NASA’s Exploration Strategy

April 2014
Why Human Space Exploration?

- Scientific and human exploration and pioneering mark advancing civilizations and expand human experience
  - Expands knowledge, fuels innovation, and spurs commerce
  - Requires risk acceptance

- Exploration and pioneering leverages humanity’s powerful motivations:
  - Ignites our imaginations
  - Leads to discovery and science & technical advances
  - Creates a vision of a better future for the next generations

- Space exploration is human and robotic explorers in partnership
  - Robots explore distant and hazardous environments to extend scientific understanding and planning for human missions
  - Human explorers provide greater speed, intuitive ease, and efficiency

- Human space exploration garners national prestige and unites nations around a common goal

Building on our investments in technology, robotic missions, ISS, Commercial Crew, SLS, and Orion, America is poised to lead the next wave of partnerships for international science and human space exploration
The Future of Human Space Exploration

NASA’s Building Blocks to Mars

- U.S. companies provide affordable access to low Earth orbit
- Mastering the fundamentals aboard the International Space Station
- Pushing the boundaries in cis-lunar space
- Developing planetary independence by exploring Mars, its moons, and other deep space destinations
- The next step: traveling beyond low-Earth orbit with the Space Launch System rocket and Orion crew capsule

<table>
<thead>
<tr>
<th>Missions: 6 to 12 months</th>
<th>Missions: 1 month up to 12 months</th>
<th>Missions: 2 to 3 years</th>
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<tbody>
<tr>
<td>Return: hours</td>
<td>Return: days</td>
<td>Return: months</td>
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Earth Reliant | Proving Ground | Earth Independent
The Capability Driven Framework

Incremental steps to steadily build, test, refine, and qualify capabilities that lead to affordable flight elements and a deep space capability.
Six key strategic principles to provide a sustainable program:

1. Executable with current **budget with modest increases**.
2. Application of **high Technology Readiness Level** (TRL) technologies for near term, while focusing research on technologies to address challenges of future missions.
3. **Near-term mission** opportunities with a defined cadence of compelling missions providing for an incremental buildup of capabilities for more complex missions over time.
4. Opportunities for **US Commercial Business** to further enhance the experience and business base learned from the ISS logistics and crew market.
5. **Multi-use, evolvable** Space Infrastructure.
Global Exploration Roadmap

International Space Station
General Research and Exploration Preparatory Activities

Note: ISS partner agencies have agreed to use the ISS until at least 2020.

Commercial or Government Low-Earth Orbit Platforms and Missions

Robotic Missions to Discover and Prepare

- LADEE
- Luna-25
- Chandrayaan-2
- Luna-26
- Luna 27
- RESOLVE
- SELENE-2
- Luna 28/29
- SELENE-3
- Rosetta
- Hayabusa2
- OSIRIS-REx
- Apophis
- MAVEN
- ISRO Mars
- ExoMars
- InSight
- ExoMars
- Mars 2020
- JAXA Mars Precursor

Mars Sample Return and Precursor Opportunities

Human Missions Beyond Low-Earth Orbit

- Explore Near-Earth Asteroid
  - Multiple Locations in the Lunar Vicinity
- Extended Duration Crew Missions
  - Humans to Lunar Surface

Missions to Deep Space and Mars System

Sustainable Human Missions to Mars Surface
EARTH RELIANT

PROVING GROUND

EARTH INDEPENDENT
International Space Station –
The Cornerstone of Exploration
NASA and the ISS

Advance benefits to humanity through research

Enable a commercial demand driven market in LEO

Enable long duration human spaceflight beyond LEO

Basis for international HSF exploration partnerships
ISS Enables Long Duration Exploration For Mars

- Health and Human Performance
- Crew Habitability and Logistics
- System and Technology Testbed
  - Docking System
  - High Reliability Closed Loop Life Support
  - Long Term System Performance
  - Extravehicular Activity
ISS is the platform to understand and develop countermeasures for Human Health & Performance Risks

- **Decreased gravity**
  (including gravity transitions and launch and landing loads)
  *bone, muscle, cardiovascular, sensorimotor, nutrition, behavior/performance, immunology, human factors, clinical medicine*

- **Isolation/confinement and altered light-dark cycles**
  *behavior/performance*

- **Hostile/closed environment**
  (including habitability: atmosphere, microbes, dust, volume/configuration, displays/controls,…)
  *behavior/performance, nutrition, immunology, toxicology, microbiology*

- **Increased radiation**
  *immunology, carcinogenesis, behavior/performance, tissue degeneration, pharmaceutical stability…*

- **Distance from Earth**
  *behavior/performance, autonomy, food systems, clinical medicine*

**Note that effect severity generally increases with mission duration.**
International Space Station: Exploration Platform

- In-Space Robotic Servicing
- Automated Rendezvous & Docking Sensors
- International Docking System
- ECLSS/Amine Swingbed
The Next Step Beyond ISS

- Crew tended habitat in cis-lunar space
  - Builds off of the Asteroid redirect mission and ISS
    - Allows for further study of gravity assist trajectory operations
    - Builds off of ISS life support with less earth support
    - Enables international partner and commercial lunar surface activities
    - Develops incremental risk management concepts to be developed and accepted
    - Exposure to galactic cosmic background radiation
  - Allows for Mars operational strategies to be developed
Commercial Cargo & Crew Transportation – Freeing Up NASA to Explore Beyond LEO
Now Acquiring ISS Cargo Services Commercially!

- **Space X C1 Launch**
  - December 8, 2010

- **SpaceX C2+ Launch**
  - May 22, 2012

- **Orbital A-ONE Launch**
  - April 21, 2013

- **Orbital ORB-D1 Launch**
  - September 18, 2013

- **SpaceX Dragon Capture**
  - May 25, 2012

- **Orbital Cygnus Capture**
  - September 29, 2013
Commercial Crew Partners

Boeing

SpaceX

Sierra Nevada
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<td><strong>Commercial Crew Development</strong></td>
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<td><strong>CCDev</strong></td>
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</table>
| 5 Partners: Blue Origin, Boeing, Paragon, Sierra Nevada, ULA  
Scope: Crew Transportation System Technologies and Concepts  
Total Amount Awarded: $50M |  |  |  |  |  |  |  |  |
| **CCDev 2** |  |  |  |  |  |  |  |  |
| 4 Partners: Blue Origin, Boeing, Sierra Nevada, SpaceX  
Scope: Elements of a Crew Transportation System  
Total Amount Awarded: $315M |  |  |  |  |  |  |  |  |
| **CCiCap** |  |  |  |  |  |  |  |  |
| 3 Partners: Boeing, Sierra Nevada, SpaceX  
Scope: Integrated Crew Transportation Systems  
Total Amount Awarded: $1,167M |  |  |  |  |  |  |  |  |
| **CPC (Phase 1)** |  |  |  |  |  |  |  |  |
| 3 Partners: Boeing, Sierra Nevada, SpaceX  
Scope: Early Certification Products  
Total Amount Awarded: $29.5M |  |  |  |  |  |  |  |  |
| **CCTCap (Phase 2)** |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |
| **Commercial Crew Integrated Capability** |  |  |  |  |  |  |  |  |
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|  |  |  |  |  |  |  |  |  |
| **Commercial Crew transportation Capability** |  |  |  |  |  |  |  |  |
| **CCTCap (Phase 2)** |  |  |  |  |  |  |  |  |
| Partners: TBD  
Scope: Full Certification Plus Initial ISS Missions |  |  |  |  |  |  |  |  |
Space Launch System & Orion – How We’ll Get There
2014 Exploration Flight Test One (EFT-1)
Exploration Mission One (EM–1)

- Outbound Flight Time: ~9 days
- Return Flight Time: ~11 days
- 5 Days in Distant Retrograde Orbit
- 26-27 Day Total Mission Duration
Orion Spacecraft

Orion is the first spacecraft in history capable of taking humans to multiple destinations in deep space.

Long Duration – Adaptable – Life Sustaining

Forward Bay
Cover Jettison
Test Denver, CO

Heat shield completed and delivered to O&C for final processing

Fairing separation test 2 at Lockheed Martin, Sunnyvale, CA

Service Module / Spacecraft Adaptor mate complete at O&C
SLS is the rocket and launch system capable of transporting humans, habitats and support systems directly to deep space. Powerful – High-Capacity – Flexible

Vertical Assembly Center (VAC) Status Progress - Tower Install / Third Upper Half Leg Installed - NW Leg

Completed MSA Shell

Center segment for QM-1 delivered to its test bay at ATK’s facility in Utah

1:100 scale model of SLS Core Stage B-2 test stand completed wind tunnel testing

Diaphragm installed and tested on MSA in support of EFT-1

F-1B gas generator – tech demo for advanced booster concept
GSDO is modernizing Kennedy’s spaceport with the capabilities to launch spacecraft built and designed by both NASA and private industry.

Adaptable – Partner-Oriented – Versatile

NASA’s Vehicle Assembly Building is undergoing major renovations so it can support a new generation of rockets and spacecraft.

The 355-foot-tall mobile launcher structure is being modified to support Space Launch System.

The Orion ground test vehicle (GTA) is in the Operations and Checkout Facility at KSC.
Asteroid Redirect Mission –
An Early Use of Exploration Capabilities in the Proving Ground
Asteroid Redirect Mission

**Identify**

Asteroid Identification:
Ground and space based near Earth asteroid (NEA) target detection, characterization and selection

**Redirect**

Asteroid Redirect Robotic Mission:
High power solar electric propulsion (SEP) based robotic asteroid redirect to lunar distant retrograde orbit

**Explore**

Asteroid Redirect Crewed Mission:
Orion and Space Launch System based crewed rendezvous and sampling mission to the relocated asteroid
• 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 the 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 required 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 asteroidal resources for commercial and exploration needs.
Asteroid Redirect Mission
Builds on Investments Already Being Made by NASA

• ARM integrates several building blocks of human space exploration to initiate deep space exploration
  – ISS experience
  – Orion and SLS
  – SEP and other technologies

• Contributes significantly to the extension of the human exploration of space beyond LEO in an affordable and sustainable way
  – Operate 1000 times farther than LEO for the first time in 4 decades.
  – Longer duration beyond LEO crewed mission than ever
Near Earth Object Identification – Key Assets

Catalina Sky Survey

Utilize Radar (Goldstone and Arecibo) increased time for NEO observations.

University of Arizona – Tucson

NEOWISE reactivated and dedicated to NEO Search & Characterization

NASA InfraRed Telescope Facility (IRTF)
- Increase On-call for Rapid Response.
- Improve Instrumentation for Spectroscopy and Thermal Signatures.
Asteroid Redirect Robotic Mission Concept
Option A

• Rendezvous with small less than 10 meter mean diameter Near Earth Asteroid (NEA)
  – Capture <1000 metric ton rotating NEA
  – Demonstrate planetary defense techniques
  – Maneuver to stable, crew accessible lunar Distant Retrograde Orbit (DRO)

• Candidate target is 2009 BD
  – 5 meter mean diameter and < 145 metric tons
  – Launch mid-2019*; Crew accessible after 2/2024

• Additional candidate targets expected to be discovered and characterized at the rate of approximately 5 per year

• Other candidates under evaluation
  • Recent Spitzer observation of 2011 MD which is crew accessible in August 2025
  • 2014 BA3 crew accessible in early 2025
  • 2013 EC 20 crew accessible in late 2025

* Launch vehicle dependent
Asteroid Redirect Robotic Mission Concept (Option B)

- Rendezvous with a larger (~100+ meter diameter) NEA
  - Collect ~2-4 meter diameter boulder (~10-70 metric tons)
  - Perform deflection demonstration(s) and track to determine effect
  - Return boulder to same lunar orbit

- Candidate asteroid Itokawa
  - 2-3 meter, 18 ton boulder to DRO in 2025 (2019 robotic mission launch)*

- Other targets to be characterized by in situ observation and crew accessible in DRO in 2025
  - Bennu by OSIRIS-Rex
  - JU3 by Hayabusa 2
  - 2008 EV5 by radar or other means

* Launch vehicle dependent
Asteroid Redirect Crewed Mission Overview

Deliver crew on SLS/Orion

Orion Docks to Robotic Spacecraft

EVA from Orion to retrieve asteroid samples

Return crew safely to Earth with asteroid samples in Orion
Crewed Mission Trajectory: Earliest Mission for 2009BD

- MECO Epoch: 2024-May-16 14:36:08 TDB
- Entry velocity: 10.99 km/s

- Total iCPS $\Delta v$: 2820 m/s (All iCPS capacity)
- Total Orion $\Delta v$: 1010 m/s
- Total Mission Duration: 25.65 days

- Outbound
  - Flight Day 1 – Launch/TLI
  - Flight Day 1-7 – Outbound Trans-Lunar Cruise
  - Flight Day 7 – Lunar Gravity Assist
  - Flight Day 7-9 – Lunar to DRO Cruise

- Joint Operations
  - Flight Day 9-10 – Rendezvous
  - Flight Day 11 – EVA #1
  - Flight Day 12 – Suit Refurbishment, EVA #2 Prep
  - Flight Day 13 – EVA #2
  - Flight Day 14 – Contingency/Departure Prep
  - Flight Day 15 – Departure

- Inbound
  - Flight Day 15 – 20 – DRO to Lunar Cruise
  - Flight Day 20 – Lunar Gravity Assist
  - Flight Day 20-26 – Inbound Trans-Lunar Cruise
  - Flight Day 26 – Earth Entry and Recovery

Mission Duration and timing of specific events will vary slightly based on launch date and trajectory strategy.
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.

Deep Space Rendezvous Sensors & Docking Capabilities
High Efficiency Large Solar Arrays
Solar Electric Propulsion (SEP)
Exploration EVA Capabilities
Next Steps –
Pathways into the Proving Ground of Cis-Lunar Space and On to Mars
Human Exploration Pathways

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

Pushing the Boundaries
- 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

Towards Earth Independent
Crewed Orbit of Mars or Phobos/Deimos

On to Mars

To Mars

Land on Mars

Bringing the moon within Earth’s economic sphere.
SSERVI provides scientific, technical and mission-defining analyses for relevant NASA programs, planning and space missions, including:

- The role of the Moon, NEAs, Phobos & Deimos in revealing the origin and evolution of the inner Solar System
- Moon, NEA, and Martian moon investigations as windows into planetary differentiation processes
- Near-Earth asteroid characterization (including NEAs that are potential human destinations)
- Lunar structure and composition
- Regolith of Target Body(s)
- Dust and plasma interactions on Target Body(s)
- Volatiles (in its broad sense) and other potential resources on Target Body(s)
- Innovative observations that will advance our understanding of the fundamental physical laws, composition, and origins of the Universe
Mars 2020 will seek signs of past life on Mars, collect and store a set of soil and rock samples that could be returned to Earth in the future, and test new technology to benefit future robotic and human exploration of Mars.

HEOMD / SMD / STMD are jointly sponsoring investigations to address high priority strategic knowledge gaps and technology development objectives for Human Exploration

- Mars Entry, Descent and Landing Instrumentation (MEDLI) to refine atmospheric entry models to inform future landing system design
- Exploration technology payloads that make significant progress towards filling at least one major Strategic Knowledge Gap.
BRINGING THE MOON INTO EARTH’S ECONOMIC SPHERE

Accelerating private-sector lunar landing capabilities with NASA expertise using public-private partnerships

STATUS

Currently evaluating proposals with partner selections in April and executed agreements in May 2014
# Evolutionary Capabilities

<table>
<thead>
<tr>
<th>Transportation</th>
<th>EARTH RELIANT</th>
<th>PROVING GROUND</th>
<th>EARTH INDEPENDENT</th>
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<tbody>
<tr>
<td>Crew Transit</td>
<td>Earth-based support: high Low-Earth Orbit</td>
<td>2-4 crew launch aboard evolvable Space Launch System</td>
<td>Up to 6 crew launch aboard Space Launch System</td>
</tr>
<tr>
<td>Cargo Transit</td>
<td>Routine cargo deliveries to LED via industry and international partners</td>
<td>Orion Earth re-entry: 5,300°F</td>
<td>Orion Earth re-entry: 5,500°F</td>
</tr>
<tr>
<td>Propulsion &amp; Energy Storage</td>
<td>Large scale use of solar panels</td>
<td>105t SLS to lunar vicinity</td>
<td>130t SLS to Mars and beyond</td>
</tr>
<tr>
<td>Planetary rendezvous &amp; landings</td>
<td>Planetary rendezvous with strong gravity field</td>
<td>Demonstrate potential resource utilization techniques</td>
<td>Crew must live and work without resupply from Earth</td>
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<tr>
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<td></td>
<td>Demonstrating high-power, advanced solar electric propulsion</td>
<td>Potential to expand resource utilization</td>
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<td></td>
<td>Deep Space Rendezvous; gravity free</td>
<td>Utilizing large-scale solar electric and other advanced propulsion</td>
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<td>Lunar surface landers</td>
<td>Phobos/Deimos micro-gravity Rendezvous</td>
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<td>Mars entry, descent, landing on surface</td>
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# Evolutionary Capabilities

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<tr>
<th>Working In Space</th>
<th>EARTH RELIANT</th>
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<th>EARTH INDEPENDENT</th>
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<tbody>
<tr>
<td><strong>Exploration and Science</strong></td>
<td>EARTH-BASED SUPPORT: HIGH Mastering the Fundamentals</td>
<td>EARTH-BASED SUPPORT: LIMITED Pushing the Boundaries</td>
<td>EARTH-BASED SUPPORT: NEGLIGIBLE Exploring Independently</td>
</tr>
<tr>
<td><strong>Communicating with Earth</strong></td>
<td>Microgravity science and human physiology research</td>
<td>Sampling asteroid for return to Earth for analysis</td>
<td>Mars moons and surface exploration and search for life with in-situ analysis</td>
</tr>
<tr>
<td><strong>Spacewalk and Mobility</strong></td>
<td>Immediate and continuous support from mission control</td>
<td>Limited delay with minimal crew impact</td>
<td>Independent and self-reliant crew operates with up to 40 min. delay</td>
</tr>
<tr>
<td><strong>Spacecraft Assembly &amp; Maintenance</strong></td>
<td>Zero-g outside spacecraft for short distances</td>
<td>Zero-g systems for short-distance, exploration</td>
<td>Surface exploration in partial gravity with longer distance and duration</td>
</tr>
<tr>
<td><strong>Human-Robotic Interactions</strong></td>
<td>Crew-assisted ISS Assembly</td>
<td>Limited deliveries require more efficient systems with common, interchangeable parts</td>
<td>Maintenance with only the parts and tools they carry or produce in-situ</td>
</tr>
<tr>
<td><strong>In-situ Resource Utilization</strong></td>
<td>Testing safety and control methods for efficient human-robotic teams</td>
<td>Human-robot teams, with periods where robots are left alone</td>
<td>Pre-deployed equipment depends on robots until humans arrive, then human-robot teams share critical tasks</td>
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<td>Recycle and reuse water and trash</td>
<td>Learning to recycle destination resources for fuel, water, oxygen, and building materials</td>
<td>Crew harvests destination resources to create fuel, water, oxygen, and building materials</td>
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## Evolutionary Capabilities

<table>
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<tr>
<th>Staying Healthy</th>
<th>EARTH RELIANT</th>
<th>PROVING GROUND</th>
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<tr>
<td>Human Health and Performance</td>
<td>• Developing onboard life support systems for long-duration missions</td>
<td>• Validating onboard recycling and regenerating life support systems without resupply</td>
<td>• Living and working in spacecraft that must fully support crew for years</td>
</tr>
<tr>
<td>Autonomous Medicine</td>
<td>• Studying space environment health risks and testing solutions</td>
<td>• Applying health and performance risk mitigation techniques</td>
<td>• Living in space for years while maintaining crew health and performance</td>
</tr>
<tr>
<td>Environmental Monitoring</td>
<td>• Developing integrated medical capability and crew-reliant medical care</td>
<td>• Testing semi-autonomous integrated medical capability and crew-reliant medical treatment</td>
<td>• Autonomous medical capability and medical crewmember for diagnosis and treatment</td>
</tr>
<tr>
<td>Advanced Space Suits</td>
<td>• Testing on-board environmental monitors with ground validation</td>
<td>• Demonstrating onboard environmental monitoring systems (no sample return)</td>
<td>• Monitoring crew environment for hazards, eliminating environmental emergencies</td>
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<td></td>
<td>• Testing next-generation space suits</td>
<td>• Demonstrating advanced space suits in deep space</td>
<td>• Conducting EVAs in unprecedented planetary environments</td>
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EVALVABLE MARS CAMPAIGN
A Pathways 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

Earth Dependent
International Space Station
Low-Earth Orbit
Space Launch System

Proving Ground
Exploration Augmentation Module
Distant Retrograde Lunar Orbit
Asteroid Redirect Vehicle
Lunar Surface
SEP Cabs

Earth Independent
Mars Surface
Mars Vicinity
Mars Cargo Pre-Deployment
Mars, Phobos, Deimos, Europa

NASA
Human Space Exploration Pathway Evaluation Criteria

• Sustainability
  – Leverage existing assets
  – Development of multi-mission use systems
  – Near term cadence of missions
  – Resource utilization
  – Develops infrastructure needed to enable solar system pioneering

• Exploration and Science objective satisfaction
  – Solar system planetary body exploration and discovery
  – Human health and research

• Risk
  – Human health
  – Technology development
  – System reliability
  – Critical events

• Affordability - executable with current budget with modest increases

• Partnerships
  – Commercial
  – International
  – Academia
  – Other Government Agencies
A DEEPER VISION, A BOLDER MISSION, ONE STEP AT A TIME

Step One: 2014