National Aeronautics and Space Administration

NASA's JOURNEY TO MARS

Pioneering Next Steps in Space Exploration

Introduction

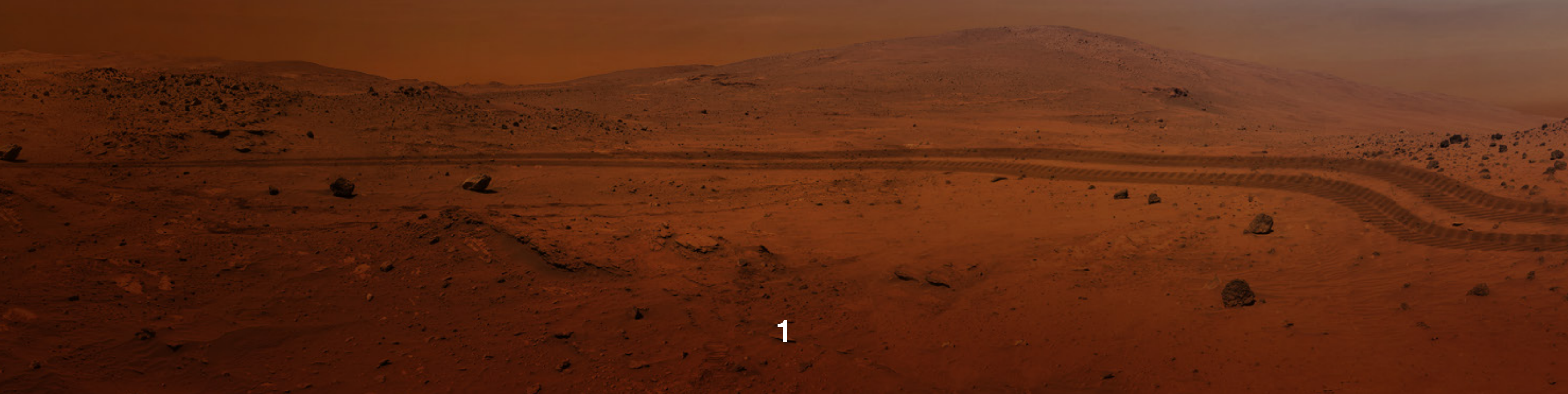
NASA is leading our nation and our world on a journey to Mars. Like the Apollo Program, we embark on this journey for all humanity. Unlike Apollo, we will be going to stay. This is a historic pioneering endeavor—a journey made possible by a sustained effort of science and exploration missions beyond low Earth orbit with successively more capable technologies and partnerships.

This pioneering endeavor carries out the direction given to us in the 2010 NASA Authorization Act and in the U.S. National Space Policy. It engages all four NASA Mission Directorates and all NASA Centers and Laboratories. It enlists the best of academia and industry across the nation and builds on our existing international partnerships while embracing new ones. And like pioneering efforts before it, the journey to Mars will foster and attract new commercial enterprises.

Why Mars? Mars is the horizon goal for pioneering space; it is the next tangible frontier for expanding human presence. Our robotic science scouts at Mars have found valuable resources for sustaining human pioneers, such as water ice just below the surface. These scouts have shown that Mars' geological evolution and climate cycles were comparable to Earth's, and that at one time, Mars had conditions suitable for life. What we learn about the Red Planet will tell us more about our Earth's past and future, and may help answer whether life exists beyond our home planet. Together with our partners, we will pioneer Mars and answer some of humanity's fundamental questions:

- Was Mars home to microbial life? Is it today?
- Could it be a safe home for humans one day?
- What can it teach us about life elsewhere in the cosmos or how life began on Earth?
- What can it teach us about Earth's past, present, and future?

Mars is an achievable goal. We have spent more than four decades on the journey to Mars, with wildly successful robotic explorers. The first human steps have been taken through science and technology research aboard the International Space Station (ISS) and in laboratories here on Earth. We are taking the next steps by developing the Space Launch System (SLS) and the Orion crewed spacecraft, demonstrating new operations to reduce logistics, and preparing for human missions into cislunar space, such as exploring a captured asteroid. There are challenges to pioneering Mars, but we know they are solvable. We are developing the capabilities necessary to get there, land there, and live there.



Technology drives exploration and many of the technologies we need are in various stages of conceptualization, development, or testing. Consequently, NASA will continue to make key decisions and further define steps on this journey as technology and knowledge mature. This is a good thing, as it allows new ideas, new technologies, and new partnerships to be developed during the next two decades of this journey.

This document communicates our strategy and shares our progress. It reflects the ongoing discussion with our stakeholders and partners, and an update on current plans and activities within an evolving architecture. It identifies the challenges facing future pioneers and our strategy for addressing these challenges. NASA's strategy provides an evolutionary, resilient framework for defining future missions. We are making progress on the journey to Mars using current missions to advance technologies and systems for the next decade, and we are conducting the technical analyses needed to plan for the decades beyond.

We are on a journey to Mars. We have already taken the first steps. We are excited by the challenges that remain, knowing they will only push us further. Come join us on the journey!

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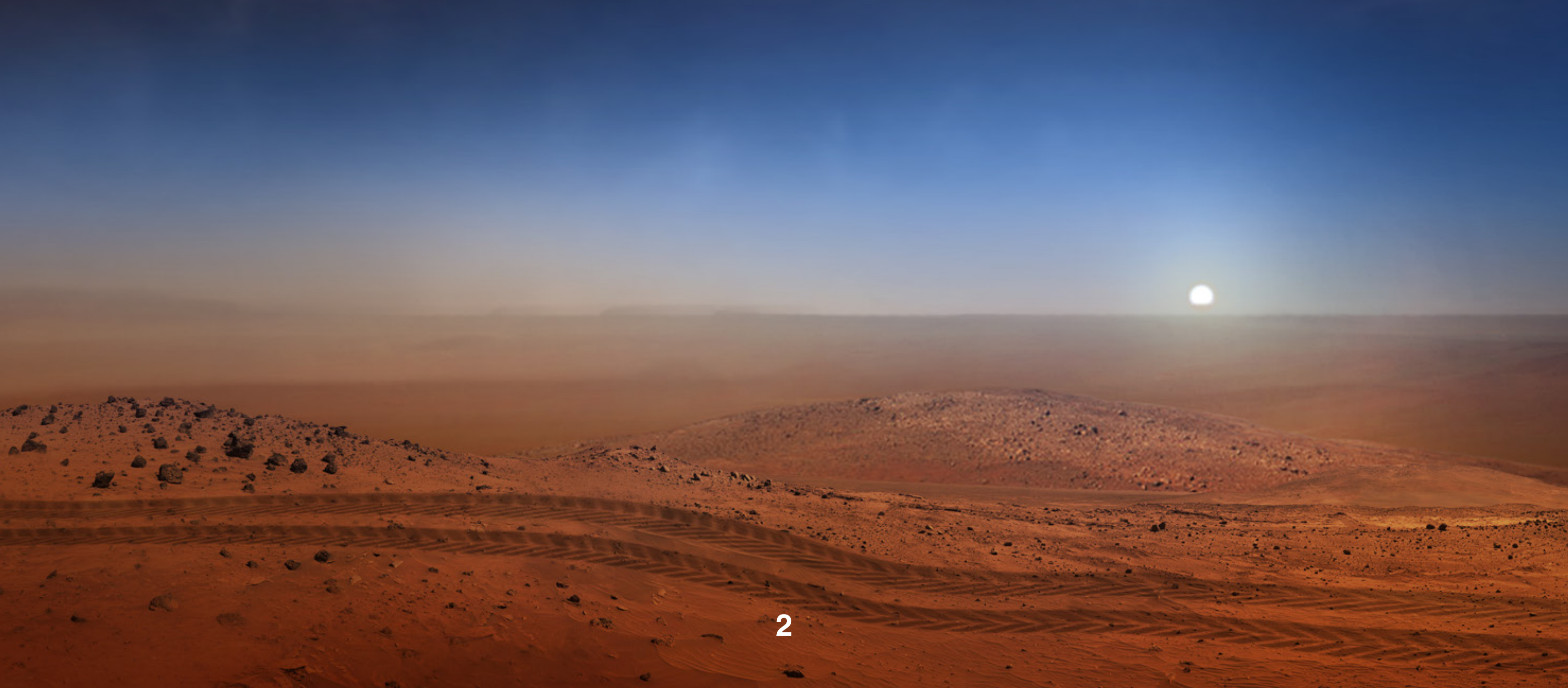
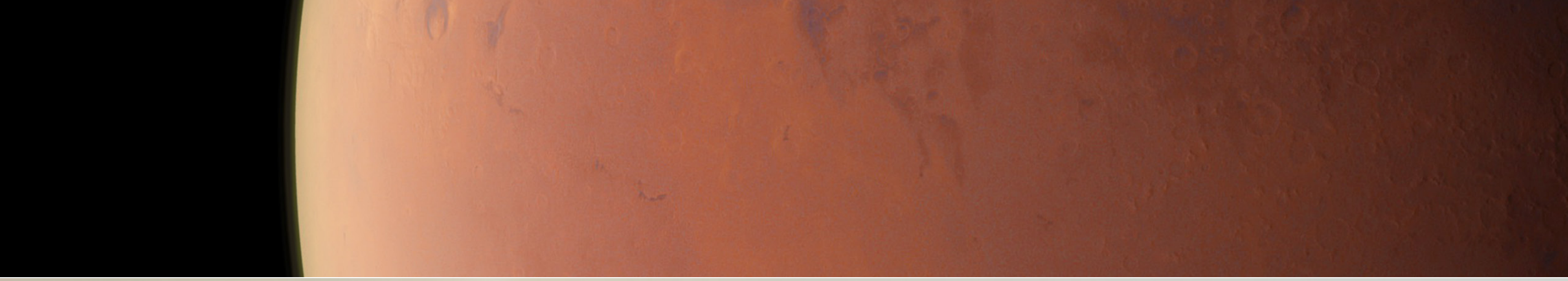


Our Goal

NASA aims to extend human presence deeper into the solar system and to the surface of Mars. In doing so, our human and robotic explorers will expand knowledge and discover the potential for life beyond Earth. Our goal is not bound by a single destination. We seek the capacity for people to work, learn, operate, and sustainably live safely beyond Earth for extended periods of time. We will achieve this goal with a growing number of international and commercial partners, realizing economic benefits and strengthening America's leadership on Earth and in space.

As pioneers, we seek to blaze the trail for others, establishing a presence that leads to economic progress and broad societal benefit. We pioneer space to discover life, identify resources, foster economic growth, inspire and educate, protect ourselves from space-based threats, and leave a better future for the next generation. This goal is embodied in the idea of a human and robotic journey to Mars. It is time for the next steps, and the agency is actively developing the capabilities that will enable humans to thrive beyond Earth for extended periods of time, leading to a sustainable presence in deep space.

NASA's efforts build upon the proven international and commercial partnerships at the core of the ISS. Our activities align with the Global Exploration Roadmap (GER), a product of 12 space agencies committed to expanding human presence in space. We will continue to build on partnerships with U.S. industry, academia, and our stakeholders. Our partners are developing technologies, systems, and missions to meet individual objectives, such as lunar surface operations, while contributing to the journey to Mars. The commonality between exploration capabilities, related scientific investigations, and the range of potential activities, allows partners to target individual objectives while working together to achieve pioneering goals.



While far away, Mars is a goal within our reach. We are closer to sending humans to Mars than at any point in NASA's history. We will journey in phases, leveraging our experience on the space station to step out into the Proving Ground of cislunar space—the volume of space around the moon featuring multiple stable staging orbits for future deep space missions. Over the next decade, NASA and our partners will use this Proving Ground to practice deep-space operations with decreasing reliance on the Earth, gaining the experience and systems necessary to make pioneering space and the journey to Mars a reality.

Our Approach: Pioneering Principles

NASA's approach to pioneering is embodied in a set of guiding principles that will increase our successes and benefits over the coming decades. These key principles are the basis for a sustainable, affordable space program and provide overarching guidance to ensure NASA's investments efficiently and effectively enable the journey to Mars. These principles are:

Strategic Principles for Space Exploration

Implementable in the **near term with the buying power of current budgets** and in the longer term with budgets commensurate with economic growth

Exploration enables science and science enables exploration, leveraging scientific expertise for human exploration of the solar system

Application of **high Technology Readiness Level (TRL)** technologies for near-term missions, while focusing sustained investments on **technologies and capabilities** to address challenges of future missions

Near-term mission opportunities with a defined cadence of compelling and integrated human and robotic missions, providing for an incremental buildup of capabilities for more complex missions over time

Opportunities for **U.S. commercial business** to further enhance the experience and business base

Resilient architecture featuring multi-use, evolvable space infrastructure, minimizing unique major developments, with each mission leaving something behind to support subsequent missions

Substantial **new international and commercial partnerships**, leveraging current International Space Station partnerships and building new cooperative ventures for exploration

These principles are integrated throughout NASA's strategy and are exemplified in current plans and activities. This document highlights a few example applications of these principles, as indicated in relevant sections by the icons above.

Three Phases on Our Journey to Mars

The journey to Mars passes through three thresholds, each with increasing challenges as humans move farther from Earth. NASA and our partners are managing these challenges by developing and demonstrating capabilities in incremental steps.

EARTH RELIANT

Earth Reliant exploration is focused on research aboard the ISS. On the space station, we are testing technologies and advancing human health and performance research that will enable deep-space, long-duration missions.

- Human health and behavioral research
- Advanced communications systems
- Material flammability tests
- Extravehicular operations
- Mars mission class environmental control and life support systems
- 3-D printing
- Material handling tests for *in-situ* resource utilization (ISRU) demonstrations

PROVING GROUND

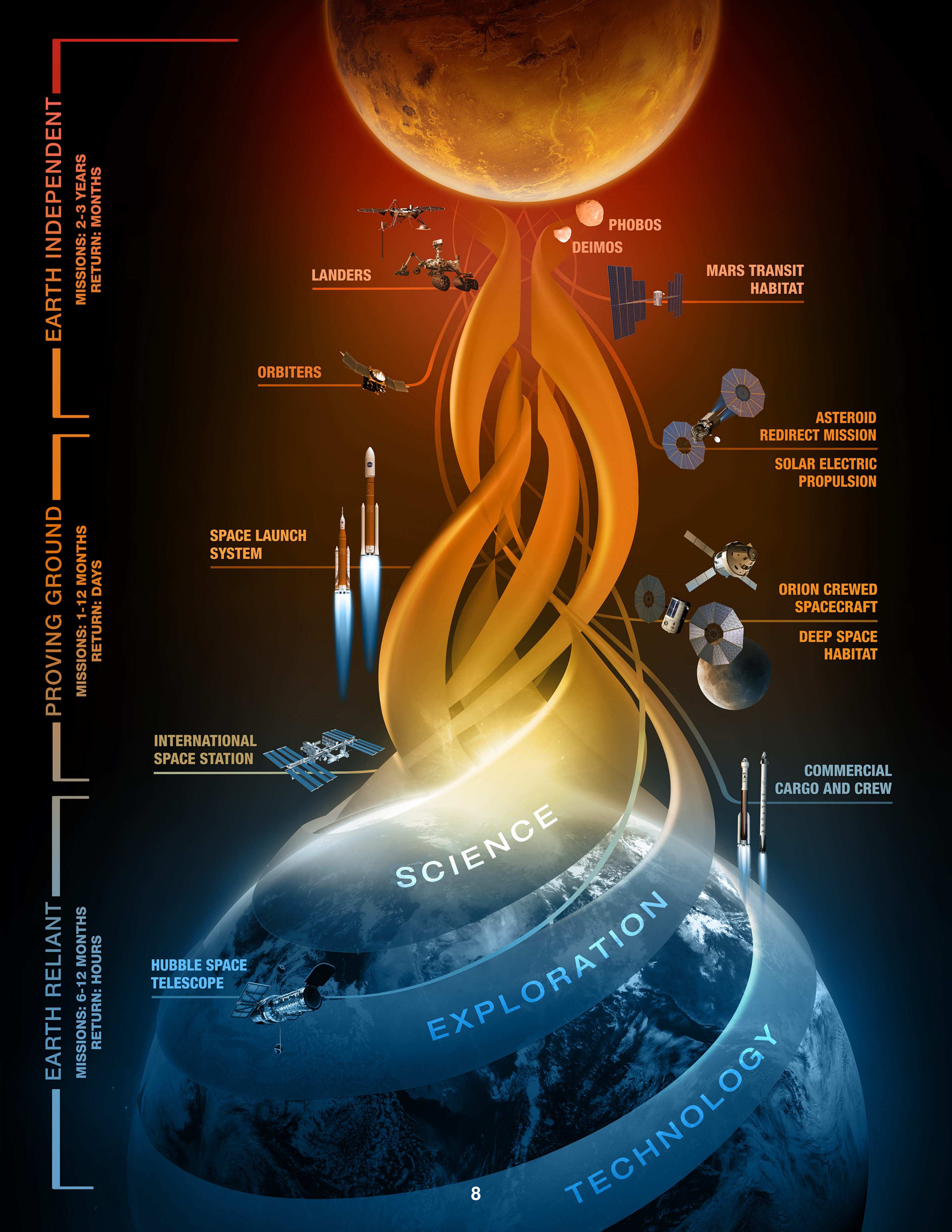
In the **Proving Ground**, NASA will learn to conduct complex operations in a deep space environment that allows crews to return to Earth in a matter of days. Primarily operating in cislunar space, NASA will advance and validate capabilities required for human exploration of Mars.

- A series of Exploration Missions (EMs), starting with EM-1, the first integrated test of SLS and Orion, anticipated in 2018
- The Asteroid Redirect Robotic Mission in 2020 that will collect a large boulder from a near-Earth asteroid, then ferry it to the Proving Ground and the Asteroid Redirect Crew Mission that will allow astronauts to investigate and sample the asteroid boulder
- An initial deep-space habitation facility for long-duration systems testing
- Autonomous operations, including rendezvous and docking and state of the art information technology solutions
- Concepts to minimize resupply needs through reduction, reuse, and recycling of consumables, packaging, and materials
- Other key operational capabilities required to become Earth Independent

EARTH INDEPENDENT

Earth Independent activities build on what we learn on ISS and in cislunar space to enable human missions to the Mars vicinity, including the Martian moons, and eventually the Martian surface. With humans on Mars, we will be able to advance science and technology in ways only dreamed of with current robotic explorers. Future Mars missions will represent a collaborative effort among NASA and its partners—a global achievement that marks a transition in humanity's expansion as we go to Mars not just to visit, but to stay.

- Living and working within transit and surface habitats that support human life for years, with only routine maintenance
- Harvesting Martian resources to create fuel, water, oxygen, and building materials
- Leveraging advanced communication systems to relay data and results from science and exploration excursions with a 20-minute delay


EARTH INDEPENDENT
MISSIONS: 2-3 YEARS
RETURN: MONTHS
PROVING GROUND
MISSIONS: 1-12 MONTHS
RETURN: DAYS
EARTH RELIANT
MISSIONS: 6-12 MONTHS
RETURN: HOURS
PHOBOS
DEIMOS
LANDERS
MARS TRANSIT HABITAT
ORBITERS
ASTEROID REDIRECT MISSION
SOLAR ELECTRIC PROPULSION
SPACE LAUNCH SYSTEM
ORION CREWED SPACECRAFT
DEEP SPACE HABITAT
INTERNATIONAL SPACE STATION
COMMERCIAL CARGO AND CREW
HUBBLE SPACE TELESCOPE
SCIENCE
EXPLORATION
TECHNOLOGY

Our Strategy for the Journey to Mars

The ISS, with flags of the partner nations.

What is Pioneering?

Pioneering space requires a sustained set of mutually reinforcing activities—science missions, technology development, capability demonstrations, and human spaceflight—to expand human presence into deep space and extend our robotic agents farther into the solar system, with the horizon goal of humans travelling to Mars and remaining on the surface.

NASA's strategy, aligned with the pioneering principles, connects near-term activities and capability development to the journey to Mars and a future with a sustainable human presence in deep space. This strategy strikes a balance between progress toward horizon goals, near-term benefits, and long-term flexibility to budgetary changes, political priorities, new scientific discoveries, technological breakthroughs, and evolving partnerships. The journey to Mars reflects an integrated NASA effort, in collaboration with our partners, to advance from today's Earth Reliant human spaceflight program through the Proving Ground of cislunar space to an Earth Independent, deep-space capability.

This strategy is a natural evolution of prior decades of space exploration. The era of modern space exploration began with remote observations through early telescopes, providing the knowledge necessary to design and send robotic missions to Earth orbit, planets, moons, comets, and asteroids. NASA's human spaceflight program has already demonstrated the capability for Earth Reliant human exploration, culminating today with the ISS, where astronauts and supplies are ferried between the station and Earth within hours. Our partners on the ISS, which now include commercial spaceflight ventures, reflect a blossoming worldwide human spaceflight capability for low Earth orbit (LEO). Meanwhile, robotic science missions are scouting resources and characterizing potential destinations for human explorers at far more distant locations within our solar system.

The Path Forward

NASA and our partners are already at Mars, operating with highly effective robotic emissaries in orbit and on the surface. NASA has exploited nearly every opportunity over the past two decades (occurring every 26 months when transit between Earth and Mars is the most efficient) to send orbiters, landers, and rovers to the Red Planet with increasingly complex experiments and sensing systems. Mars orbiters have mapped with high precision the topography of the planet, begun mapping the distribution of water ice below the surface, imaged geologically ancient river deltas, and discovered likely seasonal outflows of salty liquid water in the present. They have mapped detailed mineral composition in select areas and located suitable landing

sites for future robotic and human missions, many with incredible science potential. Robotic landers have demonstrated that the Martian environment could have supported microbial life, as we understand it here on Earth. Additionally, robotic landers have measured radiation in transit and on the surface, and gathered data for defining entry, descent, and landing (EDL) approaches for future human missions. NASA's Mars 2020 mission will measure atmospheric entry conditions and surface dust, and demonstrate production of oxygen from atmospheric carbon dioxide while selecting and encapsulating samples for potential return to Earth. The journey to Mars requires advanced human and robotic partnerships not imagined at the time of Apollo.

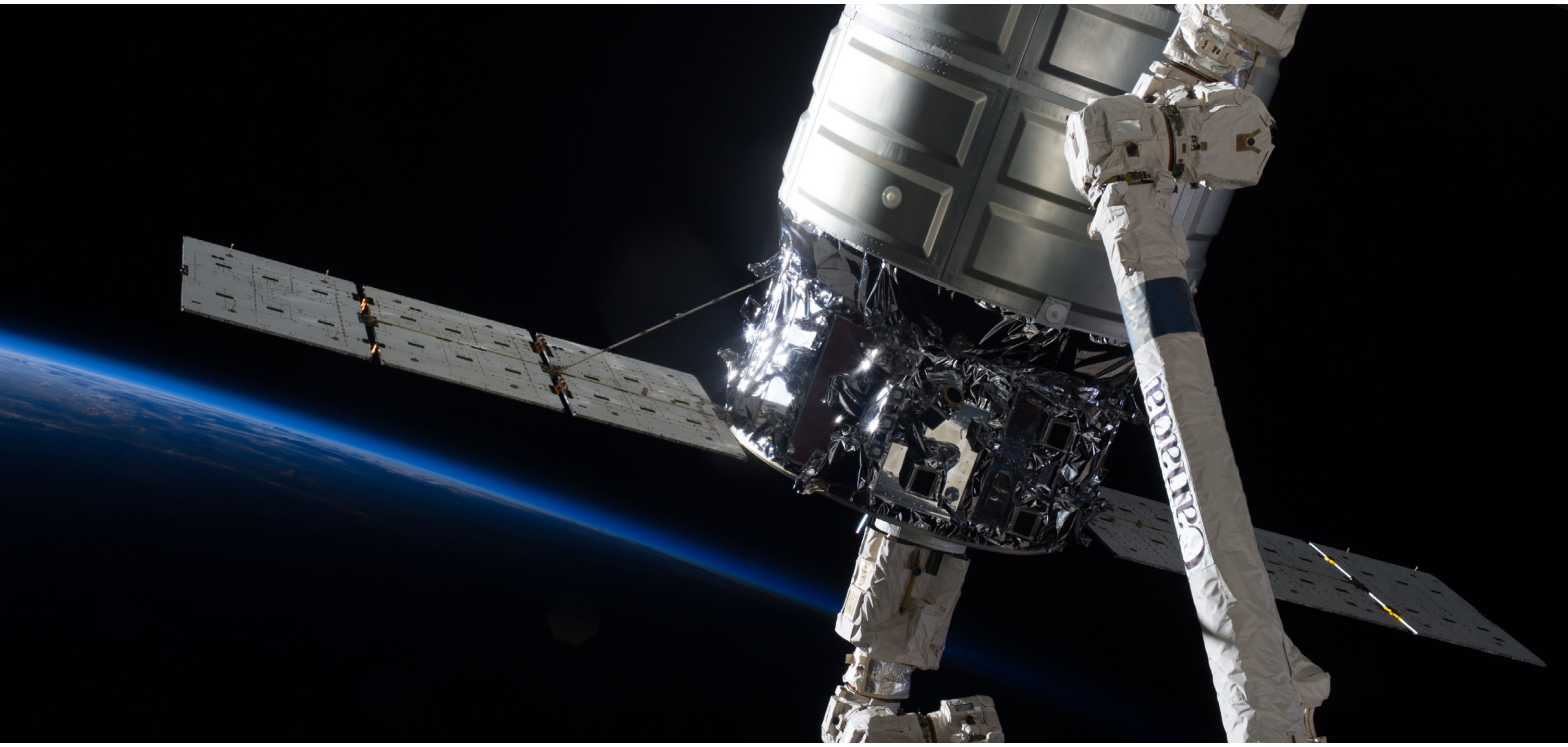
While learning about Mars with robotic science scouts, we are also developing advanced technologies to support human pioneers. NASA is investing in technologies and rapidly prototyping new systems, which benefit both NASA and our industry partners, while minimizing overall costs through innovative partnerships. Focus areas include solar electric propulsion with advanced ion thrusters, habitation systems, nuclear fission for Mars surface power, EDL systems, laser communications for high data rate transmission, deep-space atomic clocks for precise navigation, and many others. NASA will integrate these technologies into pioneering capabilities, providing the tools necessary for the journey to Mars.

Moving from Earth Reliant toward Earth Independent

In the current Earth Reliant phase of human exploration, NASA and our partners are using the ISS in LEO, supported by commercial cargo resupply services and in the near future, commercial crew transportation. The delivery and return of astronauts and cargo to the space station are measured in hours, but any journey to Mars will take many months each way, and early return is not an option. This is an entirely different operating regime, not just for physical access but also for communications with Earth-based teams. Astronauts in deep space must be more self-reliant and spacecraft systems and operations must be more automated to operate safely and productively as we explore beyond LEO. Cislunar space is the ideal Proving Ground for NASA and its partners to test systems and to practice deep-space operations, such as extravehicular activity (EVAs or spacewalks), and rendezvous and docking prior to committing crew on long missions to Mars. NASA is focusing on Proving Ground activities in cislunar space, and many of our partners see cislunar space as a step toward human missions to the lunar surface. These combined activities provide an optimal condition to demonstrate integrated human and robotic missions to build confidence that human missions to Mars can be safely conducted with an Earth Independent mode of operation.

Our Strategy for the Journey to Mars

Living and working in space require accepting risk, and the journey is worth the risk. Crews must be protected from the unique hazardous environments of deep space and on the Martian surface. Often, systems will have to operate autonomously or remain dormant for years in preparation for crew. Overcoming these challenges will be essential on the journey to Mars. These technological and operational challenges fall into three categories: *transportation*, sending humans and cargo through space efficiently, safely, and reliably; *working in space*, enabling productive operations for crew and robotic systems; and *staying healthy*, developing habitation systems that provide safe, healthy, and sustainable human exploration. Bridging these three categories are the overarching logistical challenges facing crewed missions lasting up to 1,100 days and exploration campaigns that span decades.



An Orbital ATK Cygnus is berthed to the ISS with 1.6 tons of supplies during the Orb-1 mission in January 2014.

Planning and Implementing a Pioneering Approach

A pioneering approach enables a sustained expansion of human presence into the solar system, rather than a once-in-a-generation expedition. This approach requires us to recognize and address two key challenges.

The first challenge is recognition that pioneering space is as much a logistics and supply chain challenge as a technological challenge. Historically, pioneers on Earth could not rely solely on supplies from home to sustain them and neither can the first pioneers on Mars. NASA will have to learn new ways of operating in space, based on self-reliance and increased system reliability; ISRU, including recycling

packaging materials and trash; and the ability to design, build, or repair systems with common, modular components. To enable the journey to Mars, NASA will invest in reusable systems with common components that are modular and extensible to multiple missions to reduce unique developments and the need for spares. Complex tradeoffs between resupply and use of *in-situ* resources must be first addressed before we achieve Earth Independence. NASA will use missions in the Proving Ground to validate new operational approaches and learn how to balance logistics sent from Earth with the potential benefits and challenges of using local resources.

The second challenge is recognition that achieving Earth Independence will take decades and can be impacted by multiple uncertain events. NASA's strategy must be flexible and resilient to changes in the priorities of future administrations, the emergence of breakthrough technologies, discovery of new scientific knowledge, fluctuations in funding, and new partnership opportunities. Due to these uncertainties, we must make decisions with incomplete knowledge to ensure continued momentum. However, we can plan for these changes proactively and design for uncertainty to be better positioned when change occurs. We do this by designing a resilient architecture that focuses on critical capabilities across a range of potential missions, investing in technologies that provide large returns, and maximizing flexibility and adaptability through commonality, modularity, and reusability. The journey to Mars is only possible through multi-use, evolvable space infrastructure that minimizes unique developments and associated cost. We also ensure each mission leaves something behind to reduce the cost, risk, or schedule for the next mission.

Features of a Resilient Pioneering Approach	
Logistics	Design to minimize the number of systems, use them multiple times, refresh instead of replace them, and maintain with local resources to enable self-sufficient missions.
Modularity	Standardize for flexibility, simple interfaces to enhance complex subsystems and components.
Commonality	Develop systems that serve multiple purposes across the campaign at many destinations.
Extensibility	Develop initial hardware with paths for enhanced applications.
Affordability	Optimize system development across a campaign, not a mission to minimize development costs.

Our Progress and Plans on the Journey to Mars

SpaceX's uncrewed Dragon cargo spacecraft is berthed to the ISS after arriving on September 23, 2014 with 2.5 tons of supplies and equipment.

NASA's current efforts focus on strategic investments to extend human access to deep space, learn how to operate with reduced logistics, and understand future destinations through science-guided robotic explorers. We will use the Proving Ground to demonstrate capabilities that evolve beyond the Earth Reliant exploration systems currently used on the ISS. As these capabilities are proven, NASA and our partners will further define future missions. Efforts made today and in the next decade will lay the foundation for an Earth Independent, sustained presence in deep space, addressing a challenge worthy of our nation's expertise, perseverance, and ingenuity.

The following sections describe specific architecture elements in each phase of the journey to Mars: Earth Reliant, Proving Ground, and Earth Independent. These investments, selected with guidance from strategic partners and through the lens of the pioneering principles, enable near-term missions, support resilient space infrastructure, are affordable within NASA's current budget, and offer multiple opportunities for academic, commercial, and international partnerships. They work together as an interlocking set of capabilities that enable sustainable, affordable, programmatically sound, and technically feasible architecture. Additional detail is provided for the first series of exploration missions, including initial SLS and Orion missions and the Asteroid Redirect Mission. For missions beyond the next decade, insight from ongoing studies is provided.

Earth Reliant

NASA's current human exploration activities occur in an Earth Reliant frame of operations on the ISS. To begin to break these ties, NASA is leveraging the space station as a test bed to demonstrate key exploration capabilities and operations. Current NASA missions are building on the Earth Reliant capabilities to enable missions for the next decade. The agency is also facilitating a robust commercial crew and cargo transportation capability in LEO, stimulating new markets and fostering an emerging commercial space industry that will mature to support future pioneering missions. As NASA transitions beyond LEO and continues to pioneer space, our vision is that private and public investments will sustain economic activity in LEO and create benefits for Earth through commercial supply and public and private demand.

The First Steps: International Space Station (ISS)

NASA has begun the transition from exploration to pioneering on the ISS. Occupied by an international crew continuously since November 2, 2000, the station has hosted more than 200 people from 17 countries, and is the culmination of one of the largest and most complicated international engineering efforts ever attempted.

The ISS is the only microgravity platform for the long-term testing of new life support and crew health systems, advanced habitat modules, and other technologies needed to decrease reliance on Earth. Over the next decade, we will validate many of the capabilities needed to maintain a healthy and productive crew in deep space. Currently manifested or planned experiments and demonstrations include improved long-duration life support for Mars missions, advanced fire safety equipment, next-generation spacesuit technologies, high-data-rate communications, techniques to reduce logistics, large deployable solar arrays, in-space additive manufacturing, advanced exercise and medical equipment, radiation monitoring and shielding, human-robotic operations, and autonomous crew operations.

Aboard the ISS, NASA and its partners also conduct targeted research to improve our understanding of how humans adapt and function during long-duration space travel. Current and planned risk-reducing investigations include bone and muscle loss studies, understanding the effects of intracranial pressure changes and fluid shifts, monitoring immune function and

Astronaut Scott Kelly and cosmonaut Mikhail Kornienko have teamed up for a one-year mission to understand how humans adjust to long-duration microgravity, bringing us one step closer to Mars

cardiovascular health, conducting nutritional studies, and validating exercise protocols. With these studies, NASA explores the physiology of the human body, preparing for long-duration spaceflight and supporting development of terrestrial drugs and therapeutic practices. NASA and our partners' activities on the ISS are achieving key milestones and enabling a planned transition to early pioneering missions in cislunar space.

Leveraging U.S. Industry: Commercial Crew and Cargo

NASA relies on commercial services it helped develop, leading to economically efficient exploration

The guiding principles for pioneering space include leveraging non-NASA capabilities and partnering with industry whenever possible. NASA's acquisition strategy for commercial crew and cargo services embodies these principles. The ISS plays a key role as a destination and anchor customer for emerging commercial markets in LEO. Commercial partners, who are maturing their business models and technical approaches by providing critical services for the ISS, will be essential to enabling deep-space NASA missions.

The NASA-sponsored Commercial Orbital Transportation Services (COTS) program resulted in the development of new launch vehicles and cargo spacecraft. Both Space Exploration Technologies (SpaceX) and Orbital ATK have successfully delivered cargo to the ISS using vehicles developed with NASA support. Under the Commercial Resupply Services (CRS) and follow-on contracts, commercial partners are expected to provide about six flights per year to support ISS operations. These flights are win-win arrangements for NASA and industry, as they minimize the need for costly, NASA-unique infrastructure and increase commercial access to space.

In September 2014, NASA announced the next phase of the commercial services program, Commercial Crew Transportation Capability (CCtCap), under which NASA awarded contracts for crew transportation services to Boeing and SpaceX. Once the companies complete development and are certified by NASA, the agency will purchase two flights per year to deliver and return expedition crew. CCtCap will provide NASA and our international partners with additional vehicles to deliver crews to the ISS and expand research opportunities by enabling the crew aboard ISS to increase from six to seven. NASA also continues relationships with other U.S. companies that are developing alternative transportation systems.

Beyond commercial crew and cargo transportation services, NASA is also developing strategies to stimulate sustained economic activity in LEO. This includes leveraging the ISS; supporting a policy and regulatory environment that promotes commercialization of LEO; facilitating a robust, self-sustaining, and cost-effective supply of U.S. commercial services that accommodates public and private demands; and stimulating broad sectors of the economy discovering benefits of LEO.

NASA is also leveraging industry to reinvent ground operations for a flexible, multi-user spaceport, providing launch services for both government and commercial partners. Launch complex assets once used for the space shuttle have been modernized for next-generation transportation systems. Many of these assets also provide opportunities for the commercial space industry. For example, Boeing's Crew Space Transportation (CST)-100 Starliner commercial spacecraft is processed in the former NASA orbiter processing facility, and SpaceX plans to use Launch Complex 39A, a former space shuttle launch pad, for commercial heavy-lift launch vehicles. These and other innovative commercial partnerships have reshaped the way NASA provides launch services through a multi-user spaceport.

An Orbital ATK Cygnus approaches the ISS during its demonstration flight in September 2013.

Our Progress and Plans on the Journey to Mars

Over the next 10 years, commercial partners will likely increase their presence in LEO by providing more products and services to government and non-governmental customers. A mature market provides reliable, on-demand, low-cost services, freeing NASA resources for more complex missions and system development. These commercial service providers help NASA execute an ambitious deep-space human exploration strategy within the agency's anticipated budgets.

The Proving Ground

Starting early next decade, NASA will be part of a larger international community of exploration and commercial activity in the Proving Ground—a resilient, evolvable effort to extend human presence beyond LEO. NASA identified several objectives for Proving Ground missions, which are critical steps on the journey to Mars. These objectives range from demonstrating

Proving Ground Objectives

Category	Title	Objective
Transportation	Crew Transportation	Provide ability to transport at least four crew to cislunar space.
Transportation	Heavy Launch Capability	Provide beyond LEO launch capabilities to include crew, co-manifested payloads, and large cargo.
Transportation	In-Space Propulsion	Provide in-space propulsion capabilities to send crew and cargo on Mars-class mission durations and distances.
Transportation	Deep Space Navigation and Communication	Provide and validate cislunar and Mars system navigation and communication.
Working in Space	Science	Enable science community objectives.
Working in Space	Deep Space Operations	Provide deep-space operations capabilities: • Extravehicular activity (EVA) • Staging • Logistics • Human-robotic integration • Autonomous operations
Working in Space	*In-Situ* Resource Utilization	Understand the nature and distribution of volatiles and extraction techniques, and decide on their potential use in the human exploration architecture.
Staying Healthy	Deep Space Habitation	Provide beyond LEO habitation systems sufficient to support at least four crew on Mars-class mission durations and dormancy.
Staying Healthy	Crew Health	Validate crew health, performance, and mitigation protocols for Mars-class missions.

advanced solar electric propulsion (SEP) for interplanetary cargo transportation to in-space operations and deep-space habitation. New missions and activities will become possible as NASA and its partners validate capabilities, address Proving Ground objectives, and review the specific series of near-term missions. Through these missions, we are moving toward Earth Independence and progressing together on the journey to Mars.

A Robust Transportation Infrastructure: Ground Operations, Orion, and SLS

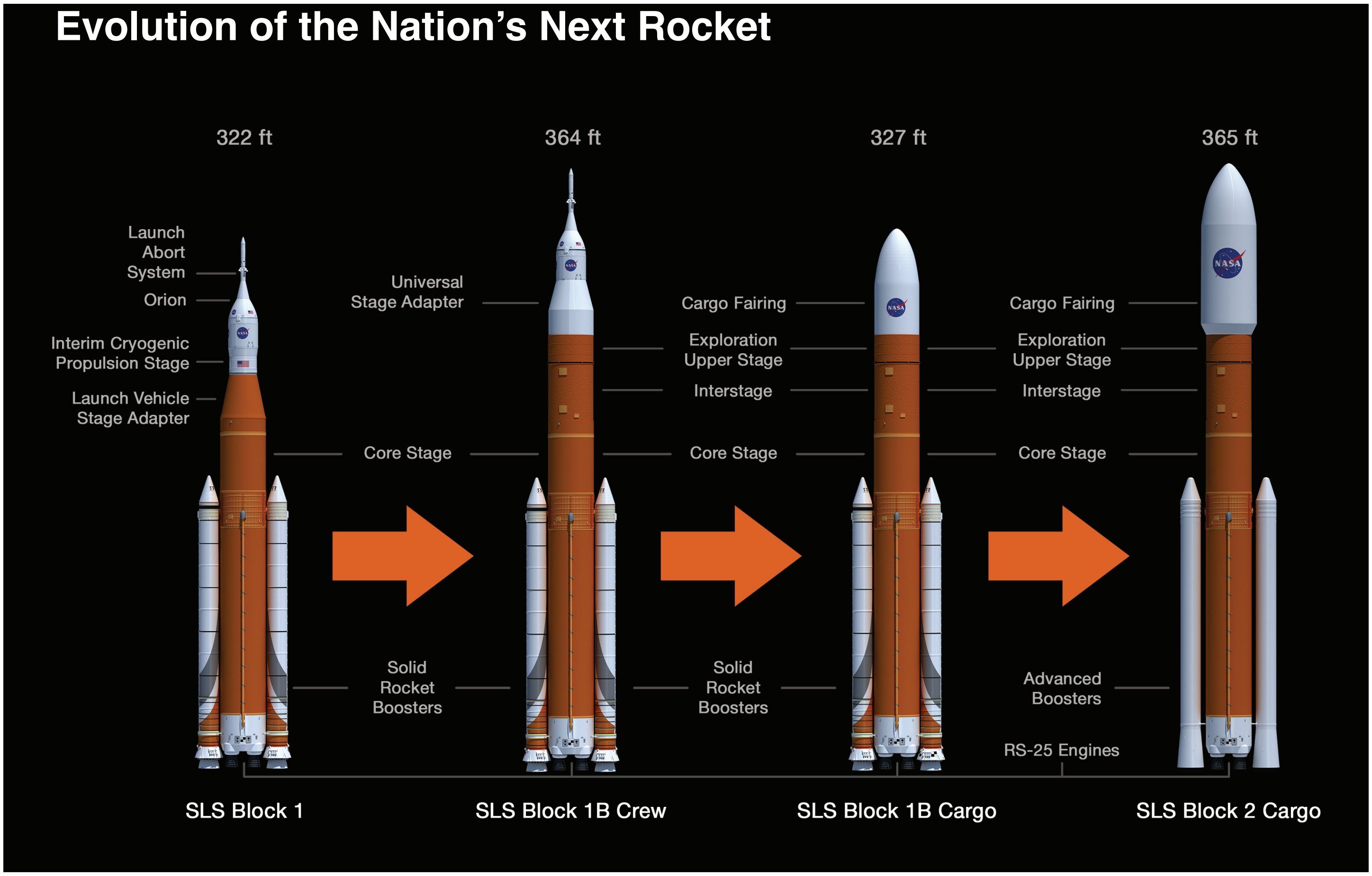
NASA is developing a robust launch services capability, which not only supports SLS and Orion, but can also be leveraged by a multitude of new commercial launch providers. With commercial partners, the agency is modernizing Launch Complex 39B, developing a mobile launcher, upgrading control systems, and demonstrating ground processing capabilities to enable Proving Ground missions, including the launch of SLS and Orion.

SLS is an evolvable launch vehicle leveraging mature technologies

Orion is a launch, reentry, and in-space crew spacecraft designed to transport a crew of four to deep space. During Proving Ground missions, Orion will protect the crew during transport to cislunar space, sustain the crew for short durations while in space, and enable safe reentry. For future missions, Orion will provide transportation between Earth and the Mars transit systems located in cislunar space. Orion's first mission, Exploration Flight Test 1 (EFT-1), was successfully conducted in 2014, on a Delta IV Heavy launch vehicle, and generated a wealth of data to enable future human missions to deep space.

The Space Launch System is Orion's ride to deep space. NASA is developing an evolvable design for SLS that leverages previous launch system investments. The initial "Block 1" SLS is designed to carry Orion, as well as cargo, equipment, and science experiments to staging points in cislunar space. We are well along the path to developing the Block 1 SLS, which uses an upper stage derived from the Delta cryogenic second stage to launch 70 metric tons (mt) to orbit. This initial version will use liquid hydrogen and liquid oxygen propulsion systems and solid rocket boosters, evolved from heritage systems. NASA plans to upgrade the boosters and develop an advanced upper stage, the Exploration Upper Stage (EUS), leading to the 105 mt Block 1B and the 130 mt Block 2 versions of the SLS. This payload capacity far exceeds the capability of current and planned commercial launch vehicles. Development of Block 1B with the EUS provides significant additional capability for Proving Ground missions, allowing NASA to send the crewed Orion spacecraft, other flight systems, and cargo to lunar orbit in a single launch. Additional developments will improve SLS performance and reduce manufacturing costs through additive manufacturing and advanced out-of-autoclave composite structures.

The initial Block 1 SLS will support the first deep-space exploration mission, Exploration Mission 1 (EM-1), anticipated in 2018. Although uncrewed, EM-1 will provide the first integrated test of SLS and Orion, including SLS's

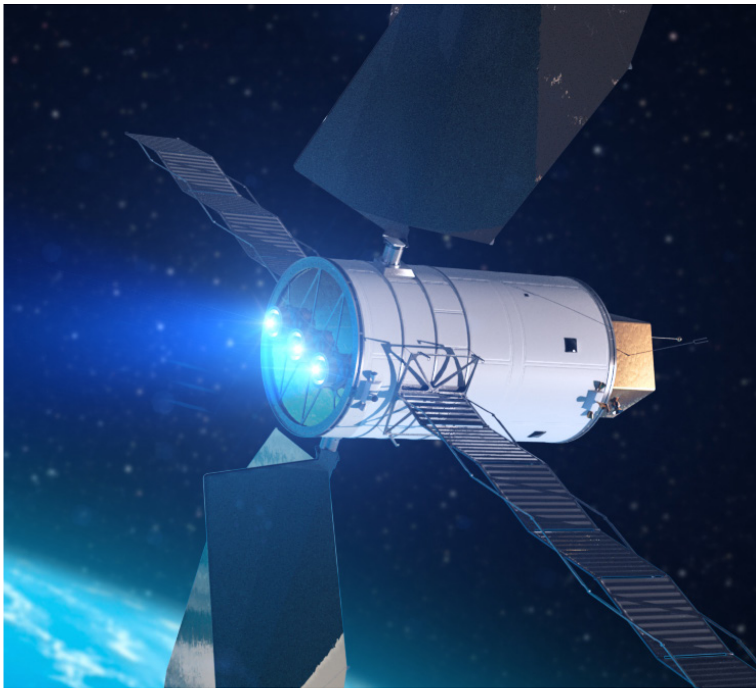


launch performance, Orion's heat shield, and deep-space navigation. NASA plans to develop the EUS for early exploration missions to cislunar space. The EUS addition could provide SLS with a critical new capability for crewed Orion missions by allowing secondary payloads to be co-manifested within the EUS-to-Orion launch vehicle adapter. While the exact mass and volume available for co-manifested payloads have not yet been determined, payloads about the same length, twice the width, and one-third the mass of a school bus could be launched to cislunar space with Orion. Co-manifested payloads, potentially launched as early as Exploration Mission 2 (EM-2), could include pressurized modules that extend the deep-space capabilities of the Orion spacecraft and help develop a deep-space habitation capability. Independent co-manifested payloads, such as robotic science missions, are also possible.

Orion and SLS (with the EUS) provide the core transportation capabilities that support Proving Ground missions and enable the journey to Mars. Beyond EM-2, NASA is considering a wide range of activities that not only demonstrate the ability to live and work in deep space, but also accomplish a suite of Proving Ground objectives and validate key operational capabilities required to become Earth Independent. While SLS and Orion flight rates

will ultimately be determined by available funding and mission requirements, NASA is working towards flying at least one crewed mission per year.

Into the Proving Ground: Solar Electric Propulsion and the Asteroid Redirect Mission



Solar electric propulsion (SEP) uses energy from the sun to accelerate ionized propellant to very high speeds. Compared to chemical propulsion, electric propulsion provides very low levels of thrust; however, it is incredibly efficient and can provide thrust continuously for months or years, allowing more mass to be transported with far less propellant. These systems are an order of magnitude more efficient than chemical propulsion systems, with a specific impulse (I_{sp}) from 2,000-3,000 seconds compared to 200-500 seconds. SEP systems are also very resilient and, if refueled, could provide a reusable, in-space transportation infrastructure. Adding a SEP capability to Orion and SLS provides a robust transportation infrastructure for human missions to support the journey to Mars.

High-power SEP is a key enabler for NASA's pioneering strategy, allowing NASA to pre-position infrastructure and resources while reducing the surge of launches. This could reduce the costs estimated in previous human Mars mission studies. Pre-positioning supplies months or years ahead of crew, rather than aggregating all necessary equipment and supplies in Earth orbit, is often called a split mission. With several tons of xenon (Xe) propellant and solar arrays capable of generating 40 kilowatts (kW), an early SEP vehicle could efficiently position several tons of cargo throughout the solar system. A more advanced SEP system with additional power and propellant could deliver landers, habitats, and supplies to Mars orbit.

SEP enables near-term missions while proving capabilities for a reusable deep space transportation system

NASA is considering several mission architectures that evolve from a 40 kW SEP vehicle. In an approach that leverages both SEP and chemical propulsion, a Mars SEP cargo vehicle would transport chemical return stages, habitats, and landers to Mars orbit, while crew travel separately. For this approach, the crew would rendezvous with the pre-positioned assets in Mars orbit including a surface lander and, on the return trip to Earth, chemical departure stages. In an alternative approach, NASA would use a hybrid SEP vehicle, supplemented with small chemical engines for strategic high-thrust maneuvers, to reduce trip times. This vehicle would still pre-position landers, habitats, and equipment in a cargo mode; however, for crew transit, the vehicle would contain enough propellant for a round trip and would not require chemical return stages. Both approaches are being studied as the Mars transportation architecture evolves.

With SEP, NASA can also aggregate, refurbish, and reuse Mars transportation infrastructure in a high-energy orbit, such as lunar distant retrograde orbit (LDRO). High performance liquid oxygen and hydrogen propulsion from the SLS Exploration Upper Stage can provide the majority of departure energy, placing payloads in these high-energy orbits and allowing the SEP or SEP-hybrid thrusters to initiate the maneuver to Mars. As an added advantage, these maneuvers can be reversed, allowing NASA to capture the Mars return vehicle for refurbishment and reuse. Developing and demonstrating advanced SEP systems early during the Proving Ground missions will accelerate our progress toward sustainable pioneering.

The Asteroid Redirect Mission (ARM) provides a near-term opportunity to demonstrate several capabilities important for longer-duration, deep-space missions, including flight-validated SEP transportation. ARM consists of two challenging flight segments, working toward the common objective of human exploration of an asteroid. In the first segment, an advanced, high-power SEP robotic vehicle will travel to an asteroid, perform detailed reconnaissance of its surface, select a boulder-sized sample, capture it, and return to a stable orbit in cislunar space. Most robotic sample return concepts are designed to return a few hundred grams of material (e.g., NASA's OSIRIS-REx mission to the asteroid Bennu). All six Apollo landings returned a total of less than 400 kilograms. Leveraging SEP and advanced robotics, ARM will return several tons of material. In the second segment, astronauts will travel to the captured boulder aboard SLS and Orion, marking a historic opportunity that will allow humans to venture outside of the spacecraft to touch, investigate, and experience an asteroid firsthand.

The Asteroid Redirect Mission also leaves deep-space infrastructure in cislunar space, providing an aggregation point to support the journey to Mars. Following the first ARM crewed mission, there will be on the order of several tons of material remaining in a stable orbit for at least 100 years, available for future exploration, scientific, commercial, or academic partners. During potential future missions, NASA could use the boulder to demonstrate ISRU identification, characterization, extraction, processing, and containment capabilities, and test EVA tools for exploring other low-gravity bodies, such as the Martian moons Phobos and Deimos. The Asteroid Redirect Robotic Vehicle (ARRV) also will be able to provide some support to visiting vehicles, including an S-band transponder for approach and docking, an X-band communications link, and about 40 kW of power. This initial cislunar infrastructure would be available to commercial partners who may also wish to understand and eventually mine resources from asteroids. Such commercial efforts could evolve into services to support in-space fueling of Mars propulsion systems.

A Home Away from Home: Deep-Space Habitat

Any mission to Mars will require highly reliable habitation systems to keep the crew healthy and productive in the deep-space environment during missions that last up to 1,100 days. Leveraging experience from the ISS, NASA and our

international and commercial partners have begun activities to evolve ISS habitation systems to meet future deep-space mission needs. With multiple crewed Orion missions to cislunar space over the next decade (launched on an evolved SLS), NASA will have many opportunities to use these habitations systems, and evolve them to a deep-space habitation capability for future Mars missions. This approach allows us to validate habitation system performance and reliability in the deep-space environment prior to committing a crew on a long journey to Mars.

NASA, together with its international and commercial partners, will develop a strategy to complete "Mars-ready" habitation system testing on Earth and on ISS. NASA and its partners will also develop an initial habitation capability for short-duration missions in cislunar space during the early 2020s and evolve this capability for long-duration missions in the later 2020s. A modular, pressurized volume would enable extended stays by crews arriving with Orion. This initial habitation capability in cislunar space would demonstrate all the capabilities and countermeasures necessary to send humans on long-duration transit missions to Mars. With this long-duration habitable volume and resources, NASA and its partners will have the opportunity to validate Mars habitat concepts and systems, including exercise systems, environmental monitoring systems, long-duration consumables storage, fire safety in high-oxygen environments, radiation shielding, and high-reliability avionics with long periods of dormancy. Understanding the transition from dormancy to crew presence and back is particularly important and can be tested with this capability. Between crewed missions, deep-space habitation capabilities could be used to test autonomous mission operations and transfer of control from the ground to vehicle systems in preparation for the longer Mars missions. Many of the capabilities developed for NASA's deep space missions will also be useful for other missions—including potential future commercial low Earth orbit space stations used by other government agencies and the private sector as the agency transitions away from the Space Station after 2024.

Standard interfaces enable multi-use, evolvable systems to support transit habitats, Mars ascent vehicles, and surface mobility

As designs for the Mars transit vehicle evolve and trajectories are determined, future Proving Ground missions could launch additional modules to incrementally build up capability. Using standardized interfaces, common structures, and modular designs, multiple pressure vessels could be aggregated, leading to a more complete habitation system to validate the full suite of capabilities needed for the journey to Mars. Commonality and standardization reduce unique developments and improve logistical efficiency. Standards also increase opportunities for international and commercial partnerships. During the habitat build-up and after initial missions, outdated or failing systems could be replaced with new capabilities that leverage the standardized interfaces. This approach provides an initial cislunar exploration capability with a pathway to a reusable, evolvable infrastructure for human missions to Mars.

Our Progress and Plans on the Journey to Mars

Becoming Earth Independent

Part of the journey to Mars is increasing our knowledge base and assessing plans and architectures that are affordable and sustainable. When the first pioneers ventured to North America, they found familiar resources in the new land and adapted to their environment. Future pioneers of Mars will have to adapt to a more foreign, hostile environment. We will need new technologies to transform local resources into water, fuel, air, and building materials. Therefore, in parallel with planning and implementing Proving Ground missions, NASA is leveraging current and planned robotic missions and studies to better understand challenges and opportunities that will inform the design of future systems. Earth Independent capabilities include those validated in the Proving Ground, Mars surface landers, advanced and efficient ISRU, surface mobility, permanent surface habitats, and crew transfer vehicles, such as the Mars ascent vehicle or a Mars vicinity crew taxi. These capabilities enable an integrated and sustainable campaign to pioneer space.

Current and planned science missions address pioneering challenges

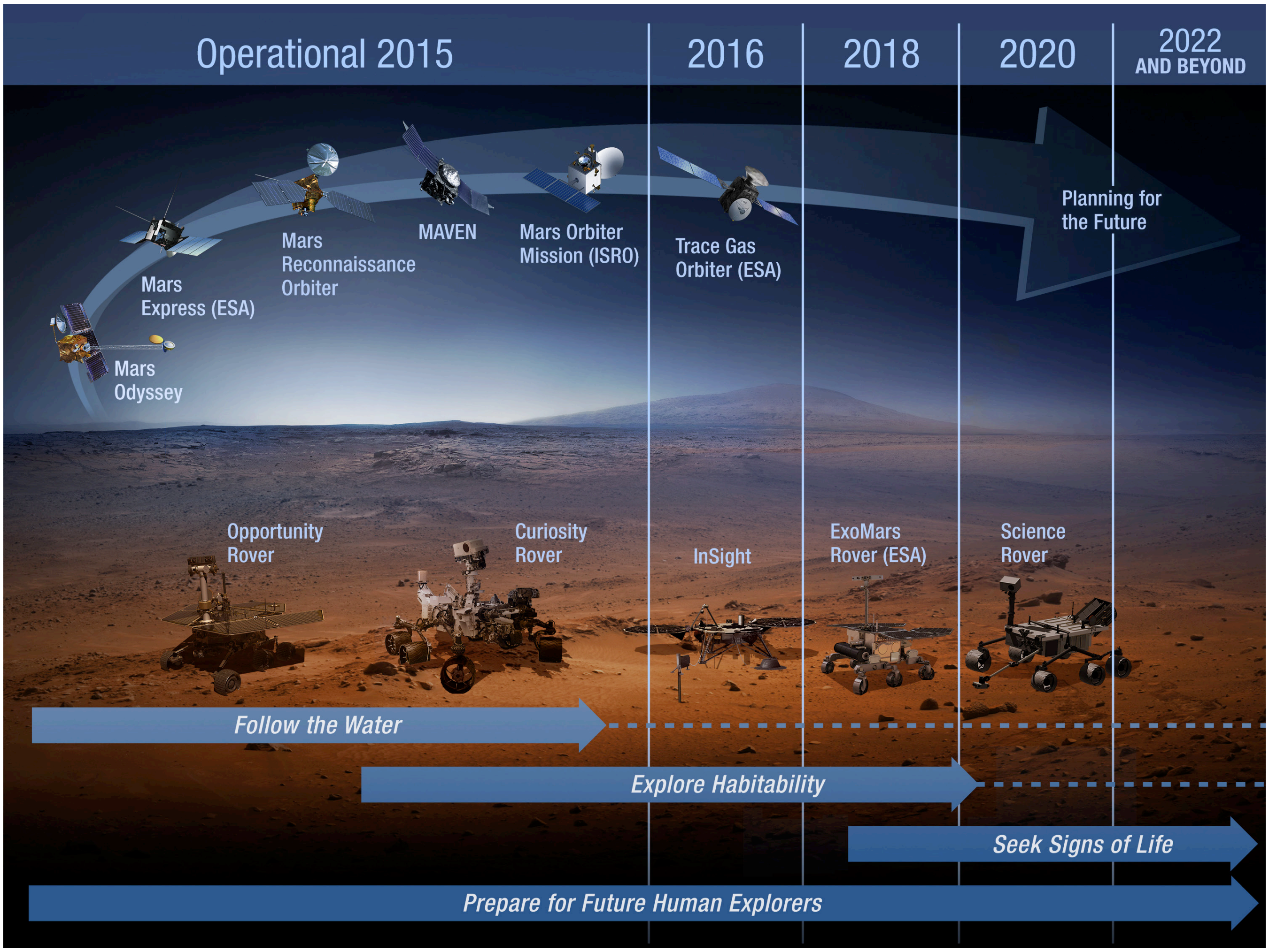
On the Red Planet: Robotic Mars Missions

We are already in orbit around and on the surface of Mars with a fleet of robotic science explorers. Robotic pathfinders like *Curiosity* address both science and human exploration objectives, answering key questions and gathering knowledge necessary to prepare human pioneers. NASA has significant experience using robotic science and exploration pathfinders, such as the Lunar Reconnaissance Orbiter (LRO) mission to the moon, the Dawn mission to asteroids Vesta and Ceres, and the Mars Exploration Rovers *Spirit* and *Opportunity*. Along with conducting their high-priority science objectives, robotic pathfinders investigate and map destinations prior to human missions, collect surface samples, characterize potential landing sites, and test technologies necessary for future robotic and human destination systems. Over the next decade, NASA will rely on robotic pathfinders to help select human-accessible landing sites, pre-emplace infrastructure, and inform the design of human destination systems.

NASA is currently working on several new robotic missions to conduct transformational science and support future human surface missions. Some missions, such as the Origins Spectral Interpretation Resource Identification and Security-Regolith Explorer (OSIRIS-REx) asteroid sample return mission, will acquire data on potential near-term destinations in collaboration with international exploration efforts. Additionally, proposed lunar robotic missions could verify the accessibility of resources to enable the journey to Mars. For Mars, NASA is currently developing the Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport (InSight) mission, set for launch in 2016, as well as the Mars 2020 rover mission. NASA also is supporting the European Space Agency's ExoMars orbiter and lander, by testing precision navigation technology and looking for evidence of the chemical building blocks for life.

InSight informs human exploration in addition to its primary science objectives. InSight is a robotic lander that will investigate the interior (geophysical) processes that formed Mars's core, mantle, and crust, comparing these processes to the Earth. InSight also will investigate seismic activity and meteorite impact rates on Mars that may affect the design of permanent human destination infrastructure.

The Mars 2020 rover is a prime example of the coordination and overlap between science and exploration objectives. Mars 2020 will broaden the search for signs of past life on the Martian surface, investigate signs of habitable environments, and collect samples for a potential future sample return mission to Earth. The mission also will provide opportunities to gather knowledge and demonstrate technologies that address the challenges of future human expeditions to Mars, including EDL. The Mars 2020 rover will carry an ISRU payload to demonstrate a method of generating oxygen from the Martian atmosphere, which can be used to produce rocket propellant. Landing site



selection for Mars 2020 is not finalized; however, one consideration is the site's potential suitability for future human surface missions. If Mars 2020 lands at a potential human landing site, it may help characterize the region for available resources, significantly increasing our ability to prepare future pioneers for the journey to Mars.

Robotic science pathfinder missions will continue well into the next decade to meet high-priority science objectives and prepare for future human missions to Mars. Robotic missions after Mars 2020 are in their conceptual stages and will address key exploration questions, such as characterizing the complex gravitational environment of the Martian moons; identifying resources and areas of scientific interest; understanding the effects of space radiation; validating EDL techniques; and studying regolith mechanics and dust.

An Evolving Architecture: Driving Near-Term Decisions and Long-Term Robustness

Like previous pioneers, NASA is charting new territory and we will adapt to new scientific discoveries and new opportunities. For example, science discoveries in just the past few years have completely changed our understanding of water on the moon and the habitability of Mars, enabling new architectures that rely on ISRU to reduce logistical burden. Our current efforts are focused on pieces of the architecture that we know are needed. In parallel, we continue to refine an evolving architecture for the capabilities that require further investigation. These efforts will define the next two decades on the journey to Mars.

Through rigorous and systematic studies, NASA and our international and industry partners have identified the core exploration capabilities necessary for Earth Independence. These studies build on a long history of designing deep-space missions, allowing NASA to adequately anticipate the challenges that future astronauts will face. NASA is leveraging prior experience to integrate these capabilities and design an open, evolvable architecture that allows us to confidently make investments without making specific decisions about missions in the distant future. This approach avoids the trap of designing a rigid architecture that becomes obsolete due to unanticipated changes. NASA's strategy, with its focus on capabilities, strikes a balance among progress toward horizon goals, near-term benefits, and the flexibility to respond to technology advancement, new scientific understanding, dynamic partnerships, and political direction in the coming decades.

Early architecture studies provided key findings and critical decision points, which help scope future work. Some of these findings, such as the commonality of key capabilities across multiple missions, are core to NASA's strategy, while other findings inform specific missions and architectures. For example, trajectory analysis has shown LDRO and some other lunar

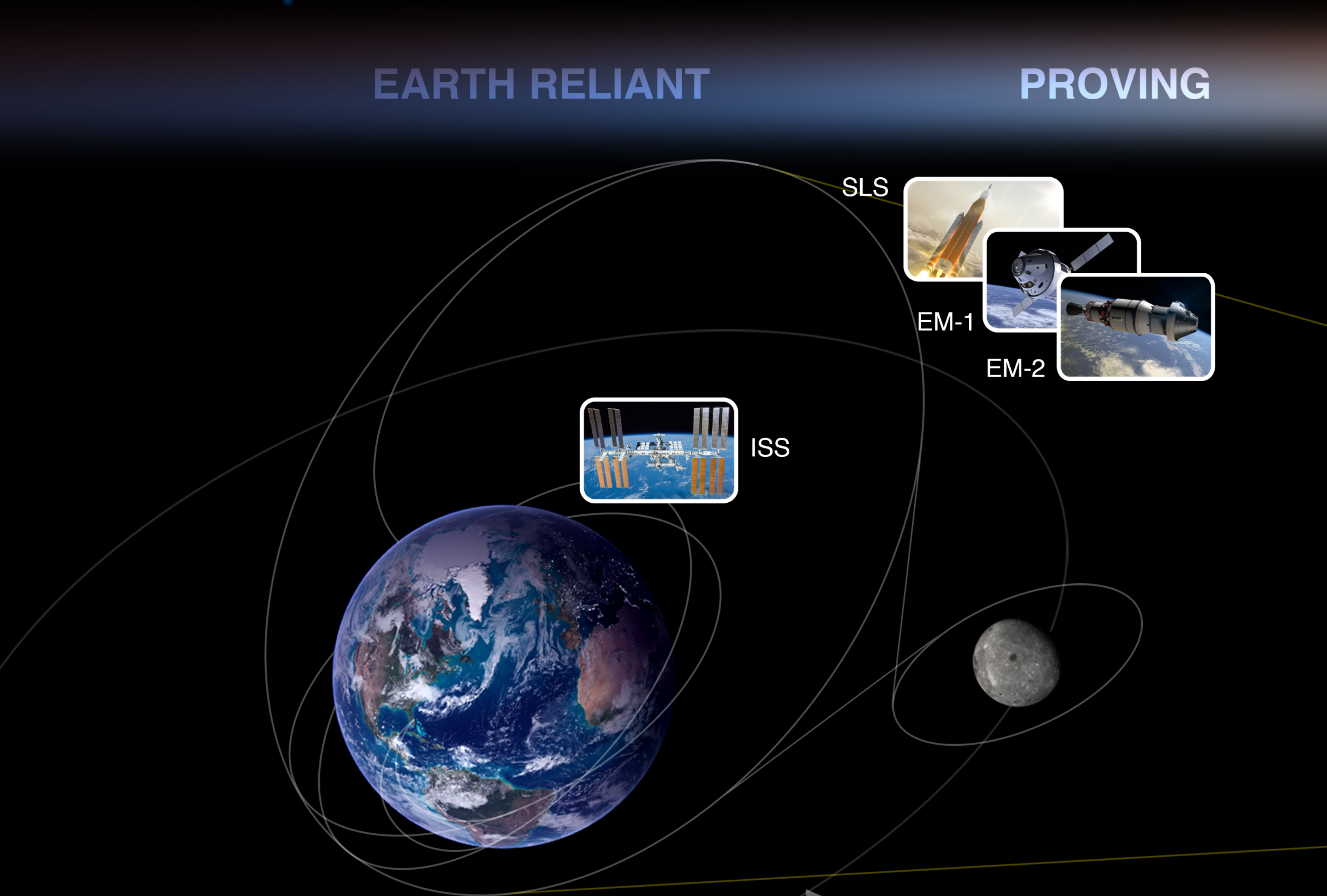
orbits are viable testing and staging locations, requiring only a small velocity change to efficiently transfer systems between a departure orbit and lunar orbits. When combined with new operations and system refurbishment, this finding supports architectures in which Mars transit systems can be reused, reducing overall costs and improving sustainability. Other architecture studies have shown that 20-30 mt Mars landers transported by SEP systems may be sufficient to enable human Mars missions with the addition of ISRU oxygen production for ascent propellant to leave the Martian surface.

These efforts are allowing NASA and its partners to develop an affordable, sustainable, and flexible pioneering architecture. Work to date has helped confirm NASA's approach and demonstrated that there is a viable path that can be executed within anticipated constraints. Leveraging the findings of current and future studies and precursor missions, NASA is poised to lead the worldwide partnership supporting an affordable journey to Mars.

Selected Critical Time Frames and Decisions

DECISIONS MADE & IMPLEMENTATION UNDERWAY	DECISIONS FOR THE NEXT FEW YEARS, IN WORK NOW	DECISIONS UNDER STUDY NOW TO BE MADE IN THE NEXT DECADE
• Extend ISS operations to at least 2024 • Pursue an evolvable SLS via Exploration Upper Stage before advanced solid rocket boosters • Select an ARM baseline mission to return an asteroidal boulder to lunar orbit for subsequent crew rendezvous • Predeploy cargo and infrastructure through split missions	• Develop an exploration EVA suit for use on Orion missions • Define initial deep-space habitation capability • Select in-space transportation systems • Identify future Mars robotic precursor missions beyond Mars 2020 • Further define potential future exploration missions in cislunar space	• Select initial human missions beyond the Proving Ground • Identify the role of ISRU in the overall logistics strategy • Design Mars surface habitats • Develop Mars surface power generation

Our Progress and Plans on the Journey to Mars



ISS Through at Least 2024

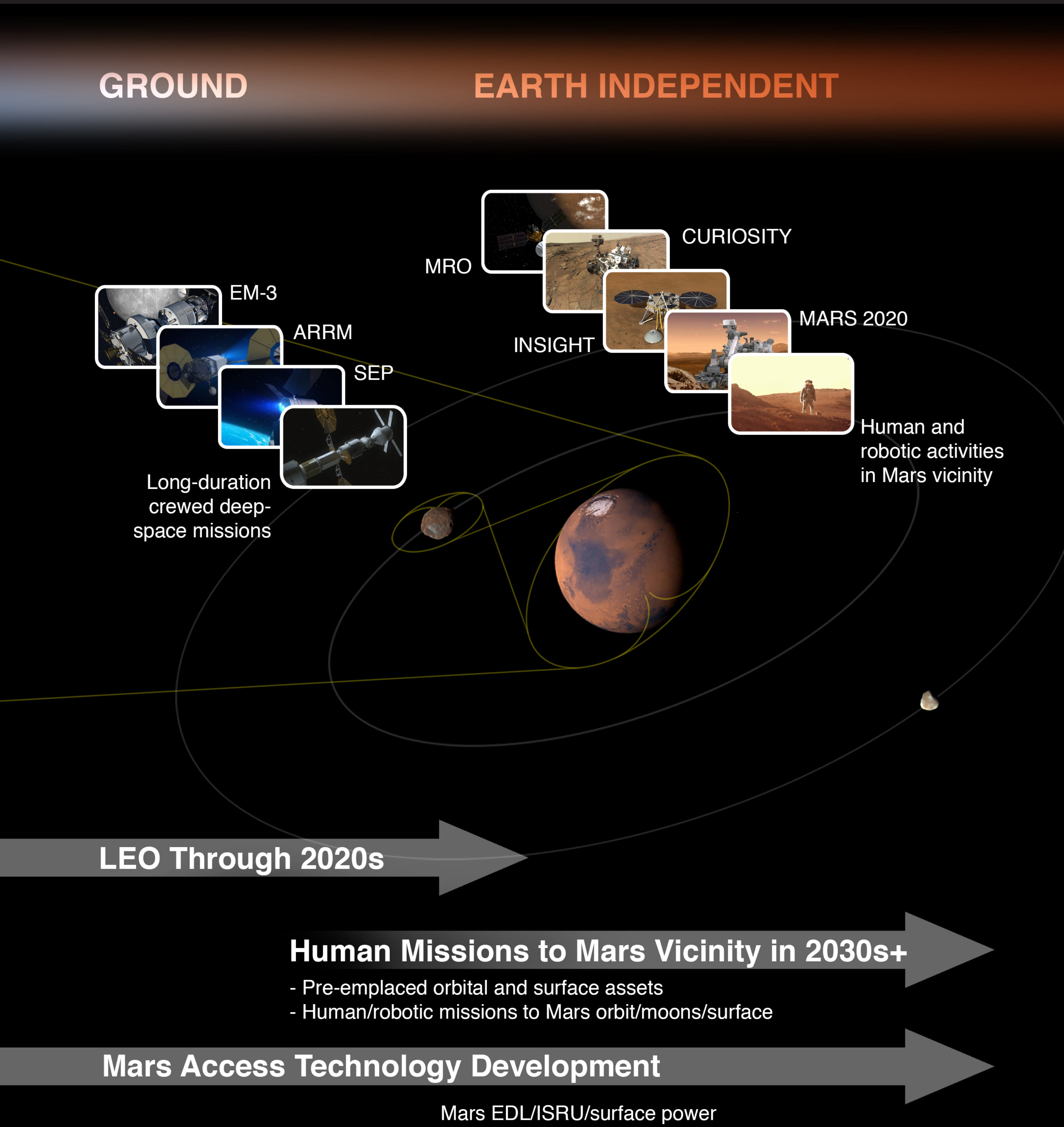
- Human Research Program risk mitigation
- Facilitate commercial LEO
- Conduct fundamental biological and physical sciences research

Crewed Missions Beyond

Resulting in Mars transit-like shakedown cruise by the end of the 2020s
- ARM/SEP
- Deep space habitat
- In-space transportation

Mars Robotic Science Missions and

Mars climate and surface mapping


GROUND
EARTH INDEPENDENT
EM-3
ARRM
SEP
Long-duration crewed deep-space missions
MRO
CURIOSITY
INSIGHT
MARS 2020
Human and robotic activities in Mars vicinity
LEO Through 2020s
Human Missions to Mars Vicinity in 2030s+
- Pre-emplaced orbital and surface assets
- Human/robotic missions to Mars orbit/moons/surface
Mars Access Technology Development
Mars EDL/ISRU/surface power

Pioneering Challenges

NASA has identified specific scientific and technical challenges for the journey to Mars through rigorous studies, including an ongoing series of architectural trade analyses, external reviews, assessments of deep-space habitation options with international partners, and high-priority objectives of science decadal studies. NASA and our partners around the world have already solved some of these challenges. The remaining challenges will be systematically addressed over the next two decades by the capabilities demonstrated through science missions, on the ISS, and in the Proving Ground as we move toward Earth Independence.

The Boeing CST-100 Starliner crewed vehicle, to be used for LEO destinations. (Boeing)

Transportation

Transportation capabilities are necessary to send humans to space affordably and reliably, provide high-thrust access to staging points in cislunar space, and efficiently and safely transport crew and exploration systems on the longer journey to Mars.

Commercial Cargo and Crew: Advances in transportation capabilities are only possible if NASA can shift to a more efficient mode of operations for current Earth-to-LEO transportation. NASA is partnering with commercial industry to make this shift possible. Through a commercial crew and cargo capability, NASA can rely on a less expensive, flexible commercial market to provide LEO transportation services, freeing up resources for beyond LEO and planetary transportation.

NASA's commercial crew and cargo program has bolstered U.S. launch market share globally

Beyond Low Earth Orbit Propulsion—SLS and Orion: A human-class Mars mission will require unprecedented amounts of mass transported farther than any previous human mission to space. A single Mars mission may require several 20-30 mt payloads delivered to the surface to support the crew as well as an in-space habitat, transportation stages, and supplies for round-trip missions of up to 1,100-days. In addition to mass, payload volume is a challenge. To enable cargo missions, NASA envisions a new 10-meter diameter fairing for the evolved SLS to accommodate unprecedented volumes. Commercial cargo services may be used to supplement the SLS's core role.

In-Space Power and Propulsion: Power is critical for exploration systems; however, it is particularly important for the transportation architecture. Each human Mars mission will require several cargo launches to pre-emplace infrastructure and supplies. NASA expects to use high-powered SEP systems (150- 200 kW) that can transport cargo in a sustainable cadence. SEP requires 50 percent less propellant than chemical propulsion and uses fewer heavy-lift launches. While SEP takes longer than chemical propulsion to deliver cargo, it gives campaign planners more timeline flexibility by providing trajectory options that are less coupled to the 26-month planetary alignment that drives traditional chemical propulsion architectures.

Entry, Descent, and Landing: EDL is one of our biggest challenges. The revolutionary sky crane landing system used for the *Curiosity* rover placed just under 1 mt of payload on the surface of Mars. The smallest viable human-scale lander concept is more than an order of magnitude larger, and it may be necessary to land multiple 20-30 mt payloads at a human landing site. Consequently, a completely new approach is needed for human-scale EDL. For instance, supersonic retropropulsion may be necessary to provide safe and accurate atmospheric entry, descent, and precision landing on Mars.

Ascent from Planetary Surfaces: A Mars Ascent Vehicle (MAV) is required to transport crews from the surface to Mars orbit. The MAV drives lander and EDL requirements, which in turn impact in-space propulsion and the total mass launched from Earth, a major driver for mission cost. Current MAV designs require a minimum lander size of just under 20 mt, assuming propellant can be generated from the Martian atmosphere via ISRU. The MAV is also critical to crew survival, requiring additional reliability and redundancy, zero boil-off cryogenic storage, and limited maintenance during years of dormancy. Current studies continue to refine our understanding of this critical element.

Communication and Navigation: Currently, Mars robotic rovers have data rates around two million bits per second, using a relay, such as the Mars Reconnaissance Orbiter. The ISS data rate is 300 million bits per second, two orders of magnitude faster. Future human Mars missions may need up to a billion bits per second at 1,000 times greater range than ISS, requiring laser communications to reduce weight and power. In addition, disruption and error-tolerant interplanetary networking and improved navigation capabilities are required to ensure accurate trajectories and precision landing.

Working in Space

Even with 50 years of human operations in space, new capabilities are necessary to sustain productive operations for crew and robotic systems at multiple destinations within the cislunar and Martian environments.

Exploration Extravehicular Activity: New EVA systems must supply basic biological needs during spacewalks, provide protection from hostile environments, and enable comfort, flexibility, and dexterity to support human exploration and investigation of new worlds. These EVA systems will be integrated and tested with vehicle interfaces, such as suitports, using lower-pressure, higher-oxygen atmospheres (e.g., 8.2 pounds per square inch with 34 percent oxygen) for rapid and frequent EVAs with minimum loss of valuable atmospheric gasses. The Asteroid Redirect Crew Mission will be an early opportunity in the Proving Ground to validate new EVA systems when crews conduct spacewalks to collect samples of an asteroid boulder. The potential effects on human health resulting from surface dust and its safe removal will also need to be thoroughly understood.

Pioneering Challenges

Human-Robotic and Autonomous Mission Operations: Key features of sustainable pioneering are pre-emplacing equipment, reusing infrastructure, and relying on robotic capabilities to support humans. Robotic systems can help deploy systems, provide assembly, and support maintenance both when crew are present and during periods of dormancy. Robotic systems designed to work with the crew increase productivity, support EVAs, and are critical to crew safety.

In-Situ Resource Utilization and Surface Power: NASA's science missions have long been searching for water beyond Earth, and they found it: everywhere. Sustainable pioneering must leverage water and other valuable in-space resources to break the logistical chain from Earth. ISRU technology enables the use of local resources, such as water in the form of ice crystals or hydrated minerals on the surface of Mars and carbon dioxide in its atmosphere, to be used as the feedstock for propellant, radiation shielding, and consumables for life support systems. Producing liquid oxygen propellant provides a significant architectural advantage—more than half of a 35 mt MAV mass is due to propellant, which could be produced locally. However, ISRU production for pioneering missions will require significant power to convert resources in an acceptable timeframe. ISRU systems will leverage high-power generation systems, such as solar or fission power, to produce ascent propellant.

Astronaut Karen Nyberg conducts an eye exam on herself on the ISS.

Surface Habitat and Mobility: The most important challenge for human pioneering missions is keeping the crew safe for long-duration missions up to 1,100 days. Habitats and associated systems and supplies, including food, clothing, atmospheric gases, and human interfaces, represent a significant portion of any exploration architecture. Habitation includes both in-space transit and Mars surface capabilities. NASA can reduce development costs, increase reliability, and ensure crew safety over a series of missions by reusing and maximizing commonality between the surface, transit, and Mars moons habitats and subsystems.

Staying Healthy

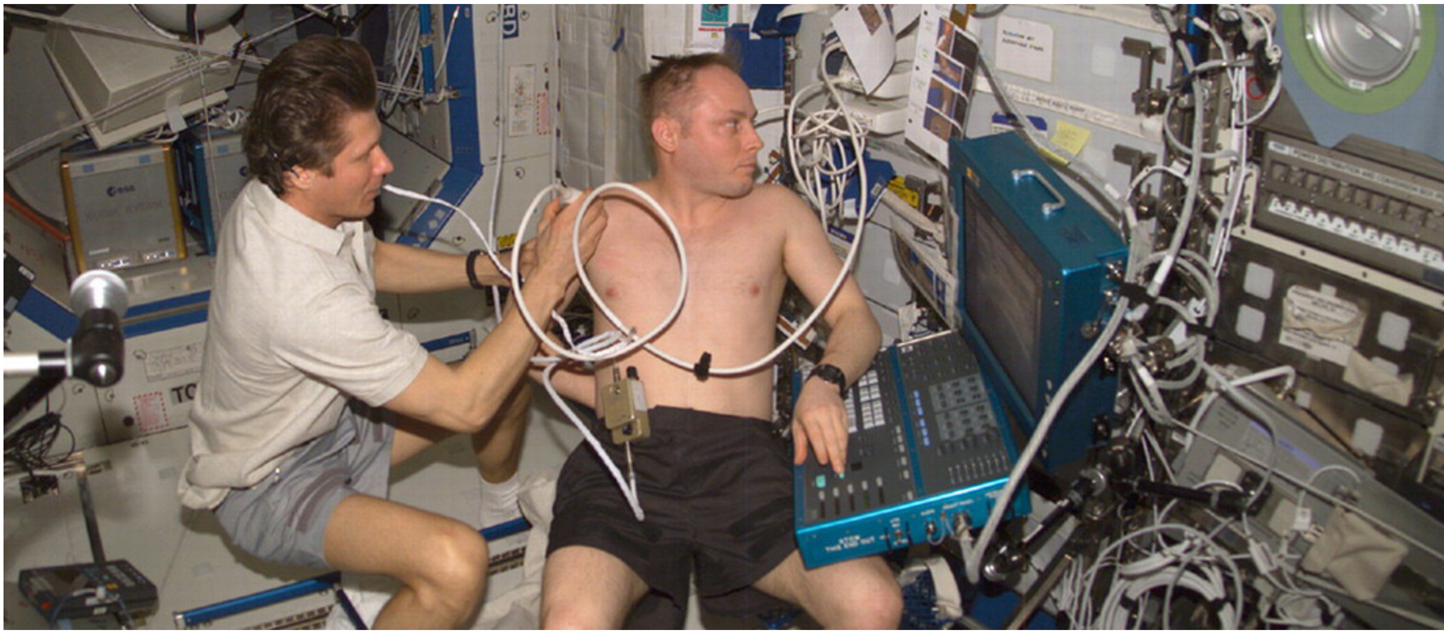
Deep-space crewed missions will not have regular access to the Earth's resources or the ability to rapidly return to Earth if a system fails. As crewed missions extend farther from Earth for longer periods, the habitation systems must become more reliable for safe, healthy, and sustainable human exploration.

Environmental Control and Life Support Systems (ECLSS): Leveraging the ISS, NASA is focused on demonstrating advanced capabilities for robust and reliable ECLSS, which must operate for up to 1,100 days with minimal spares and consumables. Systems demonstrated on the ISS and Orion will be further validated in the Proving Ground environment and incorporated into a reliable long-duration, deep-space habitation capability.

Crew Health: Long-duration human missions, including missions with up to 1,100 days in microgravity, potentially increase the risks of bone loss, atrophy, trauma, neurovestibular issues, loss of clear vision, and illness for the crew. To address these increased risks, crews will require new diagnostic, monitoring, and treatment tools and techniques, including exercise systems and other countermeasures, to maintain crew health. The ISS provides an ideal test bed to develop these capabilities.

Radiation Safety: Outside the Earth's magnetic field, crew and electronics are exposed to high-energy particles, including infrequent, but potentially deadly, solar particle events and constant exposure to galactic cosmic rays. These high-energy particles can reduce immune response, increase cancer risk, and interfere with electronics. NASA's Human Research Program is developing methods and technologies to protect, mitigate, and treat the effects of radiation on the crew and their exploration systems.

The journey to Mars will be further defined through Proving Ground missions in the next decade, as NASA and our partners retire these challenges and build on the capabilities for sustainable pioneering. We know these challenges are solvable and have a strategy in place for maturing the capabilities to address them as we expand human presence into deep space.



Cosmonaut Gennady Padalka performs an ultrasound exam on astronaut Mike Fincke aboard the ISS during Expedition 9.

Summary

We are on a journey to Mars. In the next few decades, NASA will take steps toward establishing a sustainable human presence beyond Earth, not just to visit but to stay. NASA's near-term activities focus on increasing our capacity to operate, work, and live in space while characterizing future destinations with the help of robotic science missions. Pioneering space begins with the ISS to ensure we have the reliable, long-duration systems necessary for human missions to Mars. In the Proving Ground, we will validate key capabilities through EM-1 and EM-2 along with ARM, SEP, cislunar habitation, and long-duration testing and operations. These and subsequent missions will target challenges and strategic knowledge gaps while helping develop the core capabilities necessary to expand human activity farther into deep space.

Pioneering space will require a flexible, integrated, and sustained effort to develop the capabilities and tools necessary to support humans throughout our solar system. Future missions will face increasingly difficult challenges associated with *transportation*, *working in space*, and *staying healthy*. Many of these challenges are solved or are currently being addressed on the ISS. For the rest, NASA and our partners will leverage the Proving Ground with science missions and capability demonstrations to close the remaining gaps and ensure we have the ability to get to Mars, land safely, live and work productively, and return.

NASA's strategy for pioneering space provides guidance for selecting and designing missions in the Proving Ground and enables future accomplishments on the journey to Mars. The strategy helps NASA logically progress from current Earth Reliant operations on the ISS, through the Proving Ground in cislunar space, to Earth Independent pioneering with the goal of humans living and working on Mars. This strategy provides the flexibility to respond to new discoveries, opportunities, and shifts in national priorities. NASA approaches pioneering space as a collaborative effort, within the United States and with our international partners, incorporating key capabilities from industry and academia, while engaging the public and stakeholder communities. The core capabilities NASA is working on with our partners—SEP, Mars-ready ECLSS, ISRU, and many more—will enable the journey to Mars.

NASA's human exploration, science, and technology endeavors are intertwined. As our exploration activities reach farther into the solar system, we will also broaden our reach here on Earth, enabling more participation, partners, activity, and economic and technological benefits. NASA's current investments in exploration capabilities and the decisions being made today are crucial to achieving our common goal: extending human presence into the solar system and to the surface of Mars.

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