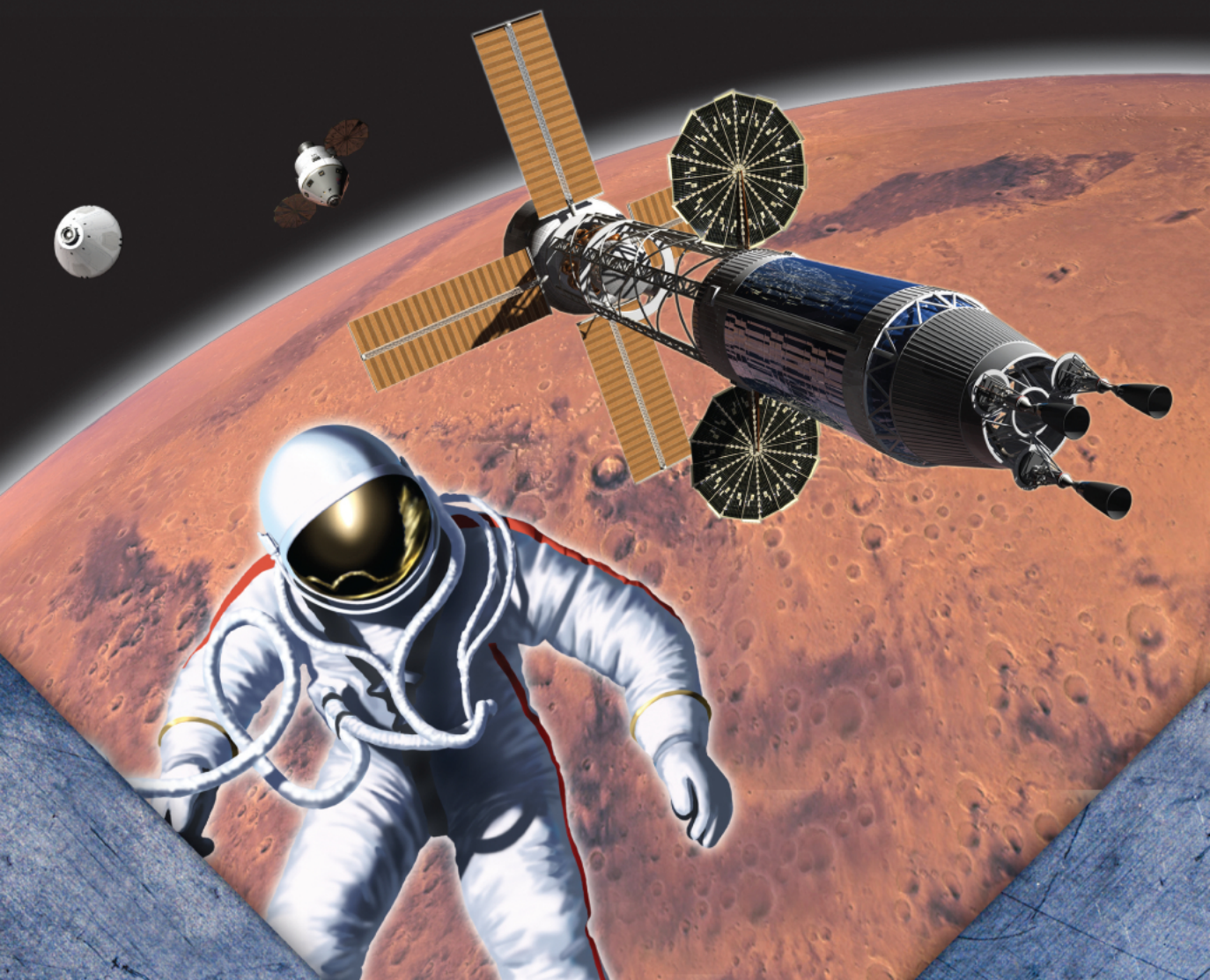


THE KNOWLEDGE

MISSION TO

MARS



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MARS



 Orpheus



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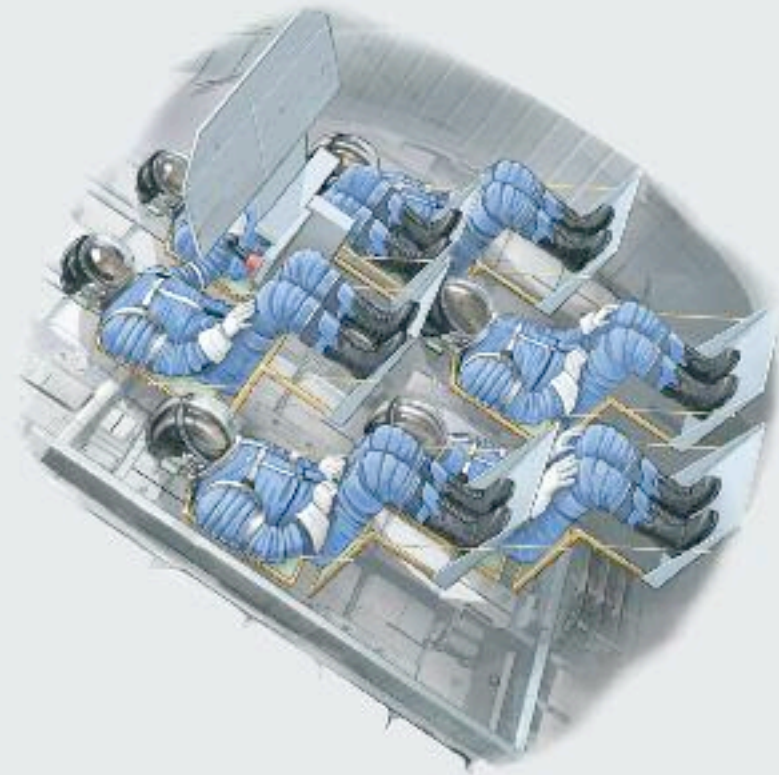
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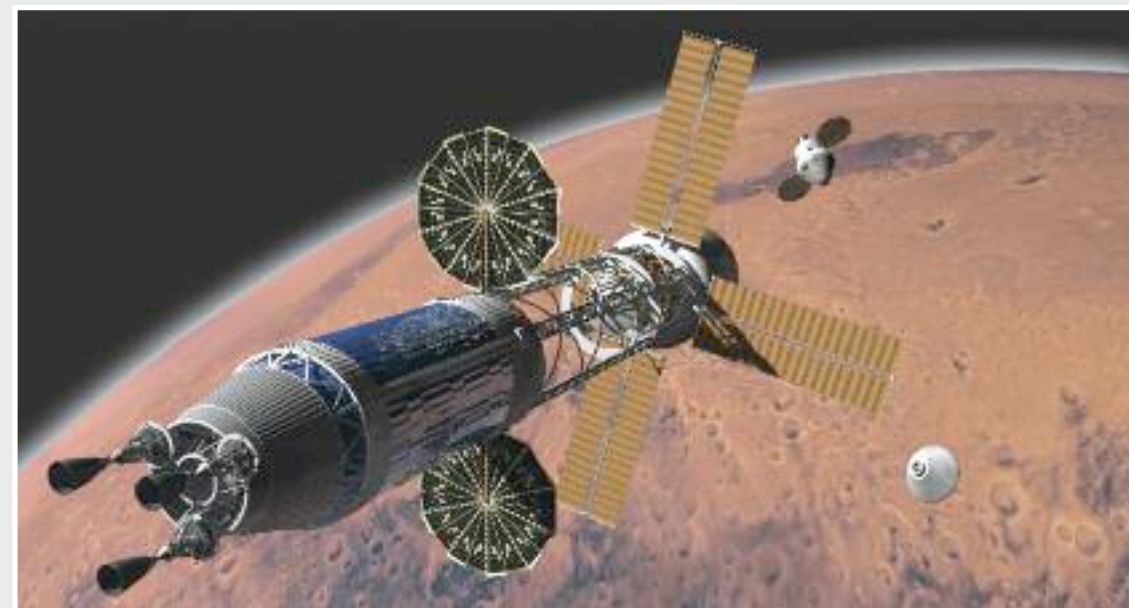
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Introduction

YOU HAVE BEEN chosen to mastermind a mission to Mars. It is down to you and your team to undertake this historic journey – the first by humans to another planet – and complete the Mars Mission successfully. You will have to plan every aspect of the mission, from choosing equipment to looking for life on Mars. But how should such a complex mission be organized?

First, you will need to learn the history of space travel and how spacecraft work. A thorough knowledge of the Solar System and its planets is an essential part of this research. Next you must plan a suitable landing site on Mars and calculate how long your journey will take.

Once these calculations have been made, you should set about assembling the technical equipment needed to transport you to Mars and keep your crew safe once you arrive. One of your main objectives on Mars is to search for signs of life, past or present. To do this you must learn the conditions required for life to exist and know the best places to look for traces of life. Finally, you are ready to take off on your historic journey to the Red Planet. Good luck!

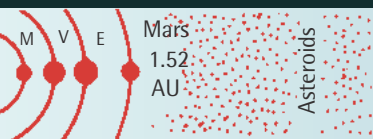
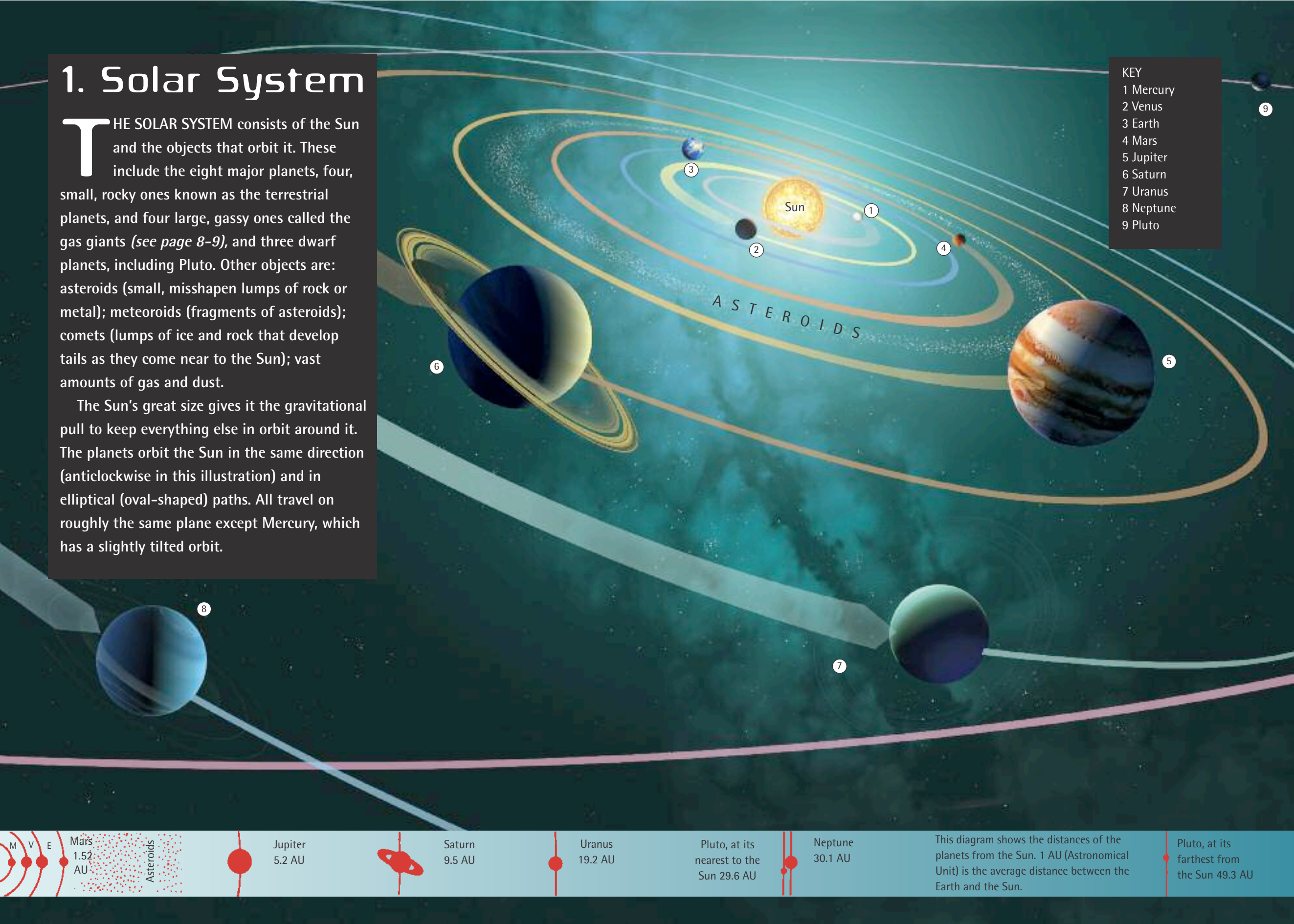


1. Solar System

THE SOLAR SYSTEM consists of the Sun and the objects that orbit it. These include the eight major planets, four, small, rocky ones known as the terrestrial planets, and four large, gassy ones called the gas giants (*see page 8-9*), and three dwarf planets, including Pluto. Other objects are: asteroids (small, misshapen lumps of rock or metal); meteoroids (fragments of asteroids); comets (lumps of ice and rock that develop tails as they come near to the Sun); vast amounts of gas and dust.

The Sun's great size gives it the gravitational pull to keep everything else in orbit around it. The planets orbit the Sun in the same direction (anticlockwise in this illustration) and in elliptical (oval-shaped) paths. All travel on roughly the same plane except Mercury, which has a slightly tilted orbit.

- KEY
- 1 Mercury
 - 2 Venus
 - 3 Earth
 - 4 Mars
 - 5 Jupiter
 - 6 Saturn
 - 7 Uranus
 - 8 Neptune
 - 9 Pluto



Jupiter
5.2 AU

Saturn
9.5 AU

Uranus
19.2 AU

Pluto, at its
nearest to the
Sun 29.6 AU

Neptune
30.1 AU

This diagram shows the distances of the planets from the Sun. 1 AU (Astronomical Unit) is the average distance between the Earth and the Sun.

Pluto, at its
farthest from
the Sun 49.3 AU



▲ Mercury:
Diameter: 4880 km
Day: 58.6 days
Year: 88 days

► Venus:
Diameter: 12,105 km
Day: 243 days
Year: 225 days



▲ Earth:
Diameter: 12,756 km
Day: 23 hours 56 mins
Year: 365.26 days
Moons: 1

► Mars:
Diameter: 6797 km
Day: 24.6 hours
Year: 687 days
Moons: 2

Terrestrial planets

The four inner planets in our Solar System are often called the "terrestrial" planets, meaning "Earth-like" because, like Earth, they are mostly made up of rocks.

MERCURY (*left*) is the smallest planet in the Solar System. Where it faces the Sun, its surface temperature can exceed 400°C, but during the long nights temperatures fall to -170°C. Its rocky surface is pock-marked with craters, the result of continual bombardment by meteorites.

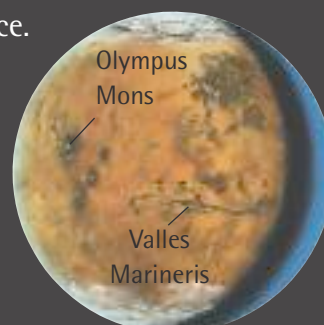


VENUS (*above, right*) is shrouded in thick clouds of sulphuric acid. Infrared radiation from the Sun gets through and the dense atmosphere stops it from escaping. The result is a surface temperature hotter than the melting point of lead. Beneath the clouds, the barren surface features thousands of volcanoes surrounded by vast lava plains.

EARTH (*left*) is the only body in the Solar System where life is known to be present. More than two-thirds of its surface is taken up by liquid water. Its atmosphere traps enough of the Sun's energy to avoid temperature extremes. It also acts as a shield against harmful solar radiation and meteorites.

MARS (*below, right*) is the Red Planet. Its colour comes from iron oxide dust (similar to rust). From time to time, dark regions appear on the surface.

These are areas of bare rock, exposed when storms remove the dusty covering. The Solar System's highest mountain, the extinct volcano Olympus Mons, and its deepest canyon, Valles Marineris, are on Mars.



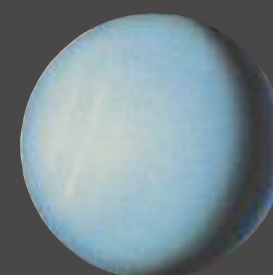
Great Red Spot

Gas giants

The four "gas giants" are so-called because they have comparatively small rocky cores surrounded by thick layers of liquid and gas.

JUPITER (*above, left*), the largest planet in the Solar System, is more massive than all the other planets combined. It spins very quickly, making its clouds separate into "zones" (lighter bands) and "belts" (darker bands). The Great Red Spot is a storm that has been raging for at least 400 years.

SATURN (*right*) is famous for its system of rings. They are made up of billions of blocks of ice and rock, ranging from boulders to tiny flakes. The rings may be the remains of a moon that was smashed apart by a passing comet. The outer ring (A) is separated from the other two (B and C) by a gap called the Cassini Division.



URANUS (*left*) is tilted 98° from the vertical, meaning it orbits the Sun almost on its side. Its relatively small, rocky core is surrounded by a slushy ocean of water with some ammonia.

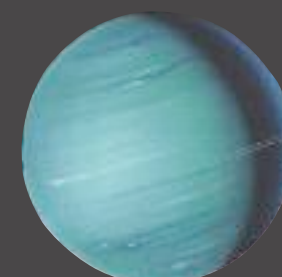
NEPTUNE (*right*) has a rocky core surrounded by a layer of water, with some ammonia and methane. Its blueness arises from small amounts of methane found in its thick atmosphere. The white streaks on its surface are fast-moving clouds, blown by winds at speeds of more than 2000 km/h.

◀ Jupiter:
Diameter: 143,884 km
Day: 9.8 hours
Year: 11.8 years
Moons: 63

▼ Saturn:
Diameter: 120,514 km
Day: 10.2 hours
Year: 29.5 years
Moons: 60

◀ Uranus:
Diameter: 51,118 km
Day: 17.2 hours
Year: 84 years
Moons: 27

▼ Neptune:
Diameter: 50,538 km
Day: 16.1 hours
Year: 164.8 years
Moons: 13

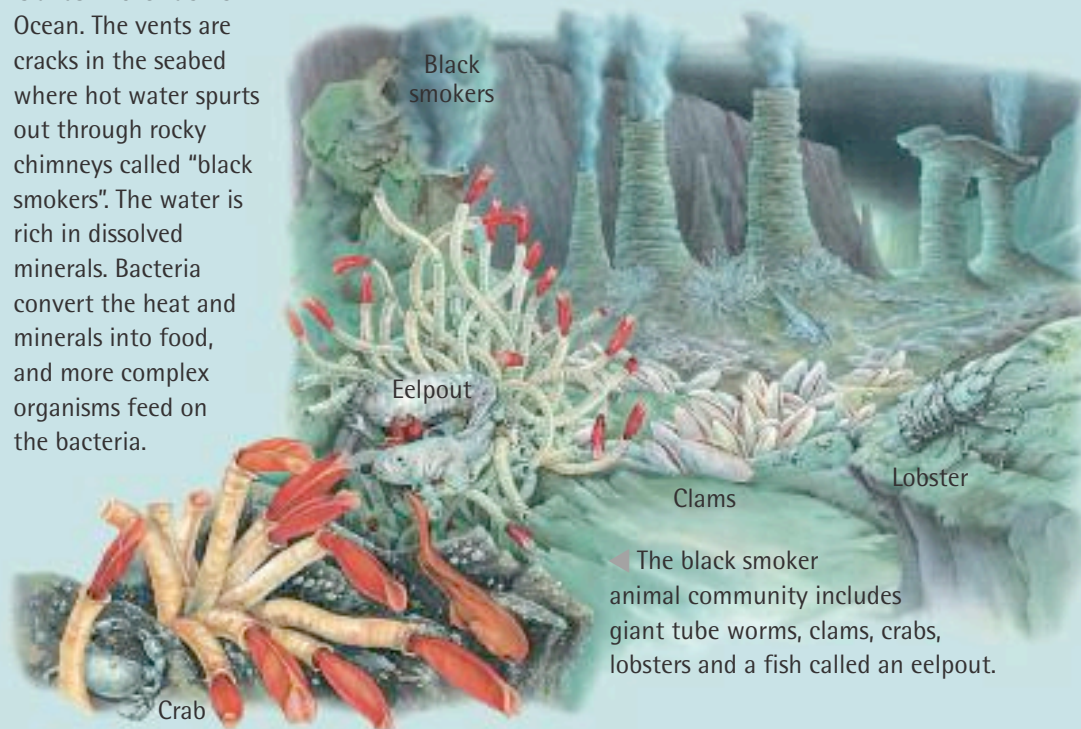


Extremophiles

Some microbes can survive in extreme environments. Known as extremophiles, they thrive in very hot, cold or acidic conditions. Endoliths (*below*), for example, live in the microscopic spaces within rocks. Extremophiles are capable of living in environments similar to those known to exist on other planets.



► Hydrothermal vents were discovered in 1977 near the Galapagos Islands in the Pacific Ocean. The vents are cracks in the seabed where hot water spurts out through rocky chimneys called "black smokers". The water is rich in dissolved minerals. Bacteria convert the heat and minerals into food, and more complex organisms feed on the bacteria.



2. Where to find life

A KEY OBJECTIVE of the mission is to find evidence of life on Mars. But first you must learn what requirements are necessary for life, and which worlds may provide possible habitats for extraterrestrial life: organisms (living things) from outside Earth.

Most scientists believe extraterrestrial life will have the same chemical composition as organisms on Earth. Carbon is the one element that can form molecules needed to make living cells. These molecules form in liquid water. There also needs to be a source of energy providing food for the organism. It was once thought this must come from the Sun. Plants use sunlight to produce sugars from carbon dioxide and water – and plants are the vital link in any food chain. Now it is known that some deep-sea organisms rely on an energy source completely separate from the Sun: bacteria that take their energy from chemicals in the Earth's crust.

Titan

Titan is the only other world apart from Earth where areas of surface liquid exist. The liquid is not water, however, but methane – natural gas – which exists in a liquid state in Titan's -170°C temperatures. There are even methane clouds, rain and snow. Titan is thought to have an internal liquid layer between its crust and core made of liquid water and ammonia, which erupts into the atmosphere, along with methane, through crustal cracks. It is just possible there may be some kind of organisms inhabiting this layer.

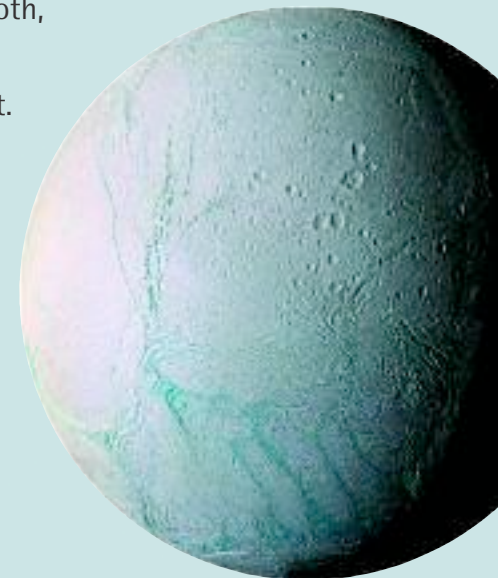


▲ Titan, Saturn's largest moon, is the only moon known to have a thick atmosphere. It is almost entirely composed of nitrogen. Titan's atmosphere is so thick, and its gravity so low, that humans could fly through it by flapping "wings" attached to their arms.

▼ Images of Titan captured by the *Cassini* probe and its lander *Huygens* in 2005 revealed a landscape of water ice crisscrossed by methane rivers and lakes. Perhaps Titan is similar to Earth when it first came into being billions of years ago.

Enceladus

Enceladus, another of Saturn's moons, is a bright, silvery-white ball (*right*). There are craters and ridges in the north, but its southern polar region is smooth, suggesting that the ice must have melted only recently, wiping out any craters from past meteorite bombardment. Snaking across this smooth region are four long cracks, each fringed by a mint-green stripe. From these so-called "tiger stripes", ice volcanoes erupt fountains of water vapour 500 km into space. Do these eruptions come from a warm-water ocean lying beneath Enceladus's icy crust? The presence of organic molecules, found in both the fountains and the stripes, increases the possibility that this ocean might harbour life.



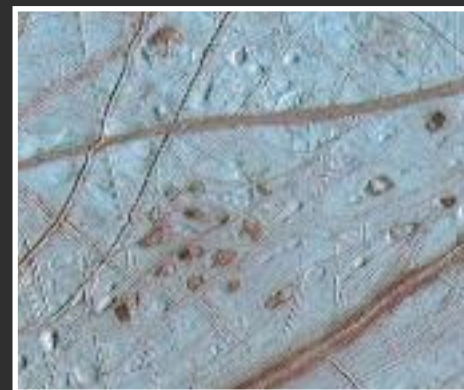
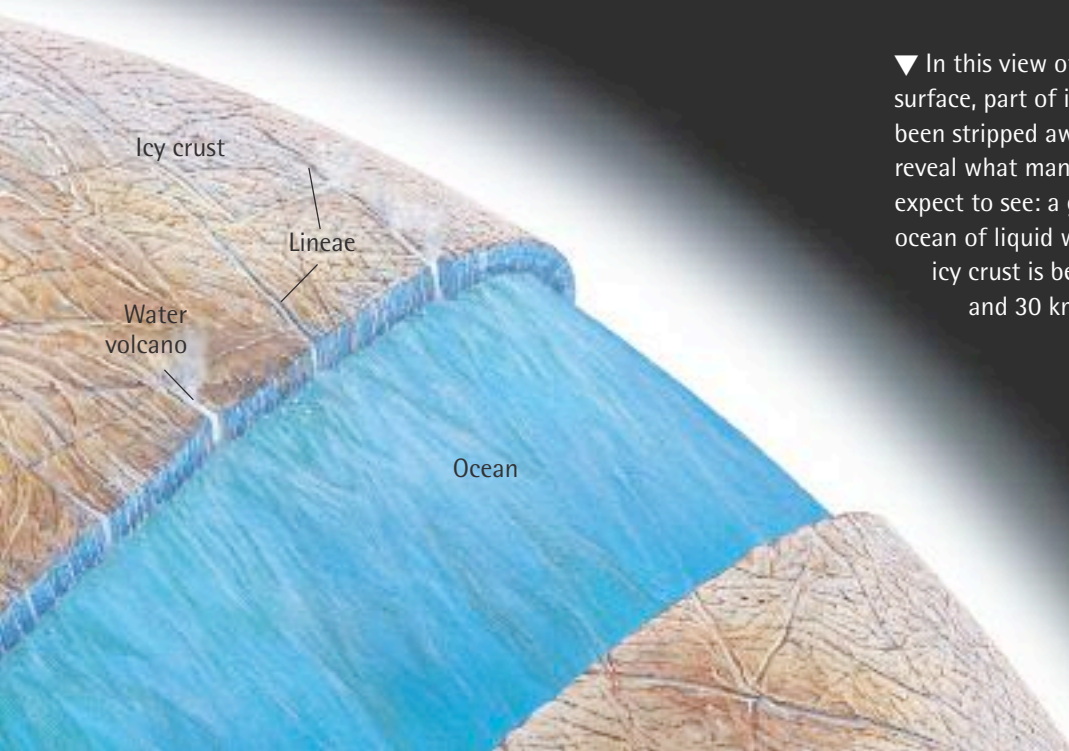
▼ Jupiter's fourth largest moon, Europa, measures 3140 km across — about the same size as our Moon. Dark streaks, called lineae, Latin for lines, crisscross its surface (see photo opposite).

Europa

For astronomers searching for life on other worlds in the Solar System, Europa, one of Jupiter's moons, is of special interest. Europa has a smooth, icy surface covered with a maze of lines, thought to be cracks in the ice. There are very few craters. Both these features are taken to be signs that Europa's icy crust is continually melting and re-solidifying, which in turn suggests the presence of a warm-water ocean lying just beneath. Could it be home to living things ...?

Just as on Earth, whose outer layer is split into a number of giant tectonic plates slowly drifting around its globe, so Europa's crust is known to be constantly on the move. Earth's plates float like rafts on a semi-liquid underlayer, and the movement of Europa's outer layer strongly indicates that it, too, is not solidly attached to its internal core. The cracks in it may have been created by eruptions of liquid water from underneath the crust along lines of weakness.

▼ In this view of Europa's surface, part of its crust has been stripped away to reveal what many scientists expect to see: a global ocean of liquid water. The icy crust is between 10 and 30 km thick.



Europa's geology may thus resemble that on Earth, where the tectonic plates are being eased apart at the mid-oceanic ridges by magma pushing up from beneath. On Europa,

these crustal movements could well be caused by the gravitational pull of its giant parent planet, Jupiter, which tugs on its moon's crust in a similar way to the Moon's (much weaker) pull on Earth's oceans, causing our tides.

Europa's internal ocean, reckoned to be about 100 kilometres deep, is thought by many scientists to be the most likely location of extraterrestrial life in the Solar System — were it to exist anywhere else at all. Organisms might live clustered around hydrothermal vents in the ocean floor just like those in Earth's oceans, or inside rocks that form the European ocean bed. Alternatively, they might float or swim freely in the ocean waters, or cling to the lower surface of the icy crust, like algae and bacteria do to the Arctic ice on Earth. The level of oxygen in the oceans might even be enough to support not just microbes, but larger, more advanced life-forms ...

▼ To discover more about Europa's "ocean", a space probe could send a cryobot down to its surface. This heated drill would then penetrate the ice by melting. Once it reaches the water beneath the ice, it would start to transmit pictures and information back to Earth.





▲ With 200 billion stars in the Milky Way Galaxy, it seems sure there will be other Earth-like planets with advanced civilizations. In order to calculate their possible number, US astronomer Frank Drake proposed an equation. It takes into account the rate of formation of suitable stars, the number that have Earth-like planets, the percentage where intelligent life develops and the fraction of those that communicate. Drake's own figure was 10, but a more recent estimate is just two.



▲ On 15th August 1977, a radio signal lasting 72 seconds was detected by a radio telescope used in the Search for Extra-Terrestrial Intelligence (SETI) project. Thinking it might be of extra-terrestrial origin, a scientist wrote "Wow!" on the computer printout, so that became the name of the signal. It has not been detected since.

Extrasolar planets

Many scientists now believe that extremophiles, even if not present in our Solar System, may be common amid the vastness of the Universe.

But what about the existence of more complex organisms, or even intelligent beings like ourselves, elsewhere in space?

If life arose on Earth, it could have arisen on other planets with similar characteristics. Astronomers have now discovered several hundred planets, called extrasolar planets or exoplanets, that orbit other stars (*right*).

If they meet certain conditions, it is possible that these planets might host complex life.

These include:

- 1) The parent star must be of average size: very big stars have short lifetimes, so life would not have a chance to evolve, while small stars may not radiate sufficient energy.
- 2) The planet should orbit the star within what is called the habitable zone, neither too close nor too far, where water can exist in a liquid state on the surface.
- 3) The planet should have an atmosphere, to trap enough of the star's energy to avoid temperature extremes, to screen it from harmful radiation and to act as a shield to bombardment by meteoroids.
- 4) There should be a gas giant like Jupiter (but not so close as to affect its orbit) which will attract comets and asteroids to itself, and thus spare the planet from devastating impacts.
- 5) The planet should have a magnetic field, to protect it from streams of charged particles, and spin on a tilted axis.



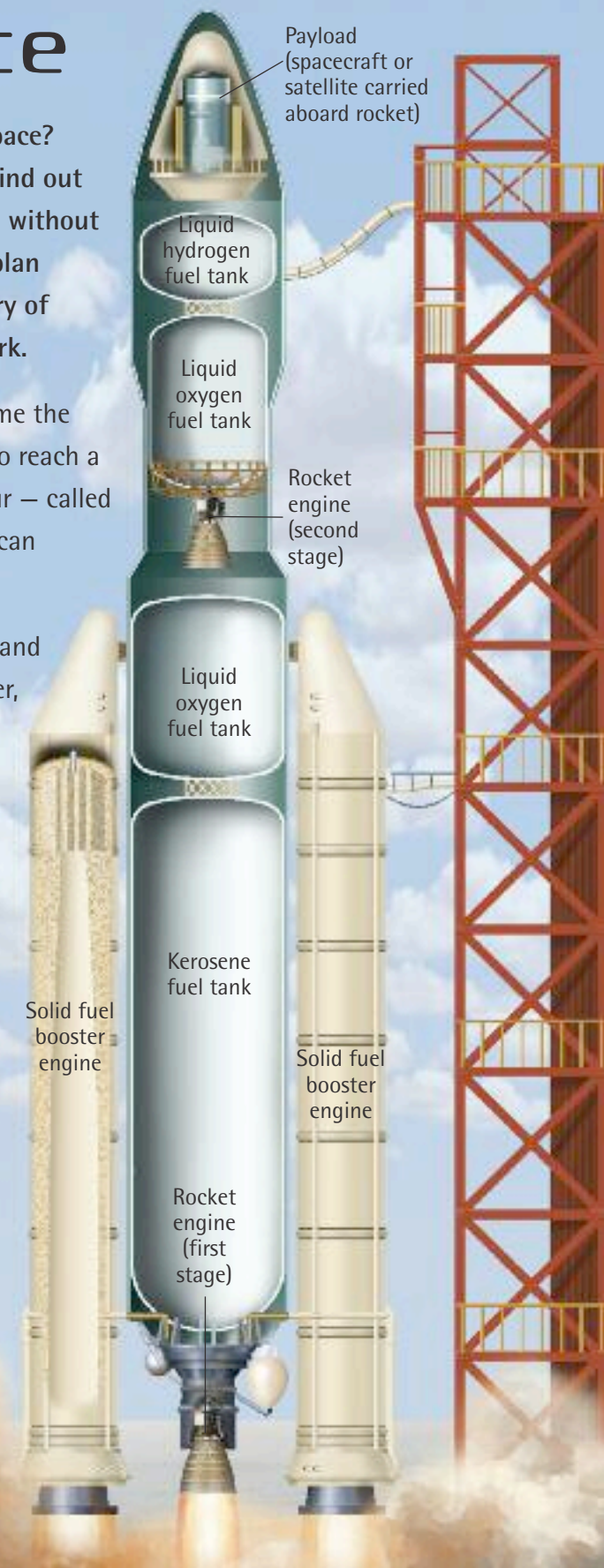
3. Into space

SO HOW can people travel into space? And how have we been able to find out so much about our Solar System without sending manned spacecraft? In order to plan your trip, you must learn about the history of space exploration and how spacecraft work.

To travel into space, a vehicle must overcome the pull of Earth's gravity. To do this, it needs to reach a speed of at least 40,320 kilometres per hour – called the escape velocity. Only powerful rockets can provide the necessary thrust.

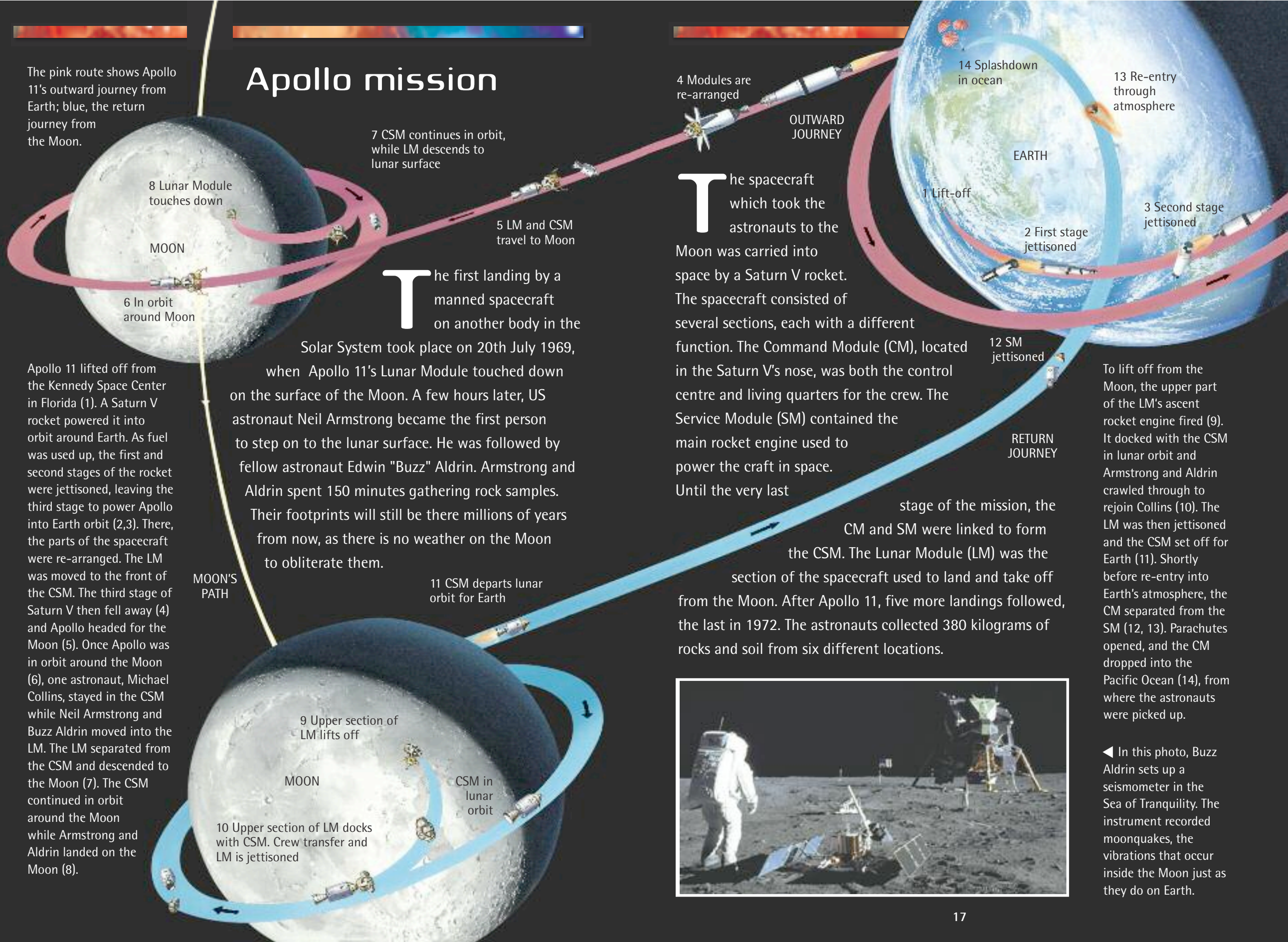
In a rocket engine, two different fuels mix and react together inside a combustion chamber, creating hot gases that rush out of a nozzle at great speed, causing the spacecraft to travel in the opposite direction. Rockets usually consist of several stages. When the fuel in one stage is burnt up, that stage is jettisoned (cast off) and the engines of the next stage fire. The rocket becomes lighter each time a stage is lost, allowing it to accelerate.

This rocket (*right*) has two stages and two solid-fuel booster engines. The first stage is fuelled by kerosene and liquid oxygen stored in tanks. To give the rocket extra thrust at lift-off, the solid fuel boosters fire as well as the first stage engine. After the boosters and first stage are jettisoned, the second stage engine, fuelled by liquid hydrogen and oxygen, fires.



Apollo mission

The pink route shows Apollo 11's outward journey from Earth; blue, the return journey from the Moon.



Apollo 11 lifted off from the Kennedy Space Center in Florida (1). A Saturn V rocket powered it into orbit around Earth. As fuel was used up, the first and second stages of the rocket were jettisoned, leaving the third stage to power Apollo into Earth orbit (2,3). There, the parts of the spacecraft were re-arranged. The LM was moved to the front of the CSM. The third stage of Saturn V then fell away (4) and Apollo headed for the Moon (5). Once Apollo was in orbit around the Moon (6), one astronaut, Michael Collins, stayed in the CSM while Neil Armstrong and Buzz Aldrin moved into the LM. The LM separated from the CSM and descended to the Moon (7). The CSM continued in orbit around the Moon while Armstrong and Aldrin landed on the Moon (8).

MOON'S PATH

9 Upper section of LM lifts off

MOON

10 Upper section of LM docks with CSM. Crew transfer and LM is jettisoned

CSM in lunar orbit

11 CSM departs lunar orbit for Earth

7 CSM continues in orbit, while LM descends to lunar surface

5 LM and CSM travel to Moon

8 Lunar Module touches down

6 In orbit around Moon

MOON

The first landing by a manned spacecraft on another body in the

Solar System took place on 20th July 1969,

when Apollo 11's Lunar Module touched down on the surface of the Moon. A few hours later, US astronaut Neil Armstrong became the first person to step on to the lunar surface. He was followed by fellow astronaut Edwin "Buzz" Aldrin. Armstrong and Aldrin spent 150 minutes gathering rock samples. Their footprints will still be there millions of years from now, as there is no weather on the Moon to obliterate them.

4 Modules are re-arranged

OUTWARD JOURNEY

The spacecraft which took the astronauts to the Moon was carried into space by a Saturn V rocket. The spacecraft consisted of several sections, each with a different function. The Command Module (CM), located in the Saturn V's nose, was both the control centre and living quarters for the crew. The Service Module (SM) contained the main rocket engine used to power the craft in space. Until the very last

stage of the mission, the CM and SM were linked to form the CSM. The Lunar Module (LM) was the section of the spacecraft used to land and take off from the Moon. After Apollo 11, five more landings followed, the last in 1972. The astronauts collected 380 kilograms of rocks and soil from six different locations.

14 Splashdown in ocean

13 Re-entry through atmosphere

EARTH

1 Lift-off

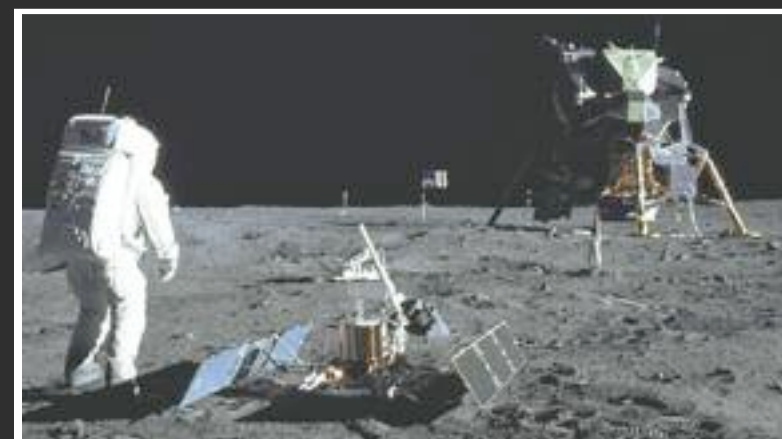
2 First stage jettisoned

3 Second stage jettisoned

12 SM jettisoned

RETURN JOURNEY

To lift off from the Moon, the upper part of the LM's ascent rocket engine fired (9). It docked with the CSM in lunar orbit and Armstrong and Aldrin crawled through to rejoin Collins (10). The LM was then jettisoned and the CSM set off for Earth (11). Shortly before re-entry into Earth's atmosphere, the CM separated from the SM (12, 13). Parachutes opened, and the CM dropped into the Pacific Ocean (14), from where the astronauts were picked up.



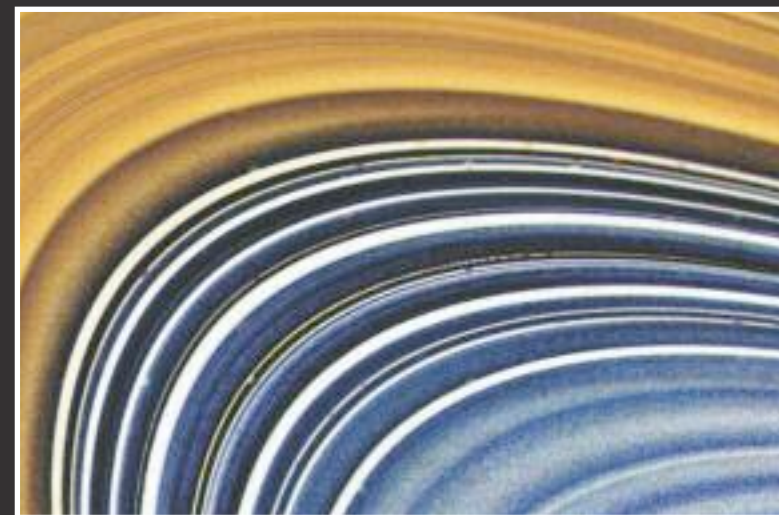
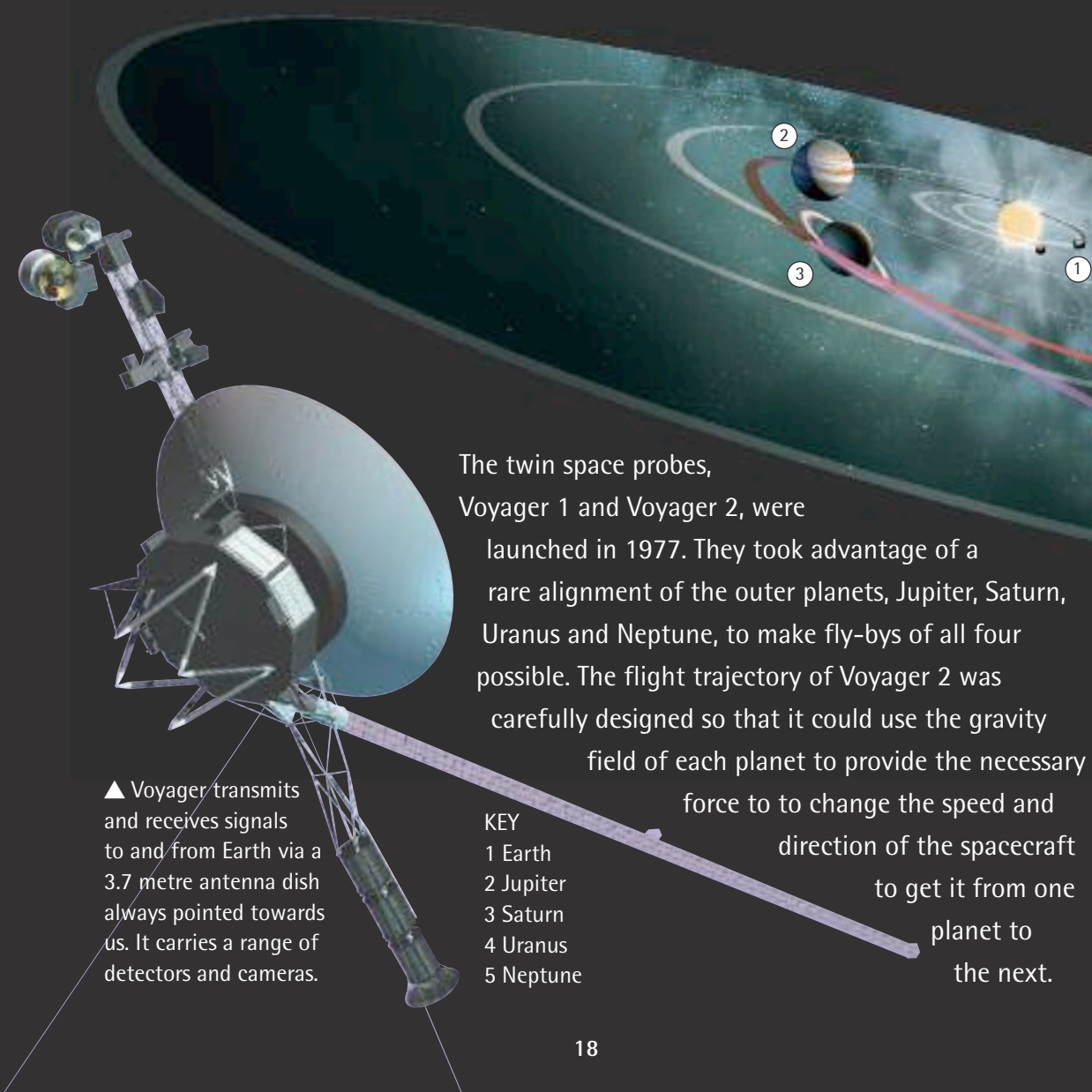
◀ In this photo, Buzz Aldrin sets up a seismometer in the Sea of Tranquility. The instrument recorded moonquakes, the vibrations that occur inside the Moon just as they do on Earth.

Making contact

In case aliens should ever come across the Voyager probes, both carry an audiovisual disc, each containing information about Earth. These include pictures and sounds, such as the calls of whales, a baby crying and greetings in 55 languages.

Space probes

Manned space missions are expensive. Most other worlds in our Solar System have environments that are too hostile or too distant for humans to explore (a trip to Neptune, for example, would take several years). In order to gather detailed information about other planets and moons, a number of space probes – unmanned, remote-controlled spacecraft – have been launched instead. Equipped with cameras and sensing equipment, they can transmit information back to Earth more cheaply and safely.

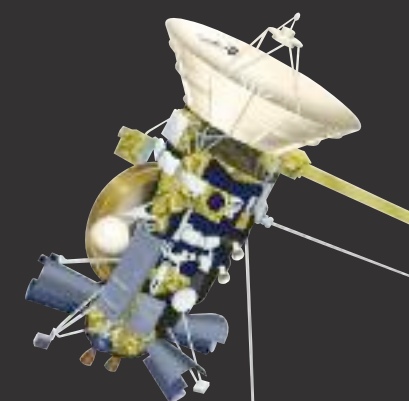


Although it took off slightly later than Voyager 2, Voyager 1 was the first to reach Jupiter in March 1979 and Saturn in November 1980. Both space probes took high-resolution images of the giants and their satellites, rings and moons.

Voyager 2 flew by Uranus in January 1986 and Neptune in August 1989, sending back amazingly clear pictures of Neptune's moon, Triton.

Initial missions accomplished, both Voyagers are now travelling out of the Solar System: Voyager Interstellar Mission is underway. They have passed through the boundary beyond which the Sun's influence ceases. Now, more than 16 billion kilometres from Earth, Voyager 1 is the most distant man-made object in the Universe. Both probes have enough electrical power to send back signals until around 2020.

◀ Although the main rings of Saturn are easily visible from Earth, the Voyager probes revealed the existence of a number of other rings. They also showed that the main ring systems were in fact made up of thousands of ringlets, each consisting of billions of blocks of ice.



▲ The *Cassini* space probe was launched in October 1997. Its objective was to study Saturn and its moons. Attached to the probe was the *Huygens* lander. It separated from the main craft and descended through the atmosphere of Titan to land on its surface in January 2005. For 90 minutes it transmitted pictures and information back to Earth. *Cassini* itself remains in orbit around Saturn.

The story of space exploration

IN ORDER TO plan your trip, you must first know the history of space exploration and how spacecraft work. The Space Age began on 4th October 1957, when the Soviet Union launched the first man-made satellite, Sputnik 1, into orbit around Earth.

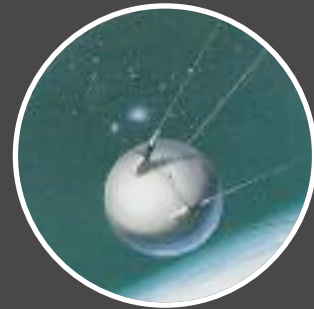
► The first liquid-fuel rocket was built by American scientist Robert Goddard in 1926.



Using gasoline and liquid oxygen for fuel, the metre-high rocket reached a height of 12.5 metres.



◀ The first long-range rocket was the V-2 missile, designed by German engineer Wernher von Braun during World War II. The 14-metre, liquid-fuelled rocket became the first man-made object in space in October 1942. After the war, von Braun worked for the US space programme.



▲ A small steel sphere weighing just 83 kg, Sputnik 1, stayed in orbit for 92 days. It sent radio signals back to Earth via its four aerials. A dog called Laika (featured in this postage stamp, below) became the first animal in orbit a month later.



▼ The Soviet cosmonaut Yuri Gagarin (*right*) made the first manned space flight in Vostok 1 (*below*) in April 1961. The spacecraft reached a height of 344 km and completed one orbit of Earth lasting 108 minutes.



Gagarin parachuted out at 7 km.



► US spacecraft Mariner 2 became the first space probe successfully to reach another planet when it flew by Venus in December 1962. From a distance of 34,800 km, its detectors captured data from Venus's surface.

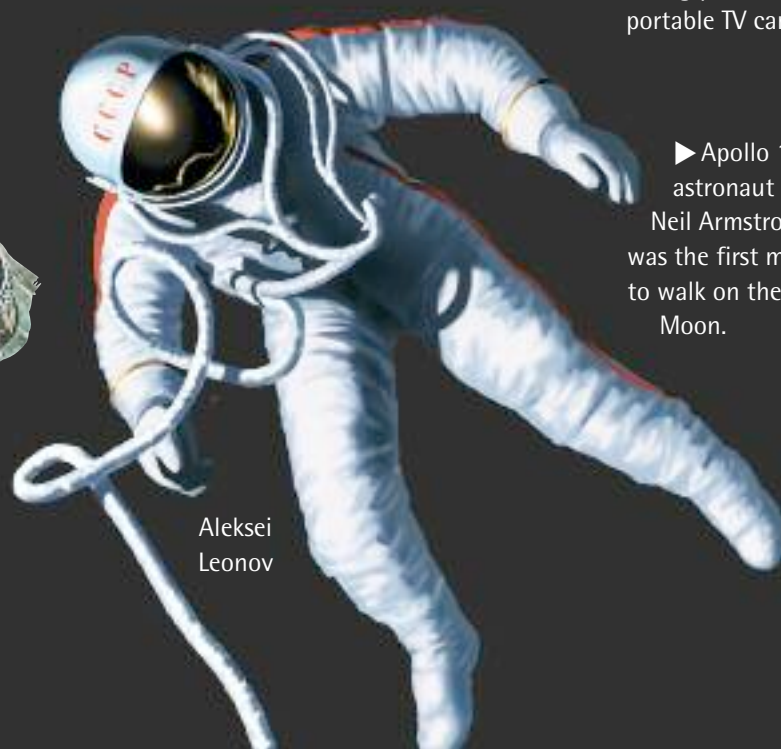


Mariner 2 flying past Venus



▲ The first woman in space was Valentina Tereshkova from the Soviet Union. She orbited the Earth 48 times on board Vostok 6 in 1963.

▼ Soviet cosmonaut Aleksei Leonov became the first human to walk in space in March 1965. He left his spacecraft, Voskhod 2, via an airlock. With the door to the spacecraft shut behind him, the airlock was de-pressurized. He then opened the exit hatch and entered space. Attached to the craft by a cable, Leonov spent 10 minutes in space, taking pictures with a portable TV camera.



Aleksei Leonov

► Apollo 11 astronaut Neil Armstrong was the first man to walk on the Moon.



▲ The first flight by a manned spacecraft to last more than a few days took place in December 1965. The purpose of Gemini 7's mission was to discover the effects of 14 days in space on the human body.



▲ The first space probe to make a successful soft landing on the Moon was the Soviet Luna 9 in 1966. It sent back TV pictures after its protective "petals" opened.

► The first landing by a manned spacecraft on another body in the Solar System took place on 20th July 1969 when Apollo 11 touched down on the surface of the Moon. The Apollo astronauts were carried into space on their way to the Moon by the 111-metre rocket, Saturn V.

Saturn V rocket

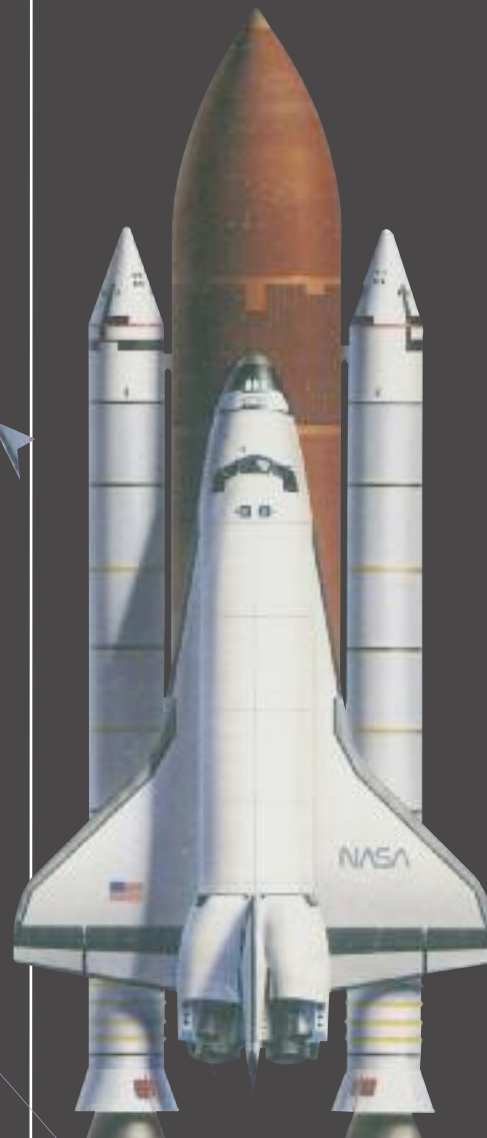


▼ The first space station, an orbiting laboratory for experiments in space, was launched by the Soviet Union in April 1971. Salyut 1 was 14.4 m long and powered by wing-like solar panels. It was manned by cosmonauts who travelled up in Soyuz spacecraft.

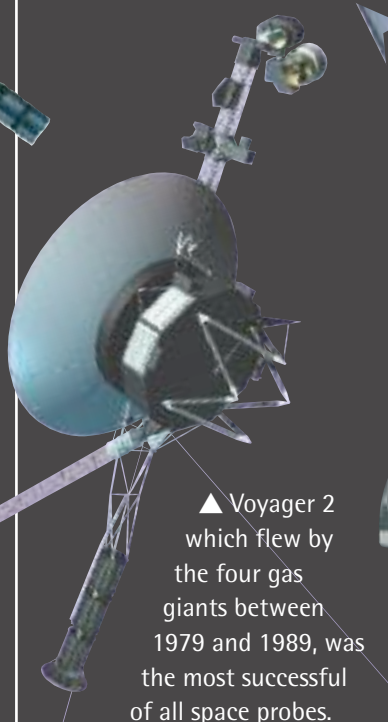


▼ The US Space Shuttle *Columbia* became the world's first reusable spacecraft when it made its second flight in November 1981. At launch, the orbiter was attached to two boosters and an external fuel tank. On completion of its mission, the orbiter glided back to Earth. Special tiles protected it from the heat on re-entering the atmosphere.

▲ The twin US probes, Viking 1 and 2 touched down on the surface of Mars in July and September 1976. They took pictures of the rocky surface, recorded weather conditions and used their robotic arms to collect soil for analysis. Although several probes had landed on Mars before, the Viking mission was the first successful one.



▲ The US space probe Pioneer 10 was the first probe to travel through the asteroid belt and fly by Jupiter. For the benefit of any intelligent aliens it may encounter, it carries on board a plaque showing the location of the Sun and planets, together with a picture of a man and a woman.

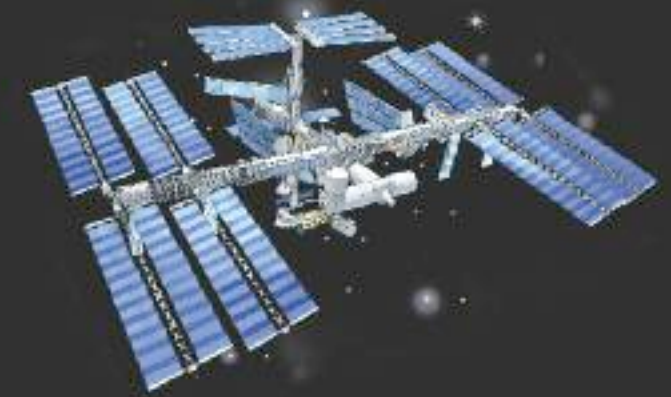


▲ Voyager 2 which flew by the four gas giants between 1979 and 1989, was the most successful of all space probes.

▼ Launched in 1989, the Magellan space probe used radar to "see" through Venus's thick atmosphere and make images of its surface.

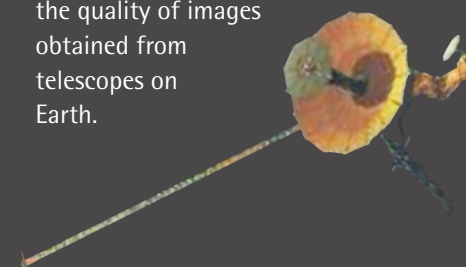


▲ Orbiting 350 km above the Earth is the International Space Station (ISS). It is made up of several modules linked together. Inside these are laboratories and living accommodation. Solar panels provide the ISS with electrical power. It is used for experiments, including the science of how living things survive in space. There is also a docking port for visiting spacecraft.



▼ The *Cassini* space probe was launched in 1997 and entered the orbit of Saturn in 2004. In January 2005 it released a lander probe, *Huygens*, bound for Saturn's moon, Titan. During its entry of Titan's atmosphere, it was protected against high by a heat shield. A parachute was deployed to slow its descent and permit a soft landing on Titan's surface.

▲ Launched in 1990, the Hubble Space Telescope is an unmanned observatory. From its orbit 616 km above Earth, the pictures it receives of distant regions of space are unaffected by atmospheric disturbance, which reduces the quality of images obtained from telescopes on Earth.



▼ The Galileo space probe entered into orbit around Jupiter, the first probe to do so, in 1995. It carried a small descent probe, which it released into Jupiter's atmosphere, from where it sent back data. Other detectors and cameras took images of Jupiter and its moons.





▲ Mars Global Surveyor (MGS) went into Martian orbit in 1997. It studied the surface of Mars, sending images of gullies that indicate liquid water must have flowed on the surface in recent geological history. Mars Reconnaissance Orbiter took over from MGS in 2006. Its HiRISE camera can identify objects as small as dinner plates from 300 km away. Other instruments can detect water and ice on or below the surface.



▲ The Mars Space Laboratory, called *Curiosity*, launched in 2011. Its objective is to find out whether Mars is, or has ever been, capable of supporting microbial life.

► Enduring duststorms and rocky terrain, *Spirit* and *Opportunity* have each travelled more than 10 km. Powered by solar panels, each rover is equipped with cameras and a robotic arm.

Exploring Mars

After the Moon, the next most likely target for a manned space mission is Mars. The Red Planet has already been the object of some 40 space probe missions, as a result of which orbiters, landers and rovers have sent back detailed pictures of the Martian surface.

The first probes to land on Mars and complete their missions were the US Viking 1 and Viking 2 probes, in 1976. Along with the first colour photos of the Martian surface, they sent back information that showed for the first time how Mars's landscape had been sculpted by running water. The first rover, *Sojourner*, was carried by the Mars Pathfinder which landed in 1997. It was followed by the twin rovers *Spirit* and *Opportunity*, which landed in 2004. *Opportunity* is still operating in 2012. The *Phoenix* lander was the first to visit the polar region of Mars, where it witnessed snow falling.



▲ An image taken by Spirit showing its tracks in the soil.



5. Destination Mars

A KEY OBJECTIVE of the Mars Mission is to find definitive evidence of whether living things once inhabited the Red Planet. The existence of liquid water is key to the presence of life. Thin clouds of water vapour or early morning surface frosts can sometimes be seen on the surface of Mars. Furthermore, canyons, beaches, and dried-up river and lake beds indicate that there was once liquid water on Mars.

From the evidence of sediments – muds and silts deposited by water – it seems probable that there were once rivers, lakes and even seas on Mars. This makes Mars a possible candidate as the only other planet where life was present in the past. If it can be proved that water currently exists in liquid form under the ground or beneath polar ice caps, then it is possible that life-forms might even inhabit the planet today. Recent observations suggesting that gullies on some steep slopes are being formed by the occasional rapid flow of liquid water at the surface, may indicate the presence of underground water in a liquid state for at least some part of the Martian year.



▲ In 1996, researchers found what looked like a fossil microbe in a meteorite from Mars. But the evidence is far from convincing.



▲ The only water left on the surface today is frozen in polar ice caps, patches of ice inside craters, or as a frozen layer below ground.

▼ The slopes of this Martian valley are etched by gullies, with fans of sediment at the bottom. On Earth, these would have been formed by running water.



Landing site

Here is a map of your destination: a region of Mars called the Shalbatana Vallis, selected because of the strong likelihood that water once flowed along this canyon – and collected in a lake, or even a nearby ocean.

A further reason for selecting this region is that the local bedrock contains minerals such as haematite that are known to have been formed in the presence of liquid water. Nearby are sedimentary rocks of the type in which fossils are known to occur on Earth. The terrain is also level, and not too difficult to roam across.

The Chryse Planitia is a low-lying, circular plain in the equatorial region of Mars. A number of valleys lead into it, suggesting it once formed the floor of a large lake, or even part of an ancient ocean. Within a wide stretch of one of these adjoining valleys, Shalbatana Vallis, there is strong evidence of a former shoreline. A landing site near where the Shalbatana Vallis opens out on to the Chryse Planitia would therefore be an excellent choice for a mission base.

SHALBATANA VALLIS

Chryse Colles

SHALBATANA
LAKE
(former shoreline)

SHALBATANA VALLIS

CHRYSE
CHAOS

✗ LANDING SITE

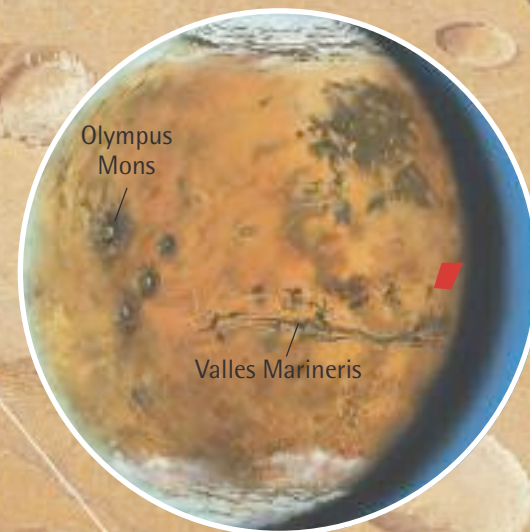
CHRYSE
PLANITIA

XANTHE TERRA

In many areas on Mars, there is a jumble of ridges, cracks, hummocks, plains and valleys. This "chaos terrain", as it is called, was probably caused by the sudden release of large volumes of water across the surface.

Shalbatana Vallis

Scientists are convinced that the shoreline discovered in the Shalbatana Vallis (here marked with a dotted white line) was once that of an ancient lake 200 square km in area and 450 m deep. A river that flowed along the 50-km-long canyon opened out into a lake that filled the wide valley. As it flowed into the lake, the river deposited sediments and divided into a number of smaller channels, forming a delta. The remains of this delta are visible today. Deltas on Earth are often muddy, marshy areas with an abundance of different plants and animals. Although Shalbatana Lake has long since dried up, there could also be fossil evidence of a past environment teeming with life.



▲ The area of the main map is shown in red on this global view of Mars. Each grid square measures approximately 100 km x 100 km.

Mission profile

This is your mission profile — a plan of the route your spacecraft will take from Earth to Mars and back, together with a list of manoeuvres to be carried out on the way.

The numbers in discs (below) indicate the points at which manoeuvres are carried out. Cargo vehicles (yellow) are launched in November–December 2034; crew vehicles (green) in January–February 2037. The mission is to have a “fast” (six-month) trajectory (top right). Lift-off from Earth will be timed so that the distance between the two planets is as short as possible. The crew will spend 500 days living and working on Mars—the period of time that elapses before Earth and Mars are once again favourably positioned for a short journey home.

CARGO VEHICLES (yellow)

1 Four *Mirihi 1* cargo launcher rockets lift off. Each carries: Ascent Vehicle (AV); Nuclear Thermal Rocket (NTR); Surface Habitat Unit (SHAB); NTR

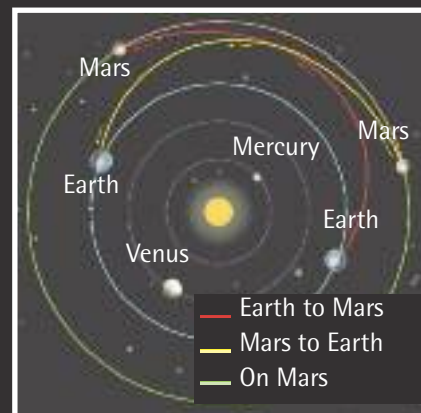
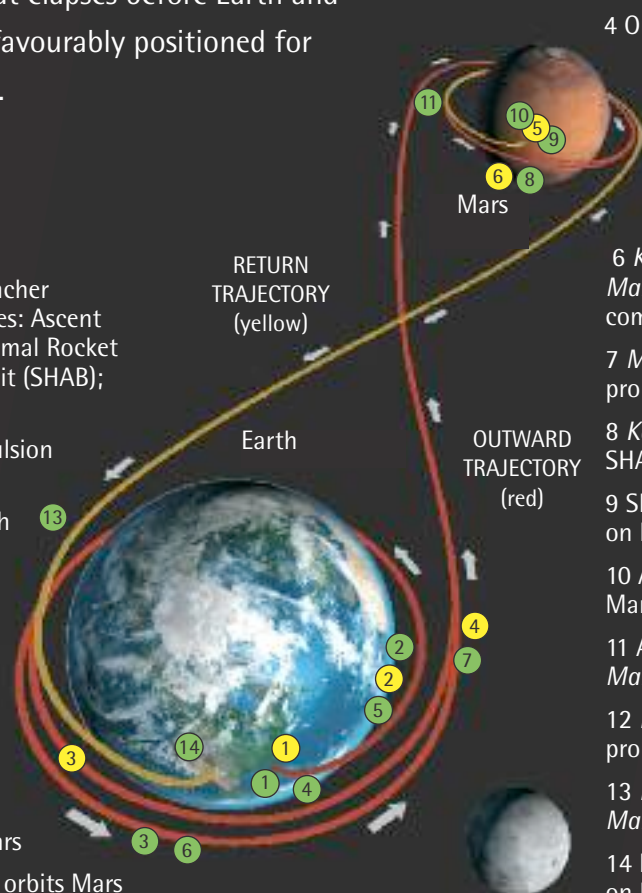
2 Boosters and core propulsion stage are jettisoned

3 In Low Earth Orbit, Earth Departure Stage (EDS) jettisoned; aeroshell containing AV docks with NTR; aeroshell containing SHAB docks with NTR

4 AV and SHAB propelled towards Mars

5 AV jettisons NTR and aeroshell and lands on Mars

6 SHAB jettisons NTR and orbits Mars



CREW VEHICLES (green)

1 Three *Mirihi 1* cargo launcher rockets lift off in sequence. They each carry: Mars Transit Vehicle (MTV) *Mangala*; fuel tank; NTR

2 Boosters, core propulsion stage and EDS are jettisoned

3 In LEO, MTV, fuel tank and NTR are assembled and dock at International Space Station (ISS)

4 One *Mirihi 2* launcher rocket lifts off, carrying Crew Module, *Kasei*

5 First and second stage jettisoned

6 *Kasei* docks with *Mangala* and other components at ISS

7 *Mangala/Kasei* propelled towards Mars

8 *Kasei* docks with SHAB in Mars orbit

9 SHAB touches down on Mars, close to AV

10 AV lifts off from Mars

11 AV docks with *Mangala* in Mars orbit

12 *Mangala/Kasei* propelled towards Earth

13 *Kasei* separates from *Mangala*

14 *Kasei* touches down on Earth

5. Equipped for space

FROM THE MOMENT the *Mihiri 2* rocket lifts off, to the time the Crew Module, *Kasei*, lands back on Earth two-and-a-half years later, the astronauts will be subjected to environments inhospitable to humans. The air in their habitat modules will be kept at the correct temperature, pressure and oxygen levels, but when walking on the surface of Mars a special suit will be required. It must be flexible so the astronauts can move easily, and will work as a mobile human environment with a range of safety devices should anything go wrong.

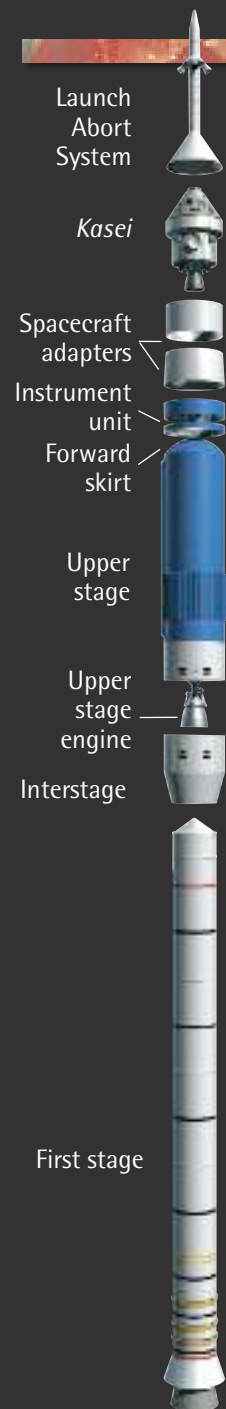


▲ Worn as a backpack, the Life Support System (LSS) regulates the oxygen supply and removes carbon dioxide breathed out. Prior to walking on Mars, crew members must “pre-breathe” pure oxygen to remove nitrogen from their blood. This prevents painful decompression sickness. The backpack also contains a transmitter linked to the Mars base (SHAB) and Mission Control, constantly providing data from the HUT body sensors.



▼ A fully fitted spacesuit consists of several layers of material. On the outside is a tough fabric to protect against damage from dust storms and to insulate the suit from extremely cold temperatures. Inside is a Liquid Cooling and Ventilation Garment (LCVG), a double-layered bodysuit containing a network of fine, water-carrying tubes. This water is pumped around the garment to remove excess heat. Underneath is a Maximum Absorbency Garment (MAG) to absorb and hold body waste hygienically.

The Hard Upper Torso (HUT) is a toughened fibreglass shell to which the various “limbs” of the suit are attached, as well as the helmet and the Life Support System backpack. The HUT contains sensors for heart rate, respiration, body temperature, suit temperature and humidity.



▲ *Mihiri 2* is designed to launch the *Kasei* module. The first stage is a re-usable solid-fuel rocket. The upper stage is propelled by a rocket engine fuelled by liquid hydrogen and liquid oxygen.

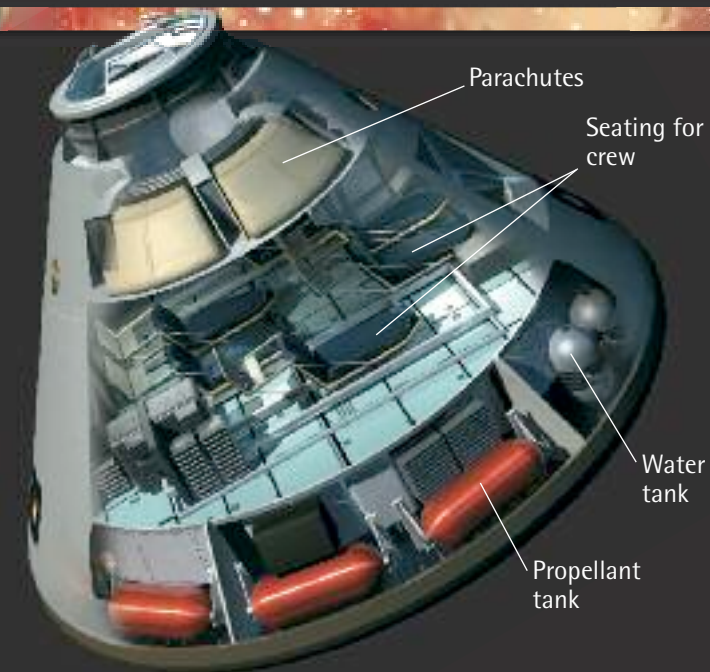
Mars Transit Vehicle

The Mars Transit Vehicle (MTV) is given the name *Mangala*, the word for Mars in Sanskrit, the ancient language of India. *Mangala* will ferry the astronauts from the International Space Station in Earth orbit to Mars orbit, from where the crew transfer to the SHAB. She remains in Mars orbit until the astronauts return from the surface in their Ascent Vehicle and dock with her. *Mangala* then travels back to Earth.

Mangala is made up of several components linked together: the Crew Module, called *Kasei*, the Transit Habitat Unit (TransHab) where the crew live during the trip to Mars orbit; a solar panel array, which provides electric power; the propulsion stage.



Mangala's propulsion stage consists of a Nuclear Thermal Rocket (NTR) and a tank containing liquid hydrogen, which provides fuel for the Trans-Martian Injection (TMI). When *Mangala* is ready to set off from the ISS, the NTR ignites, propelling her towards her destination at a speed of 100,000 kilometres per hour.



◀ The Crew Module, *Kasei*, is equipped with digital control systems, including an autodock feature, in which computers handle the docking manoeuvres. Manual piloting takes over in emergencies. Oxygen tanks provide breathing air at sea-level pressure, with a small "surge tank" for life support during re-entry and touchdown. *Kasei* is also fitted with a vacuum-driven toilet.

Crew Module

The Crew Module is given the name *Kasei*, the word for Mars in Japanese. *Kasei* carries the crew of six astronauts into space propelled by the *Mihiri 2* rocket launcher. At the ISS in Earth orbit she docks with the MTV, *Mangala*, and remains linked until the spacecraft arrives in Mars orbit. Here *Kasei* is used to transfer the crew to SHAB. Her final role is to take the crew down through Earth's atmosphere to the surface at the end of the Mission.



▼ *Kasei* consists of two parts: a Crew Module (CM) capable of holding up to six crew members and a Service Module (SM) containing the engines and supplies. On lift-off, it is connected to the Launch Abort System (LAS). Should problems arise during the ascent, the LAS ignites and pulls the CM clear of the malfunctioning rocket, allowing the CM to parachute safely down to the Earth's surface.

▼ The cargo aboard *Mirihi 1* (in this case, the AV), also known as the payload, is safely contained within an aeroshell, or shroud. This remains in place to protect the payload from the intense heat generated as it descends through the Martian atmosphere

AV (payload)

Aeroshell "exploded" to show payload inside

Jettisoned

During launch of *Mirihi 1*, the boosters and second stage engines together power the vehicle into space. After their fuel is spent, these stages are jettisoned. The EDS engine then takes over, providing the propulsion necessary to put the vehicle into LEO. The EDS is then itself jettisoned and the component, still in its aeroshell, docks with one of the NTRs

Heatshield with protective coating (black)

Earth Departure Stage (EDS)

Interstage cylinder

Cargo launcher

The rockets that launch both cargo and crew on the Mars Mission are given the name *Mirihi*, the word for Mars in Swahili, a language of East Africa. *Mirihi 2* launches the Crew Module, while a series of *Mirihi 1* rockets carry the Mars Ascent Vehicle (AV), the Surface Habitat Unit (SHAB), the Mars Transit Vehicle (MTV) and a Nuclear Thermal Rocket (NTR) to attach to each of them, into orbit around Earth.

The *Mirihi 1* is a three-stage rocket: the first and second stages burn together. The liquid-fuelled second stage has five engines connected to its tanks of liquid oxygen and liquid hydrogen. The upper stage is known as the Earth Departure Stage (EDS). It provides the propulsion needed to send its cargo, called the "payload", into Low Earth Orbit (LEO).

AV

SHAB

◀ The AV, sent directly to Mars ahead of the crew, will be the spacecraft they use to lift off from Mars. SHAB is sent to wait in orbit around Mars. It will serve as both a lander to put the crew on to the surface of Mars, and as a place to live while they are there.

The first series of four *Mirihi 1* launches takes place 26 months before the Crew Module is launched by *Mirihi 2*. The AV and SHAB components are carried into LEO during the first two launches; here they each dock automatically with an NTR sent up in the second two launches. The engines fire, propelling both vehicles on their way to Mars, the payloads still inside their aeroshells. The second series of three *Mirihi 1* launches carry the various components of the MTV, *Mangala*, into LEO, where they are assembled and dock at the ISS.

▼ *Mirihi 1*'s rocket engine burns liquid hydrogen and liquid oxygen piped into its combustion chamber. Exhaust gas is blasted out through a nozzle, creating thrust.

Solid rocket booster

Second stage (core propulsion stage)

▲ The twin reusable solid rocket boosters of *Mirihi 1*'s first stage flank the single, liquid-fuelled second stage, known as the core propulsion stage. Above this is an interstage cylinder containing booster separation motors and a forward adapter that connects it to the upper stage, or EDS. Anchored to the top is the cargo inside its aeroshell.

Solid rocket booster

Engines

▼ The buggy is steered by verbal commands or hand signals. It can go up steep slopes and climb over 30-cm rocks.

Surface transport

Once on Mars, the team will often need to travel away from their base. For short trips, a battery-powered buggy is the ideal vehicle (*left*). For longer journeys, the astronauts are supplied with a modular rover that has sufficient interior space for them to work and sleep inside (*below*). The rover will be shipped inside SHAB in parts that can be easily assembled on Mars. It consists of several modules that can be swapped according to the requirements of the mission, including a crane for heavy-lifting, robotic arms and a laboratory. The rover is powered by radioisotope thermo-electric generators (RTGs). The slow decay of small pellets of radioactive material produces heat that can be turned into electricity. This avoids depending on solar panels, which are liable to fail when Mars's frequent storms cover them with dust.

▼ The astronauts operate robotic arms attached to the outside of their rover. The windscreen is shaped to provide a wide view so the driver can navigate safely across boulder-strewn plains.



6. The mission

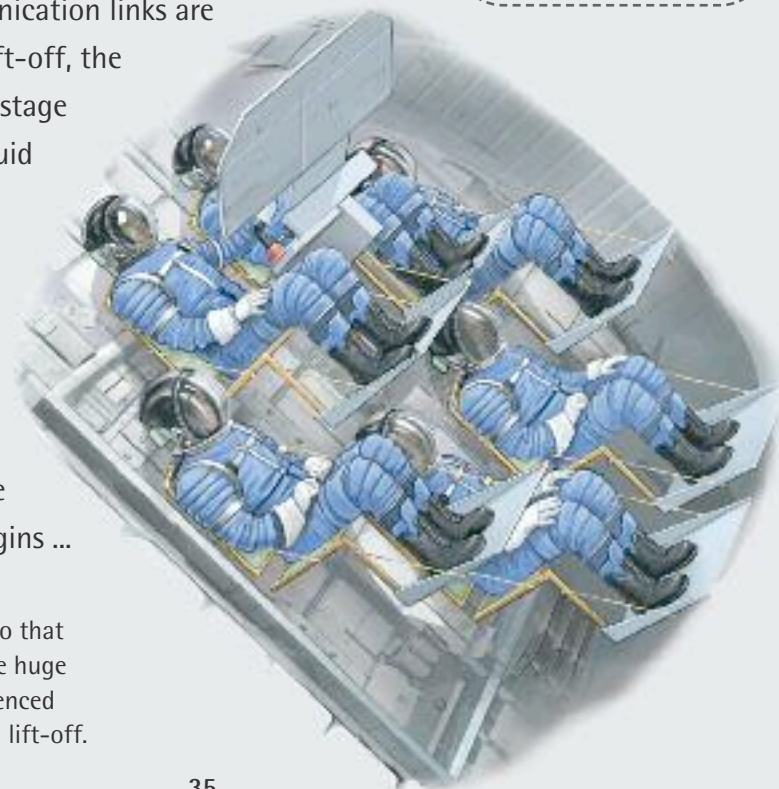
ALL THE EQUIPMENT is in place, your spacecraft and crew are ready and Mission Control is about to issue instructions for countdown to begin. It is now down to you and your team to undertake this historic journey. You must understand all the manoeuvres involved at take-off, the link-up at the International Space Station, the docking procedure in orbit and the safe descent to the planet itself. You must also be trained to carry out various tasks once you have landed on Mars.

Once all the parts arrive at the launch pad, the Mars Mission launch campaign begins. There are 21 days to go before lift-off. The parts are assembled in the vehicle assembly building. A crawler-transporter vehicle then carries the rocket stack, the launch support tower and the launcher platform to the launch pad. Countdown to lift-off, now just six hours away, begins. The flight program is loaded into the onboard computers and radio communication links are checked. Five hours before lift-off, the ground crew fills the second stage with liquid hydrogen and liquid oxygen fuel. Engineers make the site ready for launch and personnel are evacuated from the area. The crew enters the spacecraft three hours before lift-off. When everything is satisfactory, the final stage of countdown begins ...

► The astronauts are tipped back so that their bodies can withstand with the huge gravitational force, g-force, experienced when the spacecraft accelerates on lift-off.

The crew

The astronauts are an international team of men and women, trained to carry out a wide range of scientific experiments to be undertaken during the Mission. Their preparation includes rigorous survival courses, weeks spent living in underwater laboratories and enduring long periods in high-altitude conditions. Just as important as their training are the astronauts' personalities. Being able to remain cheerful and even-tempered will equip them for living and working closely with five others in isolation for up to two-and-a-half years.



Mission Control

The entire mission is managed by Mission Control, a team based on Earth. They maintain contact with the crew at all times, issuing instructions and checking on their well-being. They also monitor the computers that handle key manoeuvres, such as landing and take-off.

Launch Abort System and fairings covering *Kasei* jettisoned

Second stage rocket engines ignited

Lift-off

With three minutes to go, the ignition sequence is started.

The flame trenches in the pad directly beneath the rocket engines are flooded with water both to cool the ground and to reduce noise: excessive vibrations can damage the spacecraft. Now the onboard computers are authorized to take over. The solid rocket engine is ignited. There are just a few seconds to go: "Ten, nine, eight...."

Mirihi 2 lifts off

"We have lift-off!" The rocket engine blasts *Mirihi 2* skywards. Two minutes later, the solid fuel is already used up and the first stage is jettisoned. An interstage component that connects *Mirihi 2*'s two stages is equipped with booster separation motors to disconnect them during ascent. The first stage is re-usable, so parachutes open to slow its descent to the ocean where it is later recovered.

Kasei separates and second stage is jettisoned

Now the liquid-fuelled second stage engine is ignited. About 30 seconds later, spring-operated latches open and both the Launch Abort System and the fairings covering the command and service modules are jettisoned. Five minutes 30 seconds after lift-off, the second stage engine cuts off, and *Mirihi 2* enters an initial entry orbit. About 45 minutes later, there is a second burn of the engines, after which the *Kasei* module separates, leaving the second stage to burn up in the atmosphere. *Kasei* then extends a pair of solar panels: these will provide the module with electrical power.

After two days in orbit, *Kasei* approaches the International Space Station. Once it has received the go-ahead from Mission Control, *Kasei* docks with the Mars Transit Vehicle (MTV) already assembled at the ISS. The crew stays at the ISS, acclimatizing to zero-gravity and preparing themselves for the long journey ahead.

▼ Before *Mirihi 2* took off, several earlier *Mirihi 1* launches transported the various components of the MTV into Earth orbit. The first launch carried the Transit Habitat Unit, the second, a fuel tank and the third, a nuclear thermal rocket (NTR). The components were all assembled at the ISS, where they are now docked in readiness for the arrival of the crew in *Kasei*.

Kasei

International Space Station (ISS)

Mars Transit Vehicle, docked at ISS

Kasei approaches ISS

In transit

The astronauts enter the Mars Transit Vehicle, named *Mangala*. Its Nuclear Thermal Rocket engine fires and propels the spacecraft on its way to Mars. The crew take up residence in the Transit Habitat Unit, known as TransHab. The Unit's interior is given over completely to living and storage space.

This will be the astronauts' home for the next six months, the duration of their flight to Mars.

TransHab's outer layer is a 30-centimetre-thick inflatable shell made up of more than 20 individual layers. They are designed to break up particles of space debris and meteorites that are liable to strike the shell at speeds more than seven times as fast as a bullet. They also seal in the module's breathing air, protect it from harmful radiation and provide insulation from temperatures that can range from 121°C (in full Sun) to -128°C.

The lowest level houses a kitchen with a large communal table. There is also an exercise area with a moving walkway and stationary bicycle. Exercise is vital to keep the astronauts healthy in weightlessness for long periods. On level two are the crew's quarters. Each of the six separate cabins contains a special sleeping bag, designed for sleeping in zero-gravity. There is space for each astronaut to spend time to themselves, reading or at their PCs. The mechanical room on the top level consists of life support systems, water tanks, airflow ducts and power equipment.

TransHab is equipped with a complete health-care system. In an emergency, computers and a robotic surgeon can help one crew member carry out a medical operation on another. There are viewing windows on all levels.

▲ The MTV, *Mangala*, with the *Kasei* module still docked at its top end, fires its Nuclear Thermal Rocket engine and sets off from the ISS for the Red Planet. Soon, the engine is switched off. Once *Mangala* has escaped from Earth's gravity, it will keep going at a constant speed. Ahead of the astronauts lies a trip of around 450 million kilometres. Even travelling at a speed of 100,000 km/h, the journey will take about six months.

TransHab

The TransHab is a hi-tech but also comfortable living environment. All water and waste from the bathroom facilities is recycled. Computers maintain ideal conditions and alert Mission Control to any problems.

Kasei
docked to
Mangala

Mechanical
room

Crew's
quarters

Kitchen and
exercise area

Viewing
window

A central passageway connects all three levels inside the TransHab. It also runs through to a pressurized tunnel area, the passageway between TransHab and the other parts of *Mangala*.

Solar
panels

Cargo vehicles

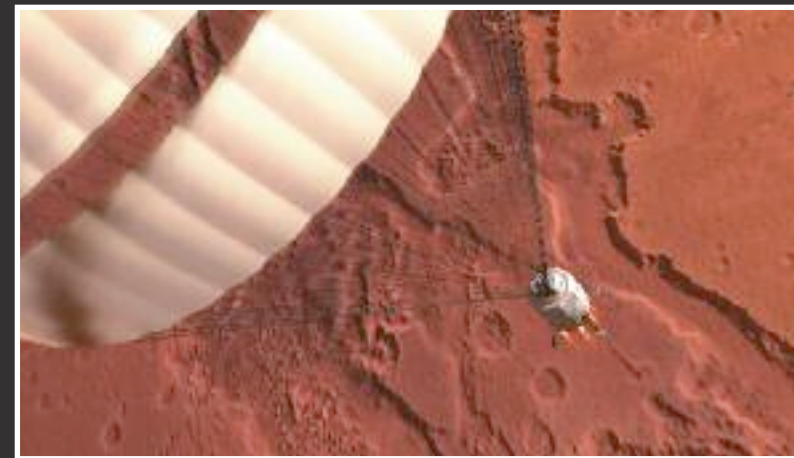
How did Surface Habitat Unit (SHAB) and the Ascent Vehicle (AV) get to Mars before the crew arrived? A pair of cargo vehicles carrying these units were launched by *Mirihi 1* rockets 26 months earlier. Each travelled to Mars with its own NTR (Nuclear Thermal Rocket) attached. The AV landed on Mars, while SHAB was put into Mars orbit. The AV began the manufacture of fuel immediately on landing. When the process was complete, it signalled to Earth that it was ready. Were the fuel production process to have failed, the launch of the crew's spacecraft would have been aborted.

Touchdown on Mars

Six months later, *Mangala* at last approaches Mars. The Red Planet will have been getting larger and larger in the viewing windows, and now its globe dominates the sky.

Now there are some important manoeuvres to undertake. Firstly, *Mangala* must slow down from its travelling speed of 100,000 km/h. To achieve this, she dips into the outer layer of the Martian atmosphere which, although much thinner than Earth's atmosphere, is still denser than the empty space *Mangala* has been travelling through. The gas molecules in the atmosphere create a drag force and *Mangala* begins to lose speed. This process is known as aerobraking.

Mangala goes into orbit round Mars. Here she meets up with another important component of the Mars Mission: the Surface Habitat Unit, known as SHAB. This had been launched by a *Mirihi 1* rocket before the crew set off; it was left in orbit around Mars waiting for *Mangala's* arrival.



As soon as the two spacecraft lie close, the crew transfers to *Kasei*, which separates from *Mangala* and moves to dock with SHAB. The astronauts climb through to SHAB. *Kasei* is needed on the way home for Earth entry, so she pulls away again and re-docks with *Mangala*. *Mangala* will continue in orbit around Mars for the period that the crew are on the Martian surface: around 500 days.

SHAB now starts its descent. It travels through the Martian atmosphere with the aeroshell's heat shield pointing downwards. Once the heat of entry eases, about 10 km above the surface, this protective aeroshell is discarded. Computer navigation systems direct the SHAB to just a few tens of metres away from the Ascent Vehicle. Small rockets fire to steer it accurately to the landing site.

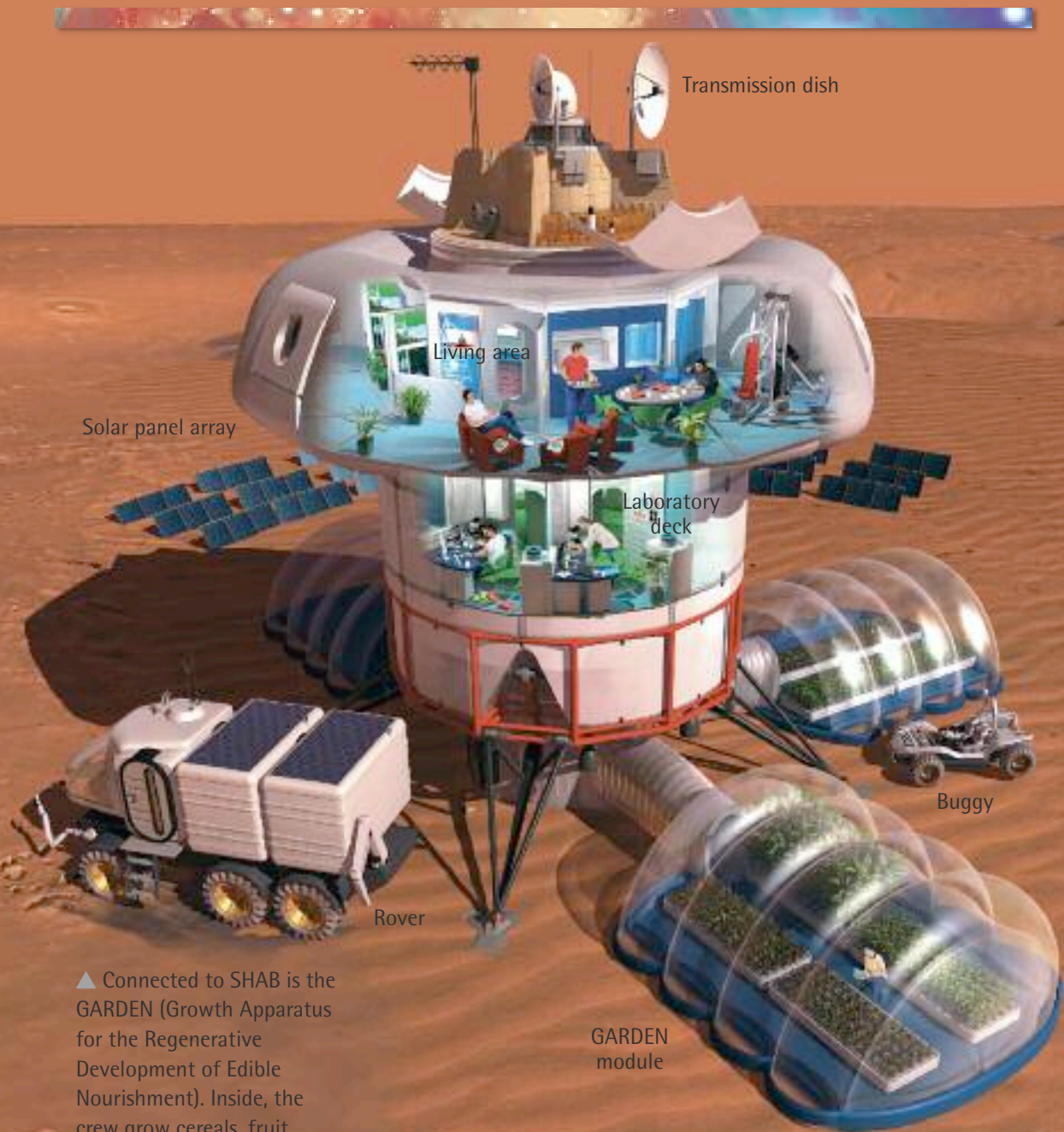


◀ The craft is slowed to a speed of just hundreds of km/h by the friction provided by the carbon dioxide molecules in Mars's atmosphere. SHAB now tilts up vertically and its parachutes open. Fifty metres above the ground, SHAB's chutes are jettisoned and its retro rockets fire up. These ensure that the very last part of the descent is made at a safe landing speed.

Time delay

Because of the great distance between Mars and Earth, radio communications between the crew and Mission Control are delayed by around 20 minutes.

◀ The moment the world has been waiting for. Watched by billions of viewers back on Earth, the astronauts take the first steps made by a human being on another planet.



▲ Connected to SHAB is the GARDEN (Growth Apparatus for the Regenerative Development of Edible Nourishment). Inside, the crew grow cereals, fruit and vegetables. Besides providing food, this is a valuable experiment to see whether plant-production on a larger scale is possible in the future. All gases and water vapour given off by the plants are recycled. Fresh oxygen is piped into SHAB as breathable air, while waste from SHAB is routed into the GARDEN.

On Mars

The SHAB is designed to make living in a lonely, cold, barren world as comfortable as possible for the team. It has three decks. The upper deck has a bedroom each for the crew members, a gym, a bathroom, an open living area and a kitchen. Although most of their food is frozen, they eat fresh fruit and vegetables they have grown themselves. They even bake their own bread.

On SHAB's second deck there is a laboratory for carrying out geology and life science research. There is also storage space for samples, airlocks for exiting on to the surface of Mars and a suiting-up area where crew members prepare for stepping out. Below that there is a parking bay for the rovers.

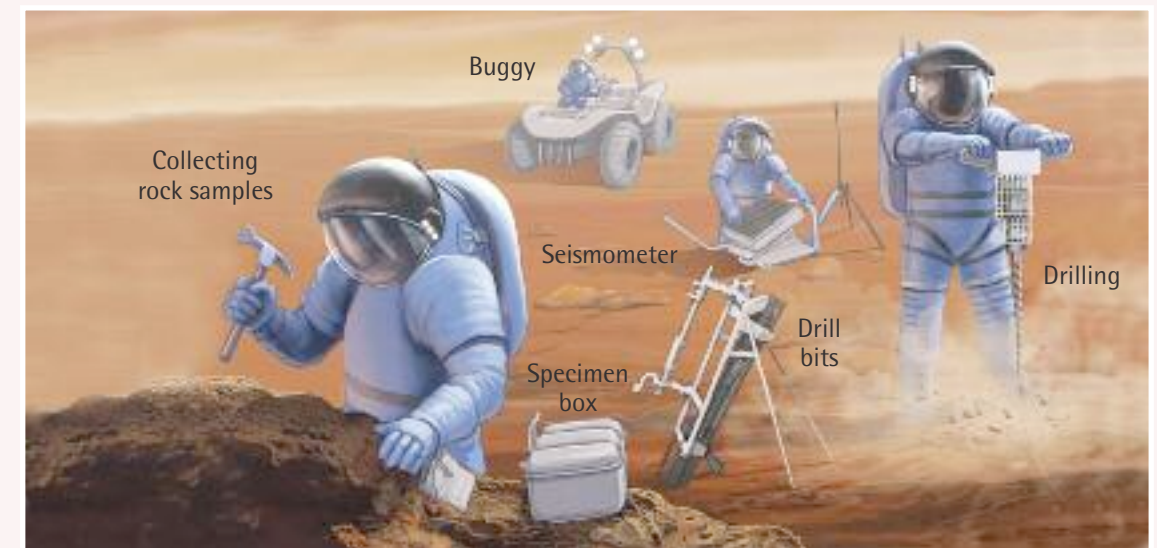
The main purpose of the Mars Mission is, of course, to gather as much information about the planet as possible. The crew are carefully directed by experts on Earth via Mission Control radio links. Most of the tasks they perform are geological: they set up a seismometer, an instrument for recording quakes and which provides much information about Mars's interior. They also drill for water that might exist underground and collect samples of rock that might contain fossils (*below*).



◀ The team sets up a weather station. Powered by solar panels, it sends information back to Earth via satellites in orbit around Mars. A weather balloon is launched to record data from high altitudes.

Mars to Stay

Mars to Stay is the proposal by which future astronauts who travel to Mars stay for the rest of their lives and establish a permanent settlement. Later missions would swell the number of people on Mars to 30. Large, underground habitats would be built – the first step toward human colonization of Mars.



Valles Marineris

More than 4000 km long, 200 km wide and up to 7 km deep, the Valles Marineris rift valley is larger than any canyon on Earth. It is located just south of the Martian equator, southwest of the Shalbatana site. It is a large crack in the Martian crust, formed as the crust bulged in the Tharsis region to the west. It was later widened by erosion. Running into it are some channels that appear to have been carved by running water.

Exploring Mars

The team has carried out extensive research of the area around their landing site, within the safe operating distance of their Exploration Rover. Now the crew members conduct surveys of regions further afield. They include: the Tharsis Bulge, a massive volcanic plateau where the Solar System's largest volcanoes, including Olympus Mons, are located; Mars's distinctive "chaos" terrain, a jumble of ridges, cracks and plains found all over the planet; the polar ice caps; and Valles Marineris, a massive system of canyons stretching east-west a quarter of Mars's circumference. To get there, the crew assembles an inflatable dirigible (a small airship) stowed on board the SHAB. Filled with hydrogen and powered by electric motors linked to solar panels, the airship flies easily in Mars's thin atmosphere.

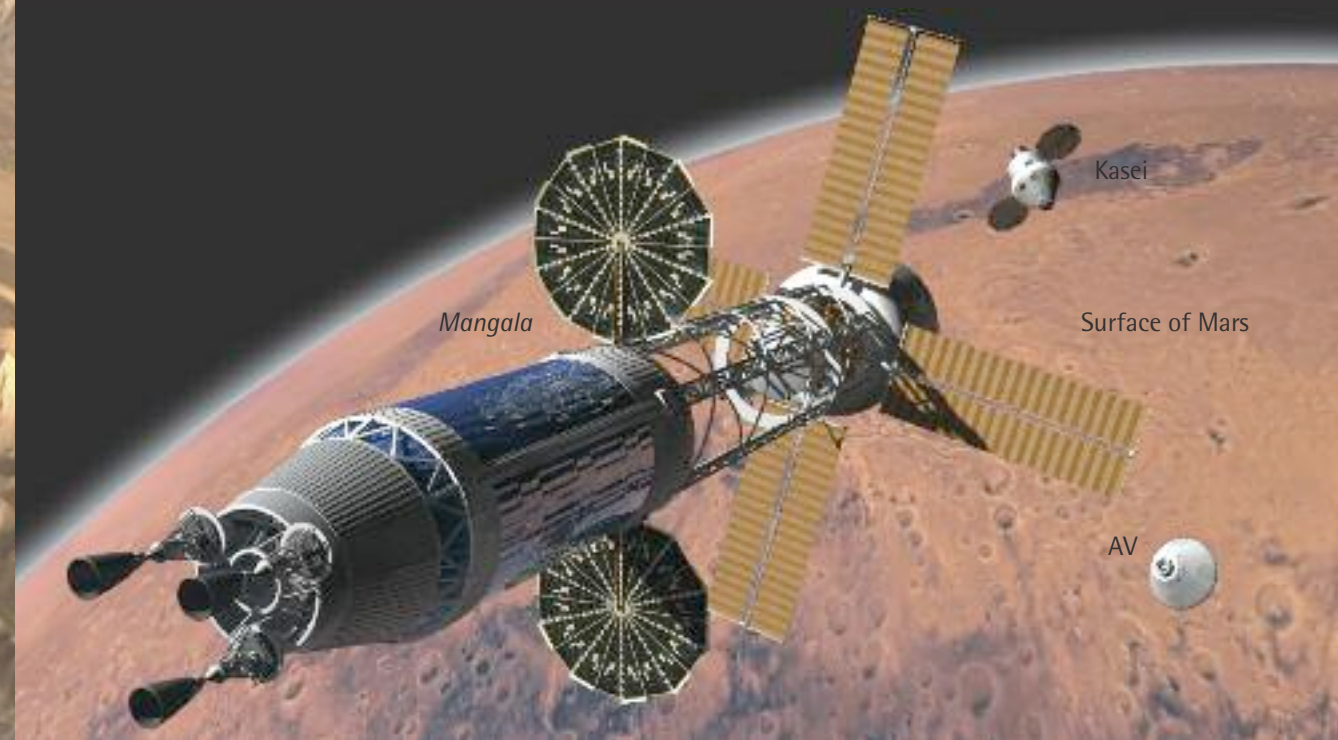


Lift-off from Mars

The team has spent 500 days on Mars. Now it is time to return to Earth. For the past few weeks, preparations have been made for what is the most dangerous moment in the whole mission: the launch of the Ascent Vehicle (AV) from the surface of Mars. The crew climb aboard the AV and take up their positions in the Command Module. After all checks are completed, Mission Control gives the all-clear for lift-off, the engines are activated and the AV blasts off. The astronauts are on their way home.

◀ The fuel needed to power the AV has already been manufactured by the spacecraft itself, soon after landing. Using a small nuclear reactor, some hydrogen brought from Earth was combined with the carbon dioxide in the Martian atmosphere in a chemical reaction to create methane and oxygen – ideal for fuel.

▼ The AV takes off vertically, gradually levelling out as it climbs until it achieves the correct velocity to enter into orbit around Mars. Soon, it encounters *Mangala*. *Kasei* separates from *Mangala* to allow the AV to dock with it, then links up again after docking is completed.





▲ At about 120 km above Earth, *Kasei* re-enters the atmosphere. Friction caused by the spacecraft speeding into dense air at a speed of 40,000 km/h produces intense heat, but a special heatshield protects the craft and her crew. Eventually, nearly two-and-a-half years after setting off, *Kasei* parachutes back to Earth.

Return to Earth

The AV is jettisoned; *Mangala* fires her rocket engines and sets a course for Earth. The six-month return flight is uneventful, but the crew keep busy, making appearances on TV programmes and internet link-ups. Three days before they reach the edge of Earth's atmosphere, the crew move through to *Kasei*. The rest of *Mangala*, including both the NTR and the TransHab, is now jettisoned. *Kasei*'s service module is jettisoned a few hours before it enters the atmosphere and arrives back on Earth. Mission completed!

► *Kasei* soft-lands in a remote spot. Her position is pinpointed and within minutes a helicopter arrives to collect the crew. The astronauts will now be subjected to careful checks of their physical and psychological well-being.



Glossary

Aerobraking A way of slowing down a spacecraft, by flying it into a planet's atmosphere where the gases are denser than space. Friction slows the craft down.

Astronaut A person who travels in space.

Atmosphere The envelope of gases surrounding a planet, moon or star.

Booster A rocket engine that gives a spacecraft the power to blast off.

Canyon A deep gorge, often formed by water flowing through a dry landscape.

Escape velocity The speed a spacecraft must reach in order to overcome the pull of Earth's gravity: at least 40,000 km/h, or 10 times the speed of a rifle bullet.

Fossil The ancient remains or traces of a once-living thing, usually found preserved in rock.

Friction A force that acts against the movement of one surface against another, creating heat.

Gravity The force that attracts all objects to each other. The larger the amount of matter an object contains, the greater its pull of gravity.

Meteorite A lump of rock that falls from space to land on the surface of a planet or moon.

Methane A gas with no smell or colour. It is used as a fuel. Natural gas is chiefly made of methane.

Nuclear reactor A unit in which heat energy is produced when uranium atoms are split.

Orbit The circular or oval-shaped path followed by one object around another in space.

Radiation The creation and transmission of heat, light and other forms of energy through space.

Recycling Recovering and reusing any waste material.

Rocket engine An engine that produces a stream of hot gases by burning fuel inside tanks. Blasting hot gases out of the back of the engine pushes it forwards.

Satellite A spacecraft that orbits the Earth.

Solar panel A device that takes in energy from the Sun and changes it to electricity.

Space probe An unmanned spacecraft. Some have passed close by, or landed on, the surface of other planets and moons.

Space station A permanent spacecraft, orbiting Earth, in which astronauts can carry out scientific research and experiments in space.



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