National Aeronautics and
Space Administration

EXPLORE SPACE TECH

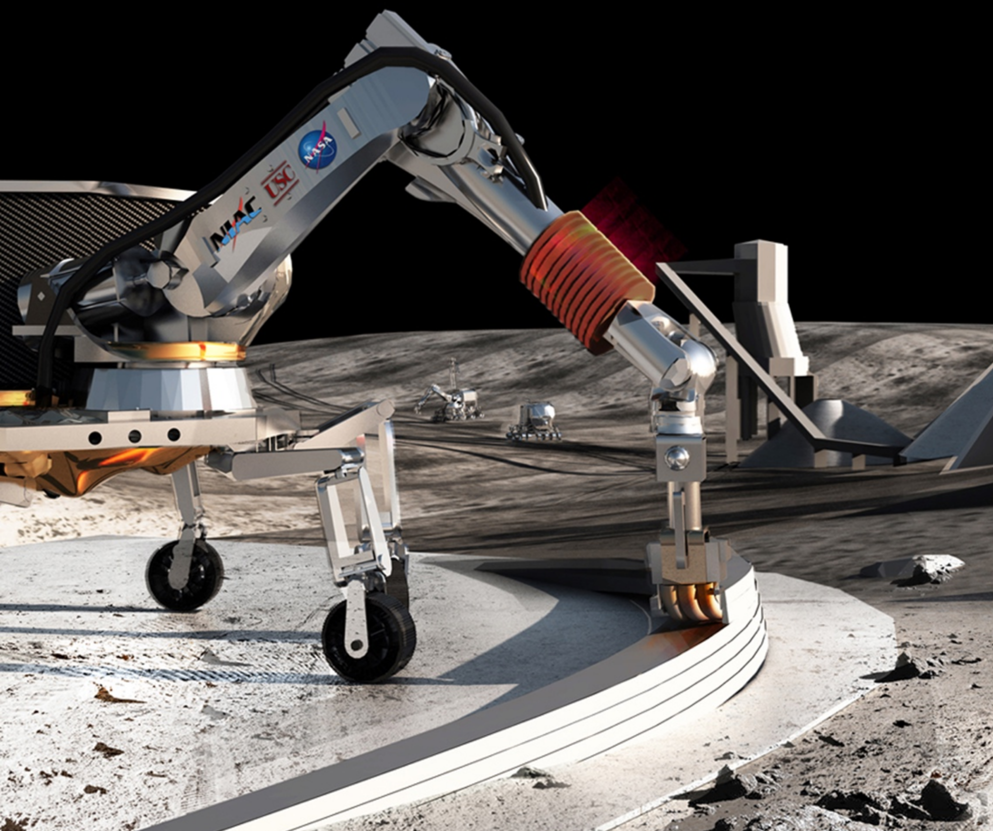
FY 2020 Exploration Technology Budget Update

NAC TI&E Committee Meeting

Mr. James Reuter, Associate Administrator (Acting) for NASA STMD | April 2019

Exploration Technology Strategic Investments

Exploration



Emphasis on the Moon
Keeping an Eye Towards Mars and Beyond

Commerce

Investing in the
Growing Space Economy

SBIR/STTR

Partnerships & Technology Transfer

- Technology Transfer
- Prizes and Challenges
- iTech

Early Stage Innovation

- NASA Innovative Advanced Concepts
- Space Tech Research Grants
- Center Innovation Fund/Early Career Initiative

Technology Demonstrations

- Technology Demonstration Missions
- Small Spacecraft Technology
- Flight Opportunities

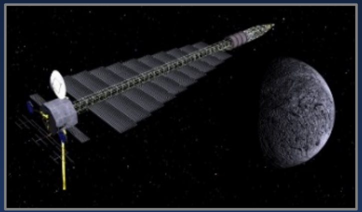
Technology Maturation

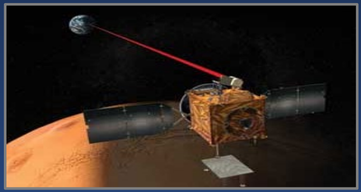
- Game Changing Development

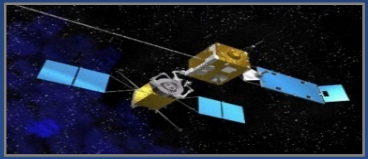
TECHNOLOGY PIPEPINE

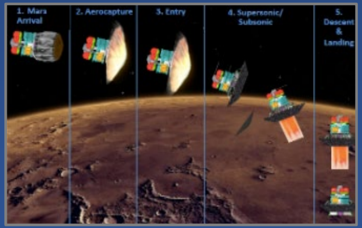
Key Technology Focus Areas

- Advanced environmental control and life support systems and In-Situ Resource Utilization
- Power and propulsion technologies
- Advanced communications, navigation and avionics
- In-space manufacturing and on-orbit assembly
- Advanced materials
- Entry, Descent and Landing
- Autonomous operations









Exploration Technology Investment Strategy

- Fund projects along a broad Technology Readiness Level (TRL) spectrum (1-7)
- Focus on enabling lunar exploration
  - Exploration Federated Team established to facilitate Exploration Campaign integration across the Mission Directorates (senior agency officials-DAA level)
- Implement critical technology demonstrations to enable lunar exploration including Lunar Gateway (e.g., SEP, fuel transfer)
- Utilize commercial lander services and infuse technology for human exploration class landers (e.g., Precision Landing, Cryo Fluid Management)
- Establish a Lunar Surface Innovation Initiative (LSII) to serve as a catalyst for enabling critical technologies required for humans to successfully operate on the lunar surface.
  - Includes fission surface power in situ resource utilization and other key technologies
- Pursue technology demonstration payloads for Commercial Lunar Payload Services, and Gateway
  - Excellent opportunity to utilize NASA personnel (especially early career) and Universities across entire portfolio
- Continue to support technologies readied for flight (e.g., LCRD, DSOC, TRN and MOXIE on Mars 2020, In-Space Manufacturing on ISS)

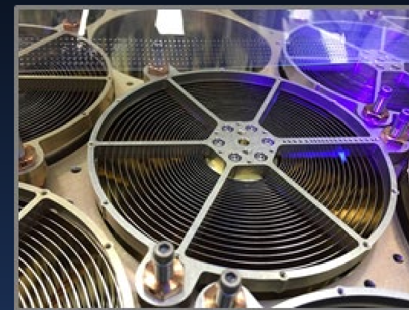
Exploration Technology Investment Strategy (cont.)

- Maintain Early Stage investments at ~8 % of Exploration Technology budget
  - Ensures a balance of lower TRL concepts sourced from academia and the NASA workforce with industry participation
  - Added emphasis on transitioning key early stage technologies to mid TRL level
- Pursue Public-Private Partnerships across portfolio
- Enhance the Flight Opportunities Program to improve research opportunities on suborbital platforms with emphasis on exploration
- Pursue Small Spacecraft Technologies to develop and demonstrate capabilities for rapid and affordable exploration beyond low Earth orbit and into deep space
  - Provide responsive platforms for scouting lunar terrain, identifying space resources, supporting missions beyond Earth
- Maintain commitment to an integrated Agency-wide SBIR/STTR program that supports both commercial interests and NASA missions with added emphasis on Lunar Exploration Campaign
- Keep an eye towards Mars tall pole critical technology development and continue to support exploration related science goals

FY 2018 Key Accomplishments

Small Spacecraft

Two small spacecraft (Integrated Solar Array and Reflect Antenna and Optical Communication and Sensor Demonstration) missions were successfully launched aboard Orbital ATK's Cygnus spacecraft.



Station Explorer for X-ray Timing and Navigation Technology (SEXTANT)

Aboard ISS demonstrated fully autonomous X-ray navigation in space — a capability that could revolutionize NASA's ability in the future to pilot robotic spacecraft to the far reaches of the solar system and beyond.

PUFFER

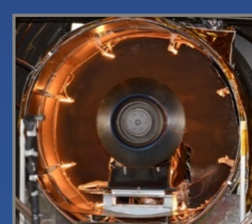
Technology demonstration of the Pop-Up Flat Folding Explorer Robot, which will advance NASA's ability to explore unchartered planetary surfaces.

Kilopower

Successful test completed demonstrating a 1-kW surface electrical power system using nuclear fission, which will enable long-duration stays on planetary surfaces with minimal to no solar power resources.

In Space Robotic Manufacturing & Assembly

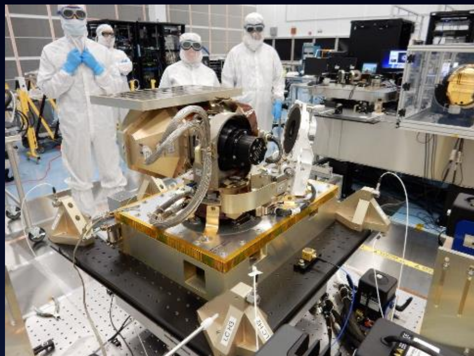
All 3 contractors completed Phase I (design, build and test/demo) successfully; pursuing flight demo with two concepts



Solar Electric Propulsion

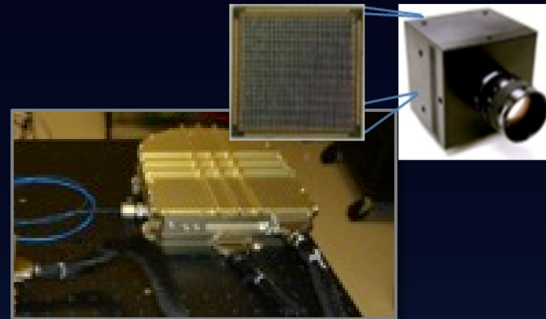
Completed preliminary design review for Advanced Electric Propulsion system

FY 2018 Key Accomplishments



Laser Communications Relay Demonstration

Successfully completed system build for testing to support a 2020 launch with STPSat-6



Deep Space Optical Communications

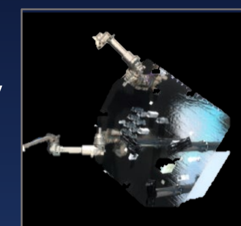
Completed System Requirements Review and KDP-B for flight demonstration on the Psyche mission

SBIR/STTR Industry Day

Over 450 innovators from across the country participated in 2nd workshop

Restore-L

Completed Preliminary Design Review on November 2017



Flight Opportunities Testing for Precision Landing Technologies

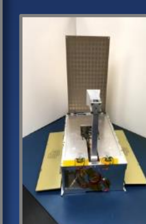
Successful flight test of a Navigation Doppler Lidar and Lander Vision System for future robotic and crewed missions

CUBES

US COMP

Space Technology Research Institutes

Successfully completed Year 1

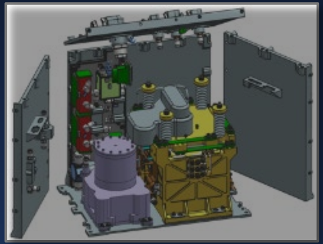


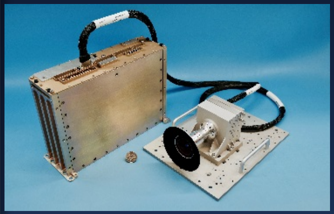
Centennial Challenges Program

Awarded more than $1.5 million for technology solutions toward the Cube Quest, 3D Printed Habitat and the Space Robotics Challenges.

FY 2019-2020 Plans

MOXIE
March 2019 delivery to Mars 2020 for **July 2020** Launch

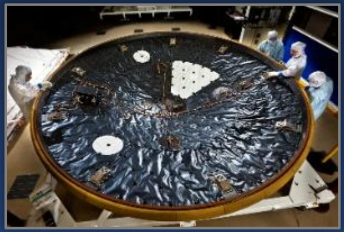




Terrain Relative Navigation
December 2018
Delivery for integration on Mars 2020

Laser Comm Relay Demo
Late 2019
Payload delivery for bus integration

Deep Space Optical Comm
Spring 2019 KDP-C for the flight terminal



MEDLI2
April 2019
Hardware Delivery for integration on Mars 2020 entry system

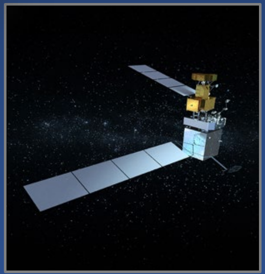
Astrobee
April 2019
Will be headed to ISS for demonstration

In Space Robotic Manufacturing and Assembly project
In 2019 will transition one or more concepts from ground to flight demonstration

High Performance Spaceflight Computing (HPSC)
FY 2020
Completion of critical design

SPLICE
October 2019
Complete NDL environmental testing

Refabricator Delivery and Installation aboard ISS February 2019
The first integrated recycler and 3D printer was successfully installed



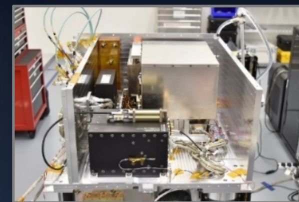
Restore-L
April 2019
Spacecraft critical design review
Late 2019
Mission CDR

Flight Opportunities Campaigns

FY 2019-2020 Plans

eCryo
December 2019
SHIVER Testing Complete

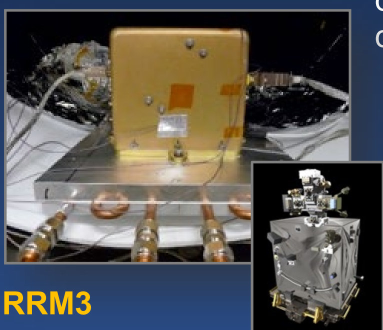
Deployable Composite Boom
August 2019
Manufactured boom and deployment system will be demonstrated



DSAC & GPIM
NET May 2019
Launch Aboard STP-2

LOFTID
April 2019
Prem. Design Review
July 2020 delivery to launch vehicle

Nuclear Thermal Propulsion
September 2019
System test of a nuclear fuel element that will reduce the risk and demonstrate feasibility of nuclear thermal propulsion

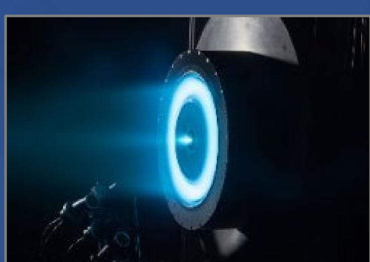


RRM3
November 2018
ISS on-orbit operations of methane cryogenic fluids demo in FY19 and FY20

Extreme Environment Solar Power
July 2019
Developing solar cell concentrator technology for low-intensity, low-temperature space power applications. Hardware will be demonstrated for subsequent technology demonstration on SMD's future mission DART

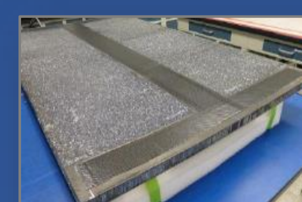
Space Technology Research Institutes 2018
STRI18 Selection Announcement expected in late March 2019

SpaceCraft Oxygen Recovery (SCOR)
June 2019
Performance test results of two advanced oxygen recovery systems will be available in June 2019 for baseline comparison of capability



Solar Electric Propulsion
FY19: Develop and test EDU/ETU/qualification hardware and complete KDP-C
FY20: Complete Critical Design Review, build qualification units and begin testing.

Composite Technology for Exploration
September 2019
Complete testing of composite joint technology that will reduce launch dry mass

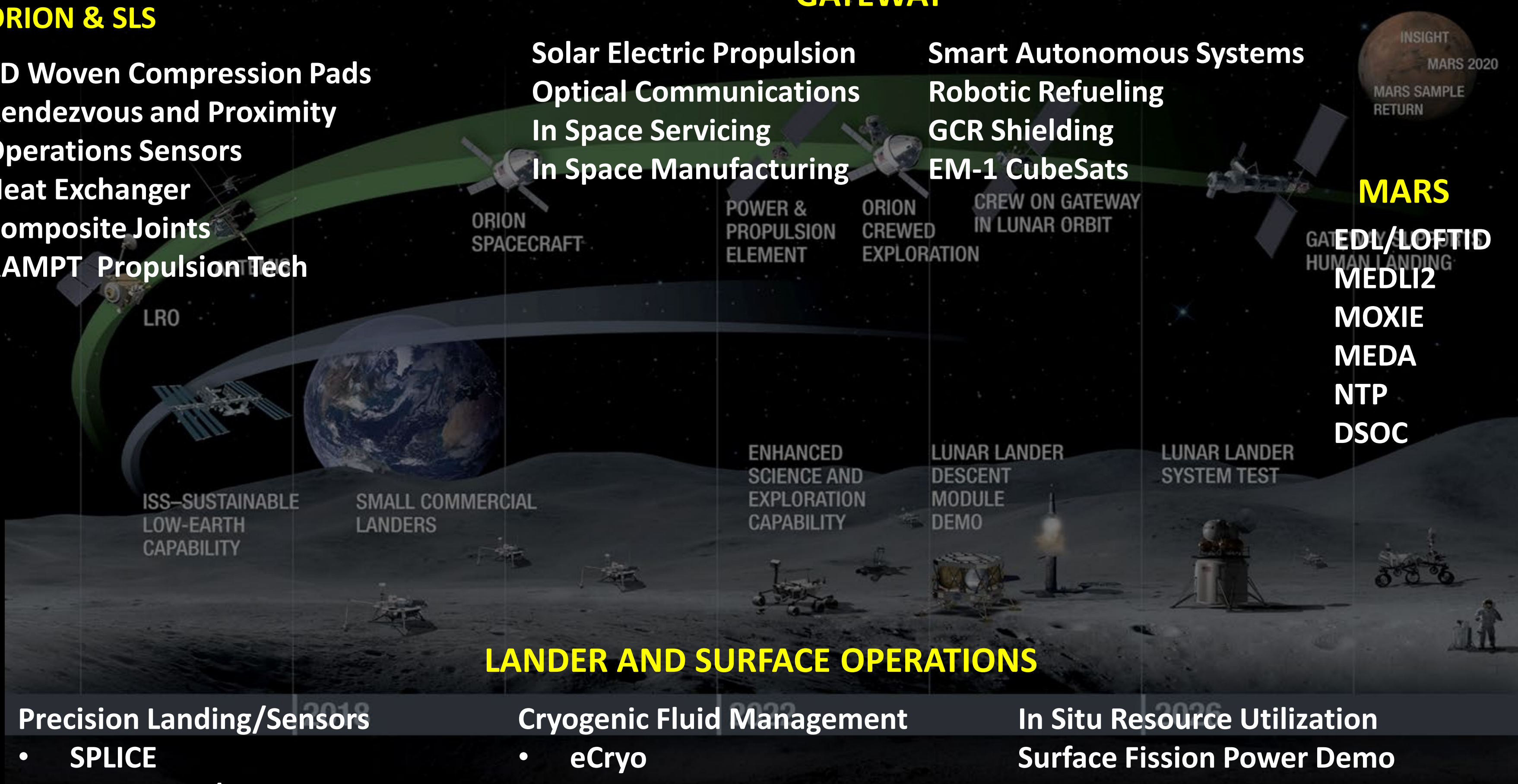


Exploration Technology FY 2020 Budget Request

Budget Authority ($M)	FY 2018 actuals	FY 2019 Appropriation	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Early Stage Innovation and Partnerships	**$91.9**		**$123.4**	**$118.0**	**$123.0**	**$118.0**	**$123.0**
Agency Technology and Innovation	$8.8		$9.4	$9.4	$9.4	$9.4	$9.4
Early Stage Innovation (NIAC, STRG, CIF/ECI)	$57.3		$77.4	$83.4	$83.4	$83.4	$83.4
Partnerships and Technology Transfer (CC, P&C, Tech Transfer, iTech)	$25.9		$36.7	$25.2	$30.2	$25.2	$30.2
Technology Maturation	**$151.5**		**$282.5**	**$227.2**	**$250.3**	**$246.7**	**$328.0**
Game Changing Development			$146.9	$148.4	$149.9	$151.4	$152.9
Lunar Surface Innovation Initiative			$119.0	$62.1	$83.7	$78.6	$158.4
Technology Demonstration	**$321.7**		**$397.5**	**$411.8**	**$391.4**	**$362.3**	**$231.2**
Restore/In-Space Robotic Servicing	$130.0	$180.0	$45.3	$45.3	$45.3	-	-
Laser Communications Relay Demonstration *	$21.5		*	*	*	-	-
Solar Electric Propulsion	$34.2		$43.4	$20.9	$4.0	$2.6	-
Small Spacecraft, Flight Opportunities & Other Technology Demonstration	$144.2		$308.8	$345.6	$342.1	$359.6	$231.2
Flight Opportunities	*$15.0*		*$20.0*	*$20.0*	*$20.0*	*$20.0*	*$20.0*
Small Spacecraft Technology	*$17.2*		*$28.3*	*$21.0*	*$20.6*	*$20.7*	*$20.3*
Deep Space Optical Communications	*$26.7*		*$21.3*	*$11.2*	*$4.6*	*$0.9*	
In-Space Robotic Manufacturing & Assembly	*18.3*		*$72.2*	*$65.0*	*$53.0*	*$3.1*	*$0.0*
Precision Landing and LOFTID	*$15.0*		*$44.8*	*$60.7*	*$56.0*	*$48.9*	*$15.2*
Nuclear Surface Power (Kilopower)			*$40.0*	*$70.0*	*$95.0*	*$100.0*	*$85.0*
Cryogenic Fluid Management	*$15.4*		*$55.0*	*$49.8*	*$31.2*	*$49.5*	*$54.6*
SBIR and STTR	**$194.8**		**$210.8**	**$219.1**	**$230.8**	**$237.5**	**$261.0**
TOTAL	**$760.0**	**$926.9**	**$1,014.3**	**$976.1**	**$995.4**	**$964.4**	**$943.1**

*LCRD estimate reflects KDP-C baseline. The project is undergoing a replan due to USAF NGIS spacecraft bus technical and bus problems. Replan is targeted for completion in April 2019.

TECHNOLOGY DRIVES EXPLORATION
SAMPLING OF CURRENT INVESTMENTS



ORION & SLS

3D Woven Compression Pads
Rendezvous and Proximity
Operations Sensors
Heat Exchanger
Composite Joints
RAMPT Propulsion Tech

GATEWAY

Solar Electric Propulsion
Optical Communications
In Space Servicing
In Space Manufacturing
Smart Autonomous Systems
Robotic Refueling
GCR Shielding
EM-1 CubeSats

MARS

EDL/LOFTID
MEDLI2
MOXIE
MEDA
NTP
DSOC

LANDER AND SURFACE OPERATIONS

Precision Landing/Sensors

- SPLICE
- Lunar TRN/Doppler Lidar
- Tipping Point Technologies
- High Performance Spaceflight Computing

Cryogenic Fluid Management

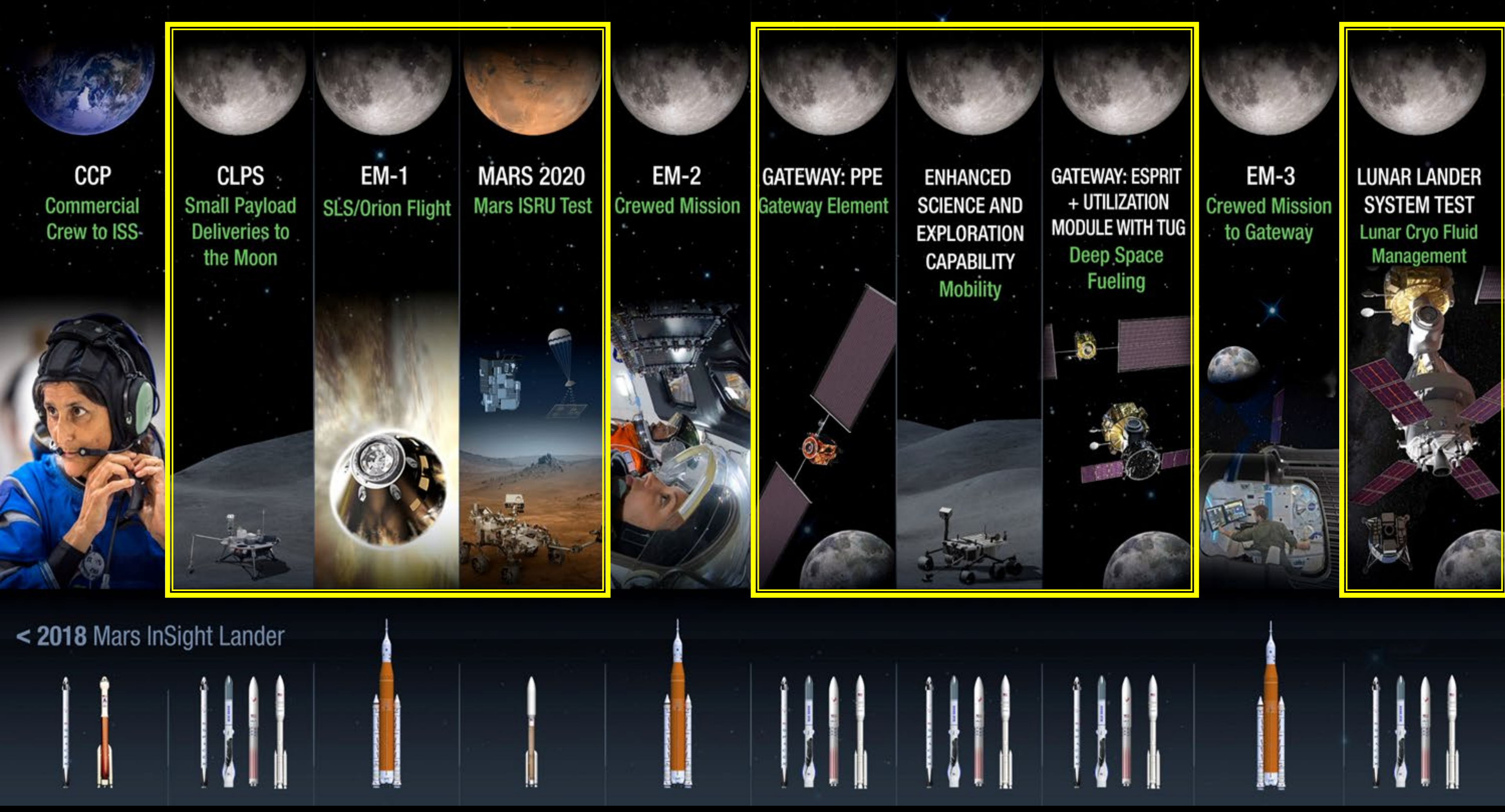
- eCryo
- High Capacity Cryocooler
- Lander Cryo Fluid Demo
- Tipping Point Technologies

In Situ Resource Utilization

Surface Fission Power Demo
Bulk Metallic Glass Gears
Surface Mobility/PUFFER
Deep Space Engine
RAMPT Propulsion Tech

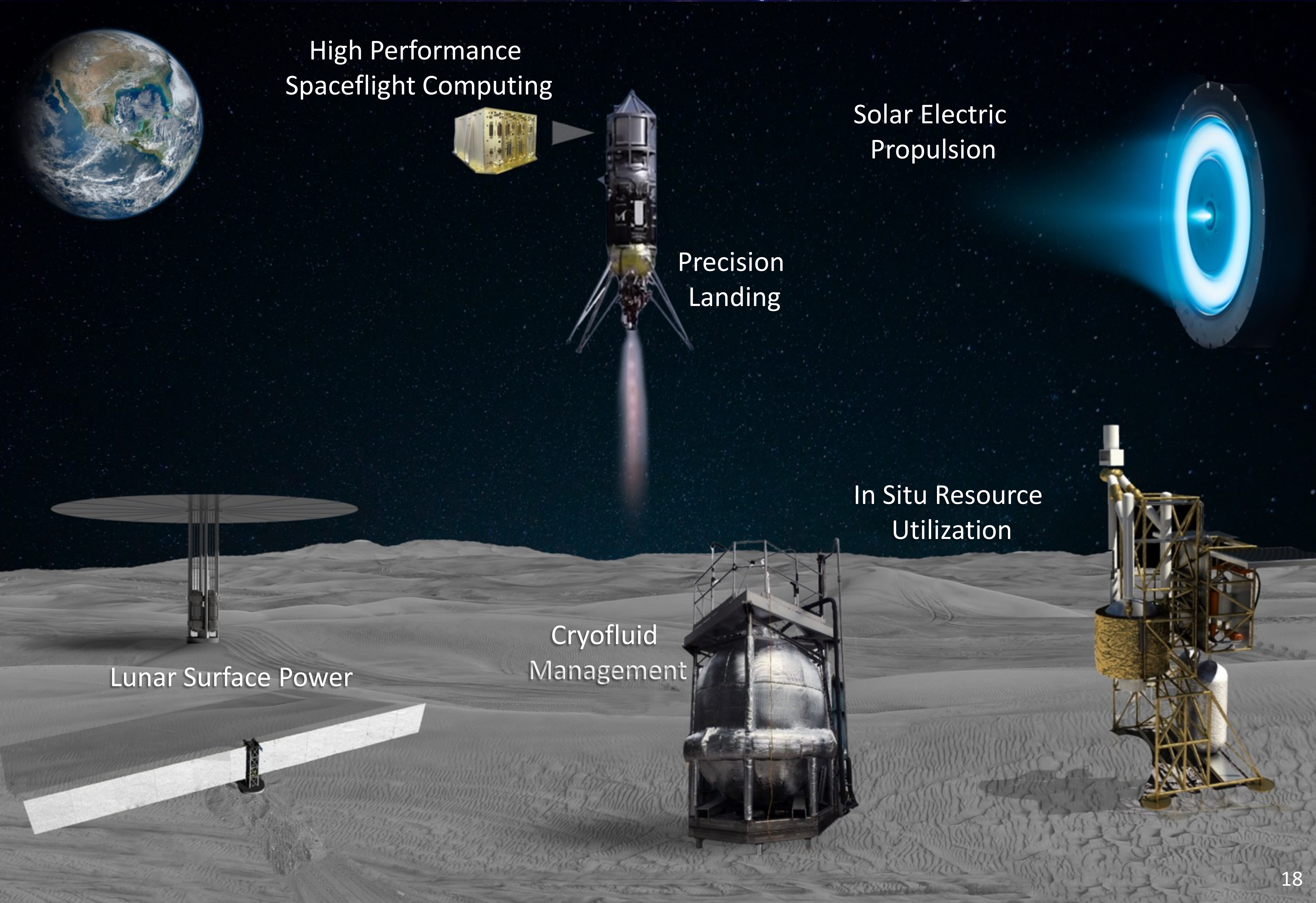
Timelines are tentative and will be developed further in FY2019

Exploration Firsts Through 2024

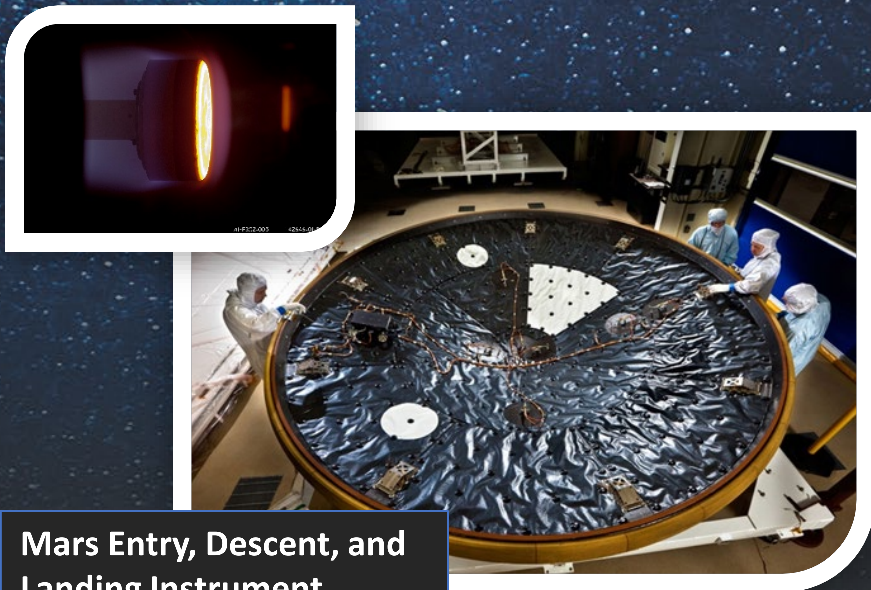


Exploration Technology key contribution

Priority Technologies for Flight Demonstration

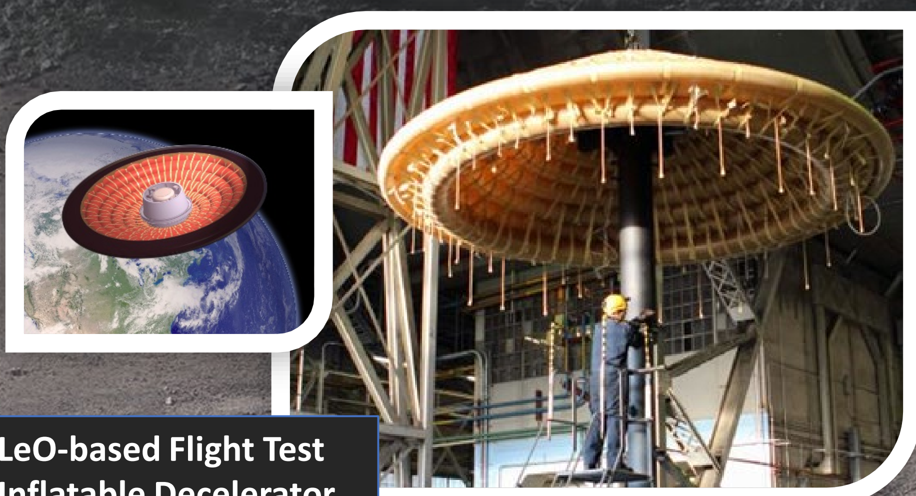


Exploration Technology in Entry, Descent, and Landing

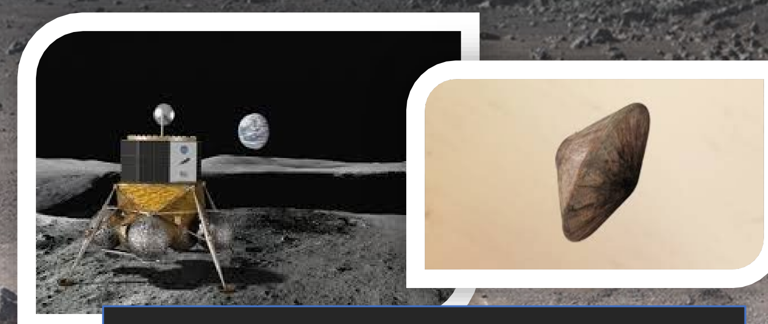


Mars Entry, Descent, and Landing Instrument (MEDLI 2) on Mars 2020

The Safe and Precise Landing Integrated Capabilities Evolution (SPLICE) project; includes high performance spaceflight computing



LeO-based Flight Test Inflatable Decelerator (LOFTID)

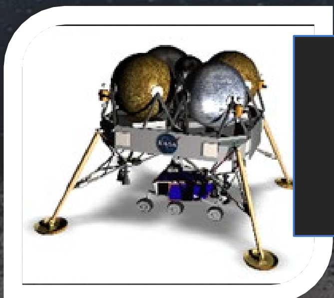


Lander Technologies through awards with Astrobotics and Blue Origins

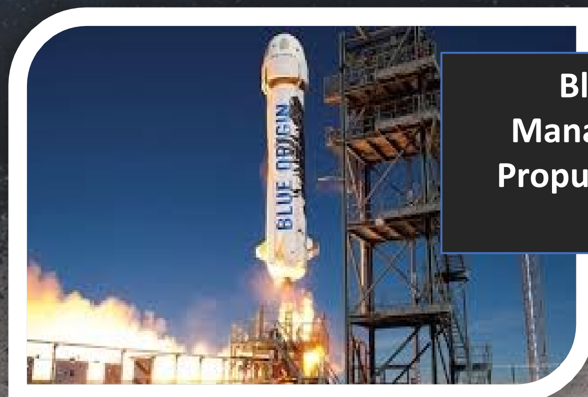
Exploration Technology in Cryogenic Fluid Management

The Robotic Refueling Mission 3(RRM3) will demonstrate cryogenic fluid transfer and storage technologies

The Evolvable Cryogenics (eCryo) project



Flight Demo Gateway & Lunar Precursor CFM Formulation



Blue Origin: "Cryogenic Fluid Management-Enhanced Integrated Propulsion Testing for Robust Lander Services"

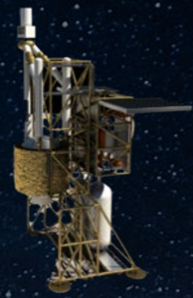
Cryocooler Development enabling zero boil-off

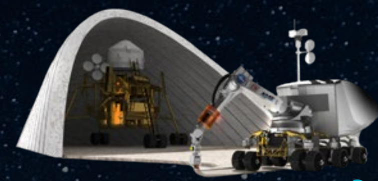
Paragon Space Development Corp.: Cryogenic Encapsulating Launch Shroud and Insulated Upper Stage (CELSIUS)

Lunar Surface Innovation Initiative

In Situ Resource Utilization

Collection, processing, storing and use of material found or manufactured on other astronomical objects



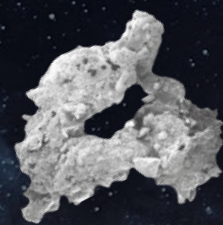


Surface Excavation/Construction

Enable affordable, autonomous manufacturing or construction

Sustainable Power

Enable continuous power throughout lunar day and night

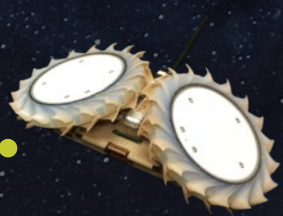


Lunar Dust Mitigation

Mitigate lunar dust hazards

Extreme Access

Access, navigate, and explore surface/subsurface areas

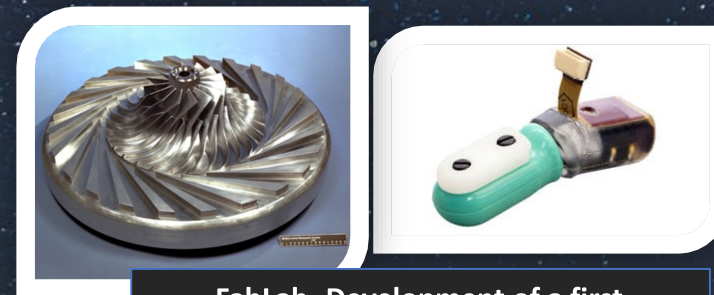


Extreme Environments

Enable systems to operate through out the full range of lunar surface conditions

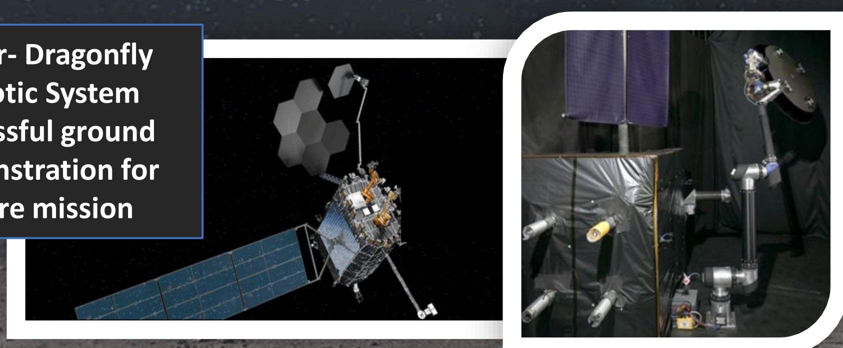
Exploration Technology for On-orbit Servicing, Assembly, and Manufacturing (OSAM)

Made In Space validated additive manufacturing and robotic assembly with a future mission –Archinaut One

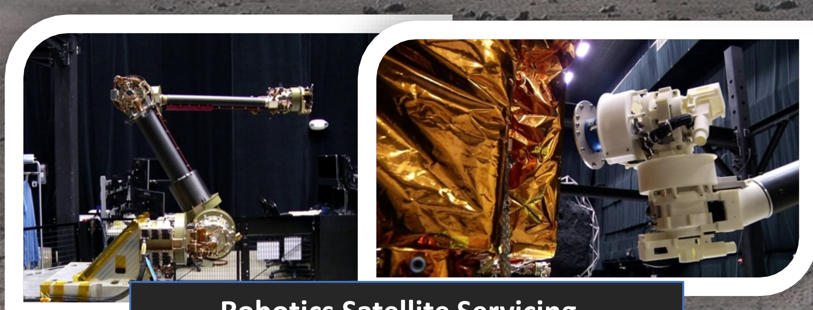


FabLab- Development of a first-generation, in-space, multi-material fabrication laboratory for space missions

Maxar- Dragonfly Robotic System successful ground demonstration for future mission

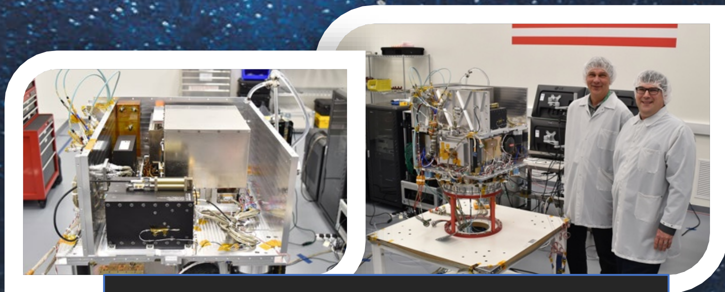


Refabricator is the first integrated 3D printer and recycler in space and currently aboard ISS



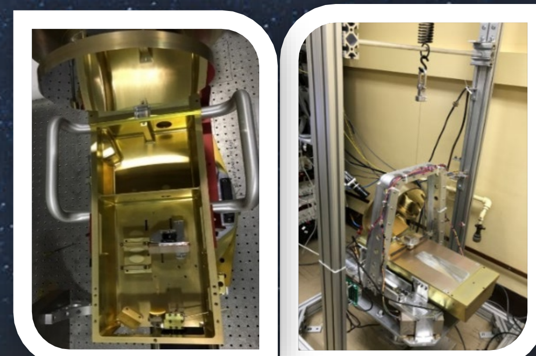
Robotics Satellite Servicing - Restore-L approaching CDR

Exploration Technology in Deep Space Communications and Navigation

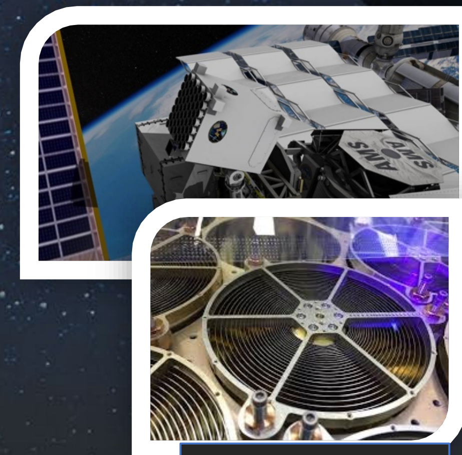


Testing of the Atomic Clock, GPS Receiver, and Ultra-Stable Oscillator which make up the Deep Space Atomic Clock Payload

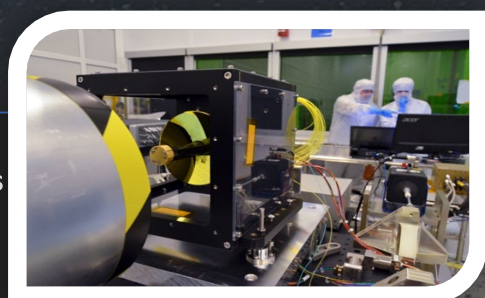
Credits: General Atomics Electromagnetic Systems



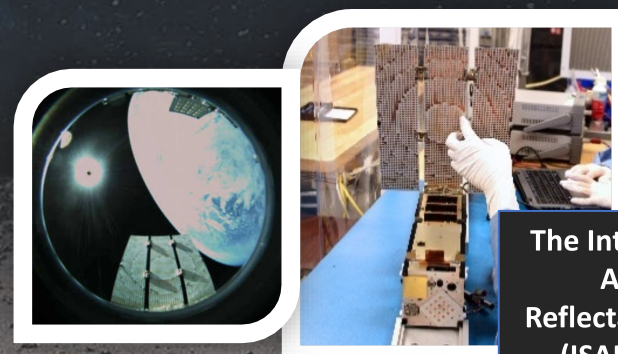
Deep Space Optical Communications project hardware being tested.



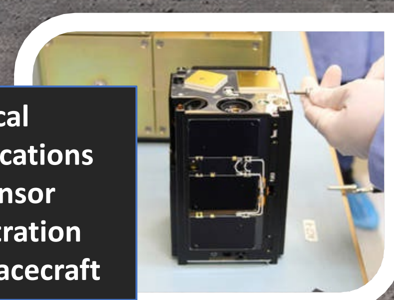
Station Explorer for X-ray Timing and Navigation Technology (SEXTANT)



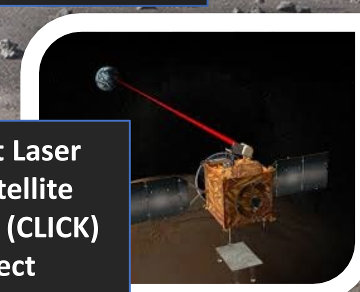
Laser Communications Relay Demonstration (LCRD) Project team integrating and testing flight hardware



The Integrated Solar Array and Reflectarray Antenna (ISARA) mission



Optical Communications and Sensor Demonstration (OCSD) spacecraft

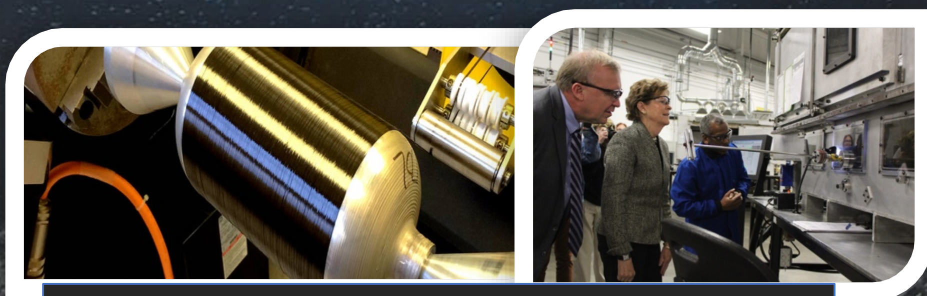


CubeSat Laser Intersatellite CrosslinK (CLICK) project

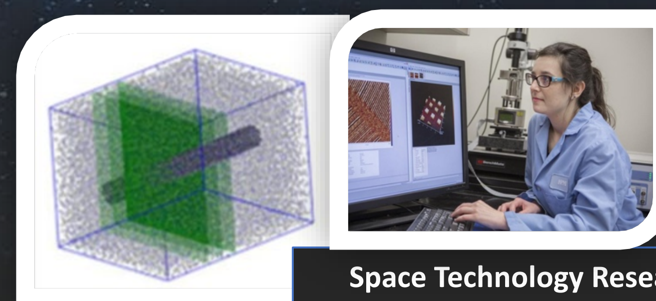
Exploration Technology in Advanced Materials

The Rapid Analysis and Manufacturing Propulsion Technology (RAMPT)

Centennial Challenges Program 3D Printed Habitat

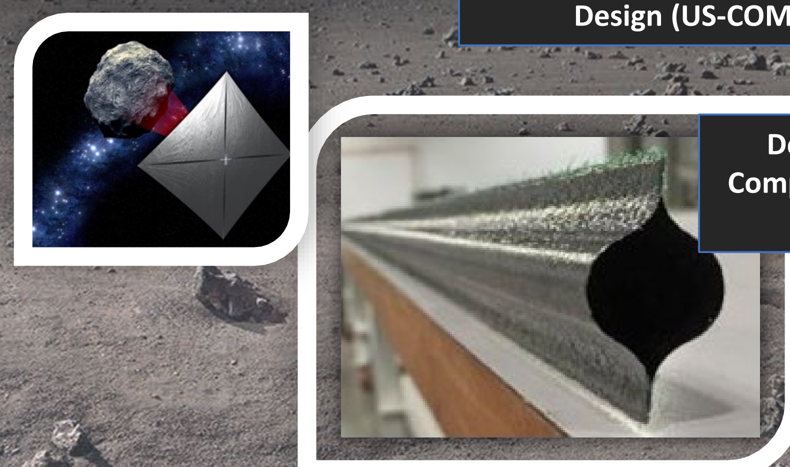


Improvement of manufacturing high-strength Carbon Nanotube Technology: >2x strength and lower costs



Space Technology Research Institute (STRI): Ultra-Strong Composites by Computational Design (US-COMP)

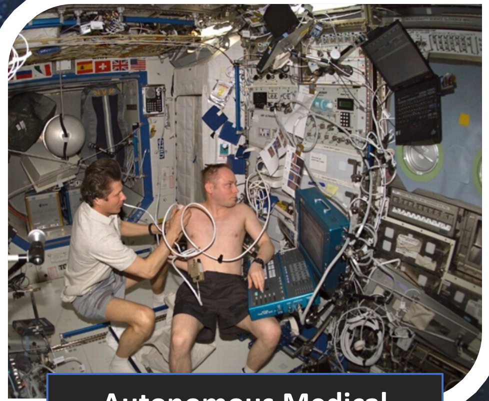
Bulk Metallic Glass Gears (BMG)



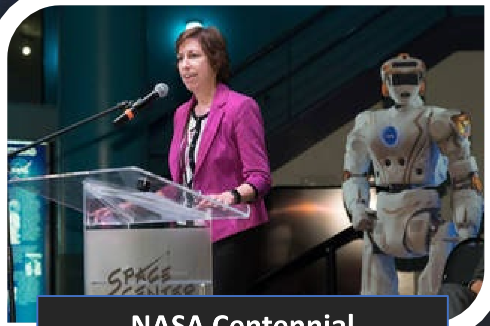
Deployable Composite Boom (DCB)

Exploration Technology in Autonomous Systems

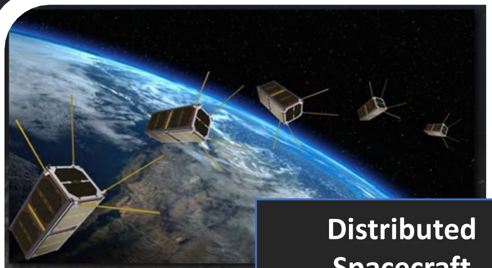
Astrobee- A self-flying robot



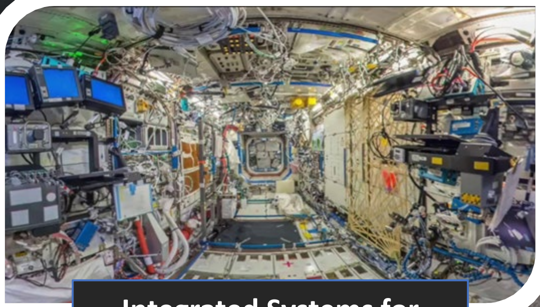
Autonomous Medical Operations (AMO)



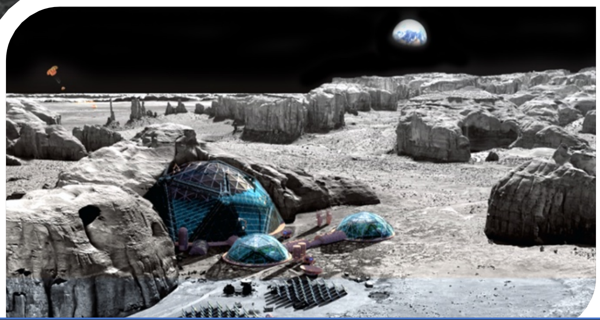
NASA Centennial Challenges Program Space Robotics Challenge Phase III



Distributed Spacecraft Autonomy (DSA)



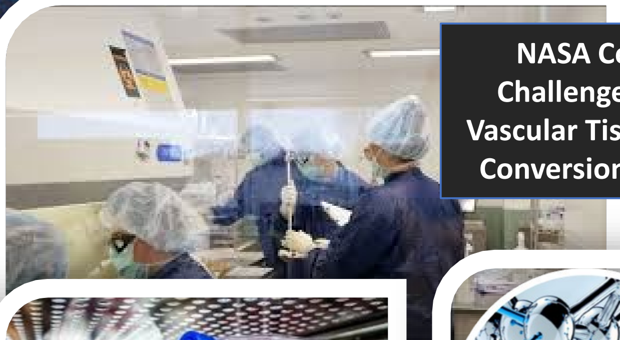
Integrated Systems for Autonomous Adaptive Caretaking (ISAAC)



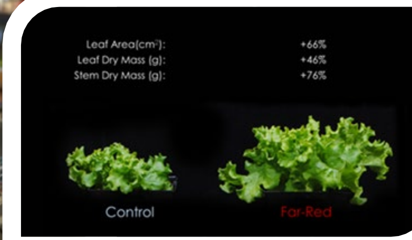
Space Technology Research Institutes (STRI): Smart Deep Space Habitats (SmartHabs) for resilient and autonomous operation.

PUFFER

Exploration Technology in Bio Manufacturing

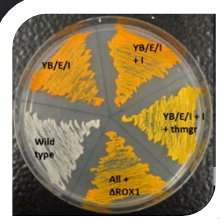


NASA Centennial Challenges Program Vascular Tissue And CO2 Conversion Challenges

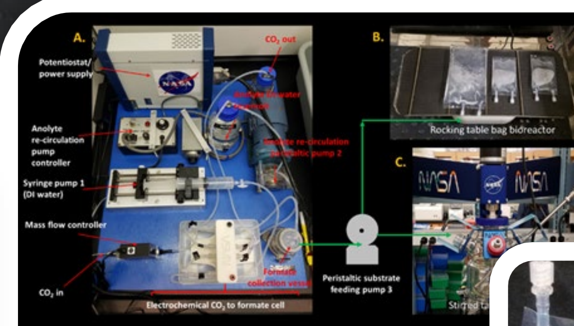


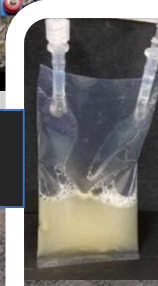
Space Technology Research Institute: The Center for the Utilization of Biological Engineering in Space (CUBES)

Biosensors for Radiation Exposure



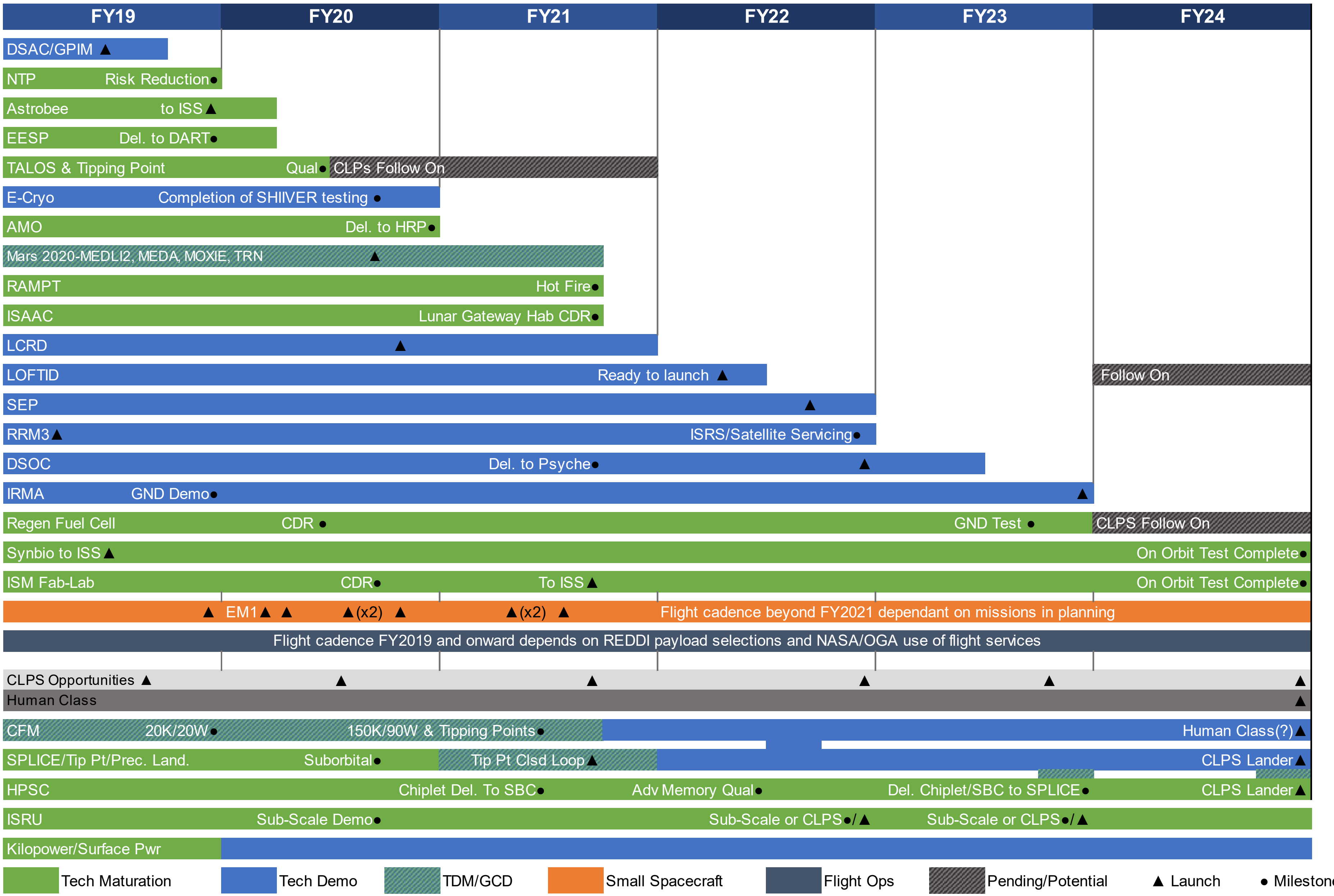
In-Space Targeted Nutrient Production





CO2-Based Biomanufacturing

Exploration Technology Milestones at a Glance



Sampling of Industry and OGA Participants in Exploration Technology

NNSA National Nuclear Security Administration
U.S. NAVAL RESEARCH LABORATORY
US Army Corps of Engineers
USGS science for a changing world
NSC
exos Aerospace
BLUE ORIGIN
DARPA
Vector Space
VENTIONS
nanodirect
ASTROBOTIC
FRONTIER AEROSPACE
PARAGON
zero G
ULA United Launch Alliance
SSL A MAXAR COMPANY
UP
Tyvak
SURREY SATELLITE TECHNOLOGY LTD
AEROJET ROCKETDYNE
SPACEX
AEROSPACE
Masten
Relativity
BOEING
HONEYBEE ROBOTICS
GENER8
Final Frontier Design
FREEDOM PHOTONICS
MOOG
NORTHROP GRUMMAN
WORLD VIEW
NEI NEI Corporation
TRANS ASTRA
Microcosm Inc
Generation Orbit
MADE IN SPACE
FREIGHT FARMS
ZONA TECHNOLOGY
FLIGHT WORKS, Inc.
X-WAVE INNOVATIONS, INC.
ExoTerra
Ball Aerospace
HRL Laboratories, LLC
E-BEAM
BRM AS AIRBORNE SYSTEMS
LOCKHEED MARTIN
VOXTELOPTO
MIT Lincoln Laboratory
BUSEK Space Propulsion and Systems
BLUE CANYON TECHNOLOGIES
IBM
FIBERTEK, INC.
Open Source Robotics Foundation
omotiv space systems
TETHERS UNLIMITED
ASTER LABS
LAUNCHPOINT
ILC DOVER creating what's next
Innoflight
PIONEER ASTRONAUTICS
Dynetics
RPM INNOVATIONS, INC.
STINGER GHAFFARIAN TECHNOLOGIES
IRIS TECHNOLOGY
Creare
IFOS Intelligent Fiber Optics Systems
MicroLink Devices, Inc.
SOUTHERN RESEARCH INSTITUTE
Princeton Lightwave
Q-PEAK
Virgin ORBIT
Aurora FLIGHT SCIENCES
ORBITEC
SIERRA LOBO
GeoOptics
SDC SAN DIEGO COMPOSITES
traclabs

STMD By The Numbers (FY 2018)

>3,500
Proposals Evaluated

>1,000
Active Technology Projects

>700
Proposals Selected

>2,900
Software Releases

>350
University Partnerships with >120 Universities

>400
Industry Collaborators

>60
Projects Leading to Flight Demonstrations

>900
Transitions since 2011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