dynamics) researchers discovered a new instability in the heliosheath. Neutral hydrogen atoms may cause the heliospheric tail to open and drive this new instability. The heliosphere is the bubble formed by the solar wind as it interacts with the local interstellar medium, and this discovery may change the way we think about the shape of the heliosphere - rather than being approximately spherical, it may be more croissant-shaped. The two Voyager spacecraft have made the only in situ observations of regions inside the heliosphere, including the termination shock, heliosheath and heliopause, as well as outside it in the local interstellar medium.

SOLAR AND HELIOSPHERIC OBSERVATORY (SOHO)

SOHO, launched in 1995, is a joint mission of the European Space Agency (ESA) and NASA, and it has been a dependable solar watchdog, providing the only Earth-Sun line coronagraph images of solar storms. Coronal Mass Ejections (CME) drive most of the space weather effects in the inner heliosphere. SOHO continues to provide essential early alert space weather observations used as inputs to models that further our understanding of the Sun's effect on the Earth. During its extended mission phase, NASA declared SOHO a national space weather asset and the mission submitted a proposal at the Heliophysics System Observatory (HSO) Infrastructure Review which occurred October 2022.

Recent Achievements

In recent years, space weather scientists use data obtained from assets located away from the Earth, such as SOHO, Parker Solar Probe, Solar Orbiter, and instruments at Mars. A new research study tests current capabilities in predicting space weather events in the inner solar system (i.e., within the orbit of Mars) for a period in late 2020. A chain of models simulates the background solar wind as well as transient phenomena such as CMEs and solar energetic protons (SEPs). Those modeling results are compared with spacecraft measurements from six well-separated locations, including Earth, Mars, and SOHO. Current forecasting tools, despite their limitations, can successfully provide reasonable predictions of both CMEs and SEPs, especially out to several tens of degrees around the corresponding eruption source region on the Sun.

OTHER MISSIONS AND DATA ANALYSIS

WIND

Wind, launched in 1994, studies the solar wind and its impact on the near-Earth environment. It provides comprehensive measurements of thermal to solar energetic particles, quasi-static fields to high-frequency radio waves, and gamma rays. In particular, the Wind instrument suite provides comprehensive and unique high-time resolution in-situ solar wind measurements that enable the investigation of wave-particle interactions. Wind provides critical measurements of the solar wind and space weather events. Correlating those critical measurements with measurements from the Parker Solar Probe and Solar Orbiter Collaboration (SOC) missions will improve our understanding of these events as they move out from the Sun. These multi-spacecraft measurements constrain models of space weather events and improve their predictive capabilities. Wind is also the only near-Earth spacecraft equipped with radio waves instrumentation. The Radio and Plasma Wave (WAVES) experiment measures electric and magnetic fields to reveal wave phenomena in the solar wind. WAVES is also the only instrument on Wind that can unambiguously measure the total electron density in the solar wind. No other L1 spacecraft has this capacity, which allows Wind to more accurately calibrate all of its thermal particle instruments. Currently in extended operations, NASA approved Wind to continue as HSO-Infrastructure at the 2020 Heliophysics Senior Review. The Wind mission will submit a proposal to the HSO Infrastructure Review in early 2023.

Recent Achievements

Recently, solar wind density observations at the Wind spacecraft showed 90 minute fluctuations, following the transit of two interplanetary shocks. Using the Wang-Sheeley-Arge model, researchers identified that the source of this solar wind stream was an active region and a mid-latitude coronal hole just prior to the crossing of the Heliospheric Current Sheet. The heliospheric current sheet is a surface separating regions of the heliosphere where the interplanetary magnetic field points toward and away from the Sun. Researchers using a combination of satellite and ground magnetometer observations determined that the magnetospheric response could be described as resembling "breathing." This work illustrates how the magnetospheric system couples to variations in the solar wind. Given that the solar wind is rarely (if ever) uniform and homogeneous, this illustrates that the magnetosphere is in a near-constant state of driving from external forces. This is relevant to the general public because such dynamic behavior leads to substorms and geomagnetic storms, both of which threaten the safety and operations of astronauts and robotic spacecraft.

GEOTAIL

Geotail, launched in 1992, enables scientists to assess data on the interaction of the solar wind and magnetosphere. Its instruments continue to function, sending back crucial information about how auroras form, how energy from the Sun funnels through near-Earth space, and the ways in which magnetic field lines move and rebound, creating explosive bursts that rearrange the very shape of our magnetic environment. The Geotail mission is a collaborative project undertaken by the Japanese Institute of Space and Astronautical Science and NASA. Although currently in extended operations, NASA approved Geotail to continue as HSO-Infrastructure at the 2020 Heliophysics Senior Review.

In June 2022, the second and final of Geotail's two data recorders failed. The Japan Aerospace Exploration Agency and NASA made efforts to recover the recorder over the next several months but were unsuccessful and the ability for continuous science data was lost. Due to these technical issues, Japan decided to end the mission and NASA concurred with Geotail terminating operations.

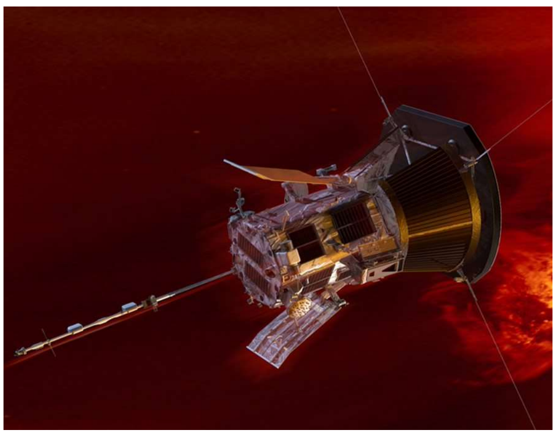
LIVING WITH A STAR

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Other Missions and Data Analysis	86.1	--	**100.0**	119.8	105.2	104.1	91.8
Total Budget	**86.1**	**147.3**	**100.0**	**119.8**	**105.2**	**104.1**	**91.8**
Change from FY 2023 Enacted			**-47.3**				
Percent change from FY 2023 Enacted			**-32.1%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



Above is an illustration of Parker Solar Probe in orbit close to the Sun. Named for the late Eugene Parker, discoverer of the solar wind, the spacecraft has flown closer to the Sun than any spacecraft before it and in 2020 because the first human-made object to enter the solar atmosphere.

The Living With a Star (LWS) Program targets specific aspects of the Sun-Earth system that affect life and society. LWS provides a predictive understanding of the Sun-Earth system, linkages among the interconnected systems, and space weather conditions at Earth and the interplanetary medium. Measurements and research from LWS missions may contribute to advances in operational space weather forecasting that help prevent damage to spacecraft, communications and navigation systems, and power grids. LWS products improve our understanding of ionizing radiation, which has human health implications on the International Space Station (ISS) and high-altitude aircraft flight, as well as operations of future space exploration with and without human presence. LWS products improve the characterization of solar radiation for global climate change, surface warming, and ozone depletion and recovery.

EXPLANATION OF MAJOR CHANGES IN FY 2024

The Budget pauses development of the Geospace Dynamics Constellation (GDC) given other priorities within the Science portfolio which also have high budgetary requirements during this same period, including the Mars Sample Return mission. NASA will reassess its priorities for future heliophysics missions following review of the upcoming Heliophysics Decadal survey and assessment of future funding constraints for space science.

OTHER MISSIONS AND DATA ANALYSIS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Geospace Dynamics Constellation	13.9	--	**10.0**	10.0	10.0	0.0	0.0
Living With a Star Future Missions	3.3	--	**5.0**	5.0	5.0	12.5	12.5
Solar Orbiter Collaboration	10.1	--	**9.5**	11.2	9.8	8.4	4.2
LWS Science	25.0	--	**30.0**	30.7	30.3	30.3	30.3
LWS Program Management	21.6	--	**21.2**	24.0	22.8	25.5	25.5
Solar Dynamics Observatory (SDO)	9.1	--	**12.3**	12.3	12.3	12.3	12.3
Parker Solar Probe (PSP)	3.2	--	**12.1**	26.6	15.0	15.0	7.0
Total Budget	**86.1**	**--**	**100.0**	**119.8**	**105.2**	**104.1**	**91.8**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Parker Solar Probe captured this image of the night side of Venus with its Wide Field Imager for Solar Probe (WISPR) camera.

Living With a Star (LWS) Other Missions and Data Analysis budget includes operating LWS missions, scientific research, program management, and funding for missions to launch in the next decade.

Mission Planning and Other Projects

LWS SCIENCE

NASA solicits proposals leading to a physics-based understanding of the integral system linking the Sun to the Earth, both directly and via the heliosphere, magnetosphere, and ionosphere. Scientists can achieve LWS Science objectives by data analysis, theory and modeling, and the development of tools and methods (e.g., software). The goal of the project is to develop the scientific understanding needed for the United States to address those aspects of heliophysics that may affect life and society. The targeted research element solicits large-scale problems that cross discipline and technique boundaries.

In addition, LWS Science includes funding to train the next generation of heliophysics experts, conduct a heliophysics graduate-level summer school, develop graduate course content, and support a limited number of space weather postdoctoral positions at universities and Government laboratories.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

In FY 2022, researchers reported exciting new results. A team of scientists investigating coupling between solar variability and the Earth's magnetosphere developed a new theory to explain the three-dimensional spread of magnetic reconnection during periods immediately following solar eruptions. These results provide evidence that reconnection itself is fundamentally an energy cascade process and that magnetic energy release occurs systematically, rather than randomly. A team studying CMEs used Parker Solar Probe measurements to develop and test models of magnetohydrodynamic (MHD) turbulence within the solar wind to further our understanding of how turbulence is generated and transported in the solar wind from Sun to Earth. A study using state-of-the-art MHD models to improve forecasting of interplanetary coronal mass ejections delivered a comprehensive data set of simulated solar wind and related magnetic field characteristics to the research community that will assist the upcoming PUNCH (Polarimeter to Unify the Corona and Heliosphere) satellite mission in preparing real time space weather forecast products.

LWS PROGRAM MANAGEMENT

The Program Management budget supports critical flight project management functions executed by the LWS program office at GSFC and provides the resources required to manage the planning, formulation, and implementation of all LWS missions. Included in LWS Program Management is the Science Mission Directorate Rideshare Office. This office implements an SMD-wide rideshare strategy for Evolved Expendable Secondary Payload Adapter-class (ESPA-class) payload opportunities. The office is responsible for coordinating rideshare opportunities and collaborating across SMD, other NASA science directorates, other Government agencies, and the greater rideshare community to foster a culture of cross-collaboration and maximize science return through shared launch opportunities and resources.

LWS FUTURE MISSIONS

The Future Missions budget supports pre-formulation activities related to the identification of LWS science and mission objectives and priorities This project also supports activities related to Orbital Debris & Space Situational Awareness (OD-SSA).

Orbital debris at all scales is present in the space environment, which affects space-based critical infrastructure, modern technological systems, and humans working in space. The NASA OD-SSA activity addresses a knowledge gap of this environment by focusing on orbital objects of both natural and anthropogenic sources that researchers cannot directly characterized by ground measurements, typically below 3cm in size and all the way to nanometer-sized dust. In addition, there is new space environment relevant science in the anthropogenic signatures caused by these objects passing through space plasmas. These interactions have received little attention to date but are becoming an increasing background signal especially in the more proliferated low-Earth Orbit, which researchers would like to differentiate from natural signals.

The NASA OD-SSA activity involves a diverse mixture of elements including competed research, directed and competed flight components, and interagency and international cooperation. This approach allows the activity to address gaps in orbital object detection and gaps in our scientific understanding of their interactions with the environment and serves to enable the efficient maturation of technologies and subsequent transfer of critical new capabilities to partner agencies such as Department of Commerce (DOC), NOAA, and DoD.

OTHER MISSIONS AND DATA ANALYSIS

Activities in FY 2023 will include the development and laboratory testing of multiple OD sensor concepts and the preparation of a prototype OD sensor that NASA will deliver for integration into the DoD Space Test Program (STP) STPSat-7 satellite, as well as the selection of awards for the development of new OD/dust sensors. In addition, new competed research programs will address the basic science of object / space plasma interactions and will further advance thermospheric density modeling for space object tracking applications.

GEOSPACE DYNAMICS CONSTELLATION (GDC)

GDC is a mission concept proposed in the 2013 Heliophysics Decadal Survey that would be the first mission to conduct a coordinated, global study of Earth's upper atmosphere, the heart of Earth’s space environment. The upper atmosphere is a dynamic region of overlapping neutral atmosphere and ionosphere, where processes are driven by mass and energy inputs from both below (Earth's lower/middle atmosphere) and above (Earth's magnetosphere and the Sun). These inputs from above and the dynamics active within the upper atmosphere include space weather processes that impact the human presence and technological assets in space. GDC would be the first mission to address this science on a global scale due to its use of a constellation of spacecraft that permit simultaneous multi-point observations.

Recent Achievements

In April 2022, NASA chartered an Independent Review Board (IRB) to provide an assessment of the overall architecture and technical concept developed in pre-Phase A and Phase A activities. The IRB published their final report and NASAs responded to it in October 2022.

NASA has selected three Interdisciplinary Scientists and five instrument investigations to integrate into the project. GDC released the request for proposals for the mission spacecraft in December 2022 and received proposals in February 2023.

The Budget proposes to pause GDC development, as continuing development would have required a significant increase in funding at a time when other space science missions, such as the Mars Sample Return mission, also have high budgetary requirements.

Operating Missions

SOLAR ORBITER COLLABORATION (SOC)

The NASA and European Space Agency (ESA) SOC mission provides measurements that will give NASA better insight on the evolution of sunspots, active regions, coronal holes, and other solar features and phenomena. The instruments explore the near-Sun environment to improve our understanding of the origins of the solar wind streams and the heliospheric magnetic field; the sources, acceleration mechanisms, and transport processes of solar energetic particles; and the evolution of CMEs in the inner heliosphere. To achieve these objectives, SOC makes in-situ measurements of the solar wind plasma, fields, waves, and energetic particles. SOC also makes imaging/spectroscopic observations. SOC provides close-up views of the Sun’s polar- regions and far side. SOC adjusts its orbit to the direction of the Sun’s rotation to allow the spacecraft to observe one specific area for much longer than is currently possible. The prime mission will continue until May 2027.

OTHER MISSIONS AND DATA ANALYSIS

ESA provided the spacecraft and manages operations. The ESA member states provided most of the instruments. NASA provided the launch vehicle and two science investigations/instruments: The Solar Orbiter Heliospheric Imager and the Heavy Ion Sensor. In return for its contributions, NASA will have access to the entire science mission data set.

Recent Achievements

On March 25, 2022, during the Solar Orbiter first close approach to the Sun at heliocentric distance of about 0.32 AU, the Metis coronagraph observed the solar corona in visible light and scientists interpreted the observation as a switchback. Switchbacks are abrupt large deflections of the solar wind magnetic field. Previously observed in the outer heliosphere, Parker Solar Probe has revealed that the presence of switchbacks increases dramatically near the Sun. Researcher's interpretation of this structure as generated by interchange reconnection between coronal loops formed above an active region and nearby open-field regions is also relevant to understand the origin of the slow solar wind.

The Solar Orbiter trajectory in space allows for multiple opportunities when the spacecraft crosses the Sun-Earth line. This unique position allows Solar Orbiter to monitor the solar wind conditions that would affect Earth several hours later. On March 11-12, 2022, Solar Orbiter was present for a CME which originated on the Sun on March 10. The Heavy Ion Sensor of the Solar Wind Analyzer on board Solar Orbiter detected significant ion intensity enhancements. Since the spacecraft was in direct contact with Earth, Solar Orbiter data arrived on the ground within a few minutes, and the team made a prediction for the arrival of these CME structures at Earth. The team used data from the magnetometer on board Solar Orbiter to predict when it would subsequently hit Earth. Announcing this news on social media allowed sky watchers to be ready for the aurora, which arrived around 18 hours later at the predicted time.

PARKER SOLAR PROBE

Parker Solar Probe (PSP), launched in 2018, is unlocking the mysteries of the Sun's atmosphere. PSP has flown through the solar corona 13 out of an expected 24 times, gradually lowering its orbit closer to the Sun using Venus' gravity during seven flybys over its seven-year mission with the prime mission ending in 2024. After the fifth Venus flyby, the spacecraft flew through the Sun's atmosphere as close as 3.8 million miles to our star’s surface - well within the orbit of Mercury. Earth’s average distance to the Sun is 93 million miles.

Flying into the outermost part of the Sun's atmosphere, the corona, with nearly every new encounter, PSP employs a combination of in-situ measurements and imaging to revolutionize our understanding of the corona and expand our knowledge of the origin and evolution of the solar wind. PSP will also make critical contributions to our ability to forecast changes in Earth's space environment that affect life and technology on Earth.

Recent Achievements

On April 29, 2022, NASA announced that the PSP achieved mission success. At that time, scientists had published over 600 peer-reviewed articles in peer-reviewed journals using PSP observations, with over 8000 citations.

Inside one-tenth of the distance of Earth from the Sun, PSP has recorded a new type of low-energy particle event. PSP encountered these events at times near the crossing of the current sheet in the solar wind, a surface that separates magnetic field polarities, outward and inward, that are present in the solar wind on either side of the current sheet. It is here where magnetic field lines can reconnect and transfer

OTHER MISSIONS AND DATA ANALYSIS

magnetic field energy into the energy of fast-flowing particles. The detailed mechanism of this energization process is still under investigation. It is likely that such particle events can only be observed very close to the Sun, and that they provide important insight into specific particle acceleration mechanisms. During the third and fourth Venus flybys, PSP flew behind the planet (i.e., over its night side). For a brief ten minutes, PSP was in an eclipse configuration, which allowed the Wide Field Imager for Solar Probe (WISPR) telescopes to image the night side of the planet. The team’s goal was to detect clouds in the opaque Venusian atmosphere. However, when WISPR returned an image with detailed structure, the project recognized that PSP observed surface features. A prominent observed feature is Aphrodite Terra, the largest highland region on the Venusian surface. This is the first time that scientists observed Venus' surface in visible-light wavelengths, a "red" glow that the hot surface of the planet emits. PSP has thus opened a new window to explore the planet's surface that future missions might exploit.

SOLAR DYNAMICS OBSERVATORY (SDO)

Launched on February 11, 2010, SDO seeks to understand the Sun’s influence on Earth and near-Earth space by simultaneously studying the solar atmosphere on small scales of space and time and in many wavelengths. The observatory enables scientists to determine how the Sun’s magnetic field is generated and structured and how stored magnetic energy is converted and released in the form of solar wind, energetic particles, and variations in the solar irradiance. SDO collects data to help explain the creation of solar activity, which drives space weather. Measurements of the interior of the Sun, the Sun’s magnetic field, the hot plasma of the solar corona, and the irradiance that creates Earth’s ionosphere are the primary data products. The mission will submit a proposal at the Heliophysics Senior Review in early 2023.

Recent Achievements

The SDO team continues to supply science data to a large, diverse community and to use that data to understand the Sun. One highlight was a white-light flare seen in the Helioseismic and Magnetic Imager (HMI) off-limb annulus model. One of these rare events, seen on May 3, 2022, displayed flare loops that are clearly visible and agree with observations at higher energies. The differences between the measurements in visible light and extreme ultraviolet wavelengths provide information about mass motions and energy transport during the flare. A survey of the HMI off-limb annulus is underway. An annulus is a ring-shaped structure.

Researchers conducted a model study motivated by the appearance of coronal loops in images of the Sun at the very short, extreme ultraviolet wavelengths. Scientists have assumed these loops trace out the magnetic field lines of the Sun, much like iron filings around a permanent magnet in a school class. A model study that included members of the SDO Team found that these loops are a more complicated visualization of what is happening on the Sun. This new interpretation will help us understand how the corona is heated to its high temperatures and how plasma behaves in other magnetic fields.

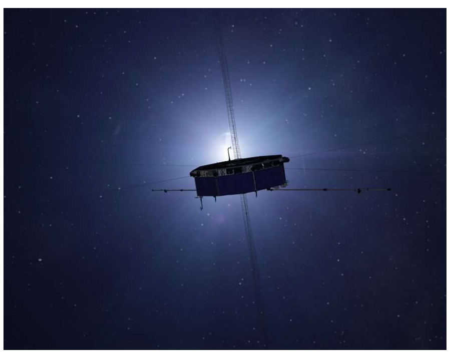
SOLAR TERRESTRIAL PROBES

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Interstellar Mapping and Acceleration Probe (IMAP)	166.3	120.8	**139.8**	63.9	39.5	23.9	15.3
Other Missions and Data Analysis	63.4	--	**54.2**	64.9	43.1	41.5	40.6
Total Budget	**229.7**	**208.0**	**194.0**	**128.8**	**82.6**	**65.3**	**55.9**
Change from FY 2023 Enacted			**-14.0**				
Percent change from FY 2023 Enacted			**-6.7%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



The illustration above is of one of the four Magnetospheric Multi-scale (MMS) spacecraft in orbit. MMS orbit Earth to study our planet's complex magnetic environment.

The Solar Terrestrial Probes (STP) Program focuses on understanding the fundamental physical processes of the space environment from the Sun to the Earth, to other planets, and beyond to the interstellar medium. STP provides insight into the basic processes of plasmas (fluids of charged particles) inherent in all astrophysical systems. STP missions focus on processes such as the variability of the Sun, responses of the planets to those variations, and the interaction of the Sun and the solar system. NASA defines specific goals for STP missions and selects investigations for each mission competitively. These missions allow the science community an opportunity to address important research focus areas and make significant progress in understanding fundamental physics.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ACHIEVEMENTS IN FY 2022

The Carruthers Geocorona Observatory formerly known as Global Lyman-alpha Imager of the Dynamic Exosphere (GLIDE) passed its mission confirmation review in January 2022 and entered the final design and fabrication phase. Carruthers successfully passed its Critical Design Review (CDR) in August 2022.

SOLAR TERRESTRIAL PROBES

Interstellar Mapping and Acceleration Probe (IMAP) continued critical design activities in preparation for the mission CDR. Most instrument critical design reviews are complete. The project has received the spacecraft structural components and making final preparations for integration.

WORK IN PROGRESS IN FY 2023

Consistent with the report language accompanying the FY 2023 appropriations bill, NASA will issue a draft Announcement of Opportunity for the Dynamic Neutral Atmosphere-Ionosphere Coupling (DYNAMIC) mission.

Carruthers is progressing towards System Integration Review (SIR) in October 2023.

IMAP will complete ground systems design and operations planning in preparation for mission operations review and continue the development design activities to complete CDR. The project will continue to fabricate hardware in preparation for the SIR and the Key Decision Point-D (KDP-D) gate review.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

Following a successful Pre-Environmental Review (PER) in May 2024, Carruthers will continue with project implementation and perform system, assembly, and integration as part of Phase D. Carruthers will then prepare for the Operational Readiness Review (ORR) in November 2024, followed by the KDP-E gate review in December 2024.

IMAP will complete system integration activities in preparation for the PER.

Program Schedule

Date	Significant Event
Q2 FY 2023	IMAP CDR
Q4 FY 2023	IMAP SIR
Q4 FY 2023	IMAP KDP-D
Q4 FY 2023	DYNAMIC AO release
Q4 FY 2023	Carruthers SIR
Q2 FY 2024	Carruthers PER
Q4 FY 2024	IMAP PER
Q4 FY 2024	Carruthers ORR
Q4 FY 2024	Carruthers KDP-E
Q2 FY 2025	IMAP ORR
Q1 FY 2025	IMAP LRD
Q1 FY 2025	Carruthers LRD

SOLAR TERRESTRIAL PROBES

Program Management

GSFC is responsible for the management of the STP Program.

Acquisition Strategy

In the acquisition of STP scientific instruments, spacecraft, and science investigations, NASA will use full and open competitions to the greatest extent possible. NASA may acquire certain instruments, missions, or mission systems without competition (e.g., through international partnerships or in-house builds) if there is a clear scientific, technological, or programmatic benefit to NASA.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	Feb 2019	Program Independent Review: Assess performance of program	Successful	Nov 2023
Performance	SRB	Nov 2023	Program Independent Review: Assess performance of program	TBD	N/A
Performance	SRB	Jan 2023	IMAP CDR Program Independent Review: Assess performance of program	Successful	Jul 2023
Performance	SRB	Jul 2023	IMAP SIR Program Independent Review: Assess performance of program	TBD	Jul 2024
Performance	SRB	Oct 2023	Carruthers SIR Program Independent Review: Assess performance of program	TBD	Nov 2024
Performance	SRB	Nov 2024	Carruthers ORR Program Independent Review: Assess performance of program	TBD	N/A
Performance	SRB	Jan 2025	IMAP ORR Program Independent Review: Assess performance of program	TBD	N/A

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

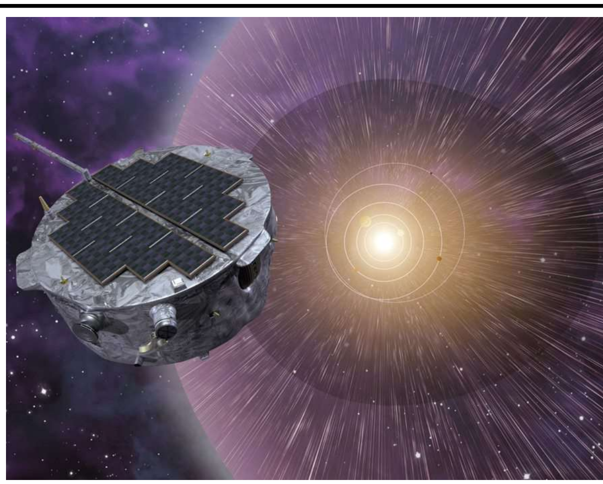
FY 2024 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028	BTC	Total
Formulation	117.6	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	117.6
Development/Implementation	94.8	166.3	120.8	**139.8**	57.8	10.0	0.0	0.0	0.0	589.5
Operations/Close-out	0.0	0.0	0.0	**0.0**	6.1	29.5	23.9	15.3	0.0	74.8
2023 MPAR LCC Estimate	**212.3**	**166.3**	**120.8**	**139.8**	**63.9**	**39.5**	**23.9**	**15.3**	**0.0**	**781.8**
Total Budget	**212.3**	**166.3**	**120.8**	**139.8**	**63.9**	**39.5**	**23.9**	**15.3**	**0.0**	**781.8**
Change from FY 2023 Enacted				**19.0**						
Percent change from FY 2023 Enacted				**15.7%**						

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The 2023 MPAR LCC Estimate reflects the most recent estimates based on current project data as of February 2023. The requested budget authority is the project's current budget requirement which has seen programmatic changes and are anticipated in the Quarter 2 Financial Report.



Shown here is an artist's conception of the IMAP spacecraft.

PROJECT PURPOSE

The Interstellar Mapping and Acceleration Probe (IMAP) mission will help researchers better understand the boundary of the heliosphere, a magnetic bubble surrounding and protecting Earth's solar system. This region is where the constant flow of particles from our Sun, called the solar wind, collides with material from the rest of the galaxy. This collision limits the amount of harmful cosmic radiation entering the heliosphere. IMAP will collect and analyze particles that make it through to the heliosphere.

Another objective of the mission is to learn more about the generation of cosmic rays in the heliosphere. Cosmic rays created both locally and from the galaxy and beyond affect human explorers in space and can harm technological systems, and likely play a role in the presence of life itself in the universe.

IMAP is the fifth mission in NASA’s Solar Terrestrial Probes (STP) Program portfolio. NASA selected IMAP following an extensive and competitive peer review of proposals submitted in 2017. The mission

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

will carry 10 science instruments provided by international and domestic research organizations and universities.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

PROJECT PARAMETERS

IMAP will study the interaction of the solar wind with the winds from other stars by directly sampling neutral atoms returning from the interstellar boundary and will elucidate how particles are accelerated to high energies in space environments. IMAP will launch on a SpaceX Falcon 9 in 2025 and will conduct operations at the Earth-Sun Lagrange Point 1, upstream of Earth at 1 percent of the distance to the Sun. IMAP will carry 10 instruments, which can be grouped into three categories: energetic neutral atom detectors (IMAP-Lo, IMAP-Hi, and IMAP-Ultra), charged particle detectors (SWAPI, SWE, CoDICE, and HIT), and other coordinated measurements (MAG, IDEX, GLOWS). The Project Management & Commitments table below describes each of the then instruments. IMAP will also supply critical real-time space weather data through its IMAP Active Link for Real-Time (I-ALiRT). With I-ALiRT, IMAP will enable new ways of forecasting space weather by streaming real-time observations of conditions headed towards Earth to operators on the ground.

Two secondary rideshare payloads will accompany the IMAP mission, taking advantage of the excess performance capability of the launch vehicle. Heliophysics is currently planning to fly an STP mission of opportunity (Carruthers) along with NOAA Space Weather Follow-On (SWFO-L1).

ACHIEVEMENTS IN FY 2022

IMAP continued critical design activities in preparation for the mission Critical Design Review (CDR). The team completed most of the instrument critical design reviews including IMAP-Ultra, IDEX, MAG, SWAPI, SWE, HIT, GLOWS, and IMAP-Hi. The project received the spacecraft structural components and made final preparations for integration.

WORK IN PROGRESS IN FY 2023

IMAP will conclude critical design activities by passing the remaining subsystem and instrument CDRs including IMAP-Lo, CoDICE, Propulsion, and Mechanical. With the completion of the mission-level CDR in January 2023, IMAP will move into the system fabrications and test phase resulting in a system integration review in July 2023 and followed by the Key Decision Point D (KDP-D) gate review in August 2023. IMAP will continue to mature the ground system elements including the mission operations center and science operations center with a mission operations review in April 2023. The project will conclude instruments engineering model testing and validation efforts and begin instruments flight assembly activities.

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

KEY ACHIEVEMENTS PLANNED FOR FY 2024

In FY 2024, IMAP will transition into the system integration and test phase. The project will deliver and integrate all major elements including spacecraft avionics, power systems, navigation and control systems, and science instruments onto the spacecraft bus. The team will complete performance, characterization, and calibration tests before moving the fully integrated system into environmental testing after passing the pre-environmental review in July 2024.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2024 PB Request
KDP-C	Jul 2021	Jul 2021
CDR	Jun 2022	Jan 2023
SIR	Jun 2023	Jul 2023
KDP-D	Jun 2023	Aug 2023
ORR	Dec 2024	Jan 2025
KDP-E	Jan 2025	Jan 2025
Launch (or equivalent)	Dec 2025	Dec 2025

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milesto ne Change (mths)
2021	$589.5M	70%	2023	$589.5M	0%	LRD	12/2025	12/2025	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**589.5**	**589.5**	**0**
Spacecraft	67.4	77.7	+10.3
Payloads	124.9	137.7	+12.8
Systems I&T	26.6	28.9	+2.3
Launch Vehicle	78.4	78.4	0
Ground Systems	33.7	37.2	+3.5
Science/Technology	21.6	14	-7.6
Other Direct Project Costs	236.9	215.4	-21.5

Project Management & Commitments

The mission Principal Investigator is from Princeton University. The Johns Hopkins University/Applied Physics Lab (JHU/APL) is responsible for project management and engineering.

Element	Description	Provider Details	Change from Baseline
Spacecraft	Provides a controlled spinning platform at the L1 Lagrange point for an extensive payload of scientific instruments.	Provider: JHU/APL Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
IMAP-Lo Instrument	Tracks the interstellar flow to precisely determine the species-dependent flow speed, temperature, and direction of the Local Interstellar Medium (LISM) that surrounds, interacts with, and determines the outer boundaries of the global heliosphere.	Provider: University of New Hampshire Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
CoDICE Instrument	Determines the Local Interstellar Medium (LISM) composition and flow properties, to discover the origin of the enigmatic suprathermal tails and advance understanding of the acceleration of particles in the heliosphere.	Provider: Southwest Research Institute Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
IDEX Instrument	A high-resolution dust analyzer that provides the elemental composition, speed, and mass distributions of Interstellar Dust (ISD) particles.	Provider: University of Colorado Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Solar Wind and Pickup Ions (SWAPI) Instrument	Delivers the high time and energy resolution required to identify local acceleration processes, fundamental to understanding the solar wind context, sources, and acceleration of particles, PUIs, and the physical processes regulating the global heliosphere.	Provider: Princeton University Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
IMAP Ultra Instrument	Images the emission of Energetic Neutral Atoms (ENAs) produced in the heliosheath and beyond.	Provider: JHU/APL Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
HIT Instrument	Delivers full-sky coverage of ion anisotropy measurements, observing the ramps of local shocks, anchoring the high-energy SEP ion spectra, and resolving particle transport in the heliosphere.	Provider: GSFC Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
SWE Instrument	Measures in situ solar wind electrons at L1 to provide context for the ENA measurements and perform the in situ solar wind observations necessary to understand the local structures that can affect acceleration and transport.	Provider: Los Alamos National Laboratory Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
IMAP-Hi Instrument	Enables unprecedented, detailed studies of structure and evolution of source plasmas in the heliosphere-LISM interaction region.	Provider: Los Alamos National Laboratory Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
GLOWS Instrument	Measures the heliospheric resonant backscatter glow of hydrogen and helium.	Provider: Polish Academy of Science, Space Research Center Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): Poland Ministry of Science	N/A
Magnetometer Instrument	Allows new insight into waves and turbulence in the solar wind to frequencies near the electron gyrofrequency and maintains an accurate baseline for space weather applications.	Provider: Imperial College of London Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): UK Space Agency	Yes
Launch Vehicle	The Falcon 9 rocket will deliver the IMAP observatory and up to four rideshare secondary payloads to a proper orbital trajectory.	Provider: SpaceX Lead Center: Kennedy Space Center (KSC) Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: The quantity, complexity or sensitivity of IMAP instruments causes issues during development or integration and testing, Then: The project could experience the need for additional testing or redesign leading to cost and schedule impacts.	1) Enhance instrument management teams with experienced personnel and supplement engineering organizational structure; 2) Augment review authorities with tiger teams to review and evaluate system level testing and verification efforts; 3) Increase early Engineering Model (EM) development and test activities; and 4) Increase early EM interface tests for critical interfaces between instruments.
If: The IMAP Primary Structure or Propulsion mechanical procurements continue to experience delays, Then: The delivery of the structure will further delay propulsion system integration resulting in a potential delay to the IMAP launch date.	1) Incentivize early delivery of structural elements; 2) Identify alternative machines shops and processes to increase the likelihoods of earlier deliveries; 3) Elevate management discussions to center and senior supplier management authorities; 4) Increase on-site support and auxiliary quality assurance personnel at structural vendor suppliers; and 5) Host schedule deep-dives and out-of-the-box brainstorming sessions to identify alternative means to expedite structure fabrication efforts.

Acquisition Strategy

NASA competitively selected the mission through the Solar Terrestrial Program-5 AO and completed final down-selection in 2018. NASA selected the launch vehicle through full and open competition via NASA's Launch Services Program at KSC.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Mission Development, IMAP-Ultra Instrument	JHU/APL	Laurel, MD
SWAPI Instrument and Science	Princeton University	Princeton, NJ
IMAP-Hi and SWE Instruments	Los Alamos National Laboratory	Los Alamos, NM
CoDICE Instrument, Instrument Common Electronics, Payload Systems Engineering	Southwest Research Institute	San Antonio, TX
IMAP-Lo Instrument	University of New Hampshire	Manchester, NH
IDEX Instrument and Science Operations Center	Laboratory for Atmospheric and Space Physics - Colorado University	Boulder, CO

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

Element	Vendor	Location (of work performance)
Launch Vehicle	SpaceX	Hawthorne, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board	May 2021	Preliminary Design Review (PDR) demonstrates that the preliminary design meets all system of interest requirements with acceptable risk and within the cost and schedule constraints and establishes the basis for proceeding with detailed design.	Successful	CDR
Performance	Standing Review Board	Jan 2023	Critical Design Review (CDR) demonstrates that the maturity of the design is appropriate to support proceeding with full-scale fabrication, assembly, integration, and test.	Successful	SIR
Performance	Standing Review Board	Jul 2023	Systems Integration Review (SIR) ensures segments, components, and subsystems are on schedule to be integrated into the system of interest, and integration facilities, support personnel, and integration plans and procedures are on schedule to support integration.	TBD	ORR
Performance	Standing Review Board	Jan 2025	ORR ensures that all system and support (flight and ground) hardware, software, personnel, procedures, supporting capabilities, and user documentation accurately reflect the deployed state of the system and are operationally ready.	TBD	N/A

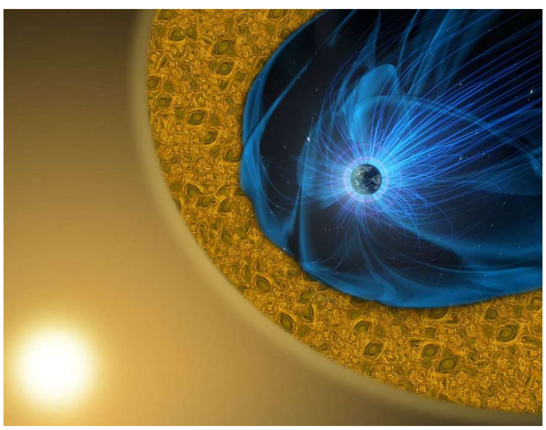
OTHER MISSIONS AND DATA ANALYSIS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Carruthers Geocorona Observatory	22.1	--	**12.4**	12.0	3.2	3.0	2.5
Solar Terrestrial Probe Future Missions	0.0	5.0	**0.4**	0.0	0.0	0.0	0.0
STP Program Management	10.9	--	**9.2**	16.4	4.3	4.3	4.5
Magnetospheric Multiscale (MMS)	17.0	26.0	**18.4**	20.2	20.1	18.9	18.4
Solar Terrestrial Relations Observatory (STEREO)	5.0	--	**4.9**	6.6	6.4	6.0	6.0
Hinode (Solar B)	6.2	--	**6.3**	6.8	6.5	6.5	6.5
TIMED	2.2	--	**2.6**	2.8	2.7	2.7	2.7
Total Budget	**63.4**	**--**	**54.2**	**64.9**	**43.1**	**41.5**	**40.6**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



Earth is surrounded by a protective magnetic environment – the magnetosphere – shown here in blue, which deflects a supersonic stream of charged particles from the Sun, known as the solar wind. As the particles flow around the Earth's magnetosphere, it forms a highly turbulent boundary layer called the magnetosheath, shown in yellow. Scientists are studying this turbulent region to help us learn more about our dynamic space environment.

The Solar Terrestrial Probes (STP) Other Missions and Data Analysis budget includes operating STP missions, program management, and funding for future missions launching in the next decade.

Mission Planning and Other Projects

CARRUTHERS GEOCORONA OBSERVATORY

In December 2020, NASA selected the Carruthers Geocorona Observatory formerly known as Global Lyman-alpha Imager of the Dynamic Exosphere (GLIDE) as an STP Mission of Opportunity. Carruthers will study variability in Earth's exosphere by tracking far ultraviolet light emitted from hydrogen. It will also gather observations at a high rate, with a view of the entire exosphere, ensuring a global and comprehensive set of data, which is currently lacking. Carruthers will help scientists better understand the ways in which Earth's exosphere changes in response to influences of the Sun. This study will provide us with better ways to forecast and, ultimately, mitigate the ways in which space weather can interfere with radio communications in space. Carruthers will be a rideshare payload on the IMAP mission, launching no earlier than February 2025.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

Carruthers passed its mission confirmation review in January 2022 and entered the final design and fabrication phase. Carruthers successfully passed its critical design review in August 2022.

STP PROGRAM MANAGEMENT

STP Program Management provides the resources required to manage the planning, formulation, and implementation of all STP missions. The program office ensures successful achievement of STP program cost and schedule goals, while managing cross-project dependencies, risks, issues, and requirements as projects progress through formal key decision points.

STP FUTURE MISSIONS

The STP Future Missions project supports strategic planning for addressing the recommendations of the Heliophysics Decadal Survey. NASA anticipates receiving recommendations from the next Heliophysics Decadal Survey in 2024.

Consistent with the FY 2023 Budget proposal, this Budget proposes no funding for the DYNAMIC mission due to the need to fund higher priorities within the Science program. NASA will reassess funding for future Solar Terrestrial Probes missions following the Heliophysics Decadal Survey.

Operating Missions

MAGNETOSPHERIC MULTISCALE (MMS)

The MMS mission investigates how the magnetic fields of the Sun and Earth connect and disconnect, explosively transferring energy from one to the other, and throughout interplanetary space. MMS uses Earth's magnetosphere as a natural laboratory to study the microphysics of magnetic reconnection, a fundamental plasma-physical process that converts magnetic energy into heat and charged particle kinetic energy. In addition to seeking to solve the mystery of the small-scale physics of the reconnection process, MMS investigates how the energy conversion that occurs in magnetic reconnection accelerates particles to high energies and what role plasma turbulence plays in reconnection events. Magnetic reconnection, particle acceleration, and turbulence occur in all astrophysical plasma systems. Researchers can only study these phenomena in-situ in our solar system, and most efficiently in Earth's magnetosphere, where these processes control the dynamics of the geospace environment and play an important role in the phenomena known as space weather. MMS also helps us understand reconnection elsewhere, such as the atmosphere of the Sun and other stars, near black holes and neutron stars, and at the boundary between the solar system's heliosphere and interstellar space, where it is more difficult to study.

The MMS mission consists of four identically instrumented spacecraft that measure particles, fields, and plasmas. The MMS instrument payload measures electric and magnetic fields and the plasmas found in the regions where magnetic reconnection occurs. Fast, multi-point measurements are enabling dramatically revealing direct observations of these physical processes. A highly elliptical orbit explores how Sun-Earth magnetic fields reconnect in Earth's neighborhood. The four spacecraft fly in a tetrahedron formation that allows them to observe the three-dimensional structure of magnetic

OTHER MISSIONS AND DATA ANALYSIS

reconnection events. The separation between the observatories is adjustable over a range of six to 250 miles during science operations areas of interest. MMS is currently in extended operations.

MMS launched in March 2015 and entered its extended mission phase in September 2017. NASA has approved MMS to continue as an extended mission, and the mission will submit a proposal at the Heliophysics Senior Review in 2023.

Recent Achievements

MMS analyses have answered a long-standing question about the speed at which the magnetic field is processed through the reconnection region (referred to as the magnetic reconnection rate). For years, researchers observed the reconnection rate to be almost constant in both computer simulations and spacecraft data; however, the physical basis of this near-constant rate had not been established. MMS combined theory and data to show that the decoupling of ions and electrons (known as the Hall effect) within the reconnection region is responsible. The strong pressure difference between this vacuum and the bounding magnetic field drives the magnetic field into the reconnection site and causes the release of immense amounts of energy at the reconnection site. This understanding of the fundamental physics of reconnection will enhance future investigations in planetary magnetospheres and is also directly applicable to studies of stellar flares, magnetically confined fusion, and astrophysical plasmas.

SOLAR TERRESTRIAL RELATIONS OBSERVATORY (STEREO)

STEREO enables studies of the origin of the Sun's coronal mass ejections (CME) and their consequences for Earth, other planets, and interplanetary space. The mission launched with two spacecraft, one Ahead of Earth (STEREO-A) and the other Behind Earth (STEREO-B) in its orbit. STEREO's instrumentation targets the fundamental process of energetic particle acceleration in the low solar corona and in interplanetary space. The mission can image the structure and evolution of solar storms as they leave the Sun and move through space toward Earth. The mission also provides the foundation for understanding space weather events and developing predictive models. The models, in turn, help to identify and mitigate the risks associated with space weather events. In addition, STEREO improves space weather situational awareness not only for Earth and in low-Earth orbit, but also throughout the solar system.

STEREO launched in October 2006 and entered its extended mission phase in January 2009. On October 1, 2014, NASA lost communication with STEREO-B just as the spacecraft was about to orbit around the other side of the Sun. In late 2015, the spacecraft orbit finally carried it out from behind the Sun and NASA was able to re-establish contact with STEREO-B for a short period in 2016. NASA attempted to establish control of the spacecraft with limited success. Beginning in December 2017, the project team made monthly attempts to re-establish contact with the spacecraft, until attempts ceased in October 2018.

STEREO-A continues to operate nominally and is still providing significant science data. NASA has approved STEREO to continue as an extended mission, the mission will submit a proposal at the Heliophysics Senior Review in 2023.

Recent Achievements

Using its long baseline of observations, STEREO documented a previously unknown structuring in the solar wind streams that injects an error into space weather forecasting. The STEREO analysis used data from 2007 (end of Solar Cycle 23) to 2020 (end of Solar Cycle 24) to compare the streams' reappearance rate to the solar rotation rate. During the declining phase of the solar cycle (moving from solar maximum to solar minimum), the streams reappeared faster than expected from the solar rotation rate. These results

OTHER MISSIONS AND DATA ANALYSIS

suggest that complex structures both persist well after solar maximum and maintain rotation speeds that differ from solar wind models. These unexpected features represent new information about the behavior of the Sun through the solar cycle and a source of error in forecasting space weather impacts from these streams.

HINODE

Hinode is a joint Japan Aerospace Exploration Agency (JAXA) and NASA mission. The mission consists of a coordinated set of optical, extreme ultraviolet, and X-ray instruments that study the basic heating mechanisms and dynamics of the active solar corona. Hinode explores the magnetic fields of the Sun to improve understanding of what powers the solar atmosphere and drives solar eruptions. By investigating the fundamental processes that connect the Sun’s magnetic field and the solar corona, Hinode is discovering how the Sun generates magnetic disturbances and the high-energy particle storms that propagate from the Sun to Earth.

Hinode’s solar optical telescope is the first spaceborne instrument to measure the strength and direction of the Sun’s magnetic field on the Sun’s surface, the photosphere. Two other Hinode instruments, the Extreme Ultraviolet (EUV) imaging spectrometer and the X-ray/EUV telescope, allow the mission to investigate the causes of eruptions in the solar atmosphere and relate those eruptions to the intense heating of the corona and the mechanisms that drive the constant outflow of solar radiation, the solar wind.

Hinode launched in September 2006 and entered its extended mission phase in November 2009. NASA has approved Hinode to continue as an extended mission, and the mission will submit a proposal at the Heliophysics Senior Review in 2023.

Recent Achievements

Hinode validated the variability of coronal mass loss predicted in solar wind models through a coordinated observations with Parker Solar Probe, Wind and SDO. Models predict that mass loss from a point on the Sun is sensitive to that region's coronal temperature, but testing that sensitivity requires a challenging set of measurements. During Parker's first solar encounter, Hinode combined observations with SDO and Wind to measure the mass loss and the coronal temperature at a variety of solar regions. This rare combination of observations confirmed the strong variation of coronal mass loss with the local temperature. This result provides confidence in the use of more-accessible temperature measurements to study solar mass loss, and further presents the opportunity to advance statistical studies of other stars.

THERMOSPHERE, IONOSPHERE, MESOSPHERE ENERGETICS AND DYNAMICS (TIMED)

The TIMED mission characterizes and studies the physics, dynamics, energetics, thermal structure, and composition of the least explored and understood regions of Earth’s atmosphere: the mesosphere, the lower thermosphere, and the ionosphere, collectively known as the ionosphere-thermosphere-mesosphere (ITM) system. This ITM system, located between altitudes of approximately 35 to 100 miles above the surface of Earth, helps protect Earth from harmful solar radiation. It is a gateway between Earth’s environment and space, where the Sun’s energy first affects Earth’s environment. Solar events, as well as temperature changes in the stratosphere, can perturb this region, but scientists do not understand the

OTHER MISSIONS AND DATA ANALYSIS

overall structure of and responses to these effects. Advances in remote sensing technology employed by TIMED enable us to explore this region on a global basis from space.

TIMED’s 19-years of data provides scientists an unrivaled perspective on changes in the upper atmosphere. The long lifespan allows scientists to track the upper atmosphere’s response to both quick-changing conditions, like individual solar storms, throughout the Sun’s 11-year activity cycle, as well as longer-term trends, such as those related to climate change. TIMED’s instruments are still producing data, enabling continuing studies of the upper atmosphere.

TIMED launched in December 2001 and entered its extended mission phase in January 2004. NASA has approved TIMED to continue as an extended mission, and the mission will submit a proposal at the Heliophysics Senior Review in 2023.

Recent Achievements

TIMED demonstrated a proxy for neutral atmospheric density measurements that are important to scientific studies and operational concerns of orbital drag. Revisiting historical data, TIMED showed a correlation between concurrent Global Ultraviolet Imager (GUVI) ultraviolet observations and CHAllenging Minisatellite Payload (CHAMP) upper atmosphere neutral density measurements. GUVI is an instrument on TIMED and CHAMP is a German small satellite mission. Ultraviolet observations are complicated by propagation effects and solar emissions, preventing this type of study without these rare concurrent observations. With this correlation established, researchers can leverage TIMED's ultraviolet observations as an indirect density measurement. This presents the possibility of future missions monitoring the atmospheric neutral density from an altitude that protects them from the orbital drag they study.

TIMED quantified structural changes to the mesosphere-lower thermosphere related to solar activity and carbon dioxide (CO2). This atmospheric region cooled up to 1.75 Kelvin to 19 Kelvin (3.1 to 34.2 degrees Fahrenheit), depending on altitude. This region also shrank by up to 1,333 meters (over 4,700 feet) over the same period of time. Scientists attributed the cooling to a combination of reduced solar activity and increased carbon dioxide levels and attributed the shrinkage to the carbon dioxide increases alone. The reduction in solar activity is due to natural variations within and between solar cycles, but the effects due to changes in the carbon dioxide levels are permanent.

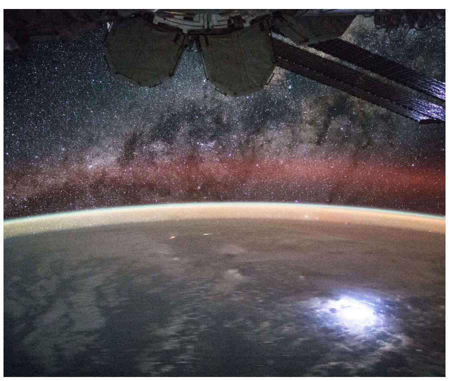
HELIOPHYSICS EXPLORER PROGRAM

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
HelioSwarm	3.3	--	**9.5**	44.3	126.8	138.2	109.0
Multi-Slit Solar Explorer	24.3	--	**47.4**	83.0	70.5	41.0	14.8
Other Missions and Data Analysis	161.7	--	**133.8**	171.3	176.7	192.8	288.8
Total Budget	**189.2**	**167.9**	**190.7**	**298.6**	**374.0**	**372.0**	**412.6**
Change from FY 2023 Enacted			**22.8**				
Percent change from FY 2023 Enacted			**13.6%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



This image taken from the ISS shows swaths of airglow hovering in Earth's atmosphere.

The Heliophysics Explorer Program provides frequent flight opportunities for world-class scientific investigations on focused and timely science topics. These investigations complement the science of strategic missions of the LWS and STP Programs. The program is highly responsive to new knowledge, new technology, and updated scientific priorities by launching smaller missions formulated and executed in a relatively short development cycle. The program features missions that are competitively selected from the scientific research community with constrained mission life-cycle costs.

The Explorers Program provides two classes (Medium-Class Explorers [MIDEX] and Small Explorers [SMEX]) of flight opportunities to accomplish the goals of the program. MIDEX missions are the most capable Explorers scientific investigations, with a cost cap of $300 million (not including launch services). SMEX missions are focused scientific missions and are limited to a $150 million cost cap (not including launch services). Explorers Missions of Opportunity (MO) are smaller investigations, which may fly as a hosted payload, sub-orbital flight, SmallSat or CubeSat mission, or ISS-attached payloads.

EXPLANATION OF MAJOR CHANGES IN FY 2024

The Budget includes new projects for the Multi-slit Solar Explorer (MUSE) and HelioSwarm missions, selected in February 2022. The Polarimeter to Unify the Corona and Heliosphere (PUNCH) mission is undergoing a replan to fly as a rideshare with the Astrophysics mission Spectro-Photometer for the History of the Universe and Ices Explorer (SPHEREx).

HELIOPHYSICS EXPLORER PROGRAM

ACHIEVEMENTS IN FY 2022

NASA recently selected two of the MIDEX-19 proposals (MUSE and HelioSwarm) to go forward into Phase B formulation, developing system requirements. NASA released the 2022 Heliophysics Explorer Program SMEX and MO final Announcement of opportunity.

Electrojet Zeeman Imaging Explorer (EZIE) completed its preliminary design reviews and confirmation in the summer of 2022, allowing entry into Phase C, the final design and fabrication phase. The Extreme Ultraviolet High-Throughput Spectroscopic Telescope (EUVST) completed its system requirements reviews. The Atmospheric Waves Experiment (AWE) completed critical design and integration and testing.

The Escape and Plasma Acceleration and Dynamics Explorers (ESCAPADE) worked with the Launch Service Program rideshare office to finalize launch opportunities. ESCAPADE successfully completed their critical design review. PUNCH will fly as a rideshare with the Astrophysics mission SPHEREx. PUNCH completed its critical design review and is building flight hardware in preparation for integration.

TRACERS completed its confirmation review and entry into implementation in as well as its critical design review and the Sun Radio Interferometer Space Experiment (SunRISE) finished its system integration review at the end of FY 2022.

WORK IN PROGRESS IN FY 2023

MUSE and HelioSwarm will continue their preliminary design and technology completion phase throughout FY 2023. The MUSE project will conduct their systems requirements review in March 2023. NASA will make step one selections from the 2022 Heliophysics Explorer Program SMEX and Mission of Opportunity (MO) Announcement of Opportunity (AO).

AWE will perform their final ship review. SunRISE will complete environmental testing leading to their final ship review in the third quarter of FY 2023.

EZIE will work toward their critical design review and will perform integration and testing in the summer of 2023.

ESCAPADE and PUNCH will complete final integration in preparation for environmental testing. ESCAPADE will go into storage until their rideshare opportunity is ready to integrate them to the launch vehicle. TRACERS will perform environmental testing and final integration.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

MUSE will complete their preliminary design review in the spring and progress towards confirmation. HelioSwarm will continue their preliminary design and technology completion phase in preparation for their system requirements review. NASA will make step two down-selections from the 2022 Heliophysics Explorer Program SMEX and MO AO.

EZIE will complete final integration and environmental testing in preparation for launch.

NASA will launch AWE to the ISS and the project will start on orbit operations onboard the ISS. SunRISE will be in storage awaiting their launch.

PUNCH will perform their environmental testing and go into storage until its rideshare opportunity is ready to integrate them to the launch vehicle.

HELIOPHYSICS EXPLORER PROGRAM

Program Schedule

Date	Significant Event
Q1 FY 2023	ESCAPADE Critical Design Review
Q2 FY 2023	AWE Pre-Ship Review
Q3 FY 2023	ESCAPADE Pre-Environmental Review
Q2 FY 2023	ESCAPADE System Integration Review
Q2 FY 2023	EZIE Critical Design Review
TBD	AWE Operational Readiness Review
TBD	PUNCH System Integration Review
Q3 FY 2023	SunRISE Pre-Storage Review
Q3 FY 2023	SMEX/MO Step 1 Selections
Q4 FY 2023	TRACERS System Integration Review
Q4 FY 2023	EUVST Preliminary Design Review
Q1 FY 2024	EZIE System Integration Review
Q1 FY 2024	TRACERS Pre-Environmental Review
Q1 FY 2024	AWE LRD
Q1 FY 2024	EZIE KDP-E
Q2 FY 2024	EZIE Pre-Environmental Review
Q2 FY 2024	TRACERS Operational Readiness Review
Q3 FY 2024	PUNCH Pre-Ship Review
Q4 FY 2024	ESCAPADE Operational Readiness Review
Q4 FY 2024	EZIE Pre-Ship Review
Q4 FY 2024	ESCAPADE KDP-E
Q4 FY 2024	SMEX/MO step 2 selections
Q1 FY 2025	ESCAPADE LRD
Q2 FY 2025	MIDEX announcement of opportunity
Q2 FY 2025	PUNCH Operational Readiness Review
Q2 FY 2025	PUNCH KDP-E
Q3 FY 2025	PUNCH LRD

HELIOPHYSICS EXPLORER PROGRAM

Date	Significant Event
Q4 FY 2025	SunRISE LRD
Q1 FY 2026	TRACERS LRD
Q2 FY 2026	EZIE LRD

Program Management & Planned Cadence

The Heliophysics and Astrophysics Explorer Programs share a common program office at GSFC and a common management structure. The Explorer Program Manager resides at GSFC, reporting functionally to the Center Director and programmatically through the Heliophysics and Astrophysics Division Directors.

The Heliophysics Explorer Program plan accommodates the Decadal Survey's recommendation of a two-to-three-year mission cadence.

Acquisition Strategy

NASA competitively selects new Explorer missions, releasing solicitations when available funding allows, with the expectation of a two-to-three-year cadence. NASA acquires launch vehicles through the Launch Services Program at KSC except when an international partner provides them under an approved agreement or when the Explorer mission is not a primary payload on the launch vehicle.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Program Independent Review	SRB	Dec 2019	Assess performance of program	Successful	Jan 2024
Program Independent Review	SRB	Jan 2024	Assess performance of program	To be determined	Jan 2029

HELIOSWARM

Formulation	Development	Operations

FY 2024 Budget

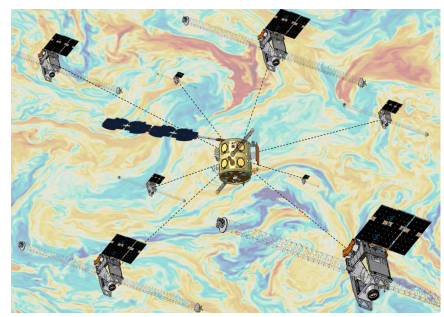
Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	3.3	--	9.5	44.3	126.8	138.2	109.0

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

PROJECT PURPOSE

HelioSwarm plans to observe the solar wind over a wide range of scales to determine the fundamental space physics processes that lead energy from large-scale motion to finer scales of particle movement within the plasma that fills space. Using a swarm of nine spacecraft (one "Hub" and eight "Nodes"), HelioSwarm will gather multi-point measurements and reveal the three-dimensional mechanisms that control the space plasma turbulence physical processes crucial to understanding the dynamics of the Sun, and the Sun-Earth connection.



Shown above, an artistic rendition of the HelioSwarm Mission which is a constellation of nine spacecraft, one hub spacecraft, and eight co-orbiting small satellites that range in distance from each other and the hub spacecraft.

EXPLANATION OF MAJOR CHANGES IN FY 2024

NASA selected HelioSwarm as a medium class Explorer mission and this is its first budget request.

PROJECT PRELIMINARY PARAMETERS

HelioSwarm is targeting a launch in FY 2029. HelioSwarm's novel implementation will unlock the mystery of how turbulence heats space plasma, which is matter that makes up key elements in the Universe, like the Sun, stars, solar wind and even the Earth's upper atmosphere. The mission will include the development of a suite, or swarm, of nine spacecraft to observe turbulence in the solar wind (charged particles ejected from the Sun), and interplanetary magnetic field. One large spacecraft, known as the "Hub", and eight smaller spacecraft, called "nodes", will co-orbit to monitor the ever-changing turbulence in space to reveal for the first time how these variations look in three dimensions and how they evolve.

Each spacecraft contains an instrument suite (IS) with Technology Readiness Levels from 6 to 8 providing measurements required to achieve HelioSwarm mission objectives. Nodes consist of three scientific instruments, Fluxgate Magnetometer (FGM), Search Coil Magnetometer (SCM), and a Faraday Cup (FC), plus an instrument data processing unit (IDPU) and two deployable magnetometer booms. The hub consists of the same elements, as well as an ion Electrostatic Analyzer (iESA). A single flight system with the nodes attached to the hub launches and transfers the instrument suites to the science orbit as a

Formulation	Development	Operations

single unit. Each of the node spacecraft then deploy from the hub, and the nine-spacecraft co-orbit in a two-week, lunar resonant orbit. HelioSwarm captures measurements in the undisturbed solar wind and interplanetary magnetic field (IMF) as well as in regions containing strongly driven turbulence. Over the course of the 12-month Science Phase, the instrument suites will rotate through all the regions of scientific interest. During the Science Phase, each of the nodes send their data to the hub and the data will be relayed to the ground via the hub downlink antennas at two-week cycles, streamlining mission operations.

ACHIEVEMENTS IN FY 2022

NASA selected the HelioSwarm mission to proceed into the preliminary design and technology completion phase (Phase B) in February 2022.

WORK IN PROGRESS IN FY 2023

The project will continue preliminary design and technology completion activities through FY 2023.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

The mission will complete its preliminary design and technology phase and proceed to a systems requirements review in the fourth quarter of FY 2024.

ESTIMATED PROJECT SCHEDULE

Milestone	Formulation Authorization Document	FY 2024 PB Request
KDP-B	N/A	Feb 2022
KDP-C	N/A	Oct 2025
KDP-D	N/A	Dec 2026
KDP-E	N/A	Nov 2028
Launch	N/A	Dec 2028

Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

Life cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows a non-advocate review and/or preliminary design review.

KDP-B Date	Estimated Life Cycle Cost Range ($M)	Key Milestone	Key Milestone Estimated Date Range
February 10, 2022	$500M - $550M	Launch	December 2028

HELIOSWARM

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details	Change from Formulation Agreement
Hub Spacecraft	The Hub is a heritage based ESPAStar spacecraft platform which will carry and deploy the nodes in space and then act as the central communication device between ground stations and the nodes both for commands and telemetry	Provider: Northrop Grumman Innovation Systems Lead Center: ARC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Node Spacecraft	The nodes are heritage-based commercial spacecraft that will each carry three instruments and communicate with the Hub	Provider: Blue Canyon Technologies Lead Center: ARC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Fluxgate Magnetometer (FGM)	The FGM is a heritage-based dual core fluxgate magnetometer designed to measure the IMF's lower frequencies	Provider: Imperial College London Lead Center: ARC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Ion Electrostatic Analyzer (iESA)	The iESA is a particle sensor designed to measure 3D ion VDFs, which provide the proton and alpha plasma parameters	Provider: Institut de Recherche en Astrophysique et Planétologie Lead Center: ARC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Search Coil Magnetometer (SCM)	The SCM is a heritage set of magnetic sensors designed to measure the IMF's higher frequencies	Provider: Laboratoire de Physique des Plasmas Lead Center: ARC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Faraday Cup (FC)	The FC instrument is a heritage-based design that makes measurements of the radial velocity distribution function (VDF) of the Solar Wind ions	Provider: Smithsonian Astrophysical Observatory Lead Center: ARC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

HELIOSWARM

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
Launch Vehicle	Deliver the spacecraft to operational orbit	Provider: TBD Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

Project Risks

None.

Acquisition Strategy

NASA competitively selected the mission through the Heliophysics Explorers 2019 Medium-class Explorer (MIDEX) Announcement of Opportunity (AO) and the final down selection occurred in 2022. The major elements of the mission and spacecraft are as proposed in the AO. NASA will competitively select the launch vehicle through the NASA Launch Services Program (LSP).

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Principal Investigator, Instrument Suite Management, Spacecraft Operations Center, and Integrated Data Processing Unit	University of New Hampshire	Durham, New Hampshire
Project Management, System Engineering, Safety & Mission Assurance, Mission Operations	NASA Ames Research Center	Mountain View, California
Launch Vehicle	Not Awarded at this time	TBD

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Oct 2024	SRR evaluates whether the functional and performance requirements defined for the system.	TBD	PDR

HELIOSWARM

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Oct 2025	PDR demonstrates that the preliminary design meets all system of interest requirements with acceptable risk and within the cost and schedule constraints and establishes the basis for proceeding with detailed design	TBD	CDR
Performance	SRB	July 2026	CDR demonstrates that the maturity of the design is appropriate to support proceeding with full-scale fabrication, assembly, integration, and test.	TBD	SIR
Performance	SRB	June 2027	SIR ensures segments, components, and subsystems are on schedule to be integrated into the system of interest, and integration facilities, support personnel, and integration plans and procedures are on schedule to support integration	TBD	ORR
Performance	SRB	October 2028	ORR ensures that all system and support (flight and ground) hardware, software, personnel, procedures, supporting capabilities, and user documentation accurately reflect the deployed state of the system and are operationally ready.	TBD	N/A

MULTI-SLIT SOLAR EXPLORER

Formulation	Development	Operations

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**24.3**	**--**	**47.4**	**83.0**	**70.5**	**41.0**	**14.8**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The MUSE observatory is shown here in the upper left pointing its telescopes towards the Sun.

PROJECT PURPOSE

The Multi-slit Solar Explorer (MUSE) mission will help scientists understand the forces driving the heating of the Sun's corona and the eruptions in that outermost region that are at the foundation of space weather. The mission will offer deeper insight into the physics of the solar atmosphere by using a powerful instrument known as a multi-slit spectrometer to observe the Sun's extreme ultraviolet radiation and obtain the highest resolution images ever captured of the solar transition region and the corona.

EXPLANATION OF MAJOR CHANGES IN FY 2024

NASA selected MUSE as a medium class Explorer mission and this is its first budget request.

PROJECT PRELIMINARY PARAMETERS

MUSE is targeting a launch no earlier than 2027. The primary goal of the MUSE mission is to investigate the causes of coronal heating and instability, such as flares and coronal mass ejections, and gain insight into the basic plasma properties of the corona. This mission consists of one spacecraft with two Spectrograph and Context Imager instruments. The Multi-slit Spectrograph collects line profiles in bright coronal lines, covering a large temperature range at a 0.4" angular and one second slit dwelling time temporal resolution. The Context Imager collects 0.33" resolution images over a larger field-of-view, showing transition region and coronal morphology and motions.

Using these instruments, MUSE will obtain high-resolution images of the evolution of solar flare ribbons in a field of view focused on a large, active region on the Sun. The mission will use breakthrough imaging spectroscopy techniques to observe radial motion and heating at 10 times the current resolution, and 100 times faster, a key capability when trying to study the phenomena driving heating and eruption processes, which occur on time scales shorter than previous spectrographs could observe.

The MUSE prime mission operations duration will be two years in a low-Earth Sun-synchronous orbit.

MULTI-SLIT SOLAR EXPLORER

Formulation	Development	Operations

ACHIEVEMENTS IN FY 2022

NASA selected the MUSE mission to proceed into the preliminary design and technology completion phase (Phase B) in February 2022.

WORK IN PROGRESS IN FY 2023

The project will continue preliminary design and technology completion activities in FY 2023.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

The project will complete the mission preliminary design review in February 2024, followed by a confirmation review in April 2024.

ESTIMATED PROJECT SCHEDULE

Milestone	Formulation Authorization Document	FY 2024 PB Request
PDR	N/A	Feb 2024
KDP-C	N/A	Apr 2024
CDR	N/A	Feb 2025
SIR	N/A	Jan 2026
KDP-D	N/A	Mar 2026
KDP-E	N/A	May 2027
Launch	N/A	Jun 2027
End of Prime Mission	N/A	Jul 2029

Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

Life cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows a non-advocate review and/or preliminary design review.

KDP-B Date	Estimated Life Cycle Cost Range ($M)	Key Milestone	Key Milestone Estimated Date Range
February 10, 2022	$300M - $350M	Launch	June 2027

MULTI-SLIT SOLAR EXPLORER

Formulation	Development	Operations

Project Management & Commitments

The Phase B contract with options for Phases C-F was awarded to the Lockheed Martin Advanced Technology Center for the Principal Investigator controlled mission. GSFC is the Implementing Center for the MUSE mission.

Element	Description	Provider Details	Change from Formulation Agreement
Instruments	Multi-slit Spectrograph Context Imager	Provider: Lockheed Martin Advanced Technology Center Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Spacecraft	Commercial spacecraft	Provider: Lockheed Martin Commercial Civil Space Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Ground Systems	Mission Operations Center	Provider: UC Berkeley Space Sciences Laboratory (SSL) Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Launch Vehicle	Delivery the spacecraft to operational orbit	Provider: TBD Lead Center: GSFC Performing Center(s): KSC Cost Share Partner(s): N/A	N/A

Project Risks

None.

Acquisition Strategy

NASA competitively selected the mission through the Heliophysics Explorers 2019 Medium-class Explorer (MIDEX) Announcement of Opportunity (AO) and the final down selection occurred in 2022.

MULTI-SLIT SOLAR EXPLORER

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Principal Investigator, Project Management, Payload (Spectrograph and Context Imager), Systems Integration & Test, Data Processing, Science Operations and Analysis, Science Operations Center	Lockheed Martin Advanced Technology Center	Palo Alto, CA
Launch Vehicle	Not awarded at this time	TBD

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Feb 2024	PDR	TBD	CDR
Performance	SRB	Feb 2025	CDR	TBD	SIR
Performance	SRB	Jan 2026	SIR	TBD	ORR
Performance	SRB	Mar 2027	ORR	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

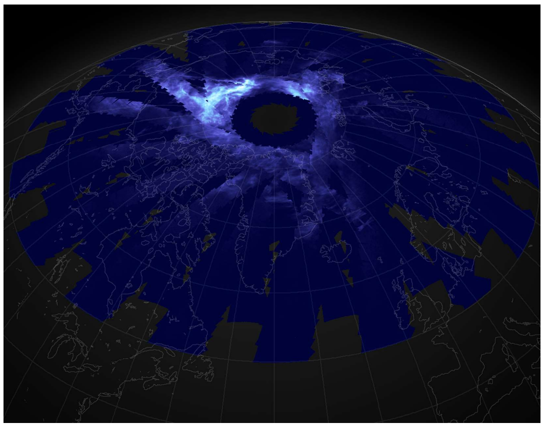
FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Electrojet Zeeman Imaging Explorer	7.7	--	**14.8**	6.6	5.4	4.1	3.1
Escape and Plasma Acceleration and Dynamics Explorers (EscaPADE)	17.3	--	**5.9**	3.0	2.8	2.3	2.0
Extreme Ultraviolet High-Throughput Spectroscopic Telescope (EUVST)	8.7	--	**8.8**	14.4	8.4	7.4	5.3
Ionospheric Connection Explorer	3.7	--	**6.9**	7.4	7.1	6.6	6.6
Global-scale Observations of the Limb and Disk (GOLD)	4.3	--	**4.6**	5.0	5.7	5.7	5.7
Heliophysics Explorer Future Missions	1.3	--	**6.0**	69.3	88.6	116.0	222.3
Heliophysics Explorer Program Management	8.9	--	**24.9**	13.6	16.8	10.6	8.9
Interface Region Imaging Spectogr (IRIS)	6.5	--	**6.3**	6.9	6.6	6.6	6.6
Interstellar Boundary Explorer (IBEX)	1.9	--	**3.0**	3.2	3.2	3.2	3.2
Aeronomy of Ice in Mesophere (AIM)	2.0	--	**2.9**	3.1	3.1	3.1	3.1
Time History of Events and Macroscale Interactions during Substorms (THEMIS)	5.2	--	**6.2**	6.4	6.4	6.4	6.4
ACE	2.0	--	**3.0**	3.1	3.1	3.1	3.1
Polarimeter to Unify the Corona and Heliosphere (PUNCH)	2.5	--	**7.7**	8.3	7.1	5.5	4.3
Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS)	70.8	--	**24.5**	12.4	6.0	6.0	4.0
Atmospheric Wave Experiment	0.3	--	**3.0**	5.0	3.8	3.8	2.5
Sun Radio Interferometer Space Experiment (SunRISE)	18.4	--	**5.4**	3.6	2.6	2.6	1.8
Total Budget	**161.7**	**--**	**133.8**	**171.3**	**176.7**	**192.8**	**288.8**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

OTHER MISSIONS AND DATA ANALYSIS



This image of noctilucent clouds is a composite of several Aeronomy of Ice in the Mesosphere (AIM) satellite passes over the Arctic on June 10, 2015. The clouds appear in various shades of light blue to white, depending on the density of the ice particles. The instrument measures how much light is reflected back to space by the clouds.

The Heliophysics Explorer Other Missions and Data Analysis budget includes operating Explorer missions, program management, missions in formulation and development with life cycle costs less than $250 million, and funding for future mission selections.

Mission Planning and Other Projects

ELECTROJET ZEEMAN IMAGING EXPLORER (EZIE)

In December 2020, NASA selected the Electrojet Zeeman Imaging Explorer (EZIE) mission (proposed as an Explorer Mission of Opportunity) to study electric currents in Earth's atmosphere linking aurora to the Earth's magnetosphere – one piece of Earth's complicated space weather system, which responds to solar activity and other factors. The Auroral Electrojet (AE) index is a common measure of geomagnetic activity levels, even though scientists do not yet understand all the details of the structure of these currents. EZIE is a trio of SmallSats that will launch together no earlier than November 2024.

ESCAPE, PLASMA, ACCELERATION AND DYNAMIC EXPLORERS (ESCAPADE)

EscaPADE will study the active processes in Mars' magnetosphere and how the solar wind controls them. Using two identical SmallSats, EscaPADE will be the first mission to characterize the flow of the solar wind and of Mars-produced plasma through the Mars space environment with the ability to distinguish variations in space (e.g., a spacecraft passes through a structure) and in time (e.g., a structure changes size). The mission will focus on the plasma boundaries that define the regions of Mars' magnetosphere, Mars' atmospheric escape, and global changes in the magnetospheric structure under different solar wind conditions. With its thin atmosphere and weak crustal magnetic field in the southern hemisphere, Mars allows the study of fundamental physical processes and their differences across different planetary environments (such as compared to Earth and Venus). Further, characterizing the global system and its variability is a necessary component of understanding the space weather environment ahead of any crewed mission to Mars.

The project team is working with the Science Mission Directorate's Rideshare Office to plan for a ride to space. The EscaPADE team completed and passed their preliminary design review and NASA confirmed the project proceed to development (Phase C). EscaPADE has a planetary launch window in October of 2024.

Recent Achievements

EscaPADE passed its instrument level CDRs spanning February 2022 to June 2022.

OTHER MISSIONS AND DATA ANALYSIS

EXTREME ULTRAVIOLET HIGH-THROUGHPUT SPECTROSCOPIC TELESCOPE EPSILON MISSION (EUVST)

In December 2020, NASA selected the EUVST mission (proposed as an Explorer Mission of Opportunity), as a contribution to the Japan Aerospace Exploration Agency (JAXA) partner-led Epsilon Mission (Solar-C EUVST Mission), along with other international partners. Targeted for launch in 2028, EUVST is a solar telescope that will study how the solar atmosphere releases solar wind and drives eruptions of solar material. These phenomena propagate out from the Sun and influence the space radiation environment throughout the solar system. NASA's hardware contributions to the mission include an intensified ultraviolet (UV) detector and support electronics, spectrograph components, a guide telescope, software, and a slit-jaw imaging system to provide context for the spectrographic measurement. NASA has adjusted the Extreme Ultraviolet High-Throughput Spectroscopic Telescope (EUVST) budget profile to accommodate partner delays.

HELIOPHYSICS EXPLORER FUTURE MISSIONS

Explorer Future Missions funding will support future Explorer missions that have yet to be selected. A typical Explorer mission cadence is an average of two to three years between AOs with alternating SMEX and MIDEX selections. NASA released the SMEX AO in 2022 and a MIDEX AO will follow in 2025.

HELIOPHYSICS EXPLORER PROGRAM MANAGEMENT

Explorer Program Management encompasses the program office resources required to manage Explorer projects. The program office is responsible for providing support and guidance to projects in resolving technical and programmatic issues and risks; for monitoring and reporting technical and programmatic progress of the projects; and for achieving Explorer cost, schedule, and technical goals and requirements. The project also includes support for the Science Office for Mission Assessments (SOMA) at Langley Research Center. SOMA is responsible for the technical and scientific evaluation of Explorer mission proposals. The FY 2024 Request includes additional funding for the evaluation of proposals related to planned announcements of opportunity.

POLARIMETER TO UNIFY THE CORONA AND THE HELIOSPHERE (PUNCH)

The PUNCH mission will focus directly on the Sun's corona and how the corona generates the solar wind. Comprised of four suitcase-size satellites, PUNCH will image and track the solar wind as it leaves the Sun. The spacecraft will also track coronal mass ejections (i.e., large eruptions of solar material that can drive large space weather events near Earth) to better understand their evolution and develop new techniques for predicting such eruptions. These observations will enhance research by other NASA missions, such as Parker Solar Probe and the ESA/NASA Solar Orbiter. PUNCH will be able to image, in real time, the structures in the solar atmosphere that these missions encounter by blocking out the bright light of the Sun and examining the much fainter atmosphere. Together, these missions will investigate how the star we live with drives radiation in space.

NASA selected PUNCH under the 2016 Small Explorers (SMEX) Announcement of Opportunity (AO). PUNCH completed preliminary design and technology (Phase B), and successfully entered the development phase in July 2021. PUNCH is in implementation (Phase C) with the system integration

OTHER MISSIONS AND DATA ANALYSIS

review scheduled in April 2023 and an expected launch date in April 2025. PUNCH will fly as a rideshare with the Astrophysics mission SPHEREx.

Recent Achievements

PUNCH passed its critical design review in June 2022.

TANDEM RECONNECTION AND CUSP ELECTRODYNAMICS RECONNAISSANCE SATELLITES (TRACERS)

The TRACERS mission will observe particles and fields at the Earth's northern magnetic cusp region (i.e., the region encircling Earth's pole) where our planet's magnetic field lines curve down toward Earth. Here, the field lines guide particles from the boundary between Earth's magnetic field and interplanetary space down into the atmosphere. In the northern magnetic cusp area, with its easy access to our boundary with interplanetary space, TRACERS will study how magnetic fields around Earth interact with those from the Sun. In a process known as magnetic reconnection, the field lines explosively reconfigure, sending particles out at speeds that can approach the speed of light. Earth's magnetic field will guide some of these particles into the region where TRACERS can observe them.

Magnetic reconnection drives energetic events all over the universe, including coronal mass ejections and solar flares on the Sun. It also allows particles from the solar wind to push into near-Earth space, affecting its space weather. TRACERS will be the first space mission to explore this process in the cusp with two spacecraft, providing observations of how processes change over both space and time. The cusp vantage point also permits simultaneous observations of reconnection throughout near-Earth space. Thus, it can provide important context for NASA's Magnetospheric Multiscale mission, which gathers detailed, high-speed observations as it flies through single reconnection events at a time. TRACERS' unique measurements will help with NASA's mission to safeguard technology and astronauts in space.

Recent Achievements

The project passed its confirmation review in March 2022 and successfully passed its critical design review in September 2022.

ATMOSPHERIC WAVE EXPERIMENT (AWE)

AWE will observe how atmospheric gravity waves in the lower atmosphere, caused by variations in the densities of different packets of air, affect the upper atmosphere. These observations will provide a broader understanding of space weather interactions, specifically the relation between terrestrial weather below and the solar wind. This interaction occurs in a dynamic region of the upper atmosphere and is important to understand due to the interference it can create in radio and GPS communications. NASA will attach AWE to the exterior of the ISS, where it will focus on colorful bands of light in Earth's atmosphere, called airglow, to determine what combination of forces drive space weather in the upper atmosphere. The expected launch date is December 2023 on Dream Chaser Cargo 2.

Recent Achievements

AWE completed its pre-environmental review in June 2022.

OTHER MISSIONS AND DATA ANALYSIS

SUN RADIO INTERFEROMETER SPACE EXPERIMENT (SUNRISE)

SunRISE will use six solar-powered CubeSats, each about the size of a toaster oven, to simultaneously observe radio images of low-frequency emission from solar activity and share them via NASA's Deep Space Network. The constellation of CubeSats will fly within six miles of each other above Earth's atmosphere, which otherwise blocks the radio signals SunRISE will observe. Together, the six CubeSats will create 3D maps to pinpoint where giant particle bursts originate on the Sun and how they evolve as they expand outward into space. This will help determine what initiates and accelerates these giant jets of radiation. The six individual spacecraft will also work together to map the pattern of magnetic field lines reaching from the Sun out into interplanetary space. This information will help improve understanding of how our solar system works and, ultimately, can help protect astronauts traveling to the Moon and Mars by providing better information on how the Sun's radiation affects the space environment through which they must travel. SunRISE will launch in September 2025.

Recent Achievements

SunRISE completed the systems integration review in March 2022 and entered system assembly, integration and test, and launch and checkout (Phase D).

Operating Missions

IONOSPHERIC CONNECTION EXPLORER (ICON)

ICON launched in 2019 and studies the ionosphere by simultaneously measuring altitude profiles of the thermosphere and ionosphere's neutral winds, composition, density, temperature, and ion density. It also makes in-situ plasma measurements. Understanding what drives variability in the ionosphere requires a careful look at a complicated system driven by both terrestrial and space weather. ICON studies the frontier of space, which is the dynamic zone high in our atmosphere where Earth's weather meets space weather. This is a hard-to-reach area that, despite being close to home, remains mysterious. ICON provides in-situ measurements of this complicated region of near-Earth space, which can be difficult to fly through given the variable drag on spacecraft. Radio communications and GPS signals travel through the ionosphere, and variations in this region can result in distortions, or even complete disruption, of these signals. As spacecraft travel through this region regularly, improved knowledge will increase NASA's situational awareness to protect satellites and astronauts.

ICON will help determine the physics of our space environment and pave the way for mitigating its effects on technology, communications systems, and society. ICON completed its prime mission in December 2021 and is in interim extended operations until the 2023 Heliophysics Senior Review.

Recent Achievements

ICON observations expose the underlying principles of how the Hunga-Tonga volcano eruption generated extreme perturbations in thermospheric winds and electric currents.

The eruption of the Hunga-Tonga volcano was a natural laboratory to test our understanding of how the lower atmosphere influences ionospheric winds and electric fields in the near-Earth space environment. A previous study showed that both quantities were radically perturbed, in ways that are consistent with theoretical understanding of dynamo electric fields. This work implies that the Tonga eruption caused a major space weather event and underscores the importance of thermospheric winds in the 100–150 kilometers (km) altitude range for prediction of Earth's space weather.

GLOBAL-SCALE OBSERVATIONS OF THE LIMB AND DISK (GOLD)

GOLD, launched in 2018, performs unprecedented imaging of Earth's thermosphere and ionosphere. GOLD is the first mission to study the weather of the thermosphere-ionosphere rather than its climate and is the first NASA mission to fly as a hosted payload on a commercial communications satellite, pioneering cost-effective access to geostationary orbit. Capturing never-before-seen images of Earth's upper atmosphere, GOLD explores our space environment, which is home to astronauts.

For the first time, GOLD will answer fundamental scientific questions about how the thermosphere/ionosphere system responds to geomagnetic storms, solar radiation, and upward propagating waves and tides. Gathering observations from geostationary orbit above the Western Hemisphere, GOLD measures the temperature and composition of neutral gases in Earth's thermosphere. This part of the atmosphere co-mingles with the ionosphere's charged particles. Both the Sun from above and terrestrial weather from below can change the types, numbers, and characteristics of the particles found here. GOLD helps track those changes.

Activity in this region is responsible for a variety of key space weather events. GOLD scientists are particularly interested in the cause of dense, unpredictable bubbles of charged gas that appear over the equator and tropics, sometimes causing communication problems. As scientists discover the very nature of the Sun-Earth interaction in this region, the mission could ultimately lead to ways to improve forecasts of such space weather and mitigate its effects. GOLD completed its prime mission in October 2020 and is currently in extended operations. GOLD will participate in the 2023 Heliophysics Senior Review.

Recent Achievements

New discoveries by GOLD demonstrate the exciting potential of a geosynchronous platform to resolve spatial versus temporal responses by the ionosphere and thermosphere to space and terrestrial weather. These results demonstrate significant improvements in ionosphere-thermosphere simulations achieved by assimilating GOLD neutral temperature disk images.

For example, recent GOLD observations of molecular oxygen revealed that molecular oxygen experiences a daily cycle of low molecular oxygen densities in the morning and high molecular oxygen densities in the late afternoon. GOLD provided first observations of thermospheric tides from geosynchronous orbit. Tides are known to impact both temperature and composition of the thermosphere. GOLD also provided compelling evidence of a connection between an intense volcanic eruption in Tonga, 15 January 2022, and a pronounced disruption in the American-sector equatorial ionosphere - 14,000 km away from the epicenter. This provided further context for the highly detailed ICON observations.

The GOLD team also implemented new capabilities and developed procedures for shorter lead time changes to the instrument operations (commands to the instrument) enabling the mission to more quickly change operations to observe events in support of the increased Solar activity.

INTERFACE REGION IMAGING SPECTROGRAPH (IRIS)

IRIS, launched in 2013, joined a network of solar spacecraft and ground-based observatories to provide unprecedented insight into a little understood region of the Sun called the interface region. IRIS makes use of high-resolution observations and state-of-the-art computer models to unravel how matter, light, and energy move through the dense region of solar material at the bottom of the Sun's atmosphere. Understanding the interface between the Sun's surface and its atmosphere, the corona, is crucial to understanding what drives heat and energy into the corona, as well as what powers solar flares and coronal mass ejections.

IRIS provides key insights into all these processes, and thereby advances our understanding of the solar drivers of space weather from the corona to the far heliosphere by combining high-resolution imaging and spectroscopy for the entire chromosphere and adjacent regions. IRIS is currently in extended operations and will participate in 2023 Heliophysics Senior Review.

Recent Achievements

IRIS research has led to a breakthrough in diagnostics of the solar chromosphere, the region between the Sun's surface and the million-degree hot atmosphere or corona. The chromosphere is a key region in the heliosphere: all mass and energy that drives space weather and that enters the heliosphere is processed in the chromosphere.

The structure and dynamics of the chromosphere are very challenging to study because of the complex interaction between radiation and plasma. Recent IRIS results utilized machine learning techniques and inversions of multiple spectral lines formed in the chromosphere to provide unique new diagnostics of the temperature, velocity, turbulence, and density. IRIS observations have also led to exciting discoveries including the first solar observations of the parametric decay instability, a process thought to play a key role in the development of turbulence in the solar wind. IRIS has also revealed coronal nanojets, a new phenomenon thought to play a role in heating the multi-million degree corona, driven by the reconnection of magnetic field lines as they are braided by motions on the Sun's surface. Researchers have also discovered new observables in the IRIS data that can help predict flares and have exploited IRIS data to provide novel input to modeling of the Sun's irradiance and its impact on the Earth's upper atmosphere.

INTERSTELLAR BOUNDARY EXPLORER (IBEX)

IBEX launched in 2008 and is the first mission designed to image the edge of the solar system. As the solar wind from the Sun flows out beyond Neptune, it collides with the material between the stars, forming several boundaries. These interactions create energetic neutral atoms, particles with no charge that move very quickly. This region emits no light that conventional telescopes can see, therefore IBEX measures particles that happen to be traveling inward from the boundary instead. IBEX contains two detectors designed to collect and measure energetic neutral atoms, providing data about the mass, direction of origin, and energy of these particles. From these data, researchers create maps of the boundary every six months.

The mission's focused science objective is to discover the nature of the interactions between the solar wind and the interstellar medium at the edge of the solar system. This region is important because it shields a large percentage of harmful galactic cosmic rays from Earth and the inner solar system. IBEX is currently in extended operations and will participate in the 2023 Heliophysics Senior Review.

Recent Achievements

The IBEX team developed a new method, spherical harmonic decomposition, that can separate measurements of different Energetic Neutral Atom (ENA) sources without making assumptions about their shape or location. The results of the separation show that the IBEX Ribbon, a source thought to be solar wind reflected and neutralized beyond the Heliopause, is spatially farther from Earth than a more

OTHER MISSIONS AND DATA ANALYSIS

general ENA source, the General Distributed Flux (GDF) that is thought to be accelerated inside the Heliopause. Further analyses of the GDF revealed that the plasma pressure inside the Heliopause is maximized at a location approximately 10 degrees below the ecliptic plane and aligned with the plane connecting the interstellar magnetic field direction, with the interstellar gas inflow direction, This behavior signifies that the forces of the interstellar magnetic field and of the interstellar plasma, both squeezing and compressing the heliosphere, are approximately balanced and both govern the shape of the outer boundary of the heliosphere.

AERONOMY OF ICE IN THE MESOSPHERE (AIM)

AIM, launched in 2007, is a mission to determine why polar mesospheric clouds form and why they vary. Polar mesospheric clouds (PMCs), Earth's highest-altitude clouds, form each summer in the coldest part of the atmosphere about 50 miles above the polar regions. When ice crystals form over tiny microparticles produced when meteors burn up in Earth's atmosphere, they create polar mesospheric clouds. These clouds have been steadily increasing over the past decade. PMCs are of particular interest, as the number of clouds in the middle atmosphere, or mesosphere, over Earth's poles has been increasing over recent years, possibly related to climate change. The spacecraft completed its prime mission in FY 2009. AIM is currently in extended operations and will participate in the 2023 Heliophysics Senior Review.

Recent Achievements

Measurements of nitric oxide (NO) descent in winter, combined with state-of-the-art atmospheric modeling, provide a new and unique view of coupling between the middle and upper atmospheres.

NO is an important, and highly variable, trace constituent of the Earth's upper atmosphere. Present in abundances that range from a few parts per billion to up to 100 parts per million, NO is an indicator of energy input into the upper atmosphere and an important radiatively active coolant of the region. NO can also act to couple the upper and lower atmospheres. The Solar Occultation for Ice Experiment (SOFIE) on AIM has been observing NO in the mesosphere and lower thermosphere (the MLT, 50-120 km altitude) at polar latitudes for the past 12 years and monitoring how NO responds to variations in both the aurora borealis, also known as, Northern lights, and the circulation at polar latitudes. Of particular interest is that NO produced by energetic electron precipitation in the upper atmosphere can be transported downwards with the winter circulation to the stratosphere where it may react with stratospheric ozone. This downward transport can be amplified under certain meteorological conditions in the stratosphere, specifically after the occurrence of very strong stratospheric warmings that perturb the middle atmospheric circulation.

AIM also provides new information on meteoric influx and the meteoric smoke composition:

Earth is under continual bombardment by tiny meteoroids, with roughly 18 percent burning up during atmospheric entry. Meteoric ablation injects primarily iron (Fe), silicon and magnesium, which later combine to form nanometer sized smoke particles that reside in the mesosphere and stratosphere. Improved sunrise signal calibrations of the SOFIE instrument on AIM resulted in the world's first global view of meteoric smoke in the mesosphere. SOFIE multi-wavelength observations combined with recent theoretical and laboratory work on the speciation of meteoric elements indicate that smoke in the mesosphere consists of Fe-rich olivine. Scientists used this knowledge with SOFIE observations to determine meteoric influx, through comparisons with smoke simulations.

OTHER MISSIONS AND DATA ANALYSIS

TIME HISTORY OF EVENTS AND MACROSCALE INTERACTIONS DURING SUBSTORMS (THEMIS)

THEMIS is a MIDEX mission that launched in February 2007. Starting as a five-spacecraft mission, the three inner probes of THEMIS now focus on collecting data related to the onset and evolution of magnetospheric substorms, while the two outer probes (now referred to as Artemis) have been repositioned into lunar orbits. Magnetospheric substorms are the explosive release of stored energy within the near-Earth space environment that can lead to space weather effects. The two Artemis probes orbit the Moon's surface at approximately 100 miles in altitude and provide new information about the Moon's internal structure and its atmosphere. Artemis provides two-point observations essential to characterizing the Moon's plasma environment and hazardous lunar radiation. THEMIS and Artemis, among others in the Heliophysics portfolio, are examples of missions offering important dynamics knowledge useful for future human spaceflight. THEMIS is currently in extended operations and will participate in the 2023 Heliophysics Senior Review.

Recent Achievements

Using 10 years of observations, ARTEMIS, which are two of the THEMIS spacecrafts repurposed to study the Moon after the THEMIS prime mission, identified a significant lunar surface charging process missing from the models that researchers can use for planning lunar exploration activities. Surface potentials calculated from ARTEMIS data had a small mismatch to model predictions in the dusk sector but were 60-85 percent below predictions in the dawn sector. Incorporating the effect of plasma produced by micrometeroid impacts helps explain this major discrepancy. This result provides a significant advance in understanding of lunar processes, including dust lofting and transport, which was an impediment to the Apollo missions.

ADVANCED COMPOSITION EXPLORER (ACE)

ACE launched in 1997 and observes particles of solar, interplanetary, interstellar, and galactic origins as they pass by its location near the L1 Lagrange point, located about one million miles from Earth toward the Sun. Changing conditions over the solar cycle are presenting new opportunities, including providing new insights relevant to space weather events.

In late 2019, NOAA requested, supported by NASA, that NASA designate ACE as a permanent operational asset. It will continue to provide essential and continuous space weather observations from its location at the Earth's L1 point. The spacecraft has enough propellant on board to maintain an orbit at L1 until approximately 2024. ACE is currently in extended operations.

Recent Achievements

Scientists still do not understand the formation of the solar wind well, with much of the data coming from near Earth. Using data from the Solar Wind Ion Composition Spectrometer on board ACE, scientists observed multiple occurrences of periodic structures in the solar wind. ACE is located near the Earth-Sun L1 Lagrange point, a million miles closer to the Sun than the Earth. The team observed these periodic structures in the heavy ion solar wind composition and charge states, which directly ties them to the solar wind source back at the Sun because the composition and charge states are "locked in" when the solar wind forms. The differences in the variations observed highlight the complexity of the multistep processes involved in the creation of these intermediate-sized structures and provide important clues to the origin of the solar wind.

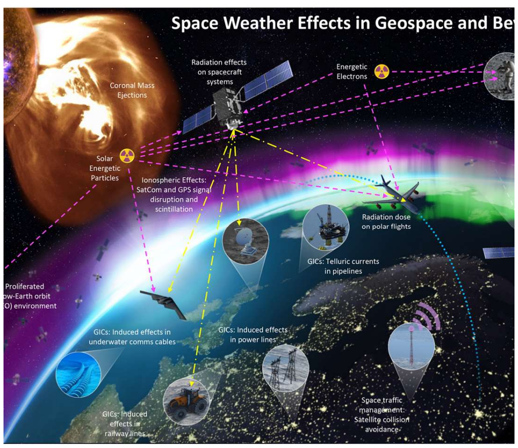
SPACE WEATHER

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**33.5**	**25.0**	**26.6**	**35.5**	**34.3**	**31.7**	**28.4**
Change from FY 2023 Enacted			**1.6**				
Percent change from FY 2023 Enacted			**6.4%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



The graphic above displays solar activity and the resulting natural processes known as "space weather" which can damage satellites and poses a significant risk to astronaut health and safety. Everyday space weather can also interfere with communications, satellite tracking and may cause unexpected changes to the orbits of space debris, increasing the likelihood of catastrophic collisions in the increasingly congested low-Earth orbit (LEO) operating environment.

Space weather phenomena pose a significant threat to ground-based and space-based critical infrastructure, modern technological systems, and humans working in space. The NASA Space Weather Program plays a vital role in the national space weather enterprise by providing unique and impactful observations and data streams for theory, modeling, and data-driven analysis. This program also supports enabling research and facilitates the transition of this research into solutions for the Nation's operational space weather needs. NASA's contributions to observing and understanding space weather will enable the Nation to better protect technology, national infrastructure, and astronauts from space weather.

The NASA Space Weather Program involves a diverse mixture of activities including competed research, directed and competed flight components, and interagency and international cooperation. This approach allows the program to address gaps in national space weather capabilities wherever they are found and serves to enable the efficient maturation of technologies and subsequent transfer of critical new capabilities to partner agencies (e.g., NOAA and DoD).

EXPLANATION OF MAJOR CHANGES IN FY 2024

The program created a new project, Space Weather Research and Analysis, to fund competitively selected research.

ACHIEVEMENTS IN FY 2023

NASA approved Heliophysics Environmental and Radiation Measurement Experiment Suite (HERMES) to proceed into development in January 2022.

SPACE WEATHER

NASA expanded its investments in the maturation of research to support space weather forecasting through a new competed research element, the "Space Weather Centers of Excellence" (Centers). The Centers are a direct response to language from PROSWIFT Act that called on NASA to support competitively awarded grants for multidisciplinary science centers that advance solar and space physics research, including research-to-operations and operations-to-research processes.

The NASA Space Weather Program commissioned the National Academies to conduct a follow-on Phase-two workshop focused on research required to undergird a national space weather operational network. The National Academies published the proceedings of this workshop in September 2022.

The program selected an initial cohort of four CubeSats to mature and demonstrate new technologies and observing strategies to address areas of concern identified in the Gap Analysis and other strategic needs.

WORK IN PROGRESS IN FY 2023

HERMES will complete instrument deliveries to GSFC by early 2023 to begin payload-level integration and testing. NASA will deliver HERMES for storage in mid-2023 after completion of integration and testing.

The program will establish a competed program element to focus on developing space weather instruments and small payloads flown on missions of opportunities to form the basis for future space weather research missions.

The program will continue to solicit competed research proposals for its Space Weather Research to Operations to Research (SWR2O2R) program element and will support its first cohort of "transition step" awardees, preparing prior SWR2O2R-funded research for transition to partners at operational agencies.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

The program will continue to solicit proposals and further develop the Space Weather portfolio. The initial cohort of four CubeSats expected to be in final preparations for launch in FY 2025.

Program Elements

SPACE WEATHER SCIENCE AND APPLICATIONS

The Space Weather Science and Applications project supports its missions as well as basic space weather research and the research to operations to research pipeline, establishing the ecosystem required to support the effective transition of heliophysics science results, tools, technology, and techniques to applications that enhance the user communities' ability to address impacts caused by the dynamic space environment. To accomplish this, the Space Weather Science and Applications project engages with users and agencies to understand their space weather needs and user communities to understand how they are impacted. This project is NASA's primary touchpoint for interagency space weather efforts and is consistent with the recommendations of the National Academy 2013 Decadal Survey for Solar and Space Physics, the Office of Science and Technology Policy 2019 National Space Weather Strategy and Action Plan, and the PROSWIFT Act of 2020.

SPACE WEATHER

Specific activities within the project includes mission support through the Moon to Mars office and space weather satellite operations center; research support through the Community Coordinated Modeling Center (CCMC) and High-End Computing; and research to operations to research support through CCMC and the Small Business Innovation Research Program.

SPACE WEATHER RESEARCH AND ANALYSIS

The Space Weather Research and Analysis (R&A) project supports competed research solicited under NASA Research Opportunities in Space and Earth Science (ROSES), including space weather research to operations to research efforts, funding HERMES interdisciplinary scientists, and the Space Weather Centers of Excellence. It also supports hardware through a partnership with the Heliophysics Technology Program and its ROSES elements (Heliophysics Technology and Instrument Development for Science [HTIDeS] and Heliophysics Flight Opportunities for Research & Technology [H-FORT]) and will solicit proposals for a new Pipeline Instruments program element starting in 2023. These competed research opportunities serve to empower the research community to tackle critical existing and emerging challenges in space weather.

HELIOPHYSICS ENVIRONMENTAL AND RADIATION MEASUREMENT EXPERIMENT SUITE (HERMES)

HERMES will be a space weather payload on the Gateway (NASA's outpost in lunar orbit) as part of NASA's Artemis Campaign. The payload will be comprised of a suite of high-maturity instruments that will enable meaningful science in the lunar environment, support crew safety at the Moon, and be a pathfinder for future missions to Mars.

HERMES will launch with the first two elements of the Gateway. HERMES will enable the investigation of fundamental science questions like the acceleration mechanisms of solar energetic particles, variability of solar wind structures and Galactic Cosmic Rays, and magnetotail dynamics. Data collected by HERMES will also provide critical safety information for astronaut operations in the lunar environment. HERMES will support operational forecasting and nowcasting, or prediction of current events, of solar energetic particles that pose a risk to astronauts during extravehicular activities on the Gateway or the lunar surface.

In coordination with the two-spacecraft mission Odyssey's Thermal Emission Imaging System (THEMIS) and Artemis already in lunar orbit, HERMES will comprise a heliophysics lunar constellation that enables science investigations and space weather observations not possible before now. A second payload installed on the Gateway (European Radiation Sensors Array, provided by the European Space Agency) will further amplify the work of HERMES by providing additional data characterizing high-energy particles that are dangerous to crew safety.

SPACE WEATHER FUTURE MISSIONS

The Space Weather Future Missions project will support future space weather investigations and future NASA participation in international space weather missions which could provide valuable science data to advance understanding of the dynamics of space weather and improve space weather predictions. This project manages the international partnership with the European Space Agency on the Vigil mission.

SPACE WEATHER

Program Schedule

Date	Significant Event
Q1 FY 2023	Release of the EUV Vigil AO
Q1 FY 2023	HERMES instruments delivered for payload integration
Q2 FY 2023	ROSES-2022 Space Weather Research to Operations to Research (SWR2O2R) selections
Q2 FY 2023	ROSES-2023 SWR2O2R and Space Weather Centers of Excellence solicitations
Q3 FY 2023	ROSES-2022 Space Weather Centers of Excellence selections
Q2 FY 2024	ROSES-2023 SWR2O2R selections no earlier than six months after receipt of proposals
Q2 FY 2024	ROSES-2024 SWR2O2R and Space Weather Centers of Excellence solicitations
Q3 FY 2024	ROSES-2023 Space Weather Centers of Excellence selections
Q2 FY 2025	ROSES-2024 SWR2O2R selections no earlier than six months after receipt of proposals
Q2 FY 2025	ROSES-2025 SWR2O2R and Space Weather Centers of Excellence solicitations
Q3 FY 2025	ROSES-2024 Space Weather Centers of Excellence selections
Q2 FY 2026	ROSES-2025 SWR2O2R selections no earlier than six months after receipt of proposals
Q2 FY 2026	ROSES-2026 SWR2O2R and Space Weather Centers of Excellence solicitations
Q3 FY 2026	ROSES-2025 Space Weather Centers of Excellence selections

Program Management & Commitments

Program Element	Provider
Space Weather Science and Applications	Provider: Various Lead Center: GSFC Performing Center(s): ARC, GSFC, HQ, JPL, LaRC, MSFC Cost Share Partner(s): None
Space Weather Research and Analysis	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, HQ, JPL, LaRC, MSFC Cost Share Partner(s): None
HERMES	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): None

SPACE WEATHER

Program Element	Provider
Space Weather Future Missions	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, HQ, JPL, LaRC, MSFC Cost Share Partner(s): None

Acquisition Strategy

NASA primarily procures tasks through full and open competition, such as the ROSES announcements. The solicitation of technology investments is competitive and selected from NASA Centers, industry, and academia, as well as other Government agencies, Federally Funded Research and Development Centers, and nonprofit organizations. NASA may directly fund critical technologies identified through a gap analysis.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Relevance	National Academies of Science	2022	Planning future space weather operations and research infrastructure	NASA will use the results to inform Space Weather Program investment priorities	TBD

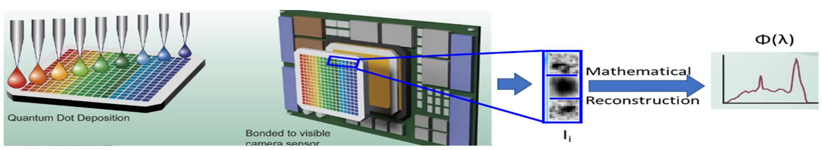
HELIOPHYSICS TECHNOLOGY

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**20.9**	**28.4**	**8.4**	**14.7**	**14.0**	**16.0**	**16.0**
Change from FY 2023 Enacted			**-20.0**				
Percent change from FY 2023 Enacted			**-70.4%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



Shown above is a Miniaturized Multispectral Imager based on Quantum Dots.

The future success of Heliophysics depends on the ability to produce novel and transformative technologies, capabilities, and mission concepts. The Heliophysics Technology Program will strategically invest in the development and demonstration of instruments and technologies to enable infusion into future missions. Investments in new technologies will enable previously infeasible science investigations; improve existing measurement capabilities; reduce the cost, risk, and/or development times for Heliophysics science instruments and advanced space missions of the future; and yield applications benefits to the broader economy in areas of strategic importance such as space weather.

The Heliophysics Technology Program includes elements competitively selected through the NASA Research Opportunities in Space and Earth Science (ROSES) solicitation: HTIDeS and Heliophysics Flight Opportunities Studies (HFOS). The program also includes the technology demonstration mission: the Magnetometers for Innovation and Capability (MAGIC).

EXPLANATION OF MAJOR CHANGES IN FY 2024

NASA decided not to confirm the Solar Cruiser technology mission of opportunity at the KDP-C review in June 2022 due to technical concerns related to instrument weight and propulsion, as well as cost and schedule concerns.

ACHIEVEMENTS IN FY 2022

NASA expanded the HTIDeS solicitation to solicit more innovative technologies. The FY 2022 HTIDeS solicitation included Space Working Environment technologies to address the need for technologies that detect and mitigate space environmental factors that affect science investigations.

The MAGIC technology demonstration completed Phase B formulation activities. MAGIC completed the single design review and proceeded into Phase C, the final design and fabrication phase.

HELIOPHYSICS TECHNOLOGY

WORK IN PROGRESS IN FY 2023

NASA will expand the HTIDeS solicitation to solicit more proposals from non-heliophysics technologists to infuse technology ideas from other disciplines into the Heliophysics community to enhance innovation and advance future Heliophysics science.

NASA will conduct a technology gap analysis and use the results to select more technologies to fill the gaps identified.

The Solar Cruiser technology mission of opportunity will complete closeout activities and develop the sail quadrant and key components needed for development of the solar sail for future flight opportunities.

The MAGIC technology demonstration will continue development toward flight.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

NASA will implement technology projects to mature, demonstrate and infuse in future science missions.

NASA will develop a virtual institute to allow the principal investigators access to the Heliophysics technology portfolio, and highlights of technology development projects.

Program Elements

TECHNOLOGY ANALYSIS AND MISSION DESIGN

The Technology Analysis and Mission Design project will invest in mission concept studies of novel and transformative applications of new technologies in future Heliophysics flight missions. This includes and expands on Heliophysics flight opportunities studies. This project also conducts periodic technology gap analyses and analyses of trends in technology development/advancement to identify gaps in Heliophysics technology. This will enable more focused solicitations in the Advanced Technology Development project.

ADVANCED TECHNOLOGY DEVELOPMENT (ATD)

The ATD project will invest in the development of critical and innovative new instruments, technologies, and novel and transformative capabilities to achieve significant progress toward the scientific and technical challenges in Heliophysics in the coming years. This includes and expands on HTIDeS. This project will also establish an incubator process for the most promising early TRL technologies to proactively nurture and advance these capabilities. This project includes direct funding for critical technologies identified through the gap analysis.

This project also includes the Alternative Initiation of Technology Exploration (AITE) element to grow and diversify the Heliophysics technology development community. As a component of the HTIDeS element, AITE will solicit proposals from non-heliophysics technologists to collaborate with heliophysics scientists and apply their technologies in solving key Heliophysics Science questions. The goal is to tap into non-heliophysics technologists to solve Heliophysics Science questions.

HELIOPHYSICS TECHNOLOGY

TECHNOLOGY PATHFINDER

The Technology Pathfinder project will advance technologies and instruments from a proof of concept to demonstration, maturing transformational technologies across the critical gap that resides between early-stage concepts and flight demonstration. The project will achieve access to relevant flight demonstration environments using ground-based facilities, flight-based platforms such as orbital SmallSats and CubeSats, and suborbital balloons and rockets through the Heliophysics Flight Opportunities for Research program element.

This project will also utilize rideshare opportunities for flight demonstration of more mature technologies to increase the potential for future infusion into larger Heliophysics missions.

MAGNETOMETERS FOR INNOVATION AND CAPABILITY (MAGIC)

MAGIC is a five-year project to develop key fluxgate magnetometer technology and to design, build, test, and fly a next-generation spaceflight fluxgate. The project designed the MAGIC tool suite to process magnetograms for use in models which require Solar Magnetic field as input and will fill a critical gap in technologies for Heliophysics science measurements.

NASA will launch MAGIC as a technology demonstration payload on the Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS) mission in 2024.

SOLAR CRUISER

NASA did not confirm the Solar Cruiser mission at the KDP-C review. The closeout plan includes completion of a full-scale quadrant prototype assembly, as well as raising the technology readiness levels of some key components.

Program Schedule

Date	Significant Event
Q1 FY 2023	MAGIC KDP-D
Q2 FY 2023	ROSES-2022 HTIDeS and HFOS selections
Q2 FY 2023	ROSES-2023 HTIDeS and HFOS solicitations released
Q2 FY 2024	ROSES-2023 HTIDeS and HFOS selections
Q2 FY 2024	ROSES-2024 HTIDeS and HFOS solicitations released
Q4 FY 2024	MAGIC KDP-E, Flight Readiness Review
Q2 FY 2025	ROSES-2023 HTIDeS and HFOS selections
Q2 FY 2025	ROSES-2024 HTIDeS and HFOS solicitations released
Q2 FY 2026	ROSES-2023 HTIDeS and HFOS selections
Q2 FY 2026	ROSES-2024 HTIDeS and HFOS solicitations released

HELIOPHYSICS TECHNOLOGY

Program Management & Commitments

NASA assigned program management responsibility of the Heliophysics Strategic Technology Office to the Wallops Flight Facility (WFF).

Program Element	Provider
Technology Analysis & Mission Design	Provider: WFF Lead Center: WFF Performing Center(s): WFF Cost Share Partner(s): None
Technology Development	Provider: Various Lead Center: HQ Performing Center(s): TBD Cost Share Partner(s): None
Technology Pathfinder	Provider: Various Lead Center: HQ Performing Center(s): TBD Cost Share Partner(s): None
MAGIC	Provider: University of Iowa Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): None

Acquisition Strategy

NASA primarily procures tasks through full and open competition, such as the ROSES announcements. The solicitation of technology investments is competitive and selected from NASA Centers, industry, and academia as well as other Government agencies, Federally Funded Research and Development Centers, and nonprofit organizations. NASA may directly fund critical technologies identified through a gap analysis.

MAJOR CONTRACTS/AWARDS

None.

HELIOPHYSICS TECHNOLOGY

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Relevance	National Academies of Science, Committee for Solar and Space Physics	2022	Independent assessment of targeted technology development priorities for Heliophysics Technology	TBD	2024
Relevance	National Academies of Science, Committee for Solar and Space Physics	2024	Independent assessment of targeted technology development priorities for Heliophysics Technology	TBD	2026

BIOLOGICAL AND PHYSICAL SCIENCES

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**82.5**	**85.0**	**96.5**	**103.2**	**105.3**	**107.4**	**109.6**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Biological and Physical Sciences

BIOLOGICAL AND PHYSICAL SCIENCES

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**82.5**	**85.0**	**96.5**	**103.2**	**105.3**	**107.4**	**109.6**
Change from FY 2023 Enacted			**11.5**				
Percent change from FY 2023 Enacted			**13.5%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Researchers are shown here observing plants grown in lunar regolith collected during the Apollo era - a scientific first that could yield valuable insights for future Artemis missions.

NASA's Biological and Physical Sciences (BPS) division conducts research in space to obtain critical insights into how biological and physical systems function in ways not possible on Earth. The unique, extreme conditions found in space, such as altered gravity and deep-space radiation, provide scientists with opportunities to probe biological and physical systems that cannot be done on Earth. The resulting knowledge can lead to new and transformative scientific discoveries and technological advancements that not only support NASA's deep-space missions, but also benefit life on Earth.

In the summer of 2023, BPS expects to receive the 2023-2032 Decadal Survey on Biological and Physical Sciences Research in Space from the National Academies of Science, Engineering, and Medicine. The division is also completing a base research program, which followed priorities recommended by the 2011 Decadal Survey and includes investigations in BPS's current focus areas, referenced below.

BPS is comprised of three programmatic elements: Space Biology, Physical Sciences, and Commercially Enabled RapId Space Science (CERISS). To achieve compelling, transformative science, BPS implements a focused research portfolio with two areas of emphasis:

- Within the Physical Sciences project, Quantum Science: Pushing the frontiers of the fundamental science of unique states of quantum matter; and
- Within the Space Biology project, Thriving In DEep Space (TIDES): Pioneering fundamental biological discoveries that enable humans to go farther and stay longer in space, as well as contribute to biomedical and agricultural advancements on Earth.

BPS will further its utilization of commercial capabilities to accelerate the pace and productivity of research through the development and demonstration of in-situ analysis, sample preparation and handling, and specialized equipment for the next generation of microgravity science. In partnership with industry and, to the extent practicable, leveraging Small Business Innovation Research (SBIR) investments, BPS plans to develop and operate space-based capabilities for transformational microgravity science that advance U.S. leadership in such areas as quantum physics, thriving in deep space, and soft matter.

BPS conducts their investigations via competitively awarded research grants to scientists at universities, research institutions across the country, and NASA centers. BPS develops critical equipment and processes to support new experiments and shares research results with academia, commercial industry, and other government agencies.

The division facilitates and oversees collaborations between a wide range of agencies, including the National Institutes of Health (NIH), National Center for Advancing Translational Sciences, NIH's National Institute of Allergy and Infectious Diseases, NIH's National Cancer Institute Division of Cancer Treatment and Diagnosis, Biomedical Advanced Research and Development Authority, and the Food and Drug Administration.

EXPLANATION OF MAJOR CHANGES IN FY 2024

This budget establishes a new project called Commercially Enabled RapId Space Science (CERISS). BPS will advance its commercial initiative, launched in FY 2022, to develop transformative research capabilities to dramatically increase the pace of research in low-Earth orbit (LEO) by 10- to 100-fold. This initiative includes laying the foundation to fly hyper-specialized scientists, “Scientist Astronaut Missions,” for up to 30 days and furthering the division’s use of human-tended commercial platforms via “Private Astronaut Missions.”

ACHIEVEMENTS IN FY 2022

The past year reflected a number of important "firsts" for BPS:

First BPS Request for Information (RFI) to the Commercial Spaceflight Industry: BPS issued an RFI to the commercial spaceflight industry to solicit input on capabilities that could accelerate the pace of research in low-Earth orbit. This RFI is NASA's first step towards exploring opportunities to become one of many customers in the growing space economy in these capabilities.

Quantum Science Firsts: The Cold Atom Laboratory aboard the International Space Station (ISS) was able to produce the first dual-species atom interferometer and Bose-Einstein condensates in space, as well as improve the atom interferometer contrast by a factor of two. These are key steps in testing current theories of gravity, studying novel states of quantum matter and complex quantum systems, and developing sensors, in ways not possible on Earth. This pathfinder experiment with atom interferometry in space will ultimately lead toward novel exquisitely sensitive sensors for precision navigation, geodesy, Earth science, and allow us to test fundamental physics at unprecedented levels.

First Biological Experiments Beyond the Van Allen Belts Aboard Artemis I: BPS completed development of the first biological experiments to be conducted beyond the Van Allen Belts since the Apollo missions – seeds, yeast, fungi, and algae. These investigations will pioneer biological research and will analyze the impacts of deep-space radiation and microgravity on biological systems. Delays in the Artemis I mission moved the launch of these experiments from FY 2022 to FY 2023.

First Plants Grown in Lunar Regolith: Researchers from the University of Florida grew *arabidopsis thaliana*, small flowering plants considered to be weeds, in regolith gathered during Apollo missions. This research builds, in part, upon BPS-supported space- and ground-based plant investigations and could provide critical insights for growing plants on the Moon during future Artemis missions and contribute to advancements in agriculture on Earth.

Selection of First BPS Lunar Science Investigation: NASA selected the Lunar Explorer Instrument for space biology Applications (LEIA) investigation for NASA's Payloads and Research Investigations on the Surface of the Moon (PRISM) for a Lunar commercial payload services mission. LEIA, the first biological research on the lunar surface, will study the response of yeast as a model organism to lunar gravity and the unique lunar surface radiation environment.

Retired Combustion Facility Aboard Space Station: FY 2022 marked accomplishments in designing more efficient, less-polluting combustion engines, ensuring fire safety in deep-space exploration, and improving thermal management in new spacecraft. After four years of studying gaseous flames aboard the space station with an eye to reducing pollution and improving efficiency on Earth, the Advanced Combustion Microgravity Experiment (ACME) facility hosted its final investigation in FY 2022. The Flame Design-II investigation collected data that will enable the development of terrestrial burners that are more efficient and less polluting than current designs.

Installed New Combustion Facility: Crew replaced ACME with the Solid Fuel Ignition and Extinction (SoFIE) facility. Investigations using this facility aim to help identify and develop countermeasures against fire hazard conditions in space exploration.

Installed New Thermal Management Studies Facility: Long-duration human exploration space missions will demand additional power and heat dissipation requirements compared to current space missions. To reduce size and weight, the transition from single-phase (liquid only) to more efficient two-phase (liquid and gas) thermal management systems may be necessary. To obtain data for flow boiling systems, NASA installed and executed the first Flow Boiling and Condensation Experiment (FBCE).

WORK IN PROGRESS IN FY 2023

CERISS: BPS will review responses to the two RFIs solicited: one for commercial space companies to identify current and future capabilities, and the second to the scientific community at large to identify which areas of research would most benefit from in-situ analysis and sample preparation. Responses to both RFIs are due in March 2023.

2023-2032 Decadal Survey: BPS will receive and review the Academies' Decadal Survey priority recommendations in late FY 2023.

Quantum Science: Cold Atom Lab (CAL) will deliver a replacement science module (SM-3B) to the ISS to provide needed upgrades. These upgrades will contribute to basic science -- the foundation for many technological advancements -- by enabling researchers to explore interacting quantum matter to gain insight into analogous systems from subatomic particles to cosmological phenomena, precision tests of gravity, and the nature of dark matter and dark energy.

Thriving In DEep Space (TIDES): Whereas Artemis I experiments focused on single-cell model organisms (e.g., algae, fungi, yeast, and plant seeds), Artemis II investigations will focus on more complex, multi-cellular organisms. BPS will begin development of Invertebrate Animal Model experiments for the Artemis II mission which will study early changes in physiological systems due to exposure to the deep-space environment using *Drosophila melanogaster* (fruit flies) or *Caenorhabditis elegans* (nematodes). The Plant Habitat-03 experiment, a generational study that examines the transmission of environmentally induced genetic changes in seeds grown in spaceflight to subsequent generations, will also analyze whether those changes stabilize or continue to accumulate over time. The

VEG-05 experiment, a joint effort with NASA's Human Research Program (HRP), will grow Red Robin tomatoes on the space station. This investigation will test different light color ratios for fruit production, microbial food safety, nutritional value, and overall crew behavioral health benefits.

Combustion Safety for Exploration: Given that scientists do not understand the full range of ignition and extinction conditions for solid fuels in microgravity, NASA will use the SoFIE facility to conduct the Growth and Extinction Limit (GEL) investigation to study thermally thick, non-flat fuels where interior sample heating causes unsteady flame propagation. Flow fields around such samples are also different than for flat samples, causing different burning and extinction characteristics.

Thermal Management: The second FBCE module, Condensation Module-Heat Transfer (CM-HT), is scheduled to be integrated on International Space Station and begin operations to investigate condensation of a flowing saturated or superheated vapor.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

CERISS: BPS will award contract(s) to the commercial space industry to develop capabilities needed to increase the pace of research in low-Earth orbit. BPS will take steps towards addressing CERISS capability needs by partnering with NASA's Suborbital-Crew (SubC) Program to fly a civil servant once SubC flights are approved, and NASA's Flight Opportunities Program to solicit for a crewed suborbital flight. Both crew-tended suborbital flights will conduct studies to develop in-situ analysis and sample preparation capabilities that will support science in LEO. In FY 2024, CERISS will also begin to develop hardware for suborbital testing that will enable the transition to in-orbit sample preparation and analysis. CERISS will also release a solicitation for investigations to be conducted during suborbital flight.

Quantum Science: The Cold Atom Lab will enable new experiments to use mixtures with improved atom numbers of rubidium and potassium gases cooled to within a billionth of a degree of absolute zero. These experiments will mature sensors to enable new studies of Earth and planetary sciences, navigation, and quantum materials.

Thriving in Deep Space: BPS will continue the Plant Habitat-03 experiment to study the multigenerational effects of spaceflight on seeds, which is key to understanding how multigenerational plant adaptation must be considered in space crop production systems for future lunar and Moon-to-Mars exploration missions. BPS will also continue investigating spaceflight effects on microbes to better understand how different strains of bacteria adapt to spaceflight and could impact astronaut health on future long-duration space flights.

Thermal Management: In FY 2024, NASA will allow the International Space Station National Laboratory to utilize FBCE hardware for National Science Foundation investigators to perform additional studies, enabling both organizations to advance their investigations and more fully optimize the hardware investment. In addition, NASA will begin development on a third module, Transfer Line (TL), to investigate the microgravity effects online chill-down of fluid transfer systems.

Flammability Studies: NASA must understand the effects of the lunar environment on flame ignition and propagation. Conditions of the Moon’s atmosphere and gravity could pose a greater fire hazard than on Earth or in microgravity; therefore, NASA will use the SoFIE facility to conduct the Residence Time Driven Flame Spread (RTDFS) investigation that will study flame propagation over solid fuels of varying thickness in microgravity. This experiment will provide important new information on flame spread in an exploration-relevant environment.

Fabrication Technique for Self-Sustaining Exploration Missions: Freeze casting is a fabrication technique that can mimic complex, efficient natural materials over several length scales using polymers, ceramics, metals, and composites. NASA seeks to understand how to optimize this process in micro- and partial-gravity environments. In FY 2024, NASA will conduct two investigations that will provide a better fundamental understanding of both solidification behavior and complex structure formation, which will allow developed improved processing techniques.

Enabling Exploration Engineering: To combat potential propellant losses on deep-space mission, a combination of techniques will be needed to reach zero-boiloff, including use of more efficient insulation systems, incorporation of active cooling refrigeration systems, efficient pressurization techniques, and tank chilldown/mixing. In FY 2024, BPS will deliver hardware to be flown on the ISS for the second experiment in the Zero Boil-Off Tank investigation series studying the effect of non-condensable gases in the propellant storage tank, (ZBOT-NC).

Materials Science: High-quality thermophysical materials data can enable developing new materials and alloys for novel applications, including both exploration and terrestrial applications. Unfortunately, terrestrial data frequently contains gravity-induced systemic error in measuring these properties. In FY 2024, BPS investigators will participate as part of an ESA-led team to collect, share, and analyze thermophysical property data collected in ESA’s Electromagnetic Levitator facility.

Program Elements

BPS PROGRAM MANAGEMENT

This project funds BPS’s institutional and crosscutting activities including: National Academies studies, proposal peer review processes, printing and graphics, information technology, the NASA Postdoctoral Fellowship program, National Research and Educational Support Services (NRESS), working group support, independent assessment studies, communications, and other administrative tasks.

SPACE BIOLOGY

The main objective of the Space Biology project is to build a better understanding of how spaceflight affects living systems in spacecraft (e.g., ISS) or in ground-based experiments that mimic aspects of spaceflight, and to prepare for future human exploration missions far from Earth. The experiments researchers conduct on these platforms examine how plants, microbes, and animals adjust or adapt to living in space. Researchers study the processes of metabolism, growth, stress response, physiology, and development. The program studies how organisms repair cellular damage and protect themselves from infection and disease in conditions of microgravity, while being exposed to space radiation—and across the spectrum of biological organization, from molecules to cells, from tissues to organs, and from systems to whole organisms, to communities of microorganisms. These studies often reveal new insights into biological functions that would be difficult or impossible to obtain only through Earth-based experiments.

In addition to providing useful information on how living organisms adapt to spaceflight, the discoveries NASA researchers make in space have significant implications for life on Earth. Space Biology's research into the virulence of pathogens in space, loss of bone density, and the changes in the growth of plants can impact the development of drugs that promote wound healing or tissue regeneration. This research will also inform treatments designed to counter osteoporosis on Earth, and high-tech fertilizers that increase crop yield.

BIOLOGICAL AND PHYSICAL SCIENCES

BPS is committed to open science via comprehensive space-related omics databases where users can upload, download, share, store, and analyze spaceflight and spaceflight-relevant data from experiments using model organisms. Omics refers to a collection of biological classes of study, such as genomics, transcriptomics, and others that focuses on the collective characterization and quantification of pools of biological molecules that translate into the structure, function, and dynamics of an organism or organisms. BPS's databases include: GeneLab, the Life Sciences Data Archive, and Ames Life Sciences Data Archive.

PHYSICAL SCIENCES

Physical Sciences research makes contributions in two distinct ways. The first, basic research, investigates physical phenomena in the absence of gravity and fundamental laws of the universe, and provides transformative understanding of the underlying mechanisms governing physics. Quantum Science is the primary focus area for basic research, which takes advantage of the ability to "float" assemblies of ultra-cold atoms in microgravity for long times with extremely gentle forces - something that researchers cannot do on Earth.

The second type of contribution is applied research, which contributes to the basic understanding of underlying space exploration technologies (e.g., power generation and storage, space propulsion, life support systems, and environmental monitoring and control) and leads to transformational capabilities for exploration. The Combustion Science, Fluid Physics, and Materials Science research is in this category. In these applied areas, microgravity is both a scientific tool but also a major challenge for engineering systems that must operate in space. The scientific advances in these areas can enable transformative advances in spacecraft systems.

BPS stores the data acquired from these investigations in NASA's Physical Sciences Informatics system (PSI) and makes it available to the public.

COMMERCIALLY ENABLED RAPID SPACE SCIENCE (CERISS)

CERISS will develop transformative research capabilities with commercial space industry partners to dramatically increase the pace of research. Long-range goals include conducting scientist astronaut missions on the ISS and commercial LEO destinations and develop automated hardware for experiments beyond low-Earth orbit, such as to the lunar surface. The benefits will include a 10- to 100-fold faster pace of research for a wide range of research sponsored by BPS, the NASA Human Research Program, other government agencies, and industry. Another benefit will be the increased demand for R&D in low-Earth orbit, facilitating growth of the commercial space industry.

BIOLOGICAL AND PHYSICAL SCIENCES

Program Schedule

The Biological and Physical Science Program solicits proposals as part of the Science Mission Directorate's annual Research Opportunities in Space and Earth Sciences (ROSES) research calls. The program issues solicitations every year.

Date	Significant Event
Q2 FY 2023	ROSES 2023 NRA solicitation release
Q2 FY 2023	ROSES 2022 Quantum Sciences Flight/Ground selection
Q4 FY 2023	Physical Sciences Informatics selection
Q4 FY 2023	Space Biology selection
Q4 FY 2023 - Q1 FY 2024	2023-2032 Decadal Survey recommendations released
Q1 FY 2024 - Q2 FY 2024	Decadal Survey response workshops
Q1 FY 2024	ROSES-2023 NRA selection within six to nine months of receipt of proposals
Q2 FY 2024	Quantum Sciences selection
Q2 FY 2024	Commercial CERISS award
Q4 FY 2024	Space Biology selections
Q4 FY 2024	Physical Sciences Informatics selection
Q4 FY 2024	Materials for Sustainable Exploration research selections
Q2 FY 2025	Quantum Sciences selection
Q2 FY 2025	CERISS Research selection
Q4 FY 2025	Space Biology selections
Q4 FY 2025	Physical Sciences Informatics selection

Program Management & Commitments

The Space Operations Mission Directorate (SOMD), through the ISS Program Vehicle Office, will retain responsibility for the sustainment, maintenance, and operation of multi-user hardware that supports the BPS research portfolio through at least FY 2024. Additionally, SOMD, through the ISS Program Research Integration Office, will retain responsibility to fund the Mission Integration and Operations (M&IO) work for BPS investigations through at least FY 2024. NASA will reassess this support as commercial low-Earth orbit capabilities evolve.

BIOLOGICAL AND PHYSICAL SCIENCES

Program Element	Provider
Space Biology (animal biology, microbiology, and open science)	Provider: Various Lead Center: Ames Research Center (ARC) Performing Center(s): ARC, Kennedy Space Center (KSC) Cost Share Partner(s): N/A
Space Biology (plant biology, cell biology, molecular biology, and plant microbiology)	Provider: Various Lead Center: KSC Performing Center(s): ARC, KSC Cost Share Partner(s): N/A
Physical Sciences (soft matter, fluids, combustion, Fluids Integrated Rack, Combustion Integrated Rack)	Provider: Various Lead Center: Glenn Research Center (GRC) Cost Share Partner(s): N/A
Physical Sciences (materials and Materials Science Research Rack)	Provider: Various Lead Center: Marshall Space Flight Center (MSFC) Cost Share Partner(s): N/A
Physical Sciences (quantum research, fundamental physics, Cold Atom Lab)	Provider: Various Lead Center: Jet Propulsion Laboratory (JPL) Cost Share Partner(s): N/A

Acquisition Strategy

BPS competitively selects its research via NASA Research Announcements (NRAs). Once selected, the principal investigator is paired with a NASA field center and a commercial partner to facilitate the implementation of the project.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Independent Review Board (IRB)	Oct 2022	SoFIE GEL: Operational Readiness Reviews (ORR)	Started Operations	May 2023 (SoFIE Material Ignition and Suppression Test [MIST]-ORR)
Performance	Biological and Physical Sciences Advisory Committee (BPAC)	Nov 2022	Annual review to assess progress against BPS's performance goals and overarching strategic objective	Successful	Fall 2023
Performance	IRB	Jan 2023	FBCE CM-HT: System Acceptance Review	Successful	Apr 2023 (ORR)

BIOLOGICAL AND PHYSICAL SCIENCES

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	IRB	Feb 2023	CAL SM-EB: System Acceptance Review	Successful	ORR
Performance	IRB	Mar 2023	SoFIE MIST: ORR	TBD	N/A
Performance	IRB	Mar 2023	SoFIE GEL: ORR	TBD	TBD
Performance	IRB	Apr 2023	FBCE (Condensation Module Heat Transfer) CMHT: ORR	TBD	N/A
Relevance	National Academies of Sciences	Jun 2023	Decadal survey review of BPS research priorities	TBD	2033
Performance	IRB	Jun 2023	CAL SM-3B: ORR	TBD	N/A
Performance	IRB	Sep 2023	SoFIE RTDFS: ORR	TBD	N/A
Performance	IRB	Sep 2024	Zero Boil-Off Tank: Non-Condensables System Acceptance Review	TBD	ORR
Performance	IRB	Nov 2024	Zero Boil-Off Tank: Non-Condensables ORR	TBD	N/A

AERONAUTICS

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Airspace Operations and Safety Program	139.1	--	**158.7**	164.4	179.4	198.2	202.8
Advanced Air Vehicles Program	250.3	--	**295.2**	311.6	305.0	273.6	257.5
Integrated Aviation Systems Program	231.5	--	**264.9**	260.5	263.5	279.7	305.5
Transformative Aero Concepts Program	142.8	--	**160.0**	161.8	170.3	184.5	188.5
Aerosciences Evaluation and Test Capabilities	117.0	--	**117.0**	117.4	117.7	120.7	123.5
Total Budget	**880.7**	**935.0**	**995.8**	**1,015.7**	**1,036.0**	**1,056.7**	**1,077.8**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

AERONAUTICS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Airspace Operations and Safety Program	139.1	--	**158.7**	164.4	179.4	198.2	202.8
Advanced Air Vehicles Program	250.3	--	**295.2**	311.6	305.0	273.6	257.5
Integrated Aviation Systems Program	231.5	--	**264.9**	260.5	263.5	279.7	305.5
Transformative Aero Concepts Program	142.8	--	**160.0**	161.8	170.3	184.5	188.5
Aerosciences Evaluation and Test Capabilities	117.0	--	**117.0**	117.4	117.7	120.7	123.5
Total Budget	**880.7**	**935.0**	**995.8**	**1,015.7**	**1,036.0**	**1,056.7**	**1,077.8**
Change from FY 2023 Enacted			**60.8**				
Percent change from FY 2023 Enacted			**6.5%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

NASA will demonstrate high-risk, high-reward technologies critical to the United States' achieving sustainable aviation goals. Shown here is the proposed Sustainable Flight Demonstrator. Credit: Boeing.

The first "A" in NASA stands for "Aeronautics." NASA Aeronautics explores technologies that reduce aircraft noise and fuel use, get you from gate-to-gate safely and on time, and transform aviation into an economic engine at all altitudes. Each of these transformations are taking place grounded in the national goals of reaching net-zero aviation emissions and growing a more productive and fair economy. Aeronautics researchers, engineers, and pilots use world-class NASA facilities to maintain U.S. global leadership in aviation safety, efficiency, and technological innovation.

NASA Aeronautics directly benefits an aviation sector that annually generates more than $1.8 trillion of total U.S. economic activity[1] and contributes a positive trade balance totaling nearly $41 billion[2]. The aviation sector supports more than 10.9 million direct and indirect jobs, including more than one million high-quality manufacturing jobs. In 2021, U.S. airlines carried 666 million passengers and 25 million tons of cargo[3].

1 *"The Economic Impact of Civil Aviation on the U.S. Economy," Federal Aviation Administration, January 2020 report using pre-COVID 2016 data*

2 *"Leading Indicators for the U.S. Aerospace Industry," International Trade Administration, March 15, 2019*

3 *"Full Year 2021 U.S. Airline Traffic Data," U.S. Bureau of Transportation Statistics*

Four Transformations for Sustainability, Greater Mobility, and Economic Growth

With the FY 2024 Budget, NASA is leading the transformation of aviation in several ways:

- Ultra-Efficient Transport: Across the Nation, NASA is enabling transformative improvements in the efficiency of commercial aviation, with particular focus on the single-aisle fleet – Boeing 737 size – through developing and demonstrating integrated electric propulsion in small to large aircraft, advanced materials, advanced propulsion systems, and new ways to design and build aircraft. The FY 2024 Budget continues funding NASA's Sustainable Flight National Partnership (SFNP) to accomplish the aviation community's aggressive sustainability agenda. Through advanced vehicle technologies, efficient airline operations, and sustainable aviation fuels, NASA is contributing to the Administration's goal of achieving net-zero greenhouse gas emissions by 2050. The SFNP will demonstrate the first-ever high-power hybrid electric propulsion system for large transport aircraft, ultra-high efficiency long and slender wings, advanced composite structures and manufacturing, and advanced engine technologies developed through NASA-industry innovation. The SFNP's centerpiece will be a large-scale sustainable flight demonstrator to validate integrated systems and their benefits. NASA will complete SFNP activities and projects by the late 2020's in order to transition to industry new tools, technologies, and procedures for the next generation of large commercial aircraft. The Advanced Air Vehicles (AAVP), Integrated Aviation Systems (IASP), and Airspace Operations and Safety (AOSP) execute NASA's SFNP activities.
- High-Speed Commercial Flight: NASA is enabling more rapid global connections through high-speed commercial flight. We are removing barriers to commercial supersonic flight over land by proving that we can reduce the enroute noise associated with supersonic flight to acceptable levels, tackling the next challenges in local noise and emissions, and investigating the potential of even higher speed flight. The FY 2024 Budget funds NASA's Quesst mission to enable U.S. industry to lead the development of a new commercial supersonic market. Currently, there is a global prohibition on commercial supersonic flight over land that has resulted from concerns about disruptive sonic boom

impacts. NASA has developed guidelines for supersonic vehicle design that, when followed, significantly reduce the annoyance factors associated with supersonic flight. NASA will complete flight acoustics testing of the X-59 quiet supersonic technologies aircraft, and then fly it over a diverse set of communities, collecting noise and community response data, and provide the data to U.S. and international regulators. This data will be used by the domestic and global regulatory communities to reassess the current commercial supersonic flight over land prohibition. The AAVP and IASP execute the Quesst mission.

- Future Airspace: NASA is transforming the efficiency and safety of the entire global aviation system through future airspace tools and system design that supports traditional operators as well as new market entrants. NASA, along with the Federal Aviation Administration (FAA) and industry stakeholders, is developing a long-term future airspace vision called "Sky for All" with a horizon of 2045 that will further evolve and improve upon today's air traffic management systems.
- Advanced Air Mobility (AAM): By developing technology for unmanned aircraft systems and electric vertical and short takeoff and landing vehicles, NASA is enabling a transformation in the ways people and goods move through the air transportation system. NASA is rallying emerging markets to tackle the challenges of creating an air transportation system featuring all-electric, highly automated or autonomous, efficient and safe systems operating over the most rural countryside to the densest, skyscraper-filled urban environment. The FY 2024 Budget continues to fund NASA's AAM mission, which aims to ensure U.S. leadership in an emerging aviation market that some studies have projected to generate an annual market value of as much as $115 billion by 2035. The AAM mission will collaborate with industry to mature system concepts and technologies for safe operations. NASA will work the second in a series of four AAM National Campaign demonstrations by industry of their vehicles and airspace management technologies. The AOSP and AAVP will execute NASA's AAM mission.

To ensure that research focuses on enabling this aviation transformation, NASA's Aeronautics Research Mission Directorate (ARMD) guides its efforts with a strategic implementation plan. The plan lays out NASA's approach to addressing the three key drivers of aviation transformation: the growing demand for global air mobility; energy efficiency and environmental sustainability; and the opportunity for convergence between traditional aeronautical disciplines and technology advances in information technology, communications, energy, and other rapidly evolving technologies. The strategic implementation plan identifies six research thrusts to comprehensively address the three key drivers.

Thrust 1: Safe, Efficient Growth in Global Operations

The Nation will need a modernized air transportation system with much greater capacity and operational efficiency, while maintaining safety. ARMD will contribute specific research and technology to support the FAA's transformation of the National Airspace System (NAS) to accommodate more diverse vehicles and increasingly complex operations in a safe and affordable manner. ARMD will work with the emerging Advanced Air Mobility ecosystem, developing concepts to enable a safe, scalable system for the growth of this new transportation sector. ARMD is working with the community to create a "Sky for All" vision of airspace management capabilities needed by 2045 with a service-based architecture, digital backbone, and artificial intelligence.

Thrust 2: Innovation in Commercial Supersonic Aircraft

The U.S. aviation industry has an opportunity to lead the development of a new commercial supersonic transcontinental and intercontinental aircraft that will generate major economic and societal benefits. ARMD will build and fly the X-59 aircraft that will demonstrate quiet supersonic flight and provide the data needed by regulatory agencies to reassess the regulations that currently ban overland commercial supersonic flight. Since overcoming these barriers involves modifications to regulations and certification standards, ARMD will conduct its research in cooperation with the FAA, International Civil Aviation Organization, and other aviation regulatory agencies. ARMD will also focus research on groundbreaking technologies that overcome barriers to supersonic flight such as reducing the environmental impact and improving economic efficiencies.

Thrust 3: Ultra-Efficient Subsonic Transports

The U.S. aviation industry faces increasing global competition in the subsonic commercial aircraft market, which represents the largest segment of the industry. To remain the global leader, the U.S. aviation industry strives for competitive advantages in aircraft efficiency, noise, and emissions. ARMD seeks to enable substantial efficiency gains along with a fundamental shift to innovative alternative energy-based propulsion systems through the electrification of aircraft propulsion in combination with sustainable aviation fuels. ARMD also is working to enable substantial reductions in time and cost to market of aircraft through advanced materials, structures, and manufacturing technologies and enhanced digitalization of the full aircraft life cycle. Under NASA's Sustainable Flight National Partnership, ARMD engages with U.S. industry to develop critical technologies including new aircraft configurations, hybrid electric propulsion, and advanced materials. These technologies will enable revolutionary improvements in economic and environmental performance measures for the next generation of subsonic transport aircraft.

Thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles

In the coming years, the aviation community expects that new and cost-effective uses of aviation, including advanced Vertical Takeoff and Landing (VTOL) vehicles, could provide options for using air travel as part of daily activities. These new vehicles could provide unprecedented accessibility and shorter door to-door travel times compared to other modes of transportation. This mode of air travel will only be successful if the advanced VTOL aircraft provide acceptable levels of safety, while reducing their environmental footprint – especially with regard to noise – compared to existing VTOL aircraft. ARMD will work across government, the transport industry, and academia to develop critical technologies to enable realization of extensive use of vertical lift vehicles for transportation services including new missions such as access to medical care and managing/fighting wildfires.

Thrust 5: In-Time System-Wide Safety Assurance

To support the projected growth in air traffic, while continuing to maintain air transportation safety, the U.S. will require the ability to identify and reduce safety risks quickly and accurately. ARMD will work with the FAA and industry to create advanced safety capabilities needed in the future air transportation system. These new capabilities will create a safety net that utilizes system-wide information to provide alerting and mitigation strategies in time to address emerging risks. In coordination with the FAA and industry, ARMD will develop and demonstrate new prognostic safety tools and concepts that will be needed to enable a successful AAM market.

Thrust 6: Assured Autonomy for Aviation Transformation

Ever-increasing levels of automation are improving the cost and efficiency of aviation and this trend will accelerate in the future. ARMD is leading the research and development of intelligent machine systems capable of operating in complex environments. To pave the way for increasingly autonomous airspace and vehicles, ARMD will explore new human-machine teaming, modeling, measuring, and testing that enable the effective evaluation of highly automated and autonomous systems in aviation applications. ARMD is developing autonomous systems to address critical challenges of the emerging AAM market and air traffic management. Additionally, ARMD is using and evaluating autonomous systems in the AAM National Campaign demonstration series.

Cross-Cutting Capabilities

In addition to research that directly aligns with specific Strategic Thrusts, ARMD conducts foundational research on cross-cutting ideas and technologies that provides critical support across multiple Strategic Thrusts. This research enables a broad range of aeronautics and aerospace applications and explores opportunities for technology convergence from disparate technology areas.

ARMD's flight and ground test capabilities, complemented by high-fidelity computational simulation, enable rapid experimentation and feasibility demonstration of advanced concepts ranging from individual experiments, to proof-of-concept tests, to demonstration of integrated concepts embodying converging technologies. Relevant assets include flight research and support aircraft; wind tunnels; propulsion, acoustic, materials, and structures laboratories and test facilities; flight research and air traffic management simulators; airspace operations laboratories; high-end computing laboratories; and test support infrastructure. These facilities and capabilities will continue to evolve in support of the research necessary to support the Strategic Thrusts.

Hypersonic Capabilities

ARMD supports fundamental research on reducing the barriers to reusable hypersonic systems (speed of greater than Mach 5). ARMD's fundamental research will enable a broad spectrum of hypersonic systems and missions by advancing the core capabilities and critical technologies for hypersonic flight. The resulting technology advancements will be a benefit to national hypersonic programs both within NASA and in collaboration with the Department of Defense (DoD).

For more information on the Aeronautics strategic plan, go to: http://www.aeronautics.nasa.gov/strategic-plan.htm

EXPLANATION OF MAJOR CHANGES IN FY 2024

NASA increased funding for elements of the SFNP as planned in last year's request. One major component of the SFNP is the Sustainable Flight Demonstrator which is increasing funding as it moves into the design/build phase of the project. Similarly, funding is increased for High-Rate Composite Aircraft Manufacturing (HiCAM) and Hybrid Thermally Efficient Core (HyTEC) projects as they move into the design/build phase of the major ground demonstrations.

NASA decreased funding for the Low-Boom Flight Demonstrator (LBFD) project as planned in last year's request. The LBFD project will move into the flight validation phase which is less costly.

NASA increased funding to develop zero-emissions aircraft concepts through the highly successful University Leadership Initiative, expand industry-led studies of advanced concepts for environmental sustainability, and sustainable aviation fuel characterization.

ACHIEVEMENTS IN FY 2022

Thrust 1: Safe, Efficient Growth in Global Operations

NASA, with industry partners, demonstrated a cloud-based trajectory management service that enables flight operators to identify efficient departure routes and improve the environmental sustainability of air transportation. In collaboration with the FAA, NASA created a web-based portal to help develop a vision of NAS operations in 2045 with input from a broad set of stakeholders. This process identified critical research and development needs. NASA conducted a series of simulations and flight tests with industry partners as part of the AAM National Campaign flight demonstrations to evaluate system-level safety, integration scenarios, and scalable system concepts.

For additional Thrust 1 achievements, see the AOSP section.

Thrust 2: Innovation in Commercial Supersonic Aircraft

NASA made significant progress on the Quesst Mission. The X-59 supersonic aircraft was shipped to a Lockheed Martin facility in Fort Worth, TX, where it successfully completed the ground proof loads and fuel system checkout tests. NASA conducted sonic boom wind tunnel testing using a 1.6 percent scale model of the X-59 quiet supersonic technologies aircraft. These wind tunnel tests provided additional experimental data to use along with X-59 flight data. NASA conducted flight experiments using test aircraft at the Armstrong Flight Research Center to evaluate the initial version of the ground-level noise recording systems. Evaluating these ground recording systems ensures that they are ready to accurately record ground-level noise from X-59 flights.

For additional Thrust 2 information, see the AAVP, IASP, and LBFD sections.

Thrust 3: Ultra-Efficient Subsonic Transports

NASA made significant progress on the SFNP Mission. NASA tested megawatt (MW)-scale aircraft electrical powertrains under flight altitude conditions. This test was the first MW-class electrified powertrain testing at the NASA Electric Aircraft Testbed facility. NASA successfully completed a Delta System Readiness Review and a flight partner Preliminary Design Review for the Electrified Powertrain Flight Demonstrations project. NASA, in collaboration with industry, conducted aerodynamic buffet testing of an advanced thin wing Transonic Truss-Braced Wing (TTBW) model to better understand the aerodynamics of this concept. NASA and its partners completed design reviews, facility preparations, hardware assembly, and a portion of testing for technology development for small-core engines. NASA selected an initial set of technologies to enable high-rate composite manufacturing.

For additional Thrust 3 information, see the AAVP, IASP, and Transformative Aeronautics Concepts Program (TACP) sections.

Thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles

NASA made significant progress toward the objectives of the AAM Mission. NASA conducted multiple wind tunnel experiments of different single-rotor and multi-rotor vertical lift vehicle configurations to validate computer-based design methods. NASA completed facility upgrades and initiated system testing for components of electric propulsion systems for AAM vehicles. Data obtained in the facility will be part of an effort to both understand and predict component failure and will provide vital data to regulatory agencies, such as the FAA. NASA demonstrated improved computer-based tools for predicting and evaluating the noise and performance of AAM vehicle configurations. These efforts benefited the AAM community by providing design tools and guidelines that increase the likelihood that their new aircraft designs will meet noise goals before the development and construction of a full-scale vehicle.

For additional Thrust 4 information, see the AAVP section.

Thrust 5: In-Time System-Wide Safety Assurance

NASA completed research that produced a number of tools and techniques for the verification and validation of critical aviation software systems. Industry partners helped to evaluate these tools, which were shown to significantly reduce verification and validation costs.

For additional Thrust 5 information, see the AOSP section.

Thrust 6: Assured Autonomy for Aviation Transformation

NASA engaged with industry to develop and evaluate novel air traffic management capabilities for AAM vehicles in flight. These capabilities were rigorously validated in a controlled environment and were transitioned for use in field demonstrations. NASA delivered draft evidence and recommendations on the use of run-time monitoring for automated components and the robustness of remote operators as a backup in case of automation failure to industry standards committees and safety and regulatory partners.

For additional Thrust 6 information, see the AOSP section.

Cross-Cutting Capabilities

NASA completed the Scalable Traffic Management for Emergency Response Operations (STEReO) activity. The objective of STEReO was to reduce response times during disasters and providing operational resiliency to changes during a disaster. In collaboration with the California Department of Forestry and Fire Protection and the U.S. Forest Service, NASA demonstrated the STEReO's systems on NASA drones. NASA developed Open Multidisciplinary Design, Analysis and Optimization (OpenMDAO). OpenMDAO provides improved speed, flexibility, and applicability of MDAO methods, which ultimately will enable improved vehicle designs.

NASA's large wind tunnels returned to full operation in FY 2022 addressing various NASA and partner mission testing needs, including those related to advanced aircraft concepts, future space exploration mission vehicle developments, planetary entry system modeling, external customer tests, and multiple classified tests in support of national security efforts. A few highlights include: a vertical lift propeller test, Low-Boom Flight Demonstrator air data probe, fundamental engine ice physics simulated inter-compressor duct test, Mars Sample Return Earth Entry System, Orion Crew Capsule Heat Shield Evaluation.

For additional cross-cutting capabilities information, see the TACP and Aerosciences Evaluation and Test Capabilities sections.

Hypersonic Capabilities

NASA developed cutting-edge methods to design hypersonic aircraft, while accounting for uncertainties in the design predictions, using validated models and flight performance data. Uncertainty prediction capabilities enable the hypersonic, airbreathing research community to make informed decisions in their designs. NASA conducted a surface roughness experiment related to a sounding rocket flight funded by the Air Force Office of Scientific Research. Using ground test data and flight data as appropriate, NASA studied hypersonic boundary layer transition on complex, three-dimensional geometries, which will reduce vehicle-level uncertainty and maximize performance.

For additional hypersonic capabilities information, see the AAVP section.

WORK IN PROGRESS IN FY 2023

Thrust 1: Safe, Efficient Growth in Global Operations

NASA will advance the capability of airspace services necessary to enable AAM operations by working collaboratively with industry partners to identify, implement, and test Urban Air Mobility (UAM) arrival and departure scheduling and demand capacity balancing services. NASA will conduct Integration of Automated Systems (IAS) Flight Testing. IAS flights focus on testing new technologies related to AAM. NASA will share lessons learned and identified requirements and standards gaps with the FAA and industry.

Thrust 2: Innovation in Commercial Supersonic Aircraft

The X-59 supersonic aircraft will undergo a series of system checkouts and ground tests including the ground vibration test, engine runs, and taxi tests. In preparation for the X-59 supersonic aircraft first flight, NASA will complete work on computational tool improvements for predicting ground acoustic sound levels. NASA will finalize ground level noise data gathering techniques which will verify the acoustic characteristics and validate computational tools. NASA will prepare test plans, develop procedures, and procure equipment in preparation for overflight tests with the X-59 aircraft over a diverse set of U.S. communities.

Thrust 3: Ultra-Efficient Subsonic Transports

NASA made the Funded Space Act award to Boeing for the aircraft design/build of the Sustainable Flight Demonstrator. The two electrified flight demonstrations contractors made progress with GE beginning modifications to its Saab 340 aircraft and magniX developing and maturing its electric propulsion system. NASA will complete development tests of aerodynamic improvements in small-core engine turbine components. NASA will select technologies to enable high-rate composite manufacturing and initiate development at the larger-scale structural panel level. Demonstrations at the structural panel-level will inform future selections for demonstration on full-scale aircraft components.

Thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles

NASA will complete work on a validated set of computer-based analysis tools, including thermal modeling, to calculate the reliability of an electric motor design for AAM applications. NASA will provide the methodology to the industry community through publications so that the capabilities can be used. NASA will contribute to the relevant SAE International Standards Committee defining technical standards for AAM power quality that will improve the reliability and safety of AAM vehicles. NASA will complete a crash test of an all-composite fuselage representative of a six-passenger AAM configuration. This will provide data to the FAA and standards organizations about the loads experienced in the cabin under impact, informing the establishment of crash safety requirements for AAM.

Thrust 5: In-Time System-Wide Safety Assurance

NASA will develop fundamental in-time system wide safety assurance data analysis techniques required for future operations by demonstrating, validating, and transferring an integrated risk-based assessment capability for use within airline operations.

Thrust 6: Assured Autonomy for Aviation Transformation

NASA began a new project, the Advanced Capabilities for Emergency Response Operations (ACERO). This project aims to improve aerial responses to wildfires. The project will leverage NASA developed Unmanned Aircraft Systems (UAS) traffic management capabilities and begin to develop an interagency concept of operations with other Federal, State, and local agencies.

NASA will form a foundation for the development and use of advanced artificial intelligence and machine learning airspace services. To achieve this, NASA will collaboratively demonstrate a prototype cloud-based digital information platform that improves the ability for operators to access and share airspace data. NASA will demonstrate automated aircraft vertiport operations using operational scenarios through the Scalable Autonomous Operations simulation and flight test execution. NASA will demonstrate integrated initial vertiport automation services in a Live, Virtual, and Constructive test environment. NASA will demonstrate algorithms to analyze safety standards for systems that rely on untrusted components, used for increasingly autonomous aviation surface and drone flight operations.

Cross-Cutting Capabilities

NASA will complete feasibility assessments on two CAS activities: Sensor-based Prognostics to Avoid Runaway Reactions and Catastrophic Ignition (SPARRCI) and Data and Reasoning Fabric (DRF). The SPARRCI activity seeks to eliminate catastrophic battery failures with early fault detection for electric air vehicles and improve safety of existing batteries and accelerate adoption of next-generation batteries. The DRF activity will review the required decisions for UAM aircraft operations based on diverse and dynamic data, looking at vehicle, airspace, weather, infrastructure, payload, and customer data. NASA will extend research efforts on 18 existing ULI awards, with a broad set of topics including new energy sources that produce zero emissions, new fuel cell technology, hybrid electric propulsion systems, and autonomous aircraft.

NASA's large wind tunnels continue to support NASA and partner mission testing needs, including those related to advanced aircraft concepts, future space exploration mission vehicle developments, planetary entry system modeling, external customer tests, and national security activities. NASA will deploy a new propulsion simulation calibration and testing capability for aircraft and spacecraft models at the NASA Langley Research Center (LaRC) National Transonic Facility. This new capability enables acquisition of next generation aerodynamic test data from aircraft and spacecraft models that integrate with propulsion simulators (e.g., air ejection nozzle or air-powered turbine propulsion simulators).

Hypersonic Capabilities

NASA will experiment with real-time automatic transitions between a turbojet engine simulator and a dual-mode ramjet simulator in a combined cycle engine system. These experiments will establish the control theory and methods for such transition. To ensure operability while maximizing system performance requires automated control for successful operation of a combined cycle system. NASA will award a contract to produce non-proprietary high-speed commercial vehicle designs that help inform technology development roadmaps and help guide future high-speed investment decisions.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

Thrust 1: Safe, Efficient Growth in Global Operations

NASA will evaluate Cooperative Operating Practices for operations in Upper Class E airspace for intent sharing and interactions with other cooperative aircraft.

NASA, in collaboration with other Federal, State, and local agencies, will publish an interagency concept of operations to improve aerial responses to wildfires.

Thrust 2: Innovation in Commercial Supersonic Aircraft

NASA will complete envelope expansion flight testing of the X-59 supersonic aircraft to confirm airworthiness and vehicle performance. The acoustic validation flight testing phase will begin following the conclusion of envelope expansion. NASA will complete preparation for the initial community test with the X-59. Plans, approvals, and equipment will be ready to begin gathering data on human acceptance to quieter sonic booms. NASA will collect data on the X-59 to understand and characterize the acoustic characteristics of the aircraft. Prediction tools will be validated and be ready for use in community test planning.

NASA will reduce the uncertainty of landing and takeoff noise predictions. NASA will provide the aeronautics community with tools and data on relevant supersonic propulsion systems, reducing risk to manufacturers in certification of future aircraft. NASA will conduct Crossflow Attenuated Natural

Laminar Flow (CATNLF) flight testing. CATNLF is a new design method that has the potential to enable natural laminar flow over the aircraft wings.

Thrust 3: Ultra-Efficient Subsonic Transports

With the Funded Space Act Agreement in place, NASA will continue formulation of the SFD project. For the EPFD project, NASA will conduct the critical design review for the magniX design. NASA will test how a thin wing TTBW architecture performs in deep stall, vibration, and icing conditions. NASA will award a Phase 2 contract(s) to demonstrate integrated core engine technologies in an environment that simulates flight conditions. NASA will select high-rate composite aircraft manufacturing technologies for further development and a capstone demonstration of a full-scale aircraft component. The capstone demonstration in FY 2027 will demonstrate production quality and structural performance of a large-scale component manufactured using high-rate techniques. NASA will develop, test, and apply a model-based systems analysis and engineering (MBSA/E) framework for integrated, multi-fidelity vehicle concept design optimization and technology assessments. MBSA/E plan will provide integrated system-level benefit assessments of the SFNP vision vehicle concepts.

NASA will complete the technology development contract(s) for small core combustor designs that provide reliable ignition and lean blowout performance when using a high blend (greater than 80 percent) sustainable aviation fuel (SAF). This contract(s) will demonstrate advanced combustor designs for small core single-aisle aircraft engines that are capable of running on SAF without compromising performance.

Thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles

NASA will complete the reliability prediction method for electric motor concepts and verify the improvement in motor reliability for advanced motor designs. NASA will demonstrate the ability to model AAM fleet noise in urban areas near vertiports and propose a method of modeling annoyance caused by AAM vehicle noise and operations. The noise and annoyance modeling will enable industry and regulators to optimize operations for minimizing noise impact. NASA will conduct a simulation to establish handling qualities for AAM vehicles during transition and cruise and to identify stimuli that impact ride quality. The simulations will improve the AAM passenger experience. NASA will complete crash safety research for AAM vehicles that includes identifying appropriate materials for use as energy absorbers, conducting artificial bird tests on surfaces, and conducting tests of battery packs. Next, the test data will be given to the FAA and standards development organizations to support the development of AAM crash safety standards.

Thrust 5: In-Time System-Wide Safety Assurance

NASA will complete final testing and provide summary findings and recommendations to external stakeholders on implementation of an In-Time System-Wide Safety Assurance data architecture to achieve required assurance levels.

Thrust 6: Assured Autonomy for Aviation Transformation

NASA will demonstrate an airspace management service that applies machine learning to improve the sustainability of aviation operations. NASA will deliver final evidence and recommendations to the FAA, Unmanned Aircraft Safety Team, and Flight Safety Foundation on a process for certification of machine learning-enabled components in aerospace systems. NASA will demonstrate automated integrated aircraft/airspace operations using operational scenarios in the Integrated Automation Systems-1 flight test. NASA will formulate the NASA Autonomous Systems Testbed to support autonomous cargo and single pilot operations.

Cross-Cutting Capabilities

NASA will develop next generation aircraft design tools for conceptual aircraft, electric motor, and aviation grade battery pack designs. In order to assess and verify the next generation of advanced computational models and tools, NASA will improve innovative measurement capabilities. NASA will develop measurement technologies for evaluating new hybrid-electric blade performance including non-destructive evaluation methods for coatings. NASA will complete the Solid-State Architecture Batteries for Enhanced Rechargeability and Safety (SABERS) activity, which proposed new battery technology that meets rigorous aerospace safety and performance for electric air vehicles. NASA will award new ULI proposals that will address technical barriers intrinsic to achieving zero-emissions aviation.

NASA's large wind tunnels will continue to support NASA and partner mission testing needs, including those related to advanced aircraft concepts, future space exploration mission vehicle developments, planetary entry system modeling, external customer tests, and multiple classified tests in support of national security efforts. NASA will deploy a new propulsion simulation calibration and testing capability for aircraft and spacecraft models at the NASA Ames Unitary Plan Wind Tunnel. This new capability enables acquisition of next generation aerodynamic test data from aircraft and spacecraft models that integrate with propulsion simulators (e.g., air ejection nozzle or air-powered turbine propulsion simulators).

Hypersonic Capabilities

NASA will conduct experiments with automatic transitions between a live turbojet engine and a dual mode ram jet simulator in a combined cycle engine system. These experiments will validate the control theory and methods for such transition. To ensure operability while maximizing system performance requires automated control for successful operation of a combined cycle system. In support of high-Mach turbine engine configurations, NASA will complete fabrication of a high-Mach inlet model tested to provide data necessary on inlet performance parameters including pressure recovery, distortion, and bleed models. This performance and operability data will be used for overall system modeling and analysis.

Programs

AIRSPACE OPERATIONS AND SAFETY PROGRAM

AOSP develops and explores fundamental concepts, algorithms, and technologies to increase throughput and efficiency of the NAS safely. The program works in close collaboration with the FAA and the aviation community to establish a vision for future airspace operations and to enable and extend the benefits of NextGen, the Nation's program for modernizing and transforming the NAS to meet evolving user needs. Integrated demonstrations of these advanced technologies will lead to clean air transportation systems and gate-to-gate efficient flight trajectories. The program researches increasingly autonomous aviation systems, including innovation in the management of UAS traffic and other novel aviation vehicles and business models. The program is also pioneering the real-time integration and analysis of data to support system-wide safety assurance, enabling proactive and prognostic aviation safety assurance. The program is addressing the need for improved aerial responses to wildfires by leveraging NASA's UAS traffic management capabilities. The program takes lead responsibility for three of ARMD's Strategic Thrusts:

- Thrust 1: Safe, Efficient Growth in Global Operations;
- Thrust 5: In-Time, System-Wide Safety Assurance; and
- Thrust 6: Assured Autonomy for Aviation Transformation.

AERONAUTICS

ADVANCED AIR VEHICLES PROGRAM

AAVP develops the tools, technologies, and concepts that enable new generations of civil aircraft that are safer, more energy-efficient, and have a smaller environmental footprint. The program focuses on enabling major leaps in the safety, efficiency, and environmental performance of subsonic fixed and rotary wing aircraft to meet challenging and growing long-term civil aviation needs; pioneering low-boom supersonic flight to achieve new levels of global mobility; and advancing fundamental hypersonic research while sustaining hypersonic competency for national needs. In collaboration with academia, industry, and other Government agencies (e.g., FAA), AAVP pioneers fundamental research and matures the most promising technologies and concepts for transition to system application by the aviation industry. The program works with the DoD to ensure that NASA and DoD vehicle-focused research is fully coordinated and leveraged. The program takes lead responsibility for three of ARMD's Strategic Thrusts:

- Thrust 2: Innovation in Commercial Supersonic Aircraft;
- Thrust 3: Ultra-Efficient Subsonic Transports; and
- Thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles.

INTEGRATED AVIATION SYSTEMS PROGRAM

IASP focuses on experimental flight research and the spirit of integrated, technological risk-taking that can demonstrate transformative innovation. Therefore, the program complements both AOSP and AAVP by conducting research on the most promising concepts and technologies at an integrated system-level. The program explores, assesses, and demonstrates the benefits of these potential technologies in a relevant environment. The program supports the flight research and demonstration needs across all six ARMD Strategic Thrusts.

TRANSFORMATIVE AERONAUTICS CONCEPTS PROGRAM

TACP cultivates multi-disciplinary, revolutionary concepts to enable aviation transformation and harnesses convergence in aeronautics and non-aeronautics technologies to create new opportunities in aviation. The program's goal is to demonstrate initial feasibility of internally and externally originated concepts to support the discovery and initial development of new, transformative solutions for all six ARMD Strategic Thrusts. The program provides flexibility for innovators to explore technology feasibility and provide the knowledge base for transformational aviation concepts through sharply focused activities. The program solicits and encourages revolutionary concepts, creates the environment for researchers to become immersed in new ideas, performs ground and small-scale flight tests, allows failures and learns from them, and drives rapid turnover into new concepts. The program also supports research and development of major advancements in cross-cutting computational tools, methods, and single discipline technologies to advance the research capabilities of all aeronautics programs.

AEROSCIENCES EVALUATION AND TEST CAPABILITIES

The aerosciences ground test research capabilities (e.g., facilities, systems, workforce, and tools) necessary to develop future air and space vehicles require efficient and effective investment, use, and management of NASA's suite of twelve world-class wind tunnels. Efforts in this area preserve and enhance those specific ground test capabilities that are necessary to achieve the missions. Among these assets are subsonic, transonic, supersonic, and hypersonic wind tunnels and propulsion test facilities at the Ames Research Center in Mountain View, CA, the Glenn Research Center in Cleveland, OH, and the Langley Research Center in Hampton, VA. These test facilities and capabilities also serve the needs of non-NASA users. NASA also offers research customers high-quality data that accurately reflect the simulated test environment and the interactions of test articles in those test environments in conjunction with the ground experimentation capabilities. Furthermore, NASA expertise helps ensure safe and successful use of the assets and high-quality of the research outcomes. The project is cross-cutting and supports all ARMD Strategic Thrusts as well as other Agency efforts and those of key industry partners.

AIRSPACE OPERATIONS AND SAFETY PROGRAM

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	139.1	--	158.7	164.4	179.4	198.2	202.8

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

As part of the Advanced Air Mobility (AAM) National Campaign, NASA has partnered with a number of new vehicle developers and service providers. NASA partnered with Wisk to validate and evolve their concept of light operations and related capabilities required for future airspace integration.

The U.S. air transportation system is one of the most efficient and safest systems in the world. NASA has substantially contributed to the Federal Aviation Administration (FAA)-led NextGen modernization effort that will meet growing air traffic demand by enabling efficient passage through the increasingly crowded skies. However, there are additional opportunities for reducing fuel burn, aircraft emissions, and environmental impacts through increased operational efficiency.

Moreover, the integration of new vehicles and types of missions into the National Airspace System (NAS) will require advanced concepts and capabilities to accommodate the volume, diversity, and complexity of operations efficiently and safely in a digitally integrated environment.

Advanced automation technologies are foundational for safe and efficient operations in this complex and dynamic environment. This automation must work in an integrated fashion across multiple domains and stakeholders and in harmony with human operators. NASA is working with FAA to develop a long-term vision for the future NAS and looking to ensure that the system will accommodate these diverse and increasingly complex operations in a safe and affordable manner for service providers, vehicle operators, passengers, and cargo. In the coming years, the sustained, integrated efforts of the FAA and its many stakeholders will systematically transform the systems and processes of today's NAS to accommodate these new operations. NASA will play a critical role in this transformation through its research and development of autonomous technologies for aircraft as well as tools and technologies for managing the airspace to support increasingly diverse operations.

The Airspace Operations and Safety Program (AOSP) performs research and technology development to enable transformational air traffic management and operational safety concepts. These technologies benefit the public by increasing capacity, decreasing fuel consumption, and reducing the total cost of air transportation. Increased operational efficiency at the vehicle-, fleet-, and system-levels reduces fuel burn and emissions; and integrated ground- and flight-based technologies will enable trajectory optimization through every phase of flight. With the FAA, industry, and academic partners, AOSP conceives, develops, and demonstrates technologies to improve the safety of current and future aircraft systems that will operate in the NAS. Furthermore, the program develops advanced technologies for a service oriented and federated NAS architecture to enable seamless integration of emergent vehicles (e.g., Unmanned Aircraft Systems [UAS] and Advanced Air Mobility [AAM] vehicles) with present-day aircraft. These

AIRSPACE OPERATIONS AND SAFETY PROGRAM

new vehicle operations can transform the way we move people and cargo and will enable a variety of public good missions, including medical missions and emergency response operations. AOSP also works with other ARMD programs to define safe NAS operational requirements for the next generation of vehicles, mature new transformative seedling concepts, and demonstrate integrated systems. AOSP directly supports three of the ARMD Strategic Thrusts:

- Thrust 1: Safe, Efficient Growth in Global Operations;
- Thrust 5: In-Time System-Wide Safety Assurance; and
- Thrust 6: Assured Autonomy for Aviation Transformation.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ACHIEVEMENTS IN FY 2022

At the end of each achievement identified in this document, there is a parenthetical to link it to the related Strategic Thrust and Program Element.

- NASA worked with industry partners to demonstrate a cloud-based trajectory management service that enables flight operators to identify efficient departure routes and improve the environmental sustainability of air transportation. (Thrust 1/ATM-X)
- NASA engaged with industry to develop and evaluate novel air traffic management capabilities for AAM vehicles in flight. These capabilities were rigorously validated in a controlled environment and were transitioned for use in field demonstrations. Version 1.2 of the UAM Airspace Research Roadmap was published. (Thrust 6/ATM-X)
- NASA collaborated with the FAA to create a web-based portal to co-develop a vision that describes characteristics of NAS operations in 2045 with a broad set of stakeholders. This process helped identify the desired outcomes and critical research and development needs. (Thrust 1/ATM-X)
- NASA conducted a series of simulations and flight tests with industry partners as part of the National Campaign-1 flight demonstrations to exercise ecosystem-wide system-level safety and integration scenarios and scalable system concepts. (Thrust 1 and 6/AAM)
- Through simulation and flight testing, NASA demonstrated automated aircraft vertiport operations involving automated small UAS flying nominal and off-nominal approach and landing operational scenarios that aligned with the UAM Concept of Operations. (Thrust 6/AAM)
- NASA delivered draft evidence and recommendations to industry standards committees and safety and regulatory partners on the use of run-time monitoring for automated components and the robustness of remote operators as a backup in case of automation failure. (Thrust 6/SWS)
- NASA completed and closed out a body of research that produced a number of tools and techniques for the verification and validation of critical aviation software systems. The industry partners helped to evaluate these tools, which were shown to significantly reduce verification and validation costs. (Thrust 5/SWS)

AIRSPACE OPERATIONS AND SAFETY PROGRAM

WORK IN PROGRESS IN FY 2023

- NASA began a new project, the Advanced Capabilities for Emergency Response Operations (ACERO). This project aims to improve aerial responses to wildfires. The project will leverage NASA developed UAS traffic management capabilities and begin to develop an interagency concept of operations with other Federal, State, and local agencies. (Thrust 1, 5, and 6/ACERO)
- NASA will form a foundation for the development and use of advanced artificial intelligence (AI) and machine learning airspace services. To achieve this, NASA will collaboratively demonstrate a prototype cloud-based digital information platform that improves the ability for operators to access and share airspace data. (Thrust 6/ATM-X)
- NASA will advance the capability of airspace services necessary to enable AAM operations by working collaboratively with industry partners to identify, implement, and test UAM arrival and departure scheduling and demand capacity balancing services for a federated environment. (Thrust 1/ATM-X)
- NASA will conduct Integration of Automated Systems (IAS) Flight Testing. IAS flights focus on testing new technologies related to AAM. NASA will share lessons learned and identified requirements and standards gaps with the FAA and industry. (Thrusts 1 and 6/AAM)
- NASA will demonstrate automated aircraft vertiport operations using operational scenarios through the Scalable Autonomous Operations simulation and flight test execution. NASA will demonstrate integrated initial vertiport automation services in a Live, Virtual, and Constructive test environment. (Thrust 6/AAM)
- NASA will develop fundamental In-Time System-Wide Safety Assurance data analysis techniques required for future operations by demonstrating, validating, and transferring an integrated risk-based assessment capability for use within airline operations. The standards committees will transfer the lessons learned to the FAA and emerging aviation partners. (Thrust 5/SWS)
- NASA will demonstrate algorithms to analyze safety standards for systems that rely on untrusted components, used for increasingly autonomous aviation surface and drone flight operations. (Thrust 6/SWS)

KEY ACHIEVEMENTS PLANNED FOR FY 2024

- NASA's ACERO project will publish a revised Concept of Operations (CONOPS v2.0). (Thrusts 1, 5, and 6/ACERO)
- NASA will demonstrate an airspace service that applies machine learning to improve the sustainability of aviation operations. NASA will conduct an operational assessment of an aviation service in complex airspace that leverages machine learning and data from cloud-based digital information platform to demonstrate improvements to the sustainability of aviation operations (e.g., reduced fuel use and emissions). (Thrust 6/ATM-X)
- NASA will evaluate Cooperative Operating Practices for operations in Upper Class E airspace for intent sharing and interactions with other cooperative aircraft. (Thrust 1/ATM-X)
- NASA will complete final testing and provide summary findings and recommendations to external stakeholders on implementation of an In-Time System-Wide Safety Assurance data architecture to achieve required assurance levels. (Thrust 5/SWS)

- NASA will deliver final evidence and recommendations to the FAA, Unmanned Aircraft Safety Team, and the Flight Safety Foundation on a process for certification of machine learning-enabled components in aerospace systems. (Thrust 6/SWS)
- NASA will demonstrate automated integrated aircraft/airspace operations using operational scenarios in the Integrated Automation Systems-1 flight test. (Thrust 6/AAM)

Program Elements

AIR TRAFFIC MANAGEMENT – EXPLORATION (ATM-X)

The ATM-X project will transform the air traffic management system to accommodate the growing demand of new entrants with new mission requirements, while also allowing established, large commercial aircraft operators to fly more user-preferred routes with improved predictability. The ATM-X project focuses on demonstrating, through an open architecture approach, that integration of air traffic technologies, system-wide data use, advances in human-machine teaming, and increasingly autonomous decision-making will provide comprehensive situational awareness, and enable coordinated decision-making and improved disruption management. This approach will incorporate advanced machine learning and artificial intelligence capabilities for air traffic management and contingency management that will enable flexible, user-preferred, predictable, and robust airspace operations. ATM-X is developing airspace requirements for managing AAM aircraft for ARMD’s AAM National Campaign. ATM-X is also exploring advanced trajectory management services and advanced flight deck capabilities to enable efficient, environmentally sustainable operations as part of the Sustainable Flight National Partnership. The project will validate and transfer key concepts and technologies to FAA and industry stakeholders to enable transformation of the NAS.

ADVANCED AIR MOBILITY (AAM)

The AAM project focuses on enabling emerging aviation markets for transformational local and intra-regional missions that will provide substantial benefit to the U.S. public and industry. This project closely coordinates with ARMD's other programs on both airspace operations and vehicle technologies to help prioritize and deliver on the key enabling technical challenges that are most appropriate for NASA to work on. The AAM project will conduct focused research in key areas, such as autonomy required to achieve NASA's vision for advanced air mobility. One of the primary functions of the project is to execute a series of AAM National Campaign demonstrations, which will promote public confidence in AAM safety, facilitate aviation community-wide learning, and help identify the focus of future research. AAM works closely with other Government and commercial entities to achieve this objective.

SYSTEM-WIDE SAFETY (SWS)

The SWS project develops tools, methods, and technologies to enable capabilities envisioned by ARMD’s Strategic Thrust 5 (In-Time System-Wide Safety Assurance). The SWS project performs research to explore and understand the impact on safety of the complexity introduced by technology advances, particularly those aimed at improving the efficiency of flight, broadening access to airspace, and expanding the types of service provided by air vehicles. The project also develops and demonstrates innovative solutions that enable the aviation transformation envisioned by ARMD through proactive mitigation of risks in accordance with target levels of safety. increased access to relevant data, integrated analysis capabilities, improved in-time detection and alerting of hazards at the domain level, decision support for mitigation, and, in some cases, automated mitigation strategies will help achieve expanded system safety awareness. The SWS project also addresses the need, identified in Strategic Thrusts 1 and 6, for safety-related advances in methods used for the verification and validation of machine learning-enabled components and advanced, increasingly autonomous systems.

ADVANCED CAPABILITIES FOR EMERGENCY RESPONSE OPERATIONS (ACERO)

The ACERO project leverages NASA-developed tools and technologies to improve aerial response for wildland fire fighting and advances NASA's efforts in Strategic Thrusts 1, 5, and 6. The ACERO project works with other Government agencies and regional fire response organizations to develop and demonstrate capabilities for the coordination of aerial assets and real-time data exchange to increase the duration and density of aerial firefighting operations. The project will initially focus on establishing a common, multi-agency concept of operations to enable more streamlined coordination of aerial wildfire response efforts. The project will demonstrate a common interoperable platform for situational awareness of all aerial assets and data. Longer term objectives include the development of advanced aircraft technologies and airspace management capabilities to enable diverse simultaneous crewed and uncrewed operations for persistent (up to 24-hours per day) observation and suppression operations.

Program Schedule

Date	Significant Event
Mar 2023	AAM – Complete AAM National Campaign 1 (NC 1)
Jul 2023	AAM – End of Scalable Autonomous Operations UAS Flight Test
Sep 2023	ATM-X – Demonstrate the use of advanced AI and machine learning airspace services by collaboratively demonstrating a prototype cloud-based digital information platform that improves the ability for operators to access and share airspace data. ATM-X – Advance the capability of airspace services necessary to enable AAM operations by working collaboratively with industry partners to identify, implement, and test community-based rules for pre-departure scheduling and strategic deconfliction services. SWS – Analyze aircraft and ground operations data from partners, flight tests, and simulations and make recommendations for applying NASA's developed safety assessment techniques to future aviation operations. ACERO – Develop an initial interagency concept of operations with other Federal, State, and local agencies for wildfire response operations.
Oct 2023	AAM – Complete Integration of Automated Systems - 1 Flight Test
Jun 2024	SWS – Delivery of final evidence and recommendations for a process for certification of machine learning-enabled components in aerospace systems.
Aug 2024	AAM – End of Vertiport Automation UAS Flight Test
Sep 2024	ACERO – Publish interagency concept of operations with other Federal, State, and local agencies for wildfire response operations that will inform future NASA research under the ACERO project.

AIRSPACE OPERATIONS AND SAFETY PROGRAM

Date	Significant Event
Sep 2024	ATM-X – Conduct an operational assessment of an aviation service in complex airspace that leverages machine learning and data from cloud-based digital information platform to demonstrate improvements to the sustainability of aviation operations
Aug 2025	AAM – Complete Integration of Automated Systems - 2 Flight Test

Program Management & Commitments

Program Element	Provider
Air Traffic Management - Exploration (ATM-X)	Provider(s): Ames Research Center (ARC), Langley Research Center (LaRC), Glenn Research Center (GRC) Lead Center: ARC Performing Center(s): ARC, LaRC, GRC, AFRC Cost Share Partner(s): FAA, German Aerospace Center (DLR), JAXA, American Airlines, Southwest, Dallas Fort Worth Airport (DFW), AURA, ANRA Technologies, ARINC Inc., Avision Inc., Metron Aviation Inc., OneSky Systems Inc., SkyGrid, Unmanned Experts Inc.
System-Wide Safety (SWS)	Provider(s): ARC, LaRC, GRC Lead Center: LaRC Performing Center(s): ARC, LaRC, GRC, AFRC Cost Share Partner(s): FAA, DoD Air Force Research Laboratory, Defense Advanced Research Projects Agency, MITRE, Boeing Research & Technology, GE Global Research, American Airlines, Delta Air Lines, Swiss International Airlines, Commercial Aviation Safety Team, Drone Safety Team, Association for Unmanned Vehicle Systems International, RTCA, Society of Automotive Engineers, Flight Safety Foundation, Texas A&M Lone Star UAS Center of Excellence, Federal Bureau of Investigation
Advanced Capabilities for Emergency Response Operations (ACERO)	Provider(s): ARC, AFRC, GRC, LaRC Lead Center: ARC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): TBD
Advanced Air Mobility (AAM)	Provider(s): ARC, AFRC, GRC, LaRC Lead Center: HQ Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): N/A

Acquisition Strategy

AOSP research and technology spans from foundational research to integrated system capabilities. This broad spectrum necessitates the use of a wide array of acquisition tools relevant to the appropriate work awarded externally through full and open competition. For all procurement actions, NASA strongly encourages teaming among large companies, small businesses, and universities.

AIRSPACE OPERATIONS AND SAFETY PROGRAM

MAJOR CONTRACTS/AWARDS

AOSP awards multiple smaller contracts, which are generally less than $5 million and widely distributed across academia and industry.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Expert Review	Oct 2022	The 12-month review is a formal independent peer review. Experts from other Government agencies report on their assessment of technical and programmatic risk and/or program weaknesses.	Determined that the projects made satisfactory progress in meeting technical challenges and all annual performance indicators.	Oct 2023

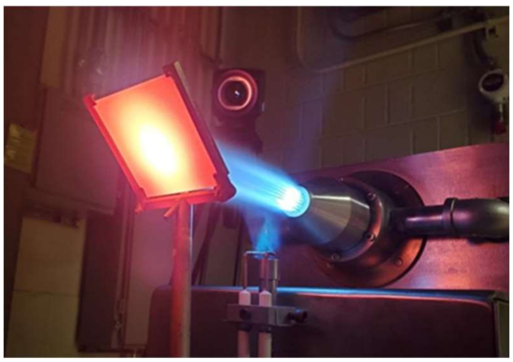
ADVANCED AIR VEHICLES PROGRAM

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**250.3**	**--**	**295.2**	**311.6**	**305.0**	**273.6**	**257.5**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



Pictured above, the High Temperature Material Testing of a Ceramic Matrix Composite with an Environmental Barrier Coating in the NASA Quick Access Rocket Exhaust Rig.

The Advanced Air Vehicles Program (AAVP) develops knowledge, technologies, tools, and innovative concepts to enable safe new aircraft that will fly faster, cleaner, and quieter and use fuel far more efficiently than in the past. All large modern United States aircraft incorporate NASA research and technology. The type of research performed by AAVP will prime the technology pipeline, enabling continued United States leadership, competitiveness, and high-quality jobs in the future. These advanced, integrated technologies and capabilities improve vehicle performance by reducing fuel consumption, noise, and emissions without adversely affecting vehicle safety. Fuel efficiency and environmental factors will play an increasingly significant role as the aviation market grows in capacity and as airlines, manufacturers, and regulators commit to new environmental targets and explore new markets.

AAVP develops a broad range of technologies that help ensure continued United States industrial leadership that will benefit both the economy and the environment. Specifically, with respect to subsonic transport aircraft and as part of NASA's leadership of the Sustainable Flight National Partnership (SFNP), AAVP accelerates development of key subsonic transport technologies to ensure they will be ready by the mid-to-late 2020s to transition into United States industry's next generation single-aisle transport aircraft. Across the program, NASA will continue to engage partners from industry, academia, and other Government agencies to maintain a broad perspective on technology solutions to these challenges, to pursue mutually beneficial collaborations, and to leverage opportunities for effective technology transition. AAVP directly supports three of the Aeronautics Research Mission Directorate (ARMD) Strategic Thrusts:

- Thrust 2: Innovation in Commercial Supersonic Aircraft;
- Thrust 3: Ultra-Efficient Subsonic Transports; and
- Thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles.

EXPLANATION OF MAJOR CHANGES IN FY 2024

NASA increased funding for key elements of the SFNP in AAVP as planned in last year's request. Funding is increased for High-Rate Composite Aircraft Manufacturing (HiCAM) and Hybrid Thermally

Efficient Core (HyTEC) projects as they move into the design/build phase of the major ground demonstrations.

NASA increased funding to expand industry led studies of advanced concepts for environmental sustainability and sustainable aviation fuel characterization.

ACHIEVEMENTS IN FY 2022

At the end of each achievement identified in this document, there is a parenthetical to link it to the related Strategic Thrust and Program Element.

- NASA conducted multiple wind tunnel experiments of different single-rotor and multi-rotor vertical lift vehicle configurations, providing data to validate several computer-based design methods for NASA and the Advanced Air Mobility (AAM) industry. (Thrust 4/Revolutionary Vertical Lift Technology [RVLT])
- NASA demonstrated improved computer-based tools for predicting and evaluating the noise and performance of AAM vehicle configurations. These efforts benefited the AAM community by providing design tools and guidelines that increase the likelihood that their new aircraft designs will meet noise goals before the development and construction of a full-scale vehicle. (Thrust 4/RVLT)
- NASA tested megawatt (MW)-scale aircraft electrical powertrains and flight-weight, flight-like inverters under flight altitude conditions (30,000 feet) to help enable future large-scale electrified aircraft propulsion systems. This testing was the first MW-class electrified powertrain testing at the NASA Electric Aircraft Testbed facility. The test established the practicality of employing these types of components in future aircraft systems while ensuring safe and efficient operations under flight conditions. Additionally, in engagement with industry and other government agencies, NASA demonstrated feasibility of fault management devices for MW- and kilovolt-class electrified aircraft powertrains with three different entities. (Thrust 3/Advanced Air Transport Technology [AATT])
- NASA, in collaboration with industry, conducted aerodynamic buffet testing of an advanced thin wing Transonic Truss-Braced Wing (TTBW) model to better understand the aerodynamics of this concept. This testing advanced the technology readiness level of the TTBW for potential flight testing and future market opportunities. (Thrust 3/AATT)
- NASA and its partners completed design reviews, facility preparations, hardware assembly, and a portion of testing for Phase 1 technology development for small-core engines. Developed technologies include advanced materials, compressor and turbine aerodynamics, and power extraction that will enable more efficient small-core engines. (Thrust 3/Hybrid Thermally Efficient Core [HyTEC])
- NASA awarded a technology development contract for small core combustor designs that are compatible with Sustainable Aviation Fuel (SAF) and that provide reliable ignition and lean blowout performance. This contract will demonstrate the effectiveness and efficiency of compact combustors that could be used in SAF-compatible turbofan engines entering service in the 2030s. (Thrust 3/HyTEC)
- NASA completed formulation of the HiCAM project. NASA set project requirements and screened manufacturing technologies for their potential impact on manufacturing rate, cost, and factory size. (Thrust 3/HiCAM)

- NASA selected an initial set of technologies to enable high-rate composite manufacturing. NASA conducted small-scale experimental evaluations to prepare to select a subset of these technologies to develop at the larger-scale structural panel level. (Thrust 3/HiCAM)
- NASA conducted flight experiments using test aircraft at the Armstrong Flight Research Center (AFRC) to evaluate the initial version of the ground-level noise recording systems. Evaluating these ground recording systems ensures that they are ready to accurately record ground-level noise from X-59 flights. (Thrust 2/Commercial Supersonic Technology [CST])
- NASA developed survey plans for community response testing and plans for communications and outreach during X-59 future community overflight testing. These community surveys will collect information on responses to the X-59's low boom flights, which NASA will provide to United States and international standards bodies. (Thrust 2/CST)
- NASA developed cutting-edge methods to design hypersonic aircraft, while accounting for uncertainties in the design predictions, using validated models and flight performance data. Uncertainty prediction capabilities enable the hypersonic, airbreathing research community to make informed decisions in their designs. (Hypersonic Technology [HT])
- NASA investigated high temperature, durable materials to advance state-of-the-art material systems and improve performance. Data on high-temperature materials enable the hypersonic, airbreathing research community to make informed decisions in their designs. (HT)

WORK IN PROGRESS IN FY 2023

- NASA will complete work on a validated set of computer-based analysis tools, including thermal modeling, to calculate the reliability of an electric motor design for AAM applications. NASA will provide the methodology to the industry community through publications so that the capabilities can be used. (Thrust 4/RVLT)
- NASA will complete a crash test of an all-composite fuselage representative of a six-passenger AAM configuration. This will provide data to the FAA and standards organizations about the loads experienced in the cabin under impact, informing the establishment of crash safety requirements for AAM. (Thrust 4/ RVLT)
- In collaboration with industry, NASA will demonstrate MW-class electric motors at altitude and integrated electrified systems for transport-class aircraft. These demonstrations will include the flight-weight and flight-like components required to bring the technology to flight. Further, the system will also meet safety requirements for fault management, redundancy, and power quality needed for use on commercial transports. In taking this approach, future transports will be able to use hybrid propulsion technologies for aircraft efficiency benefits. (Thrust 3/AATT)
- NASA will design, build, test, and evaluate a suite of novel manufacturing technologies in a relevant environment that will improve high-rate, lightweight metallic fuselage manufacturing. The demonstration addresses the problem caused by fasteners in traditional fuselage manufacturing. Fasteners increase weight and assembly time and create crack initiation sites. New metallic manufacturing processes enhance sustainability while reducing weight and cost and improving manufacturing rates. (Thrust 3/AATT)
- NASA will complete development tests at NASA and partner facilities for a suite of small-core engine materials technologies. After demonstrating high-temperature, advanced materials that enable

improved efficiency and durability, NASA's partners may incorporate select material technologies into future small core demonstrations for the next single-aisle aircraft. (Thrust 3/HyTEC)

- NASA will complete development tests at both NASA and partner facilities for advanced aerodynamic improvements in small-core engine turbine components. After demonstrating turbine aerodynamic improvements that enable enhanced cooling and efficiency benefits, NASA's partners may incorporate advanced turbine technologies into future small-core demonstrations for the next single-aisle aircraft. (Thrust 3/HyTEC)
- NASA will down-select technologies to enable high-rate composite manufacturing and initiate development at the larger-scale structural panel level. Demonstrations at the structural panel level will inform future selections for demonstration on full-scale aircraft components. (Thrust 3/HiCAM)
- NASA will award cooperative agreements for the preliminary design of full-scale aircraft components for future tests that will demonstrate structural performance and high-rate manufacturing technology. (Thrust 3/HiCAM)
- NASA will complete work on computational tool improvements for predicting ground acoustic sound levels of the X-59 in preparation for application during its validation flights. (Thrust 2/CST)
- NASA will analyze the acoustic flight test data to improve the ability to predict jet noise near airports. The results will help regulators set appropriate limits on landing and takeoff noise for new commercial supersonic aircraft. (Thrust 2/CST)
- NASA will experiment with real-time automatic transitions between a turbojet engine simulator and a dual-mode ramjet simulator in a combined cycle engine system. These experiments will establish the control theory and methods for such transition. To ensure operability while maximizing system performance requires automated control for successful operation of a combined cycle system. (HT)
- NASA will award a contract to produce non-proprietary high-speed commercial vehicle designs that help inform technology development roadmaps and help guide future high-speed investment decisions. (HT)

KEY ACHIEVEMENTS PLANNED FOR FY 2024

- NASA will demonstrate the ability to model AAM fleet noise in urban areas near vertiports and propose a method of modeling annoyance caused by AAM vehicle noise and operations. The noise and annoyance modeling will enable industry and regulators to optimize operations for minimizing noise impact. (Thrust 4/ RVLT)
- NASA will complete crash safety research for AAM vehicles that includes identifying appropriate materials for use as energy absorbers, conducting artificial bird tests on surfaces, and conducting tests of battery packs. Next, the test data is then given to the FAA and standards development organizations to support the development of AAM crash safety standards. (Thrust 4/RVLT)
- NASA will test how a thin wing architecture (transonic truss-braced wing [TTBW]) performs in deep stall, vibration, and icing conditions. This work will enable a fuel burn benefit of 4-10 percent by identifying and characterizing edge-of-envelope performance, safety, and environmental challenges and maturing the TTBW technology. TTBW testing reduces risk for future demonstration and vision vehicles, which will help enable the certification of TTBW vehicles. (Thrust 3/AATT)

- NASA will study advanced aircraft and propulsion concepts for the 2040s and beyond that could further improve aviation's environmental sustainability. (Thrust 3/AATT)
- NASA will award a Phase 2 contract(s) to demonstrate integrated core engine technologies in an environment that simulates flight conditions. An integrated demonstration will show sufficient technical maturity that the demonstrated technologies may be considered for inclusion on next-generation aircraft engines. (Thrust 3/HyTEC)
- NASA will complete the technology development contract(s) for small core combustor designs that provide reliable ignition and lean blowout performance when using a high blend (greater than 80 percent) SAF. This contract(s) will demonstrate advanced combustor designs for small core single-aisle aircraft engines that are capable of running on SAF without compromising performance. (Thrust 3/HyTEC)
- NASA will design, build, test, and evaluate a suite of composite manufacturing technologies in a laboratory environment. These technologies are relevant to high-rate, low-cost manufacturing of lightweight large composite aircraft structures. Manufacturing trials and structural tests will occur on the panel or small sub-component scale. (Thrust 3/HiCAM)
- NASA will select high-rate composite aircraft manufacturing technologies for further development and a capstone demonstration of a full-scale aircraft component. The capstone demonstration in FY 2027 will demonstrate production quality and structural performance of a large-scale component manufactured using high-rate techniques. (Thrust 3/HiCAM)
- NASA will reduce the uncertainty of landing and takeoff noise predictions. NASA will provide the aeronautics community with tools and data on relevant supersonic propulsion systems, reducing risk to manufacturers in certification of future aircraft. (Thrust 2/CST)
- NASA will collect data on the X-59 to understand and characterize the acoustic characteristics of the aircraft. Prediction tools will be validated and be ready for use in community test planning. (Thrust 2/CST)
- NASA will experiment with automatic transitions between a live turbojet engine and a dual mode ram jet simulator in a combined cycle engine system. These experiments will validate the control theory and methods for such transition. To ensure operability while maximizing system performance requires automated control for successful operation of a combined cycle system. (HT)
- In support of high-Mach turbine engine configurations, NASA will complete fabrication of a high-Mach inlet model tested to provide data necessary on inlet performance parameters including pressure recovery, distortion, and bleed models. This performance and operability data will be used for overall system modeling and analysis. (HT)

ADVANCED AIR VEHICLES PROGRAM

Program Elements

REVOLUTIONARY VERTICAL LIFT TECHNOLOGY (RVLT)

The RVLT project develops, demonstrates, and validates tools, technologies, and flight operations methods that reduce vertical take-off and landing (VTOL) aircraft noise and improve safety, enabling expanded use of VTOL aircraft in an integrated airspace environment. The unique ability of vertical lift vehicles to hover has significant applications in the civil market for human and cargo transportation and delivery systems as evidenced by the emerging urban air mobility (UAM) industry within the broader AAM industry. Additionally, advanced vertical lift technologies and capabilities are directly relevant to vehicles for public good missions, such as disaster relief, emergency services, and many more critical operations. RVLT research advances technologies that will increase safety and reduce noise and annoyance to overcome significant barriers for the emergence of a new UAM and AAM market. To accomplish this research, NASA uses advanced computer-based, multi-fidelity prediction methods, unique NASA facilities, and state-of-the-art experimental techniques. RVLT considers current and future vertical lift vehicles of many classes and sizes, focusing on configurations that are viable as inter-city and intra-city transportation. The RVLT project primarily supports ARMD Strategic Thrust 4 and the Advanced Air Mobility Mission.

ADVANCED AIR TRANSPORT TECHNOLOGY (AATT)

The AATT project seeks to enable revolutionary advancements in future aircraft performance. As part of the NASA-led Sustainable Flight National Partnership, research explores solutions to advance knowledge, technologies, and concepts, enabling major steps in energy efficiency and environmental compatibility and resulting in reductions to fuel burn, harmful emissions, and noise around airports. The research also benefits United States industrial competitiveness in the subsonic transport aircraft market, as well as potentially opening new markets for United States entrants in the regional jet and smaller size classes. The knowledge gained from this research in the form of experiments, data, system studies, and analyses is critical for conceiving and designing more efficient and quieter aircraft. Advanced air transport research directly supports ARMD Strategic Thrust 3 and focuses on developing advanced technologies and tools for future generations of commercial transport – including the emerging area of electrified aircraft propulsion and the complementary gas turbine engine research needed to develop new engines that will ultimately power the new vehicles. Although this project focuses on the long-term technology timeframe, it also contributes to both near-term and mid-term development by demonstrating interim technology advancements.

HYBRID THERMALLY EFFICIENT CORE (HYTEC)

The HyTEC project will develop small core turbofan engine technologies aimed at achieving a 5-10 percent fuel burn reduction compared to 2020 best-in-class turbofan engines and up to 20 percent power extraction at altitude, culminating in an advanced core demonstration in the 2027 timeframe. As part of this effort, HyTEC will advance design capabilities for effective and efficient, SAF-compatible small core combustors. Within the Sustainable Flight National Partnership, NASA will collaborate with industry in a cost-sharing arrangement on key technologies and will accelerate these key technologies to strengthen the United States industry position on small core-enabling technology and integrated systems for a future single aisle aircraft. HyTEC primarily supports ARMD Strategic Thrust 3.

ADVANCED AIR VEHICLES PROGRAM

HI-RATE COMPOSITE AIRCRAFT MANUFACTURING (HICAM)

The HiCAM project will demonstrate manufacturing approaches and associated technologies for large, composite primary airframe structures that enable high-rate production (up to 80 aircraft per month) with reduced cost and no weight penalty versus 2020 technology for composite structures. The project focus will be airframe structural components for single-aisle transport aircraft expected to enter service in the early to mid-2030s. HiCAM will develop model-based engineering tools to rapidly mature, optimize, and transition high-rate composite manufacturing and assembly methods. NASA will team with partners to share expertise, facilities, and resources to accelerate technology maturation efforts. As part of the Sustainable Flight National Partnership, the HiCAM project technologies will enable advanced vehicle concepts that require composite structures and will introduce manufacturing considerations into future vehicle designs. HiCAM primarily supports ARMD Strategic Thrust 3. However, the findings and techniques developed will generally advance manufacturing technology applicable to a variety of composite structures, including aircraft engine applications, urban air mobility vehicles, and space launch vehicle applications. The findings and techniques may also contribute to future in-space construction and assembly of composite structures.

COMMERCIAL SUPERSONIC TECHNOLOGY (CST)

Supersonic vehicle research includes tools, technologies, and knowledge that will help eliminate today's technical barriers to practical commercial supersonic flight. These barriers include sonic boom noise, supersonic aircraft fuel efficiency, airport community noise, high-altitude emissions, vehicle aeroservoelastic design, supersonic operations, and the ability to design vehicles in an integrated, multidisciplinary manner. The CST project directly supports ARMD Strategic Thrust 2: Innovation in Commercial Supersonic Aircraft. CST will leverage the X-59 quiet supersonic technologies vehicle to gather data on the human responses to low-level sonic booms. This human community response data will inform national and international regulatory organizations' efforts to define certification standards that commercial aircraft manufacturers can follow to create new supersonic aircraft markets. In preparation for the use of the X-59 vehicle, CST research will establish the necessary approaches and techniques for objectively measuring the level of supersonic overflight noise acceptable to communities living near future commercial supersonic flight paths. These approaches, techniques, and resulting data will be the foundation for establishing the sonic boom acoustic limits as part of the international certification standards. CST is also working to reduce the uncertainty in landing and takeoff noise prediction.

HYPERSONIC TECHNOLOGY (HT)

NASA focuses on fundamental research that explores key challenges in hypersonic flight and maintains unique, specialized facilities and experts. The HT project focuses on hypersonic propulsion systems, reusable vehicle technologies, high-temperature materials, and systems analysis. NASA applies its expertise to support and evaluate the potential for future commercial hypersonic markets. In addition, this project coordinates closely with the Department of Defense (DoD), so NASA can leverage DoD investment in ground and flight activities to develop and validate advanced physics-based computational models. At the same time, DoD benefits from NASA expertise, analyses, testing capabilities, and computational models. NASA also supports U.S. industry's emerging interest in commercial hypersonic vehicles.

Program Schedule

Date	Significant Event
Jun 2023	HiCAM – Technology down-selection based upon coupon- and element-level assessments of technologies and technical concepts for continued research and advancement.
Sep 2023	AATT – Completion of integrated manufacturing demonstration at 10-ft diameter scale and manufacturing trade study predicting benefits in both weight and manufacturing rate.
Sep 2023	RVLT – Conduct a workshop open to US industry to provide training for best-practice use of NASA-developed software for AAM performance and noise analysis.
Sep 2023	HyTEC – Completion of technology development testing for Phase 1 core technologies.
Feb 2024	HyTEC – Award of Phase 2 Core Demonstration contracts for core technology development and integration.
May 2024	HT – Development of technology for mode transition in a turbine-based combined cycle.
Sep 2024	CST – Complete verification of the X-59 acoustics and validation of the acoustic prediction tools for application in future community response testing.
Sep 2024	CST – Completion of white paper on the state-of-the-art for predicting landing and takeoff noise for supersonic aircraft and identifying future validation testing needs.
Sep 2024	HiCAM – Evaluation of a suite of composite manufacturing technologies that are relevant to high-rate, low-cost manufacturing of lightweight large composite aircraft structures.
Sep 2024	AATT –Tests of two megawatt-class motors at altitude and demonstration of integrated fault and thermal management system.

Program Management & Commitments

Program Element	Provider
Advanced Air Transport Technology (AATT)	Provider(s): ARC, AFRC, GRC, LaRC Lead Center: GRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): Boeing, Pratt & Whitney, General Electric Aerospace, Raytheon Technologies Corporation, FAA, United States Navy, Department of Energy

Program Element	Provider
Revolutionary Vertical Lift Technology (RVLT)	Provider(s): ARC, AFRC, GRC, LaRC Lead Center: LaRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): FAA, United States Army, United States Air Force, United States Navy, Moog Surefly, A&P Technologies, DLR, ONERA, Ohio State University--Gearlab and Smart Vehicle Concept Center, Pennsylvania State University – Applied Research Laboratory, University of Illinois--Power Optimization of Electro-thermal Systems, University of Maryland, Georgia Institute of Technology, National Research Council-Canada, Cleveland State University, Sikorsky Aircraft, Textron Aviation, University of Akron, University de Sherbrooke
Commercial Supersonic Technology (CST)	Provider(s): ARC, GRC, LaRC, AFRC Lead Center: LaRC Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): FAA, JAXA, Rockwell Collins, The University of Washington, Boeing Research and Technology
Hypersonic Technology (HT)	Provider(s): AFRC, GRC, LaRC Lead Center: LaRC Performing Center(s): AFRC, GRC, and LaRC Cost Share Partners: DoD, John Hopkins University/Applied Physics Laboratory, Boeing
Hi-Rate Composite Aircraft Manufacturing (HiCAM)	Provider(s): GRC, LaRC Lead Center: LaRC Performing Center(s): GRC, LaRC Cost Share Partners: FAA, Advanced Thermoplastic Composites, Aurora Flight Sciences, Boeing, Collins Aerospace, CGTech, Collier Aerospace, Convergent Manufacturing Technologies - US, Electroimpact, General Electric Aviation, Hexcel, Lockheed Martin, Northrop Grumman, Solvay, Spirit AeroSystems, Toray Advanced Composites, University of South Carolina, Wichita State University, Mississippi State University
Hybrid Thermally Efficient Core (HyTEC)	Provider(s): AFRC, ARC, GRC, LaRC Lead Center: GRC Performing Center(s): AFRC, ARC, GRC, LaRC Cost Share Partners: GE Aviation, Pratt & Whitney

Acquisition Strategy

AAVP research and technology spans from foundational research to integrated system capabilities. This broad spectrum necessitates the use of a variety of acquisition tools relevant to the appropriate work awarded externally through full and open competition. For all procurement actions, NASA strongly encourages collaboration among large companies, small businesses, and universities.

ADVANCED AIR VEHICLES PROGRAM

MAJOR CONTRACTS/AWARDS

AAVP awards multiple smaller contracts, which are generally less than $5 million, with a few exceptions, and are widely distributed across academia and industry. AAVP anticipates awarding larger contracts to support the HyTEC and HiCAM projects' large technology development and demonstrations.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Expert Review	Oct 2022	The 12-month review is a formal independent peer review. Experts from other NASA programs and Government agencies report on their assessment of technical and programmatic risk and/or program weaknesses.	The Panel provided favorable reviews to the projects. The Panel also gave constructive comments and recommendations.	Oct 2023

INTEGRATED AVIATION SYSTEMS PROGRAM

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Low Boom Flight Demonstrator	93.3	74.5	**33.0**	1.7	0.0	0.0	0.0
Electrified Powertrain Flight Demonstration	70.6	--	**87.3**	65.4	54.7	41.3	30.4
Other Projects	67.6	--	**144.6**	193.3	208.9	238.4	275.2
Total Budget	**231.5**	**--**	**264.9**	**260.5**	**263.5**	**279.7**	**305.5**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

NASA's all-electric X-57 completes battery charging as part of preparations for first flight in 2023.

Flight research continues to create a bridge between fundamental research and a level of technology readiness that enables technology transfer to the aviation community. Specifically, flight research advances technology readiness to the levels required for incorporation of new technologies into future air vehicles and operational systems.

The focus of the Integrated Aviation Systems Program (IASP) is to demonstrate integrated flight vehicle concepts and technologies in a relevant flight environment and establish a level of maturity that enables these technologies' transition to the aviation community. To support this goal, IASP focuses on the rigorous execution of highly complex flight campaigns and related experiments for the benefit of the Nation and U.S. flying public. IASP flight campaigns support all research maturity levels and often facilitate cross-cutting flight test activities. For technologies at lower Technology Readiness Levels (TRLs), IASP flight research accelerates the technologies' development and determines the feasibility of maturing them further and transitioning them to operations. For technologies at higher TRLs, flight research reduces risks and accelerates transition of those technologies to industry.

IASP supports two critical cross-program efforts: Sustainable Flight National Partnership (SFNP) and the Quesst Mission (formerly known as Low-Boom Flight Demonstration Mission). In support of SFNP, IASP leads the Sustainable Flight Demonstrator (SFD) and Electrified Powertrain Flight Demonstration (EPFD) projects. For the Quesst Mission, IASP leads the Low-Boom Flight Demonstrator (LBFD) project to build, assemble, and conduct flight validation tests for the X-59 supersonic aircraft.

The Flight Demonstrations and Capabilities (FDC) project conducts integrated research demonstrations, which include the X-57 Maxwell aircraft and Phase 2 and Phase 3 of the Quesst mission. The FDC project also conducts development of supersonic flight-testing techniques that will support X-59 community response testing. Furthermore, FDC operates, sustains, and enhances flight test range and laboratory infrastructure required to test complex flight demonstrations. More content on FDC can be found in the Low Boom Flight Demonstrator (LBFD) Project section below. Funding for FDC and SFD is consolidated into the Other Projects line in the budget table above.

INTEGRATED AVIATION SYSTEMS PROGRAM

IASP directly supports two of the ARMD Strategic Thrusts:

- Thrust 2: Innovation in Commercial Supersonic Aircraft; and
- Thrust 3: Ultra-Efficient Subsonic Transports.

EXPLANATION OF MAJOR CHANGES IN FY 2024

NASA increased funding for elements of the SFNP as planned in last year's request. One major component of the SFNP is the SFD, which is increasing funding as it moves into the design/build phase of the project.

NASA decreased the LBFD project as planned in last year's request. The LBFD project will move into the flight validation phase which is less costly.

ACHIEVEMENTS IN FY 2022

- NASA developed tools and techniques to validate sonic boom signatures in preparation for X-59 flight operations. NASA conducted a flight test of a nose mounted shock sensing probe on the NASA F-15 that will measure LBFD shock wave structure. NASA conducted a successful in-flight demonstration of a pilot assisted aircraft positioning system that will allow the F-15 research aircraft to precisely position itself with respect to the X-59 aircraft for pressure measurements or airborne imaging. (Thrust 2/FDC)
- NASA made progress on the integration and testing of the all-electric X-57 Maxwell aircraft in preparation for first flight. The high-voltage ground testing completion paved the way for final verification and validation testing of the flight batteries, cruise motors, and software. In addition, the successful testing of cruise motor controller hardware and software occurred. The Mod III wing successfully completed fit check prior to removal from the spare fuselage. Extensive Electromagnetic Interference inherent to all-electric systems were identified and resolved with novel in-house solutions. The Mod III wing successfully completed fit check prior to removal from the spare fuselage. Lessons from the integration effort are being shared with EPFD and are influencing the development of electric aircraft propulsion standards. (Thrust 3/FDC)
- NASA supported and closed-out several risk reduction activity contracts with industry and continues to mature airframe technologies for the next generation of commercial single-aisle seat-class aircraft. The SFD solicitation was posted, and a source evaluation board convened in time for a January 2023 industry partner selection. (Thrust 3/SFD)

WORK IN PROGRESS IN FY 2023

- In preparation for the X-59 first flight, NASA will deliver a validated F-15-based test capability that enables precise, near-field probing and airborne imaging of the LBFD shockwave structure. This capability ensures that the shockwave structure produced by the X-59 aircraft in flight is comparable with current simulations during the flight test campaign. (Thrust 2/FDC)
- NASA will conduct the first flight of the all-electric X-57 Maxwell aircraft. In conjunction with the flight test, NASA will support the development of manufacturing standards for electrified aircraft systems to enable progress for U.S. companies to develop more electric aircraft. (Thrust 3/FDC)

- NASA will conduct flight test operations in support of X-59 supersonic aircraft first flights. This event will initiate the first ARMD Flight Data Portal data input. The web-based integration portal supports storage and retrieval of flight test data and mission-related information to ensure retention and availability. (Thrust 2/FDC)
- NASA will conduct Crossflow Attenuated Natural Laminar Flow (CATNLF) flight testing. CATNLF is a new design method that has the potential to enable natural laminar flow over the aircraft wings. (Thrust 2/FDC)
- NASA selected The Boeing Company as the industry partner for the Sustainable Flight Demonstrator project under a Funded Space Act Agreement. The SFD project is in the formulation process. (Thrust 3/SFD)

KEY ACHIEVEMENTS PLANNED FOR FY 2024

- NASA will conclude CATNLF flight testing. CATNLF is a new design method that has the potential to enable natural laminar flow over the aircraft wings. (Thrust 2/FDC)
- NASA will formulate the NASA Autonomous Systems Testbed to support autonomous cargo and single pilot operations. (Thrust 6/FDC)
- NASA will be supporting Boeing in the development of the future sustainable flight system for the next single-aisle seat-class aircraft. (Thrust 3/SFD)
- In support of the Quesst Mission, NASA will provide data acquisition and support flights for the X-59 aircraft checkout flights. Also, NASA will be preparing for community response testing including site visits. (Thrust 2/FDC)

Program Elements

The Electrified Powertrain Flight Demonstration and Low-Boom Flight Demonstrator projects within IASP are reported in separate sections since they are major projects of greater than $250 million and have completed Key Decision Point-B.

FLIGHT DEMONSTRATIONS AND CAPABILITIES (FDC)

NASA's FDC project validates the benefits of various technologies and demonstrates the feasibility and maturity of new technologies through flight testing in a relevant environment. The flight experiments are campaigns focused on aggressive, success-oriented schedules utilizing the most appropriate set of assets available to accomplish experimental objectives, while leveraging collaborative opportunities (as appropriate) from across the aeronautical industry. While many of the technologies are at mid-level TRLs, the FDC project supports all phases of technology maturation. The FDC project also operates and maintains a support aircraft fleet that enables safety chase and in-flight experimental measurements in support of a variety of NASA missions.

SUSTAINABLE FLIGHT DEMONSTRATOR (SFD)

One of the key components of the Sustainable Flight National Partnership is the SFD project. SFD will be a large-scale integrated flight demonstration with objectives to reduce fuel burn, carbon emissions, and noise. The aircraft, notionally planned for flight in FY 2028, will deliver matured airframe technologies to industry for use in the next generation, single-aisle seat-class commercial transport aircraft.

Program Schedule

Date	Significant Event
Jan 2023	SFD – Selected The Boeing Company as its industry partner
Jul 2023	FDC – Begin Schlieren Airborne Measurements and Range Operations ready to support of the X-59 aircraft flight operations
Jul 2023	FDC – Complete X-57 Mod II First Flight
Oct 2023	SFD - Systems Requirements Review
Apr 2024	FDC – Complete Crossflow Attenuated Natural Laminar Flow Flight Test

Program Management & Commitments

Program Element	Provider
Flight Demonstrations and Capabilities (FDC)	Provider(s): ARC, AFRC, GRC, LaRC Lead Center: AFRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): DoD, Air Force Research Laboratory, Lockheed Martin, ESAero
Sustainable Flight Demonstrator (SFD)	Provider(s): ARC, AFRC, GRC, LaRC Lead Center: HQ Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): The Boeing Company

Acquisition Strategy

IASP research and technology development focuses on integrated system capabilities. The program uses a variety of acquisition tools relevant to the appropriate work awarded externally through full and open competition. For all procurement actions, NASA strongly encourages teaming among large companies, small businesses, and universities.

MAJOR CONTRACTS/AWARDS

IASP awards multiple smaller contracts, which are generally less than $7 million and widely distributed across academia and industry for efforts supporting advanced air mobility and small-scale flight demonstrations. IASP awards substantially larger contracts for the design and build of large-scale flight demonstrations (e.g., SFD).

INTEGRATED AVIATION SYSTEMS PROGRAM

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Expert Review	Oct 2022	The purpose of the 12-month review is for tracking and documenting the projects' progress made towards the Strategic Thrusts and outcomes during the fiscal year.	The Review Panel acknowledged the projects laid out an outstanding record of accomplishments.	Oct 2023

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

FY 2024 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028	BTC	Total
Formulation	100.5	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	100.5
Development/Implementation	430.3	93.3	74.5	**9.3**	0.0	0.0	0.0	0.0	0.0	607.4
Operations/Close-out	0.0	0.0	0.0	**23.2**	1.7	0.0	0.0	0.0	0.0	24.9
2023 MPAR LCC Estimate	**530.7**	**93.3**	**74.5**	**32.6**	**1.7**	**0.0**	**0.0**	**0.0**	**0.0**	**732.7**
Total Budget	**530.5**	**93.3**	**74.5**	**33.0**	**1.7**	**0.0**	**0.0**	**0.0**	**0.0**	**732.9**
Change from FY 2023 Enacted				**-41.5**						
Percent change from FY 2023 Enacted				**-55.7%**						

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The 2023 MPAR LCC Estimate reflects the Fiscal Year 2023 Quarter 1 Financial Report, which is current as of December 2022. The requested budget authority is the project's current budget requirements.

A GE Aviation F414-GE-100 engine is installed here in NASA's quiet supersonic X-59 aircraft at Lockheed Martin's Skunk Works facility in Palmdale, California.

PROJECT PURPOSE

New environmental standards are required to open the market to supersonic flight over land. Over the past decade, fundamental research and experimentation has demonstrated the possibility of supersonic flight with greatly reduced sonic boom noise. The Low-Boom Flight Demonstrator (LBFD) project will demonstrate these advancements in flight by utilizing a purpose-built experimental aircraft designated the X-59. It will provide validation of design tools and technologies applicable to overcome the sonic boom noise barrier and open the door for the development of a new generation of environment-friendly, supersonic civil transport aircraft.

The Advanced Air Vehicles Program (AAVP) and the Integrated Aviation Systems Program (IASP) co-lead the Quesst Mission in creation of a database of community response information to support the development of a noise-based standard for supersonic overland flight. IASP's LBFD project provides the flight vehicle, IASP's Flight Demonstrations and Capabilities (FDC) project will conduct flight test operations with the X-59 vehicle, and AAVP's Commercial Supersonic Transport (CST) project will conduct the assessments of community responses to the X-59 vehicle low noise sonic boom. The LBFD project leads Phase 1 of the Quesst Mission, which includes the X-59 aircraft

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

development activities. These activities started with the detailed design, continue through fabrication, and will conclude with functional checkouts and supersonic envelope expansion. In Phase 2, a NASA-led team will perform low-boom acoustic validation flights of the X-59 aircraft. These flights will characterize and evaluate the near-field, mid-field, far-field, and ground sonic boom signatures from the X-59 aircraft. All three Quesst projects (CST, LBFD, and FDC) will work collaboratively to conduct Phase 2 of the mission. Following the completion of acoustic validation at the end of Phase 2, the LBFD project will conclude, and the X-59 aircraft will transfer from the LBFD project team to the FDC project to conduct planned Phase 3 flight operations. For Phase 3, a NASA-led CST team will lead low-boom community response studies with multiple test flight campaigns using the X-59 aircraft over varied locations with aircraft operations conducted by the FDC project. In Phase 3, NASA researchers will gather data on public acceptance of the noise levels by flying over a handful of U.S. cities. In FY 2027, NASA will provide the finalized data to the Federal Aviation Administration and the International Civil Aviation Organization. Using this data, the regulatory organizations will be able to develop and adopt new rules to allow commercial supersonic flight over land. The U.S. aviation industry will position itself to lead the commercial supersonic market, and passengers will benefit from significantly shorter travel times, if a new standard is established.

EXPLANATION OF MAJOR CHANGES IN FY 2024

In FY 2024, the LBFD project will complete the aircraft fabrication and begin checkout flights which causes the budget decrease compared to FY 2023. NASA's current first flight estimate is anticipated no earlier than fourth quarter of FY 2023 (the prior estimate was May 2023). The mission target for Phase 2 completion and transfer of the aircraft to FDC is the fourth quarter of FY 2025.

PROJECT PARAMETERS

The LBFD project is responsible for building and flight validation of the X-59 aircraft. The X-59 aircraft is NASA’s newest experimental supersonic aircraft designed to reduce the sonic boom noise levels to a level acceptable to the general public. The vehicle will enable low-boom community response overflight studies with multiple test campaigns over varied U.S. locations as part of the Quesst Mission. The mission ends in FY 2027 with the delivery of the final set of community response data to the International Civil Aviation Organization and the Federal Aviation Administration.

ACHIEVEMENTS IN FY 2022

- NASA accomplished airframe integration and made significant progress towards final assembly of the X-59 aircraft. The X-59 aircraft was shipped to a Lockheed Martin facility in Fort Worth, TX on December 31, 2021, where it successfully completed the ground proof loads and fuel system checkout tests.
- The LBFD project performed the air data probe calibration test in the Glenn Research Center (GRC) 8- by 6-foot wind tunnel and completed the emergency oxygen system and cockpit pressurization testing.
- The X-59 aircraft was returned to the Lockheed Martin facility in Palmdale, CA on April 7, 2022, to continue production operations activities.

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

WORK IN PROGRESS IN FY 2023

- Upon completion of final assembly, the X-59 aircraft will undergo a series of system checkouts and ground tests including the ground vibration test, engine runs, and taxi tests. NASA will complete Flight Readiness Review (FRR) and a series of airworthiness and flight safety reviews of the X-59 supersonic aircraft in preparation for first flight, anticipated no earlier than fourth quarter of FY 2023.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

- NASA will complete envelope expansion flight testing of the X-59 supersonic aircraft to confirm airworthiness and vehicle performance. The acoustic validation flight testing phase will begin following the conclusion of envelope expansion in preparation for community response testing.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Baseline Date	FY 2024 PB Request
Key Decision Point-B (KDP-B)	Aug 2016	Aug 2016
Formulation Authorization	Sep 2016	Sep 2016
Acquisition Strategy Meeting	Nov 2016	Nov 2016
Preliminary Design Review (PDR)	Jun 2017	Jun 2017
Delta PDR	Jul 2018	Jul 2018
KDP-C	Oct 2018	Oct 2018
Critical Design Review	Aug 2019	Sep 2019
KDP-D	Oct 2019	Dec 2019
Lockheed Re-Plan Complete	-	Jul 2020
Delta KDP-D	-	Jul 2020
X-59 Ship to LM Ft. Worth for Loads Test	Jul 2021	Dec 2021
Flight Readiness Review	Oct 2021	No Earlier Than 3Q FY 2023
First Flight Complete	Jan 2022	No Earlier Than 4Q FY 2023
System Acceptance Review (Phase 1) Flight Testing Complete	Jan 2023	4Q FY 2024
Acoustic Validation (Phase 2) Complete	Oct 2023	3Q FY 2025
Aircraft Transfer Review to FDC (Phase 2)	Oct 2023	3Q FY 2025
LBFD project Close-Out Complete	Apr 2024	4Q FY 2025

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

Development Cost and Schedule

The LBFD project completed a successful Delta KDP-D Refinement on September 13, 2022, and the project received authority to implement the updated cost and schedule profile. The LBFD project lifecycle includes aircraft concept refinement studies, aircraft preliminary design, aircraft final design and build, and acoustic validation flight testing. These activities span from FY 2014 to FY 2025 (Phase 1 and Phase 2 of the Quesst Mission).

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2018	467.7	70%	2023	607.4	+29.9%	First Flight	Jan 2022	Sep 2023	20

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time of development. Estimates that include combined cost and schedule risks denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**467.7**	**607.4**	**+139.7**
Flight Sciences	19.5	27.4	+7.9
Flight Systems	17.0	29.1	+12.1
Aircraft	230.9	420.3	+189.4
Aircraft Operations	45.1	56.0	+10.9
Other Direct Project Costs	155.2	74.6	-80.6

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Flight Sciences	Vehicle sonic boom, aerodynamics, propulsion, structures, and mission performance NASA in-house flight simulation tools, and analysis of vehicle handling qualities and control laws	Provider: Ames Research Center (ARC), Armstrong Flight Research Center (AFRC), GRC, Langley Research Center (LaRC) Lead Center: LaRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): N/A	N/A
Flight Systems	Design, development, and test of Power Distribution System (PDS), Flight Test Instrumentation System (FTIS), and eXternal Vision System (XVS)	Provider: AFRC, LaRC Lead Center: AFRC Performing Center(s): AFRC, LaRC Cost Share Partner(s): N/A	N/A
Aircraft	Design, build, and initial test of a single-piloted X-plane by the end of 2023	Provider: Lockheed Martin Lead Center: AFRC Performing Center(s): N/A Cost Share Partner(s): N/A	2 years
Aircraft Operations	Demonstrate airworthiness of aircraft, flight operations, and develop key aircraft subsystems - including life support and crew escape systems Provide Government Furnished Equipment (GFE) to construct the research aircraft, support and maintain F414 engine, and perform insight/oversight of Ops-related tasks that the vehicle Contractor performs	Provider: AFRC, LaRC Lead Center: AFRC Performing Center(s): AFRC, LaRC Cost Share Partner(s)/subcontractors: GE, Northrop, Honeywell, and Lockheed Martin	N/A

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
Sonic Boom Level is Not Acceptable for Community Overflight Research Given that achieving a fully shaped sonic boom ground signature in the 70-75 PLdB range requires a complex and integrated design solution that is sensitive to outer mold line changes, there is a possibility that the mission requirements related to ground signature loudness may not be achievable - resulting in an aircraft that may not be fully acceptable for community response studies.	NASA will ensure that all configuration assessments use the latest and most mature aircraft configuration and periodically assess any updates to the aircraft configuration, such as the outer mold line or performance characteristics.
Reduced Aircraft Performance Could Impact Mission Effectiveness Given the aircraft and propulsion system selection and integration complexity, there is a possibility of reduced aircraft performance resulting in loss of mission effectiveness and leading to longer duration time to meet flight parameter(s), increased costs, and limitations of flight test points to standard-day conditions.	NASA will ensure that the contractor has sufficient margin for aircraft weight growth with propulsion configuration; assess contractor aircraft performance and thrust predictions (both computationally and experimentally) over the aircraft flight envelope; and perform a trade study on engine performance during demanding conditions.

Acquisition Strategy

The acquisition strategy for LBFD is to acquire through an industry partner the detailed design/build/test of the experimental low-boom demonstrator aircraft. NASA will provide in-house support that will include in-flight and ground systems, instrumentation and operations, simulation, wind tunnel testing, and safety and mission assurance. NASA supplies aircraft components and systems as GFE whenever feasible and considered to add value to the development of the LBFD aircraft.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
LBFD Aircraft - Design, Build, and Initial Testing	Lockheed Martin	Palmdale, CA
F414-GE-100 Engine	General Electric Aviation	Lynn, MA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	LBFD Independent Review Board (IRB)	Jun 2017	PDR	Successfully Completed	Jul 2018

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	LBFD IRB	Jul 2018	Delta PDR, Assess readiness for KDP-C	Successfully Completed	Sep 2019
Performance	LBFD IRB	Sep 2019	CDR, Assess readiness for KDP-D	Successfully Completed	NET 3Q FY 2023
Performance	LBFD Flight Readiness Review (FRR) Board	NET 3Q FY 2023	FRR	TBD	N/A

ELECTRIFIED POWERTRAIN FLIGHT DEMO.

Formulation	Development	Operations

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**70.6**	**--**	**87.3**	**65.4**	**54.7**	**41.3**	**30.4**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

NASA is collaborating with its partners to demonstrate integrated electrified powertrains in flight using industry aircraft.

PROJECT PURPOSE

The purpose of the Electrified Powertrain Flight Demonstration (EPFD) project is to mature integrated megawatt (MW)-class electrified powertrain systems and components, thereby accelerating the introduction of these systems to the U.S. commercial transport fleet. In collaboration with U.S. industry, NASA will design, build, integrate, and perform ground and flight-tests of MW-class powertrain systems. These new systems will reduce fuel consumption by up to five percent and reduce harmful emissions. EPFD is a critical component of the Sustainable Flight National Partnership and supports ARMD Strategic Thrust 3: Ultra-Efficient Subsonic Transport.

As the benefits of electrified aircraft propulsion technology become realized, electrified aircraft propulsion research and development should rapidly gain momentum and transition into production and operations. Electrified powertrain systems will provide significant benefits in terms of reduced fuel/energy consumption and emissions. Such advances could pave the way for more cost-effective commercial aviation, while also reducing adverse societal impacts.

Through industry collaboration, EPFD will:

- Demonstrate in-flight integration of MW-class electric powertrain, power distribution, and energy storage systems; and
- Identify and address technical barriers, integration risks, and regulatory and standards gaps associated with such systems.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ELECTRIFIED POWERTRAIN FLIGHT DEMO.

Formulation	Development	Operations

PROJECT PRELIMINARY PARAMETERS

EPFD is a technology demonstration project that will flight demonstrate and evaluate the performance of MW-class hybrid-electric propulsion system technologies for commercial aircraft. Incorporating this technology could lead to higher fuel efficiency, reduced noise and emissions, and lower operating costs for commercial aircraft. The EPFD project will reduce risks for key critical technologies and address specific gaps in regulations and standards associated with introducing electrified propulsion into commercial aircraft.

EPFD will mature MW-class electrified powertrain systems through flight demonstrations applicable to the short-haul, regional, or thin-haul market segments and accelerate the U.S. industry's readiness to introduce these innovative electrified systems into the next generation of aircraft. This acceleration may occur by:

- Contributing to the development of next generation commercial subsonic transports by focusing on integrated MW-class powertrain system technology;
- Focusing on next generation single-aisle (150-200 passenger seat class) commercial transport aircraft;
- Ensuring an appropriate mix of potentially disruptive concepts and commercial transport products; and
- Directly engaging U.S. industry to facilitate timely integrated MW-class electrified powertrain system development and transition from government to industry.

Partnering with General Electric Aviation (GE) of Cincinnati, Ohio and magniX USA Inc. of Redmond, Washington, EPFD will conduct two integrated MW-class powertrain system flight demonstrations, identifying and addressing regulation and standards gaps in addition to identifying and retiring barrier technical and integration risks.

EPFD demonstrations will help to rapidly mature, and transition integrated Electrified Aircraft Propulsion (EAP) technologies for introduction into the global fleet in the 2030s.

ACHIEVEMENTS IN FY 2022

- EPFD successfully completed a Delta System Readiness Review (SRR), and flight partner Preliminary Design Review (PDR).
- EPFD successfully completed the Altitude Integration Test of the electrical powertrain at the NASA Electric Aircraft Testbed (NEAT) facility. This test advances the technology readiness level and reduces three of the top project risks.
- EPFD completed a successful Convergent Aeronautics Solutions audit to ensure a reliable and safe operations for flight test.
- GE conducted a successful Flight Readiness Review and technical brief late November 2022.
- magniX has selected AeroTec as the integrated partner in the aircraft acquisition, modification, and flight test. The specialized AeroTec experience with flight test of transport category aircraft and

ELECTRIFIED POWERTRAIN FLIGHT DEMO.

Formulation	Development	Operations

electric aircraft better ensures mission success. AeroTec is fully engaged and assisting magniX in a path to the System Readiness Review (SRR).

WORK IN PROGRESS IN FY 2023

- An internal GE Flight Readiness Review (FRR) and technical brief configuration was completed in January 2023. This FRR and technical brief supports flights in the unmodified aircraft configuration to determine the aircraft performance baseline.
- GE has obtained and transported the Saab 340 to Manassas, Virginia for modification and progression toward the initial flight test. GE will continue Risk Reduction activities by obtaining measurements from the NEAT facility on the integrated power system.
- magniX continues to develop and mature the magni650 Electric Propulsion Unit, both internally and externally.
- Upon completion of industries' respective lifecycle reviews, EPFD will complete a Delta System Readiness Review (SRR) in the third quarter of FY 2023 and Integrated Baseline Review (IBR) in the fourth quarter of FY 2023. The project will conduct KDP-C in the first quarter FY 2024 prior to entering the implementation phase.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

- The magniX PDR and CDRs lifecycle reviews will be conducted.
- Spiral development testing will extend into FY 2026.

ESTIMATED PROJECT SCHEDULE

Milestone	Formulation Authorization Document	FY 2024 PB Request
KDP-A	Jun 2020	Jun 2020
Acquisition Strategy Meeting (ASM)	Jul 2020	Jul 2020
System Readiness Review (SRR)	Sep 2020	Sep 2020
Key Decision Point (KDP-B)	Oct 2020	Oct 2020
Procurement Strategy Meeting (PSM)	Oct 2020	Oct 2020
Project Level Delta System Requirements Review GE SRR magniX SRR	TBD	3Q FY 2023 May 2022 Feb 2023

ELECTRIFIED POWERTRAIN FLIGHT DEMO.

Formulation	Development	Operations

Milestone	Formulation Authorization Document	FY 2024 PB Request
Project Level Integrated Baseline Review (IBR) GE IBR magniX IBR	TBD	4Q FY 2023 3Q FY 2023 4Q FY 2023
Preliminary Design Review (PDR) GE PDR magniX PDR	Feb 2022 - Aug 2022	Aug 2022 1Q FY 2024
KDP-C	Mar 2022	1Q FY 2024
Critical Design Review (CDR) GE CDR magniX CDR	Feb 2023 - Aug 2023	4Q FY 2023 3Q FY 2024
KDP-D	Jul 2023 - Jan 2024	4Q FY 2024
Flight Readiness Review (FRR) GE FRR magniX FRR	Nov 2023 - Jul 2024	3Q FY 2025 3Q FY 2025

**The EPFD project is still in formulation, and any updates to the schedule will occur at KDP-C.*

Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

The formulation agreement documents project costs at approximately $340.3 million over the next five years during the design and build phase. The life cycle cost of $412 million includes pre-Formulation and Formulation costs and related technology maturation activities conducted by the Advanced Air Transport Technology project, which occurred between FY 2017 and FY 2020.

Life cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project reaches KDP-C, which follows a non-advocate review and/or preliminary design review.

KDP-B Date	Estimated Life Cycle Cost Range ($M)	Key Milestone	Key Milestone Estimated Date Range
October 7, 2020	$312M - $470M	First Flight	3Q FY 2025 - 4Q FY 2026

Project Management & Commitments

The following section will be updated after industry contracts are awarded.

ELECTRIFIED POWERTRAIN FLIGHT DEMO.

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
MW-class electric powertrain, power distribution, and energy storage systems.	Flight demonstration and evaluation of the performance of MW-class hybrid-electric propulsion system technologies for commercial aircraft.	Provider: ARC, AFRC, GRC, LARC Lead Center: HQ Performing Center(s): ARC, AFRC, GRC, LARC Cost Share Partner(s): General Electric and magniX	N/A

Project Risks

Assessment and mitigation of risks provides the project with the ability to understand the technical scope and associated risks to achieve a successful mission execution. EPFD's Risk Management Process, per NASA's Procedural Requirements 8000.4B, positions IASP and EPFD to be agile and responsive from Formulation through Implementation to enable achievement of the project's technical performance goals and objectives within the project's lifecycle cost and schedule.

During Phase A, EPFD's Risk Management Process identified and matured specific risks related to the MW-class powertrain flight demonstrations. During Phase B, the development of risk identification and mitigations occur. There are three risk working groups leading these efforts: technical (system and component); safety and mission assurance (including airworthiness); and cost, schedule, and acquisition. The EPFD project has a risk registry containing all active risks stored in a document management system. Mitigation plans will be developed and funded (where necessary) to mitigate technical, cost, schedule, and safety risks based on the likelihood and potential consequences.

By managing these risks during Formulation, the project can be proactive in reducing barriers to technology insertion and establish MW-class powertrain system performance by validating component-level designs and obtaining preliminary test data at the component- and subsystem-level.

The following tables shows the top risks and current mitigation steps:

Risk Statement	Mitigation
Constrained Supply Base for Critical Components Given that the performance requirements of critical components exceed those of standard, commercially available parts, there is the possibility that the engineering and manufacturing suppliers will not be able to supply these components on schedule/in budget, resulting in a schedule delay and/or cost increase.	Post contract award, begin composition and tracking of Master List of Critical Components and their proposed delivery dates for the period between October 2021 and September 2023.

ELECTRIFIED POWERTRAIN FLIGHT DEMO.

Formulation	Development	Operations

Risk Statement	Mitigation
Contractor(s) May Not be Able to Provide Sufficient Test Data to Demonstrate Technology Maturation Given that NASA will execute ground and flight tests with Industry Partners through a contract, there is a possibility that the industry partner test plan will fulfill the contract requirements but not all the data requirements for project success, resulting in a lack of data to validate EAP technologies, mature those technologies, and make the project successful.	Define Data needed to measure performance against Key Performance Parameters (Vision Vehicle) and Technical Performance Measures (TPMs) (Flight Demonstrations); measure advancement of TRL levels of MW-class powertrains; measure progress against Barrier Technical Risk (Vision Vehicle) based on progress against related Specific Technical Risks (Flight Demonstrations) Define data needed to support regulations and standards. Define data needed to provide validation data for NASA and industry tools and research. The use of validation data will reduce uncertainty in model estimation of EAP system performance in configurations not previously developed, tested, and evaluated. The following programs/projects will help support this effort: Advanced Air Vehicles Program's Advanced Air Transport Technology and Hybrid Thermally Efficient Core projects, and Transformative Aeronautics Concepts Program's Transformational Tools and Technologies project and the EPFD team. Create a Data Management Plan (preliminary) to address the data identified in the previous steps. Be sure this coincides with the Technology Development Plan and requirements for a Master Measurement List. Communicate data needs to industrial partners through Data Requirements Descriptions.
Integrated MW-Class Powertrain System Fails to Meet Technical Performance Metrics Under Flight Environments Given that Integrated MW-Class Powertrain Systems are under development, there is a possibility that they will not meet the required Technical Performance Metrics under flight environments resulting in the need for additional development with associated schedule and cost impacts.	At each lifecycle review, Industry Partners provide estimated technical performance as part of proposal in response to the Technical Data Requirements and Reporting (TDRR) and expected environments as part of their Systems Requirements Document. Industry Partners provide final assessment of overall activity in response to the Technology Maturation Report.

Acquisition Strategy

The acquisition strategy for EPFD is to collaborate with U.S. industry to design, build, integrate, and perform ground and flight tests of MW-class powertrain systems.

To conduct the necessary ground and flight demonstrations, EPFD awarded two contracts using full and open competition. EPFD will conduct integrated ground and flight demonstrations of MW-class electrified powertrain technologies and systems to identify and address electrified powertrain certification gaps during the ground-based and flight test demonstrations.

ELECTRIFIED POWERTRAIN FLIGHT DEMO.

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

The release of the Request for Proposal, proposal selection, and contract awards occurred during FY 2021.

Element	Vendor	Location (of work performance)
Electrified Powertrain	General Electric Aviation (GE)	Cincinnati, OH
Electrified Powertrain	magniX USA Inc.	Everett, WA
Aircraft Mod and Integration	General Electric Aviation (GE)	Manassas, VA
Aircraft Mod and Integration	magniX USA Inc.	AeroTEC, WA
Flight Test	General Electric Aviation (GE)	Victorville, CA
Flight Test	magniX USA Inc.	AeroTEC, WA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	EPFD Independent Review Board (IRB)	Sep 2020	System Requirements Review (SRR)	Successfully completed	Jul 2022
Performance	EPFD IRB	3Q FY 2023	Delta SRR	TBD	Apr 2023 - Jun 2023
Performance GE Performance magniX	EPFD IRB	Aug 2022 1Q FY 2024	Preliminary Design Review (PDR)	Successfully completed TBD	TBD
Performance GE Performance magniX	EPFD IRB	4Q FY 2023 3Q FY 2024	Critical Design Review (CDR)	TBD	TBD
Performance GE Performance magniX	EPFD IRB	3Q FY 2025 3Q FY 2025	Flight Readiness Review (FRR)	TBD	TBD
Performance GE Performance magniX	EPFD IRB	3Q FY 2026 4Q FY 2026	Post-Flight Assessment Review(s) (PFAR)	TBD	N/A

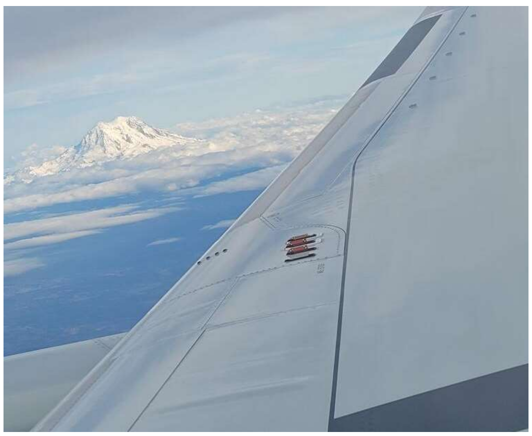
TRANSFORMATIVE AERO CONCEPTS PROGRAM

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	142.8	--	160.0	161.8	170.3	184.5	188.5

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



NASA's Transformational Tools and Technologies project tests drag-reducing vortex generators made from new shape memory alloy.

The Transformative Aeronautics Concepts Program (TACP) cultivates multi-disciplinary, revolutionary concepts to enable aviation transformation. TACP fosters innovative solutions to aviation challenges by capitalizing on advancements in the aeronautics and non-aeronautics sectors to create new opportunities in aviation. One major goal of the program is to reduce or eliminate technical barriers and infuse ground-breaking concepts into the aviation community.

TACP creates advanced and improved computational tools, technologies, and experimental capabilities for use by other aeronautics programs, industry partners, and government collaborators.

TACP's activities offer flexibility for innovators to explore technology feasibility and provide the knowledge for radical transformation. The program creates an environment for researchers to incubate and test new ideas, and leverage the knowledge gained from their discoveries. TACP addresses the need for computational and experimental tools that are critical for supporting technology development and enabling aviation transformation. Therefore, the program's investments are in brand-new areas that can provide paradigm-shifting analysis and experimental capabilities. To obtain support of the program's objectives and foster the rapid adoption of program research products, TACP aggressively engages both the traditional aeronautics community and new non-traditional entities through tailored collaborations.

EXPLANATION OF MAJOR CHANGES IN FY 2024

NASA increased funding to develop zero-emissions aircraft concepts through the highly successful University Leadership Initiative and develop modeling tools to evaluate the impact of aviation on the climate.

ACHIEVEMENTS IN FY 2022

TACP is a widely cross-cutting program as each of its achievements support multiple thrusts. At the end of each achievement identified in this document, there is a parenthetical to link it to the related Strategic Thrust and Program Element.

TRANSFORMATIVE AERO CONCEPTS PROGRAM

- NASA completed a Multidisciplinary Design, Analysis and Optimization (MDAO) study specifically focused on developing advanced design and optimization tools for coupled multidisciplinary analysis. NASA achieved integrated design methods which addressed the requirement for electric and hybrid-electric aircraft needing a high degree of propulsion-airframe integration due to multiple conflicting and interacting requirements from multiple aerodynamic considerations. NASA developed OpenMDAO ─ a multidisciplinary, multi-fidelity design and optimization framework open-source tool. OpenMDAO provides improved speed, flexibility, and applicability of MDAO methods and delivers foundation for improved designs for many design variables utilized by government, industry, and academia. (Cross-cutting/Transformational Tools and Technologies [TTT] project)
- NASA developed a new alloy, GRX-810, strengthened by an oxide dispersion. GRX-810 can endure higher temperatures, is more malleable, and has significantly increased durability than existing state-of-the-art alloys. This alloy is utilized to build aerospace parts for high-temperature applications withstanding harsher conditions like those in aircraft and rocket engines. The GRX-810 alloy will lead to future sustainable flight engines with less harmful impacts to the environment. (Cross-cutting/TTT project)
- NASA completed the High-efficiency Electrified Aircraft Thermal Research activity which minimized the wasted thermal load heat for large-scaled Electrical Aircraft Propulsion systems. These assessed technologies aimed at reducing weight and increased efficiency in High-Efficiency Megawatt Motors, which NASA patented in FY 2022. Multiple aircraft, such as single aisle, regional turboprop, and Advanced Air Mobility (AAM) aircraft, showed energy reduction benefits. The technology was also utilized to address motor controller issues with the NASA X-57 Maxwell fixed-wing aircraft. These concepts and hardware will transition to two projects in ARMD's Advanced Air Vehicles Program: Advanced Air Transport Technology and the Revolutionary Vertical Lift Technology (RVLT). (Cross-cutting/Convergent Aeronautics Solutions [CAS] project)
- NASA completed the Scalable Traffic Management for Emergency Response Operations (STEReO) activity utilizing unmanned aerial vehicles that created an unmanned aircraft traffic management ecosystem. This constructed environment reduced simulated emergency response time during disasters and provided operational resiliency to active changes during a disaster, potentially saving lives and minimizing recovery costs. The California Department of Forestry and Fire Protection and the U.S. Forest Service engaged STEReO's systems on NASA drones which flew in coordination with firefighting aircraft during a wildland fire demonstration. This activity moved to the Advanced Capabilities for Emergency Response Operations (ACERO) project in ARMD's Airspace Operations and Safety Program. ACERO will complete further technology maturation and support operation by external partners (the U.S. Department of Agriculture and U.S. Forest Service) to enhance safety for wildland firefighters. (Cross-cutting/CAS)
- NASA solicited a set of ULI proposals that included a topic focused on zero-emissions aircraft which support the goals of the Biden-Harris Administration. (Cross-cutting/University Innovation [UI])
- NASA selected four new ULI awards across 14 universities and nine industry partners. These awards will address technical barriers inherent in achieving ARMD's strategic outcomes: (Cross-cutting/UI)
  - The team led by the University of Central Florida will explore two concepts: using liquid ammonia, a non-traditional source, as fuel for a jet engine; and generating electricity from the engine's exhaust heat to save fuel and to reduce emissions.
  - The team led by Florida State University will study how hybrid hydrogen-electric power generation is combined with fuel cell technology to lower emissions.

- The team led by the Georgia Institute of Technology is taking a holistic approach that aims to co-optimally develop cleaner engine technologies and aviation systems through the lens of environmental impact related to the emerging supersonic transport market.
- The team led by the University of Illinois, Urbana-Champaign aims to deliver trustworthy autonomy tools to help Advanced Air Mobility aircrafts fly safely through complex airspace, typical of dense urban environments.

WORK IN PROGRESS IN FY 2023

- NASA will conduct validation tests in the National Transonic Facility and perform risk reduction experiments in the Basic Aerodynamic Research Tunnel facility pertaining to TTT's Reduced Life Cycle Cost subproject. NASA will use innovative measurement techniques to investigate computational tools for prediction of maximum aerodynamic lift. The predictive uncertainty quantification process demonstrates adaptive computational mesh modeling capability for unsteady scale-resolving simulations. (Cross-cutting/TTT)
- NASA will complete acoustic perception-influenced validation experiments of MDAO in the Low-Speed Aeroacoustic Wind Tunnel. NASA will use rapid aerodynamic modeling methods for the Research Aircraft for electrified vertical take-off and landing (eVTOL) Enabling Technologies for sub-scale wind tunnel/flight test to develop baseline flight control laws. (Cross-cutting/TTT)
- NASA will continue to maximize the value of zero-impact aviation while minimizing negative impacts on the Earth and society through current CAS activities: Sensor-based Prognostics to Avoid Runaway Reactions and Catastrophic Ignition (SPARRCI) and Solid-State Architecture Batteries for Enhanced Rechargeability and Safety (SABERS), which focuses on aviation battery technology and safety; and Subsonic Single Aft Engine (SUSAN), which focuses on multi-megawatt electric aircraft propulsion concepts and future activities formulating through mapping and synthesis activities. (Cross-cutting/CAS)
- NASA will complete feasibility assessments on two CAS activities: SPARRCI and Data and Reasoning Fabric (DRF). The SPARRCI activity will seek to eliminate catastrophic battery failures with early fault detection for electric air vehicles and improve safety of existing batteries and accelerate adoption of next-generation batteries. The DRF activity will review the required decisions (or reasonings) for UAM aircraft based on diverse and dynamic data (e.g., vehicle, airspace, weather, infrastructure, payload, and customer data)
- NASA will extend research efforts on 18 existing ULI awards as the project's portfolio has grown to address the public need for considering all potential energy sources in producing zero aviation emissions, new fuel cell technology, hybrid electric propulsion systems and autonomous aircraft knowledge working with many universities, industry partners, other government agencies and ARMD programs. (Cross-cutting/UI)
- NASA will make additional ULI award solicitations to address NASA Aeronautics Strategic Implementation Plan (SIP) and include zero-emission topics. (Cross-cutting/UI)

KEY ACHIEVEMENTS PLANNED FOR FY 2024

- NASA will enable the performance, reliability, and durability of electrified propulsion systems under the Foundational Electrified Aircraft Propulsion (FEAP) sub-project by conducting research and

TRANSFORMATIVE AERO CONCEPTS PROGRAM

developing innovative materials, tools and methods supporting aerospace needs. NASA will optimize the efficiency of fluid power to mechanical power conversion to minimize weight of the electric power system to integrate for an RVLT UAM concept rotor. FEAP will develop next generation aircraft design tools for conceptual aircraft, electric motor, and aviation grade battery pack designs. This multi-fidelity will utilize the latest modeling tools and methods based on OpenMDAO framework and develop battery pack architecture incorporating SABERS developed battery cells, as well as sensors established under SPARRCI integrated to battery pack design for additional safety feature. (Cross-cutting/TTT)

- In order to assess and verify the next generation of advanced computational models and tools, NASA will pursue improving innovative measurement capabilities. In order to work in harsh environments and provide new measurement parameters, new measurement techniques must continually be refined and improved. NASA will develop measurement technologies for evaluating new hybrid-electric blade performance including non-destructive evaluation methods for coatings. (Cross-cutting/TTT)
- NASA will complete SABERS CAS activity which proposes new battery technology that meets rigorous aerospace safety and performance for electric air vehicles. To help grow an impactful aviation battery research this activity is planning to transition to TTT for further development. (Cross-cutting/CAS)
- NASA will award new ULI proposals under the UI project. Proposals will address additional technical barriers intrinsic to achieving ARMD’s strategic outcomes and continue to expand investment in research for zero-emissions aviation for the future. (Cross-cutting/UI)
- NASA will close out and evaluate the results of several current ULI awards (Cross-cutting/UI):
  - University of Illinois, Urbana-Champaign: Developing a Hydrogen-Energy Electric Transport Aircraft concept using liquid hydrogen fuel cells and electrical system to power an electrically driven aircraft propulsion system;
  - North Carolina A&T State University: Developing secure and safe autonomous systems using an unmanned Advanced Air Mobility aircraft for industry to consider utilizing these technologies;
  - Stanford University: Creating fault detection and recovery method tools in unmanned Advanced Air Mobility aircrafts that ensure real-time learning in autonomous systems, particularly in situations involving taxiing, landing and collision avoidance;
  - University of Delaware: Demonstrating the ability to produce aerospace-quality components at a rate comparable to that of the automotive industry utilizing forming composite materials;
  - University of South Carolina: Producing tools and technology to understand and safely use a composite tape made of thermoplastic in designing and manufacturing parts for an Advanced Air Mobility vehicle; and
  - Oklahoma State University: Investigating to improve real-time weather forecasting of low-level winds and turbulence in both natural and urban environments improving safety for Unmanned Aircraft Systems flying in Advanced Air Mobility operations.

TRANSFORMATIVE AERO CONCEPTS PROGRAM

Program Elements

CONVERGENT AERONAUTICS SOLUTIONS (CAS)

The CAS project performs rapid feasibility assessments of early-stage innovations that challenge existing technical approaches, create alternate paths to solutions, and enable new strategic outcomes. The project focuses on merging traditional aeronautics disciplines with advancements driven by the non-aeronautics world to overcome barriers and enable new capabilities in commercial aviation. Internal research teams conduct initial feasibility studies, perform experiments, test new ideas, and identify and learn from failures. When a review determines that the developed solutions have met their goals and identified potential for future aviation impact, ARMD considers the most promising capabilities for continued development by other programs or by direct transfer to the aviation community.

TRANSFORMATIONAL TOOLS AND TECHNOLOGIES (TTT)

The TTT project advances state-of-the-art computational and experimental tools and technologies that are vital to aviation applications in the SIP's six strategic thrusts. These new computer-based tools, models, and associated scientific knowledge provide novel capabilities to analyze, understand, and predict performance for a variety of aviation concepts. Applying these tools will enable and accelerate NASA’s research and enable the aviation community to introduce advanced concepts and designs. An example, is the development and validation of new computational tools to predict complex turbulent airflow around vehicles and within propulsion systems, ultimately leading to an improved ability to predict future vehicle performance in flight. The project also explores technologies that are critical to advancing ARMD strategic outcomes, such as understanding new types of strong and lightweight materials, innovative aircraft control techniques, and experimental methods. Such technologies will support and enable concept development and benefit assessment across multiple ARMD programs and disciplines. The TTT project has an Autonomous Systems sub-project to explore new capabilities to enable improved performance and safety of innovative autonomous aircraft and their operational controls.

UNIVERSITY INNOVATION (UI)

The UI project contains a portfolio of disruptive technologies and other new concepts to meet the goals established by the ARMD strategic thrusts and support education of the next generation of engineers. The project utilizes NASA Research Announcement solicitations where university-led teams assess solving the most critical technical challenges to achieve Aeronautics SIP strategic outcomes; and propose independent, innovative research projects to find those solutions. Universities develop their own success criteria, progress indicators, and technical approaches. Universities pursue multi-disciplinary approaches and incorporate opportunities with other universities, industry, and U.S. entities.

TRANSFORMATIVE AERO CONCEPTS PROGRAM

PROGRAM SCHEDULE

Date	Significant Event
Feb 2023	UI – Plan to release ULI Round 7 solicitation
Mar 2023	CAS – Close-out/transition of Sensor-based Prognostics to Avoid Runaway Reactions and Catastrophic Ignition
Jun 2023	CAS – Close-out/transition of Data and Reasoning Fabric
Sep 2023	TTT – Deliver first high-lift common research model wind tunnel test in the National Transonic Facility
Sep 2023	TTT – Complete development of aerodynamic model for the Georgia Tech research aircraft in the Low-Speed Aeroacoustic Wind Tunnel
Sep 2023	UI – Award ULI Round 6 selections
Sep 2023	UI – Plan final annual reviews of ULI Round 2 selections for Carnegie Mellon University and University of Wisconsin
Mar 2024	UI – Plan to release ULI Round 8 solicitation
Sep 2024	TTT – Complete development of multi-fidelity design tools for conceptual aircraft electric motor and battery pack designs using latest modeling tools
Sep 2024	TTT – Produce measurement technologies for evaluating new hybrid-electric blade performance using innovative measurement capabilities
Sep 2024	CAS – Close-out/transition of Solid-state Architecture Batteries for Enhanced Rechargeability and Safety
Sep 2024	UI – Award ULI Round 7 selections
Sep 2024	UI – Plan the final annual reviews of ULI Round 2 selection for University of Illinois
Sep 2024	UI – Plan the final annual reviews of ULI Round 3 selections for North Carolina A&T State University, Stanford University, University of Delaware, Oklahoma State University and University of South Carolina

PROGRAM MANAGEMENT & COMMITMENTS

Program Element	Provider
Convergent Aeronautics Solutions (CAS)	Provider(s): ARC, GRC, LaRC, AFRC Lead Center: HQ Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): PCKrause & Associates, National Institute of Aerospace, Boeing, ESAero, Launch Point, Straight Up Imaging, DoT Volpe, Moog Inc., IDEO, Idea Couture, Tecolote Research Inc.

TRANSFORMATIVE AERO CONCEPTS PROGRAM

Program Element	Provider
Transformational Tools and Technologies (TTT)	Provider(s): ARC, GRC, LaRC, AFRC Lead Center: GRC Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): Boeing, Pratt & Whitney, Rolls Royce, Honda, United Technologies Research Center (UTRC), ESI, Blue Quartz Software, General Electric, DoD, Honeywell, BAE Systems, UTC Aerospace Systems, Ohio Aerospace Institute, U.S. small businesses
University Innovation (UI)	Provider(s): ARC, GRC, LaRC, AFRC Lead Center: HQ Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): N/A

ACQUISITION STRATEGY

TACP research and technology development focuses on foundational research capabilities. The program uses of a variety of acquisition tools relevant to the appropriate work awarded externally through full and open competition. For all procurement actions, NASA strongly encourages teaming among large companies, small businesses, and universities.

MAJOR CONTRACTS/AWARDS

TACP awards multiple smaller contracts, which are generally less than $5 million and are widely distributed across academia and industry.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Expert Review	Oct 2022	The 12-month review is a formal independent peer review. Experts from other government agencies report on their assessment of technical and programmatic risk and/or project weaknesses.	Received expert feedback on project improvement from the Panel. Determined that the projects made satisfactory progress in meeting objectives.	Oct 2023

AEROSCIENCES EVALUATION AND TEST CAPABILITIES

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**117.0**	**--**	**117.0**	**117.4**	**117.7**	**120.7**	**123.5**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Shown above, NASA tests a half-span model of the Transonic Truss-Braced Wing aircraft design inside the Unitary Plan Wind Tunnel.

The Aerosciences Evaluation and Test Capabilities (AETC) Portfolio sets the strategic direction and funds operations, maintenance, and upgrades of NASA's versatile and comprehensive portfolio of aerosciences ground-test capabilities and assets. Among these assets are subsonic, transonic, supersonic, and hypersonic wind tunnels, propulsion test facilities, and specialty tunnels at the Ames Research Center (ARC), Glenn Research Center (GRC), and Langley Research Center (LaRC). NASA's integrated approach to test capability planning, use, and management also considers complementary computational tools, software, and related systems to effectively acquire and process research data.

Through broad alliances outside of NASA, AETC optimizes the use of these capabilities across the Government. NASA participates in the National Partnership for Aeronautical Testing and collaborative working groups that include NASA, the Department of Defense (DoD), and other partners. Members of these working groups: (1) gain awareness of capabilities across the Government, academia, and industry; (2) share best practices; (3) provide technical support; and (4) refer test programs to facilities best suited to meet test requirements.

Within NASA, AETC directly supports the testing needs of five mission directorates: Aeronautics Research Mission Directorate (ARMD), Exploration Systems Development Mission Directorate (ESDMD), Space Operations Mission Directorate (SOMD), Science Mission Directorate (SMD), and the Space Technology Mission Directorate (STMD).

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ACHIEVEMENTS IN FY 2022

- AETC wind tunnels were fully operational or in planned maintenance mode. Tunnel utilizations supported various NASA mission testing needs, including those related to advanced aircraft concepts, future space exploration mission vehicle developments, planetary entry system modeling, external customer tests, and multiple classified tests in support of national security efforts. Specifically, some AETC key testing supported include:

AEROSCIENCES EVALUATION AND TEST CAPABILITIES

- ARMD:
  - Vertical Lift Propeller Test (Langley 14- by 22-Foot Subsonic Tunnel);
  - Low-Boom Flight Demonstrator Air Data Probe and X-59 Sonic Boom Tests (Glenn 8- by 6-Foot Supersonic Wind Tunnel);
  - NASA-University Slotted Natural Laminar Flow (SNLF) Semi-Span Test (Ames Unitary Plan Wind Tunnel);
  - Advanced Ducted Propulsor Fan Commissioning Test (Glenn 9- by 15-Foot Low Speed Wind Tunnel);
  - Fundamental Engine Ice Physics Simulated Inter-Compressor Duct Test (Glenn Icing Research Tunnel; and
  - Transonic Truss-Braced Wing Buffet Test (Ames Unitary Plan Wind Tunnel).
- SMD:
  - Dragonfly Coaxial Rotor Performance and Aeroshell Tests (Langley Transonic Dynamics Tunnel); and
  - Mars Sample Return Earth Entry System (Langley Transonic Dynamics Tunnel).
- ESDMD:
  - Space Launch System Buffet Validation Test (Langley Transonic Dynamics Tunnel); and
  - Orion Crew Capsule Heat Shield Evaluation (Langley National Transonic Facility).
- The Ames Unitary Plan Wind Tunnel replaced its three-stage compressor blades extending its operating life for decades.

WORK IN PROGRESS IN FY 2023

- AETC will continue to provide wind tunnel support for various mission testing needs including advanced aircraft concepts, future space exploration mission vehicle developments, planetary entry system modeling, external customer tests, and multiple classified tests in support of national security activities.
- AETC will begin digitally transforming wind tunnel operations and management by establishment of real-time tunnel performance and value metrics that will drive more effective decision-making and business outcomes.
- A new state-of-the-art system to measure, assess, and visualize unsteady aerodynamics for advanced and complex aerospace vehicles at high-resolution and unprecedented data turn-around times will be available at the Ames Unitary Plan Wind Tunnel with future applications at other tunnels.
- AETC continue to advance integration of Computational Fluid Dynamics (CFD) and experimental testing, which will allow more efficient, optimized testing for all customers, and provide a strong basis in future capability sustainment. AETC will complete an assessment of the accuracy and efficiency of computational analysis compared to the LaRC Unitary Plan Supersonic Wind Tunnel experimental data across multiple CFD models having a wide spectrum of aerodynamic prediction challenges. NASA will use methods learned from this assessment in future wind tunnel assessments.
- AETC will deploy a new propulsion simulation calibration and testing capability for aircraft and spacecraft models at the NASA LaRC National Transonic Facility. This new capability enables acquisition of next generation aerodynamic test data from aircraft and spacecraft models that integrate with propulsion simulators (e.g., air ejection nozzle or air-powered turbine propulsion simulators).

- AETC will complete installation and enter into service a new Mach 6 nozzle in the LaRC 8-Foot High Temperature Tunnel. The upgraded wind tunnel will provide high-fidelity, true enthalpy, and true pressure Mach 6 test environments for durations of up to five minutes required to meet future NASA and DoD hypersonic vehicle ground test requirements.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

- AETC wind tunnels will continue to support various mission testing needs including those related to advanced aircraft concepts, future space exploration mission vehicle developments, planetary entry system modeling, external customer tests, and multiple classified tests in support of national security requirements.
- AETC will assess the condition and health of testing capabilities at ARC, GRC, and LaRC. The review will identify equipment with a high-risk of failure due to age or maintenance issues.
- AETC will deploy a new propulsion simulation calibration and testing capability for aircraft and spacecraft models at the NASA Ames Unitary Plan Wind Tunnel. This new capability enables acquisition of next generation aerodynamic test data from aircraft and spacecraft models that integrate with propulsion simulators (e.g., air ejection nozzle or air-powered turbine propulsion simulators).
- Establishment of an Aerosciences Data Platform(s)/Portal(s) for all AETC tunnels to house test facility data assets that will be Findable, Accessible, Interoperable, and Reusable, Understandable, Secure, and Trustworthy (FAIRUST). In parallel, AETC will maintain viable data systems, instrumentation, and front-end hardware that are adaptable to customer needs.
- AETC will develop robust testing methodologies to reduce flight certification time in low speed, high lift flight envelope using the LaRC National Transonic Facility.

Program Element

AEROSCIENCES EVALUATION AND TEST CAPABILITIES (AETC)

Aerosciences ground-test capabilities (e.g., facilities, systems, workforce, and tools) that support future aircraft, space vehicles, and operations require efficient and effective investment, operations, and management. Efforts in this area preserve and enhance ground test capabilities necessary to achieve the Agency's multi-Mission requirements. Among these assets are subsonic, transonic, supersonic, and hypersonic wind tunnels and propulsion test facilities at the Ames Research Center in Mountain View, CA, the Glenn Research Center in Cleveland, OH, and the Langley Research Center in Hampton, VA. These test facilities and capabilities also serve the needs of non-NASA users and are listed below:

- ARC Unitary Plan 11- by 11-Foot Transonic and 9- by 7-Foot Supersonic Wind Tunnels
- GRC 9- by 15-Foot Low Speed and 8- by 6-Foot Supersonic Wind Tunnels
- GRC 10- by 10-Foot Supersonic Wind Tunnel
- GRC Icing Research Tunnel
- GRC Propulsion Systems Laboratory
- LaRC 14- by 22-Foot Subsonic Tunnel

AEROSCIENCES EVALUATION AND TEST CAPABILITIES

- LaRC National Transonic Facility
- LaRC Transonic Dynamics Tunnel
- LaRC Aerothermodynamics Lab
- LaRC 8-Foot High Temperature Tunnel
- LaRC 20-Foot Vertical Spin Tunnel
- LaRC Unitary Plan Wind Tunnel

NASA's integrated approach to test capability planning, use, and management will consider the complementary computational tools, software, and related systems to effectively acquire and process research data. NASA offers research customers high-quality data that accurately reflects the simulated test environment and the interactions of test articles in those test environments. Furthermore, NASA expertise helps ensure safe and successful use of the assets and the high quality of research outcomes. The portfolio is cross-cutting and supports the Aeronautics Research Mission Directorate's Strategic Thrusts, as well as other Agency efforts and those of key industry partners.

Program Schedule

Date	Significant Event
Sep 2023	AETC – Completion of report on the evaluation of CFD for testing at high supersonic speeds at LaRC Unitary Wind Tunnel
Sep 2023	AETC – New state-of-the-art system to measure, assess, and visualize unsteady aerodynamics
Sep 2024	AETC – Develop robust testing and CFD methodologies to reduce flight certification time in low speed, high lift flight envelope using the LaRC National Transonic Facility.
Sep 2024	AETC – Aerosciences Data Platform(s)/Portal(s) operational
Sep 2024	AETC – Completion of ARC Propulsion Simulator Calibration Facility

Program Management & Commitments

Program Element	Provider
Aerosciences Evaluation and Test Capabilities (AETC)	Provider: ARC, LaRC, GRC Lead Center: HQ Performing Center(s): ARC, LaRC, GRC Cost Share Partner(s): Multiple

Acquisition Strategy

AETC uses of a variety of acquisition tools relevant to the appropriate work awarded externally through full and open competition.

AEROSCIENCES EVALUATION AND TEST CAPABILITIES

Major Contracts/Awards

AETC awards multiple smaller contracts, which are generally less than $5 million, and are typically with industry, which provide systems applicable to the sustainment and operations for large-scale wind tunnel assets.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Expert Review	Dec 2022	This 12-month review is a formal independent peer review. Experts from other NASA missions report on their assessment of technical and programmatic risk and/or program weaknesses.	This was a very favorable review. The Expert Reviewers encouraged the team to continue improving its processes including those that support operational efficiency gains and improved investment and divestment decision making.	Dec 2023

STEM ENGAGEMENT

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
NASA Space Grant	54.5	58.0	**58.0**	59.2	60.3	61.5	62.8
Established Program to Stimulate Comp Research	26.0	26.0	**26.0**	26.5	27.0	27.6	28.1
Minority University Research Education Program	43.0	45.5	**48.1**	49.1	50.1	51.1	52.2
Next Gen STEM	13.5	14.0	**25.7**	26.2	26.7	27.3	27.8
Total Budget	**137.0**	**143.5**	**157.8**	**161.0**	**164.2**	**167.5**	**170.9**
Change from FY 2023 Enacted			**14.3**				
Percent change from FY 2023 Enacted			**10.0%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

STEM Engagement

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
NASA Space Grant	54.5	58.0	**58.0**	59.2	60.3	61.5	62.8
Established Program to Stimulate Comp Research	26.0	26.0	**26.0**	26.5	27.0	27.6	28.1
Minority University Research Education Program	43.0	45.5	**48.1**	49.1	50.1	51.1	52.2
Next Gen STEM	13.5	14.0	**25.7**	26.2	26.7	27.3	27.8
Total Budget	**137.0**	**143.5**	**157.8**	**161.0**	**164.2**	**167.5**	**170.9**
Change from FY 2023 Enacted			**14.3**				
Percent change from FY 2023 Enacted			**10.0%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

These photos illustrate a wide variety of NASA STEM student opportunities, including the Artemis Student Challenges, Students to Launch partnership, and MUREP Innovation Tech Transfer Idea Competition (MITTIC).

NASA makes vital investments in Science, Technology, Engineering, and Mathematics (STEM) engagement, in direct alignment with NASA's 2022 Strategic Plan and Goal 4.3 to "build the next generation of explorers," as well as the Administration's priority of building a future diverse STEM workforce. The Office of STEM Engagement (OSTEM) leads the Agency's STEM engagement function, providing strategic guidance and charting direction in partnership with the mission directorates. OSTEM will also manage the STEM Engagement Program.

The scope of NASA STEM Engagement comprises all endeavors to attract, engage, and educate students and to support educators and educational institutions. STEM Engagement encompasses a broad and diverse set of programs, projects, activities, and products. This includes student internships and fellowships; student learning opportunities (e.g., challenges and competitions, camps, and other hands-on and virtual experiences); informal education and out-of-school learning activities; educational products, tools, and platforms; educator and faculty support; competitive grants and cooperative agreements to educational institutions for research and development and institutional support; and strategic partnerships with organizations to expand reach and impact.

NASA will continue to support Federal STEM education priorities and drive strategic alignment of the Agency's STEM engagement efforts through the NASA Strategy for STEM Engagement (https://www.nasa.gov/sites/default/files/atoms/files/nasa-strategy-for-stem-2020-23-508.pdf) via three strategic goals:

1. Create unique opportunities for a diverse set of students to contribute to NASA's work;

2. Build a diverse future STEM workforce by engaging students in authentic learning experiences with NASA's people, content, and facilities; and
3. Attract diverse groups of students to STEM through learning opportunities that spark interest and provide connections to NASA's mission and work.

These goals, along with their corresponding objectives and strategies, guide the Agency's STEM engagement efforts and are complemented by five design principles: (1) mission-driven authentic STEM experiences, (2) evidence-based practices, (3) scalability, (4) outcome-driven, and (5) diversity and inclusion. These principles guide the planning and execution of work in direct support of achieving the strategic goals.

OSTEM is accountable for the management of NASA's STEM Engagement Program, which is composed of four projects: National Space Grant College and Fellowship Project (Space Grant); Established Program to Stimulate Competitive Research (EPSCoR); Minority University Research and Education Project (MUREP); and Next Generation STEM Project (Next Gen STEM). These projects are outlined in detail in subsequent sections.

NASA will continue work that began in FY 2023 to advance its work around three priority focus areas:

- First, NASA will implement strategies to broaden student participation to increase diversity, equity, and inclusion in STEM through NASA opportunities and activities. NASA will continue to foster a culture and commitment across the STEM engagement community, including its grantees, partners, and collaborators, to broaden student participation through implementation of an action plan that was developed in FY 2021.
- Second, NASA will continue to build productive strategic partnerships and networks, expanding NASA's STEM ecosystem to magnify reach and impact. This will be accomplished through establishing formal partnerships with organizations through Space Act Agreements, in order to scale activities and expand results and impact, capitalizing on existing networks and distribution systems to deploy products and opportunities.
- Third, NASA will expand contributions in engaging K-12 students in STEM pathways, with an approach toward a continuum of experiences. This will include efforts to increase the accessibility and navigability of NASA opportunities and products for students and educators.

EXPLANATION OF MAJOR CHANGES IN FY 2024

The proposed Budget increase for Next Gen STEM provides the ability to enhance critical investments in K-12, including expanding support for strategic partnerships that will strengthen the reach and effectiveness of NASA's K-12 education efforts. NASA will build on new initiatives begun in FY 2022 and continued in FY 2023 to implement a new framework for K-12 efforts that includes scalable learning activities and products in collaboration with partners, as well as cross-cutting elements devoted to serving educators and educational institutions.

NASA will develop and release an open solicitation designed to support external organizations in the development and execution of high-impact national activities to engage diverse groups of students in NASA STEM content and careers.

STEM ENGAGEMENT

WORK IN PROGRESS IN FY 2023

In FY 2023, OSTEM continues Agency-wide coordination in support of Agency and Federal Government priorities to attract, engage, and educate students toward building a future STEM workforce. OSTEM continues to implement enterprise initiatives to improve efficiency and strengthen standards and rigor in program management, fiscal accountability, and performance measurement. In FY 2023, NASA will continue to implement a mission-driven STEM Engagement Program through its four projects. Details regarding project plans and activities are provided in dedicated subsequent sections.

In FY 2023, NASA's STEM Engagement enterprise is committed to implementing the following:

- Drive strategic alignment and a mission-driven programmatic model. This includes conducting a comprehensive analysis of the portfolio and building on programmatic efforts established in partnership with the mission directorates.
- Implement cross-cutting strategies to more effectively reach and serve students, educators, and educational institutions, and to improve operations.
    - NASA will continue to evolve and enhance the new STEM Gateway, which has replaced an outdated performance measurement system with a single platform integrating student registration, functional management, and performance measurement and analytics. Work in FY 2023 includes the integration of a learning management system into Gateway and initiating the deployment to grantees.
    - NASA will also continue to further its work in significantly enhancing its digital footprint to better reach students, including improved products at https://stem.nasa.gov.
    - NASA will continue to drive progress on the Agency internships program, with objectives for growth and enhanced student experiences.
    - NASA will also continue the implementation of a partnerships strategy, cultivating new partnerships to increase reach and impact.
    - NASA will continue to implement and build upon the STEM Engagement Performance Assessment and Evaluation Learning Agenda and conduct a set of studies to inform evidence-based program changes.
    - Finally, NASA will transition efforts to an enterprise STEM engagement services contract selected in August 2022, consolidating 14 contracts and 3 cooperative agreements into a single vehicle.
- Focus on broadening student participation. NASA will continue the implementation of an integrated action plan toward broadening student participation in STEM engagement programs and activities.
- Further an enterprise operating model and focus on building skills and capabilities of the NASA STEM Engagement workforce.
- NASA is committed to continuing its annual planning process and rigorous program management practices in defining and implementing a portfolio of projects, activities, and products directed toward achieving the Agency’s Strategy for STEM Engagement goals and objectives. Ultimately, the work dedicated to this strategy will contribute to achieving NASA’s STEM Engagement vision to immerse students in NASA’s work, attract students to STEM, and inspire the next generation to explore.

KEY ACHIEVEMENTS PLANNED IN FY 2024

NASA will devote increased investments in the Next Gen STEM project to further efforts to provide unique, evidence-based K-12 student learning experiences and opportunities, and to conduct competitive opportunities for educators and educational institutions. Through efforts conducted within cross-cutting functions, NASA will advance its capacity to effectively reach students through efforts to develop and evolve a system to better access, navigate, and use NASA STEM engagement resources and products.

NASA will also further build connections with education ecosystems and networks and engage students by expanding the use of strategic partnerships and networks to magnify the impact of its efforts and investments. Increased investments in Next Gen STEM will establish competitively funded opportunities to develop a set of strategic partnerships with key organizations in the educational ecosystem with large-scale footprints to strengthen the reach and impact of NASA's K-12 STEM engagement efforts.

NASA will continue to enhance and evolve the STEM Gateway, enable performance measurement and analytics, and implement the next stage of the STEM engagement learning agenda, with completion of targeted studies to drive design and evolution of products and activities. Increased investments will also fund programmatic evaluation efforts in alignment with the Agency Learning Agenda.

Specific achievements planned for the Space Grant, MUREP, EPSCoR, and Next Gen STEM projects are summarized in subsequent sections.

NASA SPACE GRANT

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**54.5**	**58.0**	**58.0**	**59.2**	**60.3**	**61.5**	**62.8**
Change from FY 2023 Enacted			**0.0**				
Percent change from FY 2023 Enacted			**0.0%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Montana Space Grant students are shown here working on their High-Altitude Student Platform (HASP) payload. Their experiment was successful in testing multiple stratospheric balloon cut-down units for NASA certification in preparation for the Nationwide Eclipse Ballooning Project.

Space Grant is a competitive grant opportunity that actively involves 52 consortia in 50 States, the District of Columbia, and the Commonwealth of Puerto Rico. Space Grant supports science, engineering, education, and research efforts for educators and students by leveraging the resource capabilities of over 1,000 affiliates from universities, colleges, industry, museums, science centers, and state and local agencies. Cooperative Agreements with each consortium align their work with the Nation’s science, technology, engineering, and mathematics (STEM) education priorities, NASA's missions, and the annual Agency performance goals.

Space Grant utilizes key NASA resources to provide students access to research and hands-on STEM learning experiences. To maximize impact for these STEM investments, Space Grant leverages Agency resources in STEM education through strategic collaborations with NASA centers, subject matter experts, and mission directorates.

The activities conducted by the 52 consortia are in alignment with Agency goals, the Office of STEM Engagement (OSTEM) priorities, and the National Science and Technology Council's (NSTC) Committee on Science, Technology, Engineering, and Math Education (CoSTEM) priority areas. Direct student support is provided by Space Grant awards at the state level consisting of scholarships, fellowships, and/or internships. In addition to the individual efforts of each consortium, nationwide the consortia collectively support a broad array of projects including the Artemis Student Challenges.

EXPLANATION OF MAJOR CHANGES IN FY 2024

No major programmatic changes are planned.

Targeted future partnerships include new science-focused student challenges. Most current student challenges are engineering focused, but STEM is more than engineering. While some consortia do not have strong engineering academic institutions, they do have medical and science colleges and

NASA SPACE GRANT

universities. Initiating these new student challenges potentially in the medical arena and/or Earth and planetary sciences, which includes climate change, will allow Space Grant to reach a larger and more diverse group of students.

With the next total solar eclipse in 2024, Space Grant will work closely with the consortia and NASA mission directorates to support and amplify nationwide STEM engagements around the eclipse.

Additionally, Space Grant will continue to monitor the second of the three-year award of the Space Grant K-12 Inclusivity and Diversity in STEM (SG KIDS) activities. First awarded in FY 2022 with funding initiating in FY 2023, the awardees will continue executing the NASA-aligned hands-on activities that have been heavily geared towards impacting historically underrepresented student populations.

ACHIEVEMENTS IN FY 2022

In FY 2022, Space Grant Consortia each received $800,000, and received the opportunity to propose for an additional $60,000 in augmented funds to Year 3 of the current four-year base award (active through FY 2024). For this base award period, the Consortia proposed activities directly aligning with mission directorate needs and priorities, and were required to apply at least 28 percent of their NASA funds toward direct student awards (e.g., fellowships, internships).

FY 2022 saw the down-select of the two Independent Program-Level Evaluation pilot efforts competitively awarded to New Mexico State University and University of Alaska, Fairbanks. Both awards enabled the Space Grant Consortia to integrate timely and pertinent research questions about the overall efficacy of the Space Grant Program and how the States retain students in STEM. University of Alaska, Fairbanks was selected to scale up evaluation efforts for an additional two years to evaluate the entire Space Grant Consortia.

Space Grant also provided additional opportunities for the Consortia to directly participate in other mission directorate or other OSTEM projects. Space Grant continued a partnership with the Space Technology Mission Directorate (STMD) to provide the Breakthrough, Innovative, and Game-changing (BIG) Idea Challenge. The challenge provided the opportunity for Consortia student teams to design, develop, and demonstrate robotic systems with alternative rover locomotion modalities for use in off-world extreme lunar terrain applications.

Finally, FY 2022 saw Space Grant award $1.4 million for the Space Grant K-12 Inclusiveness and Diversity in STEM (SG KIDS) award which helps advance racial equity and support aligning hands-on activities in historically underrepresented student populations. For this award, four lead space grant consortia are collaborating with many others across the nation to help increase the reach and impact from SG KIDS.

Space Grant Awards in FY 2022		
Award Type	**Number of Awards**	**Funding Total**
Base Awards	52	$44,720,000
Space Grant K-12 Inclusiveness and Diversity (KIDS) Award	4	$1,400,000
Space Grant Collaborations & Special Topics	5	$1,509,847

NASA SPACE GRANT

WORK IN PROGRESS IN FY 2023

Space Grant consortia are currently implementing activities outlined in their four-year accepted proposals. In FY 2023, the Space Grant project will award a funding augmentation to each eligible Consortium, which provides the opportunity for the Consortia to propose raising their base award funding levels to $910,000. Additionally, in FY 2023, Space Grant will release a solicitation to execute the 5th year option and extend the current four-year cooperative agreement by one year.

The SG KIDS Program kicked off in the first quarter of this FY with the assistance of Space Grant ensuring the program is properly initiated and executed. Space Grant will be receiving quarterly updates on the progress of each project to help ensure the targeted student populations are truly impacted.

The Space Grant project will also continue productive partnerships with the mission directorates to engage Space Grant Consortia more effectively in mission priorities. The successful partnership with STMD in the execution of the BIG Idea engineering focused student challenge is being leveraged to develop new relationships with the Science Mission Directorate (SMD), with the goal of developing a new science, climate change, and medical focused student challenge. FY 2024 is the current target for the execution of this new student challenge.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

The Budget supports base awards for the 52 consortia to do the following:

- Provide hands-on learning experiences for U.S. graduate and undergraduate students to prepare them for the future workforce and/or academic careers;
- Expand the quantity of student internships from across all consortia;
- Conduct programs and projects that align with the NASA STEM engagement and mission directorate priorities, CoSTEM priority areas, and state-specific needs to build STEM pathways in higher education, research infrastructure, pre-college, and informal education;
- Amplify NASA's engagement around the 2024 total solar eclipse;
- Continue the Program-Level Evaluation activity;
- Monitor the progress of the new SG KIDS awardees in expanding access to NASA-aligned activities in historically underrepresented student populations; and
- Establish the groundwork for new science focused student challenges to be kicked-off in FY 2024, thus expanding the STEM portfolio beyond engineering focused student challenges.

Project Schedule

Date	Significant Event
Q2 FY 2023	Release of Year 4 Augmentation Notice of Funding Opportunity (NOFO)
Q2 and Q3 FY 2023	Release of Year 4 Base Award Funding
Q2 and Q3 FY 2023	Fund Cohorts 2 and/or 3 of ARMD and Space Grant University Student Research Challenges (USRC)

NASA SPACE GRANT

Date	Significant Event
Q3 FY 2023	Release of 5th Year Base Award Extension NOFO
Q3 FY 2023	Fund Breakthrough, Innovative, and Game-changing (BIG) Idea Challenge
Q3 and Q4 FY 2023	Consortia Site Visits
Q4 FY 2023	Year 1 Progress Review with SG KIDS awardees
Q2 FY 2024	Release of new multi-year Space Grant NOFO

Project Management & Commitments

The Space Grant Project Manager at NASA Headquarters provides management responsibility for day-to-day Space Grant operations. Civil servants at NASA centers actively engage with regional Space Grant Consortia, providing direction, oversight, and integration with center and mission directorate activities.

Acquisition Strategy

NASA solicits through competitive proposals from the 52 Space Grant consortia in 50 States, the District of Columbia, and the Commonwealth of Puerto Rico. Each Consortium program or project must align with the Administration priorities, NASA's Strategic Plan, and the NASA Strategy for STEM Engagement. All award selections undergo rigorous peer reviews by internal and external panels that evaluate technical merit, assess content, feasibility, and alignment to Agency STEM engagement, research, and technology goals. Awards are typically multi-year.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

NASA continues to use performance assessment and evaluation-driven processes to enhance the effectiveness of STEM engagement investments, executing a refined OSTEM learning agenda to understand the outcomes of its investments. Space Grant has continuously assessed its content and activities in pursuit of continuous improvement, in the context of the OSTEM learning agenda.

In FY 2022, two competitively selected Space Grant Consortia (i.e., New Mexico State University and University of Alaska, Fairbanks) completed a two-year, independent program-level evaluation pilot of the Space Grant Program. These pilot evaluations were representative of Space Grant Program offerings across multiple states with the purpose to 1) determine how and to what extent the Space Grant Program is designed and executed in alignment with Federal law and NASA's STEM engagement goals and priorities; and 2) assess the impact and degree to which the Space Grant Program is achieving its intended outputs and outcomes on a national level. These efforts provided robust evidence that can be used to drive future scaled evaluation strategy, program policy, data collection plans, and appropriated competitive awards. Overall results from the awardees' evaluation reports provide preliminary evidence that student

NASA SPACE GRANT

participation in Space Grant programming has a positive effect on both short-to-medium-term and long-term student outcomes and revealed several potential faculty-level outcomes. Proposals were submitted by both awardees describing scaled evaluation plans to assess the entire Space Grant Program (building upon the findings and recommendations of the pilot studies). University of Alaska, Fairbanks was selected to scale up evaluation efforts for an additional two-years beyond the initial two-year pilot award to evaluate the entire Space Grant Consortia.

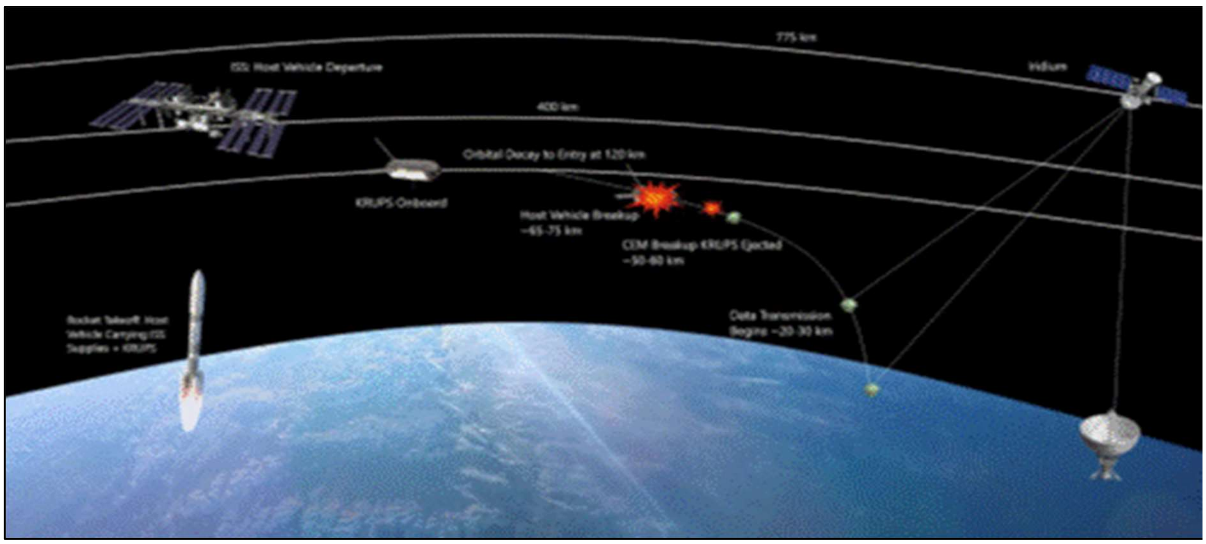
ESTABLISHED PROG TO STIMULATE COMP RSCH

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**26.0**	**26.0**	**26.0**	**26.5**	**27.0**	**27.6**	**28.1**
Change from FY 2023 Enacted			**0.0**				
Percent change from FY 2023 Enacted			**0.0%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



Kentucky EPSCoR uses the ISS to provide a low-cost testbed to quickly evaluate Thermal Protection System materials for heatshields to be used on capsules for re-entry.

The NASA OSTEM Established Program to Stimulate Competitive Research (EPSCoR) Project provides cooperative agreements (CA) designed to establish partnerships between government, higher education, and industry to build stronger research and development capabilities in 28 eligible EPSCoR jurisdictions (states or regions). The project strives to improve a jurisdiction's research infrastructure to a level such that its research and development programs contribute to its economic development. EPSCoR has established a series of individual components to facilitate this work.

- EPSCoR Research Infrastructure Development (RID) CA has a five-year base period of performance with awards up to $200,000 per year, for a total of $1 million.
- EPSCoR Research CA awards are up to $750,000 for a three-year performance.
- EPSCoR International Space Station (ISS) Flight Opportunity Cooperative Agreement utilizes the ISS as a microgravity platform for space flight research.
- EPSCoR Rapid Response Research (R3) CA is a collaborative effort between EPSCoR and the NASA Science Mission Directorate (SMD), NASA centers, commercial partners, and others, to

ESTABLISHED PROG TO STIMULATE COMP RSCH

provide a streamlined method to address high priority research issues such as advancing equity, climate change, and IT Modernization and Cybersecurity which are high priorities for NASA.

- The NSF RII Track 4: @NASA, formerly the EPSCoR Fellows Advancing Science and Technology (FAST), is a joint EPSCoR Project with the National Science Foundation on a MSI-focused program to fund research teams to conduct research in NASA facilities with a NASA researcher.
- EPSCoR normally uses the latest National Science Foundation (NSF) eligibility table to determine overall jurisdiction eligibility for NASA EPSCoR. However, the CHIPS and Science Act of 2022 effectively freezes NSF EPSCoR jurisdiction eligibility through FY 2027. EPSCoR-eligible jurisdictions will remain the same through FY 2027 to include the following jurisdictions: Alabama, Alaska, Arkansas, Delaware, Guam, Hawaii, Idaho, Iowa, Kansas, Kentucky, Louisiana, Maine, Mississippi, Montana, Nebraska, Nevada, New Hampshire, New Mexico, North Dakota, Oklahoma, Puerto Rico, Rhode Island, South Carolina, South Dakota, Vermont, US Virgin Islands, West Virginia, and Wyoming. As a result, no new jurisdictions will be considered eligible for EPSCoR funding through FY 2027 and no jurisdictions will become ineligible.

EXPLANATION OF MAJOR CHANGES IN FY 2024

No major changes.

ACHIEVEMENTS IN FY 2022

The NASA EPSCoR RID Project has grown over the years from one solicitation every three years with $125,000 per year awards to one solicitation every five years with $200,000 per year awards.

In FY 2022, NASA EPSCoR invested a total of $22,660,861 through awards via the components. Below are the amounts allocated to each element.

EPSCoR Awards in FY 2022 (Component Award Values)		
Element	**Awards**	**Total Amount**
EPSCoR Research Infrastructure Development (RID) continuation	28	$5,600,000
Research	15	$11,213,910
ISS Flight Opportunity	5	$499,510
Suborbital Flight Opportunity (SFO)	3	$1,449,407
Rapid Response Research (R3)	39	$3,898,034
Total	**90**	**$22,660,861**

The EPSCoR website document highlights EPSCoR-funded research accomplishments within the eligible jurisdictions, and is available at: https://www.nasa.gov/stem/epscor/home/index.html

EPSCoR contributes to New Innovations featured in 2023 NASA Spinoff. A bioreactor developed with the goal protein in space as a potential food source for astronauts is being adapted to generate quality proteins in under-resourced communities and Africa and Asia. The bioreactor and starter microbe were flown to the International Space Station with help from a grant from NASA EPSCoR awarded to the project's developer Nature's Fund and BioServe Space Technologies.

WORK IN PROGRESS IN FY 2023

EPSCoR will make new Research, R3, ISS, and NSF RII Track 4: @NASA awards. Each funded proposal will establish research activities with the potential to make significant contributions to NASA's strategic research and technology development priorities, while also contributing to the overall research infrastructure, science, and technology capabilities of higher education, and economic development within the EPSCoR jurisdiction.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

NASA EPSCoR will continue to issue calls for five to ten ISS Flight Opportunity awards, four to six Suborbital Flight Awards, 30-35 R3 awards, and 15-18 Research NOFO awards. Additionally, EPSCoR will increase the NSF RII Track 4: @NASA participation. In addition, EPSCoR is investigating the possibility of increasing the award amounts for the ISS Flight Opportunity awards with additional funding from other mission directorates.

Project Plan

Date	Significant Event
Q1 and Q2 FY 2023	Release of Solicitations: Research Notice of Funding Opportunity Research Infrastructure Development (RID) EPSCoR Rapid Response Research (R3) ISS Flight Opportunity NSF Research Infrastructure Improvement (RII) Track 4: @NASA
Q1 and Q2 FY 2023	Proposals Due and Review Process
Q3 & Q4 FY 2023	Selection and Awards: Research NOFO Research Infrastructure Development (RID) EPSCoR Rapid Response Research (R3) ISS Flight Opportunity NSF Research Infrastructure Improvement (RII) Track 4: @NASA

ESTABLISHED PROG TO STIMULATE COMP RSCH

Project Management & Commitments

The NASA EPSCoR project manager is responsible for overall administrative duties of this national project. The project manager is supported by a team consisting of an integration manager, grants manager, budget analyst, and contractor staff. The EPSCoR project office works closely with representatives from each OSTEM project, NASA center, mission directorate, and scientific team to ensure that current and future research requirements are in EPSCoR solicitations. The mission directorate and NASA center representatives serve as the proposal selection committee, further ensuring that the selected work contributes to NASA priorities. Technical monitors (subject matter experts) from the NASA centers and Headquarters monitor and assess the progress of each award. They provide scientific guidance and technical advice as required throughout the year regarding the overall progress of the proposed effort and review all progress reports.

NASA is a member of the Federal EPSCoR Interagency Coordinating Committee (EICC), chaired by the NSF. The committee works to improve the leveraging of Federal EPSCoR investments.

A comparison of pathogen-infested standard sand (shown here is a soil mixture [left] and Mars regolith [right] with treated soybeans) will help better understand the results of beneficial microbes to plants in harsh conditions. (Photo credit: Brandon Kleinke, Iowa State University)

Acquisition Strategy

NASA solicits and awards EPSCoR Cooperative Agreements through a competition among institutions from designated EPSCoR States called jurisdictions. Each jurisdiction's proposal must align with the Administration's priorities and NASA's Strategic Plan. All award selections undergo rigorous peer reviews by internal and external panels that assess technical merit, content, feasibility, and alignment to Agency research and technology goals. Awards are typically multi-year.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

NASA continues to use performance assessment and evaluation-driven processes to enhance the effectiveness of STEM engagement investments, executing a refined Office of STEM Engagement (OSTEM) learning agenda to understand the outcomes of its investments. EPSCoR has continuously assessed its activities in pursuit of continuous improvement within the context of the OSTEM learning.

MINORITY UNIVERSITY RESEARCH EDU PROGAM

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**43.0**	**45.5**	**48.1**	**49.1**	**50.1**	**51.1**	**52.2**
Change from FY 2023 Enacted			**2.6**				
Percent change from FY 2023 Enacted			**5.7%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Dr. Eduardo Nicolau, Puerto Rico Space Partnership for Research Innovation and Training Principal Investigator, works on an experiment for a course related to astronauts' immune systems in space at the University of Puerto Rico, Rio Piedras Campus.

The Minority University Research and Education Project (MUREP) provides grants and cooperative agreements to the Nation's Historically Black Colleges and Universities (HBCUs), Hispanic Serving Institutions (HSIs), Asian American and Native American Pacific Islander-Serving Institutions (AANAPISI), Tribal Colleges Universities (TCUs), Alaska Native and Native Hawaiian Institutions (ANNHs), Predominantly Black Institutions (PBIs), and eligible community colleges. These minority-serving institutions (MSIs) play a vital role in educating students who may be underrepresented and underserved in STEM, including women and girls, veterans, and persons with disabilities. MUREP's investments in these MSIs are part of a comprehensive approach toward advancing equity for all, including people of color and others who have been historically underserved, marginalized, and underrepresented in STEM fields.

Participation in NASA projects and research has the potential benefit of both increasing numbers of students in STEM at all education levels and encouraging them to earn degrees in STEM fields that are critical to NASA and the Nation.

NASA's MUREP investments enhance the research, academic, and technology capabilities of MSIs through competitive, multi-year awards. Awards assist faculty and students in research and provide authentic STEM engagement related to NASA missions. These funded opportunities provide NASA-specific knowledge and skills to historically underrepresented and underserved students in STEM. MUREP investments also assist NASA in meeting the goal of a diverse future workforce through student participation in internships and fellowships at NASA centers.

EXPLANATION OF MAJOR CHANGES IN FY 2024

MUREP's focus will shift to special emphasis on an often-over looked area, community colleges and other two-year institutions. This new Community College initiative seeks to create deeper engagement with this important subset of higher education institutions and the students that they serve. There is a critical need for technology development and apprenticeship programs to meet the ever-growing demands of the aerospace industry. FY 2024 will see more concentration on our student engagement efforts (e.g., competitions, challenges) at community colleges and making our offerings more scalable and inclusive for those not pursuing four-year degrees. MUREP's NASA Community College Aerospace Scholars (NCAS) activity will look to expand the number of sites around the country where students can learn about careers in STEM, project management, and various team coding activities. MUREP feels that there will be great dividends reaped from these targeted efforts.

FY 2024 will also see the next iteration of one of our most robust and financially impactful awards, the MUREP Institutional Research Opportunities (MIRO) activity. This fiscal year will highlight a significant change in MIRO's philosophy on creating a more diverse portfolio that values MSI category, size of institution, and other Diversity, Equity, Inclusion, and Access (DEIA) elements, while remaining true to the tenants of increasing overall research competitiveness and sustainability at the universities. As more agencies move into the MSI arena and provide funding opportunities, MIRO is set to usher in the next wave of institutional changing opportunities that can shift the STEM research trajectory at MSIs.

ACHIEVEMENTS IN FY 2022

In FY 2022, the Office of STEM Engagement (OSTEM) continued to lean into its use of the NASA STEM Gateway (registration/application and data management system). Further enhancements improved the ability to collect performance data within historical data collection timelines while tailoring the data to suit its various user community. Until the Performance and Evaluation Team has completed its verification and validation process, all performance data reported should be considered preliminary.

Strengthening Minority Serving Institutions (MSI):

In FY 2022, MUREP provided engagement and oversight of 132 active cooperative agreement awards at 59 MSIs across 29 states and territories.

MUREP provided 951 significant awards (e.g., internships, fellowships, engineering design challenges, student competitions) across all institutional categories and levels in FY 2022. These significant awards provided a total of approximately $3.5 million in direct financial support to higher education students at MSIs.

MUREP educator professional development participants included 33,028 in-service K-12 educators, informal educators, higher education faculty, preservice educators, and administrators. Additionally, 98,080 K-12 and higher education students participated in MUREP STEM engagement opportunities.

Growing Partnerships to Reach Target Populations:

In order to meet Mission Directorate goals of broadening participation and growing the ways in which MSIs are engaged, MUREP partnered with the Earth Science Technology Office to advance idea generation for autonomous systems that can aid future missions in space and on earth. The first MSI Space Accelerator competition was developed, and three awards were made in the summer of 2022.

Leveraging Technology to Drive Participation:

The MSI Exchange has expanded its reach to more Federal STEM agencies who utilize and site STEM MSI List as a source. Internal NASA users from STMD (Tech Port) and OSTEM (Gateway) also seek out this valuable tool to gain data on Higher Education Institutions and how they map to various

MINORITY UNIVERSITY RESEARCH EDU PROGAM

demographics and fall within certain Congressional districts. For more information, go to: https://msiexchange.nasa.gov/

MIRO aims to promote literacy in STEM at MSIs and to enhance the sustainable capabilities of institutions to perform research and education aligned to NASA's mission. Sixteen of these research awards were under cooperative agreement management going into FY 2022 and resulted in 461 peer-reviewed publications, technical papers, and presentations. Additionally, eight patents and one technology transfer were granted. Over 400 students were authors on publications.

MUREP has instituted the use of planning grants as a method to attract and prepare MSIs who desire to compete for larger funding opportunities. The planning grants have allowed MUREP to better understand the research capabilities of those MSIs who have traditionally not submitted proposals and to leverage relationships to build a more robust MSI pipeline. These planning grants yielded 12 new awards to 10 MSIs.

WORK IN PROGRESS IN FY 2023

MUREP will continue to support multiple award selections to MSIs under the annually released FY 2023 Engagement Opportunities in NASA STEM (EONS) solicitation. By continuing to align much of its funding opportunities to mission directorate research focus areas, MUREP not only adds value to accomplishing the Agency's mission, but through its collaboration and partnering relationships with other Federal Agencies, academic and industry leaders, it also develops deeper connections and engagement with MSIs.

MUREP will continue to make investments through its American Indian and Alaska Native STEM Engagement (MAIANSE) to increase engagement in STEM through authentic and unique NASA experiences. Partnership efforts with the American Indian Science and Engineering Society (AISES) as well as the American Indian Higher Education Consortium (AIHEC) will help to ensure greater reach into the academic institutions and STEM communities. Funding opportunities will again be provided to promote STEM identity for students and strengthen institutional capacity efforts.

MUREP will also aim to invigorate revamped high school bridge STEM programming approaches that balance a portfolio of activities with a diverse group of student participants and MSI types toward enhancing STEM degree attainment for underrepresented and underserved students in NASA related STEM majors. By focusing additional resources to create programs for high school students likely to matriculate at HBCUs/MSIs, MUREP can assist the academic pathway to fulfill our NASA goal of increasing the number of diverse explorers. These opportunities will drive awareness for these students. While student competitions and challenges will continue to be important, there will be greater emphasis on creating synergy amongst the different activities and finding ways to introduce more groups of students to the entire portfolio to provide multiple touchpoints into OSTEM programming.

MUREP will continue to support the advancement opportunities, access, and representation for Underserved Communities through a NASA MUREP Women's Colleges and University (WCU) initiative. NASA MUREP WCU Activity is a new initiative seeking to address the significant gender gap and disparate experiences of women in STEM in the United States, both in higher education and the workforce. The MUREP WCU funding opportunity, in response to Executive Order 14035 "Diversity, Equity, Inclusion, and Accessibility in the Federal Workforce," calls on WCUs, as identified by Department of Education data, to leverage their women-centered expertise and experience to address barriers to women seeking, retaining, and remaining in STEM degrees and employment. MUREP plans to award its first cohort of grantees under the Data Science Equity, Access, and Priority (DEAP**)** Artificial

MINORITY UNIVERSITY RESEARCH EDU PROGAM

Intelligence & Machine Learning (AI/ML) activity, in collaboration with the Science Mission Directorate (SMD). This particular effort has two key elements:

- By focusing exclusively on HBCUs/PBIs, there is intentionality around increasing the research capacity in these burgeoning fields at MSIs. Targeted solicitations also aid the Agency in meeting its White House Initiative for HBCUs (WHIHBCU) goals, objectives, and metrics; and
- Reinforce SMDs Open Science Data initiatives wherein barriers to accessing scientific data are reduced/eliminated and MSIs are encouraged to utilize NASA's rich repository of data sets to foster research and discovery.

MUREP recognizes that DEIA must reach beyond our conversation and into the fabric of our solicitations and awards. Gender disparities continue to be an issue in STEM, broadly, as well as for those attending MSIs. MUREP is launching, in conjunction with the Women in STEM Initiative, the Women-only Colleges & Universities solicitation to address gender disparity and barriers in STEM. This activity/pilot will seek to foster unique student opportunities given the targeted populations, while promoting research to bolster women/girls in STEM disciplines.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

MUREP will feature its next climate focused collaboration with SMD/Earth Sciences Division as a follow up to the OCEANS activity, and the NASA/NSF partnership on INCLUDES (focus: Broadening Student Participation in Engineering) will look to fund the second cohort of MSIs.

MUREP will continue to support the Agency's one percent Procurement/Small Business goal by creating forums for HBCUs/MSIs to leverage their strengths in the contracting arena. Jointly coordinated road tour events at strategically located MSIs with the Office of Procurement and the Office of Small Business Programs will offer new and novel ways for Higher Education Institutions (HEIs) to engage in the work of NASA outside of traditional grants and cooperative agreements. Utilizing the planning grant model to aid in training and development in addition to funded partnerships, MUREP hopes to see dividends for HBCU/MSIs in the contract arena.

Further expansion of research efforts that fund MSIs with necessary resources are critical to build capacity and develop Centers of Excellence that transcend the original awards provided by NASA. These interdisciplinary efforts are cross-cutting and align directly with mission directorate priorities.

Project Schedule

EONS is an omnibus announcement that includes a range of NASA STEM Engagement opportunities for basic and applied science and technology research and education. In FY 2023-2024, the OSTEM Program (inclusive of Space Grant, Next Gen STEM, MUREP, and EPSCoR) incorporated their various funding opportunities under the renamed Engagement Opportunities in NASA STEM (EONS). The consolidated approached was derived for the purpose of: 1) establishing best practices for the projects; 2) eliminating redundancies and duplicative efforts; and 3) generating more consistent solicitation approaches for the broader community of proposers for OSTEM opportunities.

MINORITY UNIVERSITY RESEARCH EDU PROGAM

The table below includes significant FY 2023 MUREP milestones.

Date	Significant Event
Q1 FY 2023	Open EONS Omnibus Solicitation; Release MUREP Pre-College Summer Institute (PSI) appendix
Q2 FY 2023	MUREP Women's College & University; M-STAR (space technology), Curriculum (two-year and four-year)
Q3 FY 2023	MUREP Mission Directorate Planning Grant Release(s)
Q4 FY 2023	Student Engagement Team Competitions/Challenges kickoff(s)

Project Management & Commitments

The MUREP project manager is located at NASA Headquarters and provides management and oversight for overall activity operations. NASA centers manage significant investments in project activity elements. MUREP activities map strategically to four investment pillars: Research Infrastructure and Capacity Building, Curriculum Development and Service Provider Resources, Student Engagement, and Partnerships & Sustainability.

Acquisition Strategy

NASA MUREP awards cooperative agreements, grants, and contracts (if applicable) through full and open competition.

MAJOR CONTRACTS/AWARDS

None.

Independent Reviews or Evaluation

All MUREP activities document performance through either external evaluations or internal reviews.

MUREP continues to utilize performance assessment and program evaluation to inform continuous improvement processes and evidence-based decision making. In FY 2022, NASA developed a comprehensive framework/plan for future outcome assessment of MUREP investments building upon the findings and recommendations from FY 2020 - FY 2021 MUREP Program-Level Evaluation studies. Executing a MUREP Outcome Assessment will help NASA understand the outcomes of MUREP and its associated activities in regard to student recruitment and retention and strategic partnerships. The outcome assessment framework/plan provides an approach and tools to examine how achievements related to participation in or collaboration with MUREP are realized by MUREP investments and evidence that can be used to help guide future programmatic decisions.

NEXT GEN STEM

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**13.5**	**14.0**	**25.7**	**26.2**	**26.7**	**27.3**	**27.8**
Change from FY 2023 Enacted			**11.7**				
Percent change from FY 2023 Enacted			**83.6%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

NASA SPARX challenges and competitions aim to broaden student participation in Agency STEM opportunities.

Next Gen STEM (NGS) contributes to building a strong, diverse future STEM workforce by providing learning opportunities for students in grades K-12 that infuse the excitement of NASA missions and programs into an integrated portfolio of educational products, experiences, challenges, and competitive awards. NGS reaches students in school, in after school programs, in informal education institutions, and at home. NGS employs evidence-based practices to broaden student participation in STEM, ensuring the greatest accessibility to NASA STEM opportunities while providing educator support.

NGS includes a competitive awards program for Informal Education Institutions (IEIs), Teams Engaging Affiliated Museums, and Informal Institutions (TEAM II). The TEAM II Program is supported by the Museum and Informal Education Alliance, a vibrant community of practice for all IEIs.

EXPLANATION OF MAJOR CHANGES IN FY 2024

The NASA budget provides a $11.7 million increase to the enacted FY 2023 budget. This significant increase reflects the desire to significantly grow the project’s ability to provide educational offerings and educator support to pre-college beneficiaries, to initiate funded partnerships to significantly expand reach and effectiveness, and for NGS to serve as an integration point and service provider for K-12 initiatives across the Agency, amplifying Agency effectiveness in STEM Engagement. NGS has a primary goal of building a strong future STEM workforce through lowering barriers to participation for students and educators, especially those in communities historically underserved or underrepresented in STEM, and through more effectively serving their communities with programming that positively impacts STEM learning outcomes in the context of those communities and their unique needs.

NEXT GEN STEM

Of the $11.7 million increase to Next Gen STEM:

- $5 million would support new strategic partnerships to expand NASA's reach and impact in the K-12 education space. NASA will develop and release an open solicitation designed to support external organizations in the development and execution of high impact national activities to engage diverse learners in NASA STEM content and careers.
- $0.4 million would support evaluation efforts to determine how NASA’s internships program affects student outcomes and to provide insights on how to strengthen teaching and mentoring practices within the program.
- $2 million would go to expanding strategic offerings of in-person professional development for pre-service and early career educators at community hub events hosted at Minority Serving Institutions (MSIs) and other key community partners.
- $1.5 million would fund adequate staff and materials to enable a 400 percent increase in students served over FY 2022 SPARX pilot participation numbers, or approximately 10,000 students. NASA Sparking Participation in Authentic Real-world eXperiences (SPARX) challenges deliver hands-on experiences for students of all educational levels and build STEM identity through a continuum of offerings that meets students where they are in their STEM learning journey. This budget proposal allows increased student engagement in the spring semester of the 2023-2024 school year and all of the 2024-2025 academic year.
- $1.3 million would support continued improvements to the NASA Engages online tool to match NASA role models and STEM experts to community needs across the Nation. The funds will enable recruitment and training of more NASA employees to successfully engage with students, share their knowledge and personal career journeys, and inspire students to persist in STEM and choose STEM careers. This effort will ensure the Federal workforce participating in this effort is empowered with relevant information and techniques to effectively engage with diverse student audiences.
- $1.5 million would support increased awards to IEIs through TEAM II. This will include two additional awards in the $800,000 range and 10 additional smaller Community Anchor awards over the numbers awarded in FY 2023. Community Anchor awardees receive $40,000 to help them establish themselves as new or emerging local NASA STEM informal education community resources and to reach into communities underserved and underrepresented in STEM with the most current and authentic NASA content and experiences.

ACHIEVEMENTS IN FY 2022

Next Gen STEM continued to develop innovative approaches to expand opportunities for students and educators through its extensive portfolio. A few examples of FY 2022 achievements include:

- NGS piloted a new approach to engaging underserved student communities through its first implementation of NASA SPARX. The pilot, which included simultaneous formal evaluation, accomplished the goal of increasing and broadening reach while significant feedback and evaluation fueled a re-design effort that will further address the needs of students and educators who are new to STEM challenges and NASA content. NGS educational products were reimagined to be more accessible and usable by all types of educators, while retaining academic rigor and alignment to national standards. NGS also completed development and live educator beta testing of NASA CONNECT and formally launched this new community of practice and support for educators.

NEXT GEN STEM

- Education downlinks from the International Space Station continued to have a strong impact and engaged diverse groups of students. NASA astronauts Raja Chari and Kjell Lindgren flew symbolic items on station to share with military-affiliated students. Jessica Watkins responded to questions from Kentucky students by providing a welcome diversion to a community that experienced catastrophic flooding. These virtual opportunities for students to engage with astronauts in space continue to spark excitement and genuine STEM learning through the accompanying hands-on experiences provided.
- Large-scale Virtual Engagement opportunities offered through CONNECTS allowed students to meet NASA role models and ask them questions about their diverse backgrounds, personal stories, and current work. The sessions sparked student interest in STEM, enabling them to envision themselves in STEM careers.
- TEAM II funded large Community Anchor awards to institutions to make positive impacts for STEM learning and persistence in their communities. Four large projects were funded in FY 2022 for a total of $3.2 million and the first cohort of TEAM II Community Anchors was selected with 21 informal education institutions receiving a total of $520,000 to function as NASA partners and STEM learning resources in their local communities.

WORK IN PROGRESS IN FY 2023

While plans in FY 2023 have been scaled commensurate to the enacted NGS budget, exciting efforts continue. In FY 2023, TEAM II and Community Anchor awards will be awarded and existing awards executed. NGS is continuing new initiatives begun in FY 2022 including NASA CONNECTS and SPARX with reduced growth and serving a more limited number of students and educators. NGS has provided initial funding (FY 2022 funds) for, and is spearheading the development of, a new online tool for connecting NASA professionals and role models to students, strategically and at scale. Also, through its mission focus areas (Earth, Moon, Aeronaut-X, and Solar System and Beyond), the project will continue to create standards-aligned education resources, impactful virtual and in-person student experiences, and educator training centered on NASA's mission focused areas. Some notable efforts currently in progress are:

- NGS is completing re-design of, and preparing for a public launch of, its SPARX student challenges (in early FY 2024) by using feedback and formal evaluation from the FY 2022 pilot to inform improvements and determine best approaches for reaching audiences from generally underrepresented communities. SPARX will deliver sustained STEM engagement in classroom and out-of-school environments with high-quality, standards-aligned content and ongoing educator support.
- In-flight International Space Station (ISS) education downlinks, and other activities tied to the excitement of the orbiting laboratory and its crews, will continue to reach diverse audiences by expanding its recruitment efforts. Already in FY 2023, two downlinks have connected Native American astronaut Nicole Mann with the Flathead Reservation in Montana and the Choctaw Nation in Oklahoma.
- NGS is continually improving the efficacy of its portfolio. This year NGS will fund formal evaluations, literature reviews, and benchmarking studies to inform project direction. NGS is also continuing to cultivate relationships with the States' STEM education organizations and key national educator support organizations to better understand educator needs and how NGS and NASA can help fill those needs.

NEXT GEN STEM

KEY ACHIEVEMENTS PLANNED FOR FY 2024

In FY 2024, several key efforts begun in FY 2023 will come to fruition or will be enhanced and extended, as detailed in the "Explanation of Major Changes in FY 2024" section above. In summary, key achievements planned for FY 2024 include:

- A re-designed, evidence-based NASA SPARX Program will publicly launch and deliver learning experiences inspired by the breadth of major NASA missions and projects to significantly lower barriers to participation.
- NASA CONNECTS will expand its membership and value to members by increasing offerings of NASA resources, expanding member support services, and partnering with other Federal agencies to feature a broader array of STEM resources.
- FY 2024 will include the first full year of implementation of the Agency-wide training and support initiative for NASA's employees to engage more effectively with students of all ages, called NASA Engages. With a state-of-the-art online platform to match requests for engagement with appropriately selected NASA role models, the program will enable NASA STEM professionals to make a positive impact on students in formal, informal, virtual, and in-person engagements of various types, strategically and at scale.

Project Schedule

As described in previous sections, FY 2023 and FY 2024 will be pivotal years for NGS, with many new and improved products and offerings for K-12 students, informal and formal educators, and IEIs.

Date	Significant Event
Q1 FY 2023	2023-2024 SPARX student challenges and competitions Content Development
Q1 FY 2023	Formative Evaluation Studies
Q2 FY 2023	Selection of new TEAM II full, and Community Anchor Awardees
Q3 FY 2023	Recruitment and selection of NASA STEM professionals for K-12 STEM Engagement training program
Q3 FY 2023	2023-2024 school year announcement of offerings for SPARX challenges and competitions
Q3 FY 2023	New Educator Professional Development Offerings available
Q4 FY 2023	Launch STEM Subject Matter Expert training program for effective STEM engagement with students
Q4 FY 2023	New standards and mission aligned content released for summer and 2024-2025 school year
Q4 FY 2023	Release of a FY 2024 TEAM II Full and Community Anchor Award Solicitation
Q1 FY 2024	NASA SPARX student challenges begin
Q2 FY 2024	Selection of TEAM II Full and Community Anchor Awardees
Q3 FY 2024	Conclusion of 2023-2024 School Year NASA SPARX challenges and culminating events

NEXT GEN STEM

Project Management & Commitments

The Next Gen STEM project leadership team reports to NASA Headquarters but are each located near a NASA field center. The remainder of the Next Gen STEM activity leads, and all supporting personnel for project efforts, are located at various NASA field centers. The current Next Gen STEM elements are as follows:

- Earth (Includes a focus on Earth and Climate Science, as well as activities ongoing on the ISS);
- Moon (Focused on exploration of the Moon through the Artemis Program);
- Aeronaut-X (Focuses on NASA's endeavors in aeronautics research and development);
- Solar System and Beyond (Brings the excitement of space science and exploration of the solar system to classrooms);
- Competitive Awards - TEAM II; and
- Educator Support and Development (Includes CONNECTS Community of Practice with Formal and Informal [MIE Alliance] Subgroups and opportunities for educator learning).

Acquisition Strategy

Consistent with existing NASA practices, NASA uses cooperative agreements, grants, and contracts through full and open competitions. All Next Gen STEM award selections undergo rigorous peer reviews by internal/external experts, usually including panel reviews, that evaluate proposals technical merit, feasibility, and alignment to Agency STEM Engagement goals and objectives. In-house initiatives are executed through civil servant leadership and contractor support through the newly awarded Office of STEM Engagement unified contract (NSTEM).

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

Since its inception, NGS has used program evaluation to inform its continuous improvement process. In FY 2022, NGS evaluation centered around an evaluation of the NASA SPARX challenge and competition pilot. The overall purpose of the evaluation was to build knowledge about NGS activities by understanding feasibility, appropriateness, and usability of NASA SPARX. Findings from the study focused on streamlining the requirements for participation, engaging students from underrepresented communities, and recommendations for program improvement. These findings were used to inform FY 2023 evidence-building plans.

Building on the FY 2022 findings, FY 2023 evaluation activities will focus on building evidence-based program design for four NGS efforts: SPARX, CONNECTS, the Subject Matter Expert (SME) Initiative, and Educator Professional Development. Evidence from the FY 2022 SPARX evaluation has enabled the selection of a program design framework for SPARX. The program design framework will support the implementation team in planning the FY 2024 implementation of SPARX and the FY 2024 evaluation of that implementation. The CONNECTS evaluation plan will focus on assessing how CONNECTS is meeting its goals and objectives and understanding educators' needs and use of CONNECTS. The CONNECTS evaluation planning process will create data collection tools for use by the evaluation team and CONNECTS staff. The SME Initiative evaluation activities will include a literature review and benchmarking study, and recommendations for a theory of change and logic model. An Expert Review Panel (ERP) will be formed to provide external review and feedback to the proposed recommendations. Finally, the Educator Professional Development (EPD) evaluation activities will develop an evidence-based framework for EPD implementation and evaluation. The framework will be based on a literature review and benchmarking study of approaches to and best practices in EPD. The overall outcome of these evaluation activities will be a high-quality, evidence-based program design for key NGS efforts in FY 2023 and lay the groundwork for the execution of formative evaluation studies in FY 2024.

SAFETY, SECURITY, AND MISSION SERVICES

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Mission Services & Capabilities	1,987.2	--	**2,259.3**	2,304.1	2,350.0	2,397.1	2,445.0
Engineering, Safety, & Operations	1,033.4	--	**1,110.1**	1,132.7	1,155.5	1,178.5	1,202.1
Total Budget	**3,020.6**	**3,129.5**	**3,369.4**	**3,436.8**	**3,505.5**	**3,575.6**	**3,647.1**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

SAFETY, SECURITY, AND MISSION SERVICES

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Mission Services & Capabilities	1,987.2	--	**2,259.3**	2,304.1	2,350.0	2,397.1	2,445.0
Engineering, Safety, & Operations	1,033.4	--	**1,110.1**	1,132.7	1,155.5	1,178.5	1,202.1
Total Budget	**3,020.6**	**3,129.5**	**3,369.4**	**3,436.8**	**3,505.5**	**3,575.6**	**3,647.1**
Change from FY 2023 Enacted			**239.9**				
Percent change from FY 2023 Enacted			**7.7%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

NASA's Space Launch System (SLS) rocket with the Orion spacecraft aboard is seen atop a mobile launcher at Launch Pad 39B as it prepares for launch. This milestone was supported by mission support services.

Safety, Security, and Mission Services (SSMS) enables NASA's missions by providing foundational support capabilities to meet NASA's evolving mission requirements with efficiency and effectiveness.

SSMS funding provides resources for essential business and technical functions across nine NASA centers and Headquarters (HQ). NASA manages operations with independent oversight to ensure the health and safety of NASA employees and the public. SSMS programs provide services and capabilities that ensure NASA has the technical skills, physical and information technology (IT) assets, financial resources, and top talent to be successful, safe, and reliable.

MISSION SUPPORT PRIORITIES

As shown in Table 1 below, NASA Strategic Plan 2022, Goal 4, directs NASA's mission support functions to enhance capabilities and operations to catalyze current and future mission success through three key objectives: 1) attract and develop a talented and diverse workforce; 2) transform mission support capabilities for the next era of aerospace; and 3) build the next generation of explorers. Functions and capabilities that align to these three priorities comprise the foundational business that supports NASA activities, including the Agency's mission goals.

Mission Support's strategic approach ensures that critical services are mission ready as requirements evolve and foundational services are keeping pace with cybersecurity, industry standards, and Agency needs. NASA Mission Support will continue to support the critical capabilities needed for mission success by staying focused on mission needs, center conditions, and transformational opportunities. As reflected in Table 2 below, mission support content is prioritized to achieve the Administration, NASA, and mission support goals and objectives.

SAFETY, SECURITY, AND MISSION SERVICES

Table 1: NASA Strategic Goals and Objectives

Theme	Goal Statement	Objective
DISCOVER	Expand human knowledge through new scientific discoveries	1.1 Understand the Earth system and its climate
		1.2 Understand the Sun, solar system, and universe
		1.3 Ensure NASA's science data are accessible to all and produce practical benefits to society
EXPLORE	Extend human presence to the Moon and on towards Mars for sustainable long-term exploration, development, and utilization	2.1 Explore the surface of the Moon and deep space
		2.2 Develop a human spaceflight economy enabled by a commercial market
		2.3 Develop capabilities and perform research to safeguard explorers
		2.4 Enhance space access and services
INNOVATE	Catalyze economic growth and drive innovation to address national challenges	3.1 Innovate and advance transformational space technologies
		3.2 Drive efficient and sustainable aviation
ADVANCE	Enhance capabilities and operations to catalyze current and future mission success	4.1 Attract and develop a talented and diverse workforce
		4.2 Transform mission support capabilities for the next era of aerospace
		4.3 Build the next generation of explorers

Table 2: Mission support prioritized activities to support the Administration's intent, Administrative priorities, and NASA's strategic goals

Cybersecurity
Strengthen NASA's IT infrastructure, monitoring, detection systems, encryption, cloud security, and authentication to enhance protection for data and telecommunications.

Orbital Debris
Continue to protect the safe exploration of space and national assets with modeling, monitoring, enhanced computing, policies, and standard practices to mitigate increases in orbital debris hazards.

Innovate for Equity
Implement data analytics, training, and leadership development to increase diversity, equity, inclusivity and accessibility in the NASA workforce, science community, and space partners.

Climate Change
Support NASA missions that investigate earth science, human impact, and "green innovation". Reduce NASA's footprint and support environmental stewardship, including the acquisition of a zero-emission vehicle (ZEV) fleet and support infrastructure.

Workforce, Essential Services, Partners
Support mission-critical services that enable NASA's activities and address workforce needs, including procurement of essential goods and "best-in-class" contracts.

Future of Work
Empower NASA employees by investing in IT and collaborative technologies, creating flexible HR policies for remote-work options (where appropriate), developing cyber-physical and inclusive workspaces, and utilizing of data for decision-making.

Critical Infrastructure
Conduct vital construction, repairs, and demolition to reduce risk in NASA's infrastructure portfolio and ensure the right capabilities are mission-ready at the right time.

Business Transformation
Introduce technologies and new processes to create strategic cohesion, service resilience, new efficiencies, and cutting-edge capabilities to enhance how people work and reduce costs.

SAFETY, SECURITY, AND MISSION SERVICES

BALANCING SSMS AND CECR

NASA's mission support portfolio is divided between two accounts: Safety, Security, and Mission Services (SSMS) and Construction and Environmental Compliance and Restoration (CECR). The Mission Support Directorate (MSD) utilizes both accounts to maintain NASA's critical infrastructure. SSMS and CECR programs are dependent upon each other and there is a balance between maintenance of assets and infrastructure, repairs and renewal of failing assets, and the replacement and demolition of obsolete assets. Required maintenance activities drive SSMS spending decisions, while repairs, renewals (including new construction), and associated demolition drive CECR spending.

Much of NASA's infrastructure dates back to Apollo-era space exploration. Maintenance activities funded by SSMS are necessary to prevent costly delays to missions and risks to health and safety. Meanwhile, failures require immediate repairs and account for an increasing share of the SSMS facilities maintenance budget. These activities are vital to support evolving mission requirements. SSMS also funds proactive maintenance initiatives such as Condition Based Maintenance to identify issues and provide lower cost, scheduled maintenance. Without a sufficient facilities maintenance budget, assets and facilities worsen to a state requiring CECR funding for more expensive solutions. The rapidly increasing activities in commercial space development and deep space exploration places an additional strain on NASA's infrastructure and mission-unique facilities. Both SSMS and CECR activities are vital to support mission requirements. MSD takes an Agency-wide approach to make difficult trade-off decisions that ensure critical capabilities and assets are mission-ready, while also investing in the long-term asset health, sustainability, and footprint reductions that ensure NASA's future mission success. This approach allows NASA the ability to prioritize investments in support of long-term asset health, sustainability, and footprint reductions that ensure NASA's future mission success.

EXPLANATION OF MAJOR CHANGES IN FY 2024

Funding for the Aircraft Capability Management Office (ACMO), created in MSD in FY 2022 to actively pursue the recapitalization of aging aircraft assets, is realigned from the Infrastructure and Technical Capabilities (I&TC) Program to the Center Engineering, Safety, and Operations (CESO) Program. ACMO is responsible for the establishment and management of the aviation capability portfolio with a focus on developing and advancing aircraft capabilities that support NASA’s long-term mission goals.

Funding for Library Services was realigned from the I&TC Logistics Management project to the Mission Enabling Services Office of Communications project to better ensure the preservation of NASA’s history and information services.

Funding to support the Office of the Chief Technologist (OCT) was realigned from the Space Technology Mission Directorate (STMD) to CESO to create the Office of Technology, Policy, and Strategy (OTPS). OTPS is a merger of the Office of Strategic Engagements and Assessments and the OCT. The OTPS provides data- and evidence-driven technology, policy, and strategy advice to NASA leadership to develop and guide Agency’s activities across its six mission directorates.

ACHIEVEMENTS IN FY 2022

Mission Services and Capabilities continued transforming business for greater efficiency and effectiveness, while enabling safe, sustainable, and successful mission activities. Stronger cybersecurity standards and new tools were implemented which helped improve detection of cybersecurity incidents on Agency networks and improve investigative and remediation capabilities. Virtual tools were optimized with secure, accessible, and leading-edge technologies, applications, and platforms to enable collaboration, productivity, and flexibility for NASA's hybrid workforce. Foundational business services, employee safety and security, and external communications with stakeholders and the Nation on NASA's missions were streamlined, improved, and automated. Employee opportunities for growth and development were enhanced while supporting diversity, equity, and inclusion through the utilization of critical workforce data and analytics. NASA's physical asset portfolio, including facilities, roads, and utilities, and commitment to environmental stewardship were enhanced. Significant progress was made on the Agency Master Plan (AMP), which is designed to better understand the linkage between assets and missions through centers.

Engineering, Safety, and Operations (ESO) provided guidance, testing, and oversight to ensure health, safety, and stewardship of resources, including the environment. Standards and directives supporting Agency priorities, such as orbital debris mitigation and planetary protection, were updated. An international partner summit, Artemis Medical Charters, was developed to provide a structure for medical decision-making. Personnel protective services and operational safety, investments in key center needs, and leadership of center and corporate functions were improved. Investments in labs and test equipment were implemented to upgrade and modernize capabilities.

WORK IN PROGRESS IN FY 2023

Mission Services and Capabilities is advancing cybersecurity needs, maturing business enterprise capabilities, and seeking modernized ways to maintain NASA's critical infrastructure. The IT Program is improving NASA's cybersecurity posture by enhancing encryption capabilities, upgrading licensing and software, modernizing enterprise network operations, and enhancing IT logging platform. NASA is moving forward to complete its SolarWinds action plan. NASA is strengthening Office 365 Security (utilizing the upgraded licensing features) and updating infrastructure to support hardening NASA's active directory, application authentication, and NASA's external border points. Tools that transform business are being expanded or implemented such as transitioning physical data centers to cloud operations, downlinking cloud data to quickly deliver data to users, ensuring high-speed internet is more accessible across NASA, and creating one Agency enterprise network. Improvements are being implemented to grow and acquire the right talent for current and future mission work, automate business processes, and improve the security architecture to protect human health and safety. Communications to reach broader audiences, including underserved populations and to aid in the global conversation, are being enhanced. International agreements, critical to NASA's missions, are being negotiated and implemented. Investments in better and improved management of physical assets are being implemented. NASA is implementing a plan to transition to a Zero Emission Vehicle (ZEV) Federal fleet and is partnering with the NASA Aeronautics Research Institute to create a supply chain climate resiliency model in support of climate action planning.

ESO is providing guidance, testing, and oversight to ensure health, safety, and stewardship of resources, including develop, maintain, and improve orbital debris environment models, tools, and algorithms to improve orbit predictions, understand spacecraft anomalies, and better interpret sensor data. Safety and operational needs, including independent technical support, equipment and facility recertifications, and leadership of center and corporate functions is being provided. Critical strategic investments in laboratories, technical equipment, and facilities aligned with Agency goals and objectives are being made.

SAFETY, SECURITY, AND MISSION SERVICES

KEY ACHIEVEMENTS PLANNED FOR FY 2024

Mission Services and Capabilities will improve IT management and security, provide innovative foundational business services and solutions, and transform physical asset management with more efficient and effective technologies and processes. Cybersecurity will be strengthened through deployment of new tools and implementation of a strategy to modernize and improve NASA's overall network security. Business services will be transformed through utilizing artificial intelligence, cloud adoption, and robotic process automation. NASA will invest in tools to improve collaboration capabilities across the Agency. There will be a transition to cyber-physical workspaces to increase remote and virtual collaborative work. To ensure the viability of the most critical capabilities and assets, the I&TC Program will comply with environmental and mandatory compliance standards, institutionalize the AMP processes, sustain assets in Space Environments Testing Management Office (SETMO), and modernize logistics operations. NASA will continue to prioritize and advance DEIA in accordance with the DEIA and Equity Strategic Plans. Through the Office of Diversity and Equal Opportunity (ODEO), NASA will continue to infuse DEIA across the Agency by partnering with all mission directorates in execution of their DEIA implementation plans. This cross-Agency effort includes continued barrier analysis, development of a more robust data analytics capability, and a professional development framework that advances DEIA. In addition, enterprise organizations such as OSTEM, OSBP, and OCOMM will assist the Agency in advancing external equity through increased engagement in underserved communities.

ESO will continue providing guidance, testing, and oversight to ensure health, safety, and stewardship of resources. Reliability, integrity, and security of NASA's assets will be supported through advisory panels and programs. Policies and technical guidance will be enhanced to ensure the technical workforce is optimally trained to maintain standards in key capability areas. NASA will develop, maintain, and improve orbital debris environment models, tools, and algorithms to improve orbit predictions and human spaceflight standards, which will evolve to enable lunar exploration. Safety and operational needs, including independent technical support, investments in key center needs, and leadership of center and corporate functions will continue to be provided. Critical strategic investments in laboratories, technical equipment, and facilities aligned with Agency goals and objectives are being made.

Themes

MISSION SERVICES AND CAPABILITIES

Mission Services and Capabilities (MSaC) provides enterprise solutions under three programs: Information Technology, Mission Enabling Services, and Infrastructure and Technical Capabilities. Strategically, these programs meet workforce, infrastructure, information technology, and business operations requirements necessary to enable NASA's mission. MSaC ensures that critical Agency operations are effective, efficient, safe, and meet statutory, regulatory, and fiduciary responsibilities. These mission enabling services, capabilities, and related processes provide efficient and effective administration across all NASA centers.

SAFETY, SECURITY, AND MISSION SERVICES

ENGINEERING SAFETY AND OPERATIONS

ESO provides for the ongoing management and operations of NASA Headquarters, nine centers, and component facilities under two programs: 1) Agency Technical Authority (ATA) and 2) CESO. The programs support scientific and engineering activities. They contribute to the reduction of program risks by ensuring that: technical skills and assets are ready and available to meet program and project milestones; mission and research endeavors are technically and scientifically sound; and center practices are safe and reliable, including the highly skilled staff and specialized infrastructure at the centers that facilitate NASA missions.

MISSION SERVICES & CAPABILITIES

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Information Technology (IT)	581.4	--	**681.8**	696.7	709.6	722.4	736.5
Mission Enabling Services	733.8	--	**802.4**	818.2	834.4	851.1	868.1
Infrastructure & Technical Capabilities	672.0	--	**775.1**	789.2	806.0	823.6	840.4
Total Budget	**1,987.2**	**--**	**2,259.3**	**2,304.1**	**2,350.0**	**2,397.1**	**2,445.0**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Agency facility maintenance teams continue to discover and use newer technologies that help keep our workforce safe. This autonomous rover, "Astro", is used to perform condition-based maintenance (CBM) observations within high noise areas. Using it for rounds and readings reduces workforce exposure. One example of real-time digital transformation efforts.

Mission Services and Capabilities (MSaC) provides foundational business service and enterprise solutions to all of NASA. While mission requirements evolve with Agency priorities and external conditions, MSaC is focused on the permanent and critical essentials that enable all NASA activity.

MSaC offers a range of foundational services, including, but not limited to, human capital, financial management, physical asset management, software and hardware services, communications, diversity and inclusion programs, legal services, small business program, procurement services, and safety/protective services. MSaC is broken up into three programs: Information Technology (IT), Mission Enabling Services (MES), and Infrastructure and Technical Capabilities (I&TC).

MSaC Priorities

MSaC provides foundational business services, which remain a permanent requirement as missions and conditions evolve. MSaC is focused on ensuring the delivery of quality services, improving the customer experience for centers and missions, transforming business to ensure agility, efficiency, and effectiveness as requirements evolve. NASA's long-term success will depend on a foundation of reliable support services that are responsive to mission requirements in real time and streamlined to minimize cost while maximizing impact.

MSaC ensures services and infrastructure are mission-ready and keeping pace with industry standards so that NASA can continue to lead the world in space exploration, scientific discovery, and aerospace research. MSaC not only must provide for immediate mission needs, but also must anticipate future needs and potential emergent conditions that would impact Agency goals. Business essentials, like finance, IT, human capital management, and legal services, form the bedrock of NASA operations, while efforts to transform service and improve customer experience are imperative to support NASA into the future.

MISSION SERVICES & CAPABILITIES

Key priorities include:

- Improve IT management, data access, and cybersecurity.
  - Invest in upgrades and critical IT infrastructure for better cybersecurity; and
  - Enhance the large IT asset portfolio, including personal equipment, software applications, and center networks.
- Provide novel, innovative, and foundational business services and solutions that enable NASA's missions.
  - Includes management and services for finance, human capital, IT, infrastructure, diversity and equal opportunity, legal, legislative and intergovernmental affairs, procurement, small business, protective services, communications, and international relations;
  - Transform NASA's foundational business with new processes, IT services and tools, and strategic planning; and
  - Support a diverse and inclusive workforce with recruitment and talent initiatives, training, and diversity, equity, inclusion, and accessibility (DEIA) programming.
- Transform physical asset management with technologies, processes, and data to be more efficient, effective, and environmental protective.
  - Ensure the safety and reliability of mission-critical assets by conducting routine testing, maintenance, and upgrades;
  - Invest in "green" infrastructure and methods/materials for better sustainability; and
  - Complete the Agency Master Plan (AMP) to use tiered and condition-based maintenance.

EXPLANATION OF MAJOR CHANGES IN FY 2024

See each program area for a description of significant changes.

ACHIEVEMENTS IN FY 2022

See each program area for a complete list of achievements in FY 2022 for IT, MES, and I&TC.

WORK IN PROGRESS IN FY 2023

See each program area for a complete list of work in progress in FY 2023 for IT, MES, and I&TC.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

See each program area for a complete list of planned achievements in FY 2024 for IT, MES, and I&TC.

Program Elements

INFORMATION TECHNOLOGY

The IT Program provides the information services needed to fulfill NASA's multifaceted missions and operations, including cybersecurity, IT asset planning and management, and technical support. NASA's

MISSION SERVICES & CAPABILITIES

Information Technology Program helps improve Agency outcomes by accelerating results through tools that increase productivity; sharing NASA's data and discoveries; and increasing the quality, resiliency, and cost-effectiveness of its information systems. Reliable, adaptable, and secure cloud-based IT is increasingly important to NASA's mission portfolio because it is a key enabler for advances in science, technology, aeronautics, and space exploration.

MISSION ENABLING SERVICES

The MES Program provides an enterprise approach to managing NASA's business operations and mission support activities. Missions rely on these institutional services to provide the business services and skilled staff required to accomplish their objectives. Enterprise management of these areas ensures that critical Agency operations are effective, efficient, and meet statutory, regulatory, and fiduciary responsibilities. Business services include financial management, human capital management, procurement, small business, legislative affairs, equal opportunity and diversity management, legal, communications, international and interagency relations, and protective services.

INFRASTRUCTURE AND TECHNICAL CAPABILITIES

The I&TC Program provides sustainment, operations, and maintenance for facilities and technical capabilities. The program also provides effective oversight and management of real property, environmental program activities, aircraft operations, and logistics functions. These capabilities enable NASA to meet its statutory and regulatory responsibilities and ensure that the right infrastructure is available to meet mission requirements. This mission is accomplished through effective management of assets and capabilities, proactive coordination with NASA mission directorates, institutional planning, proactive deployment of sustainable practices, ongoing regulatory compliance, and reducing current and future infrastructure-related risks.

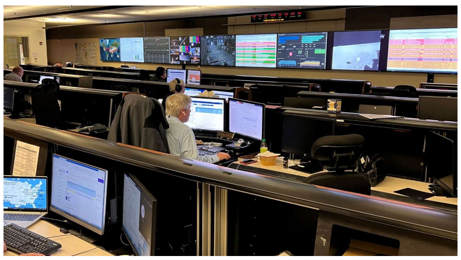
INFORMATION TECHNOLOGY (IT)

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**581.4**	**--**	**681.8**	**696.7**	**709.6**	**722.4**	**736.5**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



Shown above, Enterprise Network Operations Center (ENOC) analysts are the first line of defense of enterprise network disruptions, service degradations and infrastructure and network device failures. The ENOC is the centralized location for 24/7/365 monitoring the health and performance all NASA corporate enterprise services.

NASA's Information Technology (IT) Program provides cross-cutting corporate IT products and services such as applications, data platforms and analytics, devices, networks, and cybersecurity to support achievement of all NASA objectives. IT also provides tailored services to support specific mission support requirements such as data management, networks, cloud computing, and artificial intelligence. NASA’s IT ecosystem supports the successful execution of NASA's missions: enables the operation of the International Space Station; prepares for human exploration beyond low-Earth orbit; enables better understanding of the solar system and the universe; and enables safer, faster, and more efficient air transportation systems.

IT Priorities

NASA's inspiring missions are evolving as scientific discovery and human presence extends to the Moon and beyond. External factors, like commercial industry, global competitors, expanding data capacity requirements, disruptive conditions (e.g., climate change, natural disasters, and pandemics) and fast-evolving mission requirements challenge NASA's traditional IT support approach. Technology, data, and collaboration across organization and geographic boundaries are imperative to NASA's immediate mission goals and long-term organizational health. The IT Program provides a foundation of services that empower NASA with technology solutions, equipment, software, and support services to support NASA's future missions. The IT Program is continuing to improve NASA’s cybersecurity posture through implementation of a Zero Trust Architecture Plan, including Security Orchestration, Automation, and Response (SOAR); a single Endpoint Detection and Response (EDR) tool across the Agency; and network segmentation-based Software-Defined Access (SDA), which is foundational to support Agency zero-trust.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

INFORMATION TECHNOLOGY (IT)

ACHIEVEMENTS IN FY 2022

Cybersecurity

- Application Rationalization of 210 End of Life (EOL) applications thus reducing cybersecurity vulnerabilities and improving the cybersecurity posture of NASA;
- Enhanced reliability and security of IT assets and capabilities by isolating applications across the network that improved security, enhanced software patch management, and continued consolidation of cybersecurity logging capability;
- Enhanced cybersecurity in response to SolarWinds incident;
  - Improved Microsoft O365 licensing to secure 'work from home' environment;
  - Secured access to IT through authentication enhancements, modernized firewalls, and improved threat detection; and
  - Implemented Data Logging and Cybersecurity Analytics platform which increased data needs, aggregated logs, and provided malware analysis.
- Fully implemented the Controlled Unclassified Information (CUI) Program, including user training to ensure physical and technical safeguarding of CUI data; and
- Identified and began to implement critical cybersecurity requirements to improve cyber hygiene, zero-trust, supply chain risk management, event logging, and endpoint detection and response, per Presidential Executive Order 14028.

Business Transformation

- Expanded data access through consolidated cloud-based platforms to support key flight missions and incorporate Earth Science data (several hundred petabytes);
- Enhanced management of IT assets including implementation of low-code application platforms to speed NASA application development;
- Expanded cloud-based solutions and deployed the Agency-wide intranet;
- Implemented NASA's Human Capital Resume to Desk initiative that allowed the Office of Chief Human Capital Officer to consolidate workforce tools while being able to on-board new individuals to NASA in a much more efficient manner;
- Implemented Robotics Process Automation (RPA) to automate business processes within NASA saving over 9,500-man hours;
- Expanded the adoption and capabilities of the Enterprise Data Platform (EDP) by adding Intelligent Search to improve findability and expand access and analytics for mission datasets, translating into more efficient mission processes;
- Transitioned NASA Mission and Corporate communications services from the NICS (NASA Integrated Communications Services) contract to the Agency Enterprise Global Information Technology Solutions (AEGIS) contract to assist in computing and communications transformations;
- Consolidated disparate cybersecurity services into an enterprise-wide contract (CyPrESS) to improve cost effectiveness while strengthening cybersecurity;
- Upgraded to modern IP-based voice communication infrastructures via the first Next Generation Mission Voice solution replacing NASA's aging Mission-critical voice communications system which was deployed during the Shuttle era;
- Partnered with all NASA mission directorates in the transition of GSA Networx mission-critical services to the Enterprise Infrastructure Solutions (EIS) contract, as mandated under Federal

INFORMATION TECHNOLOGY (IT)

Information Technology Acquisition Reform Act (FITARA) and by Office of Management and Budget (OMB);
- Established a draft framework for an interoperable NASA Digital Engineering Environment that will allow engineers the ability to seamlessly team on complex engineering design, analysis, and test workflows;
- Baselined automated Smart Reviews to streamline preparation and improve real-time, data-driven discussions for more effective program/project reviews, leading to earlier detection and resolution of any programmatic issues;
- Supported novel technology development with NASA missions by providing enhanced voice, video, network services, and maintain NASA (Ground) Communications System (NASCOM) connectivity between flight projects and space communications supporting increased flight tempo;
- Formulated a Smart Centers pilot to explore leveraging of smart cities technologies (including Internet of Things sensors, autonomous surveillance, data platforms, and digital twins) on NASA's physical infrastructure to improve facility sustainability and planning;
- Tested Modern and Inclusive Collaboration Spaces (MICS) to learn and norm effective and fully inclusive on/off-site hybrid teaming collaboration tools and behaviors; and
- Successfully consolidated 109 web sites into one seamless internal intranet for all of NASA, on schedule and under budget.

WORK IN PROGRESS IN FY 2023

Cybersecurity

- Continuing migration of center end points to the new intent based, Zero Trust Network Architecture (ZTNA) compliant Software Defined Network fabric as well as transition operations to newly deployed Software Defined Access infrastructure;
- Continue Application Rationalization across NASA’s application landscape to reduce cybersecurity vulnerabilities and improve customer experience while aligning with NASA’s business and mission needs;
- Enhancing licensing and software with upgrades that increase security and operational capability;
- Implementing enterprise network operations modernization through transition to NetSecOps operations methodologies and practices and building cyber response capabilities into the current network operations landscape;
- Implementing high cybersecurity encryption and credentialing for classified and sensitive data;
- Continuing implementation of the consolidated enterprise cybersecurity contract (CyPrESS) and establishing a single enterprise third party penetration testing and assessment/authorization service, significantly reducing vulnerabilities across NASA systems; and
- Enhancing IT logging platform to meet IT event logging maturity (in response to Presidential Executive Order 14028), thereby increasing visibility for NASA's Security Operations Center (SOC) to appropriately identify, detect, and respond to a variety of IT incidents.

Business Transformation

- Downlinking high volumes of NASA Indian Space Research Organization (ISRO) Synthetic Aperture Radar (NISAR) mission data directly to the cloud and deliver in near real time to scientists once the NISAR mission is launched;

INFORMATION TECHNOLOGY (IT)

- Continue to find opportunities to automate business functions through Robotics Process Automation (RPA) with a goal of saving over 10,000-man hours;
- Expanding high-speed network accessibility across NASA locations;
- Improving mission and corporate network communications by updating the 10 center's individual, outdated servers, and networks to one Agency enterprise network operating at current required mission standards;
- Continuing engagement activities to identify value-add improvements to IT services and applications;
- Providing adoption support to customers to optimize the use of IT applications and virtual technologies;
- Piloting automated Smart Reviews at centers to streamline preparation for and improve real-time, data-driven discussions for more effective program/project reviews, leading to earlier detection and resolution of issues;
- Decommissioning physical data centers to transition to cloud operations;
- Developing Future of Work (FoW) Applications to transition away from outdated applications and transition to more sophisticated applications to support the needs of the Artemis Generation and Moon-to-Mars;
- Implementing IT Working Capital Fund (WCF) for modernization with new WCF and transfer authorities;
- Continued IT contract transition from the centers to the enterprise, as appropriate, to promote cost savings while optimizing unique and local services;
- Providing Agency intelligent search capability with well-defined processes to connect to existing data sources; and
- Preserving NASA records in digital formats according to Federal records management policies and best practices.

Supply Chain Risk Management

- Implementing the IT Supply Chain Risk Management Program to evaluate and assess software and IT hardware components for Federal and Agency cybersecurity regulation and policy compliance, such as components made in China and FedRAMP certified software.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

Cybersecurity

- Continue modernization of Enterprise Network Operations Center (ENOC) and integration with the Security Operations Center (SOC);
- Improve Network Operations and Security Operation's visibility into traffic flows between endpoints within the NASA Local Area Networks;
- Complete Trusted Internet Connection (TIC) Fire Wall upgrade:
  - Improves bandwidth capacity and performance between TIC locations;
  - Improves disaster recovery and continuity of operations benefits; and
  - Enhances security capabilities and hardware scalability.
- Implement the security features available in the Microsoft 365 G5 Licenses: Azure Active Directory Identity Protection will monitor, detect, and allow NASA SOC to investigate identity behaviors, thus ensuring continuous behavior analysis and threat reduction;

INFORMATION TECHNOLOGY (IT)

- Software-Defined Access (SDA): Continue to migrate corporate network services to Cisco SDA segments; these segments will each have specific access policies based on segment functions (e.g., printers, endpoint, phones). NASA plans to be ~60 percent migrated to the SDA fabric by end of FY 2024;
- Security Orchestration, Automation, and Response (SOAR): Implement a cloud-based Security Incident Event Management (SIEM) system that will incorporate NASA endpoint, identity, and cloud-based logs; this tool will have tight integration with the NASA SOC to improve visibility and response for security events;
- Redesign and upgrade the Agency cybersecurity logging solution to increase visibility, data retention requirements and response to potential incidents. Includes enabling monitoring, logging, and analysis of NASA's cloud platforms such as Amazon Web Services (AWS) and Google. Microsoft already implemented Specific M365 capabilities being onboarded including:
  - Expansion of contextual based access policies with Azure Activity Directory Conditional Access and Microsoft Defender for Cloud Apps (Identity): Implement new device identity signal capabilities that can be used to identify NASA authorized devices before allowing access to specific cloud hosted applications. This approach directly responds to OMB M-22-09 requirements to consider at least one device level signal alongside identity information about the authenticated user.
  - Extend protections for Microsoft 365 (M365) services with Microsoft Defender for O365: This will enhance NASA's capability to Identify, Detect, Respond and Recover from incidents where malicious content was stored, shared, or processed in the NASA M365 collaboration environment. This capability improves security of the M365 collaboration environment which is in alignment with OMB M-21-31, Event Security Logging, and the broader Executive Order 14028 (Section 7 and 8).
  - Azure Active Directory Identity Protection (Identity): Implement Azure Activity Directory user threat intelligence services; threat signals provided by Azure Active Directory Identity Protection will be evaluated to determine if they can be used with Azure Active Directory Conditional Access and/or Microsoft Defender for Cloud apps. This capability improves the security of the M365 collaboration environment which is in alignment with OMB M-22-09, Zero Trust Cybersecurity Principals (Automating security responses).
  - Azure Information Protection (AIP) Enhancement (Data): Expand on NASA's initial implementation of Azure Information Protection to support integration with Data Loss Prevention (DLP) capability. AIP and DLP integrations will improve visibility and protection for specific sensitive data types inside and outside of the NASA environment. This improves security of the Microsoft 365 collaboration environment which is in alignment with OMB M-21-31, Event Security Logging, OMB M-22-09, Zero Trust Cybersecurity Principals (data categorization) and the broader Executive Order 14028 (Section 8).
- Implement NASA Citizen Development on NASA's Low-Code Application Platforms (LCAP) environments, thus allowing non-IT resources to quickly develop applications in a secured platform.
- NASA plans to invest approximately $196 million in FY 2024 for cybersecurity. The following table identifies cybersecurity funding using the National Institute of Standards and Technology categories (Identify, Protect, Detect, Respond, Recover).

INFORMATION TECHNOLOGY (IT)

Cybersecurity Spend - NIST Category	FY2022 Actual ($M)	FY2023 Enacted ($M)	FY2024 President's Budget ($M)
Detect	25	23	21
Identify	43	49	48
M-22-16 - Cyber Human Capital	0	0	1
M-22-16 - Sector Risk Management Agency (SRMA)	0	0	1
M-22-16 - Securing Infrastructure Investments	0	0	2
Protect	78	97	96
Recover	5	5	5
Respond	23	24	23
Grand Total	**174**	**198**	**196**

Business Transformation

- Support NASA missions including Crew 5, Crew 6, and SLS/Orion, and consolidate three OCIO image management systems;
- Continue to innovate with mission/industry partners: Follow Me Print, Mobile Device Management replacement, and Smart Lockers;
- Execute NASA's Financial Management System implementation of SAP S/4HANA;
- Expand real-time secure collaboration capabilities with external Federal, university, and commercial partners to provide improved user productivity and experiences in addition to decommissioning legacy platforms;
- Downlink high volumes of science and mission data directly to the cloud and delivered in near real time to waiting scientists;
- Lead enterprise expansion of "One NASA's" data through:
  - Stewardship and data science to build out enterprise range of technical and data-oriented skills;
  - Technology capabilities to mine enterprise platforms for data insights; and
  - Information and Data Platform advancing intelligent search and analytics.
- Implementing Agency-wide relationship management and tools for managing customer information and cases;
- Develop process to optimize Application Portfolio to maximize business value and rationalize 20 percent of applications in the portfolio;
- Manage and monitor NASA's public web footprint through strengthened Agency-level governance, guidance, and compliance audits;
- Improve the public web experience by shrinking NASA's domain footprint and standardizing to one platform/design; and
- Implement a sustainable platform strategy to include ServiceNow, Salesforce, Enterprise Data Platform (EDP), UiPath, O365, and approved Cloud providers as foundation for NASA users to build upon.

INFORMATION TECHNOLOGY (IT)

Program Elements

ENTERPRISE IT

The Enterprise IT Program is multifaceted and includes the following six project elements, each with unique functions and work focus:

- Applications: anticipates and aligns customer requirements with solutions that best meet Agency needs by delivering secure, sustainable applications quickly and cost effectively, establishing a platform-centric architecture that empowers mission support, enhanced software management to reduce software license costs, and continuous portfolio rationalization.
- Communications: NASA's enterprise service provider for fully managed network and communications services supporting institutions, programs and projects located at the NASA centers. Communications is also responsible for maintaining, operating, and continually evolving services to improve delivery capabilities, strengthen NASA's cybersecurity posture, and reduce costs.
- Computing Services: brokers commercial cloud computing services for the NASA community and provides oversight of NASA's compliance with the Federal Data Center Optimization Initiative (DCOI). Cloud computing services extends to all NASA missions, mission support, and to external collaborators.
- End User Services (EUS): provides high-quality, reliable, cost-effective service desk, end-user computing services, collaboration, content management systems, and services in support of all NASA Federal and contractor employees, including support for laptops, desktops, mobile devices, printing, email, messaging, help desk services, software patching, distribution, and more.
- Information Management (IM): provides NASA with framework, guidelines, and services to ensure secure and efficient access, use, analysis, and preservation of the Agency's information resources. The program ensures NASA's compliance with Federal statutes relating to data access and integrity.
- Transformation and Data: engages the brightest minds across the Agency to guide NASA's data strategy, technology infusion, strategic investment decisions, and identification of emerging information technologies to support NASA's needs most effectively in a rapidly changing world.

SAFEGUARDING DATA AND IT ASSETS

NASA OCIO is responsible for Agency cybersecurity policy and the implementation and management of enterprise cybersecurity and privacy services. The budget is aligned to the National Institute of Standards and Technology (NIST) Cybersecurity Framework to evaluate cybersecurity gaps and investments against the NIST cybersecurity functions: Identify, Detect, Protect, Respond, and Recover. This alignment allows the Agency to make strategic investments to develop, modernize, and enhance Agency cybersecurity capabilities to address the greatest areas of risk to the Agency, its missions, and supporting functions.

INFORMATION TECHNOLOGY (IT)

IT GOVERNANCE AND OVERSIGHT

NASA OCIO provides Agency-level capabilities for intentionally managing IT and meeting Agency and Federal requirements. IT Governance and Oversight efforts involve collaborating with stakeholders across the Agency to formulate plans and manage budgetary data to meet legal mandates, OMB requirements and guidance, Executive Orders, and regulations. These efforts also include the E-Government activities and Federal CIO Council Committees in which NASA participates.

MISSION ENABLING SERVICES

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	733.8	--	802.4	818.2	834.4	851.1	868.1

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

NASA astronaut inspires DC area school students during an educational event at the National Museum of African American History (shown above). This demonstrated the collaboration between various NASA organizations to promote STEM education and Mission Support's communication expertise with hosting/sharing the event in person and via live stream.

Mission Enabling Services (MES) ensure NASA mission success with foundational support services, using enterprise service delivery to enhance problem solving and agile responses to evolving requirements. Using an enterprise approach, the MES Program eliminates duplicative capabilities, provides opportunities for employees to collaborate across geographic boundaries, and remains agile to shifting demands and surge requirements. Missions rely on MES's institutional capabilities to accomplish their objectives. Enterprise management ensures that critical Agency operations are strategic, mission-focused, agile, and streamlined.

Approximately 82 percent of the MES budget supports labor costs associated with approximately 2,300 civil servants and 1,400 support contractors who provide critical services to the Agency. Recruiting, hiring, and maintaining the right mix of high-performing talent remains a critical focus for the MES Program, in alignment with the workforce goal in the NASA Strategic Plan.

MES provides NASA with a bedrock of business functionality in human capital and financial management; procurement and protective services; small business, diversity, and equal opportunity programs; legislative affairs; communications; and international and interagency.

MES Priorities

MES prioritizes business capabilities and personnel support to NASA and its missions:

- Manage programs to ensure the health, safety, and security of NASA people, property, and the public;
- Ensure NASA has the highly talented workforce, including contractors, who are empowered with training and development to enable NASA's missions, now and in the future;
- Explore and execute innovative, effective, and efficient business solutions to optimize capabilities and operations that enable NASA's mission;
- Promote diversity, inclusion and engagement in the workforce and work environment to reflect NASA's core values;
- Develop and implement a comprehensive Equity strategy, that will advance Agency Equity initiatives, in accordance with the Executive Order on Further Advancing Racial Equity and Support for Underserved Communities Through the Federal Government;

MISSION ENABLING SERVICES

- Create workspaces enabled with modernized technology, virtual environments, and advanced solutions that support distributed work teams and flexible work environments; and
- Maintain the Agency's outreach to the public, industry, and both Federal and international partners.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ACHIEVEMENTS IN FY 2022

- Used modern broadcasting and dissemination capabilities to share NASA discoveries, science, and other content with the world and participated in, and contributed facts to, global conversations around science, climate change, and green technologies;
- Shared NASA content and discoveries through various channels of communication, including the International Space Station, the Artemis Campaign, James Webb Space Telescope, and science missions;
- Broadcasted mission progress updates and milestones on the Artemis Campaign to increase knowledge among stakeholders and raise awareness outside of traditional audiences;
- Showcased the return of launching American astronauts to space from American soil on American-built space vehicles using American rockets, highlighting the results and activities of the Commercial Crew Program;
- Advanced U.S. leadership through engagement with international organizations, including hosting senior government officials from over thirty countries at the Artemis I launch;
- Used emerging tools to engage the public, with special focus on underserved populations, in the climate conversation and the societal impacts of NASA's investment in climate research;
- Patented newly developed technology, and assisted in negotiating license agreements under which commercial entities may use the newly patented technology for commercial purposes;
- Enabled NASA to be a key contributor to the interagency focus on national security and the new approaches being fostered by National Security Presidential Memorandum (NSPM) 33;
- Established approximately 1,300 new interagency partnerships and international agreements to advance development of the Agency's programs and projects regarding exploration and operations; space and Earth science; technology; aeronautics; and STEM outreach activities;
- Strategically engaged with international partners to support growing requirements for NASA's Exploration and Earth Science programs, adding to the portfolio of Artemis Accords partners;
- Advanced the United States Government and NASA objectives through leadership of NASA/USG role in United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS);
- Supported bilateral and multilateral engagement by NASA senior leaders to advance cooperative activities and establish/enhance relationships with international partners, including co-chairing or participating in White House and State Department led working groups, initiatives, and meetings;
- Received NASA's 11th consecutive unmodified Financial Statement Audit opinion with no material weaknesses or significant deficiencies;
- Expanded public awareness on the advancement of various NASA missions and programs by garnering over 422 million engagements and increased followers by 17 percent on NASA's flagship social media accounts; and

MISSION ENABLING SERVICES

- Used drone detection and mitigation services in collaboration with the U.S. Space Force and Federal Bureau of Investigation's Counter-Unmanned Aircraft Systems (C-UAS) teams to protect launch vehicles for human space flight and Artemis I.

Business Transformation

- Utilized and leveraged the new case and document management system, and other IT tools, that collectively comprise the NASA Legal Enterprise Operating System (LEOS) to prioritize and deploy legal services across the Agency;
- Advanced communications through the Agency's web modernization project and a strategy to transition NASA TV to an on-demand streaming service;
- Developed integration to consolidate tools and on-board new employees more efficiently; and
- Created new data usage agreement template that enhances access to NASA data for commercial partners and ensures NASA benefits from users' improvements.

Strengthening Interns/Empowering the Workforce/Talent Pipelines

- Hosted approximately 60 Chief Financial Officer (CFO) University training events with more than 2,500 trainees reached;
- Executed the Agency's Strategic Workforce Plan to consolidate contracts while ensuring the right mix of civil servant and contractor support to enable the missions;
- Developed a joint strategy for Agency internships by conducting a comprehensive analysis of the Intern Life Cycle to develop and implement the design of an impactful and integrated internship experience for participants and stakeholders;
- Performed an assessment on the current state and future state envisioned for strengthening the pipeline of NASA employees in lower- or mid-level center positions from underrepresented communities to progress to supervisory or leadership roles, including coaching and mentoring programs, professional development opportunities, and training for managers on how to support diversity in career staff advancement; and
- Built the NASA talent pipeline and workforce of the future by delivering a thriving Pathways Program with approximately 600 paid interns and achieving an 86 percent rate of converting interns to civil servants.

Diversity, Equity, Inclusion, and Accessibility (DEIA) and Advancing Equity

- Conducted and hosted webinars and outreach events with internal community and industry partners to provide training to small businesses, contract specialists, technical personnel, and small business specialists, providing the opportunity for small businesses from underserved communities to gain an understanding how to do business with NASA, best practices for navigating the NASA procurement process, with the goal of increasing the number of prime and subcontract awards to small businesses;
- Conducted and supported the HBCUs/MSIs Technology Infusion Road Tour initiative to increase outreach to underserved communities;
- Enabled innovative legal approaches to engage non-traditional communities that utilize and foster small business and increase accessibility to NASA resources;
- Engaged underserved communities and improved equity in NASA's administration of grants to external institutions that conduct STEM research (e.g., colleges and universities);
- Engaged underrepresented communities for hiring opportunities;

MISSION ENABLING SERVICES

- Connected with under-represented communities through focused and deliberate STEM communications, outreach, and events;
- Developed and operationalized processes to review and adjudicate over 1,000 requests for disability and religious reasonable accommodations related to COVID-19 vaccination exceptions;
- Led the Agency-wide engagement and development of a new NASA DEIA Strategic Plan, as well as the development and implementation of new workforce DEIA data/analytics dashboard for all NASA centers and major organizations;
- Created and executed a NASA DEIA Strategic Communications Plan and led NASA's continued development and completion of deliverables required by Executive Orders and Presidential Memoranda on Equity and DEIA (including Executive Orders 13985, 13988, 14020, 14031, and 14035);
- Issued Gender Transition guidance and implemented an enterprise-wide Sign Language Interpreter contract vehicle;
- Continued support for targeted recruiting initiatives and tracking DEIA Executive Orders to support more diversity and equity in job candidate pools and applicable Federal programs;
- Created and obtained approval from the White House Domestic Policy Counsel on NASA's Gender Equity Plan;
- Supported the Administrator's leadership and staff in launching NASA's first Equity Action Plan;
- Hired a full-time DEIA-focused Public Affairs Officer to communicate with underrepresented and underserved audiences and build relationships with new diverse media;
- Established a series of policy changes to advance equity in procurement such as:
  - A pilot to include DEIA language in solicitations;
  - Established DEIA language to include in Requests for Information to enhance market research and find members of underserved communities;
  - A requirement for contractors to submit a DEIA plan one year after contract award; and
  - Updated existing PIC 18-01 policy to include a Small Business Specialist early in the contracting process.
- Created several dashboards for NASA centers, Mission Directorates, and Headquarters to view data on workforce DEIA for recruiting and succession planning;
- Increased hosting/participation in outreach events by 79 percent, including a 10 percent increase in participation by small businesses and underserved communities, which exceeded the 50 percent goal in the NASA Equity Action Plan;
- Implemented a Standardized NASA Notice of Funding Opportunity Template to ensure all NASA funding forms are consistent and compliant with Federal regulations and present one voice in public-facing grant documents; and
- Combined 13 separate cooperative agreements for STEM support services into a single award indefinite delivery/indefinite quantity contract valued at $290 million.

WORK IN PROGRESS IN FY 2023

- Share inspirational NASA content and mission milestones, including the International Space Station, the Artemis Campaign, James Webb Space Telescope, and science missions;
- Showcase the return of launching American astronauts to space from American soil on American-built spaceships using American rockets, highlighting the results and activities of the Commercial Crew Program, and the U.S. power and capability in human space exploration;

MISSION ENABLING SERVICES

- Continue investments in key communications technology, infrastructure, and talent to optimize broadcast reach and capability;
- Maintain NASA's standing as an Agency of inspiration by using new and emerging communication tools (apps, digital and social distribution, television and on demand, and photojournalism);
- Conduct, participate, and support small business outreach events;
- Increase engagements with external stakeholders to advance NASA's 2022 Strategic Plan and build support for NASA priorities, such as Artemis, climate change, STEM, and DEIA
- Assist the Small Business Administration (SBA) in its Small Business Program Surveillance Reviews at NASA centers;
- Support bilateral and multilateral engagement opportunities for senior NASA officials to advance cooperative activities, establish and enhance relationships with international partners and other foreign officials;
- Establish new international agreements and add new signatories to the Artemis Accords;
- Conclude international agreements that will enable NASA's vision for lunar exploration and further commercialization of space; and
- Develop, schedule, and host webinars, learning series, and podcasts with internal partners and industry collaborators to provide training to small businesses, contract specialists, technical personnel, and small business specialists.

Business Transformation

- Implement information technology enterprise applications to make it more streamlined and interactive, with the ability to provide increased data analytics to track usage and effectiveness;
- Continue digital transformation for Human Capital Services while improving the service delivery model; and
- Migrate centers to Enterprise consolidated financial support services contract, creating efficiencies and cross-utilization savings.

Strengthening Interns/Empowering the Workforce/Talent Pipelines

- Implement workforce strategy to ensure NASA procurement and acquisition specialists are equipped with the skills necessary to execute innovative, effective, and efficient acquisition business solutions; and
- Aggressively expand CFO University class offerings to reach more into the technical community and instruct them on the inner workings of the budget process.

DEIA and Advancing Equity

- Engage in outreach activities to ensure underserved and underrepresented communities have the same access to information and opportunities as other industry partners to compete for NASA contracts, grants, and cooperative agreements;
- Deploy new project management tool to track implementation of NASA's DEIA and external equity plans;
- Prioritize advancing equity, civil rights, racial justice, and equal opportunity in accordance with NASA's Equity and DEIA Strategic Plans, which includes increasing employee and leadership engagement and training and performing assessments and data analytics;

MISSION ENABLING SERVICES

- Reach and connect with under-represented communities through focused and deliberate STEM communications, outreach, and events;
- Conduct and support the Historically Black Colleges and Universities (HBCU)/Minority Serving Institutions (MSI) Technology Infusion Road Tour designed to inform presidents/chancellors, administrators, staff, and students from HBCU/MSI about opportunities that exist within NASA;
- Connect NASA partners and other external Government agencies with the goal of increasing contract and subcontract opportunities for HBCU/MSIs to support the Agency mission and programs;
- Use modern communication technologies, platforms, and tactics to connect with underserved populations and improve accessibility to NASA work products and engagement opportunities more effectively;
- Lead NASA's implementation of Executive Orders and Presidential Memoranda on DEIA, including implementation and evaluation of NASA's DEIA strategic plan, as well as the enhancement of workforce data and analytics capabilities;
- Update executive performance requirements to include DEIA goals;
- Expand professional development opportunities and training for managers to strengthen the pipeline of NASA employees in lower- or mid-level center positions from underrepresented communities to progress to supervisory or leadership positions; and
- Create and deploy NASA-wide climate survey to ensure effective data is collected on DEIA issues.

Future of Work

- Enable the workforce with the skills, talent, and technology to ensure mission success in a post-COVID environment; and
- Expand and extend digital transformation efforts in legal services to further enable remote client assistance and support.

Buy America/Acquisition Improvement

- Strengthen acquisition insight and oversight through gathering data on the acquisition environment and using the data and evidence to support recommendations;
- Utilize empirical data, based on Key Performance Indicators, to validate procurement effectiveness and efficiency in enabling mission success;
- Migrate all centers to the three enterprise acquisition contracts for finance, supporting our ability to provide more standard structure to providing services and potential cost savings/avoidance;
- Develop enterprise data analytics platforms to enhance access to real-time, integrated, and consistent data; and
- Continue to collaborate across mission support on Product Service Lines (PSLs), market research, and subcontracting training to all acquisition personnel.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

- Leverage intellectual property resources to support the patenting of new technology that has commercial viability and enable the transfer of such technology through negotiation and execution of license agreements;
- Maintain clean Financial Statement Audit opinion by maintaining reliable and accurate financial data and reporting to internal and external customers;

MISSION ENABLING SERVICES

- Enhance evaluation capabilities by hiring dedicated experts in evaluation design, stakeholder engagement, performance reporting, and other relevant skillsets;
- Plan bilateral and multilateral engagement opportunities for the NASA leadership, to advance cooperative activities, establishing and enhancing relationships with international partners and other foreign officials;
- Develop, schedule, and host webinars, learning series, and podcasts with internal and industry partners to provide training to small businesses, contract specialists, technical personnel, and small business specialists, providing the opportunity for small businesses from underserved communities to gain an understanding how to do business with NASA, best practices for navigating the NASA procurement process, with the goal of increasing the number of prime and subcontract awards to these small businesses;
- Increase engagements with external stakeholders to advance NASA's 2022 Strategic Plan and build support for NASA priorities, such as Artemis, climate change, STEM, and DEIA; and
- Manage NASA Mentor Protégé Program (MPP) to encourage NASA prime contractors to assist eligible Protégés (as defined in NASA FAR Supplement 1819.72), thereby enhancing the Protégés' capabilities to perform on NASA contracts and subcontracts, fostering the establishment of long-term business relationships between these entities and NASA prime contractors, and increasing the overall number of these entities that receive NASA contract and subcontract awards.

Business Transformation and IT Modernization

- Continue digital transformation of Human Capital services to streamline Human Capital service delivery and processes, enhance customer experience, and improve access to Human Capital data;
- Implement information technology enterprise applications to make small business program activities more streamlined and interactive, with the ability to provide increased data analytics to track usage and effectiveness; and
- Utilize and leverage the new case and document management system, the NASA Legal Enterprise Operating System (LEOS) to prioritize and deploy legal services across the Agency more efficiently and effectively while sharing legal knowledge more broadly across the community.

Strengthening Interns/Empowering the Workforce/Talent Pipelines

- Fully implement NASA's Aspiring Executive Cohort (ASPIRE) which will provide a comprehensive suite of learning and development experiences to prepare aspiring executives for potential future entry into the executive cadre;
- Plan to hire approximately 300 interns in FY 2023 and FY 2024 (an increase from 227 hired in FY 2022), which comprise approximately 22 percent of all hires made by NASA;
- Dedicate funding to support talent assessments which will allow the Agency to continue using OPM's Program and Project Management Assessment (PAPMA) for positions in the 0340-job series; and
- Continue to provide funding to support the Office of Personnel Management's (OPM) Hiring Experience Group.

DEIA and Advancing Equity

- Advance external civil rights compliance and expand access to limited English proficient populations within underserved communities to reduce barriers/increase opportunities for all people, including

MISSION ENABLING SERVICES

those in underserved or minority populations, to participate in the work of NASA - (Equity Action Plan Focus Area 4);

- Find new small businesses that will help the Agency increase its industrial base to support the various NASA missions, to ensure small businesses have the opportunity to participate in space-related industrial capabilities in support of critical Government functions;
- Ensure underserved communities will have a fair opportunity to compete for NASA contracts at both the prime and subcontractor levels, by increasing outreach and training internally and externally, setting-aside NASA requirements, and increasing subcontracting goals for small businesses and underserved communities in the NASA acquisition process;
- Conduct and support the Historically Black Colleges and Universities (HBCU)/Minority Serving Institutions (MSI) Technology Infusion Road Tour designed to inform presidents/chancellors, administrators, staff, and students from HBCU/MSI about opportunities that exist within NASA, with the goal of increasing contract and subcontract opportunities for HBCU/MSIs to support the Agency mission and programs;
- Implement a second NASA-wide Anti-Harassment Campaign, with strategic communication from senior leadership to include education and awareness opportunities for the entire workforce. Issue first-ever NPR on religious accommodation to ensure that all religious faiths and practices at NASA are treated inclusively;
- Integrate DEIA discussion and characteristics into Agency leadership development programs to develop culturally competent leaders that ensure leadership development programs are reflective of the needs of the workforce; and
- Enable evidence-based awareness, planning, decisions, and assessments of the current and future state of DEIA at NASA, the Agency will:
  - Develop and implement automated, analytic products aligned to EO 14035 Focus Areas.
  - Execute a data acquisition, ingestion, and cataloging blitz of critical data sources into NASA's Enterprise Data Platform.

Future of Work

- Implement the capability to perform remote identity proofing of NASA civil servants and contractors supporting fingerprint capture and document validation;
- Expand use of standardized templates, automated forms, and continue developing automated workflow processes to enable greater remote support and improved efficiency in the delivery of legal services;
- Enable the workforce with the skills, talent, and technology to ensure mission success in a hybrid work environment; and
- Expand and extend its digital transformation efforts in legal services to further enable remote client assistance and support.

Cybersecurity

- Explore technology and infrastructure improvement to ensure that the Enterprise Visitor Access Management System (EVAMS) and Remote Enrollment Services (RES) have a standardization of data, processes, and hardware requirements that enables a higher level of identity assurance that reduces physical and logical access risks.

MISSION ENABLING SERVICES

Buy America/Acquisition Improvement

- Continue current strategic acquisition strategy by soliciting offers for Goddard Space Flight Center (GSFC) Regionalized Facility Ops Contract and anticipated award of Agency NASA Consolidated and Platform Services (NCAPS) Contract; and
- Leverage other NASA initiatives to advance NASA's Made in America (MIA) progress in accordance with the Administration's agenda.

Program Elements

OFFICE OF THE CHIEF FINANCIAL OFFICER

The Office of the Chief Financial Officer (OCFO) provides leadership for the performance reporting, budget analysis, justification, control, and reporting of all Agency fiscal resources; provides co-leadership for the strategic planning of all Agency fiscal resources; directly supports the development of the Agency's overarching strategic plan and associated annual performance reports; leads the Agency's planning, programming, budgeting, and execution process; oversees all financial management activities relating to the programs and operations of the Agency; and monitors and reports the financial execution of the Agency budget. Through supporting and fostering an agile workforce and enhancing robotic process automation, the OCFO continuously develops and matures modern toolsets, services, and processes for tracking, analyzing, and reporting mission and Agency financial information. The OCFO manages the Agency's budget and financial operations, directs the preparation and submission of annual financial and budgetary reports, and coordinates Agency financial management activities with other Federal agencies.

OFFICE OF CHIEF HUMAN CAPITAL OFFICER

The Office of the Chief Human Capital Officer (OCHCO) provides services and innovative solutions to ensure it meets the needs of our mission today and tomorrow. From creating a learning culture to implementing technology that supports work/life balance, OCHCO supports and strengthens the human foundation of NASA. Game-changing programs help Agency leaders understand workforce investments, anticipate workforce needs, and easily acquire talent for the task. Game-changing programs include streamlining and modernization of the Human Capital Information Technology (HCIT), simplification of position description (PD) classification, centralized training administration, implementing a flexible and agile workforce approach through the Strategic Workforce Plan (SWP), and replacing our aging talent acquisition system. NASA's talent needs are always evolving with mission activities that test the limits of human capability. Leaning forward to be a global leader in human capital excellence, OCHCO enables the people of NASA to push the boundaries of achievement by supporting NASA's mission first and its people always.

OFFICE OF LEGISLATIVE AND INTERGOVERNMENTAL AFFAIRS

The Office of Legislative and Intergovernmental Affairs (OLIA) provides executive leadership, direction, and coordination of all communications and relationships, both legislative and non-legislative, between NASA and the United States Congress as well as State and local governments.

MISSION ENABLING SERVICES

OFFICE OF PROCUREMENT

The Office of Procurement (OP) explores and executes innovative, effective, and efficient acquisition business solutions to optimize capabilities and operations that enable NASA's mission. NASA spends approximately 85 percent of its budget on acquiring goods and services through approximately 750 procurement and small business professionals across the Agency. In FY 2022, total Agency procurement spending was $19.9 billion via approximately 26,000 procurement actions (e.g., awards, modifications) while managing more than 28,000 instruments (e.g., contracts, grants, purchase orders, task orders, and delivery orders). OP transformed workforce, optimized capabilities, and continuous training opportunities keep it poised to deliver effective and efficient procurement services that ensure mission agility, resilience, and success.

OFFICE OF SMALL BUSINESS PROGRAMS

The Office of Small Business Programs (OSBP) promotes and integrates small businesses into NASA's industry base of competitive contractors that pioneer the future of space exploration, scientific discovery, and aeronautics research. OSBP provides integration, policy, initiatives, and oversight needed to ensure compliance with law and regulation to increase the Agency's small business industry base while offering the best technical solutions and value to support the Agency's mission. OSBP conducts, sponsors, and participates in small business outreach activities which assist small businesses, including Small Disadvantaged Businesses (SDB), Women-Owned Small Businesses (WOSB), Historically Underutilized Business Zones (HUBZone), Service-Disabled Veteran-Owned Small Businesses (SDVOSB), and Historical Black Colleges and Universities (HBCU) / Minority Serving Institutions (MSI) in supporting the NASA mission.

OFFICE OF PROTECTIVE SERVICES

The Office of Protective Services (OPS) provides security services at all NASA facilities to ensure the protection of life and property across the Agency. OPS resources include a large contractor workforce in addition to its civil servant workforce. OPS provides secure access to intelligence and information essential to mission success, fire services, and emergency management at all NASA facilities and is the focal point for policy formulation, oversight, coordination, and management of Agency physical security, intelligence, counterintelligence, counterterrorism, emergency management, continuity of operations, fire services, national security, communications security (COMSEC), classified information security, personnel security, identity and credential management, electronic physical access management, insider threat, and protective services training programs. OPS provides services to ensure the safety and security of people, property, and information at 20 locations across the country.

OFFICE OF DIVERSITY AND EQUAL OPPORTUNITY

The Office of Diversity and Equal Opportunity (ODEO) leads diversity and civil rights policies, programs, and services, which enables the universe of available talent to contribute inclusively and equitably, propelling NASA organizations and people to work together more effectively to accomplish Agency missions. ODEO offers the best approaches to recruit, hire, engage, empower, and retain a highly talented workforce across a diverse landscape. ODEO programs empower and advance NASA as a leader and model Agency for diversity, equity, inclusion, and access, as well as promote external civil rights compliance in NASA-funded science, technology, engineering, mathematics, and other related programs.

MISSION ENABLING SERVICES

OFFICE OF COMMUNICATIONS

The Office of Communications (OCOMM) delivers NASA's incredible work to billions of people around the world with compelling storytelling on a variety of platforms. NASA communicates via various methods including through news and media engagement, digital services and products (e.g., streaming, web, multimedia, social media), non-technical publications, exhibits, as well as speaking and public engagement activities and events. OCOMM empowers all employees as ambassadors of NASA by providing Agency information and supports missions by providing employees with access to research material, information resources, and services. OCOMM engages the public and NASA's stakeholders through NASA's astronaut appearances, guest operations, speakers' bureaus, exhibits, and artifacts. OCOMM promotes effective and consistent NASA communications by ensuring strategic alignment and working collaboratively with other Agency organizations. With NASA's position in exploring the secrets of the universe for the benefit of all, OCOMM's work is critical to ensure NASA's advances in exploration in air and space, innovation for the benefit of humanity, and inspiring the world through discovery.

OFFICE OF INTERNATIONAL AND INTERAGENCY RELATIONS

The Office of International and Interagency Relations (OIIR) provides executive leadership and coordination for all NASA international and interagency activities, and for policy interactions between NASA and other U.S. Executive Branch offices and agencies. OIIR manages the Agency's Export Control Program, including compliance with Federally mandated requirements and all NASA and U.S. export and import laws, policies, and regulations, to maximize the benefits of the Agency's international efforts. OIIR leads international engagement for the Agency, including management of the more than 650 active international agreements in over 134 countries (and counting). OIIR provides management oversight and staff support of NASA's advisory committees, commissions, and panels.

OFFICE OF THE GENERAL COUNSEL

The Office of the General Counsel (OGC) provides legal services Agency-wide, including establishing and disseminating legal policy and interpreting new statutes and cases to enable diverse and cutting-edge Agency activities, thus ensuring NASA remains in compliance with all statutory and regulatory requirements. Additionally, OGC is responsible for developing the ethics and patent program requirements, establishing metrics, and developing quality standards. As a functional office, OGC serves in an advisory capacity to the Administrator, Enterprise Associate Administrators, and Center Directors across nearly 20 core legal disciplines. OGC provides litigation expertise to the Agency and acts as the Agency representative before the United States Patent and Trademark Office and other administrative forums. NASA attorneys also function as leaders and trusted advisors on matters of policy and legal risk, upholding NASA values and enabling the NASA mission. OGC enables commercial partnerships on non-reimbursable, reimbursable, and funded terms to accomplish NASA objectives including fostering new U.S. industry in areas such as Low Earth Orbit, Near Earth Communications, and Green Aviation.

INFRASTRUCTURE & TECHNICAL CAPABILITIES

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	672.0	--	775.1	789.2	806.0	823.6	840.4

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Seen above, the Integrated Operations Center (IOC) team supports Langley Research Center's Condition Based Maintenance (CBM) Program by utilizing real-time data from the Center's building automation system (BAS) and the Center's equipment CBM sensors. This 24-hour IOC monitoring ensures system/equipment degradation is addressed immediately in a controlled fashion that prevents any unplanned failures that have a potential to impact Center operations.

The NASA Infrastructure and Technical Capabilities (I&TC) Program addresses Agency-wide operating requirements for physical assets considered institutional, and not fully funded by a single NASA mission directorate. The program operates and maintains facilities, utilities, structures, and technical capabilities supporting all NASA's diverse missions. It also provides oversight and management of real property assets, environmental program activities, and logistics functions. Critical to supporting NASA's missions is the underlying infrastructure and skilled workforce that keep the centers and facilities operating effectively and efficiently.

I&TC Priorities

The I&TC Program ensures NASA facilities have the research and engineering capabilities to sufficiently support mission activities. I&TC divides its allocation between failure prevention, in the form of reliability centered maintenance activities comprised of predictive, preventative, condition based, and routine preventative maintenance programs and other forward-looking investments in capabilities to support NASA's future missions and reinforcing strategic goals of strengthening infrastructure readiness and resilience and driving affordability. I&TC areas of emphasis revolve around completing the Agency's first mission driven Agency Master Plan (AMP), ensuring comprehensive environmental compliance and stewardship, and maintaining effective logistics support.

EXPLANATION OF MAJOR CHANGES IN FY 2024

Funding for the Aircraft Capability Management Office (ACMO), created by the Mission Support Directorate (MSD) in FY 2022 to actively pursue the recapitalization of aging aircraft assets, is realigned from the I&TC Program to the Center Engineering, Safety, and Operations (CESO) Program. ACMO is responsible for the establishment and management of the aviation capability portfolio with a focus on developing and advancing aircraft capabilities that support NASA's long-term mission goals.

INFRASTRUCTURE & TECHNICAL CAPABILITIES

Funding for Library Services was realigned from the I&TC Logistics Management project to the Mission Enabling Services Office of Communications project to better ensure the preservation of NASA's history and information Services.

ACHIEVEMENTS IN FY 2022

Environmental Compliance, Planning, and Stewardship

- Reduced risk to mission and supported NASA's commitment to the environment through comprehensive environmental compliance programming;
- Implemented an Environmental Management Strategic Plan that defines NASA environmental goals and objectives and prioritizes initiatives;
- Improved sustainability practices, including the Energy and Water Program Management Strategic Plan, to drive efficiency and cost savings across the Agency;
- Began transitioning to a Zero Emission Vehicle (ZEV) fleet by installing the necessary recharging infrastructure and establishing acquisition criteria to begin replacing NASA's fuel-powered fleet of 2,609 vehicles with electrical vehicles; and
- Provided National Environmental Policy Act (NEPA), cultural resources, natural resources, and compliance support to centers to assist in the execution of projects, streamline the decision-making process, and reduce cost and schedule impacts to future projects.

Agency Master Plan (AMP)

- Continued Agency AMP activities to identify the linkage between capability, facility, and mission requirements through collaboration with mission customers;
- Integral to the (AMP), completed an Asset Inventory Assessment (AIA) for NASA's more than 5,300 real property assets bucketing them into invest, sustain, divest, or outgrant based on mission need and facility health; and
- Developed a dataset with all of NASA's real property asset's Mission Relevance (MR) and future state need for use by both mission and institutional managers and stakeholders.

Facility Management

- Continued installation of key technologies for condition-based maintenance of critical equipment and facilities to minimize failures and reduce operational maintenance costs;
- Began procurement of an enterprise-level, computerized maintenance management system/enterprise asset management software system to advance the Agency Maintenance Program;
- Began piloting a tiered maintenance approach at four centers to address routine and backlogged maintenance through the prioritization of risk to highly critical equipment within the mission-critical assets based on available funding and mission priorities;
- Began an Agency tiered maintenance policy and implementation plan via onsite equipment asset criticality assessments (EACA) at one center and two sites;
- Reduced arc flash and layered pressure vessel system risk through ongoing analysis, mitigation, and testing;
- Completed two Center Resiliency Studies identifying NASA's susceptibility to climate change and measures to mitigate risk and ensure mission success; and

INFRASTRUCTURE & TECHNICAL CAPABILITIES

- Developed an integrated approach to supply, store, analyze, and provide geospatial data and technical support to NASA's stakeholders, including DoD, industry, and other agencies.

Space Environments Testing Management Office (SETMO)

- Continued modernization of ARC's Arc Jet Complex, a critical Agency ground testing capability used for flight qualified thermal protection systems for atmospheric entry; and
- Provided sustainment support to SETMO Tier 1 capabilities that enabled over 1,750 operational days of testing and simulation services to NASA programs and other DoD/Industry Partners.

WORK IN PROGRESS IN FY 2023

Environmental Compliance, Planning, and Stewardship

- Reduce risk to mission and supported NASA's commitment to the environment through comprehensive environmental compliance programming;
- Implement an Environmental Management Strategic Plan that defines NASA environmental goals and objectives and prioritizes initiatives;
- Provide NEPA, Cultural Resources, Natural Resources, and compliance support to centers to assist in the execution of projects and streamline the decision-making process, reduce costs, and schedule impacts to future projects;
- Implementing NASA’s five-year plan to transition to ZEV Federal fleet, including conversion of gas-powered fleet, site-level planning tools, and training content;
- Create supply chain climate resiliency models and analysis in support of climate action planning in collaboration with the NASA Aeronautics Research Institute; and
- Begin executing the FY 2023 Carbon Pollution Free Electricity (CFE) Strategic plan submitted to Council on Environmental Quality (CEQ) through targeted initiatives to increase NASA's procurement of CFE per E.O. 14057 - Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability.

Agency Master Plan (AMP)

- Finalize and begin implementation of the AMP with the goal of driving toward a mission-driven and affordable facility portfolio through executing tiered maintenance across all of NASA's real property, prioritizing investment in mission critical degraded facilities, and prioritizing divestment of facilities no longer needed by the Agency;
- Generate an Agency-wide proposed list of prioritized divestments;
- Create the first Agency-wide Capital Investment Program Plan (CIPP) to prioritize projects tied to the AMP; and
- Develop a centralized data platform to facilitate regular updates of AIA data.

Facility Management

- Continue investments in condition-based maintenance (CBM) measures across all centers to include pressure, vibration, and temperature sensors on critical equipment to predict potential critical equipment failures and reduce operational maintenance costs from unscheduled failure events;

INFRASTRUCTURE & TECHNICAL CAPABILITIES

- Continue the Agency tiered maintenance policy and implementation plan via onsite EACA at one center and two sites;
- Reducing the administrative costs of implementing Real Estate agreements through the implementation of the Real Estate Agreement Management System (REAMS) enterprise tool, while increasing the efficiency and effectiveness;
- Use data analytics from condition-based maintenance to predict failures, ensure operational readiness, reduce maintenance costs, and use energy monitoring to drive toward efficient operations;
- Establish a centralized procurement for geospatial support and consolidating the enterprise architecture into a centrally managed solution; and
- Develop a CBM maturity model, gap analysis, and plan for all center to lean into the advanced level of CBM implementation.

Space Environments Testing Management Office (SETMO)

- Continue the modernization of the Arc Jet Complex, a critical Agency ground testing capability used for flight qualified thermal protection systems for atmospheric entry;
- Provide sustainment support to SETMO Tier 1 capabilities to provide 1,950 available operational days of testing and simulation services to NASA programs and other DoD/Industry Partners; and
- Begin piloting a reliability centered maintenance (RCM) approach at the five centers having SETMO Tier 1 assets to assess the availability risks of highly critical equipment within the mission-critical assets and develop optimized RCM based strategies to increase reliability at reduced costs.

Enterprise Transformation

- Drive the organization to adopt an enterprise attitude that allows leveraging centers' and divisions' strengths in support of the collective mission. This is manifested through the implementation of initiatives contained in the Office of Strategic Infrastructure (OSI) Strategic Plan in service of its four goals: Readiness, Affordability, Sustainability, and Workforce.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

Environmental Compliance, Planning, and Stewardship

- Reduce risk to mission and supported NASA's commitment to the environment through comprehensive environmental compliance programming. Continue implementation of an Environmental Management Strategic Plan that defines NASA environmental goals and objectives and prioritizes initiatives;
- Provide NEPA, Cultural Resources, Natural Resources, and compliance support centers to assist in the execution of projects and streamline the decision-making process, reduce costs, and schedule impacts to future projects;
- Upgrade and acquire charging infrastructure and capacity for ZEV at all NASA centers to replace petroleum-based fleet with ZEV and associated charging infrastructure;
- Improve sustainability practices by continuing to implement the Energy and Water Program Management Strategic Plan with actions that will drive efficiency and cost savings across the Agency; and

INFRASTRUCTURE & TECHNICAL CAPABILITIES

- Continue efforts toward meeting NASA's Carbon Pollution-Free Electricity strategic plan to achieve 100 percent CFE by 2030 with targeted procurement initiatives geared toward increasing NASA's CFE utilization.

Agency Master Plan (AMP)

- Align overall capabilities to mission requirements and optimize the Agency's portfolio through implementation of AMP mission-driven and affordability strategies and initiatives;
- Generate NASA's first Agency-wide Capital Investment Program Plan (CIPP) to facilitate planning and design of center projects aligned to the AMP;
- Standardize and institutionalize AMP processes and measures into policy to ensure the linkage between capability, facility, and mission requirements are sustained and that mission-driven investments are prioritized; and
- Begin Center Master Plan (CMP) updates to align to the AMP.

Facility Management

- Mature CBM performance and measures across all centers through continued investments in pressure, vibration, and temperature sensors on critical equipment to enable prediction and mitigation of potential systems and equipment failures, reduce unplanned maintenance and associated spending, and increase facility reliability;
- Begin measuring center progress toward implementing advanced CBM practices. Finalize metrics for assets monitored by CBM showing increased uptime;
- Complete the Agency tiered maintenance policy and implementation plan via onsite EACA at one center and two sites;
- Initiate EACA at two additional centers in alignment with the Agency Tiered Maintenance policy;
- Continue to reduce arc flash and layered pressure vessel system risk through ongoing mitigation and testing;
- Institutionalize tiered maintenance approach at all centers to address routine and backlogged maintenance through the prioritization of risk to mission-critical assets based on available funding and mission priorities;
- Continue implementation of an enterprise-level, computerized maintenance management system/enterprise asset management software system to advance the Agency Maintenance Program;
- Continue installation of key technologies for condition-based maintenance on critical equipment and facilities to prevent failures and reduce operational maintenance costs; and
- Integrate all centers into Enterprise Geographic Information System (GIS) Enterprise contract led from OSI's Facilities Real Estate Division.

Space Environments Testing Management Office (SETMO)

- Improve the availability of testing capabilities in support of the development of flight-qualified thermal protection systems for atmospheric entry missions through the continued modernization of the Arc Jet Complex, a critical Agency ground testing capability,
- Provide sustainment support to SETMO Tier 1 capabilities to provide 1,950 available operational days of testing and simulation services to NASA programs and other DoD/Industry Partners, and

INFRASTRUCTURE & TECHNICAL CAPABILITIES

- Advance space commercialization initiatives by sustaining NASA's unique ground-based testing and simulation capabilities for use by industry partners.

Enterprise Transformation

- Continue enterprise transformation to improve strategic coordination, resource allocation, and agile management of NASA's physical asset portfolio, including real-property and facilities, and NASA's technical capabilities; and
- Eliminate redundant Logistics applications and systems and migrate data and business processes to Agency-wide Enterprise IT systems to streamline Logistics business processes, improve asset visibility, availability of services, and supply chain resilience capabilities.

Program Elements

ENVIRONMENTAL MANAGEMENT

The Environmental Management Program enables compliance with applicable Federal, state, and local environmental laws and regulations, as well as NASA policy in day-to-day operations and mission support. Specifically, Environmental Management covers NASA's programs for local environmental policy development, Environmental Management System (EMS) implementation, environmental permitting and compliance, recycling, sustainable acquisition, hazardous materials and waste management, pollution prevention, energy and water management systems and reporting, renewable energy, natural resources, historic properties, and NEPA Program support. In contrast, the Environmental Compliance and Restoration programs (funded in the CECR account) perform restoration activities to clean up the environment from past activities. Cleanups are prioritized to ensure that the highest priority liabilities are addressed first to protect human health and the environment and preserve natural resources for future missions.

FACILITIES SERVICES

The Facilities Services Program encompasses the institutional facilities support activities throughout the Agency. The budget supports utility services, operations and maintenance services, infrastructure and facility repair projects, facilities management, real estate, and facilities engineering to include civil construction designers, engineers, and project managers. I&TC funds the civil servants and procurements that operate, maintain, and manage NASA’s institutional infrastructure. NASA recently deployed a cost model that forecasts the funding requirements to sustain its inventory of facilities at the current condition. NASA manages a portfolio of assets with over $3 billion in deferred maintenance. The I&TC budget pursues a strategy to reinforce infrastructure readiness and drive affordability by stemming growth of backlogged maintenance and systematically improving the reliability of NASA's critical institutional infrastructure (from transformers and substations to buildings, horizontal infrastructure, and test capabilities) while effectively managing risk and reliability for the remainder of the portfolio.

LOGISTICS MANAGEMENT

The Logistics Management Program encompasses the development, implementation, and management of Agency-wide logistics policies, processes, services, system innovation, and facilitates the implementation

INFRASTRUCTURE & TECHNICAL CAPABILITIES

of Government and industry best practices for NASA's centers and facilities. Logistics Management provides functional management, oversight, and coordination over the Agency's personal property equipment, supply and material, warehouse and receiving operations, property disposal, and artifact property disposition. The program also provides oversight for contractor-held property management, mail and freight management, transportation management, life cycle logistics and supply chain management, policy compliance and logistics contracts. Logistics Management ensures the readiness of material and equipment for NASA's scientific, aeronautics, and space exploration mission requirements at 10 NASA centers and three component facilities. The program includes receiving and inspecting supplies/materials as well as issuing and moving those materials so that products critical to NASA's mission arrive at the desired locations in an efficient manner.

TECHNICAL CAPABILITIES MANAGEMENT

The Space Environments Testing Management Office provides centralized and strategic management of a portfolio of specific ground-based capabilities to enable NASA's missions in science, technology, aeronautics, and space exploration. To meet requirements in support of other national interests, these capabilities are also offered to other Federal agencies and industry partners. Examples of these capabilities are provided below:

- The high-enthalpy test capability at Ames Research Center's (ARC) Arc Jet Complex provides simulated high-temperature, high-velocity environments and supports the design, development, test, and evaluation of Thermal Protection Surface materials, vehicle structures, aerothermodynamics, and hypersonic aerodynamics experienced by a vehicle during planetary atmospheric entry.
- Flight simulators are of critical importance to NASA's research in fundamental aeronautics and aviation safety. These capabilities provide scientists and engineers with tools to explore, define, and resolve issues in vehicle design and mission operations. The capabilities include the motion simulators and development laboratories used in the research and development of flight and crewed operations at the ARC Vertical Motion Simulator and the Langley Research Center (LaRC) Flight Simulation Facility.
- Space environments testing capabilities and facilities whose primary use is related to spacecraft and instrument development and qualification, space technology development, human-rated space environments, and launch environments. Capability components include vacuum, thermal/vacuum, and thermal chambers; vibration tables; acoustic labs; cleanrooms; and electromagnetic interference and electromagnetic compatibility, magnetic, optical, X-ray, solar spectrum, and ionizing radiation facilities. Located at most NASA centers, testing performed with these capabilities ensures the equipment, sub-systems, and assembled spacecraft will survive the harsh noise and vibrations experienced during launch and the ultra-low pressure and ultra-low or ultra-high temperatures experienced in space environments.
- The external radiation testing capability procures the necessary time and facility support at non-NASA facilities to meet the requirements of Agency programs and projects. The test facilities provide controlled sources of electrons, heavy ions, neutrons, protons, and other relevant types of high-energy radiation that NASA uses to simulate the impact of the natural space radiation environment on a wide range of electronic and material systems. National laboratories, private companies, and universities at both domestic and foreign locations operate these highly specialized facilities. Test activities support a wide range of assessment, development, and flight activities.

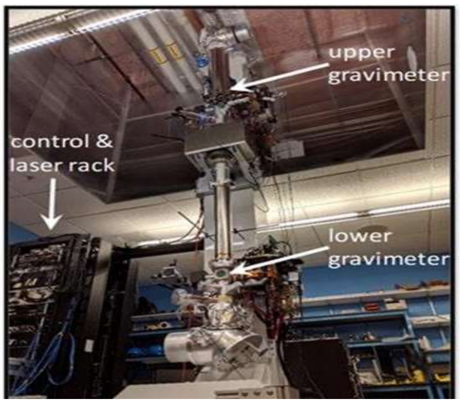
ENGINEERING, SAFETY, & OPERATIONS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Agency Technical Authority	190.0	--	**200.1**	204.1	208.2	212.3	216.6
Center Engineering, Safety, & Operations	843.4	--	**910.0**	928.6	947.3	966.2	985.5
Total Budget	**1,033.4**	**--**	**1,110.1**	**1,132.7**	**1,155.5**	**1,178.5**	**1,202.1**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



Shown here, the Atom Interferometer Gravity Gradiometer (AIGG) instrument system will contribute to climate science objectives related to time-variable gravity (TVG) measurements of Earth System mass change at Goddard Space Flight Center (GSFC).

Engineering, Safety, and Operations (ESO) supports NASA's high standard of safety and mission assurance, while maintaining center flexibilities that promote innovation and mission success. ESO is divided between two, distinct programs: Agency Technical Authority (ATA) and Center Engineering, Safety, and Operations (CESO).

ATA protects the overall health and safety of NASA's workforce and programs by providing technical oversight for safety, health, quality, and engineering. The independence of ATA offices is a vital part of NASA's checks and balances to ensure safety, quality, and engineering concerns are always vetted, analyzed, and mitigated. ATA offices develop policies, guidance, and conduct reviews at a corporate level, which are implemented at the center-level through CESO programs.

CESO provides funding for several center-level activities, including the operations and management at nine centers and component facilities, in addition to corporate leadership at NASA Headquarters (HQ), the execution of delegated technical authority at the centers, and center investments to ensure mission success, innovation, and technical excellence. CESO allows centers the flexibility to address mission-critical requirements, such as acquiring specialized scientific and engineering equipment. CESO funds center-level implementation of ATA policies and guidelines and preserves the checks and balances at each center that ensure the highest standards of health, safety, and mission assurance. It also supports NASA's competitive bid and proposal process. CESO includes center institutional operations that are not performed by NASA's enterprise functional offices. CESO encompasses a diverse set of ongoing activities and unique projects in support of center operations and infrastructure, while enabling safe and effective mission support.

ENGINEERING, SAFETY, & OPERATIONS

ESO Priorities

ESO is aligned to key objectives under the Agency and mission support strategy to deliver high-quality and affordable services to centers and missions. ESO contributes to the safe and successful exploration of space, development of aerospace research and technology, and pursuit of scientific breakthroughs. Key priorities include:

- Ensure laboratories, critical capabilities, and associated specialized equipment are mission-ready and meet NASA's standards for quality, reliability, and safety;
- Sustain the engineering and research capabilities in analytical support, test services, lab services, and fabrication capabilities, that are specific to each center;
- Apply delegated technical authorities to ensure the highest standards of quality and safety in engineering and mission assurance;
- Fund independent research and development projects that ensure centers have mission-ready technical capabilities and capacity to support NASA's missions (now and in the future);
- Support management activities at the center-level, including the operationalization of Agency policies and guidance across institutional and functional areas;
- Support Agency-level operations at NASA HQ to ensure the development and implementation of Agency-wide policies, standards, and processes are effective and efficient;
- Provide independent review and deep technical knowledge on health and safety, including medical and engineering evaluations, across all mission activities;
- Ensure ethical conduct in NASA's research and experimentation activities;
- Evaluate risks to mission, including the potential loss of life, engineering failures, health impacts, and mission failure; and
- Provide policy and technical guidance to ensure optimal mission health, safety, and success.

EXPLANATION OF MAJOR CHANGES IN FY 2024

See each program area for a description of significant changes.

ACHIEVEMENTS IN FY 2022

See each program area for a complete list of achievements in FY 2022 for ATA and CESO.

WORK IN PROGRESS IN FY 2023

See each program area for a complete list of work in progress in FY 2023 for ATA and CESO.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

See each program area for a complete list of planned achievements in FY 2024 for ATA and CESO.

ENGINEERING, SAFETY, & OPERATIONS

Programs

AGENCY TECHNICAL AUTHORITY (ATA)

ATA work is managed by the Offices of the Chief Health and Medical Officer (OCHMO), Safety and Mission Assurance (OSMA), and the Chief Engineer (OCE), and includes vital programs like the NASA Safety Center (NSC), the Independent Verification and Validation (IV&V), and the NASA Engineering and Safety Center (NESC). These activities provide the foundation for NASA's system of checks and balances, defined in NASA's Strategic Management and Governance Handbook, by providing for the technical authority over health, safety, and engineering, independent of the missions. Through independent analysis and deep subject matter expertise, ATA develops policy, designs procedural requirements, and provides recommendations to NASA's Administrator, mission directorates, center directors, and program managers, who are ultimately responsible for the safety and mission success of all NASA activities.

ATA provides training and maintains a competent technical workforce with expertise in system engineering, system safety, reliability, quality, and space medicine. Subject matter experts analyze risks and risk acceptability through an established process of independent reviews and assessments. The information and advice from these experts provide critical data required to develop authoritative decisions related to the application of requirements on programs and projects.

CENTER ENGINEERING, SAFETY, AND OPERATIONS (CESO)

NASA's Center Engineering, Safety, and Operations (CESO) is a multifaceted program that ensures Agency leadership is implemented at the center-level, while centers have the flexibility and support to ensure mission success and uphold NASA's high standard of safety and engineering excellence.

CESO ensures NASA's unique, technical, and innovative capabilities are mission-ready by supporting center-level institutional and technical capabilities through independent research, development projects, and maintenance of facilities, laboratories, and other mission-critical assets. The technical skill and specialized assets or services that support analyses, design, research, testing, laboratories, and fabrication enable the efficient and effective implementation of mission work at the centers, now and in the future. CESO funds are used by centers to ensure the technical skills and capabilities are available and mission-ready based on mission requirements and timelines.

CESO is a key component of NASA's overall approach to risk management by providing center-level independent technical authority. By funding center-level oversight and reporting activities that uphold the strategy and guidance from ATAs, checks on safety, engineering, and mission assurance remain separate from mission directorates.

CESO funds NASA HQ operations, as well as center management across the Agency. Support for institutional administration and operational safety are vital to allow centers the flexibility to address and manage conditions unique and specialized to their center. CESO also ensures that Agency policies and guidance are operationalized across centers with consistency and efficiency.

AGENCY TECHNICAL AUTHORITY

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**190.0**	**--**	**200.1**	**204.1**	**208.2**	**212.3**	**216.6**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Shown above is the Eugene Stansbery Meter Class Autonomous Telescope (ES-MCAT) on Ascension Island. The Orbital Debris Program Office (ODPO) uses ES-MCAT to survey small orbital debris in the geosynchronous Earth orbit (GEO) region.

Agency Technical Authority (ATA) Program protects the health and safety of NASA's workforce by evaluating programs, projects, and operations to ensure safe and successful completion. ATA capabilities provide expert technical excellence, mission assurance, and technical authority Agency-wide.

ATA is managed by the Offices of the Chief Health and Medical Officer (OCHMO), Safety and Mission Assurance (OSMA), and Chief Engineer (OCE). It includes vital programs such as the NASA Safety Center (NSC), the Independent Verification and Validation (IV&V), and the NASA Engineering and Safety Center (NESC). These programs provide the foundation for NASA’s system of checks and balances defined in NASA’s Strategic Management and Governance Handbook. Through independent analysis and deep subject matter expertise, ATA develops policy, designs procedural requirements, and provides recommendations to NASA's Administrator, mission directorates, center directors, and program managers, who are ultimately responsible for the safety and mission success of all NASA activities.

ATA provides training and maintains a competent technical workforce with expertise in system engineering, system safety, reliability, quality, and space medicine. Subject matter experts analyze risks and risk acceptability through an established process of independent reviews and assessments. The information and advice from these program experts provide critical data required to develop authoritative decisions related to the application of requirements.

Agency Technical Authority (ATA) Priorities

ATA programs independently focus on critical strategic objectives that advance a health and safety culture within space exploration, space technology advancements, and scientific discoveries; and supports the health and safety of NASA's workforce and the public. Specifically, ATA primarily focuses on critical objectives that support mission safety, health, and ethics:

- Provide independent review and expert technical knowledge on health and safety and includes medical and engineering evaluations across all missions;

AGENCY TECHNICAL AUTHORITY

- Ensure ethical conduct in NASA's research and experimentation activities;
- Evaluate risks to mission, including the potential loss of life, engineering failures, health impacts, and mission failure; and
- Provide policy and technical guidance to ensure optimal mission health, safety, and success.

Orbital Debris

A primary focus for NASA is to take steps to preserve the near-Earth space environment, in accordance with the National Space Policy, the National Orbital Debris Implementation Plan issued July 2022 by the National Science and Technology Council, and the U.S. Government Orbital Debris Mitigation Standard Practices to mitigate risks from orbital debris to human spaceflight and robotic missions. As more commercial and international entities become spacefaring, including the proliferation of small satellites and large constellations, and the amount of debris in orbit grows, the need to understand the debris environment and mitigate the orbital debris hazard increases. NASA's efforts will characterize the orbital debris environment, support the protection of NASA, other Government, and commercial assets, while laying the groundwork for addressing this growing environmental problem.

Independent Verification and Validation (IV&V)

Activities conducted through the IV&V Program are funded through a combination of ATA and mission directorate resources. The following table shows the funds provided by the Safety, Security, and Mission Services (SSMS), Science, Deep Space Exploration, and Space Operations accounts:

	Estimated IV&V Funding ($M)		
Mission Account	**FY 2022**	**FY 2023***	**FY 2024***
Safety, Security, and Mission Services	$39.1	$39.1	$39.1
Science	$3.0	$3.6	$4.5
Deep Space Exploration	$5.8	$1.8	$1.5
Space Operations	$1.1	$0.9	$1.1
Total	**$49.0**	**$45.4**	**$46.2**

**Note: FY 2023 and FY 2024 estimates are subject to change depending on mission schedules and Agency risk analysis.*

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

AGENCY TECHNICAL AUTHORITY

ACHIEVEMENTS IN FY 2022

Health and medical expertise to support NASA's priority missions

- Provided technical requirements for human spaceflight standards;
- Supported mission activities with Human System Integration to ensure crew capabilities and limitations were taken into consideration as part of system design to prevent loss of crew, loss of mission, and program impacts;
- Developed the Artemis Medical Charters, an International Partner summit on medical decision-making structure for Artemis missions;
- Supported critical mission milestones such as the Certification of Flight Readiness (COFR) and launch and landing readiness reviews for five launches and three landings;
- Reduced the time to update technical standards in support of human exploration missions;
- Developed tools to search and correlate technical requirements across programs created a Risk Dashboard for current HMTA-related issues;
- Along with the NASA Institutional Review Board implemented new streamlined processes to decrease turnaround times on all human subject research proposals; and
- Began engagement with Federal Aviation Administration (FAA), the National Transportation Safety Board (NTSB), and industry in regard to education on human health and performance for new Government and private spaceflight endeavors.

Safety and mission assurance independent evaluations and technical expertise

- Updated NASA's orbital debris mitigation standard for consistency with the 2019 USG Orbital Debris Mitigation Standard Practices;
- Sustained and enhanced key activities, including new radar data on debris populations optical surveys, development and testing of in-situ measurement sensors, and orbital debris shape modeling to characterize and monitor the ever-changing orbital debris environment;
- Collected timely measurement data on the Russian anti-satellite (ASAT) test fragments, developed a model of the fragment population, updated the NASA Orbital Debris Engineering Model (ORDEM) with the ASAT fragment component, and released ORDEM, as a stand-alone tool and a cloud-based application, to the public in March 2022, less than five months after the Russian ASAT test. ORDEM is one of the most-requested models in the NASA Software Catalog. ORDEM is used by hundreds of operators NASA, DoD, commercial, international, academia, and research groups around the world;
- Identified 36 severity one and two issues (if manifested during operations, these errors could result in loss of life, injury, inability to achieve minimum mission success criteria, loss of an essential capability, or complete loss of mission critical asset);
- Expanded cybersecurity assessment capabilities to find software vulnerabilities in NASA's orbital assets;
- Prepared for successful launch of the James Webb Space Telescope in December 2021;
- Continued development and evaluation of innovative approaches to planetary protection, including metagenomics for biological contamination assessment and analysis tool development to efficiently quantify spacecraft bioburden for the benefit of mission providers;
- Updated NASA's directive for Planetary Protection Provisions for Robotic Extraterrestrial Missions ensuring consistency with Committee on Space Research (COSPAR) guidelines and aligning planetary protection implementation and verification with standard project management

and systems engineering practices. Published new standard for planetary protection. Continued development and evaluation of innovative approaches for biological contamination assessment;
- The Katherine Johnson Independent Verification and Validation Facility’s Education Resource Center (ERC), part of the OSMA, supported students in foster and kinship care in the First Star Academy and students from the West Virginia Deaf Services Center (DSC). The ERC team trained and worked with these students by providing them access to drones, supporting robotics camp participation, and enabling their registration in the Robotics Education and Competition Foundation Aerial Drones (RAD) Signature Event. Based on their performance at the signature event, the West Virginia DSC team qualified for the RAD World Championship;
- The IV&V Program eliminated the need for leased office space by migrating most of the Fairmont operations into the Katherine Johnson Independent Verification and Validation (IV&V) Facility, which will save $600,000 per year that can be applied directly to IV&V technical work. IV&V also reduced contractor space in non-Fairmont locations, which will save another $600,000 per year;
- Developed machine assisted method for tailoring safety mission assurance requirements for NASA missions and created a digital repository and assistant for generating safety and mission assurance plans to guide projects early in acquisition and throughout development;
- Realigned the Apollo, Challenger, and Columbia Lessons Learned Program and the NASA Safety Reporting System under the NASA Safety Center to improve knowledge of safety awareness efforts; and
- Collaborated with NASA supply chain risk management teams to alleviate risk by centralizing activities and investments.

Technical review and engineering expertise, guidance, and oversight

- Provided engineering guidance, oversight, and review through the NESC to all NASA missions, with priority focus on astronaut spaceflight (commercial and otherwise), ISS maintenance, space exploration activities, and science missions;
- OCE supported development of a careful transition approach to implement upgrades of the Space Communications and Navigation (SCaN) network for deep space missions;
- Supported the Agency's most important programs, ensuring independent technical insight and assessment of these programs at key programmatic milestones, such as: X-57 Maxwell aircraft, X-59 Low Boom Flight Demonstrator, International Space Station (ISS), Commercial Crew Program (CCP), Artemis, Gateway, and James Webb Space Telescope;
- Conducted over 20 Safety and Mission Success Reviews (SMSR) that includes James Web Space Telescope, Artemis I, three Commercial Crew missions, and the first-ever private astronaut mission; for NASA Technical Authorities to independently assess the readiness to proceed with selected space/vehicle flights in accordance with NASA policy;
- Updated NASA's directive for Nuclear Flight Safety ensuring consistency with NSPM-20; and clarified and simplified NASA's review and approval process;
- Academy of Program/Project and Engineering Leadership Knowledge Services within OCE delivered 180 courses and held 11 Agency-wide webinars, graduating a cohort of 15 from the Systems and Engineering Leadership Program;
- Developed a toolkit of resources and published a NASA Special Publication, "Ensuring Knowledge Continuity during Employee Transitions", to lessen the impact of knowledge loss due to retirements and attrition;

AGENCY TECHNICAL AUTHORITY

- Published eight Technical Bulletins on subjects, including new methods to detect damaging vibrations and to remove contaminates in fuel, and published guidelines for knock-down factors that were applied to the space launch system (SLS) used in the Artemis mission; and
- Conducted over 70 independent assessments for X-planes, the ISS, the CCP, Artemis, Gateway, and James Webb Space Telescope. OCE also performed tests for the Artemis I launch, James Webb Space Telescope, and launch vehicle transonic flight.

WORK IN PROGRESS IN FY 2023

Health and medical expertise to support NASA's priority missions

- Enhance and provide health and medical expertise to Agency's portfolio of development and operations. Develop relationships with commercial space providers as well as other Federal agencies (e.g., Space Force, NIH).

Safety and mission assurance independent evaluations and technical expertise

- Prepare for the successful launch of Psyche in October FY 2024;
- Upgrade NASA's S&MA workforce development to ensure the talent needed to successfully design, develop, operate, and oversee the many varied future missions and the new technologies and engineering and oversight processes;
- Provide technical guidance and oversight of planetary protection as technical requirements are developed and hardware is designed for human missions to Earth’s Moon and capability is further developed for future human missions to Mars;
- Develop, maintain, and improve orbital debris environment models, tools, and algorithms to improve orbit predictions, understand spacecraft anomalies, and better interpret sensor data;
- Prepare to conduct in-situ measurements of millimeter-sized orbital debris by continuing to advance the technology readiness level of the Multi-layer Acoustics and Conductive-grid Sensor leading to a future mission opportunity to address the critical data gap on the millimeter-sized orbital debris in low-Earth orbit that cannot be remotely measured by radar or optical means;
- Maintain small orbital debris hazard environment characterization by re-coating the 1.3-meter primary mirror of the ES-MCAT to fully restore the detection sensitivity of the telescope to continue the measurement of small orbital debris in GEO region;
- Lead development of and update to orbital debris mitigation standards, measures, and policies with the United States, partnering with DoD and other agencies; and, internationally through forums and committees;
- Advance the Supply Chain Insight Central (SCIC) IT platform to support its ability to serve Agency-wide needs and to aggregate data from internal and external data repositories in support of Supply Chain Risk Management (SCRM);
- Provide software expertise to 17 projects, including 15 NASA missions, Commercial Crew Program, one multi-Agency mission, and across six NASA centers;
- Provide independent verification and validation support of the Artemis I exploration mission to be launched in FY 2023;
- Develop and provide specialized training in support of aerospace microelectronics and radiation effects workforce development;

AGENCY TECHNICAL AUTHORITY

- Establish a new capability to assess and build relationships with high-volume industry-leading microelectronics manufacturers that supports the increased utilization of COTS devices in high-reliability aerospace applications;
- Support a robust safety culture that values and pursues technical and organizational excellence by conducting the bi-annual safety culture survey, analyzing, providing out-briefs, and tracking correction action plans;
- Conduct Safety and Mission Success Reviews (SMSR) for Artemis, Commercial Crew missions, science missions, and an aeronautic demonstration, for the NASA technical authorities to independently assess the readiness to proceed with selected space/vehicle flights in accordance with NASA policy;
- Complete development and documentation of an enterprise approach for the inspection and oversight of Commercial Aviation Services (CAS) to effectively ensure aviation safety; and
- Complete integration of center and Agency activities performed to assess the health of institutional safety, including Agency audits, self-evaluations, center assessments, and identification of systemic safety risks.

Technical review and engineering expertise, guidance, and oversight

- Develop lunar communications and navigation relay capabilities, in line with Agency's LunaNet architecture, for future science and crewed Artemis missions;
- Continue provision of engineering guidance, oversight, and review through the NESC to all NASA missions, with priority focus on astronaut spaceflight (commercial and non-commercial), ISS maintenance, space exploration activities, and science missions;
- Continue support of Commercial Crew launches, ISS sustainment, Artemis missions, and science missions;
- Support development of the commercialization plan for low-Earth orbit and lunar relay communication and navigation services; and
- Advance development and implementation of cross-Agency training for the technical workforce to enhance program/project management and systems engineering skills.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

Health and medical expertise to support NASA's priority missions

- Evolve NASA human spaceflight standards and requirements to enable the lunar exploration architecture with an eye toward Mars as set forth by the Administrator's priorities memo;
- Provide health and medical support for NASA crewed flight programs and projects; and
- Continue technical, development, and human systems expertise to enable lunar and Mars architecture in support of the NASA missions, as set forth by the Administrator's priorities memo.

Safety and mission assurance independent evaluations and technical expertise

- Provide tailored, risk-driven, software through independent verification and validation to selected NASA science and crew missions to detect and resolve software defects in accordance with project approved plans;

AGENCY TECHNICAL AUTHORITY

- Continue support for elements of Artemis, the International Space Station (ISS), and five high priority science missions through independent verification and validation. Additionally, support LandSat Next (LNext) and Geospace Dynamics Constellation (GDC) that will commence in FY 2024;
- Provide software Independent Verification and Validation services to NASA's science and crew missions to mitigate the risk of software failures impacting safety and mission success;
- The Orbital Debris Program Office will:
  - Conduct radar and optical measurements to monitor the ever-changing orbital debris environment and update models to better assess risks from orbital debris for the safe operations of space missions in the near-Earth space environment;
  - Partner with Science Mission Directorate to pursue a mission opportunity to deploy MACS to 600-1,000 kilometers (km) altitude to collect direct measurement data on the millimeter-sized orbital debris, which drives the mission-ending risk to spacecraft operating in the region; and
  - Continue collaboration with Office of Technology, Policy, and Strategy and Space Technology Mission Directorate (STMD) on cost-benefit analysis of orbital debris remediation and the identification of high priority targets.
- NASA Electronics Parts and Packaging (NEPP) will improve Agency guidance for the use of commercial-off-the-shelf (COTS) electronics;
- Complete updated policy handbooks and standard operating protocols for implementing planetary protection by addressing knowledge gaps to support performance-based approaches (e.g., metagenomics and updated Bayesian modeling approaches);
- Improve software risk reporting by developing a clear set of guidance to address inconsistencies in reporting software assurance and related safety risks;
- Meteoroid Environments Office will conduct lunar meteoroid impact observations to implement real-time lunar impact modelling in support of Artemis programs;
- Complete the implementation and improvement of Supply Chain Risk Management Policy, Processes, and Partnerships' initiative;
- Provide institutional safety policy direction and oversight of all NASA centers and activities to assure that effective safety programs are in place and cross cutting issues are identified and addressed:
  - Complete the update of NPR 7900.3D (Aircraft Operations Management) to ensure NASA aircraft operations and safety policy reflects changes to NASA's approach to aviation capability management and realignment of the Aviation Management Division; and
  - Complete the implementation of the arc-flash mitigation project to ensure proper labeling of equipment, which will ensure compliance with Occupational Safety and Health Administration (OSHA) requirements.
- Support Program Mishap Preparedness and Contingency Plan and investigations to enable an effective mishap prevention and readiness program;
- Provide an objective-driven and risk-based approach to performing assessment, audit, investigation, review, and analysis activities along with NPR 8705.6 clarifications and revision;
- Conduct strategic communication, safety awareness, and knowledge sharing campaigns to inform and empower the SMA community;
- Provide relevant learning tools and resources (e.g., annual day of remembrance course to Agency, Executive Safety Leadership Program, Chief Safety Officer summit, STEP) to enhance S&MA expertise across the Agency's workforce;
- Provide proactive safety awareness initiatives that address trends across the Agency including mishap data, audit findings, center best practices and the National Safety Reporting System (NSRS); and

AGENCY TECHNICAL AUTHORITY

- Develop innovative technology and data solutions to optimize productivity, effectiveness, and stakeholder experiences while supporting OSMA digital transformation (e.g., Automated Program Plan Generator).

Technical review and engineering expertise, guidance, and oversight

- Continue collaborations between ATA programs to enhance the Agency's ability to provide technical reviews, guidance, and support to missions (e.g., Artemis, ISS, Commercial Crew, Orion / SLS, robotic missions, and Space Technology investments);
- Provide Engineering Technical Authority support to NASA's programs, ensuring independent technical insight and assessment of these programs at key programmatic milestones, such as: X-57 Maxwell aircraft, X-59 Low Boom Flight Demonstrator, ISS, CCP, Artemis, and Gateway;
- Advance development and implementation of cross-Agency training for the technical workforce to enhance program/project management and systems engineering skills;
- Consistent with recommendations of the Columbia Accident Investigation Board Report, ensure employees and reviewers can voice dissenting opinions or raise concerns regarding safety concerns;
- Examine, maintain, and improve discipline-specific talent required to ensure safe and successful future NASA mission development and operations;
- Ensure employees and reviewers can voice dissenting opinions or raise concerns regarding safety concerns;
- Enhance program/project management and systems engineering skills for the Agency’s technical workforce through formal learning and development programs as well as community and on-the-job knowledge transfer activities supported by NASA's Academy of Program/Project and Engineering Leadership (APPEL) Knowledge Services;
- Continue provision of engineering guidance, oversight, and review through the NESC Technical Assessments to all NASA missions, with priority focus on astronaut spaceflight (commercial and otherwise), ISS maintenance, space exploration activities, and science missions. Engineering will ensure robust flight rationale specifically enabling eventual Human Lunar Lander, Deep Space Gateway, certification of a second commercial provider for ISS access, and commercial science payloads to the surface of the Moon; and
- Continue technical, development, and human systems expertise to enable lunar and Mars architecture in support of the NASA missions, as set forth by the Administrator’s priorities.

Program Elements

OFFICE OF THE CHIEF HEALTH AND MEDICAL OFFICER (OCHMO)

OCHMO promulgates Agency health and medical policies and standards to support the medical technical capabilities of NASA. As a functional area, OCHMO provides independent oversight and advances expert health and medical capabilities from development through de-commissioning. It assures the physical and mental health and well-being of the NASA workforce.

OCHMO also ensures that bioethics principles and NASA’s policies and practices related to the use of human and animal subjects in research are in accordance with all relevant Federal regulations and guidelines. The program oversees NASA’s processes for reviewing the use of human and animal subjects in research.

AGENCY TECHNICAL AUTHORITY

OCHMO administers the Human Medical Technical Authority (HMTA), which engages in all crewed programs. The HMTA provides guidance, insight, and oversight, while translating health and medical standards into tailored technical requirements for all Human-Rated programs across the Agency. HMTA ensures that integrated spaceflight systems reflect the most current knowledge on health and medical impacts related to flight, life support, and environmental systems.

OFFICE OF SAFETY AND MISSION ASSURANCE (OSMA)

OSMA provides policy direction, functional oversight, and assessment for all Agency safety, reliability, maintainability, quality engineering and assurance, software assurance, risk management, orbital debris mitigation, nuclear flight safety, aviation safety, and planetary protection activities and serves as a principal advisory resource for the Administrator and other senior officials on matters pertaining to safety and mission success. The program develops technical excellence in these areas and assesses and communicates cross-cutting and significant risks to appropriate decision makers.

OSMA conducts a schedule of reviews and assessments that focuses on the life cycle decision milestones for crucial NASA programs and projects, safety, reliability, and quality processes. Embodied in this program is a structured development of methodology and investigation into system attributes that improve the probability of mission success.

OSMA includes the Mission Programs and Assessments Division, Institutional Safety Management Division, Mission Assurance Standards and Capabilities Division, and NSC, as well as the IV&V.

The NSC, an OSMA component, consolidates safety and mission assurance activities for affordable and consistent service across the Agency. It supports general technical excellence, knowledge management, audits and assessments, and mishap investigation support. NSC helps protect the safety of people, equipment, and property by verifying compliance with OSMA policies and works proactively to prevent mishaps and failures.

INDEPENDENT VERIFICATION AND VALIDATION (IV&V)

IV&V, a component of OSMA, ensures that mission critical systems and software will operate reliably, safely, and securely. It provides independent oversight and technical knowledge across NASA missions. IV&V is funded through the SSMS account with additional support from mission directorates.

Software, as an asset on NASA missions, is extremely critical. IV&V provides a proven means of identifying software problems early and helps to minimize the cost of software development and potential rework.

In support of independent evaluations of software related approaches and processes, IV&V provides resources and software expertise to other SMA elements. It supports the sustainment of software technical excellence within the SMA community, sustainment of software domain knowledge within the SMA organization, and formulation of software development improvement recommendations to the Agency.

IV&V Program's independent test capability enables advanced testing and simulations of NASA's mission and safety critical software; testing and evaluation of robotics and intelligent systems; capability development within the systems engineering disciplines; and training and education for workforce and students.

AGENCY TECHNICAL AUTHORITY

OFFICE OF THE CHIEF ENGINEER (OCE)

OCE ensures that NASA's development efforts and mission operations are planned and conducted with sound engineering practices, proper controls, and management of technical risks. The program provides independent engineering oversight and guidance to ensure that decisions have the benefit of different points of view and are not made in isolation.

OCE ensures that NASA's development efforts and mission operations are planned and conducted on sound engineering principles with proper controls and management of technical risks. Further, OCE establishes and maintains program/project management and engineering policy and technical standards. Additionally, OCE creates the foundation for excellence of program/project management and engineering workforce, system-engineering methodology, and system of engineering standards throughout the Agency.

OCE also sponsors the Academy of Program/Project and Engineering Leadership Knowledge Services (APPEL KS) to develop program and project management and systems engineering skills and support critical knowledge sharing across the Agency's technical workforce. APPEL provides a formal professional development curriculum designed to address four career levels spanning from recent college graduate to executive.

OCE manages the NESC, which enables rapid, cross-Agency responses to mission critical engineering and safety issues at NASA and improves the state of practice in critical engineering disciplines. Established in FY 2003 in response to the recommendations of the Space Shuttle Columbia Accident Investigation Board, the NESC performs independent testing, analysis, and assessments of NASA's high-risk projects to ensure safety and mission success. As an Agency-wide resource with a reporting path that is independent of the mission directorates and directly funded from OCE, the NESC helps the Agency ensure mission safety and obtain objective technical results.

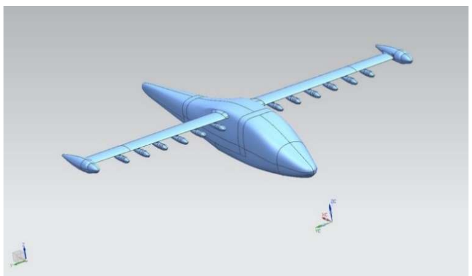
CENTER ENGINEERING, SAFETY, & OPERATIONS

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**843.4**	**--**	**910.0**	**928.6**	**947.3**	**966.2**	**985.5**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



Above is an image of the X-57 Maxwell Geometry from the GEOLAB at Langley Research Center (LaRC). The lab provides numerical geometry and mesh generation to support NASA projects such as Hypersonic Technology, Low Boom Flight Demonstrator, X-57, and Space Launch Systems.

NASA's Center Engineering, Safety, and Operations (CESO) Program provides strategic management and crucial policy direction at the Agency- and center-level in addition to center-level technical authority and capabilities that ensure mission success.

CESO maintains test capabilities, laboratories, and other mission critical assets so they are available and mission-ready based on mission requirements and timelines. The technical skill and specialized assets or services that support analyses, design, research, testing, laboratories, and fabrication enable the efficient and effective implementation of mission work at the centers.

CESO programs contribute to NASA's overall approach to risk management by providing center-level independent technical authority. By funding center-level oversight and reporting activities that uphold the strategy and guidance from Agency Technical Authorities (ATAs), checks on safety, engineering, and mission assurance remain separate from mission directorates.

CESO funds Headquarters (HQ) operations, as well as center management across the Agency. This institutional support for center operations and infrastructure allows the centers to focus on managing conditions unique to their center. CESO also ensures that Agency policies and guidance are operationalized across the centers with consistency and efficiency.

CENTER ENGINEERING, SAFETY AND OPERATIONS (CESO) PRIORITIES

CESO activities maintain the necessary technical skills and capabilities at each center, driven by mission requirements, while ensuring alignment and implementation of Agency-level policies and standards. CESO funds critical activities that maintain NASA standards for safety and engineering excellence and catalyzes technical innovation and unique capabilities. CESO priorities support the Agency and centers in their responsibility to meet mission requirements and include:

- Ensure laboratories, critical capabilities, and associated specialized equipment are mission-ready and meet NASA's standards for quality, reliability, and safety;
- Sustain the engineering and research capabilities in analytical support, test services, lab services, and fabrication capabilities that are unique and specific to each center;

CENTER ENGINEERING, SAFETY, & OPERATIONS

- Apply delegated technical authorities to ensure the highest standards of quality and safety in engineering and mission assurance;
- Fund internal research and development projects that ensure centers have mission-ready technical capabilities and capacity to support NASA's missions (now and in the future);
- Support management activities at the center-level, including the operationalization of Agency policies and guidance across institutional and functional areas; and
- Support Agency-level operations at NASA HQ to ensure the development and implementation of Agency-wide policies, standards, and processes are effective and efficient.

EXPLANATION OF MAJOR CHANGES IN FY 2024

Funding for the Aircraft Capability Management Office (ACMO), created in MSD in FY 2022, is realigned to the CESO Program from the Infrastructure and Technical Capabilities Program. ACMO is responsible for the establishment and management of the aviation capability portfolio, with a focus on developing and advancing aircraft capabilities that support NASA’s long-term mission goals.

Funding to fully support the Office of the Chief Technologist (OCT) was realigned from the Space Technology Mission Directorate (STMD) to CESO to create the Office of Technology, Policy, and Strategy (OTPS). The OTPS is a merger of the Office of Strategic Engagements and Assessments and the OCT. The OTPS provides data- and evidence-driven technology, policy, and strategy advice to NASA leadership to develop and guide the Agency’s activities across its six mission directorates.

ACHIEVEMENTS IN FY 2022

Capabilities, Facilities, Labs, and Test Equipment

- Invested in KSC’s Fluids and Propellant Infrastructure to replace aged and end-of-life hardware, thus ensuring reliable delivery of propellant and high-pressure gas services to resident program and center partners;
- Procured new White Sands Test Facility Scanning Electron Microscope (SEM), which will provide valuable capability used to gather data for multiple test customers (propulsion, materials, technical services, S&MA, environmental, and reimbursable entities);
- Ensured B-2 Test Stand supports the SLS Exploration Upper Stage (EUS) Program schedule, including the continued design and buildout of Special Test Equipment required to test the upper stage element upon its arrival in 2024;
- Modernized thermal coating test instrumentation to help meet mission requirements of GSFC managed spacecraft and space-borne scientific instruments;
- Operated the Geometry Laboratory (GEOLAB) to ensure continued technical excellence in numerical geometry and mesh generation, which will be utilized by projects such as Hypersonic Technology, Low Boom Flight Demonstrator, X-57 Maxwell aircraft, and Space Launch System;
- Developed a new, reconfigurable universal data acquisition system (DAS) to increase efficiency, reduce time-to-flight, and reduce cost across the lifecycle of Unmanned Aerial Systems (UAS) projects, such as the Integrated Aeronautics Systems Program (IASP); and
- Collaborated with National Labs to increase access to a widely used software, greatly reducing the number of vendor transactions and decreasing administrative costs.

CENTER ENGINEERING, SAFETY, & OPERATIONS

Operational Safety

- Recertified high pressure systems at the National Transonic Facility (NTF) to enable critical program tests and ensure safe and reliable operations. Planned tests include the Orion Multi-Purpose Crew Vehicle (MPCV) Heat Shield Roughness Evaluation;
- Mitigated the risk to high voltage systems and subsystems by installing three high voltage transformers; and
- Installed trolley system in 8x15 facility to improve the safety conditions for transitioning into the chamber for Earth System Observatory/Atmosphere Observing System Program.

Engineering and Safety and Mission Assurance Technical Authorities

- Led the VIPER Lunar Rover Mission Safety and Mission Assurance Team through a successful Critical Design Review (CDR); and
- Provided Safety and Mission Assurance Technical oversight to ensure the success of the multi-year ArcJet Modernization and Vertical Motion Simulator upgrade projects.

Institutional Management and Administration

- Cultivated the next wave of NASA leaders by directing nearly 50 percent of our Internal Research and Development (IRAD) opportunities to early stage and early career employees;
- Transitioned toward a future hybrid work model, including investment in conference room upgrades to enable hybrid meetings and implementation of a six-to-nine-month hybrid pilot program in 2022;
- Leveraged technology through Space Act Agreements and Broad Agency Announcements to support the MC2 Prototype Engine;
- Completed KSC's Future Development Concept supporting NASA's missions, modernizing NASA's facilities, and reducing footprint through reduced O&M costs; and
- Partnered with Chabot Space and Science Center in Oakland, California to open the NASA Experience exhibit, which will serve as a new visitor center for ARC. The exhibit includes interactive elements for visitors of all ages, inspiring an interest in science.

WORK IN PROGRESS IN FY 2023

Capabilities, Facilities, Labs, and Test Equipment

- Support maintenance/training/airworthiness and basic operations of multiple, one-of-a-kind aircraft and UAS;
- Complete Industrial Control Systems/Operational Technology cyber security improvement assessment of our NASA Critical Infrastructure facilities, top ten non-NASA Critical Infrastructure facilities, and top five research labs completed;
- Implement Intelligent Global Search (IGS) capability across MSFC technical data archives and continue development of collaborative digital environments through Model-Based Design and Manufacturing Tools operations;
- Provide users with software suite of applications designed to support Manufacturing, Buildings and Facilities, Mapping and Surveying, and more by integrating, implementing, modernizing, and enhancing commercial-off-the-shelf Government solutions;

CENTER ENGINEERING, SAFETY, & OPERATIONS

- Update gaseous helium (GHe) and gaseous nitrogen (GN2) pipelines that supply launches, enhancing capabilities and increasing our reliability;
- Procure nine new cryogenic (liquid nitrogen [LN2], liquid oxygen [LOX], liquid helium [LHe]) tankers, which provide more utility, are more economical, and assure available commodity for multiple launch schedules;
- Refurbish 3 hypergolic toxic vapor scrubbers at a greatly reduced cost to buying new. Scrubbers remove and neutralize hydrazine-based, fuel-saturated vapors so they are not released into the atmosphere;
- Procure two new hypergol Generic Propellant Transfer Units (GPTUs) and modification of the current ten GPTUs with new relief devices to allow all customers' processing to be supported at the same time and not impact launch processing; and
- Procure new components to replace obsolete components on facility gaseous regulation panels to ensure that processing will not be interrupted.

Operational Safety

- Support programs/projects with testing and conducting building inspections and mishap investigations to ensure buildings comply with buildings for life safety code;
- Recertify all vessels and systems which become uncertified in FY 2023 and make additional progress in first time certification of laboratory systems. Will also perform additional weld machining on layered vessels;
- Support Voluntary Protection Program (VPP) recertification effort, a safety program that involves a multi group effort, including management, employees, and unions, which exceeds OSHA requirements and ensures a robust safety culture and lowers risk personnel; and
- Recertify the Transonic Dynamics Tunnel (TDT) shell, two high-pressure steam distribution systems, and one high-pressure air compressor essential to support critical program tests and ensure safe and reliable operations.

Engineering and Safety and Mission Assurance Technical Authorities

- Support KSC's Range Flight Safety Analysis initiative that will use a risk-based approach to strengthen independent assessments of preliminary missions and evaluations of operations for Agency planning purposes.

Institutional Management and Administration

- Provide competitively selected opportunities to our civil servant workforce to develop concepts, develop technological capabilities, and provide leadership and partnering opportunities with the broader scientific community;
- Support Future of Work (FoW) implementation through initiatives fostering innovative and collaborative office settings, including modifying and outfitting of shared-use spaces and conference facilities necessary to successfully enable reliable and seamless access to workstations;
- Work in concert with the Center's FoW team to identify investments that normalize a hybrid work environment and enable equity for both onsite and offsite team members;

CENTER ENGINEERING, SAFETY, & OPERATIONS

- Develop the Biennial Propulsion Industrial Base and Key Decision Points Report to the Joint Army-Navy-NASA-Air Force Programmatic and Industrial Base (JANNAF PIB) Senior Advisory Group (made up of senior officials across DoD and NASA);
- Support Center's Office of Internal Controls and Management systems with support of compliance, external audits, mitigation of non-conformances, documents reviews, and processes to identify efficiencies; and
- Invest in modernization of LaRC's digital architectures/capabilities including development and implementation of a data architecture strategy; investment in Smart Center for unmanned aerial vehicle testing, condition-based maintenance monitoring, and expansion of internet of things (IoT) capabilities; and investment in digital engineering capabilities (e.g., digital lock out tag out, facility efficiency analysis, remote environmental testing, augmented reality for wind tunnel testing, and SmartLab).

KEY ACHIEVEMENTS PLANNED FOR FY 2024

Capabilities, Facilities, Labs, and Test Equipment

- Perform load testing and associated non-destructive testing (NDT) on all lifting devices and equipment via the Facilities, Operations, Maintenance Support Services (FOMSS) contract in accordance with NASA-STD-8719.9;
- Provide engineers/project managers with the Bentley Enterprise Suite of Applications, which is a Computer Aided Design (CAD) application software package that is used for design, construction, and operations and maintenance (O&M) of facility and infrastructure assets.
- The Metrology and Calibration Laboratory (MCL) will continue to support calibrations, function tests, adjustments/alignments, repairs, and other support events with focus on meeting test schedule dates for SLS, ISS, and others;
- Ensure commodities (LN2, LH2, He, & LOX) required to maintain MSFC Propellant and Pressurants Delivery Systems (PPDS) are in a Ready-To-Produce state;
- Strategically modernize aging instruments, equipment, and facilities with state-of-the-art equipment to support the next generation of NASA missions;
- Provide technical support in numerical geometry and mesh generation for the Hypersonics Technology Project, Low Boom Flight Demonstrator, Space Launch System, and Maxwell aircraft (X-57);
- Environmental Gas Laboratory: Continue clean room sampling, hydraulic sampling, and support to commercial space programs;
- Advance the state of engineering through implementation of a digital, holistic approach to the design of complex aerospace systems. Embrace model-based, probabilistic approaches to seamlessly integrate design data across a multitude of engineering models;
- Recertify the 31-Inch M10 Tunnel, two high-pressure steam distribution systems, and one thermal vacuum chamber to support critical program tests, enable materials research, and ensure safe and reliable operations; and
- Provide Metrology and Calibration Program Standard Practice and Metrology Quality Assurance, which is necessary to obtain accurate and precise measurement data for NASA's research and development experimental efforts.

CENTER ENGINEERING, SAFETY, & OPERATIONS

Operational Safety

- Recertification of Pressure Systems / layered vessel machining as vessels become available and plan to continue deployment of Nondestructive Evaluation (NDE) personnel to other centers for inspection of layered vessels;
- Ensure safety and health of employees through leadership on safety committees, including Biosafety, Ionizing and non-Ionizing Radiation Safety, Explosive Safety, and Voluntary Protection Program (VPP) Safety Leaders; and
- Perform and conduct building inspections and mishap investigations and assess buildings for life safety code compliance.

Engineering and Safety and Mission Assurance Technical Authorities

- Provide Technical Authority, Safety, Reliability and Quality support to design, development, test, and evaluation (DDT&E) for Exploration Upper Stage and Booster Obsolescence Life Extension hardware;
- Plan, conduct, and monitor results from audits supporting the Center's compliance with AS9100/ISO9000, ISO14000, and OSHA/VPP. Maintain an audited vendors list to support Program purchasing in accordance with NPR 8735.2C (Hardware Quality Assurance Program Requirements for Programs and Projects);
- Perform biennial self-assessment and declaration of compliance of the Quality Management System with ISO9001/AS9100 standards through collection and review of relevant data to demonstrate compliance; and
- Center Technical Authority function will support technical reviews and Flight Readiness Reviews for the Aeronautics Research Mission Directorate (ARMD) X-59 flight research project.

Institutional Management and Administration

- Foster regional alliances with small businesses and local communities to advance the commercialization of NASA technology;
- Represent NASA’s integrated climate science posture and strategy to USG, international, and other stakeholders;
- Invest in workforce engagement activities and speakers/events that drive towards cultural changes required for enterprise transformation and new methods to enable partnering (such as cloud platform use); and
- Continue to support establishment of a hybrid work model, fostering an inclusive culture that engages staff working on/off-site, and tools/processes improved as needed to ensure an effective hybrid model and that mission requirements continue to be met.

CENTER ENGINEERING, SAFETY, & OPERATIONS

Program Elements

AGENCY SUPPORT AND HEADQUARTERS MANAGEMENT

CESO supports Agency-level strategic leadership and planning by funding corporate activities conducted at NASA HQ. Strategic planning, budget activities, workforce management, and other foundation business functions require strategic planning, policy development, monitoring, audits, and ongoing management. These activities dovetail with center operations through mission support functional offices and senior management. CESO funds also ensure there is enterprise-enabling support for centers and missions, in functional areas not aligned to a mission support enterprise office (which would then be funded through Mission Services and Capabilities).

INSTITUTIONAL ADMINISTRATION

CESO supports certain foundation business functions at the center-level by funding center management, center reserves, and certain unique functions that were not transitioned to enterprise management due to their unique value or specification at the center. Activities deemed center-centric remained under center management to ensure location-specific conditions and decisions were considered when supporting mission requirements. These center-level activities include occupational health, local IT support, and local management personnel.

INSTITUTIONAL OPERATIONAL SAFETY

CESO funds safety and mission success requirements based upon Federal regulations and NASA standards, ensuring these requirements are properly implemented throughout NASA's programs and projects. Examples of such efforts include safety audits and assessments, safety surveillance, inspections, testing and observations, mishap investigation and reporting, hazard identification, and safety outreach.

SAFETY AND MISSION ASSURANCE (S&MA) TECHNICAL AUTHORITY

The Office of Safety and Mission Assurance (OSMA) issues policies, guidance, and corporately managed communications that ensure the consistent application of safety and quality standards. At each center, Safety and Mission Assurance (S&MA) personnel are responsible for the application and implementation of policies and instructions provided by OSMA and related governing organizations. This is accomplished through S&MA Technical Authority (TA) member participation on program/project control boards, change boards, and internal review boards. S&MA personnel also formulate and communicate the S&MA TA position on significant technical issues, disposition changes, waivers, deviations, and exceptions to respective program/project S&MA requirements. S&MA TA independently assess program/project-owned risks and execute, implement, and maintain the checks and balance of safety and quality standards. It is critical that OSMA funding is independent of mission funding to ensure there is an independent process for identifying and managing safety and quality concerns.

CENTER ENGINEERING, SAFETY, & OPERATIONS

SCIENCE AND ENGINEERING

Centers maintain highly technical laboratories, critical capabilities, and associated specialized skills and equipment thereby ensuring mission readiness. These capabilities support center mission work ensuring required technical capabilities are mission ready. Such functions include providing for the on-site capability to fabricate test articles, test fixtures, prototype, proto-flight, and flight articles necessary to support the design, development, and testing of research models, instruments, flight and related ground support hardware, technical components, and laboratory test apparatus. Centers also provide for the on-site capability to support research, development testing, and sustaining engineering for science and technologies necessary to support their program activities. These funds are specific to the centers because of the variety and distribution of highly technical work that is spread across the Agency's 10 distinct centers and other installations.

CENTER INVESTMENTS

Ensuring the right talent and technical capabilities are mission-ready for NASA priority projects and missions, centers utilize investment funding to maintain their technical skills and capabilities in support of local mission work. Investment's fund institutional research that aligns with assigned center roles, development projects, and business innovation. Centers use a competitive approach to achieve this mission work and support NASA's commitment to innovation and creativity. Center investments are also utilized through a competitive bid and proposal process ensuring mission work is distributed to the appropriate center and technical area. Centers have the flexibility to support Internal Research and Development (IRAD) pursuing collaboration with academia and private industry so that NASA has the leading-edge capabilities needed to support NASA's missions today and in the future.

ENGINEERING TECHNICAL AUTHORITY

The Office of the Chief Engineer (OCE) develops and distributes standards, policies, and guidance related to engineering safety, quality, and process. At each center, personnel are dedicated to providing independent oversight of programs and projects in support of safety and mission success as prescribed in the NASA technical authority model, thus ensuring requisite policies and processes are successfully implemented, thereby upholding NASA's high standard of engineering excellence. Key technical authority positions, including managers in research and engineering, testing, and fabrication, use these funds to conduct reviews, oversight, and management of quality and safety standards independent of mission directorates. These activities are a crucial part of NASA's checks and balances, which ensure the highest standard of engineering excellence and reporting.

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Construction of Facilities	342.1	--	**375.9**	383.4	391.1	398.7	406.6
Environmental Compliance and Restoration	74.7	--	**77.8**	79.4	81.0	82.8	84.5
Total Budget	**416.8**	**414.3**	**453.7**	**462.8**	**472.1**	**481.5**	**491.1**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects Division B funding amount of $47.3 million and Division N funding amount of $367 million, as specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Construction of Facilities	342.1	--	**375.9**	383.4	391.1	398.7	406.6
Environmental Compliance and Restoration	74.7	--	**77.8**	79.4	81.0	82.8	84.5
Total Budget	**416.8**	**414.3**	**453.7**	**462.8**	**472.1**	**481.5**	**491.1**
Change from FY 2023 Enacted			**39.4**				
Percent change from FY 2023 Enacted			**9.5%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects Division B funding amount of $47.3 million and Division N funding amount of $367 million, as specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Teams at NASA’s Michoud Assembly Facility (MAF) in New Orleans move the engine section flight hardware to the Agency’s Pegasus barge. The barge (shown here) will ferry the engine section of NASA’s Space Launch System (SLS) rocket for Artemis III to the Kennedy Space Center (KSC) in Florida. Once there, teams at KSC will finish outfitting the engine section, which comprises the tail-end of the rocket’s 212-foot-tall core stage, before integrating it with the rest of the stage. Beginning with production for Artemis III, NASA and core stage lead contractor (Boeing) will use MAF, where the SLS core stages are currently manufactured, to produce and outfit the core stage’s five elements, and available space at KSC for final assembly and integration.

Through the Construction and Environmental Compliance and Restoration (CECR) account, NASA manages two themes related to the Agency's asset portfolio: capital repairs and improvements to NASA's infrastructure, and environmental compliance and restoration activities. Activities related to the design, construction, and demolition of infrastructure, including utility systems and facilities, are funded through Construction of Facilities (CoF). Environmental compliance, cleanup, and restoration activities are funded through Environmental Compliance and Restoration (ECR).

CECR funding enables NASA to address challenging infrastructure needs. More than 83 percent of NASA's infrastructure is beyond its design life, posing significant risk of failure, inefficiency, and potential impacts to health and wellness. Apollo-era infrastructure is inefficient and costly to maintain, as well as insufficient to accomplish NASA's future missions that require facilities with leading-edge capabilities. The Agency currently faces a deferred maintenance backlog of $3 billion, resulting in unscheduled maintenance that can cost up to three times more than scheduled maintenance to repair or replace equipment after it has failed. To address these growing challenges, CECR is focused on modernizing and consolidating NASA's infrastructure into fewer, more efficient, and more sustainable facilities, and on repairing and upgrading infrastructure before it has failed.

CECR funding ensures that NASA's assets are ready, available, and appropriately sized to conduct NASA's current and future missions, while remaining compliant with the Agency and governmental environmental regulations. This funding is critical to fulfill NASA's 2022 Strategic Plan Objective 4.2 to "Transform mission support capabilities for the next era of aerospace." CECR programs strive to reduce the Agency's physical footprint and environmental burden.

CECR Priorities

CECR focuses on ensuring the viability and readiness of mission-critical infrastructure, while also supporting NASA's commitment to environmental stewardship and sustainability. The activities below outline how CECR allocations are made:

- Construct new facilities and replace, repair, or upgrade existing infrastructure to support NASA's mission requirements and timeline;
- Design facilities and infrastructure solutions to support construction and repairs, while optimizing sustainability, increasing efficiency, and reducing NASA's footprint;
- Demolish unneeded and degraded facilities to avoid costs and improve sustainability;
- Invest in energy and water savings opportunities to improve NASA's environmental stewardship; and
- Comply with mandates, regulations, and general best practices to protect the health and wellness of the environment, NASA's workforce, and the general public.

Balancing SSMS and CECR

NASA's mission support portfolio is divided between two accounts: Safety, Security, and Mission Services (SSMS) and Construction and Environmental Compliance and Restoration (CECR). The Mission Support Directorate (MSD) utilizes both accounts to maintain NASA's critical infrastructure. SSMS and CECR programs are dependent upon each other and there is a balance between maintenance of assets and infrastructure, repairs and renewal of failing assets, and the replacement and demolition of obsolete assets. Required maintenance activities drive SSMS spending decisions, while repairs, renewals (including new construction), and associated demolition drive CECR spending.

Much of NASA's infrastructure dates back to Apollo-era space exploration. Maintenance activities funded by SSMS are necessary to prevent costly delays to missions and risks to health and safety. Meanwhile, failures require immediate repairs and account for an increasing share of the SSMS facilities maintenance budget. These activities are vital to support evolving mission requirements. SSMS also funds proactive maintenance initiatives such as Condition Based Maintenance to identify issues and provide lower cost, scheduled maintenance. Without a sufficient facilities maintenance budget, assets and facilities worsen to a state requiring CECR funding for more expensive solutions. The rapidly increasing activities in commercial space development and deep space exploration places an additional strain on NASA's infrastructure and mission-unique facilities. Both SSMS and CECR activities are vital to support mission requirements. MSD takes an Agency-wide approach to make difficult trade-off decisions that ensure critical capabilities and assets are mission-ready, while also investing in the long-term asset health, sustainability, and footprint reductions that ensure NASA's future mission success. This approach allows NASA the ability to prioritize investments in support of long-term asset health, sustainability, and footprint reductions that ensure NASA's future mission success.

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ACHIEVEMENTS IN FY 2022

CECR continued to enable critical mission work while maintaining NASA's dedication to environmental stewardship. The following list highlights high-priority FY 2022 projects executed. A more robust list with project descriptions is available in each program section.

- Initiated construction, repair, or revitalization of institutional infrastructure and facilities that have capabilities and impacts that span NASA centers and enabled mission directorate priorities:
  - Construction of the Johnson Space Center (JSC) Operations and Maintenance Facility to consolidate and enhance foundational support services for all vital mission work at the Center, including the International Space Station, Orion, Commercial Crew, and numerous scientific and engineering research programs;
  - Repair of facilities damaged by Hurricane Zeta at Marshall Space Flight Center (MSFC) and Stennis Space Center (SSC) to restore operational capabilities and efficiencies, as well as ensure safety and compliance;
  - Construction of the MSFC's Marshall Exploration Facility; and
  - Upgrades to Langley Research Center's (LaRC) electrical infrastructure, including the underground 22 kilovolt (kV) electrical distribution infrastructure, to avoid risks caused by obsolete design and equipment. This effort supports vital mission activities and research conducted in LaRC's wind tunnels, research labs, flight system integration and testing facilities, and all other offices and buildings.
- Supported exploration mission work with the construction, repair, or revitalization of critical facilities and infrastructure:
  - Modifications to the launch infrastructure at Kennedy Space Center (KSC) for SLS activities and new exploration missions;
  - Repairs and upgrades to the Vehicle Assembly Building's (VAB's) Water Distribution System at KSC; and
  - Repairs to the Michoud Assembly Facility (MAF) roadways.
- Supported operations in space mission work with the construction, repair, or revitalization of critical facilities and infrastructure:
  - Continued the Deep Space Network Aperture Enhancement Program (DEAP) Beam Waveguide (BWG) antennae project at the Goldstone and Canberra Deep Space Communication Complexes;
  - Upgraded the switchgear to provide redundancy and ensure reliability at a location designated the “Apollo” site; and
  - Installed an additional underground backup power feed from one location, designated the “Mars” site, to the “Apollo” site.
- Demolished unneeded or degraded facilities to support a more sustainable NASA with a smaller footprint while avoiding repair and operational costs:
  - Demolished approximately 11 facilities with more than 253,000 square feet, including the Research Laboratory and the Pearl Young Conference Center at LaRC.

- Invested in energy savings projects that reduce operational costs and utility usage across NASA:
  - Constructed a second thermal energy storage tank at MSFC; and
  - Upgraded the energy monitoring and control system at Glenn Research Center (GRC).
- Conducted facility planning and design associated with all construction and revitalization projects to ensure optimal consolidation, energy savings, cost-effectiveness, and mission success:
  - Conducted Institutional CoF facility planning and design as a routine requirement for all projects; and
  - Planned Mission CoF projects within mission activities (not funded by CoF).
- Maintained NASA's commitment to environmental stewardship by conducting critical cleanup efforts, maintaining compliance with regulatory requirements, and managing environmental issues:
  - Continued to demolish Bravo Test Stands and begin demolition of Coca Test Stands at Santa Susana Field Laboratory (SSFL);
  - Continued site investigations of per- and polyfluoroalkyl substance (PFAS) contamination Agency-wide;
  - Continued operation of groundwater treatment systems and continue long term monitoring and management of air, groundwater, surface water, and treatment efforts;
  - Continued restoration of impacted soil across NASA; and
  - Implemented ECR policies and provided critical support to stakeholders, including planning, engagements, communications, guidance and other responses to inquiries, and program management.

Work in Progress in FY 2023

CECR will continue to enable critical mission work, while maintaining NASA's dedication to environmental stewardship. The following list highlights high-priority FY 2023 projects. A more robust list with project descriptions is available in each program section.

- Initiate construction, repair, or revitalization of institutional infrastructure and facilities that have capabilities and impacts that span across NASA centers and enable mission directorate priorities:
  - Replacing the vital Wallops Island Causeway Bridge, the single point of access to Wallops Island;
  - Constructing the Aircraft Logistics and Operations Facility at Johnson Space Center (JSC);
  - Replacing the Ames Power Management System at Ames Research Center (ARC); and
  - Repairing the Greenbelt Parkway Bridge at Goddard Space Flight Center (GSFC).
- Support exploration mission work with the construction, repair, or revitalization of critical facilities and infrastructure:
  - Continue modifying the launch infrastructure at KSC for SLS activities and new exploration missions;
  - Renovate the interior infrastructure of KSC's Booster Fabrication Facility; and
  - Refurbish the cranes needed to support the SLS and Artemis Campaign Booster flight hardware operations in the MAF.
- Support operations in space operations work with the construction, repair, or revitalization of critical facilities and infrastructure:

    - Continue the DEAP BWG antennae at the Goldstone and Canberra Deep Space Communication Complexes;
    - Build redundant data and signal processing centers to ensure the security and storage of vital mission data gathered during explorational and scientific missions; and
    - Replace fire detections systems at Goldstone for improved site operations.

- Demolish multiple facilities totaling over 471,000 square feet to reduce the Agency's footprint, reduce operational costs, and increase environmental sustainability.

- Invest in energy savings projects that reduce operational costs and utility usage across NASA:
    - Implement energy conservation measures and upgrade control systems for improve efficiency at JSC;
    - Repair vacuum jacketed electrical lines at LaRC for improved system efficiency; and
    - Install critical water meters across the Agency to improve NASA's overall consumption and reduce environmental burden.

- Conduct facility planning and design associated with all construction and revitalization projects to ensure optimal consolidation, energy savings, cost-effectiveness, and mission success:
    - Master planning for all projects, including efforts to consolidate workspace and leverage work-from-home options, which have proven effective during the Agency's response to COVID-19;
    - Study and assessment of engineering, design and construction management, facility operations and maintenance, condition-based maintenance, and facility utilization;
    - Support for engineering in facilities management systems, oversight, and capital leveraging research;
    - Assess footprint reduction, consolidation, and environmental stewardship options; and
    - Plan Mission CoF projects within mission activities (not funded by Institutional CoF).

- Maintain NASA's commitment to environmental stewardship by conducting critical cleanup efforts, maintaining Agency-wide compliance with regulatory requirements, and managing environmental issues:
    - Continue the demolition of Coca Test Stands at SSFL;
    - Continue operation of groundwater treatment systems and continue long term monitoring and management of air, groundwater, surface water, and treatment efforts Agency-wide;
    - Continue site investigations of per- and polyfluoroalkyl substance (PFAS) contamination Agency-wide;
    - Continue restoration of impacted soil across NASA; and
    - Implement ECR policies and provide critical support to stakeholders, including planning, engagements, communications, guidance and other responses to inquiries, and program management.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

CECR will continue to enable critical mission work in FY 2024, while maintaining NASA's dedication to environmental stewardship. The following list highlights high-priority FY 2024 projects. A more robust list with project descriptions is available in each program section.

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

- Construct, repair, or revitalize institutional infrastructure and facilities that have capabilities and impacts that span NASA centers and enable mission directorate priorities:
  - Construct Engineering and Mission Operations Facility at ARC;
  - Construct Integrated Logistics and Processing Facility at GSFC;
  - LaRC Compressor Station Upgrades (Phase 3 of 4);
  - Renew the High-Pressure Gas Facility at SSC (Phase 1 of 2), which supports all rocket engine testing programs;
  - Repair Crew and Thermal Systems Mechanical Infrastructure, Building 7 (JSC);
  - Repair infrastructure systems including electrical, fire, sewer, steam, fire alarm, and natural gas; and
  - Arc flash repairs and risk mitigation.
- Support Exploration Systems Development Mission Directorate (ESDMD) priorities with the construction, repair, or revitalization of critical facilities and infrastructure:
  - Modification to KSC Launch infrastructure for SLS.
- Support Space Operation Mission Directorate (SOMD) priorities with the construction, repair, or revitalization of critical facilities and infrastructure:
  - Continue construction of the DEAP;
  - Continue underground tank replacements, replace aging generators, and replace HVAC and mechanical systems; and
  - Replace obsolete BWG antenna drives and cabinets and provide additional BWG redundant power feed Apollo substations at Goldstone Deep Space Communications Complex GDSCC.
- Demolish unneeded or degraded facilities to support a more sustainable NASA with a smaller footprint while avoiding repair and operational costs.
- Invest in energy savings projects that reduce operational costs and utility usage across NASA:
  - Convert motors for power factor correction;
  - Improve water treatment system, cooling towers;
  - Upgrade energy monitoring and control systems;
  - Implement energy and water conservation measures and upgrade control systems;
  - Replace central chiller plant pumps; and
  - Implement energy and water conservation measures at various centers.
- Conduct facility planning and design associated with all construction and revitalization projects to ensure optimal consolidation, energy savings, cost-effectiveness, and mission success:
  - Plan all projects, including efforts to consolidate work and leverage work-from-home options, which have proven effective during the Agency's response to COVID-19;
  - Study and assessment of engineering, design and construction management, facility operations and maintenance, condition-based maintenance, and facility utilization;
  - Support for engineering in facilities management systems, oversight, and capital leveraging research; and
  - Assess footprint reduction, consolidation, and environmental stewardship options.
- Maintain NASA's commitment to environmental stewardship by conducting critical cleanup efforts, maintaining Agency-wide compliance with regulatory requirements, and managing environmental issues:

- Continue to implement site wide restoration activities, contaminated groundwater cleanup, and investigate soil contamination Agency-wide;
- Continue Agency-wide compliance and efficiency assessments;
- Update Agency sustainability and climate action plans and continue performance reporting;
- Continue Agency-wide execution of expanded Site Inspection and initiate Remedial Investigations at areas of potential concern for PFAS; and
- Continue the demolition of Coca Test Stands at SSFL.

Themes

CONSTRUCTION OF FACILITIES (COF)

CoF funds capital repairs and improvements to NASA's infrastructure to provide NASA programs and projects with the research, development, and testing facilities required to accomplish their missions. CoF repairs the facilities that have suffered degradations, recent failures, or deterioration from inadequate maintenance over time. Due to mission priorities, projects to address immediate needs may displace renewal or new construction projects planned to replace obsolete facilities. These necessary tradeoffs preclude the construction of new, more advanced and energy efficient facilities and infrastructure that would reduce costs and increase sustainability in the long run.

CoF is comprised of two programs: Institutional CoF and Programmatic CoF. Institutional CoF activities are divided across five project definitions: discrete projects costing over $10 million; minor revitalization and construction less than $10 million; facility planning and design; demolition; and investments in energy savings. Programmatic CoF is focused on mission directorate-funded projects for specialized capabilities that align to specific NASA missions, separated between two project definitions of either discrete projects costing over $10 million or minor revitalization and construction costing less than $10 million.

NASA's CoF budget funds the Agency's highest priority construction projects and continues to replace obsolete and deteriorating facilities that directly support NASA's mission. Institutional CoF does not fund routine maintenance and repairs projects, or projects with cost estimates of less than $1 million.

ENVIRONMENTAL COMPLIANCE AND RESTORATION (ECR)

ECR mitigates environmental risk at NASA installations and NASA-owned industrial plants supporting NASA activities. ECR supports Agency-wide environmental compliance and risk management initiatives. ECR supports remediation at current or former sites where NASA operations have contributed to environmental degradation or where the Agency is legally obligated due to past releases of pollutants, including emerging contaminants such as polyfluoroalkyl substances (PFAS).

At every center, ECR is investigating contaminated sites; remediating contaminated soil, water, and other media; and monitoring for continued compliance with Agency objectives and obligations. ECR ensures NASA's compliance with environmental requirements, including the Resource Conservation and Recovery Act (RCRA); Comprehensive Environmental Response, Compensation, Liability Act (CERCLA); state regulatory requirements; consent orders; and legal obligations.

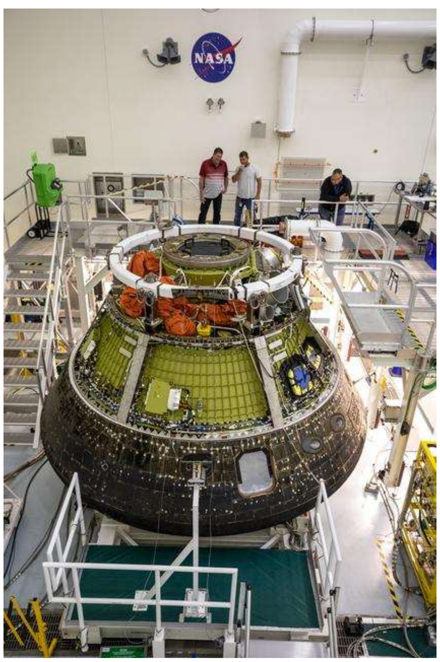
CONSTRUCTION OF FACILITIES

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Institutional CoF	225.8	--	**336.0**	383.4	391.1	398.7	406.6
Exploration CoF	90.3	--	**10.5**	0.0	0.0	0.0	0.0
Space Operations CoF	22.5	--	**29.4**	0.0	0.0	0.0	0.0
Science CoF	3.5	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**342.1**	**--**	**375.9**	**383.4**	**391.1**	**398.7**	**406.6**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects Division B funding amount of $47.3 million and Division N funding amount of $367 million, as specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



NASA's Artemis I Orion capsule is secured on a platform inside the Multi-Payload Processing Facility (MPPF) at Kennedy Space Center (KSC). Orion splashed down in the Pacific Ocean on December 11, 2022. The spacecraft was secured inside the well deck of the USS Portland and transported back to KSC for de-servicing inside the MPPF.

NASA's Construction of Facilities (CoF) Program includes both institutional and programmatic construction projects. These projects reduce facility-related risk to mission success, increase sustainability, and improve technical infrastructure capabilities in support of NASA missions. CoF provides for the design and construction of facilities projects that enable NASA's infrastructure to meet mission needs. The CoF Program mitigates risks associated with real property assets, defined by NASA as "risks to infrastructure, information technology, resources, personnel, assets, processes, operations, occupational safety and health, environmental management, security, or programmatic constraints that affect capabilities and resources necessary for mission success, including institutional flexibility to respond to changing mission needs and compliance with internal (e.g., NASA) and external requirements (e.g., Environmental Protection Agency or Occupational Safety and Health Administration regulations)." Outyear plans do not include funding for Programmatic CoF, which is not identified until annual budget formulation.

CoF Priorities

CoF spans two programs: institutional and programmatic (for a full description of these two program areas, see the Program Elements section). All CoF projects are prioritized by Agency and center leadership based upon immediate mission requirements and long-term affordability. Project priorities are best defined by a project's ability to address the following desired outcomes (for a full description of these project categories, see the Program Elements in each program section):

CONSTRUCTION OF FACILITIES

- Construct or revitalize facilities and infrastructure with discrete projects (greater than $10 million) and minor projects (less than $10 million) to meet mission and center requirements for NASA priorities;
- Plan and design facilities to ensure optimal outcomes and comply with statutory and mission requirements;
- Demolish unnecessary or degraded buildings following the consolidation or new construction of replacement facilities to reduce costs and NASA's footprint; and
- Invest in energy savings projects that significantly change utility usage, including energy and water, for reduced operational costs and increased sustainability.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ACHIEVEMENTS IN FY 2022

See each program area for a complete list of achievements in FY 2022.

WORK IN PROGRESS IN FY 2023

See each program area for a complete list of work in progress in FY 2023.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

See each program area for a complete list of key achievements planned for FY 2024.

Program Elements

INSTITUTIONAL CONSTRUCTION OF FACILITIES (INSTITUTIONAL COF)

Institutional CoF addresses infrastructure and facilities that span all mission areas and enable the effectiveness of NASA centers. Horizontal infrastructure and center-wide systems, such as roads and utilities, support all mission activities and are therefore considered "institutional." Institutional CoF also funds activities that support the overall Agency goals of reducing operating costs, maintenance obligations, and utility usage through demolition and energy savings projects.

PROGRAMMATIC CONSTRUCTION OF FACILITIES (PROGRAMMATIC COF)

Programmatic CoF is funded by mission directorates for construction of specialized capabilities that directly support specific NASA missions, with appropriate funding transferred into CoF during the formulation of each budget year. Facilities and infrastructure supporting the execution of specific mission directorate requirements or having a unique capability required specifically for the execution of mission directorate programs and/or projects are funded through Programmatic CoF. Construction, repairs, and revitalization funded by Programmatic CoF do not have center-wide or Agency-wide applications. Because projects funded through Programmatic CoF are unique to the missions they support, the description of projects are included below by mission area.

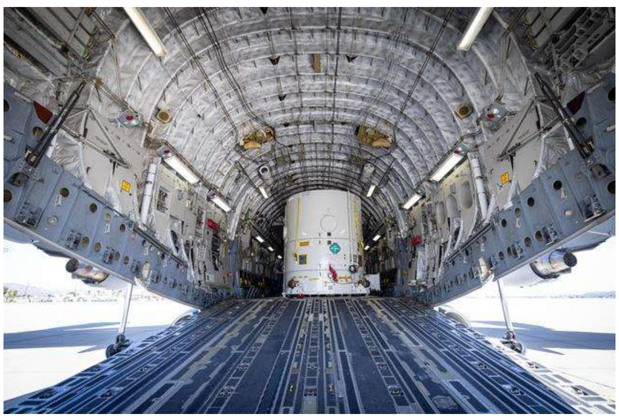
INSTITUTIONAL COF

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	225.8	--	336.0	383.4	391.1	398.7	406.6

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects Division B funding amount of $47.3 million and Division N funding amount of $367 million, as specified in Public Law 117-328, Consolidated Appropriations Act, 2023.



The main body of NASA's Europa Clipper spacecraft is seen here in its shipping container, just after arriving aboard a C-17 cargo plane at March Air Reserve Base in Riverside County, California. From there it was delivered by truck to the Jet Propulsion Laboratory in Southern California, where, over the next two years, engineers and technicians will finish assembling the craft by hand. Set to launch in October 2024, Europa Clipper will conduct nearly 50 flybys of Europa, which scientists are confident harbors an internal ocean containing twice as much water as Earth's oceans combined.

Institutional CoF sustains the readiness of NASA's physical infrastructure. Real property assets include all horizontal and limited vertical infrastructure and the associated collateral equipment. Repair and revitalization projects are prioritized using a risk-informed process that evaluates mission risks in terms of safety, schedule, cost, and technical capability. For each major facility replacement project, NASA develops a business case that includes a cost-benefit analysis.

NASA maintains an ongoing effort to identify, quantify, and prioritize institutional risks. Significant risks to a mission attributed to institutional real property are mitigated through the Institutional CoF Program. The criticality of mission risks may be reassessed as the risk posture changes due to mission and/or infrastructure condition. Currently, NASA has identified $5.4 billion worth of repairs and projects to mitigate known risks and optimize mission critical capabilities.

Institutional CoF Priorities

Institutional CoF funding is allocated across different projects depending on facility and infrastructure criticality, long-term sustainability, and mission needs. The goals of the Institutional CoF Program are to reduce risk to NASA missions and to reduce operational costs. Specifically:

- Reduce Institutional risks, including risks to personal safety and deficiencies, and enable missions with discrete (greater than $10 million) and minor (less than $10 million) projects that address critical mission requirements;
- Demolish unnecessary and degraded buildings to avoid costs, eliminate risks, and reduce NASA's overall footprint for increased sustainability;

INSTITUTIONAL COF

- Plan and design facilities to optimize capabilities, enhance sustainability, and comply with all Federal and State obligations; and
- Invest in energy savings projects that enhance sustainability and support NASA's commitment to environmental stewardship.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ACHIEVEMENTS IN FY 2022

NASA continued projects initiated in FY 2022 and prior years.

Discrete Projects

- Initiated construction of the Marshall Exploration Facility at MSFC to replace the MSFC headquarters building;
- Initiated construction of the 300 Area Operations and Maintenance Facility at JSC to consolidate and enhance foundational support services for all vital mission work at the Center, including the International Space Station (ISS), Orion, Commercial Crew, and numerous scientific and engineering research programs; and
- Initiated upgrades to the 22kV Infrastructure at LARC to improve reliability of the electrical systems at the Center.

Minor Projects

- Repaired Center-wide electrical systems at Armstrong Flight Research Center (AFRC) (Phase 1);
- Repaired the electrical substation at AFRC;
- Renewed antiquated high-power cables at GRC (Phase 1 of 4);
- Repaired the degraded and dangerous electrical distribution systems at GRC (Phase 4 of 5);
- Restored the main base electrical infrastructure for increased safety and reliability at WFF (Phase 2 of 2);
- Restored vital, cross-Center systems at GSFC, including fire alarms and electrical feeders;
- Installed seismic bracing to protect assets against earthquakes at JPL;
- Replaced the failing electrical substation at JPL;
- Replaced failing potable water storage tanks at JSC; and
- Repaired and upgrade vital sewage and potable water systems at SSC that threatened employee safety and mission success.

Demolition

- Initiated demolition of Building 4200 at MSFC.

INSTITUTIONAL COF

Energy Savings

- Constructed a second thermal energy storage tank at MSFC; and
- Upgraded the energy monitoring and control system at GRC.

WORK IN PROGRESS IN FY 2023

NASA continues projects initiated in FY 2023 and prior years along with three new discrete projects and 11 minor projects.

Discrete Projects

- Replace the vital Wallops Island Causeway Bridge that is the single point of access to Wallops Island, a component facility of GSFC:
  - Replace the existing bridge that is showing signs of deterioration and threatens collapse;
  - Maintain open access to the island during construction to avoid delays to mission work, including International Space Station resupply missions; and
- Construct the Aircraft Logistics and Operations Facility at JSC to consolidate and modernize existing, critical facilities:
  - Resolve concerns with safety, security, efficiency, cost effectiveness, sustainability, and usability that persist with existing degraded facilities; and
  - Consolidate to reduce Agency footprint and construct a modern facility with better energy and water usage infrastructure for better environmental stewardship.
- Replace the electrical distribution equipment in South Wing of the Operations and Checkout (O&C) Building at KSC:
  - Replace the over 56-year-old electrical power distribution and control equipment that has been unreliable and threatens failure; and
  - Ensure the continued, efficient, and sustainable operation of the South Wing of the O&C Building, which houses payload processing areas, control rooms, and logistics areas.

Minor Projects

- Repair Center-wide building envelopes at Armstrong Flight Research Center (AFRC) that will be resilient to extreme desert weather conditions and sonic booms, and increase the lifespan of existing facilities;
- Replace the Ames Power Management System, the failing, Center-wide electrical power management system at ARC which supports all operations and mission work;
- Repair high voltage electrical transformers at GRC's Substation J that support Center-wide operations and have exceed their design lives and are actively failing;
- Renew by incremental repair the over 70-year-old, antiquated, high-voltage, electrical cables that sustain Center-wide operations at GRC by installing modern, plastic-insulated cabling (Phase 2 of 4);
- Repair the Greenbelt Parkway Bridge at GSFC, which is the Center's primary access point and critical infrastructure for all mission activities at the Center;
- Replace and upgrade the switchgear in buildings 170 and 158 at JPL;
- Replace and upgrade the switchgear in building 230 at JPL, which will increase the current capacity, enhance monitoring capabilities, and improve safety and reliability for electrical power distribution;

INSTITUTIONAL COF

- Repair the utility tunnels at LaRC to increase the reliability of mission-critical facilities, including steam, high pressure air, service air, water, and communications (Phase 2 of 2);
- Repair the central steam plant at LaRC that sustains Center-wide critical utility systems (Phase 1 of 2);
- Replace degraded water piping systems in building 4708 at MSFC to prevent further water damage to critical areas including flight hardware, high bays, test labs, clean rooms, technical shops, and offices; and
- Mitigate the threat of low voltage arc flash issues by making sitewide electrical repairs at SSC, reducing safety hazards to personnel, fire hazards, and deteriorating infrastructure.

Demolition

- Demolish multiple facilities with more than 471,000 square feet to reduce the Agency's footprint, reduce operational costs, and increase environmental sustainability.

Energy Savings

- Implement energy conservation measures and upgrade control systems for improve efficiency at JSC;
- Repair vacuum jacketed electrical lines at LaRC for improved system efficiency; and
- Install critical water meters across the Agency to improve NASA's overall consumption and reduce environmental burden.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

NASA's Institutional CoF Program includes five discrete projects, 17 minor projects, seven energy savings investment projects, and numerous demolition projects. Depending on appropriated budgets and because all CoF projects are prioritized based on criticality and mission urgency, NASA may address some deferred projects before addressing planned FY 2024 activities.

Discrete Projects

- Construct Engineering and Mission Operations Facility at ARC, $56.4 million:
  - Construction of a 30,000 square foot building, with Multi-Mission Operation Center, SpaceShop Rapid Prototyping system, engineering collaborative spaces, payload/instrument development labs, engineering offices, and support areas;
  - Consolidate mission engineering serving aerospace systems and spaceflight projects; and
  - The facility will support work to include small spacecraft designs and small spacecraft technologies, advanced exploration technologies for Moon, Mars, and deep space missions, the study of astrobiology and life sciences, planetary and Earth entry systems, intelligent systems, the study of planetary bodies, and Earth and Space Science.
- Construct Integrated Logistics & Processing Facility at GSFC, $19.0 million:
  - Construct multiple buildings to relocate both the Logistics & Transportation Facility and the Hazardous Waste and Chemical Storage Facility;
  - The Logistics and Transportation Facility will have a 7,000 square foot building to house the functions that provide support to GSFC missions and flight projects in areas of logistics, traffic management, engineering, storage, and vehicle services in all phases of program development; and

INSTITUTIONAL COF

  - All missions utilize logistics to deliver flight hardware and payloads to other facilities. Without an adequate facility to maintain these vehicles, missions would incur significant increases for a technical / complex transportation cost.

- LaRC Compressor Station Upgrades (Phase 3 of 4), $15.0 million:
  - Replace an obsolete compressor and associated ancillary systems with a new compressor system and associated ancillary systems.
  - NASA missions and major projects that rely on the compressor station include Commercial Crew, Entry Descent and Landing, Orion, Hypersonic Technology Project, SLS, Commercial Cargo, Common Research Model – Natural Laminar Flow, and Full Span Common Research Model.

- Renew the High-Pressure Gas Facility at SSC (Phase 1 of 2), which supports all Engine Testing Programs, $14.0 million:
  - Building renovations (Roof, HVAC, electrical, finishes) to address aging equipment and code compliance issues;
  - Provide programmable logic controller (PLC) standardization and supervisory controllers for gas generation systems;
  - Replace / automate main systems valves and gas sampling / analysis systems;
  - Upgrade the closed loop cooling water system and replace fluid coolers;
  - Repair foundation and paved surfaces for commodity deliveries; and
  - Repair local High Pressure Gas Facility gas distribution, storage, and accoutrements.

- Repair Crew and Thermal Systems Mechanical Infrastructure at JSC Building 7, $12.0 million:
  - Replace 19 fifty-plus-year-old severely deteriorated AHUs, appurtenances and associated piping and valves, ductwork, corroded supply and return chill water piping, hot water piping, and obsolescent instrumentation and controls, which are in disrepair and no longer sustainable due to parts availability;
  - Relocate mechanical systems in laboratories; and
  - Reduce safety, technical, and schedule risks to programs, projects, core technical capabilities, and mission operations.

Energy Savings

- Convert Motors for Power Factor Correction, at Building 37 (GRC): Reduce GRC Lewis Field risk of losing participation in the local electric utility service provider's cost-saving load curtailment program by converting existing motors at Building 37 to enable power factor correction of GRC's electric load;
- Improve Water Treatment System, Cooling Towers 168 & 182 at GRC: Reduce GRC cooling towers 168 & 182 make-up water and chemical consumption and expenditures by converting from chemical water treatment to electrolysis to operate the cooling towers more efficiently;
- Upgrade Energy Monitoring & Control System Head End at WFF: Reduce WFF energy consumption and expenditures by modernizing the Energy Monitoring & Control System to enable buildings controls programming improvements;
- Implement Energy Conservation Measures, at Building 5 (GSFC): Reduce GSFC Greenbelt (Building 5) energy consumption and expenditures by implementing various energy conservation measures to improve the efficiency of lighting, HVAC, lab fume hoods, building envelope, and electrical transformers;
- Implement Energy Conservation Measures & Upgrade Control System (JSC), Phase 2 (JSC): Reduce JSC energy consumption and expenditures by implementing various energy conservation measures in various buildings to improve the efficiency of lighting, HVAC, and building envelope;

INSTITUTIONAL COF

- Implement Energy and Water Conservation Measures at KSC: Reduce KSC energy and water consumption and expenditures by implementing various energy and water conservation measures in various buildings to improve the efficiency of lighting, building envelope, and water fixtures; and
- Replace Central Chiller Plant Pumps, building 4473 (MSFC): Reduce MSFC Building 4473 energy consumption and expenditures by replacing aging pumps to improve efficiency and reliability.

Minor

- Repair Center-wide Electrical Systems at AFRC;
- Repair of AFRC Center-wide Sewer System;
- Restore ARC Reliability of HVAC and UPS Systems at Agency Telecom Gateway (N254);
- Reduce ARC Electrical Arc Flash Risk to Personnel;
- Repair GRC Cooling Towers 1 and 4;
- Repair of GRC Storm Sewer System (Phase 3 of 3);
- I&T Complex Mechanical Repairs at GSFC;
- Wallops GSFC Main Base Switchgear Modernization;
- Center-wide Fire Alarm System Upgrade at GSFC (Phase 3);
- Replace 16.5kV Oil Impregnated, Paper Insulated, Underground Distribution Cable at JPL;
- JSC upgrade to Mission Control Infrastructure (Phase 2 of 2);
- Install Paging Area Warning System in Propellants Serving Area at KSC;
- KSC Electrical Safety and Reliability Upgrades (Phase 5 of 5);
- Sanitary Sewer Repairs at LaRC;
- Conduct Electrical Safety Repairs at MSFC;
- SSC Arc Flash Repair & Mitigation - Area 9; and
- SSC Sewage System Conveyance and Treatment Repairs (Phase 2 of 2) - Lift Stations and Piping.

Demolition of Facilities

The FY 2024 Budget funds demolition activities of multiple facilities to reduce the Agency’s footprint, reduce operational costs, and increase environmental sustainability. This footprint reduction will be achieved over several years as the projects are completed.

Facility Planning and Design

Institutional CoF will support facility planning and design. Facility planning and design is a requirement for all CoF projects to ensure optimal outcomes, including consolidation and utility usage.

- Plan all projects, including efforts to consolidate work and leverage work-from-home options which have proven effective during the Agency's response to COVID-19;
- Study and assessment of engineering, design and construction management, facility operations and maintenance, condition-based maintenance, and facility utilization; and
- Support for engineering in facilities management systems, oversight, and capital leveraging research.
- Assess footprint reduction, consolidation, and environmental stewardship options.

EXPLORATION COF

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**90.3**	**--**	**10.5**	**0.0**	**0.0**	**0.0**	**0.0**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects Division B funding amount of $47.3 million and Division N funding amount of $367 million, as specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Exploration Construction of Facilities (CoF) supports NASA's exploration missions, including the Space Launch System (SLS), Orion, and Exploration Ground Systems (EGS) programs. Exploration CoF is managed in collaboration with institutional projects but funded through the Exploration Systems Development Mission Directorate (ESDMD).

NASA's Space Launch System and Orion spacecraft atop the mobile launcher are in view in High Bay 3 of the Vehicle Assembly Building (VAB) at Kennedy Space Center. All the work platforms have been retracted in preparation for rollout to Launch Complex 39B ahead of launch of Artemis I.

Exploration CoF Priorities

Exploration construction priorities in FY 2023 continue to support facility upgrades and modernization for the Artemis campaign at the Kennedy Space Center (KSC) and the Michoud Assembly Facility (MAF).

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ACHIEVEMENTS IN FY 2022

Exploration CoF continued infrastructure modifications necessary to support SLS and Orion launch operations, along with other exploration missions.

Discrete Projects

- Repaired and upgraded the Vehicle Assembly Buildings water distribution system to support the Artemis Program;
- Replaced Roof, Bldg. 103, MAF;
- Modified the launch infrastructure at KSC; and
  - Upgraded critical systems for nitrogen, temperature and humidity control, air supply, fabrication, and emergency evacuation; and
  - Enabled the Artemis campaign and long-distance exploration programs with SLS activities.
- Rehabilitated KSC's Launch Control Center (LCC) HVAC system.
  - Rehabilitated HVAC systems to support personnel and ongoing operations of critical launch equipment (e.g., monitoring systems, firing and computer rooms);

EXPLORATION COF

  - Replaced vital, high-tech equipment that supports launch operations (e.g., Air Handle Units [AHU], computer room air conditioning units, fan coils, chilled water pumps, valves); and
  - Utilized new HVAC systems that save energy and reduce operational costs.

Minor Projects

Conducted critical repairs, modernization, and upgrades for facilities, infrastructure, and assets that support exploration projects.

- Renovated the 200-ton bridge crane at KSC's Rotation, Processing, and Surge Facility (RPSF);
- Repaired and revitalized the Booster Fabrication Facility (BFF) Complex at KSC, including interior renovations; upgraded HVAC and security; replaced air systems, elevators, and oxygen monitors; and refurbished plumbing;
- Repaired MAF roadways; and
- Replaced essential infrastructure within MAF, including fire systems and restrooms.

WORK IN PROGRESS IN FY 2023

Exploration CoF will continue infrastructure modifications necessary to support SLS and Orion launch operations, along with other exploration missions.

Discrete Projects

- Modify the launch infrastructure at KSC:
  - Upgrade critical systems for nitrogen, temperature and humidity control, air supply, fabrication, and emergency evacuation; and
  - Enable the Artemis campaign and long-distance exploration programs with SLS activities.
- Rehabilitate KSC's LCC HVAC system:
  - Rehabilitate HVAC systems to support personnel and ongoing operations of critical launch equipment (e.g., monitoring systems, firing and computer rooms);
  - Ensure mission-critical operations (e.g., launch countdowns, controls, communication) are not impacted by system failures;
  - Replace vital equipment that supports launch operations (e.g., Air Handle Units [AHU], computer room air conditioning units, fan coils, chilled water pumps, valves); and
  - Utilize new HVAC systems that save energy and reduce operational costs.

Minor Projects

Exploration CoF will conduct critical repairs, modernization, and upgrades for facilities, infrastructure, and assets that support exploration projects.

- Renovate the interior infrastructure of KSC's Booster Fabrication Facility (Phase 2 of 2);
- Upgrade the HVAC system at KSC's Booster Fabrication Facility for improve efficiency and lower costs (Phase 1 of 2);
- Refurbish the KSC Booster Fabrication Facility complex cranes needed to support the SLS and Artemis campaign Booster flight hardware operations;
- Refurbish the cranes needed to support the SLS and Artemis campaign Booster flight hardware operations in the MAF;
- Upgrade the fire suppression system in buildings 110 and 114 at MAF to improve safety and mission assurance; and

EXPLORATION COF

- Upgrade the steam system at MAF to improve reliability in the critical manufacturing plant (Phase 3 of 3).

KEY ACHIEVEMENTS PLANNED FOR FY 2024

Exploration CoF will continue infrastructure modifications necessary to support SLS and Orion launch operations, along with other exploration missions.

Discrete Projects

- Modifications to KSC Launch Infrastructure for SLS, $10.5 million. The project will continue fabrication and installation of additional platforms in HB-3 for SLS Block 1b and start construction of the payload environmental access room in HB-4 to support EUS processing. Construction will also start on LC-39B infrastructure modifications to support the Liquid Nitrogen skid to support RL-10 engines of the EUS.

Facility Planning and Design

None.

SPACE OPERATIONS COF

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	22.5	--	29.4	0.0	0.0	0.0	0.0

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects Division B funding amount of $47.3 million and Division N funding amount of $367 million, as specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

Space Operations CoF provides construction to support Space Communications and Navigation (SCaN), the International Space Station (ISS) Program, and the Launch Services Program (LSP). Funds required for the planning and design of out-year programmatic construction remain in the applicable program accounts. Space Operations CoF is managed in collaboration with institutional projects but funded through the Space Operations Mission Directorate (SOMD).

The Goldstone Solar System Radar (GSSR) facility provides unique capabilities that allow NASA to penetrate deep into space to explore planetary systems and cosmic phenomena.

Space Operations CoF Priorities

Space Operations CoF is prioritized based on mission requirements and the criticality of mission assets.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ACHIEVEMENTS IN FY 2022

Discrete Projects

- Continued the Deep Space Network Aperture Enhancement (DAEP) Beam Waveguide (BWG) antennae projects at the Goldstone and Canberra Deep Space Communication Complexes:
  - Completed construction and started operations of DSS-53 antenna at the Madrid Deep Space Communication Complex, enabling the array of four antennae for an enhanced aperture;
  - Completed the DSS-23 antenna pedestal at the Goldstone Deep Space Communication Complex, along with other critical infrastructure including flood controls, water, HVAC systems, electrical, surveillance, and fire detection systems; and
  - Enabled both radio frequency and optical communications for deep space exploration missions.

Minor Projects

Space Operations CoF conducted repairs, modernization, and upgrades to ensure the safe and reliable continued operations of vital communication and monitoring systems. Repairs and upgrades addressed crucial systems in current assets, including electrical and fire systems, accessibility and code compliance, and additional necessary refurbishment.

SPACE OPERATIONS COF

- Upgraded the switchgear to provide redundancy and ensure reliability at the Apollo site;
- Installed an additional underground backup power feed from the Mars site to the Apollo site to support vital communications during long-term expeditions; and
- Expanded the underground fiber optic cable from the Mars site to the Apollo site at the Goldstone Deep Space Communication Complex to ensure continuous connectivity during missions.

WORK IN PROGRESS IN FY 2023

Discrete Projects

- Continuation of the DAEP BWG antennae projects at the Goldstone and Canberra Deep Space Communication Complexes:
  - Complete the construction and start operations of DSS-53 antenna at the Madrid Deep Space Communication Complex, enabling the array of four antennae for an enhanced aperture;
  - Complete the DSS-23 antenna pedestal at the Goldstone Deep Space Communication Complex, along with other critical infrastructure including flood controls, water, HVAC systems, electrical, surveillance, and fire detection systems; and
  - Enable both radio frequency and optical communications for deep space exploration missions.

Minor Projects

Space Operations CoF will conduct repairs, modernization, and upgrades to ensure the safe and reliable continued operations of vital communication and monitoring systems. Repairs and upgrades will address crucial systems in current assets, including electrical and fire systems, accessibility and code compliance, and additional necessary refurbishment.

- Modification of the DSS-14 Antenna and the Goldstone Solar System Radar facility for improved, long-range exploration and scientific missions;
- Build redundant data and signal processing centers to ensure the security and storage of vital mission data gathered during explorational and scientific missions; and
- Replace the fire detection system at Goldstone for improved site operations.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

Discrete Projects

- Continue DAEP BWG antennae projects with the construction of DSS-23 at Goldstone and the pedestal replacement of DSS-45 at Madrid, $5.8 million.

Minor Projects

- The Underground Tank Replacement Goldstone Deep Space Communications Complex (JPL/GDSCC) project will:
  - Replace existing underground storage tanks with new above ground fuel storage tanks that will support the generators. The fuel tanks will have updated leak detection, fuel lines, and pumps;
  - Replace existing underground tanks at the (JPL/GDSCC) facility for fuel and gasoline of on-site vehicles; and
  - Replace the 70m hydraulic oil storage tank.

SPACE OPERATIONS COF

- The Underground Tank Replacement Madrid Deep Space Communications Complex (JPL/MDSCC) project will:
  - Replace existing underground storage tanks with new above ground fuel storage tanks to support the generators. The fuel tanks will also have updated leak detection, fuel lines, and pumps; and
  - Replace existing underground tanks at the (JPL/MDSCC) facility for fuel and gasoline of on-site vehicles.
- The 750 kW Generators (JPL/GDSCC) Replacement project will:
  - Replace existing aging generators (50 to 60 years old) at (JPL/GDSCC) due to increased maintenance requirements and to ensure compatibility with modern control systems; and
  - Include project scope for new modern diesel generators and associated controls.
- The 750 kW Generators (JPL/MDSCC) Replacement project will:
  - Replace existing aging generators (50 to 60 years old) at (JPL/MDSCC) due to increased maintenance requirements and to ensure compatibility with modern control systems; and
  - Include project scope for new modern diesel generators and associated controls.
- The Backup Generators (JPL/GDSCC) Replacement project will replace existing aging (50 to 60 years old) backup generators at (JPL/GDSCC) due to increased maintenance requirements and to ensure compatibility with modern control systems.
- The BWG Antenna Drives and Cabinets Replacement, Subnet project (JPL) will replace obsolete antenna drives and drive cabinets and include several major hardware items (e.g., motors, drive cabinet, gear boxes, and axis angle encoders, alidade shelter, and interconnections).
  - This is a phased project that replaces six units. The first on DSS-26 was FY 2021 funded. The remaining five antennas are DSS-54, DSS-55, DSS-24, DSS-34, and DSS-25 (FY 2024 funded). The order of antennas is tentative and dependent on antenna downtime schedules. The project will run through FY 2031.
- The BWG Redundant Power Feed (JPL/GDSCC) Project provides for the addition of redundant power feeds to Apollo substations, which are currently not redundant.
- The Building 836/840 Mechanical Systems and Controls Upgrade Project will replace KSC's heating, ventilation, and air conditioning (HVAC) and other ancillary mechanical systems in Building 836. The control systems will also be upgraded in both Building 836 and Building 840.

Facility Planning and Design

None.

ENVIRONMENTAL COMPLIANCE AND RESTORATION

FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**74.7**	**--**	**77.8**	**79.4**	**81.0**	**82.8**	**84.5**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects Division B funding amount of $47.3 million and Division N funding amount of $367 million, as specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

NASA maintains a high standard for environmental stewardship and cleanup connected to its mission work, like propellant and fuel testing seen here at the Stennis Space Center.

NASA’s Environmental Compliance and Restoration (ECR) Program cleans up hazardous materials and waste products released to the surface or groundwater at current and former NASA installations or associated facilities. Over the years, NASA activities have contributed to environmental problems. It is the Agency's ethical and legal responsibility to address hazardous pollutants and environmental impacts.

ECR stewardship, compliance, and restoration activities include:

- Execution of projects, studies, assessments, investigations, sampling, plans, designs, construction, engineering, program support, monitoring, and regulatory oversight;
- Development and execution of policies, guidance, communications, risk analysis, strategy, planning, coordination, and outreach;
- Provision of critical equipment needed for containment, monitoring, treatment, and analysis of harmful substances and contaminants;
- Land acquisitions required to ensure operation of remedial treatment processes and facilities as part of remediation and cleanup measures; and
- Addressing tribal concerns for environmental actions through formal consultation.

ECR Priorities

ECR activities are prioritized based on a combination of legal and statutory requirements, assessed risk, and mission requirements. ECR’s overarching goal is to ensure public health, conserve and restore natural resources, and reduce NASA’s environmental burden. ECR activities are conducted in each of the following high priority areas:

- Stewardship: Ensure the responsible use and protection of the NASA infrastructure, assets, cultural and natural environment, and resources through the active execution of conservation efforts and sustainable practices that conform with legal requirements and presidential directives.

ENVIRONMENTAL COMPLIANCE AND RESTORATION

- Compliance: Ensure the public and the NASA workforce are not exposed to harmful chemicals from current or previous mission activities by identifying, monitoring, measuring, assessing, mitigating, treating, and identifying significant environmental risks; and executing regulatorily required compliance actions and reporting environmental compliance challenges and risks.
- Restoration: Conduct cleanup activities, including contaminant surveys, groundwater and soil investigations, groundwater treatment, soil removal, demolition and associated regulatorily required activities to eliminate harmful substances or materials and reduce environmental impacts.

EXPLANATION OF MAJOR CHANGES IN FY 2024

None.

ACHIEVEMENTS IN FY 2022

ECR continued cleanup activities at all NASA centers, with priority to protecting health and conforming to environmental regulations and statutory requirements. In addition to the specific actions below, the ECR Program continued to implement site-wide restoration activities, contaminated groundwater cleanup, and investigate soil contamination Agency-wide:

- Continued to operate groundwater treatment facilities to remove contaminants across the Agency;
- Continued to demolish Santa Susana Field Lab (SSFL) Bravo Test Stands and begin demolition of Coca Test Stands;
- Implemented pump and treat remedy and Groundwater Extraction and Treatment System optimization, design, well-head modifications, and pipeline reconfiguration at SSFL;
- Continued to operate and maintain groundwater treatment systems at JPL and continued to operate the Lincoln Avenue and Monk Hill drinking water treatment systems;
- Completed debris removal and initiate Remedial Design at Disposal Area 2A at GRC;
- Completed remediation of Quiet Engine Test Stand at GRC and submitted closeout report;
- Continued to investigate and clean up contamination at KSC, including the installation of new groundwater treatment systems, removal of contaminated soils, investigation of potential contamination, and sampling over 700 monitoring wells;
- Continued MSFC site-wide restoration activities including implementing interim actions to address the groundwater plume operable unit source areas;
- Completed the closure activities and received a "No Further Action" notification from the regulator for Area A at SSC;
- Completed the construction of Plume-Front recloser and power meter at White Sands Test Facility (WSTF);
- Provided regulatory risk analysis and communication support;
- Completed Vertical Process Facility air sparge system abandonment at KSC;
- Implemented the emulsified zero-valent iron Phase 3 enhanced remediation project at SSC;
- Executed and updated the Agency Climate Action Plan in accordance with Executive Order 14008, Tackling the Climate Crisis at Home and Abroad to integrate NASA’s climate change adaptation and climate resilience across Agency programs; and
- Continued development of NASA Tribal Consultation Plan.

ENVIRONMENTAL COMPLIANCE AND RESTORATION

WORK IN PROGRESS IN FY 2023

ECR will continue cleanup activities at all NASA centers, with priority given to protecting health and conforming to environmental regulations and statutory requirements. In addition to the specific actions below, the ECR Program will continue to implement Agency-wide compliance initiatives and site-wide restoration activities, contaminated groundwater cleanup, and investigate soil contamination Agency-wide:

- Continue to operate groundwater treatment facilities to remove contaminants across the Agency;
- Implement Agency-wide environmental compliance initiatives to comply with Federal, State, and local requirements and implement environmental risk management initiatives;
- Continue to demolish SSFL Bravo and Coca Test Stands;
- Implement soil removal action at South Wallops Island;
- Continue to investigate and clean up contamination at KSC, including the installation of new groundwater treatment systems, removal of contaminated soils, investigation of potential contamination, and sampling over 700 monitoring wells;
- Continue MSFC site-wide restoration activities including implementing interim actions to address the groundwater plume operable unit source areas;
- Continue to operate and maintain groundwater treatment systems at JPL and continue to operate the Lincoln Avenue and Monk Hill drinking water treatment systems;
- Continue site-wide restoration activities, contaminated groundwater cleanup, and investigate soil contamination at WSTF;
- Conduct Remedial Investigation/Feasibility Study at Engine Research Building at GRC;
- Conduct feasibility study and proposed plan at GRC's Disposal Area 2A and 2B. Provide regulatory risk analysis and communication support; and
- Execute and update the Agency Climate Action Plan in accordance with Executive Order 14008, Tackling the Climate Crisis at Home and Abroad to extend NASA's climate resilience across the Agency.

KEY ACHIEVEMENTS PLANNED FOR FY 2024

ECR plans to continue cleanup activities at all NASA centers, with priority given to protecting health and conforming to environmental regulations and statutory requirements. In addition to the specific actions below, the ECR program will continue to implement Agency-wide compliance initiatives, and site-wide restoration activities, contaminated groundwater cleanup, and investigate soil contamination Agency-wide:

- Continue launch complex restoration activities across the Agency;
- Implement Agency-wide environmental compliance initiatives to comply with Federal, State, and local requirements and implement environmental risk management initiatives;
- Continue infrastructure and operations environmental and sustainability performance and opportunity assessments Agency-wide;
- Continue Agency-wide compliance and efficiency assessments;
- Continue Agency-wide program development initiatives;
- Update Agency sustainability and climate action plans and continue performance reporting;
- Continue Agency-wide execution of expanded Site Inspections and initiate Remedial Investigations at areas of potential concern for polyfluoroalkyl substances (PFAS);

ENVIRONMENTAL COMPLIANCE AND RESTORATION

- Continue JPL operations and maintenance of groundwater treatment systems;
- Continue construction of operational unit (OU-3) groundwater treatment technologies at MSFC;
- Initiate final solution contaminated soil excavation and removal at SSFL;
- Continue demolition of Coca Test Stand at SSFL;
- Continue Wallops Flight Facility (WFF) - GSFC operations and maintenance of PFAS contaminated groundwater treatment systems; and
- Continue WSTF - JSC groundwater treatment systems corrective measures operations and maintenance.

INSPECTOR GENERAL

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**45.3**	**47.6**	**50.2**	**51.2**	**52.2**	**53.2**	**54.3**

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

INSPECTOR GENERAL

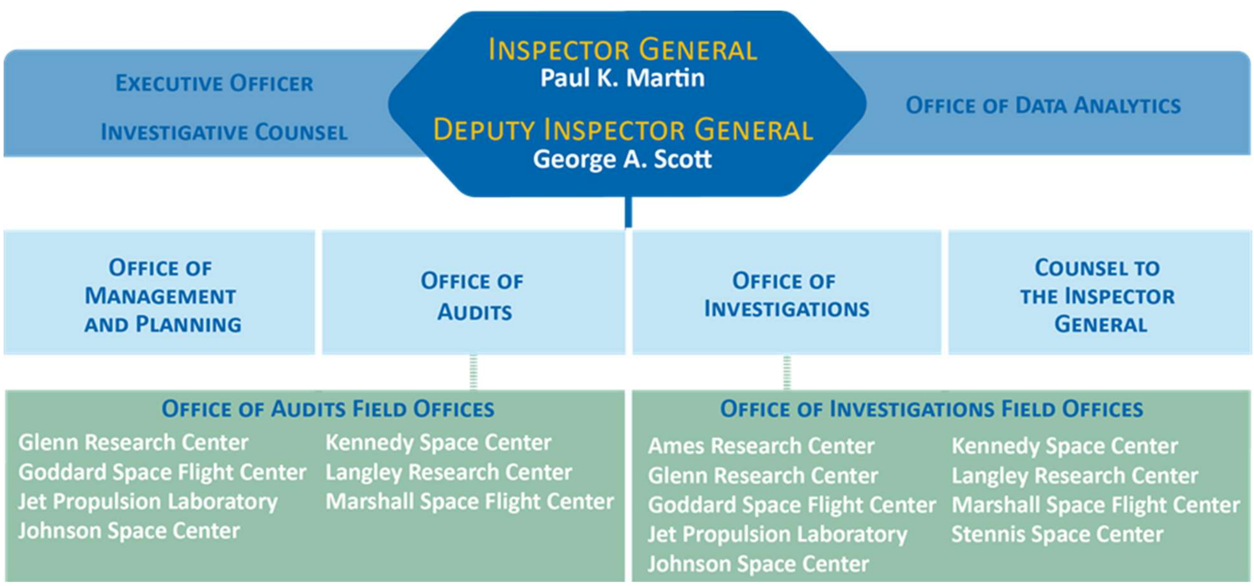
FY 2024 Budget

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**45.3**	**47.6**	**50.2**	**51.2**	**52.2**	**53.2**	**54.3**
Change from FY 2023 Enacted			**2.6**				
Percent change from FY 2023 Enacted			**5.5%**				

FY 2022 reflects funding amounts specified in Public Law 117-103, Consolidated Appropriations Act, 2022, as adjusted by NASA's FY 2022 Operating Plan, August 2022.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

The Office of Inspector General (OIG) conducts audits, investigations, and reviews of NASA programs and personnel to prevent and detect fraud, waste, abuse, and mismanagement, and assists NASA leaders and Congress in promoting economy, efficiency, and effectiveness through its oversight role. To accomplish this work, OIG employs auditors, investigators, data analysts, attorneys, and support staff at NASA Headquarters in Washington, D.C. and nine locations throughout the United States. OIG's operational offices consist of the Office of Audits (OA), Office of Investigations (OI), Counsel to the Inspector General, Office of Management and Planning (OMP), and Office of Data Analytics (ODA).



OIG Organizational Chart

OA conducts independent and objective audits of NASA programs, projects, operations, contractor activities, and oversees the work of the independent public accounting firm that conducts the annual audits of the Agency's financial statement and information security programs. OA targets high-risk areas and top management challenges to assist NASA's efforts to achieve its space exploration, scientific discovery, space technology, and aeronautics goals. OIG audits provide fact-based analysis with actionable recommendations that helps NASA improve its operations.

OI investigates allegations of cybercrime, fraud, waste, abuse, and misconduct related to NASA programs, operations, and resources. OI refers its findings to the Department of Justice (DOJ) for criminal prosecution and civil litigation or to NASA management for administrative action. OI also develops recommendations for NASA management that aim to reduce the Agency's vulnerability to criminal activity, misconduct, and administrative inefficiency. OI's caseload includes investigations of suspected false claims submitted by NASA contractors, product substitution and counterfeit parts, and conflict of interest cases that involve NASA employees placing private gain before public service.

The Counsel to the Inspector General (Office of Counsel) provides legal advice and assistance to OIG managers, auditors, and investigators. The Office of Counsel serves as counsel for administrative litigation and assists the DOJ when the OIG is part of the prosecution team, or when the OIG is a witness or defendant in legal proceedings. In addition, the Office of Counsel is responsible for educating Agency employees about prohibitions on retaliation for protected disclosures, and about rights and remedies for protected whistleblower disclosures.

OMP and staff within the Front Office provide financial, procurement, human resources, administrative, information technology (IT) services and support to OIG staff. OMP advises the Inspector General and OIG senior management on budget issues and human resources staffing matters, directs OIG internal management and support operations, and oversees development and adherence to management policies and procedures. Additionally, OMP ensures state-of-the-art IT system capabilities for OIG staff.

ODA is responsible for providing analytic consultation, data services, and data products to support audits, investigations, and management and planning functions. OIG develops and maintains a secure data analytic infrastructure that automates processes; secures data in cloud and on-premise environments; and rapidly disseminate critical information to decision makers to detect and deter fraud, waste, and abuse. ODA is comprised of statisticians, data scientists, data engineers, business intelligence experts with domain experience in audits, investigations, and management and planning functions. ODA was established as a separate office in FY 2022 to centralize core data analytic capabilities support functions that existed across several OIG offices.

BUDGET REQUEST OVERVIEW

For FY 2024, the NASA OIG requests $50.2 million in direct appropriations to support the OIG's mission to improve NASA's programs and operations through independent and objective oversight.

The FY 2024 budget request will enable the OIG to continue to deliver impactful audits and investigations, and funds statutorily mandated oversight activities such as NASA's Consolidated Financial Statements Audit and reviews of the Agency's IT security program under the Federal Information Security Management Act (FISMA). The budget supports the OIG's transition to the cloud environment as OIG restructures its IT infrastructure and phases out a longstanding reimbursable program that assisted other Offices of Inspector General by hosting audit and investigative IT systems. The other Offices of the Inspector General that we have been supporting are aware of the termination of services and are developing their own approach to replace these services. NASA OIG will continue providing technical support through this transition for our current customers.

FY 2024 BUDGET REQUEST (in millions):	FY 2023*	FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Budget Baseline	$ 47.6	$ 50.2	$ 51.2	$ 52.2	$ 53.2	$ 54.3.
Program Change		$ 0.0				
Budget Request	**$ 47.6**	**$ 50.2**	**$ 51.2**	**$ 52.2**	**$ 53.2**	**$ 54.3**
Salaries & Benefits	$ 40.2	$ 41.8	$ 42.6	$ 43.4	$ 44.3	$ 45.3
Travel	$ 0.7	$ 0.7	$ 0.7	$ 0.8	$ 0.8	$ 0.8
Operations**	$ 6.7	$ 7.7	$ 7.9	$ 8.0	$ 8.1	$ 8.2
Budget Request (Direct)	**$ 47.6**	**$ 50.2**	**$ 51.2**	**$ 52.2**	**$ 53.2**	**$ 54.3**
Anticipated Collections	**$ 0.8**	**$ 0.2**				
FTE - Direct Funded	186	189	190	190	190	190
FTE - Reimbursable Funded	4	1				
FTE Supportable	**190**	**190**	**190**	**190**	**190**	**190**

** FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.*

*** In accordance with Public Law 110-409, the Inspector General Reform Act of 2008, the Inspector General certifies that $0.4 million for staff training and $0.2 million to support the Council of the Inspectors General on Integrity and Efficiency satisfy all known training requirements and planned contributions to the Council.*

OIG's FY 2024 budget request allocation is as follows:

- $41.8 million (83 percent) for personnel and related costs, including salaries, benefits, monetary awards, and Government contributions for Social Security, Medicare, health and life insurance, retirement, and the Thrift Savings Plan, which includes increased rates for retirement contributions;
  - Salaries include an increase of 5.2 percent in base pay for cost-of-living-adjustments for employees and the required additional 25 percent law enforcement availability pay for OIG's approximately 55 criminal investigators.
  - Awards and Recognition: The estimate of salary spending, excluding salary spending for Senior Executive Service (SES), for FY 2023 is $26.5 million and for FY 2024 is $27.6 million. The estimate of awards spending as a percent of non-SES salary spending for FY 2023 and FY 2024 is 2.5 percent.
- $0.7 million (1.5 percent) for employee travel, per diem, and related expenses;
- $3.5 million (7 percent) for the statutorily required annual audits of the Agency's financial statements and IT security programs (FISMA);
- $0.4 million (0.9 percent) for training and staff development; and
- $3.8 million (7.6 percent) for operational procurements including vehicles, special equipment for criminal investigators, and information technology equipment unique to the OIG. This includes associated costs for our investigators to use body-worn cameras during law enforcement actions

required under Executive Order 14074, Advancing Effective, Accountable Policing and Criminal Justice Practices to Enhance Public Trust and Public Safety.

EXPLANATION OF MAJOR CHANGES IN FY 2024

BASE ADJUSTMENTS AND PROGRAM CHANGES

For FY 2024, the OIG requests a total of $50.2 million in direct appropriations of two-year funding authority.

FY 2024 BUDGET REQUEST (in millions)

FY 2023 Appropriations enacted in the Consolidated Appropriations Act, 2023	$ 47.6
Base Adjustments	2.6
FY 2024 Budget Baseline	**$ 50.2**
Program Changes	$0
FY 2024 BUDGET REQUEST	**$ 50.2**

Since 2005, the NASA OIG has provided information technology tools and support to several other IG offices under the IG Act and Economy Act authorities. For these services, the OIG has collected funds to offset the personnel costs of approximately five to six full-time equivalents (FTE), totaling an estimated annual $1.1 million. Due to network modernization in its IT environment (i.e., moving from a NASA OIG-owned and maintained server-based network to a cloud-based environment), NASA OIG has decided to end these services over the next several years and focus on building a more robust, secure, and cost-effective IT architecture that emphasizes data analytics.

The NASA OIG has started phasing out its reimbursable IT services in FY 2023 with significant reductions to follow in FY 2024. As these services phase out, reimbursable FTE are converted to direct FTE that will continue to perform IT functions under the new environment and must be funded from appropriations. The reduction of anticipated reimbursements in FY 2023 does not require additional budget resources due to planned spending reductions, greater efficiencies in productivity, and attrition savings. However, further reductions in offsetting collections in FY 2024 require additional appropriations to meet IT staffing requirements. In FY 2024, OIG expects that further savings will absorb $0.2 million of the additional $0.6 million reduction in offsetting collections (see table below). The OIG budget provides $0.4 million to fund the difference and continue support for the current FTE level.

FY 2024 BASE ADJUSTMENTS TO PAY & BENEFITS (in millions):

	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
IT Support Services	$ 0.9	$ 1.1	$ 1.0	$ 1.1	$ 1.1
IT Support Services Reductions in Service			$ (0.2)	$ (0.3)	$ (0.9)
Collections or Anticipated Collections related to IT Support	**$ 0.9**	**$ 1.1**	**$ 0.8**	**$ 0.8**	**$ 0.2**
Reimbursable FTE - IT Support	**5.0**	**6.2**	**4.3**	**4.0**	**1.0**
Direct FTE - IT Support	**0.0**	**0.0**	**0.0**	**0.0**	**3.0**

PROPOSED CHANGE IN FUNDING AUTHORITY

In Public Law 117-328, Consolidated Appropriations Act, 2023, $500,000 of OIG's funding was appropriated with two-year availability and the rest as annual funding. All other NASA funding has at least two-year availability. Once again, the Budget provides two-year availability for the entirety of direct OIG funding. Aligning the entire OIG appropriation with the rest of NASA improves resource planning, especially under continuing resolutions, and provides more certainty in funding and efficiencies in hiring for an organization that is 83 percent personnel driven. Moreover, it will allow the OIG to align its business processes and other financially related year-end processes within NASA's centralized systems and budgetary framework to execute the oversight mission more efficiently.

Proposed New Appropriations Language for FY 2024

For necessary expenses of the Office of Inspector General in carrying out the Inspector General Act of 1978, $50,200,000, to remain available until September 30,2025.

ACHIEVEMENTS IN FY 2022

To support the budget request, OIG has included the following select accomplishments and ongoing work performed by OI and OA.

Investigative work during Fiscal Year 2022

JUDICIAL or CIVIL ACTIONS		ADMINISTRATIVE ACTIONS		INVESTIGATIVE RECOVERIES	
Indictments and Informations	20	Administrative and Disciplinary Actions	43	Criminal, Civil, and Cost Recoveries	$34.5 Million
Convictions	15	Suspensions and Debarments from Contracting	19	Related to NASA	$14.2 Million
Civil Actions	7				

In FY 2022, the OIG issued 31 audit products containing 96 recommendations for improvement and identifying $6,816,646 in questioned costs for NASA with an additional $494 million in potential monetary savings. Audit products included reports examining NASA's management of:

- Acquisition Strategy for the Artemis Program;
- Astronaut Corps;
- Earth Science Disasters Program;
- FY 2021 Federal Information Security Modernization Act;
- FY 2021 Financial Statement Audit;
- FY 2021 Payment Integrity Information Act Compliance;
- Johns Hopkins University Applied Physics Laboratory;
- Mobile Launcher 2 Contract;

- Multi-Mission Program Cost Estimating;
- Utilization, Management, and Commercialization of Low Earth Orbit; and
- Volatiles Investigating Polar Expansion Rover (VIPER).

In FY 2022, OI investigated a wide variety of criminal and administrative matters involving procurement fraud, theft, counterfeit parts, ethics violations, and computer intrusions leading to more than $34.5 million in criminal, civil, and administrative penalties and settlements with approximately $14.2 million of these funds returned directly to NASA. OI's efforts in FY 2022 resulted in 20 indictments, 15 convictions/sentences, 7 civil settlements, 43 administrative actions, and 19 suspensions or debarments. Examples of OI's work over the past year include:

- As the result of a multi-year NASA OIG investigation, an Arlington, Virginia, company agreed to a civil settlement of $1,389,509, of which $578,591 was returned to NASA, to resolve allegations that it submitted inflated labor and indirect costs for a contract at Goddard Space Flight Center.
- As the result of a joint investigation by the NASA OIG, the U.S. Army Criminal Investigation Division, the Department of Energy OIG, and the U.S. Department of Homeland Security, two individuals, their corporation, and a fictitious shell company they created pleaded guilty to aiding and abetting unauthorized computer access, possession of false identification documents, and wire fraud. The individuals entered into plea agreements on behalf of the corporation and shell company, whereby they agreed to pay $4,652,762 in restitution, of which $1,406,250 was attributable to NASA Small Business Innovation Research contracts awarded to the company.
- A Georgia company agreed to resolve allegations under the False Claims Act. The company agreed to pay $524,404 to the United States, of which $313,484 will be returned to NASA. The company also agreed to waive payment of $137,652 for work performed under a Department of Defense contract. The investigation found the company misrepresented itself under the Women-Owned Small Business program to obtain almost $3 million in Federal contracts set aside for small businesses owned and controlled by women.
- In August 2022, a settlement agreement for $625,000 was reached with a laboratory equipment manufacturer in Boulder, Colorado, and its owner, after a joint investigation between the NASA OIG, Defense Criminal Investigative Service, U.S. Army Criminal Investigation Division, and Department of Energy OIG. The settlement resolved allegations of False Claims Act violations by a failure to comply with the requirements of the Buy American Act when selling scientific instruments to Federal agencies and national laboratories, to include the NASA Goddard Space Flight Center and Jet Propulsion Laboratory.
- A former NASA contractor employee and her spouse were sentenced to 20 months and 17 months of imprisonment, respectively, for steering contracts to a former NASA subcontractor in exchange for money and gifts as the result of joint investigation by NASA OIG, the FBI, and IRS Criminal Investigation.
- A Buffalo, New York, company agreed to a civil settlement of $128,985 to resolve allegations of breach of contract, payment by mistake, unjust enrichment, and fraud. The company overstated the number of hours a principal investigator and program manager performed services on two NASA research contracts.
- As the result of a joint investigation by the NASA OIG, FBI, and the Securities and Exchange Commission, the former CEO of a nanotechnology company was found guilty of securities fraud, wire fraud, and conspiracy. From 2013 to 2020, the former CEO misappropriated investors' funds

through false and misleading statements regarding the company's research and development activities, which included reimbursable Space Act Agreements.

- As the result of a NASA OIG investigation, a Stennis Space Center construction contractor's request for equitable adjustments resulted in a dispute before the Armed Services Board of Contract Appeals, which denied three of the five claims appealed by the contractor. The repudiated claims are valued at $9.5 million.
- A fuel delivery company used to transport rocket fuel pleaded guilty to wire fraud for falsifying tank trailer wash certificates over a nine-year period. The potentially contaminated fuel was used for ISS supply and military payload launches. Accordingly, the company and its two principals entered into voluntary exclusions wherein each agreed to be banned from Government contracting for two years. The company also agreed to forfeit $251,401 in gross profits traceable to the deliveries in question. The investigation was worked jointly by NASA OIG and the Defense Criminal Investigative Service.
- As the result of a NASA OIG investigation, the CEO, chief operating officer, and president of a Titusville, Florida, company were sentenced for their roles in a 22-year conspiracy to defraud NASA and its contractors of more than $84 million in contract awards by misrepresenting the company as a woman-owned small business. The CEO was sentenced to six months of imprisonment and three years of supervised release and ordered to pay an $893,062 criminal forfeiture and $5,000 fine. The chief operating officer and president were each sentenced to one year of unsupervised release, and the president was also ordered to pay a $183,262 criminal forfeiture. The company had previously agreed to a $250,000 civil settlement for its misrepresentations.
- In January 2022, the former general manager of a Titusville, Florida, small business was sentenced to 90 days of house arrest and one year of supervised release and ordered to pay a $5,000 fine after being convicted on multiple counts of conspiracy and wire fraud for his role in misrepresenting his company as a woman-owned small business in order to secure more than $6 million in NASA contracts. The general manager was the fourth individual sentenced in the fraud scheme.
- A former chief scientist at Ames Research Center was debarred for three years. The scientist was convicted and sentenced for making false statements to the FBI and NASA OIG regarding his employment by a Chinese government-funded program that recruited individuals with access to foreign technologies and intellectual property.
- As the result of an investigation by NASA OIG and the IRS, a former NASA Office of the Chief Financial Officer senior executive was debarred by the NASA Acquisition Integrity Program for a period of seven years. The former NASA official previously pleaded guilty to one felony count for receiving three Coronavirus Aid, Relief, and Economic Security (CARES) Act loans under the Paycheck Protection Program and was sentenced to 18 months of imprisonment, three years of supervised release, and ordered to pay $285,449 in restitution.
- A Johnson Space Center engineer was charged with submitting fraudulent applications for Economic Injury Disaster Loans administered by the Small Business Administration. The purpose of such loans is to help small businesses and other entities overcome the effects of the pandemic by providing borrowers with working capital to meet operating expenses. The charges alleged that materially false and fraudulent representations and promises were made to obtain money for personal benefit. An investigation determined that loan documents were signed utilizing a NASA network, resulting in the improper receipt of $156,500 in loan proceeds.

- In April 2022, an aircraft parts supplier in Riverside, California, was arrested for violations of Fraud Involving Aircraft or Space Vehicle Parts based upon a joint investigation between the FBI, Defense Criminal Investigative Service, Department of Transportation OIG, Office of Export Enforcement, and NASA OIG. The individual allegedly engaged in fraudulent transactions resulting in suspect parts being supplied to both the North Atlantic Treaty Organization and NASA, among other entities. The subject pled guilty and was sentenced to 46 months' imprisonment and ordered to pay $1.5 million in restitution.

WORK IN PROGRESS AND KEY ACHIEVEMENTS PLANNED FOR FY 2024

In the first three months of FY 2023, the OIG issued audit reports titled "Review of NASA's Space Technology Mission Directorate Portfolio International Space Station", and "Efforts to Commercialize Low Earth Orbit." In addition, the OIG issued the mandated Audit of NASA's Fiscal Year 2022 Financial Statements, NASA's Compliance with the Geospatial Data Act for Fiscal Year 2022, and Evaluation of NASA's Information Security Program under the Federal Information Security Modernization Act for Fiscal Year 2022.

During the remainder of the fiscal year, the OIG will examine NASA's partnerships with international space agencies for Artemis missions, Earth System Science Pathfinder program, electrified aircraft propulsion research and development efforts, On-orbit Servicing, Assembly, and Manufacturing-1 mission (OSAM-1), and contracting and performance management for programs, including the Artemis campaign's supply chain, the Space Launch System engine contacts, Mars Sample Return Program, and the Radioisotope Power Systems Program. OIG will continue to monitor the progress of the troubled Mobile Launcher 2 project. The OIG continues to provide oversight in the information technology domain, with an audit of NASA's Software Asset Management and of Management of its Artificial Intelligence Capabilities. Additionally, the OIG has an ongoing review of NASA's efforts to advance diversity, equity, inclusion, and accessibility, as well as an audit on the Agency's ability to provide stakeholders with information to help predict, prepare for, and recover from natural disasters. Ongoing OI work includes proactive initiatives designed to identify acquisition and procurement fraud schemes. Additionally, representatives from both OI and OA are working together to use OIG's advanced data analytics capabilities to help identify indicators of potentially fraudulent activity.

In FY 2023, OIG will continue to focus its work on NASA's top management and performance challenges identified in our November 2022 report. Specifically, OIG plans to undertake work in the following areas:

- Returning humans to the Moon;
- Improving management of major programs and projects;
- Sustaining a human presence in Low Earth Orbit;
- Managing and mitigating cybersecurity risks;
- Improving oversight of contracts, grants, and cooperative agreements;
- Attracting and retaining a diverse and highly skilled workforce; and
- Managing NASA's outdated infrastructure and facilities.

OIG will also continue mandated oversight in a variety of Financial Management and Quality Control areas to include:

- Payment Integrity Information Act compliance;

- Desk and quality control reviews of selected single audit reporting packages;
- Oversight of Financial Statement Audit;
- Risk assessment of purchase and travel card programs;
- Geospatial Data Act; and
- Federal Information Security Modernization Act.

As NASA continues to work toward landing the first woman and person of color on the Moon, with the eventual goal of landing humans on Mars, additional OIG funding will enable enhanced oversight of major NASA projects.

From an investigative perspective, the FY 2024 request will continue support for investigations of cybercrime, fraud, waste, abuse, and misconduct related to NASA programs, projects, personnel, operations, and resources.

Given the important role of NASA's contracting practices in Agency missions, most of OIG's proactive initiatives focus on acquisition activities that are susceptible to procurement fraud schemes. Examples of ongoing, proactive initiatives that will continue include the following:

- An Investigative Analysis Division (IAD) – Financial Accountant & Analysis (FA&A) section project to aggregate, analyze and monitor cost data related to NASA's Artemis Program in an attempt to identify indications of fraud on the part of prime contractors and subcontractors;
- An IAD - Criminal and Cyber Threat Intelligence (CaCTI) section project that will identify sensitive procurement information and other critical data that may have been improperly exfiltrated from NASA computer systems;
- An IAD-FA&A cross collaboration project with OIG's Audit component to conduct incurred cost audits of specific NASA subcontractors;
- A joint IAD project in conjunction with the NASA OIG Office of Data Analytics (ODA) and the Department of Justice Procurement Collusion Strike Force to utilize procurement data to identify potential collusion and/or anti-trust matters;
- A project to monitor and aggregate data related to NASA's Artemis Program in an attempt to identify indications of fraud on the part of prime contractors and subcontractors;
- A project with OIG's Audit component to conduct incurred cost audits of specific NASA subcontractors; and
- Multiple initiatives commenced to identify, detect, and deter fraud involving grant and contract recipients who surreptitiously receive significant financial support from foreign governments and/or fail to identify potential foreign-based conflicts of interest in violation of NASA policies and/or Federal law.

Supporting Data

FUNDS DISTRIBUTION

DISCRETIONARY BUDGET REQUEST BY MISSION BY NASA CENTER

Budget Authority ($ in millions)	FY 2024*
Deep Space Exploration Systems	42.1
Space Technology	50.4
Space Operations	14.4
Science	229.6
Aeronautics	200.7
STEM Engagement	3.0
Construction and Environmental Compliance and Restoration	75.4
Safety, Security, and Mission Services	195.8
Ames Research Center (ARC) Total	**811.4**
Deep Space Exploration Systems	0.1
Space Technology	23.7
Space Operations	0.5
Science	29.5
Aeronautics	200.7
STEM Engagement	9.9
Construction and Environmental Compliance and Restoration	12.5
Safety, Security, and Mission Services	69.3
Armstrong Flight Research Center (AFRC) Total	**346.2**
Deep Space Exploration Systems	238.2
Space Technology	46.3
Space Operations	93.6
Science	38.9
Aeronautics	221.1
STEM Engagement	3.0
Construction and Environmental Compliance and Restoration	18.0
Safety, Security, and Mission Services	218.0
Glenn Research Center (GRC) Total	**877.2**
Deep Space Exploration Systems	10.9
Space Technology	199.7
Space Operations	162.2
Science	3,278.4
Aeronautics	-
STEM Engagement	11.4
Construction and Environmental Compliance and Restoration	42.9
Safety, Security, and Mission Services	428.6
Goddard Space Flight Center (GSFC) Total	**4,134.2**

FUNDS DISTRIBUTION

Budget Authority ($ in millions)	FY 2024*
Deep Space Exploration Systems	19.2
Space Technology	28.0
Space Operations	215.0
Science	2,040.4
Aeronautics	-
STEM Engagement	1.7
Construction and Environmental Compliance and Restoration	5.0
Safety, Security, and Mission Services	9.2
Jet Propulsion Laboratory (JPL/NMO) Total	**2,318.5**
Deep Space Exploration Systems	2,157.3
Space Technology	18.3
Space Operations	2,972.4
Science	293.4
STEM Engagement	1.4
Construction and Environmental Compliance and Restoration	21.0
Safety, Security, and Mission Services	381.7
Johnson Space Center (JSC) Total	**5,845.3**
Deep Space Exploration Systems	892.5
Space Technology	51.6
Space Operations	669.7
Science	295.5
Aeronautics	-
STEM Engagement	22.1
Construction and Environmental Compliance and Restoration	11.4
Safety, Security, and Mission Services	370.7
Kennedy Space Center (KSC) Total	**2,313.3**
Deep Space Exploration Systems	23.8
Space Technology	38.5
Space Operations	7.2
Science	206.2
Aeronautics	300.3
STEM Engagement	28.2
Construction and Environmental Compliance and Restoration	23.3
Safety, Security, and Mission Services	267.7
Langley Research Center (LaRC) Total	**895.3**
Deep Space Exploration Systems	4,177.5
Space Technology	170.8
Space Operations	144.9
Science	341.5
Aeronautics	-
STEM Engagement	3.5
Construction and Environmental Compliance and Restoration	8.0
Safety, Security, and Mission Services	494.0
Marshall Space Flight Center (MSFC) Total	**5,340.2**

FUNDS DISTRIBUTION

Budget Authority ($ in millions)	FY 2024*
Deep Space Exploration Systems	374.5
Space Technology	761.6
Space Operations	222.7
Science	1,507.4
Aeronautics	72.9.
STEM Engagement	49.4
Construction and Environmental Compliance and Restoration	204.7
Safety, Security, and Mission Services	881.9
Office of Inspector General	50.2
NASA Headquarters (HQ) and Inspector General (IG) Total	**4,125.4**
Deep Space Exploration Systems	35.1
Space Technology	2.7
Space Operations	32.1
Science	0.1.
Aeronautics	-
STEM Engagement	24.0
Construction and Environmental Compliance and Restoration	31.5
Safety, Security, and Mission Services	52.4
Stennis Space Center (SSC) Total	**177.9**
	27,185.0

**Totals may not add due to rounding*

NOTE: Funds will not be fully distributed to the centers until after final acquisition decisions are made. Thus, FY 2024 allocations by center should not be considered final or directly comparable to prior year allocations.

CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION

NASA's workforce continues to be one of its greatest assets for enabling missions in space and on Earth. The Agency remains committed to applying this asset to benefit society, address contemporary environmental and social issues, lead or participate in emerging technology opportunities, collaborate and strengthen the capabilities of commercial partners, and communicate the challenges and results of Agency programs and activities. The civil service staffing levels funded in the FY 2024 budget support NASA's scientists, engineers, researchers, managers, technicians, and business operations workforce. It includes civil service personnel at NASA centers, Headquarters, and NASA-operated facilities.

NASA continually assesses and adjusts the mix of skills in its workforce to address changing mission priorities, leveraging industry and academic partnerships, and on and near-site support contracts to operate effectively in a leaner fiscal environment. A knowledgeable and well-trained civil service workforce is critical for conducting mission-essential work in research and technology. The Agency will apply the valued civil service workforce to priority mission work, adjusting the mix of skills where appropriate. Centers will explore cross-mission retraining opportunities for employees whenever possible, offer targeted buyouts in selected surplus skill areas, and continue to identify, recruit, and retain a multi-generational workforce of employees who possess skills critical to the Agency.

CIVIL SERVICE FULL-TIME EQUIVALENT (FTE) DISTRIBUTION BY CENTER – DIRECT FUNDED

	Actual	Estimate	Request
	FY 2022	**FY 2023**	**FY 2024**
ARC	1,284	1,199	1,187
AFRC	516	556	519
GRC	1,460	1,469	1,418
GSFC	3,070	3,089	2,902
JSC	2,914	3,144	3,115
KSC	2,040	2,067	2,014
LaRC	1,796	1,786	1,758
MSFC	2,298	2,364	2,252
SSC	247	271	266
HQ	1,397	1,536	1,515
NSSC	-	-	-
NASA Total*	**17,021**	**17,480**	**16,946**
OIG	176	186	189

**Totals may not add due to rounding*

NOTE: FY 2023 column is an estimate based on current funding levels. Funds will not be fully distributed to Centers until the FY 2023 operating plan is approved. Thus, Center FY 2024 allocations should not be considered final or directly comparable to prior year allocations

CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION

CIVIL SERVICE FULL-TIME EQUIVALENT (FTE) DISTRIBUTION BY CENTER – REIMBURSABLE FUNDED

	Actual FY 2022	Estimate FY 2023	Request FY 2024
ARC	21	22	22
AFRC	24	15	15
GRC	24	3	3
GSFC	173	219	219
JSC	31	-	-
KSC	22	1	1
LaRC	17	15	15
MSFC	30	-	-
SSC	26	25	25
HQ	14	2	2
NSSC	159	164	160
NASA Total*	**541**	**466**	**462**
OIG	4	4	1

**Totals may not add due to rounding*

NOTE: FY 2023 column is an estimate based on current funding levels. Funds will not be fully distributed to Centers until the FY 2023 operating plan is approved. Thus, Center FY 2024 allocations should not be considered final or directly comparable to prior year allocations

CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION

FY 2024 FTE DISTRIBUTION BY ACCOUNT BY CENTER

	Deep Space Exploration Systems	Space Operations	Space Technology	Science	Aeronautics	STEM Engagement	Safety, Security, and Mission Services	Reimbursable / Working Capital Fund**	Inspector General	NASA-Funded Total	Agency TOTAL
ARC	58	31	87	219	305	2	485	22		1,187	1,209
AFRC	0	2	18	74	216	2	206	15		519	534
GRC	188	114	125	55	420	4	512	3		1,418	1,421
GSFC	20	116	117	1,338		2	1,308	219		2,902	3,121
JSC	958	1,234	48	79		8	789			3,115	3,115
KSC	602	506	47	20		4	835	1		2,014	2,015
LaRC	77	15	101	202	555	3	806	15		1,758	1,773
MSFC	847	184	140	254		5	823			2,252	2,252
SSC	50	38	10	0		3	166	25		266	291
HQ	34	45	24	189	30	17	1,176			1,515	1,515
NSSC								162		0	162
NASA Total*	**2,834**	**2,283**	**716**	**2,430**	**1,526**	**49**	**7,107**	**462**	**-**	**16,946**	**17,408**
OIG	-	-	-	-	-	-	-	1	189	189	190

**Totals may not add due to rounding*

***Includes 162 FTE funded by Working Capital Fund; and 300 FTE anticipated FTE funded by reimbursable customers.*

NOTE: Funds will not be fully distributed to Centers until after the operating plan is approved. Thus, Center FY 2024 allocations should not be considered final or directly comparable to prior year allocations.

WORKING CAPITAL FUND

NASA established the Working Capital Fund (WCF) to satisfy specific recurring needs for goods and services through use of a business-like buyer and seller approach under which NASA's WCF entities provide goods or services pursuant to contracts and agreements with their customers. The overarching aim of WCF is to promote economy, efficiency, and accountability with fully reimbursed rates and by focusing on streamlining operations, measuring performance, and improving customer satisfaction.

IT MODERNIZATION

In FY 2023, NASA's existing authority under 51 U.S.C. 30102 was amended to authorize the Working Capital Fund for IT Modernization activities on a non-reimbursable basis and included transfer authority from the Safety, Security, and Mission Services account into the WCF to fund such activities. NASA plans to continue to utilize the WCF in FY 2024. The Administrative Provisions in the FY 2024 budget include transfer authority for up to $32,600,000 for purposes of IT modernization.

NASA's WCF is comprised of five entities:

- NASA Shared Services Center (NSSC);
- Solutions for Enterprise-Wide Procurement (SEWP) Government-Wide Acquisition Contract;
- Enterprise IT Services Program [formerly Information Technology Infrastructure Integration Program (I3P)];
- National Center for Critical Information Processing and Storage (NCCIPS); and
- IT Modernization.

WORKING CAPITAL FUNDS BUDGET SUMMARY

Spending Authority from Offsetting Collections	Actual	Estimate	Request
($ in millions)	**FY 2022**	**FY 2023**	**FY 2024**
NSSC	82	82	83
SEWP	28	42	45
Enterprise IT Services Program	252	180	224
NCCIPS	39	28	32
Total New Spending Authority	**401**	**332**	**384**
Unobligated Brought Forward, Oct. 1	55	42	1
Recoveries of Prior Yr. Unpaid Obligations	15	6	6
Total Budgetary Resources	**471**	**380**	**391**
NSSC	84	82	83
SEWP	28	37	40
Enterprise IT Services Program	276	232	224
NCCIPS	41	28	32
Total Obligations	**429**	**379**	**379**
Unobligated Balance (end-of-year)*	**42**	**1**	**12**

NASA SHARED SERVICES CENTER (NSSC)

NSSC opened in March 2006 to provide centralized administrative processing services and customer contact center operations for support of human resources, procurement, financial management, Agency IT, and Agency business support services. NASA established NSSC, a function under the NASA Headquarters Mission Support Directorate, as a public/private partnership. NSSC has awarded its major business management and IT services contract to CSRA (Computer Sciences Corporation merged with SRA International). Typical expenditures are related to the civil service workforce, support contractor, other direct procurements, and Agency training purchases.

NSSC is located on the grounds of Stennis Space Center (SSC) and operates in a manner that provides for transparency and accountability of costs and services. NASA has reduced its administrative costs through centralized processing at NSSC. The work performed by NSSC reduces duplicative efforts and increases cost efficiencies.

NSSC's revenue streams include funding from the NASA Mission Support Enterprise Offices, Mission Directorates, and various NASA mission support offices. During FY 2023, NSSC will continue to offer similar services as in FY 2022. During FY 2024, NSSC will continue to offer similar services as in FY 2023 making minor expansions to existing services.

SOLUTIONS FOR ENTERPRISE-WIDE PROCUREMENT (SEWP)

SEWP refers to operations related to the Government-Wide Acquisition Contract that was established under the authority of section 5112 of the Information Technology Management Reform Act (40 U.S.C. 1412(e)), enacted in 1996, under which NASA is designated by the Office of Management and Budget (OMB) as a Federal Government Executive Agent for SEWP contracts.

SEWP was established as a WCF entity to allow all Federal agencies use of a best value tool to purchase IT product solutions and services. Under this approach, the buying power of Federal agencies is combined to acquire best value for IT products and services more efficiently. Typical acquisitions include a wide range of advanced technologies, such as: UNIX-Linux and Windows-based desktops and servers, peripherals, network equipment, storage devices, security tools, software, and other IT products and product-based solutions.

SEWP promotes aggressive pricing using online tools to obtain multiple, competitive quotes from vendors. On average for FY 2022, SEWP quotes have a 20 percent savings for any Federal customer using SEWP contracts. In addition, SEWP offers a low surcharge to recover NASA's costs to operate the program with an average 0.34 percent fee as compared to the Government standard of 0.75 percent. SEWP revenue is generated solely from the surcharge fees on all transactions processed. For FY 2022, the Federal Government saved about $4.2 billion in fees, based on the difference between General Services Administration (GSA) and SEWP surcharge fees.

ENTERPRISE IT SERVICES PROGRAM

WCF operations supporting Enterprise IT Services Program began in early FY 2012. WCF enables Enterprise IT Services Program to improve the efficiency and economy in which contract services and management are provided to support NASA's IT strategic initiatives and to increase visibility into

NASA's IT budget and expenditures. Under the Enterprise IT Services Program, NASA has consolidated 19 separately managed contracts into four centrally managed ones described as follows:

- The Enterprise Applications Service Technologies (EAST2) contract supports Agency Applications Office (AAO) applications hosted by Marshall Space Flight Center (MSFC). The AAO operates and maintains a broad spectrum of NASA's enterprise applications, with an emphasis on fully integrating business process expertise with application and technical knowledge. A small team of civil servants and support contractors sustain operations, implement new applications and capabilities, and provide business readiness support to the stakeholders and end-users.
- The Enterprise Applications Service Technologies Web Enterprise Service Technologies (EAST2-WSO) contract provides public website hosting, web content management and integration, and search services. Goddard Space Flight Center (GSFC) and Ames Research Center (ARC) host these services.
- The End User Services Contract (NEST/EUSO) provides program management, provisioning, and support of desktops, laptops, cell phones, personal digital assistants, office automation software, and video conferencing. NSSC hosts these services.
- The Networx Telecommunications Circuits contract provides telecommunication services, which includes tele-conferencing services, core circuit services, mission network services, and regional circuit services hosted at MSFC. The work under the Networx contract slowly started transitioning to the follow-on contract, Enterprise Infrastructure Solutions Contract (EIS) in July 2019 with some services transitioning to the NASA Integrated Communications Services contract (NICS) Contract. The transition of work is still ongoing in FY 2023 and should be completely transitioned by the end of FY 2023.

Enterprise IT Services Program consolidated contracting approach benefits NASA by providing cost saving opportunities, such as the reduction in administrative burden involved with the business management of contracts and a significant reduction in procurement request transaction volume. Other Enterprise IT Services Program benefits include: streamlining the budgeting, funding, and costing of Enterprise IT Services Program services; achieving transparency through the provision of detailed customer monthly billings; and providing consolidated, consistent reporting of Agency-wide consumption of Enterprise IT Services Program-related goods and services.

Enterprise IT Services Program is unique in that revenue streams and expenditures are limited to contract costs for its four service contracts. Revenue streams include funding from the NASA centers, NASA mission directorates, and various NASA mission support offices. As reflected in the FY 2023 anticipated funding level, the Enterprise IT Services Program will continue to offer similar services as in FY 2022 with one significant change. The follow-on contract for NICS, the Advanced Enterprise Global Information Technology (IT) Solutions (AEGIS) contract will be managed outside of the working capital fund. In FY 2024, NSSC will continue to offer similar services as in FY 2023.

NATIONAL CENTER FOR CRITICAL INFO. PROCESSING AND STORAGE (NCCIPS)

NCCIPS is a Federal shared services data center designed for sensitive and secure processing and storage. NCCIPS is a 211,000 sq. ft. secure data center facility on a 64-acre campus within SSC. NCCIPS offers Federal customers collocation services from a state-of-the-art data center facility. NCCIPS offers

24x7x365 availability at a Tier III level as defined by the Uptime Institute, with complete redundancy in the cooling system and in the electrical distribution system from the national power grid to the rack-level.

NCCIPS provides the following infrastructure/services:

- Five Layer Security – Buffer Zone/perimeter fencing, armed security at all gates, roving guards, and NCCIPS armed guards, and NCCIPS Access Control System;
- Three separate commercial power generation systems available to NCCIPS;
- Tier III redundant (N + 1) power from commercial power systems down to racks on the datacenter floors with N + 1 diesel generator backup;
- Tier III redundant (N + 1) cooling;
- Expert IT staff with a proven track record of uninterrupted service;
- 24x7 facility operations staff monitoring;
- Robust network infrastructure with multiple, discreet communication paths; and
- FE-25 clean agent fire suppression.

The NASA WCF provides NASA with a mechanism to collect amounts sufficient to finance continuing operations, acquire capital assets, and adjust for prior year results of operations, in addition to normal operating expense recovery at NCCIPS. NCCIPS WCF benefits NASA and its customers by:

- Enabling funds to be collected over time and (once earned) used for new equipment and technology;
- Allowing the NSSC to incorporate a level of equipment replacement, maintenance, and technology refresh costs into customer rates;
- Helping to normalize rates charged to NCCIPS customers from year-to-year, as the need for facility repairs, infrastructure upgrades, and routine equipment maintenance increases, thus enabling NCCIPS customers to maintain their appropriation funding without incurring potentially large unplanned expenses;
- Facilitating NCCIPS business opportunities for new customers; and
- Reducing the probability of hardware failure within the NCCIPS operational environment.

The NCCIPS revenue streams include funding from the NASA SSC and NSSC Centers, NASA HQ Office of the Chief Human Capital Officer, and external Federal Agencies, including Department of Homeland Security (DHS), U.S. Army Program Executive Offices - Missiles and Space (ARMY – PEO) and Aviation (ARMY – AAVN), U.S. Navy Department of Defense Supercomputing Resource Center (DSRC), DOD High Performance Computing Modernization Program – Engineer Research and Development Center (ERDC), National Reconnaissance Office (NRO), Government Services Administration (GSA), Department of Transportation OCIO (DOT-OCIO), DOT Maritime Administration, and Department of Housing and Urban Development (HUD). During FY 2023 and FY 2024, NCCIPS will continue to offer similar services as in FY 2022 with no significant scope changes anticipated.

BUDGET BY OBJECT CLASS

FY 2024 Estimated Direct Discretionary Obligations
($ millions)

Code	Object Class	Deep Space Exploration Systems	Space Operations	Space Technology	Science	Aeronautics	STEM Engagement	Safety, Security, and Mission Services	Construction & Environmental Compliance & Restoration	Office of Inspector General	NASA Total
11.1	Full-time permanent	407	342	106	379	211	6	1,023	-	27	**2,501**
11.3	Other than full-time permanent	4	4	3	8	9	-	24	-	1	**53**
11.5	Other personnel compensation	3	2	1	2	-	-	69	-	1	**78**
11.8	Special Personal Services Payments	1	1	-	-	-	-	1	-	-	**3**
11.9	*Subtotal Personnel Compensation*	*415*	*349*	*110*	*389*	*220*	*6*	*1,117*	-	*29*	***2,635***
12.1	Civilian personnel benefits	155	127	40	140	80	2	392	-	12	**948**
13.0	Benefits to former personnel	-	-	-	-	-	-	-	-	-	**-**
	Total Personnel Compensation & Benefits	**570**	**476**	**150**	**529**	**300**	**8**	**1,509**	**-**	**41**	**3,583**
21.0	Travel & transport. of persons	9	16	-	3	-	1	16	-	1	**46**
22.0	Transportation of things	1	1,748	9	19	-	-	1	-	-	**1,778**
23.1	Rental payments to GSA	-	-	-	-	-	-	40	-	-	**40**
23.2	Rental payments to others	10	1	-	5	-	-	-	-	-	**16**
23.3	Communications, utilities & misc.	17	11	-	13	6	-	69	1	-	**117**
24.0	Printing & reproduction	-	-	-	1	-	-	2	-	-	**3**
25.1	Advisory & assistance services	500	138	72	156	19	1	493	11	-	**1,390**
25.2	Other services from non-Federal sources	39	180	34	252	23	6	269	33	1	**837**
25.3	Other purchases of goods & services from Government accounts	32	57	59	301	9	-	66	148	5	**677**
25.4	Operation & maintenance. of facilities	119	31	4	17	70	-	241	55	-	**537**
25.5	Research & development contracts	5,900	1,606	935	5,640	391	10	190	20	-	**14,692**
25.6	Medical care	-	-	-	-	-	-	7	-	-	**7**
25.7	Operation & maintenance of equipment	173	178	13	86	50	5	225	1	-	**731**
26.0	Supplies & materials	64	15	10	51	15	-	13	-	-	**168**
31.0	Equipment	444	20	15	160	39	2	153	4	2	**839**
32.0	Land & structures	54	13	1	1	7	-	35	181	-	**292**
41.0	Grants, subsidies, & contributions	39	45	90	1,027	67	125	40	-	-	**1,433**
42.0	Insurance claims and indemnities	-	-	-	-	-	-	-	-	-	**-**
	Other Object Classes	**7,401**	**4,059**	**1,242**	**7,732**	**696**	**150**	**1,860**	**454**	**9**	**23,603**
	NASA Total, Direct	**7,971**	**4,535**	**1,392**	**8,261**	**996**	**158**	**3,369**	**454**	**50**	**27,186**

**Totals may not add due to rounding.*

NOTE: The table only reflects the FY 2024 request and does not include remaining funding from previous direct or supplemental appropriations.

STATUS OF UNOBLIGATED FUNDS

The table below displays actual and estimated unobligated balances of direct and reimbursable budget authority in each NASA account at the end of each fiscal year.

END OF YEAR UNOBLIGATED FUNDS SUMMARY BY APPROPRIATIONS ACCOUNT

Budget Authority ($ millions)	Unobligated Balances Sept. 30, 2022	Estimated Unobligated Balances Sept. 30, 2023	Estimated Unobligated Balances Sept. 30, 2024
Deep Space Exploration Systems	223	356	489
Space Technology	23	53	83
Space Operations	183	387	591
Science	718	775	832
Aeronautics	30	42	54
STEM Engagement	12	14	16
Safety, Security, and Mission Services	900	900	900
Construction and Environmental Compliance and Restoration	359	548	548
Working Capital Fund	42	1	12
Science, Space, and Technology Education Trust Fund	3	-	-
Total NASA	**2,493**	**3,076**	**3,525**

**Totals may not add due to rounding.*

REIMBURSABLE ESTIMATES

Reimbursable agreements are agreements where the NASA costs associated with the undertaking are borne by the non-NASA partner. NASA undertakes reimbursable agreements when it has equipment, facilities, and services that it can make available to others in a manner that does not interfere with NASA mission requirements. Reimbursable agreements are executed under various legal authorities, including:

1. National Aeronautics and Space Act of 1958, as amended [P.L. 85–568] - Space Act Agreements (SAAs) and Enhanced Use Leasing (EUL) authority [incorporated through P.L. 117-328.
2. Commercial Space Launch Act [P.L. 98-575] – authority to outsource the use of its launching facilities and services to private companies.
3. National Historic Preservation Act (NHPA) [P.L. 89-665] – leasing authority for historic property.
4. Government Employees Training Act [P. L. 85-507] – authority to conduct employee training for other Government organizations.
5. Economy Act [P.L. 31–15359] – authority for agencies to obtain supplies or services from another agency.

The agreements are transacted in three accounts (i.e., SSMS, CECR, and OIG). Most of the work is managed by a specific NASA center and performed by the relevant mission directorate or office program at the center (i.e., Aeronautics, Exploration Systems Development, Space Operations, Space Technology, Mission Support, Office of STEM Engagement, and Office of Inspector General). Examples include the use of NASA-operated wind tunnel test facilities and rocket test stand facilities by other Government agencies or private sector users. Some larger agreements and those that involve multiple centers or mission directorates are managed by NASA Headquarters. For example, NASA serves as the acquisition agent for the *Geostationary Operational Environmental Satellites* series of satellites operated by the National Oceanographic and Atmospheric Administration.

The table below presents the budget authority for NASA's reimbursable work. As most reimbursable requests to NASA do not occur until the year of execution, the FY 2023 and FY 2024 estimates are based on anticipated reimbursable agreements reported by NASA centers and Headquarters units.

REIMBURSABLE BUDGET AUTHORITY BY APPROPRIATIONS ACCOUNT

($ millions)	Actual FY 2022	Estimate FY 2023	Request FY 2024
Safety, Security, and Mission Services (including NHPA)	1,461	2,554	2,336
Construction and Environmental Compliance and Restoration (including EUL)	20	30	30
Office of Inspector General	1	1	1
Total	**1,482**	**2,585**	**2,367**

ENHANCED USE LEASING

In 2003, Congress authorized NASA to enter into leasing arrangements at two centers. In 2007 and 2008, Congress expanded that authority such that NASA may enter into Enhanced Use Leasing (EUL) arrangements at all centers. EUL revenues help NASA maintain critical facilities and address deferred maintenance challenges as well as support centers' revitalization plans. Additionally, NASA's EUL authority supports important relationships with industry, academia, and non-profit organizations.

NASA's EUL authority expired without an extension on December 31, 2021, pursuant to the "sunset" provision in 51 U.S.C. 20145(g). However, Title III of Division B of the FY 2023 Omnibus Appropriations Act extends the existing EUL authority through December 31, 2032.

After deducting the costs of administering the leases, NASA centers are permitted to retain 65 percent of net receipt revenue. The balances are made available to NASA for use Agency-wide. These funds are in addition to annual appropriations. The table below depicts the estimated FY 2024 EUL expenses and revenues. The amounts identified under Capital Asset Account Expenditures may be adjusted between projects listed based on actual contract award. There are no civil servants funded from EUL income.

SUMMARY OF PROJECTED FY 2024 EUL ACTIVITY

FY2024 EUL Expenses and Revenues ($ Thousands)	ARC	GRC	GSFC	JPL(NMO)	MSFC	SSC	KSC	JSC	Agency	Total
Base Rent	10,973.4	52.2	51.8	109.0	8,424.0	1,059.0	8,655.1	1,228.2	1,500.0	32,052.7
Institutional Support Income	661.2		7.4		313.0	116.0	1,584.8	78.6		2,761.0
Additional Reimbursable Demand Services Requested by Lessees (including overhead)	3,667.4					15.0	3,625.3	20.0	300.0	7,627.8
Total Lease Income (N + E Funds Lease Project Code) - Program Year 2024	**15,302.0**	**52.2**	**59.2**	**109.0**	**8,737.0**	**1,190.0**	**13,865.3**	**1,326.8**	**1,800.0**	**42,441.4**
Institutional Support Costs	-661.2		-7.4		-313.0	-186.0	-1,584.8	-78.6	0.0	-2,831.0
Lease Management and Administration	-1,715.0	-6.5		-22.0	-6,264.0				0.0	-8,007.5
Tenant Building Maintenance and Repair	-455.0	-11.2							0.0	-466.2
Cost to Fulfill Reimbursable Demand Services (including overhead)	-3,667.4	0.0	0.0	0.0	0.0	-15.0	-3,625.3	-20.0	-1,300.0	-8,627.8
Total Cost Associated with Leases (N Fund) - Program Year 2024	**-6,498.6**	**-17.8**	**-7.4**	**-22.0**	**-6,577.0**	**-201.0**	**-5,210.2**	**-98.6**	**-1,300.0**	**-19,932.5**
Net Revenue from Lease Activity (E Fund) - Program Year 2024	**8,803.4**	**34.4**	**51.8**	**87.0**	**2,160.0**	**989.0**	**8,655.1**	**1,228.2**	**500.0**	**22,508.9**
Projected Balance, Capital Asset Account - Prior Program Years	**4,370.0**	**150.5**	**10.3**	**280.6**	**1,311.2**	**0.0**	**4,092.0**	**6.0**	**4,228.2**	**14,448.8**
Net Revenue from Lease Activity Retained at Center - Program Year 2024	**5,722.2**	**22.4**	**33.7**	**56.6**	**1,404.0**	**642.9**	**5,625.8**	**798.3**	**7,703.1**	**22,009.0**
Total Available, Capital Assest Account - All Program Years	**5,722.2**	**247.6**	**44.0**	**337.2**	**2,715.2**	**642.9**	**9,717.4**	**798.3**	**11,931.3**	**32,156.1**
Planned Maintenance, Various Buildings	-5,722.2		-33.0			-642.9	-7,500.0			-13,898.1
Energy and Sustainability Upgrades, Various Buildings (Various Centers)									-8,300.0	-8,300.0
Capital Asset Account (OSI Project Codes)	**-5,722.2**	**0.0**	**-33.0**	**0.0**	**0.0**	**-642.9**	**-7,500.0**	**0.0**	**-8,300.0**	**-22,198.1**
Ending Balance	**0.0**	**247.6**	**11.0**	**337.2**	**2,715.2**	**0.0**	**2,217.4**	**798.3**	**3,631.3**	**9,958.0**
In Kind Activity	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

ENHANCED USE LEASING

DEFINITIONS

Base Rent

Revenue collected from the tenant for rent of land or buildings lease.

Institutional Support Costs

Cost for institutional shared services, such as fire, security, first responder, communications, common grounds, road, and infrastructure maintenance, as well as routine administrative support and management oversight (e.g., environmental).

Total Lease Income

Total gross proceeds from EUL activities including expenses due to renting NASA property.

In-Kind Activity

Consideration accepted in lieu of rent payment (only applies to selected leases signed prior to January 1, 2009).

Reimbursable Demand Services

Services such as janitorial, communications, and maintenance that solely benefit the tenant and are provided for their convenience. There is no net income received by NASA, as these payments may only cover the costs of NASA and its vendors providing these services.

NATIONAL HISTORIC PRESERVATION ACT

The National Historic Preservation Act (NHPA) 54 U.S.C. §306121-306122 provides that:

[(a) Notwithstanding any other provision of law, any Federal agency after consultation with the Council [the Advisory Council on Historic Preservation], shall, to the extent practicable, establish and implement alternatives for historic properties, including adaptive use, that are not needed for current or projected agency purposes, and may lease an historic property owned by the agency to any person or organization, or exchange any property owned by the agency with comparable historic property, if the agency head determines that the lease or exchange will adequately insure the preservation of the historic property.

(b) The proceeds of any lease under subsection (a) may, notwithstanding any other provision of law, be retained by the agency entering into such lease and used to defray the costs of administration, maintenance, repair, and related expenses incurred by the agency with respect to such property or other properties which are on the National Register which are owned by, or are under the jurisdiction or control of, such agency. Any surplus proceeds from such leases shall be deposited into the Treasury of the United States at the end of the second fiscal year following the fiscal year in which such proceeds were received.

(c) The head of any Federal agency having responsibility for the management of any historic property may, after consultation with the Advisory Council on Historic Preservation, enter into contracts for the management of such property. Any such contract shall contain such terms and conditions as the head of such agency deems necessary or appropriate to protect the interests of the United States and insure adequate preservation of historic property.]

In FY 2014, NASA established a program for leasing its historic properties based upon the NHPA authorities. Funds received from historic property leases are expended for the purposes of operating, maintaining, and managing the properties, or for authorized demolition or removal of buildings. Federal workforce costs associated with executing the leasing program are funded from annual appropriations not leasing revenues.

NATIONAL HISTORIC PRESERVATION ACT

The table below depicts the estimated amounts of anticipated NHPA expenses and revenues for FY 2024 for the use of several historic properties at Ames Research Center Moffett Field, CA and Building 925 and adjacent land at the Lyndon B. Johnson Space Center Houston, TX. NASA currently expects total rental income of approximately $28.6 million. Of the $28.6 million in total rental income, approximately $7.7 million represents net revenue from lease activities. The net revenue amount of $7.7 million will be used for historic building maintenance and repairs at Ames Research Center and Johnson Space Center starting in FY 2024.

FY2024 NHPA Expenses and Revenues ($ thousands)	Ames Research Center	Johnson Space Center
Base Rent	15,500.0	1,879.8
Security Deposit (Reissue)	-	-
Institutional Support Income		428.4
Cost to Fulfill Reimbursable Demand Services	9,471.6	1,332.4
Total Rental Income (N Fund and E Fund Lease Project Code)	**24,971.6**	**3,640.6**
Institutional Support Costs	(9,106.7)	(428.4)
Security Deposit (Reissue)	-	-
Lease Management and Administration	(540.0)	-
Reimbursable Demand Services Requested by Leases	(9,471.6)	(1,332.4)
Total Cost Associated with Leases (N Fund)	**(19,118.3)**	**(1,760.8)**
Net Revenue from Lease Activity (E Fund Lease Project Code)	**5,853.4**	**1,879.8**
Unobligated Proceeds Prior Years (as of 9/30/2024)	**-**	**-**
Deferred Maintenance for Buildings 2, 10, 15, 16, 17, 19, 20, 25, 26, N200, N226, N227, N234, N238 & N243	(3,592.9)	
Section 106 Consultation with SHPO	(100.0)	
Renovate Building 20, Phase 3 of 4	(1,273.5)	
Historic Preservation of Bldg 19 Lodge Phase 3 of 3	(887.0)	
Capital Asset Account Expenditures (E Fund OSI Projects)	**(5,853.4)**	**-**
Capital Asset Account Ending Balance (E Fund OSI Projects)	**(0.0)**	**1,879.8**
In Kind Activity	**-**	

DEFINITIONS

Base Rent

Revenue collected from the tenant for rent of land or buildings.

In-Kind

Consideration accepted in lieu of rent payment.

Institutional Support Costs

Cost for institutional shared services such as fire, security, first responder, communications, common grounds, road, and infrastructure maintenance, as well as routine administrative support and management oversight (e.g., environmental).

Reimbursable Demand Services

Services such as janitorial, communications, and maintenance that solely benefit the tenant and are provided for their convenience. There is no net income received by NASA, as these payments may only cover the costs of NASA and its vendors providing these services.

Total Rental Income

Total gross proceeds from NHPA activities including expenses due to renting NASA property.

BUDGET FOR SAFETY OVERSIGHT

The following table provides the safety oversight budget request. This includes the Agency-wide surveillance functions as well as the project specific safety, reliability, maintainability, and quality assurance elements embedded within individual projects. NASA does not have a single safety oversight budget line item, but instead amounts are embedded in program, project, and mission support budgets.

BUDGET SUMMARY FOR SAFETY OVERSIGHT

	Actual	Estimate	Request
Budget Authority ($ millions)	**FY 2022**	**FY 2023**	**FY 2024**
Safety and Mission Assurance	48.8	51.9	53.8
Institutional Operational Safety	37.5	37.9	39.7
SMA Technical Authority	49.9	53.1	56.6
Agency-Wide Safety Oversight	**$136.2**	**$142.9**	**$150.1**
Program Specific*	**$300.0**	**$300.0**	**$300.0**
NASA Total, Safety**	**$436.2**	**$442.9**	**$450.1**

** Estimated values*

***Totals may not add due to rounding*

Agency-Wide Safety Oversight – Agency-level programs and activities that support the overarching NASA Safety and Mission Success program.

Safety and Mission Assurance – The Safety and Mission Assurance (S&MA) program administers and refines the pertinent policies, procedural requirements, and technical safety standards. The program participates in forums that provide advice to the Administrator, Mission Directorates, Program Managers, and Center Directors who are ultimately accountable for the safety and mission success of all NASA programs, projects, and operations. The program's policy focuses on protecting the public, workforce, high-value property, and the terrestrial, orbital, and planetary environments from potential harm; assuring crew safety and mission success; and cultivating a robust Safety Culture that values and pursues technical and organizational excellence to understand and reduce risk. Notable S&MA managed programs include but are not limited to, NASA's Orbital Debris program (measurements and modeling of orbital debris; characterizing the debris environment; mitigation standards development and review), the NASA Safety Center's S&MA Technical Excellence Program and NASA's Electronic Parts Program. The budget for the Safety and Mission Assurance is part of the Agency Technical Authority (ATA) program under the Safety, Security, and Mission Services (SSMS) mission account.

Institutional Safety – NASA's Institutional Operational Safety program is driven by 29 CFR 1960, Basic Program Elements for Federal Employee Occupational Safety and Health Programs and Related Matters, NASA Procedural Requirement (NPR) 8715.1A, NASA Occupational Safety and Health Programs, and NPR 7900.3, Aircraft Operations Management Manual. The program includes: risk management, safety training, safety awareness, construction safety, the voluntary protection program, safety metrics and trend analysis, contractor insight/oversight, support to safety boards and committees, support to the emergency preparedness and fire safety programs, aviation safety, explosives and propellants safety, nuclear safety, radiation safety, confined space entry, fall protection, lifting devices, pressure vessel safety, hazard reporting and abatement systems, cryogenic safety, electrical safety requirements (lock out/tag out), facility systems safety, institutional safety policy development, visitor and public safety, institutional safety engineering, and a mishap prevention program including a reporting system and investigations. The Institutional Operational Safety program requires significant Federal, State, and local coordination. The budget for Institutional Operational Safety is part of the Center Engineering, Safety, and Operations (CESO) program under the SSMS mission account.

S&MA Technical Authority – S&MA Technical Authority provides independent oversight of programs and projects in support of safety and mission success and is a key part of NASA's overall system of checks and balances. The S&MA Technical Authority program includes travel and labor only for all S&MA supervisors, branch chiefs or above and designated deputies. In addition, where the principal job function of a non-supervisory S&MA person consists of rendering authoritative decisions on S&MA matters relating to the design or operation of a program or project, that person's salary is included. Often, these positions are the lead S&MA managers for large programs where the decision-making process is nearly a full-time demand. This category does not include salaries for individuals who only occasionally work on an authority task; however, the program budget does include travel funds in direct support of these tasks when needed. The budget for S&MA Technical Authority is part of the CESO program under the SSMS mission account.

Program Specific – Program specific S&MA costs are included in individual project budgets and are reflected in the table above using a rough order of magnitude estimate. These costs include the technical and management efforts of directing and controlling the safety and mission assurance elements of the project. This incorporates the design, development, review, and verification of practices and procedures and mission success criteria intended to assure that the delivered spacecraft, ground system, mission operation, or payload meets performance requirements and function for their intended lifetimes.

BUDGET FOR PUBLIC RELATIONS

The NASA budget for Communications is funded within the Safety, Security, and Mission Services account under Mission Services & Capabilities, Mission Enabling Services. These program activities include strategic planning and coordination to ensure the consistency of information disseminated to the public through the news media, digital interfaces, and NASA websites. The content supports inherently governmental and external communications; public inquiries; NASA TV; the nasa.gov portal (see: http://www.nasa.gov); Freedom of Information Act requests; history, libraries services, archival, and artifact management; public affairs/public relations; center newsletters; guest operations (including bus transportation); and other multimedia support.

NASA Communications Budget Summary, by Center

	Actual	Estimate	Request
Budget Authority (in $ millions)	FY 2022	FY 2023	FY 2024
ARC	3.5	3.5	4.5
AFRC	1.7	1.8	1.9
GRC	4.2	4.3	4.9
GSFC	5.9	5.8	7.9
HQ	14.6	16	26.9
JSC	10.9	11	5.4
JPL	0.1	0.1	0.0
KSC	11.5	9.9	10.3
LARC	2.4	2.7	3.3
MSFC	4.6	5.4	5.4
SSC	1.9	1.9	1.9
NASA Total *	61.3	62.4	72.4

The above chart represents the Office of Communications budget that is funded from the Safety, Security, and Mission Services account. Enterprise resources (HQ) are disbursed to Center locations based on annual requirement during year of execution.

**Totals may not add due to rounding.*

CONSULTING SERVICES

NASA uses paid experts and consultants to provide advice and expertise beyond that which is available from its in-house civil service workforce. Management controls ensure that there is ample justification for consulting services before these services are obtained. Much of the Agency's expert and consultant support is for the NASA Advisory Council and the Aerospace Safety Advisory Panel. NASA uses experts and consultants to provide expertise on the selection of experiments for future space missions. The use of these experts and consultants provides the Agency with an independent view that promotes the selection of experiments likely to have the greatest scientific merit. Other individuals provide independent views of technical and functional problems to offer senior management a wide range of information to support decision-making. Historically, each mission directorate engages a few consultants to primarily support programmatic and Aerospace Safety Advisory Panel issues.

NASA CONSULTING SERVICES BUDGET SUMMARY

	Actual	Estimate	Request
(Cost in $ millions)	FY 2022	FY 2023	FY 2024
Number of Paid Experts and Consultants	37	37	37
Salaries	$1.1	$1.1	$1.1
Benefits Costs	$0.1	$0.1	$0.1
Travel Costs	$0.2	$0.2	$0.2
Total Costs	**$1.4**	**$1.4**	**$1.4**

FY 2022 are actual obligations. FY 2023 and FY 2024 are estimated Budget Authority

A broader definition of consulting services could include the total of the Advisory and Assistance Services object class as shown in the Supporting Data - Budget by Object Class section of this volume. Advisory and Assistance Services includes: (1) Quality Control, Testing, & Inspection Services; (2) Management and Professional Support Services; (3) Studies, Analysis, & Evaluations; (4) Engineering and Technical Services; and (5) IT Services.

	Actual	Estimate	Request
(Cost in $ millions)	FY 2022	FY 2023	FY 2024
Quality Control, Testing & Inspection Services	$55.9	$55.3	$61.8
Management and Professional Support Services	$747.0	$738.4	$825.2
Studies, Analysis, & Evaluations	$77.9	$77.0	$86.0
Engineering and Technical Services	$10.1	$10.0	$11.2
IT Services	$245.1	$242.3	$270.8
Total Costs, Advisory & Assistance Services	**$1,136.0**	**$1,123.0**	**$1,255.0**

CONSULTING SERVICES

DEFINITIONS

Consultant - A person who can provide valuable and pertinent advice generally drawn from a high degree of broad administrative, professional, or technical knowledge or experience. When an agency requires public advisory participation, a consultant also may be a person who is affected by a particular program and can provide useful views from personal experience.

Expert - A person who is specially qualified by education and experience to perform difficult and challenging tasks in a particular field beyond the usual range of achievement of competent persons in that field. An expert is regarded by other persons in the field as an authority or practitioner of unusual competence and skill in a professional, scientific, technical, or other activity.

These definitions are located under 5 CFR 304.102. The appointments are made under 5 U.S.C. 3109, and the use of this authority is reported to Office of Personnel Management (OPM).

E-GOV INITIATIVES AND BENEFITS

E-GOVERNMENT FUNDING CONTRIBUTIONS AND SERVICE FEES BY INITIATIVE

NASA will provide funding contributions in FY 2024 for each of the following E-Government initiatives:

Initiative	2024 Contributions (Includes In- Kind) ($ In Dollars)	2024 Service Fees* ($ In Dollars)
E-Rulemaking	-	11,287
Grants.gov	126,000	-
E-Training	-	1,583,625
Recruitment One-Stop	-	129,375
Enterprise HR Integration	-	357,500
E-Payroll	-	$5,359,290
E-Travel	-	89,520
Integrated Award Environment (IAE)	-	649,723
Financial Management LoB	124,236	-
Human Resources Management LoB	68,478	-
Geospatial LoB	225,000	-
Budget Formulation and Execution LoB**	120,000	-
Federal PKI Bridge	-	207,071
		-
Unique Entity Identifier Implementation (UEI)	328,572	-
NASA Total	**992,376**	**8,387,391**

**Service fees are estimates as provided by the E-Government initiative Managing Partners*

***Final FY 2024 commitments have yet to be finalized by Managing Partners (OMB MAX)*

After submission of the budget, NASA will post FY 2024 Exhibit 300 IT business cases on the IT Dashboard located at: https://www.itdashboard.gov

The E-Government initiatives serve citizens, businesses, and Federal employees by delivering high-quality services more efficiently at a lower price. Instead of expensive “stove-piped” operations, agencies work together to develop common solutions that achieve mission requirements at a reduced cost, which makes resources available for higher priority needs. Benefits realized by NASA through these initiatives in FY 2024 are described below:

e-Rulemaking (Managing Partner EPA) FY 2024 Benefits

NASA has benefited from the e-Rulemaking initiative by being able to better provide the public with one-stop access to the Agency’s information on rulemakings and non-rulemaking activities via the Regulations.gov website (see: https://www.regulations.gov/).

NASA uses the Federal Docket Management System (FDMS) to post its rulemakings allowing the public to gain access to review and comment on these rulemakings. NASA relies on Regulations.gov to retrieve public comments on its rulemakings. NASA’s use of the FDMS and Regulations.gov substantially improves the transparency of its rulemaking actions and increases public participation in the regulatory process. Direct budget cost savings and cost avoidance has resulted from the FDMS and Regulations.gov.

Grants.gov (Managing Partner HHS) FY 2024 Benefits

In addition to the Federal requirement for all grant-issuing agencies to, at a minimum, post a synopsis of all new grant and cooperative agreement funding opportunities to Grants.gov (see: https://www.grants.gov/), the Grants.gov initiative benefits NASA and its grant programs by providing a single location with broader exposure to publish grant and cooperative agreement funding opportunities and application packages. Posting internally, NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES), as well as externally (Grants.gov), makes the process easier for applicants to apply for funding with multiple agencies. All 26 major Federal grant-making agencies post 100 percent of their synopses for discretionary funding opportunity announcements on Grants.gov.

In addition, Grants.gov provides a single site for the grantee community to apply for grants using a standard set of forms, processes, and systems. This gives grantees greater access and ability to apply for Federal funding. Through the continued use of Grants.gov, NASA can reduce operating costs associated with online grant posting and application evaluation. Additionally, the Agency is able to improve operational effectiveness through the use of Grants.gov by increasing data accuracy and reducing processing cycle times.

e-Training (Managing Partner OPM) FY 2024 Benefits

The e-Training initiative provides access to premier electronic training systems and tools that support the training and development of the Federal workforce. The initiative supports Agency missions through efficient one-stop access to e-Training products and services. The availability of an electronic training environment enhances the ability of the Federal Government and NASA to attract, retain, manage, and develop highly skilled professionals needed for a flexible and high-performing Government workforce.

The e-Training initiative benefits NASA by reducing redundancies and achieving economies of scale in the purchase, development, and deployment of e-learning content and in the management of learning technology infrastructure. This initiative also allows NASA to remain in a positive security posture since access to applications are based upon required training being completion and real-time integrations with our identity and credential access management systems. The System for Administration, Training, and Educational Resources at NASA (SATERN) is a web-based talent management tool that serves as NASA’s training system of record for over 100,000 active civil servants and contractor accounts tracked within the system. This centralized approach allows NASA to reduce and leverage training costs by eliminating unique systems, standardizing training processes, and maintain valid data across the Agency. In 2018, NASA migrated SATERN to a software as a service (SaaS) cloud hosted solution.

Through SATERN, employees can view required training, launch online content, view training history, and self-register for approved courses and conferences. In addition, the system allows NASA officials to identify groups and individuals who have not met basic training requirements and ensure accountability for mission-critical and Federally mandated training and development. SATERN also offers employees access to career planning tools, individual development plans, and competency management assistance.

Currently, SATERN offers learners access to almost 3,000 online courses and more than 10,000 online courses, books, and training videos via our partnership with SkillSoft and /or Percipio. We are also working with other entity partnerships to enhance the overall learning experience and provide more learning opportunities. SATERN is available at all times and can be accessed from work, home or via approved mobile devices.

Recruitment One-Stop (Managing Partner OPM) FY 2024 Benefits

USAJOBS simplifies the Federal Job Search Process for Job Seekers and Agencies. The USAJOBS.gov website (see: https://www.usajobs.gov/) provides a place where citizens can search for employment opportunities throughout the Federal Government. USAJOBS is a fully operational, state-of-the-art recruitment system that simplifies the Federal job search process for job-seekers and agencies. Through USAJOBS.gov users have access to:

- A centralized repository for all competitive service job vacancies;
- Job vacancies;
- A resume repository used by agencies to identify critical skills;
- A standardized online recruitment tool and services;
- A standard application process; and
- Intuitive job searches including e-mail notifications for jobs of interest.

Integration with Recruitment One-Stop allows NASA to better attract individuals who can accomplish the Agency's mission. The USAJOBS interface allows job-seekers to view and apply for all NASA employment opportunities, as well as those from other Federal agencies.

In 2005, NASA adopted the USAJOBS resume as the basic application document for all NASA positions, except for astronaut positions. To date, NASA has not identified any specific savings, either in terms of budgeted savings or cost avoidance. Although the Agency believes that implementation of Recruitment One-Stop has resulted in significant intangible benefits in terms of providing better vacancy information to applicants, it has not resulted in any specific cost savings to NASA. The numerous intangible benefits Recruitment One-Stop provides to NASA and other agencies include:

- Decreasing hiring time for managers;
- Providing an integrated solution to Agency applicant assessment systems;
- Providing a cost-effective marketing and recruitment tool;
- Realizing cost savings over commercial job posting boards;
- Reducing the delay associated with filling critical Agency vacancies; and
- Enhancing competition with the private sector for the best and brightest talent for Federal service.

Enterprise HR Integration (Managing Partner OPM) FY 2024 Benefits

The Enterprise HR Integration (EHRI) Program supports the strategic management of human capital by providing Agency customers access to timely and accurate Federal workforce data. In support of this objective, EHRI has the following goals: 1) Streamline and automate the exchange of Federal employee human resources (HR) information Government wide; 2) Provide comprehensive knowledge management and workforce analysis, forecasting, and reporting across the Executive Branch; 3) Maximize cost savings captured through automation; and 4) Enhance retirement processing throughout Executive Branch.

A key initiative of EHRI is the electronic Official Personnel Folder (eOPF), a web-based application capable of storing, processing, and displaying the OPFs of all current, separated, and retired Federal

Employees. Specific EHRI/eOPF benefits to NASA include improved convenience in searching for information, better security and safety for electronic files, decreased costs, streamlined business processes, and the ability to have a central repository of OPF records for the Agency. NASA deployed the eOPF capability of electronic transfer of eOPFs between agencies in FY 2010. Specific NASA employee benefits include secure online access to OPFs, automatic notification when documents are added, exchange of retirement and HR data across agencies and systems, and the elimination of duplicate and repetitive personnel data in personnel folders. NASA completed its implementation to eOPF in March 2008, and transitioned personnel actions processing to the NASA Shared Service Center.

E-Payroll FY 2024 Benefits

The E-Payroll Initiative standardizes and consolidates Government-wide Federal civilian payroll services and processes by simplifying and standardizing HR/payroll policies and procedures and better integrating payroll, HR, and finance functions. Since 2004, the Department of Interior (DOI) has served as NASA's payroll provider. DOI’s system (Federal Personnel and Payroll System [FPPS]) processes NASA's HR and Payroll transactions and supplies all key delivery aspects of its payroll operation functions. The E-Payroll Initiative benefits NASA by permitting the Agency to focus on its mission-related activities rather than on administrative payroll functions. Payroll processing costs are reduced through economies of scale and avoiding the cost of duplicative capital system modernization activities. The initiative also promotes standardization of business processes and practices and unified service delivery. NASA continues to work closely with DOI to pilot innovative solutions such as Robotic Process Automation to realize cost savings and more modern data connections to more reliably exchange our HR data.

E-Travel (Managing Partner GSA) FY 2024 Benefits

NASA completed migration of its travel services to Electronic Government Travel System 2 (ETS2) - Concur Government Edition (CGE) (formerly HP Enterprise Services [FedTraveler]). Completed in 2014, this migration has allowed NASA to provide more efficient and effective travel management services. ETS2 is a streamlined, adaptable, world-class travel management service that continually applies commercial best practices to realize travel efficiencies and deliver a transparent, accountable, and sustainable service that yields exceptional customer satisfaction.

Integrated Award Environment (Managing Partner GSA) FY 2024 Benefits

The Integrated Award Environment (IAE) initiative is designed to support a common, secure business environment which facilitates and supports the cost-effective acquisition of and payment for goods and services; effective management of Federal acquisition and assistance awards; and consistent transparency into Federal awards. The IAE services enable NASA to do business with industry, whether it is through contracts, grants or loans, in a smart, streamlined, shared services platform. Services range from entity management, pre-award, post award, and common services (e.g., data governance, security, hosting, help desk, single sign-on, and search). Use of the IAE common services allows agencies to focus on specific needs (e.g., strategy, operations, and management), while leveraging shared services for common functions. Furthermore, use of a Government-wide business focused service environment reduces funding and resources for technical services and support for acquisition systems originally housed by individual agencies.

Through adoption of the tools and services provided by IAE, NASA improves its ability to make informed and efficient purchasing decisions and allows it to replace manual processes. If NASA did not use IAE systems, the Agency would need to build and maintain separate systems to record vendor and contract information and to post procurement opportunities. Agency purchasing officials would not have access to databases of important information from other agencies on vendor performance and could not use systems to replace paper-based and labor-intensive work efforts.

Integrated Award and Environment – Loans & Grants FY 2024 Benefits

All agencies participating in the posting and/or awarding of Contracts and Loans & Grants are required by the Federal Funding Accountability and Transparency Act (FFATA) of 2006 and the Digital Accountability and Transparency Act of 2014 (DATA Act) reporting requirements to disclose award information on a publicly accessible website. On December 14, 2007, OMB launched USASpending.gov (see: http://www.USASpending.gov) to meet the FFATA statutory requirements. NASA analyzes the past and present total funding amounts of each proposing entity, as well as its total number of awards to assist in assessing each grant proposer's risk level and score during the 2 Code of Federal Regulations (CFR) 200 required pre-award risk assessment process. This information is submitted and housed in USASpending.gov by funding agency. Understanding the total dollar amounts managed and the number of awards provides insight on a proposer's experience with managing Federal funds.

Federal PKI Bridge - FY 2024 Benefits

The Federal Public Key Infrastructure (FPKI) is the primary, secure mechanism that allows for electronic business transactions across Government and between Government and industry. It is the backbone and trust anchor for HSPD-12 and PIV cards and is critical to enabling cyber security via identity management. The FPKI enables secure physical and logical access using strong credentials, such as the PIV card, and allows NASA documents to be digitally signed, sent, encrypted, and archived in digital media without fear that they will be compromised, spoofed, or altered. A number of core Government-wide documents mandate NASA's use of the FPKI.

LINES OF BUSINESS

Financial Management LoB (Managing Partners DOE and DOL) FY 2024 Benefits

NASA's contribution to the FM Line of Business (LoB) supports efforts to transform Federal financial management, reduce costs, increase transparency, and improve delivery of agencies' missions by operating at scale, relying on common standards, shared services, and using state-of-the-art technology. NASA benefits from the FM LoB because it provides a forum in which Federal agencies can share information and weigh pros and cons of various initiatives (e.g., shared services). A shared services solution may be an alternative considered by NASA as part of its financial system improvements.

Human Resources Management LoB (Managing Partner OPM) FY 2024 Benefits

The HR LoB vision is to create Government-wide, modern, cost-effective, standardized, and interoperable HR solutions to provide common core functionality to support the strategic management of Human Resources through the establishment of Shared Service Centers (SSCs). NASA works in partnership with one of the approved service providers, the Department of Interior's Business Center (IBC). Through this partnership, NASA shares and receives "best-in-class" HR solutions. The IBC delivers NASA-developed solutions to their customer agencies, enabling improved efficiencies and system integrations at a fraction of the cost and delivery time of similar solutions that could have been produced by the Interior Business Center. NASA achieves the benefits of "best- in-class" HR solutions through the implementation and integration of IBC and NASA-developed HR solutions. NASA's participation in the HR LoB provides the Agency opportunities to implement modern HR solutions and benefit from Government-wide strategic HR management best practices. NASA participates in the ongoing development of a 10-year Federal Human Resources Strategic Plan and Government-wide data standards with the HR LoB managing partner (OPM) and member agencies.

Geospatial LoB (Managing Partner DOI) FY 2024 Benefits

The Geospatial LoB was sunset when OMB released the Federal IT Shared Services Strategy in 2012. However, NASA continues to be active in the Federal Geographic Data Committee (FGDC) and supports FGDC standards wherever applicable. NASA also continues to provide support and data to the Geoplatform and supports three National Geospatial Data Assets in partnership with USGS.

Budget Formulation & Execution LOB (Managing Partner Education) FY 2024 Benefits

The Budget Formulation and Execution LoB (BFELoB) provides significant benefits to NASA and other partner agencies by encouraging best practices crossing all aspects of Federal budgeting – from budget formulation and execution to performance to human capital needs. To benefit all agencies, BFELoB continues to support the idea of shared service budget systems. As NASA currently has its own budgeting tools, the Agency has not chosen to move to a new budget system; however, a shared service budget system is an option in the future.

COMPARABILITY ADJUSTMENT TABLES

FY 2022 Budget Structure Crosswalk to FY 2024 Budget Structure Budget Authority ($ in millions)	FY 2022 Structure	FY 2024 Structure
NASA TOTAL	**$24,801.5**	**$24,801.5**
Deep Space Exploration Systems	**$6,880.4**	**$6,750.2**
Exploration Systems Development - renamed Common Exploration Systems Development	**$4,483.7**	**$4,483.7**
Exploration Research & Development - renamed Artemis Campaign Development	**$2,396.7**	**$2,062.0**
Advanced Exploration Systems	$195.0	
Gateway	$785.0	$685.0
Gateway	*$785.0*	*$685.0*
xEVA Surface Suits	$100.0	
Adv Cislunar and Surface Capabilities	$91.5	$82.0
Adv Cislunar and Surface Capabilities	*$91.5*	*$82.0*
Moon and Mars Architecture	$9.5	
Human Research Program	$130.2	
xEVA and Human Surface Mobility Program		$100.0
xEVA and Surface Mobility		*$100.0*
xEVA Surface Suits		$100.0
Human Landing System	$1,195.0	$1,195.0
Mars Campaign Development		**$195.0**
Exploration Capabilities		$195.0
Advanced Exploration Systems		*$195.0*
Human Exp Requirements & Architecture		**$9.5**
Moon & Mars Architecture		$9.5
Moon & Mars Arhitecture		*$9.5*
Moon and Mars Architecture		$9.5
Space Technology	**$1,425.0**	**$1,425.0**
Space Operations	**$4,017.4**	**$4,147.6**
International Space Station	**$1,327.6**	**$1,327.6**
Space Transportation	**$1,771.7**	**$1,770.2**
Crew and Cargo Program	$1,617.2	$1,617.2
Commercial Crew Program	$154.5	$153.0
Commercial Crew	*$154.5*	*$153.0*
Commercial Space Capabilities	$1.5	
Space and Flight Support (SFS)	**$817.0**	**$947.2**
Space Communications and Navigation	$522.6	$522.6
Human Space Flight Operations	$101.8	$101.8
Launch Services	$102.7	$102.7
Rocket Propulsion Test	$47.8	$47.8
Communications Services Program	$42.0	$42.0
Human Research Program		$130.2
Commercial LEO Development	**$101.1**	**$102.6**
Commercial LEO Development Program	$101.1	$102.6
Commercial LEO Development	*$101.1*	*$102.6*
Commercial Space Capabilities		$1.5
Science	**$7,931.4**	**$7,931.4**
Earth Science	**$2,250.0**	**$2,250.0**
Earth Science Research	$537.5	$537.5
Earth Systematic Missions	$836.1	$836.1
Surface Water and Ocean Topography	*$32.8*	
NASA-ISRO SAR	*$73.3*	*$73.3*
Landsat 9	*$2.8*	
Sentinel-6	*$22.8*	*$22.8*
PACE	*$119.4*	*$119.4*
Other Missions and Data Analysis	*$585.0*	*$620.6*
Surface Water and Ocean Topography Missi		$32.8
Landsat 9		$2.8

COMPARABILITY ADJUSTMENT TABLES

FY 2022 Budget Structure Crosswalk to FY 2024 Budget Structure Budget Authority ($ in millions)	FY 2022 Structure	FY 2024 Structure
Earth System Explorers	$6.6	$6.6
Earth System Science Pathfinder	$375.3	$375.3
GeoCarb		*$57.2*
Venture Class Missions	*$326.9*	*$269.7*
GeoCarb	$57.2	
Other Missions and Data Analysis	*$48.4*	*$48.4*
Earth Science Data Systems	$330.7	$330.7
Earth Science Technology	$91.1	$91.1
Applied Sciences	$72.7	$72.7
Planetary Science	**$3,200.0**	**$3,200.0**
Planetary Science Research	$306.9	$306.9
Planetary Defense	$197.2	$197.2
NEO Surveyor		*$143.2*
DART	*$11.1*	
Other Missions and Data Analysis	*$186.1*	*$54.0*
Double Asteroid Redirection Test		$11.1
Near Earth Objects Surveyor	$143.2	
Lunar Discovery and Exploration	$497.3	$497.3
Mars Sample Return	$653.2	$653.2
Discovery	$364.8	$364.8
Lucy	*$77.3*	
Psyche	*$139.7*	*$139.7*
Other Missions and Data Analysis	*$147.8*	*$225.0*
Lucy		$77.3
New Frontiers	$271.7	$271.7
Mars Exploration	$267.8	$267.8
Outer Planets and Ocean Worlds	$494.8	$494.8
Radioisotope Power	$146.4	$146.4
Astrophysics	**$1,400.2**	**$1,400.2**
Astrophysics Research	$285.5	$285.5
Cosmic Origins	$115.0	$290.4
James Webb Space Telescope		*$175.4*
Hubble Space Telescope (HST)	*$98.3*	*$98.3*
Other Missions and Data Analysis	*$16.7*	*$16.7*
Physics of the Cosmos	$156.0	$156.0
Exoplanet Exploration	$543.3	$543.3
Astrophysics Explorer	$300.4	$300.4
Heliophysics	**$796.7**	**$796.7**
Heliophysics Research	$210.6	$210.6
Living with a Star	$115.3	$98.8
Other Missions and Data Analysis	*$115.3*	*$98.8*
Space Weather Science and Applications	$9.9	
Heliophysics Environmental & Radiation M	$6.5	
Solar Terrestrial Probes	$253.3	$253.3
Heliophysics Explorer Program	$189.2	$189.2
Heliophysics Technology	$28.3	$28.3
Space Weather		$16.5
Space Weather		*$16.5*
Space Weather Science and Applications		$9.9
Heliophysics Environmental & Radiation M		$6.5
James Webb Space Telescope	**$175.4**	
Biological and Physical Sciences	**$109.1**	**$109.1**

COMPARABILITY ADJUSTMENT TABLES

FY 2022 Budget Structure Crosswalk to FY 2024 Budget Structure Budget Authority ($ in millions)	FY 2022 Structure	FY 2024 Structure
Aeronautics	**$914.8**	**$914.8**
Airspace Operations and Safety Program	$104.5	$147.4
Airspace Operations and Safety Program	*$104.5*	*$147.4*
Advanced Air Mobility		$42.9
Advanced Air Vehicles Program	$243.7	$243.7
Aerosciences Eval. & Test Capab. Program	$117.0	$117.0
Integrated Aviation Systems Program	$301.5	$258.6
Electrified Powertrain Flight Demonstration	*$91.2*	*$91.2*
Low Boom Flight Demonstrator	*$74.6*	*$74.6*
Integrated Aviation Systems Program	*$135.7*	
Advanced Air Mobility	$42.9	
Other Projects		*$92.8*
Transformative Aero Concepts Program	$148.0	$148.0
STEM Engagement	**$147.0**	**$147.0**
Safety, Security, and Mission Services	**$3,049.2**	**$3,049.2**
Construction & Envrmtl Compl Restoration	**$390.3**	**$390.3**
Inspector General	**$46.0**	**$46.0**
NASA TOTAL	**$24,801.5**	**$24,801.5**

COMPARABILITY ADJUSTMENT TABLES

FY 2023 Budget Structure Crosswalk to FY 2024 Budget Structure Budget Authority ($ in millions)	FY 2023 Structure	FY 2024 Structure
NASA TOTAL	**$25,973.8**	**$25,973.8**
Deep Space Exploration Systems	**$7,478.3**	**$7,478.3**
Space Operations	**$4,266.3**	**$4,266.3**
Space Technology	**$1,437.9**	**$1,437.9**
Science	**$7,988.3**	**$7,988.3**
Earth Science	**$2,411.5**	**$2,411.5**
Earth Science Research	$534.9	$534.9
Earth Systematic Missions	$998.1	$998.1
Surface Water and Ocean Topography	*$47.5*	
NASA-ISRO SAR	*$58.6*	*$58.6*
Sentinel-6	*$40.3*	*$40.3*
PACE	*$112.8*	*$112.8*
Other Missions and Data Analysis	*$739.0*	*$786.5*
Surface Water and Ocean Topography Missi		$47.5
Earth System Explorers	$23.4	$23.4
Earth System Science Pathfinder	$308.4	$308.4
MAIA	*$13.1*	
GeoCarb	*$47.6*	*$47.6*
Venture Class Missions	*$194.5*	*$207.6*
Multi-Angle Imager for Aerosols		$13.1
Other Missions and Data Analysis	*$53.3*	*$53.3*
Earth Science Data Systems	$366.1	$366.1
Earth Science Technology	$102.3	$102.3
Applied Sciences	$78.2	$78.2
Planetary Science	**$3,160.2**	**$3,160.2**
Astrophysics	**$1,556.0**	**$1,556.0**
Astrophysics Research	$329.8	$329.8
Cosmic Origins	$298.5	$298.5
Physics of the Cosmos	$159.9	$159.9
Exoplanet Exploration	$522.2	$522.2
Astrophysics Explorer	$245.6	$245.6
SPHEREx	*$78.7*	*$78.7*
Compton Spectrometer and Imager (COSI)		*$51.3*
Other Missions and Data Analysis	*$166.9*	*$115.6*
Compton Spectrometer and Imager	$51.3	
Heliophysics	**$760.2**	**$760.2**
Biological and Physical Sciences	**$100.4**	**$100.4**
Aeronautics	**$971.5**	**$971.5**
STEM Engagement	**$150.1**	**$150.1**
Safety, Security, and Mission Services	**$3,208.7**	**$3,208.7**
Construction & Envrmtl Compl Restoration	**$424.3**	**$424.3**
Inspector General	**$48.4**	**$48.4**
NASA TOTAL	**$25,973.8**	**$25,973.8**

RE-BASELINED PROJECTS

FY 2024 Congressional Justification

Original Agency Baseline Commitments vs Re-baseline Life Cycle Calculation Section

As part of the NASA corrective action plan related to the Government Accountability Office (GAO) high risk list, re-baselined projects are reported periodically to Congress, GAO, and OMB. For projects that have been re-baselined due to performance (vice scope change), and for transparency purposes, NASA includes original cost and schedule Agency Baseline Commitments (ABCs) in quarterly, semi-annual, and annual external cost and schedule reports alongside the current re-baselined life-cycle costs.

Orion	Date	Prior	FY21	FY22	FY23	FY24	FY25	FY26	FY27	BTC	Total
Original Life Cycle Cost	2014	4,968	1,086	1,109	1,112	1,116	828	649	293	121	11,283
Rebaselined Life Cycle Cost	2020	11,381	970	809	404	156	92	-	-	-	13,811

On-Orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1)	Date	Prior	FY21	FY22	FY23	FY24	FY25	FY26	FY27	BTC	Total
Original Life Cycle Cost	2020	813	227	227	227	177	83	25	-	-	1,780
Rebaselined Life Cycle Cost	2022	813	227	227	227	227	175	123	29	-	2,047

Solar Electric Propulsion (SEP)	Date	Prior	FY21	FY22	FY23	FY24	FY25	FY26	FY27	BTC	Total
Original Life Cycle Cost	2014	246	49	25	9	6	-	-	-	-	335
Rebaselined Life Cycle Cost	2020	246	33	30	22	17	14	8	6	7	382

BTC: Budget To Complete

COST AND SCHEDULE PERFORMANCE SUMMARY

2023 Major Program Annual Report Summary

The 2023 Major Program Annual Report (MPAR) is provided to meet the requirements of section 103 of the NASA Authorization Act of 2005 (P.L. 109-155; 42 U.S.C. 16613). The 2023 MPAR consists of this summary and FY 2024 Congressional Justification pages designated as "Projects in Development," for the projects outlined below. These project pages constitute each project's annual report, or if this is the first year for which it is in reporting, the baseline report. The MPAR summary also includes the confidence level of achieving the commitments as requested in the Conference Report accompanying the FY 2010 Consolidated Appropriations Act (P.L. 111-117).

Changes in MPAR Composition since the FY 2023 NASA Budget Estimates

There is one new project, Near-Earth Objects (NEO) Surveyor, with an estimated lifecycle cost greater than $250 million that received authority to proceed into the development phase since NASA submitted its 2022 MPAR in the FY 2023 NASA Congressional Justification. There are seven projects that have completed reporting: Exploration Ground Systems (EGS), Space Launch System (SLS), Geostationary Carbon Cycle Observatory (GeoCarb), James Webb Space Telescope (Webb), Laser Communications Relay Demonstration (LCRD), Surface Water and Ocean Topography (SWOT), and Multi-Angle Imager for Aerosols (MAIA).

1. The NEO Surveyor project with a baseline development cost of $1,228.6 million and a joint confidence level of 86 percent.
2. EGS and SLS successfully launched the Artemis I mission on November 16, 2022.
3. GeoCarb has been cancelled with final cost estimates under review.
4. Webb successfully launched on December 25, 2021.
5. The LCRD project ended and was transitioned to the Advanced Communications Capabilities for Exploration and Science Systems (ACCESS) project in March 2022.
6. The SWOT project successfully launched on December 16, 2022.
7. MAIA's estimated cost is no longer above $250 million and is no longer considered to be subject to major program reporting.

Changes in Development Cost and Schedule Estimates from the 2022 MPAR

There are five projects that had no changes in their development cost or schedule estimates over the last year: Interstellar Mapping and Acceleration Probe (IMAP), Orion, Roman, Solar Electric Propulsion (SEP), and Spectro-Photometer for the History of the Universe, Epoch of Reionization and IcesExplorer (SPHEREx).

Three projects have been rebaselined: EGS; SLS; and On-Orbit Servicing, Assembly, and Manufacturing-1 (OSAM-1). The EGS and SLS rebaselines established a revised Launch Readiness Date (LRD) of November 2022. The OSAM-1 rebaseline established a revised development cost of $1,244.0 million and LRD of December 2026.

The Sentinel-6 project successfully launched its first spacecraft (Sentinel-6 Michael Freilich) on November 21, 2020, and this MPAR summary now includes the planned schedule for the second spacecraft launch. There are no changes to the development cost estimates in this report.

COST AND SCHEDULE PERFORMANCE SUMMARY

There are six projects with development cost increases/decreases and schedule changes.

1. Europa Clipper development costs increased by one percent with a decrease of 11 months in the schedule (i.e., LRD moved up to October 2024 from September 2025).
2. Low-Boom Flight Demonstration (LBFD) development costs increased by eight percent with a nine-month schedule delay.
3. NASA-ISRO Synthetic Aperture Radar (NISAR) development costs increased by 22 percent with a 13-month schedule delay.
    a. NASA has approved a new Life-Cycle Costs with 39 percent growth in development costs and is in the process of making the required congressional notifications.
4. Psyche development costs increased by 24 percent with a 14-month schedule delay.
5. VIPER development costs increased by 19 percent with a 12-month schedule delay.
6. PACE development costs decreased by two percent with no change to schedule.

MPAR Summary Table

Figure 1 provides cost, schedule, and confidence level information for NASA projects currently in development with lifecycle cost estimates of $250 million or more. NASA records the estimated development cost and a key schedule milestone and then measures changes from them. NASA tracks one of several key milestones, listed below, for reporting purposes:

- Initial Operating Capability (IOC);
- Full Operational Capability (FOC);
- Launch Readiness Date (LRD); or
- Launch Readiness (LR) for Artemis I or Artemis II.

As a note for clarification, LRD schedule milestones, as reported here, are not typically the launch dates on the NASA launch manifest but are the desired launch dates as determined by the payload mission and approved by the NASA Flight Planning Board (FPB). A launch manifest is a dynamic schedule that is affected by real world operational activities conducted by NASA and multiple other entities. It reflects the results of a complex process that requires the coordination and cooperation by multiple users for the use of launch range and launch contractor assets. The launch dates shown on the NASA FPB launch manifest are a mixture of confirmed range dates for missions launching within approximately six months and contractual/planning dates for the missions beyond six months from launch. The NASA FPB launch manifest date is typically earlier than the reported schedule dates reported here, thereby allowing for the operationally driven fluctuations to the launch schedule that may be outside of the project's control. The NASA FPB launch manifest is updated on a periodic basis throughout the year.

Additional information on the projects shown in the table below can be found in their individual program and project pages.

COST AND SCHEDULE PERFORMANCE SUMMARY

Figure 1: MPAR Summary and Confidence Levels

Project	Base Year	JCL (%)	Development Cost Estimate ($M)		Cost Change (%)	Key Milestone Event	Key Milestone Date		Schedule Change (months)
			Baseline	FY 2023			Baseline	FY 2023	
EGS[1]	2020	80	2,438.4	2,730.4	12%	LR for Artemis I	Nov 2021	Nov 2022	12
Europa Clipper	2020	N/A	2,412.8	2,509.0	4%	LRD	Sep 2025	Oct 2024	-11
IMAP	2022	70	589.5	589.5	0%	LRD	Dec 2025	Dec 2025	0
LBFD	2018	70	467.7	607.4	29.9%	First Flight	Jan 2022	Sep 2023	20
NEO Surveyor	2022	86	1,228.6	1,228.6	0%	LRD	Jun 2028	Jun 2028	0
NISAR	2017	70	661.0	921.1	39%	LRD	Sep 2022	Oct 2024	25
Orion[2]	2016	70	9,301.2	9,301.2	0%	LR for Artemis II	May 2024	May 2024	0
OSAM-1	2022	88	1,244.0	1,244.0	0%	LRD	Dec 2026	Dec 2026	0
PACE	2020	70	558.0	621.2	11%	LRD	Jan 2024	May 2024	4
Psyche	2020	70	681.9	813.8	19%	LRD	Aug 2022	Oct 2023	14
Roman	2021	70	2,898.1	3,270.0	13%	LRD	Oct 2026	May 2027	7
SEP[3]	2022	70	203.2	203.2	0%	AEPS Life Qual Test Report	Oct 2028	Oct 2028	0
SLS	2020	70	9,108.3	9,104.8	0%	LR for Artemis I	Nov 2021	Nov 2022	12
Sentinel-6	2017	70	465.9	402.3	-14%	LRD – Second Spacecraft	Nov 2026	Nov 2026	0
SPHEREx	2021	70	367.8	367.8	0%	LRD	Apr 2025	Apr 2025	0
VIPER	2021	70	336.2	400.1	19%	IOC	Nov 2023	Nov 2024	12

[1] The 80% Joint Cost and Schedule Confidence Level (JCL) is inferred from analysis based on FY 2014 President's Budget Request (PBR) including FY 2014 Appropriation changes. JCL analysis was completed prior to the release of the FY 2015 PBR. The Agency Baseline Commitment is informed by the 80% JCL and adjusted to reflect the FY 2015 PBR budget reduction.

COST AND SCHEDULE PERFORMANCE SUMMARY

[2] *Approximately -2% of this amount reflects a transfer of funding to formulation costs and does not represent a reduction in the life cycle cost estimates.*

[3] *Aerojet Electric Propulsion String (AEPS) Qual Test: The test demonstrates continuous long-term operation of the system sufficient to characterize and predict the capability and lifetime of the system. The report tells us what the capability is based on the results of the test.*

Launch Readiness (LR) Launch Readiness Date (LRD) Aerojet Electric Propulsion String (AEPS)

FY 2024 Proposed Appropriations Language

Deep Space Exploration Systems

For necessary expenses, not otherwise provided for, in the conduct and support of Artemis Campaign Development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $7,971,091,000, to remain available until September 30, 2025.

Space Operations

For necessary expenses, not otherwise provided for, in the conduct and support of space operations research and development activities, including research, development, operations, support and services; space flight, spacecraft control, and communications activities, including operations, production, and services; maintenance and repair, facility planning and design; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $4,534,609,000, to remain available until September 30, 2025.

Space Technology

For necessary expenses, not otherwise provided for, in the conduct and support of space technology research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $1,391,600,000, to remain available until September 30, 2025.

Science

For necessary expenses, not otherwise provided for, in the conduct and support of science research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $8,260,800,000, to remain available until September 30, 2025.

Aeronautics

For necessary expenses, not otherwise provided for, in the conduct and support of aeronautics research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $995,800,000, to remain available until September 30, 2025.

FY 2024 PROPOSED APPROPRIATIONS LANGUAGE

SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS ENGAGEMENT

For necessary expenses, not otherwise provided for, in the conduct and support of aerospace and aeronautical education research and development activities, including research, development, operations, support, and services; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $157,800,000, to remain available until September 30, 2025.

SAFETY, SECURITY, AND MISSION SERVICES

For necessary expenses, not otherwise provided for, in the conduct and support of science, aeronautics, space technology, exploration, space operations and education research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles, including zero emission passenger motor vehicles and supporting charging or fueling infrastructure; not to exceed $63,000 for official reception and representation expenses; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $3,369,400,000, to remain available until September 30, 2025.

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

For necessary expenses for construction of facilities including repair, rehabilitation, revitalization, and modification of facilities, construction of new facilities and additions to existing facilities, facility planning and design, and restoration, and acquisition or condemnation of real property, as authorized by law, and environmental compliance and restoration, $453,700,000, to remain available until September 30, 2029: Provided, That proceeds from leases deposited into this account shall be available for a period of 5 years to the extent and in amounts as provided in annual appropriations Acts: Provided further, That such proceeds referred to in the preceding proviso shall be available for obligation for fiscal year 2024 in an amount not to exceed $30,000,000: Provided further, That each annual budget request shall include an annual estimate of gross receipts and collections and proposed use of all funds collected pursuant to section 20145 of title 51, United States Code.

OFFICE OF INSPECTOR GENERAL

For necessary expenses of the Office of Inspector General in carrying out the Inspector General Act of 1978, $50,200,000, to remain available until September 30, 2025.

FY 2024 PROPOSED APPROPRIATIONS LANGUAGE

ADMINISTRATIVE PROVISIONS

Funds for any announced prize otherwise authorized shall remain available, without fiscal year limitation, until a prize is claimed or the offer is withdrawn.

Not to exceed 5 percent of any appropriation made available for the current fiscal year for the National Aeronautics and Space Administration in this Act may be transferred between such appropriations, but no such appropriation, except as otherwise specifically provided, shall be increased by more than 10 percent by any such transfers. Any funds transferred to "Construction and Environmental Compliance and Restoration" for construction activities shall not increase that account by more than 50 percent. Balances so transferred shall be merged with and available for the same purposes and the same time period as the appropriations to which transferred. Any transfer pursuant to this provision shall be treated as a reprogramming of funds under section 504 of this Act and shall not be available for obligation except in compliance with the procedures set forth in that section.

Not to exceed 5 percent of any appropriation provided for the National Aeronautics and Space Administration under previous appropriations Acts that remains available for obligation or expenditure in fiscal year 2024 may be transferred between such appropriations, but no such appropriation, except as otherwise specifically provided, shall be increased by more than 10 percent by any such transfers. Any transfer pursuant to this provision shall retain its original availability and shall be treated as a reprogramming of funds under section 504 of this Act and shall not be available for obligation except in compliance with the procedures set forth in that section.

The spending plan required by this Act shall be provided by the National Aeronautics and Space Administration at the theme and program level. The spending plan, as well as any subsequent change of an amount established in that spending plan that meets the notification requirements of section 504 of this Act, shall be treated as a reprogramming under section 504 of this Act and shall not be available for obligation or expenditure except in compliance with the procedures set forth in that section.

Not more than 20 percent or $50,000,000, whichever is less, of the amounts made available in the current-year Construction and Environmental Compliance and Restoration (CECR) appropriation may be applied to CECR projects funded under previous years' CECR appropriations. Use of current-year funds under this provision shall be treated as a reprogramming of funds under section 504 of this Act and shall not be available for obligation except in compliance with the procedures set forth in that section.

Of the amounts made available in this Act under the heading "Science, Technology, Engineering, and Mathematics Engagement" ("STEM Engagement"), up to $5,000,000 shall be available to jointly fund, with an additional amount of up to $1,000,000 each from amounts made available in this Act under the headings "Science", "Aeronautics", "Space Technology", "Exploration", and "Space Operations", projects and activities for engaging students in STEM and increasing STEM research capacities of universities, including Minority Serving Institutions.

Not to exceed $32,600,000 made available for the current fiscal year in this Act within "Safety, Security and Mission Services" may be transferred to the Working Capital Fund of the National Aeronautics and Space Administration. Balances so transferred shall be available until expended only for activities described in section 30102(b)(3) of title 51, United States Code, as amended by this Act, and shall remain available until expended. Any transfer pursuant to this provision shall be treated as a reprogramming of funds under section 504 of this Act and shall not be available for obligation except in compliance with the procedures set forth in that section.

ACRONYMS AND ABBREVIATIONS

AA	Associate Administrator
AAM	Advanced Air Mobility
AANAPISI	Asian American and Native American Pacific Islander-Serving Institutions
AATT	Advanced Air Transport Technology
AAVP	Advanced Air Vehicles Program
ABC	Agency Baseline Commitment
ABCs	Agency Baseline Commitments
ABTR	Astrophysics Biennial Technology Report
ACCESS	Advancing Collaborative Connections for Earth System Science
ACCP	Aerosols; Clouds, Convection, and Precipitation
ACD	Artemis Campaign Development
ACE	Advanced Composition Explorer
ACERO	Advanced Capabilities for Emergency Response Operations
ACF	Analytic Center Framework
ACME	Advanced Combustion Microgravity Experiment
ACMO	Aircraft Capability Management Office
ACO	Announcement of Collaboration Opportunity
ACR	Architecture Concept Review
ACRES	A Climate Resilient Ecosystem Approach
ACS	Altitude Control System
ACSC	Advanced Cislunar Surface Capabilities
ACSI	American Customer Satisfaction Index
ACT	Advanced Component Technologies
ACTIVATE	Aerosol Cloud Meteorology Interactions over the Western Atlantic Experiment
ADAP	Astrophysics Data Analysis Program
ADCAR	Astrophysics Data Curation and Archival Research
ADS	Astrophysics Data System
ADV	Advanced
AE	Auroral Electrojet
AEGIS	Agency Enterprise Global Information Technology Solutions
AEPEX	Atmosphere Effects of Precipitation through Energetic X-rays
AEPS	Advanced Electric Propulsion System
AEROMMA	Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas
AETC	Aerosciences Evaluation and Test Capabilities
AFC	Alternate Fecal Container
AFDP	ARMD Flight Data Portal
AFRC	Armstrong Flight Research Center
AFSS	Autonomous Flight Safety System
AGA	Anomaly Gas Analyzer

ACRONYMS AND ABBREVIATIONS

AGAGE	Advanced Global Atmospheric Gases Experiment
AHU	Air Handle Units
AI	Artificial Intelligence
AI&T	Assembly, Integration, and Test
AIA	Asset Inventory Assessment
AIHEC	American Indian Higher Education Consortium
AIM	Aeronomy of Ice in the Mesosphere
AIP	Azure Information Protection
AIRS	Atmospheric Infrared Sounder
AISES	American Indian Science and Engineering Society
AIST	Advanced Information Systems Technology
AITE	Alternative Initiation of Technology Exploration
AM	Additive Manufacturing
AMMOS	Advanced Multi-Mission Operation System
AMP	Agency Master Plan
AMR	Advanced Microwave Radiometer
AMR-C	Advanced Microwave Radiometer-Climate Quality
AMSU	Advanced Microwave Sounding Unit
ANGSA	Apollo Next Generation Sample Analysis
AO	Announcement of Opportunity
AoA	Analyses of Alternatives
AOS	Atmosphere Observing System
AOSP	Airspace Operations and Safety Program
APL	Applied Physics Laboratory
APMC	Agency Project Management Council
APPEL	Academy of Program/Project and Engineering Leadership
APRA	Astrophysics Research and Analysis
ARC	Ames Research Center
ARC22	Architecture Concept Review
ARCSIX	Arctic Radiation-Cloud-Aerosol-Surface Interaction Experiment
ARFC	Armstrong Flight Researh Center
ARIEL	Atmospheric Remote-sensing Infrared Exoplanet
ARMD	Aeronautics Research Mission Directorate
ARRM	Asteroid Redirect Robotic Mission
ARSET	Applied Remote Sensing Training
ASAT	Anti-satellite
ASCAN	Astronaut Candidate
ASI	Agenzia Spaziale Italiana (Italian Space Agency)
ASM	Acquisition Strategy Meeting
ASMPO	Astrophysics Strategic Mission Program Office

ACRONYMS AND ABBREVIATIONS

ASPERA	Analyzer of Space Plasmas and Energetic Atoms
ASPIRE	Aspiring Executive Cohort
ASU	Arizona State University
ATA	Agency Technical Authority
ATD	Airspace Technology Demonstration
ATF	Armstrong Test Facility
ATHENA	Advanced Telescope for High Energy Astrophysics
ATI	Advanced Technology Initiatives
ATLAS	Advanced Topographic Laser Altimeter System
ATLO	Assembly, Test, and Launch Operations
ATM	Air Traffic Management
ATP	Authority to Proceed
AU	Astronomical Units
AURA	Association of Universities for Research in Astronomy
AWE	Atmospheric Wave Experiment
AWS	Amazon Web Services
Ax	Axiom Mission
B1B	Block 1B
BAA	Broad Agency Announcement
BABAR	Black Array of Broadband Absolute Radiometers
BEO	Booster Element Office
BFELoB	Budget Formulation and Execution Line of Business
BFF	BioFabrication Facility
BIG	Breakthrough, Innovative, and Game-changing
BOLE	Booster Obsolescence and Life Extension
BPAC	Biological and Physical Sciences Advisory Committee
BPOC	Booster Production and Operation Control
BPS	Biological and Physical Sciences
BWG	Beam Waveguide
CaCTI	Criminal and Cyber Threat Intelligence
CADRE	Cooperative Autonomous Distributed Robotic Exploration
CAL	Cold Atom Laboratory
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation
CAPSTONE	Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment
CARES	Coronavirus Aid, Relief, and Economic Security
CAS	Convergent Aeronautics Solutions
CASE	Contribution to Ariel Spectroscopy of Exoplanets
CASIS	Center for the Advancement of Science in Space
CASMA	Condition and Soil Moisture Analytics

ACRONYMS AND ABBREVIATIONS

CATNLF	Crossflow Attenuated Natural Laminar Flow
CBD	Convention on Biological Diversity
CBM	Condition-based Maintenance
CCDev	Commercial Crew Development
CCiCap	Commercial Crew Integrated Capability
CCMC	Community Coordinated Modeling Center
CCP	Commercial Crew Program
CCRPP	Civilian Commercialization Readiness Pilot Program
CCRS	Capture, Containment, and Return, System
CCSC	Collaborations for Commercial Space Capabilities
CCSDS	Consultative Committee for Space Data Systems
CCtCap	Commercial Crew Transportation Capability
CDA	Coordinated Data Analysis
CDF	Common Data Format
CDFF	Commercial Destinations Free Flyers
CDISS	Commercial Destination for International Space Station
CDR	Critical Design Review
CDSCC	Canberra Deep Space Communications
CEA	Chemical Equilibrium with Applications
CECR	Construction and Environmental Compliance and Restoration
CEO	Chief Executive Officer
CEOS	Committee on Earth Observation Satellite
CEQ	Council on Environmental Quality
CERCLA	Comprehensive Environmental Response, Compensation, Liability Act
CERES	Clouds and Earth’s Radiant Energy System
CERISS	Commercially Enabled RapId Space Science
CESAS	Committee on Earth Science, and Applications from Space
CESD	Common Exploration Systems Development
CESO	Center Engineering, Safety, and Operations
CEU	Central Electronics Unit
CEVIS	Cycle Ergometer with Vibration Isolation & Stabilization
CFD	Computational Fluid Dynamics
CFE	Carbon Pollution Free Electricity
CFM	Cryogenic Fluid Management
CFO	Chief Financial Officer
CFT	Crewed Flight Test
CGI	Coronographic Instrument
CGS	Center for Geospace Storms
CHAMP	CHAllenging Minisatellite Payload
CHAPEA	Crew Health and Performance Exploration Analog

ACRONYMS AND ABBREVIATIONS

CHP	Crew Health and Performance
CHS	Crew Health and Safety
CIBER	Cosmic Infrared Background ExpeRiment
CIF	Center Innovation Fund
CIMR	Copernicus Imaging Microwave Radiometer
CIPHER	Complement of Integrated Protocols for Human Exploration Research
CIPP	Capital Investment Program Plan
CIR	Critical Integration Review
CIRBE	CubeSat Inner Radiation Belt Experiment
CIS	Commercial Services, Innovation, and Synergies
CJ	Congressional Justification
CLD	Commercial LEO Destination
CLIN	Contract Line-Item Number
CLIPS	Commercial Lunar Payload Services
CLPS	Commercial Lunar Payload Services
CLV	Commercial Launch Vehicle
CM	Crew Module
CMA	Crew Module Adapter
CMD	Charge Management Device
CME	Coronal Mass Ejections
CMHT	Condensation Module Heat Transfer
CMP	Contamination Monitoring Package
CMR	Common Metadata Repository
CMS	Carbon Monitoring System
CMV	Co-Manifested Vehicle
CNES	Centre National D'Etudes' Spatiales (French Space Agency)
CNT	Carbon Nanotube
CO2	Carbon Dioxide
CoCEI	Center of Excellence for Collaborative Innovation
CoF	Construction of Facilities
COFFIES	Consequences Of Fields and Flows in the Interior and Exterior of the Sun
COFR	Certification of Flight Readiness
COMSEC	Continuity of Operations, Fire Services, National Security, Communications Security
CONNECT	Connecting our NASA Network of Educators Collaborating in STEM
CONOPS	Concept of Operations
COR	Cosmic Origins
COSI	Compton Spectrometer and Imager
COSPAR	Committee on Space Research
CoSTEM	Committee on Science, Technology, Engineering, and Math Education

ACRONYMS AND ABBREVIATIONS

COTS	Commercial Orbital Transportation System
CP	Communications Program
CPC	Circumpolar Cyclones
CPEC	China Pakistan Economic Corridor
CPF	CLARREO Pathfinder
CPT	Comprehensive Performance Test
CRISM	Compact Reconnaissance Imaging Spectrometer for Mars
CRISTAL	Copernicus Polar Ice and Snow Topography Altimeter
CRP	Constant Rate Production
CRS	Commercial Resupply Services
CSA	Canadian Space Agency
CSBF	Columbia Scientific Balloon Facility
CSDA	Commercial SmallSat Data Acquisition
CSESP	Citizen Science for Earth Systems Program
CSI	Citizen Science Investigations
CSLI	CubeSat Launch Initiative
CSM	Crew and Service Module
CSP	Communications Services Program
CSSP	Committee for Solar and Space Physics
CST	Commercial Supersonic Technology
CTE	Composite Technology for Exploration
CTE-TDEA	Composite Technologies for Exploration - Thermoplastic Development for Exploration Applications
CTIM	Compact Total Irradiance Monitor
CTX	Context Camera
C-UAS	Counter-Unmanned Aircraft Systems
CUI	Controlled Unclassified Information
CURIE	CUbesat Radio Interferometry Experiment
CUVIS	Compact Ultraviolet to Visible Imaging Spectrometer
CY	Calendar Year
CYGNSS	Cyclone Global Navigation Satellite System
D.C.	District of Columbia
DAA	Deputy Associate Administrator
DAAC	Distributed Active Archive Center
DAEP	DSN Aperture Enhancement Project
DAILI	Daily Atmospheric Ionospheric Limb Imager
DALI	Development and Advancement of Lunar Instrumentation
DAPR	Dual Anonymous Peer Review
DARPA	Defense Advanced Research Projects Agency's
DART	Double Asteroid Redirection Test

ACRONYMS AND ABBREVIATIONS

DAS	Data Acquisition System
DAVINCI	Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging
DCC	Dream Chaser Cargo
DCCS	Dream Chaser Cargo System
DCOI	Data Center Optimization Initiative
DCOTSS	Dynamics and Chemistry of the Summer Stratosphere
DCR	Design Certification Review
DCSS	Delta Cryogenic Second Stage
DDAP	Discovery Data Analysis Program
DD-ERS	Director’s Discretionary-Early Release Science
DDT	Design, Development, Test
DEAP	Deep Space Network Aperture Enhancement
DEE	Data Environment Enhancements
DEIA	Diversity, Equity, Inclusion, and Accessibility
DEUCE	Dual-channel Extreme Ultraviolet Continuum Experiment
DFW	Dallas Fort Worth Airport
DHS	Department of Homeland Security
DIXI	Deep Impact eXtended Investigation
DLEU	DSN Lunar Exploration Upgrades
DLP	Data Loss Prevention
DLR	German Aerospace Center
DNA	Deoxy-Ribonucleic Acid
DOC	Delta Operations Center
DOD	Department of Defense
DoD	Department of Defense
DOE	Department of Energy
DOI	Department of Interior
DOJ	Department of Justice
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
Dos	Designated Observables
DPR	Dual-frequency Precipitation Radar
DR	Design Review
DRACO	Demonstration Rocket for Agile Cislunar Operations
DRaGMet	Dragonfly Geophysics and Meteorology Package
DRaGNS	Dragonfly Gamma-Ray and Neutron Spectrometer
DragonCam	Dragonfly Camera Suite
DRaMS	Dragonfly Mass Spectrometer
DRF	Data and Reasoning Fabric
DRIVE	Diversify, Realize, Integrate, Venture, Educate
DRPS	Dynamic Radioisotope Power System

ACRONYMS AND ABBREVIATIONS

DSA	Distributed Spacecraft Autonomy
DSAC	Deep Space Atomic Clock
DSC	Deaf Services Center
DSCOVR	Deep Space Climate Observatory
DSE	Data System Evolution
DSI	Decadal Survey Incubation
DSL	Deep Space Logistics
DSN	Deep Space Network
DSOC	Deep Space Optical Communications
DSS	Deep Space Station
DTE	Direct-to-Earth
DTN	Delay Tolerant Network
DTU	Technical University of Denmark
DVT	Design Verification Testing
DXL	Diffused X-ray emission from the Local galaxy
EACA	Equipment Asset Criticality Assessments
EAP	Electrified Aircraft Propulsion
EC	Exploration Capabilities
ECCPP	East Coast Commercial Payload Processing
ECF	Early Career Faculty
ECI	Early Career Innovation
ECLSS	Environmental Control and Life Support System
ECM	Europa Clipper Magnetometer
ECOSTRESS	Ecosystem Spaceborne Thermal Radiometer Experiment on Space Station
ECR	Environmental Compliance and Restoration
ECS	Environmental Control System
EDL	Entry, Descent, and Landing
EDP	Enterprise Data Platform
EDS	Electrodynamic Dust Shield
EEE	Electrical, Electronic, and Electro-mechanical
EES	Emergency Egress System
EEV	Earth Entry Vehicle
EFT	Exploration Flight Test
EGS	Exploration Ground Systems
EHP	Human Surface Mobility Program
EIC	Earth Information Center
EICC	EPSCoR Interagency Coordinating Committee
EIR	Enterprise Integration Review
EIS	Europa Imaging System
ELA	Equatorial Launch Australia

ACRONYMS AND ABBREVIATIONS

ELC	External Logistics Carriers
ELFIN	Electron Loss and Fields Investigation
ELVIS	Expendable Launch Vehicle Integrated Support
EM	Exploration Mission
EMI	Electromagnetic Interference
EMIT	Earth Surface Mineral Dust Source Investigation
EMS	Environmental Management System
ENA	Energetic Neutral Atom
ENOC	Enterprise Network Operations Center
EOL	End of Life
EONS	Engagement Opportunities in NASA STEM
EOS	Earth Observing System
EOSDIS	Earth Observing System Data and Information System
EPA	Environmental Protection Agency
EPACS	Enterprise Physical Access Control System
EPD	Educator Professional Development
EPFD	Electrified Powertrain Flight Demonstrations
EPIC	Earth Poly-Chromatic Imaging Camera
EPOC	Exploration Production and Operations Contract
EPOCh	Extrasolar Planet Observation and Characterization
EPS	Electrical Power System
EPSCoR	Established Program to Stimulate Competitive Research
ERB	Earth Radiation Budget
ERBS	Earth Radiation Budget Science
ERC	Education Resource Center
ERO	Earth Return Orbiter
ERP	Expert Review Panel
ERS	Early Release Science
ESA	European Space Agency
ESAC	Earth Science Advisory Committee
ESCAPADE	Escape and Plasma Acceleration and Dynamics Explorers
ESD	Exploration Systems Development
ESDIS	Earth Science Data and Information System
ESDMD	Exploration Systems Development Mission Directorate
ESDS	Earth Science Data Systems
ESDT	Earth System Digital Twin
ESI	Early Stage Innovations
ESIC	Early Stage Innovation and Commerce
ESIP	Early-Stage Innovation and Partnerships
ESM	European Service Module

ACRONYMS AND ABBREVIATIONS

ESO	Engineering, Safety, and Operations
ESPA	ELV Secondary Payload Adapter
ESPRIT	European Systems Providing Refueling, Infrastructure, and Telecommunications
ESSP	Earth System Science Pathfinder
ESTO	Earth Science Technology Office
ESTP	Earth Science Technology Program
ETA	Engineering Technical Authority
ETCS	External Thermal Control System
EULA	End User License Agreement
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
EUS	Exploration Upper Stage
EUV	Extreme-UV
EUVST	Extreme Ultraviolet High-Throughput Spectroscopic Telescope
EVA	Extra-Vehicular Activities
EVAMS	Enterprise Visitor Access Management System
EVAS	Exploration Extravehicular Activity Services
EVC	Earth Venture Continuity
EVI	Earth Venture Instruments
EVM	Earth Venture Missions
EVS	Earth Venture Suborbital
eVTOL	electrified vertical take-off and landing
EXCOM	Executive Committee
EZIE	Electrojet Zeeman Imaging Explorer
FA&A	Financial Accountant & Analysis
FAA	Federal Aviation Administration
FAIRUST	Findable, Accessible, Interoperable, and Reusable, Understandable, Secure, and Trustworthy
FAO	Food and Agriculture Organization
FAR	Federal Acquisition Regulation
FAST	Fellows Advancing in Science and Technology
FBCE	Flow Boiling and Condensation Experiment
FBI	Federal Bureau of Investigations
FDC	Flight Demonstrations and Capabilities
FEAP	Foundational Electrified Aircraft Propulsion
FEMA	Federal Emergency Management Agency
FFRDC	Federally-Funded Research and Development Center
FGB	Functional Cargo Block
FGM	Fluxgate Magnetometer
FIA	Forest Inventory and Analysis
FIR	Fluids Integrated Rack

ACRONYMS AND ABBREVIATIONS

FIRST	For the Inspiration and Recognition of Science and Technology
FISMA	Federal Information Security Management Act
FITARA	Federal Information Technology Acquisition Reform Act
FM2	Flammability of Materials on the Moon
FO	Flight Opportunities
FOD	Flight Operations Directorate
FOMSS	Facilities, Operations, Maintenance Support Services
FoW	Future of Work
FPGA	Field Programmable Gate Array
FRR	Flight Readiness Review
FSF	Future Systems Formulation
FSP	Fission Surface Power
FSR	Formulation Synchronization Review
F-SRR	Formulation Systems Requirement Review
FSS	Farside Seismic Suite
FTE	Full-Time Equivalent
FTIS	Flight Test Instrumentation System
FTS	Flight Termination System
FY	Fiscal Year
GAO	Government Accountability Office
GBM	Gamma-Ray Burst Monitor
GCD	Game Changing Development
GCFR	Greater Cape Floristic Region
GDC	Geospace Dynamics Constellation
GDF	General Distributed Flux
GDSCC	Goldstone Deep Space Communications Complex
GE	General Electic
GEDI	Global Ecosystem Dynamics Investigation
GeDs	Germanium Detectors
GEER	Glenn Extreme Environment Rig
GEL	Growth and Extinction Limit
GEO	Group on Earth Observations
GEOLAB	Geometry Laboratory
GEOS	Global Earth Observing System
GERS	Gateway External Robotics Systems
GFAS	Ground to Flight Application Software
GFE	Government Furnished Equipment
GFZ	German Research Centre for Geosciences
Ghe	Gaseous Helium
GHG	Greenhouse Gas

ACRONYMS AND ABBREVIATIONS

GIBS	Global Imagery Browse Services
GIS	Geographic Information System
GISS	Goddard Institute for Space Studies
GLIDE	Global Lyman-alpha Imagers of the Dynamic Exosphere
GLIMR	Geosynchronous Littoral Imaging and Monitoring Radiometer
GLOBE	Global Learning and Observations to Benefit the Environment
GLS	Gateway Logistics Services
GMI	GPM Microwave Imager
GN2	Gaseous Nitrogen
GNC	Guidance, Navigation, and Control
GNSS	Global Navigation Satellite System
GO	Guest Observers
GOFC	Global Observation for Forest Cover
GOFC-GOLD	Global Observation for Forest Cover and Land Dynamics
GOLD	Global-scale Observations of the Limb and Disk
GOMAP	Great Observatories Mission and Technology Maturation Program
GPGPU	General Purpose Graphics Processing Units
GPHS	General Purpose Heat Source
GPM	Global Precipitation Measurement
GPS	Global Positioning System
GPU	Graphical Processing Unit
GRACE	Gravity Recovery and Climate Experiment
GRACE-FO	Gravity Recovery and Climate Experiment Follow On
GRAM	Global Reference Atmospheric Model
GRB	Gamma-Ray Bursts
GRC	Glenn Research Center
GSA	Government Services Administration
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
GSI	Ground Systems Implementation
GSLV	Geosynchronous Satellite Launch Vehicle
GSSR	Goldstone Solar System Radar
GST	Global Stocktake’
GT	Ground Terminal
GUSTO	Galactic UltraLong-Duration Balloon Spectroscopic Terahertz Observatory
GUVI	Global Ultraviolet Imager
GV	Ground Validation
HAB	International Habitat
HALO	Habitation and Logistics Outpost
HARP	Hyper-angular Rainbow Polarimeter

ACRONYMS AND ABBREVIATIONS

HBCU	Historically Black Colleges and Universities
HBCUs	Historically Black College and Universities
HCC	High-Capacity Centrifuge
HCIT	Human Capital Information Technology
H-CSI	Heliophysics Citizen Science Investigations
HD	High Definition
HDTN	High-rate Delay Tolerant Networking
HEASARC	High Energy Astrophysics Science Archive Center
HEC	High End Computing
HECC	High End Computing Capability
HEOMD	Human Exploration and Operations Mission Directorate
HERA	Hybrid Electronic Radiation Assessor
HERMES	Heliophysics Environmental and Radiation Measurement Experiment Suite
HERO	Human Exploration Research Opportunity
HFOS	Heliophysics Flight Opportunities Studies
HHS	Health and Human Services
HiCAM	Hi-Rate Composite Aircraft Manufacturing
HIS	Heavy Ion Sensor
HITL	Human-In-The-Loop
HLCS	HALO Lunar Communications System
HLS	Harmonized Landsat Sentinel
HMI	Helioseismic and Magnetic Imager
HMTA	Health and Medical Technical Authority
HPC	High-Performing Computing
HPGF	High Pressure Gas Facility
HPIW	High Pressure Industrial Water
HPSC	High Performance Spaceflight Computing
HQ	NASA Headquarters
HRF	Human Research Facility
HRP	Human Research Program
HSFO	Human Space Flight Operations
HSI	Human Systems Integration
HSIs	Hispanic Serving Institutions
HSM	Human Surface Mobility
HSO	Heliophysics System Observatory
HT	Hypersonic Technology
HTPB	Hydroxyl-Terminated Polybutadiene
HTV	H-II Transfer Vehicle
HUD	Heads-Up-Display
HVAC	Geating, Ventilation, and Air Conditioning

ACRONYMS AND ABBREVIATIONS

HW	Habitable Worlds
HyTEC	Hybrid Thermally Efficient Core
I&TC	Infrastructure & Technical Capabilities
I3P	IT Infrastructure Integration Program
IA	Independent Assessment
IAD	Investigative Analysis Division
IAOP	Intercenter Aircraft Operations Panel
IAS	Integration of Automated Systems
IASP	Integrated Aviation Systems Program
IBEX	Interstellar Boundary Explorer
IBR	Independent Baseline Review
ICEMAG	Interior Characterization of Europa Using Magnetometry
ICESat	Ice, Cloud, and Land Elevation Satellite
ICG	International Committee on GNSS
ICON	Ionospheric Connection Explorer
ICPS	Interim Cryogenic Propulsion Stage
IDIQ	Indefinite-Delivery-Indefinite-Quantity
IDPU	Instrument Data Processing Unit
iESA	ion Electrostatic Analyzer
IG	Inspector General
IG3IS	Integrated Global Greenhouse Gas Information System
IGS	Intelligent Global Search
IIP	Instrument Incubator Program
ILLUMA	Integrated LCRD LEO User Modem Amplifier
ILLUMA-T	Integrated LCRD LEO User Modem Amplifier and Terminal
IM	Information Management
IMAP	Interstellar Mapping and Acceleration Probe
IMC	International Mission Contributions
IMERG	Integrated Multi-satellite Retrievals for GPM
IMF	Interplanetary Magnetic Field
IMM	Integrated Medical Model
IMPACT	Informing Mission Planning via Analysis of Complex Trade
IMPACTS	Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms
IMPALA	Information Management Platform for Data Analytics and Aggregation
INCUS	Investigation of Convective Updrafts
INL	Idaho National Laboratory
InSight	Interior Exploration using Seismic Investigations, Geodesy and Heat Transport
InSPA	In Space Production Applications
INTA	Instituto Nacional de Tecnica Aeroespacial

ACRONYMS AND ABBREVIATIONS

IOAG	Interagency Operations Advisory Group
IOC	Initial Operational Capabilities
IOP	Intensive Operating Periods
IPA	Integrated Payload Assembly
IPAC	Infrared Processing and Analysis Center
IPCC	Intergovernmental Panel on Climate Change
IPE	ISRU Pilot Excavator
IPO	Initial Power On
IRAC	Interdepartment Radio Advisory Committee
IRAD	Independent Research and Development
IRB	Independent Review Board
IRIS	Interface Region Imaging Spectrograph
iROSA	ISS Roll Out Solar Array
IRS	Internal Revenue Service
IRSA	Infrared Science Archive
IRT	Independent Review Team
IRTF	Infrared Telescope Facility
ISD	Interstellar Dust
ISEP	Integrated Solar Energetic Proton
ISM	In-Space Manufacturing
ISPF	In-Space Propulsion Facility
ISRO	Indian Space Research Organization
ISRU	In-Situ Resource Utilization
ISS	International Space Station
ISSNL	ISS National Laboratory
IT	Information Technology
ITCS	Internal Thermal Control System
ITM	Ionosphere/Thermosphere/Mesosphere
IV&V	Independent Verification and Validation
IXPE	Imaging X-ray Polarimetry Explorer
JANNAF	Joint Army-Navy-NASA-Air Force
JANUS	Joint Advanced Propulsion Institute
JAXA	Japanese Aerospace Exploration Agency
JCL	Joint Confidence Level
JHU	Johns Hopkins University
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System
JRC	Joint Research Centre
JSC	Johnson Space Center
JUICE	Jupiter Icy Moons Explorer

ACRONYMS AND ABBREVIATIONS

KARI	Korea Aerospace Research Institute
KASI	Korea Astronomy and Space Science Institute
KBO	Kuiper Belt Object
KBR	Kellogg Brown & Root
KDP	Key Decision Point
KGS	Kuiper Government Solutions
KIDS	K-12 Inclusivity and Diversity in STEM
KOA	Keck Observatory Archive
KORUS	Korea- U.S.-United States Air Quality
KORUS-AQ	Korea-United States Air Quality
KPF	Keck Planet Finder
KPLO	Korea Pathfinder Lunar Orbiter
KSC	Kennedy Space Center
kW	Kilowatt
LAM	Laboratoire d'Astrophysique de Marseille
LAN	Local Area Network
LANCE	Land, Atmosphere Near real-time Capability for EOS
LANL	Los Alamos National Laboratory
LARC	Langley Research Center
LaRC	Langley Research Center
LAS	Launch Abort System
LASF	Launch Abort System Facility
LASP	Laboratory for Atmospheric and Space Physics
LAT	Large Area Telescope
LBFD	Low Boom Flight Demonstrator
LC-39B	Launch Complex-39B
LCAP	Low-Code Application Platforms
LCC	Launch Control Center
LCLUC	Land-Cover and Land-Use Change
LCOT	Low-Cost Optical Terminal
LCPSO	Land Cover Project Science Office
LCRD	Laser Communications Relay Demonstration
LCRNS	Lunar Communications Relay and Navigation Systems
LCROSS	Lunar Crater Observation and Sensing Satellite
LCS	Launch Communications Segment
LDEP	Lunar Discovery and Exploration Program
LEAP	Large Area Burst Polarimeter
LEED	Leadership in Energy and Enviromental Design
LEGS	Lunar Exploration Ground System
LEIA	Lunar Explorer Instrument for space biology Applications

ACRONYMS AND ABBREVIATIONS

LEO	Low-Earth Orbit
LEOS	Legal Enterprise Operating System
LETF	Launch Equipment Test Facility
Lhe	liquid helium
LHS	Luyten Half-Second Catalogue
LIGO	Laser Interferometer Gravitational-wave Observatory
LIS	Lightning Imaging Sensor
LISA	Laser Interferometer Space Antenna
LISM	Local Interstellar Medium
LITMS	Lunar Interior Temperature and Materials Suite
LLC	Limited Liability Corporation
LLITED	Low-Latitude Ionosphere/ Thermosphere Enhancements I n Density
LLVIS	Launch Loads Vibration Isolation System
LMOC	LCRD Mission Operations Center
LN2	Liquid Nitrogen
LoB	Line of Business
LOFTID	Low-Earth Orbit Flight Test of Inflatable Decelerator
LOX	Liquid Oxygen
LRA	Laser Retro-reflector Assembly
LRD	Launch Readiness Date
LRO	Lunar Reconnaissance Orbiter
LSAH	Lifetime Surveillance of Astronaut Health
LSIC	Lunar Surface Innovation Consortium
LSII	Lunar Surface Innovation Initiative
LSITP	Lunar Surface Instrument and Technology Payloads
LSP	Launch Services Program
LTV	Lunar Terrain Vehicle
LTVS	Lunar Terrain Vehicle Services
LUCI	Lunar Combustion Investigation
LuGRE	Lunar GNSS Receiver Flight Experiment
Lunar-VISE	Lunar Vulkan Imaging and Spectroscopy Explorer
LVSA	Launch Vehicle Stage Adapter
LWRHU	Light Weight Radiosotope Heater Unit
LWS	Living With a Star
M&IC	Monitoring and Information Center
M&MA	Moon and Mars Architecture
MAA	MUREP Aerospace Academy
MACS	Multi-layer Acoustics & Conductive-grid Sensor
MAF	Michoud Assembly Facility
MAGIC	MAGnetometers for Innovation and Capability

ACRONYMS AND ABBREVIATIONS

MAIA	Multi-Angle Imager for Aerosols
MAIANSE	MUREP for American Indian and Alaska Native STEM Engagement
MAPTIS	Materials and Processes Technical Information System
MARCI	Mars Color Imager
MARSIS	Mars Advanced Radar for Subsurface and Ionospheric Sounding
MASPEX	MAss SPectrometer for Planetary EXploration/Europa
MATA	Motor Adapter Truss Assembly
MAV	Mars Ascent Vehicle
MAVEN	Mars Atmosphere and Volatile EvolutioN
MAXI	Monitor of All-sky X-ray Image
MBSA	Model-Based Systems Analysis
MBSE	Model-Based Systems Engineering
MCAT	Meter Class Autonomous Telescope
MCC	Mission Control Center
MCD	Mars Campaign Development
MCL	Metrology and Calibration Laboratory
MCR	Mission Concept Review
MCS	Mars Climate Sounder
MDA	MacDonald, Dettwiler and Associates Inc
MDAO	Multi-disciplinary Design, Analyses, and Optimization
MDECE	Motors for Dusty and Extremely Cold Environments
MDR	Mission Definition Review
MDSCC	Madrid Deep Space Communications Complex
MEaSUREs	Making Earth System Data Records for Use in Research Environments
MEGA	Mars-Earth Gravity Assist
MEGANE	Mars-moon Exploration with Gamma rays and Neutrons
MERCRII	Metallic Environmentally Resistant Coating Rapid Innovation Initiative
MES	Mission Enabling Services
MEVV	Multi-Element Verification & Validation
MHD	Magnetohydrodynamic
MIA	Made in America
MICS	Modern & Inclusive Collaboration Spaces
MIDEX	Medium-Class Explorer
MIE	Museum and Informal Education
MinXSS-3	Miniature X-ray Solar Spectrometer
MIO	Maturation and Integration Office
MIR	Mission Integration Review
MIRI	Mid-Infrared Instrument
MIRO	MUREP Institutional Research Opportunity
MISE	Mapping Imaging Spectrometer for Europa

ACRONYMS AND ABBREVIATIONS

MIST	Material Ignition and Suppression Test
MIT	Massachusetts Institute of Technology
ML	Mobile Launcher
MLM	Multi-purpose Laboratory Module
MLS	Microwave Limb Sounder
MLT	Mesosphere and Lower Thermosphere
MMGIS	Multi-Mission Geographic Information System
MMPACT	Moon-to-Mars Planetary Autonomous Construction Technology
MMRTG	Multi-Mission Radioisotope Thermoelectric Generator
MMS	Magnetospheric Multiscale
MMX	Martian Moons eXploration
MO	Missions of Opportunity
MODE	Mesoscale Ocean Dynamics and Vertical Transport
MODIS	Moderate-Resolution Imaging Spectroradiometer
MOMA	Mars Organic Molecule Analyzer
MOXIE	Mars Oxygen In-Situ Resource Utilization Experiment
MPCV	Multi-Purpose Crew Vehicle
MPH	Multi-purpose Habitat
MPIA	Max Planck Institute for Astronomy
MPP	Mentor Protégé Program
MR	Microwave Radiometer
MRI	Magnetic Resonance Imaging
MRO	Mars Reconnaissance Orbiter
MRSS	Multimission Resource Scheduling Service
MSaC	Mission Services and Capabilities
MSD	Mission Support Directorate
MSFC	Marshall Space Flight Center
MSI	Minority Serving Institutions
MSL	Mars Science Laboratory
Msolo	Mass Spectrometer observing lunar operations
MSR	Mars Sample Return
MTHR	Mission Transition and Handover Review
MUREP	Minority University Research and Education Project
MURI	Multi-Band Uncooled Radiometric Imager
MUSE	Multi-slit Solar Explorer
MUSS	Multi-User Systems Support
MW	Megawatt
NAFPA	NASA–Air Force Precipitation Analysis
NAS	National Airspace System
NASA	National Aeronautics and Space Administration

ACRONYMS AND ABBREVIATIONS

NASCOM	NASA Communications
NASS	National Agriculture Statistics Service
NAVO	NASA Astronomical Virtual Observatories
NCAPS	NASA Consolidated and Platform Services
NCAS	NASA Community College Aerospace Scholars
NCATS	National Center for Advancing Translational Sciences
NCI	NASA Critical Infrastructure
NCRP	National Council on Radiation Protection
NDE	Nondestructive Evaluation
NDMC	National Drought Mitigation Center
NDS	NASA Docking System
NDT	Nondestructive Testing
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NEA	Near Earth Asteroid
NEAR	Near Earth Asteroid Rendezvous
NEAT	NASA Electric Aircraft Testbed
NED	NASA Extragalactic Database
NEK	Nezemnyy Eksperimental’nyy Kompleks
NEO	Near Earth Object
NEOO	Near-Earth Object Observations
NEOS	Near-Earth objects
NEOWISE	Near Earth Object Wide-field Infrared Surveyor Explorer
NEPA	National Environmental Protection Act
NEPP	NASA Electronics Parts & Packaging
NESC	NASA Engineering and Safety Center
NET	No Earlier Than
NExScI	NASA Exoplanet Science Institute
NextSTEP	Next Space Technologies for Exploration Partnerships
NFS	NASA Federal Acquisition Regulation Supplement
NG	Northrop Grumman
NGIS	Northrop Grumman Innovation Systems
NGO	Non-Government Organization
NGS	Northrop Grumman Space
NIAC	NASA Innovative Advanced Concepts
NIBIB	National Institute of Biomedical Imaging and Bioengineering
NICER	Neutron Star Interior Composition Explorer
NICS	NASA Integrated Communications Services
NIH	National Institutes of Health
NIKA	Ka-band Advancement

ACRONYMS AND ABBREVIATIONS

NIR	Near Infrared
NIRCam	Near-Infrared Camera
NIRSpec	Near-Infrared Spectrograph
NIRVSS	Near InfraRed Volatiles Spectrometer System
NISAR	NASA-ISRO Synthetic Aperture Radar
NIST	National Institute of Standards and Technology
NISTAR	National Institute of Standards and Technology Advanced Radiometer
NLS	NASA Launch Services
NMNH	National Museum of Natural History
NOAA	National Oceanic and Atmospheric Administration
NOFO	Notice of Funding Opportunity
NOMAD	Nadir and Occultation for MArs Discovery
NORR	Normal Operations Readiness Review
NOS	New Observing Strategies
NPLP	NASA Provided Lunar Payloads
NPP	National Polar-Orbiting Partnership
NPR	NASA Procedural Requirements
NPS	National Park Service
NRA	NASA Research Announcement
NRESS	National Research and Educational Support Services
NRHO	Near Rectilinear Halo Orbit
NRPTG	National Rocket Propulsion Test Group
NSC	NASA Safety Center
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
NSIDS	National Snow and Ice Data Center
NSN	Near Space Network
NSpC	National Space-Based PNT Advisory Board and the National Space Council
NSPM	National Security Presidential Memorandum
NSRS	National Safety Reporting System
NSS	Neutron Spectrometer System
NSSC	NASA Shared Services Center
NSTC	National Science and Technology Council's
NSTEM	NASA Office of STEM Engagement
NSTGRO	NASA Space Technology Graduate Research Opportunities
NTF	National Transonic Facility
NTIA	National Telecommunications and Information Administration
NTL	NASA Tournament Lab
NTSB	National Transportation Safety Board
NTTS	NASA's Technology Transfer System

ACRONYMS AND ABBREVIATIONS

NWS	National Weather Service
O&C	Operation and Checkout
O&C	Operations and Checkout
O&M	Operations and Maintenance
O2OGS	Orion/Artemis-II Optical Ground Segment
OA	Office of Audits
OBA	Outer Barrel Assembly
OCE	OSMA, and the Chief Engineer
OCFO	Office of the Chief Financial Officer
OCHCO	Office of Chief Human Capital Officer
OCHMO	Office of Chief Health and Medical Officer
OCI	Ocean Color Instrument
OCIO	Office of the Chief Information Officer
OCO	Orbiting Carbon Observatory
OCOMM	Office of Communications
OCSS	Orion Crew Survival System Suit
OCT	Office of the Chief Technologist
OCTL	Optical Communications Telescope Laboratory
ODA	Office of Data Analytics
ODEO	Office of Diversity and Equal Opportunity
ODMSP	Orbital Debris Mitigation Standard Practices
ODPO	Orbital Debris Program Office
OFT	Orbital Flight Test
OGA	Oxygen Generation Assembly
OGAs	Other Government Agencies
OGC	Office of the General Counsel
OGRE	Off-Plane Grating Rocket Experiment
OHMAN	Orbiting High-energy Monitor Alert Network
OI	Office of Investigations
OIG	Office of Inspector General
OIIR	Office of International and Interagency Relations
OLIA	Office of Legislative and Intergovernmental Affairs
OLIF	Orion Life Support Integration Facility
OMB	Office of Management and Budget
OME	Orion Main Engine
OMI	Ozone Monitoring Instrument
OMP	Office of Management and Planning
OMPS	Ozone Mapping and Profiler Suite
OMS	Orbital Maneuvering System
OMS-Es	Orbital Maneuvering System Engines

ACRONYMS AND ABBREVIATIONS

OPOC	Orion Production and Operations Contract
OPS	Office of Protective Services
ORCA	Optimized and Repeatable Components in Additive Manufacturing
ORDEM	Orbital Debris Engineering Model
ORFOM	Orbital Fiber Optic Production Module
ORR	Operational Readiness Review
OSA	Orion Stage Adaptor
OSAM	On-orbit Servicing, Assembly, and Manufacturing
OSBP	Office of Small Business Programs
OSHA	Occupational Safety and Health Administration
OSI	Office of Strategic Infrastructure
OSIRIS	Origins-Spectral Interpretation-Resource Identification-Security
OSIRIS-REx	Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer
OSMA	Office of Safety and Mission Assurance
OSS	Open Source Software
OSST	Ocean Salinity Science Team
OSTEM	Office of STEM Engagement
OSTST	Ocean Surface Topography Science Team
OTPS	Office of Technology, Policy, and Strategy
OU	University of Oklahoma
OWL	Origins, Worlds, and Life
OWST	Ocean Winds Science Team
P&G	Procter & Gamble
PAC	Planetary Science Advisory Committee
PACE	Payload Accelerator for CubeSat Endeavors
PALLETE	Lunar Environment Thermal Toolbox Elements
PAM	Private Astronaut Mission
PASS	Precision Assembled Space Structure
PBAN	Polybutadiene Acrylonitrile
PCC	Prizes, Challenges and Crowdsourcing
PCM	Post Certification Mission
PCOS	Physics of the Cosmos
PD	Parkinson’s disease
PDCO	Planetary Defense Coordination Office
PDP	Plasma Diagnostics Package
PDR	Preliminary Design Review
PDS	Planetary Data System
PEA	Programmatic Environmental Assessment
PEAR	Payload Enclosed Access Room

ACRONYMS AND ABBREVIATIONS

PER	Pre-Environmental Review
PetiSat	Plasma Enhancements in the Ionosphere-Thermosphere
PFAR	Post-Flight Assessment Review
PFAS	Polyfluoroalkyl Substances
PHO	Potentially Hazardous Objects
PhysCOS	Physics of the Cosmos
PI	Principal Investigator
PIB	Programmatic and Industrial Base
PIC	Photonic Integrated Circuit
PIMS	Plasma Instrument for Magnetic Sounding
PIR	Program Implementation Review
PLA	Payload Adapter
PLAR	Post-Launch Assessment Review
PLC	Programmable Logic Controller
PM	Particulate Matter
PMPO	Planetary Missions Program Office
PMT	Program Management Team
PNT	Positioning, Navigation, and Timing
PODAAC	Physical Oceanography Distributed Active Archive Center
POWER	Prediction of Worldwide Energy Resources
PPDS	Propellant & Pressurants Delivery Systems
PPE	Power and Propulsion Element
PPF	Payload Processing Facility
PPMS	Primary Progressive Multiple Sclerosis
PPS	Precipitation Processing System
PREFIRE	Polar Radiant Energy in the Far Infrared Experiment
PRIME	Polar Resources Ice Mining Experiment
PRISM	Payloads and Research Investigations on the Surface of the Moon
P-Sampler	Pneumatic Sampler
PSC	Polar Stratospheric Cloud
PSEF	Planetary Science Enabling Facilities
PSI	Physical Sciences Information System
PSM	Procurement Strategy Meeting
PSP	Parker Solar Probe
PSR	Pre-Ship Review
PSRE	Propulsion System Rocket Engine
PTD	Pathfinder Technology Demonstrator
PUEO	Payload for Ultrahigh Energy Observation
PUFFER	Pop Up Flat Folding Exploration Robot
PUNCH	Polarimeter to Unify the Corona and Heliosphere

ACRONYMS AND ABBREVIATIONS

PyHC	Python in Heliophysics Community
QA	Quality Assurance
QM	Quality Management
QSAR	Qualification System Acceptance Review
R&D	Research and Development
R3	Rapid Response Research
RAAMBO	Refractory Alloy Additive Manufacturing Build Optimization
RAD	Radiation Assessment Detector
RAMPT	Rapid Analysis Manufacturing Propulsion Technology
RAP	Robotics Alliance Project
RBI	Radiation Budget Instrument
RCC	Range Commanders Council
RCM	Reliability Centered Maintenance
RCRA	Resource Conservation and Recovery Act
RDAP	Rosetta Data Analysis Program
RDRE	Rotating Detonation Rocket Engine
REAMS	Real Estate Agreement Management System
REASON	Radar for Europa Assessment and Sounding: Ocean to Near-surface
RES	Remote Enrollment Services
RF	Radio Frequency
RFI	Request for Information
RFP	Request For Proposal
RID	Research Infrastructure Development
RIME	Radar for Icy Moons Exploration
RISE	Rotation and Interior Structure Experiment
RMO	Resource Management Office
ROI	Research Operations and Integration
ROSA	Roll Out Solar Array
ROSES	Research Opportunities in Space and Earth Sciences
RPA	Robotic Process Automation
RPOD	Rendezvous, Proximity Operations and Docking
RPS	Radioisotope Power Systems
RPSF	Rotation, Processing, and Surge Facility
RPT	Rocket Propulsion Test
RSL	Recurring Slope Lineae
RST	Roman Space Telescope
SoFIE	Solid Fuel Ignition and Extinction
RTDFS	Residence Time Driven Flame Spread
RTG	Radioisotope Thermoelectric Generator
RVLT	Revolutionary Vertical Lift Technology

ACRONYMS AND ABBREVIATIONS

RWA	Reaction Wheel Assembly
S&MA	Safety and Mission Assurance
SABERS	Solid-State Architecture Batteries for Enhanced Rechargeability and Safety
SAC	Super-lightweight Aerospace Composites
SAF	Sustainable Aviation Fuel
SAGE	Stratospheric Aerosol and Gas Experiment
SALMON	Stand Alone Missions of Opportunity
SAM	Spacecraft Atmosphere Monitor
SANS	Spaceflight Associated Neuro-ocular Syndrome
SAR	Synthetic Aperture Radar
SASA	S-Band Antenna Sub Assembly
SASSIE	Salinity and Stratification at the Sea Ice Edge
SAT	Strategic Astrophysics Technology
SATCOM	Satellite Communications
SBA	Small Business Administration
SBG	Surface Biology and Geology
SBIR	Small Business Innovation Research
SC	Scientific Computing
SCA	Sensor Chip Assembly
SCALPSS	Stereo Camera for Lunar Plume Surface Studies
SCaN	Space Communications and Navigation
SCaN	Space Communications and Navigation
SCAs	Sensor Chip Assemblies
SCCS	Spacecraft Command and Control System
SCE	Sensor Chip Electronics
SCIC	Supply Chain Insight Central
SCLT	System Capabilities and Leadership Team
SCM	Search Coil Magnetometer
SCRM	Supply Chain Risk Management
SDA	Software-Defined Access
SDAC	Solar Data Center
SDB	Small Disadvantaged Businesses
SDC	Surface Deformation and Change
SDE	Science Discovery Engine
SDL	Space Dynamics Laboratory
SDO	Solar Dynamics Observatory
SDR	Single Design Review
SDS	Survey Data System
SDTS	Six-Degree-of-Freedom Test System
SDVOSB	Service-Disabled Veteran-Owned Small Businesses

ACRONYMS AND ABBREVIATIONS

SE&I	Systems Engineering and Integration
SE&I	System Engineering and Integration
SEDAC	Socio-economic Data and Applications Center
SEFI	Single-Event Functional Interrupt
SEIS	Seismic Experiment for Interior Structure
SEM	Scanning Electron Microscope
SEP	Solar Electric Propulsion
SERFE	Spacesuit Evaporation Rejection Flight Experiment
SETI	Search for Extraterrestrial Intelligence),
SETMO	Space Environments Testing Management Office
SFCO	Space Flight Crew Operations
SFD	Sustainable Flight Demonstrator
SFNP	Sustainable Flight National Partnership
SFO	Suborbital Flight Opportunities
SFS	Space and Flight Support
SG	Space Grant
SG KIDS	Space Grant K-12 Inclusivity and Diversity in STEM
SGP	Space Geodesy Project
SGSS	Space Network Ground Segment Sustainment
SGTRC	Space to Ground Transmitter Receiver Controller
SHREC	The Supplemental Heat Evaporative Cooler
SI C&DH	Science Instrument Command and Data Handling
SICA	Central American Integration System
SIEM	Security Incident Event Management
SIF	Solar-Induced Fluorescence
SIM	Spectral Irradiance Monitor
SIMPLEx	Small Innovative Missions for Planetary Exploration
SIP	Strategic Implementation Plan
SIPS	Science Investigator-led Processing Systems
SIR	System Integration Review
SIRIUS	Scientific International Research in Unique Terrestrial Station
SIT	System Integration and Test
SLC	Space Launch Complex
SLD	Sustaining Lunar Development
SLI	Sustainable Land Imaging
SLOPE	Simulated Lunar Operations
SLR	Satellite Laser Ranging
SLS	Space Launch System
SM	Service Module
SMA	Safety and Mission Assurance

ACRONYMS AND ABBREVIATIONS

SMAP	Soil Moisture Active Passive
SMD	Science Mission Directorate
SME	Subject Matter Expert
SMEX	Small Explorers
SMOS	Soil Moisture and Ocean Salinity
SMSR	Safety and Mission Success Reviews
SNC	Sierra Nevada Corp
SNLF	Slotted Natural Laminar Flow
SNOOPI	SigNals-Of-Opportunity P-band Investigation
SNWG	Satellite Needs Working Group
SOA	State of the Art
SOAR	Security Orchestration, Automation, and Response
SOC	Solar Orbiter Collaboration
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOFIE	Solar Occultation For Ice Experiment
SOHO	Solar and Heliospheric Observatory
SOMA	Science Office for Mission Assessments
SOMD	Space Operations Mission Directorate
SORCE	Solar Radiation and Climate Experiment
SPARRCI	Sensor-based Prognostics to Avoid Runaway Reactions and Catastrophic Ignition
SPARX	Sparking Participation in Authentic Real-world eXperiences
SPDA	Space Physics Data Archive
SPDF	Space Physics Data Facility
SPEC	Stages Production and Evolution Contract
SPEXOne	Spectro-Polarimeter for Exploration
SPIDER	SPace Infrastructure DExterous Robot
SPIE	Spacecraft Payload Integration and Evolution
SPLICE	Safe and Precise Landing – Integrated Capabilities Evolution
SPORT	Scintillation Prediction Observations Research Task
SPR	Surface Pressurized Rover
SPRITE	Supernova Remnants and Proxies for ReIonization Testbed Experiment
SpX	SpaceX
SRB	Standing Review Board
SRC	Sample Return Capsule
SRG	Spectrum-Roentgen-Gamma
SRH	Sample Recovery Helicopters
SRL	Sample Retrieval Lander
SRON	Netherlands Institute for Space Research
SRR	Systems Requirements Review
SRU	Stellar Reference Unit

ACRONYMS AND ABBREVIATIONS

SSA	Space Situational Awareness
SSC	Stennis Space Center
SSFL	Santa Susana Field Lab
SSI	Spectral Solar Irradiance
SSL	Space Sciences Laboratory
SSMO	Space Science Mission Operations
SSMS	Safety, Security, and Mission Services
SSR	Solid-State Recorder
SSS	Sea Surface Salinity
SST	Small Spacecraft Technology
SSV	Space Service Volume
STA	Structural Test Article
STAQS	Synergistic TEMPO Air Quality Science
STAR	Strategic Technology Architecture Roundtable
STARRS	Survey Telescope and Rapid Reporting System
STAR-X	Survey and Time-domain Astrophysical Research eXplorer
STDT	Science and Technology Definition Team
STEM	Science, Technology, Engineering, and Mathematics
STEREO	Solar Terrestrial Relations Observatory
STMD	Space Technology Mission Directorate
STP	Solar Terrestrial Probes
STRG	Space Technology Research Grants
STRI	Space Technology Research Institutes
STROFIO	Start from a ROtating FIeld mass spectrOmeter
STScI	Space Telescope Science Institute
STTR	Small Business Technology Transfer
SubC	Suborbital Crew
SUDA	SUrface Dust Analyzer
SunRISE	Sun Radio Interferometer Space Experiment
SUSAN	Subsonic Single Aft Engine
SWAPI	Solar Wind and Pickup Ions
SWFO	Space Weather Follow-On
SWOT	Surface Water and Ocean Topography
SWP	Strategic Workforce Plan
SWPC	Space Weather Prediction Center
SWR2O2R	Space Weather Research to Operations to Research
SWRI	Southwest Research Institute
SWS	System-Wide Safety
T2U	Technology Transfer University
T2X	Technology Transfer Expansion

ACRONYMS AND ABBREVIATIONS

TA	Technical Authority
TACP	Transformative Aeronautics Concepts Program
TALOS	Thruster Advancement for Low-temperature Operation in Space
TAMD	Technology Analysis and Mission Design
TBD	To Be Determined
TBIRD	TeraByte InfraRed Delivery
TCCON	Total Carbon Column Observing Network
TDAMM	Time Domain and Multi Messenger
TDE	Tidal Disruption Event
TDEA	Thermoplastic Development for Exploration Applications
TDM	Technology Demonstration Missions
TDO	Technology Demonstration Opportunity
TDRR	Technical Data Requirements and Reporting
TDRS	Tracking and Data Relay Satellites
TDT	Transonic Dynamics Tunnel
TEAM	Teams Engaging Affiliated Museums
TEAM II	Teams Engaging Affiliated Museums, and Informal Institutions
TEMPEST	Temporal Experiment for Storms and Tropical Systems
TEMPO	Tropospheric Emissions: Monitoring of Pollution
TESS	Transiting Exoplanet Survey Satellite
TGO	Trace Gas Orbiter
THEMIS	Time History of Events and Macroscale Interactions during Substorms
TIC	Trusted Internet Connection
TIDES	Thriving In Deep Space
TIGERISS	Trans-Iron Galactic Element Recorder for the International Space Station
TIM	Total Irradiance Monitor
TIMED	Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics
TIR	Thermal Infrared
TLI	Trans-Lunar Injection
TM	Test Management
TMP	Technology Management Plan
TMR	Technology Maturation Review
TOA	Top of Atmosphere
TOCA	Total Organic Carbon Analyzer
TOI	Twin Otter International
TOPEX	Topography Experiment
TOPS	Transform to Open Science
TOPST	Transform to Open Science Training
TP	Technology Pathfinder
TPS	Thermal Protection System

ACRONYMS AND ABBREVIATIONS

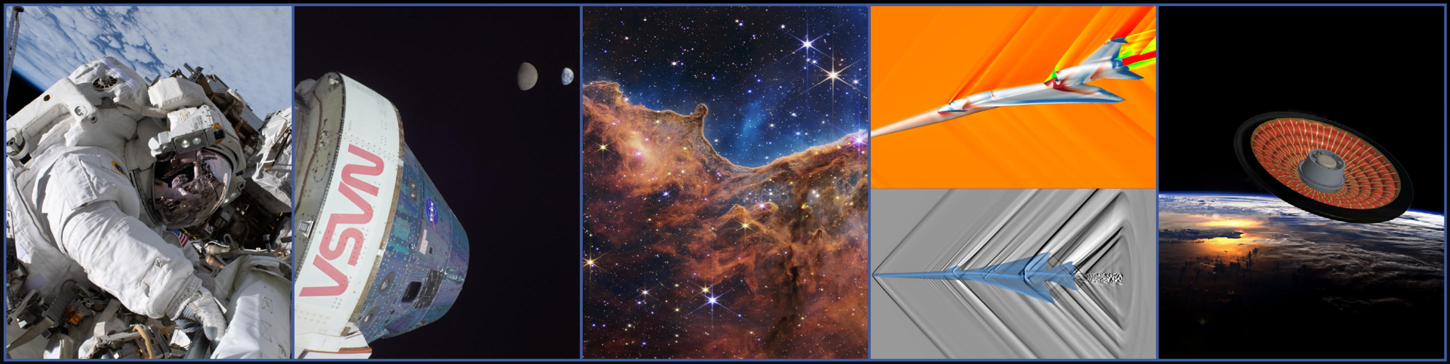
TRACERS	Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites
TRIDENT	The Regolith and Ice Drill for Exploring New Terrain
TRISH	Translational Research Institute for Space Health
TRL	Technology Readiness Level
TRMM	Tropical Rainfall Measuring Mission
TROPICS	Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats
TRR	Test Readiness Review
TSC	Telescience Support Center
TSI	Total Solar Irradiance Sensor
TSIS	Total and Spectral Solar Irradiance Sensor
TTBW	Transonic Truss-Braced Wing
TTT	Transformational Tools and Technologies
TVAC	Thermal Vacuum Testing
UAE	United Arab Emirates
UAG	Users' Advisory Group
UAM	Urban Air Mobility
UAS	Unmanned Aircraft Systems
UAV	Unmanned Ariel Vehicle
UAVSAR	Uninhabited Aerial Vehicle Synthetic Aperture Radar
UCB	University of California at Berkeley
UCLA	University of California, Las Angeles
UFE	Unallocated Future Expenses
UHF	Ultra-High Frequency
UI	University Innovation
UK	United Kingdom
UKSA	United Kingdom Space Agency
ULA	United Launch Alliance
ULI	University Leadership Initiative
ULS	United Launch Services
ULTRASAT	Ultraviolet Transient Astronomy Satellite
UMBC	University of Maryland Baltimore County
UN	United Nations
UNCOPUOS	United Nations Committee on the Peaceful Uses of Outer Space
UPA	Urine Processor Assembly
UPS	Uninterruptible Power Supplies
URT	Underway Recovery Test
USA	Universal Stage Adapter
USACE	U.S. Army Corps of Engineers
USAID	United States Agency for International Development

ACRONYMS AND ABBREVIATIONS

USDA	United States Department of Agriculture
USFS	U.S. Forest Services
USGCRP	United States Global Change Research Program
USGS	The U.S. Geological Survey
USOS	United States Orbital Segment
USRC	University Student Research Challenges
USSF	United States Space Force
USTP	University SmallSat Technology Partnership
UTAS	UTC Aerospace Systems
UTM	UAS Traffic Management
UTRC	United Technologies Researh Center
UV	Ultraviolet
UVEX	Ultraviolet Explorer
UVS	Europa Ultraviolet Spectrograph
UWMS	Universal Waste Management System
VA	Veterans Administration
VAB	Vehicle Assembly Building
VADR	Venture-Class Acquisitions of Dedicated and Rideshare
VAFB	Vandenberg Air Force Base
VALUABLES	Valuation of Applications Benefits Linked to Earth Science
VASI	Venus Atmospheric Structure Investigation
VCLS	Venture Class Launch Services
VDF	Velocity Distribution Function
VEDA	Visualization, Exploration, and Data Analysis
VERITAS	Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy
VIIRS	Visible Infrared Imaging Radiometer Suite
VIPER	Volatiles Investigating Polar Exploration Rover
VIS	Vibration Isolation System
VISE	Vehicle Interfaces to Suit Equipment
VISOR	Venus Imaging System for Observational Reconnaissance
VISTA	Vector Interferometry Space Technology using AERO
VLBI	Very Long Baseline Interferometry
VMS	Venus Mass Spectrometer
VNIR	Visible - Near infrared
VPP	Voluntary Protection Program
VRT	VIPER Review Team
VSAT	Vertical Solar Array Technology
VSFB	Vandenberg Space Force Base
VSWIR	Visible and Short Wave Infrared
VTLS	Venus Tunable Laser Spectrometer

ACRONYMS AND ABBREVIATIONS

VTOL	Vertical Takeoff and Landing
WAVES	Radio and Plasma Wave Experiment
WCCPP	West Coast Commercial Payload Processing Contract
WCF	Working Capital Fund
WCU	Women's Colleges and University
WDR	Wet Dress Rehearsal
WFF	Wallops Flight Facility
WGCV	Working Group on Calibration and Validation
WHIHBCU	White House Initiative for Historically Black Colleges and Universities
WISE	Wide-field Infrared Survey Explorer
WISPR	Wide Field Imager for Solar Probe
WIYN	Wisconsin-Indiana-Yale-National Optical Astronomy Observatory
WMKO	W.M. Keck Observatory
WOMA	Wide Field Instrument Opto-Mechanical Assembly
WOSB	Woman-owned Small Business
WPA	Water Processor Assembly
WSC	White Sands Complex
WSTF	White Sands Test Facility
WWAO	Western Water Applications Office
xEMU	Exploration Extravehicular Mobility Unit
xEVA	Exploration Extravehicular Activity
xEVAS	Exploration Extravehicular Activity Services
XMM	X-ray Multi-Mirror Mission
XQC	X-ray Quantum Calorimeter
XRISM	X-ray Imaging and Spectroscopy Mission
XROOTS	eXposed Root On Orbit Test System
XVS	Xternal Vision System
ZBOT-NC	Non-Condensable Gases in the Propellant Storage Tank
ZEV	Zero Emission Vehicle
ZTNA	Zero Trust Network Architecture



National Aeronautics and Space Administration

NASA Headquarters
300 E Street SW
Washington, DC 20546
www.nasa.gov/centers/hq

www.nasa.gov

NP-2023-02-3108-HQ