National Aeronautics and Space Administration

Evolvable Mars Campaign and Technology Development

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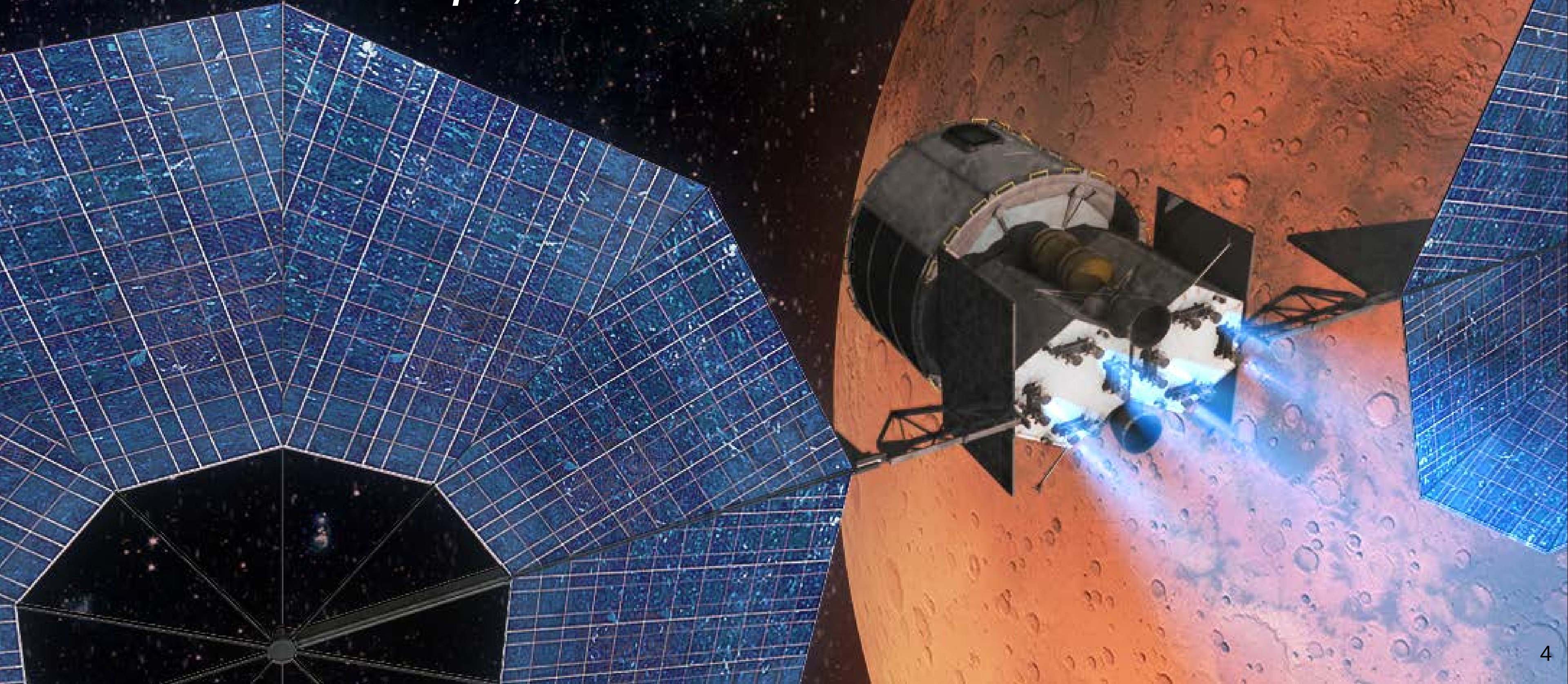
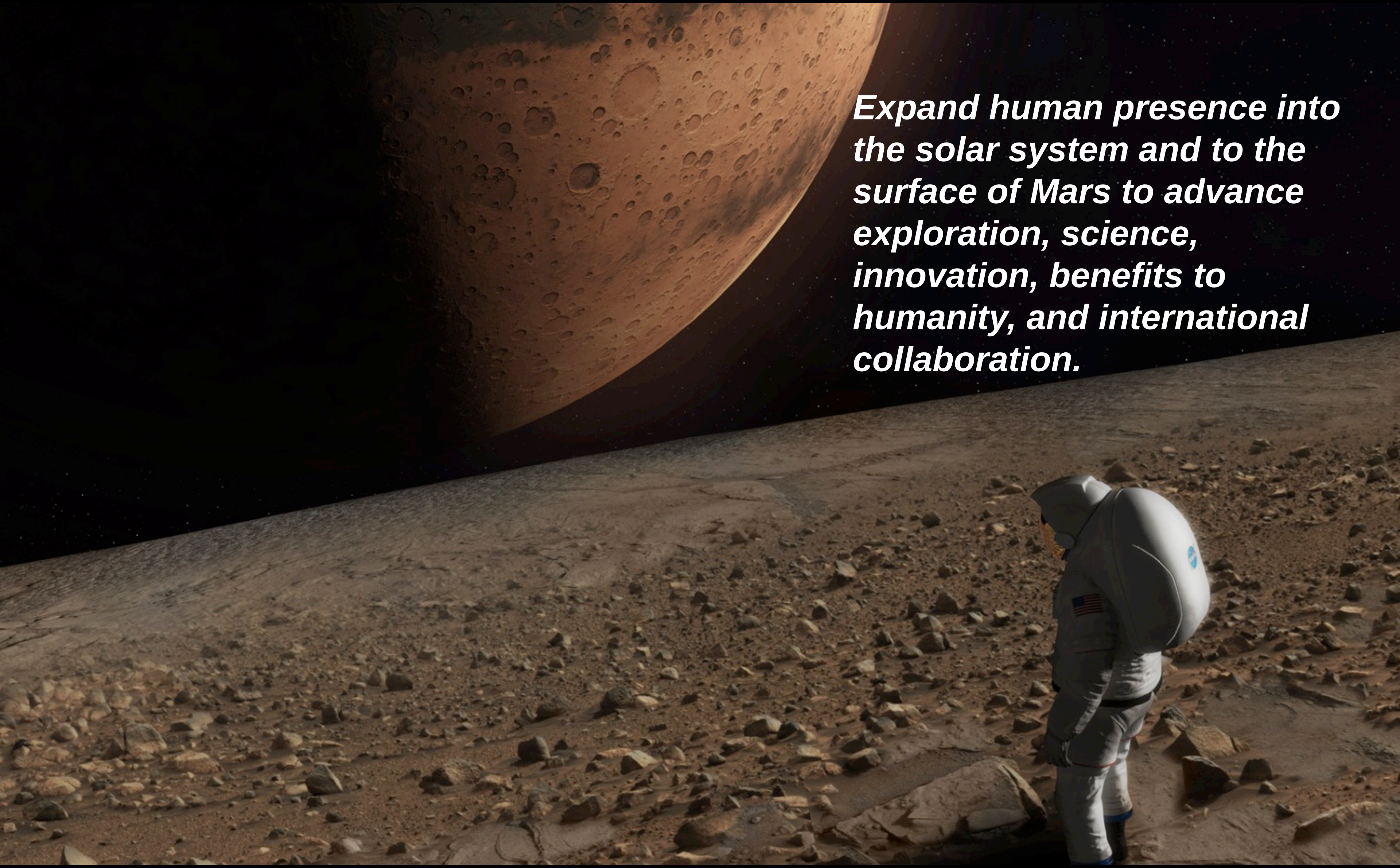
Pioneering Space - Goals

"Fifty years after the creation of NASA, our goal is no longer just a destination to reach. Our goal is the capacity for people to work and learn and operate and live safely beyond the Earth for extended periods of time, ultimately in ways that are more sustainable and even indefinite. And in fulfilling this task, we will not only extend humanity's reach in space -- we will strengthen America's leadership here on Earth."

- President Obama - April, 2010



NASA Strategic Plan Objective 1.1



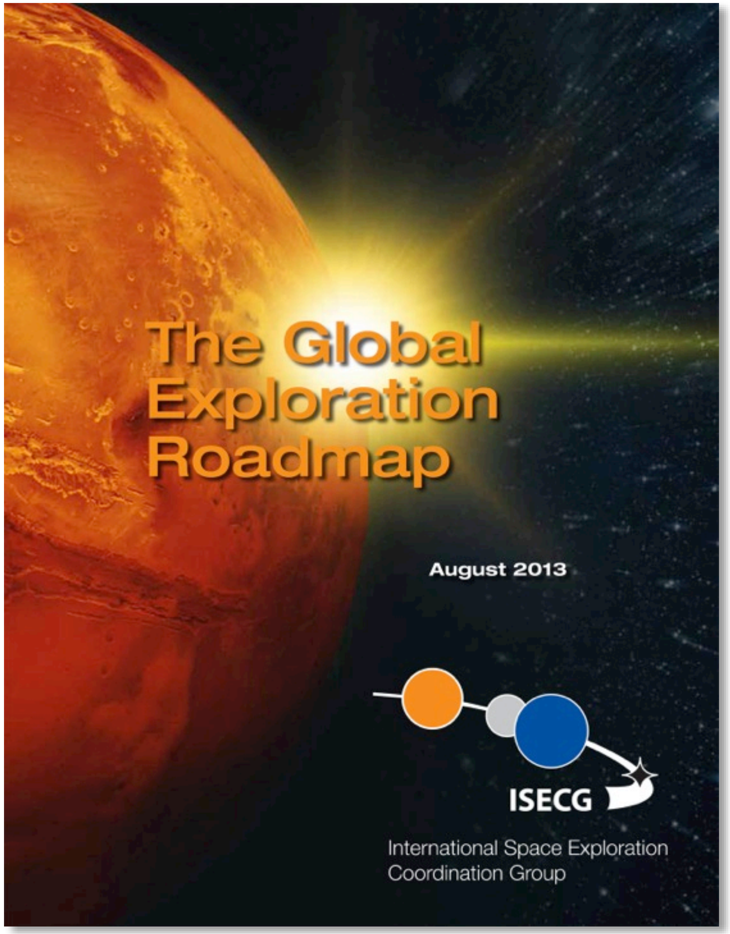
Expand human presence into the solar system and to the surface of Mars to advance exploration, science, innovation, benefits to humanity, and international collaboration.

Strategic Principles for Sustainable Exploration

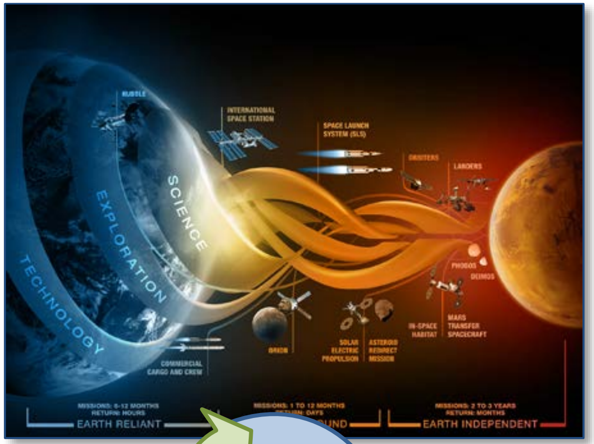
- Implementable in the ***near-term with the buying power of current budgets*** and in the longer term with budgets commensurate with economic growth*;*
- ***Exploration enables science* and science enables exploration***, leveraging robotic expertise for human exploration of the solar system*
- Application of ***high Technology Readiness Level*** (TRL) technologies for near term missions, while focusing sustained investments on ***technologies and capabilities*** to address challenges of future missions;
- ***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;
- Opportunities for ***U.S. commercial business*** to further enhance the experience and business base;
- ***Multi-use, evolvable*** space infrastructure, minimizing unique major developments, with each mission leaving something behind to support subsequent missions; and
- Substantial ***new international and commercial partnerships***, leveraging the current International Space Station partnership while building new cooperative ventures.

Global Exploration Roadmap: Common Goals and Objectives

- Develop Exploration Technologies and Capabilities
- Enhance Earth Safety
- Extend Human Presence
- Perform Science to Enable Human Exploration
- Perform Space, Earth, and Applied Science
- Search for Life
- Stimulate Economic Expansion



Design Reference Missions vs Design Philosophy



Body of Previous Architectures, Design Reference Missions, Emerging Studies and New Discoveries

- Internal NASA and other Government
- International Partners
- Commercial and Industrial
- Academic
- Technology developments
- Science discoveries

Evolvable Mars Campaign

- An ongoing series of architectural trade analyses that we are currently executing to define the capabilities and elements needed for a sustainable human presence on Mars
- Builds off of previous studies and ongoing assessments
- Provides clear linkage of current investments (SLS, Orion, etc.) to future capability needs

Comparison

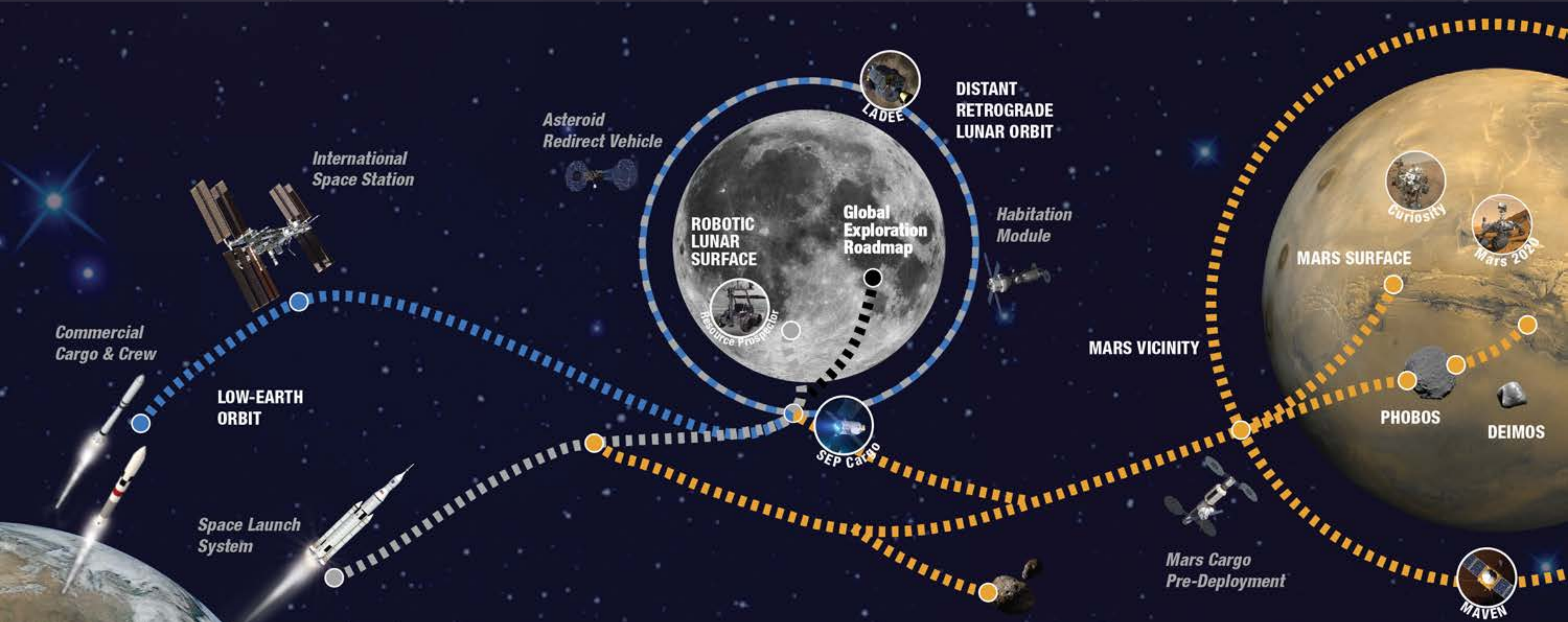
DRA 5.0: **Global science driven approach for the human exploration of Mars. Emphasis placed on mission return with reasonable risk.**	**EMC:** **An ongoing series of architectural trade analyses that we are currently executing to define the capabilities and elements needed for a sustainable human presence on Mars.**
• A reference architecture (circa 2009)	• A series of on-going studies which provide strong linkage between possible future with current investments (SLS, Orion)
• Science driven, all expendable architecture	• Balanced approach with emphasis on the “ilities” - affordability, sustainability, and reusability
• Assumed full lunar and test program prior to Mars missions	• Cis-lunar Proving Ground and dedicated pathfinder missions to reduce risk and develop capabilities
• Simultaneous crew and cargo missions drives high launch rate and cost profile	• Cadence of missions spread by assuming pre-emplacement to reduce to manageable flight rate and budget profile
• Aggressive and simultaneous technology investment portfolio	• Progressive technology advancement and demonstration
• Emphasis on minimizing crew and systems exposure to deep-space environment	• Long-duration exposure to deep space considered manageable. Radiation Assessment Detector data returns indicate radiation levels in transit, and on the surface less than previously thought.
• Pre-deployment of landers and surface systems	• Pre-deployment of landers, surface systems, and return stages
• Vehicle assembly and departure from LEO	• Vehicle assembly and departure from cis-lunar space provides lunar opportunities for commercial and international
• Orion (6 crew) to Mars and back	• Orion (4 crew) in cis-lunar space only
• Ares V (~130 t) with a peak of 6/year flight rate	• SLS (~130 t) with a peak of 3/year flight rate
• Zero Boil-off Nuclear Thermal Propulsion	• Solar Electric/Chemical
• Mars ascent via ISRU (O_2)	• Mars ascent via ISRU (O_2) with ongoing analysis for additional opportunities

EVOLVABLE MARS CAMPAIGN

A Pioneering Approach to Exploration

NASA

EARTH RELIANT — PROVING GROUND — EARTH INDEPENDENT



THE TRADE SPACE

Across the Board | Solar Electric Propulsion • In-Situ Resource Utilization (ISRU) • Robotic Precursors • Human/Robotic Interactions • Partnership Coordination • Exploration and Science Activities

Cis-lunar Trades

- Deep-space testing and autonomous operations
- Extensibility to Mars
- Mars system staging/refurbishment point and trajectory analyses

Mars Vicinity Trades

- Split versus monolithic habitat
- Cargo pre-deployment
- Mars Phobos/Deimos activities
- Entry descent and landing concepts
- Transportation technologies/trajectory analyses

Evolvable Mars Campaign

EMC Goal: Define a pioneering strategy and operational capabilities that can extend and sustain human presence in the solar system including a human journey to explore the Mars system starting in the mid-2030s.

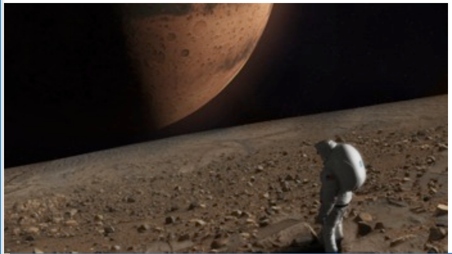
- **Identify a plan that:**
  - Expands human presence into the solar system to advance exploration, science, innovation, benefits to humanity, and international collaboration.
  - Provides different future scenario options for a range of capability needs to be used as guidelines for near term activities and investments
    - In accordance with key strategic principles
    - Takes advantage of capability advancements
    - Leverages new scientific findings
    - Flexible to policy changes
  - Identifies linkages to and leverage current investments in ISS, SLS, Orion, ARM, short-duration habitation, technology development investments, science activities
  - Emphasizes prepositioning and reuse/repurposing of systems when it makes sense
    - Use location(s) in cis-lunar space for aggregation and refurbishment of systems

<u>Internal analysis team members:</u>
- ARC, GRC, GSFC, HQ, JPL, JSC, KSC, LaRC and MSFC
- HEOMD, SMD, STMD, OCS and OCT

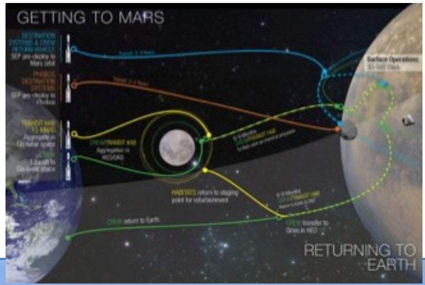
<u>External inputs from:</u>

International partners, industry, academia, SKG analysis groups

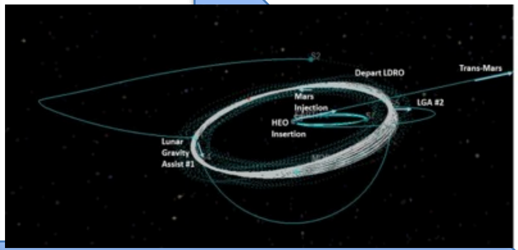
Evolvable Mars Campaign Studies in FY15 - Pointing the Way Forward



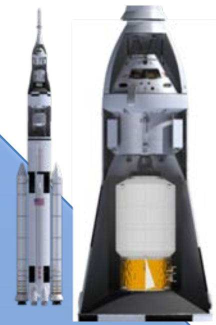
Mars and Mars Moons Surface Exploration



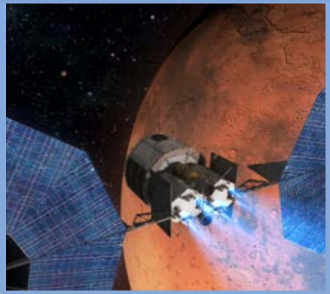
Transportation Analysis

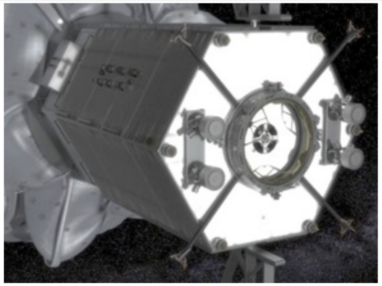


Staging Point Location



SLS Exploration Upperstage and Co-Manifested Cargo

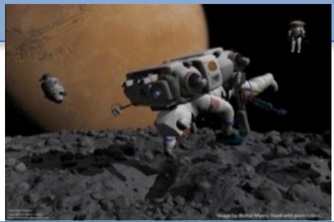




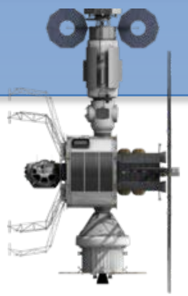
SEP

ARM Extensibility

Deep Space Surface Operations in micro-g



Human Class Mars Surface Lander



Mars Campaign Habitation

Capability Development Analysis

EMC FY16 Plans

- **Transportation**
  - Refinement of Hybrid and SEP/Chem transportation architectures for closure
  - Sensitivities of additional capability investments for transportation architectures
  - Assessments of alternate transportation scenarios as needed
- **Habitation**
  - AES Mars Habitat driven design (Definition of advanced habitation roadmaps, we know what we need to get to, but don't know how to get there)
  - Assessments of alternate habitation system designs (FCT Modular and BAA commercial) on EMC architecture
- **Pathfinders**
  - EDL path finder strategy and assessment
  - Provide Mars Moon SKGs for Mars Orbiter/moon pre-cursor
- **Teleoperations**
  - Define low latency teleoperations for Mars Moons and for Mars surface via Mars moons. Link back to FTOs in cis-lunar and ISS
- **Mars Surface Pioneering**
  - Develop Surface strategy, capabilities and layout beyond initial boots on Mars that leads to Earth Independence
- **ISRU**
  - An ISRU strategy that begins on ISS, expands to cislunar space, proceeding to the Mars vicinity and ultimately the Mars surface will be developed.
  - FTOs and system concepts for each step will be developed
- **Partnerships and External Engagement**
  - FY16 EMS reports
  - Engagement Workshop(s)
  - ISESG Engagement
  - Media Products

Major Results to Date

- **Regardless of Mars vicinity destination, common capability developments are required**
  - **Mars vicinity missions selection not required before 2020**
- **ISS provides critical Mars mission capability development platform**
- **Lunar DRO is efficient for aggregation and potential refurbishment due to stable environment**
  - **Use of gravity assist trajectories enable use of DRO**
- **Orion Block 1 is sufficient for Mars architectures with reusable habitats**
- **SLS co-manifested cargo capability increases value of crewed missions and improves cadence**
- **Deep-space habitation serves as initial starting point regardless of implementation or destination**
- **ARV derived SEP vehicle can serve as an effective tool for human Mars missions**
  - Reusability can enable follow-on use in cis-lunar space
  - **Refuelability under study to enable Mars system follow-on use**
  - **Current SEP evolvability enables Mars system human missions**
- **Mars Phobos /Deimos as initial Mars vicinity mission spread out development costs and meets policy objectives of Mars vicinity in 2030's**
  - **Common crew transportation between Mars Phobos / Deimos and Mars Surface staging**
  - **Phobos provides 35% reduction of radiation exposure compared to other Mars orbit missions**
  - **Provides ability to address both exploration and science objectives**
  - **ARM returned asteroid at Lunar DRO serves as good location for testing Mars moon's operations**

Transportation of Crew and Cargo To/From Deep Space

Challenges

Deliver crew and cargo to deep space

Return crew from deep space

Space Launch System

Transport crew and cargo to cis-lunar space

- ✓ Initial launch vehicle that can launch 36 t to TLI
- ✓ Upgraded launch vehicle that can launch 43 t to TLI
- ✓ Option for 5, 8.4, or 10 m diameter shroud
- ✓ 1/year launch rate with surge to 2/year for cis-lunar missions
- ✓ 2/year launch rate with surge to 3/year for Mars missions

Orion

Support crew during trip to/from cis-lunar space

- ✓ 4 crew for 21 days
- ✓ Contingency EVA in a Launch, Entry, and Abort (LEA) suit using umbilical life support
- ✓ Ability to rendezvous and dock with other in-space elements
- ✓ Earth to cis-lunar navigation
- ✓ Earth entry from cis-lunar space: 11 km/s

Commercial Launch

Use commercial launch vehicles to deliver logistics and small cargo to cis-lunar space

- ✓ Small cargo vehicle to deliver up to 11 t to TLI
- ✓ Shroud = 5 m diameter

Living in Space: Habitation

Challenges

Protect and support crew in deep space for up to 60 days (cislunar) or 1100 days (Mars vicinity)

Uncrewed operations during deployment and between uses

Reduced logistics and spares

Earth-independent operations

Common Capabilities

4 Crew for 500-1100 days

Common pressure vessel

15 year lifetime with long dormancy periods

Design for reusability across multiple missions

100 m^3 habitable volume and dry mass < 22 t

Autonomous vehicle health monitoring and repair

Advanced Exploration ECLSS with >85% H_2O recovery and 50% O_2 recovery from reduced CO_2

ECLSS System (w/o spares): <5 t mass, <9 m^2 volume, <4 kW power

Environmental monitoring with >80% detection rate without sample return

14-kW peak operational power and thermal management required

Autonomous mission operations with up to 24 minute one-way time delay

Autonomous medical care, behavioral health countermeasures, and other physiological countermeasures to counteract long duration missions without crew abort

Exercise equipment under 500 kg

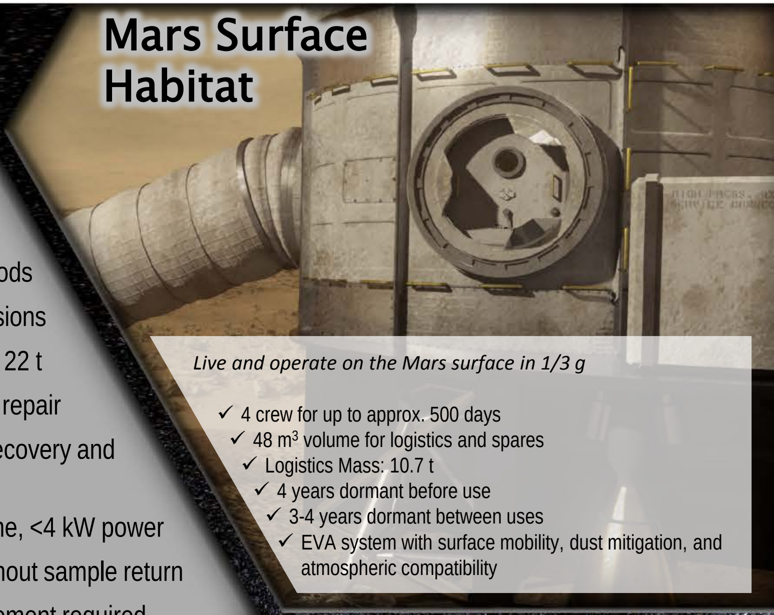
Provide 20-40 g/cm^2 of radiation protection

EVA pressure garment and PLSS <200 kg

Contingency EVA operations with 1 x 2-person EVA per month

Communications to/from Earth and between elements

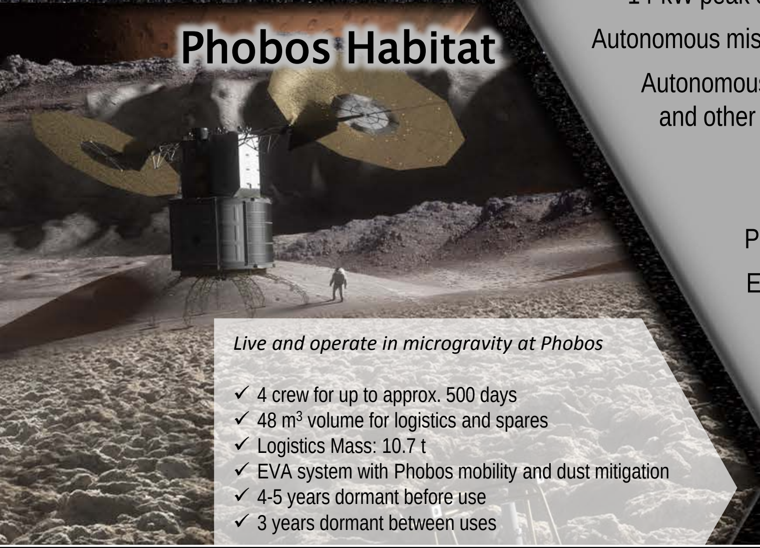
Mars Surface Habitat



Live and operate on the Mars surface in 1/3 g

- ✓ 4 crew for up to approx. 500 days
- ✓ 48 m^3 volume for logistics and spares
- ✓ Logistics Mass: 10.7 t
- ✓ 4 years dormant before use
- ✓ 3-4 years dormant between uses
- ✓ EVA system with surface mobility, dust mitigation, and atmospheric compatibility

Phobos Habitat



Live and operate in microgravity at Phobos

- ✓ 4 crew for up to approx. 500 days
- ✓ 48 m^3 volume for logistics and spares
- ✓ Logistics Mass: 10.7 t
- ✓ EVA system with Phobos mobility and dust mitigation
- ✓ 4-5 years dormant before use
- ✓ 3 years dormant between uses

Transit Habitat

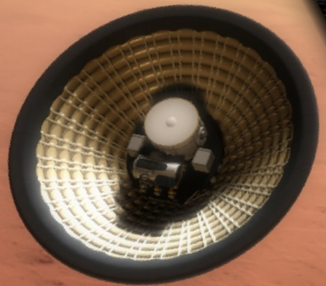
Live and operate in microgravity during trip to/from Mars

- ✓ 4 crew for up to 1,100 days
- ✓ 93 m^3 volume for logistics and spares
- ✓ Logistics Mass: 21 t
- ✓ 4 years dormant before use and between uses

Any initial, short-duration habitation module in the Proving Ground of cislunar space will serve as the initial building block required for Mars-class habitation

In-Space Transportation

Mars EDL



Deliver crew and cargo to Mars surface

- ✓ Possible aerocapture at 6.3 km/s if not propulsively delivered to orbit
- ✓ Entry velocity of 3.8 – 4.7 km/s
- ✓ 100 m precision landing with hazard avoidance
- ✓ Supersonic retropropulsion with LOX/CH_4 engine
- ✓ Deployable/Inflatable (16-23 m) entry systems
- ✓ Surface access at +2 km MOLA
- ✓ 20-30 t payload to the surface, 40-60 t arrival at Mars

Challenges

Transport crew and cargo to/from Mars vicinity

Provide transportation within the Mars system

Provide access to Mars surface

Uncrewed operations during deployment and between uses

Common Capabilities

Chemical Propulsion

Common LOX/CH_4 Pump-Fed Engine:

- ✓ Thrust: 25 klbf
- ✓ Isp: 355-360 s
- ✓ Up to 15 year lifetime
- ✓ 150-500 s burn time
- ✓ 5:1 throttling
- ✓ Near-ZBO storage with 90 K cryocooler

LOX/CH_4 Pressure-Fed RCS:

- ✓ Thrust: 100-1000 lbf; Isp: 320 s

Electric Propulsion

Deliver approx. 40-60 t to Mars orbit

200-kW class solar array system (BOL at 1 AU) using 30% efficient GaAs, triple junction solar cells

300 V array system converted to 800 V for EP and 28 V for spacecraft

ARRM-Derived Hall Thruster:

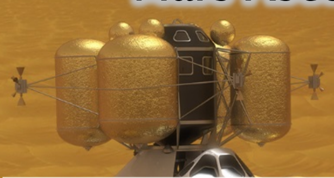
- ✓ Common Xe storage and feed system with 13.3 kW thruster
- ✓ Isp: 2000 s or 3000 s modes

SEP – Hybrid

Combined SEP and hypergolic propulsion system delivers crew and cargo to Mars vicinity

- ✓ 2 x 200-kW class arrays
- ✓ 1,100 days total trip mission time, 300 days at Mars
- ✓ >16 kW thermal rejection
- ✓ Ability to refuel 24 t of Xe on orbit
- ✓ 15 year lifetime, 3 uses, 3 refuelings

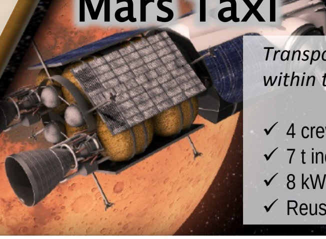
Mars Ascent



Return crew and cargo from Mars surface

- ✓ 4 crew and 250 kg payload from ±30 deg latitude, 0 km MOLA to Mars parking orbit
- ✓ 26 t prop (20 t O_2, 6 t CH_4), 35 t total liftoff mass, 8 t Earth launch dry mass
- ✓ Up to 3 days flight duration
- ✓ 5 years dormant before use
- ✓ Use of ISRU-produced oxygen

Mars Taxi



Transport crew and cargo within the Mars system

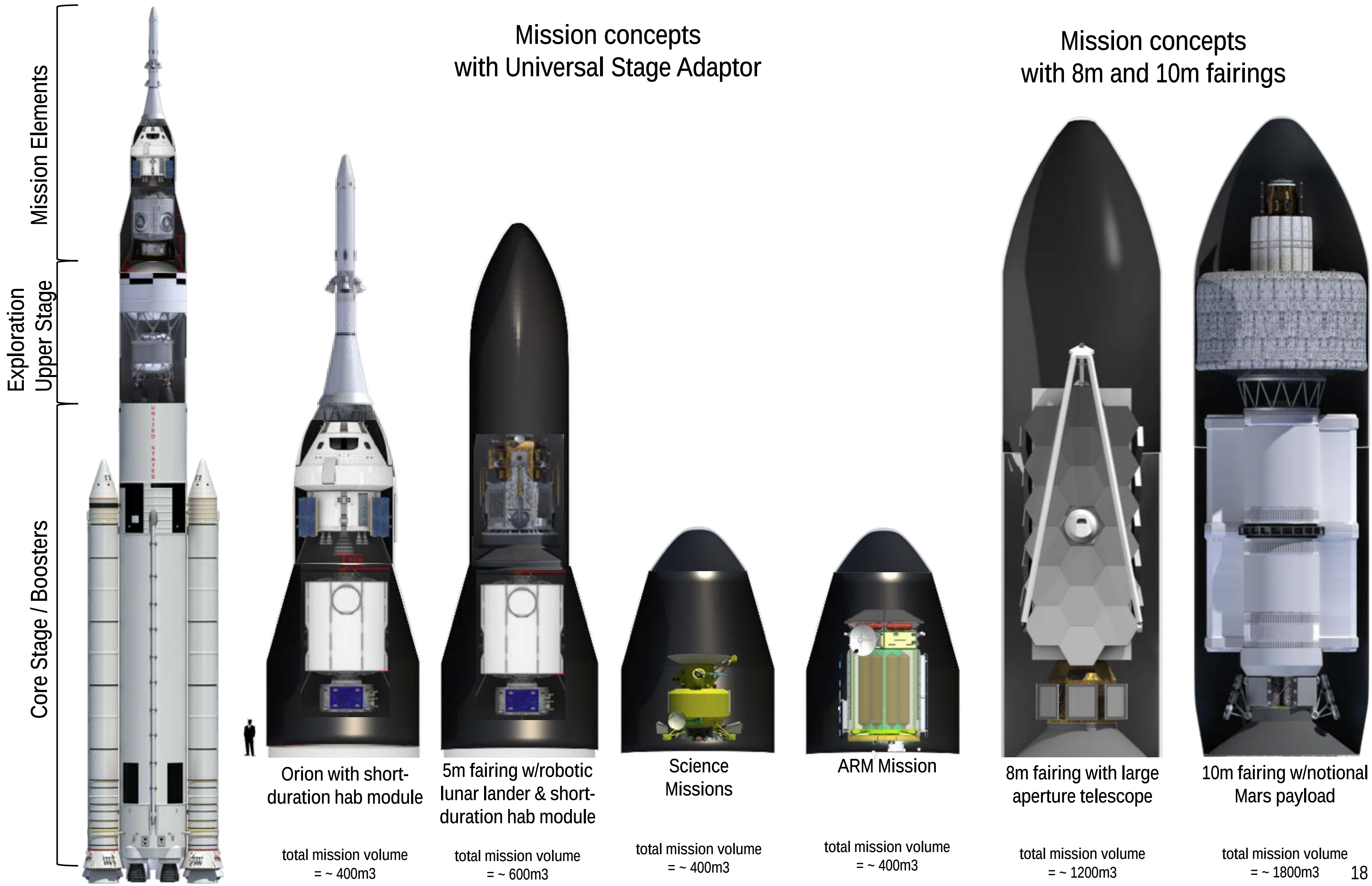
- ✓ 4 crew for up to 2.5 days
- ✓ 7 t inert mass, 14 t wet mass
- ✓ 8 kW EOL at Mars solar power
- ✓ Reusable and refuelable

SEP – Chemical

SEP delivers cargo to Mars vicinity, and LOX/CH_4 propulsion delivers crew to/from Mars vicinity

- ✓ 1 x 200-kW class solar array
- ✓ >8 kW thermal rejection
- ✓ Flight times to Mars approx. 1,400 days
- ✓ 4-6 years dormant before use

SLS Block 1B & Mission Element Concepts Under Study

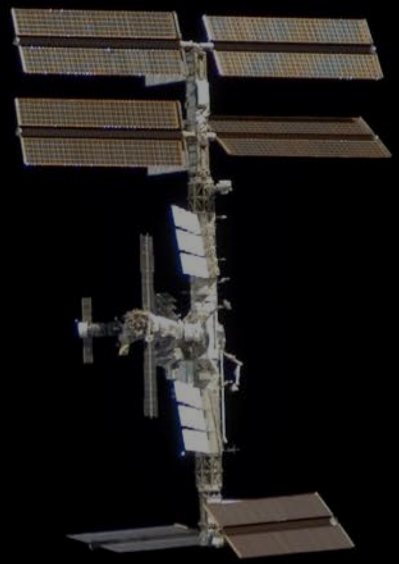


EARTH RELIANT

NEAR-TERM OBJECTIVES

<u>DEVELOP AND VALIDATE EXPLORATION CAPABILITIES IN AN IN-SPACE ENVIRONMENT</u>

- Long duration, deep space habitation systems
- Next generation space suit
- Autonomous operations
- Communications with increased delay
- Human and robotic mission operations
- Operations with reduced logistics capability
- Integrated exploration hardware testing



LONG-DURATION HUMAN HEALTH EVALUATION

- Evaluate mitigation techniques for crew health and performance in micro-g space environment
- Acclimation from zero-g to low-g

COMMERCIAL CREW TRANSPORTATION

- Acquire routine U.S. crew transportation to LEO

PROVING GROUND OBJECTIVES

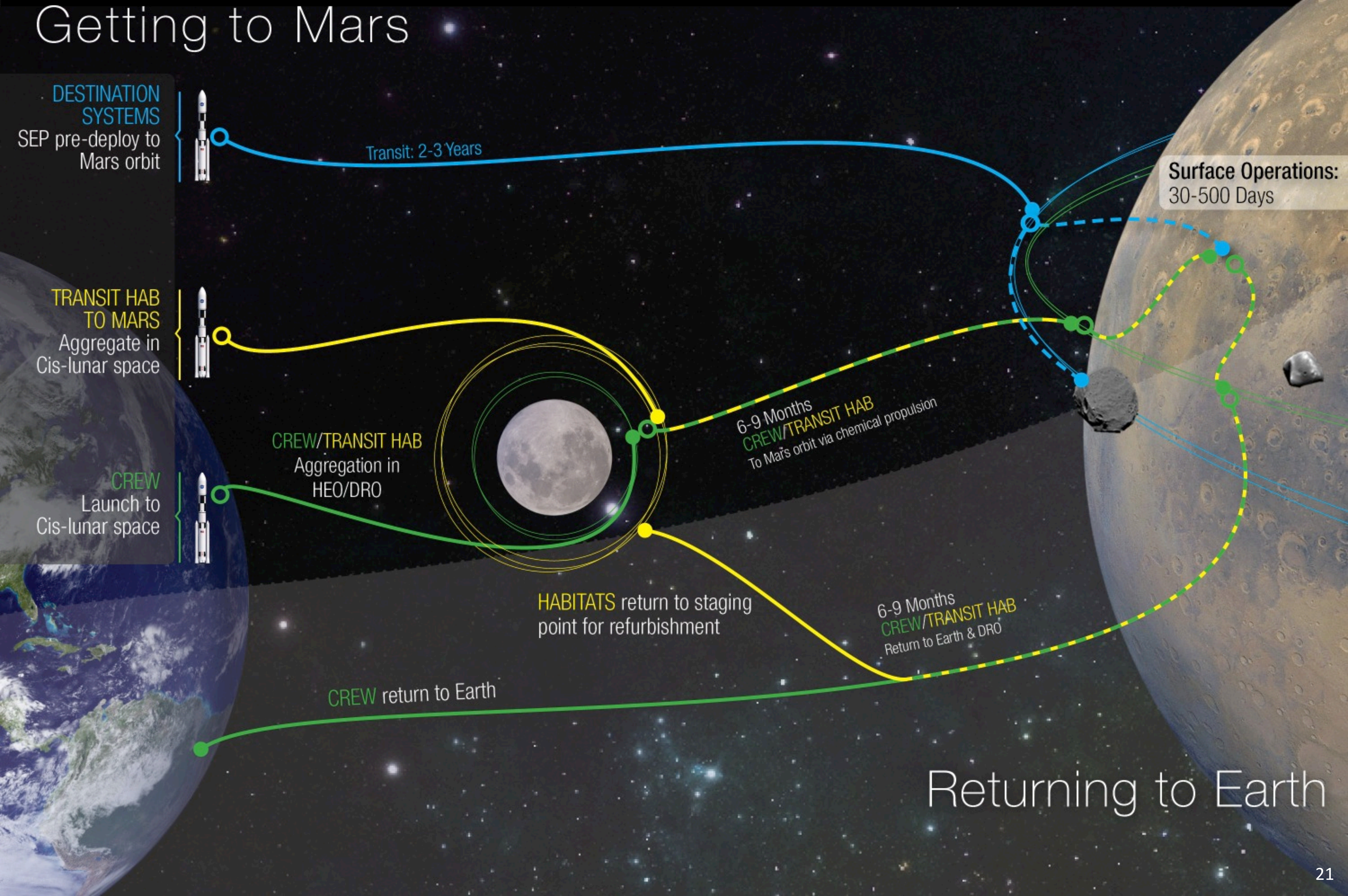
Enabling Human Missions to Mars

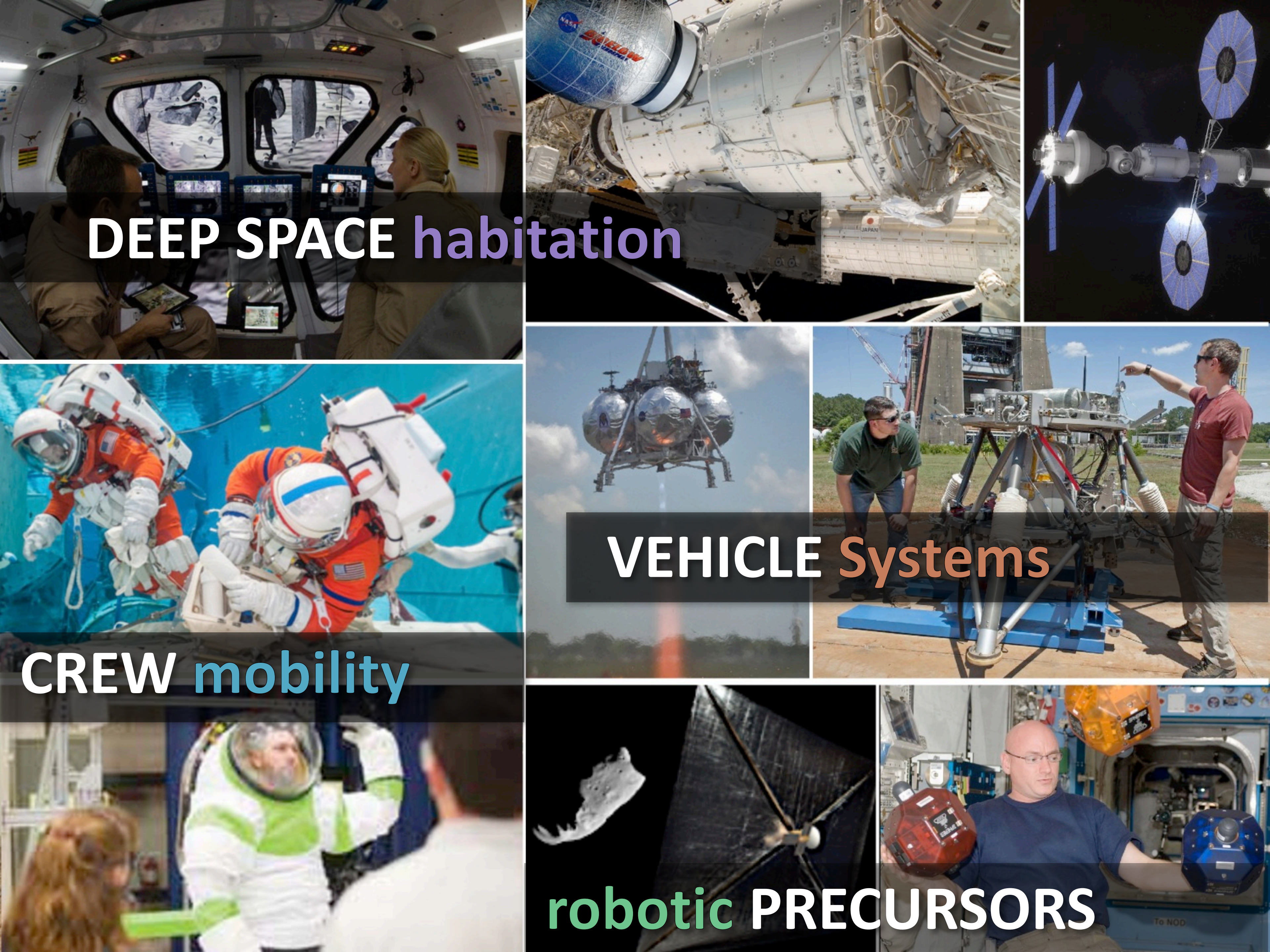
<u>VALIDATE through analysis and flights</u>

- Advanced Solar Electric Propulsion (SEP) systems to move large masses in interplanetary space
- Lunar Distant Retrograde Orbit as a staging point for large cargo masses en route to Mars
- SLS and Orion in deep space
- Long duration, deep space habitation systems
- Crew health and performance in a deep space environment
- In-Situ Resource Utilization in micro-g
- Operations with reduced logistics capability
- Structures and mechanisms

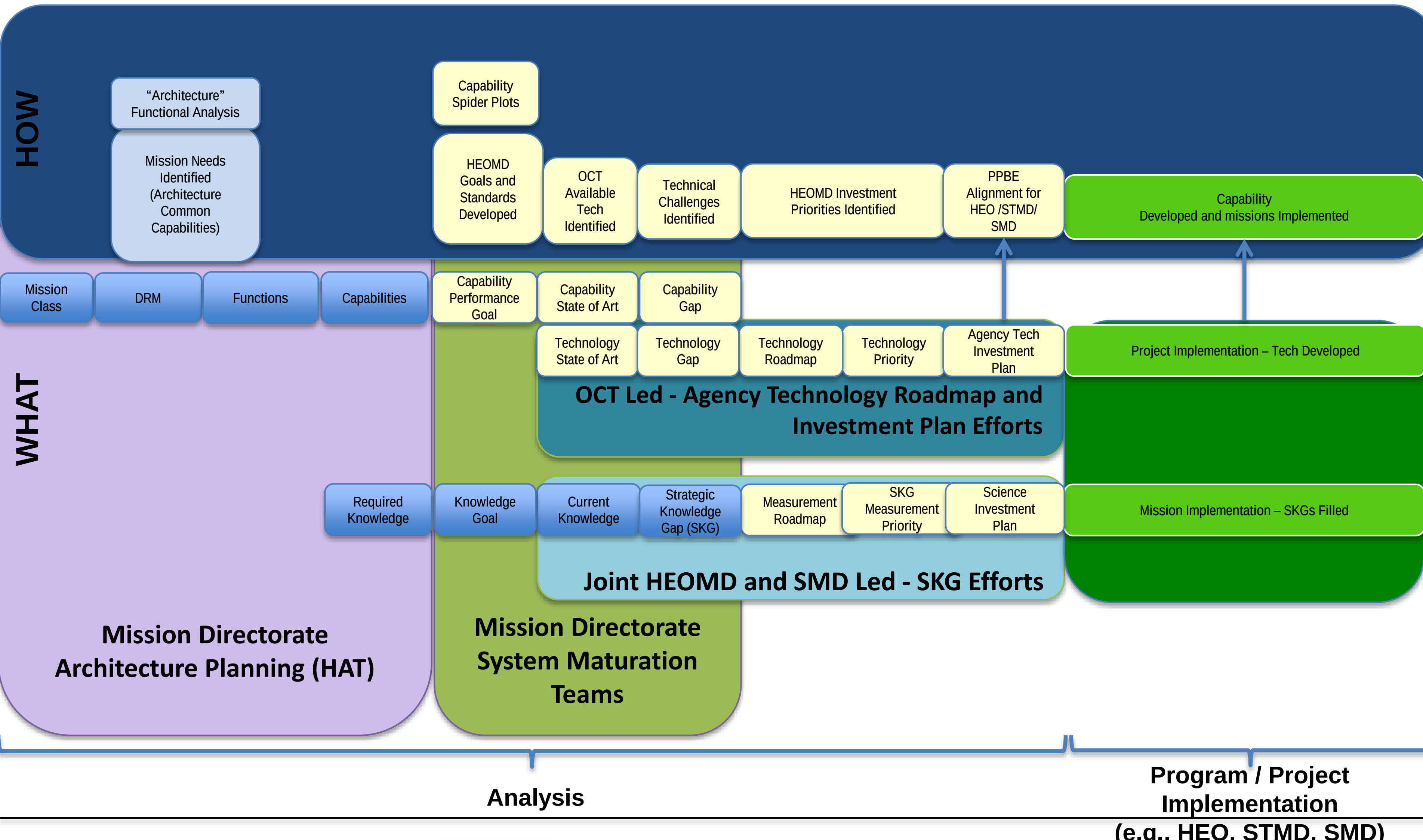
- <u>CONDUCT</u>
- EVAs in deep space with sample handling in micro-g
- Integrated human and robotic mission operations
- Capability Pathfinder and Strategic Knowledge Gap missions

Split Mission Concept



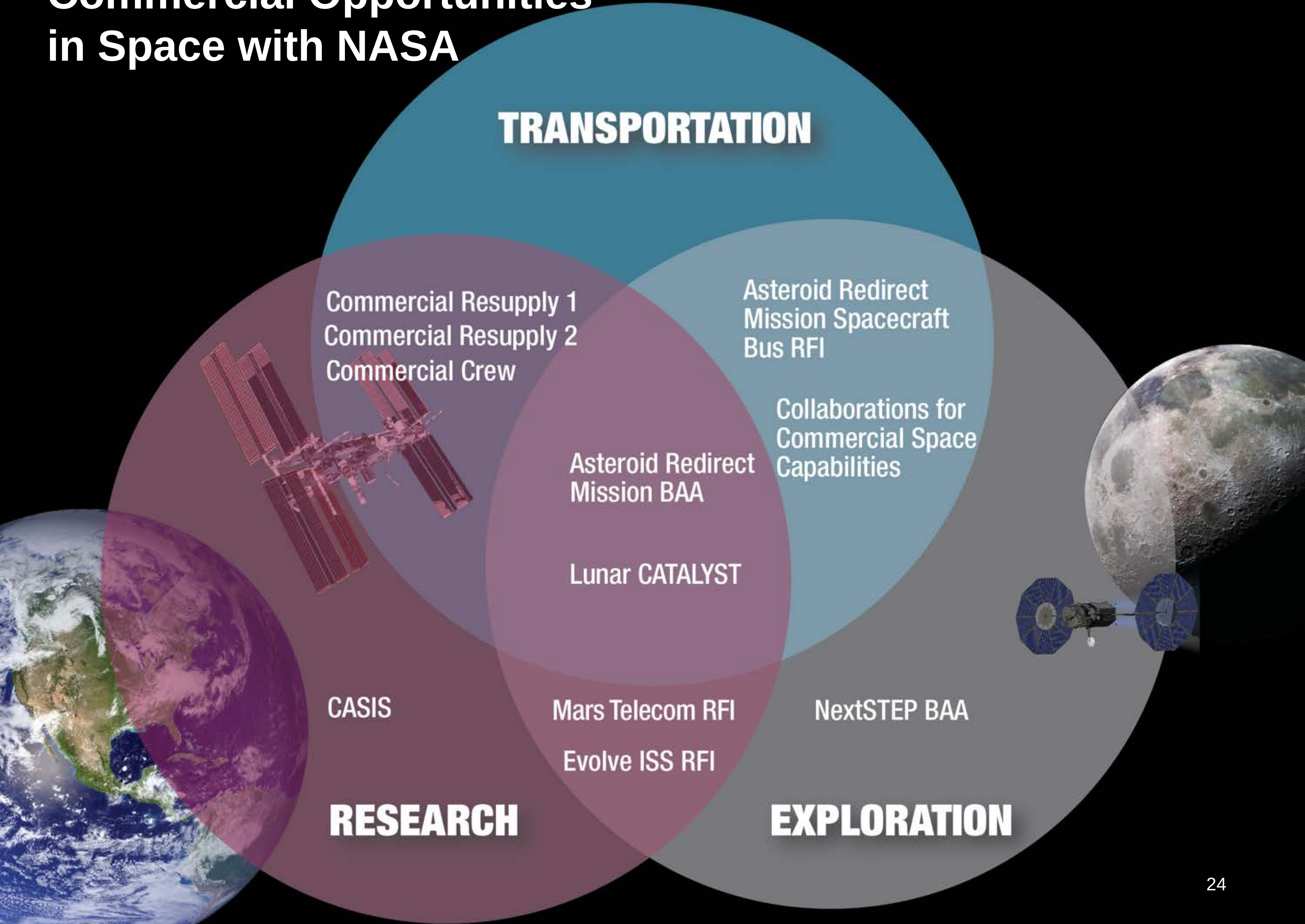

DEEP SPACE habitation
VEHICLE Systems
CREW mobility
robotic PRECURSORS

NASA Technology Roadmaps & Investment Plan



LEGEND: In Progress | Completed | Implementation Phase

Commercial Opportunities in Space with NASA



ADVANCED EXPLORATION SYSTEMS

Rapid development and testing of prototype systems and validation of operational concepts to reduce risk and cost of future exploration missions:

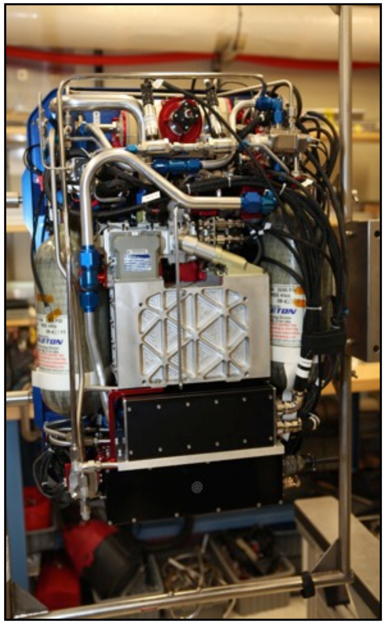
- **Crew Mobility Systems**
  - Systems to enable the crew to conduct “hands-on” surface exploration and in-space operations, including advanced space suits, portable life support systems, and EVA tools.
- **Habitation Systems**
  - Systems to enable the crew to live and work safely in deep space, including beyond earth orbit habitats, reliable life support systems, radiation protection, fire safety, and logistics reduction.
- **Vehicle Systems**
  - Systems to enable human and robotic exploration vehicles, including advanced in-space propulsion, extensible lander technology, modular power systems, and automated propellant loading on the ground and on planetary surfaces.
- **Foundational Systems**
  - Systems to enable more efficient mission and ground operations and those that allow for more earth independence, including autonomous mission operations, avionics and software, in-situ resource utilization , in-space manufacturing, synthetic biology, and communication technologies.
- **Robotic Precursor Activities**
  - Robotic missions and payloads to acquire strategic knowledge on potential destinations for human exploration to inform systems development, including prospecting for lunar ice, characterizing the Mars surface radiation environment, radar imaging of NEAs, instrument development, and research and analysis

Summary for FY15

- AES has established 72 milestones for FY15 (see backup)
- Over 60% include flight demonstration elements
- Goal is to achieve at least 80%
- AES includes 580 civil servants in FY15

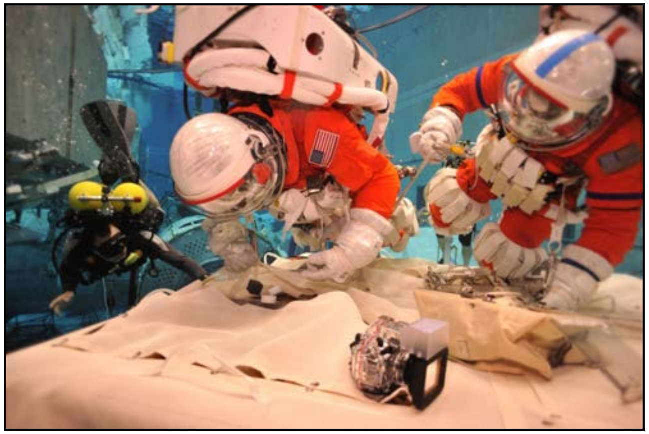
Crew Mobility Systems Domain

Advanced EVA: Development and testing of next generation space suits and portable life support systems (JSC).



Portable Life Support System 2.0 incorporates new technology components for CO_2 removal, thermal management, pressure regulation, and energy storage.

Z-2 Space Suit



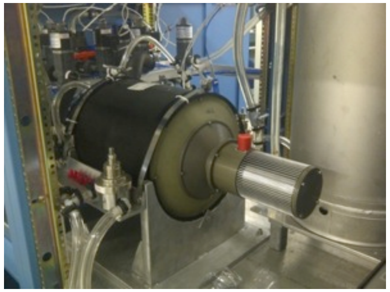
Testing Modified Advanced Crew Escape Suit (MACES) in Neutral Buoyancy Lab for Asteroid Redirect Mission.

Deep Space Habitation Systems Domain

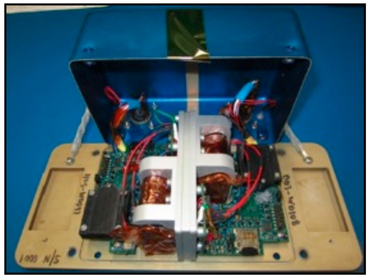
Initial Short-Term Habitation Systems: Integration of key systems in prototype habitat ground test unit (JSC).

Bigelow Expandable Activity Module (BEAM): Test of commercial inflatable module on ISS (JSC).

Atmosphere Resource Recovery & Environmental Monitoring: Integrated ground testing of ISS-derived life support system components (MSFC).

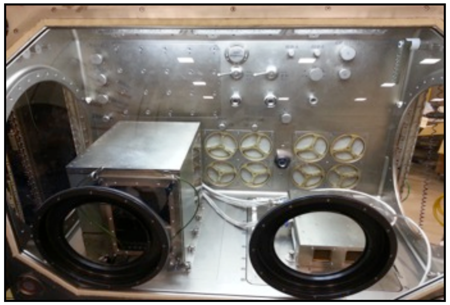


Water Recovery: Development of processes and systems for recycling wastewater (JSC).

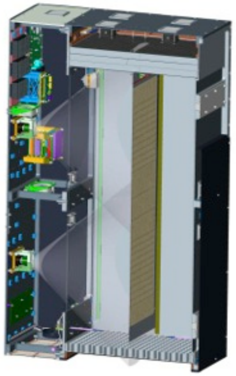


Radiation Protection: Development and testing of radiation sensors and shielding (JSC).

Logistics Reduction: Waste processing to reduce logistics mass (JSC).

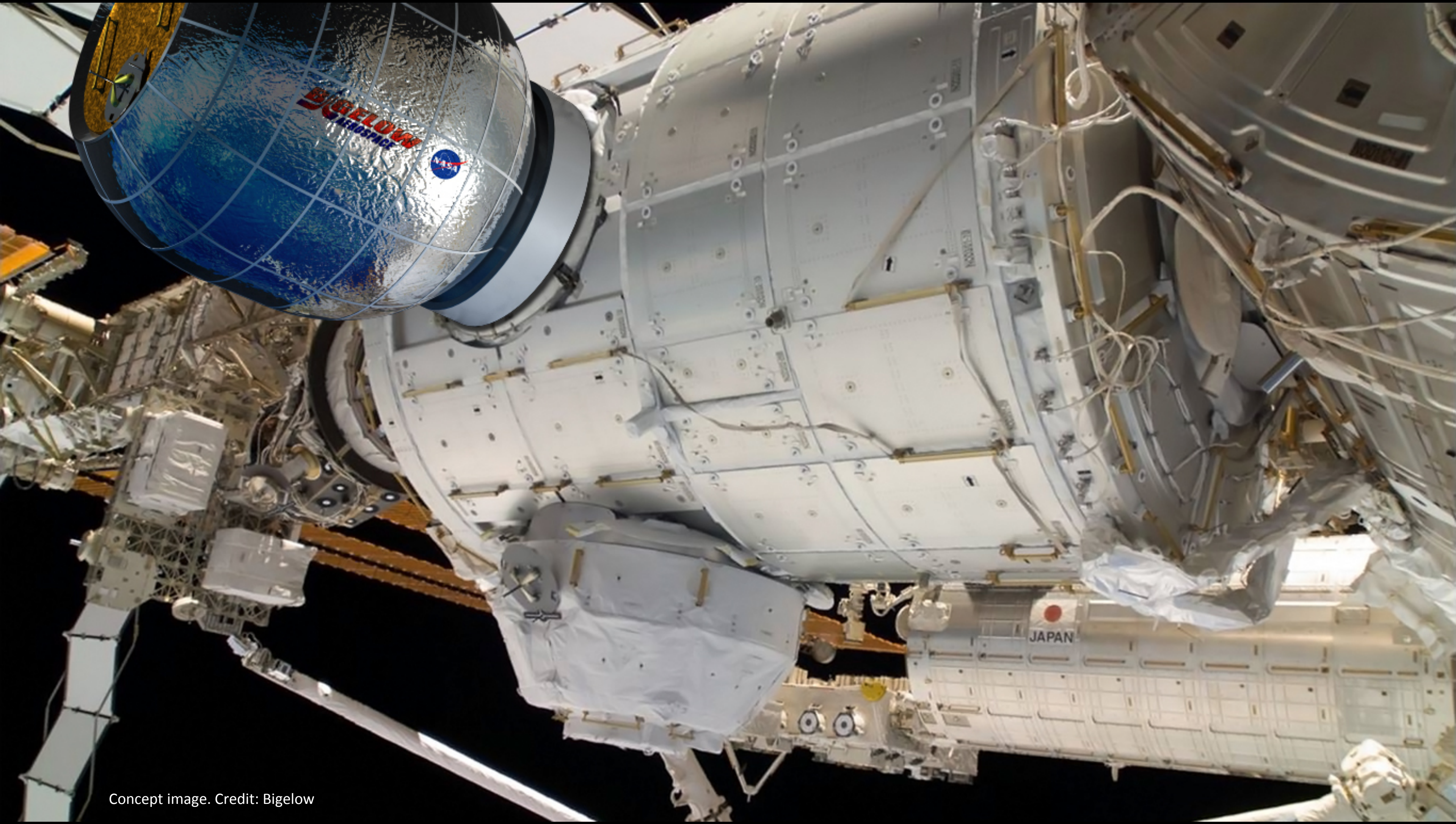


Additive Manufacturing: Demonstration of 3D printing on ISS to fabricate spare parts (MSFC).



Spacecraft Fire Safety: Flight experiment on Cygnus to investigate how large-scale fires propagate in microgravity (GRC).

Cost Sharing Contract – Bigelow Expandable Activity Model

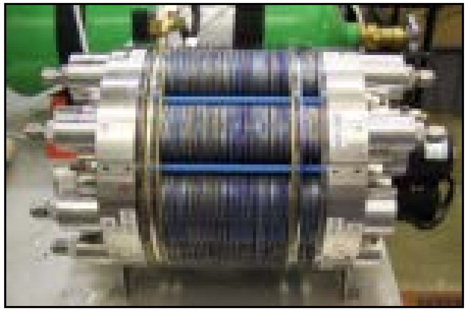


Concept image. Credit: Bigelow

- BEAM was initiated in January 2013
- BEAM will be berthed to Node 3 Aft
- BEAM planned launch on SpaceX8 mission
- Total Internal Inflated Volume ~565 ft^3

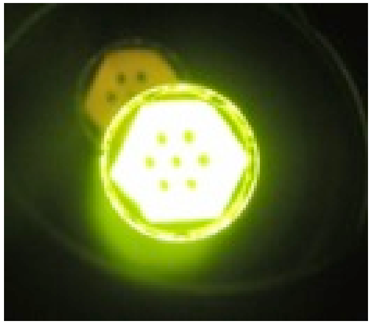
Vehicle Systems Domain

Morpheus/ALHAT: Flight demonstration of autonomous landing and hazard avoidance technology (ALHAT) on Morpheus lander (JSC).

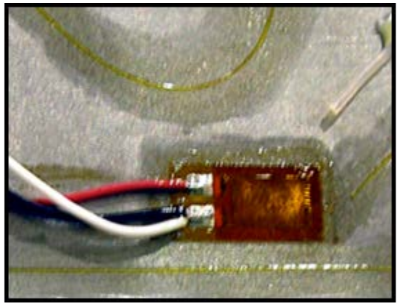


Modular Power Systems: Modular power systems for Habitation Systems, SLS, and EVA suit (GRC).

Lunar CATALYST: Supporting commercial partners to develop lunar landing capabilities (MSFC).



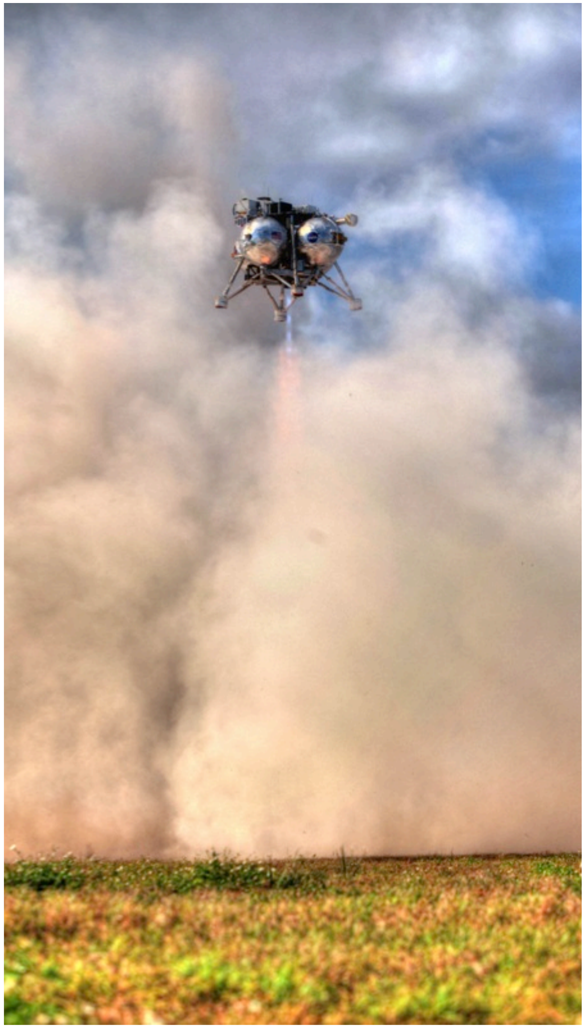
Nuclear Cryogenic Propulsion Stage: Development of reactor fuel elements for nuclear thermal propulsion (MSFC, DOE).



Fiber Optic Sensors: Development and testing of fiber optic sensors for measuring engineering data on launch vehicles (AFRC).

Morpheus

Rapid Prototype Lander Development

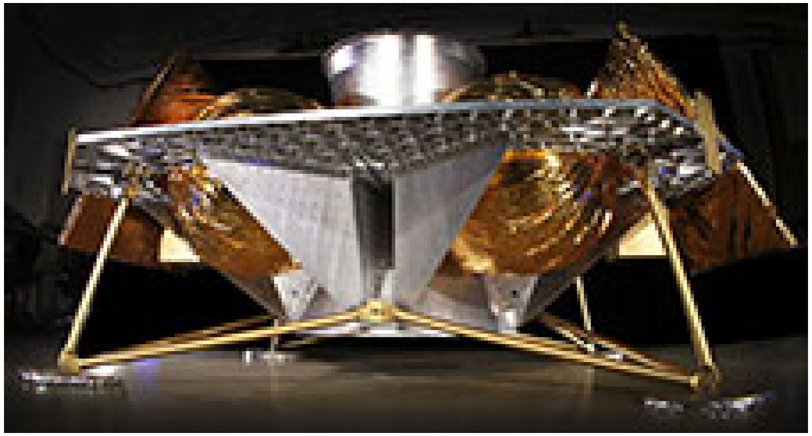


Lunar CATALYST

(Lunar CArgo Transportation And Landing bY Soft Touchdown)

- **Private investment in space transportation systems is increasing**
- **Commercial lunar cargo transportation is a potential new area of opportunity that could provide services to both public and private customers and enable science and exploration missions**
- **Per National Space Transportation Policy, NASA is "committed to encouraging and facilitating a viable, healthy, and competitive U.S. commercial Space Transportation Industry."**
- **NASA has accumulated decades of technical experience relevant to lunar cargo transportation**

Lunar CATALYST Selectees – April 2014



Griffin Lander

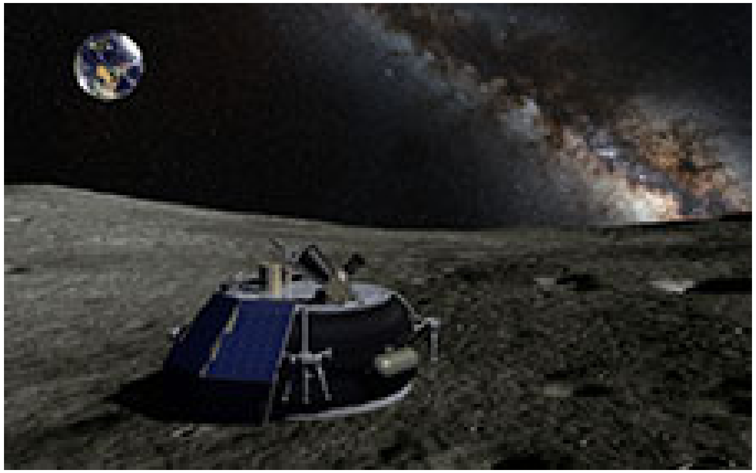
Astrobotic Technology Inc., Pittsburgh, PA

Credit: Astrobotic Technology, Inc.

XEUS Lander

Masten Space Systems Inc., Mojave, CA

Credit: NASA/Masten Space Systems, Inc.



MX-1 Lander

Moon Express Inc., Moffett Field, CA

Credit: Moon Express Inc.

Lunar CATALYST – Selected Accomplishments

http://www.nasa.gov/lunarcatalyst

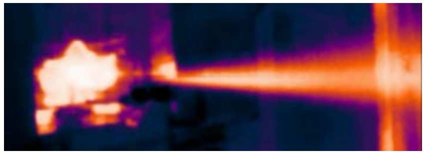
Astrobotic Technology

- Validated visual terrain relative navigation and hazard avoidance capability by integrating Astrobotic sensors and software onto a vertical takeoff vertical landing (VTVL) rocket and using the Astrobotic system to control and guide the vehicle to a safe landing location.
- Completed end-to-end mission simulation to verify attitude control, trajectory planning, pose estimation, and fuel usage.

Astrobotic Navigation/Guidance System Test on MSS VTVL Rocket

Masten Space Systems

- Completed lunar lander propulsion system requirements definition document.
- Completed propulsion system preliminary design review.



Masten Space System Engine Hotfire Test

Moon Express

- Completed system-level tethered flight tests (ascent, hover, descent) of the MTV-1 test article at NASA/KSC.

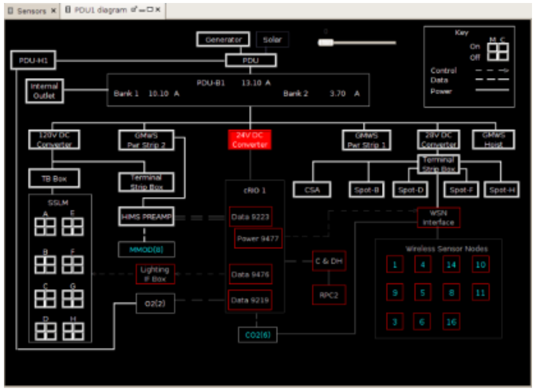
Moon Express MTV-1X Flight Test

All 3 companies indicate that NASA’s contributions to this collaborative partnership are providing them significant value:

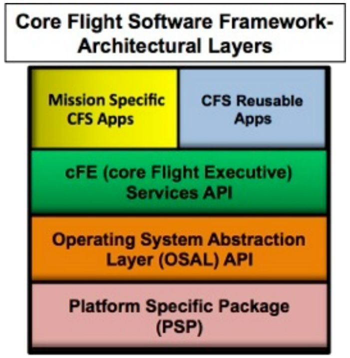
“CATALYST resources have been a critical force-multiplier and have unequivocally accelerated the progress of our robotic lunar lander program.”

~ Reuben Garcia, Director of Technical Operations, Masten Space Systems

Foundational Systems Domain



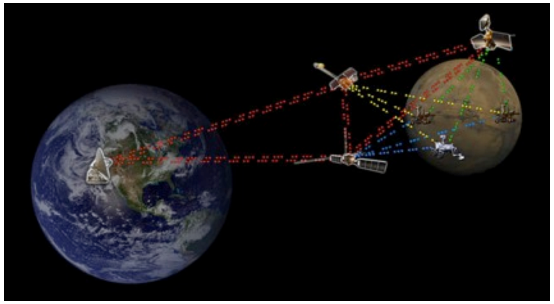
Autonomous Mission Operations: Software tools to reduce crew's dependence on ground-based mission control (ARC).



Core Flight Software: Development of core flight software for exploration systems (JSC).

Integrated Ground Operations Demonstration Units: Automation of cryogenic propellant handling and storage (KSC).

Avionics Architectures: Common avionics components and architectures for exploration systems (JSC).



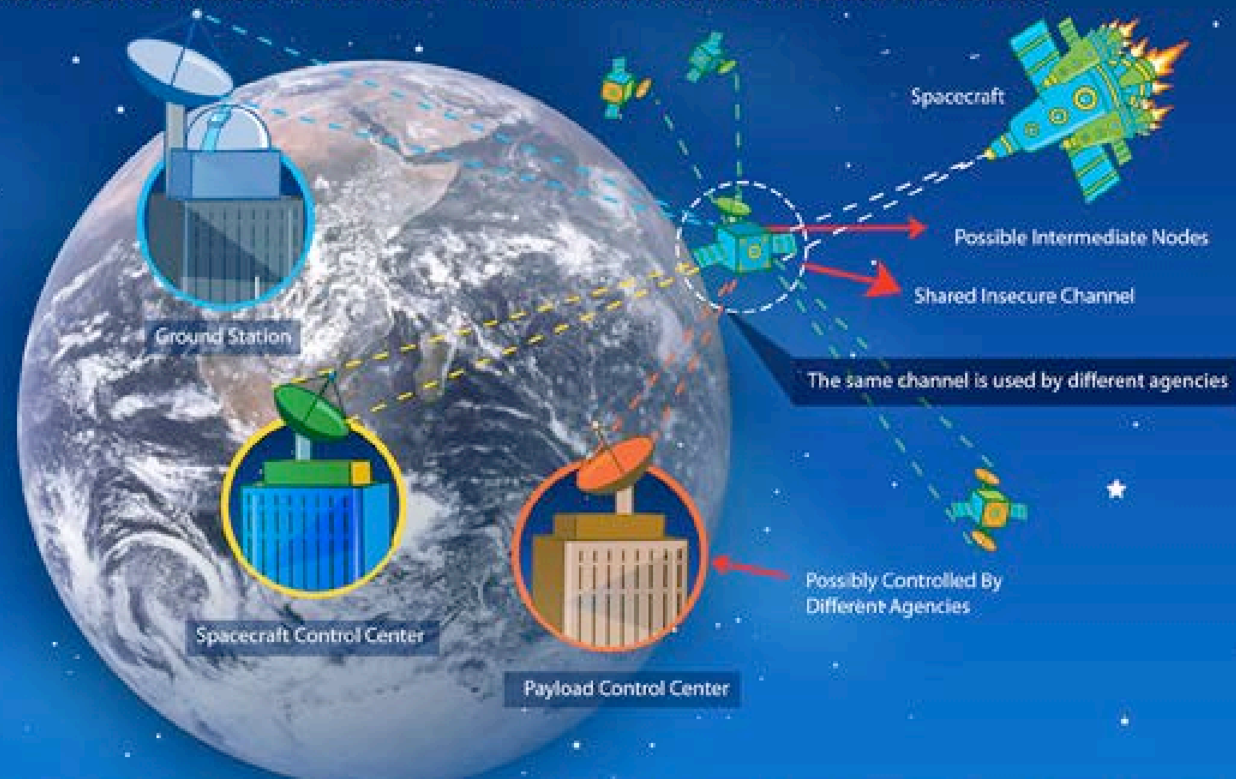
Disruption Tolerant Networking: Demonstrating protocols and technologies to enable efficient and reliable space communications (JSC).

Ka-Band Objects Observation & Monitoring: Phased antenna array to detect orbiting objects and near-Earth asteroids (KSC).

NASA Tournament Lab

While the speed of light is our friend here on Earth allowing people on the other side of the globe to communicate via the Internet in just a fraction of a second, this same speed of light works against us as we start to travel to other planets. To explore the Solar System, we must overcome the communication time delays caused by the vast distances between planets and the disruptions caused by planetary rotation, orbits, or just limited transmission power.

EXAMPLE SCENARIO OF A BASIC "SPACE INTERNETWORKING SERVICE" IN A DISRUPTION TOLERANT NETWORK

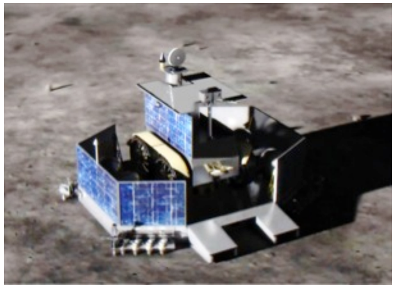


We need your help in building a suite of protocols that can work over long time delays and that can hop from point to point using a store and forward approach, in a secure, interoperable manner. Help us now and maybe you'll be able to communicate with systems on other planets in the not too distant future!

To Learn More About NASA's Disruption Tolerant Networking Challenge, Please Go To: www.topcoder.com/DTN

[TOPCODER]

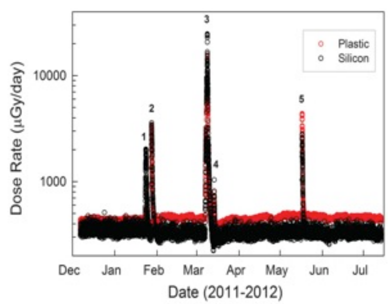
Robotic Precursors Domain



Resource Prospector: Development of lunar volatiles prospecting mission in partnership with JAXA (ARC).

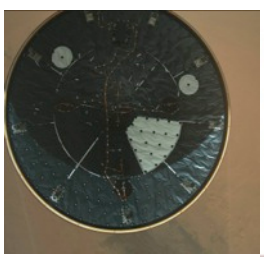
EM-1 Secondary Payloads: CubeSats for investigating deep space radiation effects on simple organisms, remote sensing of lunar volatiles, and flyby of near Earth asteroid (ARC, JPL, MSFC).

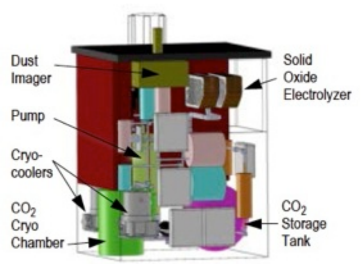
Solar System Exploration Research Virtual Institute (SSERVI): Research on moon and small bodies to support exploration and science objectives (ARC).



Radiation Assessment Detector: Mission operations for RAD to acquire radiation data from surface of Mars (JPL).

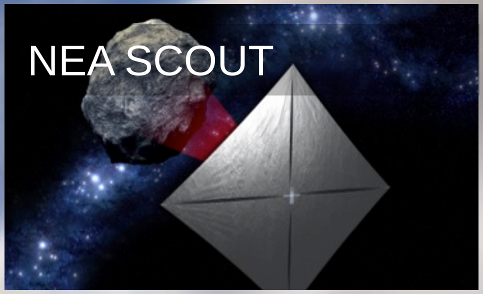
Goldstone Radar: Ground-based radar to image near-Earth asteroids (JPL).





Mars 2020: MEDLI-2 temperature and pressure sensors on heat shield to validate aerothermal models (LaRC); Demonstration of oxygen production from Mars atmosphere (JPL).

Exploration Mission 1: Secondary Payloads



NEA Characterization

Lunar resource potential

Human Health Performance

Strategic Knowledge Gaps

A Strategic Knowledge Gap (SKG) is an unknown or incomplete data set that contributes risk or cost to future human missions to the moon, Mars or Near-Earth objects

- **SKG development is ongoing and is jointly sponsored by HEOMD and SMD, who enlist the expertise of international partners and three analysis groups: the *Lunar Exploration Analysis Group* (LEAG), the *Mars Exploration Program Analysis Group* (MEPAG), and the *Small Bodies Assessment Group* (SBAG).**

- **SKGs inform mission/system planning and design and near-term agency investments**

SKGs: Common Themes and Some Observations

- **There are common themes across potential destinations (not in priority order)**
  - The three R's for enabling human missions: Radiation, Regolith, Reliability
  - Geotechnical properties
  - Volatiles (i.e., for science, resources, and safety)
  - Propulsion-induced ejecta
  - In-Situ Resource Utilization (ISRU)/Prospecting
  - Operations/Operability (all destinations, including transit)
  - Plasma Environment
  - Human health and performance (critical, and allocated to HRP)
- **Some Observations**
  - The required information is measurable and attainable
  - These measurements do not require "exquisite science" instruments but could be obtained from them
  - Filling the SKGs requires a well-balanced research portfolio
    - Remote sensing measurements, in-situ measurements, ground-based assets, and research & analysis (R&A)
    - Includes science, technology, and operational experience

Payloads On the Mars 2020 Mission Will Address Strategic Knowledge Gaps for Human Exploration.

NextSTEP BAA Overview

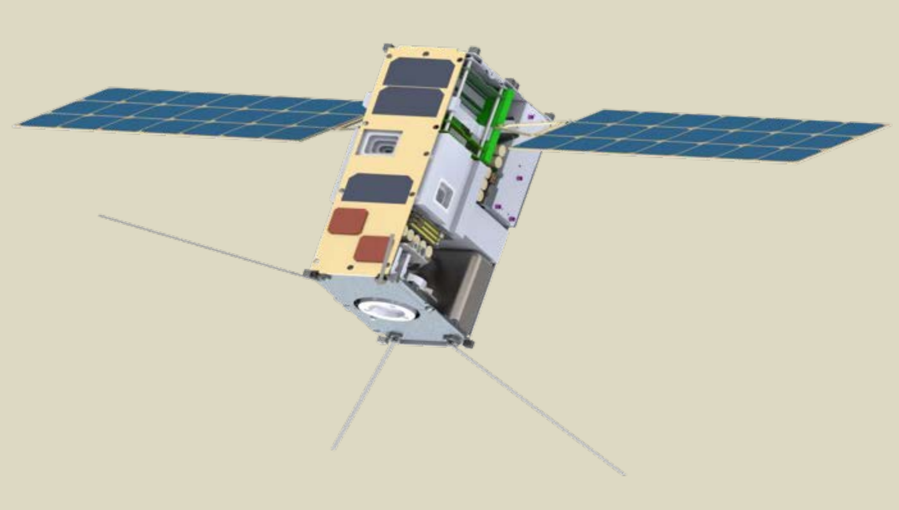
- **Solicited three critical areas for technology maturation:**
  - Advanced Propulsion Systems
  - Habitation Systems (Including Life Support)
  - Small Satellite Missions (EM-1 secondary payloads)

- **Facilitates development of deep space human exploration capabilities in the cis-lunar proving ground and beyond**
- **Continues successful public-private partnership model and spurs commercial endeavors in space**
- **Selected 12 proposals and will proceed to enter into *Fixed Price Contracts* with technical/payment milestones with private-sector partners**
  - Emphasis for eligibility and execution placed on contribution of private corporate resources to the private-public partnership to achieve goals and objectives
  - Selected partners with the technical capability to mature key technologies and demonstrate commitment toward potential commercial application

NextSTEP: Two BAA Small Satellite Awards

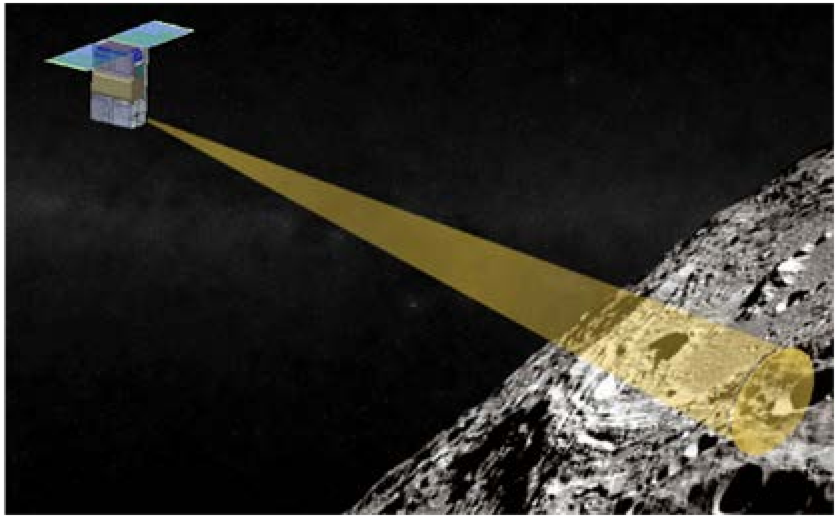
Two CubeSat projects will address Strategic Knowledge Gaps

Morehead State University
Morehead, KY



6U Lunar IceCube
Prospect for water in ice, liquid, and vapor forms and other lunar volatiles from a low-perigee, highly inclined lunar orbit using a compact IR spectrometer

Lockheed Martin
Denver, CO

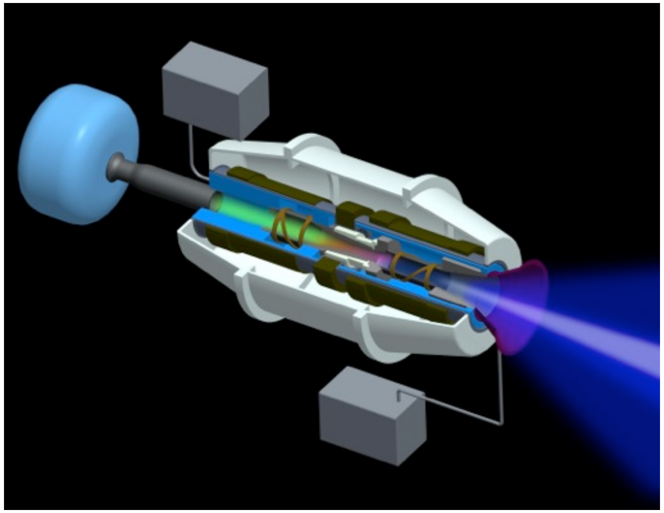


Skyfire 6U CubeSat
GEO Technology Demo
Will perform lunar flyby, collecting spectroscopy and thermography address both Moon and Mars SKGs for surface characterization, remote sensing, and site selection.

NextSTEP BAA: Three Propulsion Awards

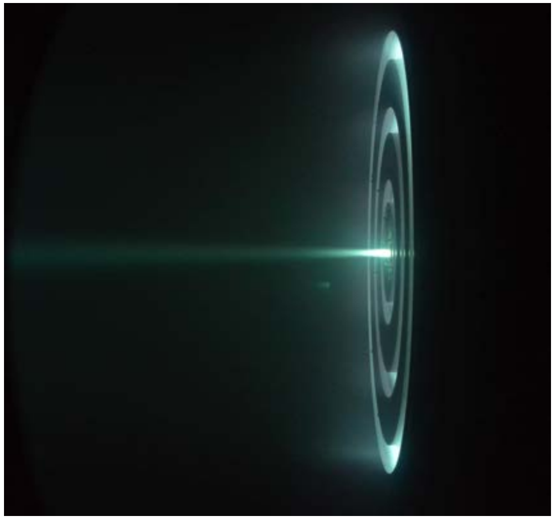
Developing propulsion technology systems in the 50- to 300-kW range to meet the needs of a variety of deep-space mission concepts

Ad Astra Rocket Company
Webster, Texas



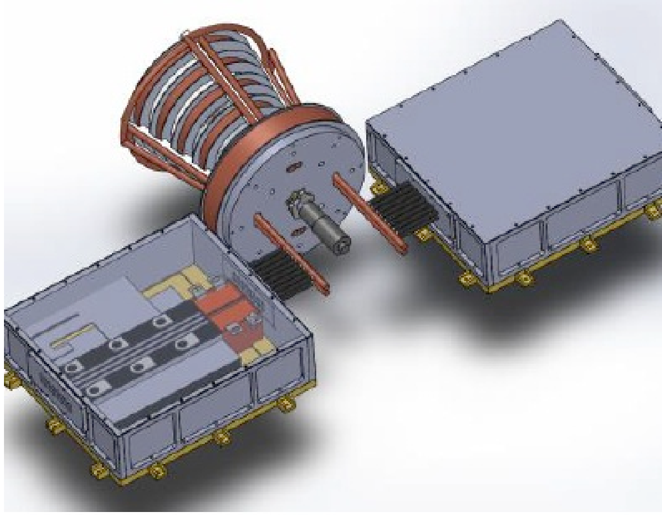
Thermal Steady State Testing of a VASIMR Rocket Core with Scalability to Human Spaceflight

Aerojet Rocketdyne Inc.
Redmond, Washington



Operational Demonstration of a 100 kW Electric Propulsion System with 250 kW Nested Hall Thruster

MSNW LLC,
Redmond, Washington

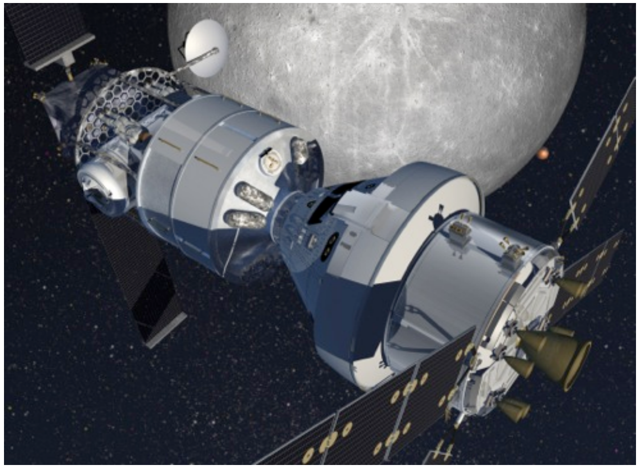


Flexible High Power Electric Propulsion for Exploration Class Missions

NextSTEP BAA: Seven Habitation Awards (1 of 3)

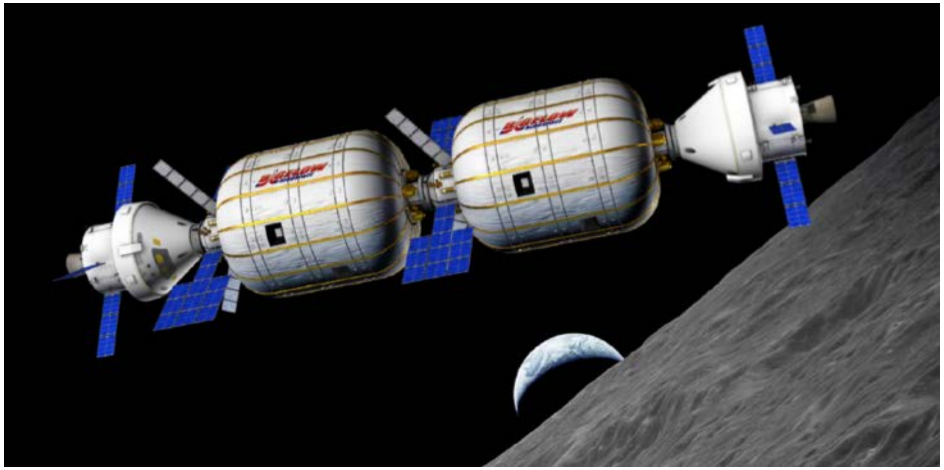
NASA awarded seven habitation projects. Four will address habitat concept development, and three will address Environmental Control and Life Support Systems (ECLSS)

Lockheed Martin
Denver, CO



Habitat to augment Orion's capabilities. Design will draw strongly on LM and partner Thales Alenia's heritage designs in habitation and propulsion.

Bigelow Aerospace LLC
Las Vegas, NV

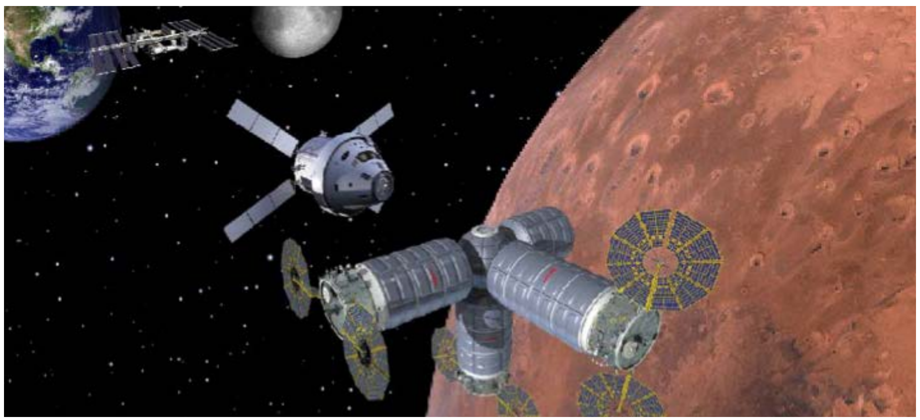


The B330 for deep-space habitation will support operations/missions in LEO, DRO, and beyond cis-lunar space

NextSTEP BAA Habitation Awards (2 of 3)

NASA awarded seven habitation projects. Four will address habitat concept development, and three will address Environmental Control and Life Support Systems (ECLSS)

Orbital ATK
Dulles, VA



Habitat that employs a modular, building block approach that leverages the Cygnus spacecraft to expand cis-lunar and long duration deep space transit habitation capabilities and technologies

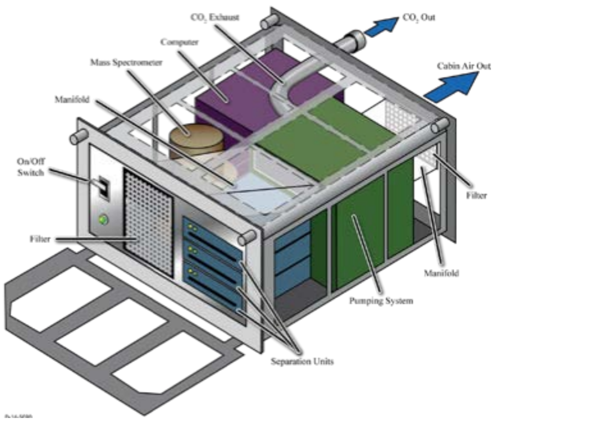
Boeing
Houston, TX

Developing a simple, low cost habitat that is affordable early on, allowing various technologies to be tested over time, and that is capable of evolving into a long-duration crew support system for cis-lunar and Mars exploration

NextSTEP BAA Habitation Awards (3 of 3)

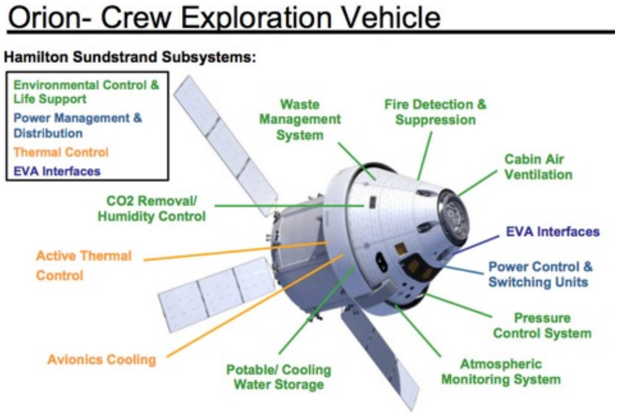
NASA awarded seven habitation projects. Four will address habitat concept development, and three will address Environmental Control and Life Support Systems (ECLSS)

Dynetics, Inc
Huntsville, AL



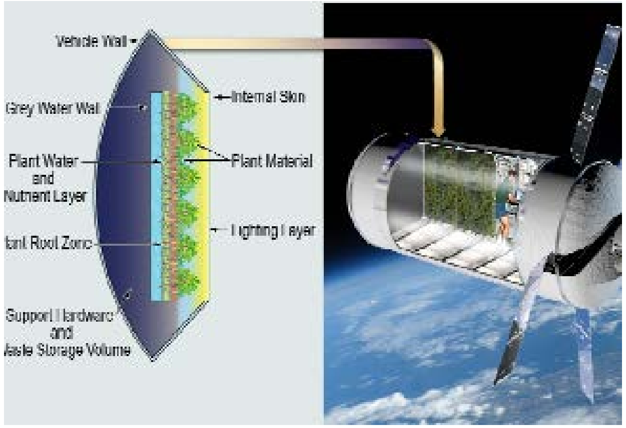
Miniature atmospheric scrubbing system for long-duration exploration and habitation applications. Separates CO2 and other undesirable gases from spacecraft cabin air

Hamilton Sundstrand Space Systems International
Windsor Locks, CT



Larger, more modular ECLSS subsystems, requiring less integration and maximize component commonality

Orbitec
Madison, WI



Hybrid Life Support Systems integrating established Physical/Chemical life support with bioproduction systems

@NASAexplores