National Aeronautics and Space Administration

NASA Advisory Council
HEO Committee

July 28, 2014

Greg Williams

DAA for Policy and Plans

Human Exploration and Operations Mission Directorate

Executive & Legislative Policy Direction

- **US National Space Policy**
  - "Set far-reaching exploration milestones. By 2025, begin crewed missions beyond the moon, including sending humans to an asteroid. By the mid-2030s, send humans to orbit Mars and return them safely to Earth;"
  - "Maintain a sustained robotic presence in the solar system to: conduct scientific investigations of other planetary bodies; demonstrate new technologies; and scout locations for future human missions;"
- **2010 NASA Authorization Act**
  - "The **long term goal** of the human space flight and exploration efforts of NASA shall be to expand permanent human presence beyond low-Earth orbit and to do so, where practical, in a manner involving international partners."
  - "Finding (1) The extension of the human presence from low-Earth orbit to other regions of space beyond low-Earth orbit will enable missions to the surface of the Moon and missions to deep space destinations such as near-Earth asteroids and Mars."
  - "Finding (7) Human space flight and future exploration beyond low-Earth orbit should be based around a pay-as-you-go approach…"

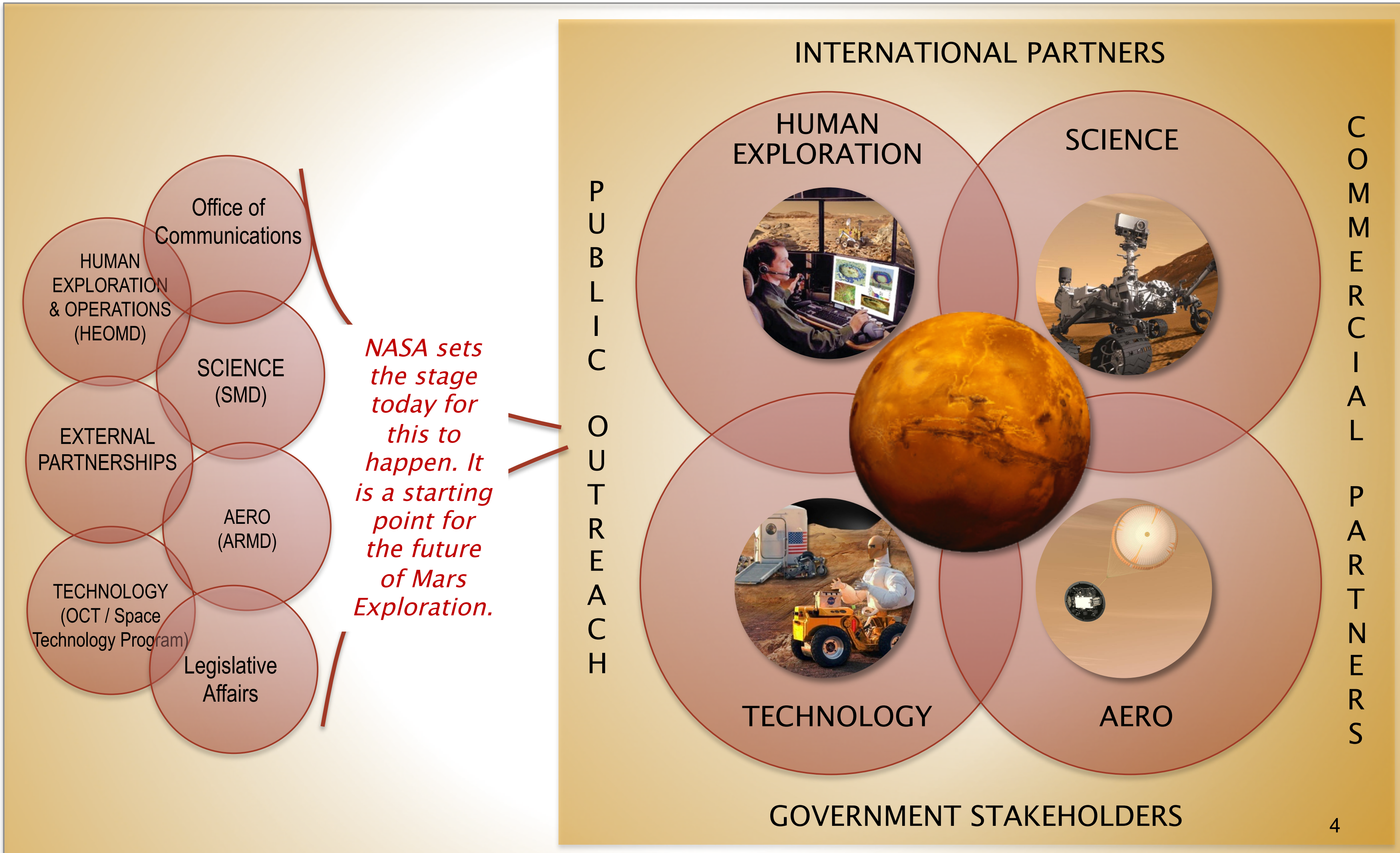
Planning in the Policy & Budget Environment

- **Start with the NASA Strategic Plan**
  - Goal 1: Expand the frontiers of knowledge, capability, and opportunity in space.
  - 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.
  - Objective 1.2: Conduct research on the International Space Station (ISS) to enable future space exploration, facilitate a commercial space economy, and advance the fundamental biological and physical sciences for the benefit of humanity.
  - Objective 1.3: Facilitate and utilize U.S. commercial capabilities to deliver cargo and crew to space.

- ***Pioneering Space* is the idea that captures this strategy of moving beyond LEO into the solar system with long term purpose and multiple partners**

Achieve Mission Directorate Alignment for Pioneering Space

T O D A Y **F U T U R E**



Strategic Principles for Exploration Implementation

Six key strategic principles to provide a sustainable program:

- Implementable in the ***near-term with the buying power of current budgets*** and in the longer term with budgets commensurate with economic growth*;*
- 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 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 learned from the ISS logistics and crew market;
- ***Multi-use, evolvable*** space infrastructure;
- Substantial ***international and commercial participation***, leveraging current International Space Station partnerships.

Evolvable Mars Campaign: Guiding Philosophy

- **Leverages strong linkage to current investments in ISS, SLS, Orion, ARM, EAM, technology development investments, science investments**
- **Develops Earth independence for long-term human presence leading to the surface of Mars, starting in the Proving Ground, through the cis-lunar environment, enabling science along the way, and providing infrastructure for human exploration missions beyond Mars**
- **Accommodates the budget, both in escalation and peaks coupled with a cadence of missions**
- **Emphasizes prepositioning and reuse/repurposing of systems when it makes sense**
- **"Provides a basis for architecture development and identification and analysis of trade studies with our partners and stakeholders and incorporates the flexibility to adjust to changing priorities across the decades. From this work will emerge the roadmap we will follow through cis-lunar space to pioneer Mars." (from Pioneering Space paper)**
- **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**

6

Evolvable Mars Campaign Study Trades

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

PROVING GROUND

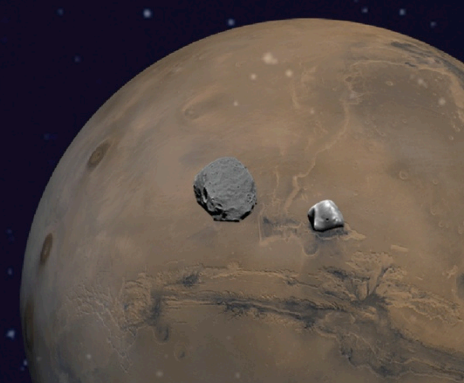
Cis-lunar Trades

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

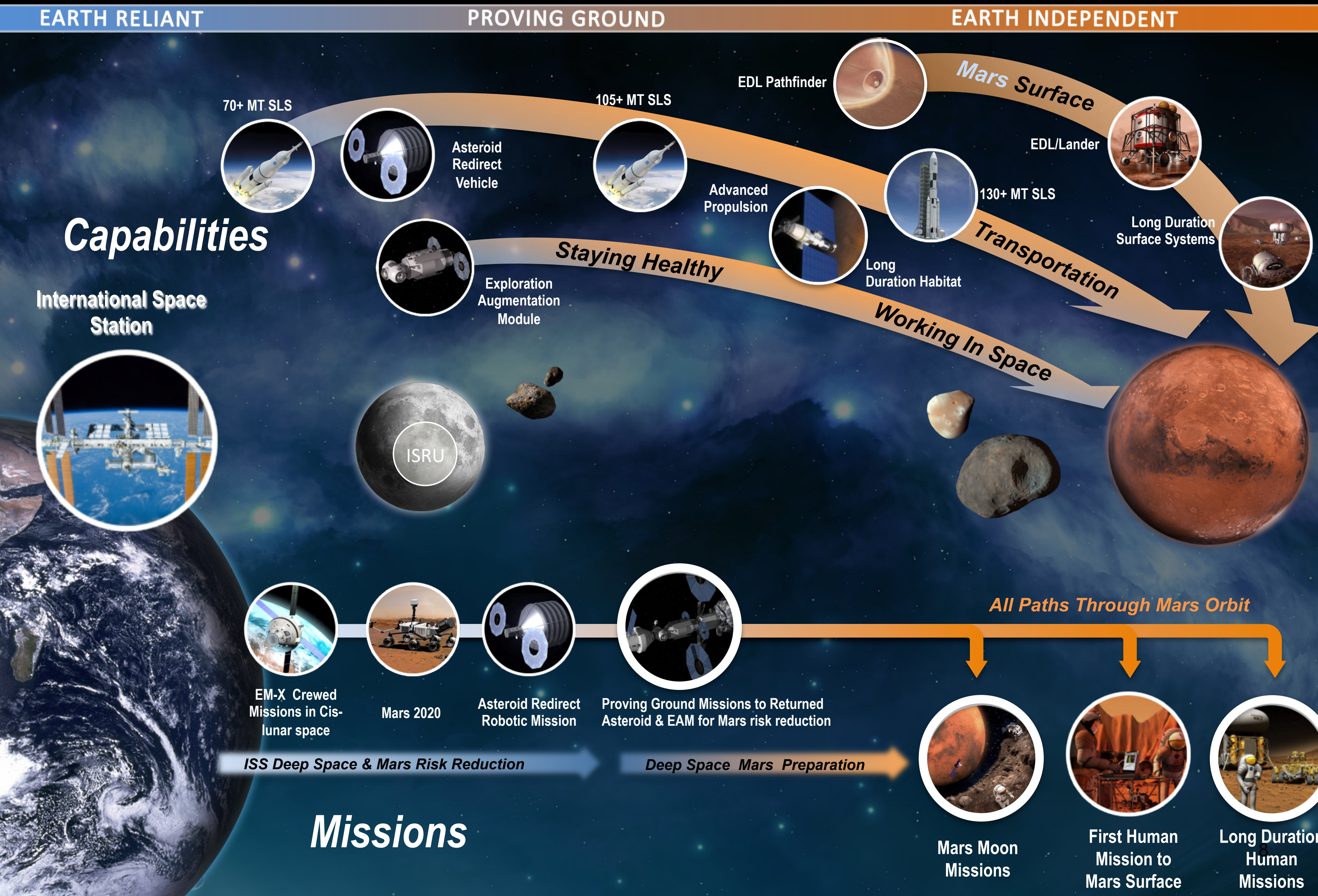
EARTH INDEPENDENT

Mars Vicinity Trades

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

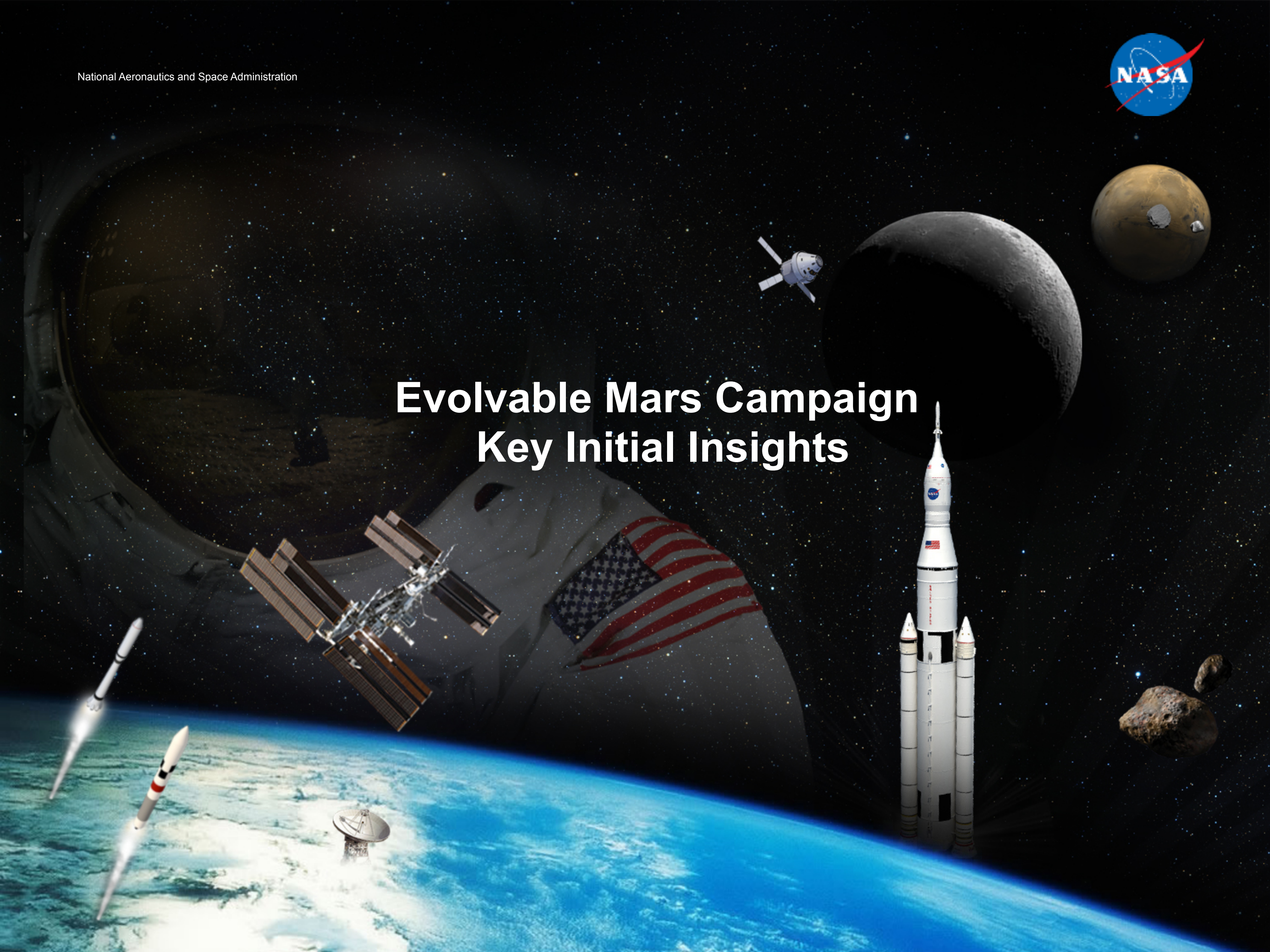


Evolvable Mars Campaign – Capability & Mission Extensibility

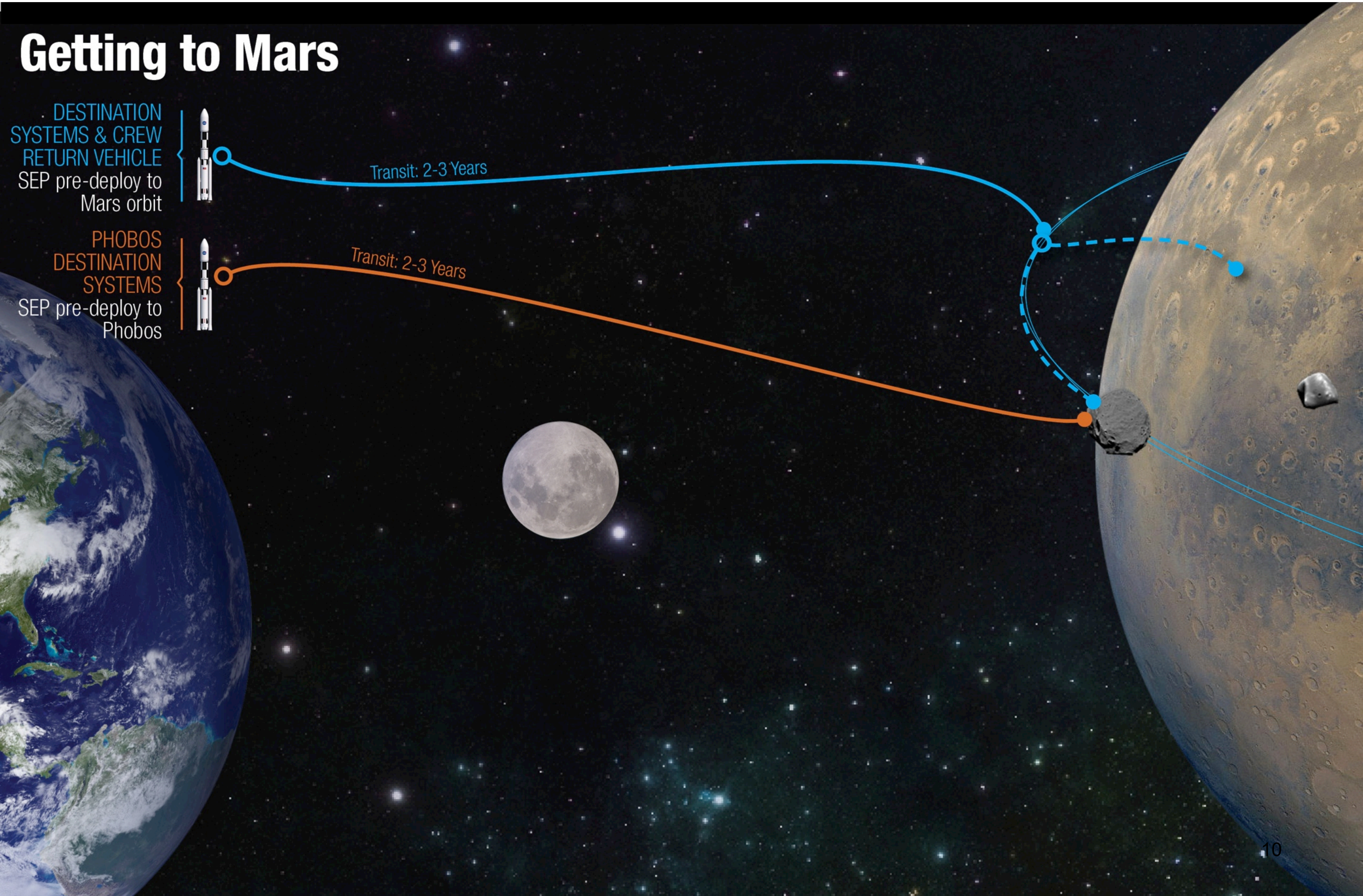


National Aeronautics and Space Administration

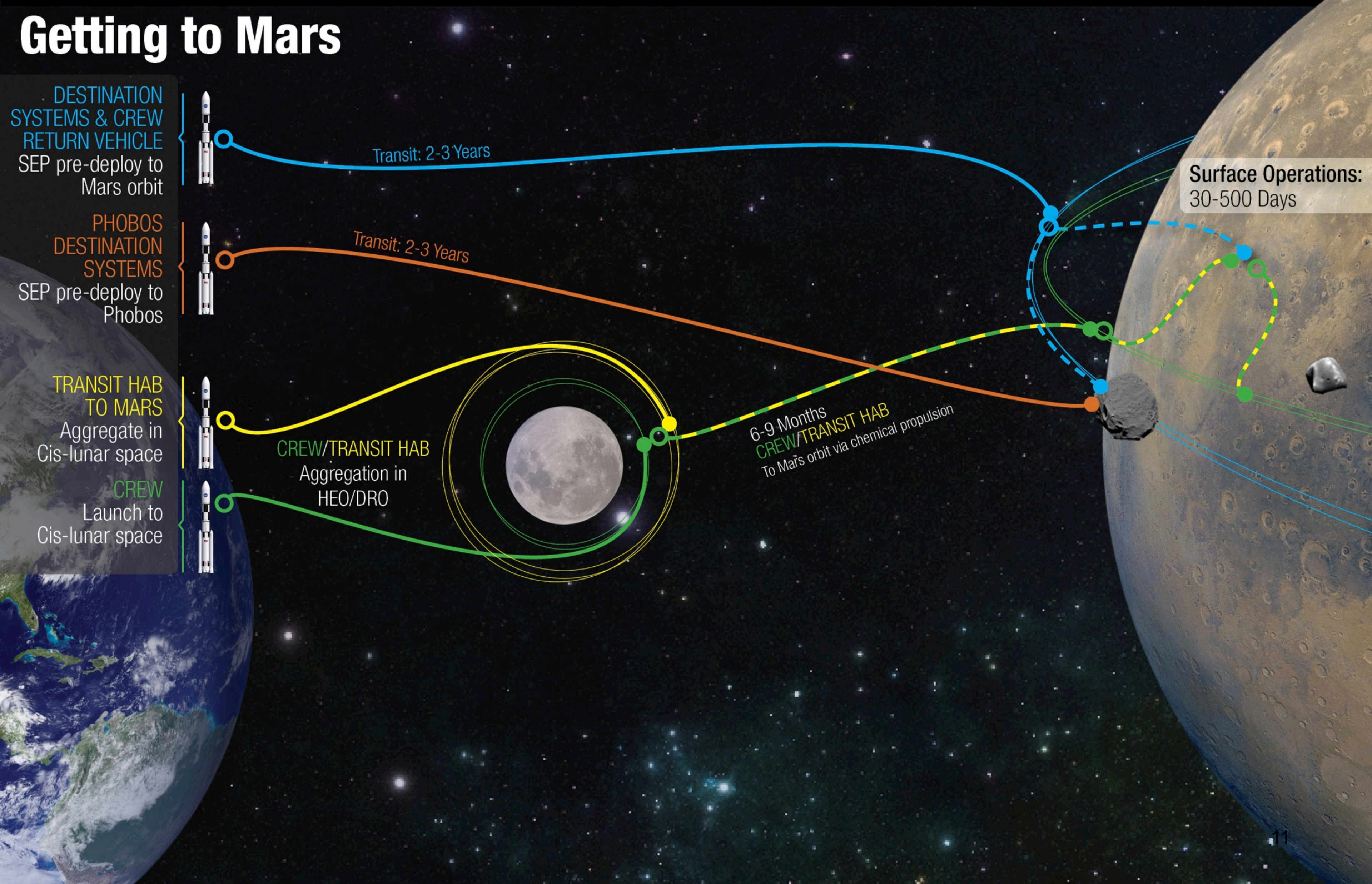
Evolvable Mars Campaign
Key Initial Insights



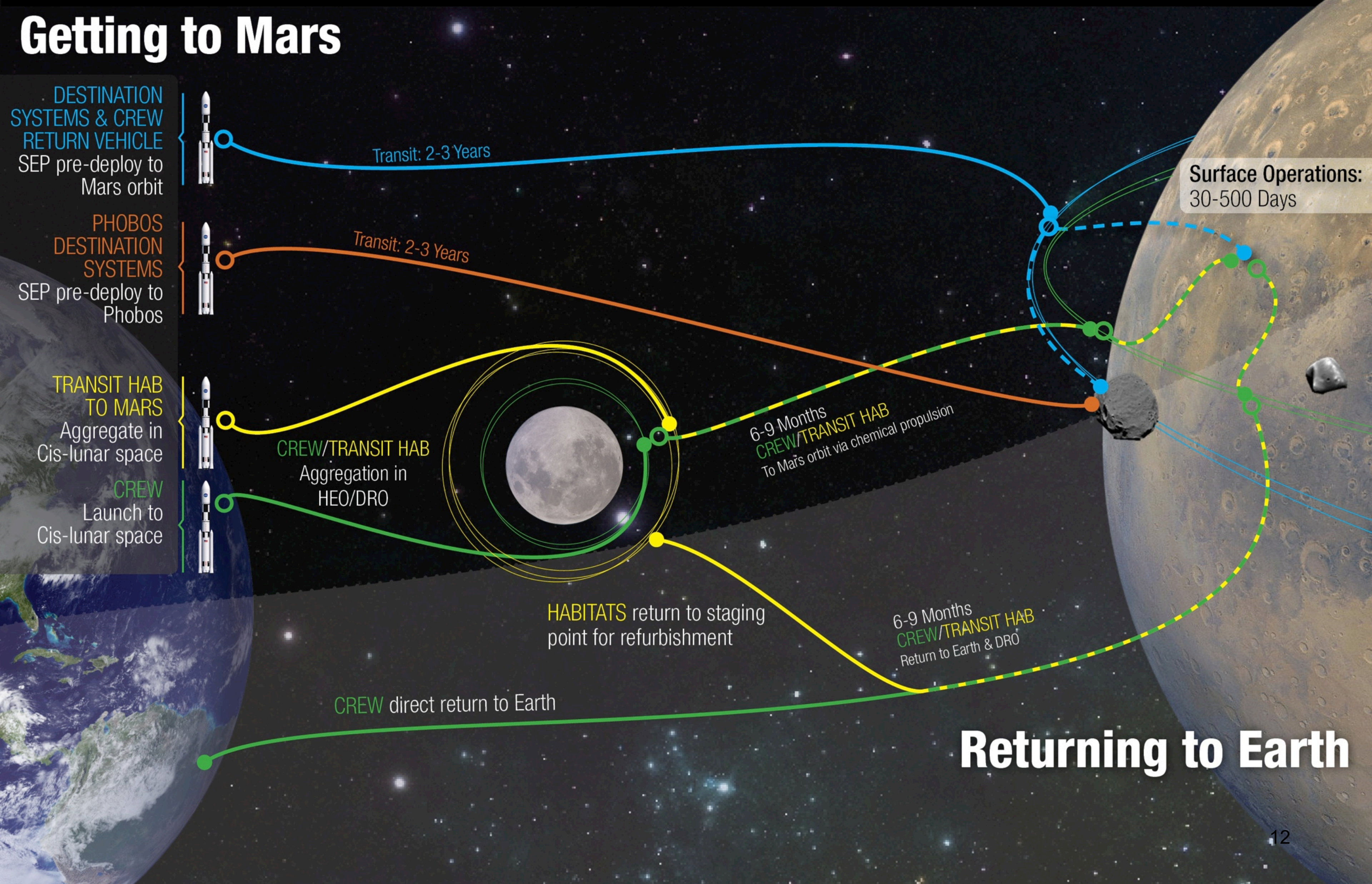
1: Mars Split Mission Concept



1: Mars Split Mission Concept



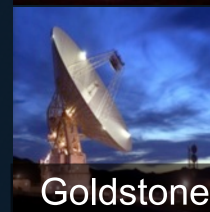
1: Mars Split Mission Concept



2. Asteroid Redirect Mission: Into the Proving Ground

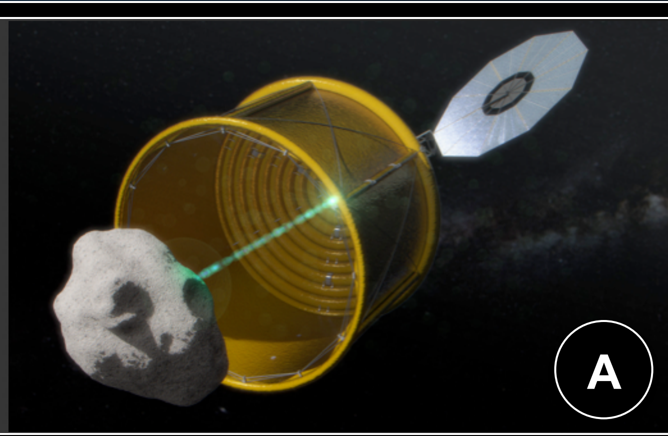
IDENTIFY

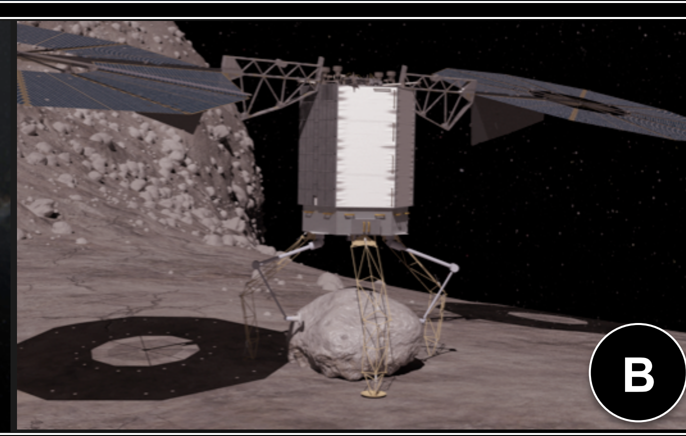
Ground and space based assets detect and characterize potential target asteroids



REDIRECT

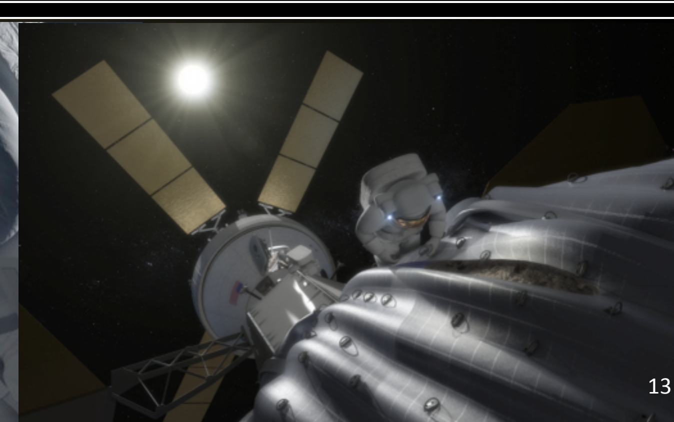
Solar electric propulsion (SEP) based system redirects asteroid to cis-lunar space (two capture options)





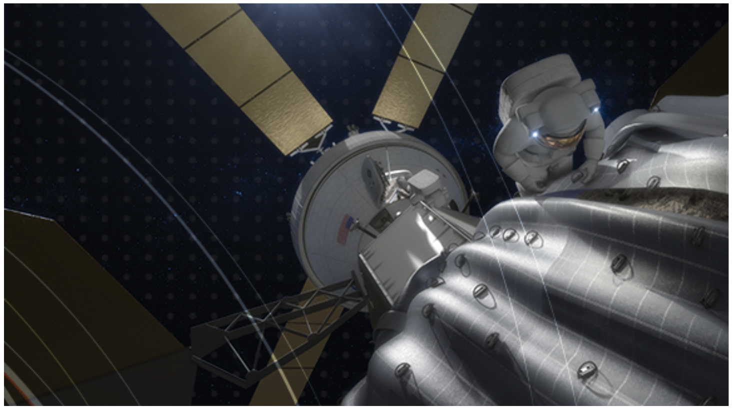
EXPLORE

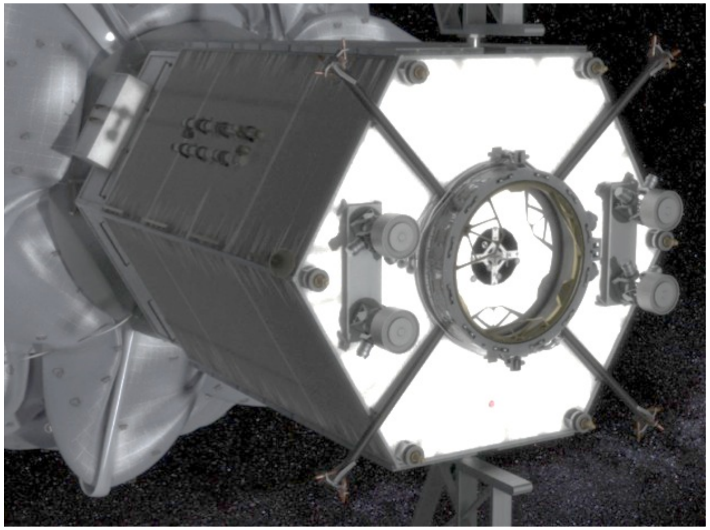
Crews launches aboard SLS rocket, travels to redirected asteroid in Orion spacecraft to rendezvous with redirected asteroid, studies and returns samples to Earth



Objectives of Asteroid Redirect Mission

- Conduct a human exploration mission to an asteroid in the mid-2020's, providing systems and operational experience required for human exploration of Mars.
- Demonstrate an advanced solar electric propulsion system, enabling future deep-space human and robotic exploration with applicability to the nation's public and private sector space needs.
- Enhance detection, tracking and characterization of Near Earth Asteroids, enabling an overall strategy to defend our home planet.
- Demonstrate basic planetary defense techniques that will inform impact threat mitigation strategies to defend our home planet.
- Pursue a target of opportunity that benefits scientific and partnership interests, expanding our knowledge of small celestial bodies and enabling the mining of asteroid resources for commercial and exploration needs.





ARM in NASA's Exploration Strategy

- ARM leverages **on-going activities** across the Agency to implement a **compelling** and **affordable** human exploration mission **in the proving ground**, providing systems and operational experience for human missions to **Mars**

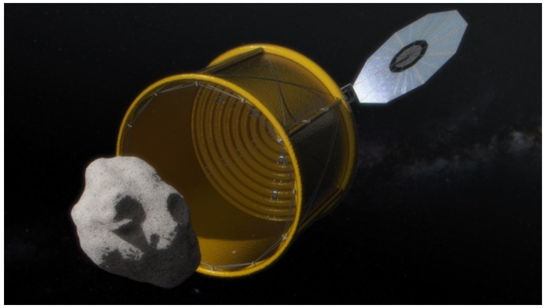
- ARM technologies, systems, capabilities are part of a sustainable exploration strategy
  - High power SEP systems scalable to support human missions to Mars, e.g. pre-emplacement of cargo
  - Industry inputs on options for upgradable SEP spacecraft systems/bus options sought through recent Broad Agency Announcement (BAA)
  - Common rendezvous sensors, international docking system, beyond LEO in-space EVA capabilities
  - Opportunities for science, in-space resource utilization demonstrations and strategic partnerships sought through recent BAA

- Our studies have determined that essentially the same flight system can support both robotic mission capture options A and B. Regardless of the capture option, the SEP spacecraft can make substantial asteroid mass available for crewed exploration and sampling in the mid 2020's.

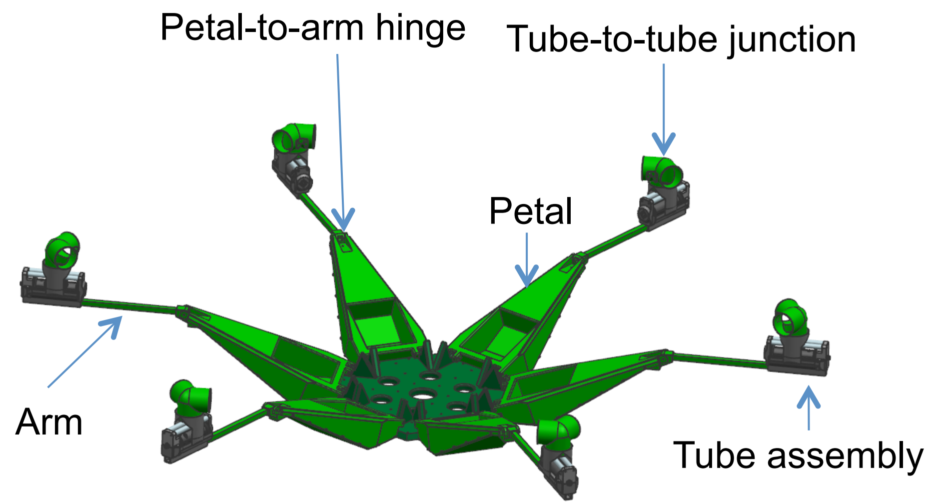
Currently Known Candidate Asteroids for ARM

- **For Option A:**
  - – Currently, 9 potential candidates; 3 found last year
  - – 3 validated candidates:
    - **2009 BD** – ~ 4 meter size inferred by Spitzer data
    - **2013 EC20** – ~ 2 meter size determined by radar imaging
    - **2011 MD** – ~ 6 meter size determined by Spitzer data
  - – Possibly another candidate validated in 2016: **2008 HU4** – radar opportunity
  - – Additional valid candidates expected at a rate of 1-2 per year
- **For Option B:**
  - – Lots of potential candidates
  - – Currently, 3 validated candidates:
    - **Itokawa** - imaged by Hayabusa
    - **Bennu** and **2008 EV5** – imaged by radar
  - – 1 possible valid candidate in 2018: **1999 JU3** - Hayabusa 2 target
  - – Potentially future valid candidates with inferred boulders, rate of ~1 per year

Asteroid Redirect Robotic Mission Option A: Development and Risk Reduction Status



- Building new, high fidelity 1/5 scale testbed, 3 m dia x 2 m long, inflatable structure supported capture bag
- Design features mechanical initial deployment of 6 arms with inflatable booms at the end of the arms that deploy and control the bag material
- System is designed to be fully operational in 1 g including deployment and capture
- Testbed testing complete by end of FY14
- Initiate testing of deployment/inflation, “docking” to the asteroid, and bag closure, with force measurements, to be completed by 9/15/14



Stowed

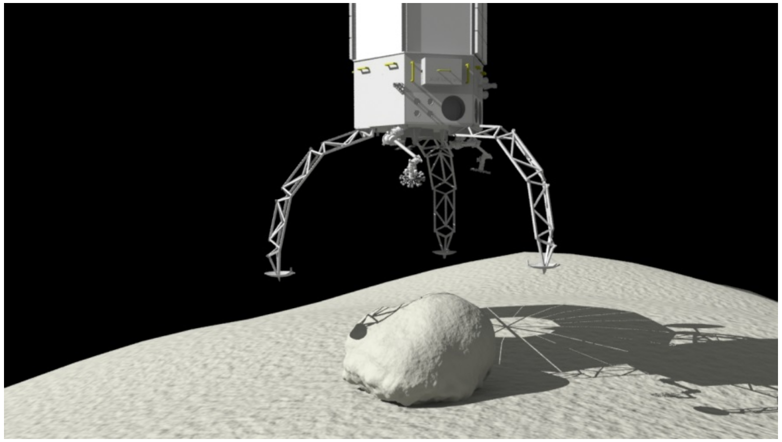
Deployed

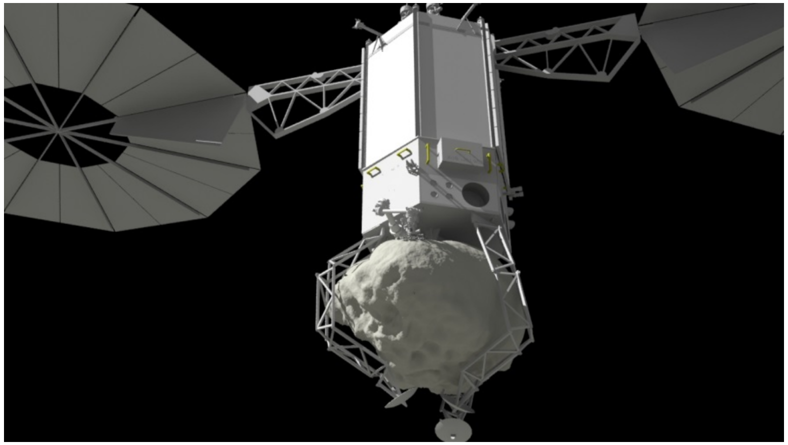
Tube assembly prototype

Asteroid Redirect Robotic Mission
Option B: Development and Risk Reduction Status

Capture System Option-B Risk Reduction Testing

- Team making progress on four major FY14 activities to reduce engineering and technology development risks
- Tests scheduled to complete prior to December down-select review





Capture Arm &Tool

- *Full scale testing of Microspine tool w/arm*
- Collected initial results from boulder material sensitivity study 6/11
- Optimized Microspine 2.0 peer review held 6/25
- Microspine 2.0 fab started
- 2.0 testing Aug/Sep/Oct

Contact/Restraint "Legs"

- *Full scale 2-D flat-floor testing of landing, ascent, and boulder restraint*
- Leg design geometry studies completed 6/1
- Peer review held 6/24
- Fab started, complete Aug
- Restraint testing, Fall
- Ascent testing, Fall

Closed-Loop Sim

- *6-DOF simulations of descent, surface operations, and ascent*
- Open loop simulations of descent trajectories completed 5/28
- Initial closed-loop testing started 6/3
- ADAMS analysis underway of landing/ ascent

Relative Navigation

- *Sensor and algorithm testing to validate RN approach*
- Completed imaging of boulder mockup with LIDAR VNS sensor at LM 6/6
- Data in process of being run through navigation algorithms July/Aug

STMD Solar Array Technology Work in FY 2014

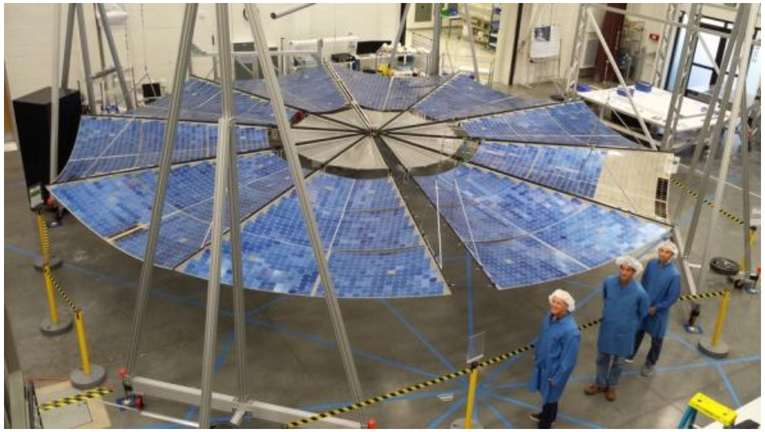
Design, Build and Test of Solar Arrays
- MegaFlex "fold out" solar array
- Mega-ROSA "roll out" solar array

Environmental Testing Completed
- Thermal vacuum full scale deployment
- Stowed wing vibration or acoustic exposure

Analyses and Models include:
- Design extensibility to 250kW system
- Finite element (stowed and deployed)
- CAD models (stowed and deployed)
- Structural Dynamics (stowed and deployed)
- Thermal

Design, Build and Test Solar Cell Coupons for 300V operation

Test Power Electronics for 800V operation
- Transistors, diodes, drivers
- Destructive single event radiation testing



Each wing sized for nominally 20kW BOL

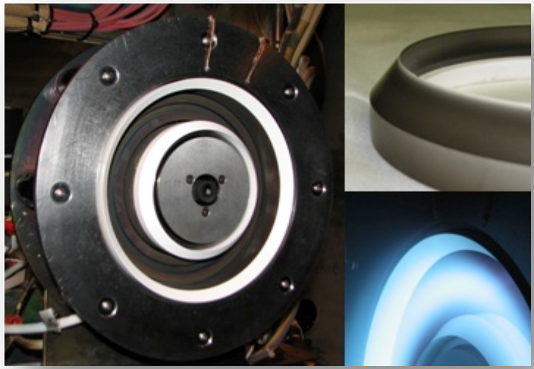
STMD Electric Propulsion Work in FY14

NASA's Goal

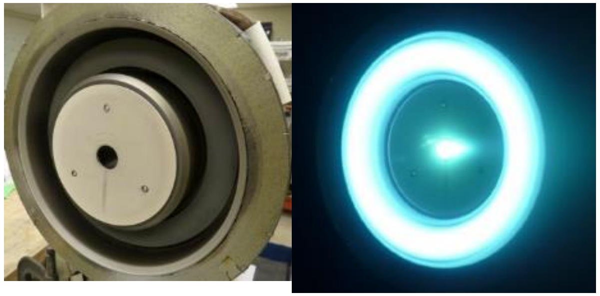
- Develop high power Hall thruster 12.5 kW-class (2X current SOA)
- Developed magnetically shielded design to provide long life commensurate with ARM and future missions
- Pursued high voltage (i.e. 300V input) PPU system compatible with high power thrusters

Path Forward for Advancement

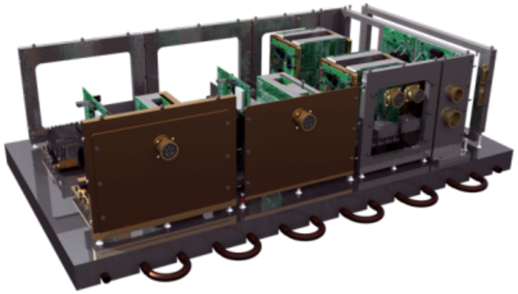
- Designing and building 12.5 kW EDU at GRC
- Testing the magnetic shielding design now demonstrated up to 3000-sec specific impulse and 20 kW power with JPL H6 and NASA 300M thrusters.
- Designing and building moderate- and high-voltage PPU TDUs (120 V input with 800 V output to thruster, 300 V input with 400 V output to thruster; both are throttleable)
- Designing and building high-voltage Direct Drive Unit TDU
- Integrating Thruster EDU and PPU for test by end of FY14



JPL H6 with magnetic shielding



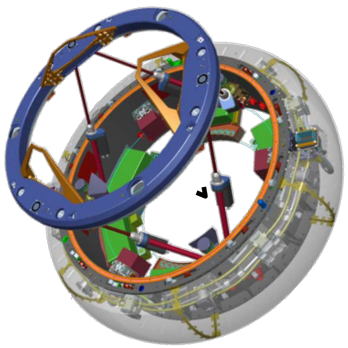
GRC 300M with magnetic shielding



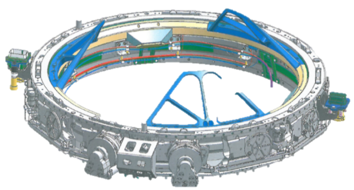
Cut away of NASA 300V PPU

Crewed Mission Segment Design & Development

Docking Systems leverage International Docking System Block 1

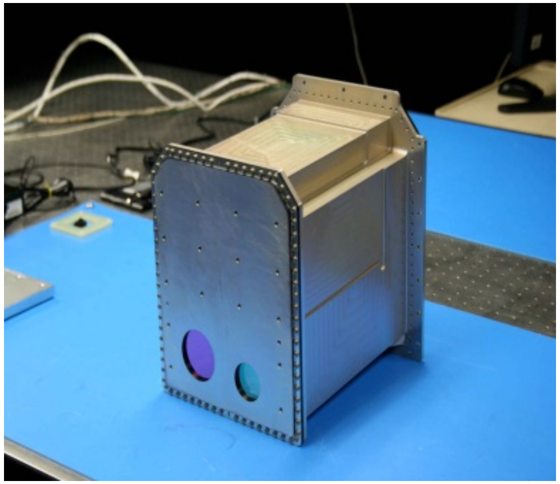


Orion Active Docking Mechanism



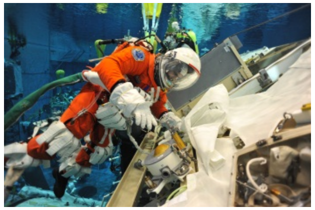
Robotic Spacecraft Passive Docking Mechanism

AR&D Vision Navigation Sensor testing in May/June 2014



Neutral Buoyancy Lab testing throughout 2014

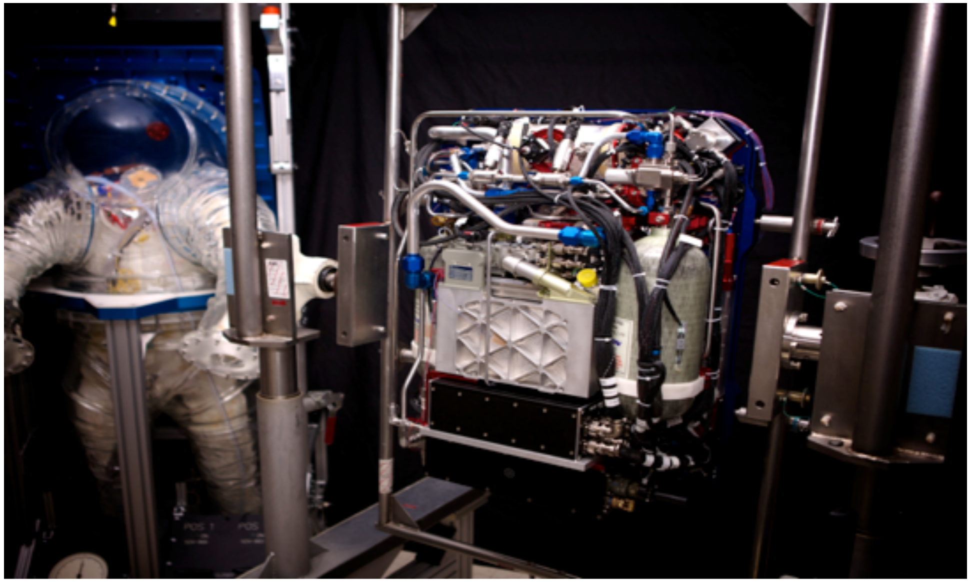
NBL Series #2 – 5 tests (2, 3 and 4 hours long)



Task complexity increases while improvements are made to the suit including EMU gloves, drink bag, etc.

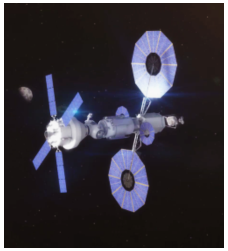
Need for improved stability and work envelope

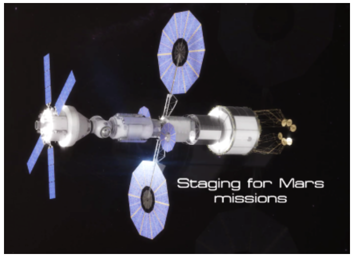
Primary Life Support System Backpack Design & Build



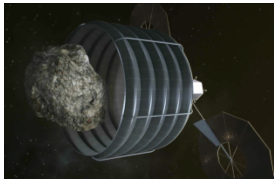
ARM Risk Reduction for Future Mars/Deep Space

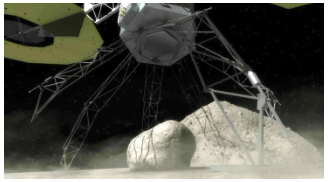
Sensor suites and proximity operations required for aggregating Mars mission vehicle stacks in deep space, deep space rendezvous and docking with Orion



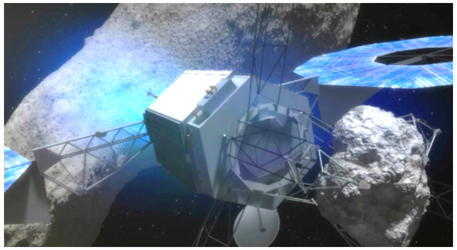


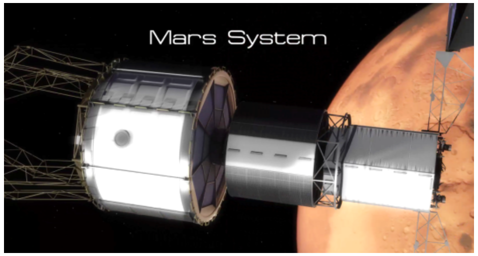
Enhanced understanding of uncooperative, low-G targets as will be experienced with Mars Moons





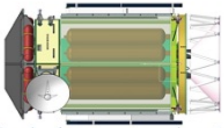
Long duration human scale systems operating in deep space thermal / radiation environment. Pre-deployment of crewed mission elements via solar electric propulsion with long quiescent periods

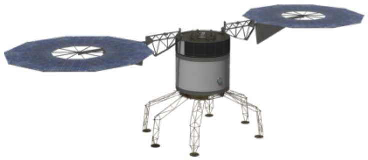




Solar Electric Propulsion (SEP)

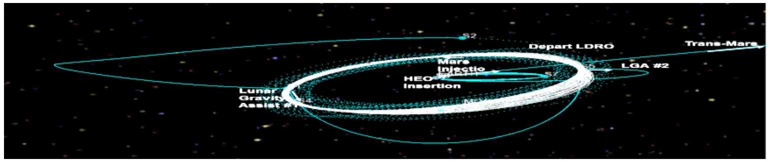
Solar arrays, thrusters, PMAD, Xenon storage.



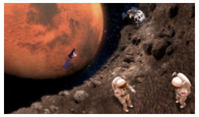


Mission Operations

Deep space trajectory guidance, rendezvous and docking, pre-deployment of systems,



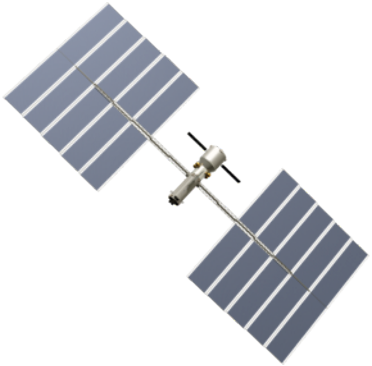
Advanced EVA ops on micro-g body (Phobos), sample handling, and ISRU



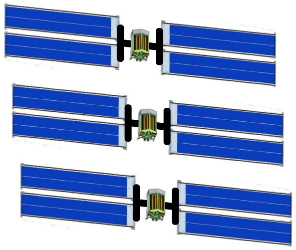
Use of ARM Solar Electric Propulsion (SEP)

- Previous assessments have shown that human Mars missions utilizing a single round-trip monolithic vehicle architecture requires very high power SEP (up to 1 MW total power)
- Current architecture concepts utilize ARM derived SEP
  - Pre-deploy crew mission assets to Mars utilizing high efficient SEP, such as
    - Orbit habitats: Supports crew while at Mars
    - Return propulsion stages and/or return habitats
    - Exploration equipment: Unique systems required for exploration at Mars.
  - High thrust chemical propulsion for crew
    - Low-thrust SEP too slow for crew missions
    - Crew travels on faster-transit, minimum energy missions: 1000-day class round-trip (all zero-g)

One Very Large SEP



Multiple ARM derived SEPs (100-250 Kw Class)



ARM Milestones to Mission Concept Review, February 2015

➢ FY14 Risk Reduction Plan for Boulder Capture Concept Option	Apr 3, 2014
➢ BAA Notice of Intent Due	Apr 4, 2014
➢ PPBE16 program submits due	Apr 28, 2014
➢ BAA Proposal Due Date	May 5, 2014
➢ STMD Solar Array Systems development Phase 1 complete	Jun 2014
➢ BAA Awards	NET Jul 14, 2014
➢ **Option A Testbed Operational**	**End of Jul 2014**
➢ **STMD Integrated Thruster performance Test with 120V PPU**	**Sep 2014**
➢ **HEOMD MACES EVA end-to-end mission sim complete**	**Sep 2014**
➢ **Planned STMD SEP Solar Array RFP release**	**Oct 2014 (TBR)**
➢ **Option B full scale 2D flat floor testing**	**Oct 2014**
➢ **BAA Interim Reports**	**Oct 31, 2014**
➢ **Planned STMD Electric Propulsion RFP release**	**Nov 2014 (TBR)**
➢ **Robotic mission concept Option A/B downselect**	**Mid Dec 2014**
➢ **BAA Period of Performance Ends**	**Jan 15, 2014**
➢ **Mission Concept Review**	**Feb 2015**

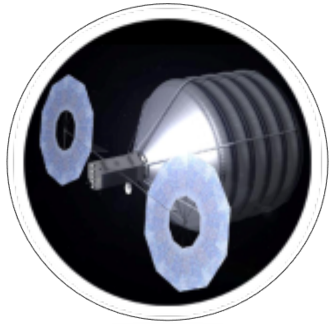
Proving Ground

Exploration Transportation Systems BEO

- SLS provides heavy lift transportation of crew and cargo to deep space
- Orion provides early crew transportation and life support along with navigation and operations for deep space crew missions

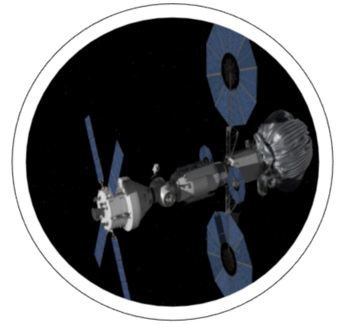
Capability Pathfinders / SKG Missions

- Resource Prospector
- Mars 2020 payload
- Potential Phobos precursor mission
- EDL /Lander / ISRU / Surface Power
- Pathfinder of deep space chemical stage



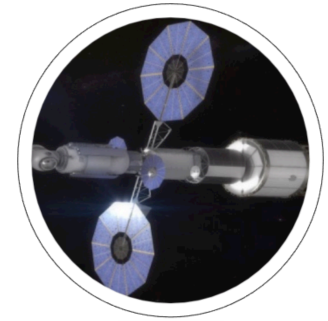
Asteroid Redirect Mission

- Advanced solar electric propulsion (SEP) demonstration
- Maneuvering large objects in interplanetary trajectories w/SEP
- Integrated robotic/Orion vehicle stack operations in deep space orbits
- Deep space navigation and common rendezvous
- International docking system
- Deep space advanced EVA capability
- Sample handling and return
- Operations at low gravity bodies



Exploration Augmentation Module

- Deep space system and operational testing including long duration robotic tended spacecraft
- Deep space testing on radiation mitigation and general strategic knowledge gap closure for long duration human missions
- Deep space testing of advanced EVA and other systems and operations
- Tele-operations in space and on lunar surface
- Sample handling and return



Mars Habitat Prototype

- Spacecraft life testing in deep space
- 500-900 day Deep Space Habitat including long duration dormancy time periods
- Advanced maintenance & logistics packaging

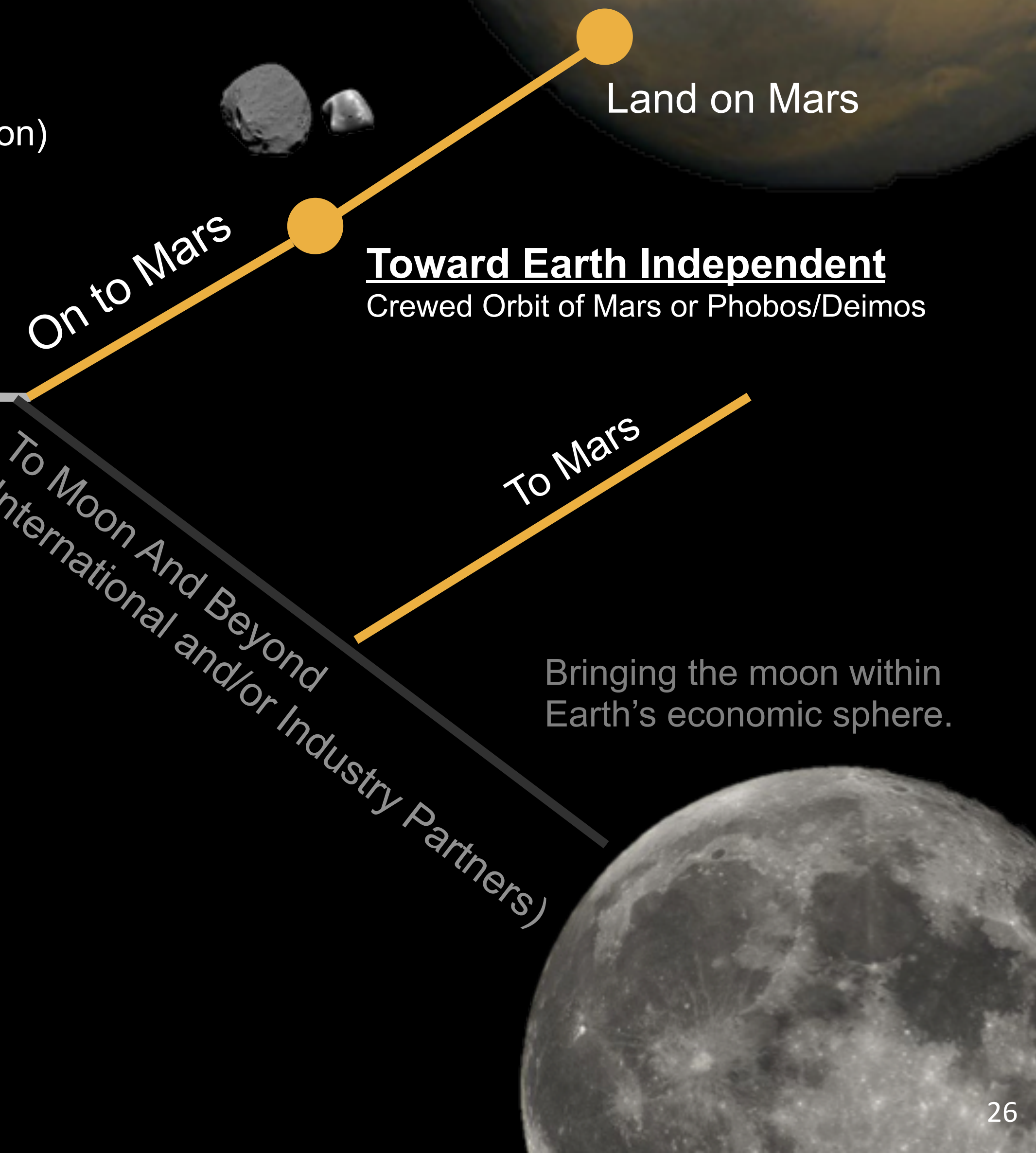
Human Exploration Pathways

<u>Mastering the Fundamentals</u>

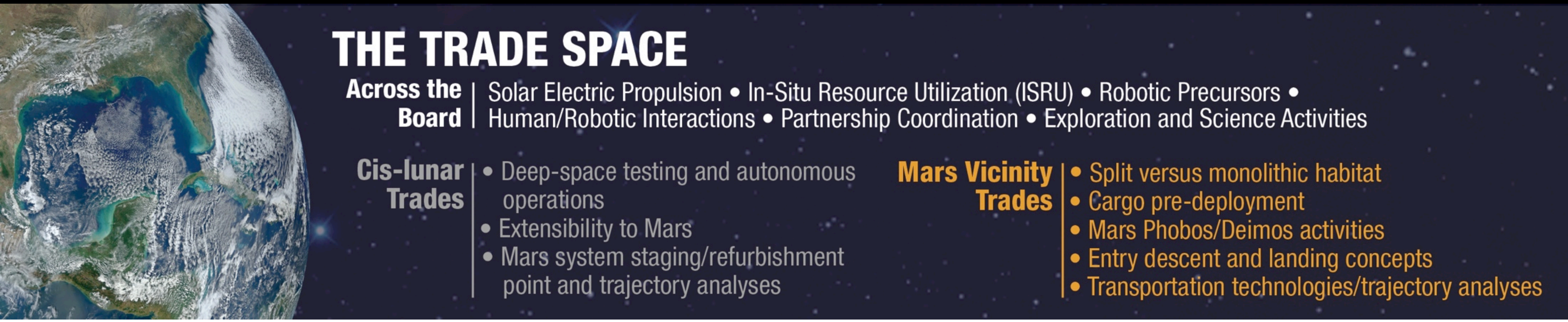
- Extended Habitation Capability (ISS)
  - High Reliability Life Support
- Deep-space Transportation (SLS and Orion)
- Exploration EVA
- Automated Rendezvous & Docking
- Docking System

<u>Pushing the Boundaries</u>

- Deep Space Operations
  - Deep Space Trajectories
  - Deep Space Radiation Environment
  - Integrated Human/Robotic Vehicle
- Advanced In-Space Propulsion (SEP)
  - Moving Large Objects
- Exploration of Solar System Bodies



EMC Forward Work



- **Across the Board**
  - SEP sizing, ISRU benefits
  - Study potential of a common small pressure shell that could be used for the Mars ascent cabin, the Mars moons taxi, the Phobos exploration vehicle, and EAM component
  - Pathfinder mission developments (Phobos precursor, capability pathfinder missions for EDL and in-space propulsion)
  - Global Exploration Roadmap
  - Identify key near-term decisions
  - End of Year Report – support development of Pioneering Space and development of capability roadmaps

- **Cis-lunar Trades**
  - ARM, ISRU, sample management extensibility
  - Exploration Augmentation Module concepts

- **Mars Vicinity Trades**
  - Refined element concept development activities to drive out technology/capability key performance metrics, packaging needs, configuration layouts and refined mass estimates
    - Long duration habitat systems, exploration mobility systems, surface power, in-space stages, landers, ascent modules, taxis, etc. to include SLS packaging
  - Fission reactor requirements
  - Mars surface operations and site selection
  - Impact of small Mars lander on surface ops and EDL capability

Comparison: Augustine, NRC and GER HSF Strategies

EXPLORATION PHILOSOPHY

Similarities	Topic Area	Augustine Report 2009	NRC Report 2014	GER Document 2013
🟢	**Why Explore?**	"…the ultimate goal of human exploration is to chart a path for human expansion into the solar system."	"How far from Earth can humans go? What can humans discover and achieve when we get there?"	Multiple benefits to society with common goals and objectives
🟡	**Key Strategy**	Mars First, Moon First and/or Flexible Path	"Pathways"- a specific sequence of destinations "Pathway Principles"	"Asteroid Next" and "Moon Next"
🟡	**Strategy Approach**	Choose goals, then destination for beyond LEO and human extension into solar system	Rather than 'capabilities based' or 'flexible path' approach, recommends selection of a specific pathway but does not recommend one pathway over another. Recommends eliminating/minimizing 'dead end' hardware development.	Sustainability requires a stepwise approach to reduce risk, test advanced technology and demonstrate capability while each mission is a step toward Mars, maximizing science and tech objectives and public engagement
🟢	**NASA Funding Position**	2010 funding "does not allow for a viable exploration program." Additional $3B/year allows for Moon First or Flexible Path with reasonable timetable.	Current funds plus inflation not enough	n/a
🟢	**NASA Outreach Emphasis**	Low	High	High

(cont'd) Comparison: Augustine, NRC and GER HSF Strategies

DESTINATIONS

Similarities	Topic Area	Augustine Report 2009	NRC Report 2014	GER Document 2013
●	**Final Destination**	Mars is "ultimate destination", but "not best *first* destination."	"Thus the horizon goal for human space exploration is Mars." [surface implied]	"…begins with the ISS, and expands human presence into the solar system, leading to humans missions on the surface of Mars."
●	**Direct to Mars?**	No	No	No
●	**Interim Location before Mars**	Lagrange points, NEOs, asteroids, moons of Mars, lunar surface to test and build capabilities	HEO/Cis-lunar to test and build capabilities	Cis-lunar/asteroid/HEO/lunar surface to test and build capabilities
●	**Lunar Surface Role**	Included in 'Moon first' scenario	Included in the Moon-to-Mars and Enhanced Exploration pathways	Included in international roadmap.

(cont'd) Comparison: Augustine, NRC and GER HSF Strategies

LEVERAGING CURRENT ASSETS

Similarities	Topic Area	Augustine Report 2009	NRC Report 2014	GER Document 2013
●	**ISS Role**	Utilize as testbed, extend to 2020 (+11 years)	Use ISS to determine physiological tolerance to and countermeasures for the lengthy microgravity environments. HRP is critical.	Platform to prepare for future exploration missions. Technology, human health, ops sims and other critical capabilities.
●	**Commercial Space Role**	Encourage LEO deliveries to obtain lower life cycle costs and allow NASA to focus on beyond LEO spacecraft and missions.	Assumed - recognizes commercial space industry successes to date, policies to encourage commercial space but notes "…a commercial space-based economy, heavily utilizing HSF, is highly speculative at this point." Profit-creating BLEO systems is a challenge.	"Support or encourage provision of technology, systems, hardware, and services from commercial entities and create new markets based on space activities…."
●	**Partnerships Position**	Encourages International and commercial partnerships	Vigorously pursue existing and new International and commercial partnerships, including China	Relies on International and commercial partnerships

(cont'd) Comparison: Augustine, NRC and GER HSF Strategies

SCIENCE & TECHNOLOGY DEVELOPMENT

Similarities	Topic Area	Augustine Report 2009	NRC Report 2014	GER Document 2013
🟡	**Critical Technologies Required**	Human research, propellant storage and transfer, ISRU, EDL, in-space propulsion	EDL, radiation safety, advanced in-space propulsion	Propulsion, habitation, EDL, robotics, comm, human health, destination systems
🟢	**Science Integration with Exploration**	"…America is best served by a complementary and balanced space program involving both a robotic component and a human component."	Recognizes science missions and robotic capabilities are precursors and cooperative capabilities for human missions	Science missions provide benefits to science *and* inform preparations for human missions.
🟡	**Technology Development**	Endorses NASA as technology development force. "Investment in a well-designed and adequately funded space tech program is critical to enable progress in exploration."	Recognizes the development challenges of long duration human missions is 'profoundly daunting'.	Use mission technology needs to focus international technology investments.
🟢	**Heavy Lift**	New launch vehicle required for human exploration, with benefits for science and national security	Assumed use of SLS in DRMs.	Reflects variety of launch vehicle capabilities for robotic and human missions
🟢	**Crewed Vehicle**	Constellation	Required	New vehicle required

Reference: Definitions of CDF, Flexible Path, and Pathways

- **Flexible Path Approach – framework from 2009 Augustine Committee Report**
  - How Augustine defined it: "The goal is to take steps toward Mars, learning to live and work in free space and near planets, under the conditions humans will meet on the way to Mars. We must learn to operate in free space for hundreds of days, beyond the protective radiation belts of the Earth, before we can confidently commit to exploring Mars."
  - How NRC Defines it: A "flexible-path approach is a more sophisticated version of capability-based planning that takes into consideration what destinations might be desirable."
- **Capability Driven Framework – from January 2010 HEFT public outbrief. Inspired by flexible path approach**
  - How NASA defines it: "Multiple possible destinations/missions would be enabled by each discrete level of capability…Would allow reprioritization of destination/missions by policymakers without wholesale abandonment of then--existing exploration architecture". Showed Mars as a goal early on, emphasized need for decision-trees.
  - How NRC defines it: "A "capability-based" approach to space exploration focuses research and technology development resources on systems and capabilities that are expected to be of value in the future, with no particular destination in mind. The process of selecting future missions then tends to favor those missions that can make use of the systems and capabilities that have been developed." The Asteroid Redirect Mission (ARM) is an example of this process in action.
- **Pathways Approach – from 2014 NRC Pathway report**
  - "By contrast, a pathway-based approach would commit the U.S. HSF program to a pathway with a specific sequence of missions normally of increasing difficulty and complexity that target specific exploration goals that are typically tied to various destinations that humans may explore. A pathways approach would facilitate continuity of development of required systems for increased capability and efficiency." Focus on *decision rules*, a planned sequence of missions, and having Mars as a horizon goal.
- **Current NASA studies rely on best features of external reports and recommendations**
  - Requires flexible and budget-resilient execution of long term Mars effort
  - Incorporates reusability and extensibility of new systems
  - Recognizes challenges in projecting technology development, science goals, political priorities, and partnership changes for far term planning

Summary: Integrating Policy Direction and Points of Agreement with Various Studies

- **We will expand human presence into the solar system and to the surface of Mars**
  - NASA will go forward with international and commercial partners to fulfill shared and compatible goals
  - Architectures, systems developments, and interim destinations will feed forward to Mars to the extent possible
- **This time, we are going into deep space to stay (pioneering)**
  - We will pursue a long-term program, using the lessons from ISS and SMD's Mars Exploration Program
- **We will proceed at a pace defined by the budget, by technological progress, and by evolving partnerships**
  - We can and will make substantial progress within currently available resources, including SLS and Orion in both initial and evolved forms
  - We will gain from increasing alignment of HEOMD, SMD, and STMD
- **An affordable, sustainable, and realistic program takes a stepwise approach**
  - E.g., from ISS to cis-lunar space to the moons of Mars to the Martian surface
  - Trade studies now underway will inform the choice and order of future steps in both capabilities (e.g., EUS), approaches (e.g, split missions; useful orbits), and destinations (e.g., smaller vs larger asteroid)
  - Emphasizes the build up and exploitation of space infrastructure/reuse of in-space systems
  - ARM emerged from the nexus of affordability, exercise of SLS and Orion capabilities, leveraging of current developments (e.g, SEP), and extensibility toward Mars
- **A sustainable program emphasizes near-term accomplishment, mid-term stretch goals, and long term flexibility and resilience**
  - We are not planning the "perfect 30 year program"…there is no such thing.
  - E.g, cis-lunar missions in the 2020s, moons of Mars in the 2030's, and Mars surface as budget and technology allows
  - Adapts to changing budgets and policy priorities with the larger, long term goal of human space exploration
- **Again, Pioneering Space is the idea that best frames this approach**

Strategy Document Development: *Pioneering Space*

Pioneering Space

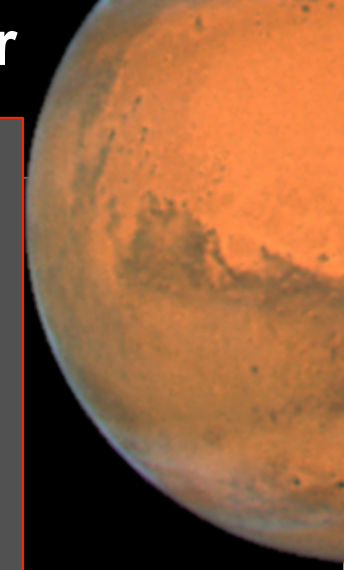
Update *Voyages* (2011) to incorporate Evolvable Mars Campaign study results and provides additional details in the HSF plans for the pioneering of deep space leading to Mars.

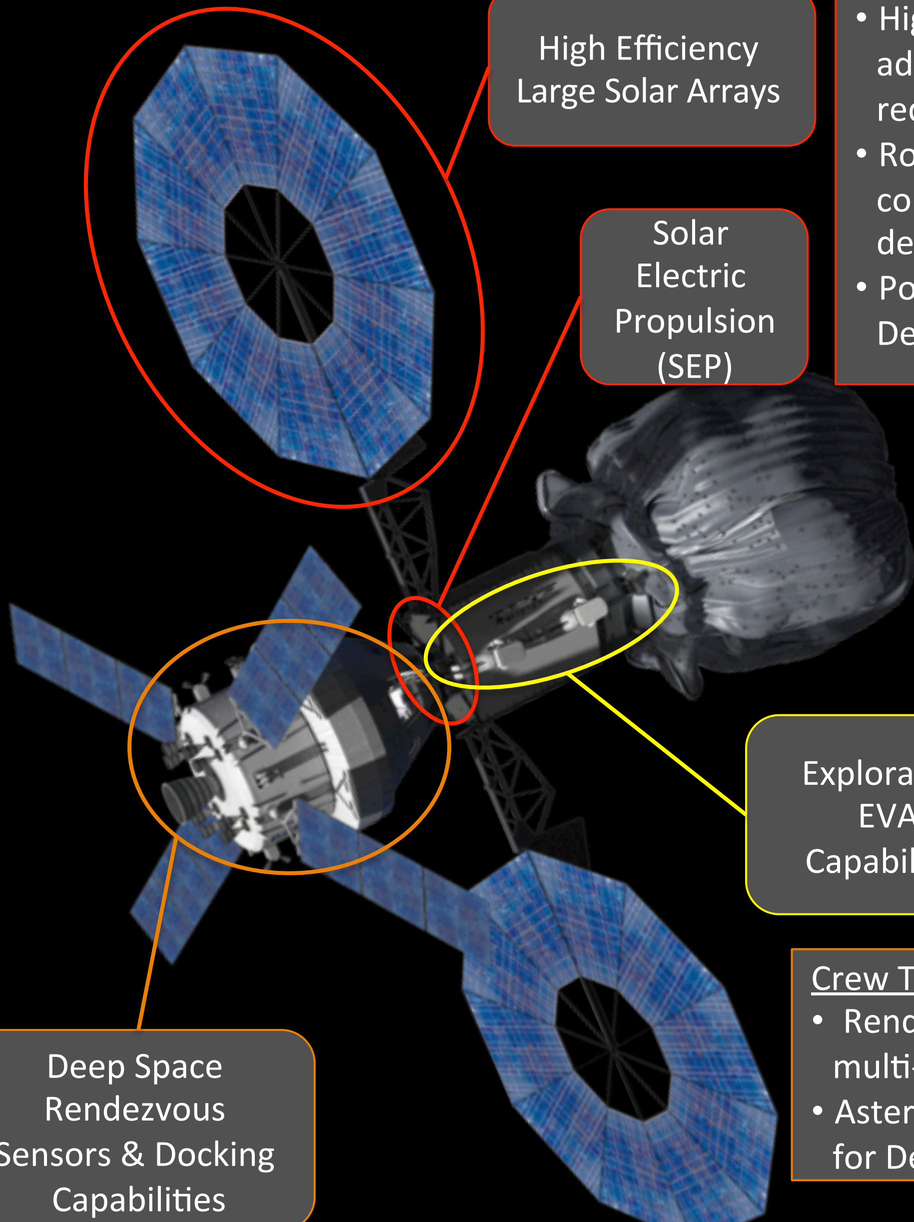
Pioneering Space development schedule:

Dec 2013	- **Evolvable Mars Campaign** kickoff
May	- **Pioneering Space White Paper** released
July	- NAC Committees & NAC meetings
Sept	- **EMC** FY14 outbrief
Sept	- **EMC** FY14 findings integrated into draft
Sept-Oct	- Stakeholder discussions
Fall	- NAC Committees & NAC meetings
Dec	- ***Pioneering Space*** document ready for publication
2015	- Continue technical analyses and dialogs

Back up

Asteroid Redirect Mission Provides Capabilities For Deep Space/Mars Missions





In-space Power and Propulsion :
- High Efficiency Solar Arrays and SEP advance state of art toward capability required for Mars
- Robotic ARM mission 40kW vehicle components prepare for Mars cargo delivery architectures
- Power enhancements feed forward to Deep Space Habitats and Transit Vehicles

EVA:
- Build capability for future exploration through Primary Life Support System Design which accommodates Mars
- Test sample collection and containment techniques including planetary protection
- Follow-on missions in DRO can provide more capable exploration suit and tools

Crew Transportation and Operations:
- Rendezvous Sensors and Docking Systems provide a multi-mission capability needed for Deep Space and Mars
- Asteroid Initiative in cis-lunar space is a proving ground for Deep Space operations, trajectory, and navigation.

Key Thrusts for Advancement

THERE & BACK

- The ability to launch a very powerful rocket
- High-reliability spacecraft systems
- Size requirements of crew capsule
- Validation of performance of SLS and Orion in the deep space environment *(hotter, colder, radiation)*
- Deep space navigation
- Rendezvous and docking
- Life support systems
- High speed re-entry

HAPPY & HEALTHY

- Air, water, food
- Waste containment
- Psychological impact
- Low- / no-gravity
- Medical emergencies
- Bone loss
- Radiation
- Ocular degeneration
- Hygiene

WELL EQUIPPED & PRODUCTIVE

- Sample handling
- Microgravity operations
- Space suits
- Advanced training and tools
- Mission planning
- Situational awareness and decision making
- Crew relationships