Essence of Space Exploration

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Space Exploration

Saturn V rocket, used for the American manned lunar landing missions

Space exploration is the use of astronomy and space technology to explore outer space. Physical exploration of space is conducted both by human spaceflights and by robotic spacecraft. While the observation of objects in space, known as astronomy, predates reliable recorded history, it was the development of large and relatively efficient rockets during the early 20th century that allowed physical space exploration to become a reality. Common rationales for exploring space include advancing scientific research, uniting different nations, ensuring the future survival of humanity and developing military and strategic advantages against other countries. Various criticisms of space exploration are sometimes made.

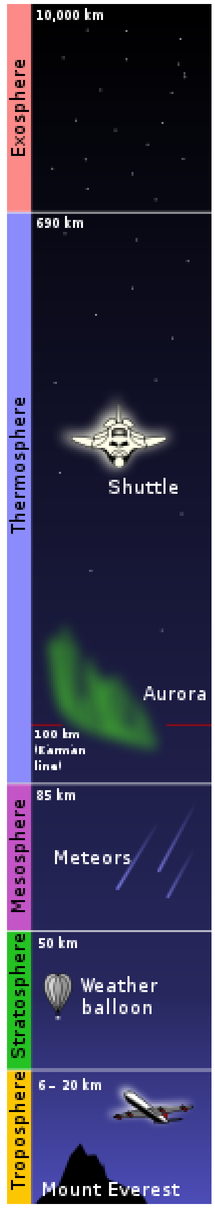
Space exploration has often been used as a proxy competition for geopolitical rivalries such as the Cold War. The early era of space exploration was driven by a "Space Race" between the Soviet Union and the United States; the launch of the first man-made object to orbit the Earth, the USSR's Sputnik 1, on October 4, 1957, and the first Moon landing by the American Apollo 11 craft on July 20, 1969 are often taken as the boundaries for this initial period. The Soviet space program achieved many of the first milestones, including the first living being in orbit in 1957, the first human spaceflight (Yuri Gagarin aboard Vostok 1) in 1961, the first spacewalk (by Aleksei Leonov) in 1965, the first automatic landing on another celestial body in 1966, and the launch of the first space station (Salyut 1) in 1971.

After the first 20 years of exploration, focus shifted from one-off flights to renewable hardware, such as the Space Shuttle program, and from competition to cooperation as with the International Space Station.

From the 1990s onwards, private interests began promoting space tourism and then private space exploration of the Moon.

In the 2000s, the People's Republic of China initiated a successful manned spaceflight program, while the European Union, Japan, and India have also planned future manned space missions. The United States has committed to return to the Moon by 2018 and later Mars. China, Russia, Japan, and India have advocated manned missions to the Moon during the 21st century, while the European Union has advocated manned missions to both the Moon and Mars during the 21st century.

History of exploration in the 20th Century

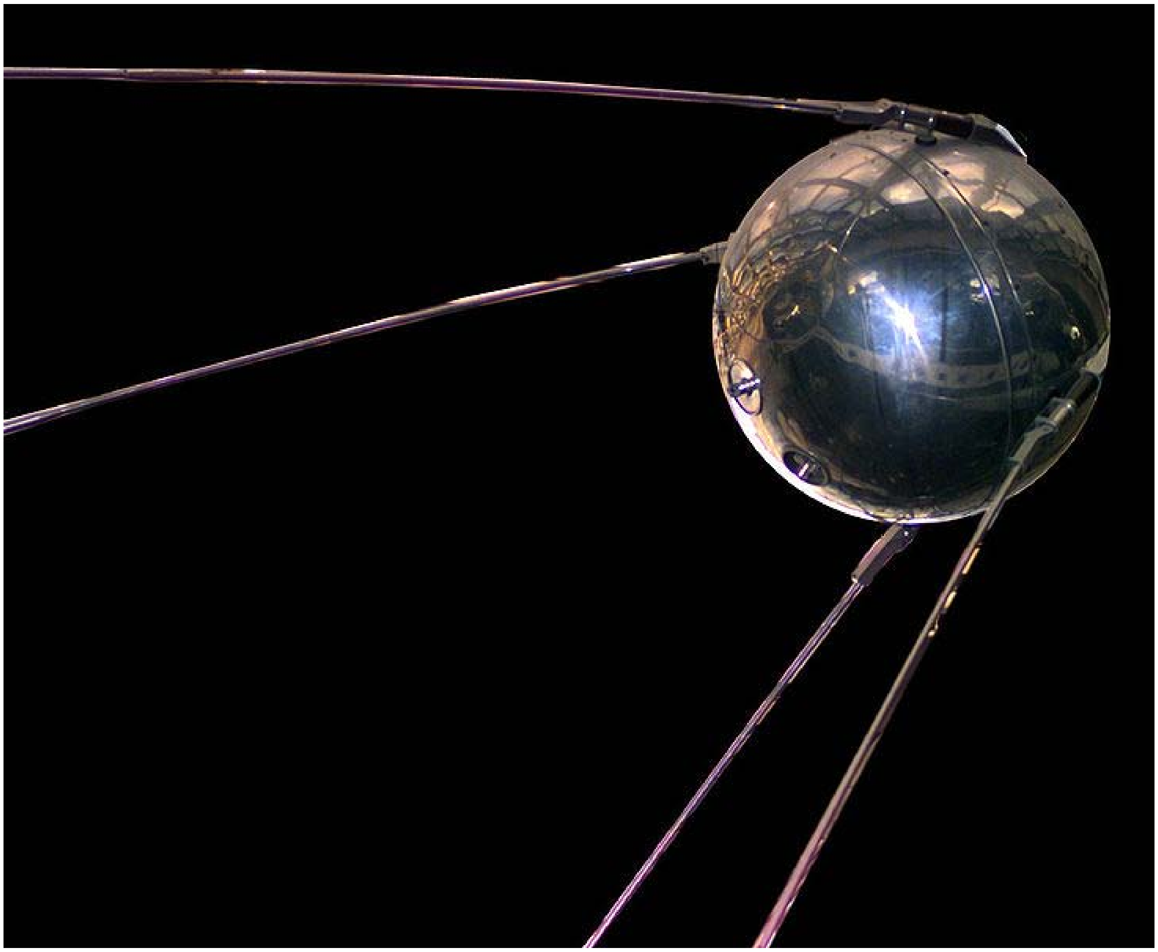


Most orbital flight actually takes place in upper layers of the atmosphere, especially in the thermosphere (not to scale)

In July 1950 the first bumper rocket is launched from Cape Canaveral, Florida. The Bumper was a two-stage rocket consisting of a Post-War V-2 topped by a WAC Corporal rocket. It could reach then-record altitudes of almost 400 km. Launched by General Electric Company, this Bumper was used primarily for testing rocket systems and for research on the upper atmosphere. They carried small payloads that allowed them to measure attributes including air temperature and cosmic ray impacts.

The first steps of putting a man-made object into space were taken by German scientists during World War II while testing the V2 rocket which became the first human-made object in space on October 3, 1942 with the launching of V-4. After the war, the Allies used German scientists and their captured rockets in programs for both military and civilian research. The first scientific exploration from space was the cosmic radiation experiment launched by the U.S. on a V2 rocket on May 10, 1946. The first images of Earth taken from space followed the same year while the first animal experiment saw fruit flies lifted into space in 1947, both also on modified V2s launched by Americans. Starting in 1947, the Soviets launched sub-orbital V2 rockets and their own variant, the R-1, including radiation and animal experiments on some flights. These suborbital experiments only allowed a very short time in space which limited their usefulness.

First flights



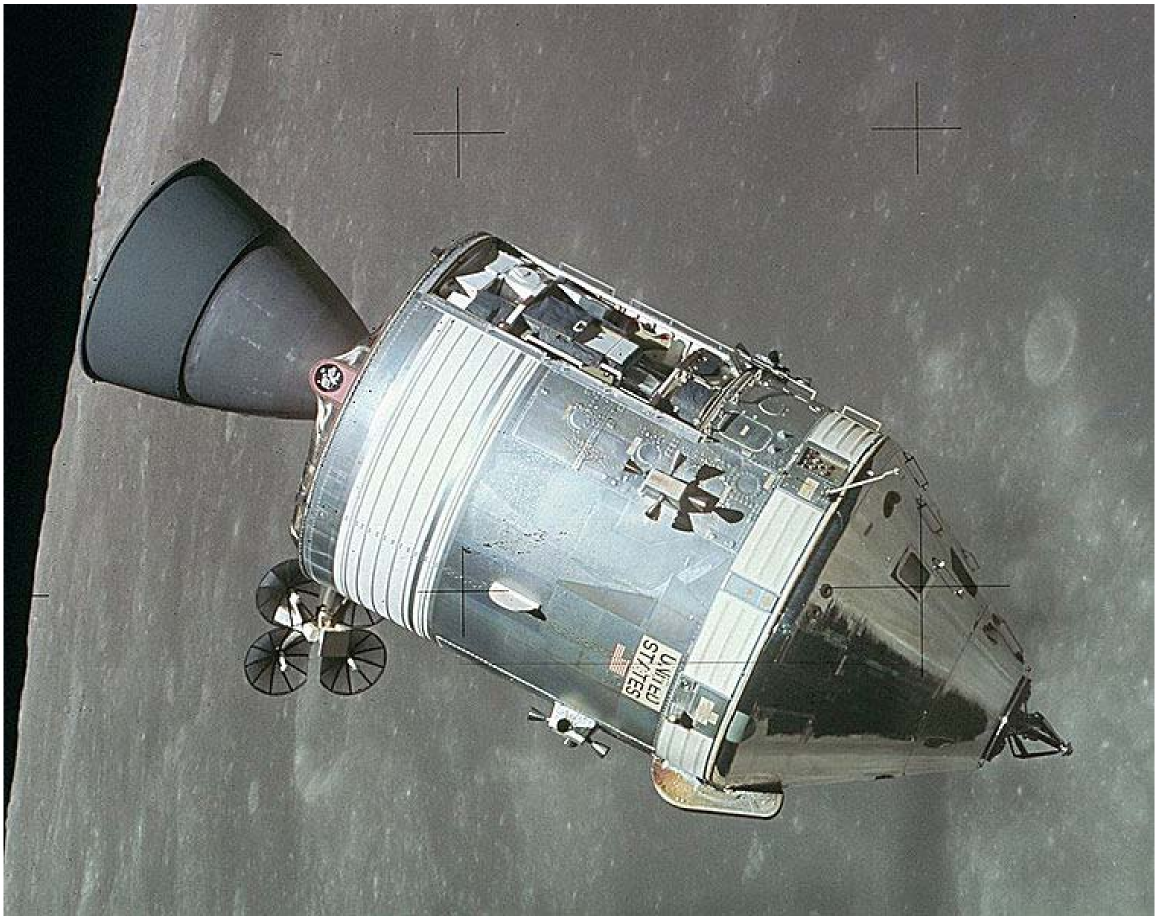
Sputnik 1, the first artificial satellite orbited earth at 939 km (583 mi) to 215 km (134 mi) in 1957, and was soon followed by Sputnik 2.

The first successful orbital launch was of the Soviet unmanned *Sputnik* ("Satellite I") mission on October 4, 1957. The satellite weighed about 83 kg (184 pounds), and is believed to have orbited Earth at a height of about 250 km (150 miles). It had two radio transmitters (20 and 40 MHz), which emitted "beeps" that could be heard by radios around the globe. Analysis of the radio signals was used to gather information about the electron density of the ionosphere, while temperature and pressure data was encoded in the duration of radio beeps. The results indicated that the satellite was not punctured by a meteoroid. Sputnik 1 was launched by an R-7 rocket. It burned up upon re-entry on January 3, 1958.

This success led to an escalation of the American space program, which unsuccessfully attempted to launch Vanguard 1 into orbit two months later. On January 31, 1958, the U.S. successfully orbited Explorer 1 on a Juno rocket. In the meantime, the Soviet dog Laika became the first animal in orbit on November 3, 1957.

First human flights

The first successful human spaceflight was *Vostok 1* ("East 1"), carrying 27 year old Russian cosmonaut Yuri Gagarin on April 12, 1961. The spacecraft completed one orbit around the globe, lasting about 1 hour and 48 minutes. Gagarin's flight resonated around the world; it was a demonstration of the advanced Soviet space program and it opened an entirely new era in space exploration: human spaceflight.



Apollo CSM in lunar orbit

The U.S. first launched a person into space within a month of Vostok 1 with Alan Shepard's suborbital flight in Mercury-Redstone 3. Orbital flight was achieved by the United States when John Glenn's Mercury-Atlas 6 orbited the Earth on February 20, 1962.

Valentina Tereshkova, the first woman in space, orbited the Earth 48 times aboard Vostok 6 on June 16, 1963.

China first launched a person into space 42 years after the launch of Vostok 1, on October 15, 2003, with the flight of Yang Liwei aboard the Shenzhou 5 (Spaceboat 5) spacecraft.

First planetary explorations

The first artificial object to reach another celestial body was Luna 2 in 1959. The first automatic landing on another celestial body was performed by Luna 9 in 1966. Luna 10 became the first artificial satellite of another celestial body.

The first manned landing on another celestial body was performed by Apollo 11 in its lunar landing on July 20, 1969.

The first successful interplanetary flyby was the 1962 Mariner 2 flyby of Venus (closest approach 34,773 kilometers). Flybys for the other planets were first achieved in 1965 for Mars by Mariner 4, 1973 for Jupiter by Pioneer 10, 1974 for Mercury by Mariner 10, 1979 for Saturn by Pioneer 11, 1986 for Uranus by Voyager 2, and 1989 for Neptune by Voyager 2.

The first interplanetary surface mission to return at least limited surface data from another planet was the 1970 landing of Venera 7 on Venus which returned data to earth for 23 minutes. In 1971 the Mars 3 mission achieved the first soft landing on Mars returning data for almost 20 seconds. Later much longer duration surface missions were achieved, including over 6 years of Mars surface operation by Viking 1 from 1975 to 1982 and over 2 hours of transmission from the surface of Venus by Venera 13 in 1982 (the longest ever Soviet planetary surface mission).

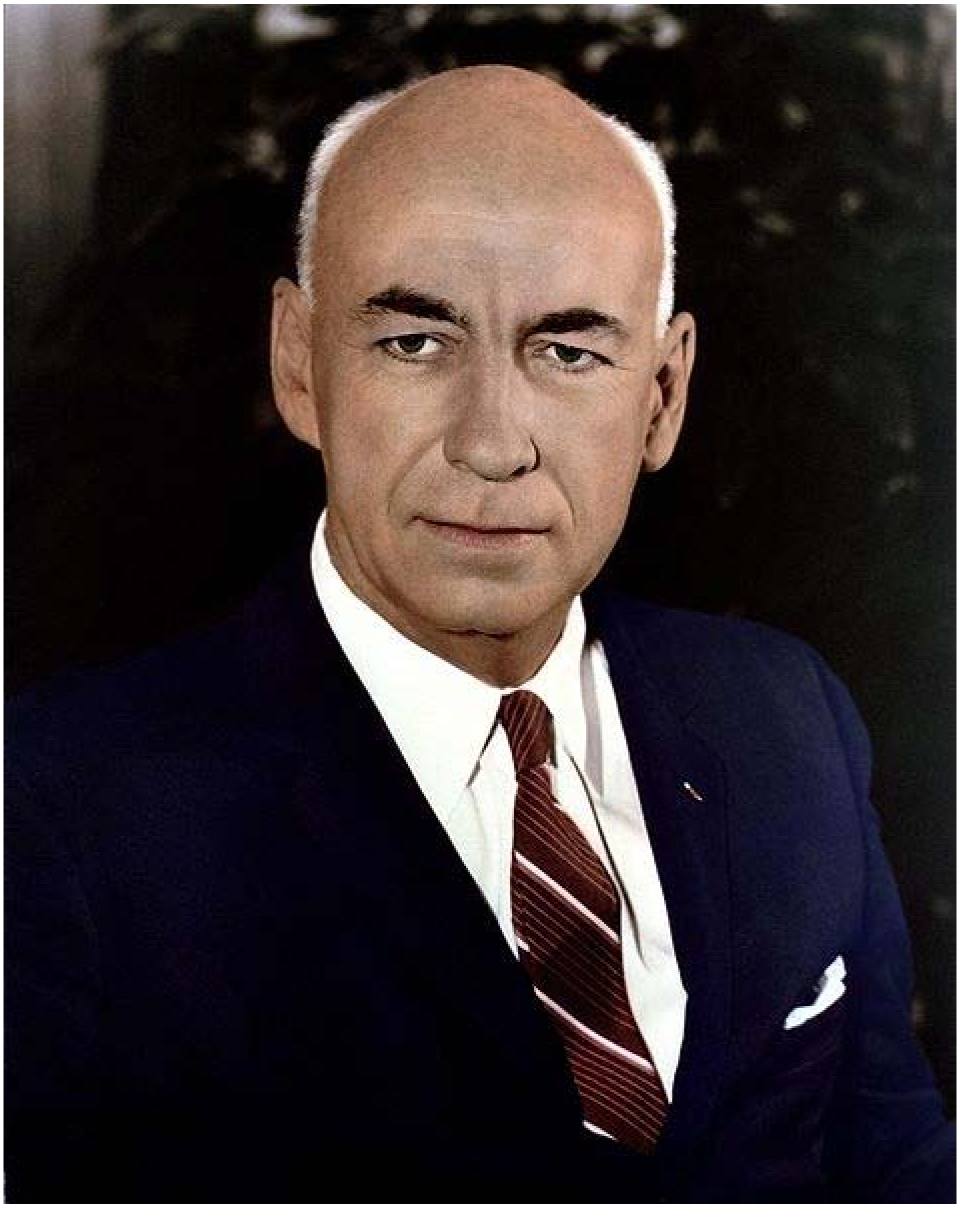
Key people in early space exploration

The dream of stepping into the outer reaches of the Earth's atmosphere was driven by rocket technology. The German V2 was the first rocket to travel into space, overcoming the problems of thrust and material failure. During the final days of World War II this technology was obtained by both the Americans and Soviets as were its designers. The initial driving force for further development of the technology was a weapons race for intercontinental ballistic missiles (ICBMs) to be used as long-range carriers for fast nuclear weapon delivery, but in 1961 when USSR launched the first man into space, the U.S. declared itself to be in a "Space Race" with Russia.

- **Konstantin Tsiolkovsky, Robert Goddard, Hermann Oberth**, and **Reinhold Tilling** laid the groundwork of rocketry in the early years of the 20th century.
- **Wernher von Braun** was the lead rocket engineer for Nazi Germany's World War II V-2 rocket project. In the last days of the war he led a caravan of workers in the German rocket program to the American lines, where they surrendered and were brought to the USA to work on U.S. rocket development. He acquired American citizenship and led the team that developed and launched Explorer 1, the first American satellite. Von Braun later led the team at NASA's Marshall Space Flight Center which developed the Saturn V moon rocket.
- Initially the race for space was often led by **Sergei Korolyov**, whose legacy includes both the R7 and Soyuz—which remain in service to this day. Korolev was the mastermind behind the first satellite, first man (and first woman) in orbit and first spacewalk. Until his death his identity was a closely guarded state secret;

not even his mother knew that he was responsible for creating the Russian space program.

- **Kerim Kerimov** was one of the founders of the Soviet space program and was one of the lead architects behind the first human spaceflight (Vostok 1) alongside Sergey Korolyov. After Korolyov's death in 1966, Kerimov became the lead scientist of the Soviet space program and was responsible for the launch of the first space stations from 1971 to 1991, including the Salyut and Mir series, and their precursors in 1967, the Cosmos 186 and Cosmos 188.

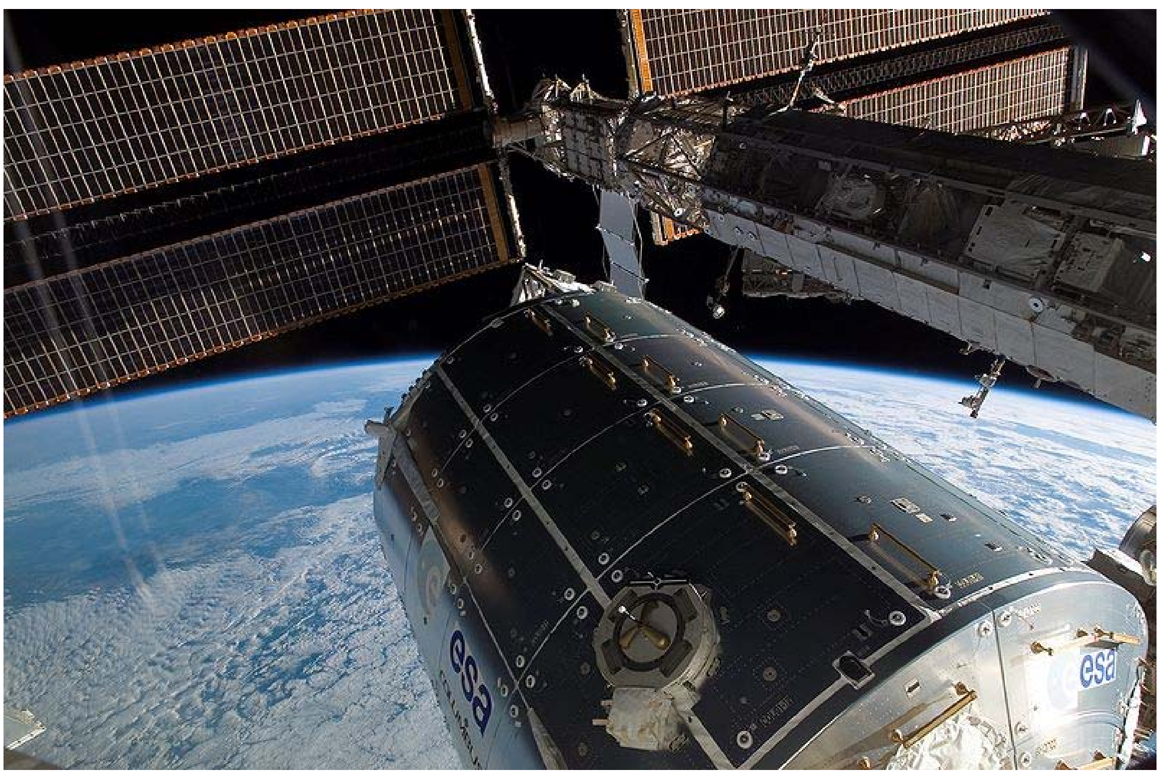


Robert Gilruth

Other key people included:

- **Valentin Glushko** held the role of Chief Engine Designer for USSR. Glushko designed many of the engines used on the early Soviet rockets, but was constantly at odds with Korolyov.
- **Vasily Mishin** was Chief Designer working under Sergey Korolyov and one of first Soviets to inspect the captured German V2 design. Following the death of Sergei Korolev, Mishin was held responsible for the Soviet failure to be first country to place a man on the moon.
- **Bob Gilruth** was the NASA head of the Space Task Force and director of 25 manned space flights. Gilruth was the person who suggested to John F. Kennedy that the Americans take the bold step of reaching the Moon in an attempt to reclaim space superiority from the Soviets.
- **Christopher C. Kraft, Jr.** was NASA's first flight director, who oversaw development of Mission Control and associated technologies and procedures.
- **Maxime Faget** was the designer of the Mercury capsule; he played a key role in designing the Gemini and Apollo spacecraft, and contributed to the design of the Space Shuttle.

Future of space exploration



The European Space Agency's Columbus Module at the International Space Station, launched into space on the U.S. Space Shuttle mission STS-122 in 2008

In the 2000s, several plans for space exploration have been announced; both government entities and the private sector have space exploration objectives.

Targets of exploration

Astrobiology

Astrobiology is the interdisciplinary study of life in the universe, combining aspects of astronomy, biology and geology. It is focused primarily on the study of the origin, distribution and evolution of life. It is also known as **exobiology** (from Greek: έξω, *exo*, "outside"). The term "Xenobiology" has been used as well, but this is technically incorrect because its terminology means "biology of the foreigners". Astrobiologists must also consider the possibility of life that is chemically entirely distinct from any life found on earth.

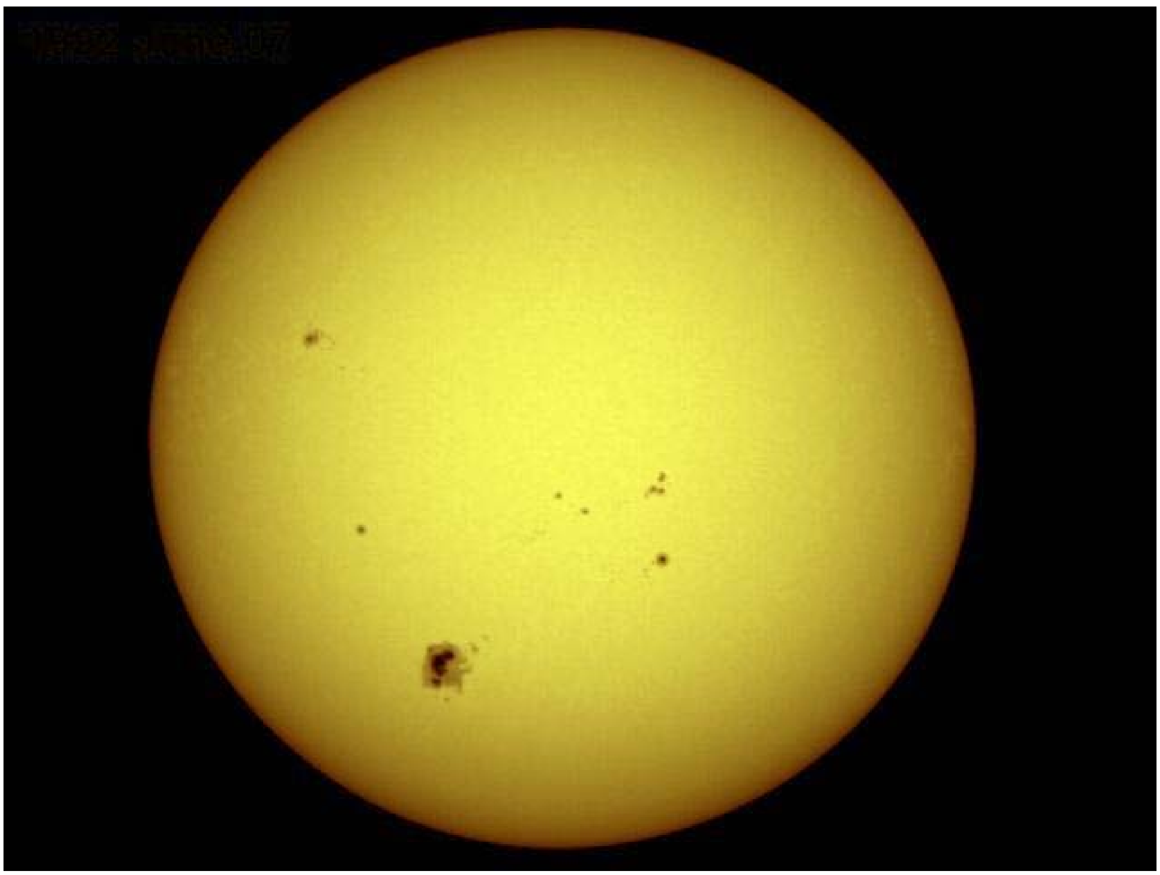
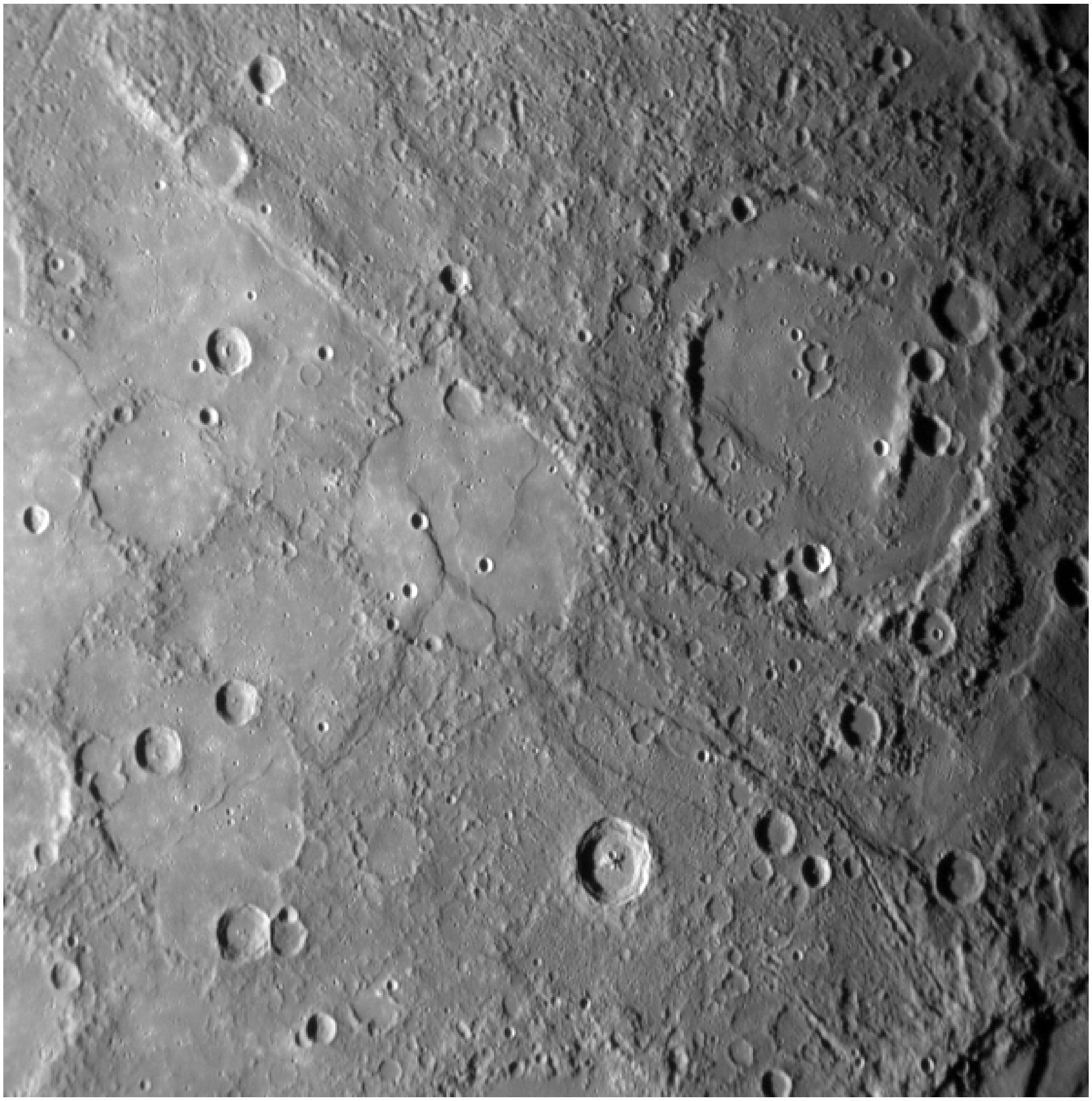


Image of the Sun from 7 June 1992 showing some sunspots

The Sun

While the Sun will probably not be physically explored in the close future, one of the reasons for going into space includes knowing more about the Sun. Once above the atmosphere in particular and the Earth's magnetic field, this gives access to the Solar wind and infrared and ultraviolet radiations that cannot reach the surface of the Earth. The Sun generates most space weather, which can affect power generation and transmission systems on Earth and interfere with, and even damage, satellites and space probes.

MESSENGER image of Mercury



A MESSENGER image from 18,000 km showing a region about 500 km across

Mercury

Mercury remains the least explored of the inner planets. As of January 2008, the Mariner 10 and MESSENGER missions have been the only missions that have made close observations of Mercury. MESSENGER made a fly-by of Mercury on 14 January 2008, to further investigate the observations made by Mariner 10 in 1975 (Munsell, 2006b). A third mission to Mercury, scheduled to arrive in 2020, BepiColombo is to include two probes. BepiColombo is a joint mission between Japan and the European Space Agency. MESSENGER and BepiColombo are intended to gather complementary data to help scientists understand many of the mysteries discovered by Mariner 10's flybys.

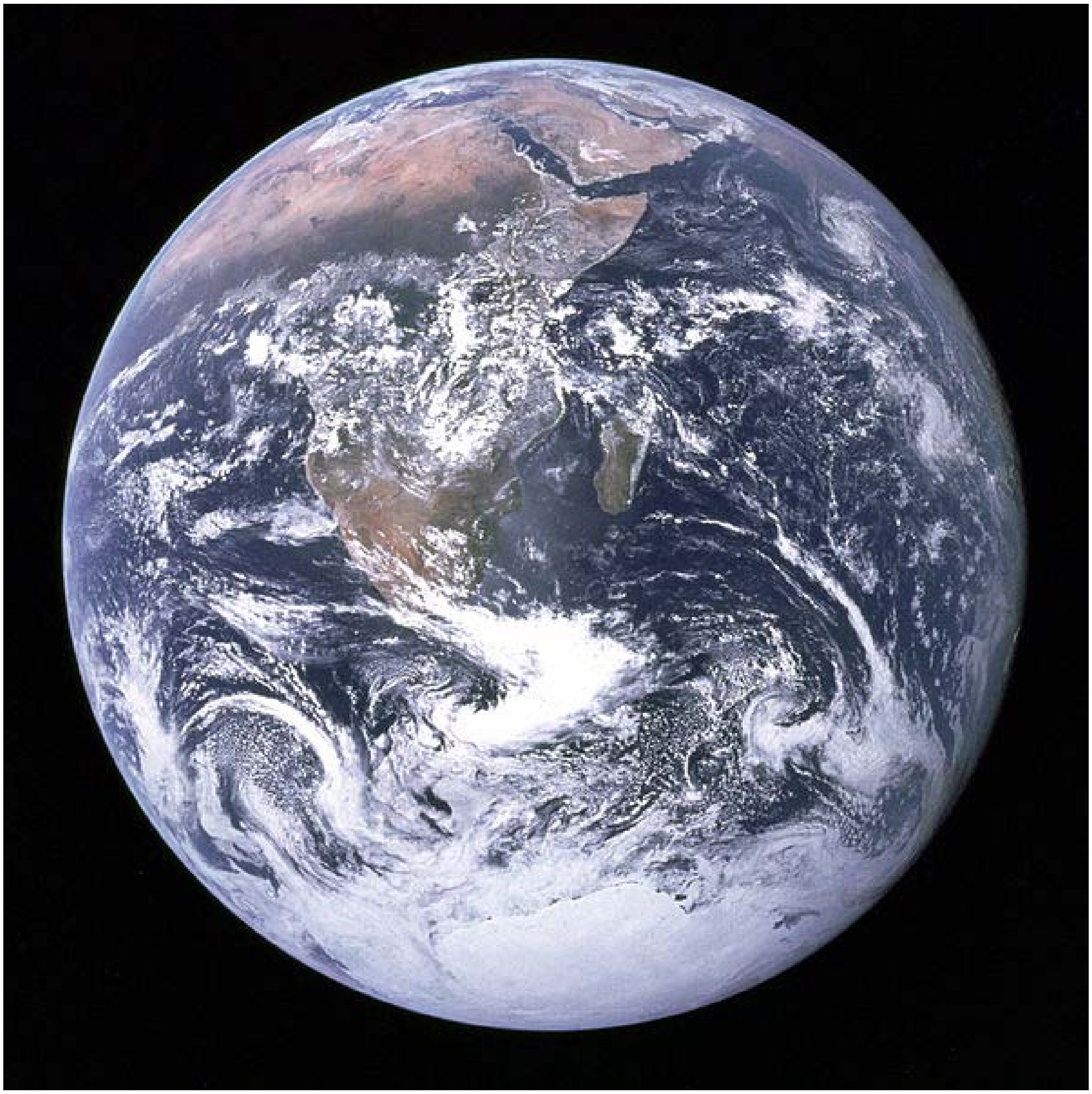
Flights to other planets within the Solar System are accomplished at a cost in energy, which is described by the net change in velocity of the spacecraft, or delta-v. Due to the relatively high delta-v to reach Mercury and its proximity to the Sun, it is difficult to explore and orbits around it are rather unstable.

Mariner 10 image of Venus

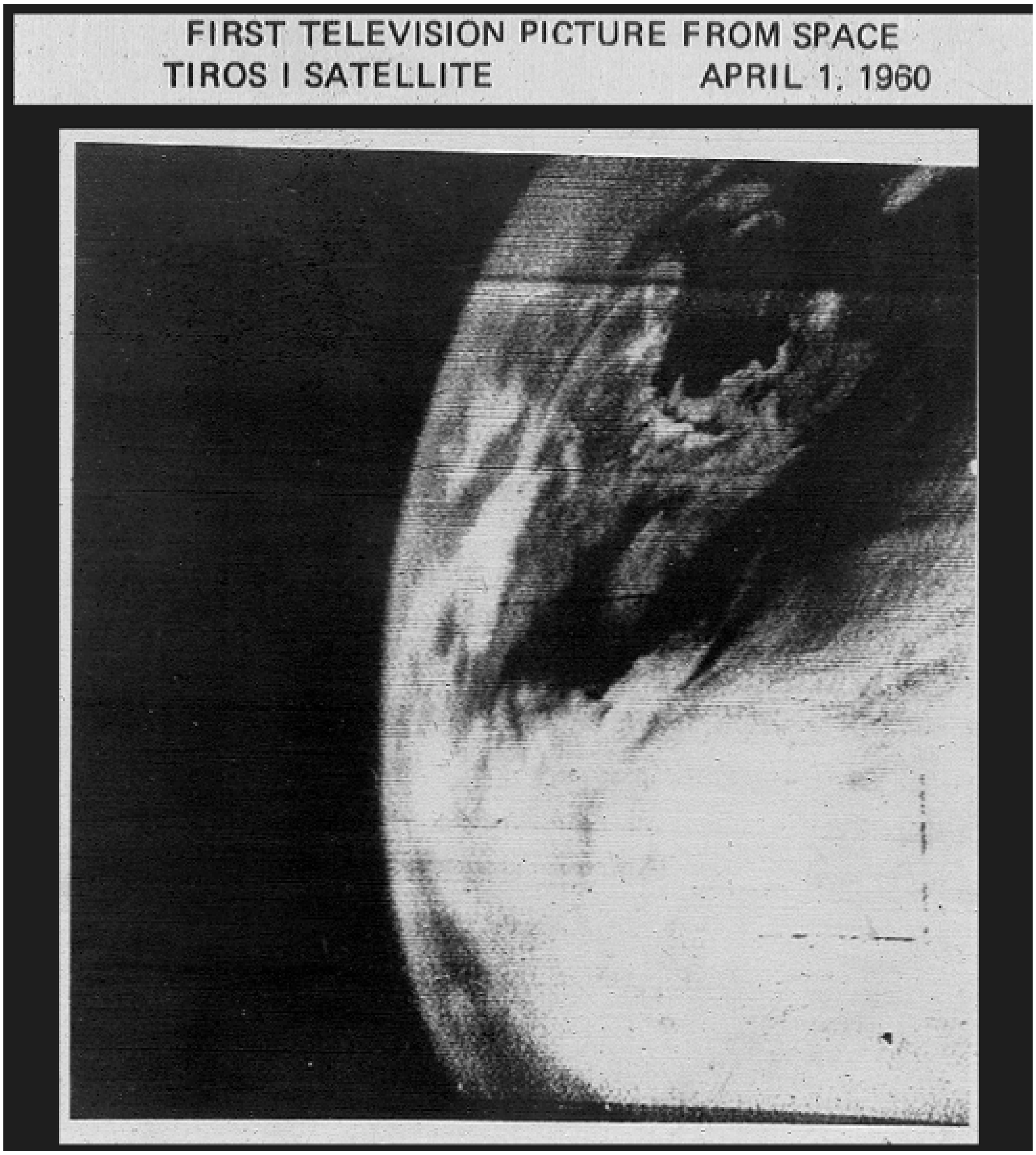
Venus

Venus was the first target of interplanetary flyby and lander missions and, despite one of the most hostile surface environments in the solar system, has had more landers sent to it (nearly all from the Soviet Union) than any other planet in the solar system. The first successful Venus flyby was the American Mariner 2 spacecraft, which flew past Venus in 1962. Mariner 2 has been followed by several other flybys by multiple space agencies often as part of missions using a Venus flyby to provide a gravitational assist en route to other celestial bodies. In 1967 Venera 4 became the first probe to enter and directly examine the atmosphere of Venus. In 1970 Venera 7 became the first successful lander to reach the surface of Venus and by 1985 it had been followed by eight additional successful Soviet Venus landers which provided images and other direct surface data.

Starting in 1975 with the Soviet orbiter Venera 9 some ten successful orbiter missions have been sent to Venus, including later missions which were able to map the surface of Venus using radar to pierce the obscuring atmosphere.



The "marble" Earth picture taken by Apollo 17



First television image of Earth from space

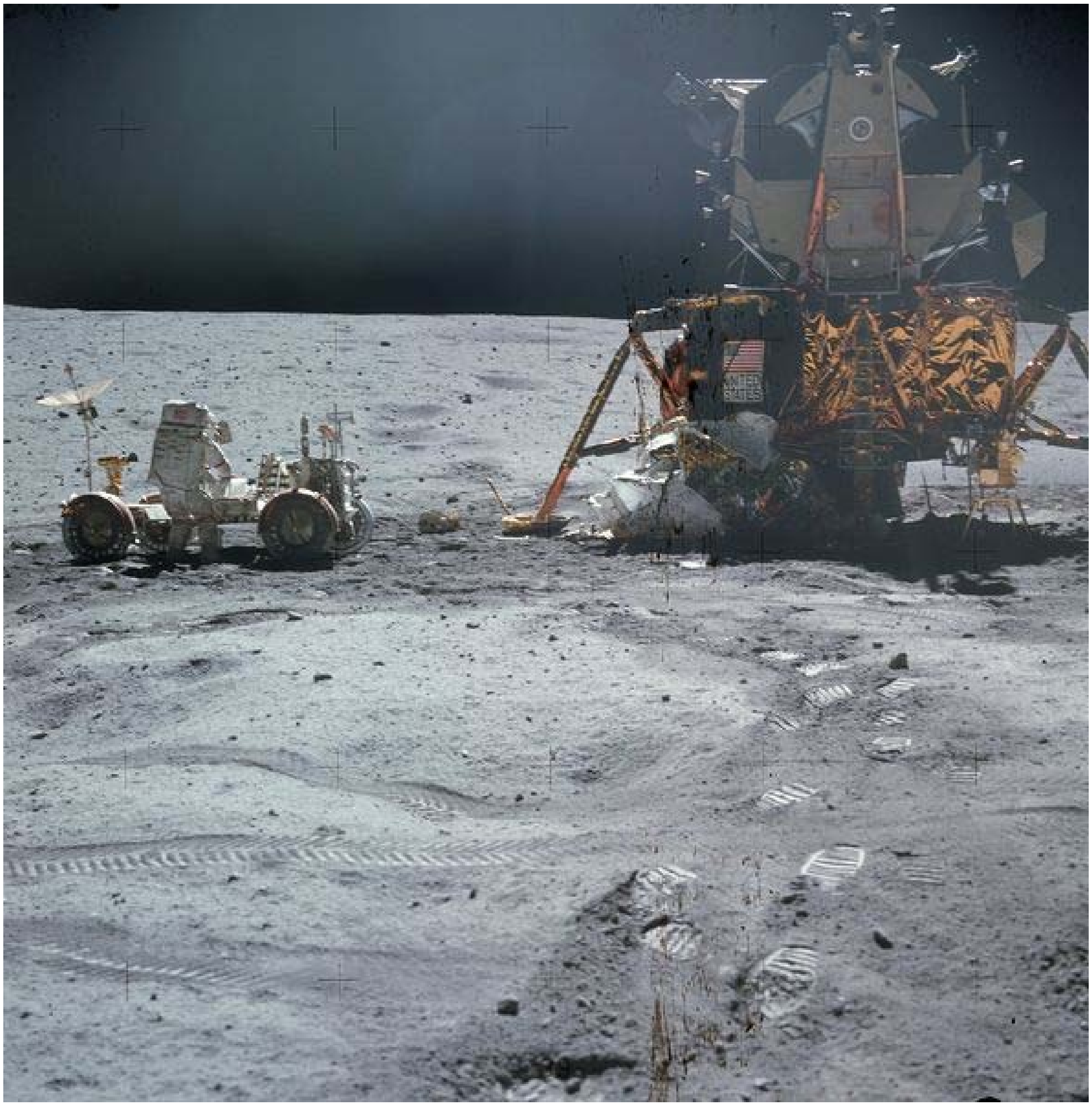
Earth

Space exploration has been used as a tool to understand the Earth as a celestial object in its own right. Orbital missions can provide data for the Earth that can be difficult or impossible to obtain from a purely ground-based point of reference.

For example, the existence of the Van Allen belts was unknown until their discovery by the United States' first artificial satellite, Explorer 1. These belts contain radiation trapped by the Earth's magnetic fields, which currently renders construction of habitable space stations above 1000 km impractical. Following this early unexpected discovery, a large number of Earth observation satellites have been deployed specifically to explore the

Earth from a space based perspective. These satellites have significantly contributed to the understanding of a variety of earth based phenomena. For instance, the hole in the ozone layer was found by an artificial satellite that was exploring Earth's atmosphere, and satellites have allowed for the discovery of archeological sites or geological formations that were difficult or impossible to otherwise identify.

The Moon as seen from the Earth
Luc Viatour (Belgium)



Apollo 16 astronaut John Young

Earth's Moon

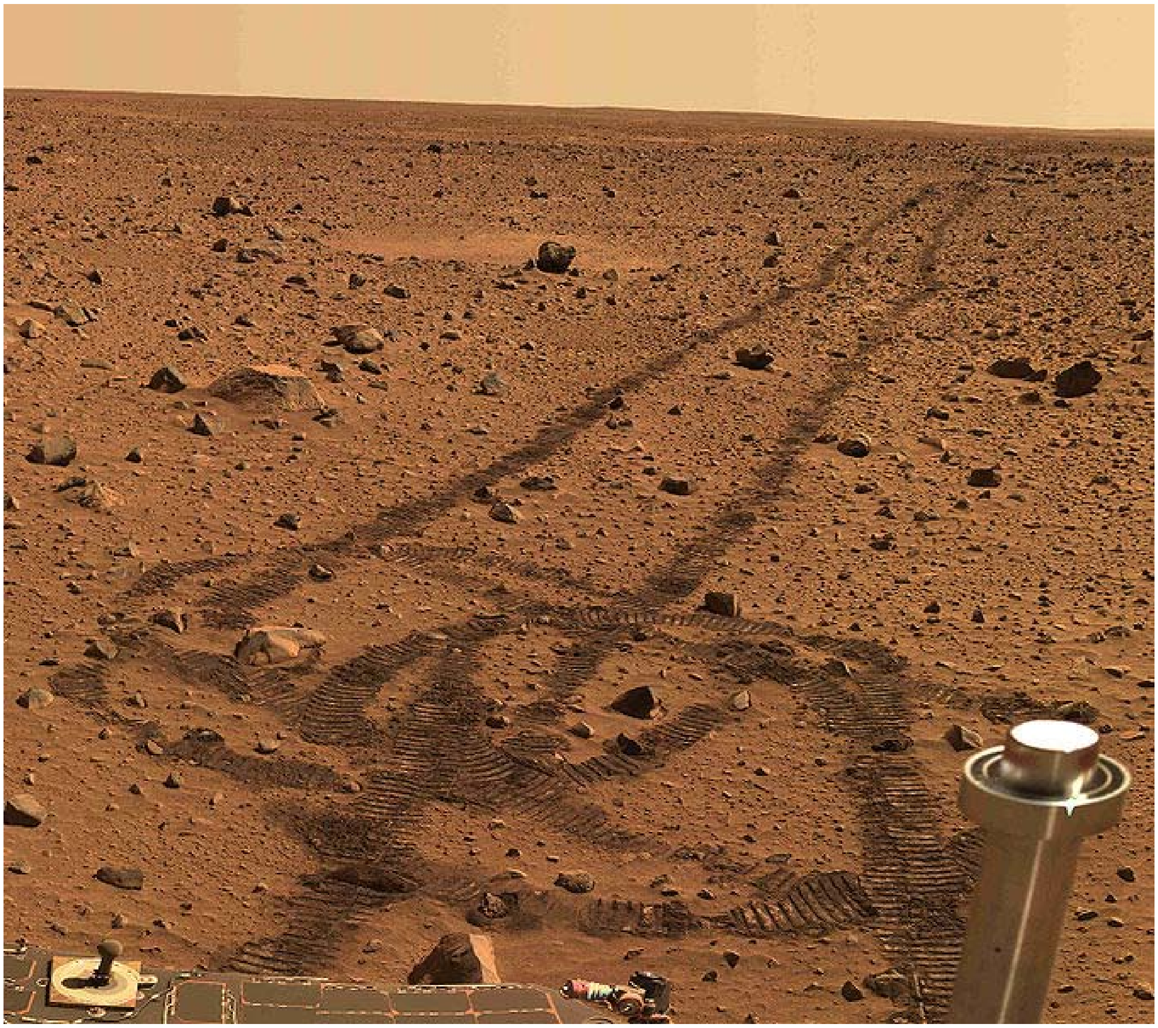
Earth's Moon was the first celestial body to be the object of space exploration. It holds the distinctions of being the first remote celestial object to be flown by, orbited, and landed upon by spacecraft, and the only remote celestial object ever to be visited by humans.

In 1959 the Soviets obtained the first images of the far side of the Moon, never previously visible to humans. The U.S. exploration of the Moon began with the Ranger 4 impactor in 1962. Starting in 1966 the Soviets successfully deployed a number of landers to the Moon which were able to obtain data directly from the Moon's surface; just four months later, Surveyor 1 marked the debut of a successful series of U.S. landers. The

Soviet unmanned missions culminated in the Lunokhod program in the early '70s which included the first unmanned rovers and also successfully returned lunar soil samples to the Earth for study. This marked the first (and to date the only) automated return of extraterrestrial soil samples to the Earth. Unmanned exploration of the Moon continues with various nations periodically deploying lunar orbiters, and in 2008 the Indian Moon Impact Probe.

Manned exploration of the Moon began in 1968 with the Apollo 8 mission that successfully orbited the Moon, the first time any extraterrestrial object was orbited by humans. In 1969 the Apollo 11 mission marked the first time humans set foot upon another world. Manned exploration of the Moon did not continue for long, however. The Apollo 17 mission in 1972 marked the last time humans would visit the Moon in any form and no human exploration mission is planned to reach the Moon any time in the near future.

Mars as seen by the HST



Part of a panorama taken by the Spirit rover in 2004

Mars

The exploration of Mars has been an important part of the space exploration programs of the Soviet Union (later Russia), the United States, Europe, and Japan. Dozens of robotic spacecraft, including orbiters, landers, and rovers, have been launched toward Mars since the 1960s. These missions were aimed at gathering data about current conditions and answering questions about the history of Mars. The questions raised by the scientific community are expected to not only give a better appreciation of the red planet but also yield further insight into the past, and possible future, of Earth.

The exploration of Mars has come at a considerable financial cost with roughly two-thirds of all spacecraft destined for Mars failing before completing their missions, with some failing before they even began. Such a high failure rate can be attributed to the complexity and large number of variables involved in an interplanetary journey, and has led researchers to jokingly speak of *The Great Galactic Ghoul* which subsists on a diet of Mars probes. This phenomenon is also informally known as the *Mars Curse*.

Phobos

The Russian space mission Phobos-Grunt, Scheduled to launch in 2011 , will begin exploration of the Phobos and Martian circumterrestrial orbit, and study whether the moons of Mars, or at least Phobos, could be a "trans-shipment point" for spaceships travelling to Mars.

Voyager 1 image of Jupiter

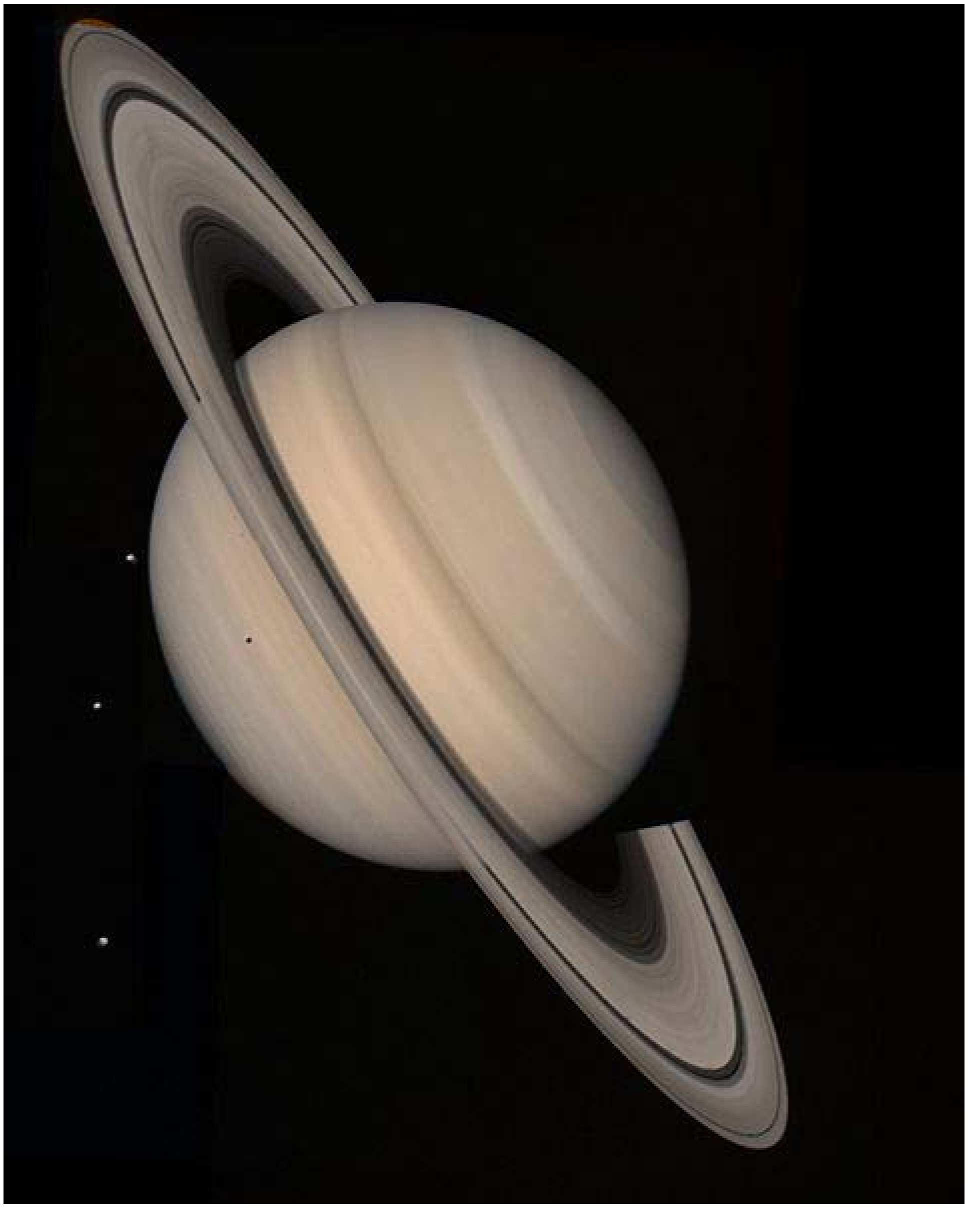
Image of Io taken by the Galileo spacecraft

Jupiter

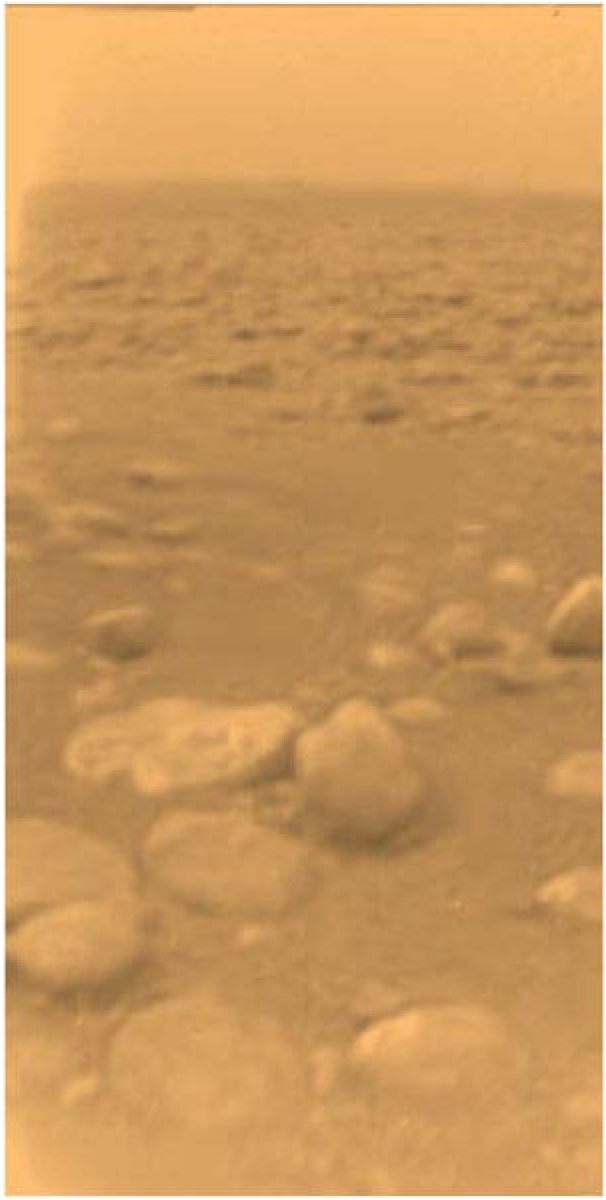
The exploration of Jupiter has consisted solely of a number of automated NASA spacecraft visiting the planet since 1973. A large majority of the missions have been "flybys", in which detailed observations are taken without the probe landing or entering orbit; the *Galileo* spacecraft is the only one to have orbited the planet. As Jupiter is believed to have only a relatively small rocky core and no real solid surface, a landing mission is nearly impossible.

Reaching Jupiter from Earth requires a delta-v of 9.2 km/s, which is comparable to the 9.7 km/s delta-v needed to reach low Earth orbit. Fortunately, gravity assists through planetary flybys can be used to reduce the energy required at launch to reach Jupiter, albeit at the cost of a significantly longer flight duration.

Jupiter has over 60 known moons, many of which have relatively little known about them.



A picture of Saturn taken by Voyager 2.



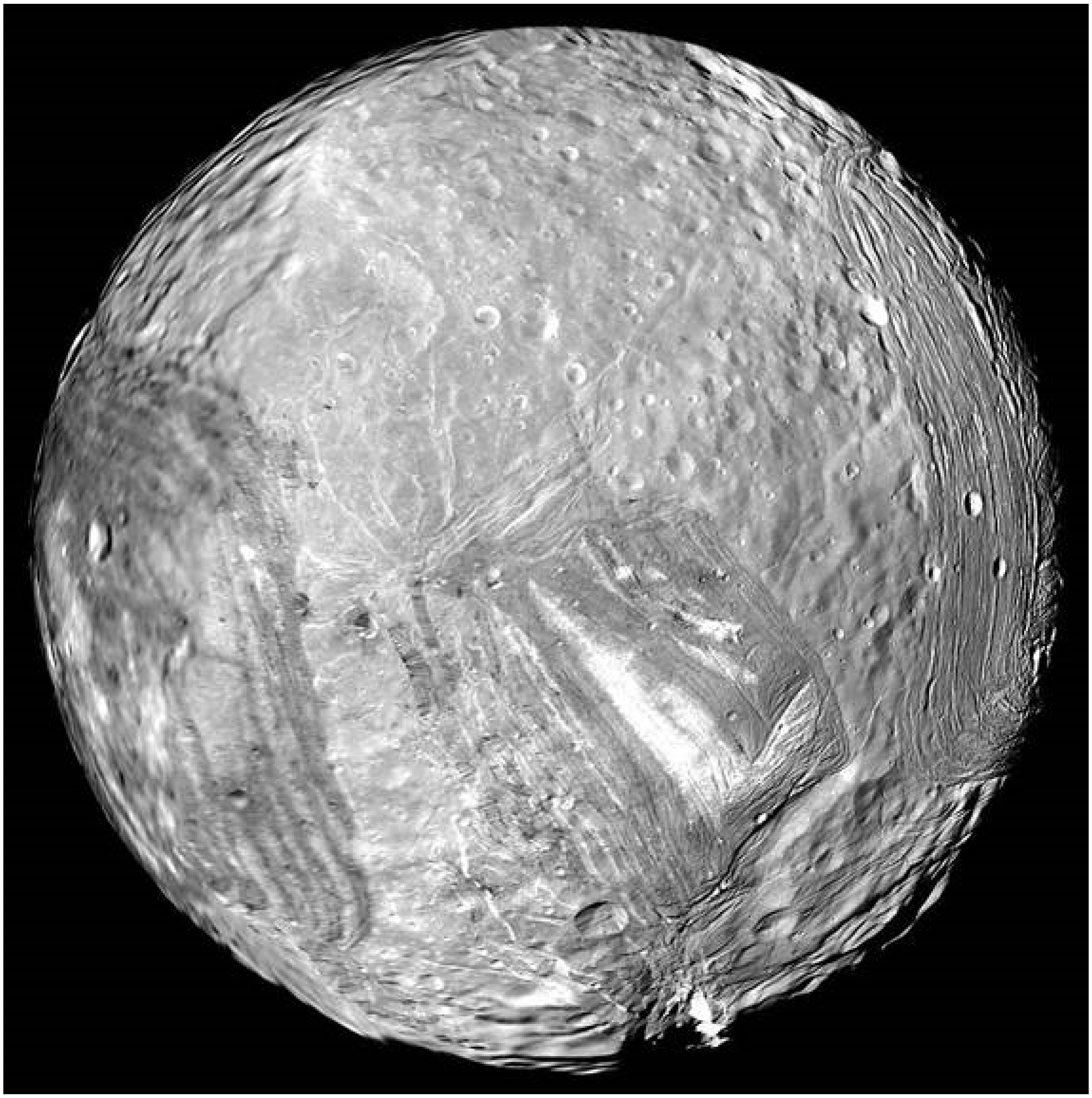
Huygens image from the surface of Titan

Saturn

Saturn has been explored only through unmanned spacecraft launched by NASA, including one mission (Cassini–Huygens) planned and executed in cooperation with other space agencies. These missions consist of flybys in 1979 by Pioneer 11, in 1980 by Voyager 1, in 1982 by Voyager 2 and an orbital mission by the Cassini spacecraft which entered orbit in 2004 and is expected to continue its mission well into 2010.

Saturn has at least 62 satellites, although the exact number is debatable since Saturn's rings are made up of vast numbers of independently orbiting objects of varying sizes. The largest of the moons is Titan. Titan holds the distinction of being the only moon in the solar system with an atmosphere denser and thicker than that of the Earth. As a result of the deployment from the Cassini spacecraft of the Huygens probe and its successful landing on Titan, Titan also holds the distinction of being the only moon (apart from Earth's own Moon) to be successfully explored with a lander.

Uranus from Voyager 2

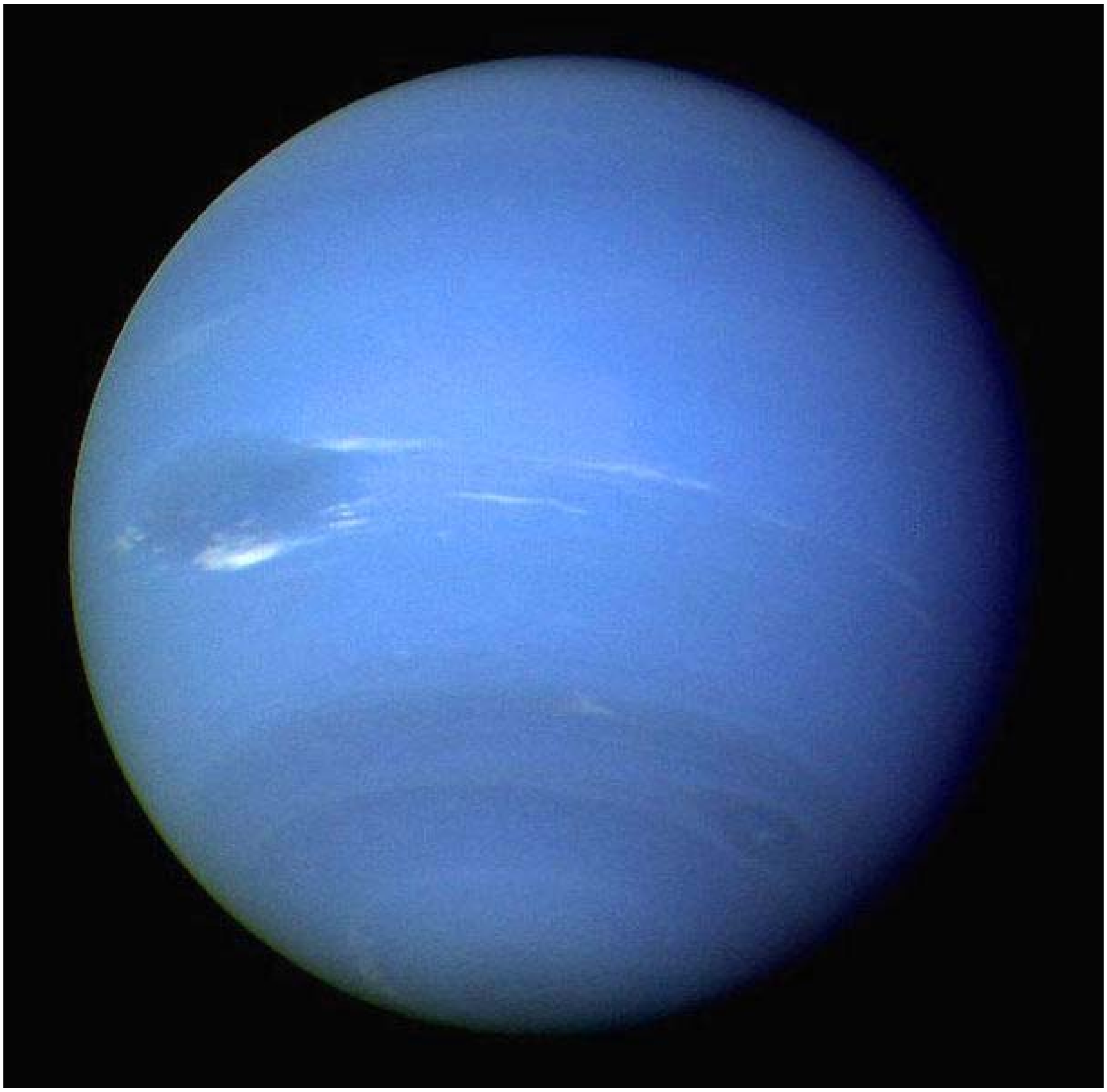


Voyager 2 image showing the tortured surface of Miranda

Uranus

The exploration of Uranus has been entirely through the Voyager 2 spacecraft, with no other visits currently planned. Given its axial tilt of 97.77°, with its polar regions exposed to sunlight or darkness for long periods, scientists were not sure what to expect at Uranus. The closest approach to Uranus occurred on January 24, 1986. *Voyager 2* studied the planet's unique atmosphere and magnetosphere. *Voyager 2* also examined its ring system and the moons of Uranus including all five of the previously known moons, while discovering an additional ten previously unknown moons.

Images of Uranus proved to have a very uniform appearance, with no evidence of the dramatic storms or atmospheric banding evident on Jupiter and Saturn. Great effort was required to even identify a few clouds in the images of the planet. The magnetosphere of Uranus, however, proved to be completely unique and proved to be profoundly affected by the planet's unusual axial tilt. In contrast to the bland appearance of Uranus itself, striking images were obtained of the moons of Uranus, including evidence that Miranda had been unusually geologically active.



Picture of Neptune taken by Voyager 2

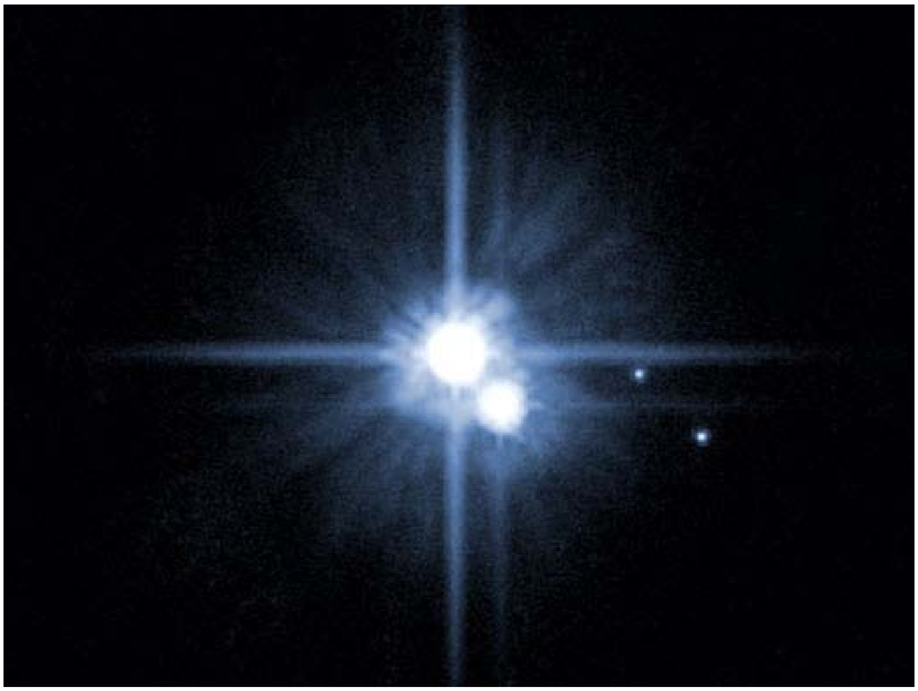
Triton as imaged by Voyager 2

Neptune

The exploration of Neptune began with the August 25, 1989 Voyager 2 flyby, the sole visit to the system as of 2009. The possibility of a Neptune Orbiter has been discussed, but no other missions have been given serious thought.

Although the extremely uniform appearance of Uranus during Voyager 2's visit in 1986 had led to expectations that Neptune would also have few visible atmospheric phenomena, Voyager 2 found that Neptune had obvious banding, visible clouds, auroras, and even a conspicuous anticyclone storm system rivaled in size only by Jupiter's small Spot. Neptune also proved to have the fastest winds of any planet in the solar system, measured as high as 2,100 km/h. Voyager 2 also examined Neptune's ring and moon system. It discovered 900 complete rings and additional partial ring "arcs" around Neptune. In addition to examining Neptune's three previously known moons, Voyager 2 also discovered five previously known moons, one of which, Proteus, proved to be the last largest moon in the system. Data from Voyager further reinforced the view that Neptune's largest moon, Triton, is a captured Kuiper belt object.

Dwarf planets



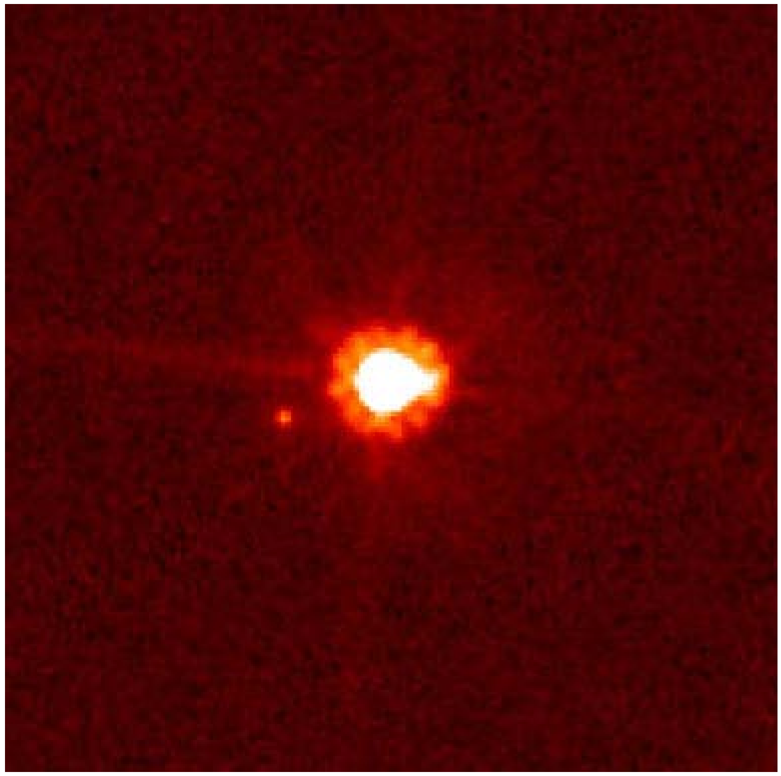
Pluto with its moons

Pluto

Pluto and Charon (1994)

The dwarf planet Pluto (considered a planet until the IAU redefinition of "planet" in October 2006) presents significant challenges for spacecraft because of its great distance from Earth (requiring high velocity for reasonable trip times) and small mass (making capture into orbit very difficult at present). *Voyager 1* could have visited Pluto, but controllers opted instead for a close flyby of Saturn's moon Titan, resulting in a trajectory incompatible with a Pluto flyby. *Voyager 2* never had a plausible trajectory for reaching Pluto.

Pluto continues to be of great interest, despite its reclassification as the lead and nearest member of a new and growing class of distant icy bodies of intermediate size, in mass between the remaining eight planets and the small rocky objects historically termed asteroids (and also the first member of the important subclass, defined by orbit and known as "Plutinos"). After an intense political battle, a mission to Pluto dubbed *New Horizons* was granted funding from the US government in 2003. *New Horizons* was launched successfully on January 19, 2006. In early 2007 the craft made use of a gravity assist from Jupiter. Its closest approach to Pluto will be on July 14, 2015; scientific observations of Pluto will begin five months prior to closest approach and will continue for at least a month after the encounter.



Eris and Dysnomia by Hubble

Ceres

Ceres is relatively ill explored at present, but in 2015 Nasa's Dawn space probe is expected to arrive at and enter into orbit around the dwarf planet.

951 Gaspra

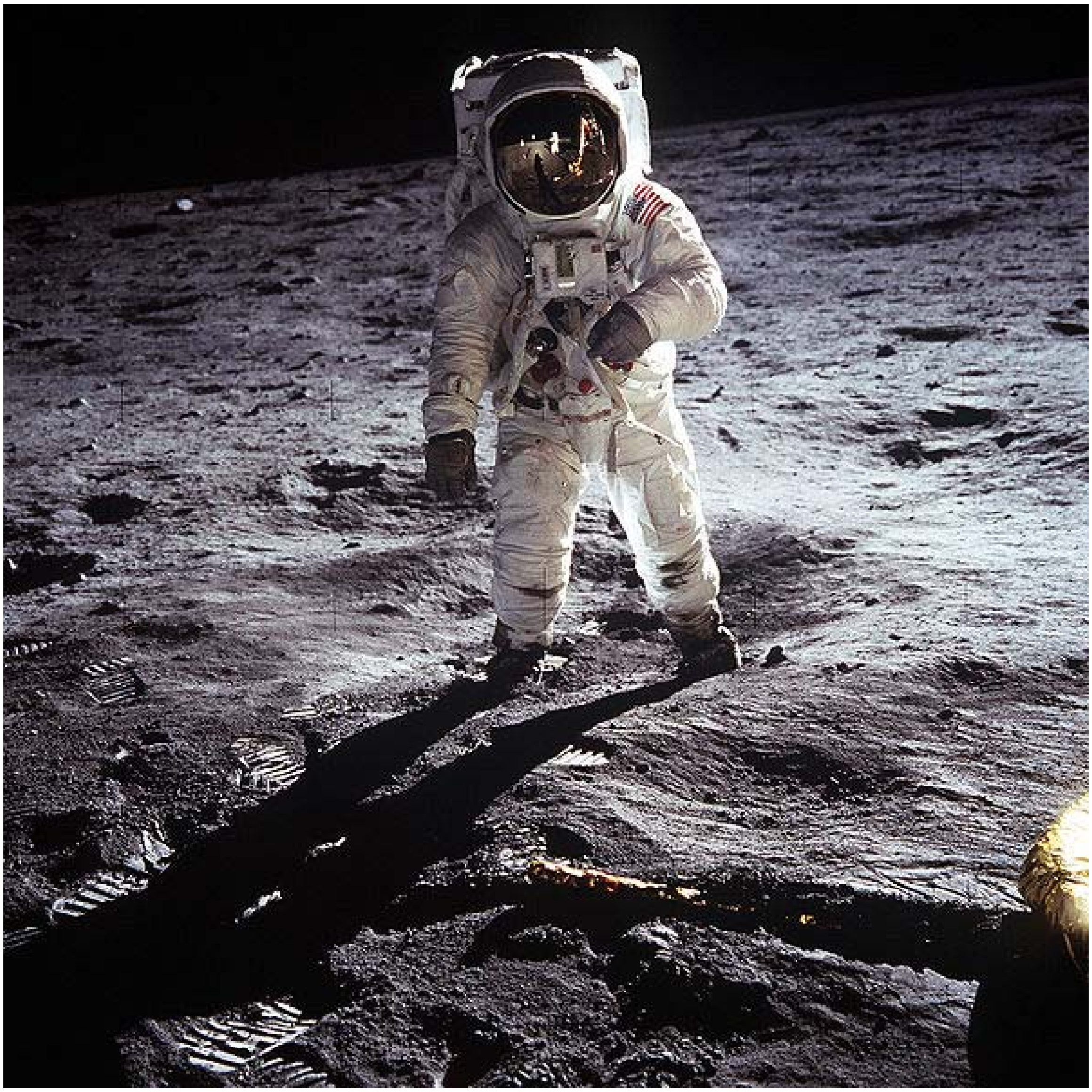
Asteroids and comets

Until the advent of space travel, objects in the asteroid belt were merely pinpricks of light in even the largest telescopes, their shapes and terrain remaining a mystery. Several asteroids have now been visited by probes, the first of which was *Galileo*, which flew past two: 951 Gaspra in 1991, followed by 243 Ida in 1993. Both of these lay near enough to Galileo's planned trajectory to Jupiter that they could be visited at acceptable cost. The first landing on an asteroid was performed by the NEAR Shoemaker probe in 2000, following an orbital survey of the object. The dwarf planet Ceres and the asteroid 4 Vesta, two of the three largest asteroids, are targets of NASA's Dawn mission, launched in 2007 September.

While many comets have been closely studied from Earth sometimes with centuries-worth of observations, only a few comets have been closely visited. A few long-period comets are currently the furthest known objects in the solar system. In 1985, the International Cometary Explorer conducted the first comet fly-by (21P/Giacobini-Zinner) before joining the Halley Armada studying the famous comet. The Deep Impact probe smashed into 9P/Tempel to learn more about its structure and composition while the Stardust mission returned samples of another comet's tail. The Philae lander will attempt to land on a comet in 2014.

Hayabusa was an unmanned spacecraft developed by the Japan Aerospace Exploration Agency to return a sample of material from a small near-Earth asteroid named 25143 Itokawa to Earth for further analysis. Hayabusa, formerly known as **MUSES-C** for Mu Space Engineering Spacecraft C, was launched on 9 May 2003 and rendezvoused with Itokawa in mid-September 2005. After arriving at Itokawa, Hayabusa studied the asteroid's shape, spin, topography, colour, composition, density, and history. In November 2005, it landed on the asteroid and attempted to collect samples but it is not clear whether the sampling mechanism worked as intended. Nevertheless, there is a high probability that some dust was trapped in the sampling chamber during contact with the asteroid, so the chamber was sealed, and the spacecraft returned to Earth on 13 June 2010.The spacecraft also carried a detachable minilander, MINERVA, but this failed to reach the surface.

Rationales



Astronaut Buzz Aldrin, had a personal Communion service when he first arrived on the surface of the Moon.

The research that is conducted by national space exploration agencies, such as NASA and Roscosmos, is one of the reasons supporters cite to justify government expenses. Economic analyses of the NASA programs often showed ongoing economic benefits (from things such as spin-offs), generating many times the revenue of the cost of the program.

Another claim is that space exploration is a necessity to mankind and that staying on our home planet will lead us to extinction. Some of the reasons are lack of natural resources, comets, nuclear war, and worldwide epidemic. Stephen Hawking, renowned British theoretical physicist, said that "I don't think the human race will survive the next thousand years, unless we spread into space. There are too many accidents that can befall life on a single planet. But I'm an optimist. We will reach out to the stars."

NASA has produced a series of Public Service Announcement videos supporting the concept of space exploration.

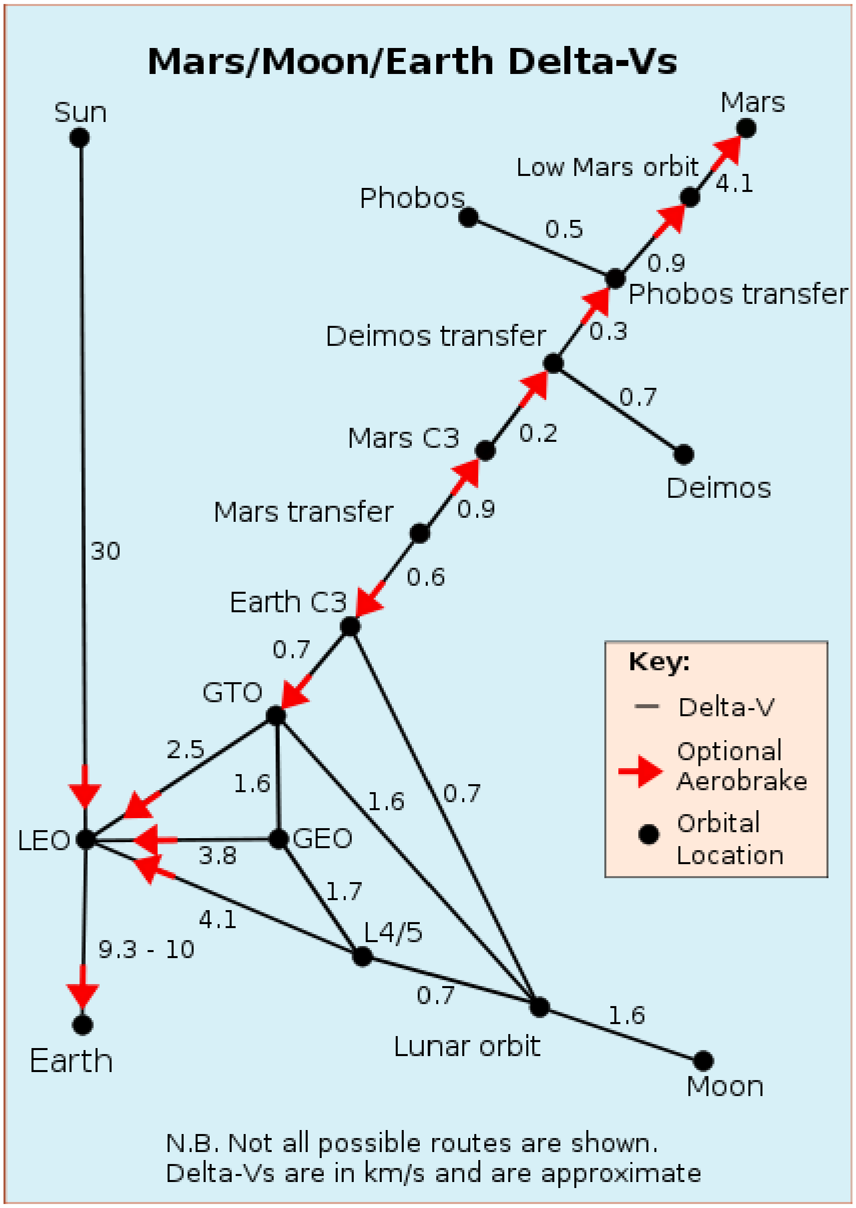
Overall, the public remains largely supportive of both manned and unmanned space exploration. According to an Associated Press Poll conducted in July 2003, 71% of U.S. citizens agreed with the statement that the space program is "a good investment", compared to 21% who did not.

Arthur C. Clarke (1950) presented a summary of motivations for the human exploration of space in his non-fiction semi-technical monograph *Interplanetary Flight*. He argued that humanity's choice is essentially between expansion off the Earth into space, versus cultural (and eventually biological) stagnation and death.

Opposition

Critics such as the late physicist and Nobel prize winner Richard Feynman have contended that human space travel (as distinguished from space exploration in general, such as robotic missions) has never achieved any major scientific breakthroughs.

Related topics



Delta-v's in km/s for various orbital maneuvers

Spaceflight

Spaceflight is the use of space technology to achieve the flight of spacecraft into and through outer space.

Spaceflight is used in space exploration, and also in commercial activities like space tourism and satellite telecommunications. Additional non-commercial uses of spaceflight include space observatories, reconnaissance satellites and other earth observation satellites.

A spaceflight typically begins with a rocket launch, which provides the initial thrust to overcome the force of gravity and propels the spacecraft from the surface of the Earth. Once in space, the motion of a spacecraft—both when unpropelled and when under propulsion—is covered by the area of study called astrodynamics. Some spacecraft remain in space indefinitely, some disintegrate during atmospheric reentry, and others reach a planetary or lunar surface for landing or impact.

Satellites

Satellites are used for a large number of purposes. Common types include military (spy) and civilian Earth observation satellites, communication satellites, navigation satellites, weather satellites, and research satellites. Space stations and human spacecraft in orbit are also satellites.

Militarization of space

Militarisation of space took place since the 1960s, and is now evolving into weaponisation of space with actual placement of weapons by space-faring nations for decisive military advantage.

While military activities have certainly taken place in space and space is an operating location for many military spacecraft (such as imaging & communications satellites) or a temporary transit medium for weapons (such as ballistic missiles), permanent placement of large-scale operational weapons in space has never been conducted.

Space colonization

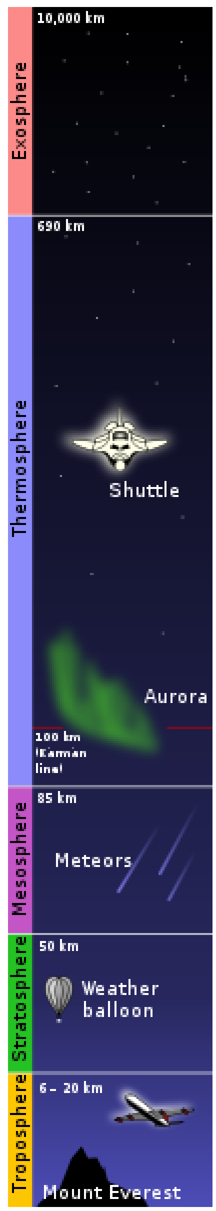
Space colonization, also called space settlement and space humanization, would be the permanent autonomous (self-sufficient) human habitation of locations outside Earth, especially of natural satellites or planets such as the Moon or Mars, using significant amounts of in-situ resource utilization.

To date, the longest human occupation of space was the space station Mir, which was continuously inhabited for almost ten years, including Valeri Polyakov's record single spaceflight of almost 438 days. Long-term stays in space reveal issues with bone and muscle loss in low gravity, immune system suppression, and radiation exposure.

Many past and current concepts for the continued exploration and colonization of space focus on a return to the Moon as a "stepping stone" to the other planets, especially Mars. At the end of 2006 NASA announced they were planning to build a permanent Moon base with continual presence by 2024.

Chapter- 2

Outer Space



The boundaries between the Earth's surface and outer space, at the Kármán line, 100 km (62 mi) and exosphere at 690 km (430 mi).

Outer space (often simply called **space**) is the void that exists beyond any celestial body including the Earth. It is not completely empty (i.e. a perfect vacuum), but contains a low density of particles, predominantly hydrogen plasma, as well as electromagnetic radiation, magnetic fields, and neutrinos. Theoretically, it also contains dark matter and dark energy.

Discovery

In 350 BC, Greek philosopher Aristotle suggested that *nature abhors a vacuum*, a principle that became known as the *horror vacui*. Based on this idea that a vacuum could not exist, it was widely held for many centuries that space could not be empty. As late as the seventeenth century, the French philosopher René Descartes argued that the entirety of space must be filled. It became known to Galileo Galilei that air had weight and so was subject to gravity. He also demonstrated that there was an established force that resisted the formation of a vacuum. However, it would remain for his pupil Evangelista Torricelli to create an apparatus that would produce a vacuum. At the time this experiment created a scientific sensation in Europe. The French mathematician Blaise Pascal reasoned that if the column of mercury was suspended by air then the column ought to be shorter at higher altitude. His brother in law, Florin Périer, repeated the experiment on the Puy-de-Dôme mountain in central France and found that the column was shorter by three inches. This decrease in pressure was further demonstrated by carrying a half-full balloon up a mountain and watching it gradually inflate, then deflate upon descent. These and other experiments were used to overthrow the principle of *horror vacui*.

Further work on the physics of the vacuum was performed by Otto von Guericke. He correctly noted that the atmosphere of the Earth surrounds the planet like a shell, with the density gradually declining with altitude. He concluded that there must be a vacuum between the Earth and the Moon.

Early speculations as to the infinite dimension of space was performed in the sixteenth century by the Italian philosopher Giordano Bruno. He extended the Copernican heliocentric cosmology to the concept of an infinite universe that is filled with a substance he called aether, which did not cause resistance to the motions of heavenly bodies. English philosopher William Gilbert arrived at a similar conclusion, arguing that the stars are visible to us only because they are surrounded by a thin aether or a void. This concept of an aether originated with ancient Greek philosophers, including Aristotle, who conceived of it as the medium through which the heavenly bodies moved.

The concept of a universe filled with a luminiferous aether remained in vogue among some scientists up until the twentieth century. This form of aether was viewed as the medium through which light could propagate. In 1887, the Michelson-Morley experiment was carried out as an attempt to detect the Earth's motion through this medium by looking for changes in the speed of light based on the direction of the planet's motion. However, the null result indicated something was wrong with the concept. Since then the idea of the luminiferous aether had essentially been abandoned, to be replaced by Albert Einstein's theory of special relativity. The latter held that the speed of light is a constant in a vacuum, regardless of the observer's motion or frame of reference.

The first professional astronomer to support the concept of an infinite universe was the Englishman Thomas Digges in 1576. However, the true scale of the universe remained unknown until the first successful measurement of the distance to a nearby star was performed in 1838 by the German astronomer Friedrich Bessel. He showed that the star 61 Cygni had a parallax of just 0.31 arcseconds (compared to the modern value of 0.287″). This corresponded to a distance of over 10 light years. The distance scale to the Andromeda galaxy was determined in 1923 by American astronomer Edwin Hubble when he measured the brightness of cepheid variables within that galaxy. This established that the Andromeda galaxy, and by extension all galaxies, lay well outside the Milky Way.

The modern concept of outer space is based upon the Big Bang cosmology, which was first proposed in 1931 by the Belgian physicist Georges Lemaître. This theory holds that the observable universe originated from a very compact form that has since undergone continuous expansion. Matter that remained following the initial expansion has since undergone gravitational collapse to create stars, galaxies and other astronomical objects, leaving behind a deep vacuum that forms what is now called outer space.

The term *outer space* was first recorded by the English poet Lady Emmeline Stuart-Wortley in her poem "The Maiden of Moscow" in 1842, and later popularized in the writings of HG Wells in 1901. The shorter term *space* is actually older, first used to mean the region beyond Earth's sky in John Milton's *Paradise Lost* in 1667.

Environment

Outer space is the closest natural approximation of a perfect vacuum. It has effectively no friction, allowing stars, planets and moons to move freely along ideal gravitational trajectories. However, even in the deep vacuum of intergalactic space there are still a few hydrogen atoms per cubic meter. By comparison, the air we breathe contains about 10^{25} molecules per cubic meter. The sparse density of matter in outer space means that electromagnetic radiation can travel great distances without being scattered; the mean free path for a photon in intergalactic space is about 10^{23} km, or 10 billion light years. The deep vacuum of space could make it an attractive environment for certain industrial processes, for instance those that require ultraclean surfaces.

Stars, planets, asteroids and moons keep their atmospheres by gravitational attraction, and as such, atmospheres have no clearly delineated boundary: the density of atmospheric gas simply decreases with distance from the object. The Earth's atmospheric pressure drops to about 1 Pa at 100 kilometres (62 mi) of altitude. This is known as the Kármán line, a common definition of the boundary with outer space. Beyond this line, isotropic gas pressure rapidly becomes insignificant when compared to radiation pressure from the Sun and the dynamic pressure of the solar wind, so the definition of pressure becomes difficult to interpret. The thermosphere in this range has large gradients of pressure, temperature and composition, and varies greatly due to space weather. Astrophysicists prefer to use number density to describe these environments, in units of particles per cubic centimeter.

Temperature

All of the observable Universe is filled with photons that were created during the Big Bang, which is known as the cosmic microwave background radiation (CMB). There is quite likely a correspondingly large number of neutrinos called the cosmic neutrino background. The current black body temperature of this photon radiation is about 3 K (−270 °C; −454 °F). Some regions of outer space can contain highly energetic particles that have a much higher temperature than the CMB.

Effect on human bodies

Contrary to popular belief, a person suddenly exposed to the vacuum would not explode, freeze to death or die from boiling blood. Air would immediately leave the lungs due to the enormous pressure gradient. Any oxygen dissolved in the blood would empty into the lungs to try to equalize the partial pressure gradient. Once the deoxygenated blood arrived at the brain, death would quickly follow.

Humans and animals exposed to vacuum will lose consciousness after a few seconds and die of hypoxia within minutes. Blood and other body fluids do boil when their pressure drops below 6.3 kPa, the vapor pressure of water at body temperature. This condition is called ebullism. The steam may bloat the body to twice its normal size and slow circulation, but tissues are elastic and porous enough to prevent rupture. Ebullism is slowed by the pressure containment of blood vessels, so some blood remains liquid. Swelling and ebullism can be reduced by containment in a flight suit. Shuttle astronauts wear a fitted elastic garment called the Crew Altitude Protection Suit (CAPS) which prevents ebullism at pressures as low as 2 kPa. Water vapor would also rapidly evaporate off from exposed areas such as the lungs, cornea of the eye and mouth, cooling the body. Rapid evaporative cooling of the skin will create frost, particularly in the mouth, but this is not a significant hazard. Space may be cold, but it's mostly vacuum and transfers heat ineffectively; as a result the main temperature regulation concern for space suits is how to get rid of naturally generated body heat.

Cold or oxygen-rich atmospheres can sustain life at pressures much lower than atmospheric, as long as the density of oxygen is similar to that of standard sea-level atmosphere. The colder air temperatures found at altitudes of up to 3 kilometres (1.9 mi) generally compensate for the lower pressures there. Above this altitude, oxygen enrichment is necessary to prevent altitude sickness, and spacesuits are necessary to prevent ebullism above 19 kilometres (12 mi). Most spacesuits use only 20 kPa of pure oxygen, just enough to sustain full consciousness. This pressure is high enough to prevent ebullism, but simple evaporation of blood can still cause decompression sickness and gas embolisms if not managed.

Rapid decompression can be much more dangerous than vacuum exposure itself. Even if the victim does not hold his breath, venting through the windpipe may be too slow to prevent the fatal rupture of the delicate alveoli of the lungs. Eardrums and sinuses may be ruptured by rapid decompression, soft tissues may bruise and seep blood, and the stress of shock will accelerate oxygen consumption leading to hypoxia. Injuries caused by rapid decompression are called barotrauma. A pressure drop as small as 13 kPa, which produces no symptoms if it is gradual, may be fatal if it occurs suddenly.

Boundary

There is no clear boundary between Earth's atmosphere and space, as the density of the atmosphere gradually decreases as the altitude increases. There are several designated scientific boundaries, namely:

- The Fédération Aéronautique Internationale has established the Kármán line at an altitude of 100 kilometres (62 mi) as a working definition for the boundary between aeronautics and astronautics. This is used because above an altitude of roughly 100 km, as Theodore von Kármán calculated, a vehicle would have to travel faster than orbital velocity in order to derive sufficient aerodynamic lift from the atmosphere to support itself.
- The United States designates people who travel above an altitude of 50 miles (80 km) as astronauts.
- NASA's mission control uses 76 miles (122 km) as their re-entry altitude, which roughly marks the boundary where atmospheric drag becomes noticeable (depending on the ballistic coefficient of the vehicle), thus leading shuttles to switch from steering with thrusters to maneuvering with air surfaces.

In 2009, scientists at the University of Calgary reported detailed measurements with an instrument called the Supra-Thermal Ion Imager (an instrument that measures the direction and speed of ions), which allowed them to determine that space begins 118 kilometres (73 mi) above Earth. The boundary represents the midpoint of a gradual transition over tens of kilometers from the relatively gentle winds of the Earth's atmosphere to the more violent flows of charged particles in space, which can reach speeds well over 600 miles per hour (1,000 km/h).

This was only the second time that direct measurements of charged particle flows have been conducted at this region, which is too high for balloons and too low for satellites. It was however the first study to include all the relevant elements for this kind of determination – for example, the upper atmospheric winds.

The instrument was carried by the JOULE-II rocket on January 19, 2007, and traveled to an altitude of about 124 miles (200 km). From there it collected data while it was moving through the "edge of space".

Legal status

The Outer Space Treaty provides the basic framework for international space law. This treaty covers the legal use of outer space by nation states, and includes in its definition of *outer space* the Moon and other celestial bodies. The treaty states that outer space is free for all nation states to explore and is not subject to claims of national sovereignty. It also prohibits the deployment of nuclear weapons in outer space. The treaty was passed by the United Nations General Assembly in 1963 and signed in 1967 by the USSR, the United States of America and the United Kingdom. As of January 1, 2008 the treaty has been ratified by 98 states and signed by an additional 27 states.

Between 1958 and 2008, outer space has been the subject of multiple resolutions by the United Nations General Assembly. Of these, more than 50 have been concerning the international co-operation in the peaceful uses of outer space and preventing an arms race in space. Four additional space law treaties have been negotiated and drafted by the UN's Committee on the Peaceful Uses of Outer Space. The 1979 Moon Treaty turned the jurisdiction of all heavenly bodies (including the orbits around such bodies) over to the international community. However, this treaty has not been ratified by any nation that currently practices manned spaceflight.

Space versus orbit

To perform an orbit, a spacecraft must travel faster than a sub-orbital spaceflight. A spacecraft has not entered orbit until it is traveling with a sufficiently great horizontal velocity such that the acceleration due to gravity on the spacecraft is less than or equal to the centripetal acceleration being caused by its horizontal velocity. So to enter orbit, a spacecraft must not only reach space, but must also achieve a sufficient orbital speed (angular velocity). For a low-Earth orbit, this is about 7,900 m/s (28,400 km/h; 17,700 mph); by contrast, the fastest airplane speed ever achieved (excluding speeds achieved by deorbiting spacecraft) was 2,200 m/s (7,900 km/h; 4,900 mph) in 1967 by the North American X-15.

Konstantin Tsiolkovsky was the first person to realize that, given the energy available from any available chemical fuel, a several-stage rocket would be required. The escape velocity to pull free of Earth's gravitational field altogether and move into interplanetary space is about 11,000 m/s (39,600 km/h; 24,600 mph) The energy required to reach velocity for low Earth orbit (32 MJ/kg) is about twenty times the energy required simply to climb to the corresponding altitude (10 kJ/(km·kg)).

There is a major difference between sub-orbital and orbital spaceflights. The minimum altitude for a stable orbit around Earth (that is, one without significant atmospheric drag) begins at around 350 kilometres (220 mi) above mean sea level. A common misunderstanding about the boundary to space is that orbit occurs simply by reaching this altitude. Achieving orbital speed can theoretically occur at any altitude, although atmospheric drag precludes an orbit that is too low. At sufficient speed, an airplane would need a way to keep it from flying off into space, but at present, this speed is several times greater than anything within reasonable technology.

A common misconception is that people in orbit are outside Earth's gravity because they are "floating". They are floating because they are in "free fall": they are accelerating toward Earth, along with their spacecraft, but are simultaneously moving sideways fast enough that the "fall" away from a straight-line path merely keeps them in orbit at a constant distance above Earth's surface. Earth's gravity reaches out far past the Van Allen belt and keeps the Moon in orbit at an average distance of 384,403 kilometres (238,857 mi).

Regions

Space is not a perfect vacuum: its different regions are defined by the various atmospheres and "winds" that dominate within them, and extend to the point at which those winds give way to those beyond. Geospace extends from Earth's atmosphere to the outer reaches of Earth's magnetic field, whereupon it gives way to the solar wind of interplanetary space. Interplanetary space extends to the heliopause, whereupon the solar wind gives way to the winds of the interstellar medium. Interstellar space then continues to the edges of the galaxy, where it fades into the intergalactic void.

Geospace

Aurora australis observed by *Discovery*, on STS-39, May 1991 (orbital altitude: 260 km).

Geospace is the region of outer space near the Earth. Geospace includes the upper region of the atmosphere, as well as the ionosphere and magnetosphere. The Van Allen radiation belts also lie within the geospace. The region between Earth's atmosphere and the Moon is sometimes referred to as **cis-lunar space**. In some contexts **geospace** may refer to the entire region of outerspace from the surface of the sun to the upper atmosphere of Earth. In this extended sense geospace is closely related to heliophysics.

Although it meets the definition of outer space, the atmospheric density within the first few hundred kilometers above the Kármán line is still sufficient to produce significant drag on satellites. Most artificial satellites operate in this region called low earth orbit and must fire their engines every few days to maintain orbit. The drag here is low enough that it could theoretically be overcome by radiation pressure on solar sails, a proposed propulsion system for interplanetary travel.

Geospace is populated by electrically charged particles at very low densities, the motions of which are controlled by the Earth's magnetic field. These plasmas form a medium from which storm-like disturbances powered by the solar wind can drive electrical currents into the Earth's upper atmosphere.

During geomagnetic storms two regions of geospace, the radiation belts and the ionosphere, can become strongly disturbed. These storms increase fluxes of energetic electrons that can permanently damage satellite electronics, disrupting telecommunications and GPS technologies, and can also be a hazard to astronauts, even in low-Earth orbit. They also create aurorae seen near the magnetic poles.

Geospace contains material left over from previous manned and unmanned launches that are a potential hazard to spacecraft. Some of this debris re-enters Earth's atmosphere periodically.

The absence of air makes geospace (and the surface of the Moon) ideal locations for astronomy at all wavelengths of the electromagnetic spectrum, as evidenced by the spectacular pictures sent back by the Hubble Space Telescope, allowing light from about 13.7 billion years ago — almost to the time of the Big Bang — to be observed.

The outer boundary of geospace is the interface between the magnetosphere and the solar wind. The inner boundary is the ionosphere. Alternately, geospace is the region of space between the Earth's upper atmosphere and the outermost reaches of the Earth's magnetic field.

Interplanetary

Interplanetary space, the space around the Sun and planets of the Solar System, is the region dominated by the interplanetary medium, which extends out to the heliopause where the influence of the galactic environment starts to dominate over the magnetic field and particle flux from the Sun. Interplanetary space is defined by the solar wind, a continuous stream of charged particles emanating from the Sun that creates a very tenuous atmosphere (the heliosphere) for billions of miles into space. This wind has a particle density of 5–10 protons/cm^3 and is moving at a velocity of 350–400 km/s. The distance and strength of the heliopause varies depending on the activity level of the solar wind. The discovery since 1995 of extrasolar planets means that other stars must possess their own interplanetary media.

The volume of interplanetary space is an almost pure vacuum, with a mean free path of about one astronomical unit at the orbital distance of the Earth. However, this space is not completely empty, and is sparsely filled with cosmic rays, which include ionized atomic nuclei and various subatomic particles. There is also gas, plasma and dust, small meteors, and several dozen types of organic molecules discovered to date by microwave spectroscopy.

Interplanetary space contains the magnetic field generated by the Sun. There are also magnetospheres generated by planets such as Jupiter, Saturn, Mercury and the Earth that have their own magnetic fields. These are shaped by the influence of the solar wind into the approximation of a teardrop shape, with the long tail extending outward behind the planet. These magnetic fields can trap particles from the solar wind and other sources, creating belts of magnetic particles such as the Van Allen Belts. Planets without magnetic fields, such as Mars, but excluding Venus, have their atmospheres gradually eroded by the solar wind.

Interstellar

Interstellar space is the physical space within a galaxy not occupied by stars or their planetary systems. The interstellar medium resides—by definition—in interstellar space.

Intergalactic

Intergalactic space is the physical space between galaxies. Generally free of dust and debris, intergalactic space is very close to a total vacuum. The space between galaxy clusters, called the voids, is probably nearly empty. Some theories put the average density of the Universe as the equivalent of one hydrogen atom per cubic meter. The density of the universe, however, is clearly not uniform; it ranges from relatively high density in galaxies (including very high density in structures within galaxies, such as planets, stars, and black holes) to conditions in vast voids that have much lower density than the universe's average.

Surrounding and stretching between galaxies, there is a rarefied plasma that is thought to possess a cosmic filamentary structure and that is slightly denser than the average density in the universe. This material is called the *intergalactic medium (IGM)* and is mostly ionized hydrogen; i.e. a plasma consisting of equal numbers of electrons and protons. The IGM is thought to exist at a density of 10 to 100 times the average density of the universe (10 to 100 hydrogen atoms per cubic meter). It reaches densities as high as 1000 times the average density of the universe in rich clusters of galaxies.

The reason the IGM is thought to be mostly ionized gas is that its temperature is thought to be quite high by terrestrial standards (though some parts of it are only "warm" by astrophysical standards). As gas falls into the Intergalactic Medium from the voids, it heats up to temperatures of 10^5 K to 10^7 K, which is high enough for the bound electrons to escape from the hydrogen nuclei upon collisions. At these temperatures, it is called the Warm-Hot Intergalactic Medium (WHIM). Computer simulations indicate that on the order of half the atomic matter in the universe might exist in this warm-hot, rarefied state. When gas falls from the filamentary structures of the WHIM into the galaxy clusters at the intersections of the cosmic filaments, it can heat up even more, reaching temperatures of 10^8 K and above.

Chapter- 3

Human Spaceflight

Edward White on a spacewalk during the Gemini 4 mission

Human spaceflight is spaceflight with a human crew and possibly passengers. This makes it unlike robotic space probes or remotely-controlled satellites. Human spaceflight is sometimes called **manned spaceflight**, a term now deprecated by major space agencies in favor of its gender-neutral alternative.

The first human spaceflight was accomplished on April 12, 1961 by Soviet cosmonaut Yuri Gagarin. The only countries to have independent human spaceflight capability are Russia, United States and China. As of 2010, human spaceflights are being actively launched by the Soyuz programme conducted by the Russian Federal Space Agency, the Space Shuttle program conducted by NASA, and the Shenzhou program conducted by the China National Space Administration.

The US will lose governmental human spaceflight launch capability upon retirement of the Space Shuttle, expected in 2011. Under the Bush administration, the Constellation program included plans for canceling the Shuttle and replacing it with the capability for spaceflight beyond low Earth orbit. In the 2011 United States federal budget, the Obama administration proposed canceling Constellation. Under the new plan, NASA would rely on transportation services provided by the private sector, such as Space X's Falcon 9. The period between the retirement of the Shuttle and the initial operational capability of new systems (either Constellation or the new commercial proposals), similar to the gap between the cancellation of Apollo and the first Space Shuttle flight, is often referred to as the human spaceflight gap.

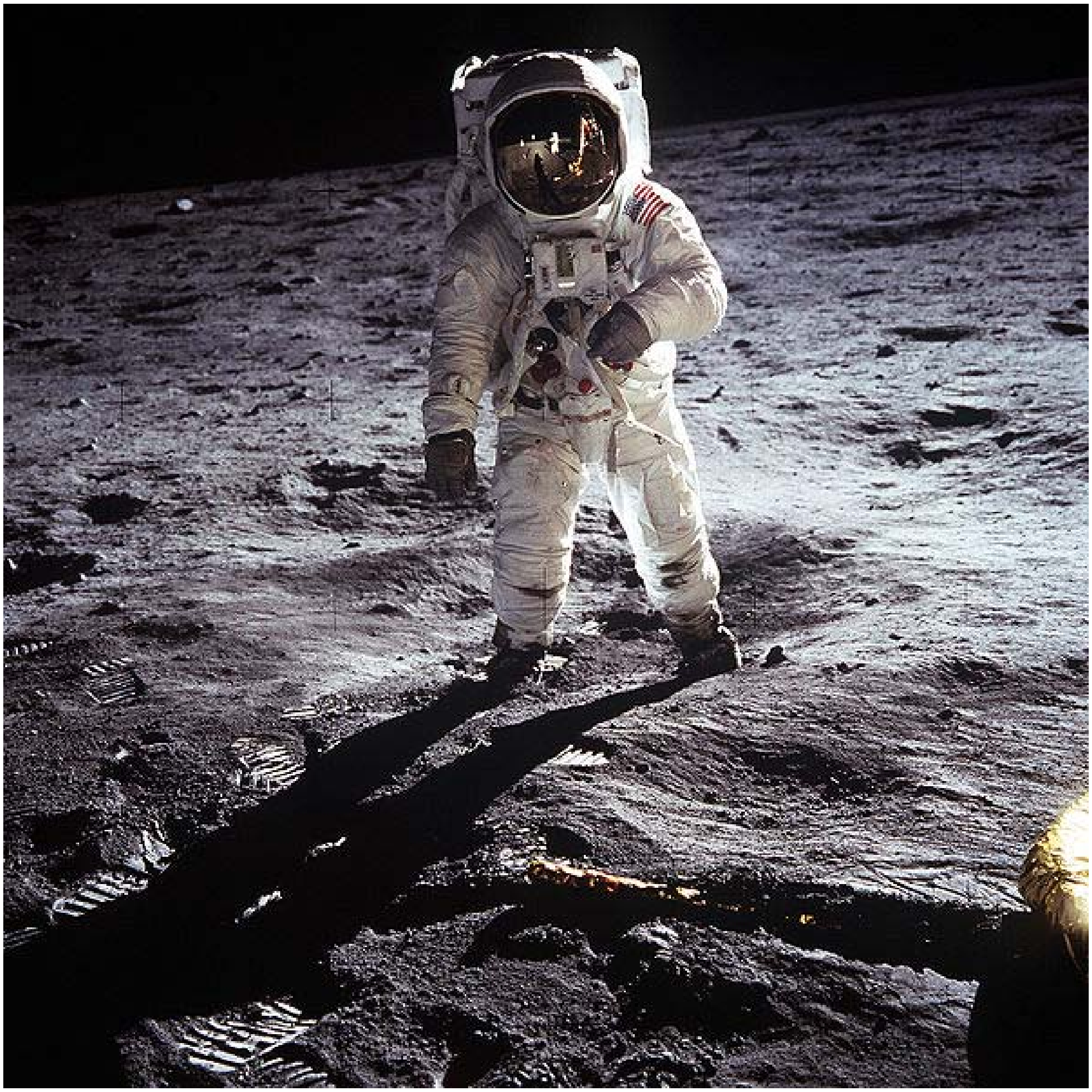
In recent years there has been a gradual movement towards more commercial forms of spaceflight. A number of non-governmental startup companies have sprung up in recent years, hoping to create a space tourism industry. For a list of such companies, and the spacecraft they are currently building. NASA has also tried to stimulate private spaceflight through programs such as Commercial Crew Development (CCDev) and Commercial Orbital Transportation Services (COTS). With its 2011 budget proposals released in early February 2010, the Obama administration is moving towards a model where commercial companies would supply NASA with transportation services of both crew and cargo to low Earth orbit. The vehicles used for these services would then serve both NASA and potential commercial customers. NASA intends to spend $6 billion in the coming years to develop commercial crew vehicles, using a model similar to that used under COTS.

History

First human spaceflights

Yuri Gagarin, the first man in space, in his space suit during the Vostok 1 mission

The first human spaceflight took place on April 12, 1961, when cosmonaut Yuri Gagarin made one orbit around the Earth aboard the Vostok 1 spacecraft, launched by the Soviet space program and designed by the rocket scientist Sergey Korolyov. Valentina Tereshkova became the first woman in space on board Vostok 6 on June 16, 1963. Both spacecraft were launched by Vostok 3KA launch vehicles. Alexei Leonov made the first spacewalk when he left the Voskhod 2 on March 8, 1965. Svetlana Savitskaya became the first woman to do so on July 25, 1984.



Buzz Aldrin on the surface of the Moon during Apollo 11

The United States became the second nation to achieve manned spaceflight, with the suborbital flight of astronaut Alan Shepard aboard *Freedom 7*, carried out as part of Project Mercury. The spacecraft was launched on May 5, 1961 on a Redstone rocket. The first U.S. orbital flight was that of John Glenn aboard *Friendship 7*, which was launched February 20, 1962 on an Atlas rocket. Since 1981 the U.S. has conducted all its human spaceflight missions with reusable Space Shuttles. Sally Ride became the first American woman in space in 1983. Eileen Collins was the first female Shuttle pilot, and with

Shuttle mission STS-93 in July 1999 she became the first woman to command a U.S. spacecraft.

The People's Republic of China became the third nation to achieve human spaceflight when Yang Liwei launched into space on a Chinese-made vehicle, the Shenzhou 5, on October 15, 2003. The flight made China the third nation to have launched its own manned spacecraft using its own launcher. Previous European (Hermes) and Japanese (HOPE-X) domestic manned programs were abandoned after years of development, as was the first Chinese attempt, the Shuguang spacecraft.

The farthest destination for a human spaceflight mission has been the Moon. The only missions to the Moon have been those conducted by NASA as part of the Apollo program. The first such mission, Apollo 8, orbited the Moon but did not land. The first Moon landing mission was Apollo 11, during which—on July 20, 1969—Neil Armstrong and Buzz Aldrin became the first people to set foot on the Moon. Six missions landed in total, numbered Apollo 11–17, excluding Apollo 13. Altogether twelve men walked on the Moon, the only humans to have been on an extraterrestrial body. The Soviet Union discontinued its program for lunar orbiting and landing of human spaceflight missions on June 24, 1974 when Valentin Glushko became General Designer of NPO Energiya.

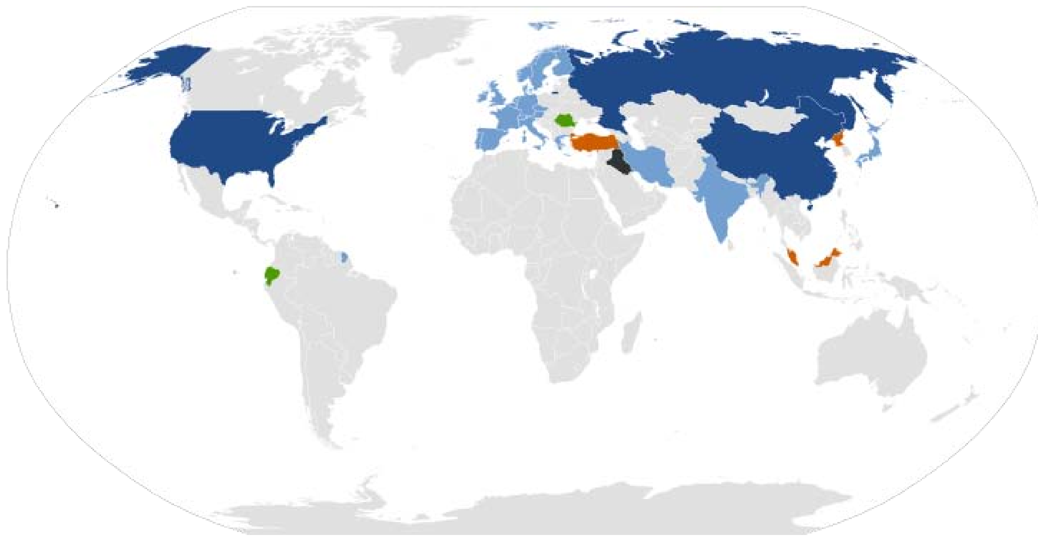
The longest single human spaceflight is that of Valeriy Polyakov, who left earth on January 8, 1994, and didn't return until March 22, 1995 (a total of 437 days 17 hr. 58 min. 16 sec. aboard). Sergei Krikalyov has spent the most time of anyone in space, 803 days, 9 hours, and 39 seconds altogether. The longest period of continuous human presence in space lasted as long as 3,644 days, eight days short of 10 years, spanning the launch of Soyuz TM-8 on September 5, 1989 to the landing of Soyuz TM-29 on August 28, 1999.

For many years beginning in 1961, only two countries, the USSR (later Russia) and United States, had their own astronauts. Citizens of other nations flew in space, beginning with the flight of Vladimir Remek, a Czech, on a Soviet spacecraft on March 2, 1978. As of 2010, citizens from 38 nations (including space tourists) have flown in space aboard Soviet, American, Russian, and Chinese spacecraft.

Space programs

As of 2010, human spaceflight missions have been conducted by the former Soviet Union/(Russia), the United States, the People's Republic of China and by the private spaceflight company Scaled Composites.

Several other countries and space agencies have announced and begun human spaceflight programs by their own technology, including India (ISRO), Ecuador (EXA), Japan (JAXA), Iran (ISA) and Malaysia (MNSA).



Countries which have human spaceflight agendas.

Currently the following spacecraft and spaceports are used for launching human spaceflights:

- Soyuz with Soyuz rocket—Baikonur Cosmodrome
- Space Shuttle—Kennedy Space Center
- International Space Station (ISS)—Assembled in orbit; crews transported by the previous two spacecraft
- Shenzhou spacecraft with Long March rocket—Jiuquan Satellite Launch Center

Historically, the following spacecraft and spaceports have also been used for human spaceflight launches:

- Vostok—Baikonur Cosmodrome
- Mercury—Cape Canaveral Air Force Station
- Voskhod—Baikonur Cosmodrome
- X-15—Edwards Air Force Base, (two internationally recognized suborbital flights in program)
- Gemini—Cape Canaveral Air Force Station
- Apollo—Kennedy Space Center (Apollo 7 at Cape Canaveral Air Force Station)
- Salyut space station—Baikonur Cosmodrome
- Almaz space station—Baikonur Cosmodrome (Almaz was a series of military space stations under cover of the civilian name Salyut)
- Skylab space station—Kennedy Space Center
- Mir space station—Baikonur Cosmodrome
- SpaceShipOne with White Knight—Mojave Spaceport

Numerous private companies attempted human spaceflight programs in an effort to win the $10 million Ansari X Prize. The first private human spaceflight took place on June

21, 2004, when SpaceShipOne conducted a suborbital flight. SpaceShipOne captured the prize on October 4, 2004, when it accomplished two consecutive flights within one week. SpaceShipTwo, launching from the carrier aircraft White Knight Two, is planned to conduct regular suborbital space tourism.

Most of the time, the only humans in space are those aboard the ISS, whose crew of six spends up to six months at a time in low Earth orbit.

NASA and ESA now use the term "human spaceflight" to refer to their programs of launching people into space. Traditionally, these endeavors have been referred to as "manned space missions."

National spacefaring attempts

Successfully executed manned programs are in **bold**.
Suborbital spaceflights are in *italics*.

Nation/Organization	Space agency	National term	First launched astronaut	Date	Spacecraft	Launcher
Soviet Union	Soviet space program (OKB-1 Design Bureau)	cosmonaut космонавт (Russian) kosmonavt	Yuri Gagarin	April 12, 1961	Vostok spacecraft	Vostok
United States	National Aeronautics and Space Administration (NASA)	astronaut	Alan Shepard	May 5, 1961	Mercury spacecraft	Redstone
China	China space program	宇航员 (Chinese) yǔhángyuán 航天员 (Chinese) hángtiānyuán	...	1973 (abandoned)	Shuguang 1	Long March 2A
China	China space program	宇航员 (Chinese) yǔhángyuán 航天员 (Chinese) hángtiānyuán	...	1981 (abandoned)	Piloted FSW	Long March 2
ESA	European Space Agency (ESA)	astronaut spationaut spationaute (French)	...	1992 (abandoned)	Hermes	Ariane V
Iraq	...	رجل فضاء (Arabic) rajul faḍā’ رائد فضاء (Arabic) rā’ib fa ḍā’ ملاح فضائي (Arabic)	...	2001 (abandoned)	...	Tammouz 2 or 3

		mallāḥ faḍā’iy				
Japan	Japan Aerospace Exploration Agency (JAXA)	宇宙飛行士 (Japanese) uchūhikōshi	...	2003 (abandoned)	HOPE-X	H-II
China	China National Space Administration (CNSA)	taikonaut 太空人 (Chinese) tàikōng rén 宇航员 (Chinese) yǔhángyuán 航天员 (Chinese) hángtiānyuán	Yang Liwei	October 15, 2003	Shenzhou spacecraft	Long March 2F
India	Indian Space Research Organisation (ISRO)	vyomanaut gaganaut aakashagaami □□□□□□□□: (Sanskrit) brahmāndagaami □□□□□□□□□□□□□□: (Sanskrit) antarikshyaatri □□□□□□□□□□□□□□□: (Sanskrit)	...	2016 (approved)	Orbital Vehicle (OV)	GSLV Mk II
Iran	Iranian Space Agency (ISA)	فضانورد (Persian) faza navard	...	2017 (planned)	ISA manned spacecraft	...
ESA	European Space Agency (ESA)	astronaut spationaut spationaute (French)	...	2020 (approved conceptually but full development not begun)	ARV phase-2 (may be changed to CSTS)	Ariane V
Japan	Japan Aerospace Exploration Agency (JAXA)	宇宙飛行士 (Japanese) uchūhikōshi	...	2025 (planned)	HTV-based spacecraft	H-IIB
Romania	Romanian Cosmonautics and Aeronautics Association (ARCASPACE)	astronaut astronaut (Romanian)	...	TBA (approved)	Stabilo-mission8	ARCASPACE air-balloon

Safety concerns

Planners of human spaceflight missions face a number of safety concerns.

Life support

The immediate needs for breathable air and drinkable water are addressed by the life support system of the spacecraft.

Medical issues

Effects of microgravity

Medical data from astronauts in low earth orbits for long periods, dating back to the 1970s, show several adverse effects of a microgravity environment: loss of bone density, decreased muscle strength and endurance, postural instability, and reductions in aerobic capacity. Over time these deconditioning effects can impair astronauts' performance or increase their risk of injury.

In a weightless environment, astronauts put almost no weight on the back muscles or leg muscles used for standing up. Those muscles then start to weaken and eventually get smaller. If there is an emergency at landing, the loss of muscles, and consequently the loss of strength can be a serious problem. Sometimes, astronauts can lose up to 25% of their muscle mass on long term flights. When they get back to ground, they will be considerably weakened and will be out of action for a while.

Astronauts experiencing weightlessness will often lose their orientation, get motion sickness, and lose their sense of direction as their bodies try to get used to a weightless environment. When they get back to Earth, or any other mass with gravity, they have to readjust to the gravity and may have problems standing up, focusing their gaze, walking and turning. Importantly, those body motor disturbances after changing from different gravities only get worse the longer the exposure to little gravity. These changes will affect operational activities including approach and landing, docking, remote manipulation, and emergencies that may happen while landing. This can be a major roadblock to mission success.

Radiation

Without proper shielding the crews of missions beyond low Earth orbit (LEO) might be at risk from high-energy protons emitted by solar flares. Lawrence Townsend of the University of Tennessee and others have studied the most powerful solar flare ever recorded. That flare was seen by the British astronomer Richard Carrington in September 1859. Radiation doses astronauts would receive from a Carrington-type flare could cause acute radiation sickness and possibly even death.

Another type of radiation, galactic cosmic rays, present further challenges to human spaceflight beyond LEO.

Radiation damage to the immune system

There is also some scientific concern that extended space flight might slow down the body's ability to protect itself against diseases. Some of the problems are a weakened immune system and the activation of dormant viruses in the body. Radiation can cause both short and long term consequences to the bone marrow stem cells which create the blood and immune systems. Because the interior of a spacecraft is so small, a weakened immune system and more active viruses in the body can lead to a fast spread of infection.

Isolation

During long missions, astronauts are isolated and confined into small spaces. Depression, cabin fever and other psychological problems may result that impact crew safety and mission success.

Astronauts may not be able to quickly return to Earth or receive medical supplies, equipment or personnel if a medical emergency occurs. The astronauts may have to rely for long periods on their limited existing resources and medical advice from the ground.

Launch safety

Reentry safety

Reliability

Fatality risk

As of 2009, 18 crew members have died during actual spaceflight missions (see table). Over 100 others have died in accidents during activity directly related to spaceflight missions or testing.

Year	#of Deaths	Mission	Known or likely cause
1967	1	Soyuz 1	
1971	3	Soyuz 11	Asphyxia
1986	7	Space Shuttle Challenger	(mission never reached space)
2003	7	Space Shuttle Columbia	Asphyxia from cabin breach, trauma from object impact, or burns from re-entry heat

Chapter- 4

Spacecraft

Soyuz 19 spacecraft for the Apollo Soyuz Test Project

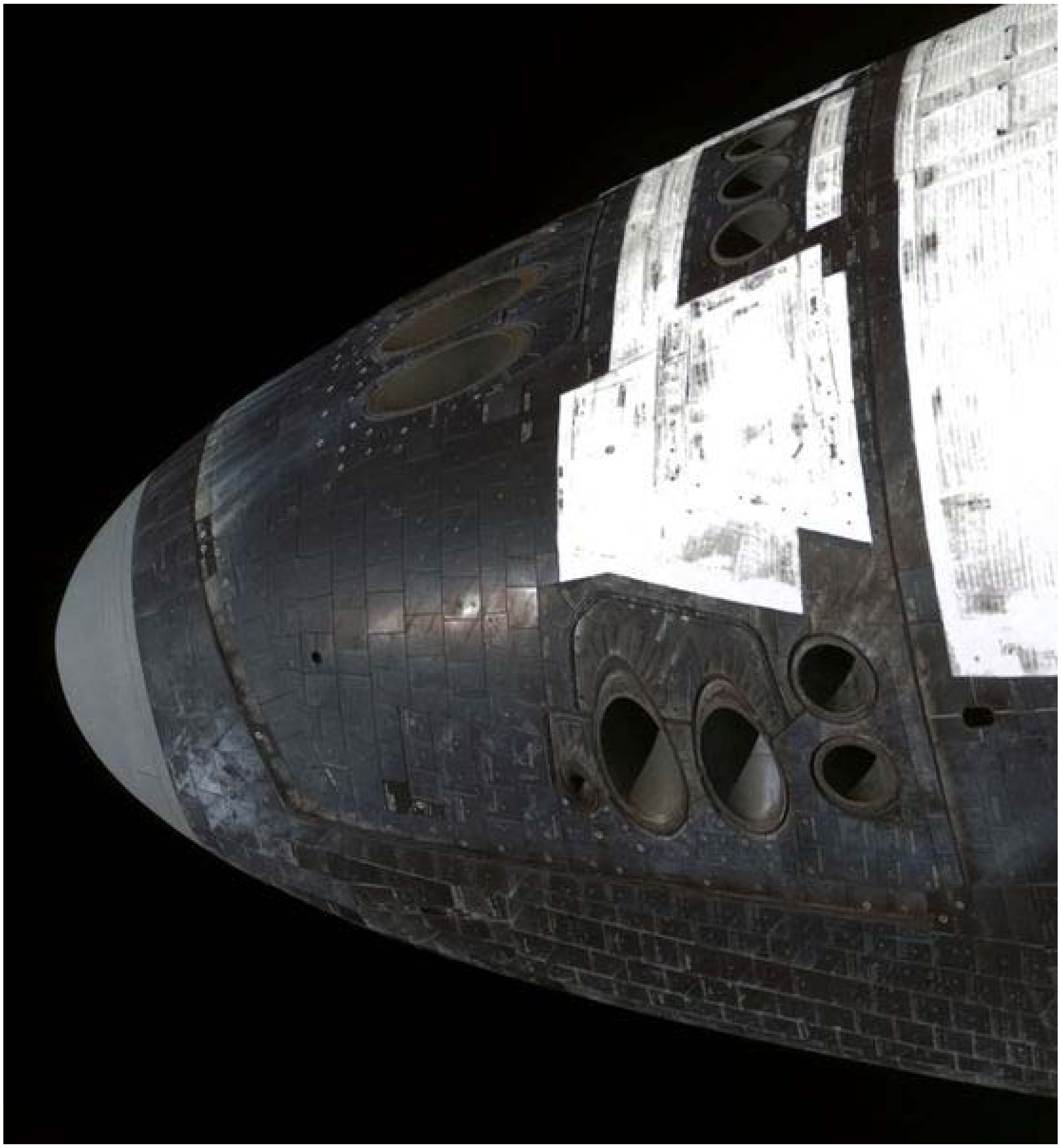
A **spacecraft** or **spaceship** is a craft or machine designed for spaceflight. Spacecraft is used for a variety of purposes, including communications, earth observation, meteorology, navigation, planetary exploration and space tourism. Spacecraft and space travel are common themes in works of science fiction.

On a sub-orbital spaceflight, a spacecraft enters space and then returns to the surface, without having gone into an orbit. For orbital spaceflights, spacecraft enter closed orbits around the Earth or around other celestial bodies. Spacecraft used for human spaceflight carry people on board as crew or passengers, while those used for robotic space missions operate either autonomously or telerobotically. Robotic spacecraft used to support scientific research are space probes. Robotic spacecraft that remain in orbit around a planetary body are artificial satellites. Only a handful of interstellar probes, such as Pioneer 10 and 11, Voyager 1 and 2, and New Horizons, are currently on trajectories that leave our Solar System.

Subsystems

A spacecraft system comprises various subsystems, dependent upon mission profile. Spacecraft subsystems comprise the spacecraft "*bus*" and may include: attitude determination and control (variously called ADAC, ADC or ACS), guidance, navigation and control (GNC or GN&C), communications (Comms), command and data handling (CDH or C&DH), power (EPS), thermal control (TCS), propulsion, and structures. Attached to the bus are typically *payloads*.

Life support
: Spacecraft intended for human spaceflight must also include a life support system for the crew.



Reaction control system thrusters on the nose of the U.S. Space Shuttle

Attitude control

A Spacecraft needs an attitude control subsystem to be correctly oriented in space and respond to external torques and forces properly. The attitude control subsystem consists of sensors and actuators, together with controlling algorithms. The attitude control subsystem permits proper pointing for the science objective, sun pointing for power to the solar arrays and earth-pointing for communications.

GNC

Guidance refers to the calculation of the commands (usually done by the CDH subsystem) needed to steer the spacecraft where it is desired to be. Navigation means determining a spacecraft's orbital elements or position. Control means adjusting the path of the spacecraft to meet mission requirements. On some missions, GNC and Attitude Control are combined into one subsystem of the spacecraft.

Command and data handling

The CDH subsystem receives commands from the communications subsystem, performs validation and decoding of the commands, and distributes the commands to the appropriate spacecraft subsystems and components. The CDH also receives housekeeping data and science data from the other spacecraft subsystems and components, and packages the data for storage on a data recorder or transmission to the ground via the communications subsystem. Other functions of the CDH include maintaining the spacecraft clock and state-of-health monitoring.

Power

Spacecraft need an electrical power generation and distribution subsystem for powering the various spacecraft subsystems. For spacecraft near the Sun, solar panels are frequently used to generate electrical power. Spacecraft designed to operate in more distant locations, for example Jupiter, might employ a Radioisotope Thermoelectric Generator (RTG) to generate electrical power. Electrical power is sent through power conditioning equipment before it passes through a power distribution unit over an electrical bus to other spacecraft components. Batteries are typically connected to the bus via a battery charge regulator, and the batteries are used to provide electrical power during periods when primary power is not available, for example when a Low Earth Orbit (LEO) spacecraft is eclipsed by the Earth.

Thermal control

Spacecraft must be engineered to withstand transit through the Earth's atmosphere and the space environment. They must operate in a vacuum with temperatures potentially ranging across hundreds of degrees Celsius as well as (if subject to reentry) in the presence of plasmas. Material requirements are such that either high melting temperature, low density materials such as beryllium and reinforced carbon-carbon or (possibly due to the lower thickness requirements despite its high density) tungsten or ablative carbon/carbon composites are used. Depending on mission profile, spacecraft may also need to operate on the surface of another planetary body. The thermal control subsystem can be passive, dependent on the selection of materials with specific radiative properties. Active thermal control makes use of electrical heaters and certain actuators such as louvers to control temperature ranges of equipments within specific ranges.

A launch vehicle, like this Proton rocket, is typically used to bring a spacecraft to orbit.

Propulsion

Spacecraft may or may not have a propulsion subsystem, depending upon whether or not the mission profile calls for propulsion. The *Swift* spacecraft is an example of a spacecraft that does not have a propulsion subsystem. Typically though, LEO spacecraft (for example *Terra (EOS AM-1)* include a propulsion subsystem for altitude adjustments (called drag make-up maneuvers) and inclination adjustment maneuvers. A propulsion system is also needed for spacecraft that perform momentum management maneuvers. Components of a conventional propulsion subsystem include fuel, tankage, valves, pipes, and thrusters. The TCS interfaces with the propulsion subsystem by monitoring the temperature of those components, and by preheating tanks and thrusters in preparation for a spacecraft maneuver.

Structures

Spacecraft must be engineered to withstand launch loads imparted by the launch vehicle, and must have a point of attachment for all the other subsystems. Depending upon mission profile, the structural subsystem might need to withstand loads imparted by entry into the atmosphere of another planetary body, and landing on the surface of another planetary body.

Payload

The payload is dependent upon the mission of the spacecraft, and is typically regarded as the part of the spacecraft "that pays the bills". Typical payloads could include scientific instruments (cameras, telescopes, or particle detectors, for example), cargo, or a human crew.

Ground segment

The ground segment, though not technically part of the spacecraft, is vital to the operation of the spacecraft. Typical components of a ground segment in use during normal operations include a mission operations facility where the flight operations team conducts the operations of the spacecraft, a data processing and storage facility, ground stations to radiate signals to and receive signals from the spacecraft, and a voice and data communications network to connect all mission elements.

Launch vehicle

The launch vehicle is used to propel the spacecraft from the Earth's surface, through the atmosphere, and into an orbit, the exact orbit being dependent upon mission configuration. The launch vehicle may be expendable or reusable.

Reusable vessels

Space Shuttle Columbia's first launch.

Columbia orbiter landing

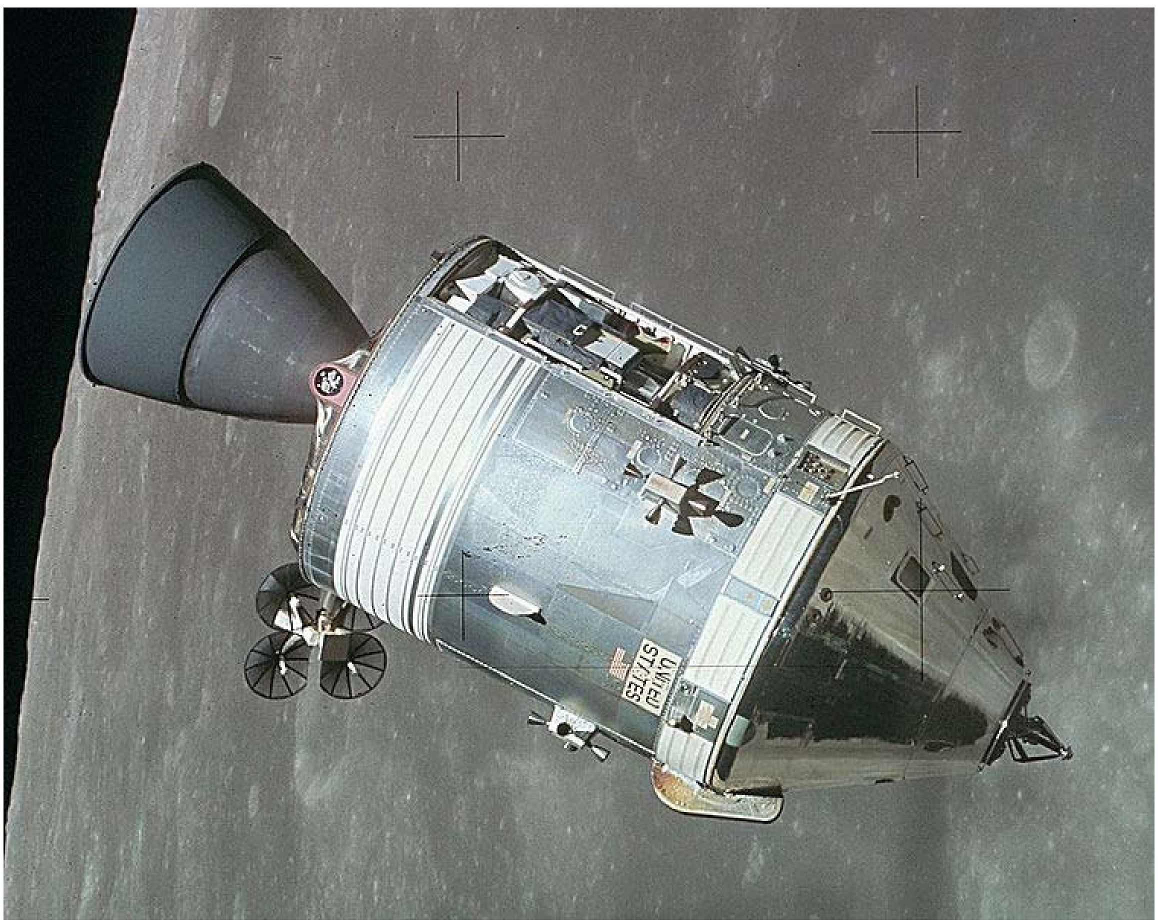
The first reusable spacecraft, the X-15, was air-launched on a suborbital trajectory on July 19, 1963. The first partially reusable orbital spacecraft, the Space Shuttle, was launched by the USA on the 20th anniversary of Yuri Gagarin's flight, on April 12, 1981. During the Shuttle era, six orbiters were built, all of which have flown in the atmosphere and five of which have flown in space. The *Enterprise* was used only for approach and landing tests, launching from the back of a Boeing 747 and gliding to deadstick landings at Edwards AFB, California. The first Space Shuttle to fly into space was the *Columbia*, followed by the *Challenger*, *Discovery*, *Atlantis*, and *Endeavour*. The *Endeavour* was built to replace the *Challenger* when it was lost in January 1986. The *Columbia* broke up during reentry in February 2003.

The first automatic partially reusable spacecraft was the Buran (Snowstorm), launched by the USSR on November 15, 1988, although it made only one flight. This spaceplane was designed for a crew and strongly resembled the U.S. Space Shuttle, although its drop-off boosters used liquid propellants and its main engines were located at the base of what would be the external tank in the American Shuttle. Lack of funding, complicated by the dissolution of the USSR, prevented any further flights of Buran. The Space Shuttle has since been modified to allow for autonomous re-entry via the addition of a control cable running from the control cabin to the mid-deck which would allow for the automated deployment of the landing gear in the event a un-crewed re-entry was required following abandonment due to damage at the ISS.

Per the Vision for Space Exploration, the Space Shuttle is due to be retired in 2010 due mainly to its old age and high cost of program reaching over a billion dollars per flight. The Shuttle's human transport role is to be replaced by the partially reusable Crew Exploration Vehicle (CEV) no later than 2014. The Shuttle's heavy cargo transport role is to be replaced by expendable rockets such as the Evolved Expendable Launch Vehicle (EELV) or a Shuttle Derived Launch Vehicle.

Scaled Composites' SpaceShipOne was a reusable suborbital spaceplane that carried pilots Mike Melvill and Brian Binnie on consecutive flights in 2004 to win the Ansari X Prize. The Spaceship Company will build its successor SpaceShipTwo. A fleet of SpaceShipTwos operated by Virgin Galactic should begin reusable private spaceflight carrying paying passengers in 2011.

Manned spacecraft



The Apollo 15 Command/Service Module as viewed from the Lunar Module on August 2, 1971.

A Russian Soyuz bringing a crew to the ISS.

Orbital

Transport

Soviet/Russian

- Vostok Spacecraft
- Voskhod Spacecraft
- Shuttle Buran
- Soyuz Spacecraft

American

- Mercury Spacecraft
- Gemini Spacecraft
- Apollo Spacecraft
- Space Shuttle

Chinese

- Shenzhou Spacecraft

Spacestation

- Salyut
- Skylab
- Mir
- International Space Station

Other

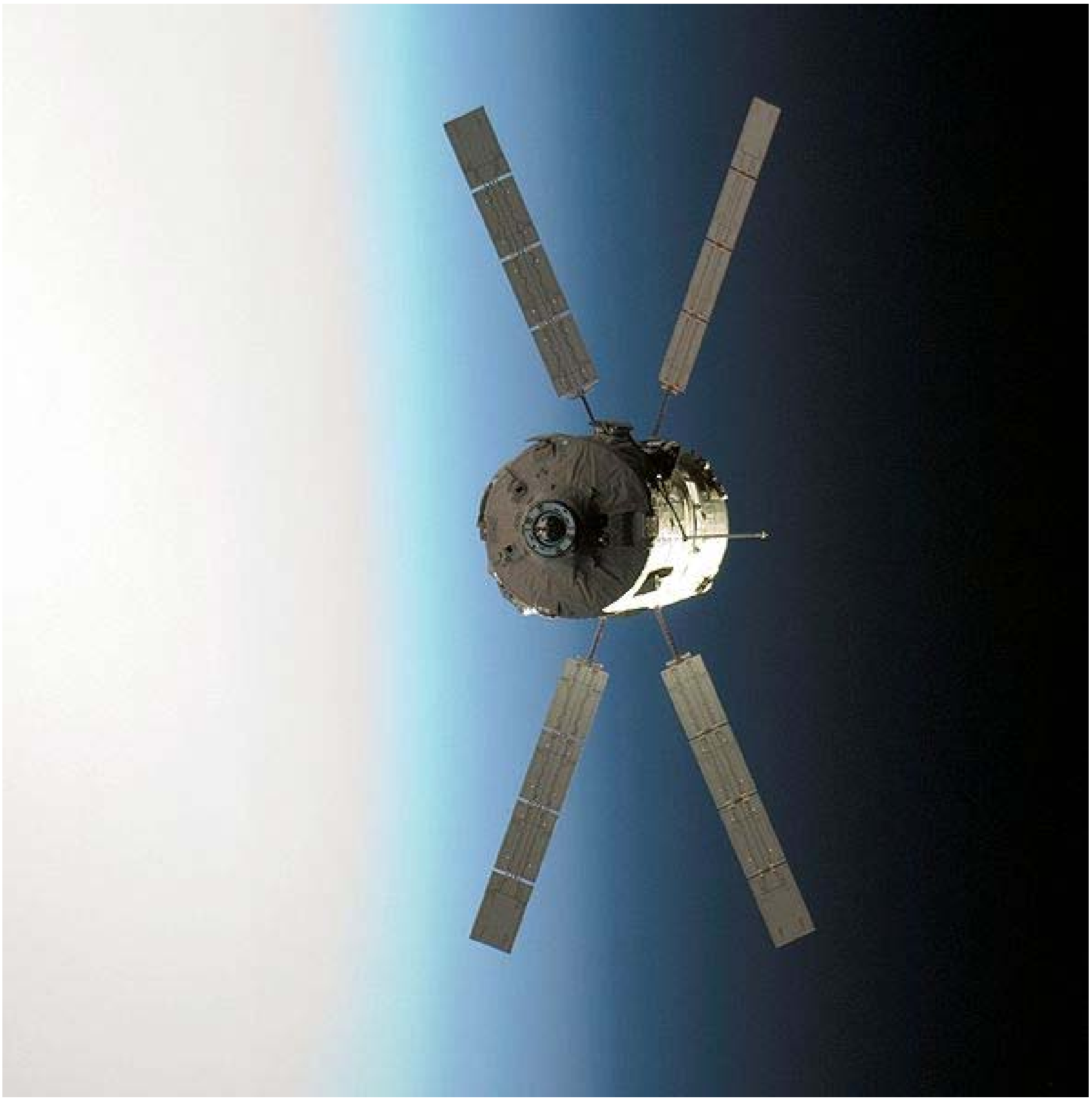
- Manned Maneuvering Unit – world's smallest manned spacecraft

Suborbital

- X-15 suborbital
- SpaceShipOne (commercial) suborbital
- SpaceShipTwo (commercial) suborbital

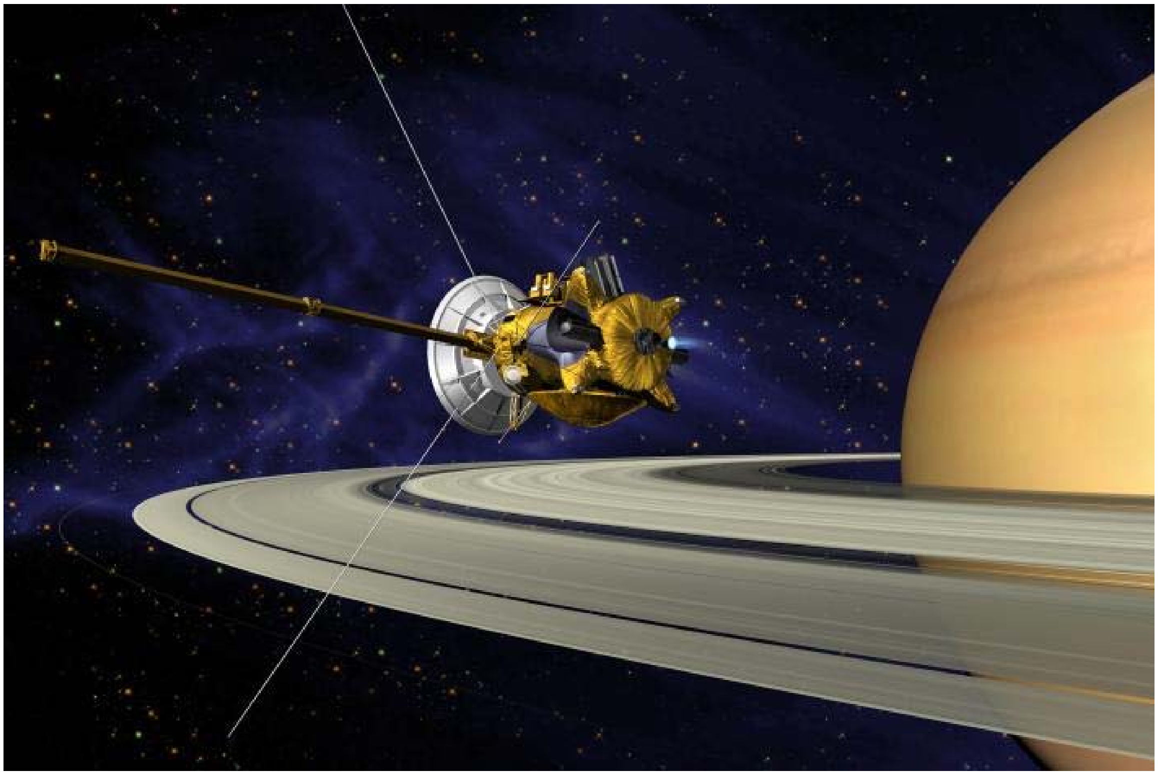
Unmanned spacecraft

The Hubble Space Telescope



The Jules Verne Automated Transfer Vehicle (ATV) approaches the International Space Station on Monday, March 31, 2008.

Soft landing capsule (NASA)



Artist's conception of Cassini-Huygens as it enters Saturn's orbit
Semi-manned or manned-spec unmanned spacecraft

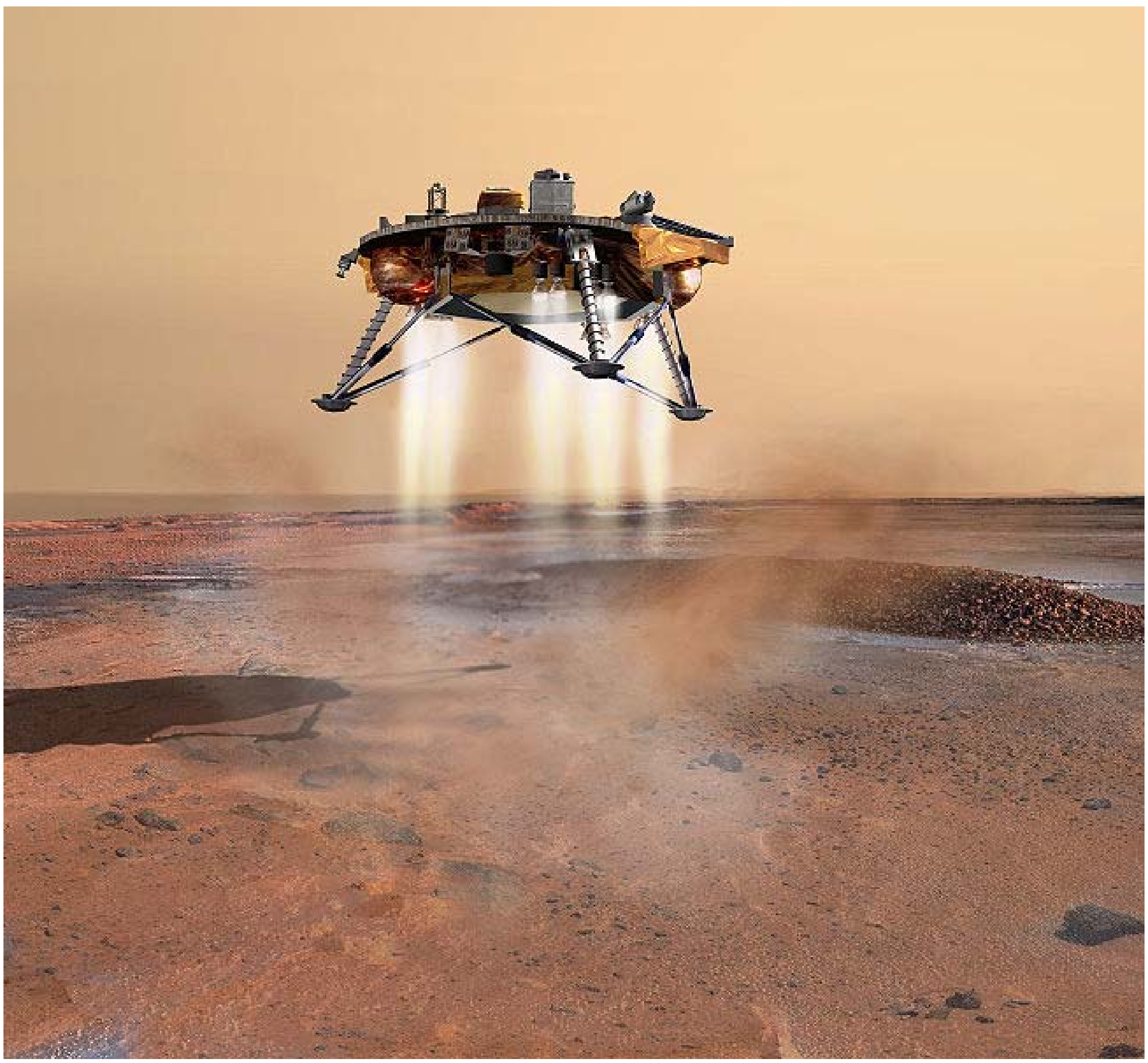
- Automated Transfer Vehicle (ATV) – unmanned European cargo spacecraft
- Buran manned-spec Soviet shuttle (one mission only)
- H-II Transfer Vehicle (HTV) – unmanned Japanese cargo spacecraft
- Progress – unmanned USSR/Russia cargo spacecraft
- TKS – manned-spec unmanned USSR cargo spacecraft

Earth Orbit

- Explorer 1 – first US satellite
- Project SCORE – first communications satellite
- SOHO
- Sputnik 1 – world's first artificial satellite
- Sputnik 2 – first animal in orbit (Laika)
- Sputnik 5 – first capsule recovered from orbit (Vostok precursor) – animals survived
- STEREO – Earth environment observation
- Syncom – first geosynchronous communications satellite
- X-37 – spaceplane
- There are more than over 2,000 spacecrafts in orbit.

Lunar

- Clementine – US Navy mission, orbited Moon, detected hydrogen at the poles
- Kaguya JPN – Lunar orbiter
- Luna 1 – first lunar flyby
- Luna 2 – first lunar impact
- Luna 3 – first images of lunar far side
- Luna 9 – first soft landing on the Moon
- Luna 10 – first lunar orbiter
- Luna 16 – first unmanned lunar sample retrieval
- Lunar Orbiter – very successful series of lunar mapping spacecraft
- Lunar Prospector – confirmed detection of hydrogen at the lunar poles
- Lunar Reconnaissance Orbiter – Identifies safe landing sites & Locates moon resources
- SMART-1 ESA – Lunar Impact
- Surveyor – first USA soft lander
- Chandrayaan 1 – first Indian Lunar mission



Artist's conception of the Phoenix spacecraft as it lands on Mars

Planetary

- Akatsuki JPN – a Venus orbiter
- Cassini-Huygens – first Saturn orbiter + Titan lander
- Galileo – first Jupiter orbiter+descent probe
- IKAROS JPN – first solar-sail spacecraft
- Mariner 4 – first Mars flyby, first close and high resulution images of Mars
- Mariner 9 – first Mars orbiter
- Mariner 10 – first Mercury flyby, first close up images
- Mars Exploration Rover – a Mars rover
- Mars Express – a Mars orbiter
- Mars Global Surveyor – a Mars orbiter
- Mars Reconnaissance Orbiter – an advanced climate, imaging, sub-surface radar, and telecommunications Mars orbiter
- MESSENGER – first Mercury orbiter (arrival 2011)
- Mars Pathfinder – a Mars lander + rover
- New Horizons – first Pluto flyby (arrival 2015)
- Pioneer 10 – first Jupiter flyby, first close up images
- Pioneer 11 – second Jupiter flyby + first Saturn flyby (first close up images of Saturn)
- Pioneer Venus – first Venus orbiter+landers
- Venera 4 – first soft landing on another planet (Venus)
- Viking 1 – first soft landing on Mars
- Voyager 2 – Jupiter flyby + Saturn flyby + first flybys/images of Neptune and Uranus

Other – deep space

- Cluster
- Deep Space 1
- Deep Impact (space mission)
- Genesis
- Hayabusa
- Near Earth Asteroid Rendezvous
- Stardust
- WMAP

Fastest spacecraft

- Helios I & II *Solar Probes* (252,792 km/h/157,078 mph)

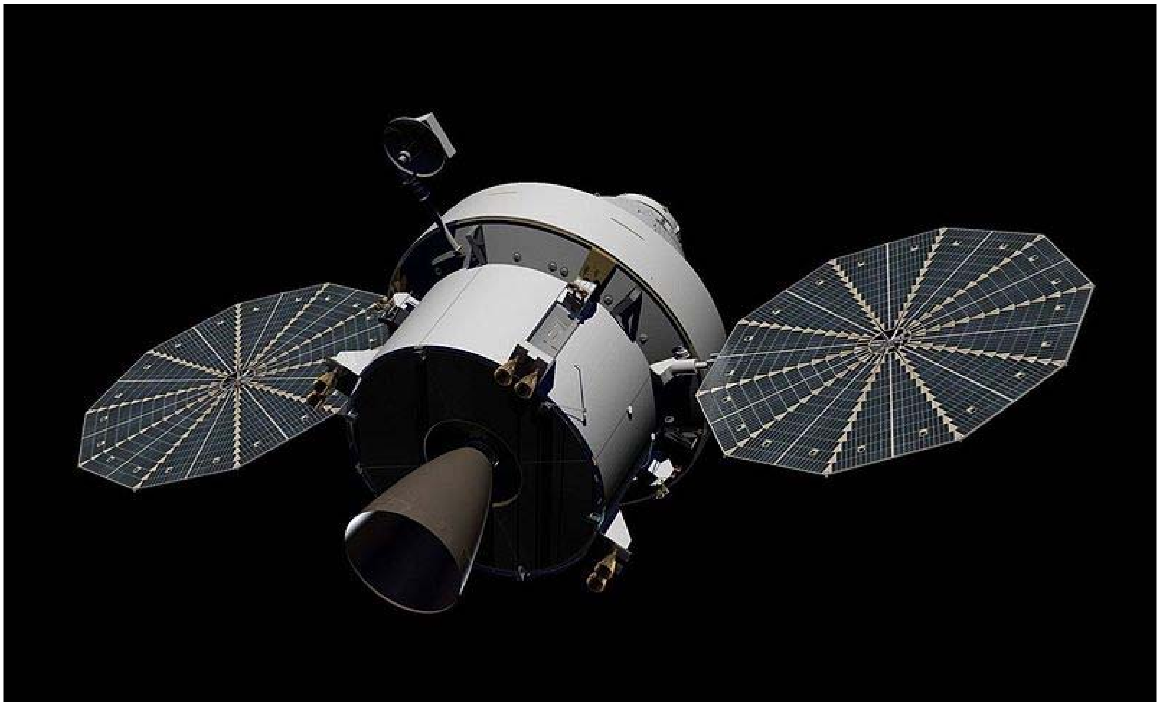
Furthest spacecraft from the Sun

- Voyager 1 at 106.3 AU as of July 2008, traveling outward at about 3.6 AU/year
- Pioneer 10 at 89.7 AU as of 2005, traveling outward at about 2.6 AU/year
- Voyager 2 at 85.49 AU as of July 2008, traveling outward at about 3.3 AU/year

Heaviest spacecraft

- NASA *STS* Space Shuttle/Orbiter (109,000 kilograms / 107 long tons; 120 short tons)

Programs under development



The Orion spacecraft

Manned

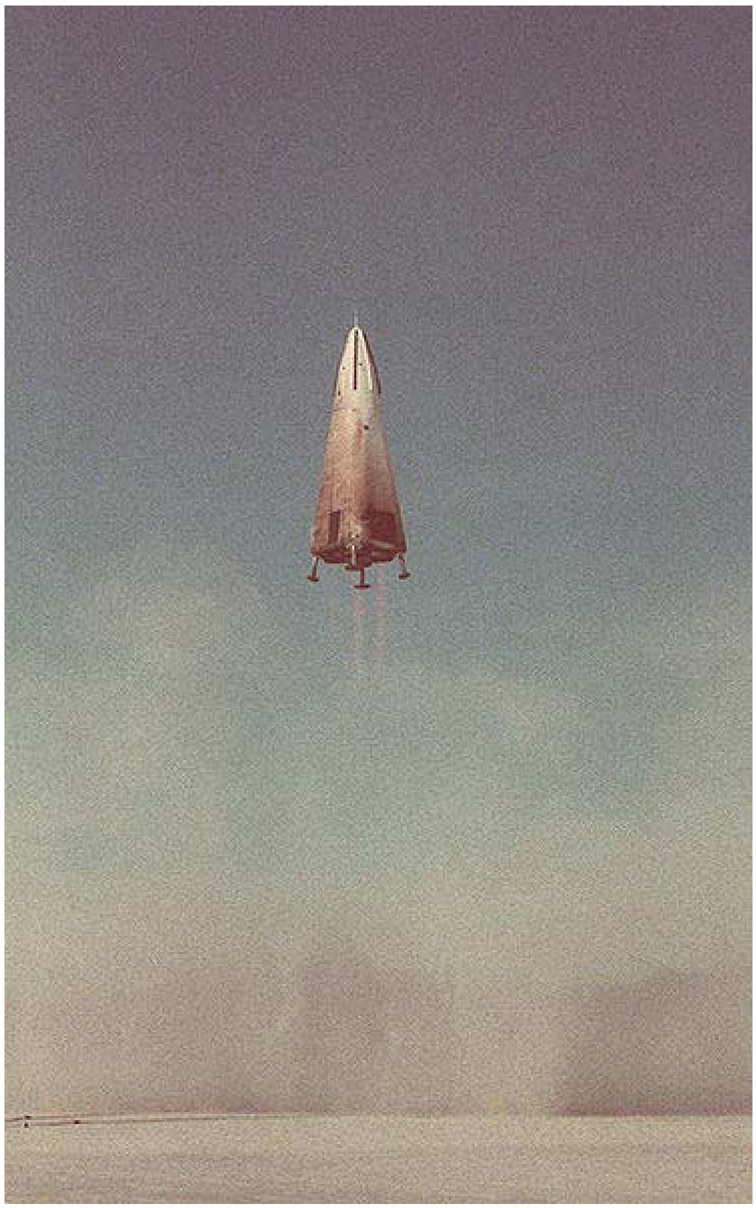
- Orion - capsule
- SpaceX Dragon - capsule
- Lynx rocketplane - suborbital
- ISRO Orbital Vehicle - capsule
- PTK NP spacecraft- capsule
- Dream Chaser - spaceplane
- Boeing CST-100 - capsule
- ESA Advanced Reentry Vehicle - capsule
- Skylon - single-stage-to-orbit spaceplane

Unmanned

- SpaceX Dragon - cargo delivery to the ISS
- Orbital Sciences Cygnus - cargo delivery to the ISS
- CNES Mars Netlander

- James Webb Space Telescope (delayed)
- ESA Darwin probe
- Mars Science Laboratory rover
- Shenzhou spacecraft Cargo
- Terrestrial Planet Finder probe
- System F6—a DARPA Fractionated Spacecraft demonstrator

Unfunded / canceled programs



The First Test Flight of the Delta Clipper-Experimental Advanced (DC-XA)
Multi-stage

- Chinese Project 921-3 Shuttle
- Kliper—Russian "Clipper"
- ESA Hermes Shuttle
- Soviet Buran Shuttle
- Soyuz Kontakt
- Teledesic
- Manned Orbiting Laboratory
- X-20
- Altair - lunar lander

SSTO

- RR/British Aerospace HOTOL
- ESA Hopper Orbiter
- McDonnell Douglas DC-X (Delta Clipper)
- Roton Rotored-Hybrid
- Lockheed-Martin VentureStar

Chapter- 5

Space Architecture

A 1990 artist rendering of Space Station Freedom, a project that eventually evolved into the International Space Station

Space architecture, in its simplest definition, is the theory and practice of designing and building inhabited environments in outer space. The architectural approach to spacecraft design addresses the total built environment, drawing from diverse disciplines including physiology, psychology, and sociology as well as technical fields. Like architecture on Earth, the attempt is to go beyond the component elements and systems and gain a broad understanding of the issues that affect design success. Much space architecture work has been in designing concepts for orbital space stations and lunar and Martian exploration ships and surface bases for the world's space agencies, chiefly the National Aeronautics and Space Administration (NASA).

The practice of involving architects in the space program grew out of the Space Race, although its origins can be seen much earlier. The need for their involvement stemmed from the push to extend space mission durations and address the needs of astronauts including but beyond minimum survival needs. Space architecture is currently represented in several institutions. The Sasakawa International Center for Space Architecture (SICSA) is an academic organization with the University of Houston that offers a Master of Science in Space Architecture. SICSA also works design contracts with corporations and space agencies. In Europe, International Space University is deeply involved in space architecture research. The International Conference on Environmental Systems meets annually to present sessions on human spaceflight and space human factors. Within the American Institute of Aeronautics and Astronautics, the Space Architecture Technical Committee has been formed. Despite the historical pattern of large government-led space projects and university-level conceptual design, the advent of space tourism threatens to shift the outlook for space architecture work.

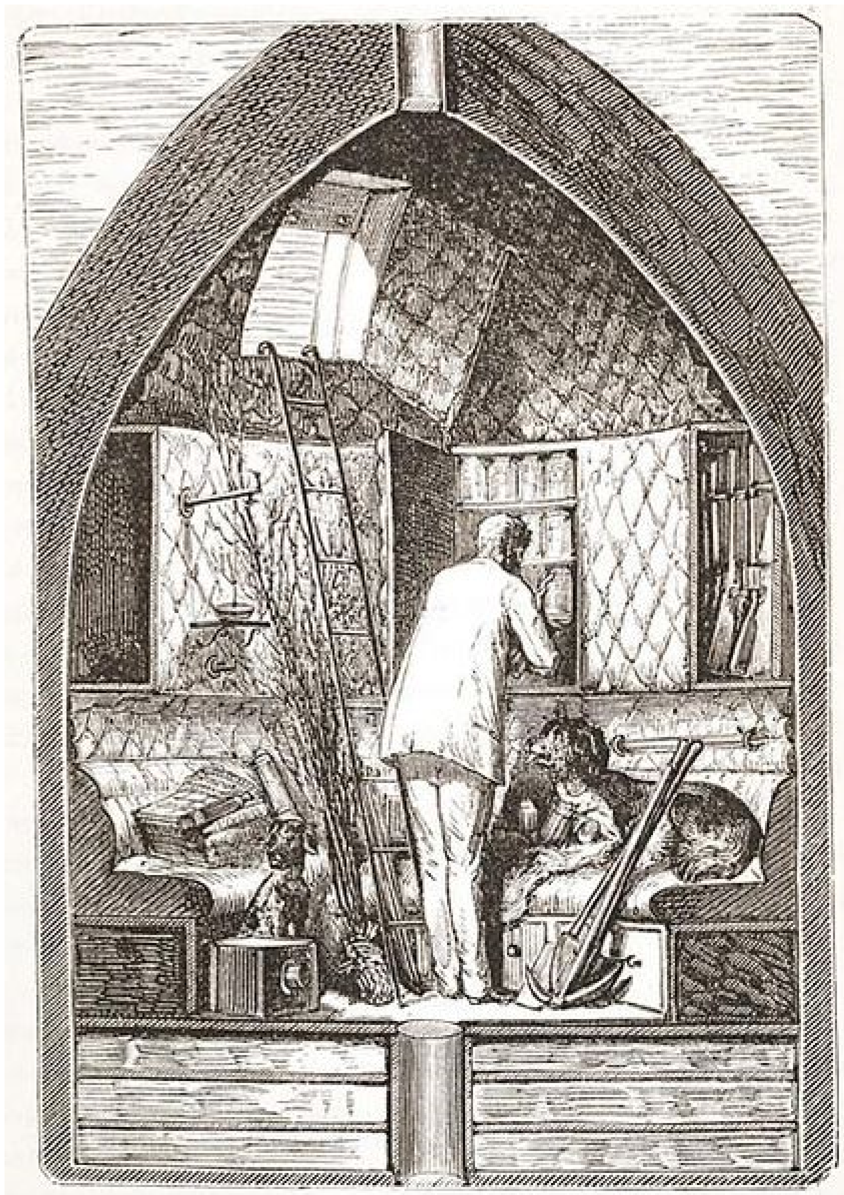
Etymology

The word *space* in space architecture is referring to the *outer space* definition, which is from English *outer* and *space*. *Outer* can be defined as "situated on or toward the outside; external; exterior" and first originated around 1350-1400 in Middle English. *Space* is "an area, extent, expanse, lapse of time," the aphetic of Old French *espace* dating to 1300. *Espace* is from Latin *spatium*, "room, area, distance, stretch of time," and is of uncertain origin. In space architecture, speaking of *outer space* usually means the region of the universe outside Earth's atmosphere, as opposed to outside the atmospheres of all terrestrial bodies. This allows the term to include such domains as the lunar and Martian surfaces.

Architecture, the concatenation of *architect* and *-ure*, dates to 1563, coming from Middle French *architecte*. This term is of Latin origin, formerly *architectus*, which came from Greek *arkhitekton*. *Arkitekton* means "master builder" and is from the combination of *arkhi-* "chief" and *tekton* "builder". The human experience is central to architecture - the primary difference between space architecture and spacecraft engineering.

There is some debate over the terminology of space architecture. Some consider the field to be a specialty within architecture that applies architectural principles to space applications. Others such as professor Ted Hall of the University of Michigan see space architects as generalists, with what is traditionally considered architecture (Earth-bound or terrestrial architecture) being a subset of a broader space architecture. Any structures that fly in space will likely remain for some time highly dependent on Earth-based infrastructure and personnel for financing, development, construction, launch, and operation. Therefore it is a matter of discussion how much of these earthly assets are to be considered part of space architecture. The technicalities of the term space architecture are open to some level of interpretation.

Origins



The interior of Verne's moon-bound projectile

Humans have looked to the cosmos in wonder since time immemorial. Ideas of people traveling to space were first published in science fiction stories, like Jules Verne's 1865 *From the Earth to the Moon*. In this story several details of the mission (crew of three, spacecraft dimensions, Florida launch site) bear striking similarity to the Apollo moon landings that took place more than 100 years later. Verne's aluminum capsule had shelves stocked with equipment needed for the journey such as a collapsing telescope, pickaxes and shovels, firearms, oxygen generators, and even trees to plant. A curved sofa was built into the floor and walls and windows near the tip of the spacecraft were accessible by ladder. The projectile was shaped like a bullet because it was gun-launched from the ground, a method infeasible for transporting man to space due to the high acceleration forces produced. It would take rocketry to get humans to the cosmos.

An illustration of von Braun's rotating space station concept

The first serious theoretical work published on space travel by means of rocket power was by Konstantin Tsiolkovsky in 1903. Besides being the father of astronautics he conceived such ideas as the space elevator (inspired by the Eiffel Tower), a rotating space station that created artificial gravity along the outer circumference, airlocks, space suits for extra-vehicular activity (EVA), closed ecosystems to provide food and oxygen, and solar power in space. Tsiolkovsky believed human occupation of space was the inevitable path for our species. In 1952 Wernher von Braun published his own inhabited space station concept in a series of magazine articles. His design was an upgrade of earlier concepts but he took the unique step in going directly to the public with it. The spinning space station would have three decks and was to function as a navigational aid, meteorological station, Earth observatory, military platform, and way point for further exploration missions to outer space. It is said that the space station depicted in *2001: A Space Odyssey* traces its design heritage to Von Braun's work. Werner von Braun went on to devise mission schemes to the moon and Mars, each time publishing his grand plans in Collier's Weekly.

The flight of Yuri Gagarin on April 12, 1961 was humanity's maiden spaceflight. While the mission was a necessary first step, Gagarin was more or less confined to a chair with a small view port from which to observe the cosmos - a far cry from the possibilities of life in space. Following space missions gradually improved living conditions and quality of life in low earth orbit. Expanding room for movement, physical exercise regimens, sanitation facilities, improved food quality, and recreational activities all accompanied longer mission durations. Architectural involvement in space was realized in 1968 when a group of architects and industrial designers led by Raymond Loewy, over objections from engineers, prevailed in convincing NASA to include an observation window in the Skylab orbital laboratory. This milestone represents the introduction of the human psychological dimension to spacecraft design. Space architecture was born.

Theory

The subject of architectural theory has much application in space architecture. Some considerations, though, will be unique to the space context.

Ideology of building

Louis Sullivan famously coined the phrase 'form ever follows function'

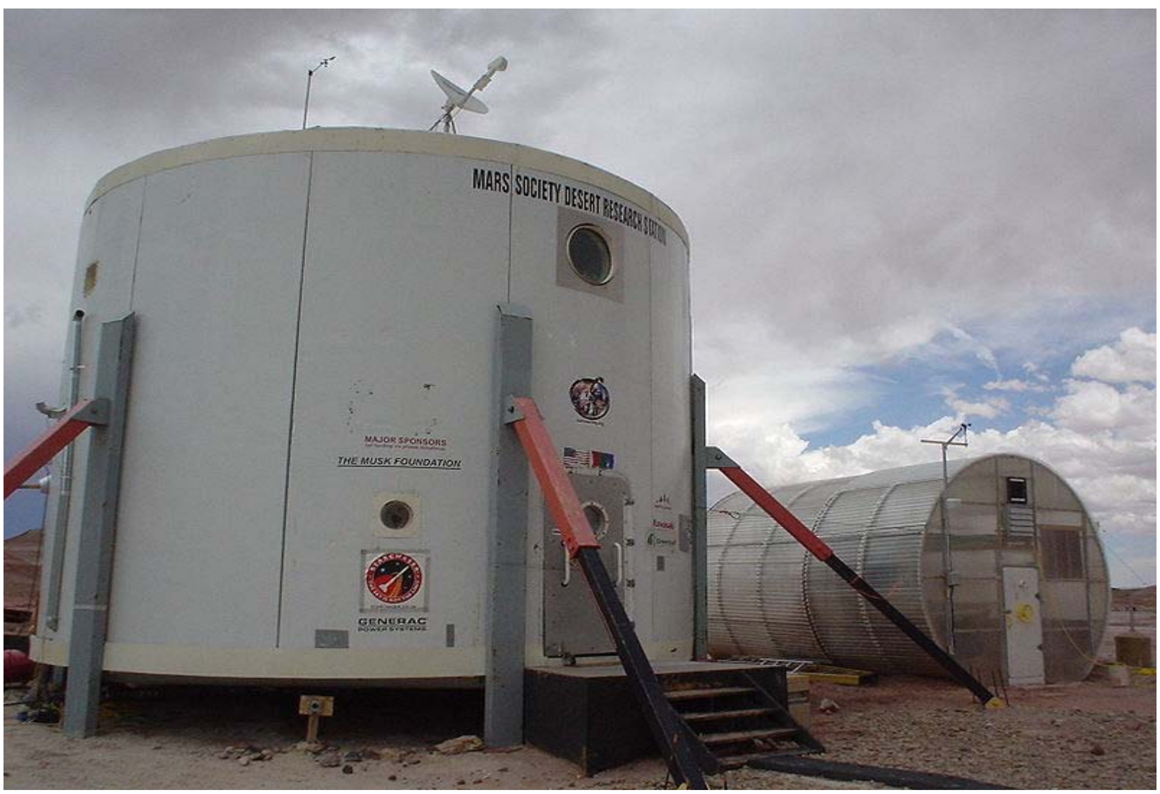
In the first century BC, the Roman architect Vitruvius said all buildings should have three things: strength, utility, and beauty. Vitruvius's work *De Architectura*, the only surviving work on the subject from classical antiquity, would have profound influence on architectural theory for thousands of years to come. Even in space architecture these are some of the first things we consider. However, the tremendous challenge of living in space has led to habitat design based largely on functional necessity with little or no applied ornament. In this sense space architecture as we know it shares the form follows function principle with modern architecture.

Some theorists link different elements of the Vitruvian triad. Walter Gropius writes:

> “ 'Beauty' is based on the perfect mastery of all the scientific, technological and formal prerequisites of the task ... The approach of Functionalism means to design the objects organically on the basis of their own contemporary postulates, without any romantic embellishment or jesting. ”

As space architecture continues to mature as a discipline, dialogue on architectural design values will open up just as it has for Earth.

Analogs



The Mars Desert Research Station is located in the Utah desert because of its relative similarity to the Martian surface

A starting point for space architecture theory is the search for extreme environments in terrestrial settings where humans have lived, and the formation of analogs between these environments and space. For example humans have lived in submarines deep in the ocean, in bunkers beneath the Earth's surface, and on Antarctica, and have safely entered burning buildings, radioactively contaminated zones, and the stratosphere with the help of technology. Aerial refueling enables Air Force One to stay airborne virtually indefinitely. Nuclear powered submarines generate oxygen using electrolysis and can stay submerged for months at a time. Many of these analogs can be very useful design references for space systems. In fact space station life support systems and astronaut survival gear for emergency landings bear striking similarity to submarine life support systems and military pilot survival kits, respectively.

Space missions, especially human ones, require extensive preparation. In addition to terrestrial analogs providing design insight, the analogous environments can serve as testbeds to further develop techonologies for space applications and train astronaut crews. The Flashline Mars Arctic Research Station is a simulated Mars base, maintained by the Mars Society, on Canada's remote Devon Island. The project aims to create conditions as similar as possible to a real Mars mission and attempts to establish ideal crew size, test equipment "in the field", and determine the best extra-vehicular activity suits and procedures. To train for EVAs in microgravity, space agencies make broad use of underwater and simulator training. The Neutral Buoyancy Laboratory, NASA's underwater training facility, contains full scale mockups of the Space Shuttle cargo bay and International Space Station modules. Technology development and astronaut training in space-analogous environments are essential to making living in space possible.

In space

Fundamental to space architecture is designing for physical and psychological wellness in space. What often is taken for granted on Earth - air, water, food, trash disposal - must be designed for in fastidious detail. Rigorous exercise regimens are required to alleviate muscular atrophy and other effects of space on the body. That space missions are (optimally) fixed in duration can lead to stress from isolation. This problem is not unlike that faced in remote research stations or military tours of duty, although non-standard gravity conditions can exacerbate feelings of unfamiliarity and homesickness. Furthermore confinement in limited and unchanging physical spaces appears to magnify interpersonal tensions in small crews and contribute to other negative psychological effects. These stresses can be mitigated by establishing regular contact with family and friends on Earth, maintaining health, incorporating recreational activities, and bringing along familiar items such as photographs and green plants. The importance of these psychological measures can be appreciated in the 1968 Soviet 'DLB Lunar Base' design:

> “ ...it was planned that the units on the moon would have a false window, showing scenes of the Earth countryside that would ”

change to correspond with the season back in Moscow. The exercise bicycle was equipped with a synchronized film projector, that allowed the cosmonaut to take a 'ride' out of Moscow with return.

Mir was a 'modular' space station. This approach allows a habitat to function before assembly is complete and its design can be changed by swapping modules.

The challenge of getting anything at all to space, due to launch constraints, has had a profound effect on the physical shapes of space architecture. All space habitats to date have used modular architecture design. Payload fairing dimensions (typically the width but also the height) of modern launch vehicles limit the size of rigid components launched into space. This approach to building large scale structures in space involves launching multiple modules separately and then manually assembling them afterward. Modular architecture results in a layout similar to a tunnel system where passage through several modules is often required to reach any particular destination. It also tends to standardize the internal diameter or width of pressurized rooms, with machinery and furniture placed along the circumference. These types of space stations and surface bases can generally only grow by adding additional modules in one or more direction. Finding adequate working and living space is often a major challenge with modular architecture. As a solution, flexible furniture (collapsible tables, curtains on rails, deployable beds) can be used to transform interiors for different functions and change the partitioning between private and group space.

Eugène Viollet-le-Duc advocated different architectural forms for different materials. This is especially important in space architecture. The mass constraints with launching push engineers to find ever lighter materials with adequate material properties. Moreover challenges unique to the orbital space environment, such as rapid thermal expansion due to abrupt changes in solar exposure, and corrosion caused by particle and atomic oxygen bombardment, require unique materials solutions. Just as the industrial age produced new materials and opened up new architectural possibilities, advances in materials technology will change the prospects of space architecture. Carbon-fiber is already being incorporated into space hardware because of its high strength-to-weight ratio. It will interesting to see whether carbon-fiber or other composite materials will be adopted for major structural components in space. The architectural principle that champions using the most appropriate materials and leaving their nature unadorned is called truth to materials.

A notable difference between the orbital context of space architecture and Earth-based architecture is that structures in orbit do not need to support their own weight. This is possible because of the microgravity condition of objects in free fall. In fact much space hardware, such as the space shuttle's robotic arm, is designed only to function in orbit and wouldn't be able to lift its own weight on the Earth's surface. Microgravity also allows an astronaut to move an object of practically any mass, albeit slowly, provided she is adequately constrained to another object. Therefore structural considerations for the orbital environment are dramatically different from those of terrestrial buildings, and the biggest challenge to holding a space station together is usually launching and assembling the components intact. Construction on extraterrestrial surfaces still needs to be designed to support its own weight, but its weight will depend on the strength of the local gravitational field.

Ground Infrastructure

Human spaceflight currently requires a great deal of supporting infrastructure on Earth. All human orbital missions to date have been government-orchestrated. The organizational body that manages space missions is typically a national space agency, NASA in the case of the United States and Roscosmos for Russia. These agencies are funded at the federal level. At NASA, flight controllers are responsible for real-time mission operations and work onsite at NASA Centers. Most engineering development work involved with space vehicles is contracted-out to private companies, who in turn may employ subcontractors of their own, while fundamental research and conceptual design is often done in academia through research funding.

Varieties

Suborbital

Structures that cross the boundary of space but do not reach orbital speeds are considered suborbital architecture. For spaceplanes, the architecture has much in common with airliner architecture, especially those of small business jets.

Virgin Galactic

A mockup of the SpaceShipTwo interior

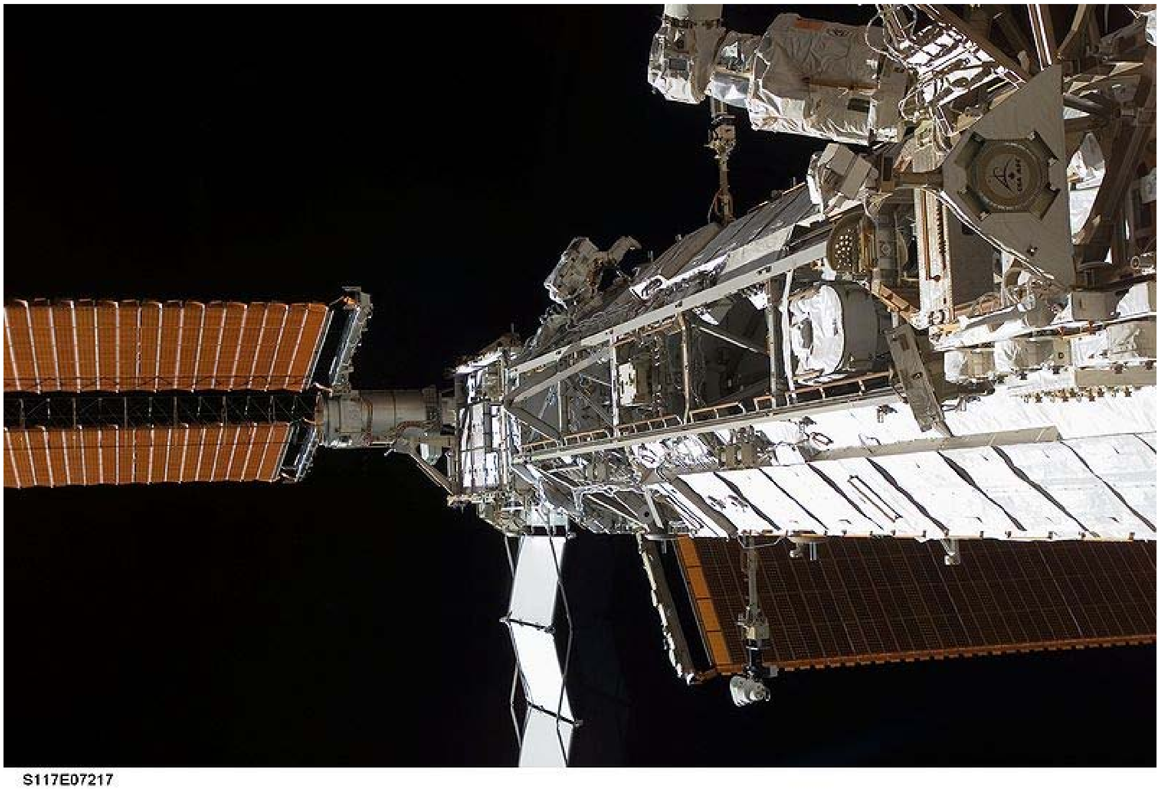
A new milestone was reached on June 21, 2004 when Mike Melvill pierced the boundary of space funded entirely by private means. The vehicle, SpaceShipOne, was developed by Scaled Composites as an experimental precursor to a privately operated fleet of spaceplanes for suborbital space tourism. The operational spaceplane model, SpaceShipTwo (SS2), will be carried to an altitude of about 15 kilometers by its B-29 Superfortress-sized carrier aircraft, WhiteKnightTwo. From there SS2 will detach and fire its rocket motor to bring the craft to its apogee of approximately 110 kilometers. Because SS2 is not designed to go into orbit around the Earth, it is an example of suborbital or aerospace architecture.

The architecture of the SpaceShipTwo vehicle is somewhat different than what is common in previous space vehicles. Unlike the cluttered interiors with protruding machinery and many obscure switches of previous vehicles, this cabin looks more like something out of science fiction than a modern spacecraft. Both SS2 and the carrier aircraft are being built from lightweight composite materials instead of metal. When the time for weightlessness has arrived on a SS2 flight, the noise and turbulent vibration of the rocket motor will give way to silence and calm. Passengers will be able to see the sky turn from blue to black and make out the curvature of the Earth. Numerous double-paned windows that encircle the cabin will offer views in nearly all directions. Cushioned seats will recline flat into the floor to maximize room for floating. An always-pressurized interior will eliminate the need for bulky space suits. The spaceflight experience offered by Virgin Galactic promises to transform access to space and indeed the very idea of an astronaut.

Orbital

Orbital architecture is the architecture of structures designed to orbit around the Earth or another astronomical object. Examples of currently-operational orbital architecture are the International Space Station and the re-entry vehicles Space Shuttle, Soyuz spacecraft, and Shenzhou spacecraft. Historical craft include the Mir space station, Skylab, and the Apollo spacecraft. Orbital architecture usually addresses the condition of weightlessness, a lack of atmospheric and magnetospheric protection from solar and cosmic radiation, rapid day/night cycles, and possibly risk of orbital debris collision. In addition, re-entry vehicles must also be adapted both to weightlessness and to the high temperatures and accelerations experienced during atmospheric reentry.

International Space Station



Astronaut (upper center) works on the Integrated Truss Structure of the ISS

The International Space Station (ISS) is the only permanently inhabited structure currently in space. It is the size of an American football field and has a crew of six. With a living volume of 358 m^3, it has more interior room than the cargo beds of two American 18-wheeler trucks. However, because of the microgravity environment of the space station, there are not always well-defined walls, floors, and ceilings and all pressurized areas can be utilized as living and working space. The International Space Station is still under construction. Modules are primarily launched using the Space Shuttle and are assembled by its crew with the help of the working crew on-board the space station. ISS modules are often designed and built to barely fit inside the shuttle's payload bay, which is cylindrical with a 4.6 meter diameter.

An interior view of the Columbus module

Life aboard the space station is distinct from terrestrial life in some very interesting ways. Astronauts commonly "float" objects to one another; for example they will give a clipboard an initial nudge and it will coast to its receiver across the room. In fact, an astronaut can become so accustomed to this habit that he forgets it doesn't work anymore when he returns to Earth. The diet of ISS spacefarers is a combination of participating nations' space food. Each astronaut selects a personalized menu before flight. Many food choices reflect the cultural differences of the astronauts, such as bacon and eggs vs. fish products for breakfast (for the US and Russia, respectively). More recently such delicacies as Japanense beef curry, kimchi, and swordfish (Riviera style) have been featured on the orbiting outpost. As much of ISS food is dehydrated or sealed in pouches MRE-style, astronauts are quite excited to get relatively fresh food from shuttle and Progress resupply missions. Food is stored in packages that facilitate eating in microgravity by keeping the food constrained to the table. Spent packaging and trash must be collected to loaded into an available spacecraft for disposal. Waste management is not nearly as straight forward as it is on Earth. The ISS has many windows for observing Earth and space, one of the astronauts' favorite leisure activities. Since the sun rises every 90 minutes, the windows are covered at "night" to help maintain the 24-hour sleep cycle.

When a shuttle is operating in low earth orbit, the ISS serves as a safety refuge in case of emergency. The inability to fall back on the safety of the ISS during the latest Hubble Space Telescope Servicing Mission (because of different orbital inclinations) was the reason a backup shuttle was summoned to the launch pad. So, ISS astronauts operate with the mindset that they may be called upon to give sanctuary to a shuttle crew should something happen to compromise a mission. The International Space Station is a colossal cooperative project between many nations. The prevailing atmosphere on board is one of diversity and tolerance. This does not mean that it is perfectly harmonious. Astronauts experience the same frustrations and interpersonal quarrels as their Earth-based counterparts.

A typical day on the station might start with wakeup at 6:00am inside a private soundproof booth in the crew quarters. Astronauts would probably find their sleeping bags in an upright position tied to the wall, because orientation does not matter in space. The astronaut's thighs would be lifted about 50 degrees off the vertical. This is the neutral body posture in weightlessness - it would be excessively tiring to "sit" or "stand" as is common on Earth. Crawling out of his booth, an astronaut may chat with other astronauts about the day's science experiments, mission control conferences, interviews with Earthlings, and perhaps even a space walk or space shuttle arrival.

Bigelow Aerospace

Bigelow Aerospace took the unique step in securing two patents NASA held from development of the Transhab concept in regard to inflatable space structures. The company now has sole rights to commercial development of the inflatable module technology. On July 12, 2006 the *Genesis I* experimental space habitat was launched into low earth orbit. *Genesis I* demonstrated the basic viability of inflatable space structures, even carrying a payload of life science experiments. The second module, *Genesis II*, was launched into orbit on June 28, 2007 and tested out several improvements over its predecessor. Among these are reaction wheel assemblies, a precision measurement system for guidance, nine additional cameras, improved gas control for module inflation, and an improved on-board sensor suite.

While Bigelow architecture is still modular, the inflatable configuration allows for much more interior volume than rigid modules. The BA 330, Bigelow's full-scale production model, has more than twice the volume of the largest module on the ISS. Inflatable modules can be docked to rigid modules and are especially well suited for crew living and working quarters. NASA is considering attaching a Bigelow module to the ISS, after abandoning the Transhab concept more than a decade ago. The modules will likely have a solid inner core for structural support. Surrounding usable space could be partitioned into different rooms and floors. Bigelow Aerospace may choose to launch many of their modules independently, leasing their use to a wide variety of companies, organizations, and countries that can't afford their own space programs. Possible uses of this space include microgravity research and space manufacturing. Or we may see a private space hotel composed of numerous Bigelow modules for rooms, observatories, or even a recreational padded gymnasium. There is the option of using such modules for habitation quarters on long-term space missions in the solar system. One amazing aspect of spaceflight is that once a craft leaves an atmosphere, aerodynamic shape is a non-issue. For instance it's possible to apply a Trans Lunar Injection to an entire space station and send it to fly by the moon. Bigelow has expressed the possibility of their modules being modified for lunar and Martian surface systems as well.

Lunar

Lunar architecture exists both in theory and in practice. Today the archeological artifacts of temporary human outposts lay untouched on the surface of the moon. Five Apollo Lunar Module descent stages stand upright in various locations across the equatorial region of the Near Side, hinting at the extraterrestrial endeavors of mankind. From a distant past the moon has beckoned, rich with mystery and enigma. The leading hypothesis on the origin of the moon did not gain its current status until after lunar rock samples were analyzed. The moon is the furthest any humans have ever ventured from their home, and space architecture is what kept them alive and allowed them to function as humans.

Apollo

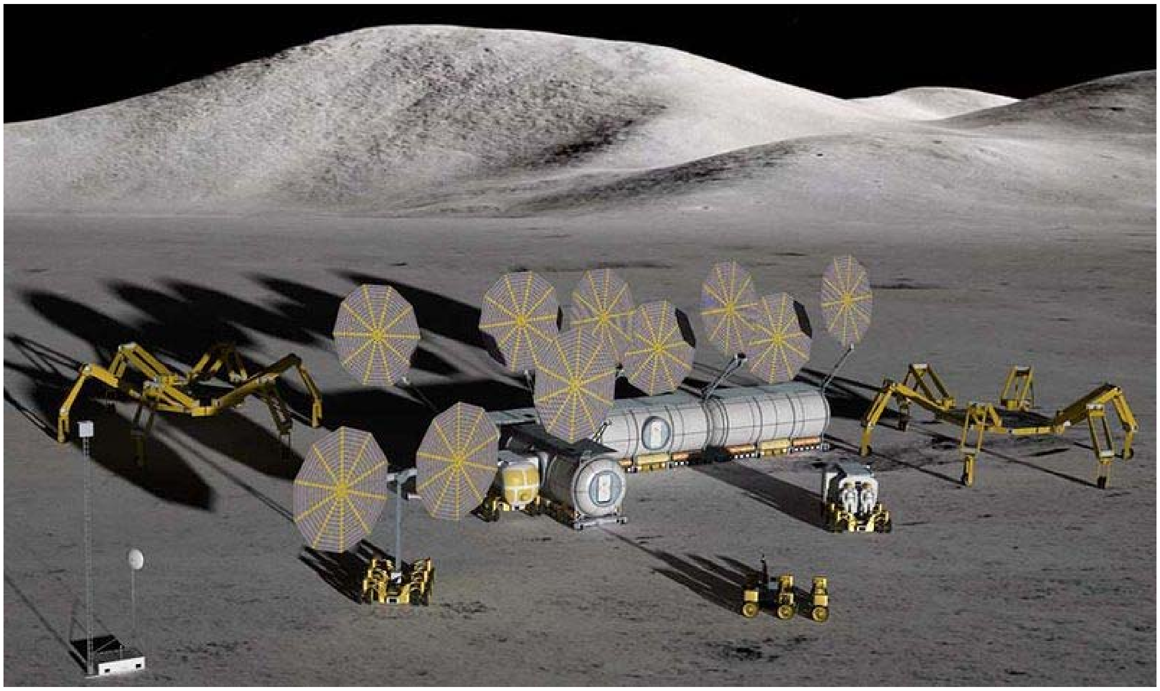
Lunar Module ascent stage blasts off the moon in 1972, leaving the descent stage behind.

On the cruise to the moon, Apollo astronauts had two "rooms" to choose from - the Command Module (CM) or the Lunar Module (LM). Indeed one can witness this in the film *Apollo 13* where the three astronauts were forced to use the LM as an emergency life boat. Passage between the two modules was possible through a pressurized docking tunnel, a major advantage over the Soviet design, which required donning a spacesuit to switch modules. The Command Module featured five windows made of three thick panes of glass. The two inner panes, made of aluminosilicate, ensured no cabin air leaked into space. The outer pane served as a debris shield and part of the heat shield needed for atmospheric reentry. The CM was a sophisticated spacecraft with all the systems required for successful flight but with an interior volume of 6.17 m^3 could be considered cramped for three astronauts. It had its design weaknesses such as no toilet (astronauts used much-hated 'relief tubes' and fecal bags). The coming of the space station would bring effective life support systems with waste management and water reclamation technologies.

The Lunar Module had two stages. A pressurized upper stage, termed the Ascent stage, was the first true spaceship as it could only operate in the vacuum of space. The Descent stage carried the engine used for descent, landing gear and radar, fuel and consumables, the famous ladder, and the Lunar Rover during later Apollo missions. The idea behind staging is to reduce mass later in a flight, and is the same strategy used in an Earth-launched multistage rocket. The LM pilot stood up during the descent to the moon. Landing was achieved via automated control with a manual backup mode. There was no airlock on the LM so the entire cabin had to be evacuated (air vented to space) in order to send an astronaut out to walk on the surface. To stay alive, both astronauts in the LM would have to get in their space suits at this point. The Lunar Module worked well for what it was designed to do. However, a big unknown remained throughout the design process - the effects of lunar dust. Every astronaut who walked on the moon tracked in lunar dust, contaminating the LM and later the CM during Lunar Orbit Rendezvous. These dust particles can't be brushed away in a vacuum, and have been described by John Young of Apollo 16 as being like tiny razor blades. It was soon realized that for humans to live on the moon, dust mitigation was one of many issues that had to be taken seriously.

Project Constellation

The Exploration Systems Architecture Study that followed the Vision for Space Exploration of 2004 recommended the development of a new class of vehicles that have similar capabilities to their Apollo predecessors with several key differences. In part to retain some of the Space Shuttle program workforce and ground infrastructure, the launch vehicles are to use Shuttle-derived technologies. Secondly, rather than launching the crew and cargo on the same rocket, the smaller Ares I is to launch the crew with the larger Ares V to handle the heavier cargo. The two payloads are to rendezvous in low earth orbit and then head to the moon from there. The Apollo Lunar Module could not carry enough fuel to reach the polar regions of the moon but the Altair lunar lander is being designed to access any part of the moon. While the Altair and surface systems are equally necessary for Project Constellation to reach fruition, the focus now is on developing the Orion spacecraft to shorten the gap in US access to orbit following the retirement of the Space Shuttle in 2010.



Some of the concepts NASA is working on

Even NASA has described Constellation architecture as 'Apollo on steroids'. Nonetheless, a return to the proven capsule design is a move welcomed by many. The Orion Crew Module will have 2.5 times the interior volume of the Apollo CM and will be able to carry up to six crew member to the ISS and four to the moon. All astronauts will go to the surface of the moon and the Service Module will orbit the moon empty. As is standard practice for spacecraft, Orion will be equipped with 'almost state of the art' technology. This strategy to reduce risk by using proven technologies has been successfully demonstrated in numerous robotic missions. Accordingly, the CM will feature a glass cockpit, automated docking, and a private unisex toilet. It will be constructed of a lightweight aluminum lithium alloy and covered in a Nomex felt-like layer for thermal protection. Like its Apollo predecessor Orion will have a launch escape system, an ablative heat shield for reentry, and parachute recovery for water landing.

Planned stays on the surface are on the order of months rather than days. Surface systems will be more advanced than Apollo equipment and will explore the possibility of in-situ resource utilization (ISRU). Lunar rocks contain oxygen, silicon, and a variety of metals whose successful extraction and use in local manufacturing could revolutionize the prospects for living on the moon. If oxygen and thus rocket propellant oxidizer could be produced on the moon, it would create an economic incentive to develop a base, a sort of interplanetary gas station that could supply Mars-bound ships with fuel and air. The potential of using lunar regolith as a construction material similar to the way concrete is used has been suggested. Surface transport for Constellation will be more advanced than Apollo. The Lunar Electric Rover with possible suitports, legged walkers such as the ATHLETE, and even habitat modules themselves could have a significant surface range.

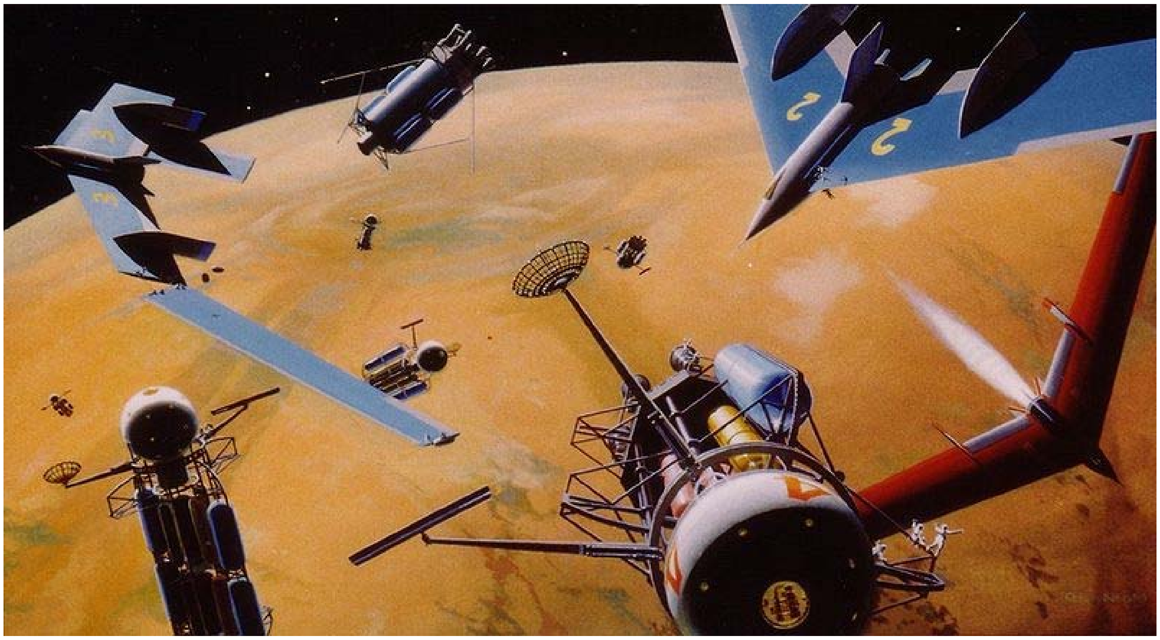
Establishing a presence on the moon is one goal of Constellation, but much of this effort is aimed at preparing for the exploration of Mars.

Martian

Martian architecture is architecture designed to sustain human life on the surface of Mars, and all the supporting systems necessary to make this possible. The direct sampling of water ice on the surface, and evidence for geyser-like water flows within the last decade have made Mars the most likely extraterrestrial environment for finding liquid water, and therefore alien life, in the solar system. Moreover some geologic evidence suggests that Mars could have been warm and wet on a global scale in its distant past. Intense geologic activity has reshaped the surface of the Earth, erasing evidence of our earliest history. Martian rocks can be even older than Earth rocks, though, so exploring Mars may help us decipher the story of our own geologic evolution including the origin of life on Earth. Mars has an atmosphere, though its surface pressure is less than 1% of Earth's. Its surface gravity is about 38% of Earth's. Although a human expedition to Mars has not yet taken place, there has been significant work on Martian habitat design. Martian architecture usually falls into one of two categories: architecture imported from Earth fully assembled and architecture making use of local resources.

Von Braun and other early proposals

Wernher von Braun was the first to come up with a technically compreshensive proposal for a manned Mars expedition. Rather than a minimal mission profile like Apollo, von Braun envisioned a crew of 70 astronauts aboard a fleet of ten massive spacecraft. Each vessel would be constructed in low Earth orbit, requiring nearly 100 separate launches before one was fully assembled. Seven of the spacecraft would be for crew while three were designated as cargo ships. There were even designs for small "boats" to shuttle crew and supplies between ships during the cruise to the Red Planet, which was to follow a minimum-energy Hohmann transfer trajectory. This mission plan would involve one-way transit times on the order of eight months and a long stay at Mars, creating the need for long-term living accommodations in space. Upon arrival at the Red Planet, the fleet would brake into Mars orbit and would remain there until the seven human vessels were ready to return to Earth. Only landing gliders, which were stored in the cargo ships, and their associated ascent stages would travel to the surface. Inflatable habitats would be constructed on the surface along with a landing strip to facilitate further glider landings. All necessary propellant and consumables were to be brought from Earth in von Braun's proposal. Some crew remained in the passenger ships during the mission for orbit-based observation of Mars and to maintain the ships. The passenger ships had habitation spheres 20 meters in diameter. Because the average crew member would spend much time in these ships (around 16 months of transit plus rotating shifts in Mars orbit), habitat design for the ships was an integral part of this mission.



Von Braun's flotilla of ships in Martian orbit as illustrated in Collier's magazine

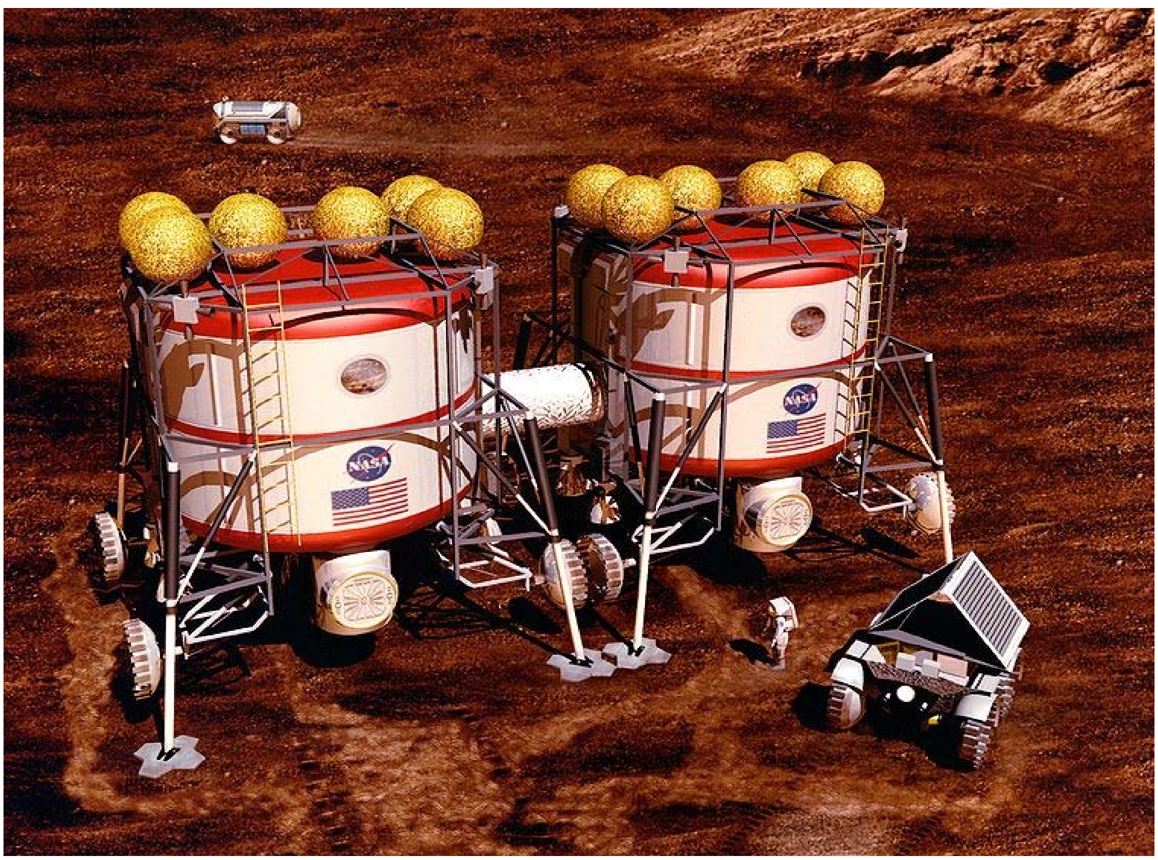
Von Braun was aware of the threat posed by extended exposure to weightlessness. He suggested either tethering passenger ships together to spin about a common center of mass or including self-rotating, dumbbell-shaped "gravity cells" to drift alongside the flotilla to provide each crew member with a few hours of artificial gravity each day. At the time of von Braun's proposal, little was known of the dangers of solar radiation beyond Earth and it was cosmic radiation that was thought to present the more formidable challenge. The discovery of the Van Allen belts in 1958 demonstrated that the Earth was shielded from high energy solar particles. For the surface portion of the mission, inflatable habitats suggest the desire to maximize living space. It is clear von Braun considered the members of the expedition part of a community with much traffic and interaction between vessels.

The Soviet Union conducted studies of human exploration of Mars and came up with slightly less epic mission designs (though not short on exotic technologies) in 1960 and 1969. The first of which used electric propulsion for interplanetary transit and nuclear reactors as the power plants. On spacecraft that combine human crew and nuclear reactors, the reactor is usually placed at a maximum distance from the crew quarters, often at the end of a long pole, for radiation safety. An interesting component of the 1960 mission was the surface architecture. A "train" with wheels for rough terrain was to be assembled of landed research modules, one of which was a crew cabin. The train was to traverse the surface of Mars from south pole to north pole, an extremely ambitious goal even by today's standards. Other Soviet plans such as the TMK eschewed the large costs associated with landing on the Martian surface and advocated piloted (manned) flybys of Mars. Flyby missions, like the lunar Apollo 8, extend the human presence to other worlds with less risk than landings. Most early Soviet proposals called for launches using the ill-fated N1 rocket. They also usually involved fewer crew than their American counterparts.

Early Martian architecture concepts generally featured assembly in low earth orbit, bringing all needed consumables from Earth, and designated work vs. living areas. The modern outlook on Mars exploration is not the same.

Recent initiatives

In every serious study of what it would take to land humans on Mars, keep them alive, and then return them to Earth, the total mass required for the mission is simply stunning. The problem lies in that to launch the amount of consumables (oxygen, food and water) even a small crew would go through during a multi-year Mars mission, it would take a very large rocket with the vast majority of its own mass being propellant. This is where multiple launches and assembly in Earth orbit come from. However even if such a ship stocked full of goods could be put together in orbit, it would need an additional (large) supply of propellant to send it to Mars. The delta-v, or change in velocity, required to insert a spacecraft from Earth orbit to a Mars transfer orbit is many kilometers per second. When we think of getting astronauts to the surface of Mars and back home we quickly realize that an enormous amount of propellant is needed if everything is taken from the Earth. This was the conclusion reached in the 1989 '90-Day Study' initiated by NASA in response to the Space Exploration Initiative.



The NASA Design Reference Mission 3.0 incorporated many concepts from the Mars Direct proposal

Several techniques have changed the outlook on Mars exploration. The most powerful of which is in-situ resource utilization. Using hydrogen imported from Earth and carbon dioxide from the Martian atmosphere, the Sabatier reaction can be used to manufacture methane (for rocket propellant) and water (for drinking and for oxygen production through electrolysis). Another technique to reduce Earth-brought propellant requirements is aerobraking. Aerobraking involves skimming the upper layers of an atmosphere, over many passes, to slow a spacecraft down. It's a time-intensive process that shows most promise in slowing down cargo shipments of food and supplies. NASA's Constellation program does call for landing humans on Mars after a permanent base on the moon is demonstrated, but details of the base architecture are far from established. It is likely that the first permanent settlement will consist of consecutive crews landing prefabricated habitat modules in the same location and linking them together to form a base.

In some of these modern, economy models of the Mars mission, we see the crew size reduced to a minimal 4 or 6. Such a loss in variety of social relationships can lead to challenges in forming balanced social responses and forming a complete sense of identity. It follows that if long-duration missions are to be carried out with very small crews, then intelligent selection of crew is of primary importance. Role assignments is another open issue in Mars mission planning. The primary role of 'pilot' is obsolete when landing takes only a few minutes of a mission lasting hundreds of days, and when that landing will be automated anyway. Assignment of roles will depend heavily on the work to be done on the surface and will require astronauts to assume multiple responsibilities. As for surface architecture inflatable habitats, perhaps even provided by Bigelow Aerospace, remain a possible option for maximizing living space. In later missions, bricks could be made from a Martian regolith mixture for shielding or even primary, airtight structural components. The environment on Mars offers different opportunities for space suit design, even something like the skin-tight Bio-Suit. A human mission to Mars is also an opportunity to include men on a major exploration mission. Space architecture can allow humanity to send a truly diverse and representative crew on its first expedition to another planet.

Robotic

It is widely accepted that robotic reconnaissance and trail-blazer missions will precede human exploration of other worlds. Making an informed decision on which specific destinations warrant sending human explorers requires more data than what the best Earth-based telescopes can provide. For example landing site selection for the Apollo landings drew on data from three different robotic programs: the Ranger program, the Lunar Orbiter program, and the Surveyor program. Before a human was sent, robotic spacecraft mapped the lunar surface, proved the feasibility of soft landings, filmed the terrain up close with television cameras, and scooped and analysed the soil.

A robotic exploration mission is generally designed to carry a wide variety of scientific instruments, ranging from cameras sensitive to particular wavelengths, telescopes, spectrometers, radar devices, accelerometers, radiometers, and particle detectors to name a few. The function of these instruments is usually to return scientific data but it can also be to give an intuitive "feel" of the state of the spacecraft, allowing a subconscious familiarization with the territory being explored, through telepresence. A good example of this is the inclusion of HDTV cameras on the Japanese lunar orbiter SELENE. While purely scientific instruments could have been brought in their stead, these cameras allow the use of an innate sense to perceive the exploration of the moon.

The modern, balanced approach to exploring an extraterrestrial destination involves several phases of exploration, each of which needs to produce rationale for progressing to the next phase. The phase immediately preceding human exploration can be described as anthropocentric sensing, that is, sensing designed to give humans as realistic a feeling as possible of actually exploring in person. More, the line between a human system and a robotic system in space is not always going to be clear. As a general rule, the more formidable the environment, the more essential robotic technology is. Robotic systems can be broadly considered part of space architecture when their purpose is to facilitate the habitation of space or extend the range of the physiological senses into space.

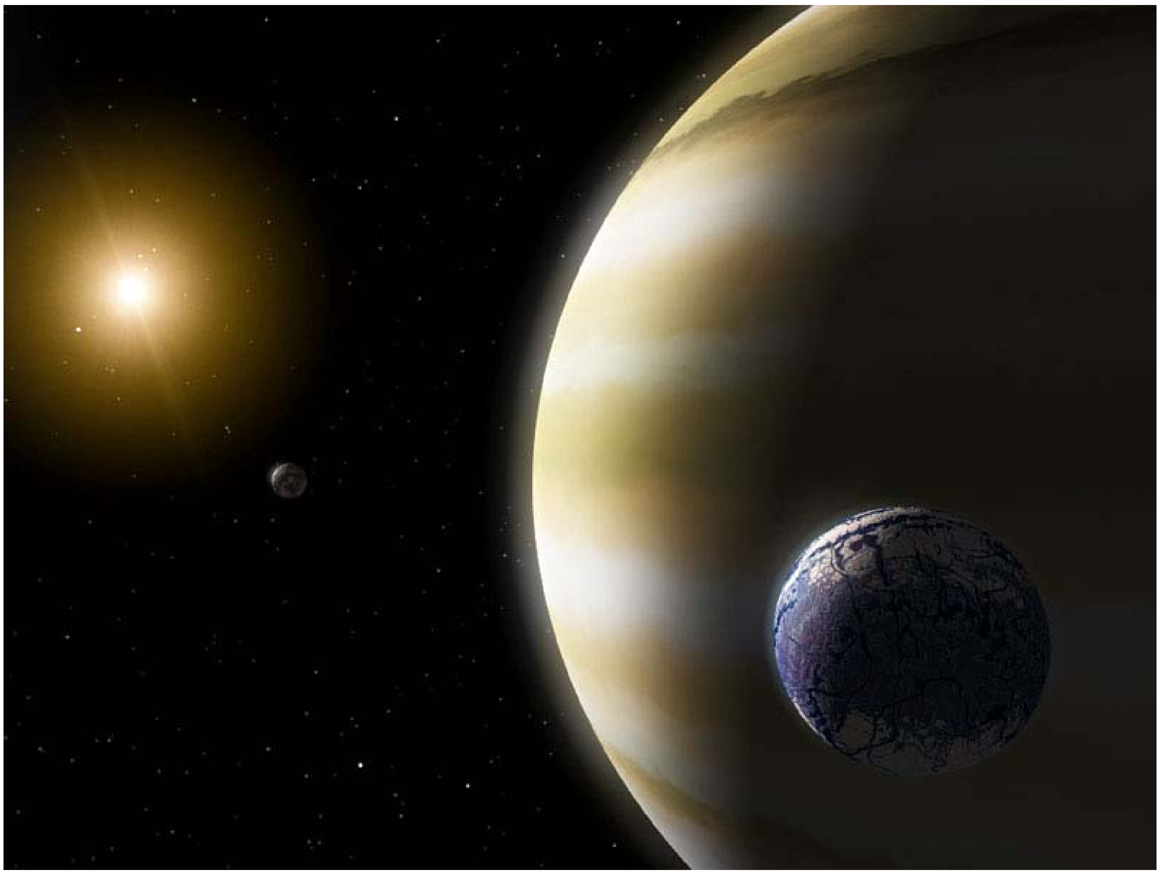
Future

The future of space architecture hinges on the colonization of space. Under the historical model of government-orchestrated exploration missions initiated by single political administrations, space structures are likely to be limited to small-scale habitats and orbital modules with design life cycles of only several years or decades. The designs, and thus architecture, will generally be fixed and without real time feedback from the spacefarers themselves. The technology to repair and upgrade existing habitats, a practice widespread on Earth, is not likely to be developed under short term exploration goals. If exploration takes on a multi-administration or international character, the prospects for space architecture development by the inhabitants themselves will be broader. Private space tourism is a way the development of space and a space transportation infrastructure can be accelerated. Virgin Galactic has indicated plans for another ship, SpaceShipThree, that will be an orbital craft. The demand for tourism is one without bound. It's not difficult to imagine lunar parks or cruises by Venus. Another impetus to become a spacefaring species is planetary defense.

The classic space mission is the Earth-colliding asteroid interception mission. Using nuclear detonations to split or deflect the asteroid is risky at best. Such a tactic could actually make the problem worse by increasing the amount of asteroid fragments that do end up hitting the Earth. Robert Zubrin writes:

> “If bombs are to be used as asteroid deflectors, they cannot just be launched willy-nilly. No, before any bombs are detonated, the asteroid will have to be thoroughly explored, its geology assessed, and subsurface bomb placements carefully”

determined and precisely located on the basis of such knowledge. A human crew, consisting of surveyors, geologists, miners, drillers, and demolition experts, will be needed on the scene to do the job right.



Robotic probes have explored much of the solar system but humans have not yet left the Earth's influence

If such a crew is to be summoned to a distant asteroid, there may be less risky ways to divert the asteroid. Another promising asteroid mitigation strategy is to land a crew on the asteroid well ahead of its impact date and to begin diverting some its mass into space to slowly alter its trajectory. This is a form of rocket propulsion by virtue of Newton's third law with the asteroid's mass as the propellant. Whether exploding nuclear weapons or diversion of mass is used, a sizable human crew may need to be sent into space for many months if not years to accomplish this mission. Questions such as what the astronauts will live in and what the ship will be like are questions for the space architect.

When motivations to go into space are realized, work on mitigating the most serious threats can begin. One of the biggest threats to astronaut safety in space is sudden radiation events from solar flares. The violent solar storm of August 1972, which occurred between the Apollo 16 and Apollo 17 missions, could have produced fatal consequences had astronauts been caught exposed on the lunar surface. The best known protection against radiation in space is shielding; an especially effective shield is water contained in large tanks surrounding the astronauts. Unfortunately water has a mass of 1000 kilograms per cubic meter. A more practical approach would be to construct solar "storm shelters" that spacefarers can retreat to during peak events. For this to work, however, there would need to be a space weather broadcasting system in place to warn astronauts of upcoming storms, much like a tsunami warning system warns coastal inhabitants of impending danger. Perhaps one day a fleet of robotic spacecraft will orbit close to the sun, monitoring solar activity and sending precious minutes of warning before waves of dangerous particles arrive at inhabited regions of space.

Nobody knows what the long-term human future in space will be. Perhaps after gaining experience with routine spaceflight by exploring different worlds in the solar system and deflecting a few asteroids, the possibility of constructing non-modular space habitats and infrastructure will be within capability. Such possibilities include mass drivers on the moon, which launch payloads into space using only electricity, and spinning space colonies with closed ecological systems. A Mars in the early stages of terraformation, where inhabitants only need simple oxygen masks to walk out on the surface, may be seen. In any case, such futures require space architecture.