National Aeronautics and
Space Administration

ADVANCED EXPLORATION SYSTEMS

Deep Space Exploration

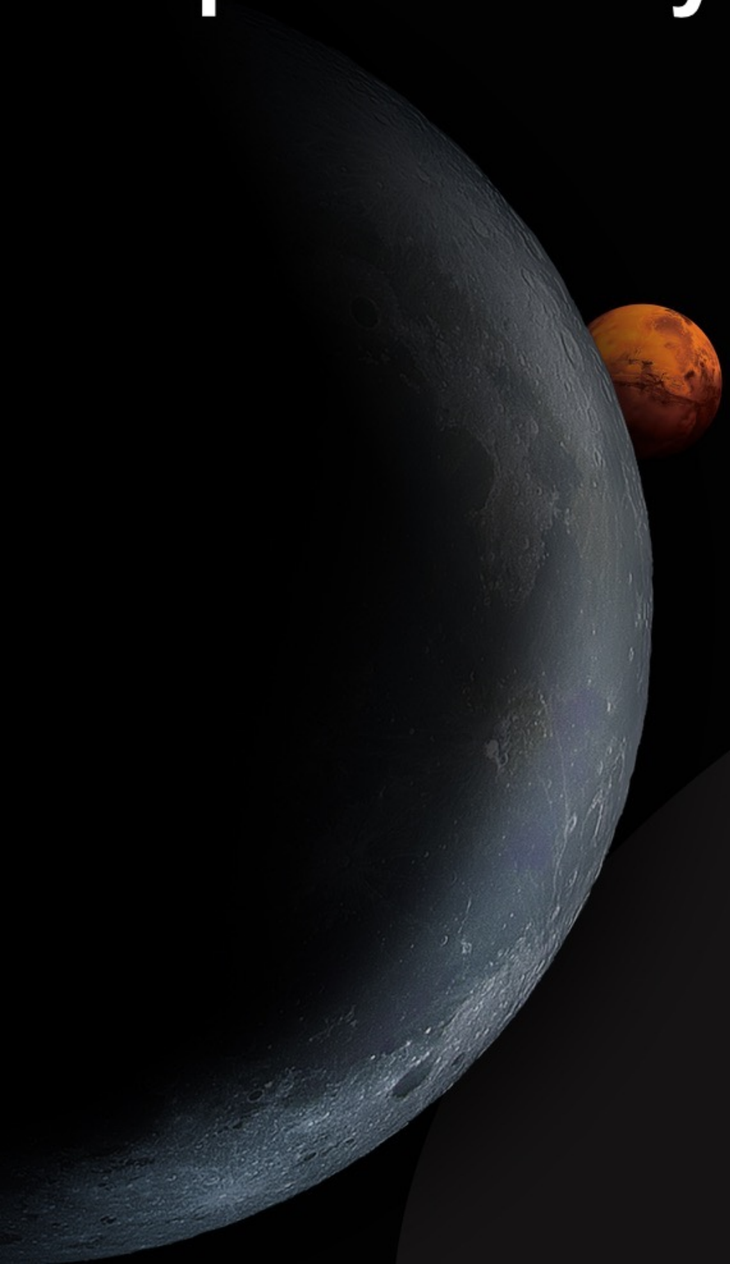
MARSHALL SMITH

Director, Human Lunar Exploration Programs

30 October 2019

ARTEMIS

Space Policy Directive 1: To The Moon, Then Mars



"Lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities. Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations…"

Why go to The Moon?

Proves technologies and capabilities for sending humans to Mars

Establishes American leadership and strategic presence

Inspires a new generation and encourages careers in STEM

Leads civilization changing science and technology

Expands the U.S. global economic impact

Broadens U.S. industry and international partnerships in deep space

Moon Before Mars

On the Moon, we can take reasonable risks while astronauts are just three days away from home.

There we will prove technologies and mature systems necessary to live and work on another world before embarking on what could be a 2-3 year mission to Mars.

The Artemis Program

Artemis is the twin sister of Apollo and goddess of the Moon in Greek mythology. Now, she personifies our path to the Moon as the name of NASA’s program to return astronauts to the lunar surface by 2024.

When they land, Artemis astronauts will step foot where no human has ever been before: the Moon’s South Pole.

With the horizon goal of sending humans to Mars, Artemis begins the next era of exploration.

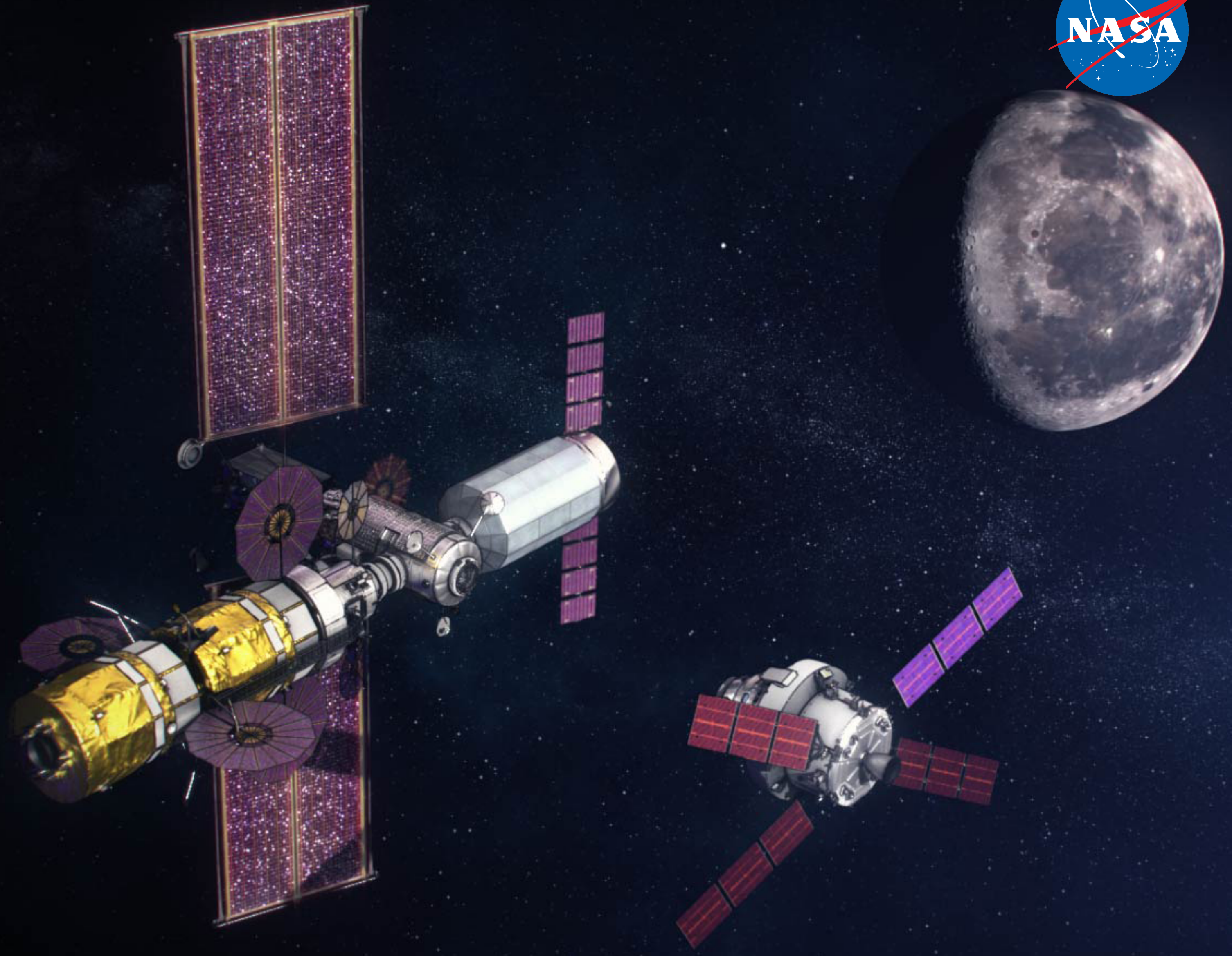
Gateway

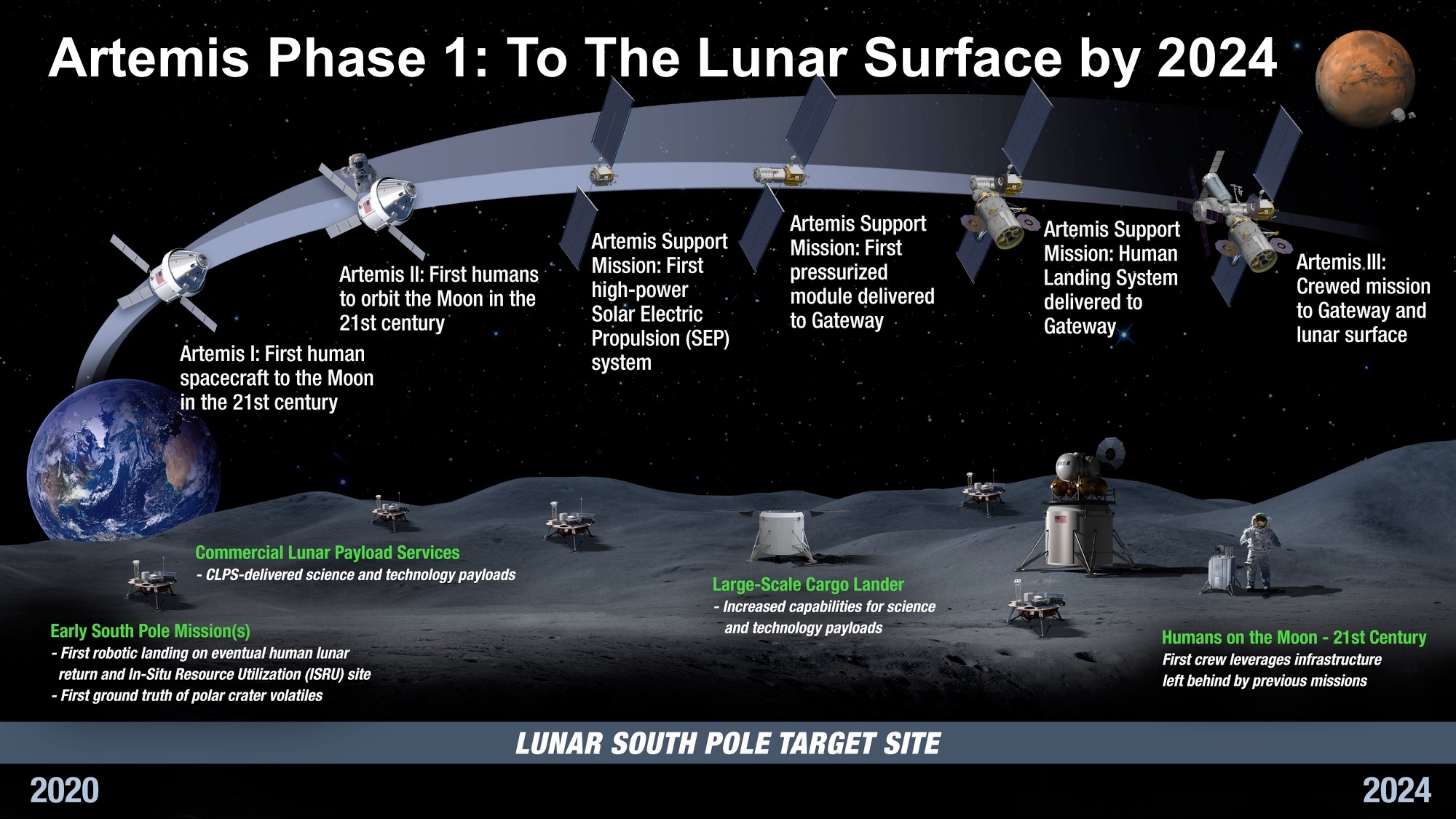
Today through 2024

Missions and systems required to achieve landing humans on the surface of the Moon in 2024

Sustainability by 2028

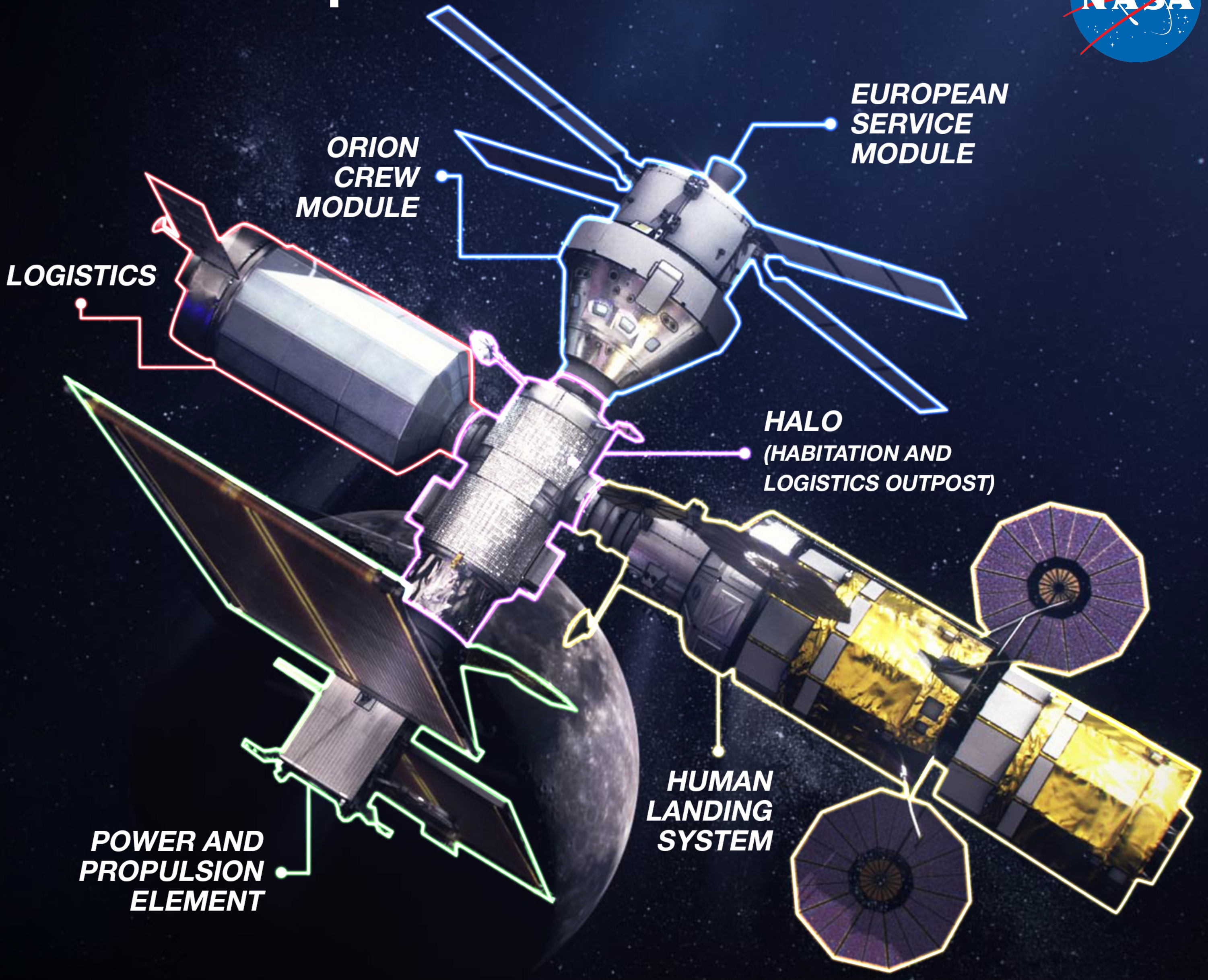
Establish a sustainable long-term presence on and around the Moon




Artemis Phase 1: To The Lunar Surface by 2024
Artemis I: First human spacecraft to the Moon in the 21st century
Artemis II: First humans to orbit the Moon in the 21st century
Artemis Support Mission: First high-power Solar Electric Propulsion (SEP) system
Artemis Support Mission: First pressurized module delivered to Gateway
Artemis Support Mission: Human Landing System delivered to Gateway
Artemis III: Crewed mission to Gateway and lunar surface
Commercial Lunar Payload Services
- CLPS-delivered science and technology payloads
Early South Pole Mission(s)
- First robotic landing on eventual human lunar return and In-Situ Resource Utilization (ISRU) site
- First ground truth of polar crater volatiles
Large-Scale Cargo Lander
- Increased capabilities for science and technology payloads
Humans on the Moon - 21st Century
First crew leverages infrastructure left behind by previous missions
LUNAR SOUTH POLE TARGET SITE
2020
2024

Gateway Enables Lunar and Mars Exploration '

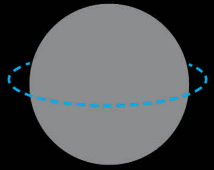
- Minimum systems required to support a 2024 human landing while also supporting Phase 2
- Command center and aggregation point for 2024 human landing
- Strategic presence around the Moon
- Resilience sustainability and robustness in the lunar architecture
- Open architecture and interoperability standards are building blocks for partnerships and future expansion



GATEWAY ORBIT

Cislunar space offers innumerable orbits for consideration, each with merit for a variety of operations. The Gateway will support missions to the lunar surface and serve as a staging area for exploration farther into the solar system, including Mars.

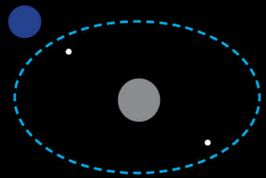
ORBIT TYPES



LOW LUNAR ORBITS

Circular or elliptical orbits close to the surface. Excellent for remote sensing, difficult to maintain in gravity well.

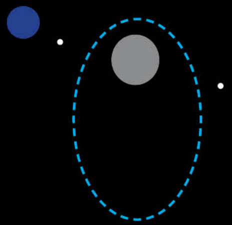
» Orbit period: 2 hours



DISTANT RETRO-GRADE ORBITS

Very large, circular, stable orbits. Easy to reach from Earth, but far from lunar surface.

» Orbit period: 2 weeks



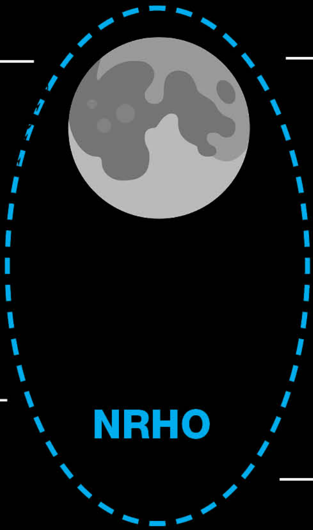
HALO ORBITS

Fuel-efficient orbits revolving around Earth-Moon neutral-gravity points.

» Orbit period: 1-2 weeks

NEAR-RECTILINEAR HALO ORBIT (NRHO)

1,500 km at its closest to the lunar surface, 70,000 km at its farthest.



ACCESS

Easy to access from Earth orbit with many current launch vehicles. Staging point for both lunar surface and deep space destinations.

ENVIRONMENT

Deep space environment useful for radiation testing and experiments in preparation for missions to the lunar surface and Mars.

SCIENCE

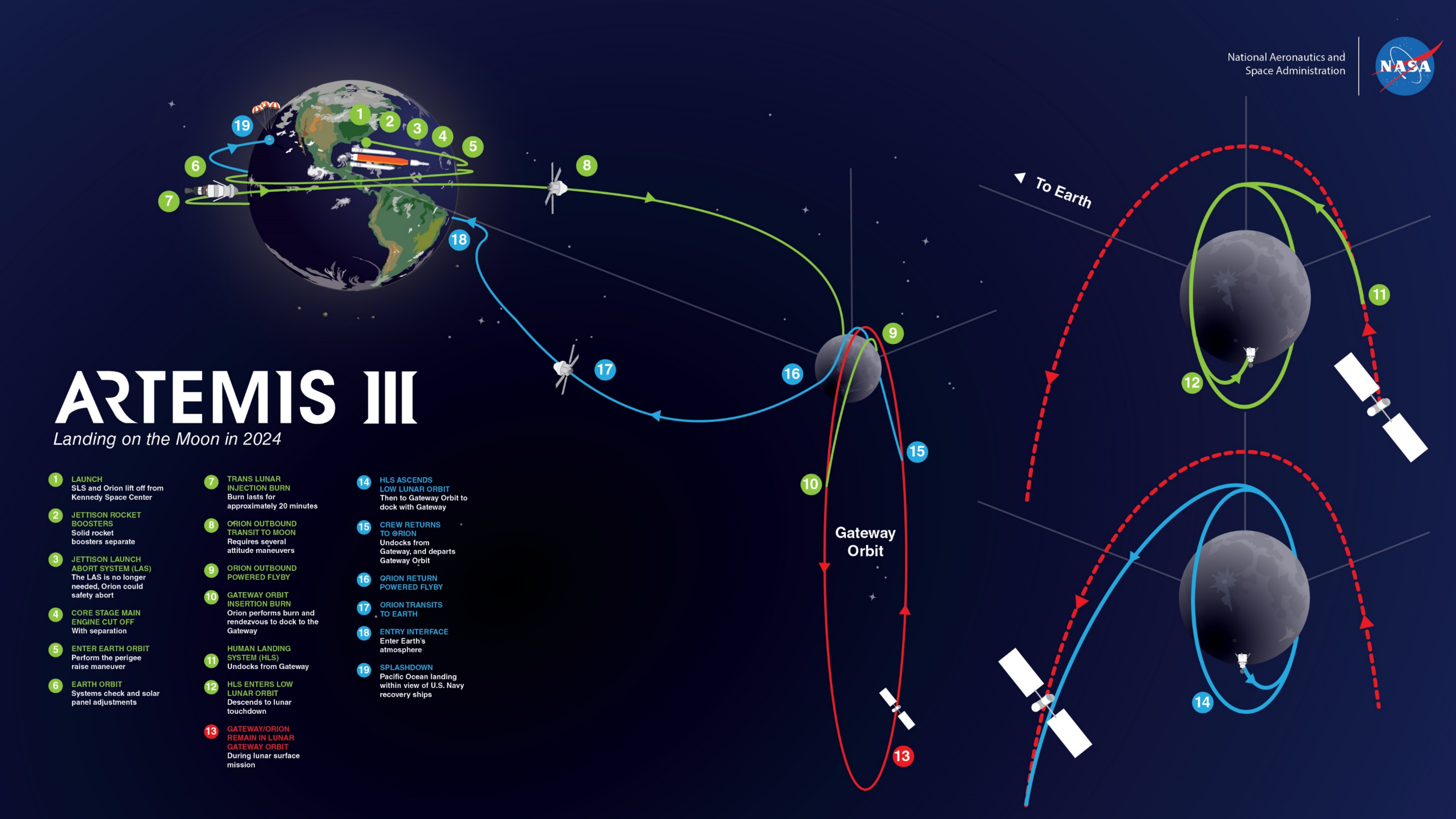
Favorable vantage point for Earth, sun and deep space observations.

COMMUNICATIONS

Provides continuous view of Earth and communication relay for lunar farside.

SURFACE OPERATIONS

Supports surface telerobotics, including lunar farside. Provides a staging point for planetary sample return missions.


National Aeronautics and Space Administration
NASA
ARTEMIS III
Landing on the Moon in 2024
To Earth
Gateway Orbit
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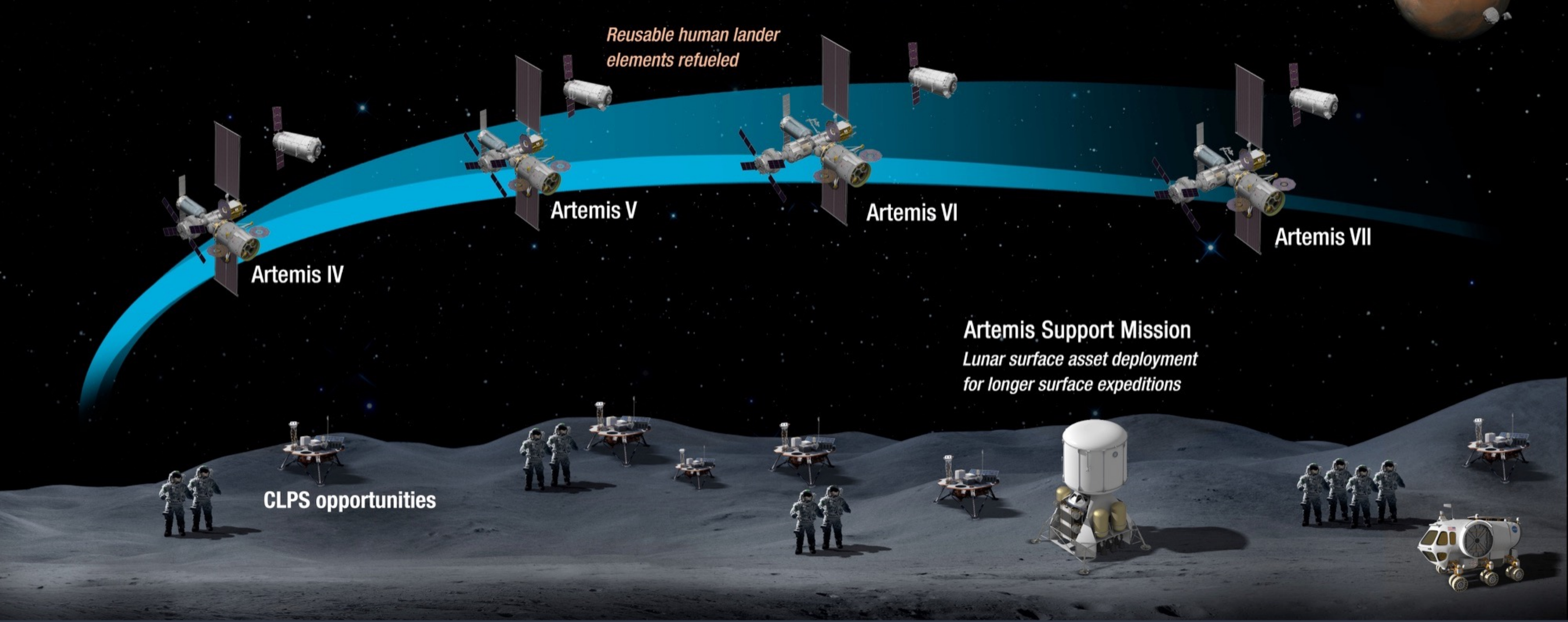
1 LAUNCH SLS and Orion lift off from Kennedy Space Center
2 JETTISON ROCKET BOOSTERS Solid rocket boosters separate
3 JETTISON LAUNCH ABORT SYSTEM (LAS) The LAS is no longer needed, Orion could safety abort
4 CORE STAGE MAIN ENGINE CUT OFF With separation
5 ENTER EARTH ORBIT Perform the perigee raise maneuver
6 EARTH ORBIT Systems check and solar panel adjustments
7 TRANS LUNAR INJECTION BURN Burn lasts for approximately 20 minutes
8 ORION OUTBOUND TRANSIT TO MOON Requires several attitude maneuvers
9 ORION OUTBOUND POWERED FLYBY
10 GATEWAY ORBIT INSERTION BURN Orion performs burn and rendezvous to dock to the Gateway
11 HUMAN LANDING SYSTEM (HLS) Undocks from Gateway
12 HLS ENTERS LOW LUNAR ORBIT Descends to lunar touchdown
13 GATEWAY/ORION REMAIN IN LUNAR GATEWAY ORBIT During lunar surface mission
14 HLS ASCENDS LOW LUNAR ORBIT Then to Gateway Orbit to dock with Gateway
15 CREW RETURNS TO ORION Undocks from Gateway, and departs Gateway Orbit
16 ORION RETURN POWERED FLYBY
17 ORION TRANSITS TO EARTH
18 ENTRY INTERFACE Enter Earth's atmosphere
19 SPLASHDOWN Pacific Ocean landing within view of U.S. Navy recovery ships

Artemis Phase 2: Building Capabilities For Mars Missions



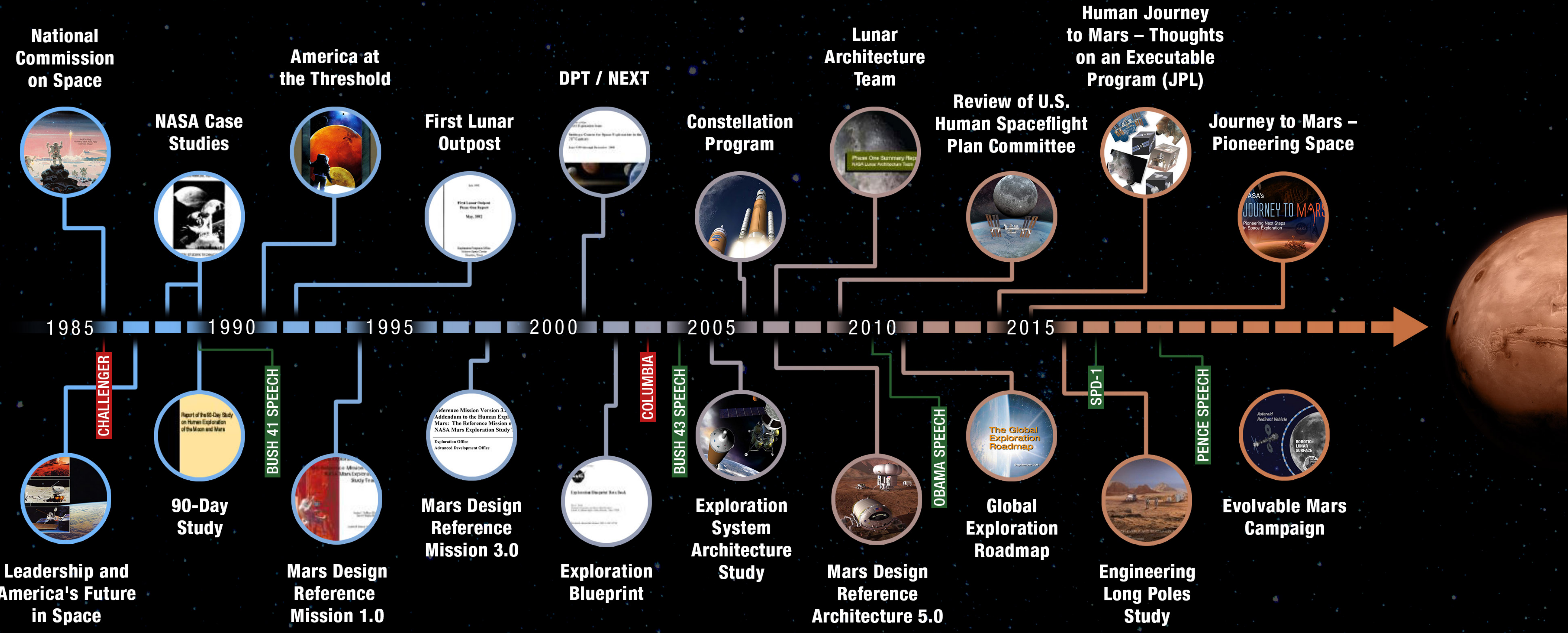
SUSTAINABLE LUNAR ORBIT STAGING CAPABILITY AND SURFACE EXPLORATION

MULTIPLE SCIENCE AND CARGO PAYLOADS | INTERNATIONAL PARTNERSHIP OPPORTUNITES | TECHNOLOGY AND OPERATIONS DEMONSTRATIONS FOR MARS

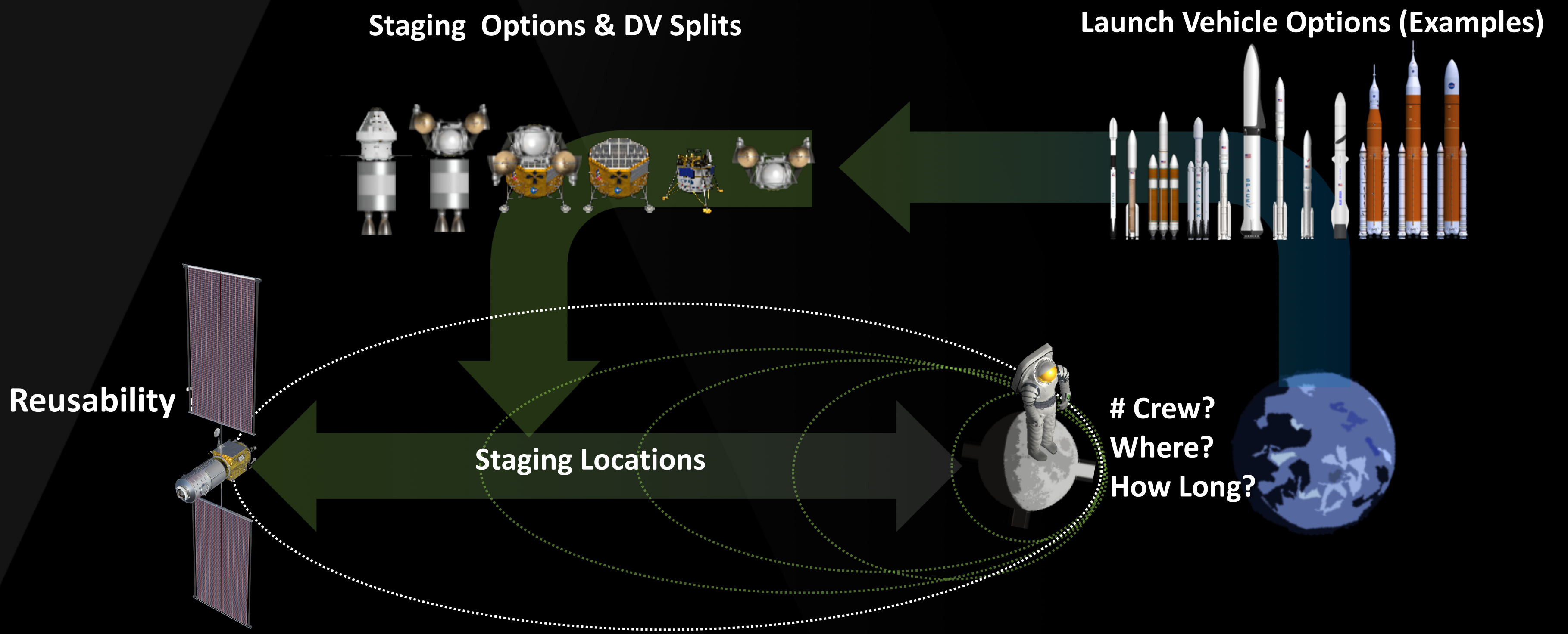
2025 — 2029

LUNAR ARCHITECTURE UPDATES

A Brief History of Beyond LEO Human Exploration Studies '



Broad Trade Space for Sustainable Human Lunar Access



The architecture for returning humans to the lunar surface is a function of physics, available technology and weighted figures of merit

Key Takeaways from Recent Architecture Studies (1/3)

- **Global Point of Departure:**
  - Remote-control robotic mobility between crew expeditions can reduce logistics needed to explore across multiple locations.
- **Constellation Surface Architecture Reference Document (SARD)**
  - Permanent human presence at a large lunar base requires a substantial amount of logistics delivered into the lunar gravity well, even with ISRU.
  - The lunar polar environment is energy friendly due to abundant solar viewing and moderated temperatures.
  - Mobility, both unpressurized and pressurized, enables significant exploration capability beyond the lunar base.

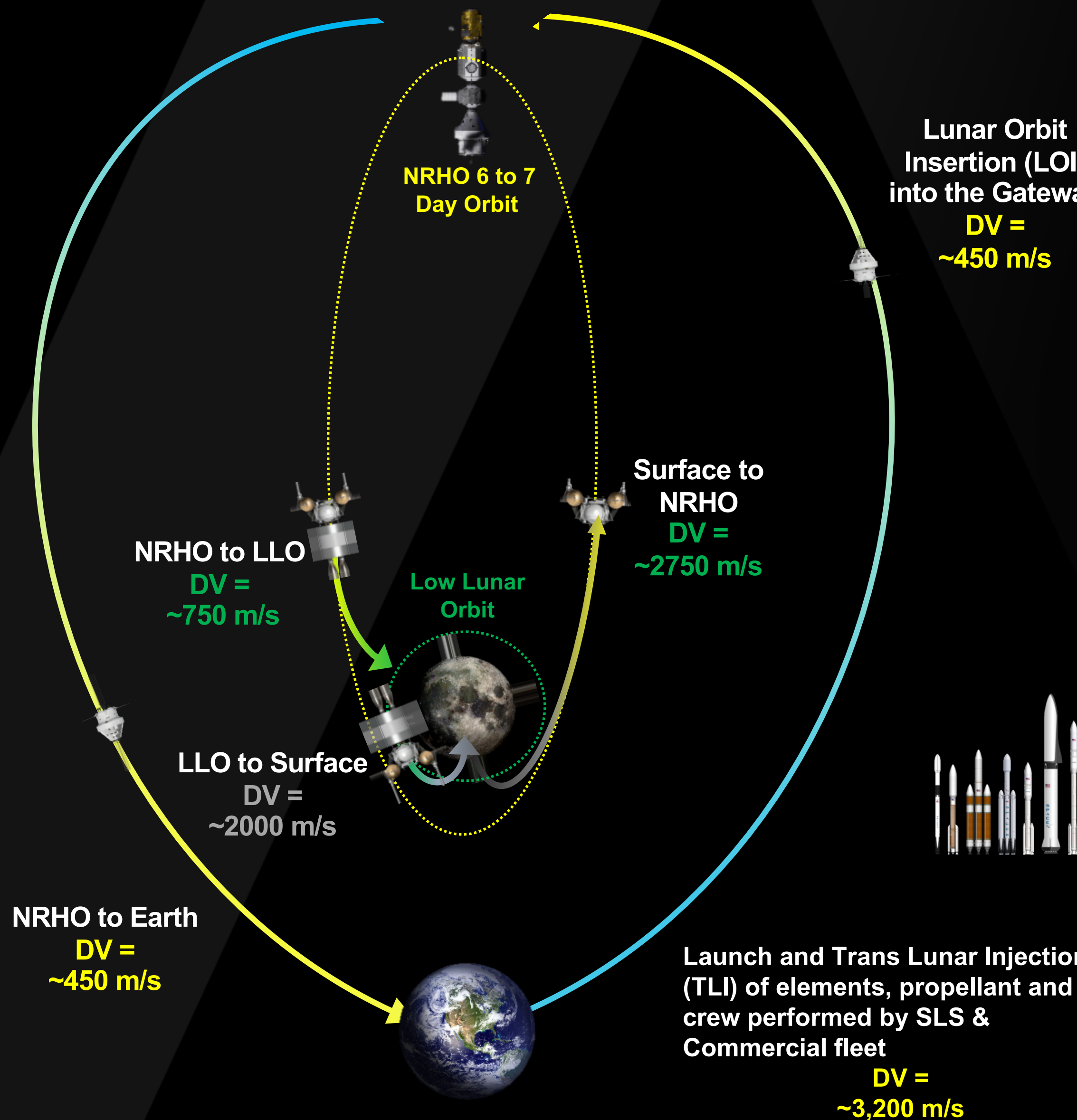
Key Takeaways from Recent Architecture Studies (2/3)

- **Desert RATS (and other analogs)**
  - Lunar surface mobility is key to any long-term presence.
  - Compared to Apollo, the large increase in data bandwidth will enable greater crew autonomy and the use of teleoperations of the surface assets.
- **Evolvable Mars Campaign**
  - ISS is required for human research and technology development (particularly ECLSS) in microgravity, and early Mars analogs.
  - Gateway is required for deep space biological research and systems stress-testing.
  - Gateway is required for assembling and outfitting the deep space transport and for refueling and aggregation of propulsion systems for subsequent Mars missions.

Key Takeaways from Recent Architecture Studies (3/3)

- **NextSTEP Activities**
  - Short duration habitats can be built using existing technologies – longer duration habitats require additional ECLSS investments.
  - Interoperability standards are necessary to foster commitments and investments from broadest range of stakeholders.
  - Ground-based human-in-the-loop testing is advantageous for early determination of key layout features and requirements.
  - Larger habitats foster more efficiency for crew tasks due to less interference amongst the other required ongoing activities.

The Physics Driving Lunar Architecture Choices



Crewed lunar surface missions to polar regions require 9,590 m/s roundtrip through Gateway.

ΔV for equivalent Direct to LLO mission is approximately ~7% lower but requires slightly more mass for first mission. However, for subsequent missions, the Gateway approach significantly reduces mass and cost

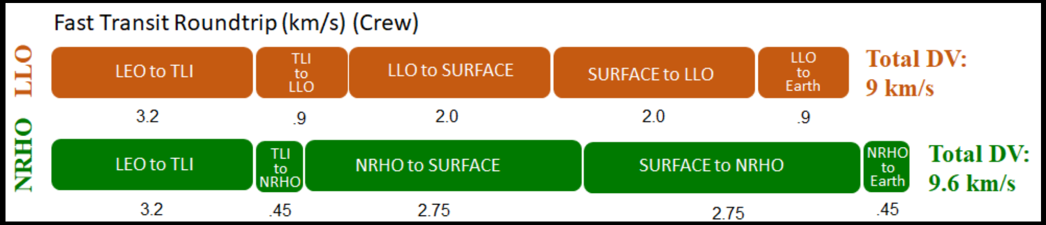
Gateway approach allows for ΔV to be distributed across multiple elements reducing mass per launch

Commercial Launch Vehicles projected to be capable of sending up to 15 mT to TLI (using upper stage for TLI burns and service module or integrated propulsion for NRHO insertion burn).

SLS projected to be capable of sending 10 mT (Block 1B, co-manifested with Orion) to 40 mT (Block 1B cargo) to TLI.

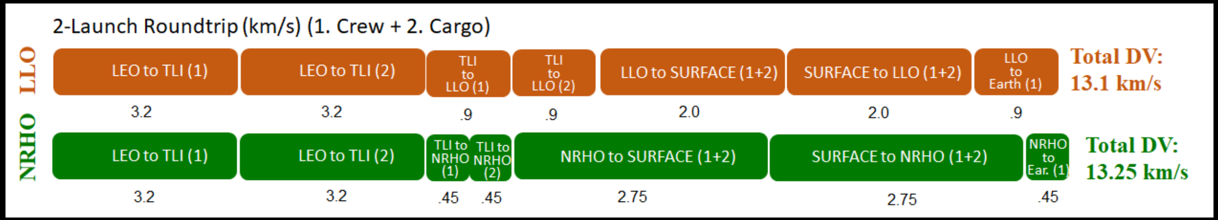
Delta V Comparisons for NRHO to LLO

Crew on Fast Transit



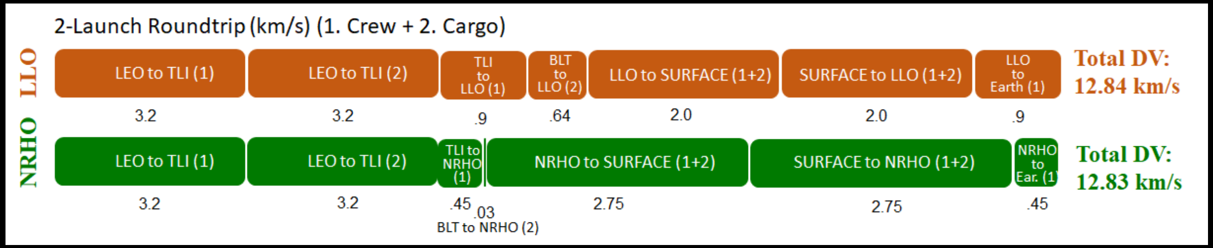
Round trip transits where everything is delivered fast on a single launch incur about .6 km/s penalty (6.7% of total).

Scenario 1: Two Launch Scenario (Cargo Fast Transit)



Round trip fast transits for 2 launches incur only a .15 km/s penalty (1.1% of total).

Scenario 2: Two Launch Scenario (Cargo on Ballistic Lunar Transfer)



Round trip transits for 2 launches where cargo is delivered on ballistic lunar transfer incurs 0 km/s penalty (0% of total).

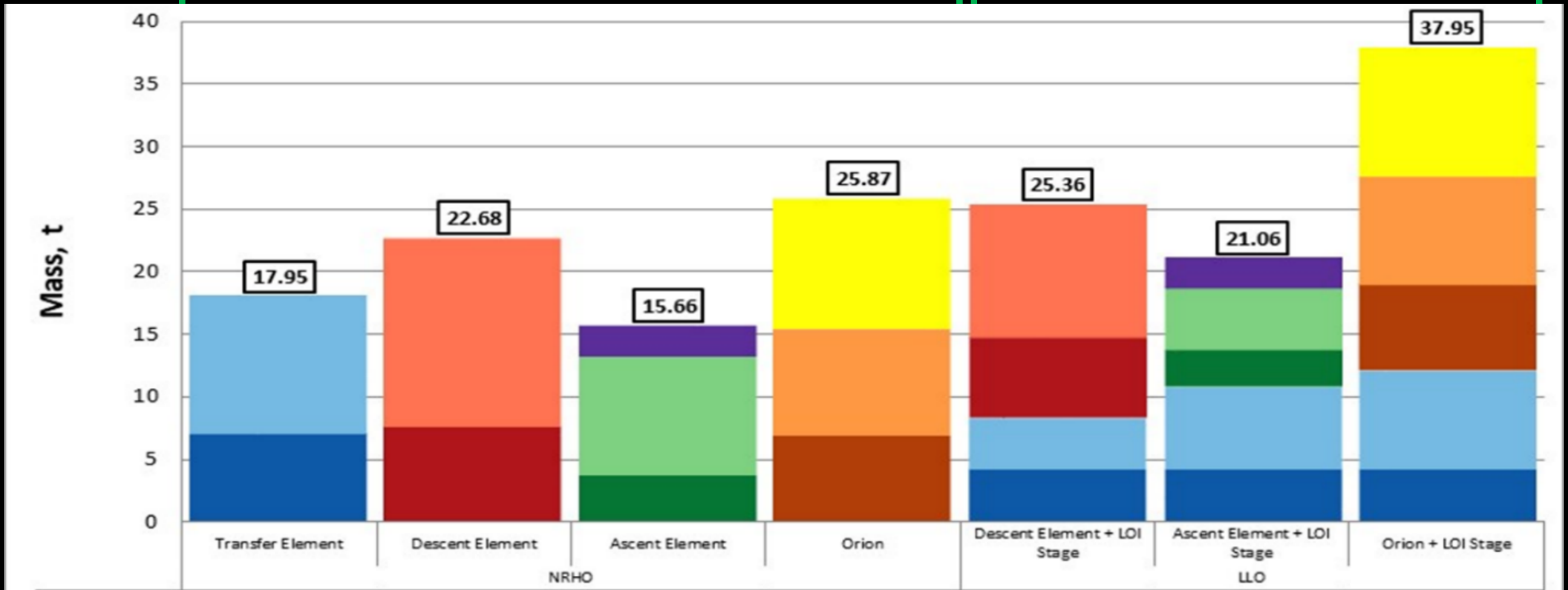
- Reduced spacecraft ΔV
- Reduced operational cadence (more time between maneuvers)
- Increased launch window
- Smaller bus required for LOI (~ 3 mt)

ΔV penalties for direct vs. NRHO are negligible for integrated crew and cargo missions

Mass Comparison for Post-TLI NRHO vs. LLO

NRHO Scenario (82.2t)

LLO Scenario (84.4t)



	NRHO				LLO		
	Transfer Element	Descent Element	Ascent Element	Orion	Descent Element + LOI Stage	Ascent Element + LOI Stage	Orion + LOI Stage
Total	17.95	22.68	15.66	25.87	25.36	21.06	37.95
CM				10.39			10.39
SM Usable				8.60			8.60
SM Inert				6.88			6.88
ACM Down-only			0.00			0.00	
ACM Down+Up			2.50			2.50	
ASM Usable			9.41			4.85	
ASM Inert			3.76			2.90	
DE Usable		15.13			10.60		
DE Inert		7.55			6.51		
TE Usable	10.97				4.02	6.57	7.85
TE Inert	6.98				4.23	4.23	4.23

Ballistic transfers into NRHO (65 m/s) are extremely efficient relative to ballistic transfers into LLO (640 m/s). The LOI penalty for LLO cases offsets the mass cost to transfer between NRHO and LLO.

The relative differences in total TLI mass between the two paths are minimal

Near-Rectilinear Halo Orbit

Lunar Science by 2024

Polar Landers and Rovers

- First direct measurement of polar volatiles, improving understanding of lateral and vertical distribution, physical state, and chemical composition
- Provide geology of the South-Pole Aitken basin, largest impact in the solar system

Non-Polar Landers and Rovers

- Explore scientifically valuable terrains not investigated by Apollo, including landing at a lunar swirl and making first surface magnetic measurement
- Using PI-led instruments to generate Discovery-class science, like establishing a geophysical network and visiting a lunar volcanic region to understand volcanic evolution

Orbital Data

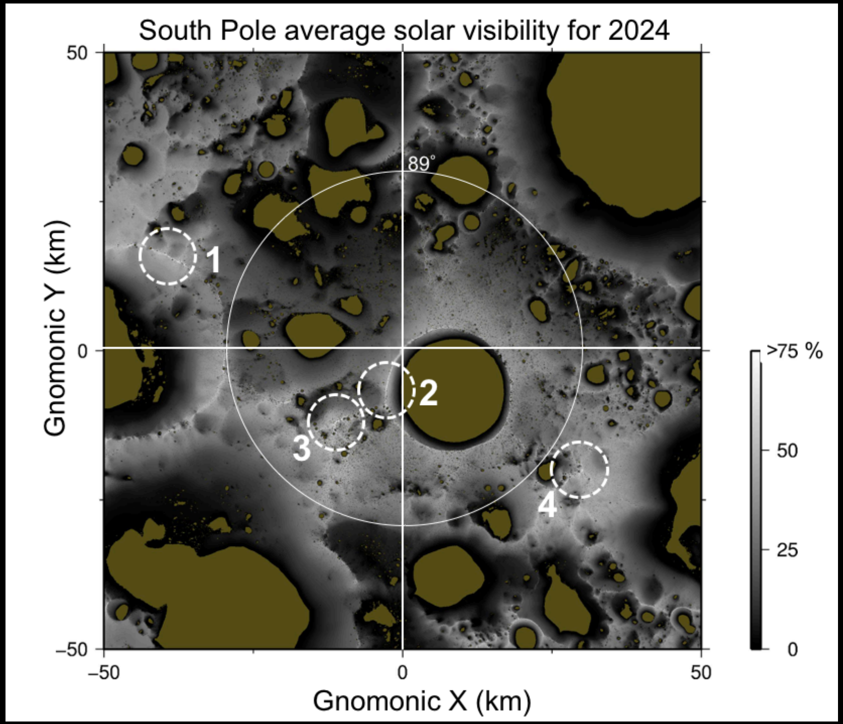
- Deploy multiple CubeSats with Artemis 1
- Potential to acquire new scientifically valuable datasets through CubeSats delivered by CLPS providers or comm/relay spacecraft
- Global mineral mapping, including resource identification, global elemental maps, and improved volatile mapping

In-Situ Resource Initial Research

- Answering questions on composition and ability to use lunar ice for sustainment and fuel

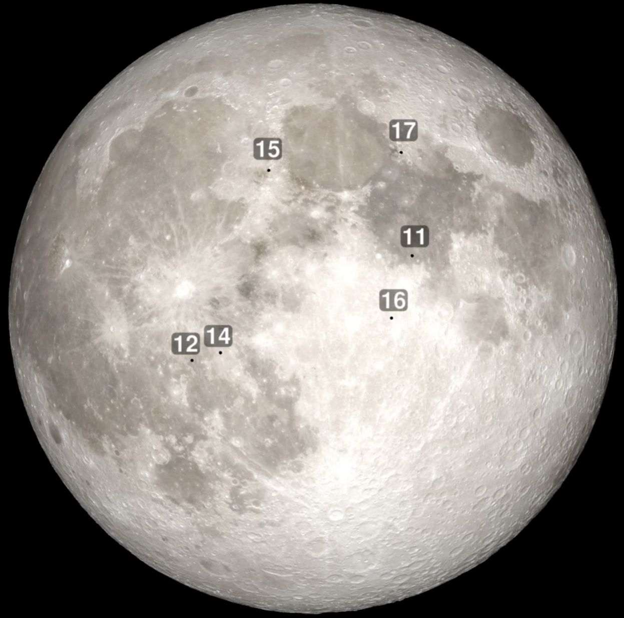
American Strategic Presence on the Moon –

High solar illumination areas within 2 degrees (<50 km) of the lunar south pole.



Four highly illuminated areas shown above:

1. De Gerlache Rim,
2. Shackleton Rim
3. Shackleton – De Gerlache Ridge
4. Plateau near Shackleton



High Priorities for Sustained Surface Activities

- **Long duration access to sunlight:** A confirmed resource providing power and minimal temperature variations
- **Direct to Earth communication:** Repeatable Earth line-of-sight communication for mission support
- **Surface roughness and slope:** Finding the safest locations for multiple landing systems, robotic and astronaut mobility
- **Permanently Shadowed Regions and Volatiles:** Learning to find and access water ice and other resources for sustainability

Reaching The Moon And Mars Faster With NASA Technology

PROGRESS UPDATES

Power and Propulsion Element

- **Power** – 60 kW+ provided by Roll Out Solar Array (ROSA) and Maxar's 1300 commercial power subsystem
- **Propulsion** – Leverage NASA development of 12.5 kW Electric Propulsion (EP), and internal Maxar advanced EP development, with Maxar expertise in system accommodation of EP elements
- **Communications** – Ka-band, X-band
- **Guidance Navigation and Control**
- **Gateway Interface Support** –docked components, visiting vehicles, robotics, science payloads, Human Landing System
- **Payload Transfer** – 1000kg for lunar lander or science instruments

Gateway HALO

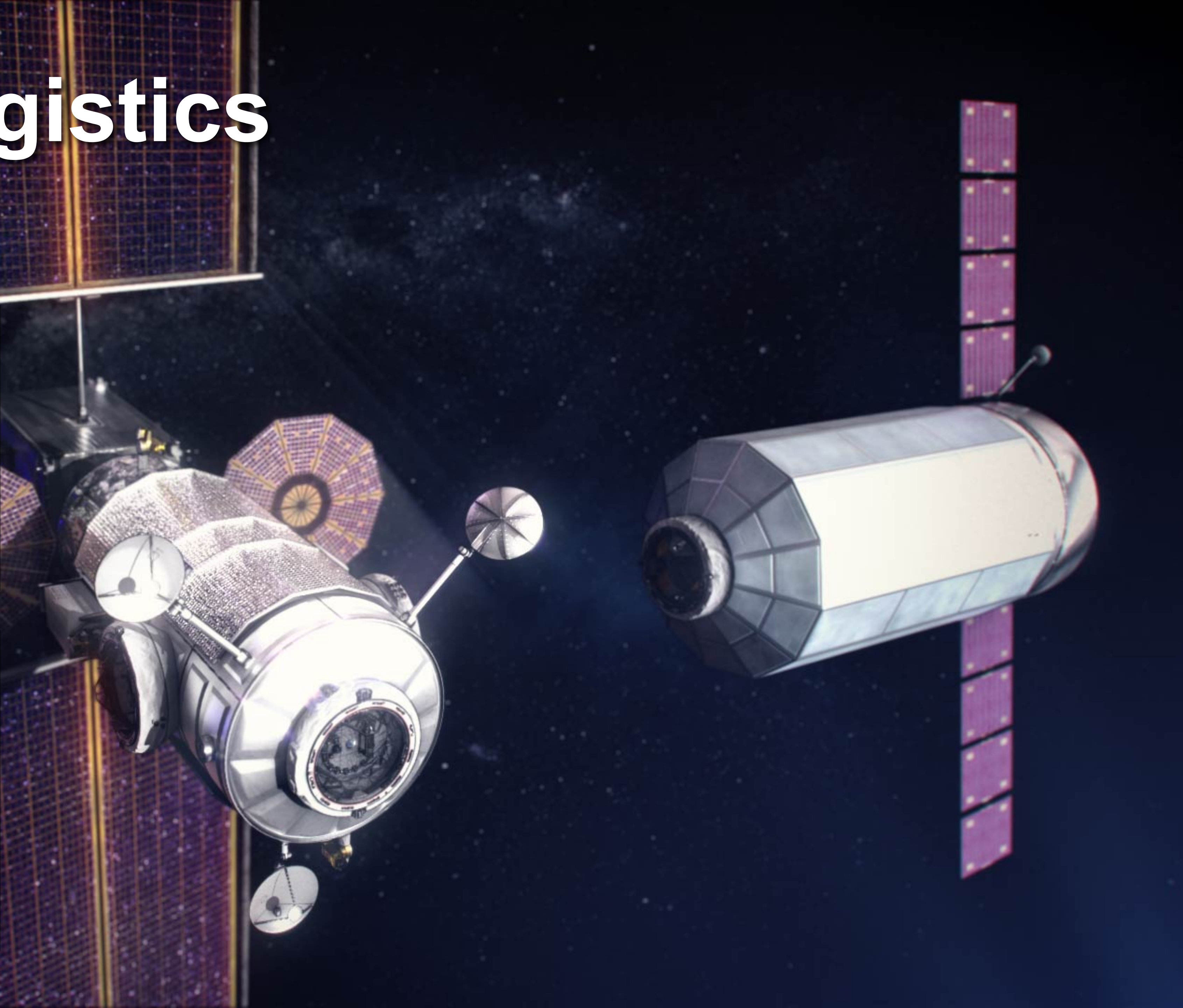
(Habitation and Logistics Outpost)

- RFP issued to Northrop Grumman
- Minimum capability necessary to support a lunar mission, with significant reliance on Orion life support and crew systems

Gateway Logistics Services

U.S. industry to begin delivering cargo, experiments, and supplies to deep space beginning in 2024.

- **June 14** – Draft RFP issued to U.S. industry
- **June 26** – Industry forum with media availability
- **Aug 16** – final solicitation for firm fixed-price contract; proposals received Oct. 16



Human Landing System

NextSTEP Appendix H: Human Landing System

- Synopsis Issued: April 8, for **Ascent Element**
- Synopsis updated: April 26, for **development, integration, and crewed demonstration of integrated landing system**
- Draft solicitation: July 19
- Second draft solicitation: Aug 30
- Final solicitation: Sept 30
- Proposals due: Nov. 5

Risk reduction studies and prototypes contracted separately under Appendix E in March 2019 are ongoing

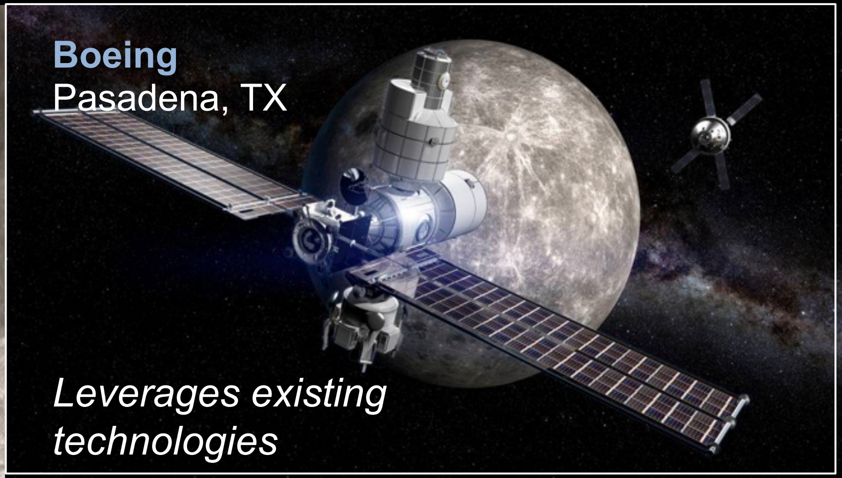
Surface Suit

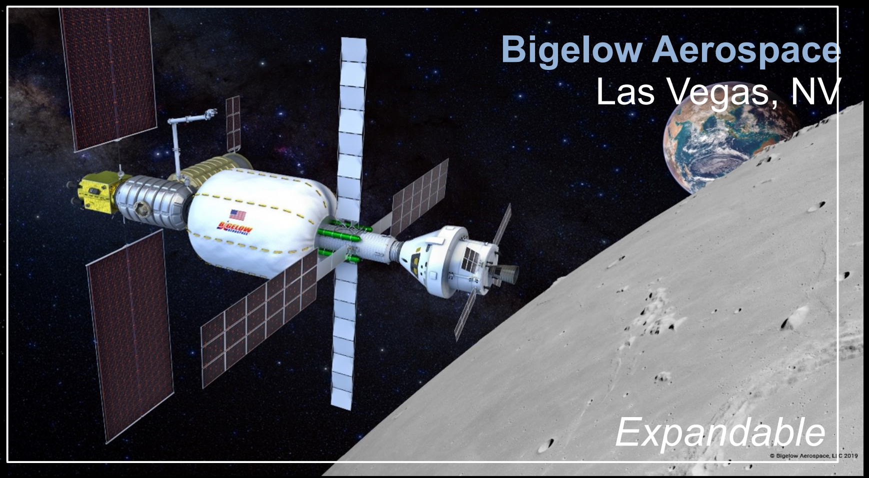
Exploration Extravehicular Mobility Unit (xEMU)

- In-house build for 2024 expedition
- Testing component and full suit on ISS through 2023
- RFI issued Oct. 4 seeking industry input on transitioning production line to private sector for 2025 and beyond

NextSTEP Habitat Prototype Testing

Five full-sized ground prototypes delivered for testing in 2019.





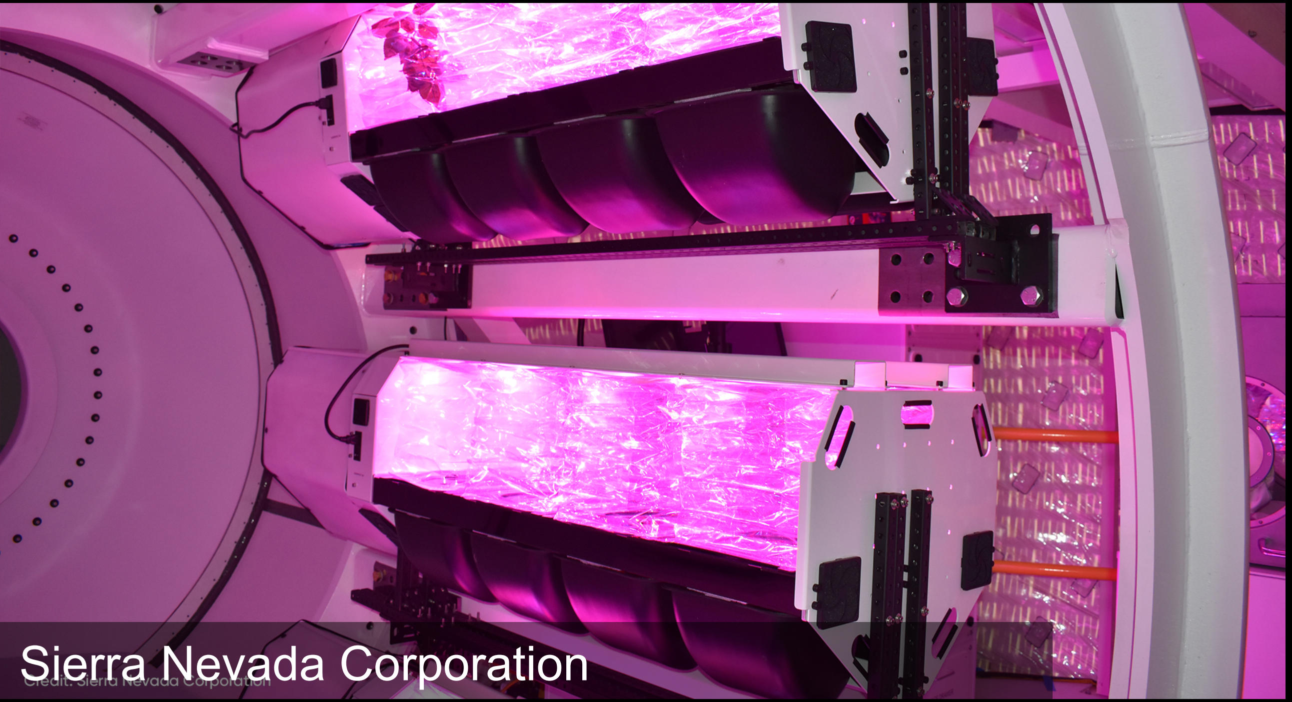
"Because of this prototyping exercise, we are 12-18 months farther along than we would normally be at this stage of concept development. Future programs should go through this approach along with requirements iteration with NASA."

"The NextSTEP approach has been really helpful. The mockup showed us we had more cargo space in our habitat than we originally believed based on the CAD models."

Lockheed Martin


Boeing

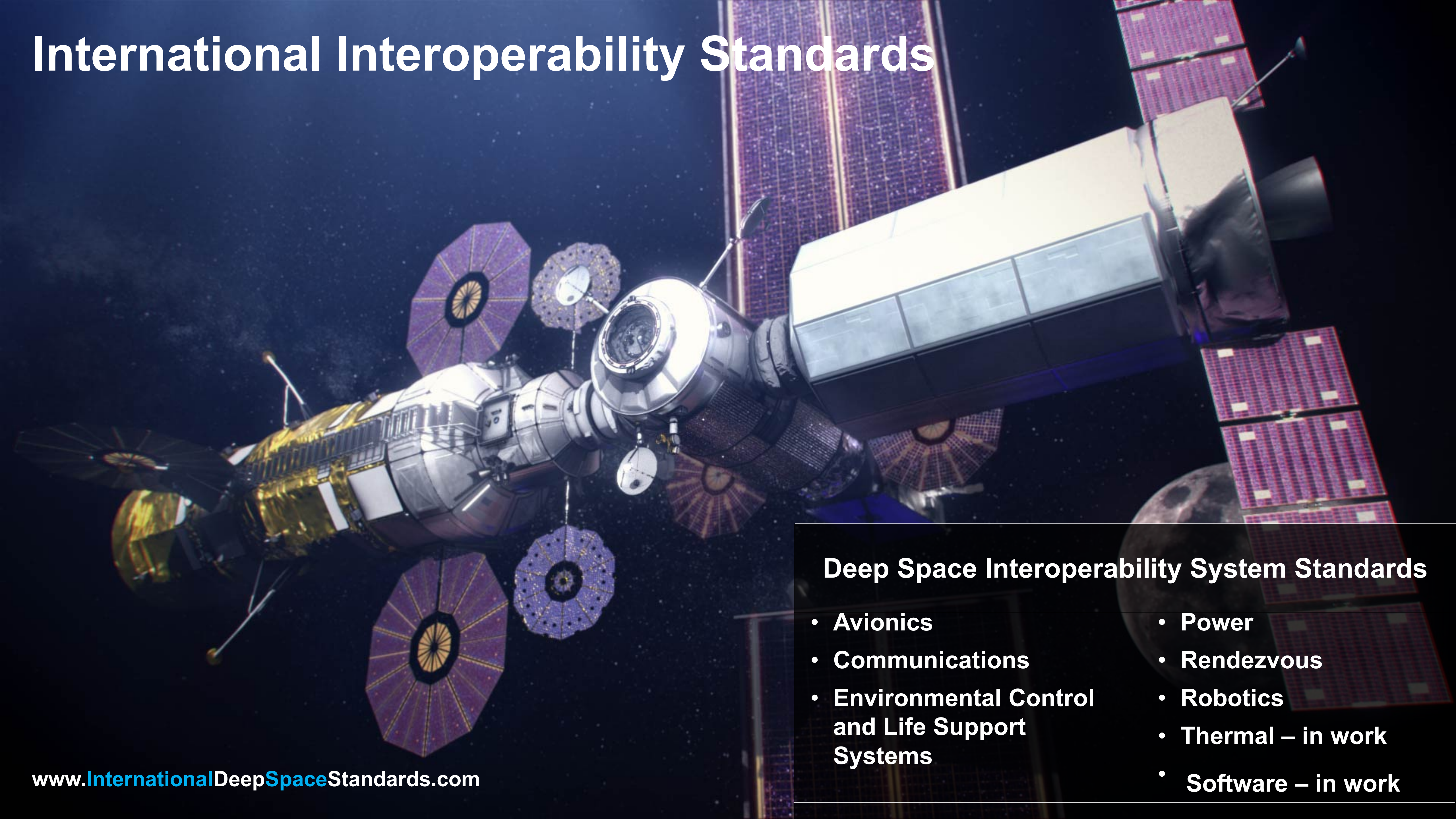
Northrop Grumman


Sierra Nevada Corporation

Credit: Sierra Nevada Corporation

Bigelow Aerospace

International Interoperability Standards



Deep Space Interoperability System Standards

- Avionics
- Communications
- Environmental Control and Life Support Systems
- Power
- Rendezvous
- Robotics
- Thermal – in work
- Software – in work

www.InternationalDeepSpaceStandards.com

Artemis Moon to Mars: Accomplishments Since March 26

Accomplishment	Date
HLS Design Analysis Cycle (DAC) 2 Kickoff	March 25-27
Space Council directs lunar surface landing in 2024	March 26
National Space Symposium	April 8-10
Gateway Formulation Sync Review; Gateway Program Established	April 18
APMC review of human rating approach	April 24
House Science, Space, and Aeronautics Subcommittee Hearing on Exploration	May 8
FY2020 budget amendment of $1.6 billion sent to Congress	May 13
HLS NextSTEP Appendix E (lunar descent, transfer, refueling) selections announced	May 16
International Multilateral Coordination Board	May 22
HLS Acquisition Strategy Meeting	May 22
Gateway PPE Award	May 24
NASA Advisory Council Briefings	May 28-29
First Commercial Lunar Payload Services (CLPS) delivery awards	May 31
Thruster for the Advancement of Low-temp.Operations in Space (TALOS) on Astrobotic Lander	June
Gateway Program Managers Meeting, ESTEC, The Netherlands	June 3-7
Aerospace Safety Advisory Council Briefings	June 4
Lunar Ice Drill Competition	June 6
Gateway Logistics Services draft RFP Released	June 14
Solar Electric Propulsion (SEP) Key Decision Point-C (KDP-C)	June 18
CLPS Mobility and Enhanced Lander study awards	June 18

Accomplishment	Date
HLS tailoring of NASA program and project management requirements	June 19/24
CLPS Enhanced Landing Delivery Services On-Ramp Synopsis Release	June 20
CLPS Enhanced Landing Delivery Services On-Ramp RFP Release	July 30
Lunar Surface Instrument and Technology Payloads selections	July 1
Gateway JOFOC for Habitation and Logistics Outpost (HALO)	July 19
HLS NextSTEP Appendix H, First Draft, Released	July 19
First NextSTEP Appendix H Industry Forum	July 23
HLS DAC 2 Complete	July
Comments received on NextSTEP Appendix H First Draft	Aug 2
Multilateral Coordination Board	Aug 6
Gateway Logistics Services Final RFP Released	Aug 16
HLS Program announced at MSFC	Aug 16
Gateway tailoring of NASA program and project management requirements	Aug 19
HLS NextSTEP Appendix H, Second Draft, Released	Aug 30
Second NextSTEP Appendix H Industry Forum	Sep 3
Aerospace Safety Advisory Council Briefings	Sep 4
HALO Request for Proposal Released to Northrup Grumman	Sep 6
Comments received on NextSTEP Appendix H Second Draft	Sep 9
HLS NextSTEP Appendix H, Final Solicitation Released	Sep 30
Surface Suit Request for Information	Oct 1