National Aeronautics and Space Administration

Power and Propulsion Element Studies Industry Day

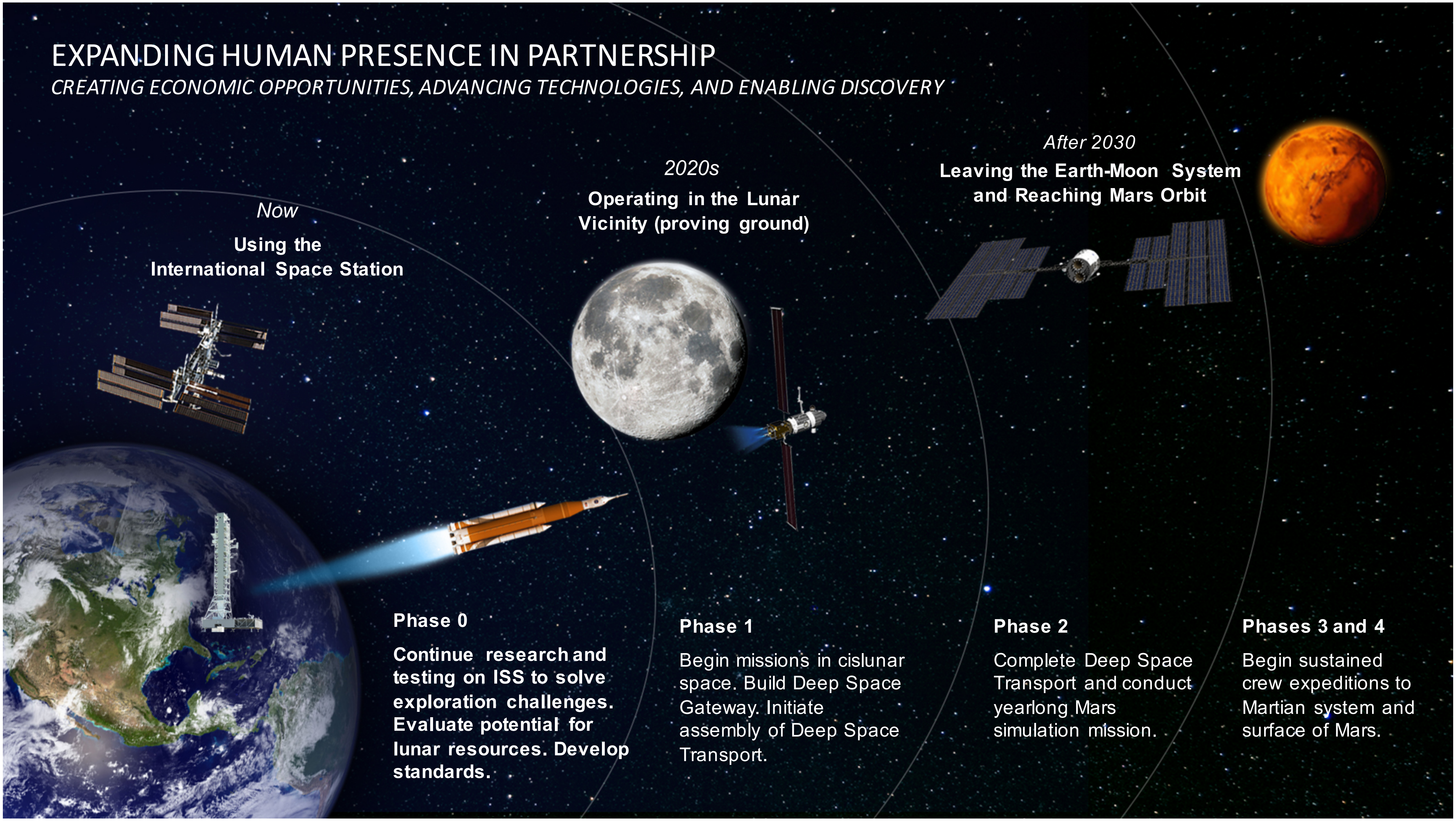
August 17, 2017

Industry Forum Ground Rules

- **NASA will address questions during this forum to clarify the content of the Draft BAA Appendix**
- **A question and answer session will take place after all speakers have completed their presentations**
  - Virtual participants, please submit questions via WebEx Chat, or by pressing *1 to enter the queue.
  - Questions that require further assessment to address will be resolved as soon as possible after the forum, and the answers will be included in the Q&A log
- **NASA will not provide evaluations, opinions, or recommendations regarding any suggested approaches or concepts**
- **Deadline for written technical questions is August 22 – submit questions to the email identified in the draft solicitation**
- **Today's presentation and any questions answered in this forum will be posted to the NextSTEP web page: https://www.nasa.gov/nextstep**

Associate Administrator for Human Exploration and Operations

WILLIAM GERSTENMAIER


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.

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;

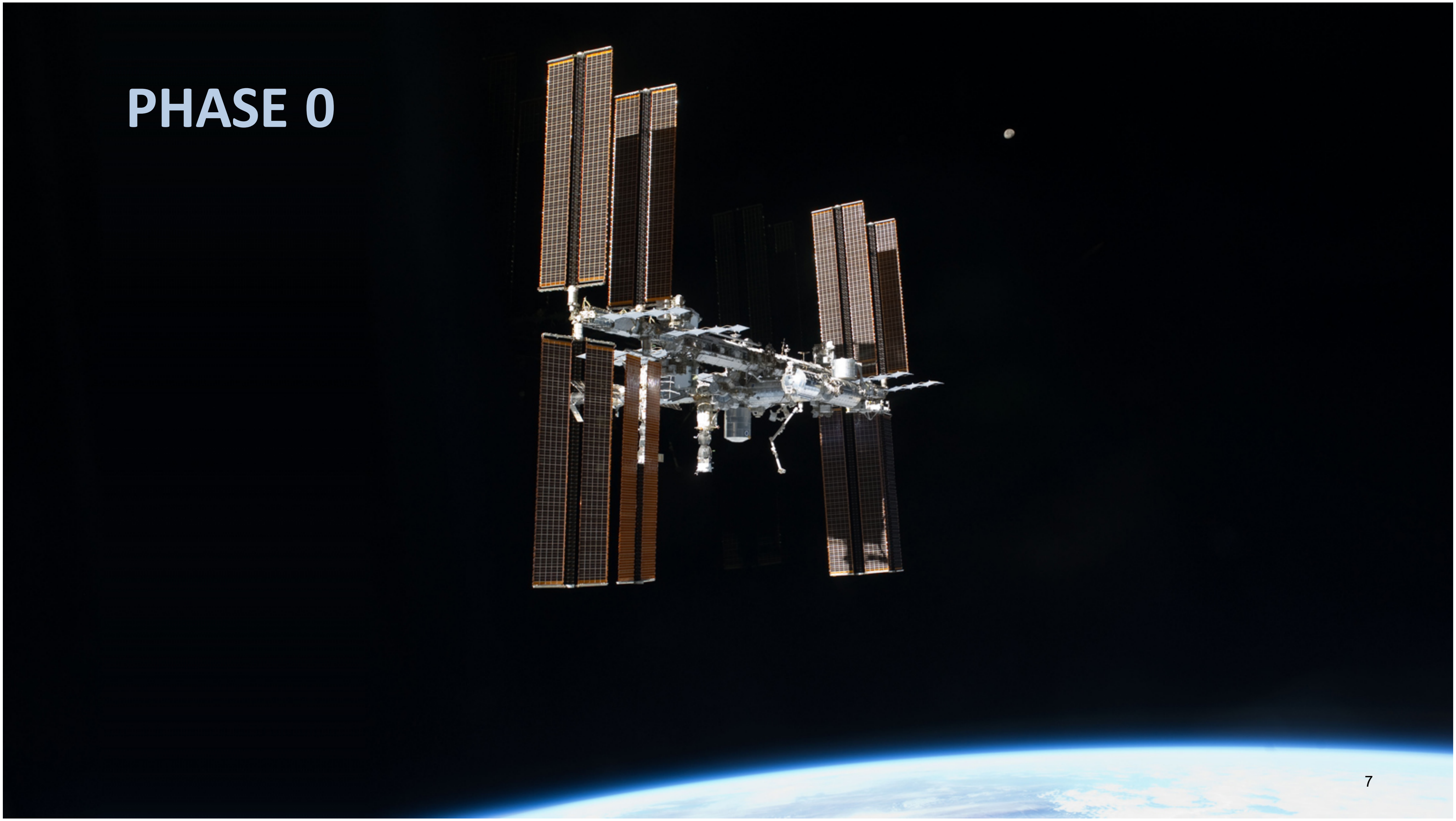
- **GLOBAL COLLABORATION AND LEADERSHIP**
  Substantial new international and commercial partnerships, leveraging current International Space Station partnerships and building new cooperative ventures for exploration; and

- **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.

Director of Advanced Exploration Systems

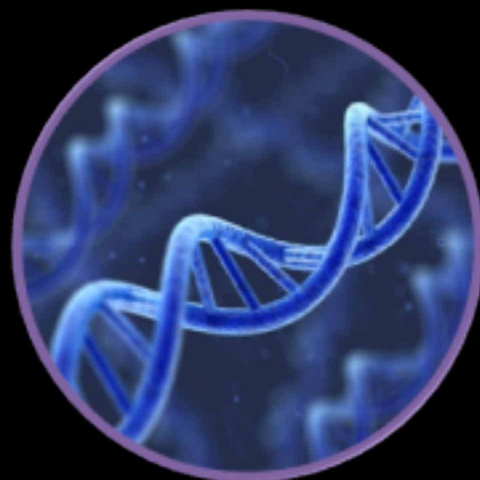
JASON CRUSAN

PHASE 0



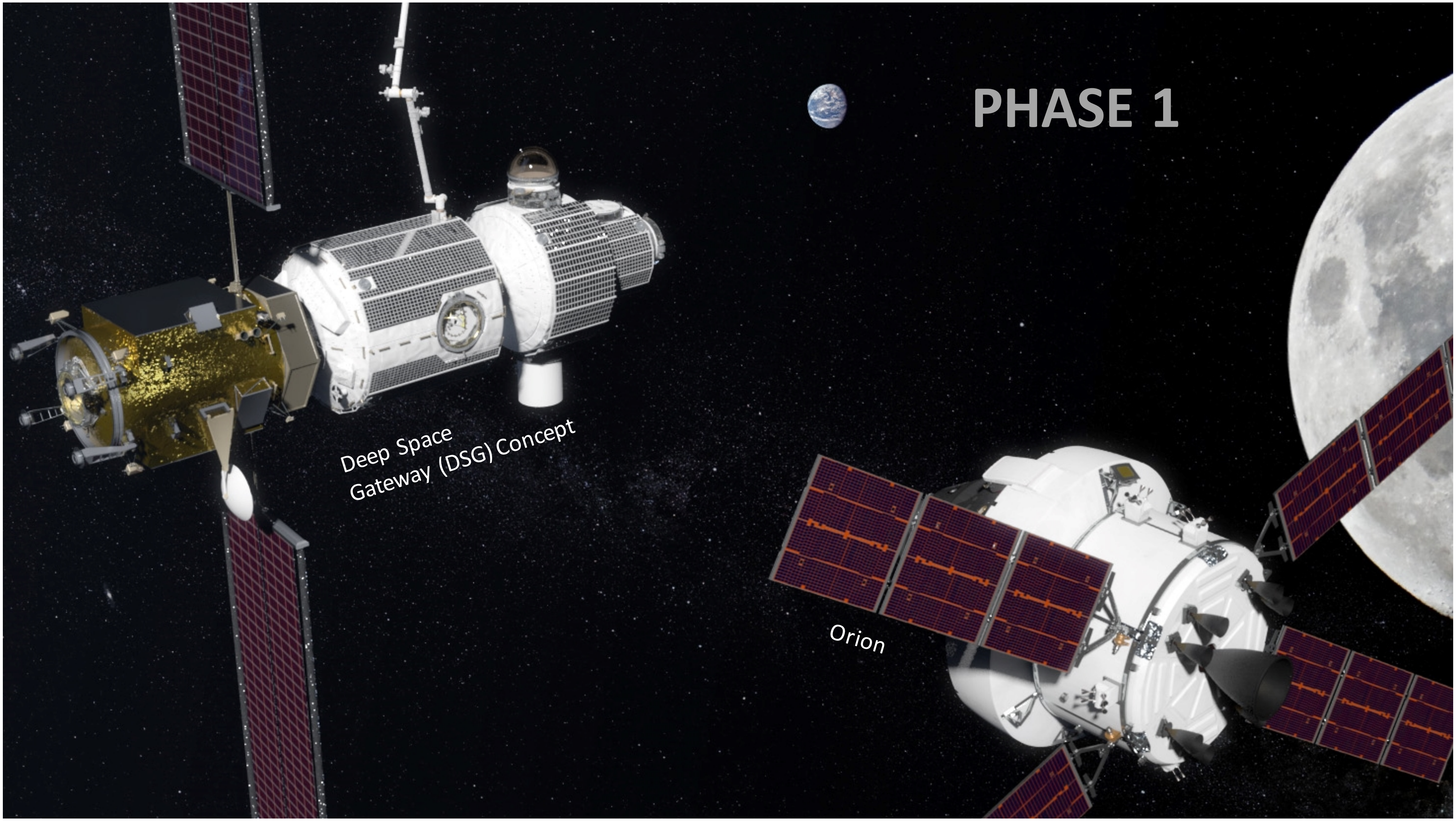
Benefits from Research on the International Space Station

Enabling Deep Space Exploration



Scientific Discovery

Benefits for Humanity

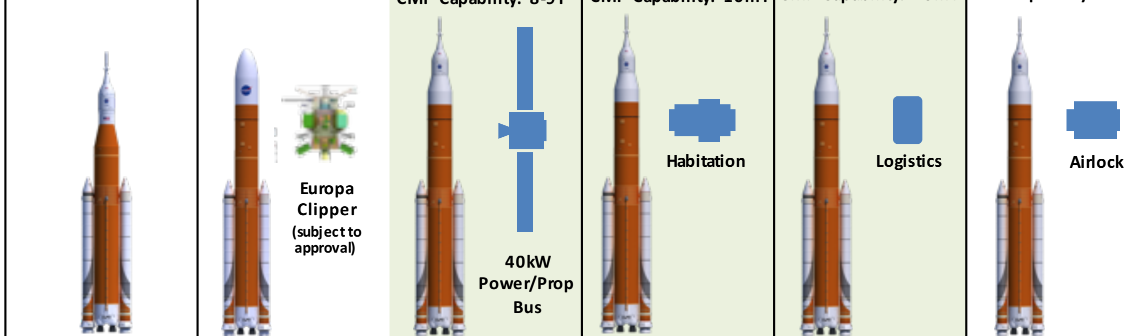

PHASE 1
Deep Space
Gateway (DSG) Concept
Orion

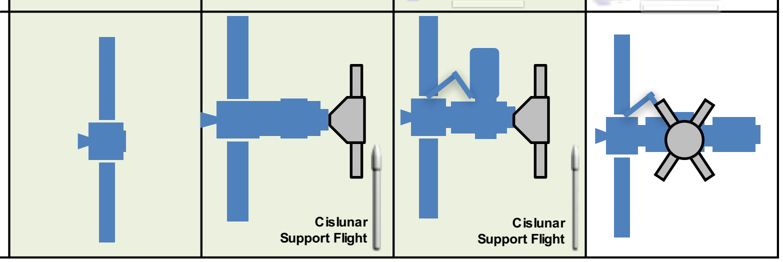
- **Assumptions**
  - Deep Space Gateway provides ability to support multiple NASA, U.S. commercial, and international partner objectives in Phase 1 and beyond
  - The Gateway is designed for deep space environments
    - Supports (with Orion docked) crew of 4 for a minimum of 30 days
    - Supports buildup of the Deep Space Transport
- **Emphasis on defining early Phase 1 elements**
  - Gateway Power Propulsion Element
  - Gateway Habitat
  - Logistics Strategy
- **Future work to refine later elements; early feasibility trades complete**
  - Airlock
  - Deep Space Transport

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 Europa Clipper (subject to approval)	SLS Block 1B Crew: 4 CMP Capability: 8-9T 40kW Power/Prop Bus	SLS Block 1B Crew: 4 CMP Capability: 10mT Habitation	SLS Block 1B Crew: 4 CMP Capability: 10mT Logistics	SLS Block 1B Crew: 4 CPL Capability: 10mT 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 26-42 days	NRHO, w/ ability to translate to/from other cislunar orbits 26-42 days
Gateway (blue) Configuration (Orion in grey)			Cislunar Support Flight	Cislunar Support Flight	





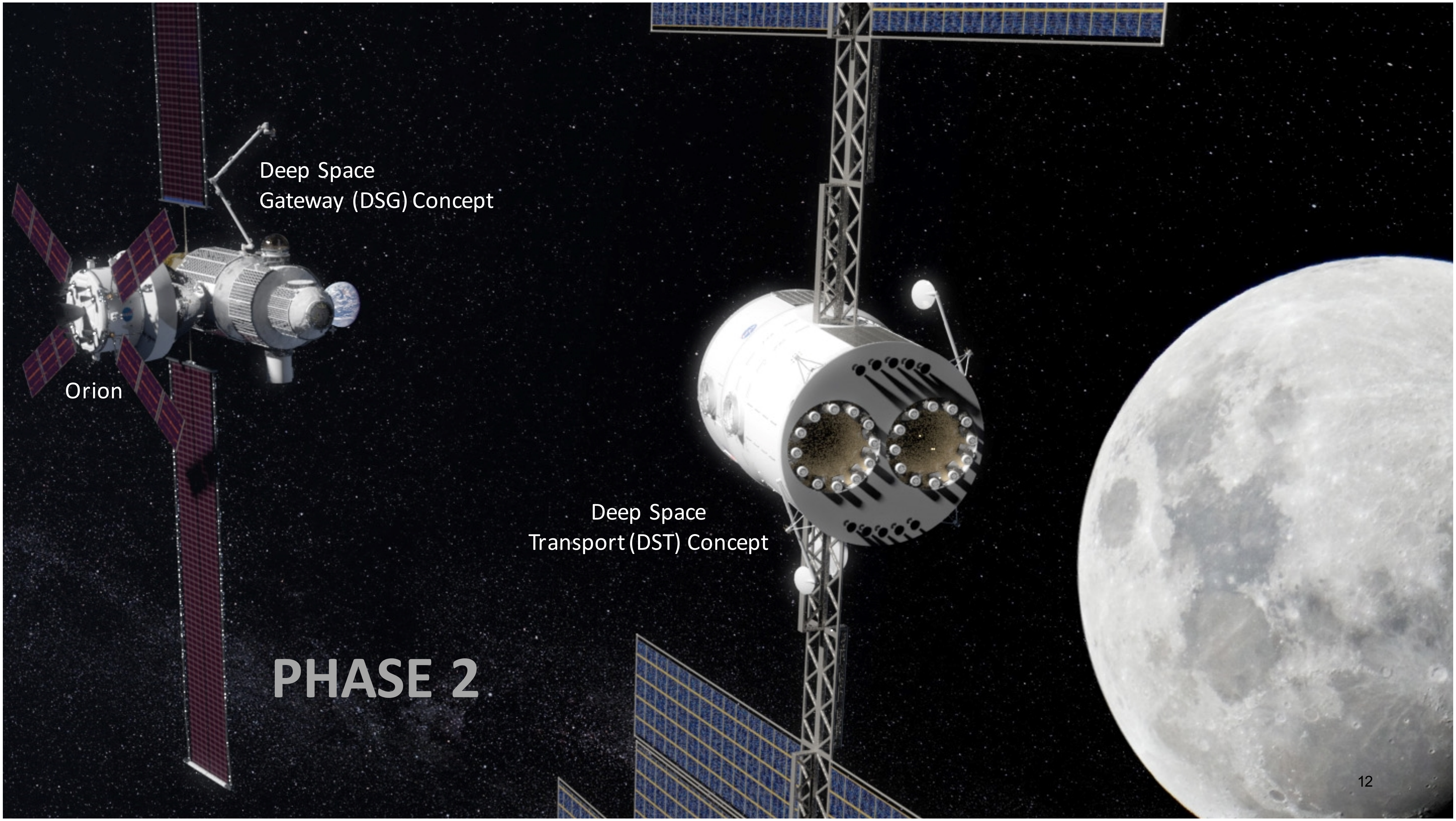
These essential Gateway elements can support multiple U.S. and international partner objectives in Phase 1 and beyond

Known Parameters:

- Gateway 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


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

- **Assumptions**
  - Deep Space Transport provides habitation and transportation needs for transporting crew into deep space including supporting human Mars-class missions
  - The Transport system life will be designed for
    - Reuse for 3 Mars-class missions with resupply and minimal maintenance
    - Crew of 4 for 1,000 day-class missions in deep space
    - Launch on one SLS 1B cargo vehicle - resupply and minimal outfitting to be performed in cislunar space
- **Emphasis on supporting shakedown cruise by 2029**
  - Shakedown cruise to be performed in lunar vicinity
  - Utilizes deep space interfaces and common design standards
- **Future work trades**
  - Shakedown cruise objectives
  - Mars reference mission functional requirements

(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
Deep Space Transport	Logistics	DST Logistics & Refueling	Logistics	DST Logistics & Refueling	Logistics
DST checkout in NRHO 191-221 days Cislunar Support Flight		DSG: continued operations in cislunar space DST: shakedown in cislunar space with return to DSG in NRHO 300-400 days Cislunar Support Flight		DSG: continued operations in cislunar space DST: Mars transit and return to DSG in NRHO Cislunar Support Flight	

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:

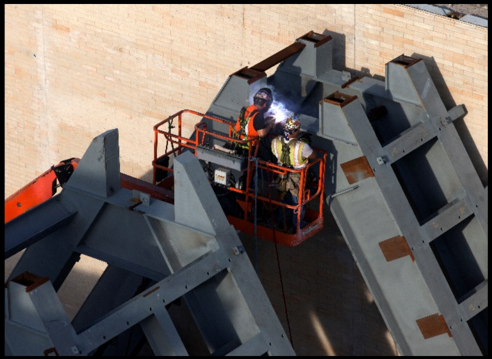
- Order of logistics flights and logistics providers
- Shakedown cruise vehicle configuration and destination/s
- Ability to support lunar surface missions

Director, Cross Program Systems Integration
NASA Exploration Systems Development

MARSHALL SMITH

EM-1 Test and Flight Hardware in Production

Successful test of the third RS-25 flight controller

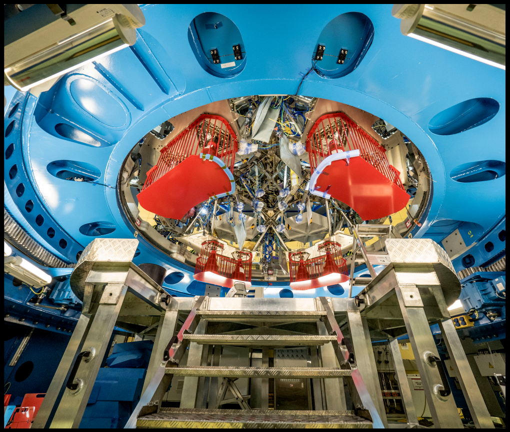


Flame deflector welding in progress at Launch Pad 39B

Orion CM Prop and ECLSS tank/tube welding complete

Core stage forward skirt umbilical installed on the mobile launcher

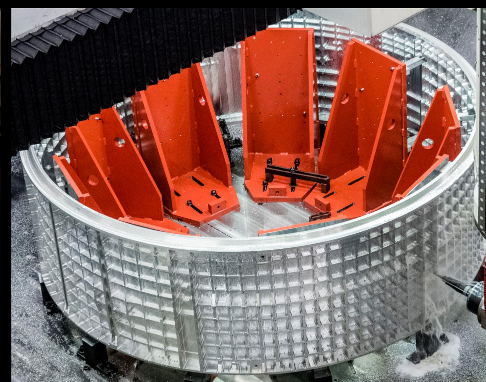
SLS Interank Structural Assembly Completed



ESA service module at Airbus Defence and Space in Bremen, Germany

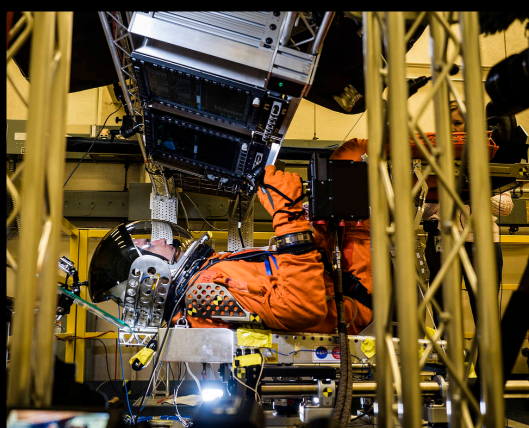
EM-2 Test and Flight Hardware in Production

EM-2 crew module cone panel at AMRO Fabricating Corporation



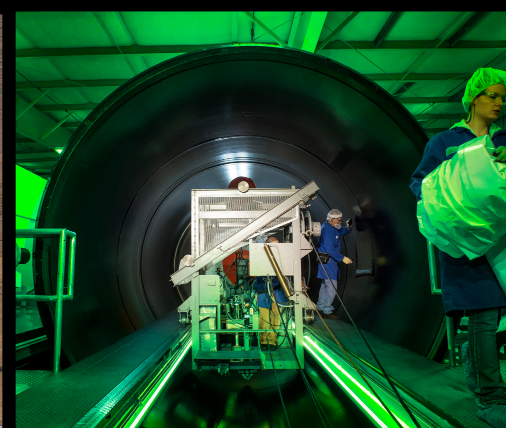
EM-2 barrel machining at Ingersoll in Rockford, IL

Vacuum Pressure Integrated Suit Test



EM-2 launch condition simulation at Johnson Space Center

Abort motor for launch abort system test fire



Orbital ATK lining center forward booster segment case for EM-2

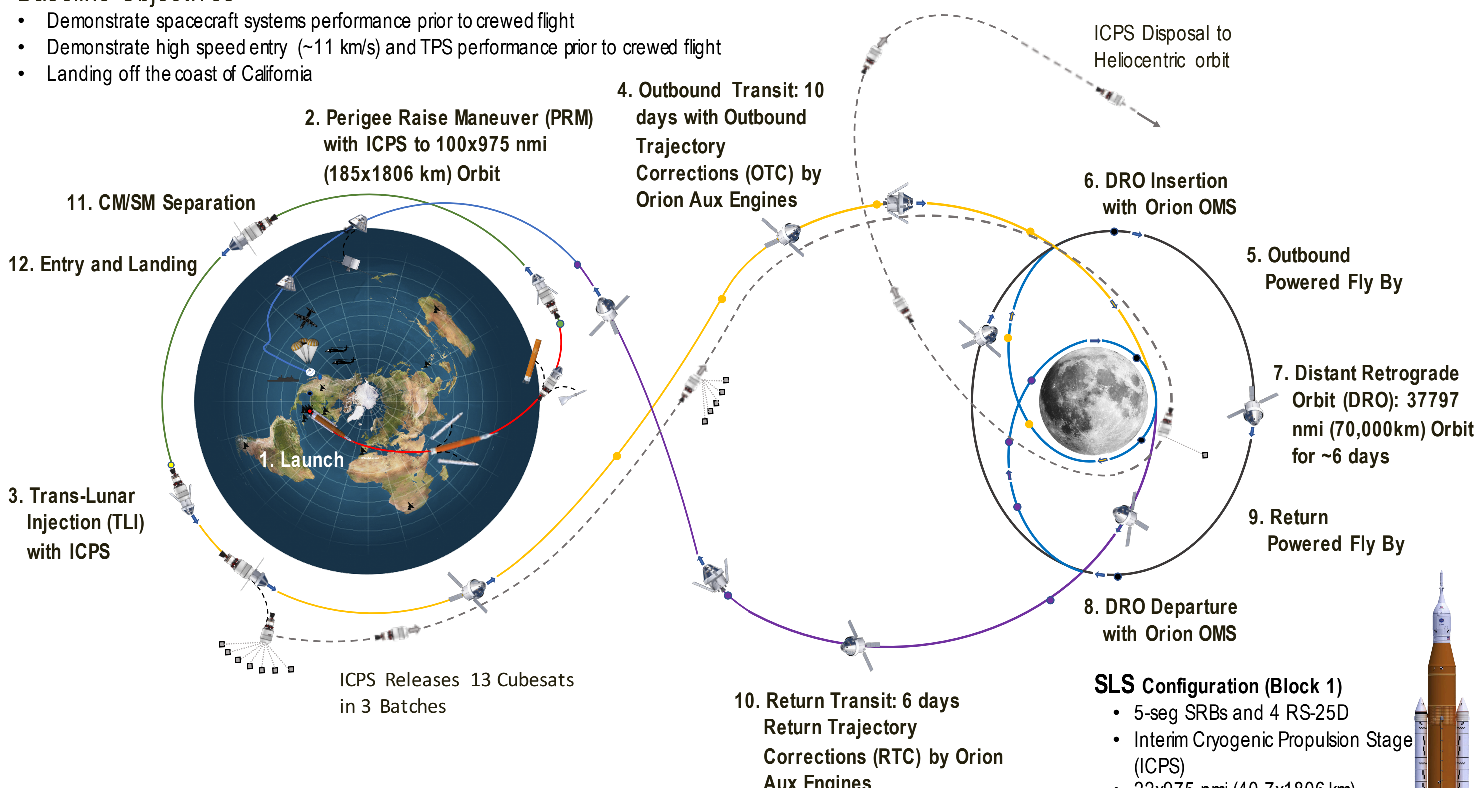
EXPLORATION MISSION 1

Uncrewed Distant Retrograde Orbit

Total Mission Duration: 25 Days

Baseline Objectives

- Demonstrate spacecraft systems performance prior to crewed flight
- Demonstrate high speed entry (~11 km/s) and TPS performance prior to crewed flight
- Landing off the coast of California



SLS Configuration (Block 1)

- 5-seg SRBs and 4 RS-25D
- Interim Cryogenic Propulsion Stage (ICPS)
- 22x975 nmi (40.7x1806 km) insertion orbit
- 28.5 deg inclination

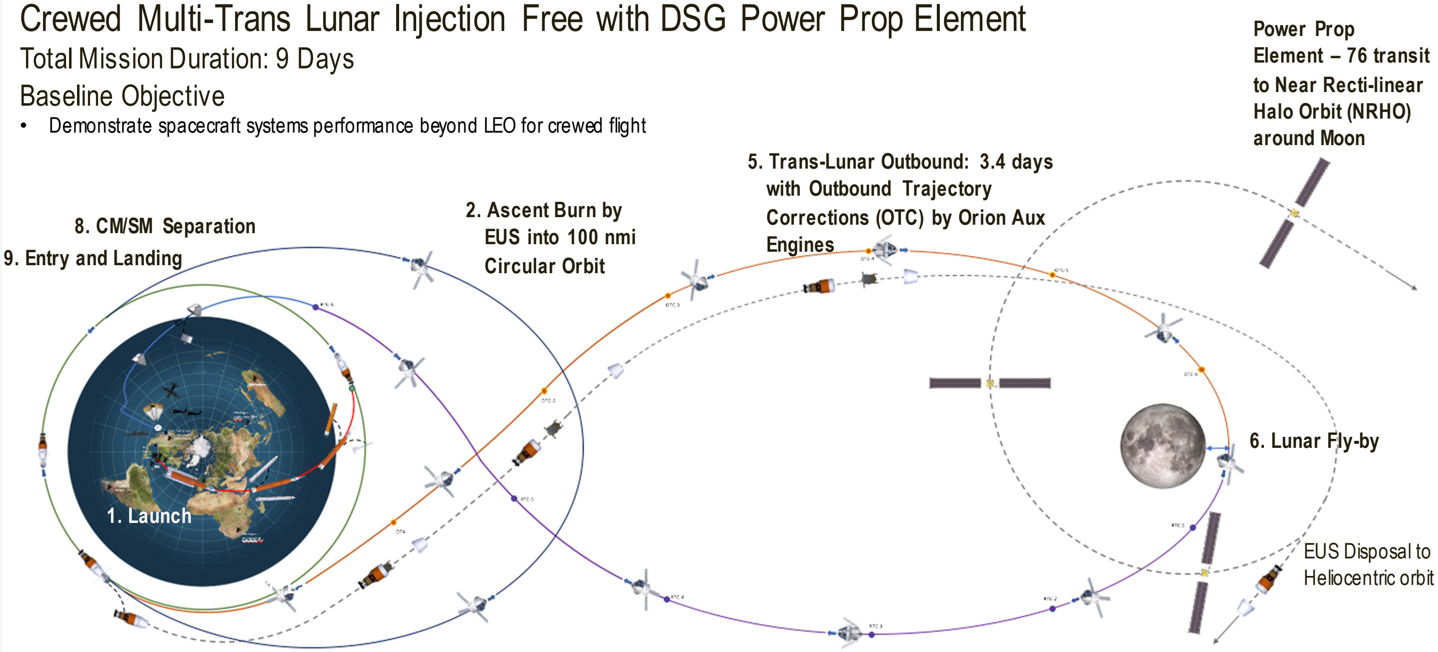
EXPLORATION MISSION 2

Crewed Multi-Trans Lunar Injection Free with DSG Power Prop Element

Total Mission Duration: 9 Days

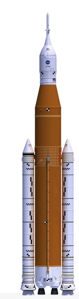
Baseline Objective

- Demonstrate spacecraft systems performance beyond LEO for crewed flight



SLS Configuration (Block 1B)

- 5-seg SRBs and 4 RS-25D
- Exploration Upper Stage (EUS)
- 22x975 nmi (40.7x1806 km) insertion orbit
- 28.5 deg inclination



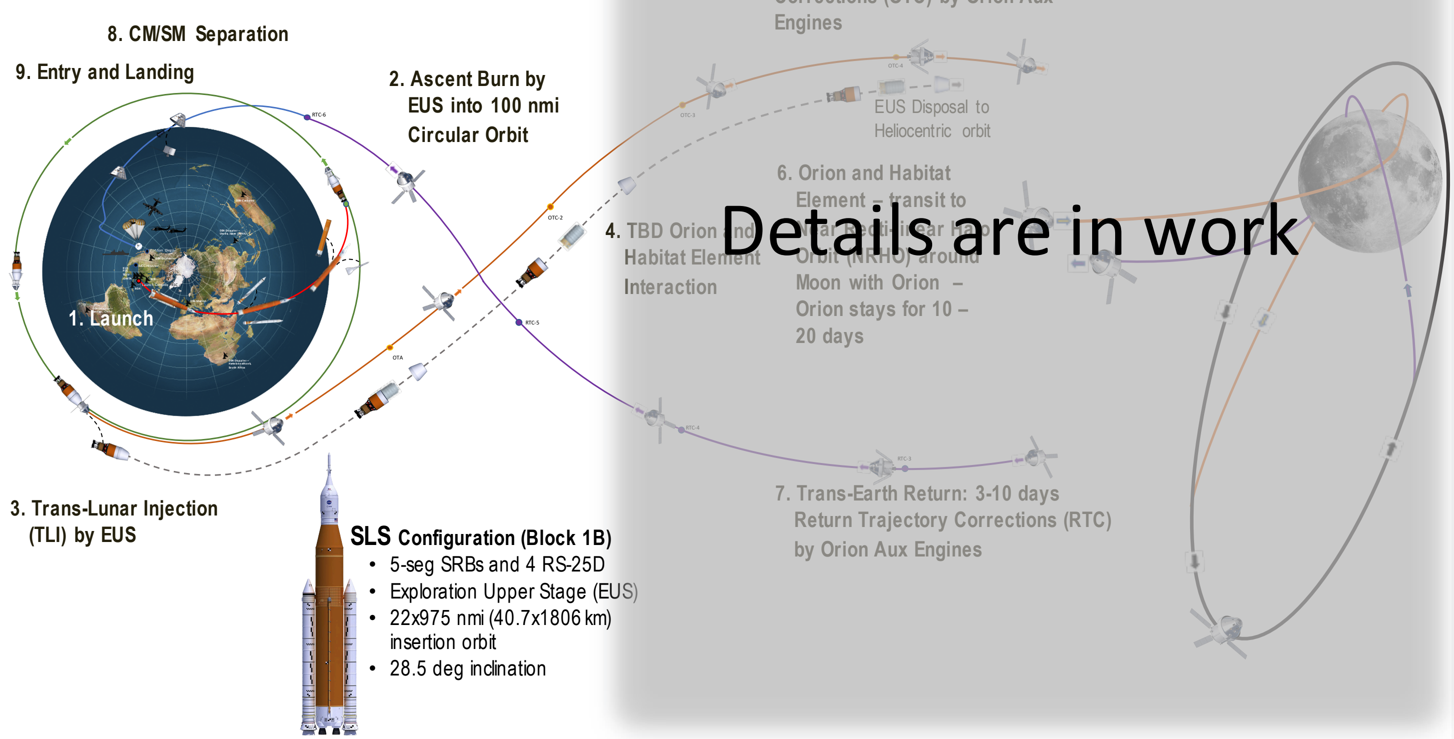
EXPLORATION MISSION 3

Crewed NRHO with DSG Habitat Element

Total Mission Duration: 16-26 Days

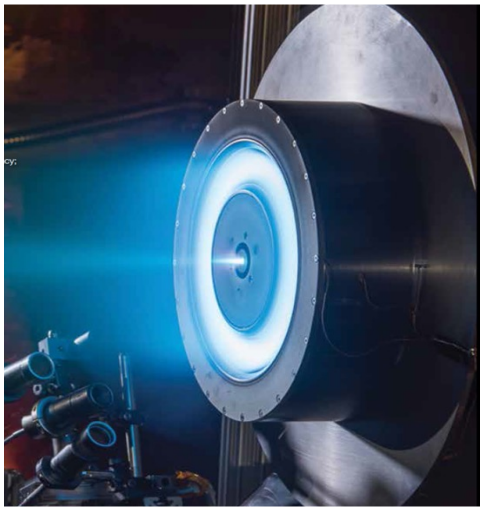
Baseline Objective

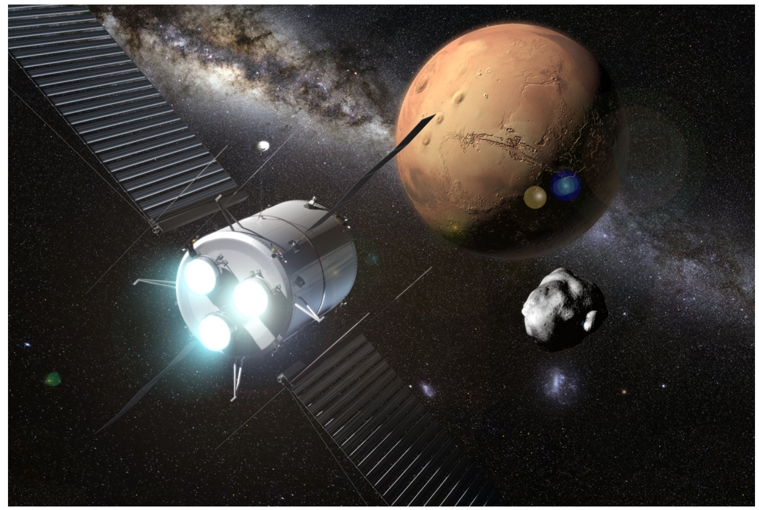
- Demonstrate spacecraft systems performance beyond LEO for crewed flight
- DSG Habitat Transport



SOLAR ELECTRIC PROPULSION TECHNOLOGY

August 17, 2017





Andrew Petro

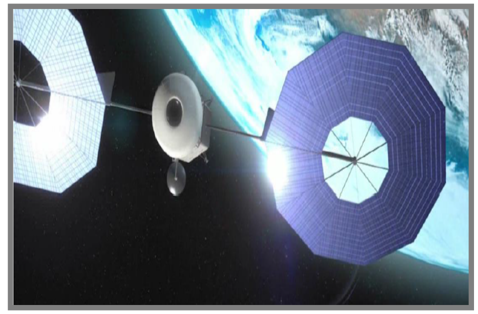
Solar Electric Propulsion Program Executive

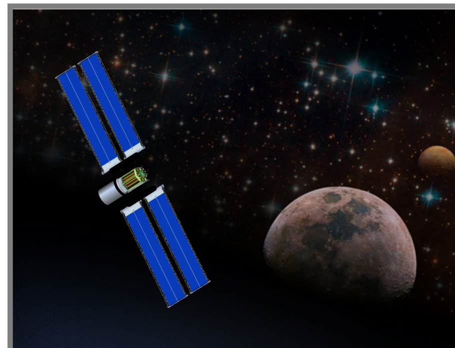
Space Technology Mission Directorate (STMD)

NASA Headquarters

Potential SEP Applications

- **Science and Exploration**
  - observatory placement and station keeping
  - reaching distant destinations at less cost
  - higher power for communications or other payloads
  - transportation for cislunar, Mars, asteroid exploration
- **Communications Satellites and Government Missions**
  - more efficient orbit shaping and transfer
  - increased maneuvering flexibility
  - affordable power increase for communications or other payloads
- **Satellite Servicing and Refueling**
- **Drag Compensation in Low Earth Orbit**
- **Space Tug between LEO, GEO or other Orbits**
  - single use or reusable
  - multiple orbits and plane changes
- **Space Resource Access and Utilization**
- **Orbital Debris Mitigation**
- **Planetary Defense**



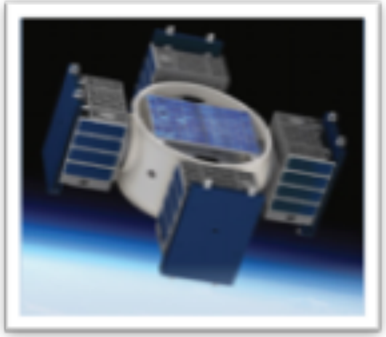


Developing Commercial Markets for SEP

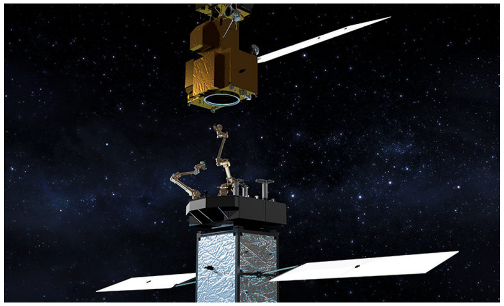
Dual Manifest Satellites

Mission Extension

Electric Upper Stage / Transfer Tug



Satellite Servicing



Current NASA Investments in SEP

STMD has been advancing SEP engine and solar array technology with a focus on a 13 kW Hall thruster with longer life and more efficient solar array structures

- for NASA's exploration and science missions
- for commercial and other government applications – orbit transfer and communication satellites

STMD also sponsors a wide range of technology development for electric propulsion including systems for small spacecraft (< 1 kW) and anticipates additional new efforts to advance more revolutionary SEP technologies.

- Micro-electrospray, small ion and Hall, iodine propellant thrusters

SMD sponsors development of NEXT-C, a 7 kW gridded ion thruster for science missions

HEOMD is funding development to TRL 5, of three more advanced electric propulsion technologies intended for operation at 100 kW and above (NextSTEP)

Numerous NASA SBIR investments in SEP

Solar Array Technology Development

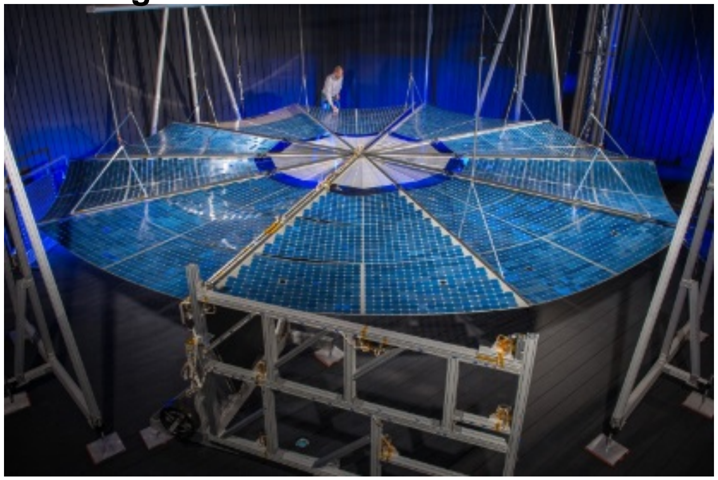
Solar Array System development contracts fully successful (2013-2015)

- Orbital ATK MegaFlex engineering development unit
- Deployable Space Systems ROSA (roll-out solar array) engineering development unit
- Both arrays achieved all performance metrics including:
  - radiation tolerance increased by 4x
  - power to mass ratio increased by 1.7x
  - stowed volume efficiency increased by 4x
  - deployed strength increased by 20x

Both systems completed successful vacuum chamber deployment tests

DSS ROSA

ATK MegaFlex

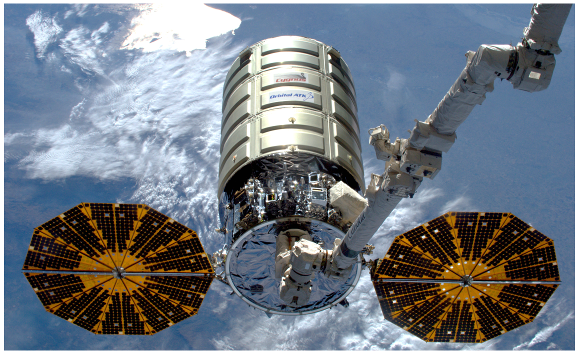


Commercial Infusion of Solar Array Technology

Space Systems Loral and Deployable Space Systems are flight qualifying a 12.5 kW ROSA for use in its commercial communication satellites.

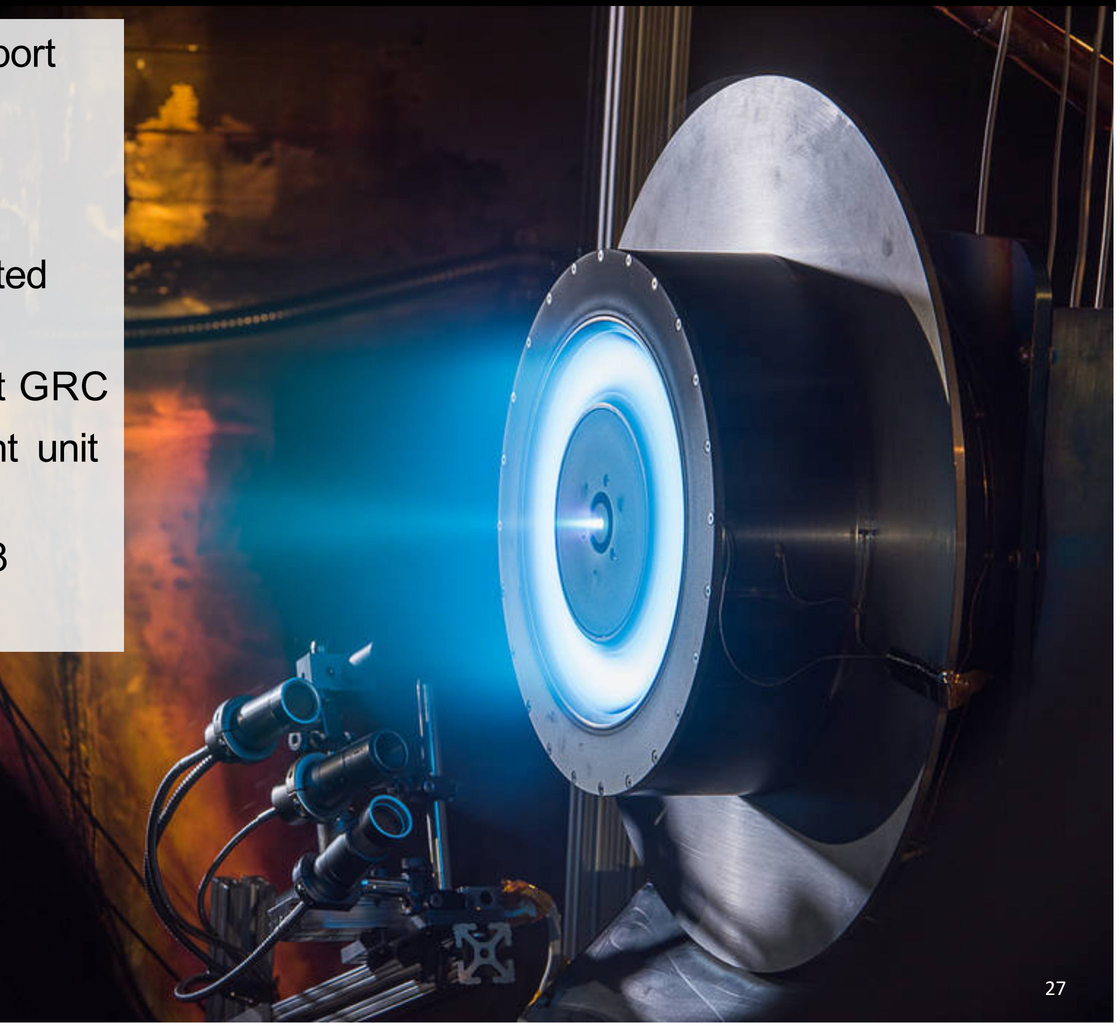
A spaceflight demonstration of a ROSA on the ISS, sponsored by the Air Force Research Laboratory – June 2017

Orbital ATK is using a smaller version of technology similar to MegaFlex on the Cygnus cargo vehicle.



Advanced Electric Propulsion Development

- Led by Glenn Research Center with JPL support
- Developed 13 kW Hall thruster
  - with magnetic shielding to extend lifetime
  - Isp: 2000-3000 sec
- Three test development units (TDU's) fabricated and tested (TDU-1 shown here)
- Integrated power testbed being assembled at GRC
- Vendor for engineering development and flight unit delivery under contract - Aerojet Rocketdyne
- Development to be completed by end of 2018
- Flight unit delivery by 2019



Request for Information
SEP Flight Demonstration Partnership

NASA would like to conduct a flight demonstration of the advanced EP technology as soon as possible after ground qualification

- Technology demonstration to promote more rapid commercial infusion
- Additional technical risk reduction for subsequent NASA applications including the Deep Space Gateway PPE

Seeking information from industry or other government agencies regarding interest in a partnership

- NASA provides one or more EP strings, plasma diagnostic instrumentation, SEP technical expertise
- Partner provides spacecraft, mission, and launch
- Partner can use the spacecraft and mission for their own additional commercial, scientific, or government purposes

RFI accessible at:

https://nspires.nasaprs.com NNH17ZOA003L

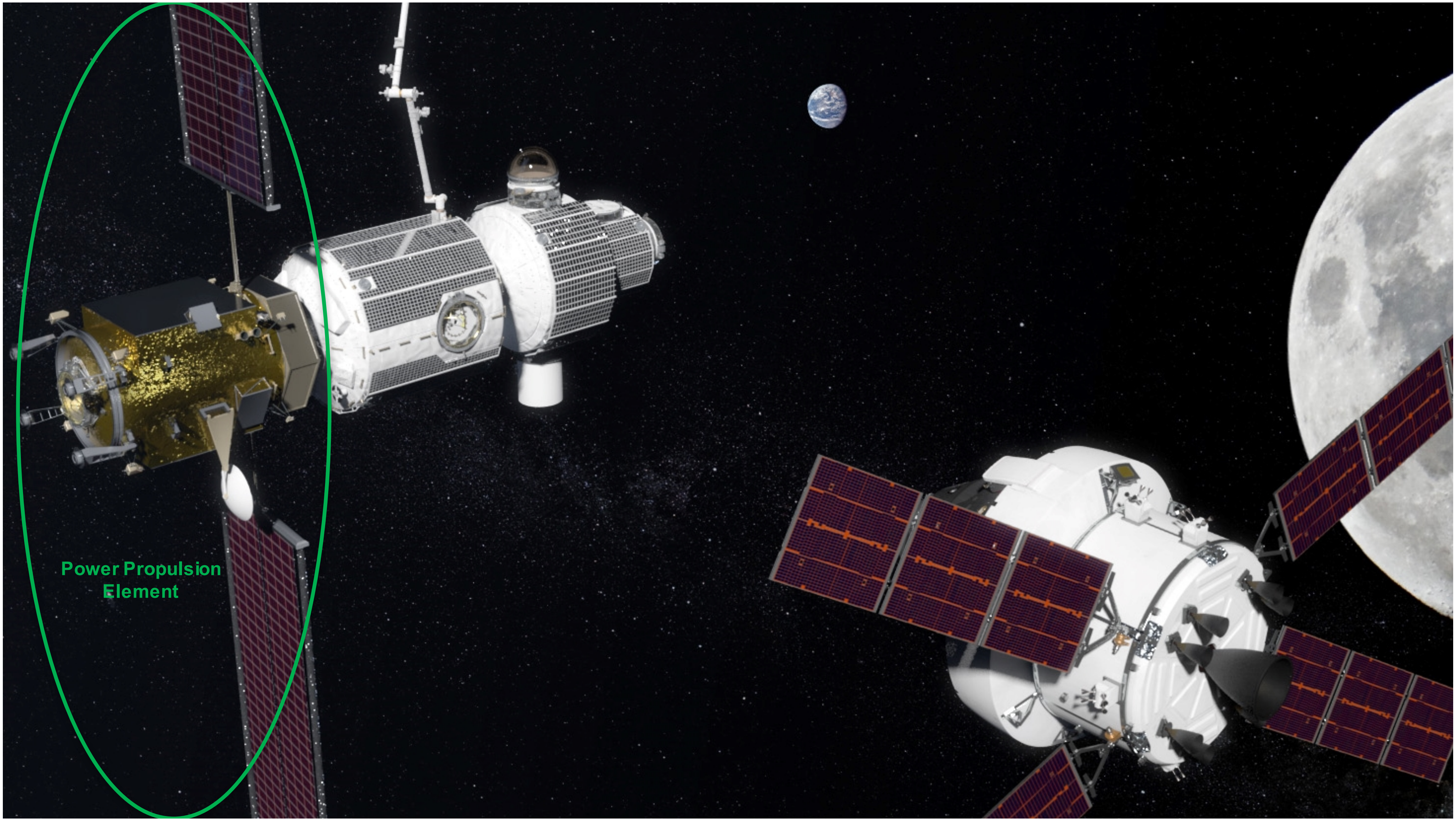
Released: August 8, 2017 Reponses Due: September 8, 2017

Conclusion

- SEP offers significant benefits for in-space transportation for many mission applications
- NASA's current SEP technology investments directly support exploration plans and can meet the needs of other users as well
- NASA plans to
  - continue current SEP technology development,
  - encourage its infusion into government and commercial missions, and
  - pursue development of even more advanced concepts for solar and nuclear electric propulsion – technologies that can make the entire solar system more accessible

Director of Power and Propulsion Element

MICHELE GATES

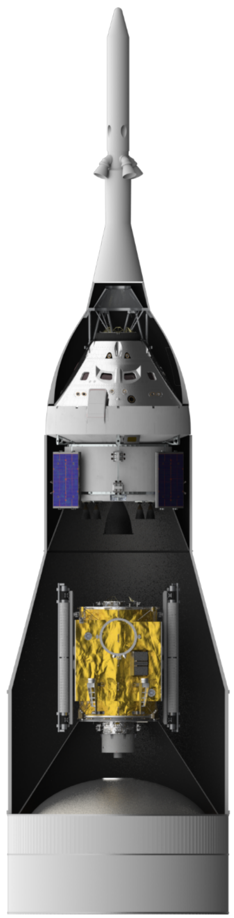

Power Propulsion
Element

Power & Propulsion: 1st Element in Gateway Concept

- Start deep space gateway when we fly crew to vicinity of the moon

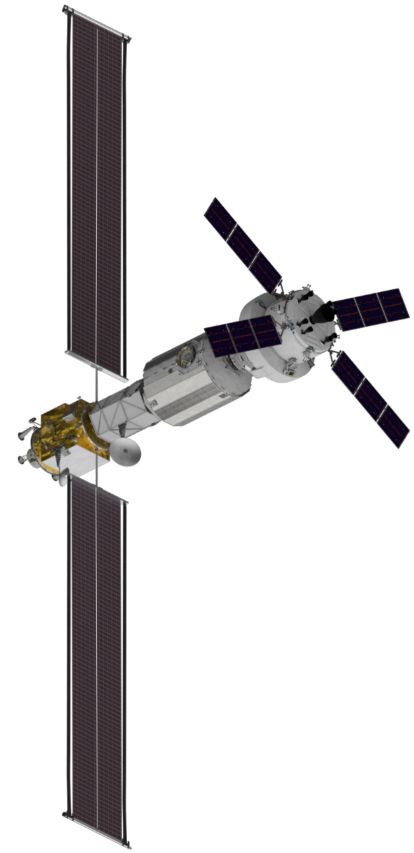
- A power propulsion element (PPE) would be the first element in a cislunar gateway
  - Also would host communications and command/control functions
  - Potentially a partner system/payload contribution

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



Advantages of Solar Electric Propulsion (SEP) in Cislunar Space

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



Approach to PPE Development

- PPE will leverage advanced solar electric propulsion (SEP) technologies developed and matured during ARM activities
  - Directly use commercially-available U.S. flight hardware
  - Infuse SMTD-developed advanced SEP technology
  - Align with U.S. industry plans for future use of SEP

Objectives of Next STEP Appendix C

The objectives of this solicitation are to seek proposals from industry for the conduct of studies specifically focused on areas of differences between previous architectures/configurations for 50kW-class SEP demonstration and the envisioned DSG PPE capability.

- **Specific objectives include:**
  - Identification and understanding of areas of **significant potential synergies between the PPE and current commercial capabilities**. This includes innovative ideas for business models, including intellectual property, asset ownership, and timing of delivery of the asset and/or services to the Government.
  - Evaluate and understand **driving technical differences and implications between prior concepts and approaches developed under the Asteroid Redirect Robotic Mission (ARRM) and the proposed concept for the PPE**, such as implications to meeting reference technical requirements and/or drivers for validating a concept of operations.
  - Identification and understanding of areas of **significant potential synergies between the PPE and future commercial capabilities.** This includes innovative ideas for future business models, including intellectual property, asset ownership, and timing of delivery of the asset and/or services to the Government.
  - Identification of options and potential approaches to meeting potential requirements and to contributing reliability and verification/validation data **for a PPE to a human rated DSG system**.

NextSTEP BAA Draft Appendix C: Power & Propulsion Studies Timeline

✓ Release of PPE Request for Information	Jul 17
✓ Synopsis for Studies through NextSTEP BAA Appendix C	Jul 17
✓ RFI Responses Due	Jul 28
✓ STMD Electric Propulsion System Preliminary Design Review	Aug 1-3
✓ Draft NextSTEP BAA Appendix C for PPE Industry Studies Release	Aug 11
✓ PPE virtual industry day	Aug 17
• Last day for written questions and comments on the Draft Appendix C	Aug 22
• Final Release, NextSTEP BAA Appendix C: Power & Propulsion Studies	Aug 30
• Submissions Due	Sep 26

Deputy Manager of Power and Propulsion Element

DAVID IRIMIES

NextSTEP Appendix C - Power and Propulsion Element Studies

- On Friday, August 11, NASA released a draft solicitation under the NextSTEP-2 BAA to seek proposals from industry for the conduct of studies specifically focused on areas of differences between previous architectures/configurations for 50kW-class SEP demonstrations and the envisioned DSG PPE capability

NextSTEP BAA Draft Appendix C: Power and Propulsion Element Studies (CLIN-1)

Draft Study Areas:
An approach for the PPE design and verification to provide the required functionality with sufficient reliability, fault protection and availability to operate as part of a human-rated system for all crewed mission phases. This could include the use of relevant data from on-orbit operation of subsystems if the PPE use case is applicable, sufficient number of units and cumulative operating have been achieved, and failure modes are sufficiently well understood to establish the confidence and margin needed for use as part of a human-rated system.
The use of standards, specifications, and engineering processes to assure a PPE design that cost-effectively minimizes the probability of the occurrence of failure modes through the application of selective redundancy, factors of safety, or other design margins as necessary for operation as part of a human-rated system.
An approach to providing and validating propulsive and non propulsive attitude control for a DSG with a range of possible stack configurations. Include an assessment of: The integrated stack envelope mass versus the contractor's standard payload and accommodation of the same by contractor's bus primary structure Whether new structure is added below the existing bus structure, or if new primary structure would have to reside inside the bus.
An approach to performing propulsive orbital maintenance maneuvers for entire DSG integrated with a range of possible stack configurations.

NextSTEP BAA Draft Appendix C: Power and Propulsion Element Studies (CLIN-1)

Draft Study Areas:
An approach for PPE operation during the rendezvous and docking of crewed and uncrewed visiting vehicles including Orion with a DSG.
An approach for the PPE to provide a DSG with uncrewed autonomous orbit-transfer capability.
An approach for the design, development, and operation of a high-reliability PPE power generation and power transfer capability as part of a DSG. Exploration power standard not met (98-136 V) if applied to internal PPE power architecture
An approach to hosting two IDSS passive interfaces and assessment for how this drives system technical risk, cost, and schedule
An approach to addressing the minimal 15 year PPE operational lifetime requirement.
An approach to long-term autonomous operation in the cis-lunar environment including fault monitoring, detection, and handling.
An approach for the PPE to provide high-reliability communications for a DSG.
An assessment of the impacts of accommodating an optical communication demonstration onboard the PPE.
An assessment of the impact of the application of NASA defined engineering design & construction standards, interoperability standards, and safety and mission assurance standards that may be proposed for the PPE in a human rated DSG.. Please refer to 8705.2C, Human-Rating Requirements for Space Systems, Chapter 3.

NextSTEP BAA Draft Appendix C: Power and Propulsion Element Studies (CLiN-2)

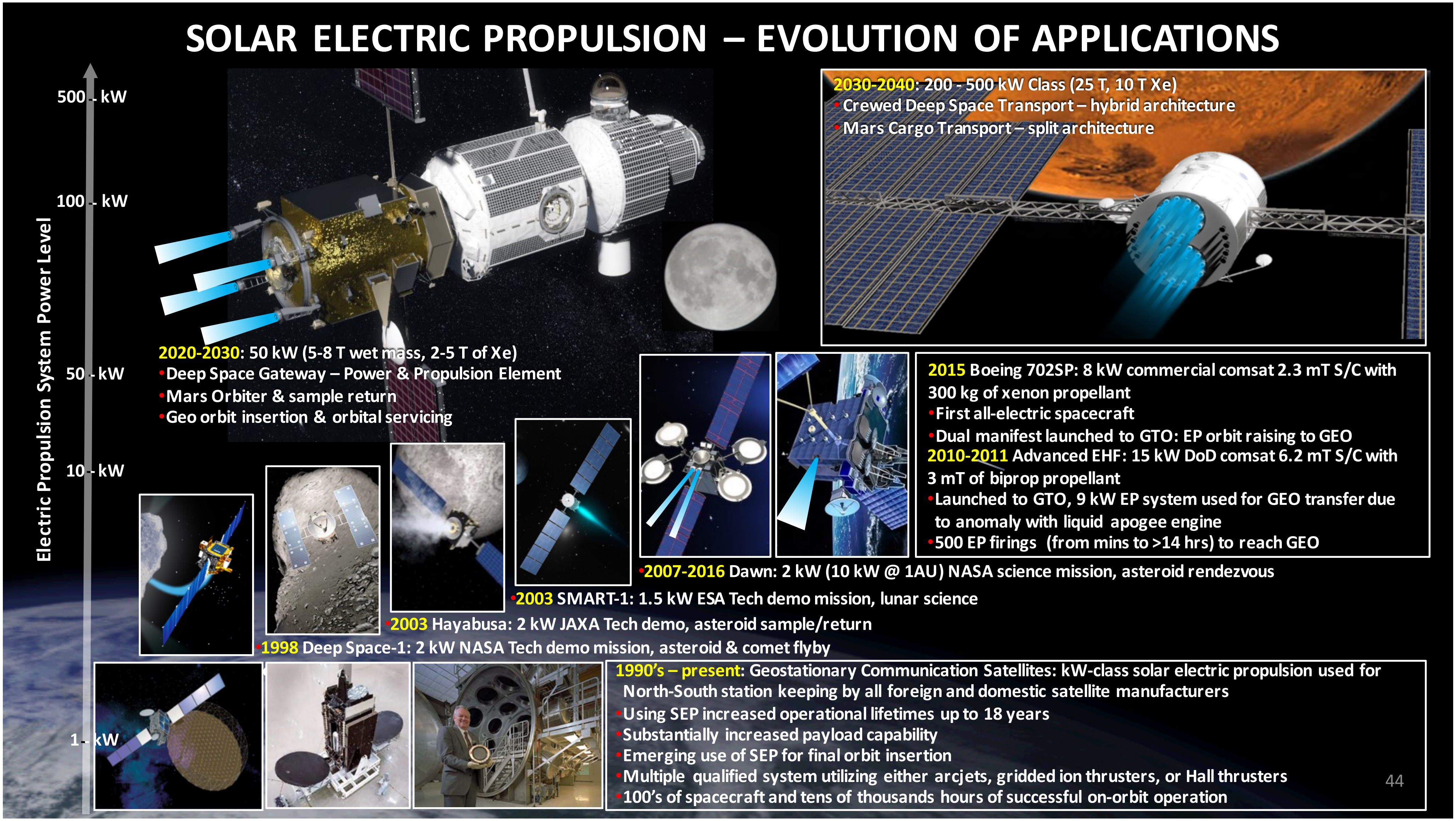
Draft Study Areas:
Options for cost share/cost contributions.
An assessment of impacts of acquiring high power, high throughput EP strings as part of the commercial bus, rather than through a Government Furnished Equipment route.
An approach to providing accommodations of potential (international or domestic partner provided) hardware such as robotic fixtures, science and technology utilization and other possible elements.
An approach to addressing ability to manage batteries charge and discharge during different eclipse durations.
Conceptual layout including identification of any potential clearance or blockage issues which may exist for the PPE.
A PPE approach that is tolerant to crew exercise and implications of extended crew stay durations.
An approach to a PPE lunar communication system that could operate as part of a larger and separate system from the DSG as an additional proving ground segment separate from the PPE.
An approach to avionics, time-triggered Gigabit Ethernet, internal modular avionics & software.
An approach to PPE Assembly, Integration and Test, including a description of industry practices and available data and identification of unique Government capabilities if needed.
An approach to extensibility and possible future PPE configurations or use of systems/subsystems for possible future exploration vehicles/activities.

NextSTEP BAA APP C Study Core Areas – Panel

SEP Spacecraft – Then and Why Now? (Gov't & Commercial Synergy)	David Manzella
Systems Engineering – What are key & driving needs?	Leah McIntyre
System Certification Requirements – How should we address Human Rating?	Joe Gard
Extensibility – How is PPE an investment in the future?	Kurt Hack
Procurement Plan for Study Contracts – What next?	Kathy Schubert

Deputy Chief Engineer of Power and Propulsion Element

DAVID MANZELLA



SOLAR ELECTRIC PROPULSION – EVOLUTION OF APPLICATIONS
Electric Propulsion System Power Level
500 - kW
100 - kW
50 - kW
10 - kW
1 - kW
2030-2040: 200 - 500 kW Class (25 T, 10 T Xe)
• Crewed Deep Space Transport – hybrid architecture
• Mars Cargo Transport – split architecture
2020-2030: 50 kW (5-8 T wet mass, 2-5 T of Xe)
• Deep Space Gateway – Power & Propulsion Element
• Mars Orbiter & sample return
• Geo orbit insertion & orbital servicing
2015 Boeing 702SP: 8 kW commercial comsat 2.3 mT S/C with 300 kg of xenon propellant
• First all-electric spacecraft
• Dual manifest launched to GTO: EP orbit raising to GEO
2010-2011 Advanced EHF: 15 kW DoD comsat 6.2 mT S/C with 3 mT of biprop propellant
• Launched to GTO, 9 kW EP system used for GEO transfer due to anomaly with liquid apogee engine
• 500 EP firings (from mins to >14 hrs) to reach GEO
• 2007-2016 Dawn: 2 kW (10 kW @ 1AU) NASA science mission, asteroid rendezvous
• 2003 SMART-1: 1.5 kW ESA Tech demo mission, lunar science
• 2003 Hayabusa: 2 kW JAXA Tech demo, asteroid sample/return
• 1998 Deep Space-1: 2 kW NASA Tech demo mission, asteroid & comet flyby
1990's – present: Geostationary Communication Satellites: kW-class solar electric propulsion used for North-South station keeping by all foreign and domestic satellite manufacturers
• Using SEP increased operational lifetimes up to 18 years
• Substantially increased payload capability
• Emerging use of SEP for final orbit insertion
• Multiple qualified system utilizing either arcjets, gridded ion thrusters, or Hall thrusters
• 100's of spacecraft and tens of thousands hours of successful on-orbit operation

Lead Systems Engineer of Power and Propulsion Element

LEAH MCINTYRE

Power and Propulsion Element Reference Requirements

Draft PPE Reference Requirements	Heritage ARM Requirements
PPE Lifetime 15 years • 0.97-1.03 AU minimum and maximum solar distance • Disposal per NASA Standard	**ARRM 6 years with heliocentric distance (0.8-1.7 AU)**
PPE Power Transfer 27kW (32 kW study) to External Elements • 8kw transfer during eclipse through end of life • 27kw transfer absence of eclipse through end of life	**Provide Power to future visiting vehicles**
PPE Orbit Transfer and Attitude Control the different configurations of Stack per mass and center of mass tables • Includes propulsive and non-propulsive control	**Asteroid return and control**
PPE 2000kg class tank Xenon capacity	**Xenon capacity 5300 kg**
PPE SLS EM-2 Launch	**SLS Compatible**

Power and Propulsion Element Reference Requirements

Draft PPE Reference Requirements	Heritage ARM Requirements
PPE provide two International Docking System Standard Interfaces forward and aft • Additional interfaces include: storage ports, passive base interface plate, wedge mounting interface and Core Flight Software	**Support** Rendezvous Proximity Operations Docking/Undocking
PPE Communications provide X-Band, Ka-Band, S-Band and UHF communications	**Provide Comm for future visiting vehicles**
PPE is an element of the human rated Deep Space Gateway System • Pointer to NASA standard to include safe configurations, health and status data, fault tolerance and safety inhibits. • Commercial reliability and availability could be used to meet requirements	**ARRM Crew Safe**
PPE Refuelability for Xenon and Hydrazine	**Required fueling interface**

Power and Propulsion Element Reference Requirements

Draft PPE Reference Requirements	Heritage ARM Requirements
PPE Extensibility to Mars class missions • Capability of processing 5000kg Xenon • Extensible systems to Mars class missions: Solar Array Technology Demonstration and High-Power Solar Electric Propulsion (SEP) System	**Extensibility power level 150 kW**
PPE Near Rectilinear Halo Orbit (NRHO)	**Distant Retrograde Orbit**
PPE Mass 7500kg including the Payload Adaptor	**Launch vehicle dependent**
PPE Optical Communication Demonstration	**Contributed hardware**
PPE translation path for EVA	**Crew EVA activity**
PPE 1200kg Xenon Loading allocation	**N/A**

Crewed Phase Lead of Power and Propulsion Element

JOE GARD

PPE As Part of a Human Rated System

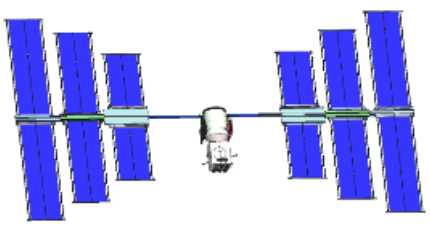
- **NASA has been working to right size the Human Rating process for exploration missions.**
  - Intelligently applying fault tolerance and reliability to the most vulnerable systems.
- **Historically, NASA spacecraft do not have access to extended reliability data**
  - Leverage the industry experience, and use flight proven reliability data to deliver a cost effective human rated spacecraft.
- **Understand the potential impact of the Human Rating standards that may be proposed for the PPE in a human rated DSG.**
  - NPR 8705.2C Human Ratings Requirements for Space Systems

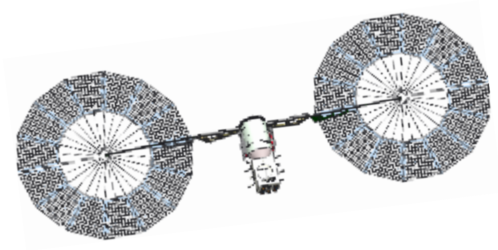
Architecture Integration Lead of Power and Propulsion Element

KURT HACK

Extensibility to Higher Power Systems for Deep Space Human Exploration

- **High-power, 50-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 electric propulsion 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





Acquisition Lead of Power and Propulsion Element

KATHY SCHUBERT

What’s Next ?

- The final NextSTEP Appendix C is targeted for release on **August 30, 2017**.
- Proposals along with a signed model contract will be due on **September 26, 2017**
  - Proposals shall be submitted electronically in Adobe pdf format to the Point of Contact e-mail address specified in Appendix C.
  - Hard copies will not be accepted.
- A NASA Evaluation Panel will evaluate proposals deemed compliant according to the evaluation criteria described in the omnibus BAA and Appendix C.
- The Government intends to evaluate proposals and award a contract(s) based on initial proposals, without discussions. Accordingly, each Offeror should submit its initial proposal to the Government using the most favorable terms from a cost and technical standpoint.
- Selection for funding and contract start is planned for **November 2017**

General Instructions

- **A Model Contract is provided as Attachment C of the Appendix.**
  - All sections designated with the text [OFI] represent "Offeror Fill-Ins". Offerors should fill in [OFI]'s and submit as part of the model contract with proposal submittal.
  - Additionally, sections designated with the text [TBD] stand for "To Be Determined". Offerors should not fill in [TBD]'s. The Government will update these after contract award.
  - Offerors may take exception to, or have unique interpretations of any model contract clauses. These exceptions and/or unique interpretations should be listed clearly in a Summary of Exceptions.
    - Note, taking exception to, or having unique interpretations of any required clauses MAY have a negative impact on potential selection.
- **NASA anticipates individual award amounts of $250-$500K per study contract across multiple potential efforts.**
- **Contracts shall be firm fixed price with two milestone payments, and have content separated by two CLINs which align with the topics listed in Appendix C, Section 3. NASA may select one CLINs, or the entire proposed effort.**

Comments and Questions on the Draft Appendix C

- Written Comments or Questions on the DRAFT Appendix C and Attachments are appreciated.
  - Attachment B: PPE Capabilities and Attachment C: Model Contract was posted to FedBizOps on **August 16, 2017**

- Provide comments or questions via email to Leahmarie.Koury@nasa.gov by **August 22, 2017**, no later than 5:00pm Eastern Time.
  - In the field of the email Subject, please reference
    - **NNH16ZCQ001K-PPE Appendix C**

- Comments and questions received on the draft Appendix C and Attachments will not be posted or responded to however will be considered by the Government for the final Appendix C release.

NASA Questions to Industry

- Are the PPE Appendix C due dates and page counts adequate?
- Are any of the PPE Appendix C requirements unclear or overly constraining?
- Are there any suggestions for additional study topics or any study topics that are unclear?

Appendix C Points of Contact

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***** Disclosure *****

In the event of *any* discrepancy between information you hear today and information in the Final Appendix C, the Final Appendix C is the controlling document.

NASA