National Aeronautics and Space Administration

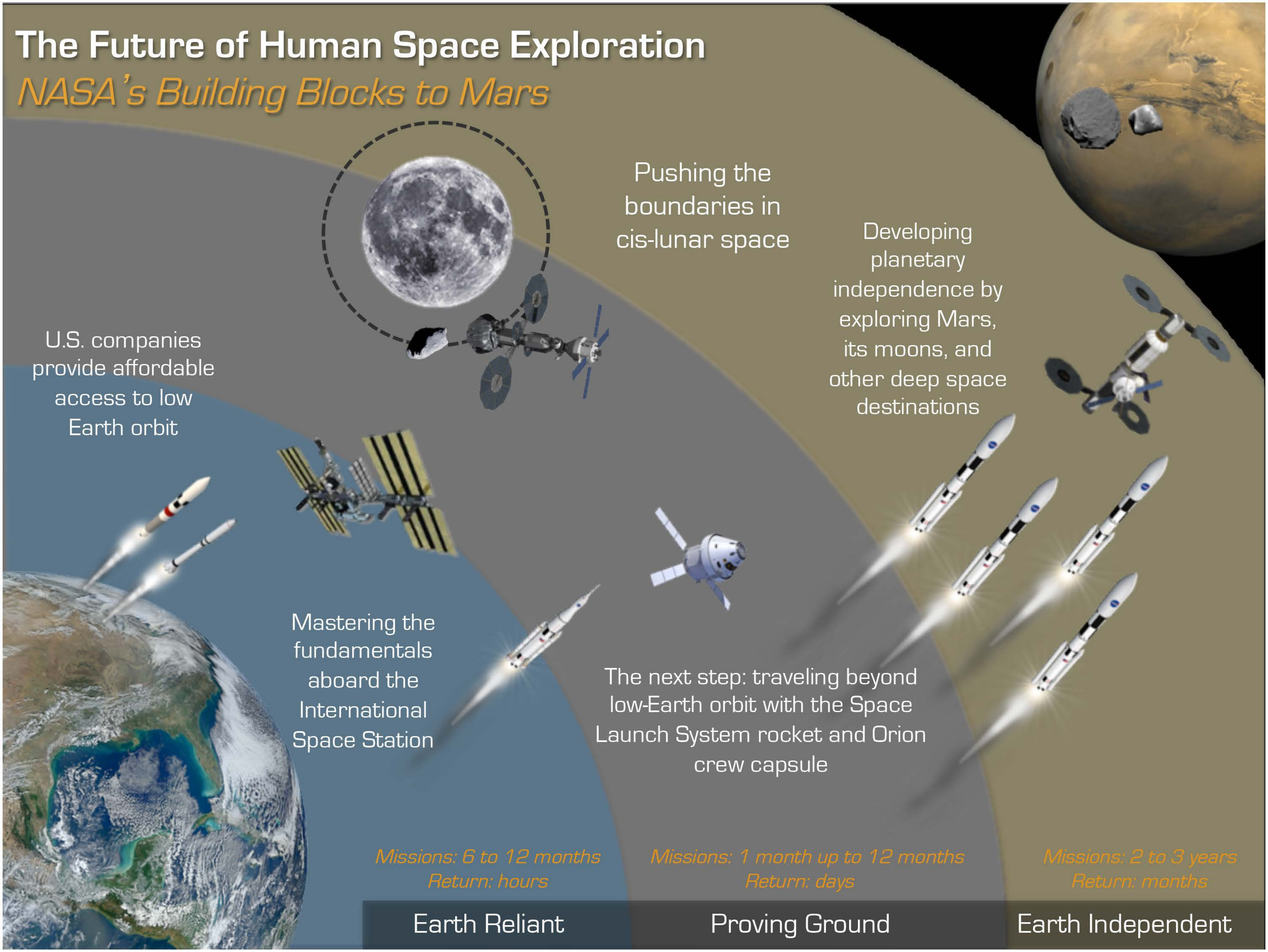
NASA's Exploration Strategy

April 2014

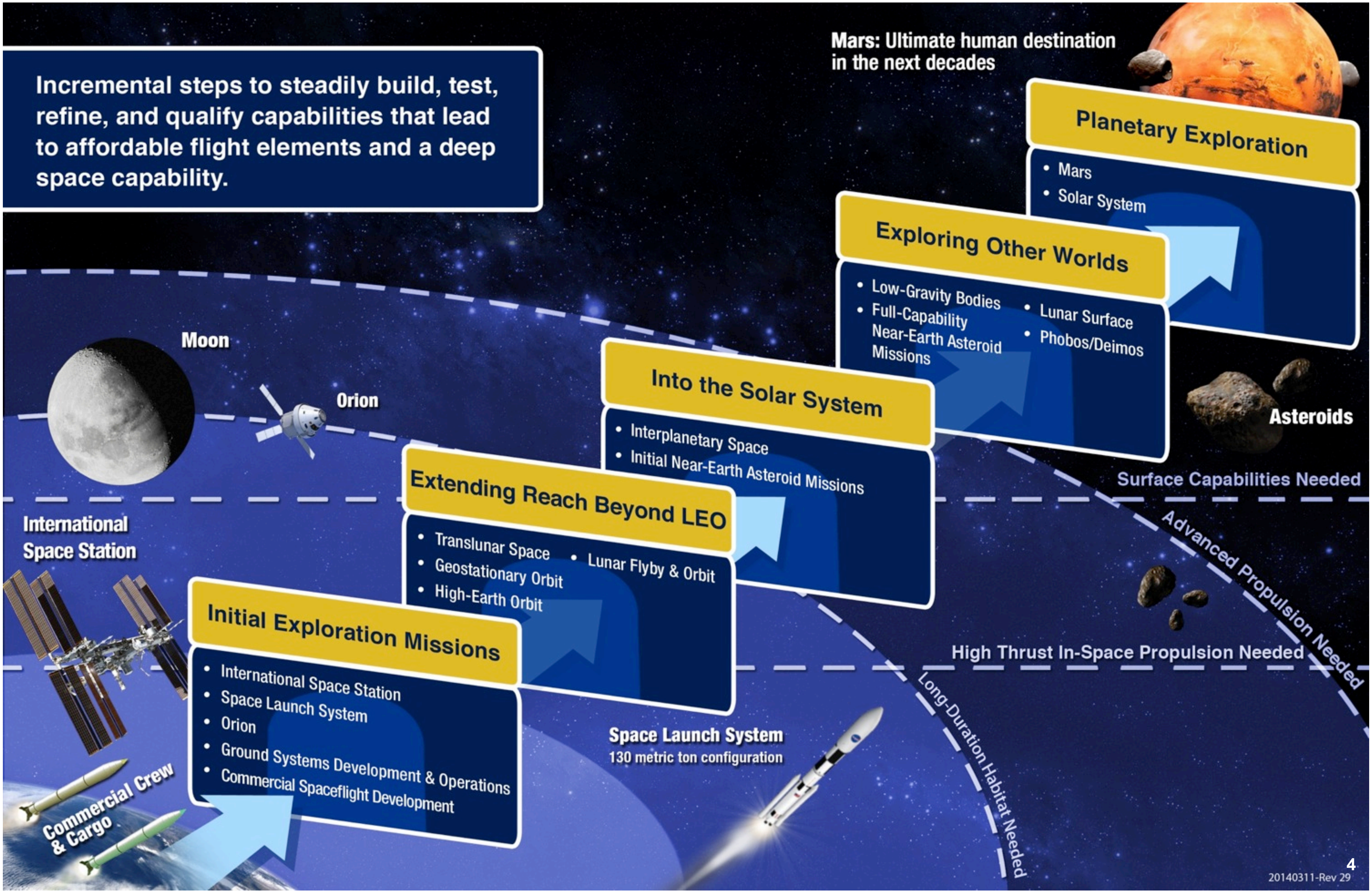
Why Human Space Exploration?

- 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
Pushing the boundaries in cis-lunar space
Developing planetary independence by exploring Mars, its moons, and other deep space destinations
U.S. companies provide affordable access to low Earth orbit
Mastering the fundamentals aboard the International Space Station
The next step: traveling beyond low-Earth orbit with the Space Launch System rocket and Orion crew capsule
Missions: 6 to 12 months
Return: hours
Missions: 1 month up to 12 months
Return: days
Missions: 2 to 3 years
Return: months
Earth Reliant
Proving Ground
Earth Independent

The Capability Driven Framework



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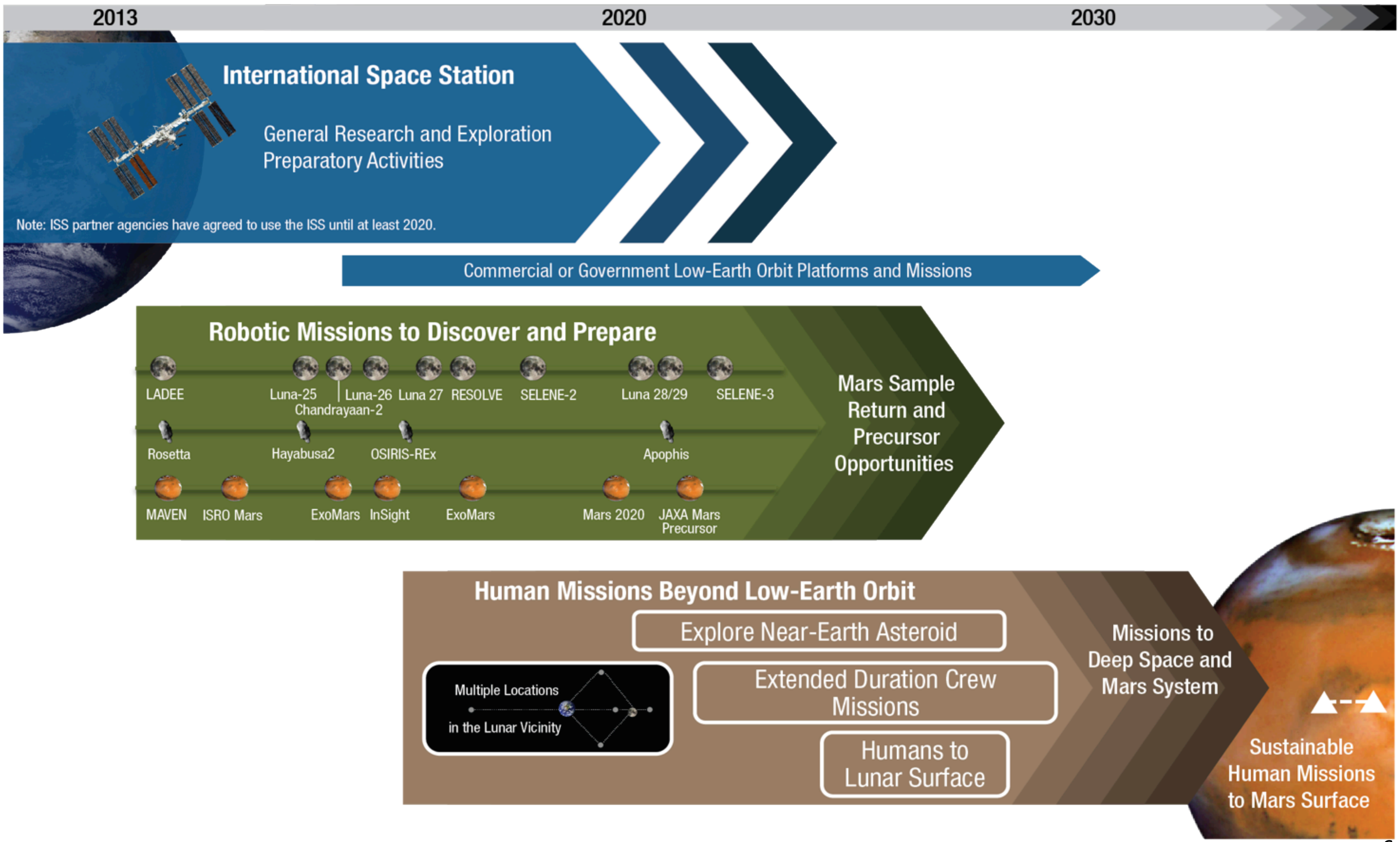
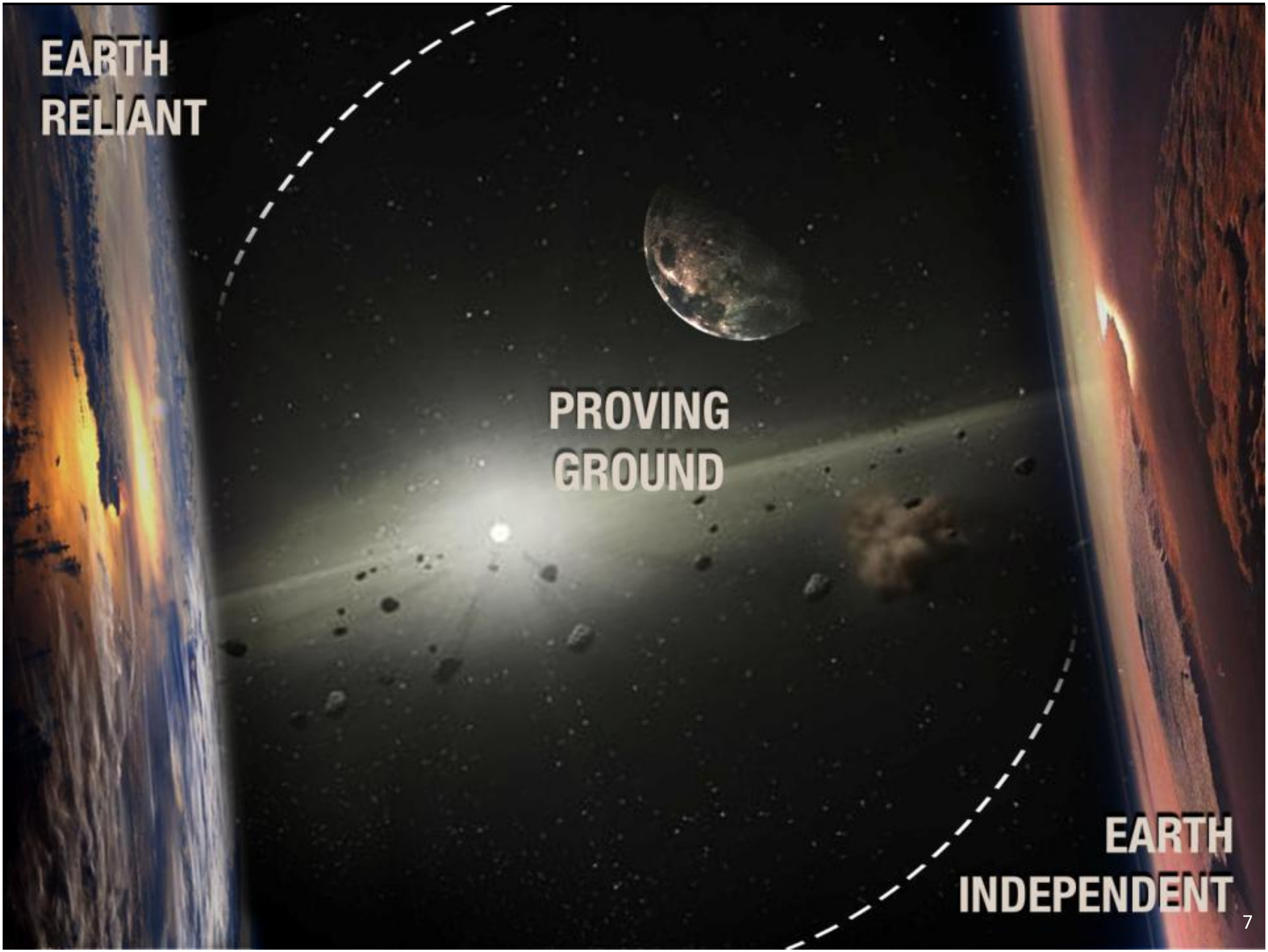
Strategic Principles for Exploration Implementation

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
6. Significant ***International and Commercial participation***, leveraging current International Space Station partnerships

Global Exploration Roadmap




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

Human and Health and Performance

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

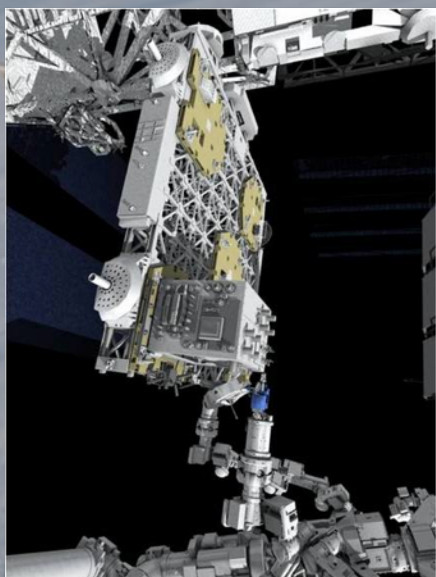
- **Hostile/closed environment**
  (including habitability: atmosphere, microbes, dust, volume/configuration, displays/controls,…)
  behavior/performance, nutrition, immunology, toxicology, microbiology

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

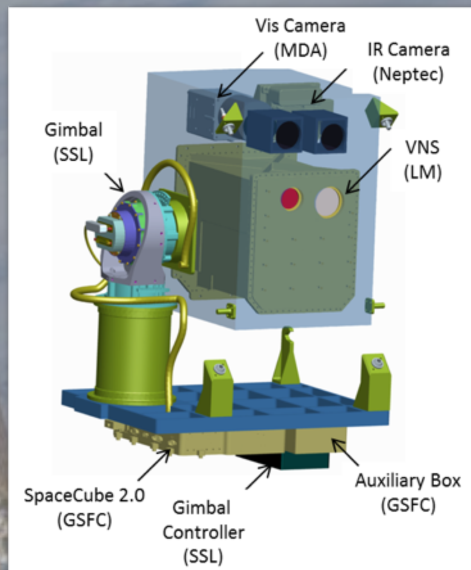
- **Distance from Earth**
  behavior/performance, autonomy, food systems, clinical medicine

Note that effect severity generally increases with mission duration.

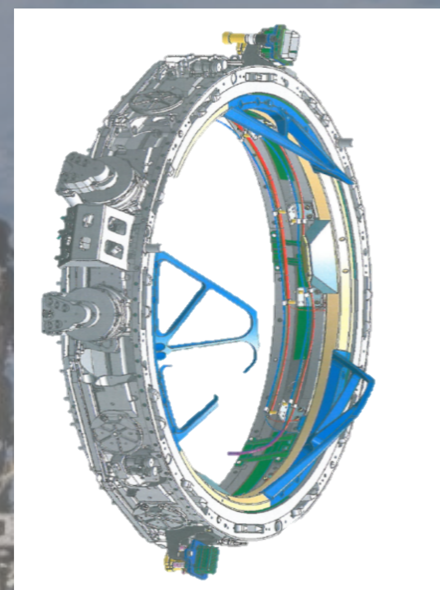
International Space Station: Exploration Platform



In-Space Robotic Servicing



Automated Rendezvous & Docking Sensors



International Docking System

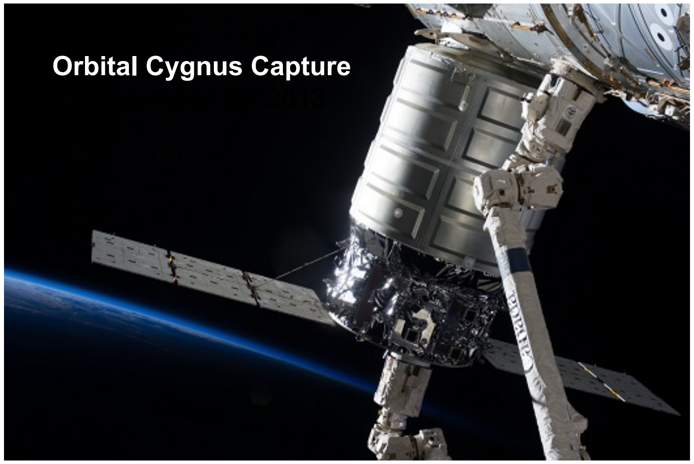
ECLSS/Amine Swingbed

The Next Step Beyond ISS

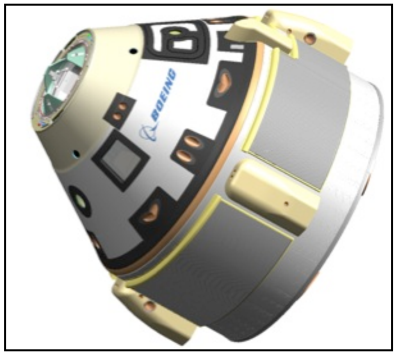
- Crew tended habitat in cis-lunar space
  - Builds off of the Asteroid redirect mission and ISS
    - Allows for further study of gravity assist trajectory operations
    - Builds off of ISS life support with less earth support
    - Enables international partner and commercial lunar surface activities
    - Develops incremental risk management concepts to be developed and accepted
    - Exposure to galactic cosmic background radiation
  - Allows for Mars operational strategies to be developed

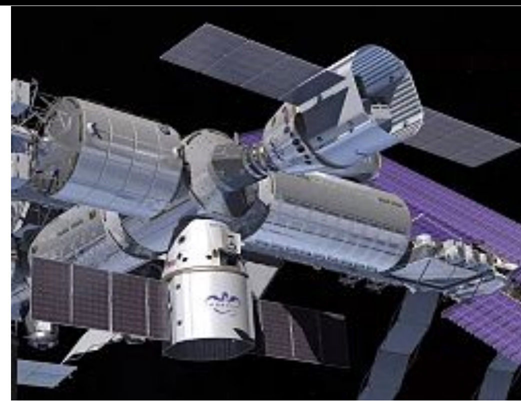

Commercial Cargo & Crew Transportation –
Freeing Up NASA to Explore
Beyond LEO

Now Acquiring ISS Cargo Services Commercially!



Commercial Crew Partners

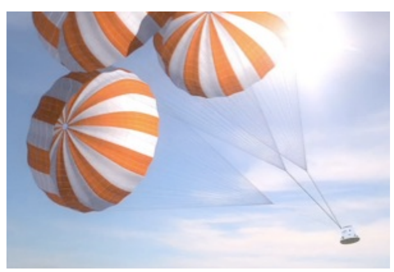




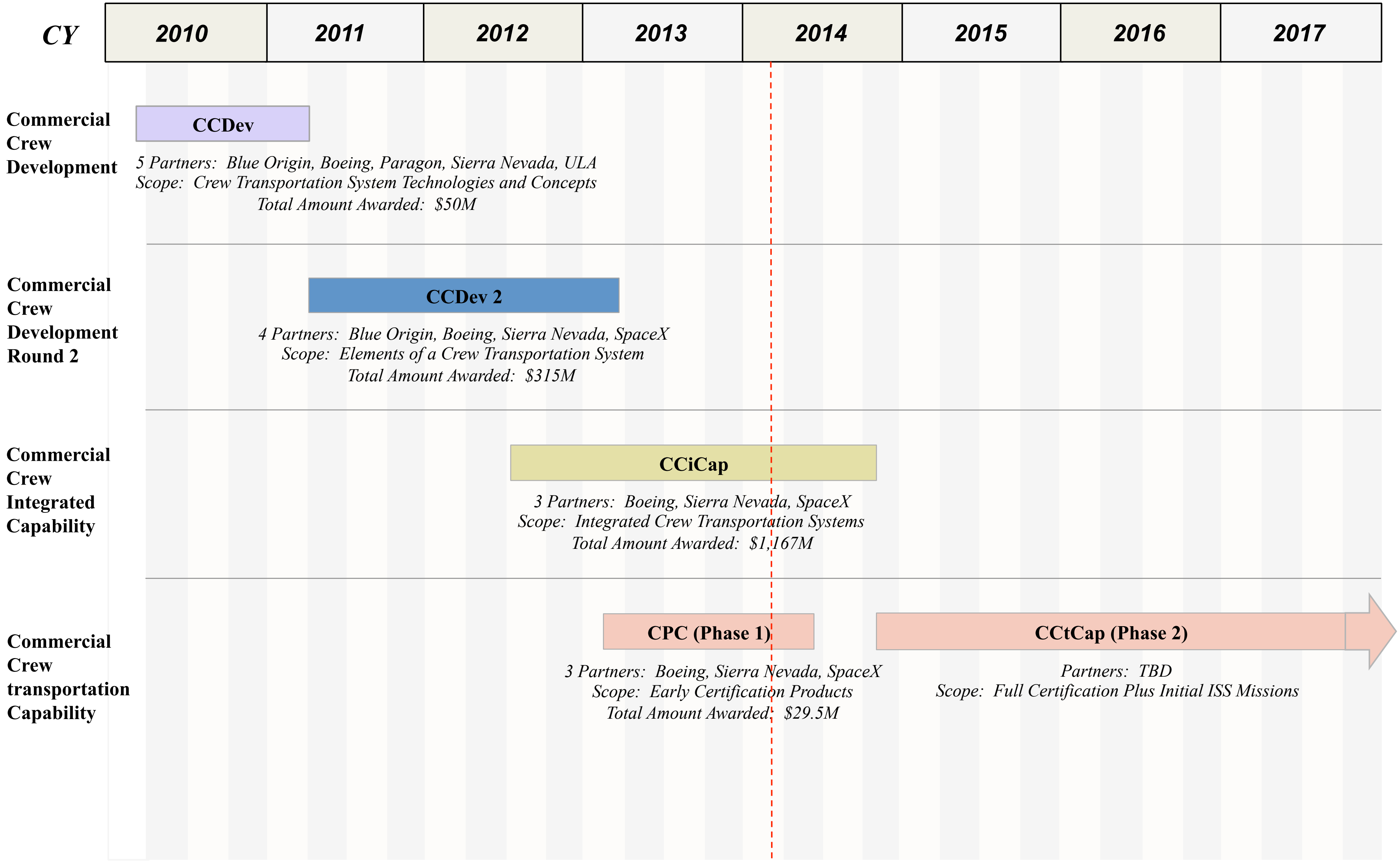
Boeing

Sierra Nevada

SpaceX

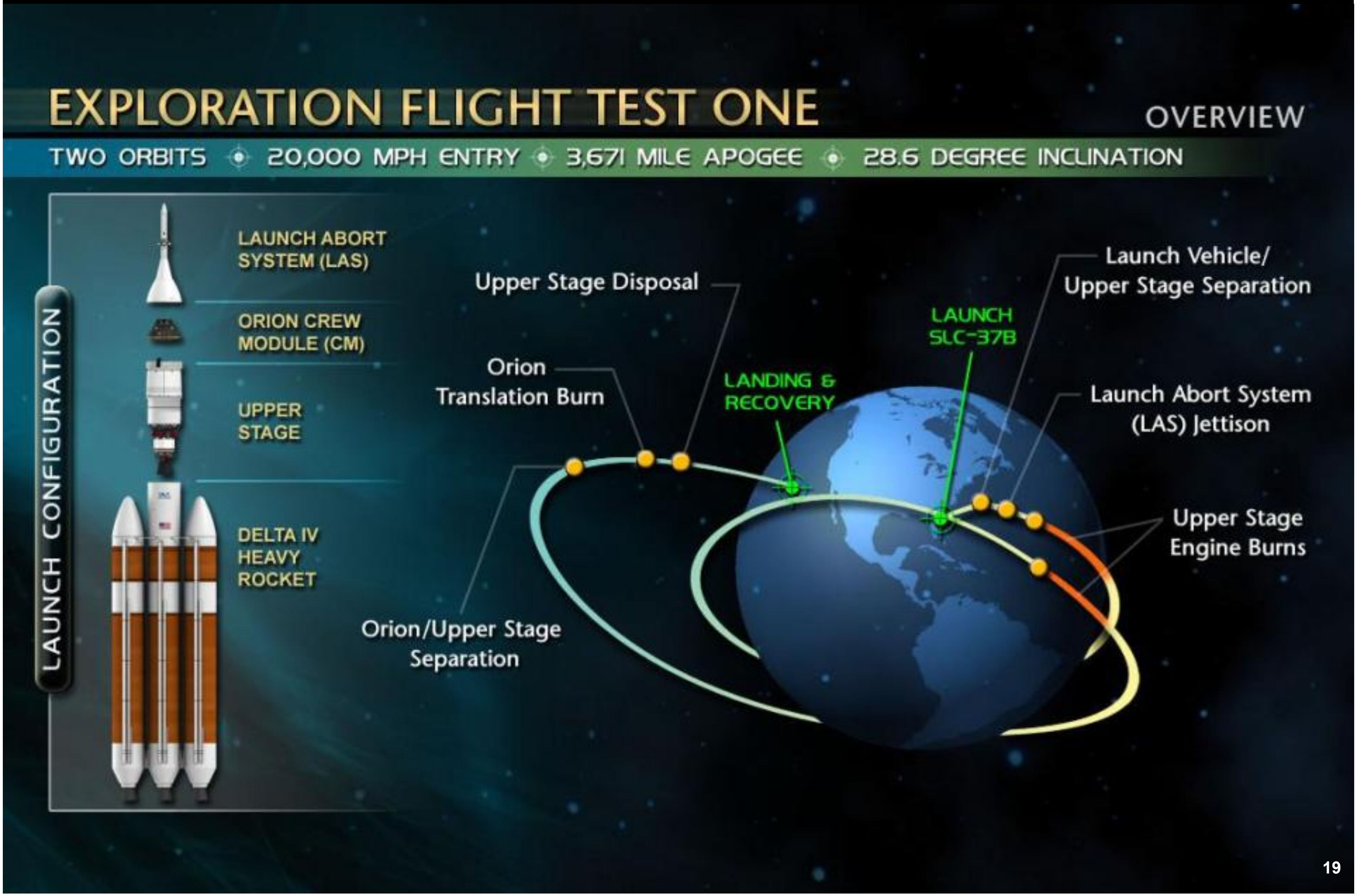


Human Exploration and Operations
Commercial Crew Program: Acquisition

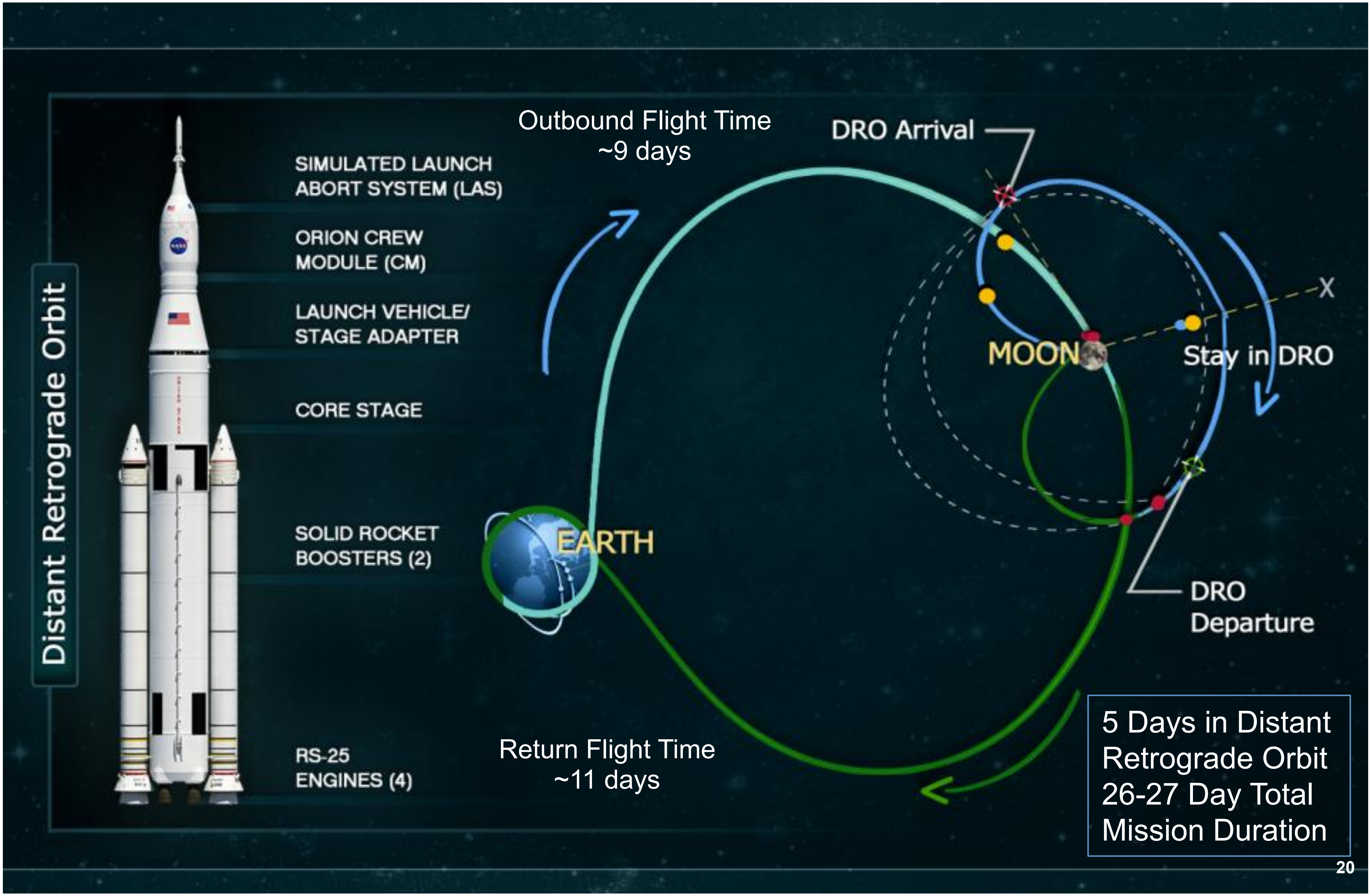


Space Launch System & Orion
– How We'll Get There

2014 Exploration Flight Test One (EFT-1)



Exploration Mission One (EM–1)

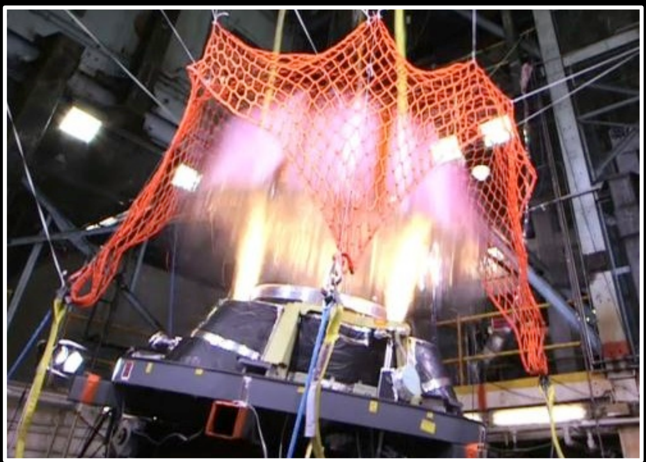


5 Days in Distant Retrograde Orbit
26-27 Day Total Mission Duration

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

Fairing separation test 2 at Lockheed Martin, Sunnyvale, CA

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

Service Module / Spacecraft Adaptor mate complete at O&C

Space Launch System

SLS is the rocket and launch system capable of transporting humans, habitats and support systems directly to deep space.

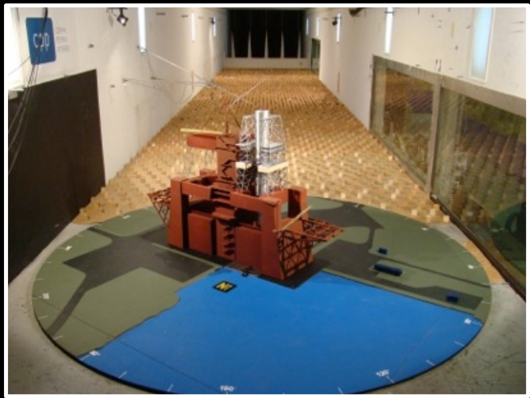
Powerful – High-Capacity – Flexible

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

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



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

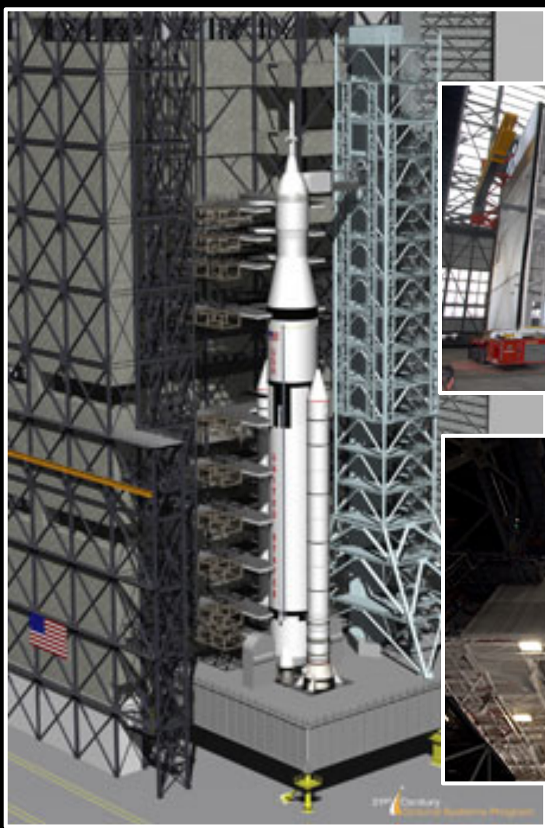
F-1B gas generator – tech demo for advanced booster concept

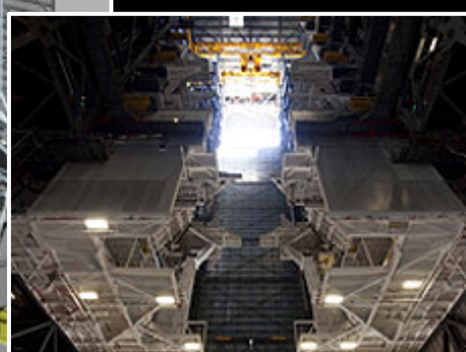
Ground Systems Development and Operations

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:

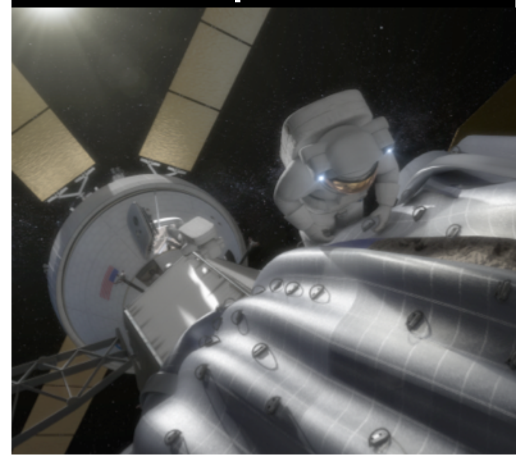
Ground and space based near Earth asteroid (NEA) target detection, characterization and selection

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

Asteroid Redirect Mission Objectives

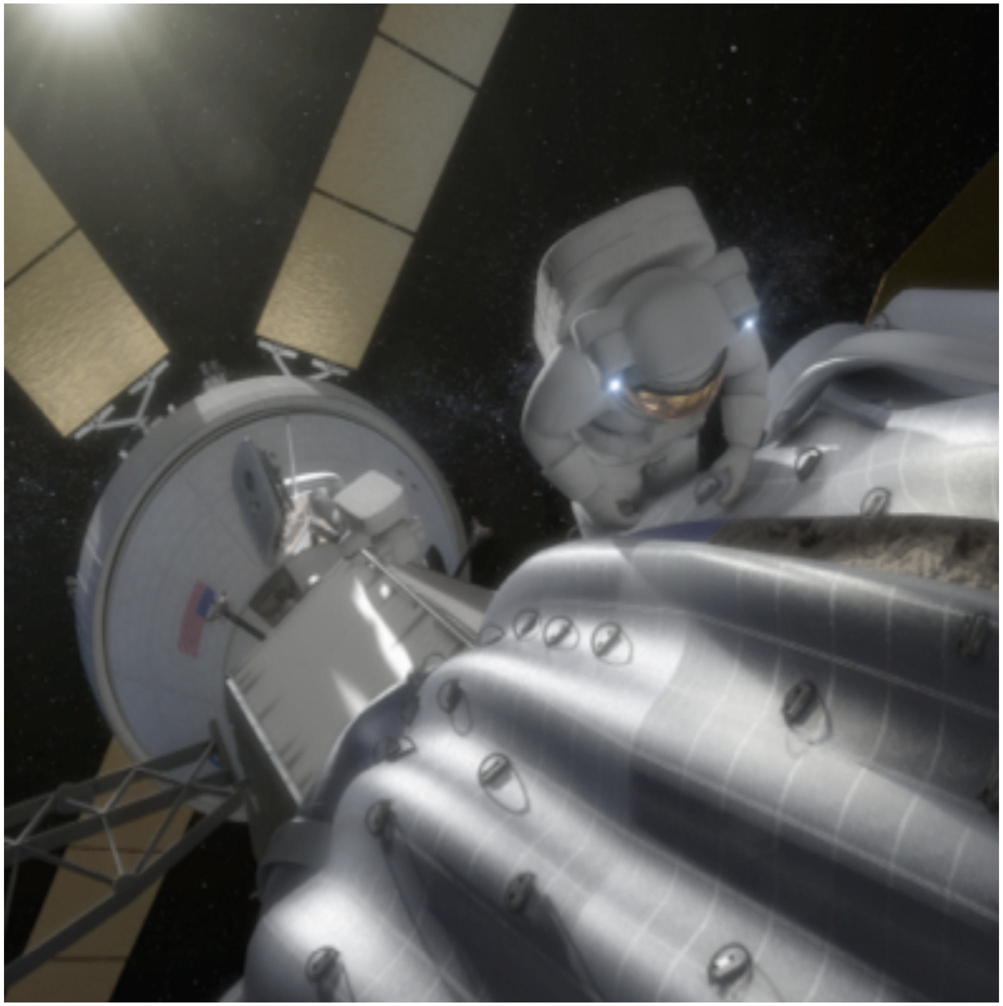
- Conduct a human exploration mission to an asteroid in the mid-2020's, providing systems and operational experience required for human exploration of Mars.
- Demonstrate an advanced solar electric propulsion system, enabling future deep-space human and robotic exploration with applicability to the nation's 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

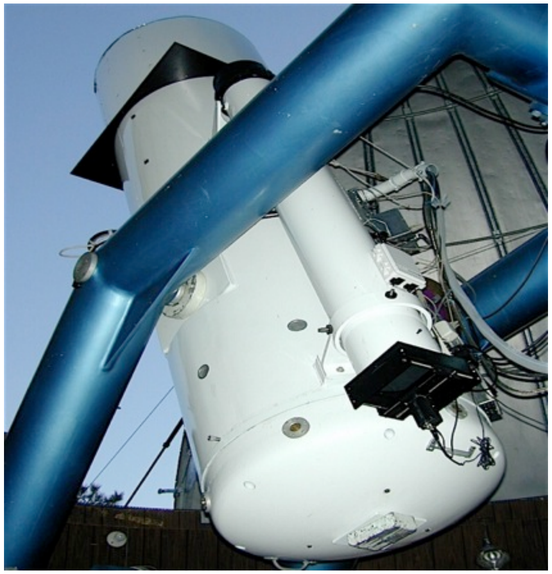
- **ARM integrates several building blocks of human space exploration to initiate deep space exploration**
  - **ISS experience**
  - **Orion and SLS**
  - **SEP and other technologies**

- **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

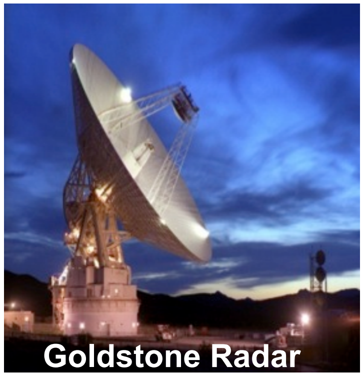
Catalina Sky Survey



University of Arizona – Tucson

NEOWISE reactivated and dedicated to NEO Search & Characterization

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

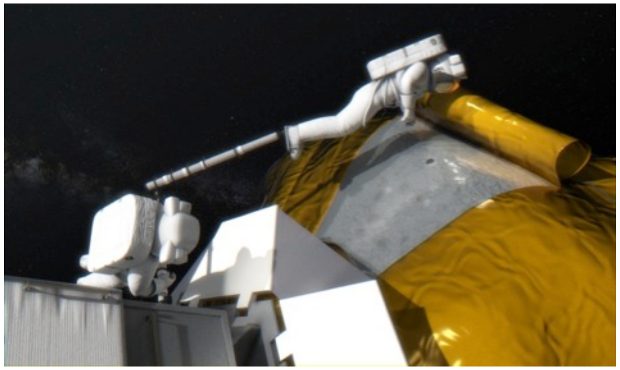


NASA InfraRed Telescope Facility (IRTF)

- Increase On-call for Rapid Response.
- Improve Instrumentation for Spectroscopy and Thermal Signatures.

Asteroid Redirect Robotic Mission Concept
Option A

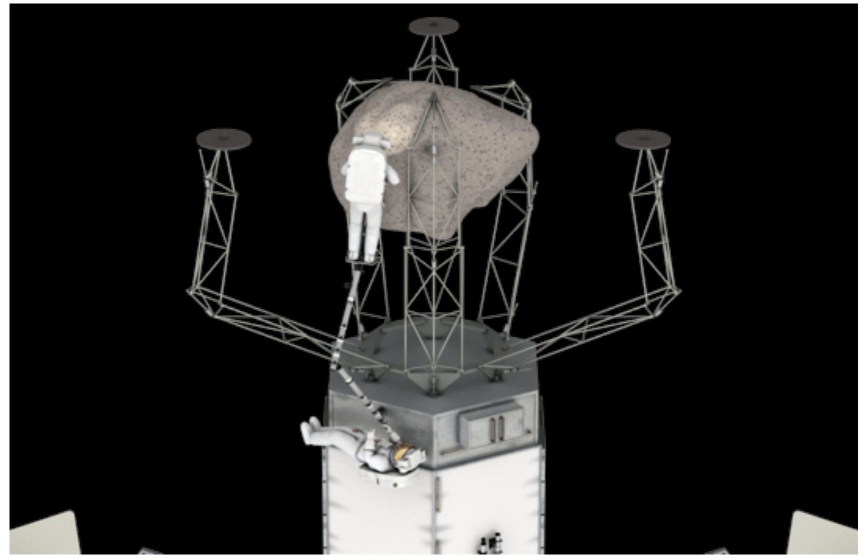
- **Rendezvous with small** less than **10 meter mean diameter Near Earth Asteroid (NEA)**
  - **Capture <1000 metric ton rotating NEA**
  - **Demonstrate planetary defense techniques**
  - **Maneuver to stable, crew accessible lunar Distant Retrograde Orbit (DRO)**
- **Candidate target is 2009 BD**
  - **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**



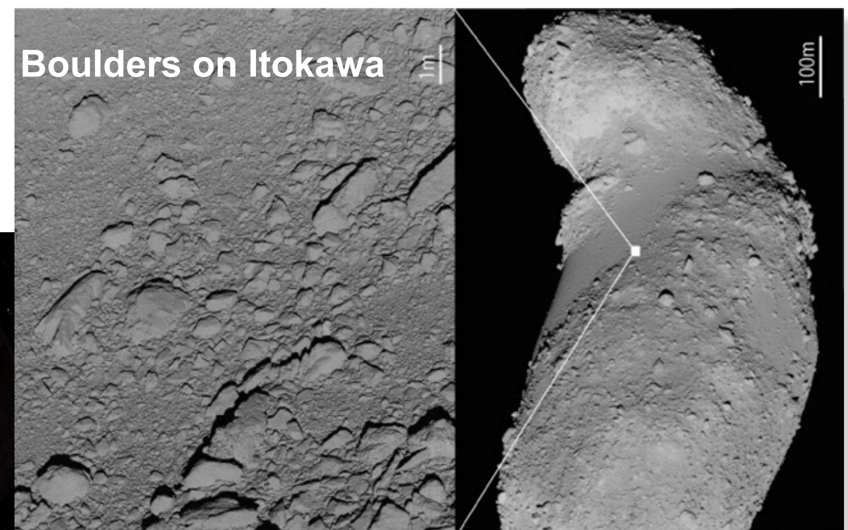
*** Launch vehicle dependent**

Asteroid Redirect Robotic Mission Concept (Option B)

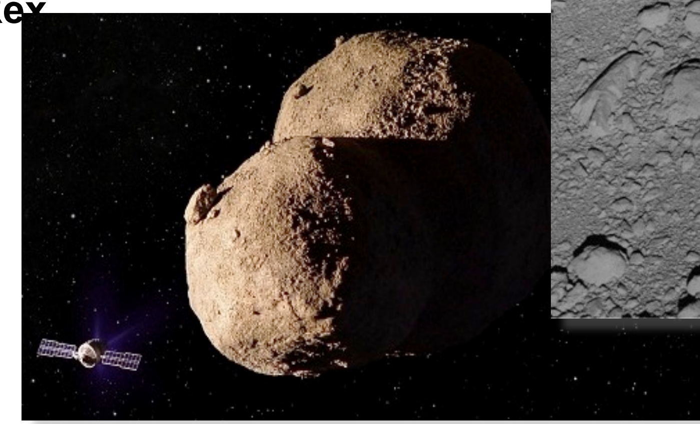
- Rendezvous with a larger (~100+meter diameter) NEA
  - **Collect ~2-4 meter diameter boulder (~10-70 metric tons)**
  - **Perform deflection demonstration(s) and track to determine effect**
  - **Return boulder to same lunar orbit**



- 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**

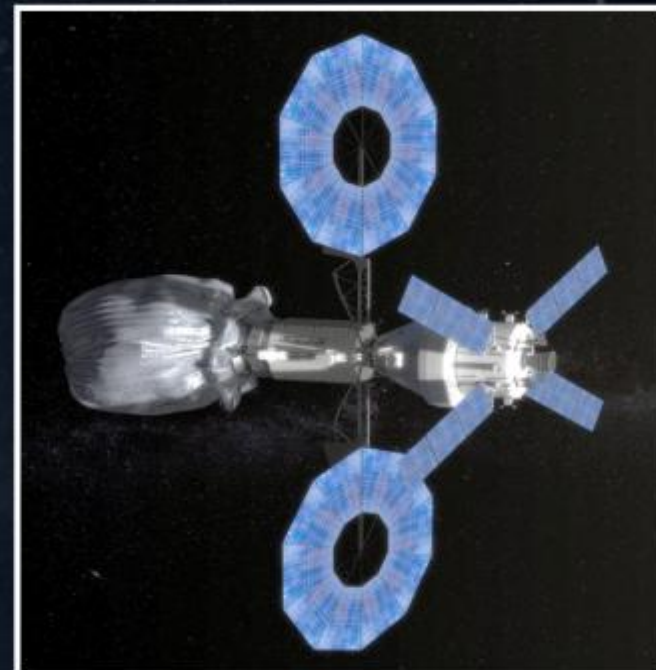


*** Launch vehicle dependent**

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

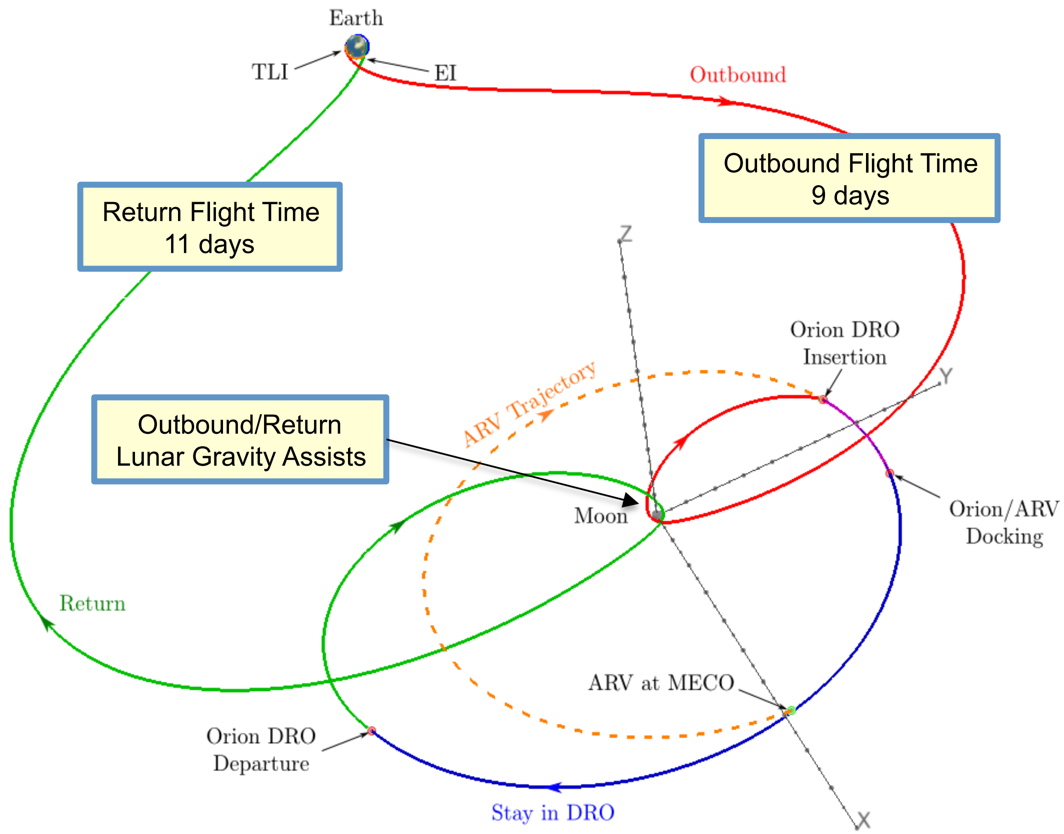
Crewed Mission Trajectory: Earliest Mission for 2009BD

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

- Total iCPS Δv: 2820 m/s (All iCPS capacity)
- Total Orion Δv: 1010 m/s
- Total Mission Duration: 25.65 days

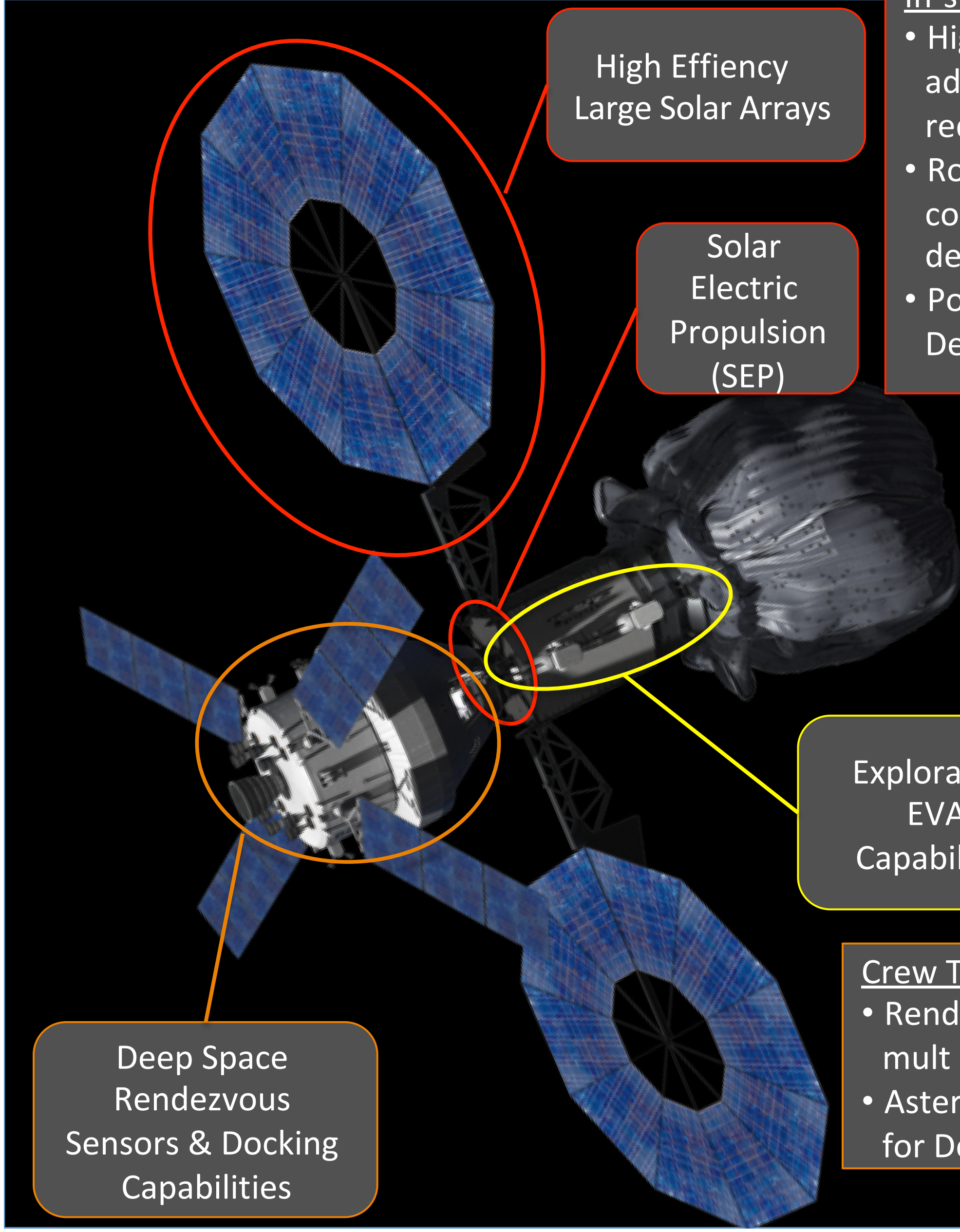
- Outbound
  - Flight Day 1 – Launch/TLI
  - Flight Day 1-7 – Outbound Trans-Lunar Cruise
  - Flight Day 7 – Lunar Gravity Assist
  - Flight Day 7-9 – Lunar to DRO Cruise
- Joint Operations
  - Flight Day 9-10 – Rendezvous
  - Flight Day 11 – EVA #1
  - Flight Day 12 – Suit Refurbishment, EVA #2 Prep
  - 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



Outbound Flight Time: 8 days, 9 hrs
Return Flight Time: 11 days, 6 hrs
Rendezvous Time: 1 day
DRO Stay Time: 5 days

Asteroid Redirect Mission Provides Capabilities For Deep Space/Mars Missions



<u>In-space Power and Propulsion:</u>

- 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

<u>EVA</u>:

- 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

<u>Crew Transportation and Operations:</u>

- Rendezvous Sensors and Docking Systems provide a mult i-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.

Next Steps –
Pathways into the Proving Ground of Cis-Lunar Space and On to Mars

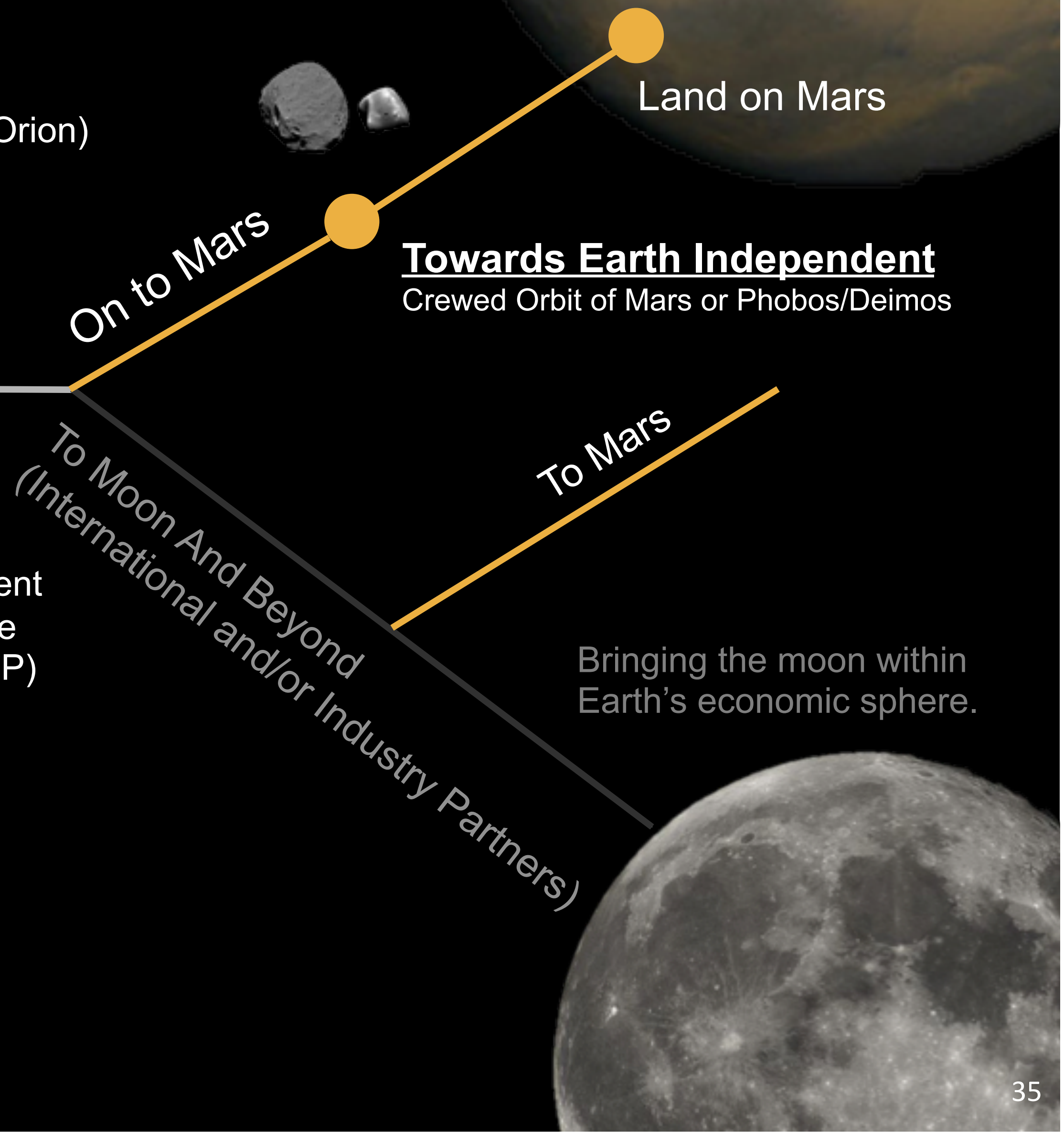
Human Exploration Pathways

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

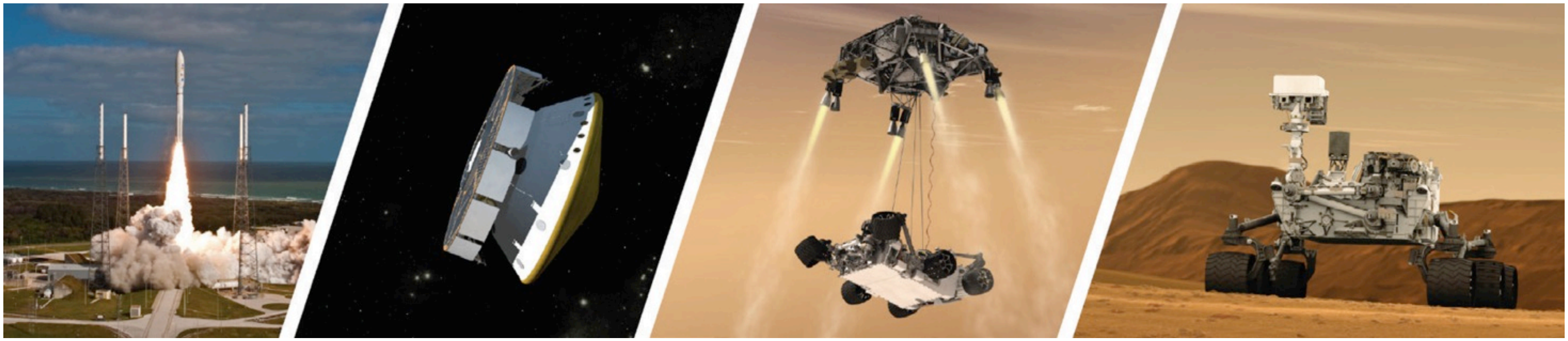


Solar System Exploration Research Virtual Institute (SSERVI)

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
Collaboration Among SMD, HEOMD and STMD



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.

Lunar
CATALYST

Lunar CArgo Transportation And Landing bY Soft Touchdown

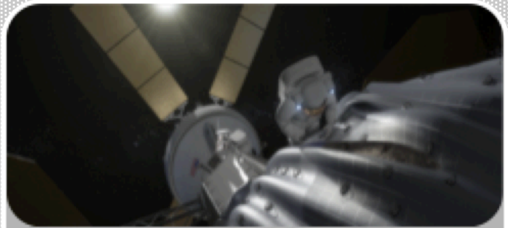
BRINGING THE MOON INTO EARTH'S ECONOMIC SPHERE

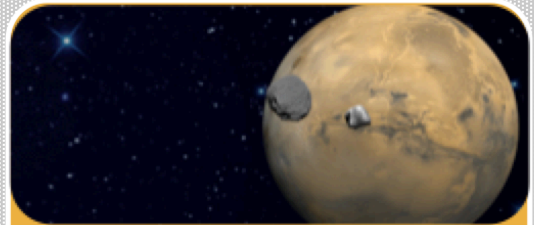
Accelerating private-sector lunar landing capabilities with NASA expertise using public-private partnerships

STATUS

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

Evolutionary Capabilities



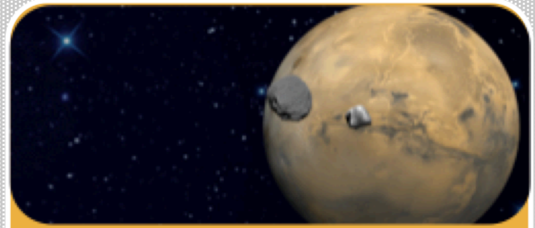


	EARTH RELIANT Return to Earth: hours	PROVING GROUND Return to Earth: days	EARTH INDEPENDENT Return to Earth: many months
Transportation	EARTH-BASED SUPPORT: HIGH *Low-Earth Orbit*	EARTH-BASED SUPPORT: LIMITED *Cis-lunar Space*	EARTH-BASED SUPPORT: NEGLIGIBLE *Mars and Beyond*
Crew Transit	• Routine crew rotations via international and industry partners • Earth Re-entry: 3,000°F	• 2-4 crew launch aboard evolvable Space Launch System • Orion Earth Re-entry: 5,300°F	• Up to 6 crew launch aboard Space Launch System • Orion Earth Re-entry: 5,500°F
Cargo Transit	• Routine cargo deliveries to LEO via industry and international partners	• 105t SLS to lunar vicinity	• 130t SLS to Mars and beyond • Crew must live and work without resupply from Earth
Propulsion & Energy Storage	• Large scale use of solar panels	• Demonstrate potential resource utilization techniques • Demonstrating high-power, advanced solar electric propulsion	• Potential to expand resource utilization • Utilizing large-scale solar electric and other advanced propulsion
Planetary rendezvous & landings	• Planetary rendezvous with strong gravity field	• Deep Space Rendezvous; gravity free • Lunar surface landers	• Phobos/Deimos micro-gravity Rendezvous • Mars entry, descent, landing on surface

Evolutionary Capabilities

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

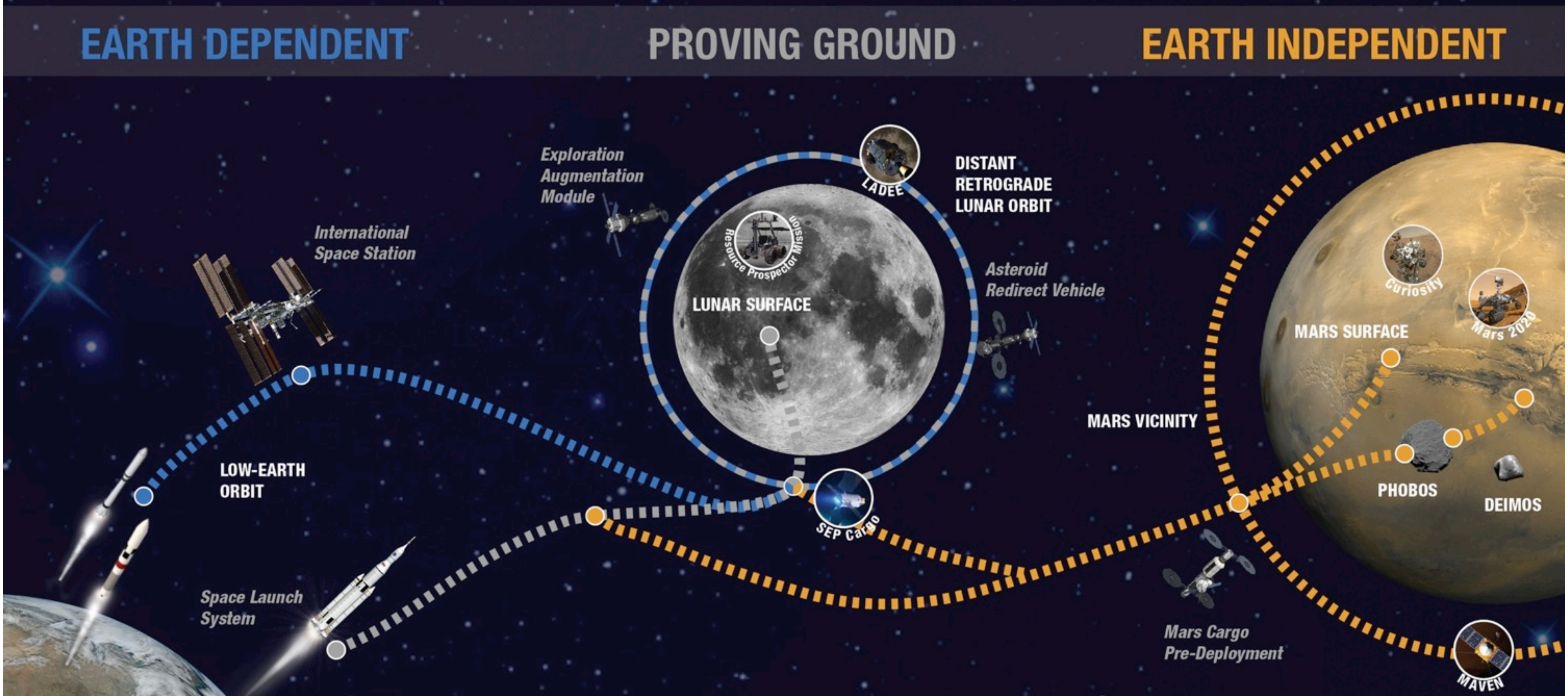
Evolutionary Capabilities



Staying Healthy	EARTH RELIANT Return to Earth: hours EARTH-BASED SUPPORT: HIGH *Mission Duration: 6-12 months*	PROVING GROUND Return to Earth: days EARTH-BASED SUPPORT: LIMITED *Mission Duration: 1-12 months*	EARTH INDEPENDENT Return to Earth: many months EARTH-BASED SUPPORT: NEGLIGIBLE *Mission Duration: 2-3 years*
Spacecraft Life Support Systems	• Developing onboard life support systems for long-duration missions	• Validating onboard recycling and regenerating life support systems without resupply	• Living and working in spacecraft that must fully support crew for years
Human Health and Performance	• Studying space environment health risks and testing solutions	• Applying health and performance risk mitigation techniques	• Living in space for years while maintaining crew health and performance
Autonomous Medicine	• Developing integrated medical capability and crew-reliant medical care	• Testing semi-autonomous integrated medical capability and crew-reliant medical treatment	• Autonomous medical capability and medical crewmember for diagnosis and treatment
Environmental Monitoring	• Testing on-board environmental monitors with ground validation	• Demonstrating onboard environmental monitoring systems (no sample return)	• Monitoring crew environment for hazards, eliminating environmental emergencies
Advanced Space Suits	• Testing next-generation space suits	• Demonstrating advanced space suits in deep space	• Conducting EVAs in unprecedented planetary environments

EVOLVABLE 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

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