National Aeronautics and Space Administration

Evolvable Mars Campaign

Status Update to NASA Advisory Council HEO & Science Committees

January 12, 2015

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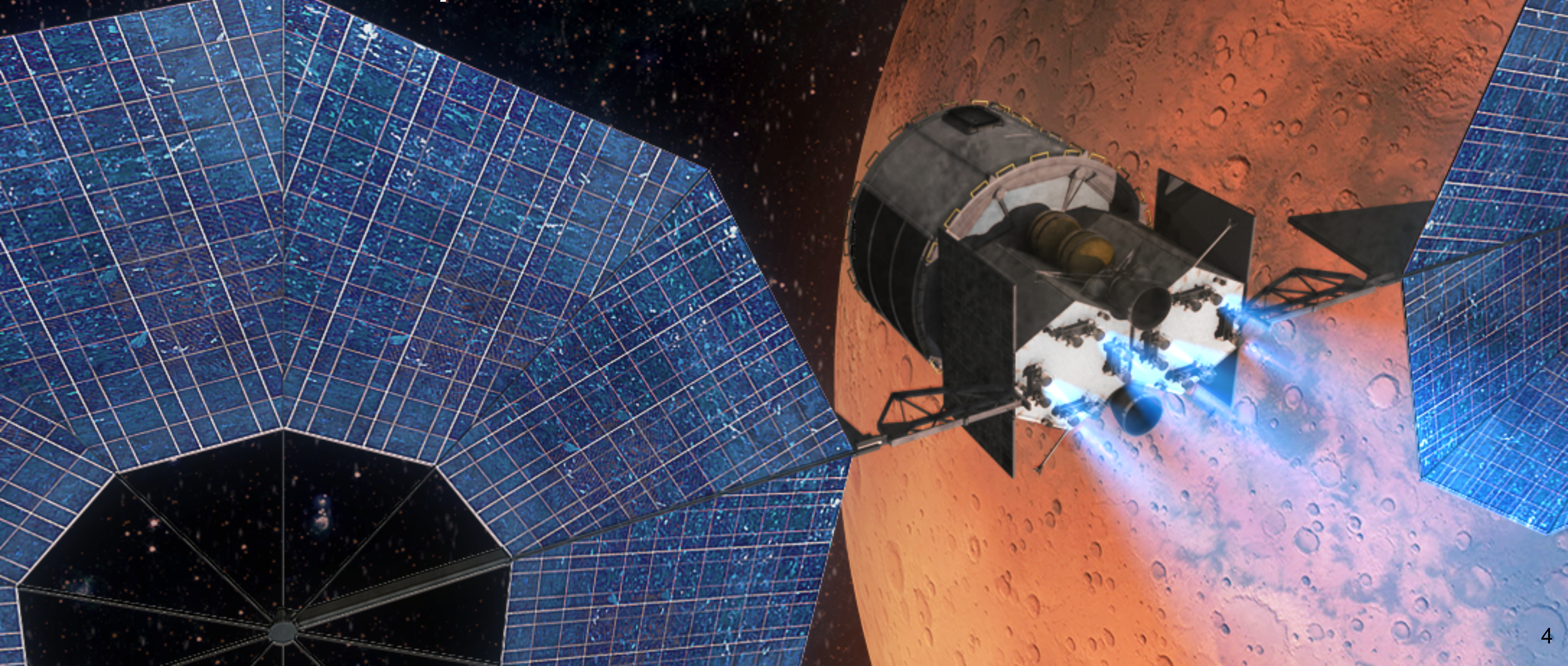
Human Exploration and Operations Mission Directorate

Pioneering Space

"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.

The Big Picture

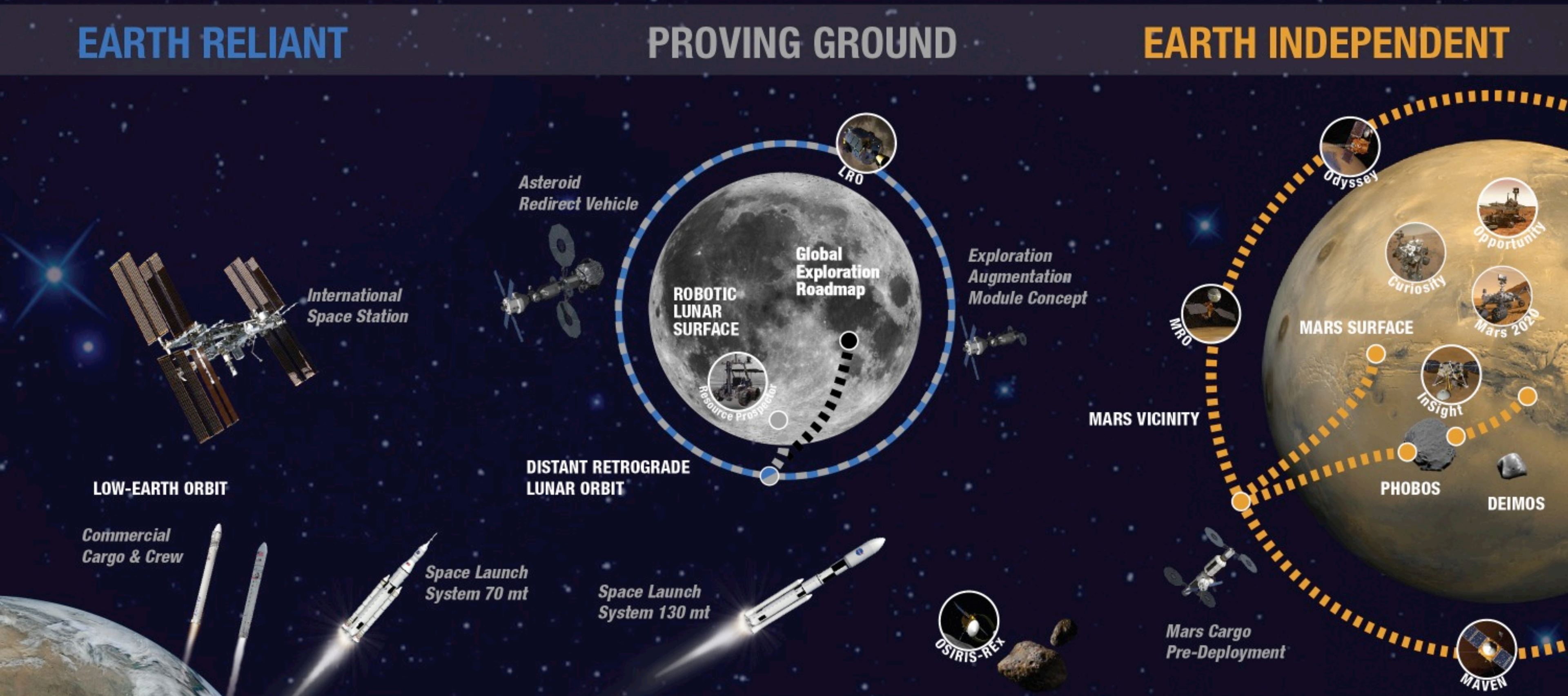
- **Our emerging Exploration Strategy implements NASA's first strategic objective:**
  - "Expand human presence into the solar system and to the surface of Mars" – What we call 'Pioneering Space'

- **The Mission Directorates have important linkages in both goals and assets, and have begun to exercise those, e.g., Mars 2020**

- **The nation is investing considerable resources in NASA for this endeavor. We need to make as much progress as possible toward a program of human and robotic exploration that is sustainable over the long term.**

EVOLVABLE MARS CAMPAIGN

A Pioneering Approach to Exploration

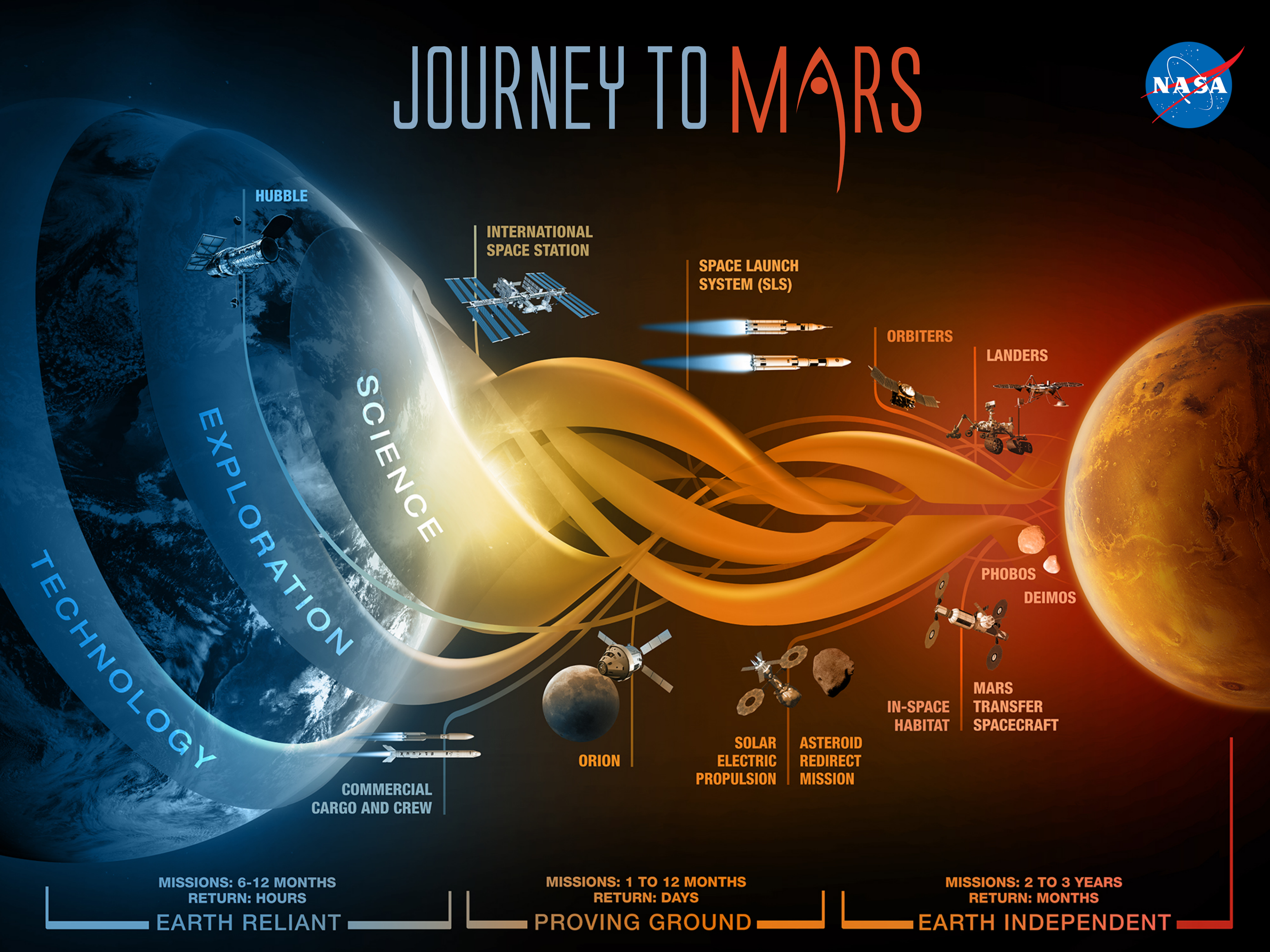


THE TRADE SPACE

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


JOURNEY TO MARS
NASA
HUBBLE
INTERNATIONAL SPACE STATION
SPACE LAUNCH SYSTEM (SLS)
ORBITERS
LANDERS
SCIENCE
EXPLORATION
TECHNOLOGY
PHOBOS
DEIMOS
ORION
SOLAR ELECTRIC PROPULSION
ASTEROID REDIRECT MISSION
IN-SPACE HABITAT
MARS TRANSFER SPACECRAFT
COMMERCIAL CARGO AND CREW
MISSIONS: 6-12 MONTHS
RETURN: HOURS
EARTH RELIANT
MISSIONS: 1 TO 12 MONTHS
RETURN: DAYS
PROVING GROUND
MISSIONS: 2 TO 3 YEARS
RETURN: MONTHS
EARTH INDEPENDENT

Strategic Principles for Sustainable Exploration

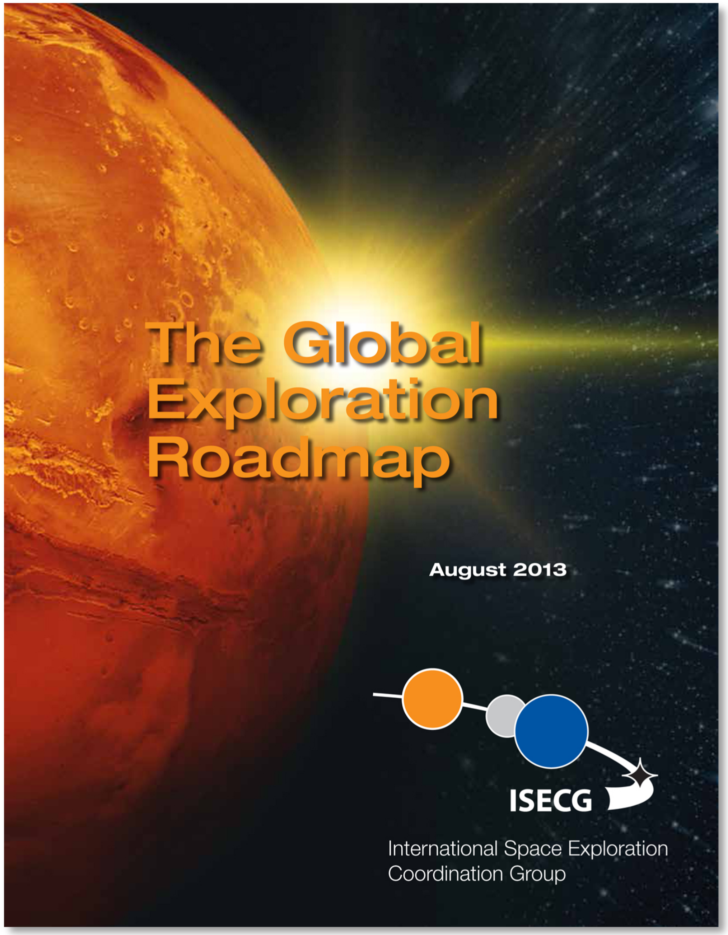
- Implementable in the ***near-term with the buying power of current budgets*** and in the longer term with budgets commensurate with economic growth*;*
- ***Exploration enables science* and science enables exploration***, leveraging robotic expertise for human exploration of the solar system*
- Application 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;
- Substantial ***international and commercial participation***, leveraging current International Space Station and other partnerships.

…But We Need to Strike the Right Balance

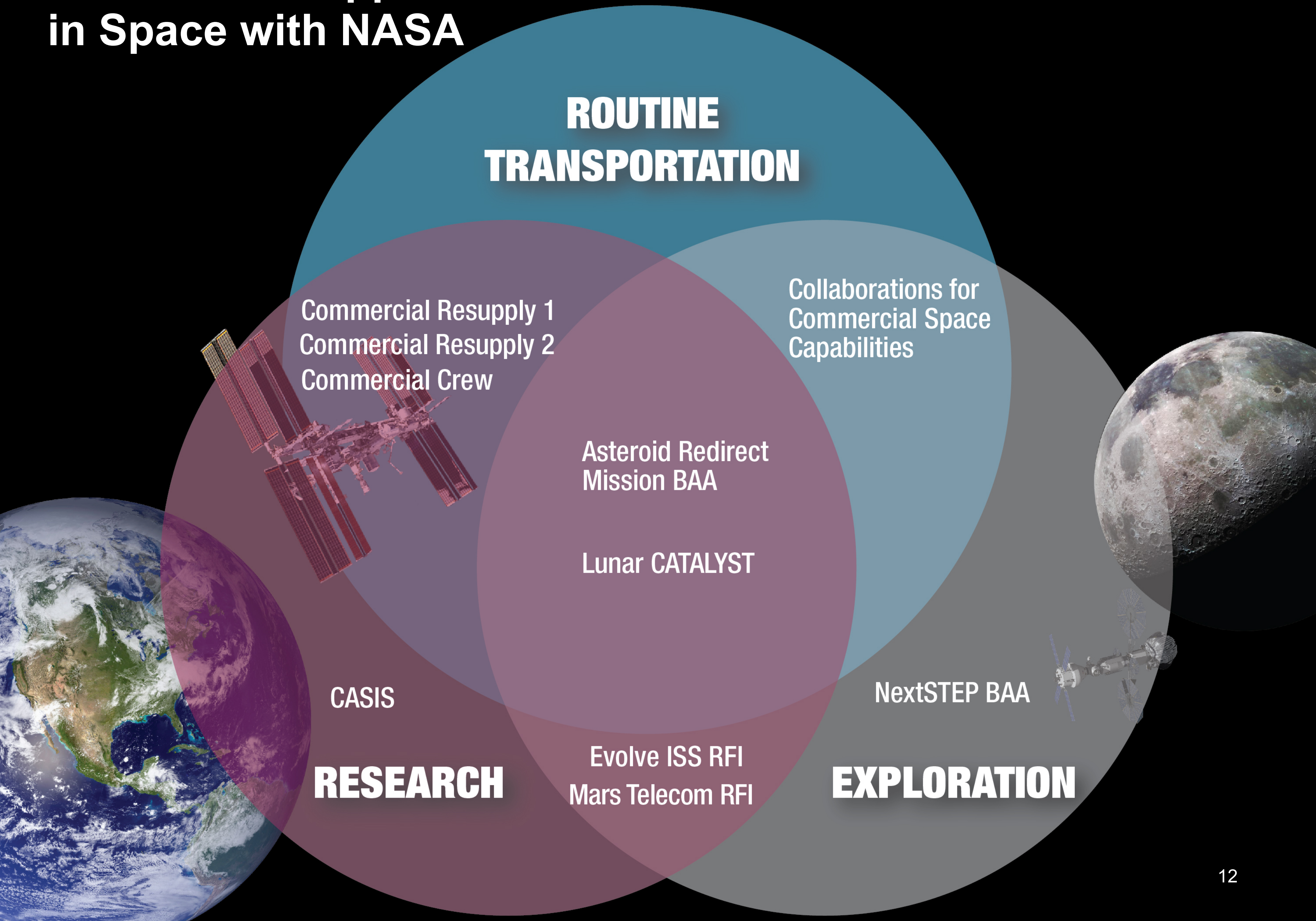
- **Mars provides the right pull for our Proving Ground work, but we should avoid the trap of a "boots on the surface of Mars by 20XX" goal, and be conscious of the risks of an impression of a singular monolithic program or goal**
- **We want to build a sustainable program to pioneer space, and not repeat the start/stop/start experience of Apollo and Shuttle**
- **We have a LOT of work to do before we are ready to send humans to Mars.**
- **We need to work with our partners on our joint interests over the long term (i.e., into the 2030s)**
  - International interests (currently expressed in GER 2.0)
  - Commercial interests
    - In the 2030's, we aim to purchase LEO services commercially
    - We will continue to work with the commercial world on their beyond-LEO interests (e.g., SMD's Mars telecom RFI, NextSTEP BAA)

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**



Commercial Opportunities in Space with NASA



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

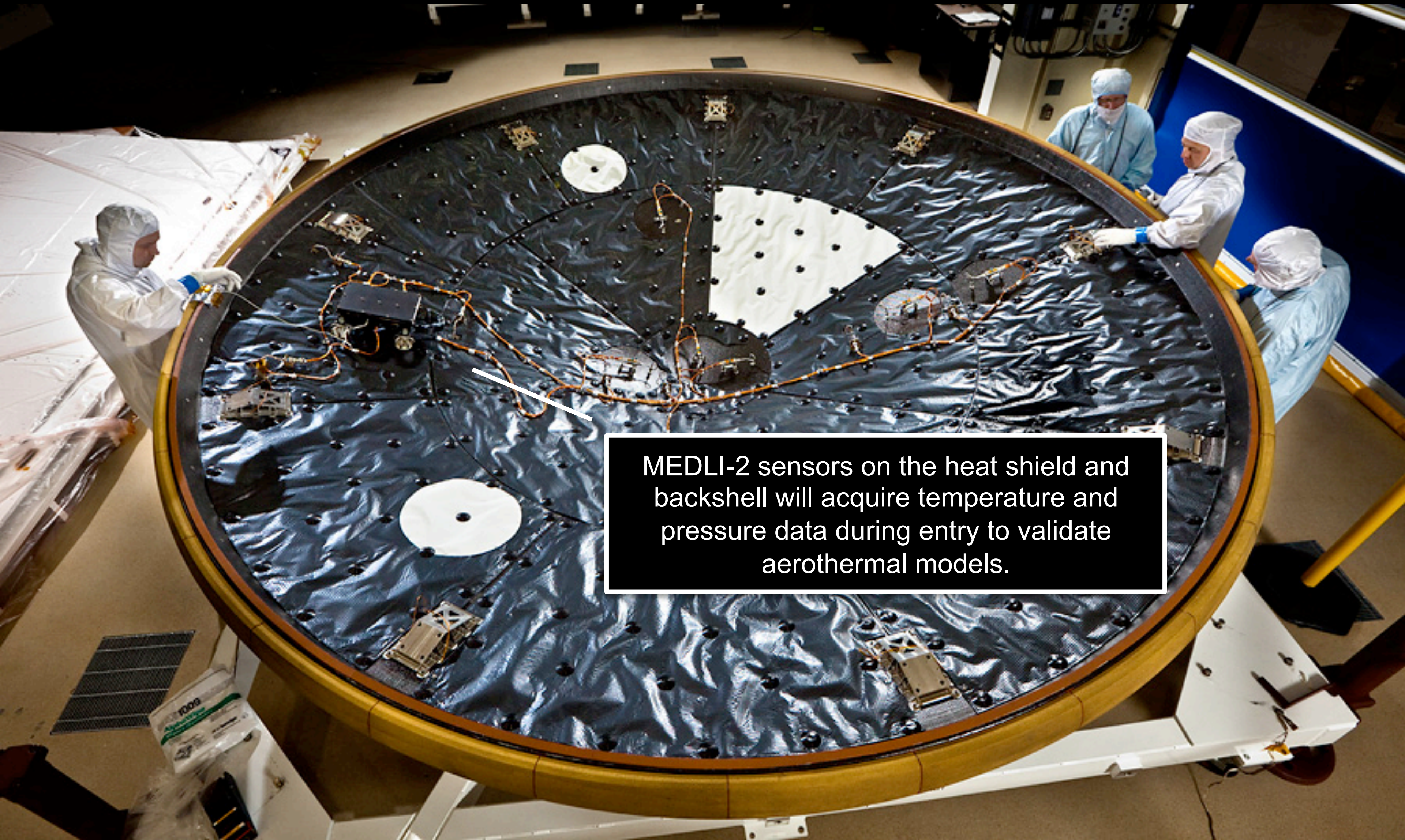
- **SKG development is ongoing and is jointly sponsored by HEOMD and SMD, who enlist the expertise of international partners and three analysis groups: the *Lunar Exploration Analysis Group* (LEAG), the *Mars Exploration Program Analysis Group* (MEPAG), and the *Small Bodies Assessment Group* (SBAG).**

- **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.



MEDLI-2 sensors on the heat shield and backshell will acquire temperature and pressure data during entry to validate aerothermal models.

Evolvable Mars Campaign

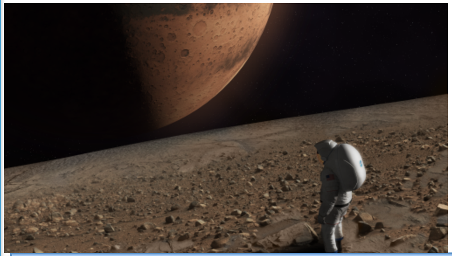
EMC Goal: Define a pioneering strategy and operational capabilities that can extend and sustain human presence in the solar system including a human journey to explore the Mars system starting in the mid-2030s.

- **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, EAM, 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

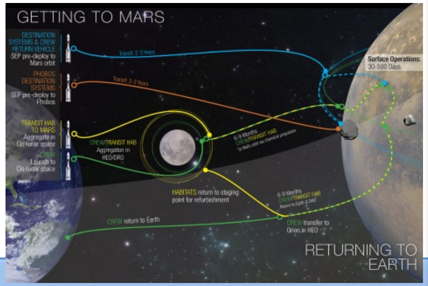
<u>Internal analysis team members:</u>
- ARC, GRC, GSFC, HQ, JPL, JSC, KSC, LaRC and MSFC
- HEOMD, SMD, STMD, OCT, OCS

<u>External inputs from:</u>
- International partners, industry, SKG analysis groups

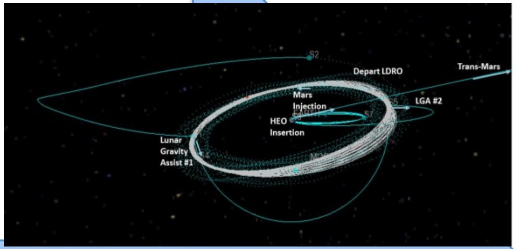
Evolvable Mars Campaign Studies in FY14 - Pointing the Way Forward



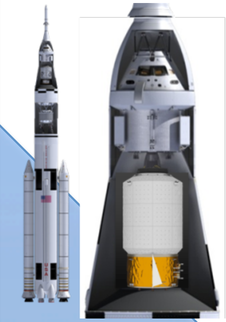
Mars and Mars Moons Surface Exploration



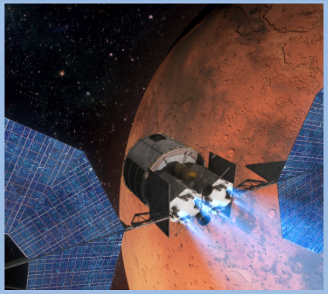
Transportation Analysis

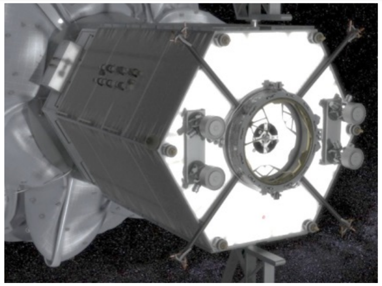


Staging Point Location



SLS Exploration Upperstage and Co-Manifested Cargo

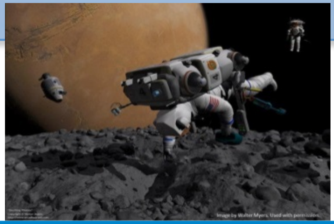


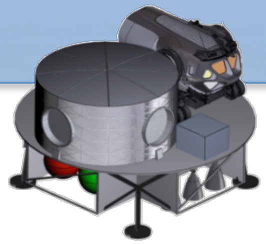


SEP

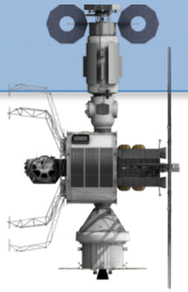
ARM Extensibility

Deep Space Surface Operations in micro-g

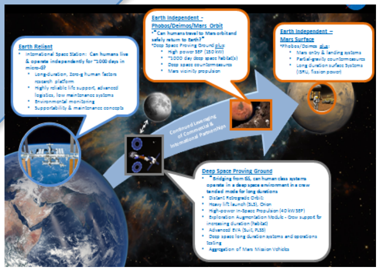




Human Class Mars Surface Lander



Mars Campaign Habitation

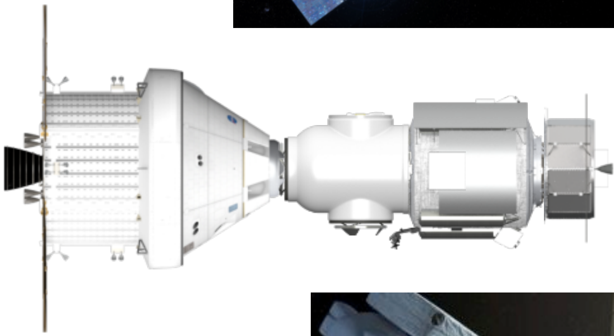


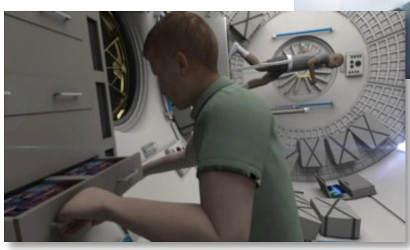
Capability Development Analysis

Proving Ground Objectives Enable Mars Missions

- **Demonstrate SLS and Orion in deep space**
  - Critical Mission Events
    - Separation Events, Key Maneuvers, Re-entry, Landing and Recovery
  - Co-manifested cargo capability with Orion, including loads, dynamics.
  - Demonstrate integrated vehicle systems in flight
    - Deep space communications, power and thermal systems, in-space maneuvering
  - Validate environments
  - Autonomous operations
- **Demonstrate use of LDRO as a staging point for large cargo masses en route to Mars**
- **Conduct deep-space EVAs with sample handling**
- **Integrated human and robotic mission operations**
- **Evaluate crew health and performance in a deep space environment**
- **Demonstrate advanced Solar Electric Propulsion (SEP) systems to move large masses in interplanetary space**
- **Demonstration of In-Situ Resource Utilization in micro-g**
- **Learn to operate with reduced logistics capability**
- **Demonstrate long duration, deep space habitation systems**
- **Demonstrate structures & mechanisms**
  - Low temperature and mechanisms for long duration, deep space missions
  - Inflatable structures

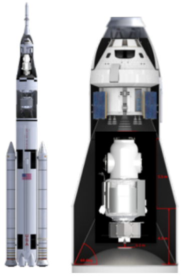




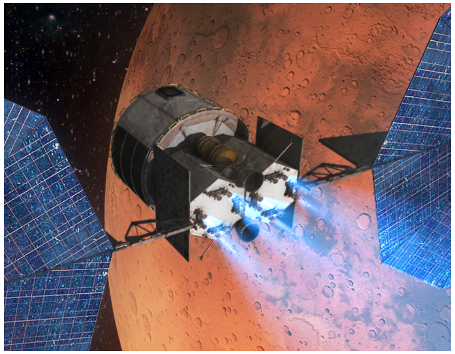


Major Results to Date

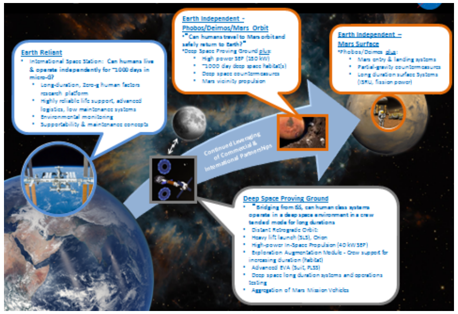
- **SLS one launch per year flight rate combined with Exploration Upper Stage (EUS) and associated co-manifested cargo capability greatly increases value of crewed missions**



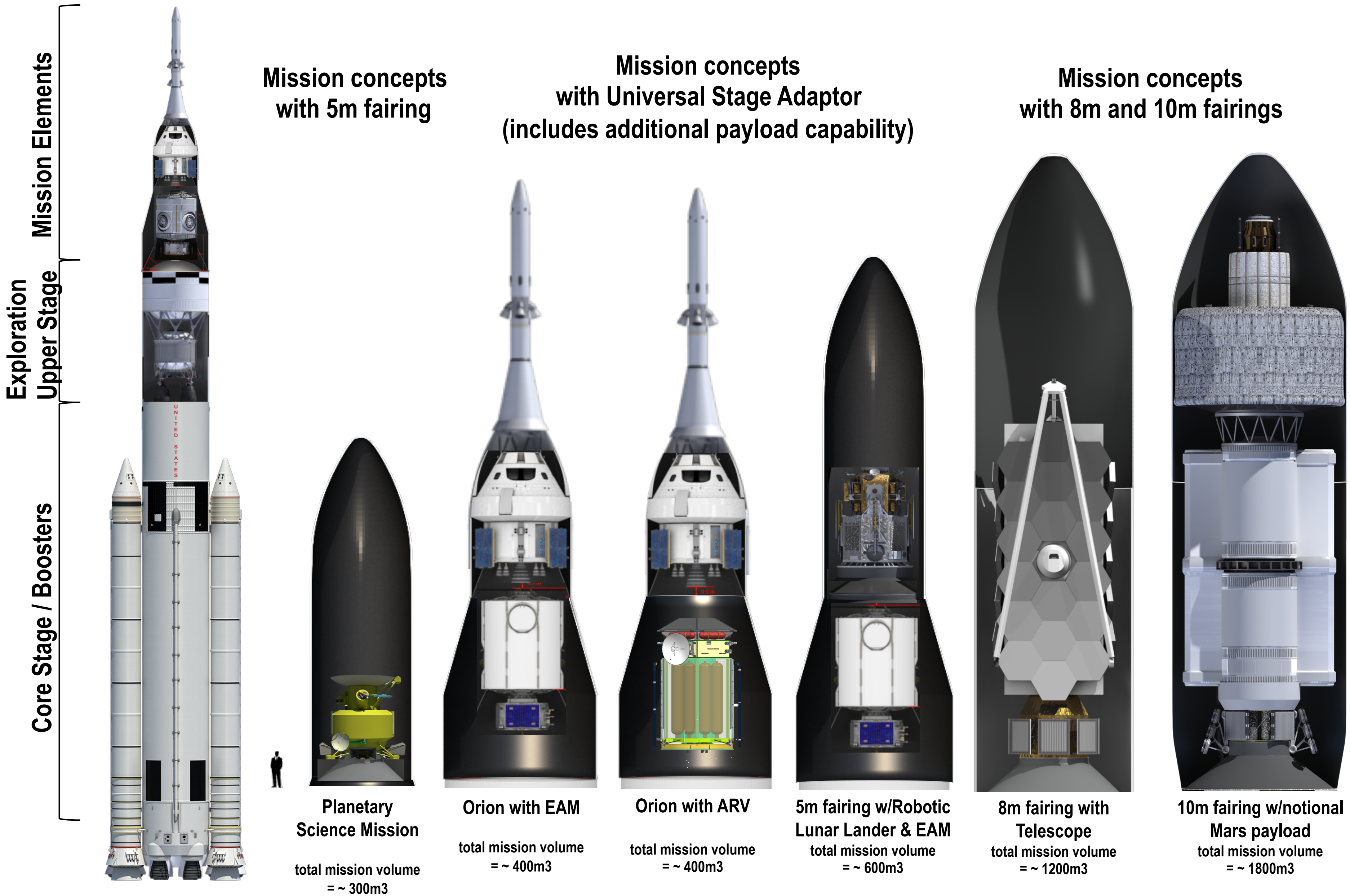
- **ARV-derived SEP vehicle can serve as an effective tool for human Mars missions**
  - SEP provides more sustainable and efficient transportation



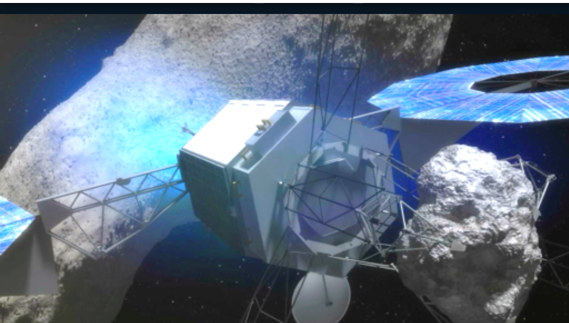
- **Regardless of Mars vicinity destination, common capability developments are required**
  - ISS provides critical Mars mission capability development platform
  - Proving Ground approach enables development of capabilities regardless of future Mars vicinity destination
    - Habitation in cis-lunar space will be an essential next step

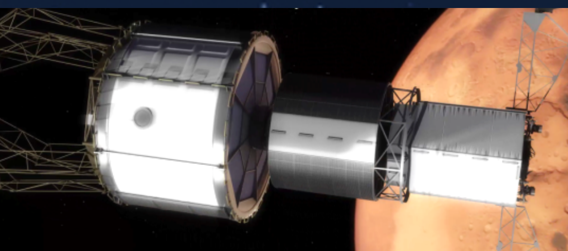


EUS & Payload Accommodation Options

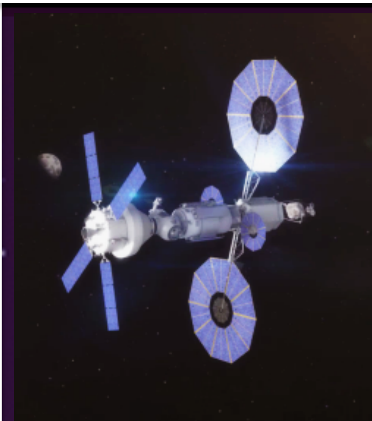


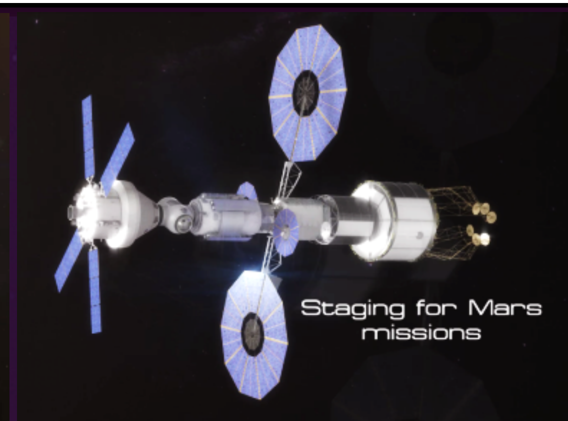
ARM Risk Reduction for Future Mars & Deep Space Missions



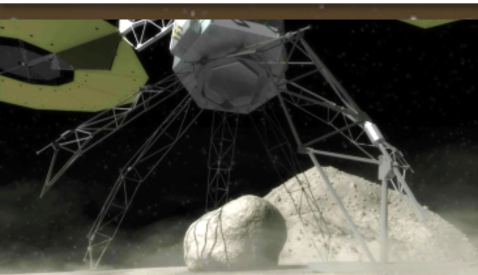


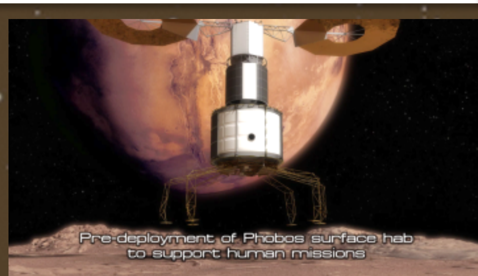
Long duration **human-scale systems operating in deep space**. Pre-deployment of crewed mission elements via solar electric propulsion with long quiescent periods.





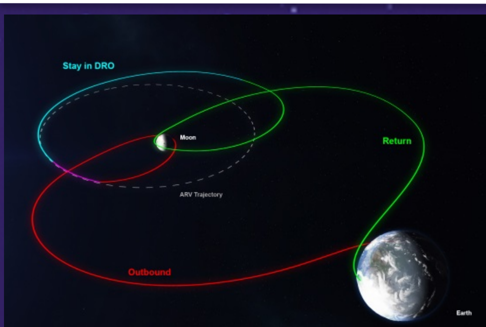
Sensor suites and proximity operations required for aggregating Mars mission vehicle stacks, deep space rendezvous and docking with Orion.





Enhanced interaction with **uncooperative, low-G targets** as will be experienced with Mars moons.

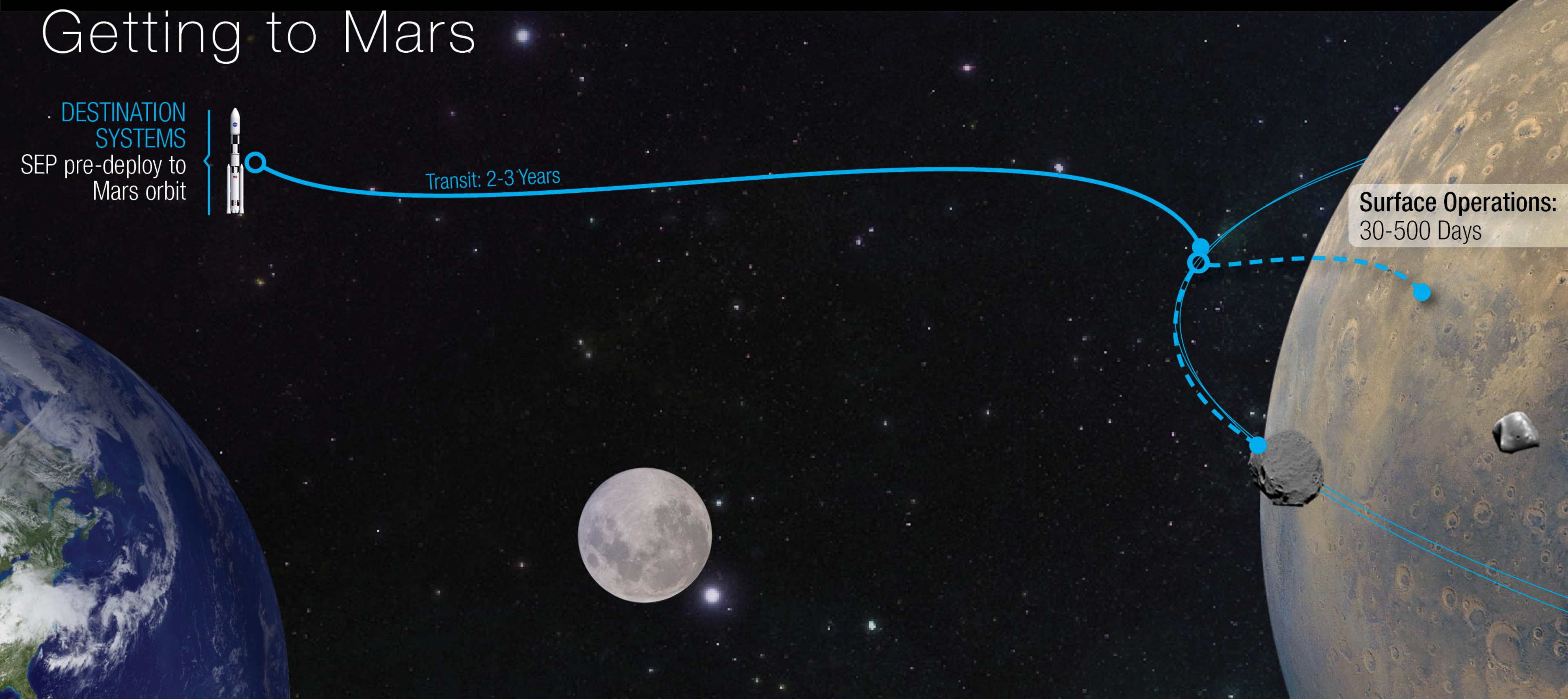
In-space EVA ops and on micro-g body (Phobos), sample handling, and ISRU.



Mission Operations: Deep space trajectories, rendezvous and docking, pre-deployment of systems.

Long duration, high-power **Solar Electric Propulsion:** Solar arrays, thrusters, PMAD, Xenon storage.

Split Mission Concept

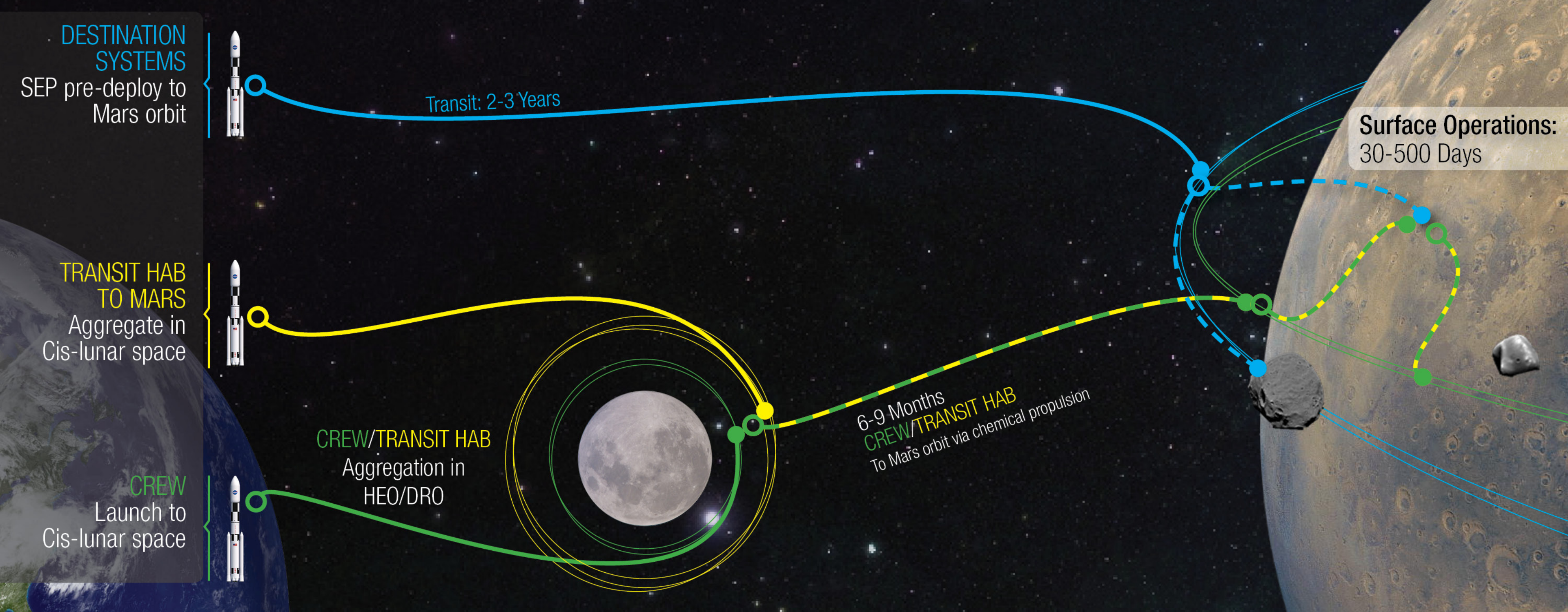


Using SEP for pre-emplacement of cargo and destination systems enables sustainable Mars campaign

- Minimizes the cargo needed to be transported with the crew on future launches
- Enables a more sustainable launch cadence
- Pre-positions assets for crew missions allows for system checkout in the Mars vicinity prior to committing to crew portion of mission

Split Mission Concept

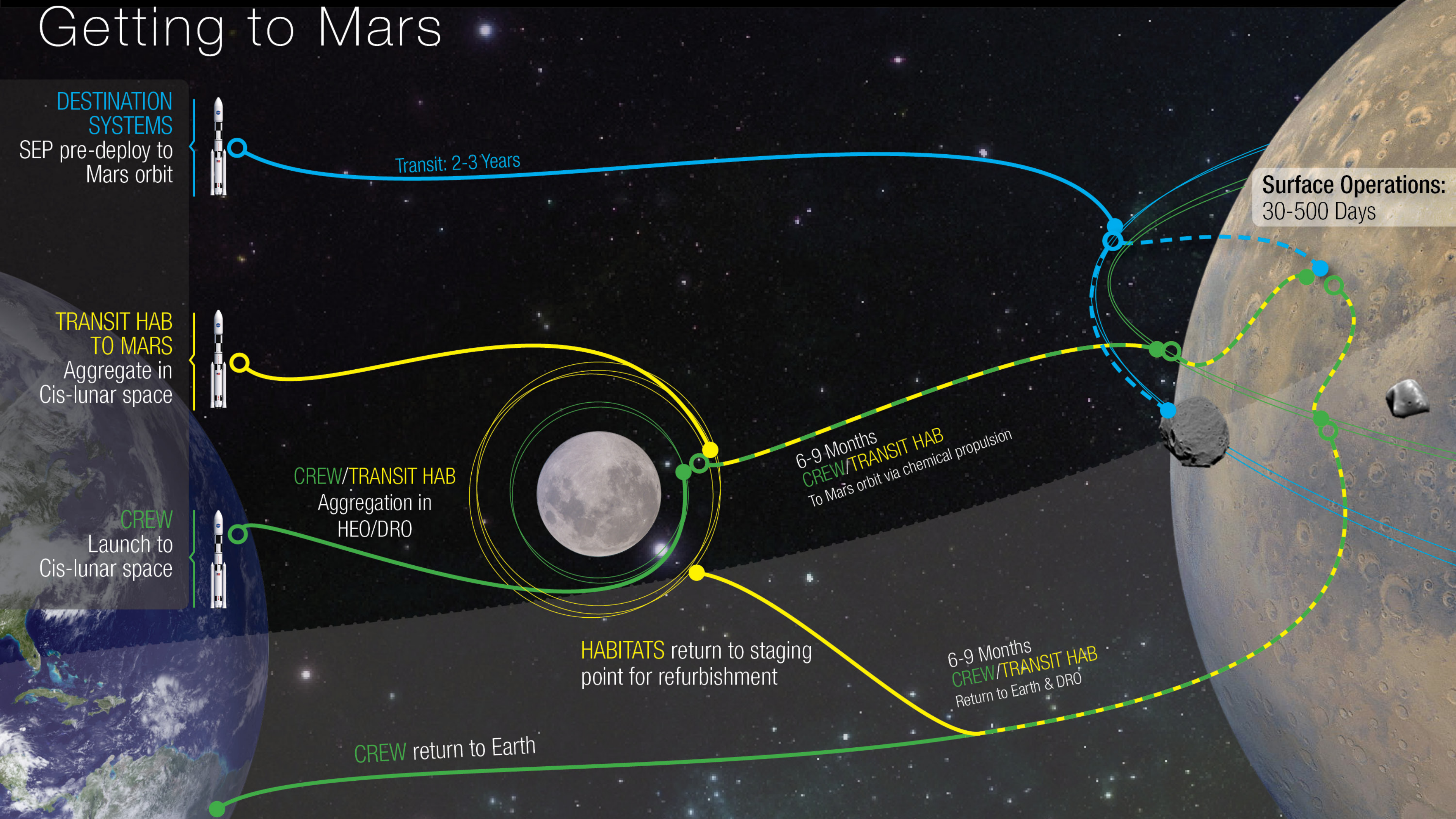
Getting to Mars



DRO as an aggregation point for Mars habitation systems

- Provides a stable environment and ease of access for testing Proving Ground capabilities
- Allows for Mars transit vehicle build-up and checkout in the deep-space environment prior to crew departure
- Able to transfer Mars Transit Vehicle from DRO to High Earth Orbit with small amount of propellant to rendezvous with crew in Orion – HEO is more efficient location to leave Earth-moon system for Mars vicinity

Split Mission Concept



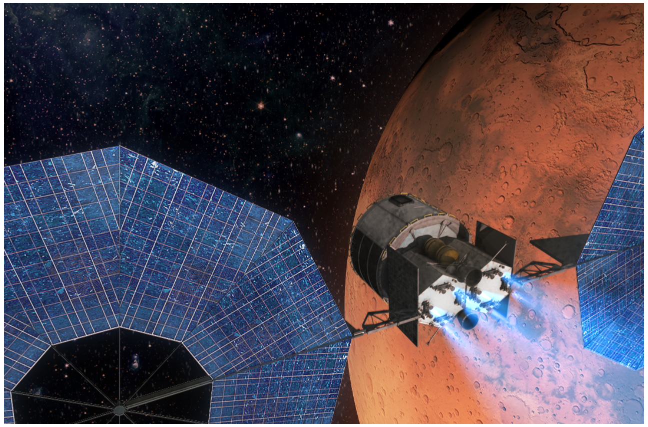
Returning to Earth

- Returning from Mars, the crew will return to Earth in Orion and the Mars Transit Habitat will return to the staging point in cis-lunar space for refurbishment for future missions

FY15 Forward Study Work

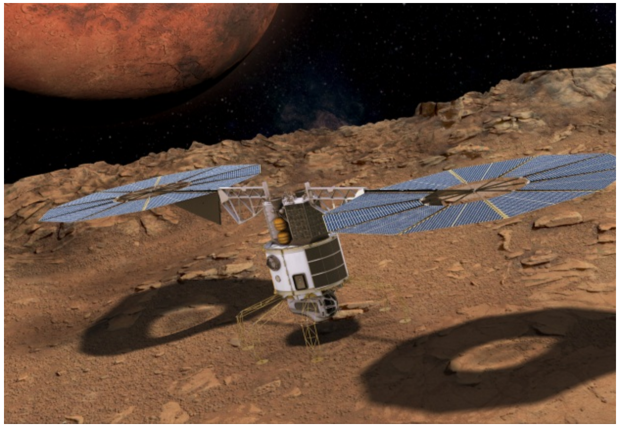
- **Launch Vehicle**
  - Exploration Upper Stage (ESD, EMC)
  - Co-manifested cargo opportunities (ESD, EMC, SMD, STMD)
- **Concept development in coordination with Science and STMD**
  - Human Mars site selection options (EMC, Mars Exploration Program (MEP)/SMD)
  - Human assisted Mars /lunar/other planetary body sample return study (ISECG, and MEP/SMD)
  - Lunar polar volatile study (ISECG, LEAG)
  - Pathfinder development (Phobos / Deimos pathfinder, Mars surface pathfinder) (EMC, SMD, STMD)
  - Phobos / Deimos human exploration (EMC, SSERVI)
  - ISRU Integrated Test Plan (EMC, STMD)
- **Habitation Refinement**
  - Cis-lunar Habitation study (HEO)
  - NextSTEP BAA (AES)
  - Mars transit habitat – large monolithic versus modular (EMC)
  - Mars ascent cabin, Mars taxi commonality (EMC)
- **In-space Transportation**
  - Continue investigation into extensibility and utilization of ARM/ARV bus for human Mars exploration missions (EMC/ARM, STMD)
  - NextSTEP BAA (AES)
  - Mars lander sizing refinement and impact to EDL technology selection (EMC, STMD)

Mars Vicinity Missions Provide the "Pull"



Mars Orbit

- Opportunities for integrated human-robotic missions:
  - Real time tele-operation on Martian surface
  - Mars sample return
- Demonstrate sustainable human exploration split-mission Mars concept
- Validate transportation and long-duration human systems
- Validate human stay capability in zero/ micro-g



Mars Moons

- Opportunities for integrated human-robotic missions:
  - Real time tele-operation on Martian surface
  - Mars & moons sample return
- Demonstrate sustainable human exploration split-mission Mars concept
- Moons provides additional radiation protection
- In-situ resource utilization
- Validate human stay capability in low-g environment

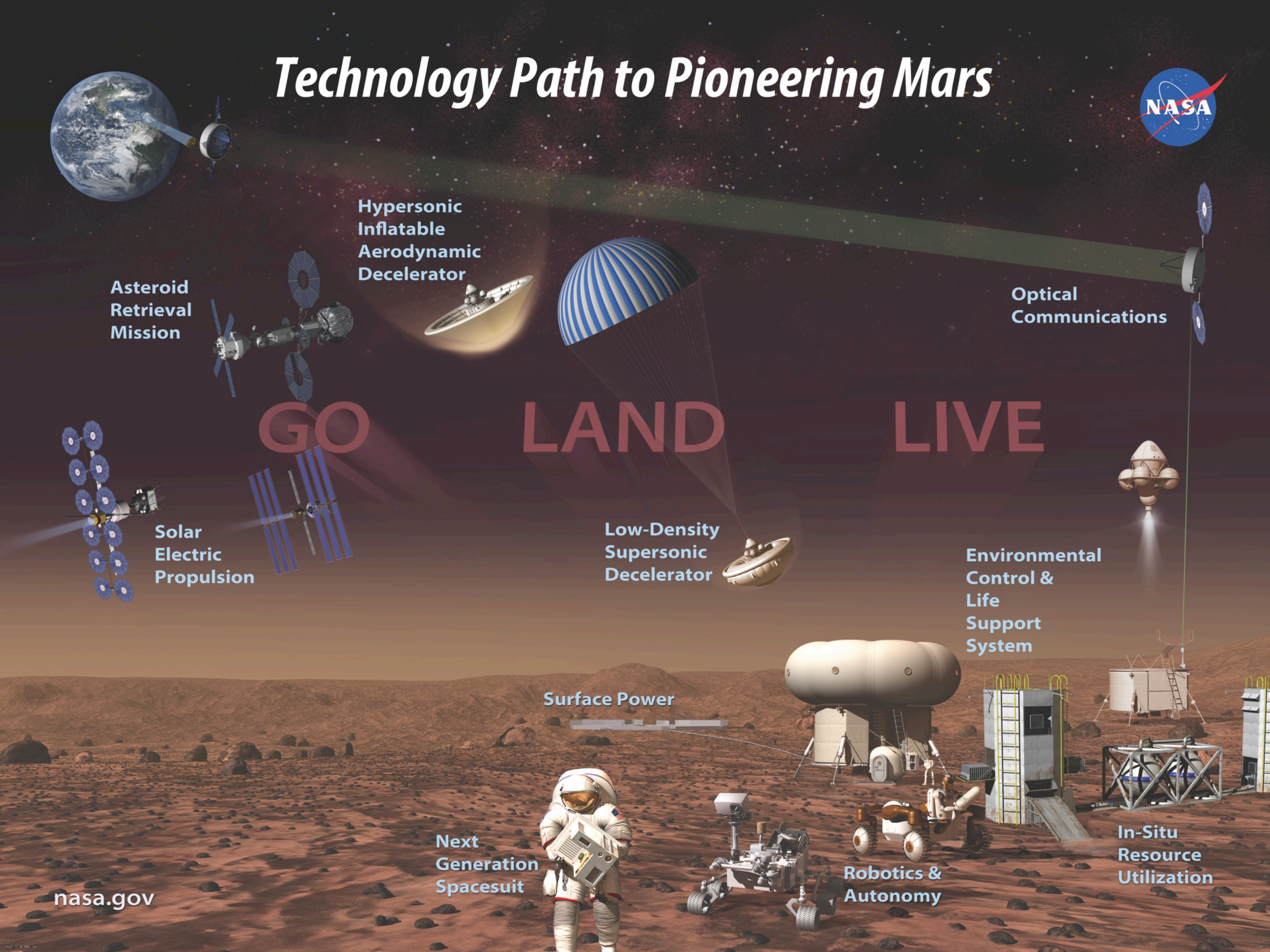
Mars Surface

- Opportunities for integrated human-robotic missions:
  - Search for signs of life
  - Comparative planetology
  - Understanding Mars climate changes
  - Geology/geophysics
- Planet provides radiation protection
- Entry, descent, landing
- EVA surface suits
- In-situ resource utilization
- Validate human stay capability in partial-g

Mars Site Selection: Early Stages of SMD/HEOMD Development

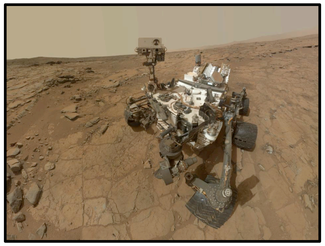
- **SMD and HEOMD initiated a collaborative site selection study in Dec. 2014.**
  - Co-chaired by Rick Davis (SMD) and Ben Bussey (HEOMD)

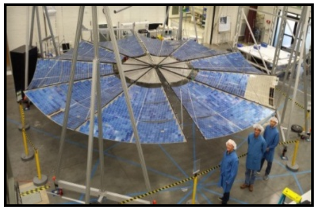
- **Forward work in FY2015:**
  - Identify existing work to identify a set of sites that would meet meet both human exploration and science requirements.
  - Identify those that have not yet been imaged by MRO and prioritize future observations
  - Refine HEOMD preliminary human landing site requirements
  - Jointly present Human Exploration Landing Site study at the MEPAG Mars 2020 site selection workshop in Aug. 2015

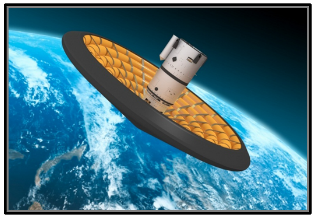

Technology Path to Pioneering Mars
NASA
Hypersonic Inflatable Aerodynamic Decelerator
Asteroid Retrieval Mission
Optical Communications
GO
LAND
LIVE
Solar Electric Propulsion
Low-Density Supersonic Decelerator
Environmental Control & Life Support System
Surface Power
Next Generation Spacesuit
Robotics & Autonomy
In-Situ Resource Utilization
nasa.gov

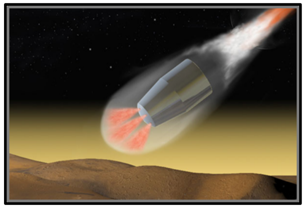
Advancements in Mars Capabilities

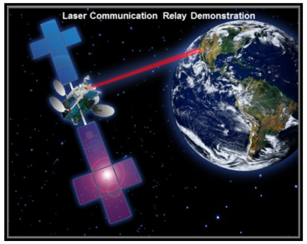
- **Progress through Flight and Missions**
  - Progress on Mars
    - Mars Curiosity: understanding the environment (e.g., RAD instrument)
  - In-situ resource utilization (ISRU)
    - Next goal: Demonstrate oxygen conversion on Mars 2020
  - Entry, descent, and landing (EDL)
    - Next goal: 2-5 mT to the surface post Mars 2020 leading to Mars Sample Return; possible ISS downmass capability; measurements on Mars 2020; TPS for Venus entry in Discovery 14 and Orion EM-1 ;
  - Optical communication
    - Next goal: GEO-to-surface for TRDSS and deep-space optical communications on Discovery 14
  - In-space propulsion and power
    - Next goal: high-power SEP for ARM and possible array for ISS
    - Next goal: modular surface power
  - Habitats
    - Next goal: Bigelow demonstration on ISS
- **Progress on Ground Testbeds and ISS**
  - Radiation safety
  - Planetary ascent propulsion
  - Environmental control and life support system
  - Extravehicular activity (EVA) suits
  - Crew health







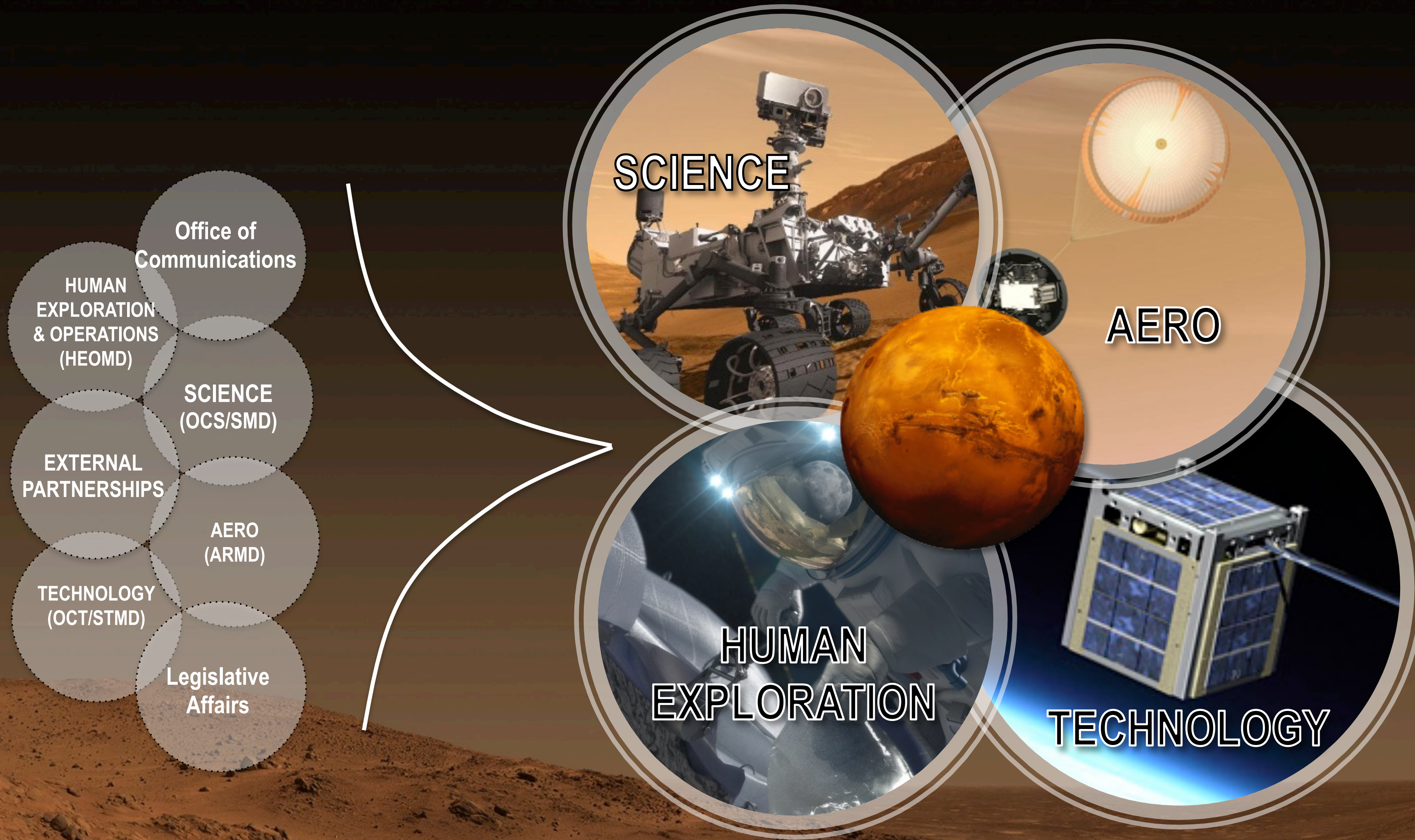




So, We Need:

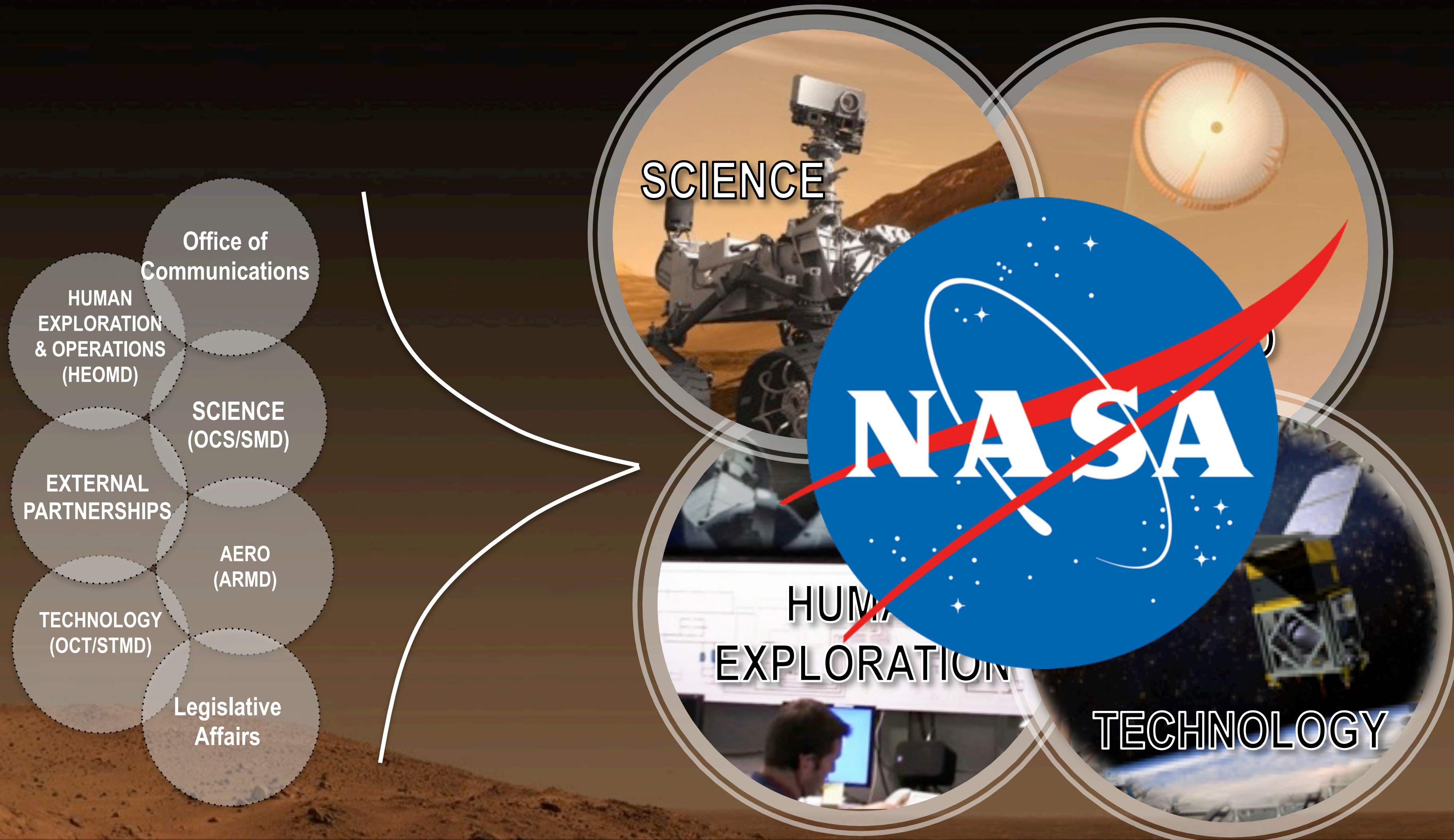
- **Sustainability**
  - Define a program that is robust across election cycles and economic conditions,
  - Achieving regular milestones of recognized value within budget levels we can reasonably expect; ones that feed forward
- **Agility**
  - Must be responsive to changes in the national and international environment
- **Focus**
  - Examine current and planned expenditures in light of priorities
  - Alignment of priorities among MDs, Centers, and across to contractors and partners
- **Affordability**
  - Achieve a minimum once per year flight rate for SLS after 2022 within currently projected resources
  - Engage partners to provide elements of the overall exploration architecture

Achieving Alignment for Pioneering Space



Commercial & International Partners • Other Government Agencies • Citizen Innovators

Achieving Alignment for Pioneering Space



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