GLOBAL EXPLORATION ROADMAP

AUGUST 2024

ISECG

International Space Exploration Coordination Group

What is ISECG?

The International Space Exploration Coordination Group (ISECG) is a voluntary, non-binding coordination forum of 27 space agencies with the common aim of advancing space exploration through exchanging information, objectives, and plans. ISECG participating agencies coordinate to develop consensus-based, non-binding products (e.g., roadmaps, white papers, and technical reports).

ISECG member agencies are committed to fostering discussions among participating agencies and developing products that enable members to effectively plan space exploration activities. This work is implemented through working groups and guided by a group of senior agency managers from ISECG participating agencies.

ISECG's flagship product is the Global Exploration Roadmap, which reflects a coordinated vision for long-term human and robotic exploration of the solar system.

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What's New in the Global Exploration Roadmap?

This fourth edition of the International Space Exploration Coordination Group's (ISECG) Global Exploration Roadmap conveys international support for the expansion of humanity's presence in the solar system. It is a consensus-based, non-binding product that articulates a common vision for space exploration through 2050, focusing on the priorities of participating ISECG agencies, rooted in the foundation of activities in low-Earth orbit and intensifying activities on and around the Moon to prepare for initial human exploration of Mars. It also discusses other destinations in the solar system and the synergy between robotic and human exploration activities.

This roadmap reflects common exploration objectives and shared principles for sustained exploration. Worldwide exploration programmes are evolving rapidly, with more and more countries flying missions. This edition of the roadmap presents an update to the overall exploration mission scenario and summarises planned missions by participating ISECG member agencies. The Moon remains the consensus near-term focus for sustained exploration activities. Accordingly, this roadmap reflects recent updates to participating ISECG agencies' national exploration architectures, which increasingly incorporate international cooperation.

High-level refinements to this edition of the Global Exploration Roadmap:

- An expanded vision that includes more space agencies.
- Increased emphasis on contributions from emerging space agencies and their participation in future space exploration activities.
- Updated examples of the benefits of space exploration.
- Recognition of the continued growth in private sector interest and activities.
- A summary of the high-level advancements in scientific knowledge and scientific partnerships that will be made possible through international collaboration.
- A planning horizon extended to 2050, with an emphasis on sustained exploration.
- Highlights of exploration activities beyond the Moon and Mars, with an emphasis on synergies between robotic and human exploration.
- An updated critical technologies list, including technologies that will enable humans to live on and explore the Moon for long periods of time.

ISECG member agencies continue to envision a future of expanding partnerships and collaboration, with an increasing number of actors, to realise the ambitious shared goal of expanding human and robotic presence in the solar system. The continued increase in the number of well-established and emerging space agencies supporting the Global Exploration Roadmap reflects a global interest in space exploration and dedication to exploring together for the benefit of humanity.

A composite of a series of images photographed from a mounted camera on the Earth-orbiting International Space Station, from approximately 240 miles above Earth by Expedition 31 Flight Engineer Don Pettit. (NASA)

The sun rises over Earth as viewed from the International Space Station. (NASA)

Chapter 1

Why We Explore

The International Space Station orbits above the north Pacific near Alaska's Aleutian Islands. (NASA)

Space exploration stands as a beacon of human potential. It responds to humanity's innate desire to venture out and discover what lies just beyond the known frontiers. Despite the challenges, the urge to explore benefits society in many ways. The daring journeys of astronauts in space are a universal source of inspiration, captivating the imagination of current and future generations and creating enthusiasm for science, technology, engineering, arts, and mathematics fields. Space exploration serves as a catalyst for technological innovation and scientific discovery, driving economic growth and leading to the development of new products and services that improve life on Earth. It enhances international collaboration and diplomacy on a global scale, uniting nations in pursuit of common goals and fostering mutual respect and understanding.

The exploration goals and objectives, developed by participating ISECG agencies, are highly interlinked with the benefits of space exploration. As we venture toward increasingly distant and challenging destinations, the overarching aim of space exploration remains constant: to harness benefits for humanity. Achieving these benefits requires advancing our knowledge of the universe while actively engaging the citizens and communities on our own planet.

Exploration Goals and Objectives

1. Expand Human Presence into the Solar System in a Sustainable Manner

- Ensure continuity for human spaceflight and continued utilisation of low-Earth orbit
- Enable sustained living and working around and on the Moon
- Enable sustained human missions living and working around and on Mars

2. Understand Our Place in the Universe

- Study the origin and evolution of the Earth and Moon system, the solar system, and the universe
- Search for evidence of past or present life and the origin of life on Earth
- Investigate habitability of potential human destinations

3. Engage the Public

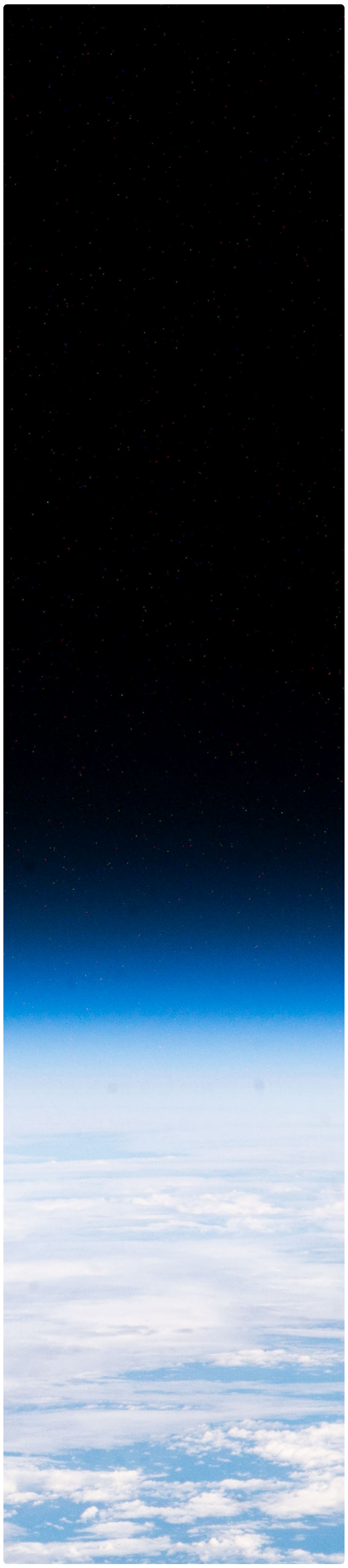
- Inspire, educate, and foster critical thinking
- Create opportunities for participation in space exploration
- Deliver benefits to society

4. Stimulate Economic Prosperity

- Promote industrial capability and competitiveness for space exploration
- Facilitate the development of commercial markets at exploration destinations
- Promote collaboration with the private sector

5. Foster International Collaboration

- Encourage and embrace the participation of nations in space exploration initiatives
- Promote interoperability to increase opportunities for international partnerships



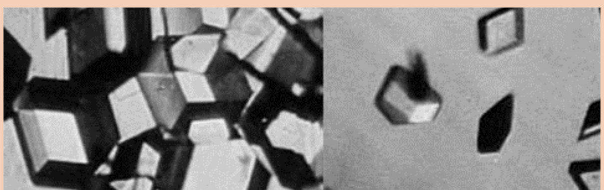
The Earth's horizon as viewed from low-Earth orbit. (NASA)

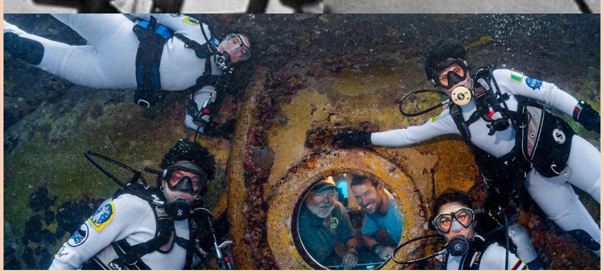
Benefits Stemming from Space Exploration

Countries investing in space exploration see numerous benefits generated both within and beyond their borders. The recent growth in interest and diversity of participants and customers in space exploration is evidence that a wide range of stakeholders recognises the benefits of space exploration. Participating ISECG agencies identified five categories of benefits stemming from space exploration that create wide-ranging value for people on Earth:

Science Benefits

Research conducted by humans and robots in outer space reveals new knowledge about the physical, planetary, and life sciences. By exploring space, we also learn more about the human body and our home planet.



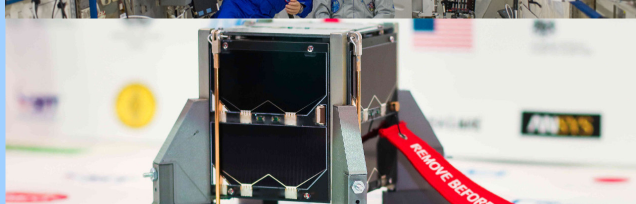


Top: Crystals of insulin grown in space (left) and Earth-grown crystals (right). (NASA)
Bottom: NEEMO 23 crew at the Aquarius underwater habitat. (NASA/K. Shreeves)

Economic Benefits

The technologies developed for space exploration have wide-ranging applications back on Earth, boosting national economies and improving quality of life. Space exploration spin-off technologies have become ubiquitous in medicine, communications, transportation, and other industries.

Top: The moment when Intuitive Machines 1 landed on the Moon on 22 February, 2024. (Intuitive Machines)
Bottom: Lunar Gateway's Habitation And Logistics Outpost (HALO) in progress. (Thales Alenia Space)



Global Cooperation Benefits

Space exploration partnerships enable larger, more complex missions. Expanding partnerships also fosters the peaceful exploration of space for the benefit of humanity.

Top: 280 individuals from 23 countries have visited the ISS. (ESA)

Bottom: Quetzal-1 cubesat, the first ever Guatemalan satellite deployed from Kibo. (Universidad del Valle de Guatemala)

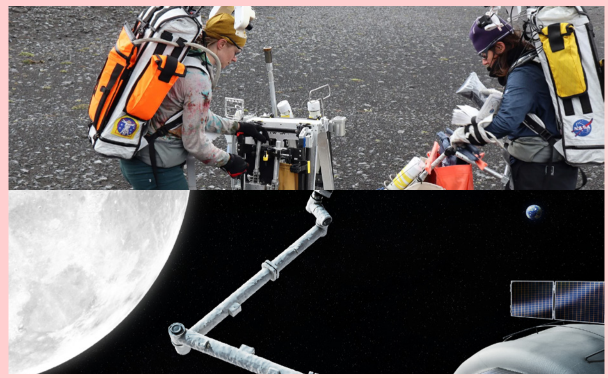
Inspirational and Societal Benefits

Space exploration inspires people around the world, especially younger generations, to develop science, technology, engineering, arts, and mathematics skills; to expand the limits of human knowledge; and to work together to overcome immense challenges. Knowledge and capabilities created for demanding exploration missions have the potential to make life on Earth more sustainable.

Top: Shaun the Sheep, the woolly specialist aboard Artemis I. (ESA/Aardman)
Bottom: Luxembourg Space Agency's Astronaut for a Day competition, inspired by the original initiative launched in 2022 by the Portuguese Space Agency. (Novespace/LSA)

Exploration Ecosystem Benefits

Nations investing in space exploration secure future opportunities for involvement in exploration missions. Established space agencies create opportunities for emerging agencies and commercial entities to conduct science and develop new technologies, creating mutually advantageous outcomes.

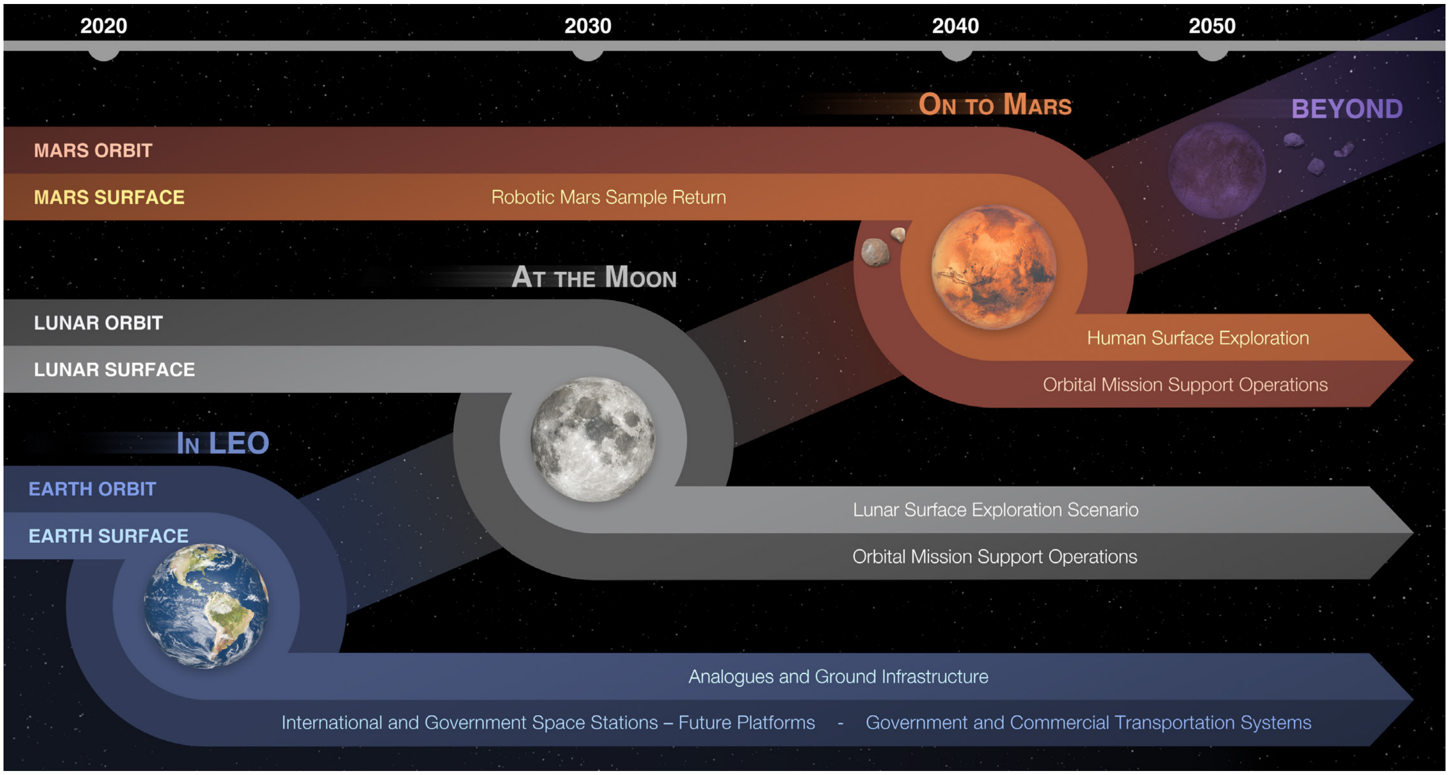


Top: Testing of the Joint EVA and Human Surface Mobility Test Team (JETT). (NASA)
Bottom: Artist's impression of the Canadarm3 on Gateway. (CSA/NASA)

The world's space agencies have many—and sometimes different—exploration goals, but they share common drivers: expanding human presence in space; enabling the study of the origin and evolution of the Earth, the Moon, Mars, and the solar system; and understanding our place in the universe.

Chapter 2

Exploring Together



The ISECG Global Exploration Roadmap.

International cooperation in space exploration has grown significantly in recent years. Partnerships and collaborations are integral to current and future missions, especially as we explore farther from Earth. When they collaborate, countries share their spaceflight expertise and the costs and risks of spaceflight, ensuring the success of cooperative missions.

Space exploration is an opportunity for countries to come together for the benefit of humanity. We explore together with common goals: the peaceful use of space, a sustainable and responsible approach to exploration, and ever-increasing knowledge of the solar system and beyond.

Successful exploration requires the disciplines of science, robotics, and human exploration to progress together. Scientific observations and robotic precursor missions prepare humans to journey into deep space and accomplish their exploration objectives.

In recent years, many participating ISECG agencies have developed and published space strategies, policies, architectures, and roadmaps. The ISECG Global Exploration Roadmap depicted here is an aid for developing and executing such plans. While it does not commit agencies to specific steps and activities, the roadmap ultimately represents a common understanding about exploring together.

ISECG Exploration Principles

The following principles guide the development of the Global Exploration Roadmap. They represent attributes of an enduring, sustainable, and responsible human space exploration endeavour. Exploration activities should be approached in a way that is transparent and respects the traditions of all peoples.

Affordability
Build innovative approaches to enable more with available budgets: Cost must be considered throughout exploration programme formulation and execution. Architectures should favour reusable and reliable in-space systems implemented in partnership to share cost.

Exploration Benefit
Meet exploration objectives and generate public benefits: Sustainable human space exploration must respond to exploration goals and objectives and provide value to the public and other stakeholder communities. Synergies between space and other domains are crucial.

Partnerships
Provide early and sustained opportunities for diverse partners: International cooperation is critical for enabling and sustaining increasingly complex exploration missions. Collaborations should consider the long-term interests of each partner, large or small. Working with the private sector, where goals align, can enable new approaches and create markets for services to support space exploration.

Capability Evolution and Interoperability
Evolve capabilities with standard interfaces: Building upon existing capabilities and increasing performance with each step. Using common interfaces and modular architectures facilitates addition of new partners, reduces mass, and increases safety.

Human-Robotic Partnership Synergy
Maximise synergies between human and robotic missions: Combining the unique and complementary capabilities of humans and robotic systems enables a greater set of goals to be met effectively, cost-efficiently, and safely.

Robustness
Provide resilience to technical and programmatic challenges: Plans and actions must have flexibility to cope with unplanned changes or crisis situations, whether due to catastrophic events, changes in partner priorities, adjustments in available funding, or the evolution of objectives. Dissimilar redundancies of critical functions should be applied early, where practicable.

Responsible Exploration
Explore peacefully together: Exploration activities should be conducted for peaceful purposes and in a manner that is consistent with international obligations and principles in space. This includes attempting to limit the impact of exploration activities on the space environment, preserving it for future generations.

Ground Stations: Murriyang, CSIRO's Parkes radio telescope (pictured), a 64-metre radio telescope located in New South Wales, Australia, complements the capabilities of the Canberra Deep Space Communication Complex operated by CSIRO for NASA's Deep Space Network. Murriyang has supported lunar communications for Apollo missions and more recent robotic missions, including Intuitive Machines' first lunar mission, IM-1. (CSIRO)

These exploration principles enable all space agencies to collaborate in space. They also create meaningful opportunities for emerging space agencies to participate in missions and develop their own capabilities and expertise based on their own scale and ambitions. International collaboration includes Earth-based infrastructure. The operation of ground stations, simulation and training facilities, and analogue sites and research and development in radio and optical communication technology represent ripe areas for ISECG member agency participation, partnerships, and commercialisation.

Emerging Space Agencies

ISECG also serves as a venue to build collaboration between emerging space agencies and established agencies. In the past, emerging space agencies faced significant barriers to mounting large-scale exploration missions. Traditional approaches to exploration require large investments in complex technology and national capabilities. Recently, however, space exploration has changed dramatically, including a significant decrease in the magnitude of resources necessary to participate in meaningful exploration. Participation in groups like ISECG can help emerging agencies identify partnerships to support their exploration objectives.

The value of space exploration lies not only in the results of successful missions, but also in the lessons learnt along the way.

Australian Space Agency and CSIRO

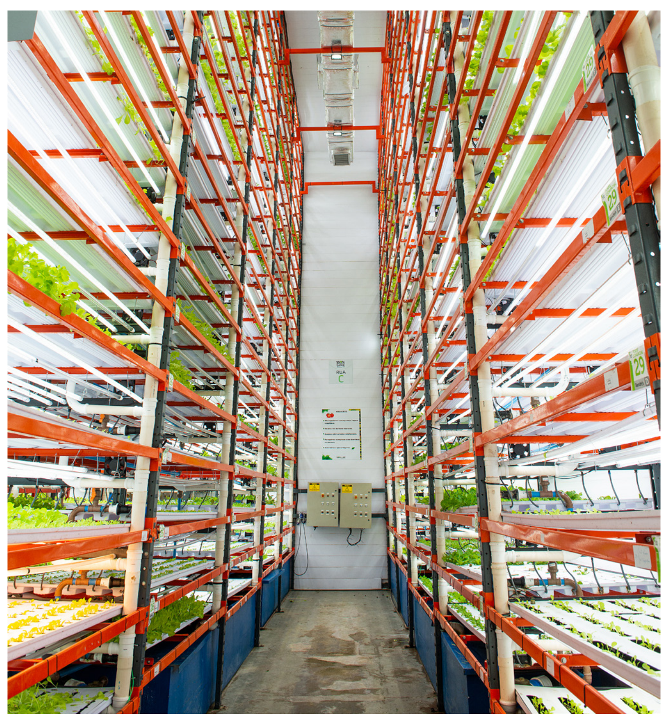
Thanks to its geographic location, large landmass, and quiet skies, Australia has provided deep space communications for human and robotic space exploration missions for over six decades. The Australian natural environment also offers a diverse range of lunar and Martian surface analogues. The stromatolites, layered sedimentary formations created by microorganisms, in the Pilbara region are a prime example of some of the oldest known evidence of life of Earth and have been studied by scientists in support of the search for evidence of past life on Mars. Australia's world-leading capabilities in remote and autonomous operations of mining sites offer an opportunity for technology spin-in for in-situ resource utilisation (ISRU). The Australian Space Agency's (ASA) Moon to Mars Initiative Trailblazer Program will see an Australian-designed and -built lunar rover, Roo-ver, launched on a future National Aeronautics and Space Administration (NASA) mission.

CSIRO's In-Situ Resource Utilisation Facility includes a lunar testbed that simulates some of the physical characteristics of the Moon's surface for realistic testing and evaluation of assets such as rovers and related equipment. (CSIRO)

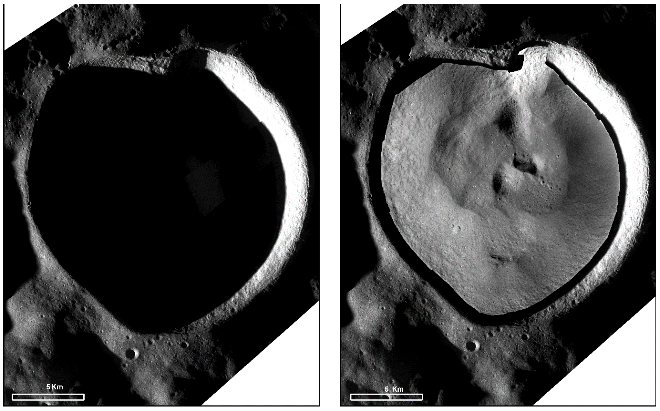
Stromatolites in the Pilbara, Australia. (ASA)

Brazilian Space Agency

Space farming is an opportunity for a significant Brazilian contribution to human space exploration. The Brazilian Space Agency (AEB) and the Brazilian Agricultural Research Corporation (EMBRAPA) established the Brazilian Space Farming Research Network to develop food production systems that are adaptable to space, seeking solutions to the complex challenges of high radiation, low gravity, and the absence of soil. Researchers chose to develop pilot systems prioritising two species, sweet potatoes and chickpeas, based on adaptability to adverse conditions in space and the ability to meet the dietary needs of astronauts. One of the research network's expectations is that the development of space agriculture will inspire innovations for agriculture on Earth, generating economic growth.



Vertical farming in Brazil. (EMBRAPA/Lilian Alves)



Lunar Terrain Imager (LUTI) only (left) and LUTI-ShadowCam simultaneously observed image (right) of lunar permanently shadowed region near the north pole, Hermite-A. KPLO hosts LUTI and ShadowCam, developed by Korea Aerospace Research Institute and Arizona State University, respectively. (KASA, NASA)

Korea AeroSpace Administration

Korea placed the Korea Pathfinder Lunar Orbiter (KPLO) in lunar orbit in 2022. This was Korea's first step outside Earth's orbit, paving the way for future endeavours. Next, the Korea AeroSpace Administration (KASA) will begin the development of a robotic lunar lander, with the goal of landing on the Moon in 2032. It also has plans to launch a Mars orbiter in 2035 and a Mars lander by 2045.

Colmena team at LINX facilities at the end of the assembly, integration, and testing phase of Colmena-1. (LINX-ICN-UNAM)

Mexican Space Agency

The Mexican Space Agency's (AEM) Colmena project consists of three lunar missions between 2023 and 2030 to develop swarm microrobotics for lunar and asteroid prospecting and mining, developed and managed by the National Autonomous University of Mexico's Laboratory of Space Instrumentation (LINX). The first of those missions, Colmena-1, was launched aboard a NASA Commercial Lunar Payload Services (CLPS) provider lander on 8 January, 2024. Although a technical issue prevented landing, Colmena-1 was able to validate up to 75 per cent of its technical objectives in deep space. The information collected is enabling the development of Colmena-2, which is targeting a launch in late 2027 or early 2028.

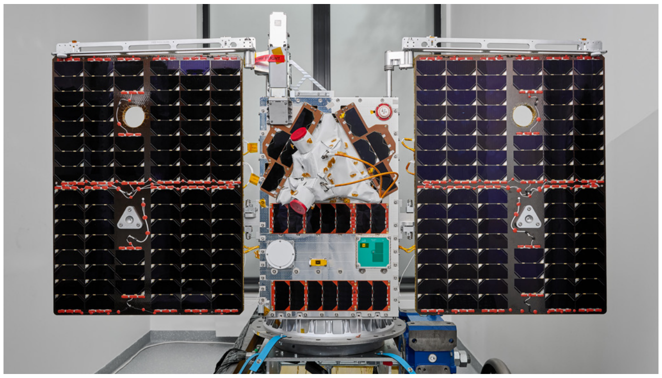
The gold-plated Rimfax electronics unit integrated into the Perseverance rover. (NASA)

Norwegian Space Agency

Norway's exploration activities have grown considerably over the last decade. In 2021, the ground-penetrating Rimfax radar on the NASA Perseverance rover became the first Norwegian instrument to operate on Mars. The Analysing Interferometer for Ambient Air (ANITA) air analyser has been upgraded from a technology demonstrator to a formal tool for monitoring air quality aboard the International Space Station (ISS) and is being considered for operation aboard Gateway. Norwegian researchers are studying food production in microgravity to prepare for sustained presence in deep space. Norway hosts astronaut field training in geological analogue environments and facilities for curation and analysis of analogue sample materials. The European Space Agency (ESA) uses Norwegian virtual reality tools in astronaut training.

Polish Space Agency

2024 was a historic year for Polish spaceflight. In July, the suborbital ILR-33 AMBER 2K rocket became the first Polish rocket to reach space. It is also the world's first rocket to use 98 per cent hydrogen peroxide as an oxidizer. On 16 August, 2024, EagleEye, Poland's largest and most advanced satellite, successfully launched to low-Earth orbit (LEO). EagleEye was developed by collaborators from national industry and academia. Work on the first Polish lunar mission began in 2022; the Polish Space Agency estimates that it may launch by 2030.



Polish EagleEye observation satellite. (Creotech Instruments)

Portuguese Space Agency

Portugal has witnessed a growing scientific and industrial interest—particularly in the fields of space medicine and analogues—since the publication of its national space strategy in 2018. The Portuguese Space Agency is listing potential analogue sites and facilities across the country, with a particular interest in locations that offer complementary features to complement existing worldwide sites (e.g., Selvagens islands and Capelinhos volcano). Portugal is also home to ESTHER (European Shock-Tube for High Enthalpy Research), a research infrastructure whose primary mission is to support future planetary exploration missions through the reproduction of atmospheric entry plasmas at the ground level.

European Shock-Tube for High Enthalpy Research. (Instituto de Plasmas e Fusão Nuclear)

ISECG offers emerging space agencies unique insights into exploration programmes and opportunities to join in a coordinated manner. Nations harness space for socio-economic development, to grow highly skilled workforces, and to strengthen international partnerships. With an increasing number of emerging space agencies and a solid foundation of exploration principles, ISECG member agencies will continue to grow and explore together.

Astromaterials processors use tools to collect asteroid particles from the base of the OSIRIS-REx science canister. (NASA)

Chapter 3

Science Leads the Way

Space exploration has opened new horizons and advanced our understanding of who we are, where we come from, and where we are going. From examining planetary origins and processes to searching for signs of life, we continue to unravel the fundamental mysteries that surround us.

Science and exploration are inextricably entwined. As humanity ventures beyond Earth, it has accumulated new knowledge, answering some fundamental questions while opening many more. The latest scientific instruments produce unprecedented quantities of data, and the proliferation of spaceflight and exploration missions offers more opportunities than ever to conduct new and novel science to answer questions about planetary science, cosmology, and the origins of life.

The relationship is reciprocal: exploration enables us to tackle scientific questions, and scientific results enable increasingly ambitious exploration. For example, characterising the resources available on the Moon helps us understand the history of the Earth, the Moon, and the solar system, while also opening the possibility of manufacturing fuel or sustaining life on the Moon through ISRU. Studying the effects of dust and plasma interactions on exploration instruments and robotics enhances our understanding of space and solar phenomena. Space missions, whether they are led by humans or robots, provide opportunities to test theories within constrained parameters, leading to new avenues of inquiry.

Why We Explore: Overarching Science Themes

Space exploration enables crucial investigations into the physical and life sciences. These investigations will address the major scientific topics listed below. Scientific investigations are also key to enabling exploration: What new materials and technologies will we need to reach new destinations? What local resources can we identify and sustainably utilise? How do we make the best use of key insights and data for future missions and investigations? And perhaps most importantly, how can these adventures help us advance our well-being as a species back here on Earth? Ultimately, learning about our planetary neighbours allows us to learn more about our own home. By exploring other planets, we also explore Earth's past, present, and future.

In the broadest terms, the Global Exploration Roadmap reflects a consensus to investigate some key areas of science:

Cosmic Genesis Investigation
Understand the origins of the universe and investigate the fundamental processes that led to the emergence of life.

Extra-terrestrial Life Exploration
Seek signs of life beyond Earth and explore the potential for current or past life in our solar system.

Planetary Science
Explore planetary geology and scientific phenomena to enhance our understanding of geologic, atmospheric, and chemical processes both on Earth and throughout the solar system.

Earth-centric Environmental Science
Address Earth-facing science questions, focusing on our environment, climate, natural hazards, and trends to inform improved decision-making on our home planet.

Leveraging Technology for Science
Explore the applicability of technologies for conducting scientific investigations in novel or extreme environments and explore the terrestrial applications of space-derived technologies.

Resource Discovery and Utilisation
Search for resources beyond Earth and assess their feasibility for utilisation in space missions, with a focus on enabling science activities for long-term human and robotic exploration.

Biological and Life Science
Study the effects of space environments on humans, plants, and animals.

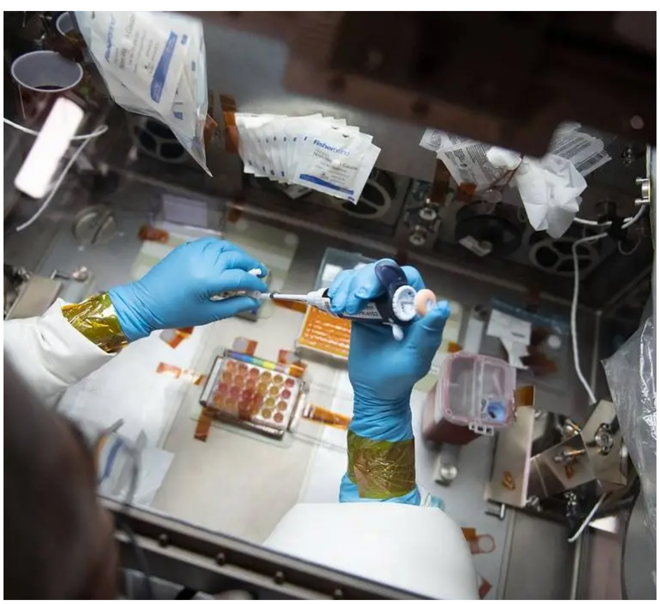
Who Explores: The Value of Human Exploration for Science

Human space exploration, in tandem with robotic missions, plays a pivotal role in advancing scientific knowledge both in space and back on Earth. The synergistic collaboration between human and robotic exploration methods opens new avenues for understanding our solar system and beyond. Human exploration is also a source of inspiration for people around the world—human adventures in space inspire great accomplishments back on Earth.

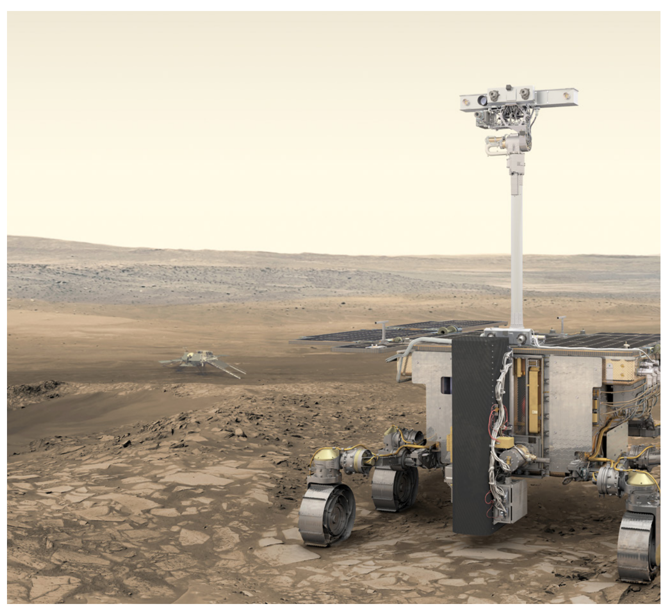
Human and Robotic Exploration: Complementary Approaches

Scientific investigation beyond LEO has historically been the domain of robotic assets, which offer long-term, large-scale observation with a low risk profile. While robotic missions excel at performing specific tasks, human exploration introduces unmatched advantages. Human crews provide greater local terrain mobility, flexibility, and dexterity, enabling a broader range of mission activities, including the collection and analysis of specific samples for geological and scientific investigations. Human crews can operate various tools, including drills, and offer high flexibility in adapting mission planning.

Robotic assets can access areas humans cannot, operating both remotely and in tandem with human explorers, and augmented with artificial intelligence. Robotic assets will also serve as precursors to planned human missions, identifying locations of interest, scouting for volatiles and other resources, and pre-positioning equipment and cargo that human explorers will use. Robotic missions will also continue to lead the ongoing exploration of the solar system beyond the Moon and Mars, continuing to expand our scientific horizons. Future missions will combine the unique capabilities of both human and robotic explorers to maximise crew time, enhance scientific capabilities and quality, and reduce the riskiness of extravehicular activities (EVA).



NASA astronaut Mark Vande Hei conducting the Celestial Immunity study aboard the ISS. This study may provide insights into new vaccines and drugs to prevent and treat existing and emerging human diseases. (NASA)



ESA's Rosalind Franklin rover (artist's concept). This rover will traverse the surface of Mars and drill up to 2 metres below the surface to look for signs of extinct and extant life. (ESA/ATG MediaLab)

How We Explore: Responsible Exploration, Planetary Protection, and Scientific Integrity

As humanity embarks on global exploration efforts, the need for responsible space exploration has never been more apparent. While economic robustness and cost-effectiveness are integral aspects of responsible, resilient, and sustained space exploration, the concept of planetary protection—the need to safeguard solar system bodies from forward contamination by terrestrial matter and prevent backward contamination of Earth from extra-terrestrial sources—is also essential.

Cooperative Science Missions: International Collaboration and Knowledge Sharing

Cooperative science missions foster resilience in international efforts. By leveraging international expertise and workforces, responsible exploration ensures optimal use of resources. International collaborative initiatives encourage knowledge sharing to address forward-thinking science goals.

An astronaut operates an uncrewed aerial vehicle on Mars (artist's concept). (NASA)

Human-assisted robots are being developed to explore planetary surfaces and collect data in extreme environments. (CSIRO)

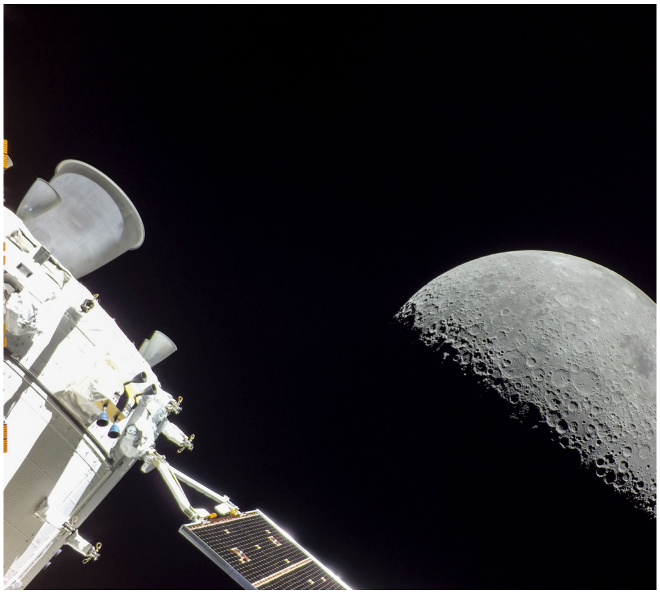
Opportunities

International collaborative efforts are critical to advancing science. Strategic coordination between space agencies offers diversity of thought, innovative concepts, and technological advances. International forums and bilateral and multilateral agreements can create a foundation for cooperation and coordination to pursue priority scientific goals. The growing lunar economy and availability of commercial exploration services will provide the science community, including previously unrepresented communities and space agencies, with reliable and affordable access to the Moon and other planetary bodies. Synergy between robotic and human exploration initiatives can push scientific knowledge further and faster than either can alone.

The following research and technology areas are particularly ripe for collaboration:

- Planetary geophysical networks
- Lunar astronomical observatory
- In-situ research and analysis
- Volatile prospecting and mapping
- Data transfer infrastructure

Open science and data sharing policies, broad communication of objectives, and international coordination are key to identifying collaborative activities ranging from scientific analyses, to technical expertise, to provision of hardware for accomplishing scientific initiatives.



Orion passes by the Moon during Artemis I. (NASA)

Curiosity and Exploration

Science is a key driver of space exploration and serves as an opportunity for global collaboration and knowledge sharing. By conducting robotic and human missions, we not only uncover answers to our deepest scientific questions, but also develop technology that improves life on Earth and enables increasingly ambitious exploration. Science acts as both foundation and motivation for space exploration initiatives. Not only does exploration infrastructure rely on scientific observations to inform design decisions, but scientific questions provide the rationale for exploration: why we explore, what we want to do, and where we need to do it. Science and space exploration both require each other to flourish. Ensuring that science is integrated at every step along the paths of exploration initiatives and technology development will ultimately inform future exploration enterprises, buy down risk associated with human and robotic spaceflight, and promote discovery of the universe around us.


The International Space Station as viewed from STS-130 in 2010. (NASA)

Chapter 4

Low-Earth Orbit

LEO is the nearest part of the frontier—it has long served as the doorway of exploration, hosting space stations and their crews, space telescopes, and thousands of satellites with countless commercial, communication, and scientific applications. Humanity's continued presence in LEO enables cutting-edge science and serves as a stepping stone for exploration of the Moon, Mars, and beyond.

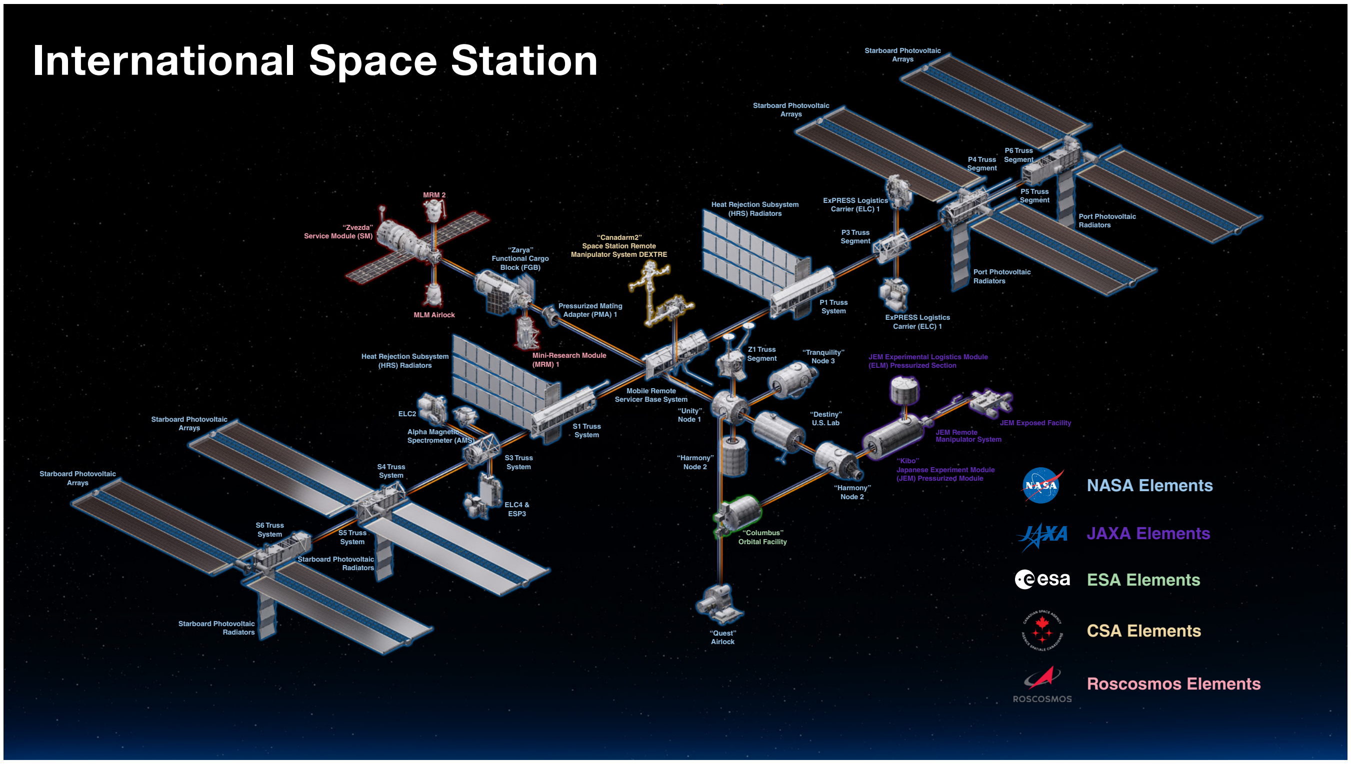
The International Space Station and the Evolution of Low-Earth Orbit

The launch of the first modules of the International Space Station (ISS) in 1998 ushered in an era of collaboration in LEO. The ISS, a partnership among 15 nations, is one of the greatest examples of international cooperation. It has hosted 280 individuals from 23 countries and supported numerous technological discoveries and advancements. The success of the ISS is a direct result of the significant international commitment to a truly cooperative and collaborative space station.

To date, well over 3,000 experiments from more than 100 countries have been conducted on the ISS across the fields of biology and biotechnology, Earth and space science, human research, physical science, and material science and technology. As a laboratory, the ISS offers the unique conditions of long-duration microgravity, exposure to space, and a view of the Earth from above.

It has four dedicated science modules: the U.S. Destiny module (2001), the ESA Columbus module (2008), Japanese Experiment Module Kibo (2008), and the Russian Nauka module (2021), as well as external science facilities.


NASA astronaut Jessica Meir trims leaves and harvests a crop of Mizuna mustard greens grown inside the International Space Station's Veggie botany facility located in the Columbus laboratory module. (NASA)



Research highlight areas and examples of their applications include the following:

Fundamental science
Molecular biology, materials science, plasma physics, combustion, fluid behaviour

Astrophysics
Cosmic rays, dark matter, antimatter

Earth observation
Collecting climate-related data, responding to disasters in real time

Human health
Airway monitoring, immune function, muscle and bone loss, eye degeneration, psychology, lightweight and compact diagnostic technology

Plant growth
Food crops in microgravity, exposure of seeds to space environment

Drug discovery
Study of diseases, targeted treatments, tissue chips

Manufacturing
Artificial retinas, fibre optics, 3D printing

Bioprinting
Template-free 3D-printed tissues and organs

Robotics
Robotic arms, collaborative robots

Tiangong space station. (CMSA)

Chinese Orbital Activities

China's Manned Space Agency's (CMSA) space station project was first launched in 2011 with the Tiangong 1 Space Laboratory, which was followed by the Tiangong 2 Space Laboratory in September 2016. Both have since de-orbited.

In 2021 and 2022, three modules of a larger Tiangong station launched: Tianhe launched in April 2021, Wentian launched in July 2022, and Mengtian launched in October 2022.

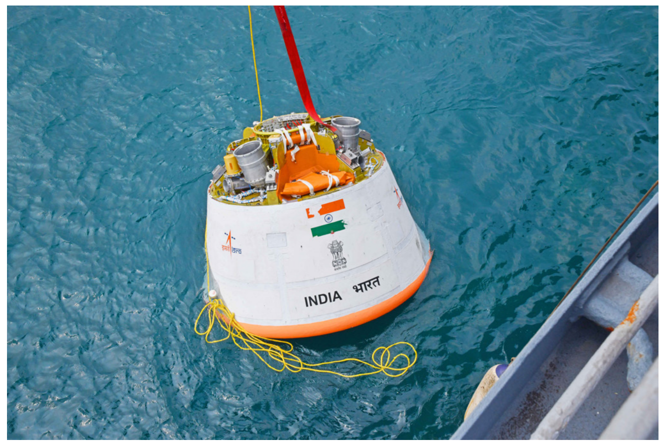
The first crewed mission to the new station arrived in June 2021, with the Chinese astronauts (taikonauts) spending 90 days aboard Tianhe. CMSA is anticipating continuous habitation by three astronauts for six-month stays on the station for the next 15 years, hosting various experiments from China and international partners.

The primary research and application areas of the space station include space medicine, space life science and biotechnology, microgravity fluid physics, space material science, microgravity basic physics, space astronomy and astrophysics, space environment and space physics, aerospace components, space geosciences and applications, space-based information technology, new aerospace technologies, and new space applications research.

China plans to further develop Tiangong from three modules to six, including six docking ports to accommodate additional full-size modules. International cooperation on the Tiangong station could include module-level cooperation during other countries' spacecraft visits, joint flights by astronauts, and collaboration in space science and space applications research. As of August 2023, Tiangong had conducted over 60 experiments. In 2019, the United Nations Office of Outer Space Affairs (UNOOSA) collaborated with CMSA to conduct experiments aboard the station, approving experiments from 23 institutes and 17 countries.

Indian Orbital Activities

The Indian Space Research Organisation's (ISRO) Gaganyaan programme aims to launch a crew of three astronauts to an orbit for a three-day mission, followed by splashdown in the Indian Ocean. ISRO successfully tested vehicle sub-systems, the crew escape system, and capsule recovery in October 2023. In February 2024, India announced the selection of its first four astronaut designates. ISRO is also working toward establishing the Bharatiya Antariksha Station, which serves as a crucial foundation for future missions, by 2035.



ISRO test vehicle launch (left) and crew module recovery (right). (ISRO)

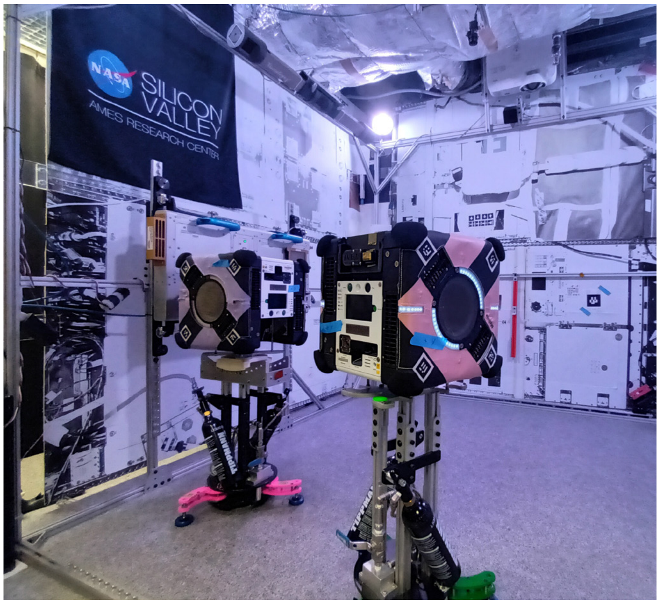
Commercialisation in Low-Earth Orbit

Historically, LEO space exploration, testing, and capability demonstrations were primarily achieved through government support and resources. However, private-sector LEO capabilities have increased in recent years, stimulated by contracting opportunities with governments. Although governments remain key investors in space exploration activities, many ISECG member agencies are leveraging the capabilities of private companies to support human spaceflight, science, and exploration activities in LEO.

Enabling private sector companies to increase their activities in LEO can reduce costs, build robust national space economies, enable space agencies to shift their exploration activities beyond LEO, and support technological discovery and progress. ISECG member agencies embrace these partnerships with the knowledge that they benefit not only each country's economy, but global space exploration more broadly. For example, private companies continue to launch astronauts to the ISS to conduct missions that include scientific and outreach activities.

Axiom Mission 1 (Ax-1) SpaceX Dragon Freedom spacecraft docked with the ISS. Ax-1 carried four astronauts to the ISS in a fully commercial mission. (NASA)

The research performed and operational experience gained aboard the ISS is increasingly being transferred to space companies, which, alongside decreasing launch costs, is boosting the growth of the space economy. The ISS hosts over 30 commercial experiments, platforms, facilities, or pieces of equipment (e.g., Bartolomeo, International Commercial Experiment Cubes, Bioreactor Express Service, and Astrobee), creating a pathway for future commercial research and manufacturing in LEO.



CSIRO's multi-resolution scanning payload attached to an Astrobee robot platform in a simulated ISS environment at NASA Ames Research Center. (CSIRO)

The ISS serves as a platform for developing and testing technologies to enable long-duration exploration, such as power generation, air and water recycling, carbon dioxide removal, communications, and robotics; in many cases, these technologies have also been spun out for commercial applications back on Earth. For example, technology based on ESA's Minus Eighty-Degree Laboratory Freezers on ISS is now used to reduce boil-off on liquid natural gas tankers, reducing greenhouse gas emissions. Robotics work aboard the ISS, such as the Dextre robotic arm and Robonaut, has led to adaptive gripper technology and wearable robotic gloves that are commonly used in collaborative robotics in factories on Earth.

More and more companies are offering commercialisation platforms and services aboard the ISS, creating opportunities for a diverse range of stakeholders. These companies provide access to the unique microgravity environment and offer services such as payload integration, deployment, and operations (for applications in Earth observation, robotics, material science, and astrophysics), making it easier and more cost effective for commercial organisations to access space.

The commercially provided facilities on the ISS fall into two main categories:

Satellite deployment:
The ISS serves as an important platform for satellite deployment. Hundreds of CubeSats have been deployed from the station, many of which offered small and emerging space agencies to access space. The rise of commercial providers has helped reduce costs and ease the process of launching and positioning a satellite in orbit.

Platforms for science experiments and technology demonstration:
Commercial partners leverage the ISS's unique internal and external infrastructure to perform work in orbit. ISS infrastructure provides power, data management, communications, and payload controls.

The HSKSAT developed by Haradaseiki is deployed from the Japanese Experimental Module Small Satellite Orbital Deployer. (JAXA)

Several private companies are also engaged in studying new concepts of completely commercial space stations in LEO, which can also include cooperation with institutional actors. LEO presents promising opportunities for private companies to leverage the unique conditions of microgravity. Reduced cost of access to space, increased frequency of launches, and access to modern orbital infrastructure aboard future commercial LEO destinations will drive significant innovation and growth in the LEO economy. The capabilities of commercial "new space" companies will also create more options for national space agencies—especially small and emerging space agencies—to participate in space exploration.

The Moon. (NASA)

Chapter 5

Exploration On and Around the Moon

Since release of the 2018 Global Exploration Roadmap and the expansion of LEO spaceflight plans, many space agencies have renewed their focus on the Moon. The Moon offers opportunities to conduct cutting-edge science and to develop and demonstrate capabilities for long-term, sustainable exploration and future human missions to Mars. Sustainable lunar exploration will require new capabilities, including ISRU, mature communication and navigation systems, short- and long-distance lunar transportation systems, reliable habitation systems, surface power, and lunar dust mitigation technologies.

These capabilities, combined with new commercial payload delivery services, will help nations achieve their space exploration goals and offer the scientific and academic communities more frequent, more diverse, and lower-cost access to many interesting locations on and around the Moon. Lunar exploration drives innovation and economic growth, spurring advances in technologies that touch every aspect of daily life on Earth—health and medicine, public safety, consumer goods, industrial productivity, transportation, and many others.

Lunar Surface Exploration Operation Concept

This updated Global Exploration Roadmap presents ISECG's latest lunar surface mission scenario. Rather than looking at individual missions, the lunar scenario depicts a stepwise development of increasingly capable lunar transportation systems, surface traversing systems, and supporting infrastructure that will enable cooperative science and human exploration efforts, leading to a sustained presence in the lunar South Pole region. These efforts emphasise landed downmass to eventually support four crewmembers per mission and mobility systems that enhance science return and exploration distances, beginning at the lunar South Pole region and eventually expanding to other locations.

These exploration plans follow the established spaceflight practice where robotic missions with scientific and technology demonstration objectives come first, followed by human explorers and more complex and capable robotic systems. The lessons we learn from these human-robotic partnerships will also inform the planning of future missions to Mars and beyond. This chapter presents the surface scenario and then covers the robotic and human missions that participating ISECG agencies are planning to reach that state. The scenario reflects 12 ISECG lunar exploration objectives.

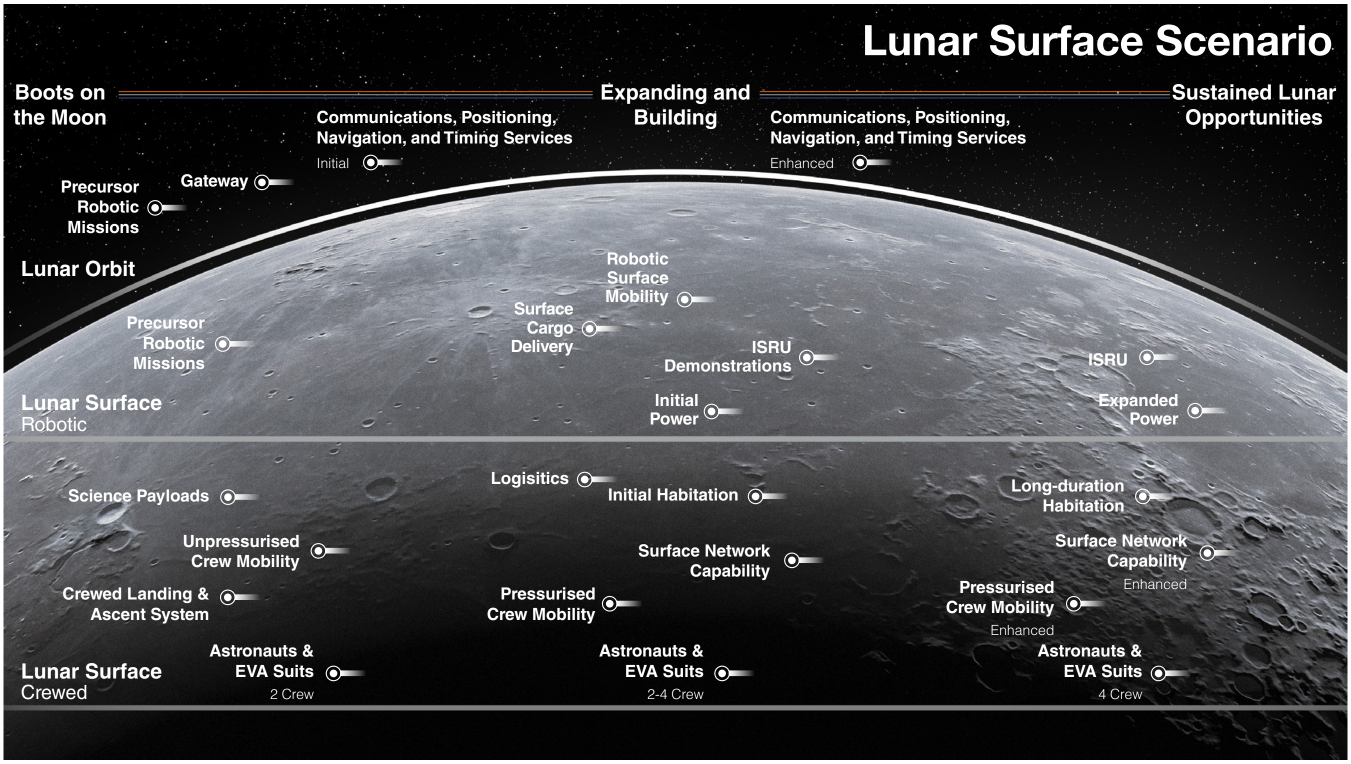
Lunar Surface Exploration Scenario Objectives

Expand Human Presence into the Solar System | Understand Our Place in the Universe | Engage the Public | Stimulate Economic Prosperity | Foster International Cooperation

Objective	ISECG Goal	Performance Measure Target
Demonstrate human landing/ascent capability and establish regular access to and from the lunar surface		Establish a cadence of at least three 4-crew missions in a 5-year period
Demonstrate a range of cargo delivery capabilities on the lunar surface for large surface elements and logistics		>9 t for large surface elements >1 t for logistics
Demonstrate extravehicular activity (EVA) capabilities on the lunar surface		Reusable EVA systems with minimal maintenance, including on-site dust management/mitigation and science sampling/curation techniques
Demonstrate human long-range traversing capability on the lunar surface		10,000 km (cumulative)
Demonstrate reliability of human long-duration habitation capability and operational procedures on the lunar surface		500 days (cumulative)
Demonstrate crew health and performance sustainability to live and work on the lunar surface for a sufficient duration to validate Mars surface missions		Missions with 30–60 days of lunar surface time, increasing microgravity durations, and approximately 10 subjects for each mission duration: **Research missions** with ≈ 90 days pre-surface microgravity **Risk reduction missions** with ≈ 180 days pre-surface microgravity **Mars validation missions** with 360 days pre-surface microgravity and 270 days post-surface microgravity

Expand Human Presence into the Solar System | Understand Our Place in the Universe | Engage the Public | Stimulate Economic Prosperity | Foster International Cooperation

Objective	ISECG Goal	Performance Measure Target
Demonstrate in-situ resource production and utilisation capability sufficient for crew transportation between lunar surface and Gateway and lunar surface utilisation needs		Produce 50 t propellant per year
Conduct effective global human/robotic cooperative exploration to perform groundbreaking science		Comprehensive evaluation needed to determine value of science
Develop infrastructure (e.g., power, communication, and navigation systems) with high availability necessary to achieve the objectives for sustained exploration and continuous human presence		**Power:** 300 kW of power generation **Communications:** 1 Gbps for global lunar coverage Moon-Earth data rate; 100+ Mbps for Earth-Moon data rate **Navigation:** A few meters' accuracy with the reference station on the lunar surface **Additional systems:** TBD
Engage the public in general and the youth in particular with human/robotic lunar surface exploration by bringing the action to large audiences, making full use of the state-of-the-art technology and new methods of communication		On national level, as feasible, measuring positive public attitude towards lunar surface exploration through surveys, website hits, social media impact, etc.
Implement new commercial arrangements that stimulate economic prosperity, foster commercial opportunities, and increase resiliency with dissimilar redundancy		Increasing number of commercial partners or stakeholders providing lunar services year after year
Provide a large number of collaboration opportunities for international partners to contribute to the lunar surface scenario		More than 100 nations' participation in lunar surface scenario



Note: Not to scale; positioning in graphic does not indicate landing location.

Over the course of the phases, participating agencies will build up increasingly diverse and complex capabilities. The scenario is element-agnostic, meaning that a wide variety of partners can contribute to achieving the capabilities. Phase 1 begins with robotic precursor missions and the essentials of human exploration: landing and ascent, logistics delivery, and surface mobility. The capabilities then progress to include longer-duration habitation, power, enhanced communications and navigation, and ISRU, allowing space agencies to pursue increasingly ambitious scientific and exploration objectives. Phase 2 emphasises exploring a diverse range of surface sites and identifying the most beneficial sites for longer-duration missions. Phase 3 lays the foundation for a sustained and vibrant lunar presence in the coming decades through partnerships between international governments, academia, and industry. During this phase, governments would begin to expand the exploration frontier, including developing Mars exploration missions.

This scenario represents a collaborative, international approach to exploration, where each participating agency can contribute elements, mission architectures, or resources. International partnerships also offer the advantage of dissimilar redundancy, where capabilities can be filled by multiple independent elements, reducing the dependency on any single piece of technology or hardware. This sharing of effort and risk ensures that the next era of lunar exploration will be defined by sustained, progressively complex missions. The robotic and human missions discussed below will build the capabilities and technologies necessary for sustained lunar exploration.

Some ISECG member agencies are increasingly using a services-based model in which private companies execute entire missions as part of larger national and international exploration architectures. While governments will continue to invest in key space technologies, projects, and missions to explore the Moon, ISECG member agencies expect to leverage emerging non-government capabilities for future spaceflight science and exploration activities, creating a vibrant space economy.

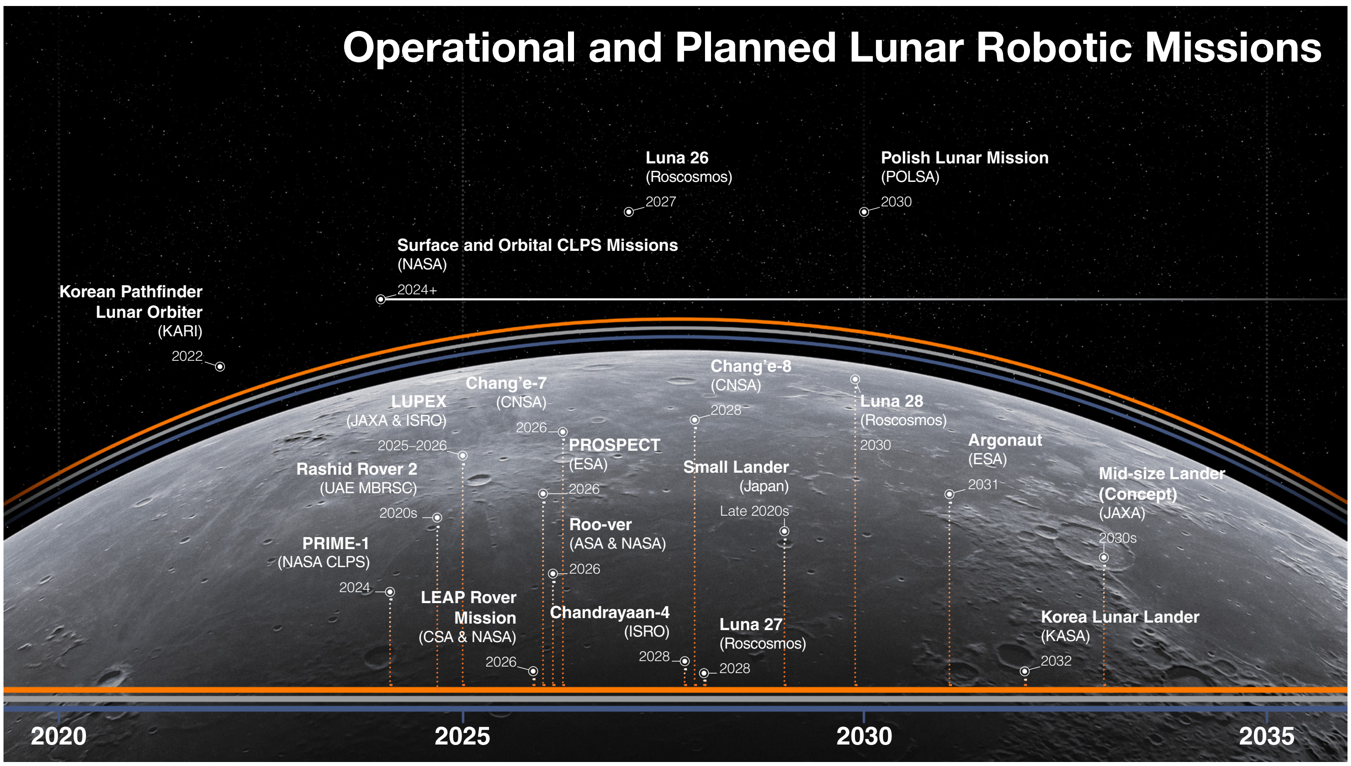
Surface exploration will also require extensive contingency planning. ISECG's international architecture working group identified numerous lunar surface contingency cases that drive architectural design, element functionality, and operational implementation, including loss of power or life support capabilities, crew incapacitation during EVAs, mechanical failures, and the need for remote operation of equipment (local or off-surface). All of these considerations will be further analysed during element design and concept development.

Communications and Navigation for Lunar Exploration

Successful, long-term exploration on and around the Moon will require communication, positioning, navigation, and timing (CPNT) technology for orbiting and surface assets. This CPNT architecture links elements such as spacecraft in lunar and Earth orbit, nodes on the lunar surface, and ground stations on Earth.

Robotic Lunar Exploration Missions

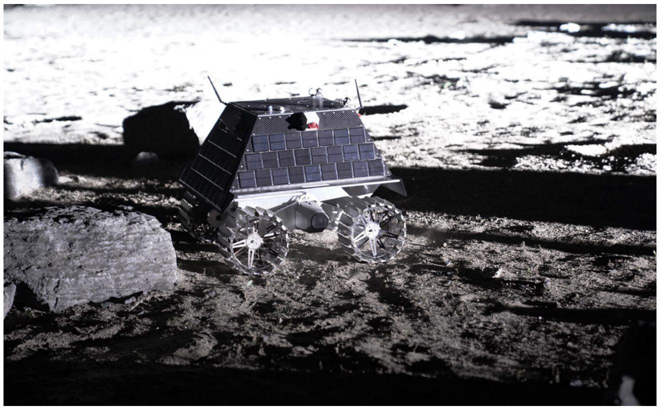
Many individual robotic missions will investigate the lunar poles and help guide future human mission plans. These missions form a de-facto international polar exploration campaign, beginning with regional surveys that will establish ground truth for ice, resources, and local geochemistry at diverse locations. These surveys will be followed by site exploration and preparation of high-priority locations. This series of missions will ultimately inform and support sustained international lunar surface activity. The growing portfolio of national space agency missions, complemented by private-sector initiatives, underscores continued scientific interest in the lunar surface and highlights both the scale of this cooperative effort globally and the human-robotic partnership required for sustained lunar surface exploration.



Note: Not to scale; positioning in graphic does not indicate landing location.

Canadian Space Agency

The Canadian Space Agency (CSA) began the Lunar Exploration Accelerator Program (LEAP) in 2019 to support lunar technology development, in-space demonstration, and science missions. The initial programme includes a lunar rover payload and other science and technology demonstrations that will progress in conjunction with international partners.



LEAP Rover Mission prototype during tests on the CSA's analogue terrain. (CSA)

China National Space Administration

On 17 December, 2020, the Chang'e-5 mission successfully returned 1,731 grams of lunar samples to Earth, marking the successful implementation of the China National Space Administration's (CNSA) first three lunar exploration goals: orbiting, landing, and return. The China Lunar Exploration Program is currently carrying out phase four, which includes the Chang'e-4, Chang'e-6, Chang'e-7 and Chang'e-8 missions. Chang'e-4 achieved the first soft landing on the far side of the Moon on 3 January, 2019, and deployed the Yutu-2 rover. Chang'e-6, a mission to collect samples from the far side of the Moon, launched on 3 May, 2024, and landed back on Earth on 25 June, 2024. Chang'e-7, scheduled to launch around 2026, will focus on investigating water ice in the Moon's South Pole region. Chang'e-8, scheduled to launch around 2028, will continue to investigate the South Pole region and demonstrate key technologies for the construction of the future infrastructure on the Moon. CNSA plans to complete the construction of the basic model of International Lunar Research Station (ILRS) around 2035 to carry out routine scientific exploration, technological verification, and utilisation of lunar resources.

Chang'e-6 lander and ascender on the surface of the Moon. (CNSA)

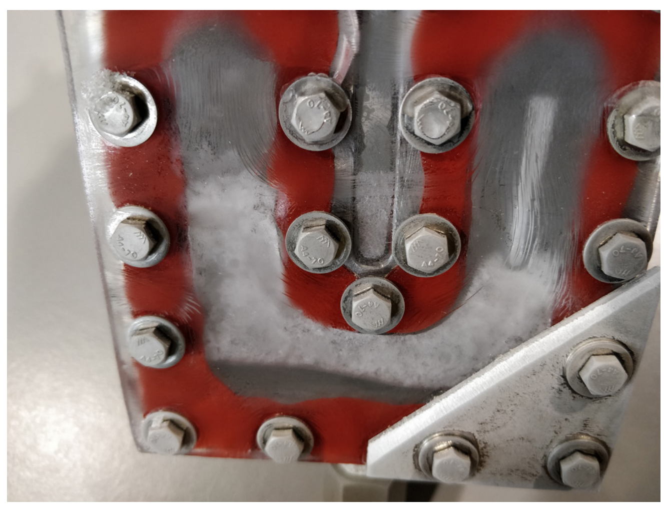
European Space Agency

ESA contributed the Peregrine Ion Trap Mass Spectrometer to the first CLPS mission and the Negative Ions at the Lunar Surface (NILS) experiment to CNSA's Chang'e-6, which landed on the lunar surface in June 2024. Several other planned payloads will study the lunar environment and resources and derisk technology. A 2026 NASA CLPS mission will carry ESA's first small-scale ISRU experiment, Package for Resource Observation and in-Situ Prospecting for Exploration, Commercial exploitation and Transportation (PROSPECT), which includes a drill, sample handling mechanisms, and two spectrometers. The first lunar Global Navigation Satellite System (GNSS) receiver, a laser ranging experiment, and a radiation monitor will fly on the Lunar Pathfinder Orbiter (an ESA commercial partnership). The Exosphere Mass Spectrometer will fly on the ISRO/Japan Aerospace Exploration Agency (JAXA) Lunar Polar Exploration Mission (LUPEX) to measure the lunar exosphere. ESA contributions to future CLPS surface missions will include the Moonlight retroreflector to test relativity and measure the lunar interior using LandCam-X guidance, navigation, and control technology and an ultra-wideband communications and positioning demonstrator. Through ESA's PRODEX (PROgramme de Développement d'Expériences scientifiques) Programme, Switzerland will deploy a Laser Ablation Ionisation Mass Spectrometer on a future CLPS mission. ESA's Argonaut, capable of landing 1.5 tons of payload on the Moon by 2031, will support communication and navigation services and science.

Argonaut lander (artist's concept). (ESA)

Italian Space Agency

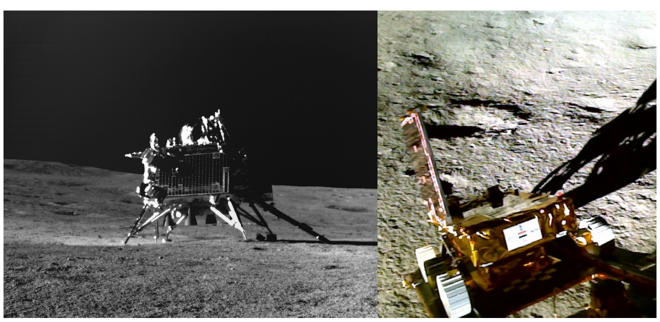
The Italian Space Agency's (ASI) Oxygen Retrieval Asset by Carbothermal-reduction in Lunar Environment (ORACLE) payload will validate ISRU technologies for water and oxygen extraction from lunar regolith. As a contributor to ESA, Italy is a key player in the development of scientific instruments, like the PROSPECT package and the Moonlight Pointing Actuators (MPAc) retroreflector. Italy is a prominent leader in ESA's Lunar Meteoroid Impact Observer (LUMIO) mission. The joint NASA-ASI Lunar GNSS Receiver Experiment (LuGRE) will be deployed and operated on the lunar surface aboard the Firefly Blue Ghost Mission 1 (BGM1). ASI is also part of the national consortium active in the Earth Moon Mars Project to make use of the lunar surface as a privileged site to observe the Earth and the universe and as a unique environment for developing and testing scientific instruments. ASI is also developing its Lunar Robotic Mission Simulation and Control Center to support the validation and implementation of future initiatives. ASI will contribute to the MoonIS IR spectrometer, which aims to detect ice in the regolith of the lunar South Pole region, to the United Arab Emirates Rashid RX3 rover.



Water ice extracted from lunar regolith simulant trapped in a laboratory condenser during development of ASI's ORACLE. (ASTRA team – Politecnico di Milano)

Indian Space Research Organisation

ISRO launched Chandrayaan-2 in 2019 with the goal of demonstrating an end-to-end lunar mission capability, including insertion of an orbiter into lunar orbit and soft landing and roving on the lunar surface. The mission was originally designed to last one year. The orbiter, which was equipped with eight advanced payload instruments, successfully inserted into orbit and performed scientific experiments. However, the mission was unable to soft-land the lander and rover. The Chandrayaan-3 mission achieved soft landing in August 2023 at the Moon's southern high latitudes, making India the fourth country to soft-land on the Moon and the first country to do so in the South Pole region. After landing, the rover moved around the landing site, covering approximately 100 metres. The payloads on the lander, rover, and propulsion module collected data on elemental composition, thermo-physical properties, the plasma environment, and lunar seismicity. ISRO is currently conducting a feasibility study for LUPEX, a collaboration with JAXA. Chandrayaan-4, a lunar sample return mission, is also in the study phase.



Chandrayaan-3 lander (left) and rover roll-out (right). (ISRO)

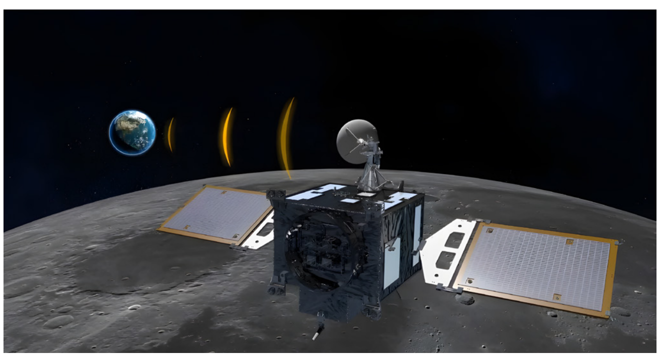
Japan Aerospace Exploration Agency

JAXA's Smart Lander for Investigating Moon (SLIM) successfully landed on the lunar surface in January 2024. Analysis of the image data captured at an altitude of around 50 metres confirmed that SLIM landed with accuracy of about 10 metres, far exceeding the target accuracy of 100 metres. SLIM carried out scientific spectroscopic observations on specific rocks, which may reveal important data about the origin of the Moon. LUPEX, a collaboration with ISRO to study lunar water resources and to explore the suitability of the lunar polar region for the establishment of a lunar base, is slated for launch in the Japanese FY 2025–2026 timeframe. Japan is planning a small-sized lander for technical and science demonstration, targeting launch in late 2020s, and JAXA is considering a medium-sized lander for providing logistics support for human lunar surface missions, including the Artemis campaign. The Pressurized Rover, a collaboration with the Japanese automotive industry for human exploration, will also provide opportunities for uncrewed exploration and scientific research. In order to support these activities on lunar surface, Japan will contribute to provide CPNT capacity by participating in the LunaNet architecture.

*SLIM on the lunar surface.
(JAXA/TOMY company/Sony Group Corporation/Doshisha University)*

Korea AeroSpace Administration

Korea Aerospace Research Institute launched the Korea Pathfinder Lunar Orbiter (KPLO)—officially named ‘Danuri’—in August 2022, representing South Korea’s first step into lunar exploration. KPLO orbits the Moon at an altitude of about 100 kilometres, carrying an array of instruments, including the U.S.-built ShadowCam, which acquires high-resolution images of polar permanently shadowed regions. KPLO’s main objectives are to develop and validate critical technologies for lunar exploration and perform scientific investigations and topographic mapping of the Moon for a future landing mission. Korea Astronomy and Space Science Institute provided the Lunar Surface Environment Monitor (LUSEM) as part of NASA’s CLPS programme to measure high-energy charged particles on the lunar surface. Korea is also developing a lunar vehicle radiation dosimeter, a lunar surface magnetometer, and lunar surface micron-scale structure cameras to conduct additional lunar surface science. KASA’s second lunar mission is a robotic lunar landing planned for launch in 2032. The mission will demonstrate capabilities of safe, precise landing and mobility on the lunar surface and will carry scientific instruments.



Danuri – Korea Pathfinder Lunar Orbiter. (KASA)

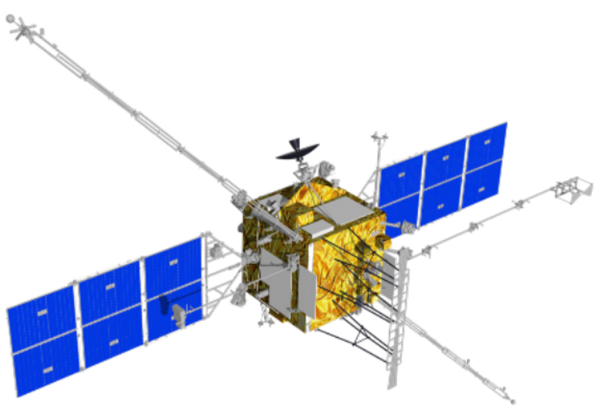
National Aeronautics and Space Administration

Launched in 2022, the Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) serves as a pathfinder for the Gateway space station, validating communications technologies and verifying a unique elliptical orbit around the Moon. NASA developed the Commercial Lunar Payload Services (CLPS) programme to procure delivery of payloads to the lunar surface from commercial providers and promote the development of low-cost commercial lunar payload delivery services. CLPS currently includes 14 companies, all of whom can compete when NASA releases a request for a lunar surface delivery. Early CLPS missions will conduct science experiments, test technologies, and demonstrate capabilities to help NASA explore the Moon and prepare for crewed missions. CLPS missions will carry a variety of payloads from NASA, universities, commercial entities, other U.S. government agencies, and international space agencies. NASA has awarded contracts for surface deliveries to both polar and non-polar lunar locations, with an expected cadence of approximately two deliveries per year. In February 2024, the first CLPS mission by Intuitive Machines, IM-1, successfully landed on the lunar surface. A 2024 CLPS mission will land the Polar Resources Ice Mining Experiment-1 (PRIME-1), the first ISRU demonstration on the Moon, to look for water and other volatiles at the lunar South Pole. NASA is also preparing to initiate acquisition of commercial lunar communication and navigation services for delivery to the Moon via CLPS missions.

Intuitive Machines 1 (IM-1), launched in February 2024, was the first successful CLPS mission to the lunar surface. (NASA)

Roscosmos

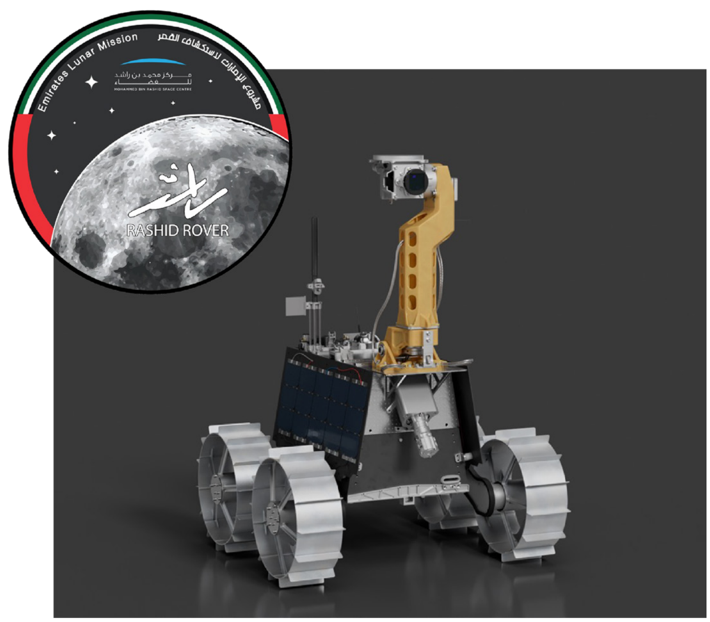
The Luna-25 lunar lander (Luna-Glob-Lander) launched in 2023 but did not successfully land. The launch of Luna-26 (Luna-Resurs-Orbiter) is scheduled for 2027. This expedition will study the lunar surface from a low polar orbit (approximately 50–100 km). The Luna-27 lander (Luna-Resurs-Lander) is scheduled to launch in 2028. Luna-28 (Luna-Resurs 2 or Luna-Grunt-Rover), a mission to deliver cryogenic polar volatiles from the Moon to the Earth, is scheduled for launch after 2030. Russian manufacturers and research institutes are conducting research and development for advanced methods and systems to provide navigation and communication services for lunar exploration users.



Luna-26. (Roscosmos)

UAE and the UAE Space Agency

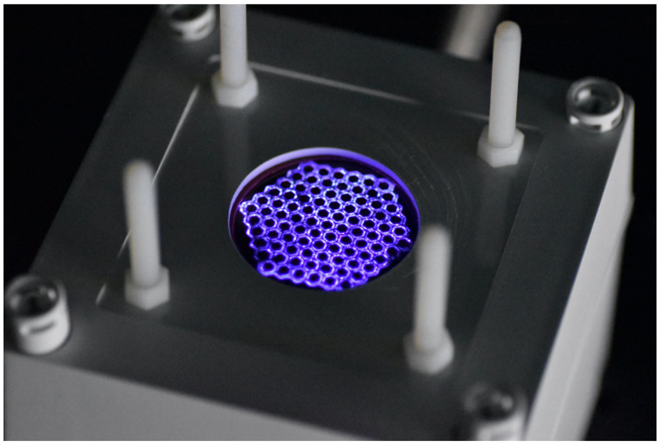
The Emirates Lunar Mission is a programme of multiple rover missions, including Rashid 1, 2, 3, and beyond. Rashid Rover 1, developed by the Mohammed Bin Rashid Space Centre (MBRSC), was the first of a series of rovers that are primarily used as a platform to develop national capabilities in space robotics. Building upon the MBRSC's experience from previous missions, a team of Emirati engineers and scientists designed and built the rover, which launched in 2022 but did not land successfully. Rashid 2 is under development.



Rashid Rover 1. (UAE, Mohammed Bin Rashid Space Centre)

UK Space Agency

The UK Space Agency is a significant contributor to Argonaut, ESA's future lander for delivering payloads to the lunar surface. Argonaut is intended to support the development of infrastructure for Artemis missions, but also represents a significant robotic capability to conduct ground-breaking science. UK organisations are also supporting cutting-edge work in space resources, including oxygen generation from lunar regolith and plasma water purification. The UK developed a key component, the Exospheric Mass Spectrometer, for the NASA-ESA Peregrine Ion-Trap Mass Spectrometer and will also deploy the Lunar Thermal Mapper and laser rangefinder to NASA CLPS and other international missions. The UK also supports space nuclear power technologies, contributing to ESA's EuropeaN Devices Using Radioisotope Energy (ENDURE) programme, which will produce a Radioisotope Heater Unit for the ESA Rosalind Franklin Rover Lander and is working towards the European Large Heat Source for Argonaut.



Plasma water purifier. (University of Southampton)

Human Lunar Exploration

ISECG has developed an exploration scenario that will enable human explorers to return to the Moon. Lunar missions will progressively increase in complexity, building to a sustained presence both in lunar orbit and on the lunar surface. Human lunar exploration will require highly trained astronauts and supporting robotic systems. Upcoming robotic missions, as described earlier in this chapter, will contribute to the development of human missions.

Lunar Orbit

Lunar Vicinity Orbits Support a Variety of Exploration Objectives

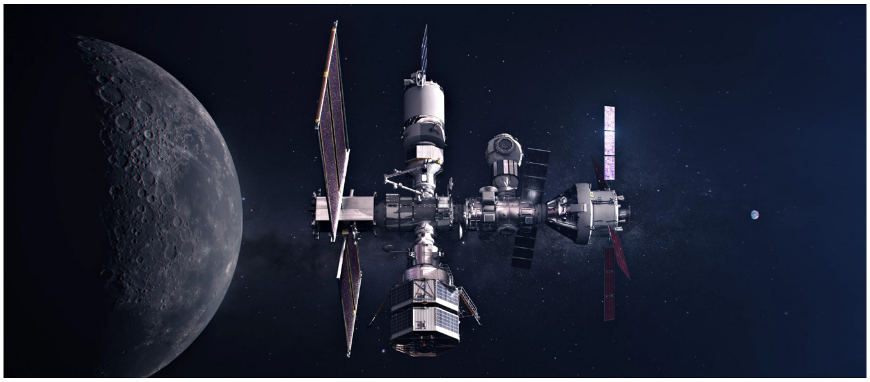
Balancing orbital energy between the Earth and Moon gravity wells and maintaining favourable communications and thermal attributes are important considerations when choosing lunar orbits for robotic and crewed spacecraft. The most promising locations in the lunar vicinity are a family of halo orbits around the collinear Earth-Moon Libration points that pass within a few thousand kilometres of the lunar surface every seven days. A human-tended spacecraft in this near-rectilinear halo orbit (NRHO) enables several benefits:

Reusability
The lunar vicinity is an excellent location for staging and refurbishing reusable elements for exploration of the Moon and other destinations, including Mars. The location contains stable orbits outside of Earth's deep gravity environment and provides a convenient jumping-off point for reusable robotic and human lunar landing systems, including refuelling and servicing between missions.

Testing
The lunar vicinity environment offers similar conditions to those that astronauts and spacecraft will experience in deep space during long-duration missions. Technologies, propulsion systems, procedures, and risk management protocols can be tested relatively close to Earth in case of emergencies. For example, in-space capabilities for human missions to Mars can be tested in NRHO to ensure flight readiness.

Accessibility
The lunar vicinity is reachable by existing government and commercial launch transportation systems, promoting robustness, commercial services, and collaborations between governments and the private sector.

One of the first exploration systems to leverage this unique orbit is the lunar Gateway space station.



Gateway (artist's concept). (NASA)

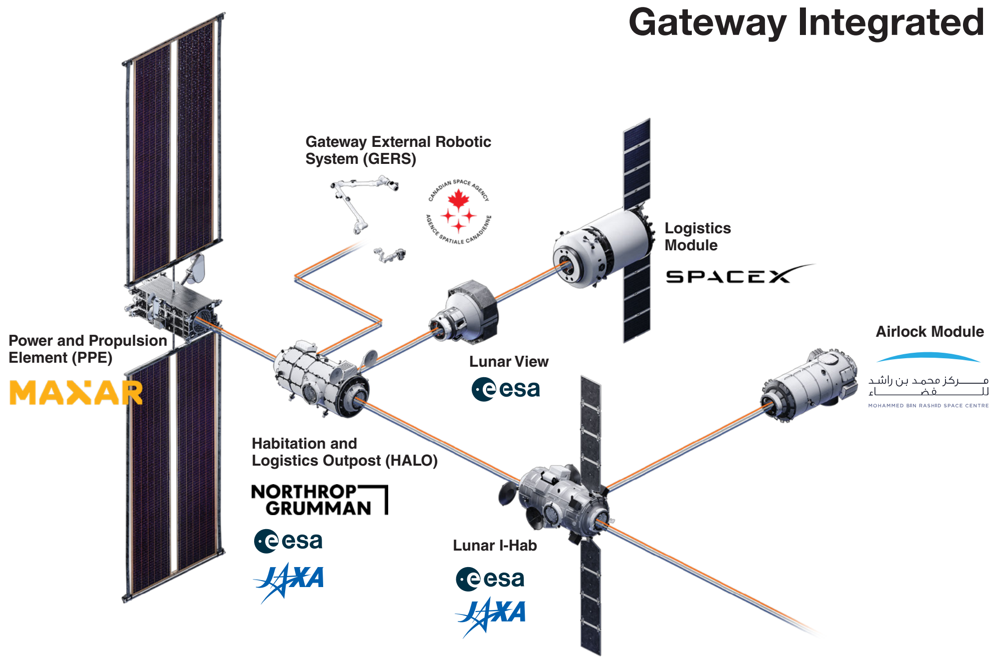
Lunar Gateway

The first components of Gateway are planned to launch in 2028. Gateway will be a habitable station in NRHO established through contributions from NASA, ESA, CSA, Japan/JAXA, and the UAE's MBRSC. Gateway will provide a next-generation deep space platform from which to conduct operations and science investigations outside the protection of the Earth's Van Allen radiation belts. The international science community has identified heliophysics, radiation, and space weather as high-priority investigation areas for Gateway.

Since the release of the 2018 Global Exploration Roadmap, the Gateway concept has matured to include a high-output solar electric Power and Propulsion Element (PPE) and a pressurised Habitation and Logistics Outpost (HALO) that will be integrated for the initial Gateway launch. ESA and its member countries are also developing an enhanced communication string to supplement Gateway's lunar communication system (Lunar Link); the International Habitation Module (Lunar I-Hab), with contributions from Japan/JAXA, which will increase the Gateway's habitation capability and the number of docking ports; and a refuelling system and viewing capability (Lunar View). Japan/JAXA will also provide logistic resupply capability. Gateway will include habitation capabilities to support a crew science airlock provided by the MBRSC, and the Gateway External Robotic System (Canadarm3) provided by CSA. Gateway will provide communication to Earth and the surface of the Moon, opening new opportunities for exploration of the lunar far side and polar regions.

Gateway crews will perform science, assess habitation capabilities for future missions, and investigate exploration technologies that require testing in the deep space environment. Private entities may also utilise Gateway through public-private partnerships. During uncrewed periods, Gateway will be operated from Earth to continue to support science and other activities and provide vital support to lunar surface missions.

Gateway Integrated Spacecraft



Human Missions to the Lunar Surface

While exploring the Moon via orbiting assets is very scientifically valuable, most ISECG member agencies are committed to exploring the Moon with surface-based assets and implementing long-term, sustained surface exploration missions with international cooperation and commercial participation.

An astronaut deploys a science instrument on the lunar surface (artist's concept). (NASA)

National Aeronautics and Space Administration

In 2022, NASA established its Moon to Mars Objectives with input from U.S. industry, academia, international space agencies, and its workforce. NASA's Moon to Mars Architecture, updated annually, serves as a roadmap to accomplish those objectives, identifying the technologies and capabilities needed to return to the lunar surface and venture on to Mars.

The first step in the exploration plan is the Artemis campaign, which will enable human missions to the Moon in a long-term, sustainable manner and test the systems and operations necessary to prepare for future human Mars missions. Artemis I, an uncrewed mission in lunar distant retrograde orbit, launched in November 2022. The next crewed lunar orbital mission, Artemis II, is planned for no earlier than 2025. NASA's goal is to enable human missions to the lunar surface, beginning with Artemis III as early as 2026, with a target of sustained lunar exploration near the end of the decade.

Many international partnerships will support NASA's Artemis campaign. ESA is providing the European Service Module (ESM) that powers the Orion spacecraft. ESM1 supported the Orion capsule for the Artemis I mission, ESM2 has been delivered for Artemis II, ESM3 is ready for shipment for Artemis III, and six additional ESMs are under development or planned. Gateway includes international participation by ESA, CSA, JAXA, and MBRSC. NASA has also expanded its international partnerships to the lunar surface. In April 2024, NASA and Japan signed an agreement under which Japan will provide a pressurised rover. NASA is also engaged in discussions with multiple agencies on potential cooperation on and around the Moon.

European Space Agency

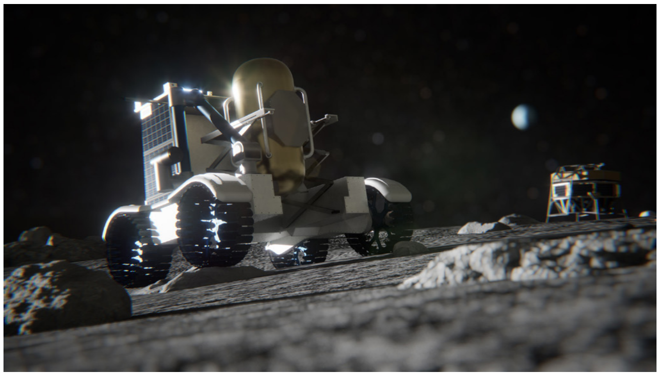
As the space agency of its member states, ESA develops and implements space exploration activities and programmes and operates respective infrastructures. ESA's European Explore2040 Strategy (2024) guides ESA to implement strategic autonomy in selected areas of its lunar exploration activities while also strengthening international partnerships. Argonaut, which includes contributions from multiple European space agencies, will enable European surface science and technology demonstrations and support logistics and infrastructure deployment for international human missions. To support the expanding and building phase, ESA is studying Argonet, a basic infrastructure for lunar surface communication, PNT for enhanced landing accuracy, and night survival (e.g., providing power to passenger elements), as a primary payload on Argonaut in 2031. The Argonet infrastructure would have a service lifetime of at least five years and would complement and enhance the communications and navigation capabilities of the orbital Moonlight Initiative and Gateway's Lunar Link.

ESA contributes essential capabilities to NASA's Moon to Mars Architecture with the ESM and Gateway. ESA is developing the Argonaut lander and is studying additional essential transportation capabilities, including heavier landing capabilities and Gateway sample return.

The Italian Space Agency (ASI) supports lunar exploration through ESA, with several Italian companies working on key technologies, capabilities, and elements of the European exploration strategy. ASI is also leading the design of a multi-purpose habitation module to support future crewed exploration campaigns.

Canadian Space Agency

In 2021, CSA commenced the Lunar Surface Exploration Initiative, which focuses on identifying major infrastructure investments Canada could make to support sustainable human presence on the lunar surface and engage Canadian astronauts in the exploration of the Moon, including in agriculture and food, rovers and robotics, power generation and distribution, communication, and mining (remote sensing, surface prospecting, and ISRU). CSA's Health Beyond Initiative and Food Production Initiative study deep space healthcare technologies and food technologies, respectively. CSA will also develop and contribute a lunar utility vehicle to support logistics, crew operations, and science on the lunar surface.



Lunar utility vehicle (artist's concept). (CSA)

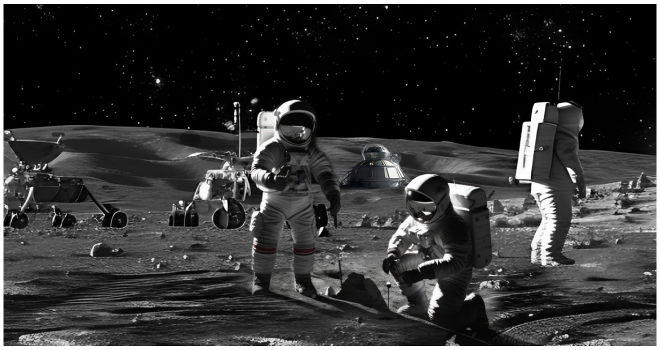
Japan Aerospace Exploration Agency

In June 2020, Japan renewed its Basic Plan on Space Policy, which states that Japan will support the Artemis campaign by contributing habitation technologies and logistics resupply capabilities to Gateway and will contribute to human lunar surface missions by providing transportation vehicles on the lunar surface. JAXA is collaborating with the Japanese automotive industry to develop the Pressurized Rover, which will dramatically expand the exploration area for crewed and uncrewed missions and increase flexibility in scientific research. Japan underlined the importance of international space exploration, including the Artemis campaign, in the Basic Plan on Space Policy, which was renewed in 2023. Under the Japanese government's Stardust Program, JAXA is also developing key lunar communication and navigation technologies to enable long-term exploration, including precision targeting and landing technology.

Pressurized Rover (artist's concept). (TOYOTA)

Indian Space Research Organisation

After successfully landing the Chandrayaan-3 lander-rover on the Moon, India announced its goal of landing an Indian astronaut on the surface of the Moon by 2040.



Astronauts explore the lunar surface (artist's concept). (ISRO)

China National Space Administration

CNSA plans to complete the construction of the basic model of ILRS around 2035 and an extended model around 2045, with long-term autonomous operation and short-term human participation.

ILRS (artist's concept). (CNSA)

Utopia Planitia on Mars,the largest known impact basin in the solar system. Frost formation has been observed in this region. (ESA/TGO/CaSSIS)

Chapter 6

Mars

Mars, one of Earth's nearest neighbours, presents a wide range of science and exploration possibilities, including the search for evidence of life; the study of Mars' surface, interior, and atmospheric and climate processes; and the opportunity to gradually establish human presence in orbit and on the surface. Mars is the focus of increasingly ambitious robotic and human exploration missions; it remains the horizon target for many space agencies around the world.

Mars Science Objectives

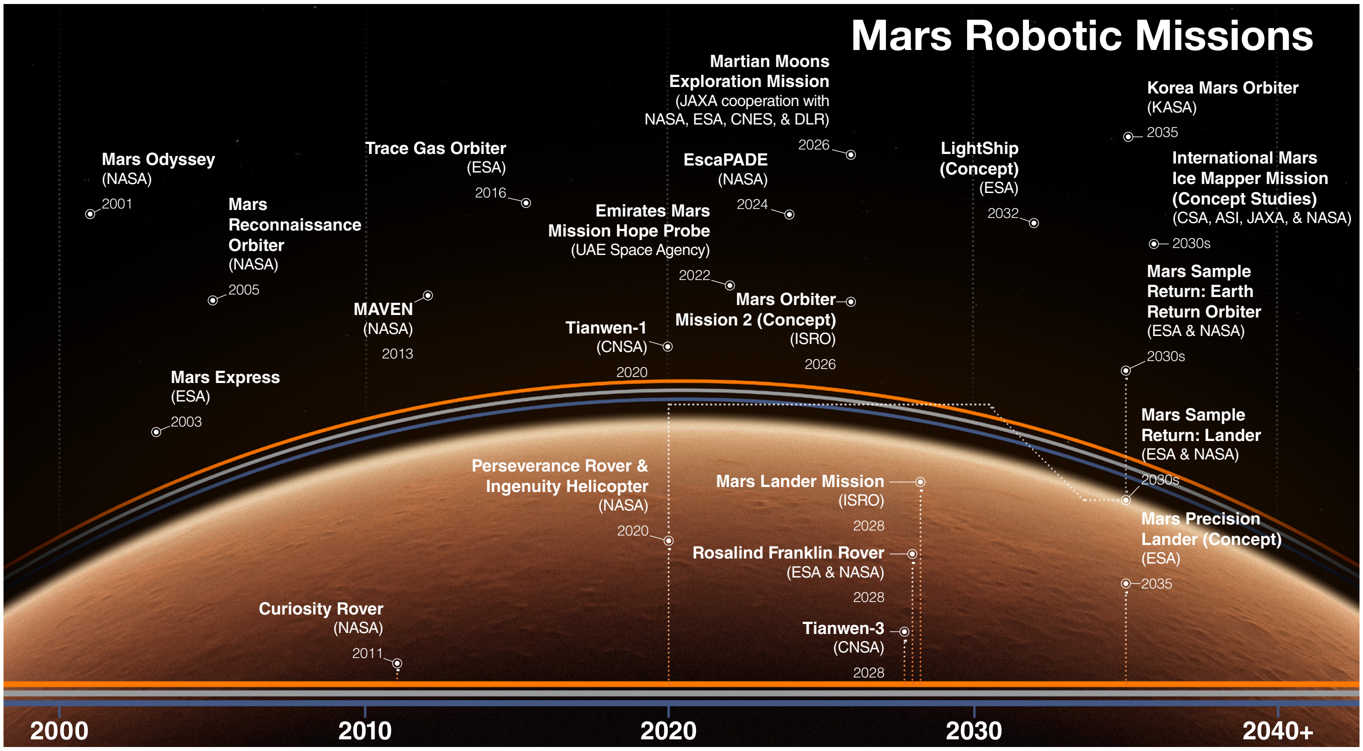
Missions to Mars allow us to learn not only about the Red Planet itself, but also about fundamental planetary processes, climatology, the potential for life beyond Earth, and human physical and social health. Mars can also help us to learn more about the Earth and the formation of rocky bodies in our solar system and beyond through comparative planetology. Evidence suggests that Mars was once warmer, liquid water flowed on its surface, and a thicker atmosphere offered a habitable environment. But Mars experienced drastic climate change that has left the planet's surface cold, dry, and inhospitable to life as we know it. Research and training at Mars analogues on Earth will help scientists understand the similarities and differences between the planets and help maximise opportunities for other science investigations at the Red Planet. Investigating the history of water, minerology, and organic chemistry on Mars could help us discover how life might have emerged and potentially survived. Further, planetary geologists can study rocks, sediments, and soils for clues about the history of Mars. Volcanoes, craters from asteroid and comet impacts, signs of atmospheric or photochemical effects, and geomorphological and geophysical processes all capture aspects of Mars' history. Samples of the Martian atmosphere could reveal crucial details about its formation and evolution. These and many other science objectives will be among the highest priorities for the coming decades of human and robotic exploration.

Mars Robotic Exploration Missions

Robotic exploration missions collect data to address scientific questions about Mars' geological history, climate, and potential for life, past or present. They can also assess environmental conditions to prepare for future human exploration. Robotic capabilities continue to grow, allowing more missions to visit more places across Mars. Both traditional (e.g., large orbiters and rovers) and new (e.g., aerial assets, networked missions, and CubeSats) mission models will play a role in Mars science and exploration.

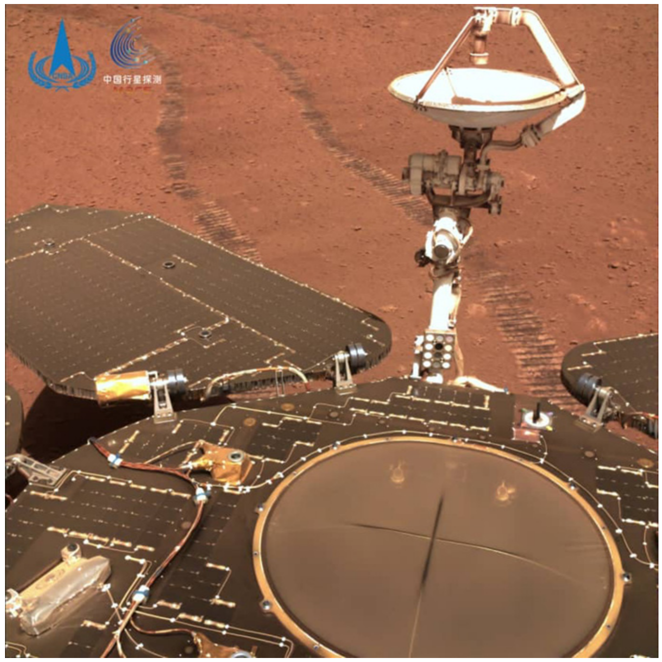
Robotic missions can scout ahead to identify potential resources and risks and pre-position equipment and supplies to help mitigate the costs and dangers that human explorers face. Mapping and characterising the Martian surface, subsurface, and atmosphere in advance of human presence is essential for planetary protection—avoiding inadvertent damage to resources and contamination by biological materials originating on Earth and minimising any dangers posed by materials on Mars (biological or geological) to astronauts and our home planet. The return of carefully selected and contained samples from Mars is a top priority, enabling scientists to leverage the far greater capabilities of terrestrial laboratories to conduct analyses that will inform our targets, strategies, and technologies for future exploration.

Currently, long-duration human spaceflight missions in LEO must bring everything they need from Earth. A crewed Mars mission, however, may eventually rely on resources that are already available locally (i.e., via ISRU), including water, which could be treated for both consumption by astronauts and propellant generation. Samples sensed, mapped, and gathered by in-situ robots and measurements taken from orbit could help to evaluate where potential resources are located. Resource definition will encourage development and testing of suitable methods and technologies for human explorers to access and use them. Returned samples are critical for preparing accessible analogue experimentation and development facilities.



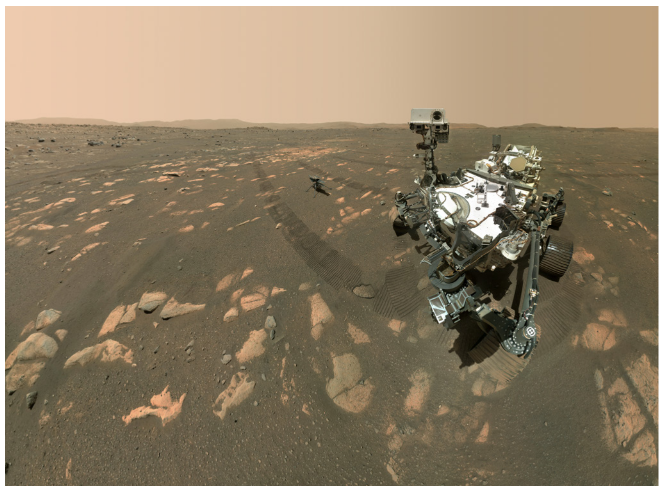
Note: Not to scale; positioning in graphic does not indicate landing location.

Robotic and human exploration missions will benefit from interoperable systems and services, with common infrastructure elements or capabilities. Technology development will be key to enable the next generation of missions. For example, interoperable Mars proximity communication and navigation service infrastructure could reduce reliance on direct-to-Earth communication for some missions, allowing scientific spacecraft to dedicate more mass to payloads. High-efficiency propulsive transfers (e.g., electric propulsion) with payload hosting and delivery capabilities could increase access to Mars for a variety of low-cost mission concepts from a broader range of participants (e.g., international, commercial, and academia). Finally, reliable access to the surface of Mars requires robust and precise entry, descent, and landing capabilities. Future missions will need to land heavy masses precisely at a wide range of locations and terrain types.



Tianwen-1 lander on the surface of Mars, as seen from the Zhurong rover. (CNSA)

ESA's LightShip concept: A Mars Propulsive Tug capability building on Earth Return Orbiter technology, including communications and navigation services and science payloads. The LightShip can also deliver multiple scientific passenger spacecraft to Mars. (ESA)



NASA's Perseverance rover takes a selfie with the Ingenuity helicopter. (NASA/JPL)

Human Mars Exploration

Human missions to Mars will expand the scope of scientific and exploration activities and serve as an inspiration to the entire world. Establishing sustained human exploration in cislunar space and on the lunar surface will provide a foundation for developing the capabilities required for human missions to Mars, including validation of exploration elements beyond LEO. Nevertheless, the distance and time required for a round trip to Mars are orders of magnitude greater than for lunar missions, dramatically increasing the complexity of the mission.

Human Mars exploration (artist's concept). (NASA)

Human Mars Mission Capabilities

Human missions to Mars will require participating ISECG agencies to develop and validate several key capabilities:

- Characterisation of potential landing sites by orbital and landed spacecraft prior to human missions to inform site selection, assess science targets, and provide high-resolution sensing to assist with precision landing and development and implementation of the mission elements.
- Scouting of the selected human landing site by surface robotic missions to characterise surface and environmental conditions and identify potential resources. This will allow definition and development of the appropriate technologies required for protection from the harsh environment (e.g., radiation), to improve crew safety. Deeper understanding of the environment will also inform local climate modelling, establish baseline measurements for science investigations, and advise on planetary protection mitigation.
- Habitation, tools, and systems to enable astronauts to work effectively and autonomously during the trip to and from Mars, as well as on the surface, including planning for contingency situations.
- Crew vehicle(s) for entry, descent, and precision landing and ascent from the surface to orbit. Precise robotic delivery of increasingly heavy payloads to specific locations on the Martian surface, enabling deployment of cargo and infrastructure elements to support human surface exploration missions.
- Capabilities and infrastructure to support and enhance the crew's exploration activities (e.g., instrumentation and tools, sample handling, robotic assets, and ISRU).
- Robotic inspection and maintenance systems.
- Radiation impact mitigation for long-term deep-space missions.
- Support for crew physical and psychological health, including long-duration life support.
- Orbital and surface communication and navigation services.
- Power generation and distribution.

Sample Return and Planetary Protection

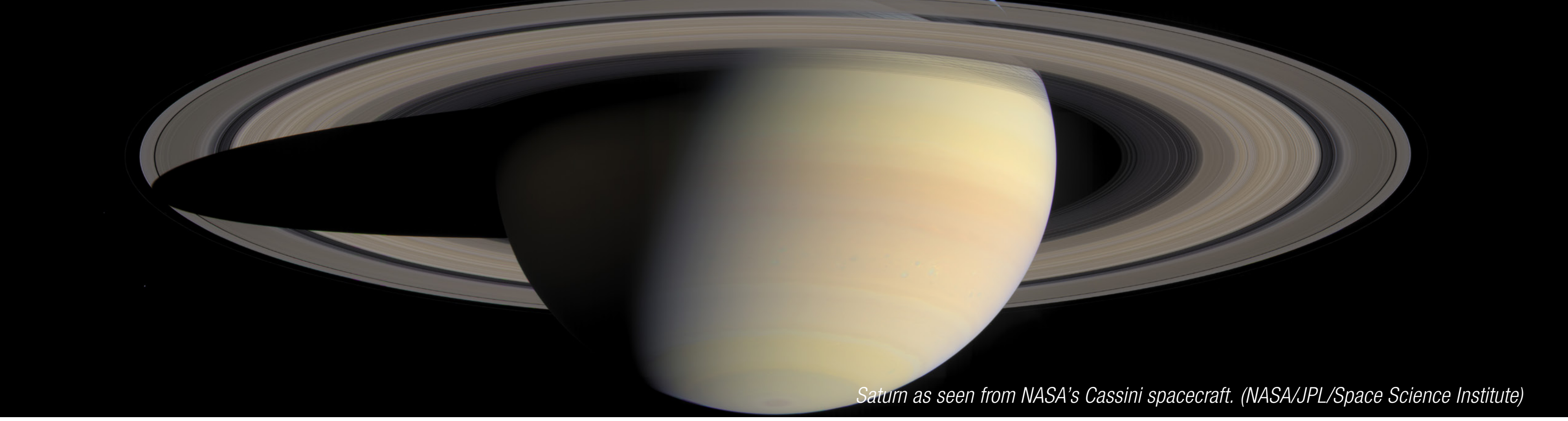
The return of carefully selected samples from the Martian surface, sub-surface, moons, and atmosphere to the Earth is a top priority for the global planetary science community. Returned samples can be subjected to the full range of tools and techniques available in terrestrial laboratories, permitting studies that are difficult or impossible to achieve solely with in-situ analysis. This includes addressing key objectives identified in decadal surveys and other planetary science strategies, such as identifying evidence of life. Furthermore, samples returned by robotic missions may provide information about potential health risks associated with the Martian soil and dust, aiding development of appropriate mitigation techniques for subsequent human missions. Atmosphere samples that are expected to be captured and returned together with the solid phase will also provide critical information.

Several robotic sample return mission campaigns are currently being developed to return samples to Earth in the 2020s and 2030s. The Martian Moons Exploration Mission, led by JAXA and in collaboration with the German Aerospace Centre (DLR), the French National Centre for Space Studies (CNES), NASA, and ESA, will return samples from Mars' moon Phobos to investigate the origin of the Martian moons and the transportation of water and organic materials to planets in the solar system. The joint ESA-NASA Mars Sample Return campaign consists of a combination of landing, ascent, and Earth return elements to return samples collected by the Perseverance rover. The Chinese Tianwen-3 mission consists of a lander/ascent vehicle and an Earth return orbiter. Subsequent human missions would provide an opportunity for more extensive sampling at different sites, selected by trained crew members on the surface and potentially using more elaborate sample retrieval methods, such as subsurface drilling or cooperative human-robotic systems.

Given the potential for life on Mars, all missions to the Martian surface must address planetary protection to avoid any forward contamination that can jeopardise the search for life itself (e.g., a "false positive" due to detection of organisms moved from Earth by previous missions). Robotic sample return missions and human missions to the surface must also incorporate appropriate measures to prevent back contamination to Earth.

Mars as a Horizon Goal

Fully characterising and mitigating the risks and challenges for human Mars missions will require extensive research and dedicated incremental technology and capability development. Mars missions are part of a continuum of sustained human exploration, one that expands from the Earth, to LEO, to the Moon, and on to Mars and beyond, that maximises the use of common technologies and capabilities across all destinations. The lessons we learn and technologies we develop on the Moon will enable us to continue to Mars and beyond.

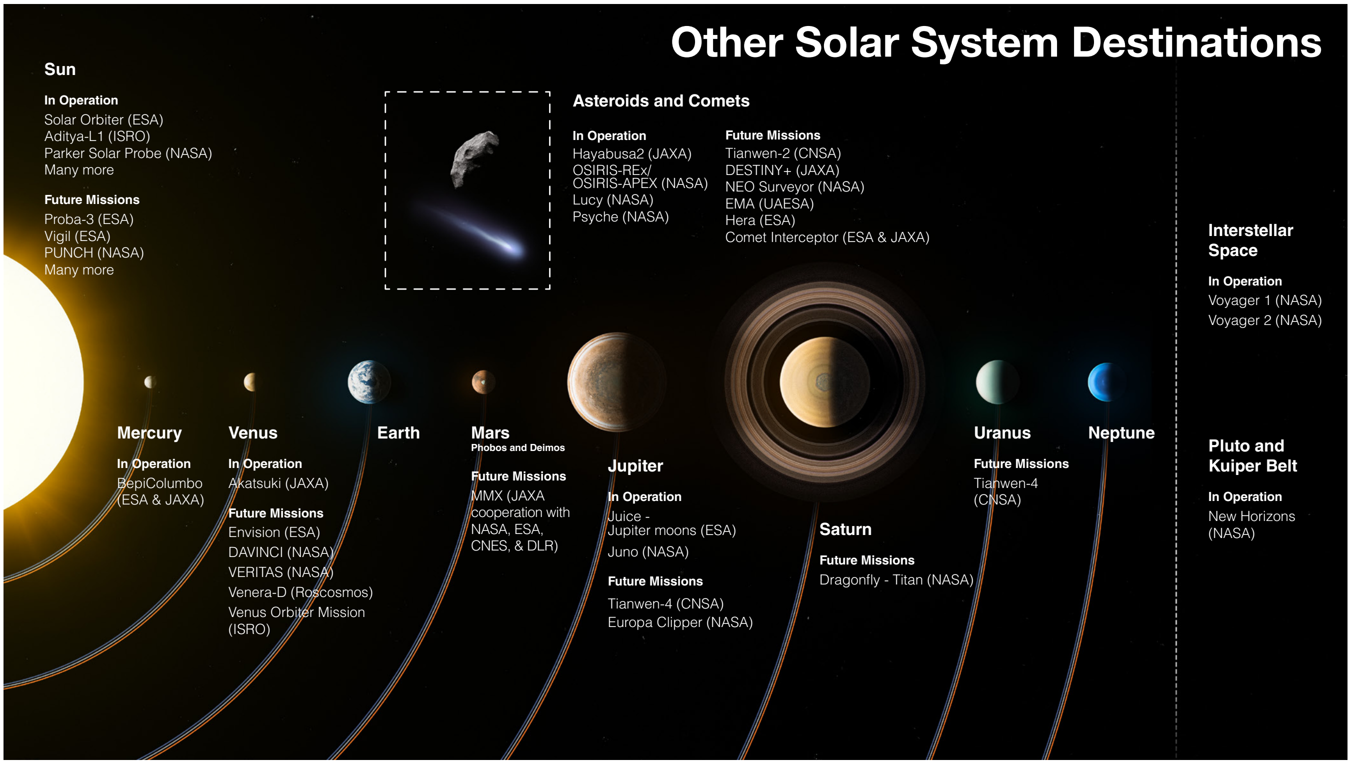


Saturn as seen from NASA's Cassini spacecraft. (NASA/JPL/Space Science Institute)

Chapter 7

Other Solar System Destinations

Although current space exploration programmes emphasise the exploration of the Moon and Mars, international interest in the robotic exploration of other solar system destinations is at an all-time high. Robotic missions have now visited all the planets in the solar system, the Sun, asteroids, comets, other small bodies, moons, the dwarf planet Pluto, and other Kuiper Belt objects. While there are currently no concrete plans to send humans beyond the Moon and Mars, these robotic missions are conducting great science that shapes our understanding of our place in the universe.



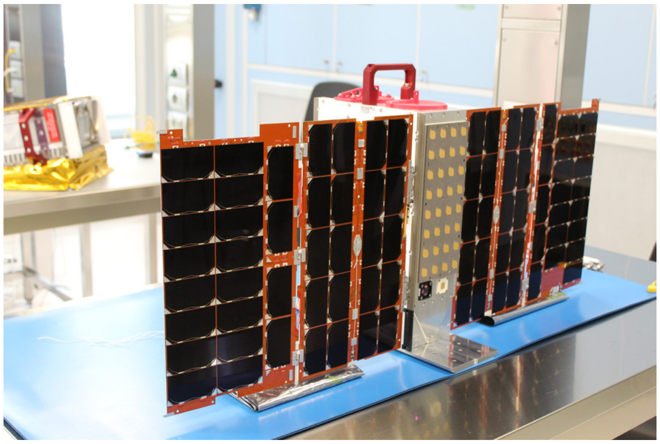
These missions also accomplish objectives beyond science: many asteroid missions are focused on improving planetary defence, while other missions are realising objectives associated with technology demonstration, helping inform and advance future human missions to the Moon, Mars, and beyond. The feats these missions accomplish, like the return of asteroid samples from Bennu by the OSIRIS-REx mission in 2023, capture the imagination of people around the world.

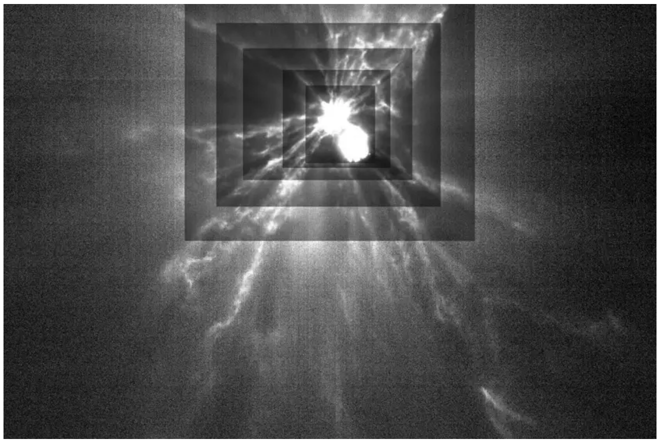
In the past, space exploration missions to destinations other than the Moon and Mars have typically been led by more established space agencies. NASA, for example, operates its well-known Discovery, New Frontiers, and Flagship programmes—which range from lower-cost missions to large strategic exploration missions—and has flown probes to a wide range of solar system destinations.

Other agencies are now planning deep space exploration missions, including CNSA's Tianwen-2 asteroid sample return mission and Tianwen-4 mission to Jupiter (Callisto) and Uranus, ISRO's ADITYA-L1 mission to study the Sun and planned Venus mission (currently in the concept study phase), and the UAE Space Agency's (UAESA) Emirates Mission to the Asteroid Belt (EMA) to study the origins and evolution of water-rich asteroids, assess the resource potential of asteroids, and prepare the way for future asteroid resource use. Scientists (e.g., co-investigators) can also contribute distinct payloads to missions, enabling smaller agencies to actively participate in deep space exploration. Although some preceding examples certainly exist (e.g., the joint NASA-ESA Cassini-Huygens mission), the involvement of smaller agencies in deep space exploration has evolved over recent years to include more varied examples of larger contributions.

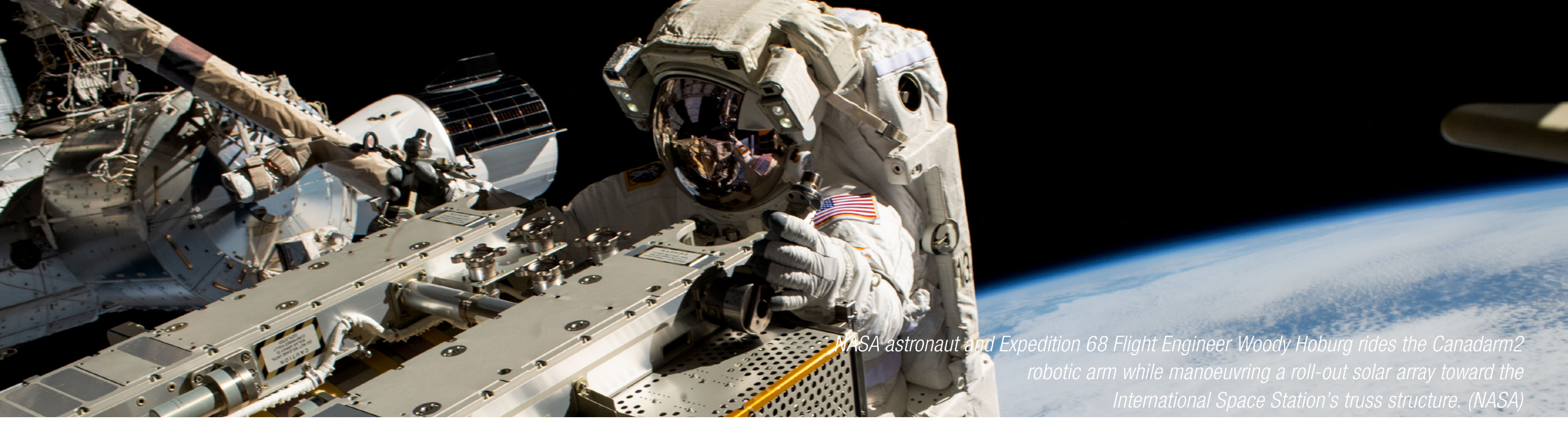
Space agencies can contribute not just payloads to missions being led by other countries, but entire elements and vehicles. Examples include the ESA-led BepiColombo mission to Mercury, which carries distinct ESA and JAXA orbiters; the NASA Double Asteroid Redirect Test (DART), which included the ASI-developed 6U LICIACube autonomous microsat that photographed the ejecta plume released after DART's impact on the asteroid Dimorphos; and the CNES-DLR IDEFIX Phobos rover. These and other ongoing collaborations demonstrate an increasingly wide range of opportunities for established and emerging space agencies to contribute to exploration beyond the Moon and Mars.

These and other future robotic planetary exploration missions will continue to conduct ground-breaking scientific investigations and prepare us for future human exploration missions to the Moon, Mars, and beyond.





LICIACube microsat (top) and the asteroids Didymos and Dimorphos, just impacted by DART (bottom). (ASI/NASA/Argotec/APL)



NASA astronaut and Expedition 68 Flight Engineer Woody Hoburg rides the Canadarm2 robotic arm while manoeuvring a roll-out solar array toward the International Space Station's truss structure. (NASA)

Chapter 8

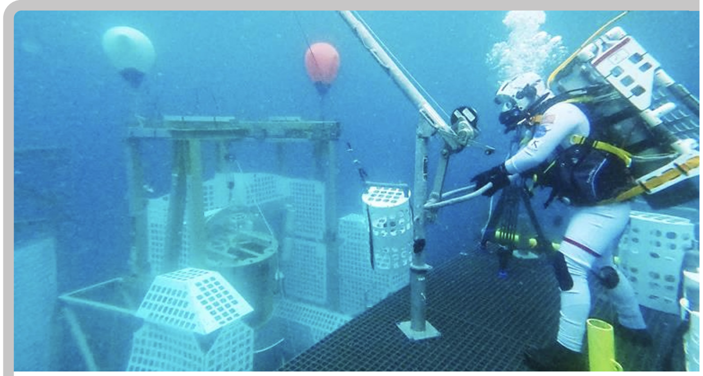
Technologies for Space Exploration

Technological readiness and capability building are essential for achieving the exploration goals outlined in the previous chapters. Future missions will require reliable, efficient technologies to explore LEO, the Moon, Mars, and beyond. From novel launch systems to habitation modules for astronauts in deep space, each development compounds and builds capability for our exploration ambitions. Space agencies must work together to develop and demonstrate these technologies. They must also leverage their collective resources to maximise the impact of the technology development process—an approach that not only more deftly improves capability but also fosters synergies that enhance our collective planning. The critical technologies list serves as a guiding framework, providing a roadmap for aligning activities, identifying development gaps, and advancing participating ISECG agencies' collective efforts toward the common goal of advancing exploration.

Analogues are settings that represent destinations or environments of interest to ISECG member agencies. They represent a diverse spread of settings and subjects, ranging from naturally occurring terrestrial locations, to constructed environments, to customised virtual settings. Analogues are valuable tools in the technology development process.

Training at Sea: Space Environment Analog for Training, Engineering, Science, and Technology (SEATEST)

Missions like NASA's SEATEST 6, hosted at the University of Southern California's Wrigley Marine Science Center, use naturally occurring underwater locations to simulate partial gravity environments (e.g., the Moon or Mars). Human crews can test rapidly developed prototypes of tools, equipment, technology, and vehicles and their proposed concepts of operation.



Testing methods for EVA crew-supported logistics handling on the Moon during SEATEST 6. (NASA)

Critical Technology List

ISECG identifies gaps between state-of-the-art technology and the technology required for both near-term lunar operations and future Mars missions. The critical technologies list undergoes continuous analysis and updates to ensure alignment with the latest exploration roadmaps, with a focus on closing critical technology gaps and fostering collaboration among agencies working on these technologies.

The list categorises critical technology needs into eight key areas:

» Propulsion, Landing, and Return
» Autonomous Systems
» Life Support and Habitability
» Crew Health and Performance
» Communications and Positioning, Navigation, and Timing
» Power
» Transversal Technologies
» EVA, Mobility, and Robotics

Global Exploration Roadmap Critical Technologies (Summary Table)	Today ISS & Spaceflight Heritage	Near Future Moon Vicinity/Surface	Future Mars Vicinity/Surface
Propulsion, Landing, Return			
LOX/Liquid Methane/Cryogenic Propulsion System		Throttleable regeneratively cooled engines for landing	Throttleable regeneratively cooled engines for landing
Electric Propulsion and Power Processing	DART (2022) 3.5 kW NEXT gridded ion thruster	12 kW thrusters for lunar Gateway	~30-50 kW per thruster (for some mission options)
Nuclear Thermal Propulsion (NTP) Engine	Earth orbit demonstration (DRACO) in development		High-I_{sp} systems for fast round trips (<2.5 years)
In-Space Cryogenic Fluid Management and Transfer		μg vapor-free liquid tank to propulsion transfer, sufficient low-power LOX and H_2 storage for months	μg vapor-free liquid tank to propulsion transfer
In-Space Cryogenic Propellant Storage (Zero Boil Off LO_2; Reduced/Zero Boil Off LH_2)		Systems for propellant depots, ISRU commodities	Systems to support efficient ascent propulsion, efficient low-power LOX and H2 storage > 1 year
Multi-MWe Nuclear Power for Electric Propulsion (NEP)			
Precision Landing with Hazard Avoidance	Mars 2020 radar altimeters, optical TRN	~100 m accuracy, 10s cm hazard recognition, support all lighting conditions	
Mars EDL Technologies for Heavy Payloads	Mars 2020 class; LOFTID 6-m demonstration		Large robotics > 5,000 kg; human ~40,000 kg
Robust Ablative Heat Shield (Beyond Lunar Return) - Thermal Protection System	Orion heat shield test flight (Artemis I)	Survival of lunar return demonstrated by Artemis I	Entry environments defined by direct/orbit rendezvous approaches
Autonomous Systems			
Robots Working Side-By-Side With Suited Crew	Astrobee in ISS, limited support for EVA	Remote-controlled and autonomous robots assist Artemis mission crews	Robotic systems controlled by early Martian astronauts assist with exploration and maintenance tasks
Autonomous Vehicle System Management	ISS: limited on-board management functions, <5 sec communication delay	On-board systems management functions (handles > 5 second communication delay)	On-board systems management functions (handles > 40 min communication delay)
Automated/Autonomous Rendezvous and Docking	ISS: autonomous docking	High reliability, all lighting conditions, loiter with zero relative velocity	
In-Space Timing and Navigation for Autonomy	ISS: limited to GPS Range / Spacecraft: DSN ranging	Demonstration of advanced technology in deep space environment	Provide high-spec absolute and relative positioning, space-qualified clocks > 10x beyond SoA
Mission Control Automation Beyond LEO	ISS: limited autonomy	Routine operations primarily autonomous with crew supervision	Routine operations autonomous, exception reporting for crew management
Autonomous Surface Habitation Systems	ISS: orbital repair systems demonstrated	Autonomous surface habitation systems, including automation capabilities to maintain integrity during occupation and vacancy	
Life Support and Habitability			
Closed-Loop Life Support Systems	ISS: 42% O_2 recovery from CO_2, 90% H_2O recovery	Demonstration of advanced technology in deep space environment	O_2/CO_2 loop closure; H_2O recovery further closure; solid waste, reduce volume/storage
Enhanced Reliability Life Support Systems	ISS: MTBF <10^{-6}, monitored/operated by ground control	More robust & reliable components (eliminate dependence on Earth supply logistics) Increased systems autonomy, failure detection capabilities, and in-flight repairability	
In-Flight Environmental Monitoring	ISS cabin atmosphere monitoring, e.g., ANITA	On-board analysis for air, water, contaminants	
Fire Prevention, Detection, and Suppression	Low-flammability materials, CO_2 fire extinguishers. In-orbit fire safety experiments (e.g., Saffire on Cygnus).	Improve performance, adaptability, and sustainability of current solutions; enable common fire safety strategies across element architectures	
Mission Control Automation Beyond LEO	Scientific experiments, e.g., Veggie, bioregenerative ground experiments, inc. small-scale demos on ISS	Long-duration missions will require that crew intake diets must be complemented with in-situ produced food	
Autonomous Surface Habitation Systems	ISS: partially protected by Earth Apollo: (accepted risk)	Advanced detection and shielding New biomedical countermeasures	

Global Exploration Roadmap **Critical Technologies** (Summary Table)	Today **ISS** & Spaceflight Heritage	Near Future **Moon** Vicinity/Surface	Future **Mars** Vicinity/Surface
Crew Health and Performance			
Crew Autonomy Beyond LEO	Limited autonomy	Support for real-time decision making	Advanced technology for optimum autonomy
Long-Duration Spaceflight Medical Care	Remote medical systems	Medical devices for prognosis, diagnosis, and contingency management; modular health data; just-in-time medical training	Advanced medical monitoring and decision support systems; modular health data; just-in-time medical training capabilities
Long-Duration Spaceflight Behavioural Health & Performance	Monitoring by ground team	Advanced technology for monitoring human performance and psychological well-being	Advanced behavioral health and performance monitoring
Deep Space Mission Human Factors	ISS: large treadmills, other exercise equipment	Protocols and devices to counter the adverse effects of deep space environment	Compact devices to assess/limit disorders, reduced weight/volume aerobic and resistive equipment
Mission Control Automation Beyond LEO	ISS: large crew volume, food and consumables regular resupply	Optimised human systems interfaces for reduced cognitive loads during operations and contingencies	Optimised human systems factors/interfaces assess human cognitive load, fatigue, health
Nutrition, Quality, and Storage of Perishable Goods	Food and consumables preservation	Maintain nutritional stability of perishable goods for extended duration of time	Technology for nutrient stability and dietary intake monitoring
Communication and PNT			
Optical Communication for Downlink to Earth	Ground (DSN): 10Mbs return link	Optical communication for downlink to Earth from lunar vicinity carrying mission data, voice, and HDTV	Optical communication for downlink evolved from lunar architecture adapting increased and variant latency
High Data-Rate Forward Link (Flight) Communications	Ground(DSN): 256 kbs forward link	High data-rate forward link to lunar vicinity from Earth carrying mission command data and voice	High data-rate forwardlink to Mars requiring critical software uploads in addition to lunar forwardlink
Wireless LAN and 3GPP for Lunar and Mars Surface Network	Limited capabilities	Terrestrial technologies, such as internet, mobile communication, applied for lunar surface activities	Mars surface communications to closely mirror the lunar architecture with technologies advancement
Complete Coverage High-Rate Communication and Delay-Tolerant Network (DTN)	DTN demo	Complete high-rate lunar comms and DTN, covering all sides and poles, for multiple assets	Complete-coverage high-rate Mars communication and DTN for multiple Mars assets simultaneously
Positioning, Navigation, and Timing (PNT) on Cislunar Service and Beyond	Limited to GPS range Spacecraft: DSN ranging	Lunar navigation service provides geometric diversity, local dynamics, simultaneous obs for navigation insights	Mars navigation capabilities expanded and evolved from lunar navigation to close knowledge gaps
Power			
Large-Scale, Flexible, and Deployable On-Surface Solar Arrays	Mars Phoenix arrays	High-efficiency deployable arrays; robust vertical towers for polar regions, 10–100 kW class	Large-scale, dust-tolerant/self-cleaning
Deployable High-Power In-Space Arrays	IROSA array structure; DART inverted, metamorphic (IMM) solar cells, reflective concentrators	High-efficiency support to in-space vehicles	High-efficiency arrays on orbital assets
Nuclear Poer for Surface Missions	Mars Perseverance MMRTG	Potential test-bed for Mars-forward, and enhance lunar missions	Fission reactor (10s of kWe)
High-Energy Density Fuel Cells	Space Shuttle: 12kW KOH fuel cells	High specific energy, maintenance-free, low temperature	High specific energy, maintenance-free
Low-Temperature and Long-Life Batteries	ISS: Lithium-ion, limited life at cold temperatures	Lunar night temperatures and duration	
Radiation-Tolerant Power Management and Distribution		Reliable, environmentally tolerant technologies to support continuous exploration over broad regions	Demonstration of advanced technology on Mars surface
Transversal Technologies			
In-Situ Resource Utilisation (ISRU)	Mars oxygen production from CO_2 atmosphere, e.g., MOXIE	Technologies for processing resources into useful products and their storage/supply (e.g., propellant production 50 tons/year)	LOX/LCH_4 and LOX/LH_2 generation from both atmosphere processing and sub-surface water extraction
Dust Mitigation	Apollo: limited three-day crew operations. Rovers: limited mitigation.	Multiple active and passive technologies required significant advances in life cycle	
Inflatable Structures and Materials for Inflatable Modules	ISS: Bigelow Expandable Activity Module (BEAM)		
Low-Temperature Mechanisms	ISS: +121 to -157°C	Operations to -230°C (cryo compatible); multi-year life	
Thermal Management	ISS: Mars asset	Improve thermal control and reliablity required to reduce mass transportation and enable higher performance	
EVA, Mobility and Robotics			
Deep Space Suit	ISS: EVA operations at 0.3 Bar (4.3 Psid)	EVA operations at 0.55 Bar (~8 Psid), extended EVA life cycle, on-back regen CO_2 and humidity control, high specific-energy batteries	
Surface Space Suit	Apollo: three-day max (lunar)	30-day minimum duration, improved lower torso mobility, dust-tolerant	1 year+ duration, thermal insulation (CO_2 atmosphere)
Rapid Access Extra Vehicular Activity (EVA)		Rapidly starting and ending lunar EVAs	Rapidly starting and ending Mars EVAs
Surface Mobility and Exploration	Spacecraft: lunar and Mars rovers state-of-the-art	Autonomous and crewed capability; less ground control; extended range, speed, payload; navigate soft/steep varying soils	
Tele-Robotic Control of Partially Autonomous Robot with Time Delay	ISS: < 1–10-second delay for ground control operations / Spacecraft: lunar/Mars rovers	Few to 10s of sec dynamic environments with variable delays and LOC under partial autonomous tele-robotic ops	Up to 40 minutes

Critical Technology Areas

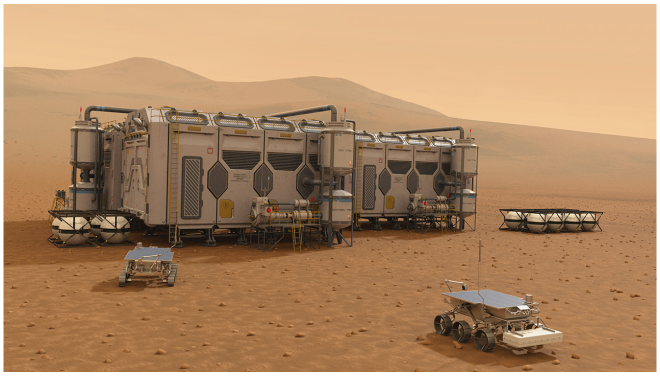
Propulsion, Landing, and Return

Manoeuvring in space, transiting to destinations of interest, landing on surfaces, and returning safely to Earth are all fundamental exploration mission capabilities. As we perform missions farther from Earth and for longer durations, cryogenic fluid management will be critical. Advanced in-space propulsion systems with radically improved specific impulse can enable mass efficiency and/or faster transits to and from Mars. Technologies for safe and precise entry and landing will support asset aggregation for sustained operations and facilitate access to scientifically interesting locations. Commercial entities are working to quickly change the rapidly advancing propulsion landscape—including nuclear propulsion.

The 6-metre Low-Earth Orbit Flight Test of an Inflatable Decelerator flight test article on the recovery ship in November 2022, following a successful demonstration replicating Mars flight conditions. (NASA/Gregory Swanson)

Autonomous Systems

Autonomous systems enable human explorers or independent robotic systems to conduct operations under nominal and off-nominal conditions independent of assistance from Earth. Autonomous surface habitation systems, for example, are designed to accommodate periods of active use and long-term inactivity, including autonomous maintenance, thermal regulation, and robotic repair of damage from events such as micrometeorite impacts and plume debris. Advances in electronics, computing architectures, and software are critical; national space agencies should leverage the latest technology from the commercial sector.



Enhancing future planetary operations with autonomous systems (artist's concept). (CSIRO)

Analogue

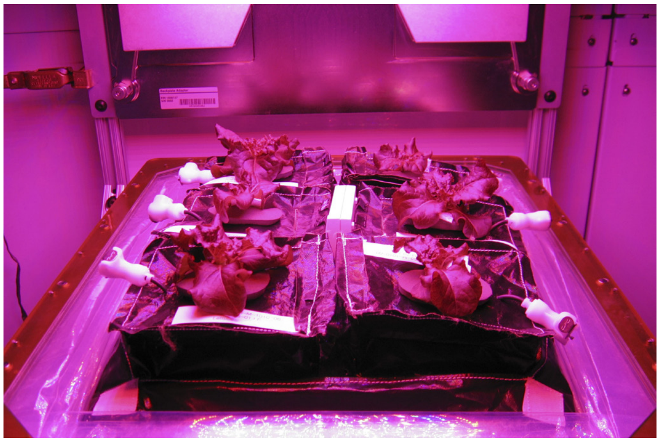
Robots on Mt. Etna: Autonomous Robotic Networks to Help Modern Societies (ARCHES)

An effort led by DLR, with significant ESA participation, uses the harsh environment of Italy's Mt. Etna as a lunar analogue during technology validation for standard payload interfaces. A recent simulation demonstrated modular interfaces with 26 different payloads. The entire campaign, which included more than 65 participants, was carried out over four weeks. A control centre in the city of Catania, 26 km away, operated four different rovers and a drone at the top of Mt. Etna. This campaign included three different mission scenarios: the return of geological samples, in-situ analyses, and infrastructure construction in the form of a low-frequency antenna array.

Two Lightweight Rover Unit (LRU) rovers pick up a modular payload from a lander in a cooperative mission scenario during the ARCHES analogue campaign at Mt. Edna, 2022 (DLR)

Life Support and Habitability

Life support and habitability comprises technology that is essential for creating and preserving conditions that support life in space. This includes closed-loop systems to preserve and reuse resources such as water and air, enhanced reliability life support systems (to decrease need for maintenance and excess consumables or spares), and in-flight environmental monitoring. Fire prevention, detection, and suppression technology and in-situ food production will also be critical for long-duration missions.



Cabbage growing in the Vegetable Production System ("Veggie") experiment on the ISS. (NASA)

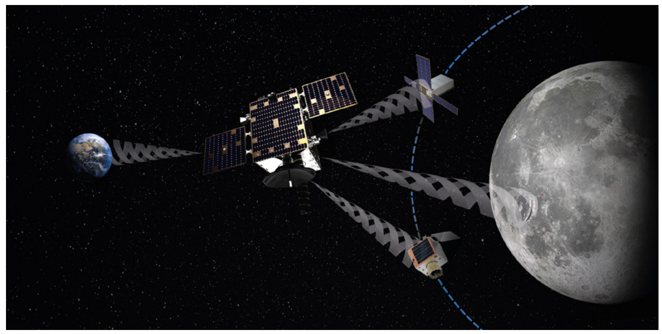
Crew Health and Performance

Crew health and performance comprises numerous subsystems that enable in-flight health maintenance, medical care, behavioural health, and performance monitoring. Existing crew health and performance systems rely heavily on terrestrial support, which will be limited for deep-space exploration, necessitating autonomy and self-sufficiency. Novel in-flight medical systems will consist of modular, agile technology solutions that support interoperable medical devices and centralised crew health data acquisition and analysis.

Blood sampling aboard ISS as part of an experiment that examines space-related effects on crew health. (CSA/NASA)

Communications and Positioning, Navigation, and Timing

Communications and PNT are essential for all space exploration missions. Long-distance communication between space elements and ground stations requires secure, high-speed transmission of housekeeping data, audio, high-definition video, and mission-related information. Robotic and human activities on the Moon or Mars require positioning and interactive communication coverage across multiple elements. Interoperability and standardisation present many opportunities for international collaboration.



Visualisation of a future lunar telecommunications and navigation infrastructure. (SSTL)

Analogue

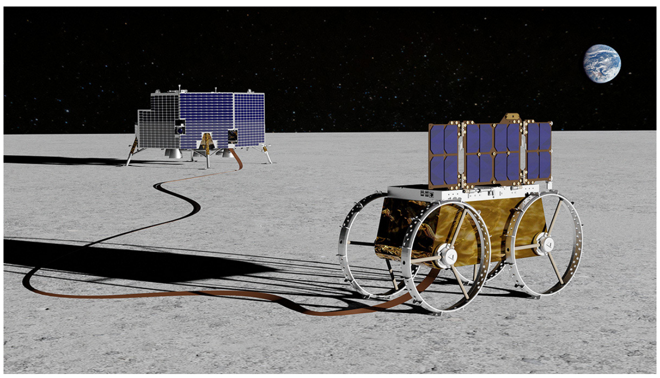
Roving in Virtual Reality: Virtual Operational Test Campaign

In preparation for the deployment of Canada's first rover at the lunar South Pole, CSA organised a mission simulation to test the concepts of operation under a realistic operational framework. This analogue environment framework allows for the rover and the site to be either real (i.e., hardware deployed in the field) or virtual (i.e., simulated assets deployed in a game engine), providing flexibility in customising the virtual environment to meet development and testing needs.

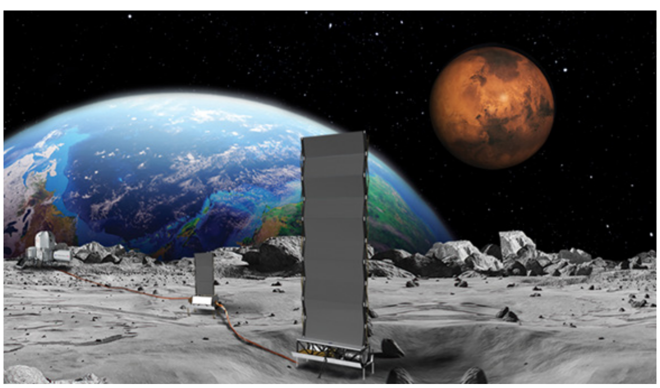
Unreal Engine rendering of the rover within the Moonscape using the scaled version of a Lunar Orbiter Laser Altimeter Digital Elevation Model. (CSA)

Power

Power is at the core of all space exploration activities. Sustainable exploration of the Moon and Mars requires the provision of reliable power sources accompanied by efficient energy storage and distribution systems. Robust and safe surface power infrastructures using technologies such as solar power, nuclear power, fuel cells, and batteries are critical to a sustained human and robotic presence on the lunar surface. Collaboration across agencies and industries will be necessary to develop interoperable systems and power standards.



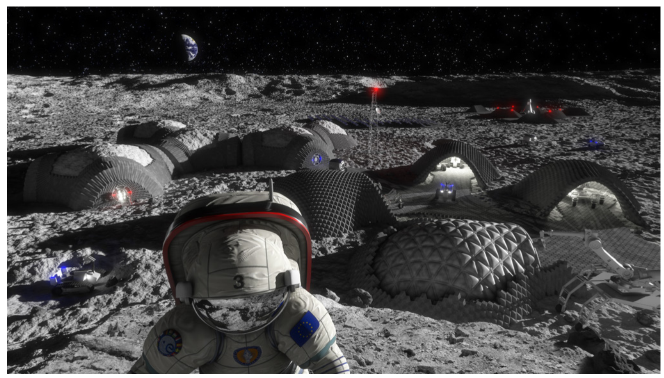
Lunar surface power systems will include converters, cables, and deployment devices. (Astrobotic)



Fission surface power systems could provide electrical power to habitats, rovers, and equipment on the lunar surface. (NASA)

Transversal Technologies

Transversal, or cross-cutting, technologies are the essential elements for achieving sustained human exploration. This includes critical technologies for ISRU, which converts available resources to useable materials, reducing dependence on supplies from Earth; dust mitigation, which will be critical on both the Moon and Mars; and inflatable structures, which will be an essential component of pressurised habitation modules. All of the equipment must also be able to operate reliably in the harsh space environment (with thermal control).



Artist's rendering of a future Moon base that could be constructed and maintained using ISRU technologies.
(RegoLight Consortium, visualisation: LIQUIFER)

Analogue

Bringing the Lunar Surface to Earth: Dusty Thermal Vacuum Chamber

ESA has procured a new Dusty Thermal Vacuum Chamber (DTVC) to enable testing of payloads under simulated lunar conditions. A special feature of the DTVC is a dust dispersion system that allows tests to evaluate the impact of very fine dust deposition on payloads at discrete time points. The DTVC is designed for full automation, remote control, and monitoring of operational parameters of chamber and payload performance under extremes of lunar environmental conditions. The first of its kind in Europe, this facility will be hosted at the European Space Resources Innovation Centre (ESRIC) in Luxembourg, providing opportunities for breakthroughs in research, testing, and innovation in ISRU.

Render of the Dusty Thermal Vacuum Chamber. (ESA)

EVA, Mobility, and Robotics

EVA, mobility, and robotics capabilities enhance space exploration and human presence in space. EVA suits for deep space and surface activities enable human activities outside of pressurised habitation modules. Telerobotics and mobility will help humans and their robotic companions to reach farther into unexplored regions. Terrestrial technologies such as autonomous robots and self-driving automobiles are highly applicable to space exploration, and the creation of standards and interoperable equipment presents opportunities for international collaboration.

An astronaut conducting scientific exploration on the Martian surface (artist's concept). (CSIRO)

Technology Connections

Critical technologies in space exploration are highly connected to activities on Earth. Technological developments for space exploration, in turn, enrich life on Earth, and vice versa. Incorporating technologies that have rapidly developed for terrestrial applications shortens the development period for critical space technologies and increases reliability. The potential benefits are significant, prompting space agencies to accelerate their investments in space technology. Additionally, the technologies needed to explore Mars must be demonstrated—for example, on the Moon—before being used on Mars. A sustainable exploration campaign will develop technology that can be used for lunar exploration and then developed further for exploring Mars.

Terrestrial to Space

Advances in terrestrial technology have reached remarkable levels. Leveraging state-of-the-art technologies can have a significant impact on long-term exploration activities. Terrestrial technologies like Wi-Fi, cellular telephone networks, nuclear power, and mining are all relevant to Moon and Mars exploration missions.

Space to Terrestrial

Critical technologies for sustained lunar surface activity and Mars exploration have the potential to generate significant socio-economic benefits. Medical procedures and technologies developed for deep space exploration are applicable to people living in remote places on Earth, and technologies for growing food in space or on other planetary bodies can enhance terrestrial food cultivation.

Sustained Lunar Surface to Mars Exploration

By developing lunar surface technology and applying it to Mars exploration, sustained lunar surface activities can play an important role in the technological development for Mars exploration. Delay-tolerant communication, radiation mitigation, human performance research, and long-duration life support systems developed for lunar exploration will be highly applicable to Mars missions.

Constraints of Lunar Environment on All Technologies

Understanding and addressing the challenges imposed by the unique lunar environment is crucial for technological development and mission success. Technology on the Moon must tolerate dust and regolith effects, low temperatures, lack of solar power, reduced gravity, and unique effects on sensor performance.

Analogue

Simulating the Moon: LUNA

LUNA is a collaborative project between ESA and DLR that will provide a training ground for astronauts and a test centre for technology, equipping partners and users with the knowledge and skills to explore the Moon, with a strong focus on developing operations concepts for surface activities. Uses include robotic system simulation, validation, and operations; human-machine interactions, including scientific activities, infrastructure build-up and maintenance, and operational processes and emergency procedures; and research and development for materials, tools, and manufacturing, including the handling of lunar dust and ISRU.

ESA-DLR LUNA analogue facility with rendering of the internal 700 m^2 regolith testbed area (insert). (ESA/DLR-S. Asineta, F. Saling)

Technology Gap Assessments and ISRU:

ISECG forms gap assessment teams of subject matter experts to evaluate technology topics at the international level, identify technology gaps, and produce reports identifying key technology and engineering solutions to close those gaps. Previous topics included Liquid Oxygen/Methane Propulsion (2016), Dust Mitigation (2016), Telerobotics (2018), Autonomy (2020), In-Situ Resource Utilisation (2021), and Nuclear Power and Propulsion (2023). All reports are available on the ISECG website.

ISECG also produces technology analyses, like the overview of ISRU on the next page:

Most recent gap assessment reports. (ISECG)

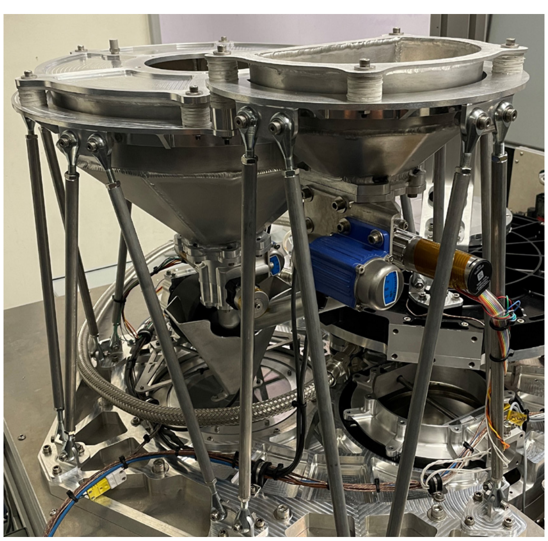
In-Situ Resource Utilisation

ISRU involves any hardware or operation that harnesses and utilises local or in-situ resources to create products and services for robotic and human exploration and sustained presence. ISRU covers the three broad capability areas: 1. in-situ propellant and consumable production, 2. in-situ construction, and 3. in-space manufacturing. The ISRU value chain can be illustrated by the following five-stage process:

ISECG established a gap assessment team to examine and identify technology needs related to ISRU in 2019. Their work resulted in the ISRU gap assessment report published in 2021. Key conclusions from this report are summarised below:

Key Findings and Benefits

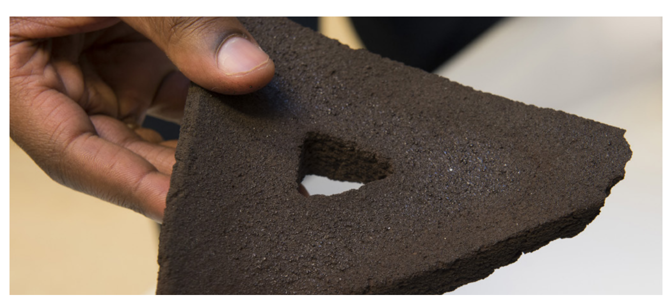
- ISRU is disruptive and requires an architecture-level integrated system design approach from the start.
- ISRU's two most significant impacts on missions and architectures are the ability to reduce launch mass and the ability to extend life of assets or reuse assets multiple times.
- The highest impact ISRU products that can be used early in human lunar operations are mission consumables, including propellants, fuel cell reactants, and life support commodities from lunar resources.



Flight-like carbothermal reduction system for lunar oxygen production. (Sierra Space)

Current Work and Recommendations

- A significant amount of work is underway or planned for ISRU development, particularly in the areas of resource assessment, robotics/mobility, and oxygen extraction from regolith.
- Focus on the defined strategic knowledge gaps for lunar exploration.
- Early emphasis should be placed on geotechnical properties and resource prospecting for regolith near and inside permanently shadowed regions.
- Analyse ISRU-based radiation shielding options.
- Dedicated plume-surface interaction analysis and mitigation techniques.
- International coordinated and collaborative work, including public-private partnerships with terrestrial industry.
- Continue the effort in closing the technology gaps in each of the three capability areas.



A triangular brick 3D printed out of simulated moondust using concentrated sunlight. (ESA/G. Porter)

NASA's Space Launch System rocket carrying the Orion spacecraft launches on the Artemis I flight test on November 16, 2022, from Launch Complex 39B at NASA's Kennedy Space Center in Florida. (NASA)

Chapter 9

Following a Shared Path

The Global Exploration Roadmap reflects international efforts to define a sustainable pathway for human exploration of the solar system, with Mars as the horizon goal. The roadmap is updated over time as space agencies across the world develop and implement exploration missions.

Space exploration produces economic growth, fuels the development of new technologies, stimulates curiosity about our place in the universe, and inspires people around the world. The challenges of spaceflight bring nations together to develop the capabilities needed to explore the solar system.

While each space agency follows its own national policies, international collaboration and the shared exploration architectures and mission designs produced by collaboration make each agency's exploration plans more sustainable and effective. Established space agencies are able to welcome contributions from emerging space agencies, who can contribute expertise and skills to exploration missions that they would be unable to undertake on their own. National space agencies are also increasingly engaged with space exploration efforts by private-sector entities, creating new opportunities for collaboration and innovation and strengthening national economies.

Although the Global Exploration Roadmap does not create any specific mutual commitments for participating ISECG member agencies, it represents a global, strategic, coordinated, and comprehensive approach to space exploration.

This edition of the Global Exploration Roadmap reflects the updated ambitions and plans of an extended number of space agencies, considers an increasing contribution from private entities, and incorporates scientific investigations beyond Mars, paving the way for collaborative, sustained human and robotic exploration of the solar system.

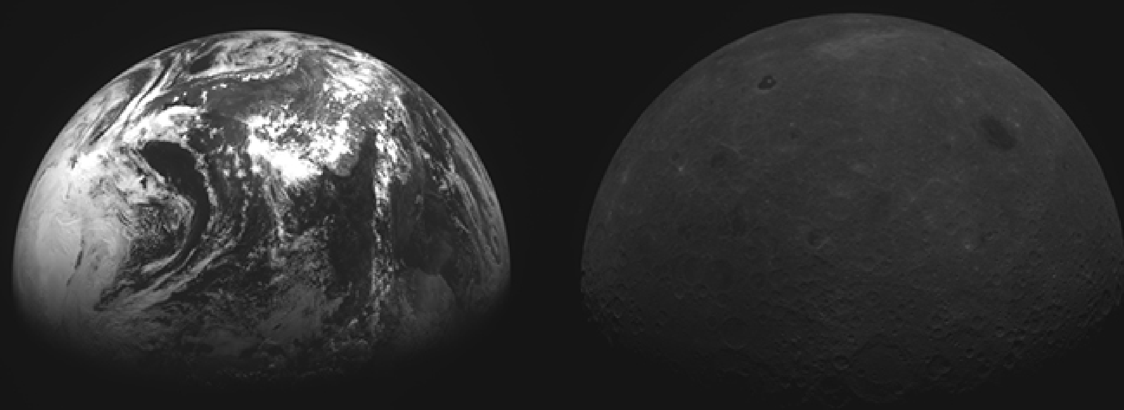
Appendix: Abbreviations & Acronyms

AEB	Brazilian Space Agency
AEM	Mexican Space Agency
ASA	Australian Space Agency
ASI	Italian Space Agency
CLPS	Commercial Lunar Payload Services
CMSA	China Manned Space Agency
CNES	National Centre for Space Studies (France)
CNSA	China National Space Administration
CPNT	Communication, positioning, navigation, and timing
CSA	Canadian Space Agency
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DLR	German Aerospace Centre
EMBRAPA	Brazilian Agricultural Research Corporation
ESA	European Space Agency
EVA	Extravehicular activity
GER	Global Exploration Roadmap
GISTDA	Geo-Informatics and Space Technology Development Agency (Thailand)
GNSS	Global Navigation Satellite System
HALO	Habitation and Logistics Outpost
ILRS	International Lunar Research Station
ISECG	International Space Exploration Coordination Group
ISRO	Indian Space Research Organisation
ISRU	In-situ resource utilisation
ISS	International Space Station
JAXA	Japan Aerospace Exploration Agency
KASA	Korea AeroSpace Administration
LEAP	Lunar Exploration Accelerator Program
LEO	Low-Earth orbit
LINX	Laboratory of Space Instrumentation
LSA	Luxembourg Space Agency
MBRSC	Mohammed Bin Rashid Space Centre
NASA	National Aeronautics and Space Administration (United States)
NOSA	Norwegian Space Agency
NRHO	Near-rectilinear halo orbit
POLSA	Polish Space Agency
PPE	Power and Propulsion Element
ROSA	Romanian Space Agency
UAESA	United Arab Emirates Space Agency
UKSA	United Kingdom Space Agency
UNOOSA	United Nations Office of Outer Space Affairs

ISECG Accomplishments

The purpose of ISECG is to provide a forum to discuss and promote space exploration interests, engagement, objectives, and plans. Over the past 17 years, this group of international space agencies has followed this guiding purpose and built a series of significant accomplishments, including the following:

- ISECG has grown from 14 founding member agencies in 2007 (all of whom have remained with ISECG) to 27 member agencies in 2024.
- The original 2007 ISECG Terms of Reference were reaffirmed by agency leaders in 2022.
- ISECG, originally authorised for a six-year period of existence, has been authorised by agency leaders to continue through December 2030.
- The original three standing working groups and two special teams have evolved and grown into seven standing working groups and several special teams to provide forums for topic areas and projects of mutual interest to member agencies.
- With the release of this document, ISECG has now published four editions of the Global Exploration Roadmap, indicating both the evolving nature of agency interests and a sustained desire to follow a common path forward. The group has also published two roadmap supplements, largely focused on lunar exploration, to reflect rapidly changing member agency plans.
- ISECG has published several topical documents responding to agency interests, including an updated white paper on the benefits from space exploration, a white paper on the science goals of space exploration, the Global Exploration Roadmap Critical Technology Needs report, and six technology gap assessment documents, with more to follow in the coming years.



Explorando juntos

Explorăm împreună

Nós exploramos juntos

Мы исследуем вместе

我们一起探索

We Explore Together   우리는 함께 탐사합니다

เราสำรวจด้วยกัtน

Vi utforskar tilsammans

Mir exploréieren zesummen   نستكشف معاً

Chúng ta cùng nhau khám phá

Esploriamo insieme

Badamy razem

Ми досліджуємо разом

Nous explorons ensemble

私たちは、ともに探査する

Vi utforsker sammen   Wir erkunden gemeinsam

Ka torotoro tahi tatou   हम एक साथ अन्वेषण करते हैं

The Global Exploration Roadmap is a non-binding product of the International Space Exploration Coordination Group (ISECG) space agencies. This fourth edition will be followed by periodic updates as the content evolves and matures. ISECG is committed to the development of products that enable participating agencies to take concrete steps toward partnerships that reflect a globally coordinated exploration effort.

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