# Space exploration

Space exploration and development have been stimulated by a complex mixture of motivations, including scientific inquiry, intense competition between national governments and ideologies, and commercial profit. Underlying them has been a vision of the outward movement of humans from Earth, ultimately leading to permanent settlements in space or on other celestial bodies. In reality, however, only 27 people have travel beyond Earth orbit, all of them Apollo astronauts during the primarily politically inspired race to the Moon. Twenty-four of these astronauts visited the Moon, 12 of them walked on its surface, and additional astronauts are scheduled to do so by 2025 as part of the Artemis space program.

nanosatellite A Nano Racks CubeSats Deployer releasing a set of CubeSats—small research spacecraft, classed as nanosatellites, to be used to conduct Earth observations and advanced electronics testing—from the International Space Station, 2014.

Scientists will continue to seek answers to leading questions about the physical and biological universe through the deployment of increasingly advanced instruments on orbiting satellites and space probes. The principal space-faring countries appear willing to continue their substantial support for space science. The availability of government funding will set the pace of scientific progress.

Protecting satellites from space debrisLearn about space debris, including efforts to eliminate the danger it poses to satellites, spacecraft, and other objects.

The various applications of space capability hold the greatest promise for significant change. If other commercial ventures equal or surpass the success of the satellite communications sector, space could become a major centre of business activity. If governments decide to expand the activity in space of their armed forces, space could become another major military theatre—like the land, the sea, and the air on Earth—for waging war and deploying weapons. If observing Earth from space becomes crucial for effective planetary management, an assortment of increasingly varied and specialized observation satellites could be launched. Thus, outer space could become a much busier area of human activity in the 21st century than it was in the 20th century. At some point, it even may become necessary to establish a space traffic-control system analogous to traffic-control systems on Earth. Already, debris from exploding upper rocket stages, dead satellites, accidental collisions of space objects, and at least one test of an antisatellite weapon are threats to the use of the space environment, and governments and private operators are taking steps to avoid creating additional space debris.

The development of space as an arena for multiple government and private activities will pose significant policy and legal challenges. The legal framework for space activities is based on the 1967 Outer Space Treaty and four subsequent United Nations treaties implementing its provisions. These agreements were negotiated at a time when governments were the principal players in space and commercial space activities were in their infancy. Whether they form an adequate and appropriate framework for current and future space activities requires review. One suggestion is to create a voluntary code of conduct setting out the principles for responsible use of space.

The Outer Space Treaty prohibits the deployment of weapons of mass destruction in outer space and on celestial bodies. Other treaties have limited some military activities in space, but there is no general framework regulating the military uses of space. The wisdom of developing space weapons—or, alternatively, of limiting their development and keeping space a weapons-free environment—is an issue for discussion and debate.

To date, the benefits of space exploration and development have accrued mainly to those countries that have financed space activities. The contributions of space to the economic and social development of large regions of Earth have been limited. The Outer Space Treaty identifies space as "the common heritage of mankind." How to ensure that the benefits of this common heritage are more equitably distributed will be a continuing challenge.

**Mars Exploration Rover**, either of a pair of U.S. robotic vehicles that explored the surface of Mars from January 2004 to June 2018. The mission of each rover was to study the chemical and physical composition of the surface at various locations in order to help determine whether water had ever existed on the planet and to search for other signs that the planet might have supported some form of life.

The twin rovers, Spirit and Opportunity, were launched on June 10 and July 7, 2003, respectively. Spirit touched down in Gusev crater on January 3, 2004. Three weeks later, on January 24, Opportunity landed in a crater on the equatorial plain called Meridiani Planum, on the opposite side of the planet. Both six-wheeled 174-kg (380-pound) rovers were equipped with cameras and a suite of instruments that included a microscopic imager, a rock-grinding tool, and infrared, gamma-ray, and alpha-particle spectrometers that analyzed the rocks, soil, and dust around their landing sites.

The landing sites were chosen because they appeared to have been affected by water in Mars's past. Both rovers found evidence of past water; perhaps the most dramatic was the discovery by

Opportunity of rocks that appeared to have been laid down at the shoreline of an ancient body of salty water.

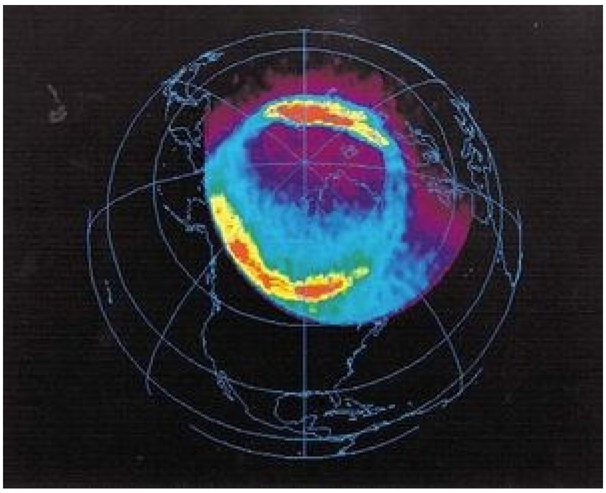
Cape Verde on Mars, as seen by the rover OpportunityThe promontory on Mars called Cape Verde, on the rim of Victoria crater, as seen by Opportunity, a Mars Exploration Rover, in 2006. This cliff of layered rocks, about 50 metres (165 feet) away from the rover, is about 6 metres (20 feet) tall.(more)

Each rover was designed for a nominal 90-day mission but functioned so well that operations were extended several times. NASA finally decided to continue operating the two rovers until they failed to respond to commands from Earth. In August 2005 Spirit reached the summit of Husband Hill, 82 metres (269 feet) above the Gusev crater plain. Spirit and Opportunity continued to work even after a significant Martian dust storm in 2007 coated their solar cells. Opportunity entered Victoria crater, an impact crater roughly 800 metres (2,600 feet) in diameter and 70 metres (230 feet) deep, on September 11, 2007, on the riskiest trek yet for either of the rovers. On August 28, 2008, Opportunity emerged from Victoria crater and set off on a 12-km (7-mile) journey to the much larger (22 km [14 miles] in diameter) Endeavour crater.

In May 2009 Spirit became stuck in soft sandy soil; its wheels were unable to gain any traction. Scientists on Earth strove for months to free the rover, sending it commands to move in various directions, but without success, and in January 2010 NASA decided that Spirit would work from then on as a stationary lander. The rover had traveled more than 7.7 km (4.8 miles) in its mobile lifetime. On March 22, 2010, Spirit ceased transmitting to Earth, and NASA considered it to be dead. By that time its twin, Opportunity, had driven more than 20 km (12.4 miles).

Opportunity continued to explore the Martian surface. The rover arrived at the edge of Endeavour crater on August 9, 2011, and traveled along the crater rim for the rest of its mission. In June 2018 a planetwide dust storm covered Mars, and the last transmission from Opportunity was received on June 10. In February 2019, after months of unsuccessful attempts to contact Opportunity, NASA announced that the rover was dead. Opportunity had covered 45 km (28 miles) over 14 years, which were records for distance driven and mission time spent on another planet.

**Solar and space physics**

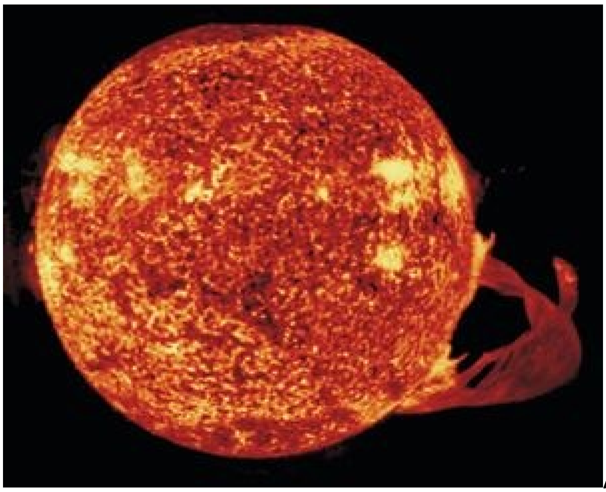


auroral oval Earth's full North Polar auroral oval, in an image taken in ultraviolet light by the U.S. Polar spacecraft over northern Canada, April 6, 1996. In the colour-coded image, which simultaneously shows dayside and nightside auroral activity, the most intense levels of activity are red, and the lowest levels are blue. Polar, launched in February 1996, was designed to further scientists' understanding of how plasma energy contained in the solar wind interacts with Earth's magnetosphere.

The first scientific discovery made with instruments orbiting in space was the existence of the Van Allen radiation belts, discovered by Explorer 1 in 1958. Subsequent space missions investigated Earth’s magnetosphere, the surrounding region of space in which the planet’s magnetic field exerts a controlling effect (*see* Earth: The magnetic field and magnetosphere). Of particular and ongoing interest has been the interaction of the flux of charged particles emitted by the Sun, called the solar wind, with the magnetosphere. Early space science investigations showed, for example, that luminous atmospheric displays known as auroras are the result of this interaction, and scientists came to understand that the magnetosphere is an extremely complex phenomenon.

NASA's Parker Solar Probe spacecraft NASA's Parker Solar Probe spacecraft has travel closer to the Sun than any other mission in history to investigate its highly charged magnetic field.

The focus of inquiry in space physics was later extended to understanding the characteristics of the Sun, both as an average star and as the primary source of energy for the rest of the solar system, and to exploring space between the Sun and Earth and other planets (*see* interplanetary medium). The magnetospheres of other planets, particularly Jupiter with its strong magnetic field, also came under study. Scientists sought a better understanding of the internal dynamics and overall behaviour of the Sun, the underlying causes of variations in solar activity, and the way in which those variations propagate through space and ultimately affect Earth’s magnetosphere and upper atmosphere. The concept of space weather was advanced to describe the changing conditions in the Sun-Earth region of the solar system. Variations in space weather can cause geomagnetic storms that interfere with the operation of satellites and even systems on the ground such as power grids.



A spectacular flare on the Sun, photographed in extreme ultraviolet light on December 19, 1973, by the third astronaut crew aboard the U.S. space station Skylab.(more)

To carry out the investigations required for addressing these scientific questions, the United States, Europe, the Soviet Union, and Japan developed a variety of space missions, often in a coordinated fashion. In the United States, early studies of the Sun were undertaken by a series of Orbiting Solar Observatory satellites (launched 1962–75) and the astronaut crews of the Skylab space station in 1973–74, using that facility's Apollo Telescope Mount. These were followed by the Solar Maximum Mission satellite (launched 1980). ESA developed the Ulysses mission (1990) to explore the Sun's polar regions. Solar-terrestrial interactions were the focus of many of the Explorer series of spacecraft (1958–75) and the Orbiting Geophysical Observatory satellites (1964–69).

## Risks and benefits

astronauts John Grunsfeld and Richard Linnehan with the Hubble Space Telescope, 2002Astronauts John Grunsfeld and Richard Linnehan near the Hubble Space Telescope, temporarily hosted in the space shuttle *Columbia*'s cargo bay, March 8, 2002.

Human spaceflight is both risky and expensive. From the crash landing of the first crewed Soyuz spacecraft in 1967 to the breakup of the shuttle orbiter *Columbia* in 2003, 18 people died during spaceflights. Providing the systems to support people while in orbit adds significant additional costs to a space mission, and ensuring that the launch, flight, and reentry are carried out as safely as possible also requires highly reliable and thus costly equipment, including both spacecraft and launchers.

Opportunity, artist's conceptionThe U.S. robotic rover Opportunity traversing the Martian surface, as depicted in an artist's conception.(more)

From the start of human spaceflight efforts, some have argued that the benefits of sending humans into space do not justify either the risks or the costs. They contend that robotic missions can produce equal or even greater scientific results with lower expenditures and that human presence in space has no other valid justification. Those who support human spaceflight cite the still unmatched ability of human intelligence, flexibility, and reliability in carrying out certain experiments in orbit, in repairing and maintaining robotic spacecraft and automated instruments in space, and in acting as explorers in initial journeys to other places in the solar system. They also argue that astronauts serve as excellent role models for younger people and act as vicarious representatives of the many who would like to fly in space themselves. In addition is the long-held view that eventually some humans will leave Earth to establish permanent outposts and larger settlements on the Moon, Mars, or other locations.