National Aeronautics and Space Administration

Evolvable Mars Campaign

November 18, 2014

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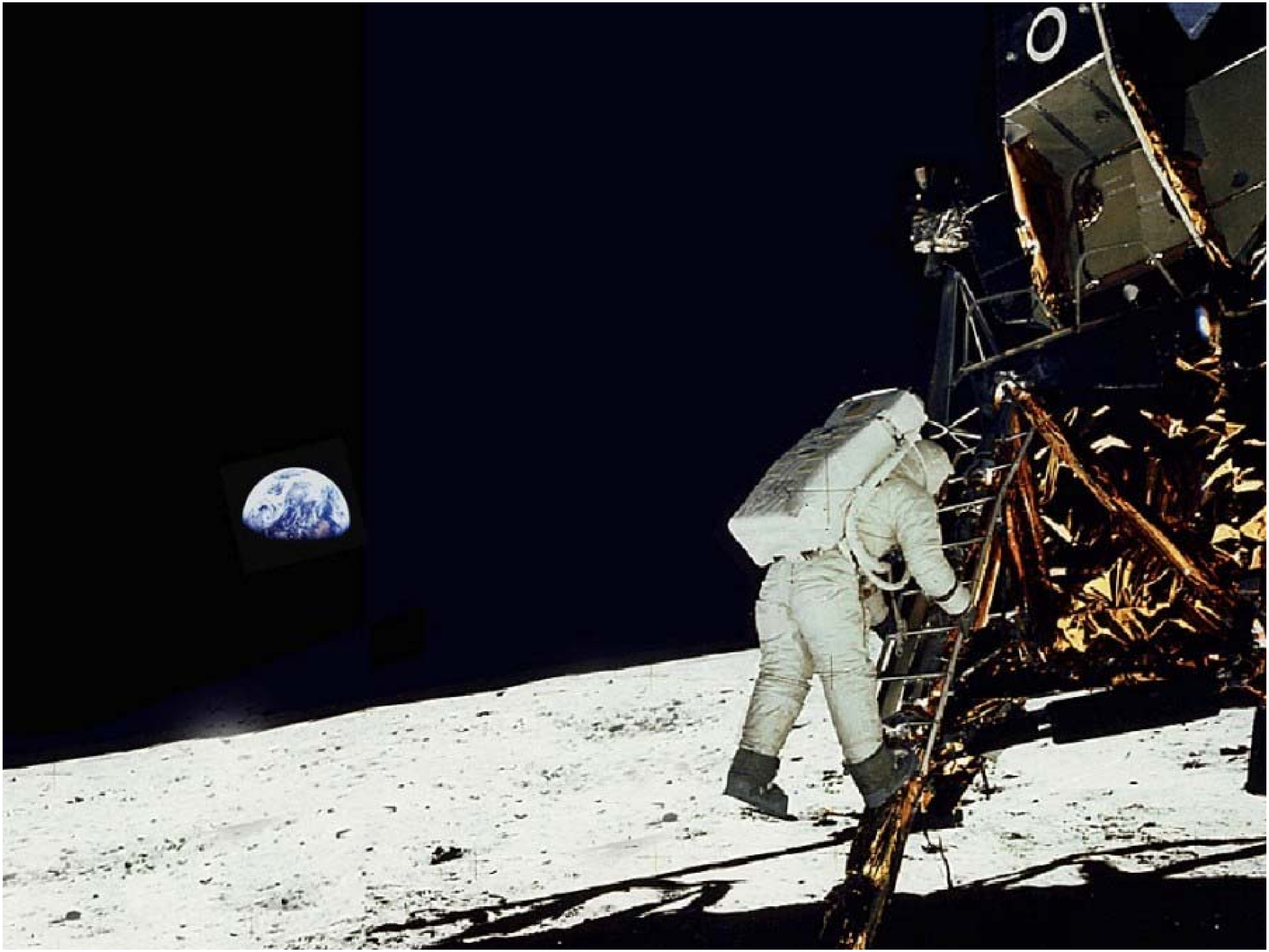
Human Exploration and Operations Mission Directorate

Agenda

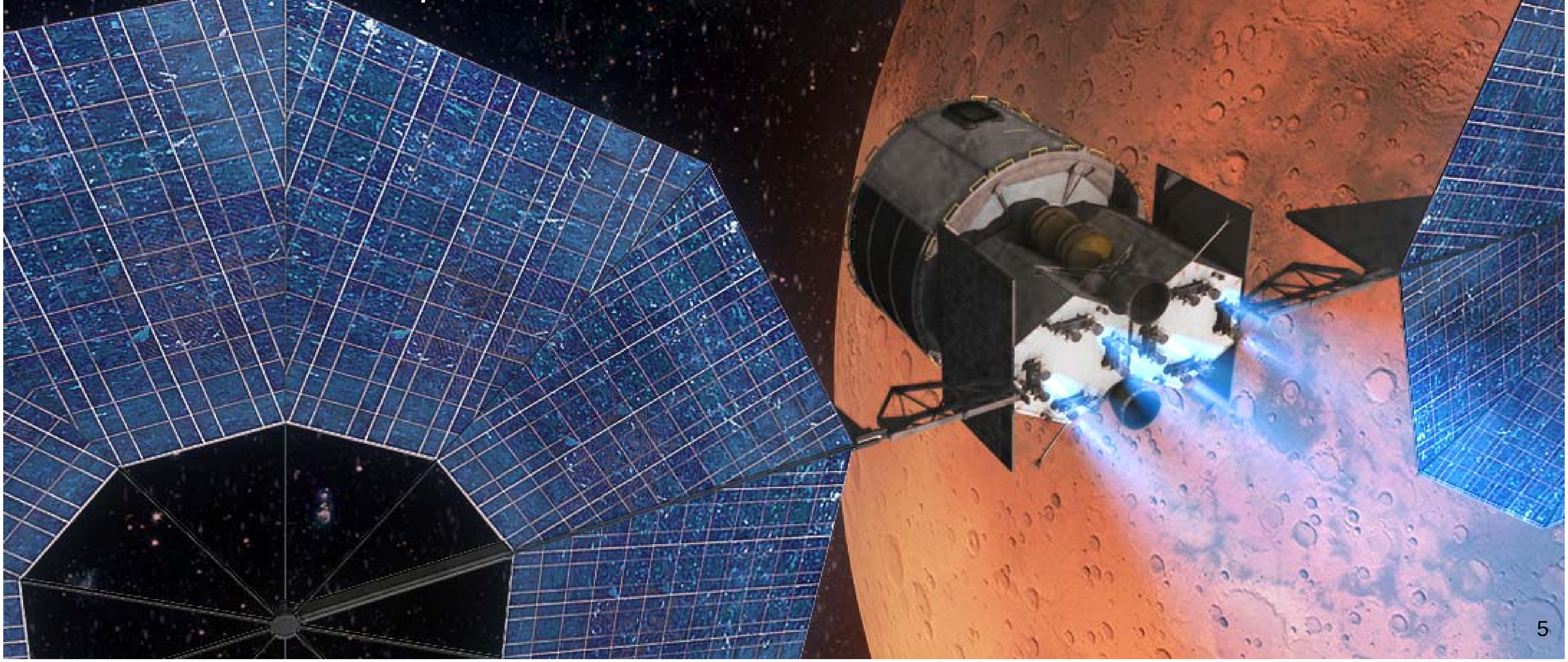
- Pioneering Space Background
- Evolvable Mars Campaign
- Planetary Protection Considerations

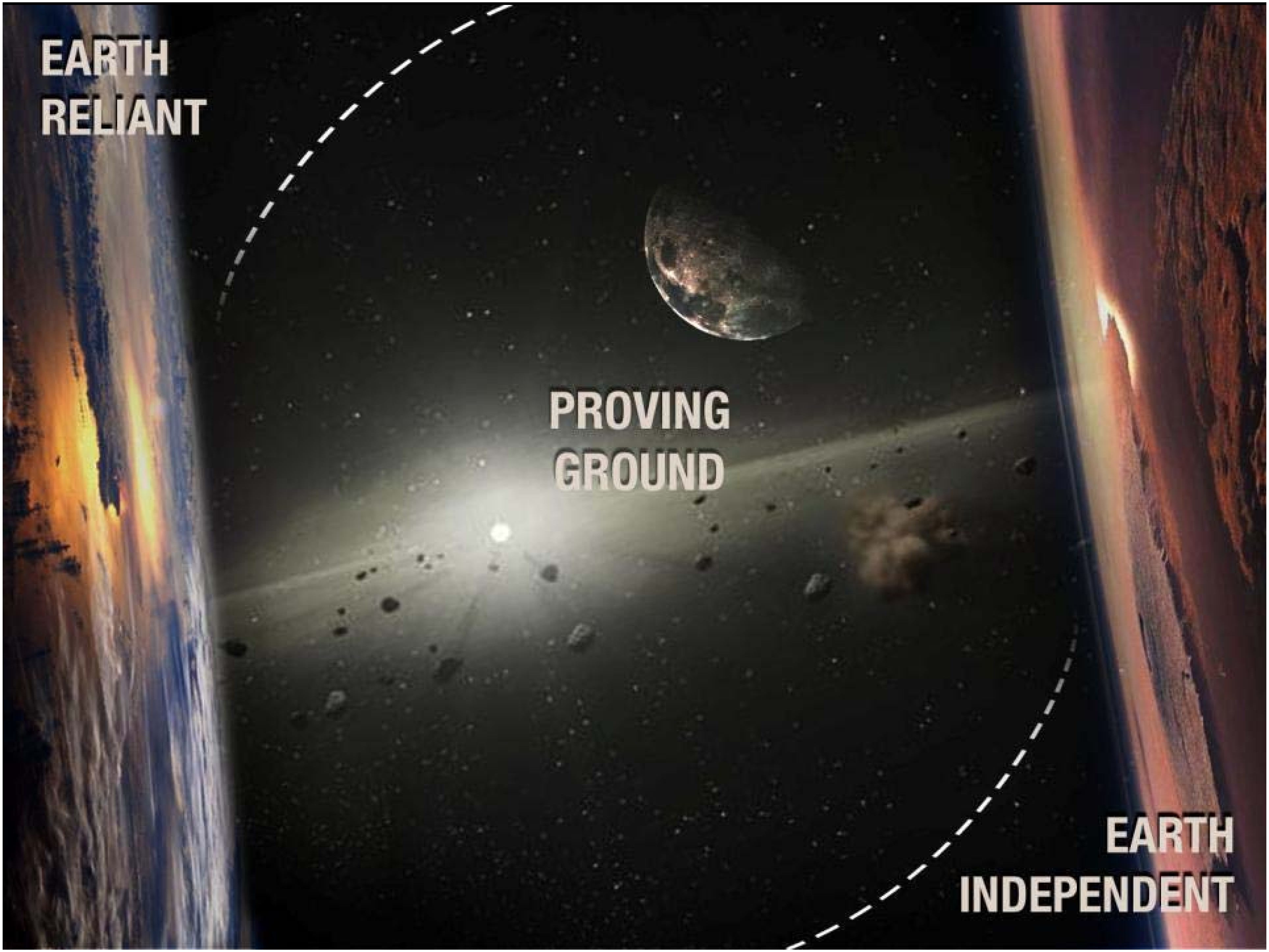


Pioneering Space - Goals

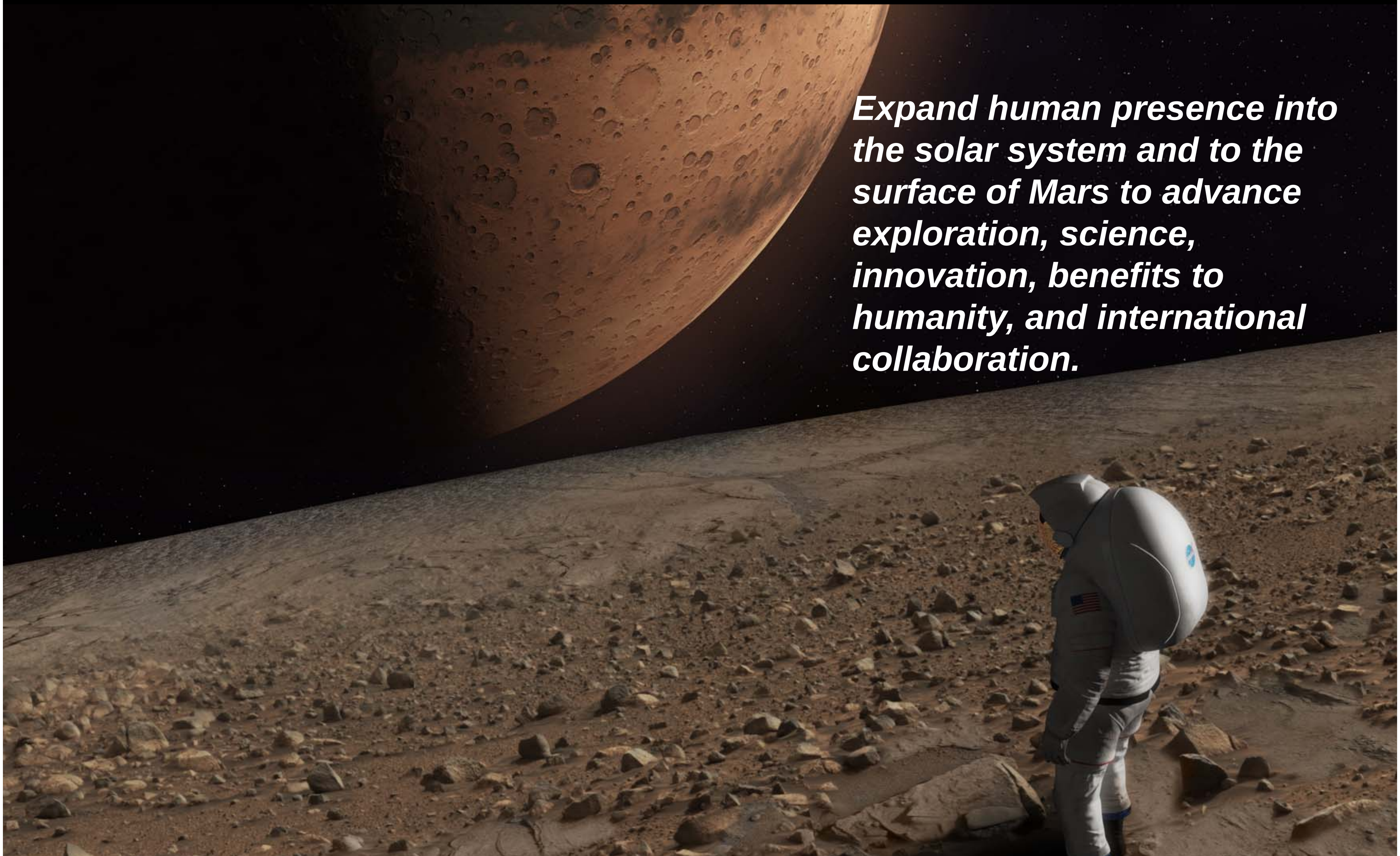
“Fifty years after the creation of NASA, our goal is no longer just a destination to reach. Our goal is the capacity for people to work and learn and operate and live safely beyond the Earth for extended periods of time, ultimately in ways that are more sustainable and even indefinite. And in fulfilling 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

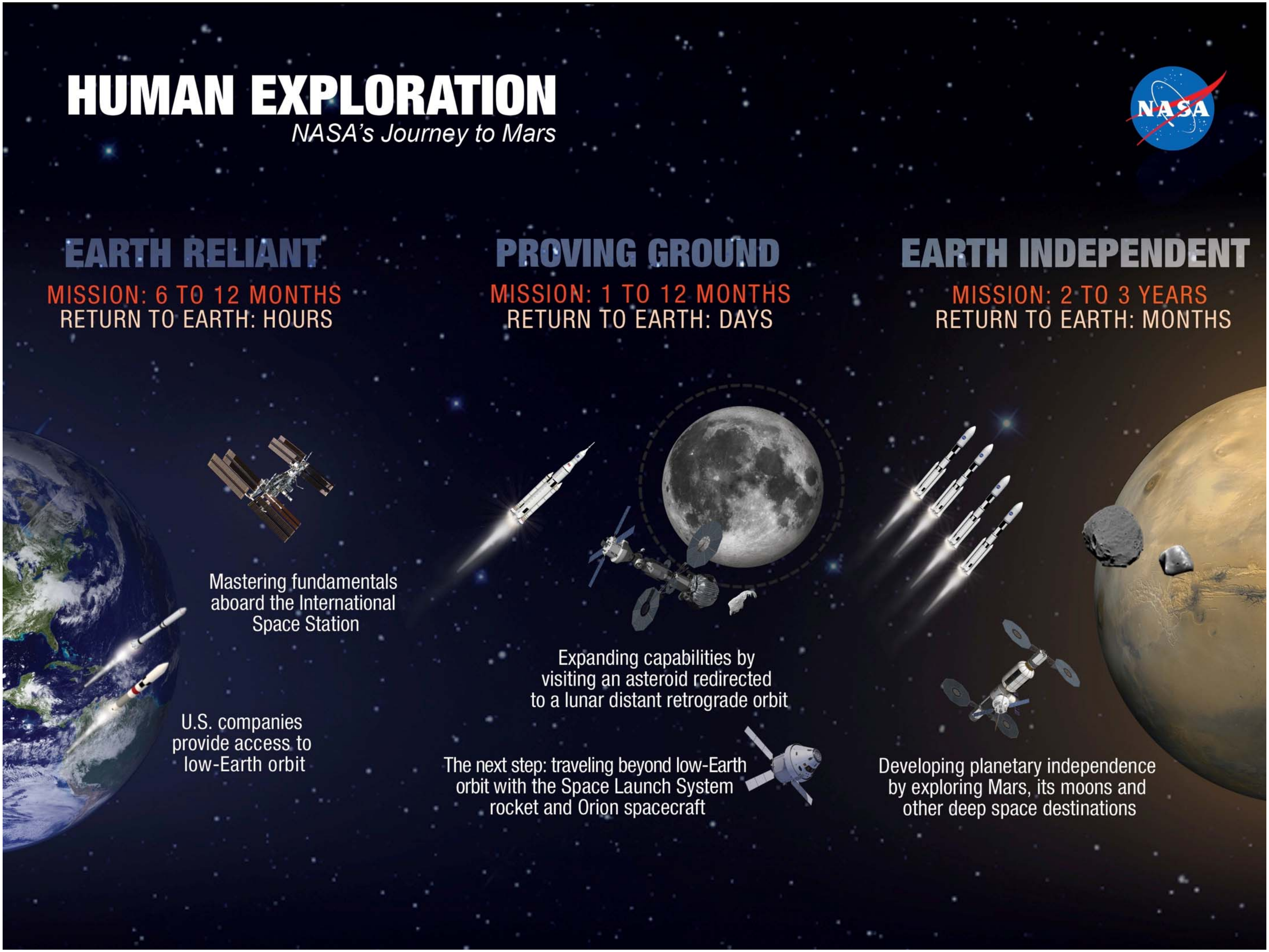


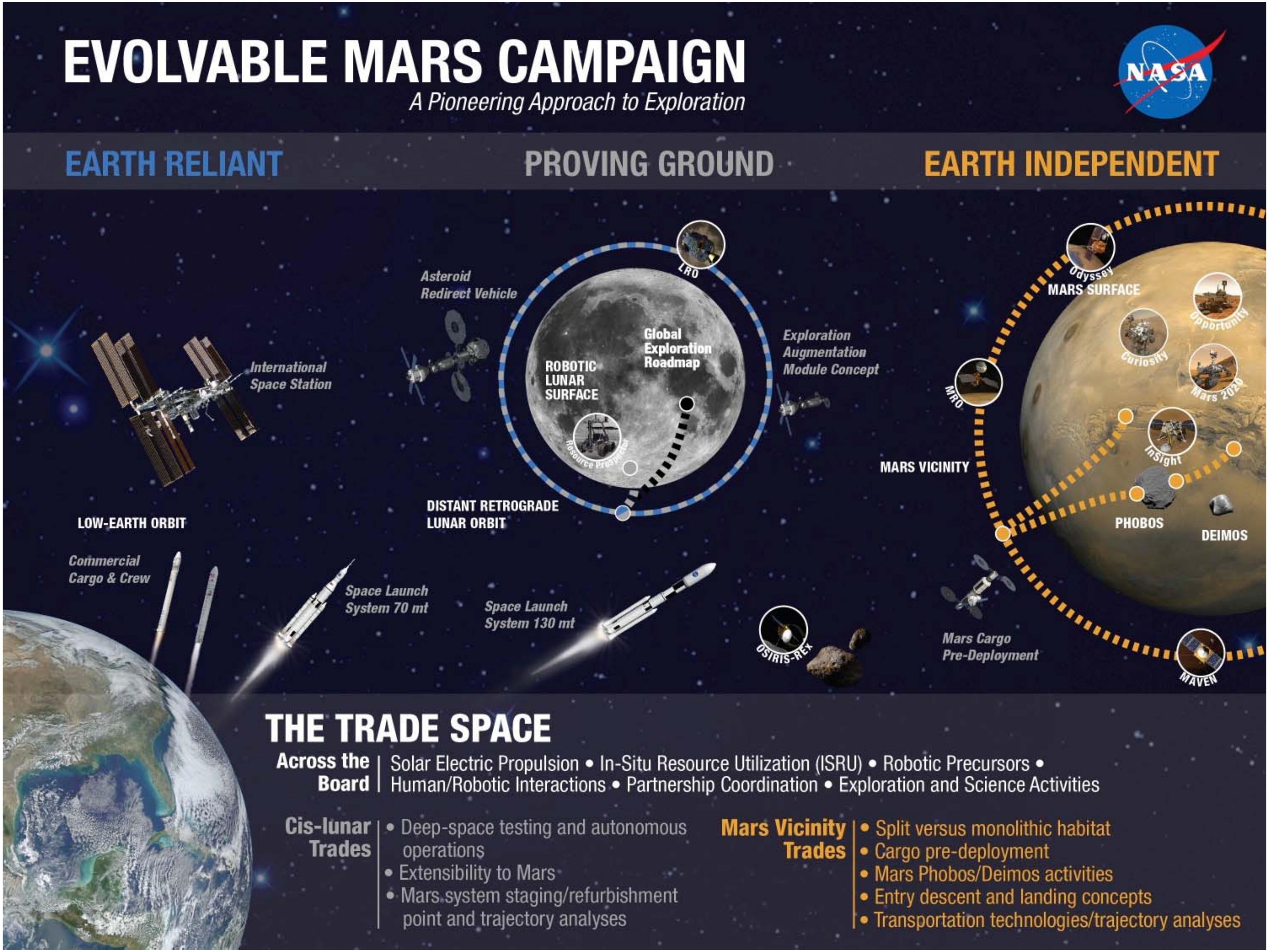

EARTH RELIANT
PROVING GROUND
EARTH INDEPENDENT

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.


HUMAN EXPLORATION
NASA's Journey to Mars
NASA
EARTH RELIANT
MISSION: 6 TO 12 MONTHS
RETURN TO EARTH: HOURS
PROVING GROUND
MISSION: 1 TO 12 MONTHS
RETURN TO EARTH: DAYS
EARTH INDEPENDENT
MISSION: 2 TO 3 YEARS
RETURN TO EARTH: MONTHS
Mastering fundamentals aboard the International Space Station
U.S. companies provide access to low-Earth orbit
Expanding capabilities by visiting an asteroid redirected to a lunar distant retrograde orbit
The next step: traveling beyond low-Earth orbit with the Space Launch System rocket and Orion spacecraft
Developing planetary independence by exploring Mars, its moons and other deep space destinations


EVOLVABLE MARS CAMPAIGN
A Pioneering Approach to Exploration
NASA
EARTH RELIANT
PROVING GROUND
EARTH INDEPENDENT
International Space Station
LOW-EARTH ORBIT
Commercial Cargo & Crew
Asteroid Redirect Vehicle
LRO
Global Exploration Roadmap
ROBOTIC LUNAR SURFACE
Resource Prospector
DISTANT RETROGRADE LUNAR ORBIT
Exploration Augmentation Module Concept
Space Launch System 70 mt
Space Launch System 130 mt
OSIRIS-REx
Mars Cargo Pre-Deployment
MRO
MARS VICINITY
Odyssey
MARS SURFACE
Opportunity
Curiosity
Mars 2020
InSight
PHOBOS
DEIMOS
MAVEN
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

EARTH RELIANT

NEAR-TERM OBJECTIVES

DEVELOP AND VALIDATE EXPLORATION CAPABILITIES IN AN IN-SPACE ENVIRONMENT

- 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

NEAR-TERM OBJECTIVES

VALIDATE

- SLS and Orion in deep space
- Solar Electric Propulsion (SEP) systems
- Long duration, deep space habitation systems
- Mitigation techniques for crew health and performance in a deep space environment
- In-Situ Resource Utilization
- Operations with reduced logistics capability

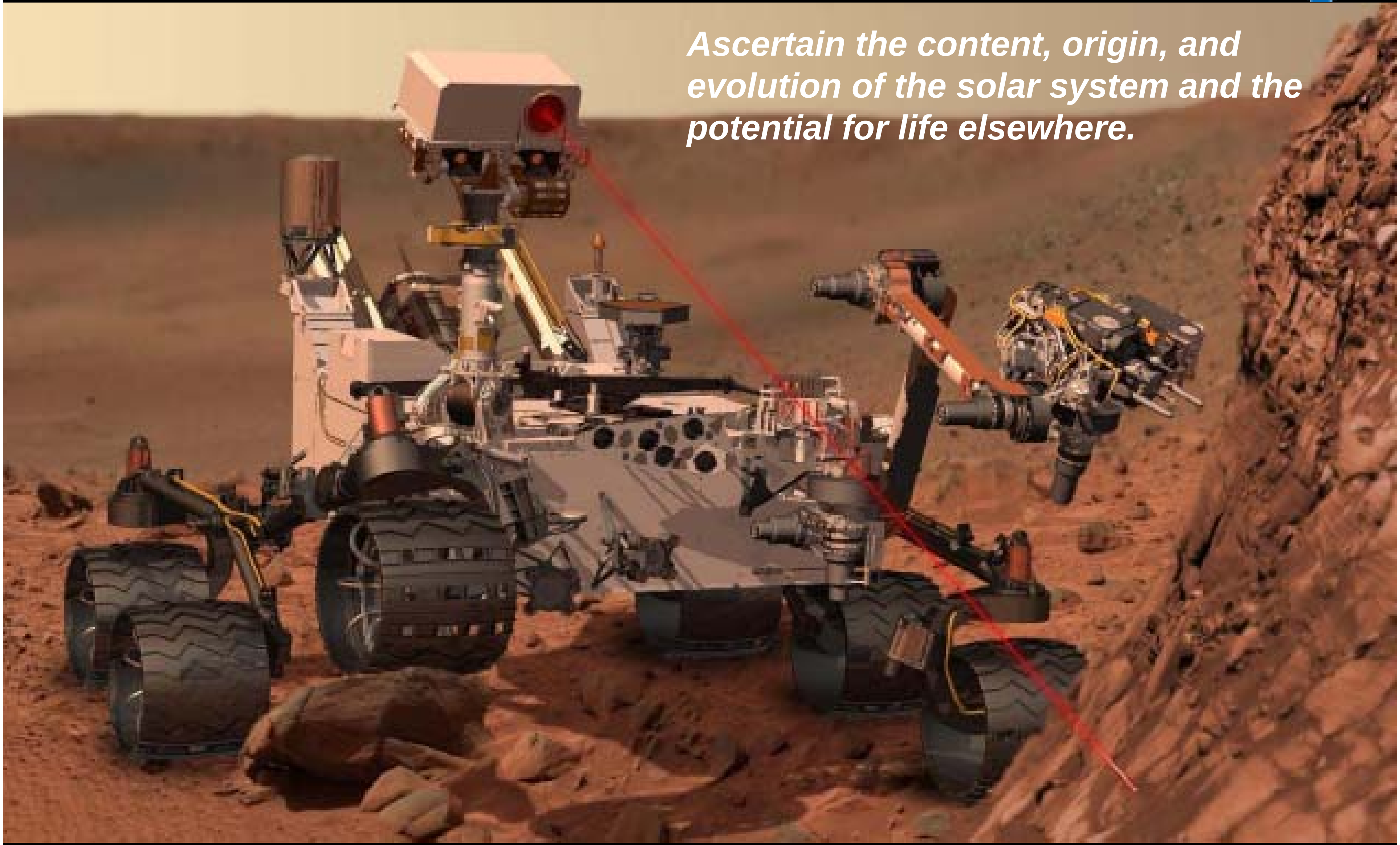
CONDUCT

- EVAs in deep space, micro-g environments
- Human and robotic mission operations
- Capability Pathfinder and SKG missions

Strategic Principles for Sustainable Exploration

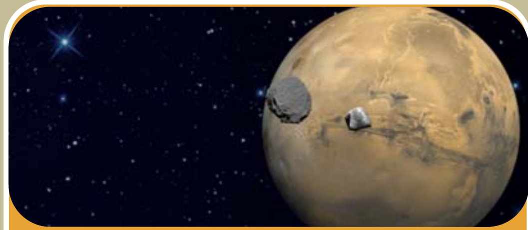
- Implementable in the ***near-term with the buying power of current budgets*** and in the longer term with budgets commensurate with economic growth*;*
- ***Exploration enables science*** **and science enables exploration***;*
- Application of ***high Technology Readiness Level*** (TRL) technologies 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.

NASA Strategic Plan Objective 1.5



Ascertain the content, origin, and evolution of the solar system and the potential for life elsewhere.

Evolutionary Capabilities

	 **EARTH RELIANT** Return to Earth: hours	 **PROVING GROUND** Return to Earth: days	 **EARTH INDEPENDENT** Return to Earth: many months
Transportation	EARTH-BASED SUPPORT: HIGH *Low-Earth Orbit* • Routine crew and cargo delivery to/from low-Earth orbit via international/industry partners • Rendezvous and docking in single-body system	EARTH-BASED SUPPORT: LIMITED *Cis-lunar Space* • Crew & cargo to cis-lunar space • High-power Solar Electric Propulsion • Rendezvous and docking with uncooperative target	EARTH-BASED SUPPORT: NEGLIGIBLE *Mars and Beyond* • Crew & cargo to Mars vicinity • Multi-use in-space stage • Long duration and extended quiescent periods • Mars entry, descent and landing
Staying Healthy	EARTH-BASED SUPPORT: HIGH *Mission Duration: 6-24 months* • Long-duration life support systems • Mitigation of long-duration micro-g effects on crew	EARTH-BASED SUPPORT: LIMITED *Mission Duration: 1-24 months* • Reliable and robust long-duration life support systems • Mitigation of deep-space effects on crew • Semi-autonomous medical treatment	EARTH-BASED SUPPORT: NEGLIGIBLE *Mission Duration: 2-3 years* • Reliable and robust long-duration closed-loop life support • Living in deep space for several years • Autonomous medical diagnosis and treatment
Working In Space	EARTH-BASED SUPPORT: HIGH *Mastering the Fundamentals* • Mission operations directed from ground • EVA in zero-g around spacecraft • Full-time operations w/crew	EARTH-BASED SUPPORT: LIMITED *Pushing the Boundaries* • Mission operations shared between ground and crew with limited time delay • Surface EVA in zero-g • Partial crew tended spacecraft	EARTH-BASED SUPPORT: NEGLIGIBLE *Exploring Independently* • Mission operations directed from crew • Robotic maintenance & support • Surface EVA in micro & partial-g • In-situ resource utilization

Mars Capability Categories

THEME	SYSTEMS MATURATION TEAMS	NATIONAL RESEARCH COUNCIL	OCT ROADMAPS
Transportation	**Power and Energy Storage**	In-Space Propulsion and Power	Space Power and Energy Storage Systems
	Propulsion		In-Space Propulsion Systems
		Heavy Lift Launch Vehicles	Launch Propulsion Systems
		Planetary Ascent Propulsion	In-Space Propulsion Systems
	Entry, Descent and Landing (EDL)	Mars Entry, Descent and Landing (EDL)	Entry, Descent and Landing (EDL)
	Thermal (including cryo)		Thermal Management Systems
	Avionics		Modeling, Simulation, Information Technology and Processing
	Logistics		Human Exploration Destination Systems
	Habitation	Habitats	Human Health, Life Support and Habitation Systems
	Ground Operations		Ground and Launch Systems Processing
Working In Space	**Extravehicular Activities (EVA)**	Extravehicular Activities (EVA) Suits	Human Exploration Destination Systems; Human Health, Life Support and Habitation Systems
	Human-Robotic Mission Ops		Robotics, Tele-Robotics, and Autonomous Systems
	Autonomous Mission Operations		Modeling, Simulation, Information Technology and Processing
	Communications and Navigation		Communications and Navigation Systems
	ISRU	In-Situ Resource Utilization (ISRU) (using the Mars atmosphere as a raw material)	Human Exploration Destination Systems
Staying Healthy	**Environmental Control and Life Support Systems (ECLSS)**	Environmental Control and Life Support Systems (ECLSS)	Human Health, Life Support and Habitation Systems
	Crew Health and Performance	Crew Health	
	Radiation	Radiation Safety	
	Fire Safety		
Other			Nanotechnology
	Structures and Materials		Materials, Structures and Mechanical Systems and Manufacturing

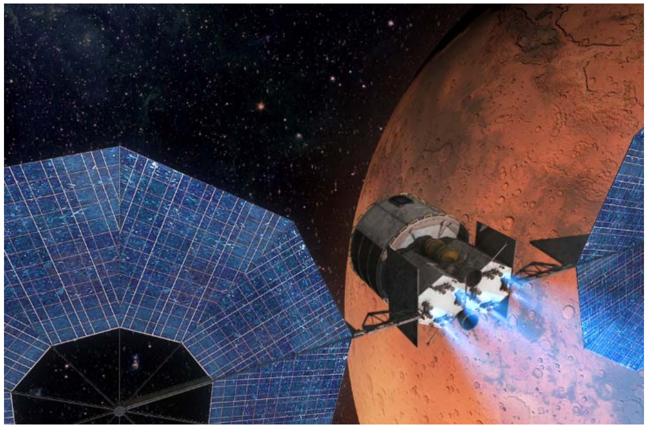
Evolvable Mars Campaign Goal:

Define the pioneering strategy and operational capabilities required to extend and sustain human presence in the solar system including a journey towards the Mars system in the mid-2030s

Evolvable Mars Campaign: Guiding Philosophy

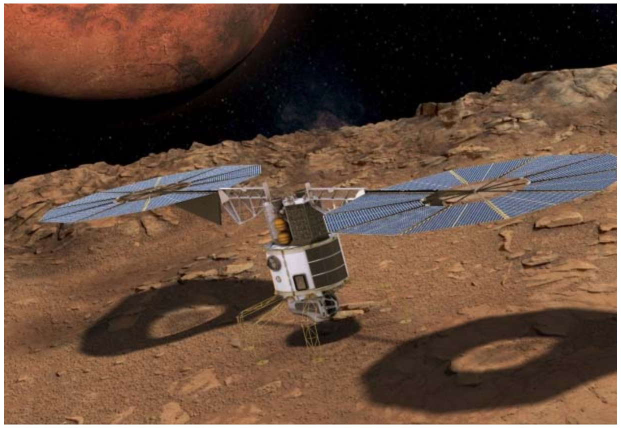
- **Not to develop "the plan" but develop different options to provide a range of capability needs to be used as guidelines for near term activities and investments**
  - In accordance with key strategic principles
- **Develop strategy(ies) for Earth independence that leads to the surface of Mars, moving from Low Earth Orbit through the Proving Ground while enabling science and providing infrastructure for human exploration missions beyond Mars**
- **Identify linkages to current investments in ISS, SLS, Orion, ARM, EAM, technology development investments, science investments**
- **Emphasize prepositioning and reuse/repurposing of systems when it makes sense**
  - Use location(s) in cis-lunar space for aggregation and refurbishment of systems
- **Strategy to enable missions to Mars vicinity by the mid 2030s**
  - Building upon science and exploration investments (e.g., Mars 2020)

Mars Vicinity Options Provide the "Pull"



Mars Orbit

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

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

Planetary Protection Topic Areas for Mars Human Surface Exploration

- **Sample Handling**
  - Collection (e.g. via teleoperations, subsurface) & documentation
  - Containment, transport, delivery & receiving
  - Sample Analysis: Laboratory location, instrumentation, handling protocols, crew interactions, BSL requirements
- **Contamination Control**
  - Specs for instruments, EVA suits, surface elements
  - Protocols and crew operations
  - In-situ cleaning/sterilization
- **Planetary Protection / "Special Regions"**
  - Environmental sampling of landing zone to determine biological status
  - Transport mechanisms
  - Venting: Leak rates, constituents, amount
  - "Inducing" Special Regions
- **Crew Safety**
  - Protocols (e.g., quarantine), criteria, operations, surface element design

Mars Mission Ground Rules & Constraints

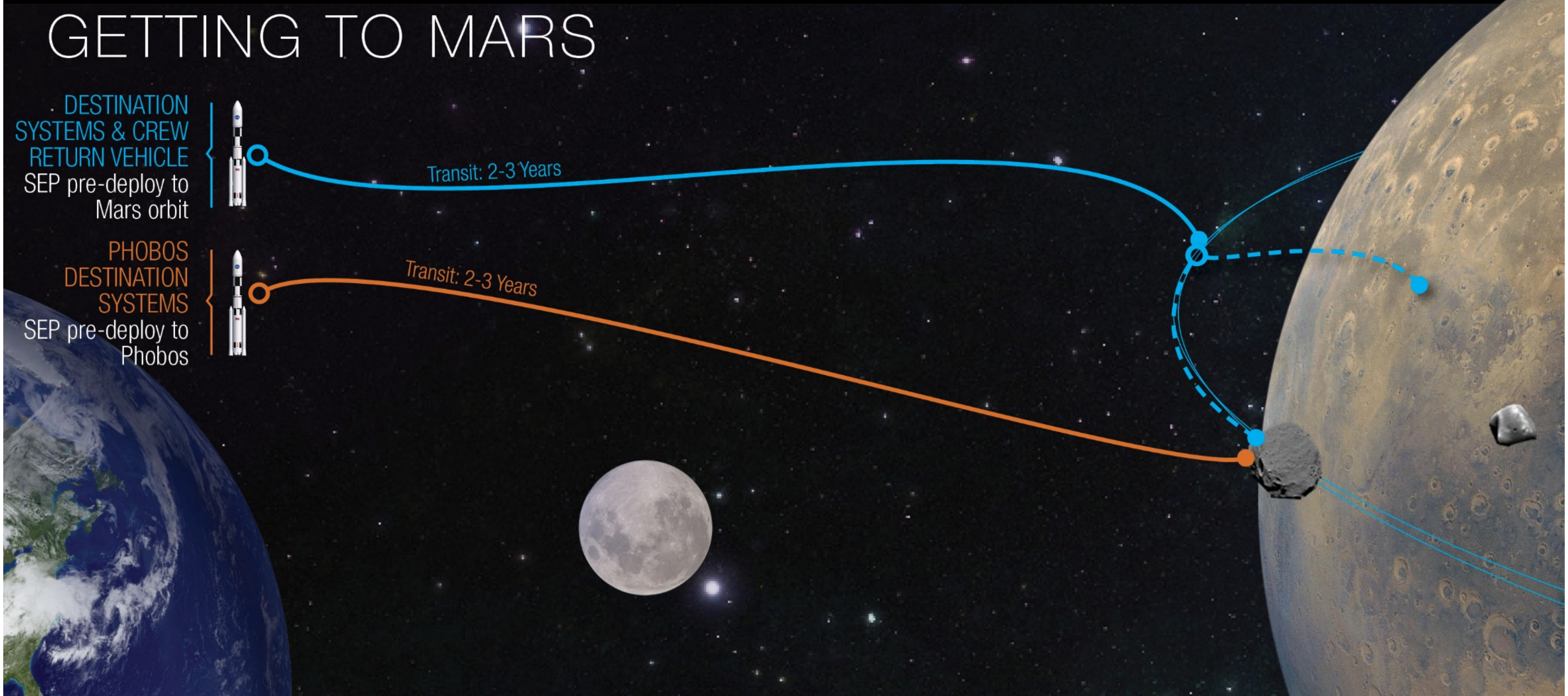
- **Humans to the Mars System by mid-2030's**
  - Could imply Orbital, Phobos/Deimos and/or Surface
  - Mars Mission opportunities throughout the 2030s will be evaluated to avoid overly restrictive mission availability
- **Propulsion technology will utilize solar-electric systems extensible from the Asteroid Redirect Vehicle (ARV) spacecraft bus**
- **SLS Block 2B launch vehicle will be available (4xRS25 Core + EUS + Advanced Boosters + 10-m shroud)**
- **Orion spacecraft will be available**
- **SLS/Orion launch rate of 1 per year is sustainable**
- **Vehicle checkout/aggregation in a lunar distant retrograde orbit (LDRO) may be advantageous due to infrastructure established during "Proving Ground" phase**
- **Crew of four to Mars system assumed**
- **Crewed vehicle reusability is highly desirable for sustainability and potential cost advantages**

Near-Term Activities in the Proving Ground

- **Strategic objectives from across all of HEOMD coming into alignment**
  - Bridging from ISS
  - Early SLS/Orion EM-missions
  - Asteroid Redirect Mission capabilities
  - Exploration Augmentation Module and habitat extensions to extend deep-space operating envelope.

- **Key strategic principals emerging**
  - SLS and Orion are critical initial elements
  - SLS Exploration Upper Stage (EUS) and resulting co-manifested cargo delivery are key capabilities for cis-lunar and eventual Mars missions
    - Co-manifested cargo capability provides additional mission opportunities
  - One crew flight per year to maintain cadence of accomplishments
  - ARM sets a good initial foundation of advanced transportation needed for deep-space exploration
  - Capability Pathfinders / SKG Precursor missions critical for future missions

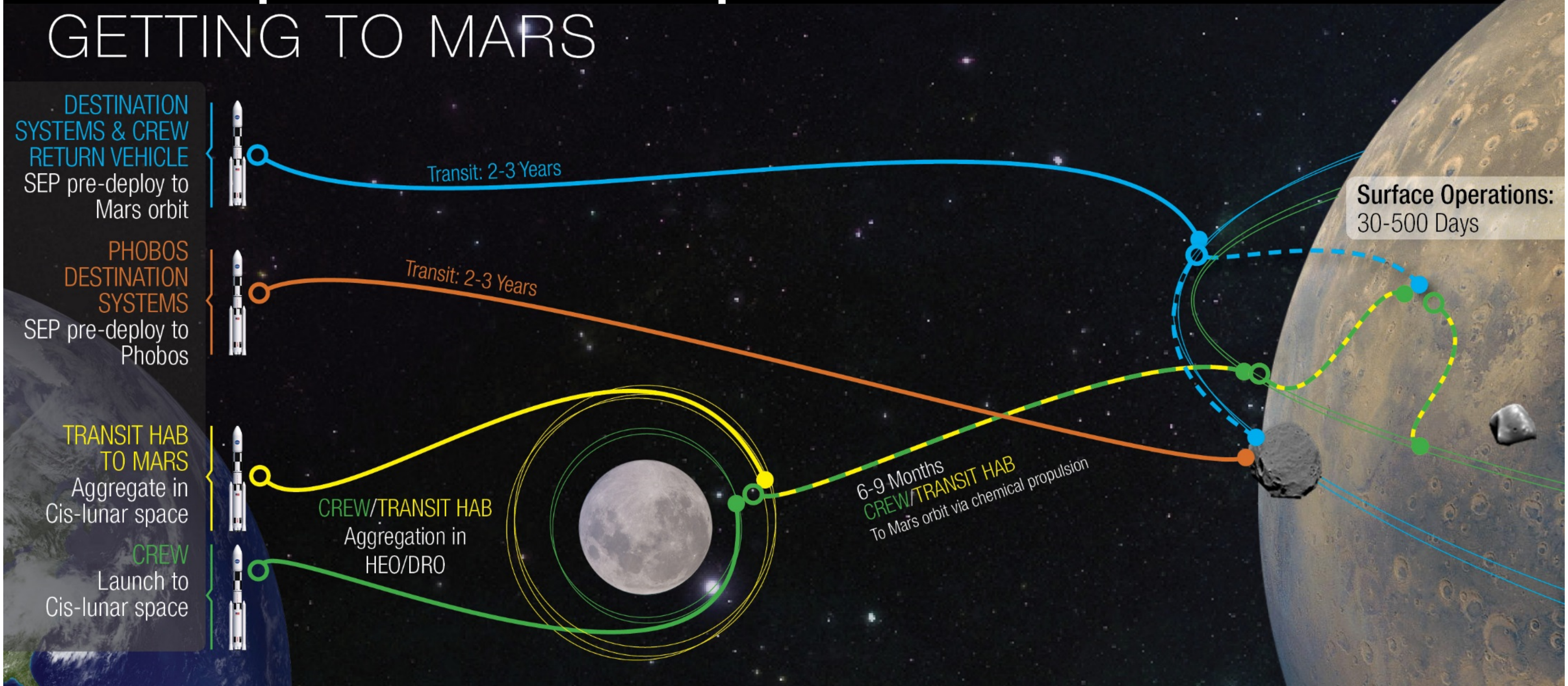
Mars Split Mission Concept



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

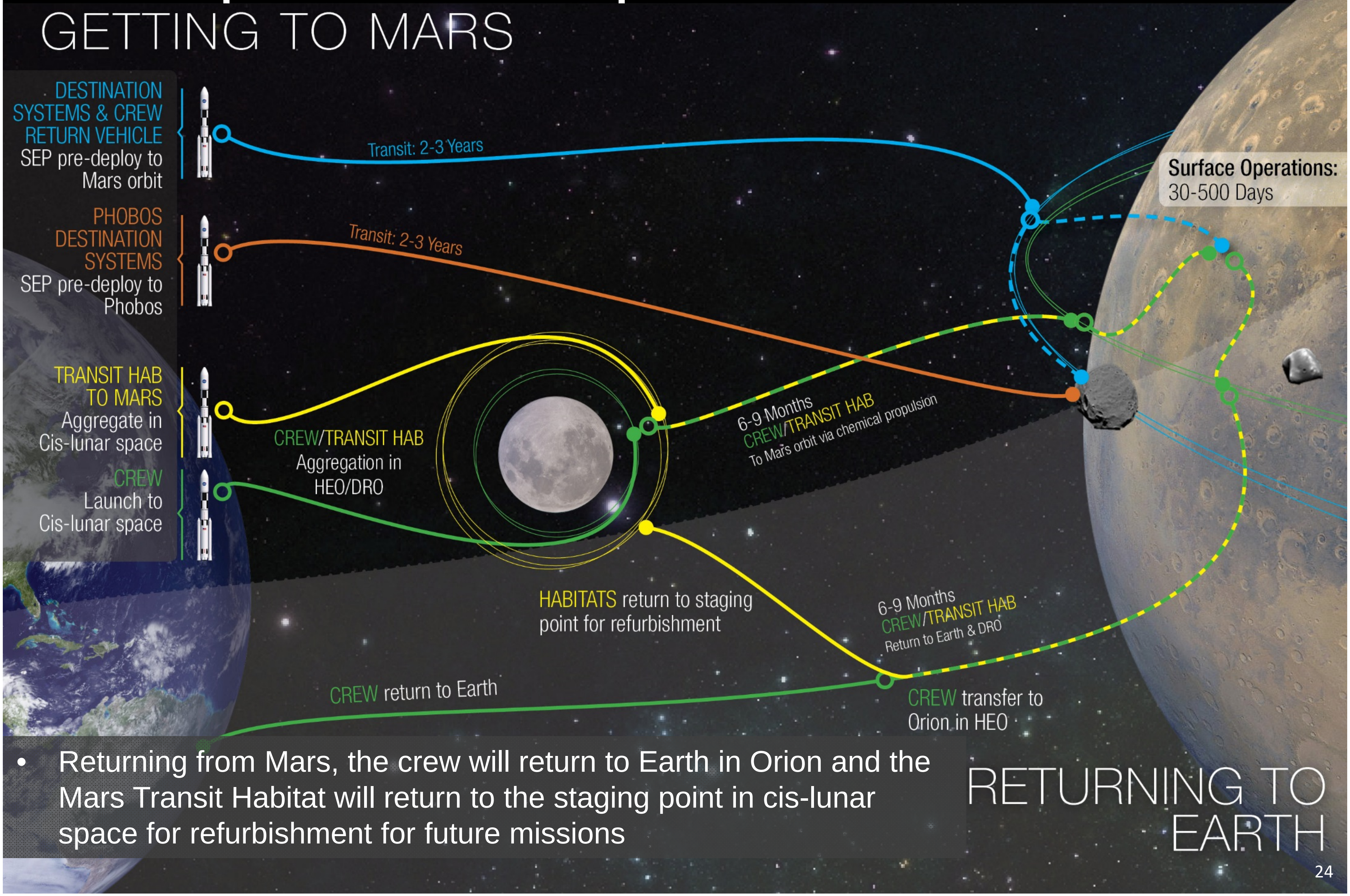
Mars Split Mission Concept



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

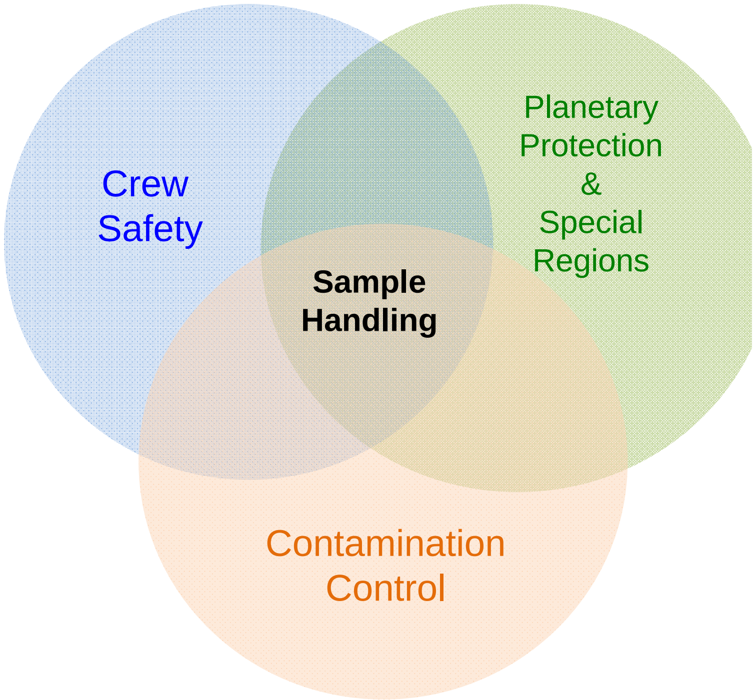
Mars Split Mission Concept



- 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

Leveraging Planetary Protection Expertise in Mars Human Mission Analyses

- **Received expert inputs to integrate into our analyses. Special Briefings from:**
  - Dr. Cassie Conley/NASA HQ: Mars Planetary Protection
  - Dr. Katharine Rubins/JSC CB: Biocontainment of Earth and Mars Pathogens
  - Mr. Roy Long/DOE: Deep Drilling on Earth & Mars
- **Interviewed Dr. Peter Doran/UI-Chicago, regarding PP impacts on Mars mission Concepts of Operations**
  - drilling, sampling, data collection, sample analysis & return, crew + robot activities, contamination control, data rate, precursor information required
- **Toured JSC Sample Curation Labs, utilizing sample handling concepts in Mars mission concepts**
- **PP Subject Matter Experts sit on our analysis teams**
  - Dr. Margaret Race/SETI
  - James Johnson/JSC
  - Dr. Andy Spry/JPL



Planetary Protection Considerations For Human Mars Surface Exploration

- **Mars samples: acquisition, handling, containment, analysis, return**
  - How close can EVA-suited crew member get to surface samples?
  - How close to habitat can samples be transported? Stowed?
  - How do we “break the chain” and get dusty, EVA-suited crew into the ascent vehicle (AV)
  - Do we return science samples inside AV crew cabin or outside? Reliable sample containment?
- **“Sterilization” needs**
  - prior to leaving Earth, EVA-suited crew, “spills” on Mars, rover
- **How to create a “layered dust control/ containment” system to “keep Mars outside”; suit port; handling injured EVA-suited crewmember**
- **Do we need to provide decontamination on Mars**
  - of crew, of EVA suits, of rover
- **Reducing potential for contamination of Mars**
  - habitat, rover, AV, EVA crew, trash leakage/ venting
- **Interaction of crew and crew systems with Mars’ surface**
  - boots, gloves, tools
  - Systems, e.g., habitat, ISRU, fission surface power
- **How to maintain crew systems over long durations on Mars, including rover**
- **Horizontal mobility**
  - robot & crew traversing beyond habitat zone (~100+ km)
- **Vertical subsurface access**
  - drilling (up to 200+ m)
- **Mars surface habitat and laboratory needs**
  - crew needs to perform in situ detailed sample analysis, including potentially extant life
- **How crew and mobile robots interact on Mars’ surface to prevent forward & back contamination**

NASA