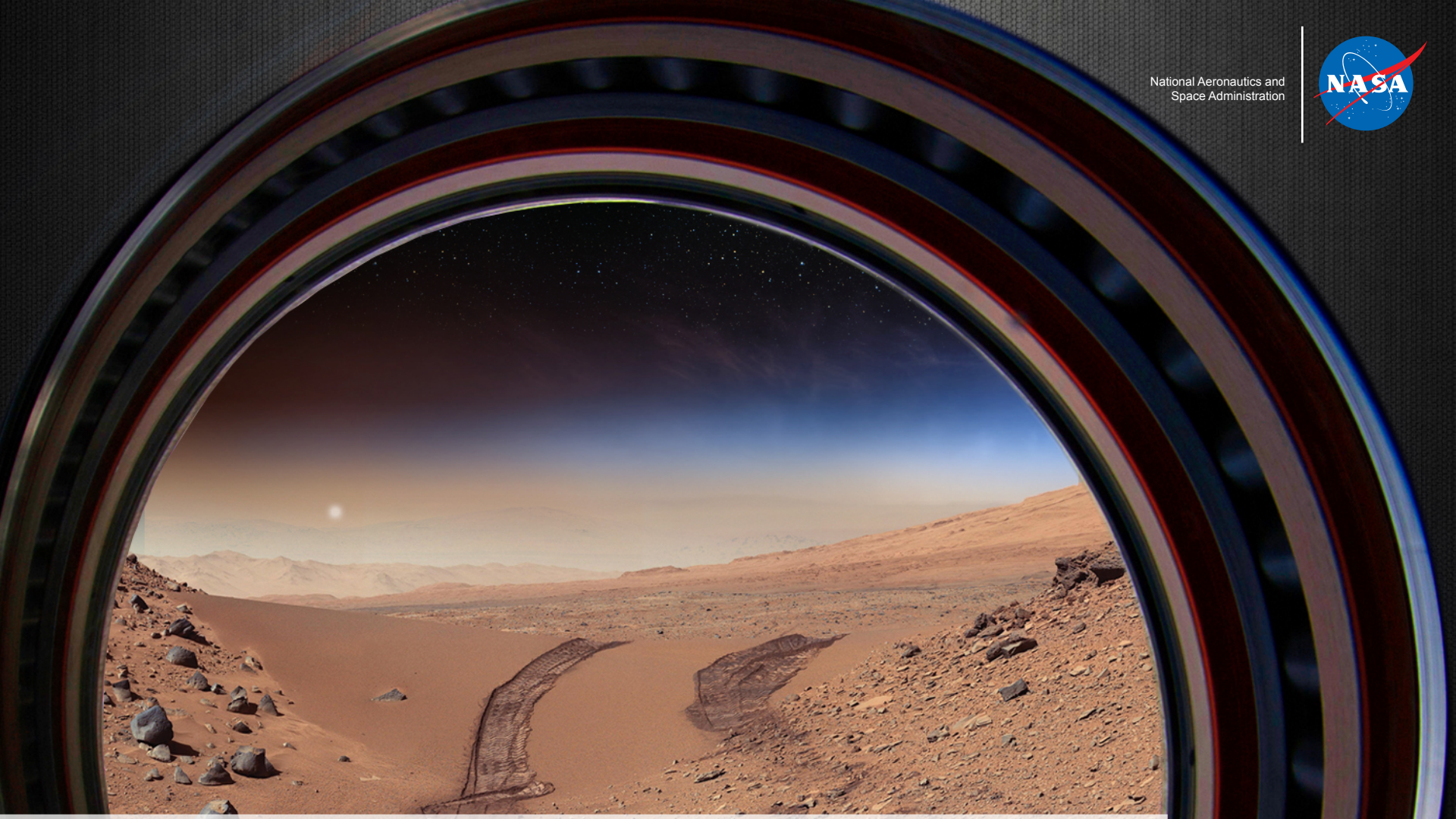
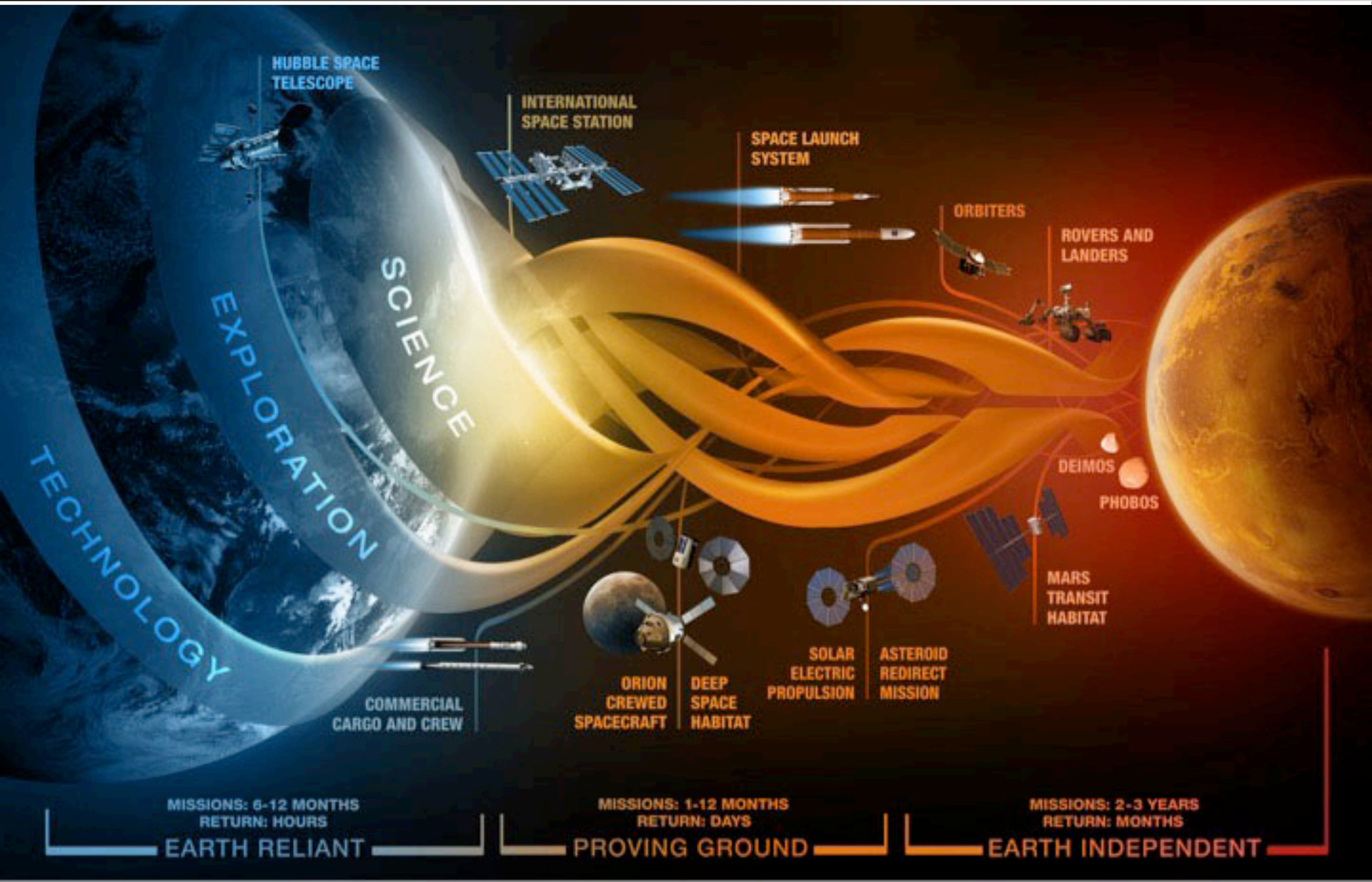
National Aeronautics and Space Administration



Human Exploration & Operations Update for NAC HEO Committee

Greg Williams | DAA – Policy & Plans | HEO | November 14, 2016

Extending Human Presence into the Solar System



JOURNEY TO MARS

All elements needed for a human Mars mission are in development now.

EARTH RELIANT
NOW - MID-2020s

International Space Station operation through commercial development of low-Earth orbit
Development of deep space systems life support and human health

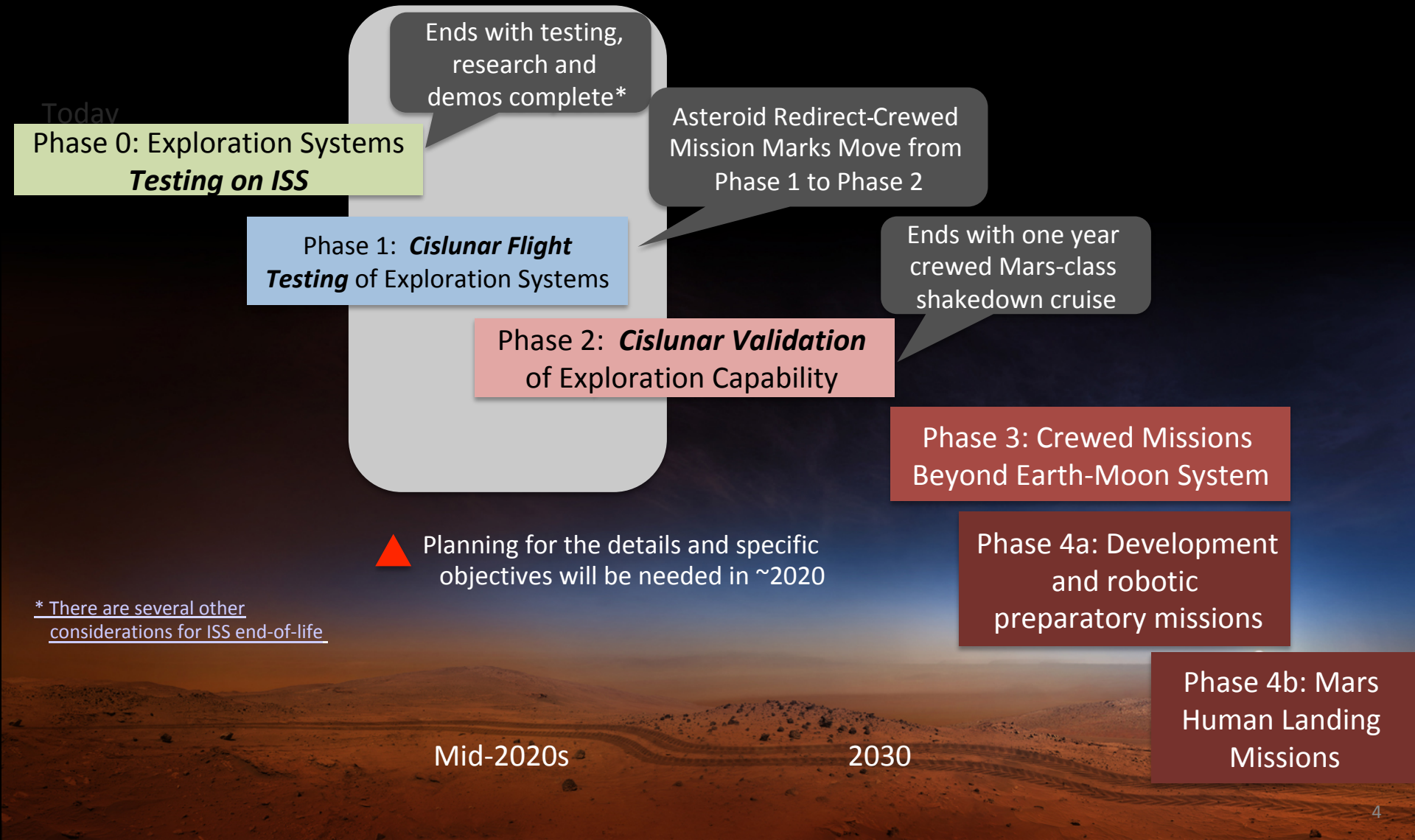
PROVING GROUND
2018-2030

Regular crewed missions and spacewalks in cislunar space
Verify deep space habitation and conduct a yearlong mission to validate readiness for Mars Demonstrate integrated human and robotic operations by redirecting and sampling an asteroid boulder

EARTH INDEPENDENT
NOW – 2030s and beyond

Science missions pave the way to Mars
Demonstrate entry, descent, and landing and in-situ resource use
Conduct robotic roundtrip demonstration with sample return in the late 2020s
Send humans to orbit Mars in the early 2030s

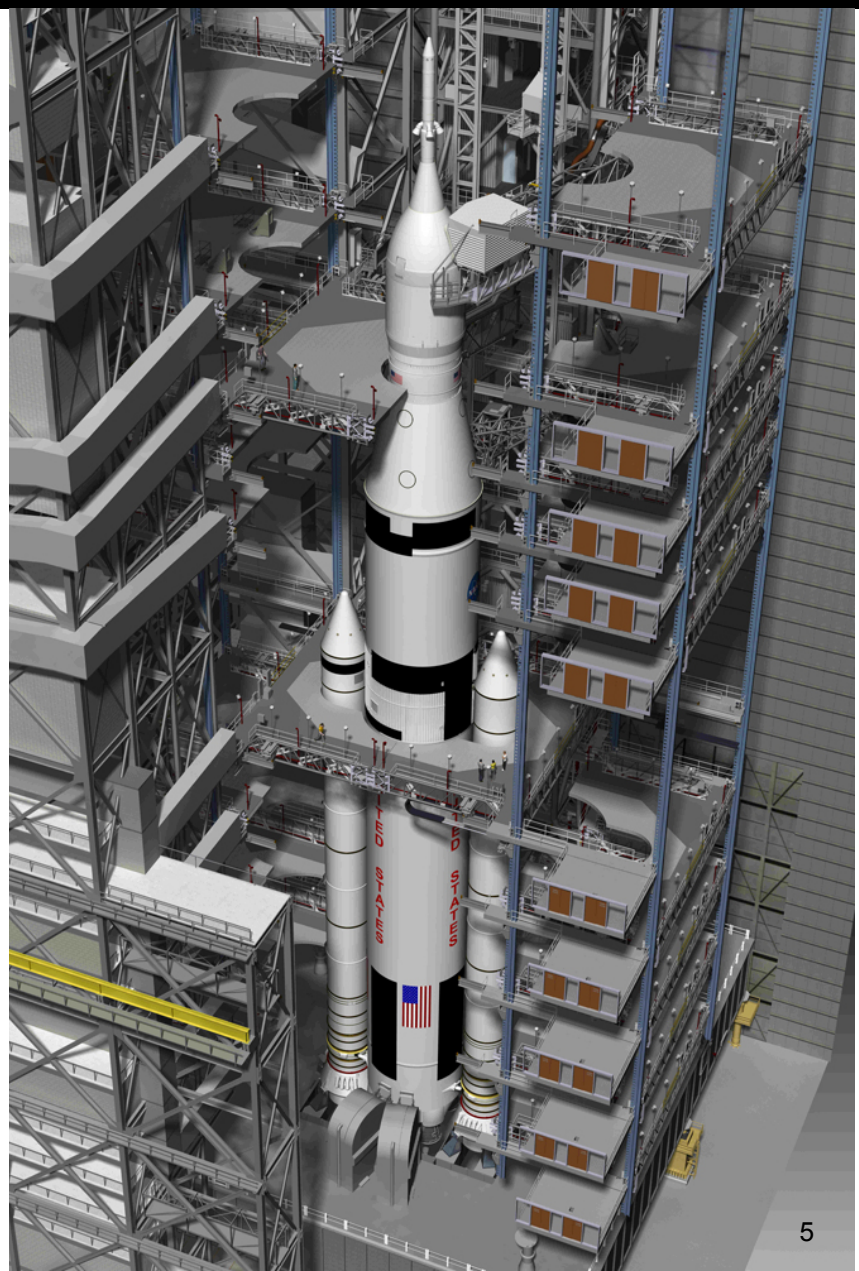
Human Space Exploration Phases From ISS to the Surface of Mars



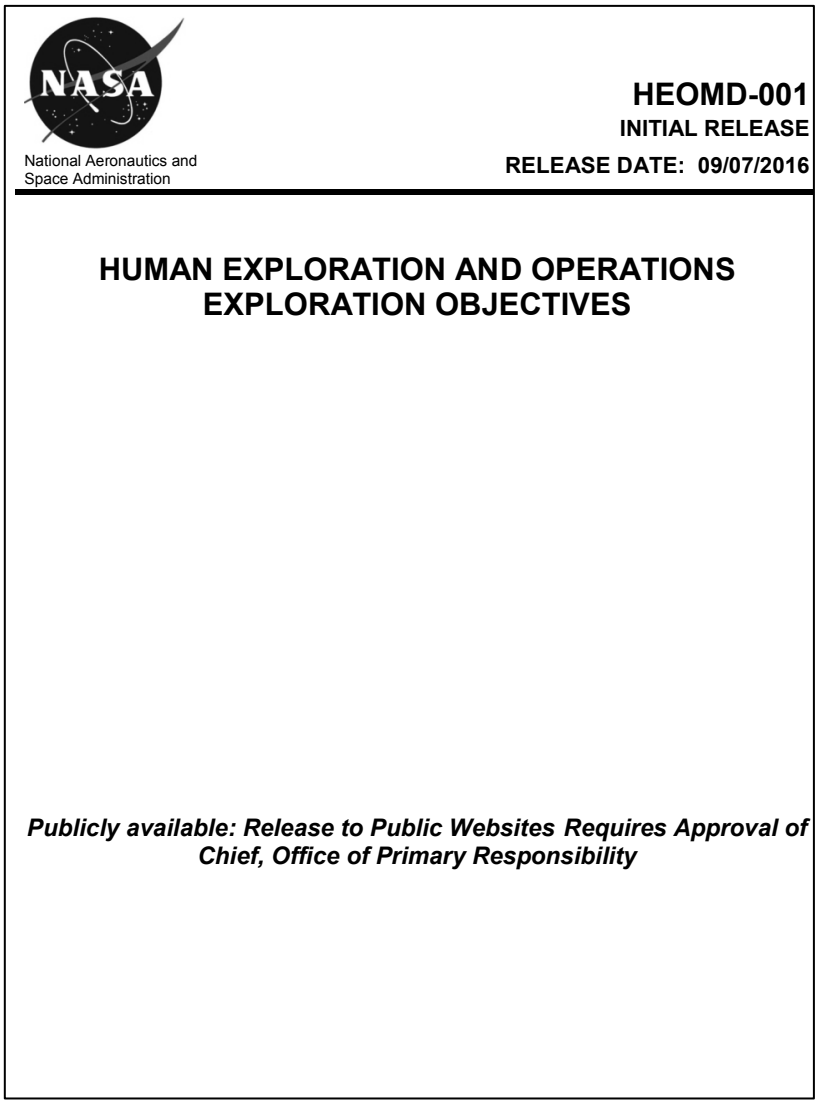
* There are several other considerations for ISS end-of-life

HEOMD-Level Progress & Current Activity

- Baselined Exploration Objectives document for Phases 0-1-2
- On-going Directorate executive level dialog on becoming an “ambidextrous organization” – one that can simultaneously exploit and explore
- Working to collaborate across Mission Directorates to achieve agency goals
- New Director, SLPSRA Division – Dr. Craig Kundrot
- Operating under FY17 CR
- Preparing for transition to new Administration & Congress; building consensus on the phases of progression of human exploration from ISS to the surface of Mars



Exploration Objectives Baselined for Phase 0/1/2



National Aeronautics and Space Administration

HEOMD-001
INITIAL RELEASE
RELEASE DATE: 09/07/2016

HUMAN EXPLORATION AND OPERATIONS EXPLORATION OBJECTIVES

Publicly available: Release to Public Websites Requires Approval of Chief, Office of Primary Responsibility

Phase 0: Exploration Systems Testing on ISS and in LEO

Leverage the ISS as a test bed to demonstrate key exploration capabilities and operations, and foster an emerging commercial space industry in LEO.

Phase 1: Cislunar Demonstration of Exploration Systems

Demonstration of the integrated SLS and Orion; culminates in the Asteroid Redirect Crewed Mission (ARCM) in the mid-2020s.

Phase 2: Cislunar Validation of Exploration Systems

Validation of integrated SLS, Orion, habitation, crew, and in-space transportation systems in cislunar space; culminates in the capstone a one- to three- year crewed “shakedown cruise” of a Mars transit habitation capability in the 2030 timeframe.

HEO Exploration Planning (cont'd)

- **The next step is to allocate Phase Objectives to flight objectives for EM-2 through 8; this work will be conducted in 2017-20**
- **Progress to date:**
  - EM-1 well-defined: first test of integrated of integrated SLS/Orion stack; DRO around the moon; deploy 13 Cubesats (selected)
  - EM-2: first flight of SLS/Orion with crew. Working toward EUS (not in FY17 PBR, but in FY16 Appropriations and FY17 Approps bills); flight profile under study.
  - Working toward 1 flight/yr cadence after EM-2; start of this cadence depends on FY17 appropriations
  - Initial cislunar habitation capability in early 2020s, depending on outcome of NextSTEP activity and international planning
  - Asteroid Redirect Crewed Mission in ~2026
  - Build up of cislunar habitation/logistics capability in mid/late 2020s leading to one-year shakedown cruise in 2029
- **NASA is studying options for implementing this framework; budget uncertainties and evolving partnership landscape mean it is too early to baseline a full manifest of missions thru 2030.**
- **In parallel, HEO, SMD, and STMD are collaborating on technology developments, precursors, and trade studies for Mars missions**

Exploration Systems Development Progress & Current Activity

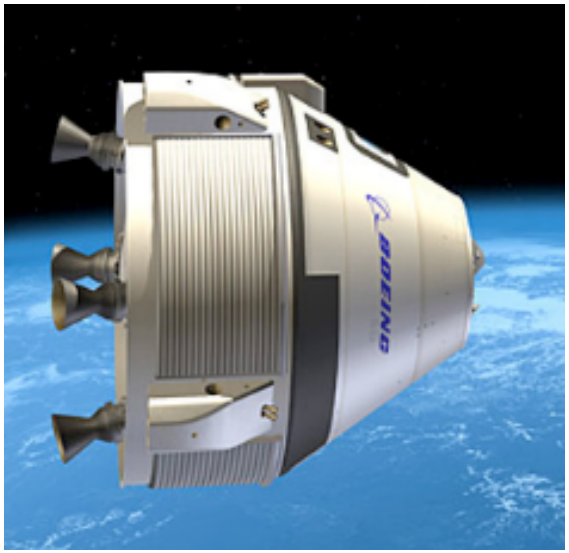
- Accomplished “Build-to-Sync” review milestone (Enterprise-level CDR)
- Worked with ESA to complete the Service Module CDR
- Orion assembly underway
- SLS Exploration Upper Stage PDR underway; RL-10 engine procurement in process
- RS-25 existing engines tested; testing continues with SLS engine controllers; restarting production line for new engines
- 8 of 10 VAB platforms installed
- Umbilical testing underway
- Progressing on GSDO software integration

International Space Station Progress & Current Activity

- International Docking Adapter installed
- Orbital/ATK Antares return to flight successful; planning to use Atlas V for next flight for overall cargo upmass needs
- Working with SpaceX to identify next cargo flight readiness
- HTV-6 on track for December 9
- Crew time availability for research has exceeded goals in recent increments
- Russia temporarily goes to two crew beginning in March 2017
- CASIS recently signed multi-million dollar, multi-year agreements with NIH and NSF to conduct research onboard the ISS

Commercial Crew Program Progress & Current Activity

- Successfully completed 2016 Annual Review at Agency level
- Significant progress on the Phase 2 safety review; ~90% of the hazard reports have been delivered for NASA review
- Awarded two operational missions to the ISS for each partner
- Boeing completed mass reduction effort; Crew Access Tower continues to be outfitted at L-41
- SpaceX completed Delta CDR; Pad 39A nearing completion
- Milestone schedules remain optimistic (SpaceX certification in Feb 2018, Boeing certification in May 2018)



Other Programs Progress & Current Activities

SLPS /HRP

- Initial results of one-year mission to be presented in January
- Formulating Open Science investigations using a team of competitively-selected Co-PIs

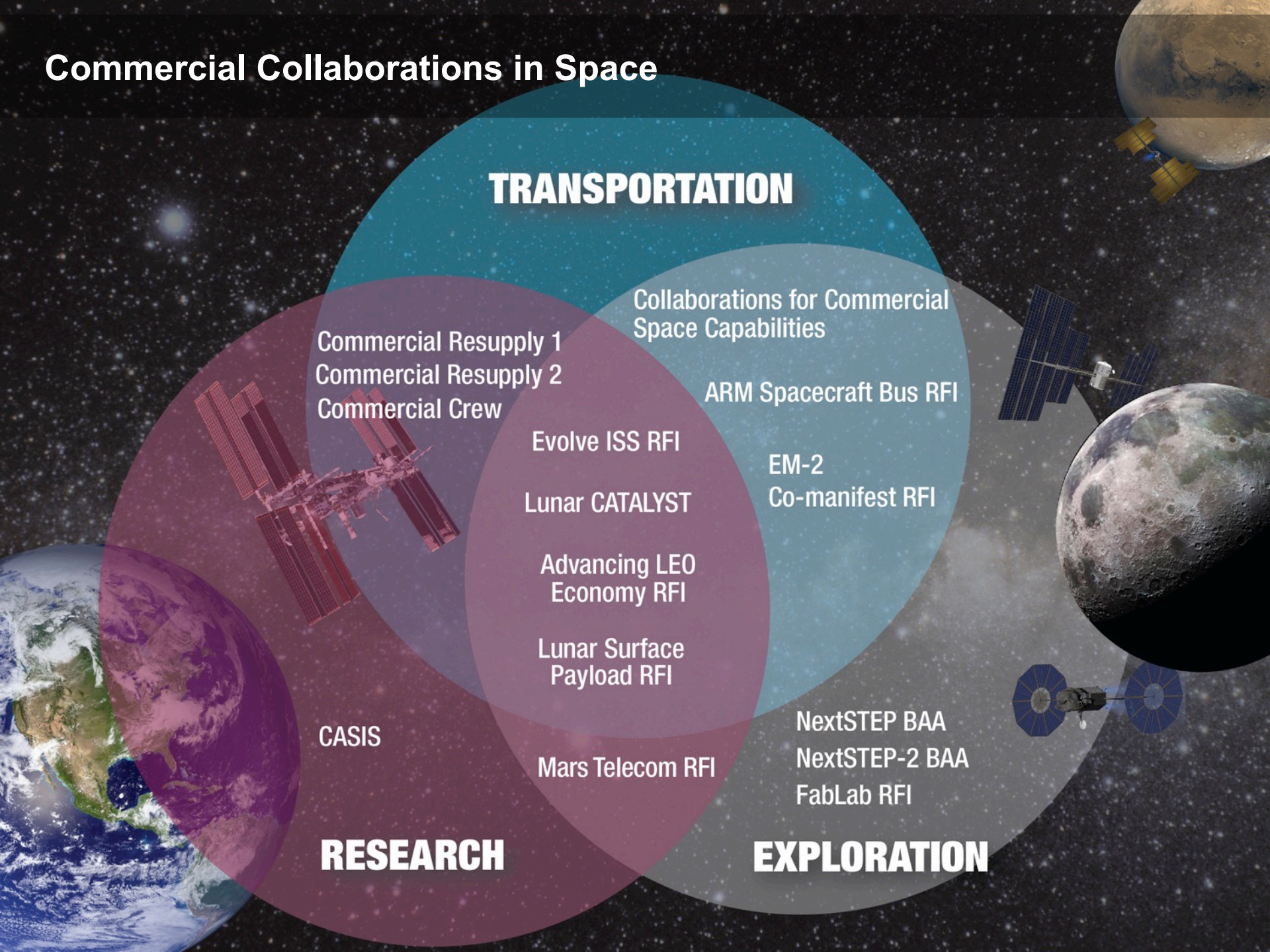
SCaN

- SCaN 34m antenna dedicated at Canberra; two beginning installation at Madrid
- Preparing TDRS-M for launch in 2017
- Focusing SGSS effort on software development to achieve FY17 milestones within budget

LSP

- LSP preparing for upcoming launches: GOES-R on Atlas V (19 Nov) and CYGNSS on Pegasus (12 Dec)

Commercial Collaborations in Space



Habitation Development Approach

Phase 1

- Obtain Innovative Cislunar Habitation Concepts that leverage Commercialization Plans for LEO (NextSTEP Phase 1)
- Develop required deliverables include Concept Desription with concept of operations, Phase 2 proposal and SOW
- Initial discussions with international partner contributions

Phase 2

Continue concept refinement and development of domestic ground prototype module(s) and lead the development of standards and common interfaces (US/International)

- **Contractor(NextSTEP Phase 2)**: Concept description with concept of operations, provide Phase 3 proposal and SOW, delivery of ground prototype module(s)
- **NASA**: Define reference habitat architecture based on contractor and international concepts and identified GFE in preparation for Phase 3

Phase 3

- Determine acquisition approach including domestic and international partnerships
- Development of Deep Space Habitat for Proving Ground Phase 1 Objectives
- Deliverables include Flight Unit(s) (note may be multiple modules integrated via common interfaces and standards)

2015-2016

Ends with Industry Developed Concepts – Decision on contract(s) continuation

2016 - 2018

Ends with: 1) Industry Developed Ground Prototype Module performing integrated tests, 2) identified standards and common interfaces, and 3) identified what would be provided as GFE from NASA. – Decision point on contract continuation, what focus and NASA provided GFE

2018+

Ends with Deployment and Operational Status of Deep Space Habitat

Specific Habitation Systems Objectives

Habitation Systems Elements

TODAY ISS

FUTURE Deep Space

1 LIFE SUPPORT

Atmosphere Management | Water Management | Waste Management

- TODAY: 42% O_2 Recovery from CO_2; 90% H_2O Recovery; < 6 mo mean time before failure (for some components)
- FUTURE: 75%+ O_2 Recovery from CO_2; 98%+ H_2O Recovery; >30 mo mean time before failure

2 ENVIRONMENTAL MONITORING

Pressure O_2 & N_2 | Moisture | Particles | Microbes | Chemicals | Sound

- TODAY: Limited, crew-intensive on-board capability; Reliance on sample return to Earth for analysis
- FUTURE: On-board analysis capability with no sample return; Identify and quantify species and organisms in air & water

3 CREW HEALTH

Monitoring | Exercise | Diagnostics | Treatment | Food Storage & Management

- TODAY: Bulky fitness equipment; Limited medical capability; Frequent food system resupply
- FUTURE: Smaller, efficient equipment; Onboard medical capability; Long-duration food system

4 EVA: EXTRA-VEHICULAR ACTIVITY

Mobility | Life Support | Science and Exploration

- TODAY: High upper body mobility for limited sizing range; Low interval between maintenance, contamination sensitive, and consumables limit EVA time; Construction and repair focused tools; excessive inventory of unique tools
- FUTURE: Full body mobility for expanded sizing range; Increased time between maintenance cycles, contamination resistant system, 25% increase in EVA time; Geological sampling and surveying equipment; common generic tool kit

Specific Habitation Systems Objectives

Habitation Systems Elements

TODAY ISS

FUTURE Deep Space

5 RADIATION PROTECTION

Monitoring | Tracking | Modeling | Mitigation

TODAY
- Node 2 crew quarters (CQ) w/ polyethylene reduce impacts of proton irradiation.
- RAD, REM – real-time dosimetry, monitoring, tracking, model validation & verification
- TEPC, IVTEPC – real-time dosimetry
- CPD, RAM – passive dosimeters

FUTURE
- Solar particle event storm shelter, optimized position of on-board materials and CQ
- Distributed REM/HERA system for real-time monitoring & tracking
- CPAD – real-time dosimeter

6 FIRE SAFETY

Detection | Protection | Suppression | Cleanup

TODAY
- Large CO_2 Suppressant Tanks
- 2-cartridge mask
- Obsolete combustion prod. sensor
- Only depress/repress clean-up

FUTURE
- Water Mist portable fire extinguisher
- Single Cartridge Mask
- Exploration combustion product monitor
- Smoke eater

7 LOGISTICS

Tracking | Clothing | Packaging | Trash

TODAY
- Manual scans, displaced items
- Disposable cotton clothing
- Packaging disposed
- Bag and discard

FUTURE
- Automatic, autonomous RFID
- Long-wear clothing & laundry
- Bags/foam repurposed w/3D printer
- Resource recovery, then disposal

8 CROSS-CUTTING

Robotics | Power | Communication | Docking | Autonomy & Software | Thermal | Materials

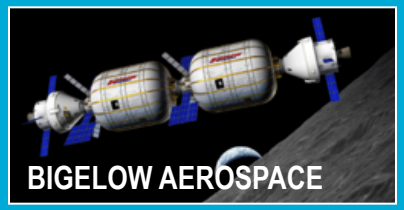
TODAY
- Minimal on-board autonomy
- Near-continuous ground-crew comm
- Some common interfaces, modules controlled separately

FUTURE
- Ops independent of Earth & crew
- Up to 40-minute comm delay
- Widespread common interfaces, modules/systems integrated
- Manufacture replacement parts in space

Habitation Systems
NextSTEP Habitation Overview

NextSTEP Phase 1: 2015-2016

Cislunar habitation concepts that leverage commercialization plans for LEO

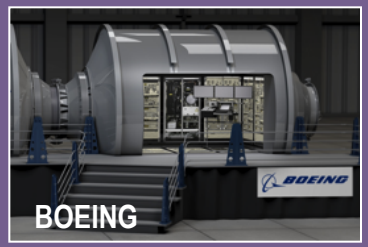


FOUR SIGNIFICANTLY DIFFERENT CONCEPTS RECEIVED

Partners develop required deliverables, including concept descriptions with concept of operations, NextSTEP Phase 2 proposals, and statements of work.

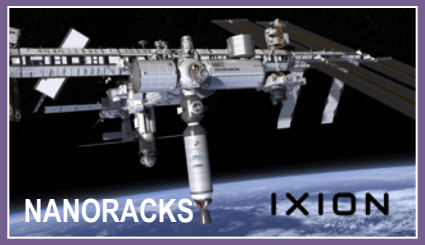
NextSTEP Phase 2: 2016-2018

FIVE GROUND PROTOTYPES BY 2018



- Partners refine concepts and develop ground prototypes.
- NASA leads standards and common interfaces development.

ONE CONCEPT STUDY



Initial discussions with international partners

Define reference habitat architecture in preparation for Phase 3.

Phase 3: 2018+

- Partnership and Acquisition approach, leveraging domestic and international capabilities
- Development of deep space habitation capabilities
- Deliverables: flight unit(s)

NextSTEP Phase 2 Habitation Capability – Goal

Develop a deep space habitat with fully functional systems for ground-based testing by 2018, while at the same time stimulating commercial habitats in LEO.

- **Develop long duration deep space habitation capabilities that lead towards a deep space transit habitat and can be flown on SLS flight(s) (or alternative launch vehicles) starting by the early to Mid 2020s.**
- **Advance the long duration deep space habitation capability concepts and mature the design and development of the integrated system(s) to achieve a high level of fidelity.**
  - Developing prototype deep space habitation capability options to test a full size ground prototype unit(s) by the end of Phase 2 in 2018 to support first flight opportunities in Early to Mid 2020s
- **Potential for different capabilities from domestic and international suppliers will require standards and common interfaces for aggregation. NASA led standards working group will be implemented during Phase 2.**

Ground Prototype units delivered to NASA for testing and integration of NASA developed habitation systems

- Testing includes form, fit, volumetric, subsystem integration, and interface standards
- May use NASA-developed node/airlock and hab mockups for integration testing with contractor modules
- Ensures consistent test and interface verification approach, allows us to incorporate and test other AES subsystems, facilitates crew training and feedback on human factors, shows stakeholders progress

NextSTEP Phase 2 Ground Prototype Integration Testing

The habitation prototypes will be used for three primary purposes:

- ***supporting system integration, human factors and operations, and system functionality***

Top level objective of testing is Phase 3 requirement refinement and risk reduction.

- **Systems Integration: The prototypes will, at a minimum, serve as an integration platform at the form and fit level:**
  - Flight unit mockups of systems (not necessarily functional)
    - Standard interfaces for mechanical, power, thermal and data tested
    - Layout, installation, fit access tested
- **Human Factors & Operations: The prototypes will enable mission simulations with humans in the habitation environment:**
  - Habitability
  - Mission Operations (Command and Control, Science, Teleops, Robotics, Crew Training, Maintenance and Repair)
  - Health and Medical
  - Logistics and Waste Management Operations
  - EVA operations
  - Contingency/Emergency Scenarios
- **System Functionality: Testing may incorporate combinations of crew (human-in-the-loop) mission simulation, analytical modeling, laboratory analysis, computer based simulation, or other testing techniques.**

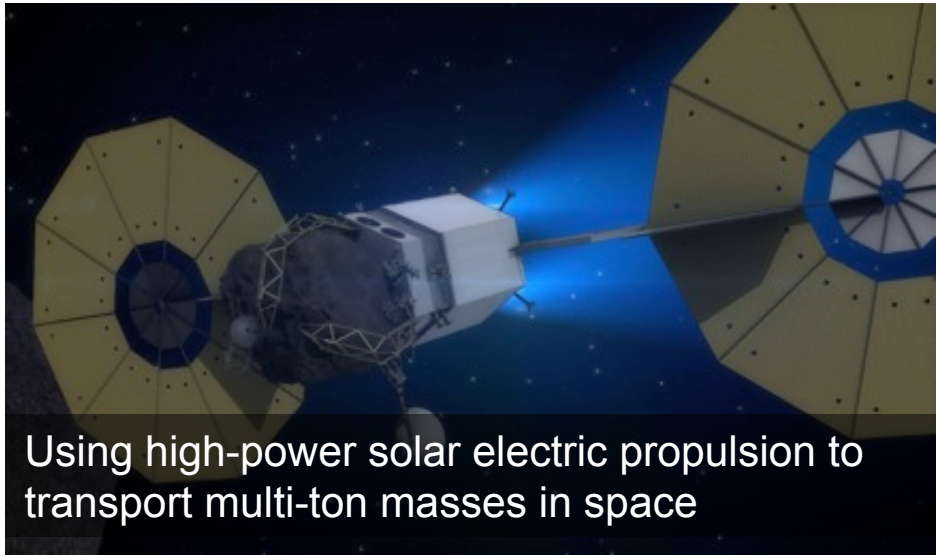
NextSTEP-2 Habitation Common Interfaces and Standards

Activities

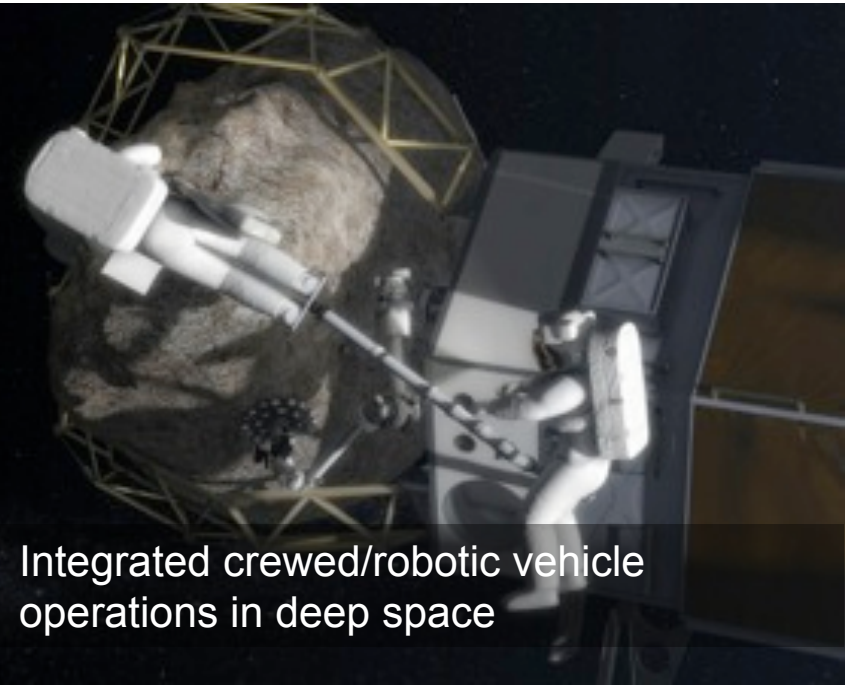
- **Negotiation inputs to include the participation, evaluation and concurrence interfaces and standards applicability – August 2016**
  - Identify Interfaces
    - ➢ NASA proposed
    - ➢ International and Commercial Partners inputs
  - NASA Habitation Standards to enable NASA, industry, and International Partners to contribute safe, reliable, and cost-effective interoperable systems and elements
- **Develop Habitation Standard Evaluation and Approval Process**
- **Baseline Habitation Standards to be used for Phase 3 – leverage from Commercial Crew and ISS Visiting Vehicle**
- **Support HEO Common Interface Standards Working Group**
  - – Common Interface Standards (e.g., Memo for Records, ICDs (e.g., Orion, SLS)) that will be used by industry and international partners (FCT)

ARM Key Contributions to the Journey to Mars

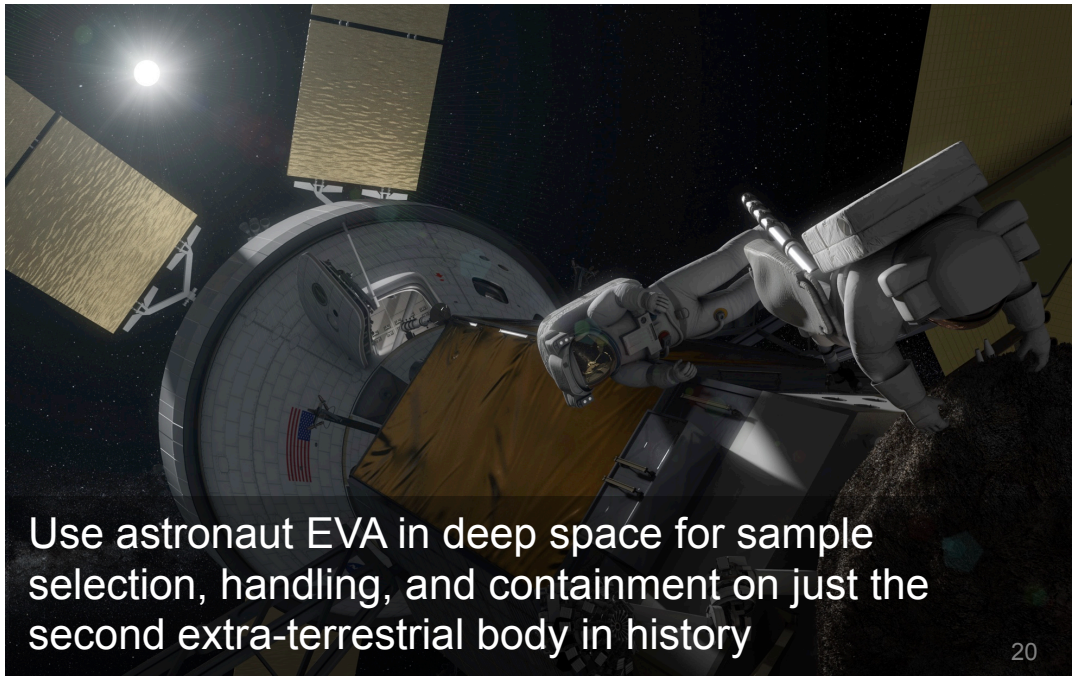
Advanced autonomous proximity operations in deep space and with a natural body



Using high-power solar electric propulsion to transport multi-ton masses in space



Integrated crewed/robotic vehicle operations in deep space



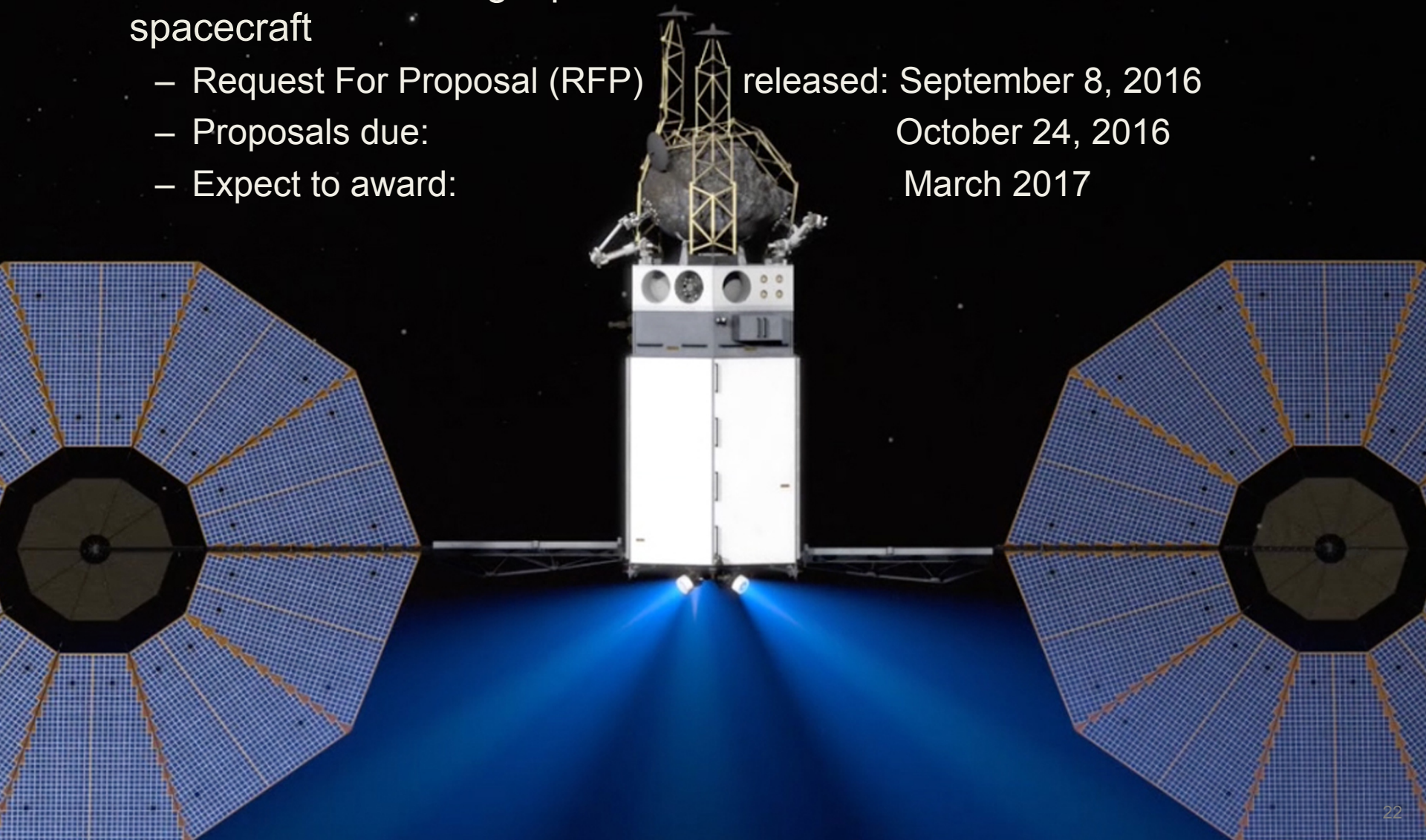
Use astronaut EVA in deep space for sample selection, handling, and containment on just the second extra-terrestrial body in history

ARM Recent Progress and Upcoming Milestones

✓ **SRB Face-to-Face at JPL**	**May 3-5**
✓ **Asteroid Redirect Robotic Mission (ARRM) Project Implementation Plan Vol 1 ready for signature**	**May 6**
✓ **ARRM requirements freeze for Key Decision Point (KDP) -B**	**May 13**
✓ ***External event:*** **Humans to Mars Summit:** ARM update	**May 17-19**
✓ **ARRM MDR-Lite**	**May 18-19**
✓ ***ARM HQ:*** **Periodic update to House Science Committee staff**	**May 23**
✓ ***ARM HQ:*** **cleared messages for external pre-announcement**	**mid-June**
✓ **Asteroid Redirect Crewed Mission (ARCM)/ARRM interface kickoff safety review**	**Jun 22-23**
✓ ***External event:*** **New Space Conference Panel – NASA as an Accelerator**	**Jun 21-23**
✓ **Kick-off ARCM safety review**	**Jun 22-23**
✓ **ARRM spacecraft contractor study final presentations**	**Jun 24**
✓ **ARRM KDP-B**	**Jul 15**
✓ **ARRM strategic partner intent closure**	**Aug 5**
✓ **ARM-Umbrella for Partnerships (ARM-UP) Broad Agency Announcement synopses release**	**Aug 15**
✓ **ARM-UP BAA incl partner p/l and ARM Investigation Team release**	**Sep 6**
✓ ***ARM HQ event:*** **ARM Community Update and Virtual Industry Day**	**Sep 14**
✓ ***External event:*** **IAC**	**Sep 26-30**
✓ ***External event:*** **DPS**	**Oct 16-21**
• **ARRM capture module architecture study complete**	**Jan 2017**
• **STMD/SEP electric propulsion string Preliminary Design Review**	**Mar 2017**
• **HQ checkpoint prior to ARM IT, ARRM hosted p/l, and ARRM spacecraft bus awards**	**Mar 2017**
• **ARM IT, ARRM hosted p/l, and ARRM spacecraft bus aware selections announcement**	**Apr 2017**

Two-Step Spacecraft Procurement Process

- **Phase 2:**
- Down-select to a single provider to build and deliver the robotic spacecraft
  - Request For Proposal (RFP) released: September 8, 2016
  - Proposals due: October 24, 2016
  - Expect to award: March 2017



NASA's Approach to Human Spaceflight is to Move Human Presence into the Solar System

- Pursuing a sustained program that builds capabilities that feed forward to next steps
- Consistent with budget projections and focused on lowering future production and operating costs
- Making significant real progress (SLS/Orion, ISS discoveries and advances over 15 years, ISS future plans and systems testing, Commercial crew and enabling private sector demand to emerge in Low Earth Orbit)
- Huge technical challenge that will need the best from the private sector, academia, and international partner communities; NASA does not need to fund or develop everything
- Budget environment is challenging (overall uncertainty and short term focus) , but we are receiving needed support
- Continue and advance standards development for exploration systems
- Utilize private sector and international partners where appropriate