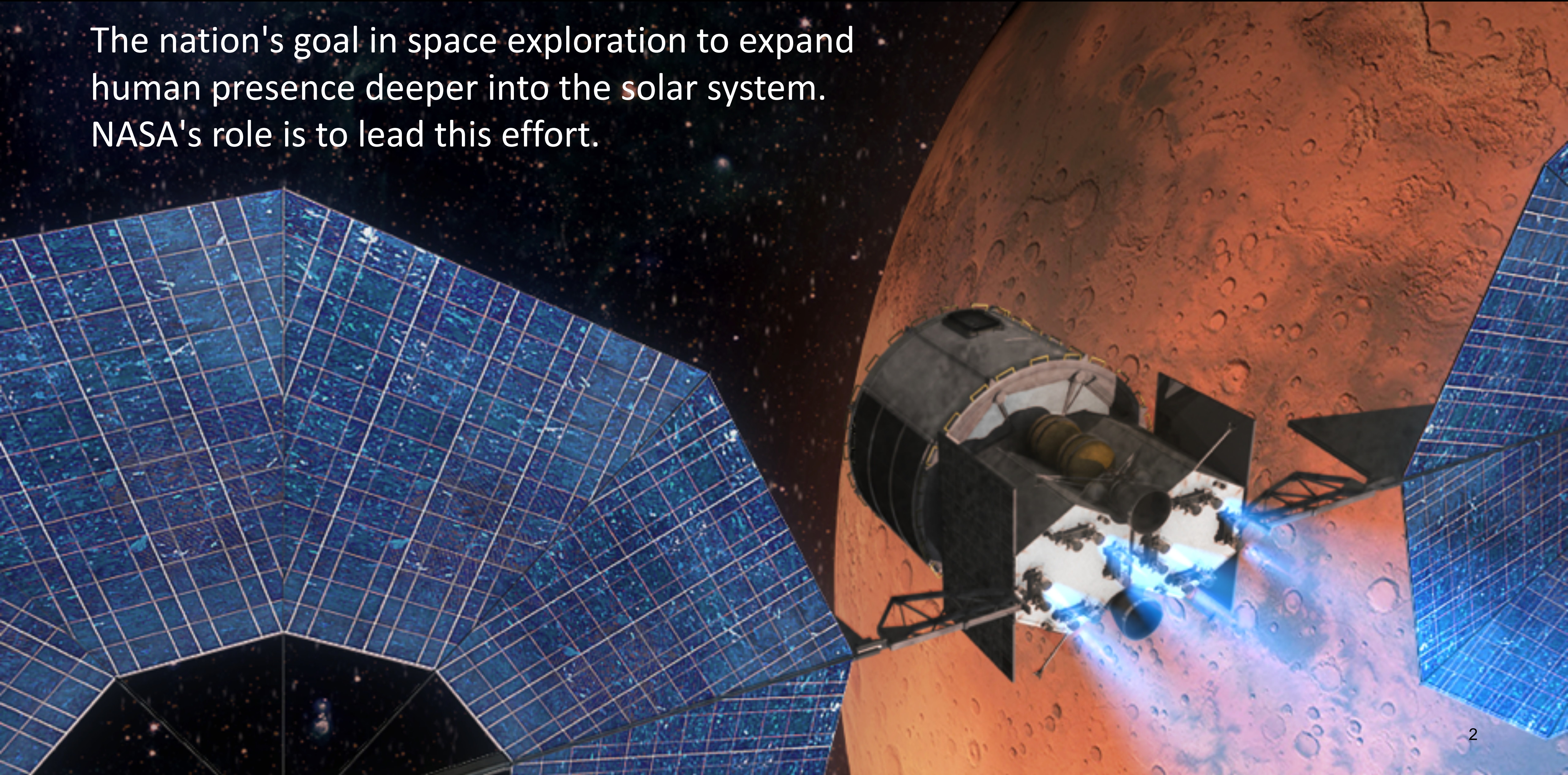
National Aeronautics and Space Administration

Human Exploration Plans

Greg Williams | **HEOMD | July 25, 2017**

The nation's goal in space exploration to expand human presence deeper into the solar system. NASA's role is to lead this effort.



SEC. 202. GOALS AND OBJECTIVES.

(a) LONG TERM GOALS - The long-term goals of the human space flight and exploration efforts of NASA shall be -

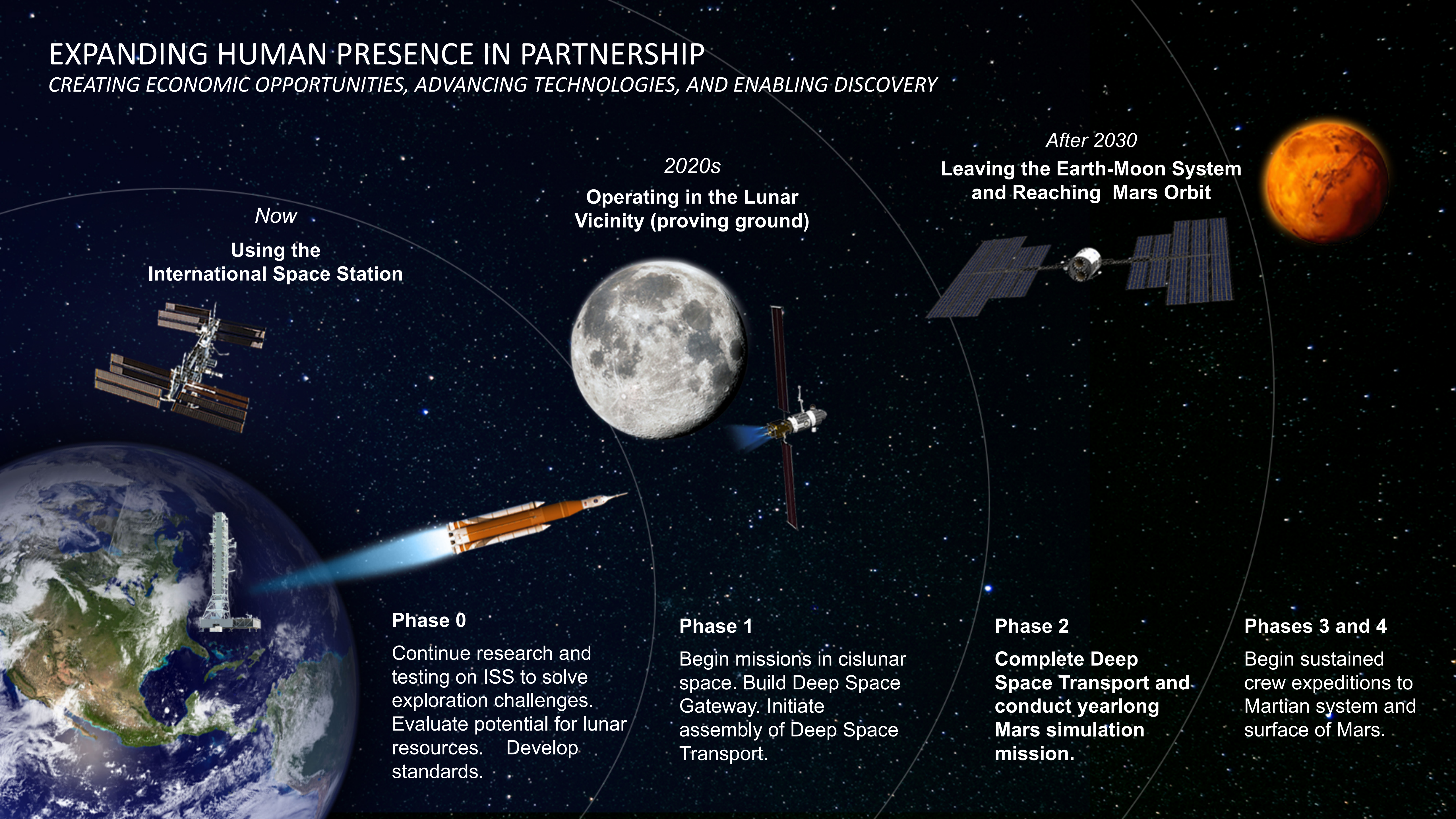
(1) to expand permanent human presence beyond low-Earth orbit and to do so, where practical, in a manner involving international, academic, and industry partners;

(2) crewed missions and progress toward achieving the goal in paragraph (1) to enable the potential for subsequent human exploration and the extension of human presence throughout the solar system; and

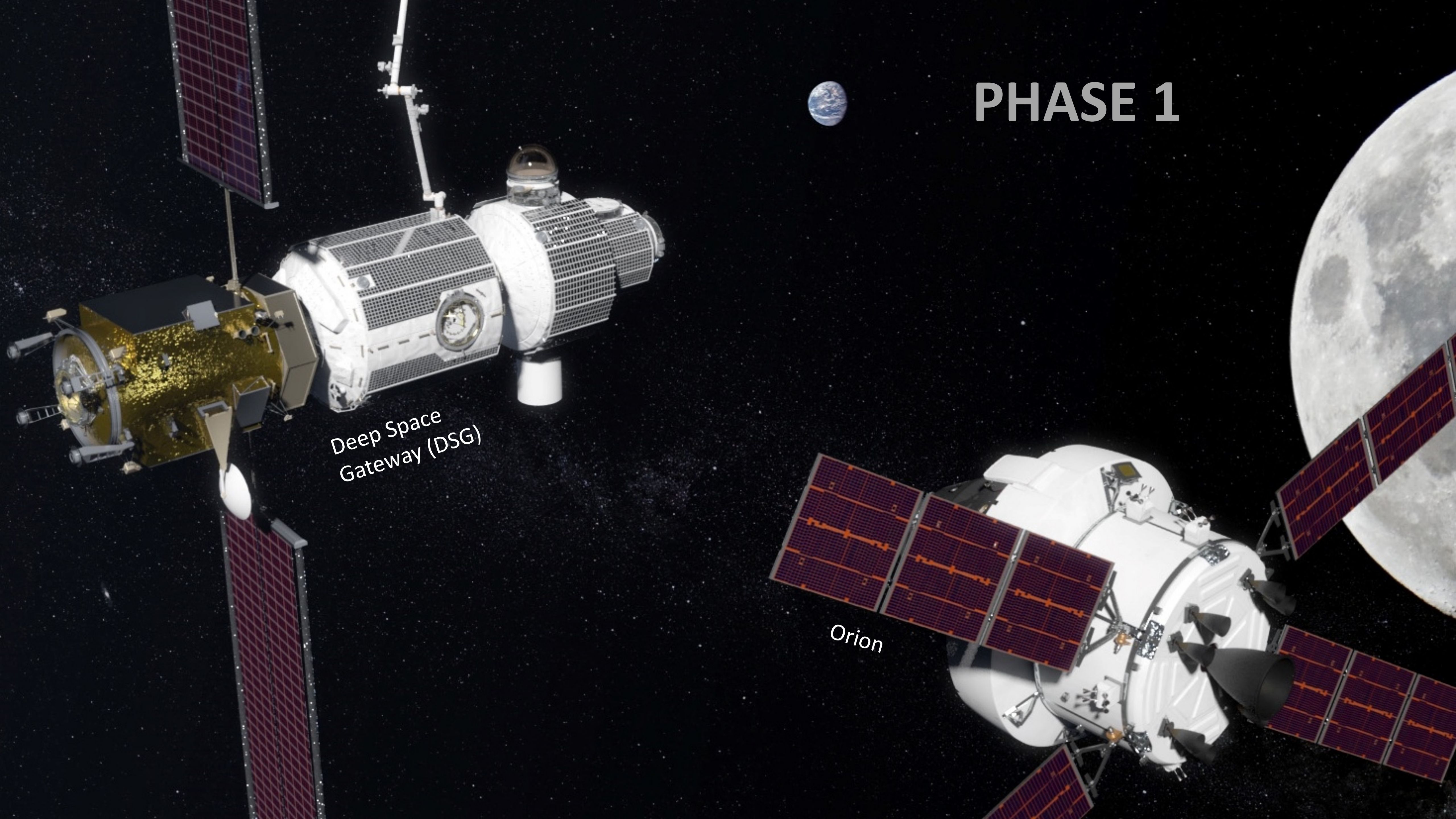
(3) to enable a capability to extend human presence, including potential human habitation on another celestial body and a thriving space economy in the 21st Century.

STRATEGIC PRINCIPLES FOR SUSTAINABLE EXPLORATION

- **FISCAL REALISM:** Implementable in the near-term with the buying power of current budgets and in the longer term with budgets commensurate with economic growth;
- **SCIENTIFIC EXPLORATION:** Exploration enables science and science enables exploration; leveraging scientific expertise for human exploration of the solar system.
- **TECHNOLOGY PULL AND PUSH:** Application of high TRL technologies for near term missions, while focusing sustained investments on technologies and capabilities to address the challenges of future missions;
- **GRADUAL BUILD UP OF CAPABILITY:** Near-term mission opportunities with a defined cadence of compelling and integrated human and robotic missions, providing for an incremental buildup of capabilities for more complex missions over time;
- **ECONOMIC OPPORTUNITY:** Opportunities for U.S. commercial business to further enhance their experience and business base;
- **ARCHITECTURE OPENNESS AND RESILIENCE:** Resilient architecture featuring multi-use, evolvable space infrastructure, minimizing unique developments, with each mission leaving something behind to support subsequent missions;
- **GLOBAL COLLABORATION AND LEADERSHIP:** Substantial new international and commercial partnerships, leveraging current International Space Station partnerships and building new cooperative ventures for exploration; and
- **CONTINUITY OF HUMAN SPACEFLIGHT:** Uninterrupted expansion of human presence into the solar system by establishing a regular cadence of crewed missions to cis-lunar space during ISS lifetime.

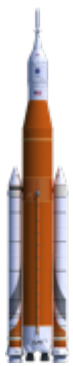
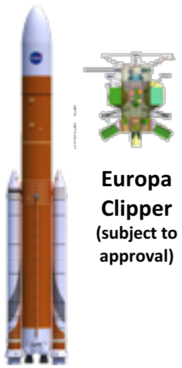
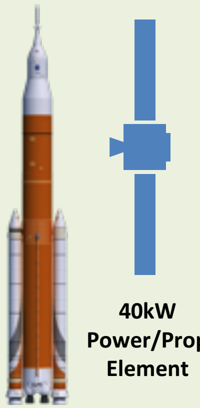
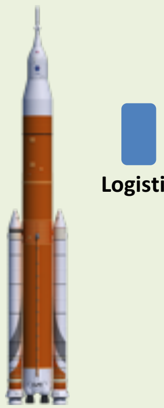
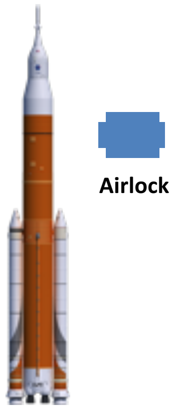
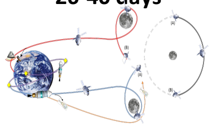
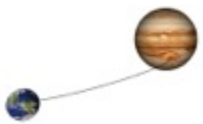
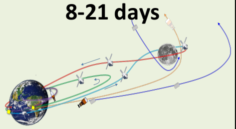
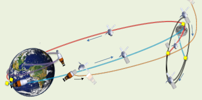
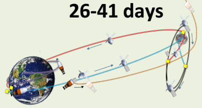
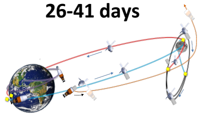
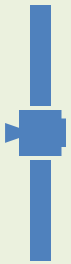
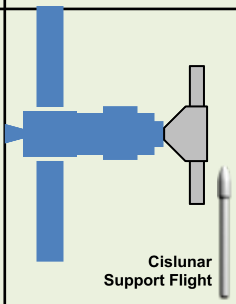
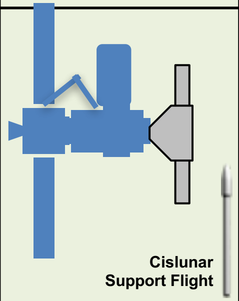
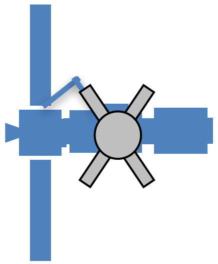

EXPANDING HUMAN PRESENCE IN PARTNERSHIP
CREATING ECONOMIC OPPORTUNITIES, ADVANCING TECHNOLOGIES, AND ENABLING DISCOVERY
Now
Using the International Space Station
2020s
Operating in the Lunar Vicinity (proving ground)
After 2030
Leaving the Earth-Moon System and Reaching Mars Orbit
Phase 0
Continue research and testing on ISS to solve exploration challenges. Evaluate potential for lunar resources. Develop standards.
Phase 1
Begin missions in cislunar space. Build Deep Space Gateway. Initiate assembly of Deep Space Transport.
Phase 2
Complete Deep Space Transport and conduct yearlong Mars simulation mission.
Phases 3 and 4
Begin sustained crew expeditions to Martian system and surface of Mars.


PHASE 0
The International Space Station (ISS) is a platform for deep space exploration, scientific research, economic growth and global diplomacy. ISS brings the world together to discover, develop and advance solutions for a better life both here on Earth and in space.


PHASE 1
Deep Space Gateway (DSG)
Orion

PHASE 1 PLAN

Establishing deep-space leadership and preparing for Deep Space Transport development

		Deep Space Gateway Buildup			
EM-1	**Europa Clipper**	**EM-2**	**EM-3**	**EM-4**	**EM-5**
2019 - 2025					**2026**
SLS Block 1 Crew: 0	SLS Block 1B Cargo	SLS Block 1B Crew: 4 CMP Capability: 8-9t	SLS Block 1B Crew: 4 CMP Capability: 10t	SLS Block 1B Crew: 4 CMP Capability: 10t	SLS Block 1B Crew: 4 CPL Capability: 10t
	 Europa Clipper (subject to approval)	 40kW Power/Prop Element	 Habitation	 Logistics	 Airlock
Distant Retrograde Orbit (DRO) 26-40 days 	Jupiter Direct 	Multi-TLI Lunar Free Return 8-21 days 	Near Rectilinear Halo Orbit (NRHO) 16-26 days 	NRHO, w/ ability to translate to/from other cislunar orbits 26-41 days 	NRHO, w/ ability to translate to/from other cislunar orbits 26-41 days 
Gateway (blue) Configuration (Orion in grey)			 Cislunar Support Flight	 Cislunar Support Flight	

These essential Gateway elements can support multiple U.S. and international partner objectives in Phase 1 and beyond

Known Parameters:
- Gateway to architecture supports Phase 2 and beyond activities
- International and U.S. commercial development of elements and systems
- Gateway will translate uncrewed between cislunar orbits
- Ability to support science objectives in cislunar space

Open Opportunities:
- Order of logistics flights and logistics providers
- Use of logistics modules for available volume
- Ability to support lunar surface missions

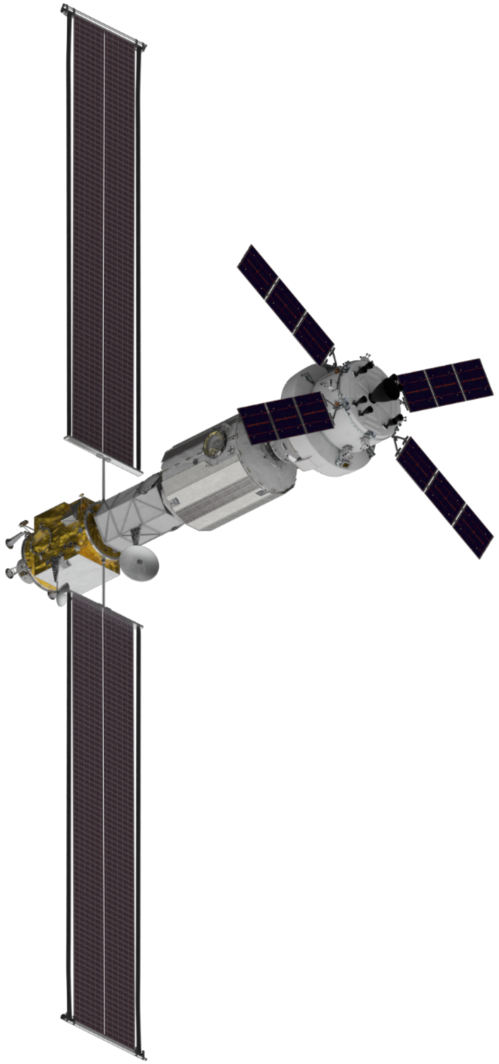
ADVANTAGES OF SOLAR ELECTRIC PROPULSION (SEP) IN CISLUNAR SPACE

- **Fuel is storable, does not boil off, and can be resupplied**

- **Advanced EP provides the ability to move habitat systems to various orbits around the moon**
  - Halo, Lagrangian, or other Earth-Moon orbits

- **Analyses of in-space orbit transfers in the lunar vicinity shows a 5 to 15 fold savings in propellant with this system as compared to chemical-only systems with equivalent trip times**

- **Early use supports ensured extensibility to Mars class system**
  - Also directly applicable to a wide range of robotic and human spaceflight missions



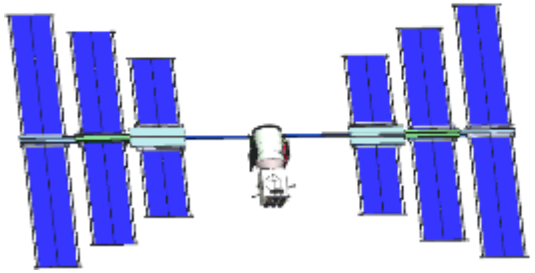
SCALABILITY TO HIGHER POWER SYSTEMS FOR DEEP SPACE HUMAN EXPLORATION

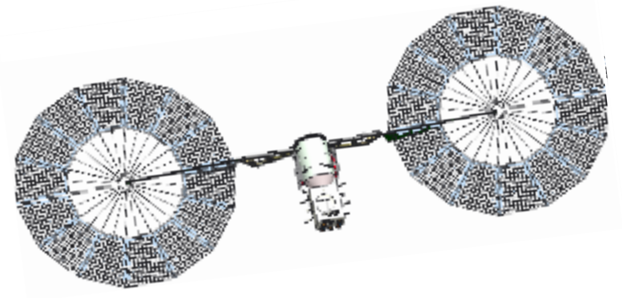
- **High-power, 40-kW class system would be a step up from current technology and on the path to much higher power systems.**
  - Range of powers: 150 kW to 300 kW

- **Electric propulsion technology scalable**
  - Several Hall thrusters of higher power (~50kW) have been validated in a laboratory environment
  - Power Processing Unit (PPU) design is modular

- **The solar array is scalable beyond the 90kW class with the use of additional wings.**

- **The power per thruster/PPU string is a mission dependent system-level trade between fewer higher-power strings and more numerous lower-power strings.**
  - Current technology to demonstrate large scale SEP capability and performance also scales to the higher power vehicles to validate higher power generation and EP system capability in deep space



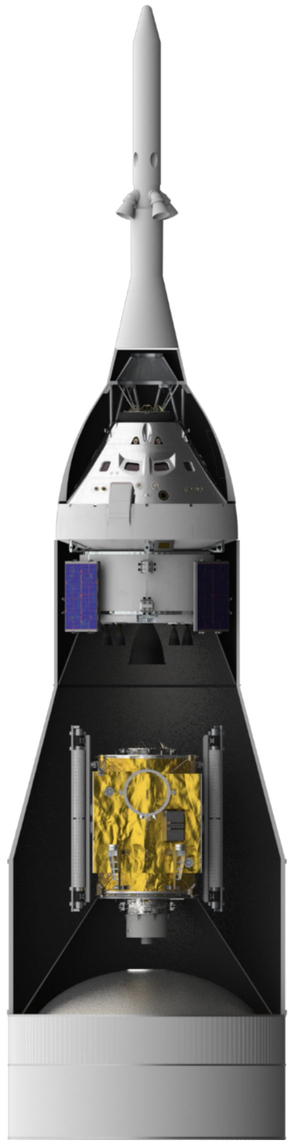


POWER & PROPULSION AS A 1ST ELEMENT IN GATEWAY CONCEPT

- As discussed in March 2017 NAC, NASA's plan is to start deep space gateway when we fly crew to vicinity of the Moon

- A power propulsion element (PPE) would be the first element in a cislunar gateway
  - Also would host communications and command/control functions
  - Potentially a partner system/payload contribution

- PPE would launch co-manifested on SLS with Orion on EM-2



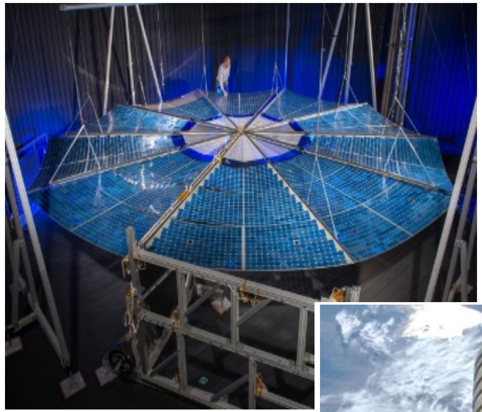
APPROACH TO PPE DEVELOPMENT

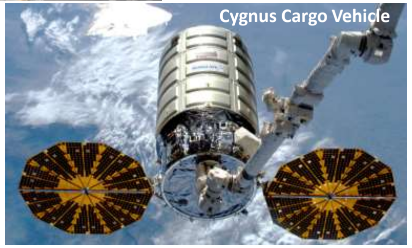
- **PPE would leverage advanced solar electric propulsion (SEP) bus formulation progress from ARM**
  - **Directly use U.S. industry current commercially available spacecraft capabilities**
  - **Infuse STMD developed advanced SEP technology**
  - **Align with U.S. industry plans for future use of SEP**

SOLAR ELECTRIC PROPULSION PROGRESS (SOLAR ARRAY)

- **Solar Array Development Contracts Fully Successful**
  - MegaFlex Engineering Development Unit
  - Rollout Solar Array (ROSA) Engineering Development Unit
  - Both arrays achieved all SOA-related goals including 4x rad tolerance, 1.7x power/mass (kW/kg), 4x stowed volume efficiency, and 20x deployed strength

- **Subsequent Commercial Infusion of Solar Array Technology:**
  - Orbital ATK using smaller version of similar technology to Megaflex on the Cygnus cargo vehicle to ISS
  - Space Systems Loral and Deployable Space Systems are flight qualifying a 12.5 kW ROSA for use on commercial satellites
  - ROSA flight experiment on ISS successfully completed its science objectives: unfurl for the first time on-orbit; measure structural dynamics and power generation performance





NASA SEP technology development led by Space Technology Mission Directorate

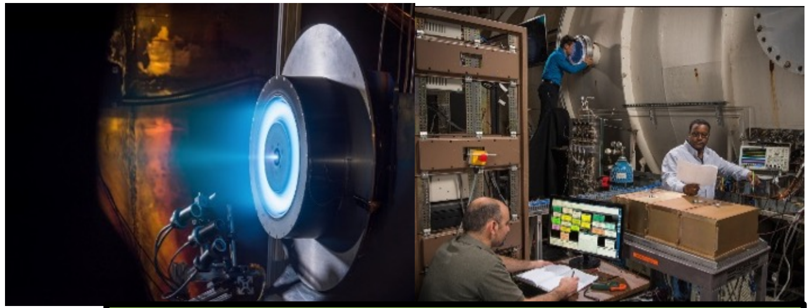
SOLAR ELECTRIC PROPULSION PROGRESS (ELECTRIC PROPULSION)

Risk Reduction

- **Technology Development Unit Thruster (TDU-1) and Power Processing Unit (PPU) Risk Reduction Tests at NASA-Glenn**
  - Confirmed thruster magnetic shielding (enables long-life operation)
  - PPU vacuum tests successfully completed
  - Conducted 12.5 kW thruster integrated tests w/ 300-V & 120-V PPUs
  - 2200 hours of testing completed
- **TDU-2 vibe and thermal balance testing**
  - Successfully completed random vibe, will run thermal test in chamber at JPL after sputter test and graphite chamber risk reduction tests are completed
- **TDU-3 wear testing in Vacuum Facility 5 at NASA-Glenn**
  - Represents flight-like configuration of downstream thruster on Advanced EP System (AEPS)
  - Final short duration risk reduction test segment completed at 600 V, 12.5 kW, 250 G
  - Over all four risk reduction test segments, the thruster was operated for 940 hours and consumed a total of 75 kg of xenon. Long duration 3000 hour wear test to follow.

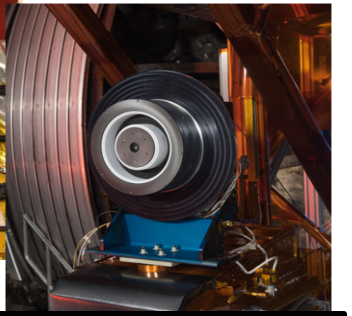
AEPS Contract

- Early Integrated System Test in Vacuum Facility 6 - successfully conducted a series of hot-fire tests to demonstrate stable operation and characterize performance of Aerojet's PPU discharge module, a key PPU assembly. Test results inform AEPS design leading up to August Preliminary Design Review (PDR).

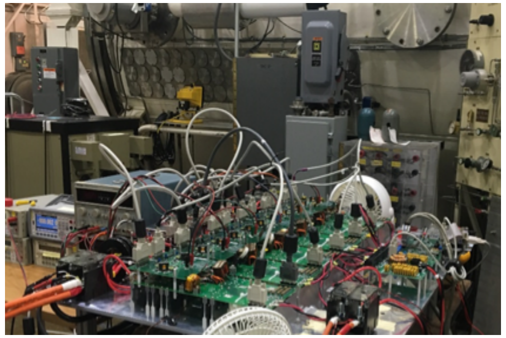


Demonstrated full performance compatibility between thruster and PPUs

TDU-2 on Vibe table

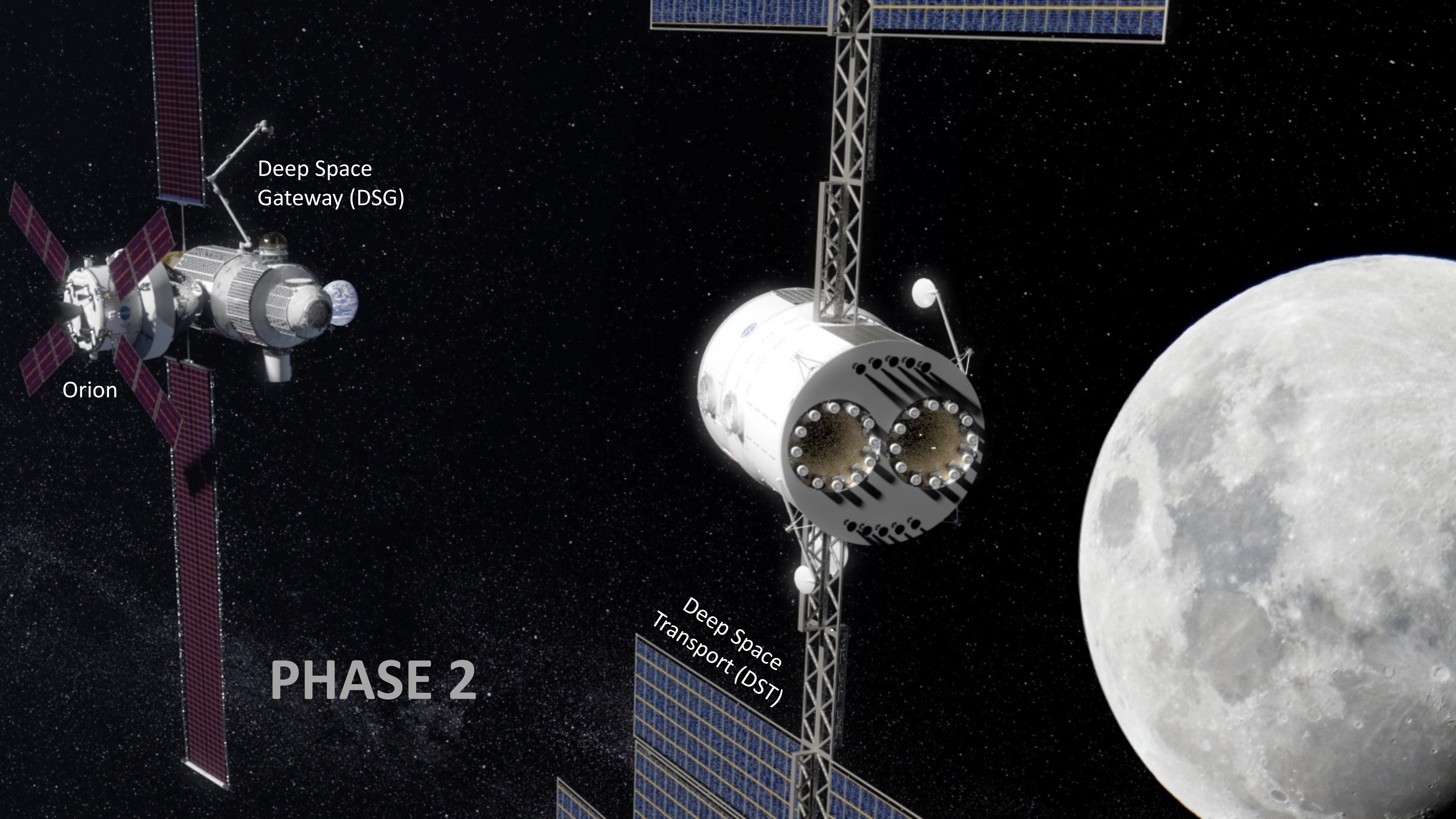


TDU-3 Test Preparations



POWER & PROPULSION ELEMENT (PPE) NEAR TERM EVENTS

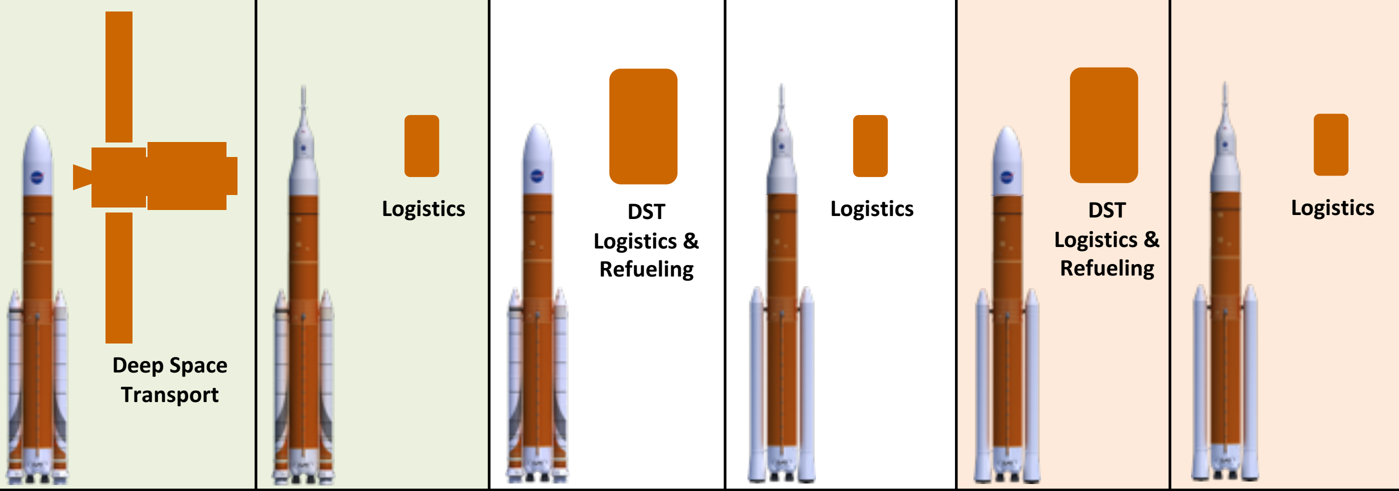
✓ Release of PPE Request for Information and Synopsis for Studies through NextSTEP BAA Appendix C	Jul 17, 2017
• NASA Update to NASA Advisory Council HEO Committee	Jul 24, 2017
• RFI Responses Due	Jul 28, 2017
• STMD Electric Propulsion System Preliminary Design Review	Aug 1-3, 2017
• NextSTEP BAA Appendix C for PPE Industry Studies Release	Aug 2017
• PPE virtual industry day	Aug 17, 2017

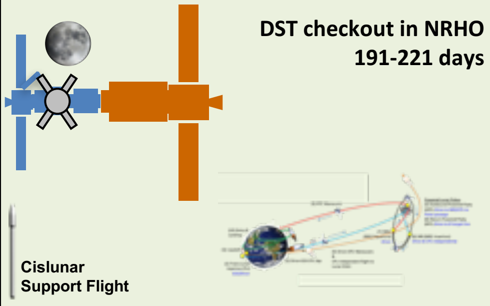

Deep Space
Gateway (DSG)
Orion
PHASE 2
Deep Space
Transport (DST)

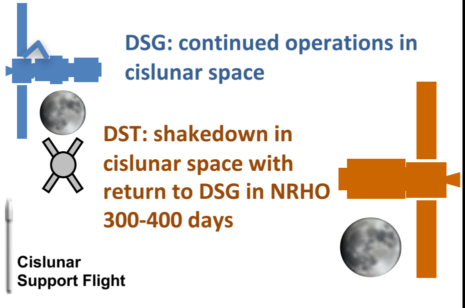
(PLANNING REFERENCE) Phase 2 and Phase 3

Looking ahead to the shakedown cruise and the first crewed missions to Mars

Transport Delivery		Transport Shakedown		Mars Transit	
EM-6	EM-7	EM-8	EM-9	EM-10	EM-11
2027		2028 / 2029		2030+	
SLS Block 1B Cargo P/L Capability: 41t TLI	SLS Block 1B Crew: 4 CMP Capability: 10t	SLS Block 1B Cargo P/L Capability: 41t TLI	SLS Block 2 Crew: 4 CMP Capability: 13+t	SLS Block 2 Cargo P/L Capability: 45t TLI	SLS Block 2 Crew: 4 CMP Capability: 13+t







Reusable Deep Space Transport supports repeated crewed missions to the Mars vicinity

Known Parameters:
- DST launch on one SLS cargo flight
- DST shakedown cruise by 2029
- DST supported by a mix of logistics flights for both shakedown and transit
- Ability to support science objectives in cislunar space

Open Opportunities:
- Order of logistics flights and logistics providers
- Shakedown cruise vehicle configuration and destination/s
- Ability to support lunar surface missions

- **HEOMD is directing the maturation of the Deep Space Gateway Concept**
  - Ensuring that it enables evolution to Deep Space Transport and is part of Mars plans
    - Crew transportation to/from Mars
    - Possibly plays a role in Mars sample return
  - Ensuring that it enables Lunar activities

- **New board process (highly leveraged from ESD) established for this activity**
  - Integrates activities from ESD, Domestic (NextSTEP), and International (ISS partners)

- **HEOMD and DSG Products refined and identified**

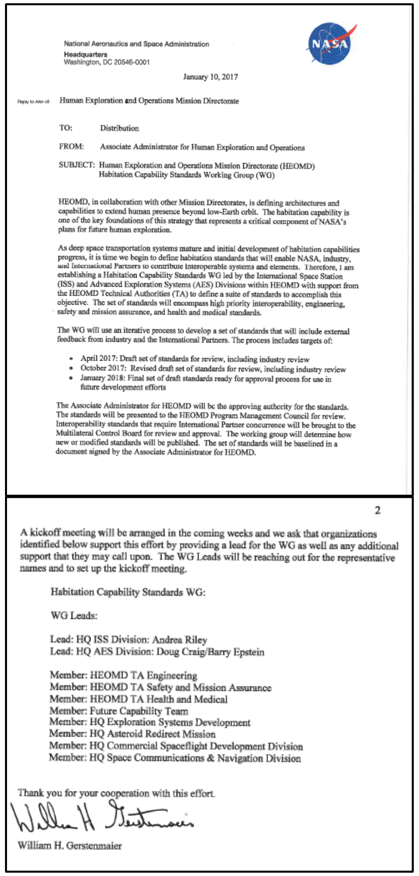
- **Products include:**
  - 1) DSG objectives and utilization plans;
  - 2) DSG requirements;
  - 3) Concept of operations that enables these objectives;
  - 4) Integrated acquisition strategy; and
  - 5) Definition of interoperability standards.

Leads:

- International Space Station (ISS) Division and Advanced Exploration Systems (AES) Division

Members:

- Commercial Spaceflight Development Division
- Exploration Systems Development
- Space Communications & Navigation Division
- Engineering Technical Authority
- Safety and Mission Assurance Technical Authority
- Health and Medical Technical Authority
- HEOMD Gateway Concept Formulation Team
  - ISS led Future Capabilities Team (International)
  - AES NextSTEP Habitation Team (Domestic)
  - Gateway Power Propulsion Team



National Aeronautics and Space Administration
Headquarters
Washington, DC 20546-0001

January 10, 2017

Reply to Attn of: Human Exploration and Operations Mission Directorate

TO: Distribution

FROM: Associate Administrator for Human Exploration and Operations

SUBJECT: Human Exploration and Operations Mission Directorate (HEOMD) Habitation Capability Standards Working Group (WG)

HEOMD, in collaboration with other Mission Directorates, is defining architectures and capabilities to extend human presence beyond low-Earth orbit. The habitation capability is one of the key foundations of this strategy that represents a critical component of NASA's plans for future human exploration.

As deep space transportation systems mature and initial development of habitation capabilities progress, it is time we begin to define habitation standards that will enable NASA, industry, and International Partners to contribute interoperable systems and elements. Therefore, I am establishing a Habitation Capability Standards WG led by the International Space Station (ISS) and Advanced Exploration Systems (AES) Divisions within HEOMD with support from the HEOMD Technical Authorities (TA) to define a suite of standards to accomplish this objective. The set of standards will encompass high priority interoperability, engineering, safety and mission assurance, and health and medical standards.

The WG will use an iterative process to develop a set of standards that will include external feedback from industry and the International Partners. The process includes targets of:

- April 2017: Draft set of standards for review, including industry review
- October 2017: Revised draft set of standards for review, including industry review
- January 2018: Final set of draft standards ready for approval process for use in future development efforts

The Associate Administrator for HEOMD will be the approving authority for the standards. The standards will be presented to the HEOMD Program Management Council for review. Interoperability standards that require International Partner concurrence will be brought to the Multilateral Control Board for review and approval. The working group will determine how new or modified standards will be published. The set of standards will be baselined in a document signed by the Associate Administrator for HEOMD.

2

A kickoff meeting will be arranged in the coming weeks and we ask that organizations identified below support this effort by providing a lead for the WG as well as any additional support that they may call upon. The WG Leads will be reaching out for the representative names and to set up the kickoff meeting.

Habitation Capability Standards WG:

WG Leads:

Lead: HQ ISS Division: Andrea Riley
Lead: HQ AES Division: Doug Craig/Barry Epstein

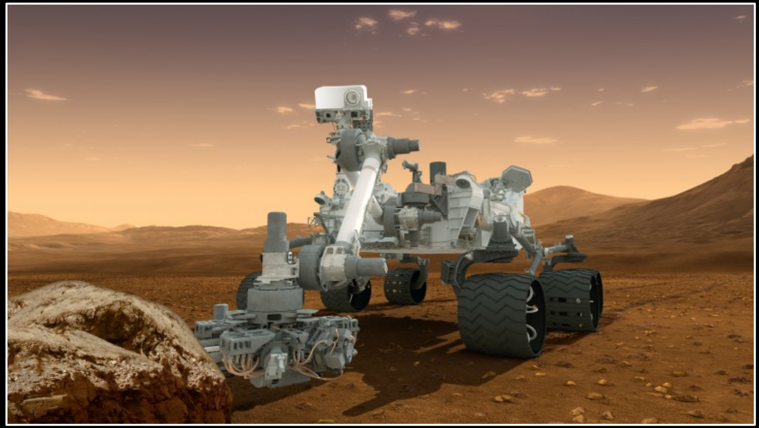
Member: HEOMD TA Engineering
Member: HEOMD TA Safety and Mission Assurance
Member: HEOMD TA Health and Medical
Member: Future Capability Team
Member: HQ Exploration Systems Development
Member: HQ Asteroid Redirect Mission
Member: HQ Commercial Spaceflight Development Division
Member: HQ Space Communications & Navigation Division

Thank you for your cooperation with this effort.

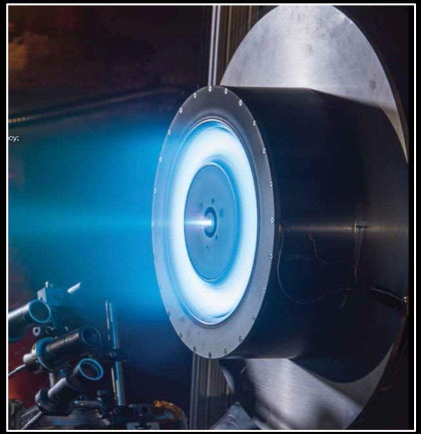
William H. Gerstenmaier

- **Interface and Environment Interoperability Standards**
  - Established
    - International Docking System Standard
- **Design Specification for Natural Environments**
    - SLS Launch Environment
  - In work
    - International Avionics Data Interface Standard
    - International Communications System Standard
    - International Environmental Control Life Support System Standard
    - International Power System Standard
    - International Thermal System Interfaces Standard
    - International Rendezvous Standard
    - International External Robotic Interfaces Standard
  - Future additions
    - Software System Standards
    - Internal Architecture (including secondary structures)
    - Electromagnetic Compatibility (EMC)

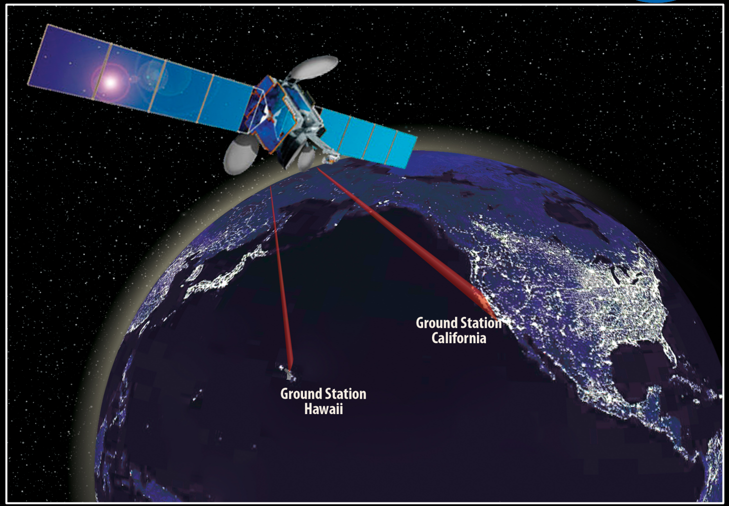
HEOMD-STMD Collaboration



HEOMD & STMD are co-funding three payloads on Mars 2020: MOXIE, MEDA, MEDLI-2



STMD is developing the solar electric propulsion system for the Deep Space Gateway Power & Propulsion Element



STMD is developing Laser Communications Relay Demonstration and HEO/SCaN is providing the ground terminals

STMD is developing a prototype rover for Resource Prospector

HEOMD is flight testing a Navigation Doppler Lidar and lander vision system on a STMD Flight Opportunities Program lander

Joint development of Deep Space Atomic Clock for precision navigation

HEOMD & SMD JOINT ACTIVITY AREAS (1/3)

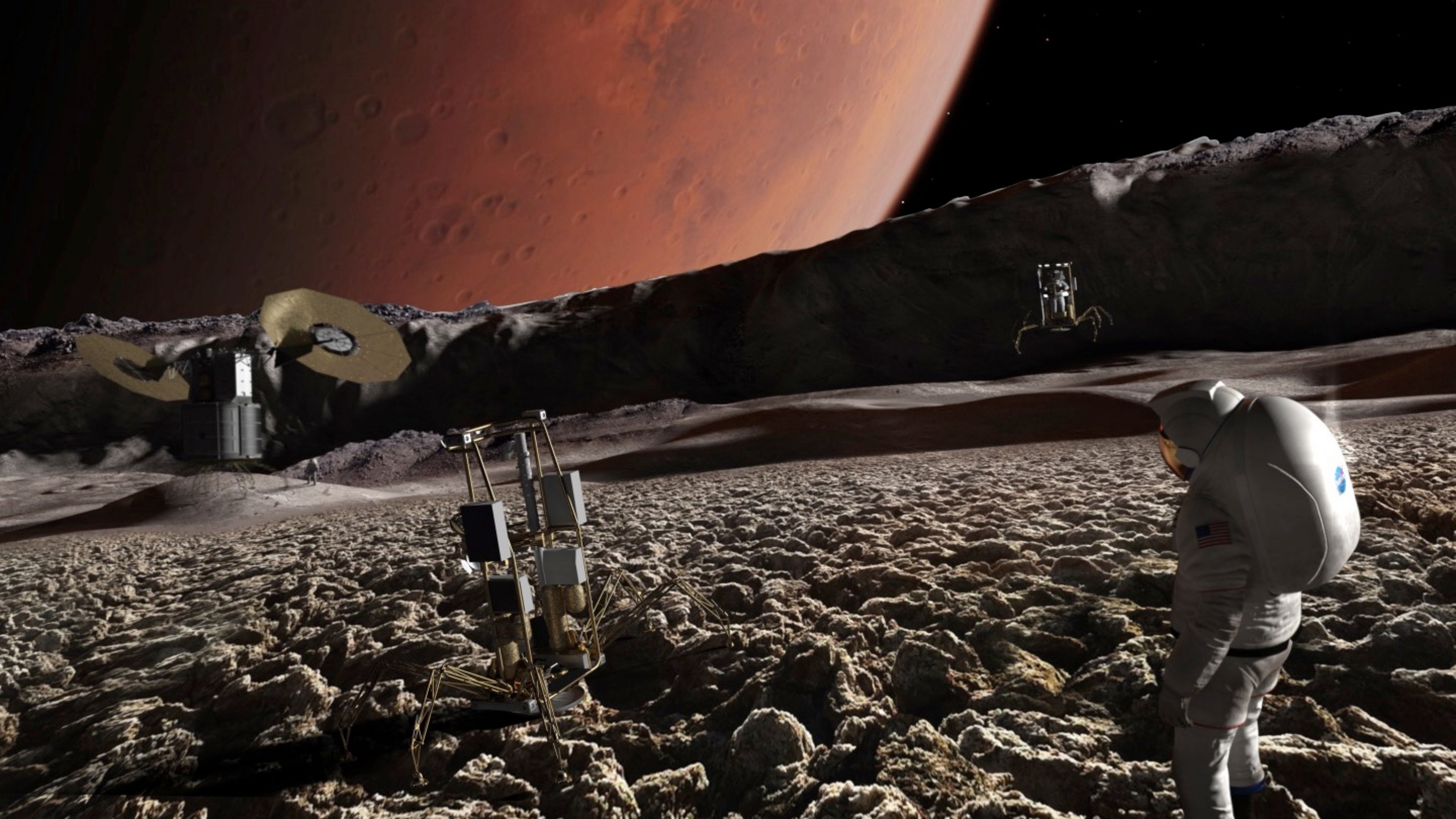
- **Mars Exploration Program**
  - Mars 2020 Partnership – borne out of current Mars strategy discussions
  - Mars Science Laboratory (Curiosity)
  - Partnership on HEO/Space Technology Mission Directorate (STMD) instrumentation - Mars EDL Instrumentation (MEDLI-2), Mars Oxygen ISRU Experiment (MOXIE), and Mars Environmental Dynamics Analyzer (MEDA)
  - Working together to study potential future landing sites for crewed missions to Mars
- **Science Instruments on the International Space Station (ISS)**
- **Discussions about potential collaboration on satellite and telescope servicing**
- **Studying space weather and the effect of space radiation on astronauts**
- **Deep Space Optical Communications (DSOC)**
- **Resource Prospector:**
  - STMD funded early development of the RP rover. SMD funds participation of several members of the science team and provides considerable data support from LRO. Continued collaboration is anticipated through the Participating Scientist program.

HEOMD & SMD JOINT ACTIVITY AREAS (2/3)

- **Frontier Development Lab (FDL) 2.0:**
  - Originally funded by OCT/Asteroid Grand Challenge, FDL 2.0 is focusing this year on important questions for both science and exploration. Focusing last year on Planetary Defense, this year FDL has added challenges in Space Weather (funded by SMD/Helio), and Space Resources (not funded by NASA but working on NASA-identified questions such as mapping lunar polar volatiles), in addition to Planetary Defense (funded by SMD/PDCO).
- **Science in Cislunar Space Workshop:**
  - Joint HEOMD/SMD Executive Committee leadership for a 2018 workshop that will identify science opportunities that may be enabled by the presence of a human-tended Deep Space Gateway concept near the moon.
- **Korea Pathfinder Lunar Orbiter:**
  - Working to initiate a SMD-funded Participating Scientist program for a HEO-funded KPLO instrument.
- **ISECG Science White Paper:**
  - HEOMD/SMD collaboration to ensure agency approval of the ISECG Science White paper.

HEOMD & SMD JOINT ACTIVITY AREAS (3/3)

- **ASM-SAT:**
  - HEOMD membership on the SMD-initiated Advances of the Moon Specific Action Team (ASM-SAT) that will review recent scientific progress as measured to the Scientific Context for the Exploration of the Moon (SCEM) report.
- **Other**
  - **SSERVI:** co-funded originally, and now funded by SMD, SSERVI teams address both science and exploration questions. SSERVI actively promotes Exploration science questions and is responsible for addressing critical SKGs related to asteroid and lunar science. SSERVI's benefit to HEO far exceeds our investment. AES also hosts a SSERVI staff member on a 1 year detail to HQ.
  - **Advisory Groups (LEAG, SBAG, MEPAG):** responds jointly to requests for analysis from both SMD and HEOMD
  - **Planetary Defense Coordination Office:** HEOMD/AES member on part-time detail to PDCO to lead development of intergovernmental agreements and program planning
  - **Launch Services**
  - **Space Communications and Navigation (SCaN)**
  - **Planetary Protection**
  - **Joint Robotic Precursor**



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