National Aeronautics and Space Administration

NASA's Capability Driven Roadmap for Human Spaceflight

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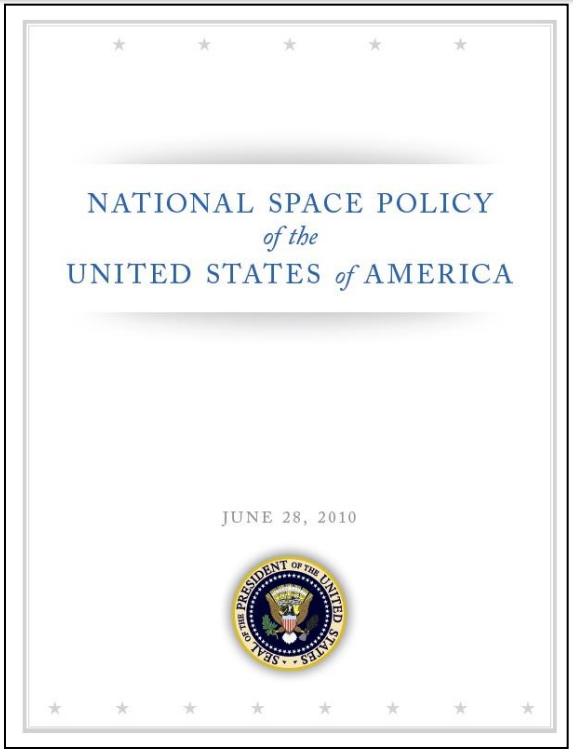
U.S. National Space Policy Goals

- **Energize competitive domestic industries**
- **Expand international cooperation**
- **Strengthen stability in space**
- **Increase assurance and resilience of mission-essential functions**
- **Pursue human and robotic initiatives**
- **Improve space-based Earth and solar observation**



"NASA has a key role in achieving the goals defined in the new policy. We are committed to working with other agencies, industry, and international partners to achieve national goals in exploration - human and robotic - and technology development that will ensure a robust future for the U.S. and our friends around the world." – *NASA Administrator Charles Bolden, June 28, 2010*

U.S. Law: NASA Authorization Act of 2010, 2012 Appropriations

- **The U.S. Congress approved and President Obama signed the NASA Authorization Act of 2010 (section 202) and 2012 Appropriations Act**
  - Bipartisan support for human exploration beyond low Earth orbit
- **The law authorizes:**
  - Extension of the International Space Station until at least 2020
  - Support for a commercial space transportation industry
  - Development of a Multi-purpose Crew Vehicle and heavy lift launch capabilities
  - A "flexible path" approach to space exploration opening up vast opportunities including near-Earth asteroids (NEA), moon, and Mars
  - New space technology investments to increase the capabilities beyond low Earth orbit




NASA Authorization Act of 2010, Section 202

- **SEC. 202. GOALS AND OBJECTIVES.**
-

(a) LONG TERM GOAL. 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.

(b) KEY OBJECTIVES. The key objectives of the United States for human expansion into space shall be-

(1) to sustain the capability for long-duration presence in low-Earth orbit, initially through continuation of the ISS and full utilization of the United States segment of the ISS as a National Laboratory, and through assisting and enabling an expanded commercial presence in, and access to, low-Earth orbit, as elements of a low-Earth orbit infrastructure;
(2) to determine if humans can live in an extended manner in space with decreasing reliance on Earth, starting with utilization of low-Earth orbit infrastructure, to identify potential roles that space resources such as energy and materials may play, to meet national and global needs and challenges, such as potential cataclysmic threats, and to explore the viability of and lay the foundation for sustainable economic activities in space;
(3) to maximize the role that human exploration of space can play in advancing overall knowledge of the universe, supporting United States national and economic security and the United States global competitive posture, and inspiring young people in their educational pursuits; and
(4) to build upon the cooperative and mutually beneficial framework established by the ISS partnership agreements and experience in developing and undertaking programs and meeting objectives designed to realize the goal of human space flight set forth in subsection (a).

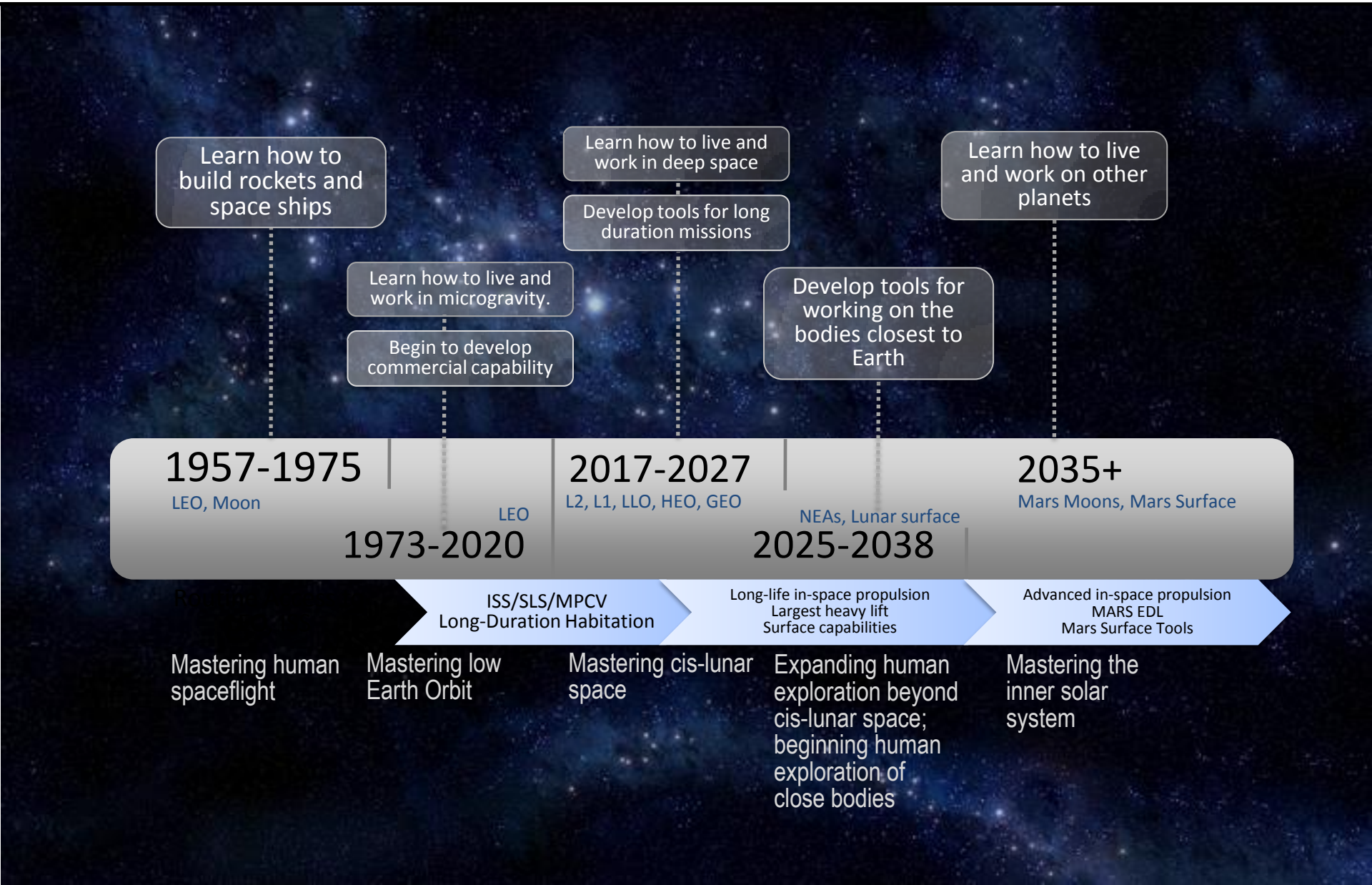
The NASA Vision

To reach for new heights and reveal the unknown, so that what we do and learn will benefit all humankind.

NASA Strategic Goals

- **Extend and sustain human activities across the solar system.**
- **Expand scientific understanding of the Earth and the universe in which we live.**
- **Create the innovative new space technologies for our exploration, science, and economic future.**
- **Advance aeronautics research for societal benefit.**
- **Enable program and institutional capabilities to conduct NASA's aeronautics and space activities.**
- **Share NASA with the public, educators, and students to provide opportunities to participate in our mission, foster innovation, and contribute to a strong national economy.**

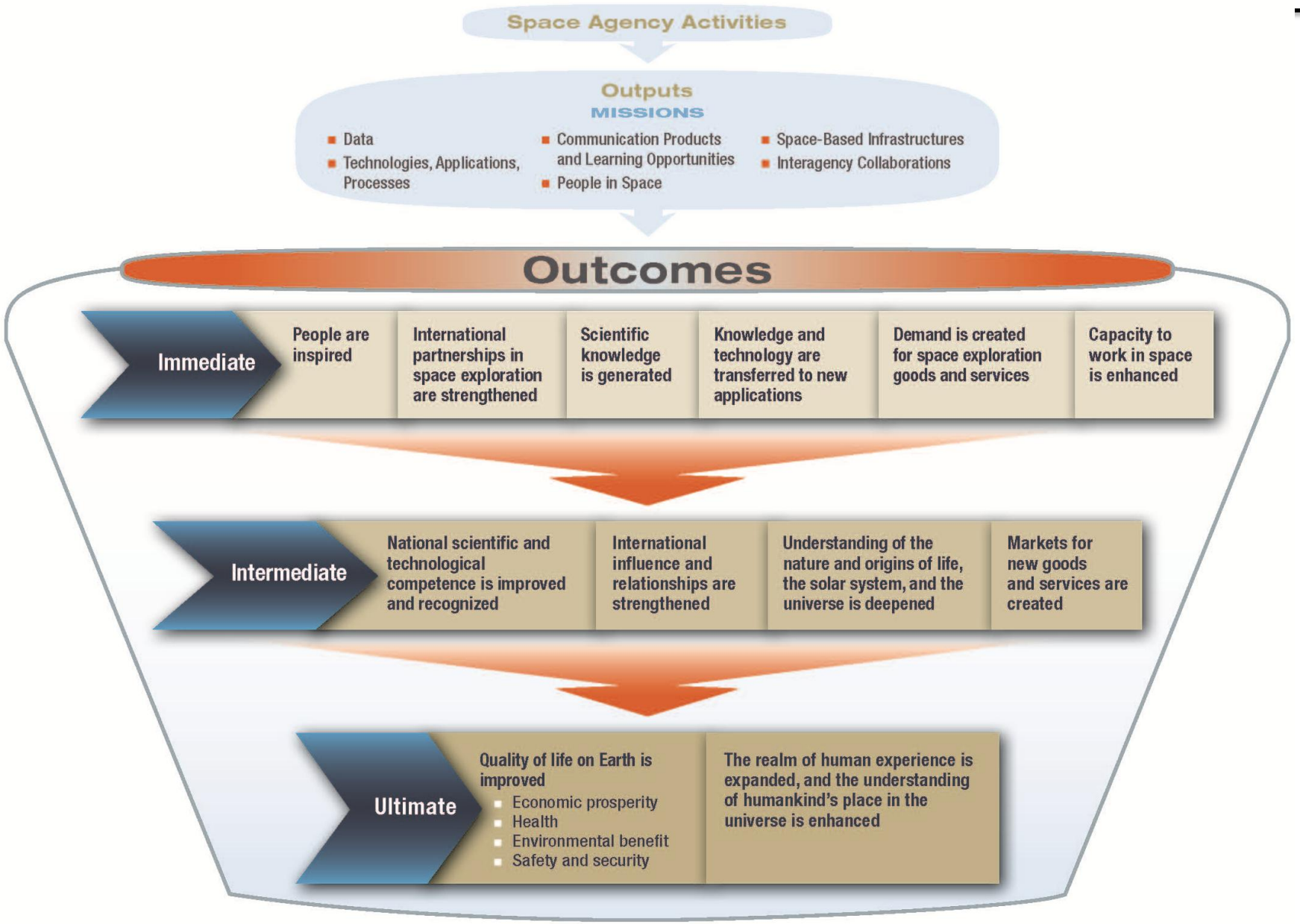
The Story of Human Space Exploration (Animated)



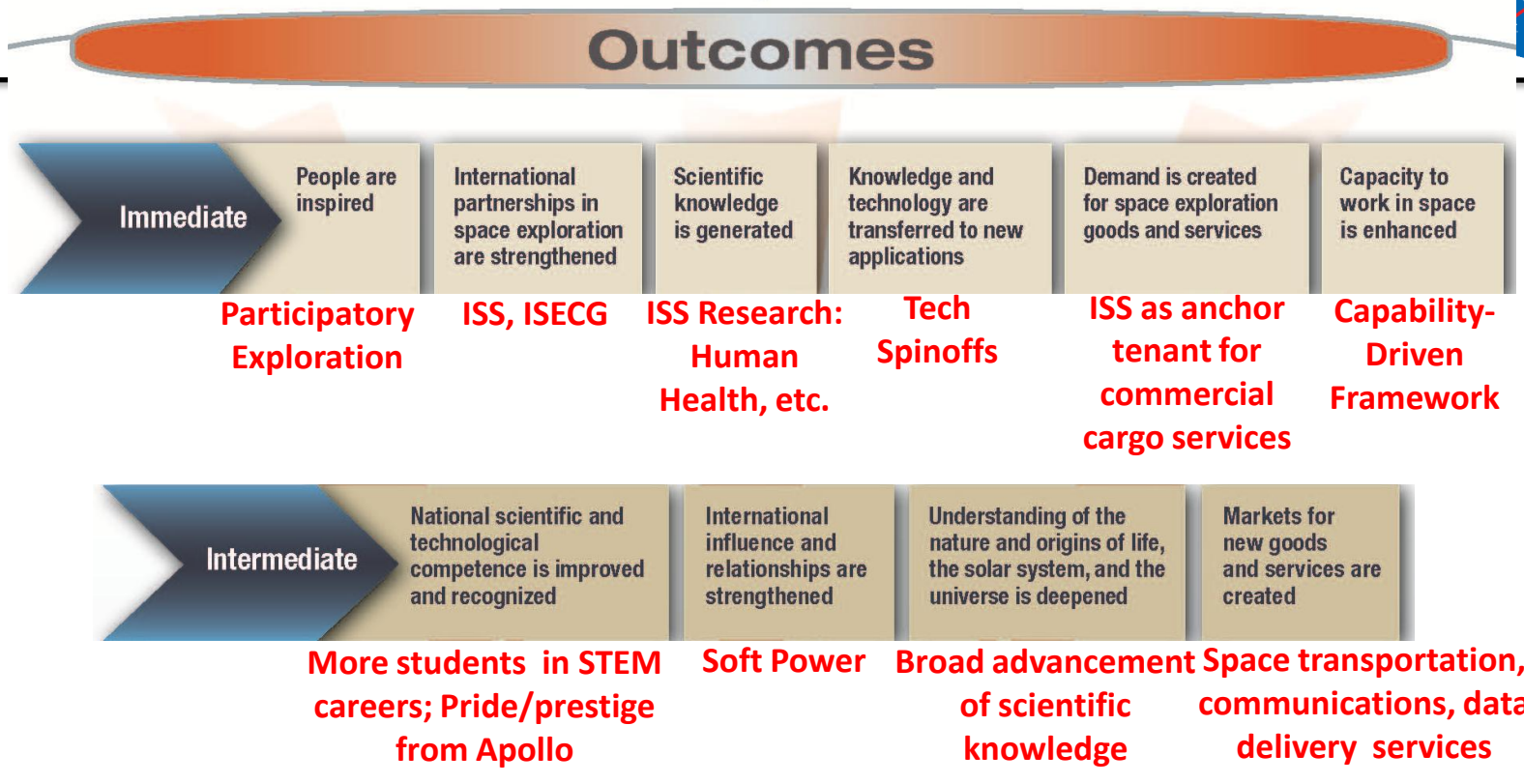
Common International Space Exploration Coordination Group (ISECG) Goals

- Common goals are needed, but recognized individual agency goals are what is important to an agency
  - Search for Life
  - Extend Human Presence
  - Perform Space, Earth, and Applied Science
  - Perform Science to Support Human Exploration
  - Develop Exploration Technologies and Capabilities
  - Stimulate Economic Expansion
  - Enhance Earth Safety
  - Engage the Public in Exploration
- GER reflects common goals and supporting objectives
- These are to be iterated and will reflect agency/national priorities

An Evolving Space Exploration Logic Model



The NASA Context: Some Examples...



INCREMENTAL EXPANSION OF HUMAN EXPLORATION CAPABILITIES (Initial Version)

Capabilities required at each destination are determined by the mission and packaged into elements. Capability-Driven Framework approach seeks to package these capabilities into a logical progression of common elements to minimize DDT&E and embrace incremental development.

Distance

Surface Capabilities Needed

Long Duration Habitation Needed

Advanced Propulsion Needed

High Thrust in-Space Propulsion Needed

Mission Duration

Mars Missions 35A 35B

Mars Elements

6: Enable Mars Missions

Full Capability NEA ...ions 34B

Space Explo... Vehicle (SEV)

Solar Electric Propulsion (SEP)

5: Enable Deep Space Missions

Minimal NEA Missions 34A

Deep Space Habitat (DSH)

4: Enable Long Duration Missions

Lunar Surface Missions

Crew EVA Suit Block 2

Lunar Lander & GPOD

3: Enable Lunar Surface Missions

Lunar Flyby &Orbital Missions 33A 33B

GEO/HEO Missions 32A 32B

Cryogenic Propulsion Stage (CPS)

2: Enable Missions Beyond LEO

Robotics & EVA Module (REM)

Crew EVA Suit Block 1

New LEO Missions 31A

Multi-Purpose Crew Vehicle (MPCV)

Space Launch System - HLLV

1: Enable New LEO Missions

Key

Capability Gates

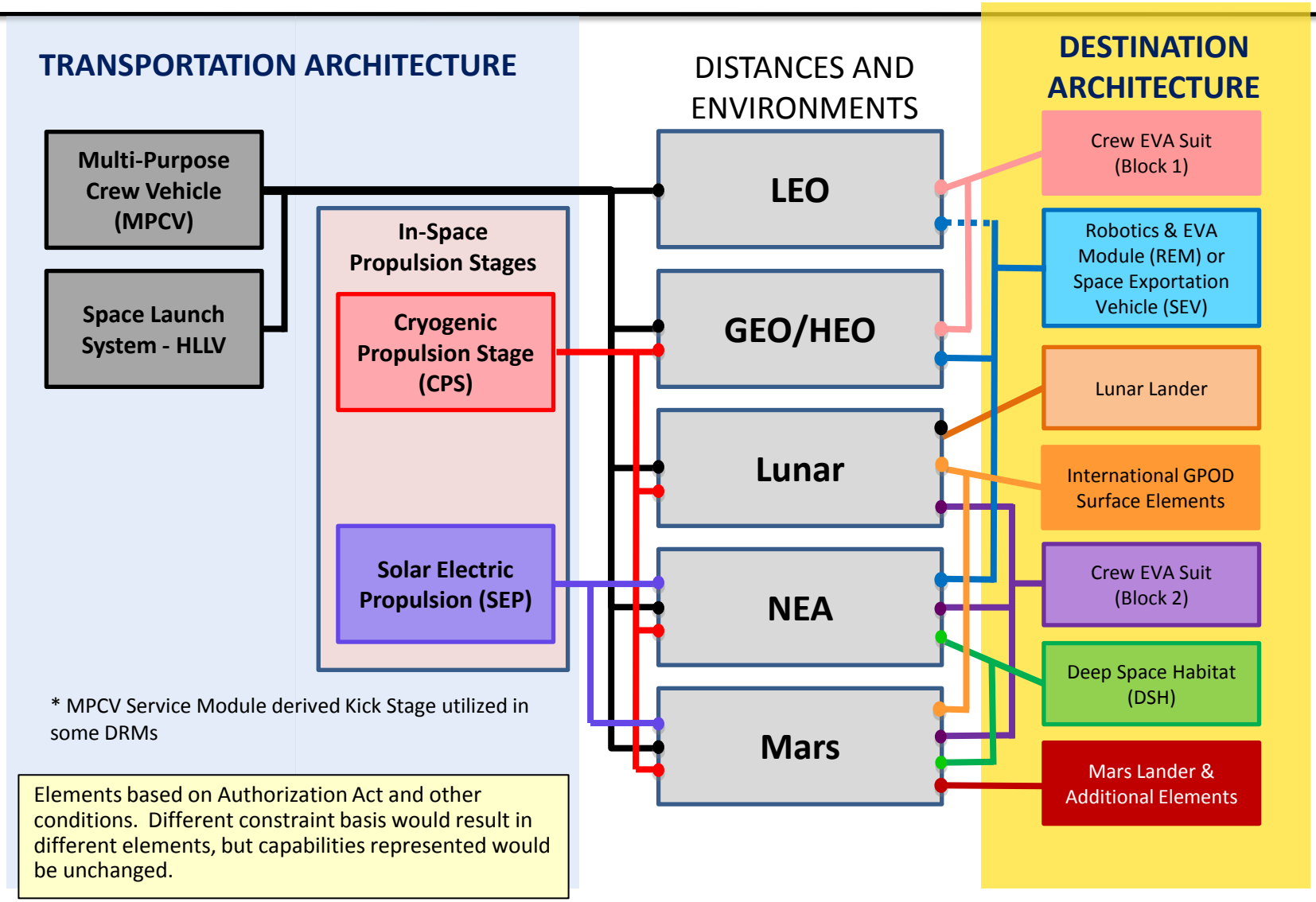
Candidate Destination

Ultimate Destination Goal

Element Capability

DRM

Transportation and Destination Architectures for Flexible Path (Initial Version)



Capability Driven Human Space Exploration (Current Version)

Capability-Driven Framework Overview

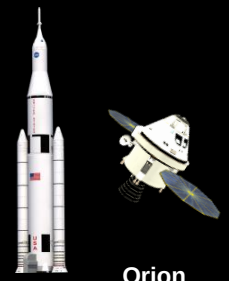
- **Objective: Enable a capability-driven approach to human exploration rather than one based on a specific destination and schedule**
- **Rationale: Most viable approach given political and economic dynamics – enables incremental and sustained progress**
- **Evolving capabilities are based on:**
  - Previously demonstrated capabilities and operational experience
  - New technologies, systems and flight elements development
  - Concept of minimizing destination-specific developments
- **Multiple possible destinations/missions are enabled by each discrete level of capability (known by analysis and evolved through experience)**
- **Allows reprioritization of destination/missions by decision-makers without wholesale abandonment of then-existing exploration architecture**

A Capability-Driven Framework enables multiple destinations and provides increased flexibility, greater cost effectiveness, and sustainability.

Common Capabilities Identified for Exploration

Capability Driven Human Space Exploration

ISS



SLS

Orion MPCV

Architecture Common Capabilities (Building Blocks)

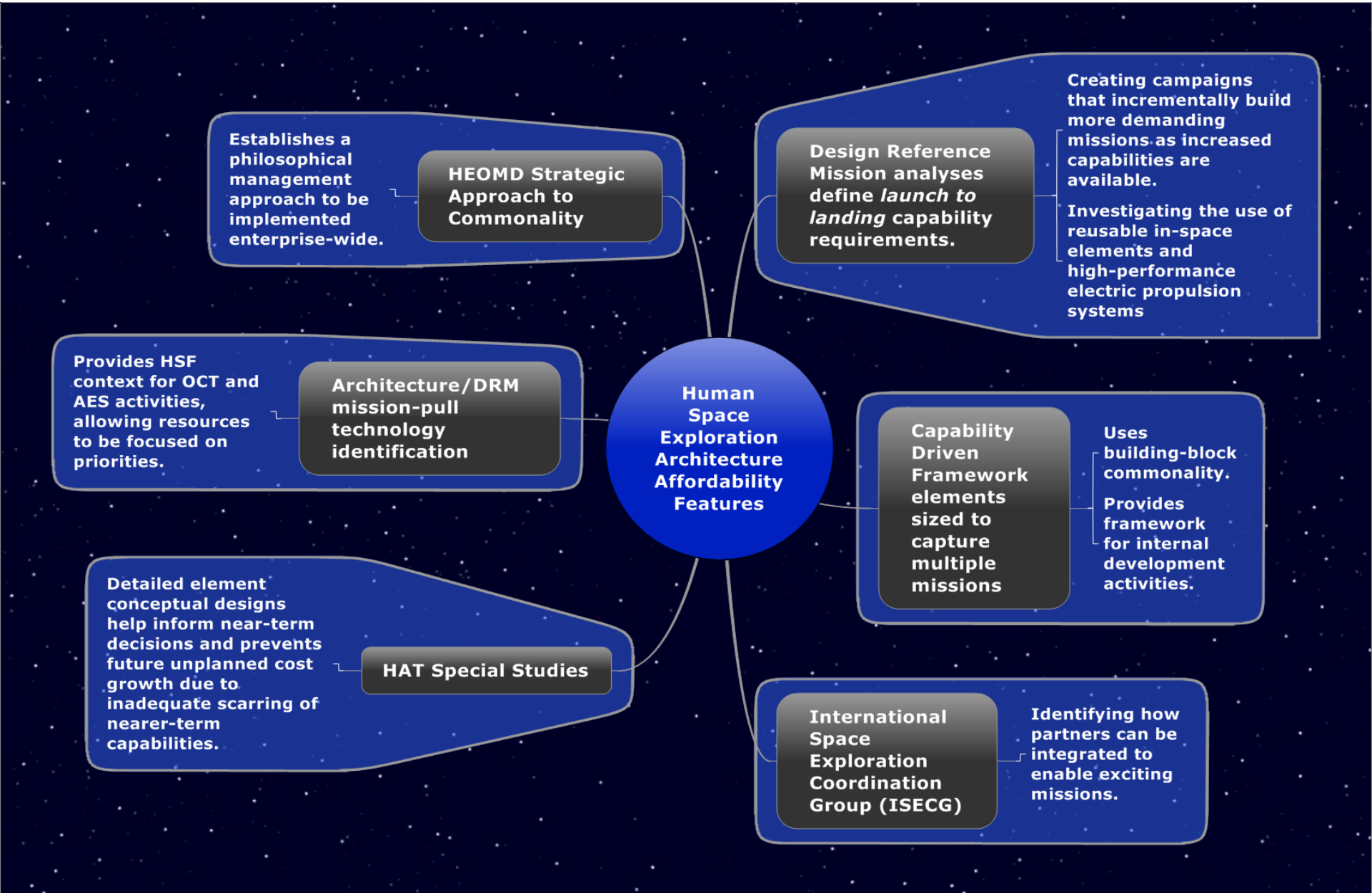
Low Earth Orbit Crew and Cargo Access	Human -Robotic Mission Ops	In-Space Propulsion	Adv. In-Space Propulsion	Deep Space Habitation	Ground Operations
Beyond Earth Orbit Crew and Cargo Access	Robotic Precursor	EVA	Mobile EVA and Robotic Platform	Destination Systems	Autonomous Mission Operations

Technologies, Research, and Science

OCT Technology Development Efforts	AES Proposals
HEO and SMD Cross Cutting Research & Science	Human Exploration Specific Technologies

ISS, SLS, and MPCV are the cornerstones of the Exploration Enterprise, but concurrent, innovative, and extremely lean Beyond-LEO incremental capability development is vital.

Affordable Human Space Exploration: Key Driver



NASA's Human Spaceflight Architecture Team (HAT)

- **On-going, cross-Agency, multi-disciplinary, study team that conducts strategic analysis cycles to assess integrated development approaches for architectures, systems, mission scenarios, and Conops for human and related robotic space exploration.**
  - During each analysis cycle, HAT iterates and refines design reference mission (DRM) definitions to inform integrated, capability-driven approaches for systems planning within a multi-destination framework.
- **Key Activities in 2011 – Cycles A, B, C, D**
  - Prepared DRMs that frame key driving level 1 requirements for SLS & Orion MPCV
  - Developed technical content & mission definitions for discussion with the international community developing the Global Exploration Roadmap
  - Advanced Capability Driven Framework (CDF) concept including more extended reviews of both capabilities needed and development options.
  - Provided technical links between CDF and level 1 requirements for SLS/MPCV
  - Developed performance data for key decisions on SLS initial capability and upper stage options

HAT Areas of Focus

Recent Architecture Work Is Focusing More Here

Initial Architecture Work Focused Here

Future Architecture Work Will Refine Here

Design Reference Missions (DRMS)

- *Destination DRMS – What is done at the destination: drives mission operations, element functions and transportation needs*
- *Transportation DRMs – How the crew and supporting systems get to the destination and back to Earth: drives element functions for transportation segment, launch vehicle requirements*

Elements Required By Destination

Phase	Required Element	Capability	For Destinations				
			L1/L2	Lunar Surface	Asteroid	Mars Orbit	Mars Surface
Getting There	Space Launch System (SLS)	Launch	X	X	X	X	X
	Cryo Propulsion Stage (CPS)	High Thrust/Near Earth	X	X	X	Option	Option
	Solar Electric Propulsion (SEP)	Low Thrust/Near Earth			Option	Option	Option
	Nuclear Thermal Propulsion (NTP)	High Thrust/Beyond LEO			Option	Option	Option
	Nuclear Electric Propulsion (NEP)	Low Thrust/Beyond LEO			Option	Option	Option
	Depot	In-Space Logistics	Option	Option		Option	Option
	Deep Space Habitat (DSH)	In-Space Habitation	X		X	X	X
	Landers	Descent		X			X
Working There	Surface Hab	Surface Habitation		X			X
	Multi-Mission Space Exploration Vehicle (MMSEV)	Micro-g Sortie			X	X	
	Cargo Hauler	Cargo Mobility	Option	Option	Option	Option	Option
	Robotics and EVA Module (REM)	Logistics/Resupply	Option		Option	Option	
	In-Situ Resource Utilization (ISRU)	In Situ Resource Utilization		X			X
	Fission Surface Power System	Surface Power		Option			X
	Surface Rover	Surface Mobility		X			X
	EVA Suits	EVA (nominal)	X	X	X	X	X
Coming Home	Ascent Vehicle	Ascent		X			X
	Orion	Crew Return	X	X	X	X	X

Exploration Capabilities

Required

Increasing Energy From Earth

	LEO	E-M L1/L2	LLO	Lunar Surface	GEO	E-S L1/L2	NEA	Phobos Deimos	Mars Surface
In-Space Propulsion		■	■	■	■	■	■	■	■
DSH - Zero g		■				■	■	■	■
DSH - Partial g				■					■
Mobile EVA/Robotic				■			■	■	■
Fixed EVA/Robotic		■			■	■			
Adv. EVA for Exploration				■			■	■	■
Expl. ECLS (Regen, 8psi)		■		■		■	■	■	■
Autonomous Mission Ops.			■	■	■	■	■	■	■
Human-Robotic Mission Ops	■	■	■	■	■	■	■	■	■

Matured Using Cis-lunar Gateway

Increasing Energy From Earth

	LEO	E-M L1/L2	LLO	Lunar Surface	GEO	E-S L1/L2	NEA	Phobos Deimos	Mars Surface
In-Space Propulsion		■	■	■	■	■	■	■	■
DSH - Zero g		■				■	■	■	■
DSH - Partial g				■					■
Mobile EVA/Robotic				■			■	■	■
Fixed EVA/Robotic		■			■	■			
Adv. EVA for Exploration				■			■	■	■
Expl. ECLS (Regen, 8psi)		■		■		■	■	■	■
Autonomous Mission Ops.			■	■	■	■	■	■	■
Human-Robotic Mission Ops	■	■	■	■	■	■	■	■	■

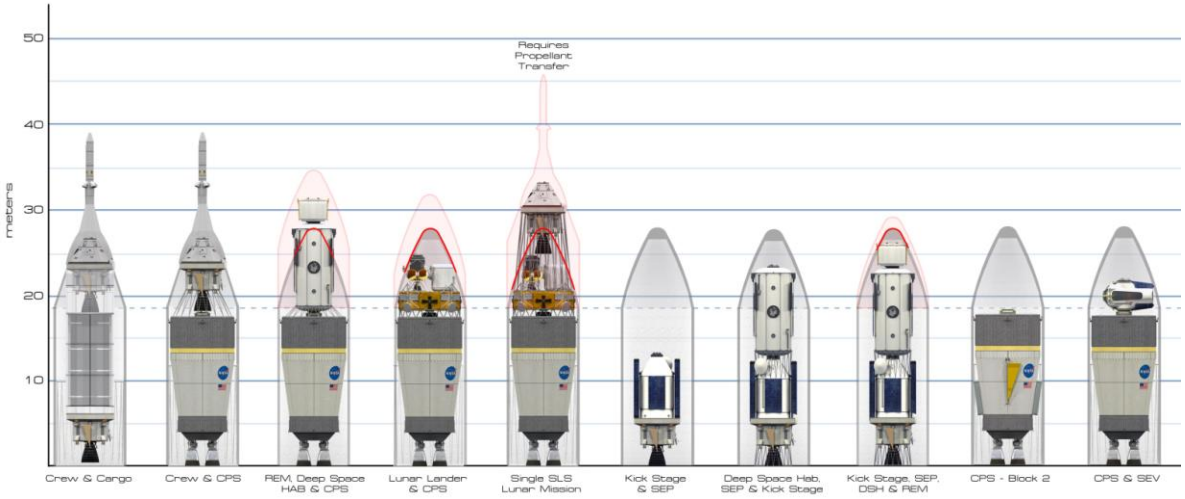
Expansion to cis-lunar space and beyond requires confidence in certain capabilities.
We need anchor missions that collectively lead to this.

L2 Gateway development opens up cis-lunar space & expands exploration capability

(Red denotes where investments are needed to support missions to that destination)
(Green denotes where capabilities can be advanced)

Key Findings from Multiple Analysis Cycles

- **It's important to look at multiple DRMs to understand which cases drive requirements**
- **SLS Performance**
  - 105t to LEO captures majority of DRMs; HAT input to Level 1 requirements
  - Payload volume remains a challenge for more complex missions; Big rocket = Good
- **Developed a consistent set of ground rules, assumptions and margins across DRMs that must be regularly coordinated with the programs**
- **Activities at the destination need as much attention as the transportation components**
- **A focused technology investment program is needed to enable future missions; integration & dialogue with AES & OCT is critical to ensure priorities are aligned**



Exploring Further

NASA is embarking on a new era of space exploration in which humans will travel deeper into the solar system than ever before. The International Space Station is the centerpiece for space operations. Serving as a test bed for research and new technologies, the space station is a steppingstone toward future exploration destinations. The commercial industry will transport cargo and eventually crew to the space station while NASA focuses on developing the Orion Multi-Purpose Crew Vehicle, Space Launch System, and advanced exploration systems that will enable a sustainable human presence to destinations such as the moon, near-Earth asteroids and Mars.

To learn more, visit *http://www.nasa.gov/exploration*.

The Future of American Human SPACEFLIGHT

National Aeronautics and Space Administration

"This is the next chapter that we can write together here at NASA. We will partner with industry. We will invest in cutting-edge research and technology. We will set far-reaching milestones and provide the resources to reach those milestones. And step by step, we will push the boundaries not only of where we can go but what we can do...."

— President Barack Obama

Following NASA's innovative partnership activities and investments in U.S. commercial launch capabilities, the agency has purchased cargo transportation services to and from the Space Station and will continue to partner in the development of crew transportation capabilities to low Earth orbit.

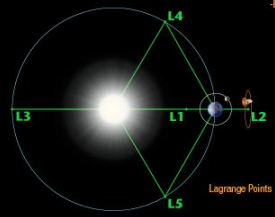
Commercial Partners

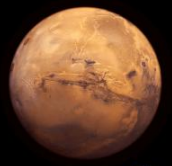
The research and technology breakthroughs aboard the space station will facilitate travel to destinations beyond low Earth orbit.

Preparation, testing and validation to advance exploration

NASA will use the Orion Multi-Purpose Crew Vehicle (MPCV) and Space Launch System, with additional exploration capabilities, to provide the means for crewed exploration missions beyond low Earth orbit.

Space Launch System and Orion MPCV





Destinations

Lagrange Points
Lagrange Points are microgravity destinations beyond low Earth orbit that provide opportunities for construction, fueling and repair of complex in-space systems. These points in space can serve as a gateway to reaching multiple destinations in our solar system.

Near-Earth Asteroids
These near-Earth objects may provide answers to some of humankind's most compelling questions, such as these: How did the solar system form? Where did Earth's water and other organic materials come from?

Moon
Earth's nearest neighbor provides significant opportunities for commercial and international collaboration and has critical resources needed to sustain human explorers.

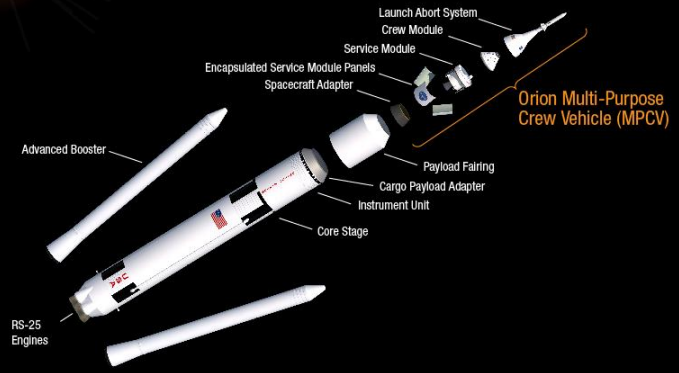
Mars
Mars provides the best opportunity to demonstrate that humans can live for extended — even permanent — stays beyond low Earth orbit. The technology and space systems required to transport and sustain explorers on Mars will expand scientific knowledge and drive technological innovation.

Commercial Spaceflight Development

NASA is investing financial and technical resources to stimulate efforts within the commercial industry to develop and demonstrate cargo and crew space transportation capabilities to and from low Earth orbit.

Cargo Partners	Commercial Company	Spacecraft	Launch Vehicle
	Space Exploration Technologies (SpaceX)	Dragon (Cargo)	Falcon 9
	Orbital Sciences Corporation (Orbital)	Cygnus	Antares

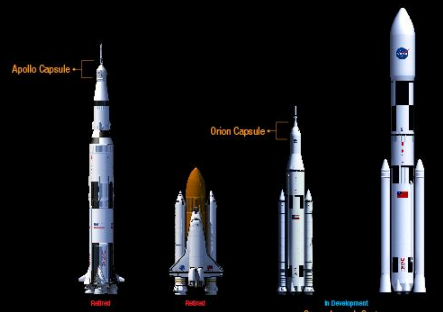
Funded Crew Partners			
	Blue Origin	Crew Transportation System	Initial — Atlas V Final — Own Reusable Booster System
	Sierra Nevada Corporation	Dream Chaser	Atlas V
	SpaceX	Dragon (Crew)	Falcon 9
	The Boeing Company	Crew Space Transportation (CST)-100	Initial — Atlas V



Human Spaceflight Capabilities

NASA is developing next-generation spaceflight technology to explore multiple destinations throughout the solar system. New technology systems include the following:

Mobile Extravehicular Activity and Robotic Platform | Deep Space Habitation | Advanced Spacesuits | Advanced Space Communication | Advanced In-Space Propulsion | In Situ Resource Utilization | Human-Robotic Systems



Launch Vehicle	Saturn V	Space Shuttle	Space Launch System Initial Lift Capability	 Evolved Lift Capability
Years	1967–1973	1981–2011	First uncrewed launch planned for 2017	to be determined
Height	111 m (363 ft)	56 m (184 ft) (Orbiter 122 ft)	97 m (318 ft) →	115 m (376 ft)
Lift Capability to Low Earth Orbit	118 metric tons	28 metric tons (to 28.5° inclination)	70 metric tons →	130 metric tons
Crew Capsule/ Capacity	Apollo Spacecraft	Orbiter	Orion MPCV	Cargo Configuration Shown

www.nasa.gov

Looking Toward the Future

- ISS will be the centerpiece of human spaceflight activities until at least 2020
- Research and technology breakthroughs aboard ISS will facilitate travel to destinations beyond low Earth orbit
- A capability driven framework will enable affordable and sustained human spaceflight exploration
- Destinations for human exploration remain ambitious: the moon, asteroids and Mars
- Continue to undertake world-class science missions to observe our planet, reach destinations throughout the solar system and peer even deeper into the universe
- Continue to inspire the next generation of scientists, engineers and astronauts by focusing on STEM education initiatives