children's illustrated encyclopedia

Stars and Planets

Orpheus

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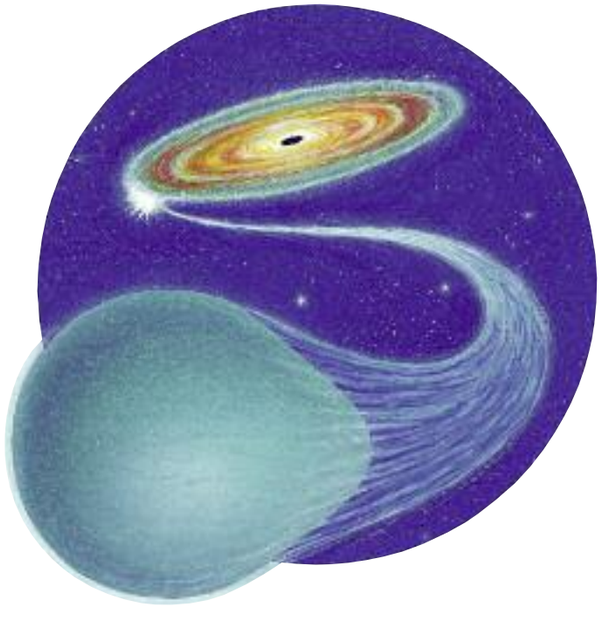
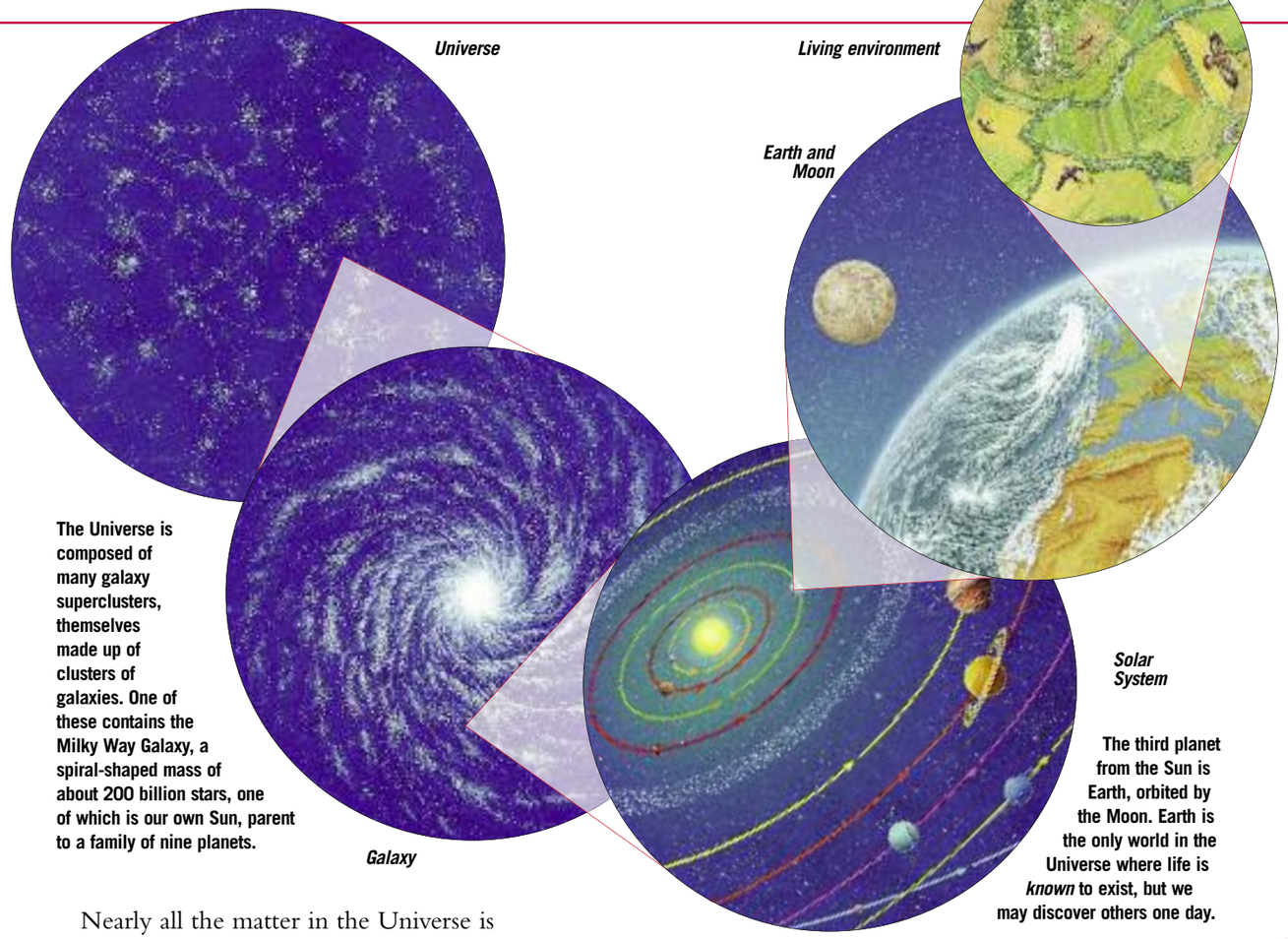


CONTENTS

UNIVERSE

EVERYTHING that we can think of—and everything else that exists—all belong to the Universe. From grains of sand to tall buildings, from particles of dust to giant stars and planets, from microscopic bacteria to people—all are part of the Universe. It even includes empty space.

The Universe is unimaginably vast: billions upon billions of kilometres wide. Distances in the Universe are so great that we have to use a special measure to record them. This is a light year, or the distance that light, which moves at a speed of about 300,000 kilometres per second, travels in one year: about 9,460,528,405,000 kilometres. The nearest star to Earth (after the Sun), Proxima Centauri, is 4.2 light years away. The most distant objects we know in the Universe are more than 13 billion light years away from Earth.



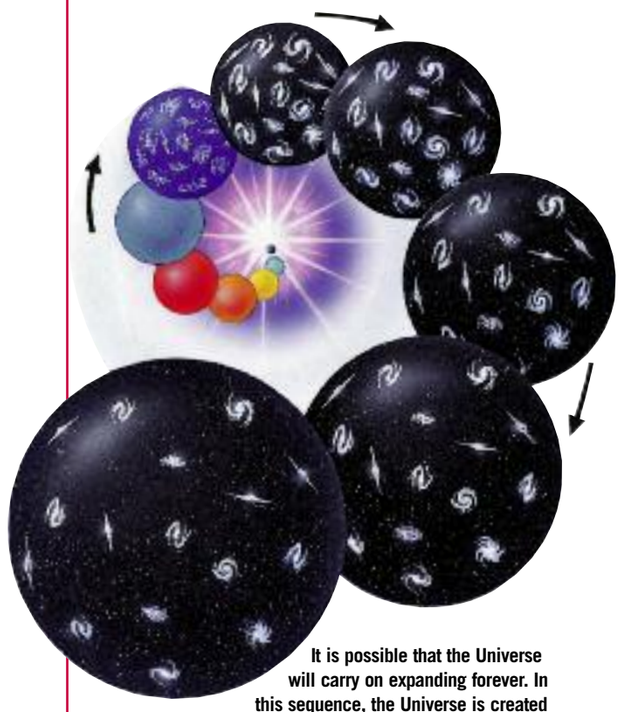
The Universe is composed of many galaxy superclusters, themselves made up of clusters of galaxies. One of these contains the Milky Way Galaxy, a spiral-shaped mass of about 200 billion stars, one of which is our own Sun, parent to a family of nine planets.

The third planet from the Sun is Earth, orbited by the Moon. Earth is the only world in the Universe where life is *known* to exist, but we may discover others one day.

Nearly all the matter in the Universe is contained in **galaxies,** enormous masses of stars, gas and dust *(see page 6)*. There may be about about 100 billion galaxies, each containing hundreds of billions of stars. Galaxies are grouped into giant "clouds" of galaxies, called superclusters. These are spread round the Universe like a net, made up of strings and knots. In between there are gigantic empty spaces.

The superclusters are, themselves, made up of smaller clusters of galaxies. One of these, a cluster of 30 galaxies or so, is called the Local Group. It contains the Milky Way Galaxy, the vast spiral of stars to which our own local star, the Sun, belongs.

Astronomers have discovered that all galaxies are rushing away from one another. This means that, a long time ago, they were once all close together. So the Universe had a definite beginning—and may have an end.



It is possible that the Universe will carry on expanding forever. In this sequence, the Universe is created in an immense explosion called the Big Bang. It expands rapidly, with all the galaxies moving away from one another as the Universe inflates like a balloon.

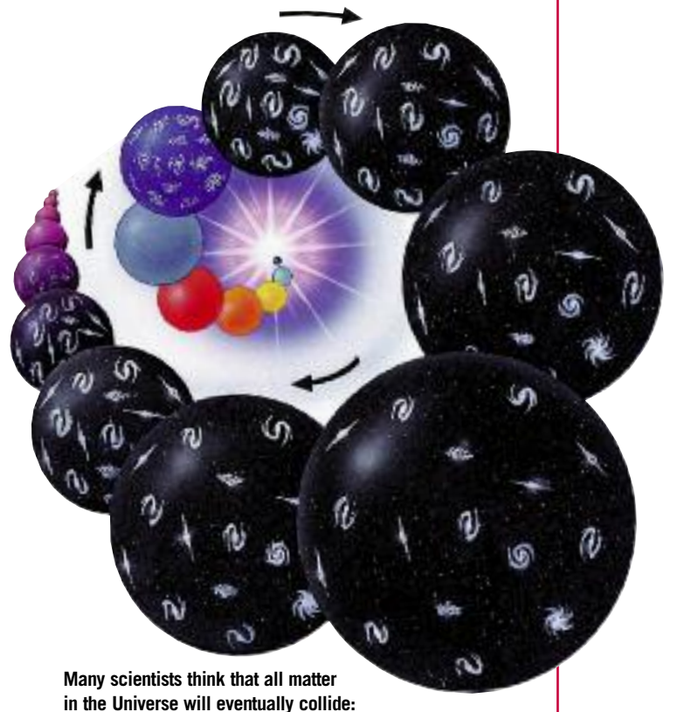
BIG BANG

Many astronomers believe that the Universe began life in a single momentous event. This was an incredibly hot, dense explosion called the Big Bang, which took place about 15 billion years ago. During this explosion, all matter, energy, space—and time itself—were created.

In the first few millionths of a second, the particles that make up atoms, the building blocks of all matter, were formed. It took about 100,000 years for the first atoms, those of the gases hydrogen and helium, to come together. By this time, the searing heat of the Big Bang had cooled, space had expanded and the gases began to spread out. Gradually, however, gravity drew the gases together, leaving vast regions of empty space in between.

About a billion years after the Big Bang, the clouds of gas started to form into galaxies. Matter inside the galaxies went on clumping together until stars were created *(see page 7)*. Our own Sun was born in this way about 5 billion years ago. Its family of planets, including our Earth, was formed from the debris spinning round the infant Sun *(see page 17)*. With billions and billions of stars and planets forming in the same way across the Universe, it seems almost certain that life will have also evolved elsewhere. Will we on Earth one day make contact with these alien life-forms?

The expansion of the Universe is slowing down. Some astronomers think that gravity may eventually bring the expansion to a halt, then collapse all matter once more to a single point in a "Big Crunch". Others believe that there is not enough material in the Universe to do this and that the Universe will carry on expanding forever.



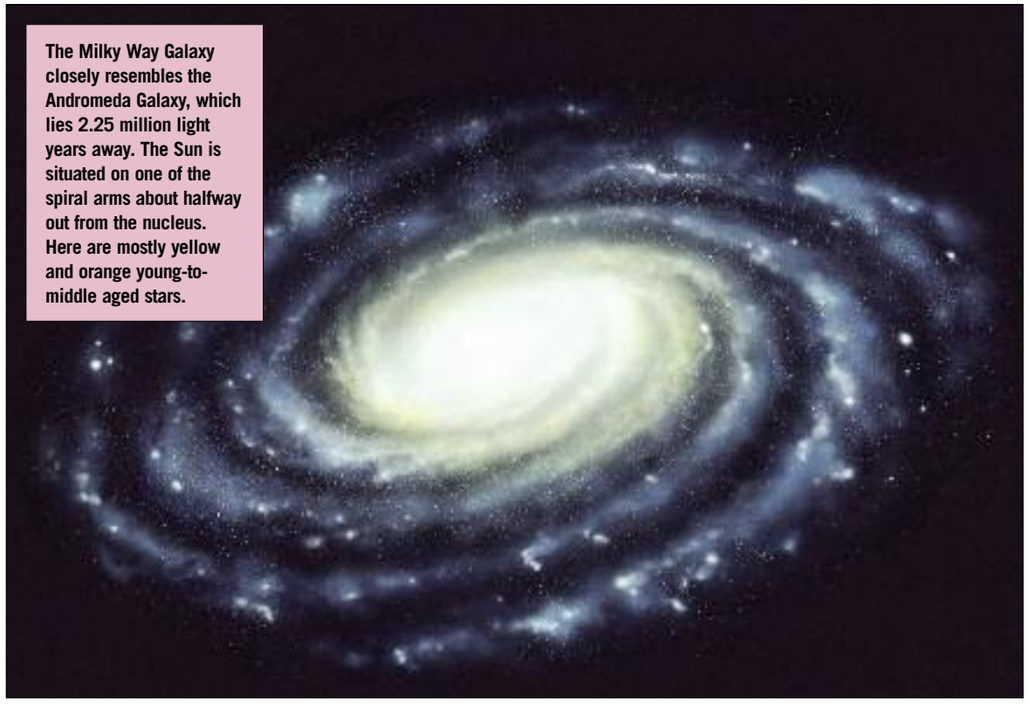
Many scientists think that all matter in the Universe will eventually collide: the "Big Crunch". Vast amounts of invisible "dark matter" in the Universe may exert sufficient gravity to halt its expansion and cause the galaxies to compress together.

GALAXIES

GALAXIES are gigantic collections of stars. The galaxy in which the Sun is situated, the Milky Way Galaxy, is a vast spiral of about 200 billion stars measuring about 100,000 light years across. There are billions more galaxies in the Universe, most of which are elliptical (oval) in shape. There are also others that have irregular shapes.

The Milky Way has a bulge at its centre, the nucleus, where older red stars are concentrated. Four giant arms radiate out from the nucleus. These contain younger blue stars as well as areas of gas and dust—the raw material for the creation of new stars. The whole spiral spins at a speed of about 250 kilometres per second.

The Horsehead Nebula is really a gigantic cloud of dust and gas that has taken on a familiar shape. It is one of many clouds in our Galaxy where stars start to form.



The Milky Way Galaxy closely resembles the Andromeda Galaxy, which lies 2.25 million light years away. The Sun is situated on one of the spiral arms about halfway out from the nucleus. Here are mostly yellow and orange young-to-middle aged stars.

This illustration *(below)* is a view of the Milky Way Galaxy seen from the side. It looks like a pair of fried eggs stuck together back-to-back. The "yolks" form the central bulge, or nucleus, while the "whites" form the spiral-shaped, flattened disc surrounding it. The Sun lies about 25,000 light years (halfway out) from the central point.

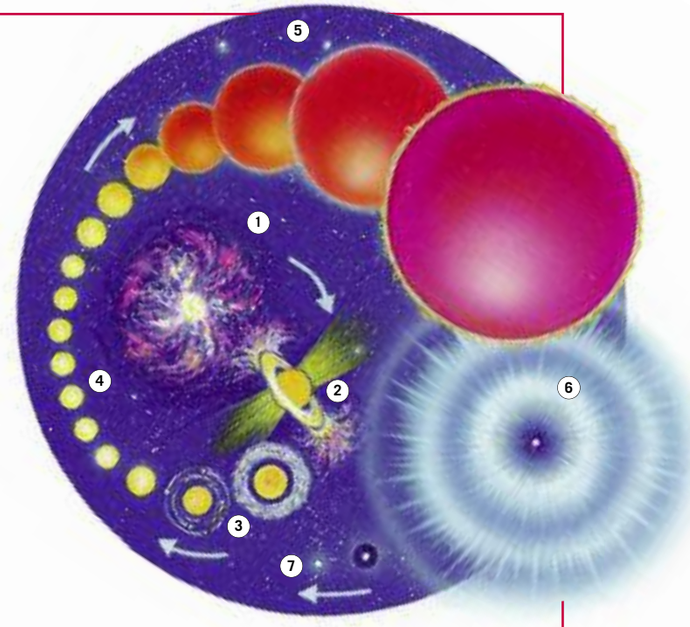
STARS

STARS are giant spinning balls of hot gases. Like massive nuclear power stations, they produce vast amounts of energy in the form of heat and light, which they radiate across space as they shine.

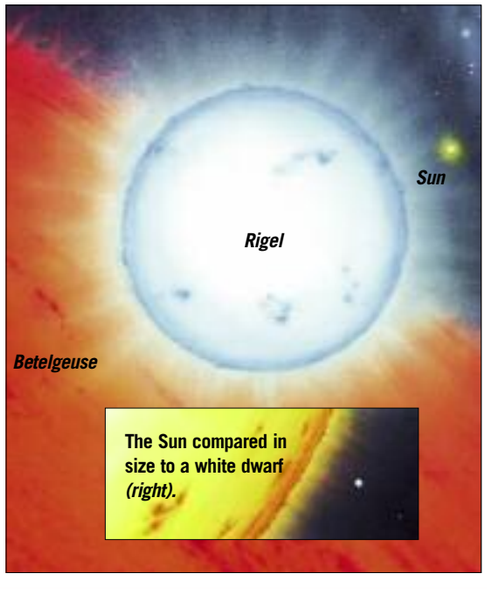
They may look like tiny points of light in the night sky, but many stars are incredibly big. Betelgeuse, in the constellation of Orion, is 800 times the size of the Sun, our local star. Stars vary enormously according to the amount of light they emit. Some of the most powerful give off more than 100,000 the light of the Sun, while others are 100,000 times weaker.

Stars are born when clouds of dust and gas in space, known as nebulae, compress together under the force of gravity to become dense "blobs", called protostars. It is not certain why this happens. Maybe the pressure of an exploding star nearby at the end of its life triggers the process.

After a star has formed it becomes a stable "main sequence" star. The Sun is a typical star of average brightness. More massive stars, like Rigel (also in Orion), glow blue-white, while at the other end of the scale, a white dwarf, the collapsed core of an old star, is no bigger than the Earth.



A star begins its life as a dense mass of gas and dust called a protostar (1). The core becomes so hot that nuclear reactions start deep inside it. Gas and dust are blown away (2), although some remain in a disc surrounding the new star. Planets may form here (3). The star is now a main sequence star (4). When the fuel it uses to produce energy runs out, the core collapses and the star swells into a red giant (5). A massive star will become a supergiant that will blast apart in a mighty explosion called a supernova (6). It ends its days as a neutron star or a black hole (7). A red giant will puff away into space, leaving behind a white dwarf.



The Sun compared in size to a white dwarf *(right).*

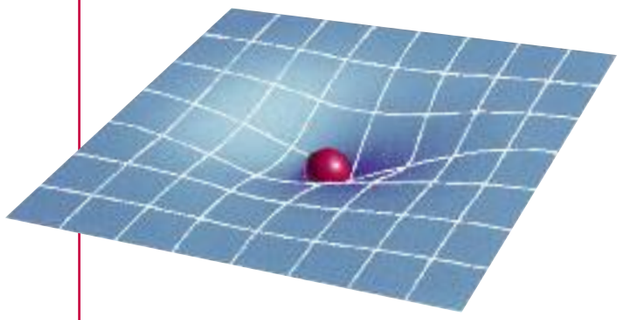
A red giant's outer layers eventually flake off into space, leaving a planetary nebula *(right).* A supergiant goes out in a supernova. The Crab Nebula is the remains of one *(below).*

Black Holes

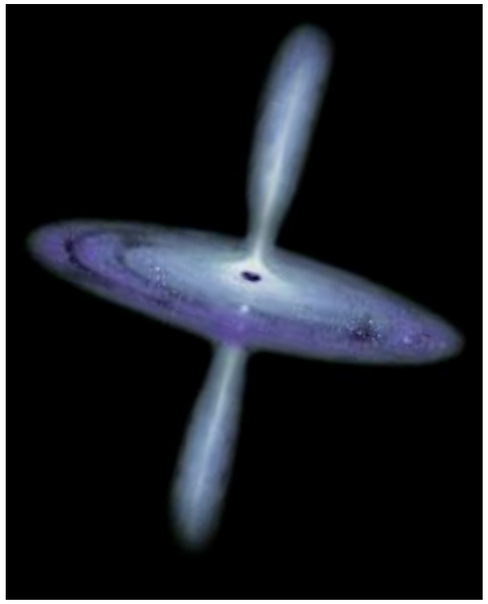
BLACK HOLES are the strangest objects in the Universe. No-one has ever seen one, but most astronomers are convinced that they exist. They are tiny regions of space surrounded by a force of gravity so strong that nothing, not even light, can escape from them.

All bodies in space exert a force of gravity, the force which attracts other things towards them. The greater an object, the stronger its gravitational pull, and the harder it is to escape from it. A rocket launched from Earth must go faster than 40,000 kilometres per hour (its "escape velocity") to escape Earth's gravitational pull. The Sun is many thousands of times more massive than Earth, so a rocket would have to travel much faster: more than 2 million kilometres per hour. If there was an object much bigger or denser than the Sun, an escape velocity equal to that of the speed of light may be needed to escape from it.

Where might an object of such high density be found? Stars more than 10 times as heavy as the Sun burn up their fuel in a much shorter time—a few million years, compared to the Sun's 10 billion years. They swell into massive supergiants before blasting apart in supernovas *(see page 7)*. A supernova's core compresses in seconds to a tiny, super-dense body called a neutron star.



Imagine a star in space as ball on a rubber sheet. A massive object like a star will "bend" space and anything close to it will fall in towards it. If the ball were so heavy that the sheet stretched into a long, deep tube, the result would be a black hole.



Billions of light years away, a huge, disc of gas and dust swirls around a giant black hole at the core of a quasar. The incredible energy blasts two jets of particles—the component parts of atoms—out into space.

If it weighs more than the three Suns, it squeezes further. An escape velocity of the speed of light would be needed to travel away from it. Any light rays would be pulled back in, so the object is invisible: a black hole.

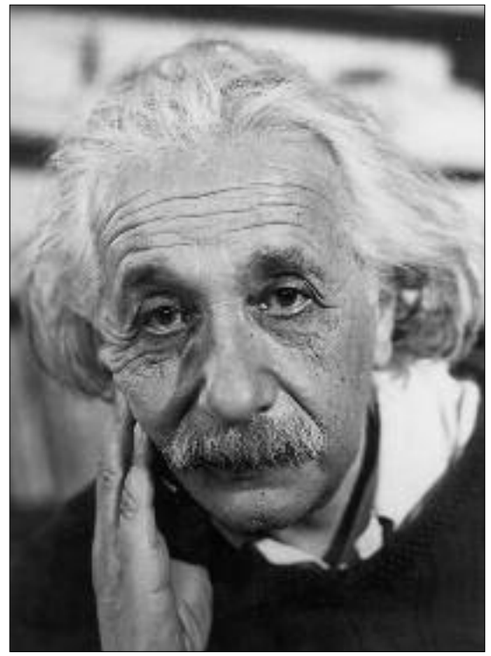
Einstein's General Theory

The great German physicist Albert Einstein (1879-1955) found another way to explain how space, light and matter would behave close to a black hole. In his General Theory of Relativity of 1915, Einstein proposed that the gravitational pull of an object would result in the "curving" of space, in the same way that a person can curve a trampoline. A massive object creates a large "dent" in space into which light and matter would fall. The denser the object, the greater the dent. So the Sun would make only a shallow dent, whereas a neutron star would create a very deep dent. A black hole, the densest object of all, creates a dent so deep that nothing can escape from it.

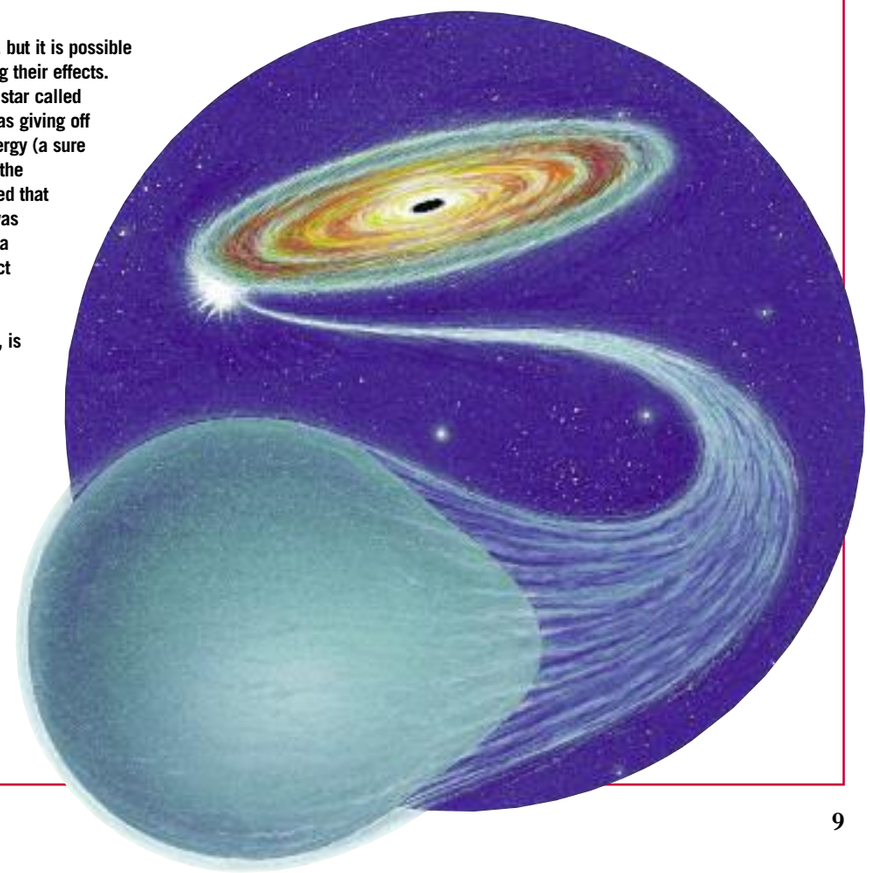
Quasars

Incredibly powerful, massive black holes may, astronomers think, be found lurking at the centres of galaxies. There could even be one at the centre of our own Milky Way Galaxy. Astronomers have detected a ring of fast-moving, hot gas swirling around the centre. The ring of gas is probably in the grip of a powerful gravitational pull—most likely, astronomers suspect, to be the work of a black hole.

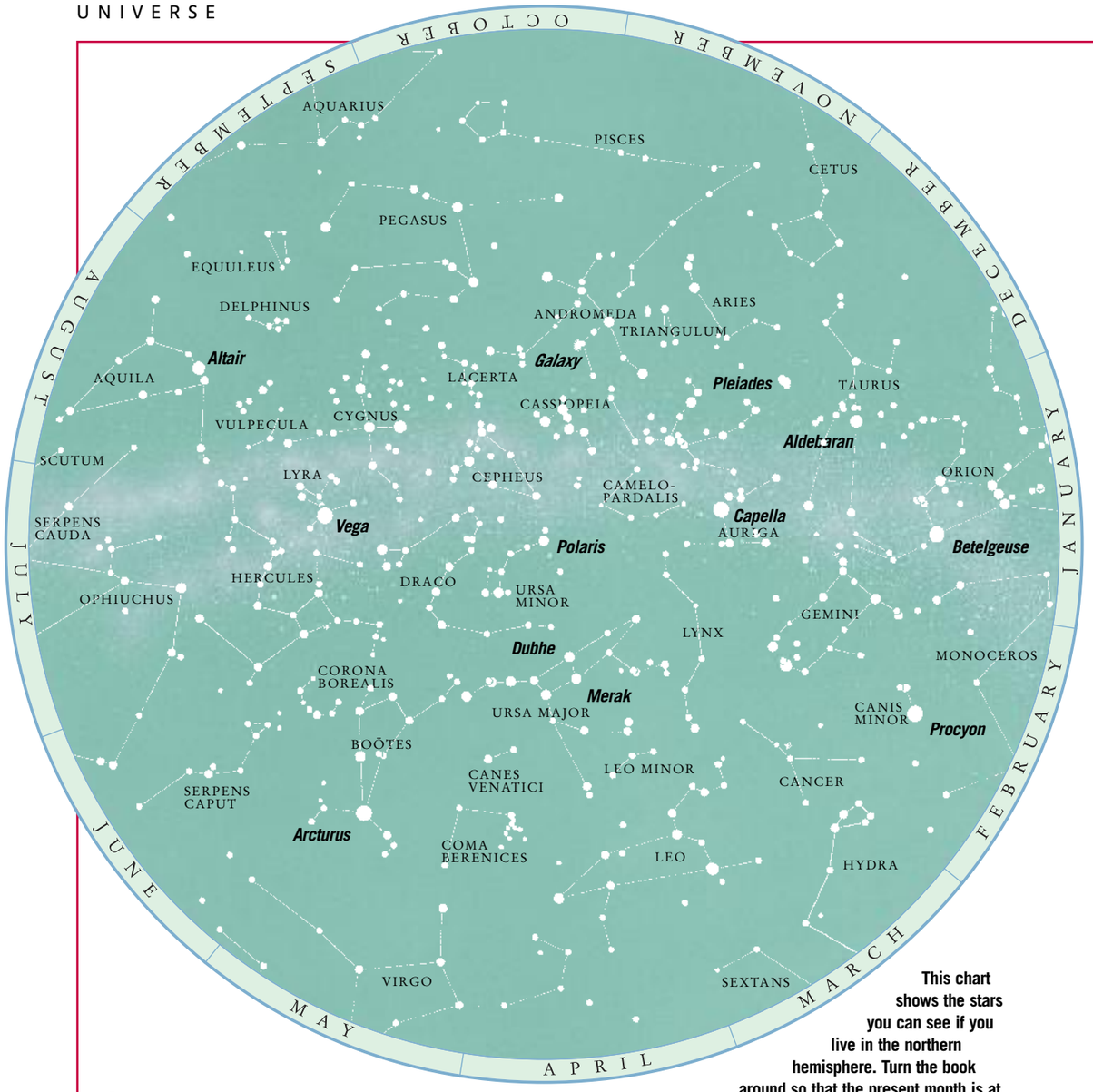
The activity at the centre of our Galaxy is as nothing compared to that of quasars. These objects look like stars, but they lie at incredible distances from us: the farthest quasars are 13 billion light years away. To be visible at that distance means they must be giving off immense amounts of energy. Quasars are the centres of extremely violent galaxies containing supermassive black holes, weighing up to 100 billion Suns. The brilliant light comes from the disc of hot gas and dust spiralling into the black hole.

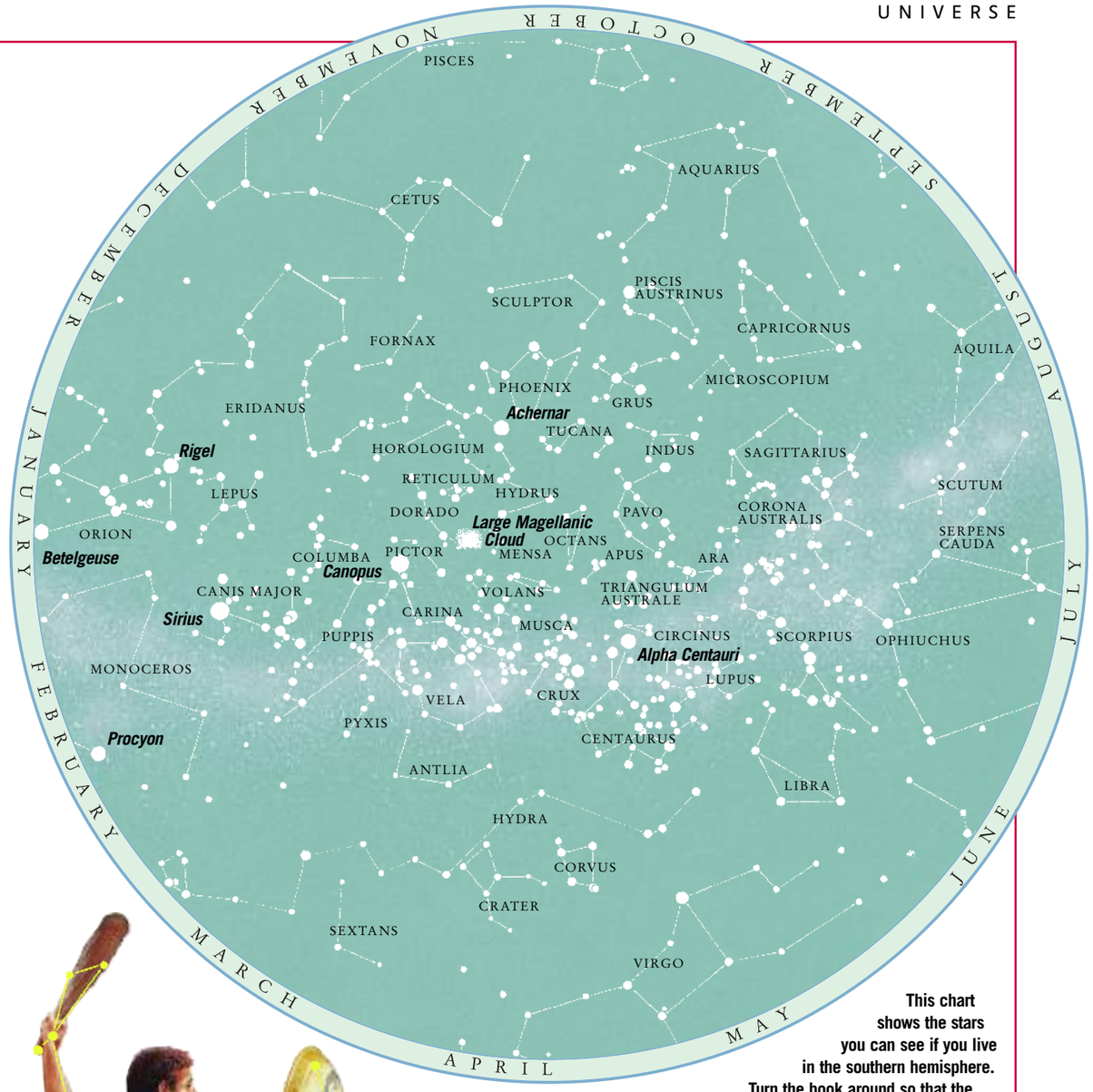


To Albert Einstein, gravity was a property of space and not a force between objects.



Black holes are invisible, but it is possible to detect them by studying their effects. Astronomers observing a star called Cygnus X-1 saw that it was giving off enormous amounts of energy (a sure sign of violent activity in the Universe). They discovered that this huge, hot blue star was being dragged around in a circle by an unseen object with a huge gravitational pull. That unseen object, astronomers now believe, is a black hole, which is tearing gas from the star. The gas forms a whirling disc before plummeting into the black hole. As it falls, it travels faster and faster until it moves almost at the speed of light itself. Close to the hole, the gas becomes so hot it emits massive amounts of energy.





This chart shows the stars you can see if you live in the northern hemisphere. Turn the book around so that the present month is at the bottom. Then face south at 10 pm. On a clear night you should be able to locate many of the stars on the chart.

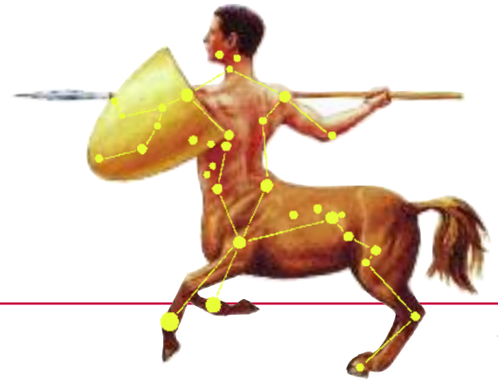
CONSTELLATIONS

CONSTELLATIONS are areas of the sky, divided up for the purpose of identifying stars, galaxies and other objects in the heavens. Years ago, before telescopes were invented, early astronomers grouped the stars together into patterns, imagining their shapes to look like gods, heroes and sacred beasts from popular legends. The 88 constellations that exist today include 48 known to the ancient Greeks, who inherited some from the Babylonians.

A line running from two stars in the constellation Ursa Major (Great Bear) points to the Pole Star, almost exactly due north. Years ago, seafarers used this observation for navigation.

Orion, a hunter in Greek myths *(left)*, is an easy constellation to spot. Three stars in a diagonal line form his belt, while others make up his dagger and shield. The belt stars point down towards Sirius, the brightest star in the night sky. In Greek myths, Centaurus *(right)* was half man, half horse.

This chart shows the stars you can see if you live in the southern hemisphere. Turn the book around so that the present month is at the bottom. Then face north at 10 pm. On a clear night you should be able to locate many of the stars on the chart.



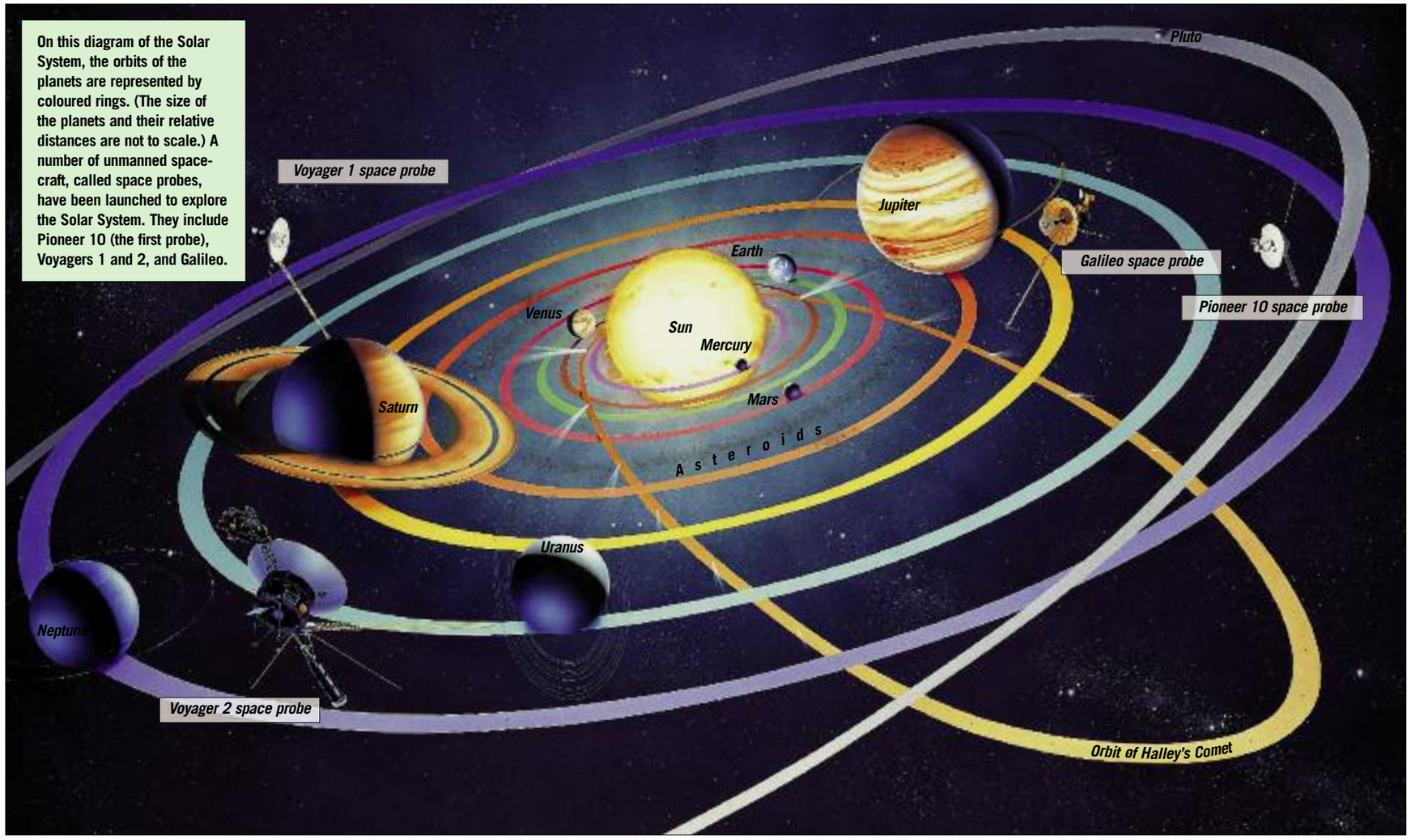
SOLAR SYSTEM

Solar System

THE SOLAR SYSTEM consists of the Sun and an array of objects that orbit it. These objects include the eight known planets, their moons, a number of dwarf planets, asteroids, comets, meteoroids and huge amounts of gas and dust. The Sun's great size relative to the other objects in the Solar System gives it the gravitational pull to keep those objects, including Earth, permanently in orbit around it.

The planets orbit the Sun in the same direction (anticlockwise in this illustration) and in elliptical (oval-shaped) paths. All the planets, and most of their moons, travel on approximately the same plane, with the exception of Mercury, which has a slightly tilted orbit. Pluto, now re-classified as a dwarf planet, has an orbit somewhat more elliptical and tilted than the true planets.

Constantly streaming away from the Sun in all directions is the solar wind, made up of electrically-charged particles (parts of atoms). Travelling at more than 400 kilometres per second, it produces electric currents inside a giant magnetic "bubble" called the heliosphere. The heliosphere protects the Solar System from cosmic rays arriving from space. Its edge, some 18 billion kilometres from the Sun, marks the true boundary of the Solar System.



On this diagram of the Solar System, the orbits of the planets are represented by coloured rings. (The size of the planets and their relative distances are not to scale.) A number of unmanned spacecraft, called space probes, have been launched to explore the Solar System. They include Pioneer 10 (the first probe), Voyagers 1 and 2, and Galileo.

Nicolaus Copernicus (1473-1543)

Early Astronomers

Thousands of years ago, in the time of the ancient civilizations of Egypt and China, people thought that the Sun and Moon were gods, the Earth was flat and the sky was a great dome suspended above it.

In later years, astronomers from ancient Greece proved that the Earth was round. Many believed that the stars were fixed to a great sphere that rotated around the Earth each day. One Greek astronomer, Aristarchus, proposed that the planets, including Earth, orbited the Sun, a star, but most astronomers of this time thought that the Sun, Moon and planets all travelled in circular paths around Earth, the centre of the Universe. Ptolemy, who lived in the 2nd century AD, observed that, while the stars moved across the night sky along regular paths, the planets appeared to "wander" from theirs. He proposed that they each moved in their own small circles, called epicycles, as they orbited Earth.

The Polish priest and astronomer, Nicolaus Copernicus, challenged Ptolemy's view of the Solar System, declaring that the Sun lay at the centre of a system of orbiting planets. Only the Moon orbited the Earth. Copernicus wrongly believed that the planets' orbits were perfect circles and that they moved in epicycles. It was left to the German astronomer Johannes Kepler (1571-1630), who showed that the planets moved in elliptical, rather than perfectly circular, orbits. The shapes of their orbits also explained the "wandering" that so perplexed earlier observers, thus disproving the idea that the planets moved in epicycles.

The Italian astronomer Galileo (1564-1642) was the first to use a telescope. From his observations of the moons of Jupiter in orbit around that planet, and the changing shape of Venus as it orbited the Sun, he concluded that Copernicus had been correct: the planets do orbit the Sun.

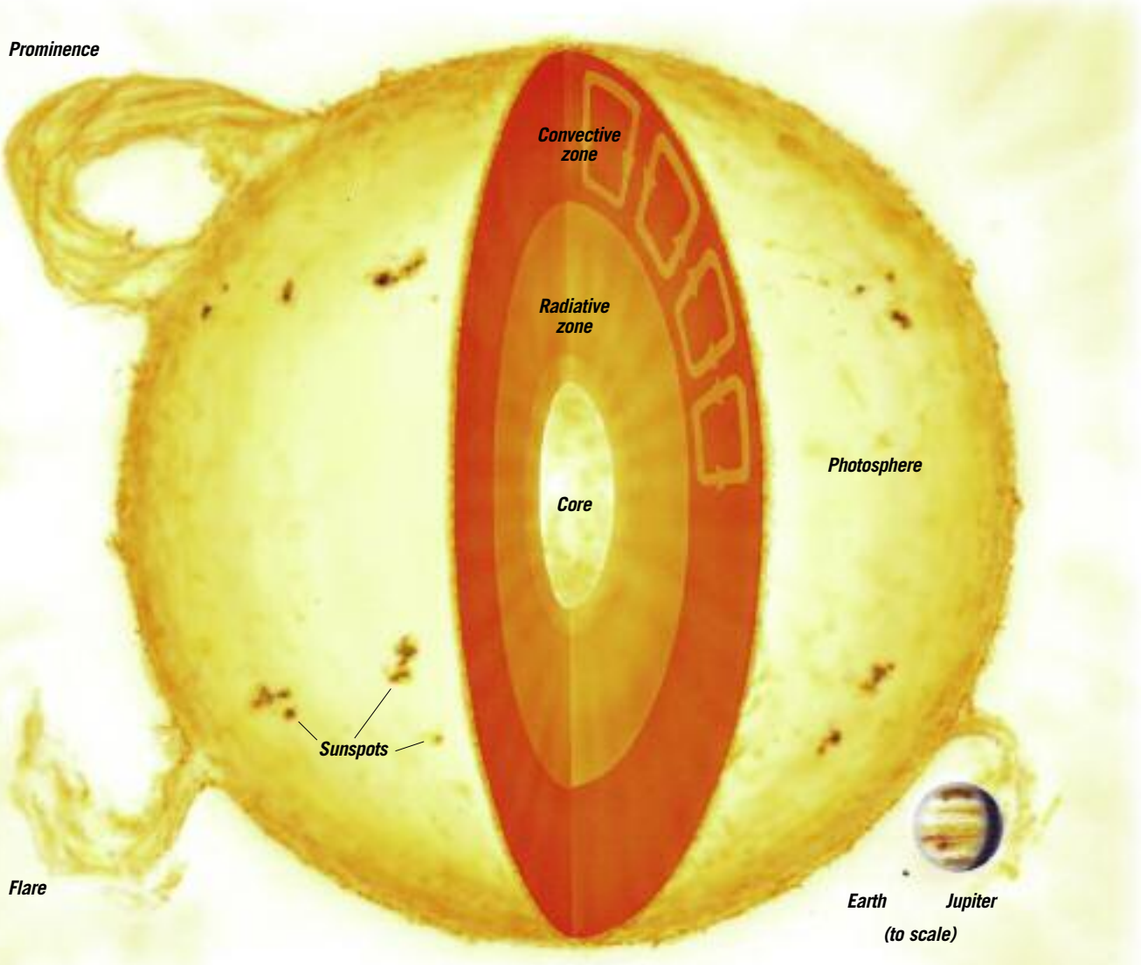
THE SUN

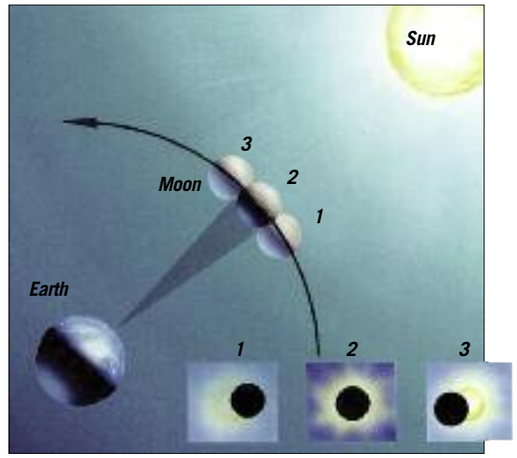
THE SUN is an ordinary star. To us on Earth it is of crucial importance since no life could exist without it, but it is simply one of billions of stars in the Milky Way Galaxy *(see page 6)*, itself one of billions of galaxies in the Universe. For a star, the Sun is below average size—some astronomers classify it as a "yellow dwarf". Yet it is massive when compared to the planets. The Sun contains more than 99 per cent of all the matter in the Solar System. Its diameter of 1,400,000 kilometres is more than 100 times that of Earth.

The Sun is a spinning ball of intensely hot gas made up almost entirely of hydrogen (three-quarters of its mass) and helium. It produces massive amounts of energy by "burning" about four million tonnes of hydrogen every second.

INTERNAL LAYERS

At the centre of the Sun is the core, a region of incredible pressure (200 billion times that on the Earth's surface) and intense heat—about 15 million°C. This is the Sun's nuclear furnace, where the energy that keeps it shining is released. Hydrogen atoms fuse together to form helium. Energy from this reaction flows out from the core through the radiative zone to the convective zone. Here, in a continuous cycle, hot gas bubbles up to the surface before sinking down to be reheated again.

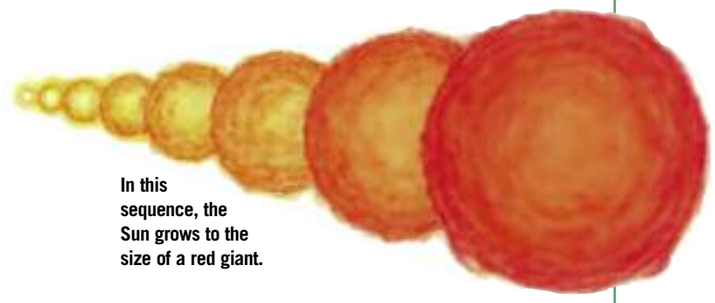




By coincidence, the Moon and Sun appear to be the same size in the sky. So when the Moon passes between the Earth and the Sun *(seen in the sequence 1-3),* it may block out our view of the Sun, a solar eclipse. During a total eclipse, an event only rarely witnessed, the Moon covers the Sun's surface entirely and the corona shines out from behind a black disc. For a short while, dusk falls. In a partial eclipse, part of the Sun still remains visible.

Invisible lines of magnetic force that twist around the Sun's globe are the cause of many extraordinary features. Huge arches of fire, called prominences, can be held up above the Sun by magnetism. Flares, sudden, massive explosions of energy, burst forth when the magnetic field shifts. Where magnetic field lines erupt through the photosphere, there are dark, cooler areas (about 4300°C) known as sunspots.

Beyond the chromosphere lies the corona, the Sun's hot, shimmering outer atmosphere. This is visible from Earth only during a total solar eclipse.



In this sequence, the Sun grows to the size of a red giant.

THE SURFACE OF THE SUN

The Sun's outer shell, the photosphere, is only about 500 kilometres thick and, at 5500°C, much "cooler" than at the core. It is in a state of constant motion, like water in a boiling kettle. Hundreds of thousands of flaming gas jets, called spicules, leap up to 10,000 kilometres into the Sun's atmosphere, known as the chromosphere.

DEATH OF THE SUN

When the Sun's fuel of hydrogen starts to run out, it will grow into a much bigger and brighter star, called a red giant. It will eventually shed its outer layers into space. All that will remain of the Sun itself will be, at first, a small, extremely dense star (a white dwarf), before it eventually cools and wastes away (a black dwarf).

About 7 billion years from now, the hydrogen that the Sun uses as fuel to create energy will start to run out. Eventually the Sun will balloon into a red giant, engulfing Mercury and perhaps Venus, too. This is what Earth's landscape may look like when this happens. Its oceans and atmosphere have gone and its rocky surface is melting in temperatures of 1500°C. Venus is seen as a black dot against the Sun. It may soon be swallowed up by the colossal star.

THE PLANETS

A PLANET is a large object in orbit around a star. It can be made of rock, metal, liquid, gas or a combination of these. Planets do not produce light, but they reflect the light of their parent star.

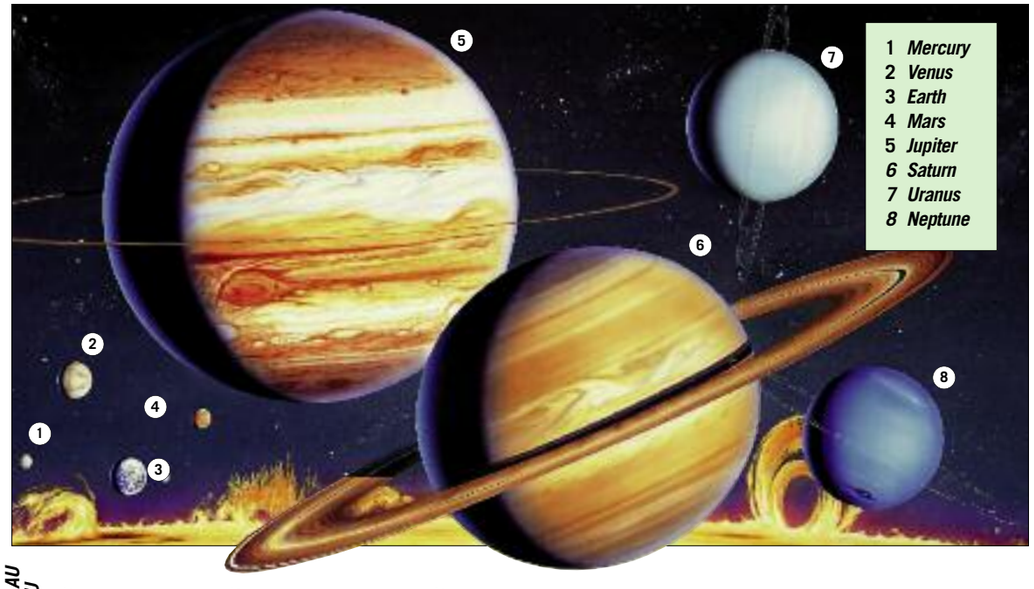
In our own Solar System, there are eight planets, including Earth, orbiting the Sun, our parent star. Observations of other stars made by astronomers using powerful telescopes indicate that they, too, have planets. There could therefore be billions of other planets in the Universe.

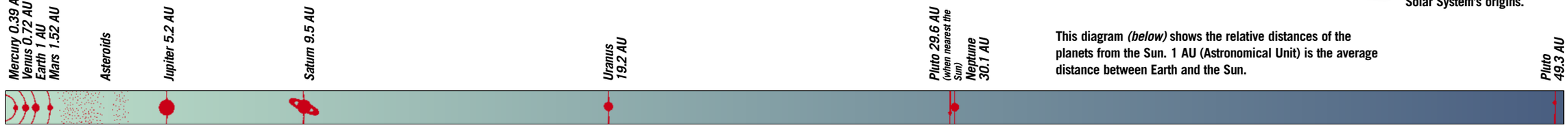
The Earth is the largest of the four inner, or "terrestrial", planets: Mercury, Venus, Earth and Mars. They are dwarfed by the four "gas giants", Jupiter, Saturn, Uranus and Neptune, so called because they have comparatively small rocky cores surrounded by thick layers of liquid and gas. Pluto—once a considered a planet, too—is known as a "dwarf planet", along with a number of other small objects in the Solar System.

The diagram at the foot of this page shows the relative distances of the planets from the Sun. Pacing out their positions would give an even better idea of the huge distances between them. If the Sun were a football, Mercury would be a pinhead 10 paces away from it. Earth (the size of a peppercorn) is a further 16 paces on from Mercury, with the Moon a thumb's length away from Earth. Another 209 paces would bring you to Jupiter (a large marble), while the dwarf planet Pluto lies 884 paces further. To reach the nearest star, Proxima Centauri, you must walk another 6700 kilometres!

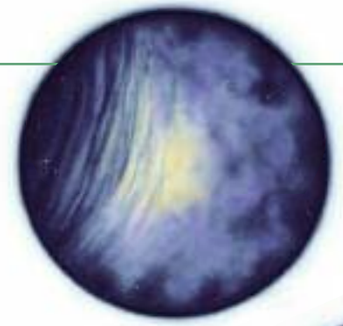
EXPLORING THE PLANETS

Because the giant planets lie so far from Earth, it would take too long for people to travel to them. So space probes have been launched to "fly by" every planet and send back pictures. Voyager 2 *(see page 26)* made the greatest journey. Space probe Cassini visited Saturn in 2004-05.

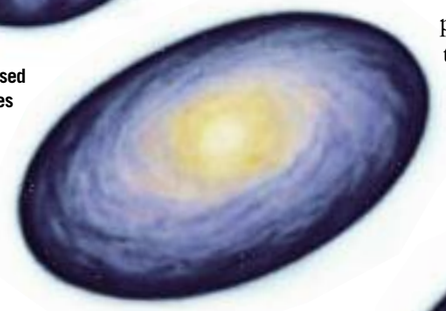




This diagram *(below)* shows the relative distances of the planets from the Sun. 1 AU (Astronomical Unit) is the average distance between Earth and the Sun.



1 A shock wave, possibly from a nearby supernova, causes a cloud of gas and dust to collapse under its own gravity.



2 The collapsed cloud becomes a swirling disc of matter with a bulge at its centre.

THE PLANETS FORM

The Solar System began life as a cloud of gas and dust drifting across the Milky Way Galaxy. It is thought that a supernova may have sent shock waves racing across space, striking the cloud and somehow causing it to collapse under its own gravity.

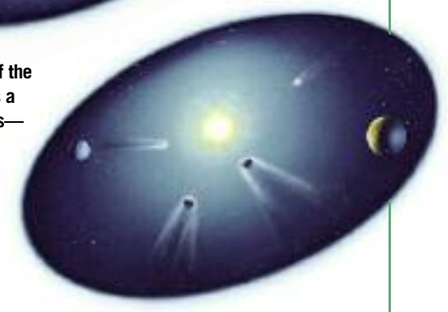
Within 100,000 years, the collapsed cloud became a swirling disc, called a solar nebula. Under pressure from gas and dust spiralling inwards, the centre became hotter and denser and began to bulge. It would soon evolve into the infant Sun.

Away from this central furnace, particles of dust began to clump together like snowflakes, first into small fragments of rock, then becoming large boulders. Over millions of years, some grew into blocks several kilometres across, called planetesimals. These eventually started to collide with one another, building up like snowballs to become the four rocky inner planets, Mercury, Venus, Earth and Mars, and the cores of the four gas giants, Jupiter, Saturn, Uranus and Neptune.

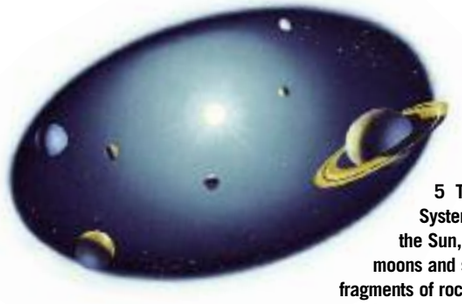
The solar wind stripped away any remaining dust and gas, including the atmospheres around the four inner planets. The giant planets lay beyond the solar wind's fiercest blast, so they were able to hold on to their thick blankets of gas.

Jupiter's gravitational pull caused nearby planetesimals to destroy one another rather than build up into another planet, leaving a belt of rock fragments, known as asteroids, still orbiting the Sun, as they do today.

3 Small fragments of rock clump together in large blocks called planetesimals.



4 The core of the disc becomes a ball of hot gas—a star. The solar wind strips the four inner planets of their atmospheres.



5 The Solar System today: the Sun, planets, moons and small fragments of rock, gas, dust and ice left over from the Solar System's origins.

MERCURY

MERCURY, the closest planet to the Sun, is the second smallest planet in the Solar System. Because it is so near the Sun, it can be seen from Earth only with difficulty—low in the dawn or twilight sky close to the Sun.

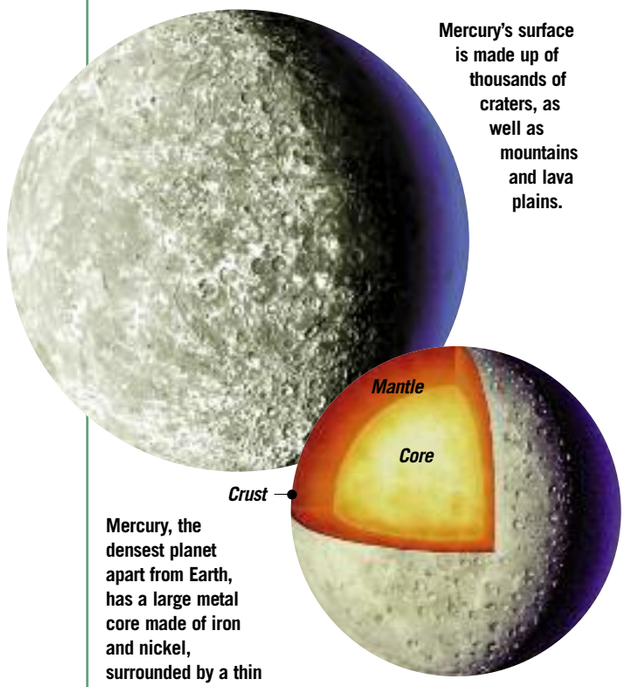
Mercury's surface looks quite similar to that of our Moon. Bare and rocky, it is covered with craters, the result of continual bombardment by meteorites during the first billion years of its existence. Originally molten, Mercury's surface shrank as it

When a meteorite strikes the surface of Mercury, it punches a saucer-shaped crater in the ground. Debris is blasted out in all directions, creating long streaks.

cooled after the bombardment eased, resulting in "wrinkles"—long mountain chains. With no winds or water to erode the rocks, Mercury's landscape has remained the same ever since.

Mercury's orbit has an unusual shape. The other planets have nearly circular orbits but Mercury's is elliptical—more like an oval. At its closest, Mercury is 46 million kilometres from the Sun, 70 million kilometres away at its most distant.

Mercury has great extremes of temperature. Where it faces the Sun, it can exceed 400°C, but during the long nights (lasting about 59 Earth days) and with no atmosphere to keep the heat in, temperatures can plummet to -170°C.



Mercury's surface is made up of thousands of craters, as well as mountains and lava plains.

Mercury, the densest planet apart from Earth, has a large metal core made of iron and nickel, surrounded by a thin rocky shell.

FACTFILE

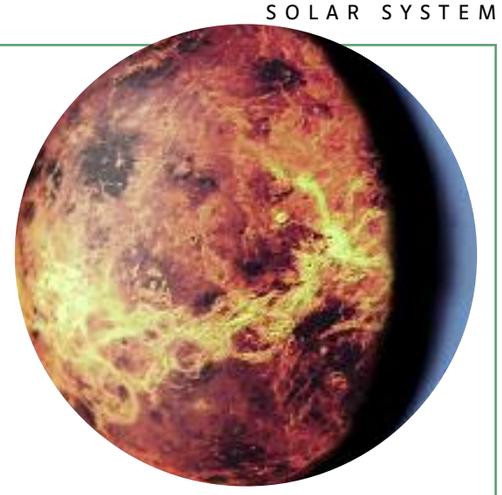
Diameter: 4880 km
Day: 58.6 days
Year: 88 days
Average distance from the Sun: 58 million km
Surface temperature: -180 to +430°C
Atmosphere: traces of helium
Moons: none

The landscape of Mercury is dominated by thousands of craters. The huge Sun burns with a fierce heat—turning to severe cold when this face of the planet is turned away from it. Large boulders falling from space have produced craters in Mercury's surface measuring many kilometres across, some with smaller craters inside. Because there is hardly any atmosphere, Mercury's skies remain black even during the day.

VENUS

ABOUT THE SAME SIZE as Earth, Venus is shrouded in thick, unbroken clouds made of droplets of deadly sulphuric acid. Because its cloud cover reflects the light of the Sun from its surface, Venus is a very bright object in the night sky.

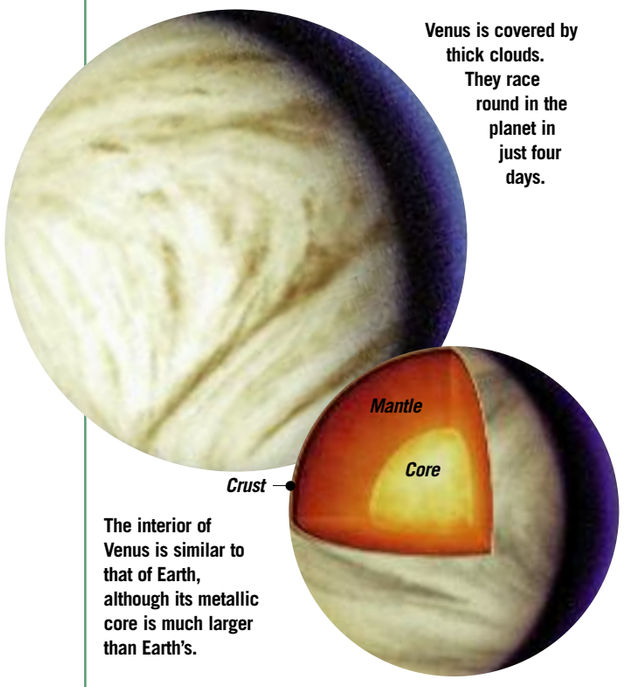
Some 25 kilometres thick, the clouds prevent most sunlight from reaching the surface. But another kind of radiation from the Sun, called infrared, does get though and Venus's dense atmosphere stops it from escaping. The result is a constant surface



This is what Venus would look like if it were not permanently obscured by clouds. The dark areas are lava plains.

temperature hotter than the melting point of lead and the hottest in the Solar System. If any space explorer landed on Venus, he or she would be simultaneously incinerated, suffocated by the unbreathable carbon dioxide air, dissolved by acid and crushed by air pressure about 90 times that on Earth.

Venus spins slowly on its axis, actually taking longer to complete one rotation than to orbit the Sun. Relative to all the other true planets, it spins backwards.



Venus is covered by thick clouds. They race round in the planet in just four days.

The interior of Venus is similar to that of Earth, although its metallic core is much larger than Earth's.

FACTFILE

Diameter: 12,105 km
Day: 243 days
Year: 225 days
Average distance from the Sun: 108 million km
Surface temperature: 490°C
Atmosphere: carbon dioxide, traces of nitrogen
Number of moons: none

Beneath the clouds, Venus's barren surface features tens of thousands of volcanoes (some possibly still active) surrounded by vast lava plains. Lava flows have cut channels in the ground that look as if they may have been carved by rivers. Odd, dome-shaped volcanoes, or "pancakes", as they have been described, have formed where lava has oozed to the surface, then cooled as it spread out in all directions.

EARTH

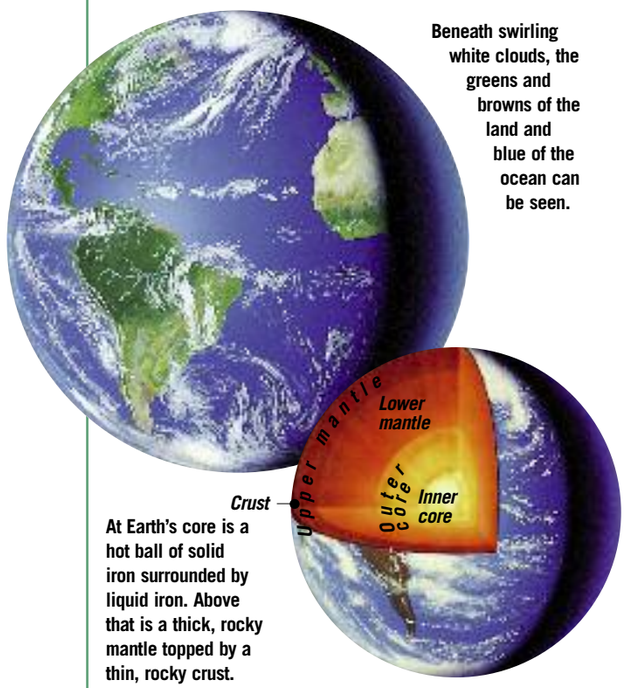
OUR OWN PLANET, Earth, is the largest of the four inner planets. Third in order of from the Sun, 71% of its surface is taken up by oceans. Water is also present as droplets or ice particles that make up the clouds, as vapour in the atmosphere and as ice in polar areas or on high mountains.

Liquid water is essential for the existence of life on Earth, the only body in the Solar System where life is known to be present. Earth's distance from the Sun—neither too close nor too far—produces exactly the right temperature range. The atmosphere traps enough of the Sun's energy to avoid temperature extremes. It also screens the harmful rays of the Sun and acts as a shield against bombardment by meteoroids.

When Earth lies directly between the Sun and the Moon it casts its shadow on the Moon. This is called a lunar eclipse.

Earth's magnetic field is generated by electrical currents produced by the swirling motion of the liquid inner core. The magnetic field protects Earth from the solar wind *(see page 12)*.

Earth's outer shell, made up of the rocky crust and partly-molten upper mantle, is divided into about 15 separate pieces, called tectonic plates. Volcanoes and earthquakes occur where plate edges meet.



Beneath swirling white clouds, the greens and browns of the land and blue of the ocean can be seen.

At Earth's core is a hot ball of solid iron surrounded by liquid iron. Above that is a thick, rocky mantle topped by a thin, rocky crust.

FACTFILE

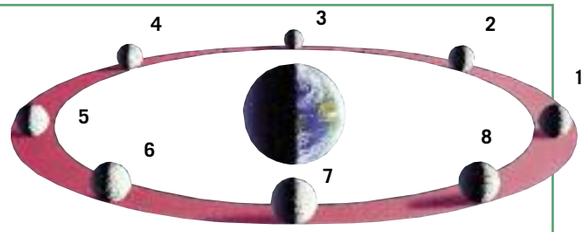
Diameter: 12,756 km
Day: 23 hours 56 minutes
Year 365.26 days
Average distance from the Sun: 149.7 million km
Surface temperature: -70 to +55°C
Atmosphere: nitrogen, oxygen, water vapour
Number of moons: 1

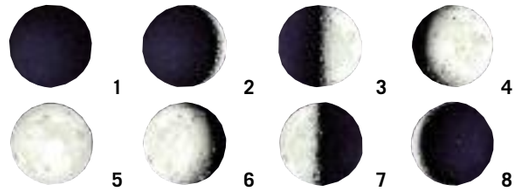
In contrast to the barren landscapes of the other planets, much of Earth's is covered by vegetation, including forest, scrub and grassland. Different climates determine the types of plants and animals that live in different places. Large areas show the important influence of humans: for example, farmland, roads and cities. Land areas are continually sculpted by the weather and moving water or ice.

MOON

THE MOON is neither a star nor a planet. It is a ball of rock that travels around Earth, taking about 27 days to complete the circle. It is the brightest object in the night sky, although the light it "shines" is reflected from the Sun.

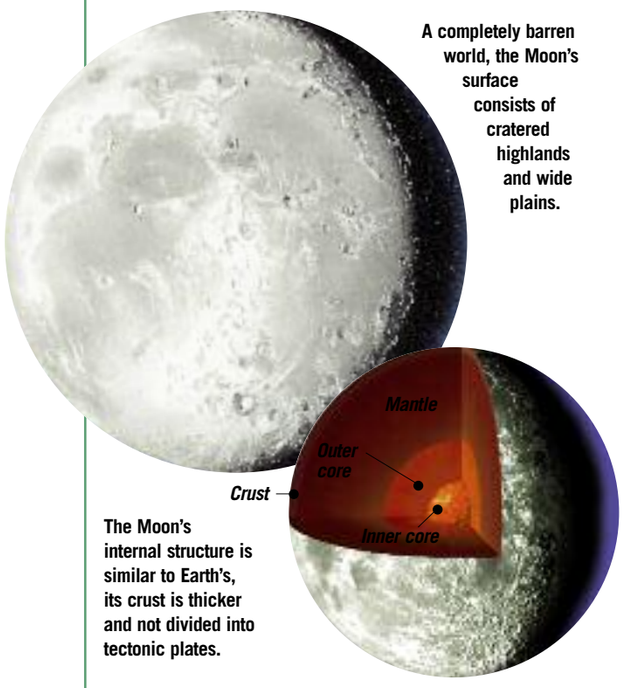
The Moon may have formed when a large object or planetesimal *(see page 17)* collided with the newly-formed Earth more than four billion years ago. The impact "splashed" into space vast amounts of debris that later came together to form the Moon.





PHASES OF THE MOON

The shape of the Moon appears to change from one night to the next. This happens because, as it travels round Earth *(above)*, it spins only once, so the same face remains pointed towards us at all times. It is our view of the sunlit part that changes. When the face pointed towards us is turned away from the Sun, we cannot see the Moon at all: a New Moon (1). When it is turned towards the Sun, we see a complete disc: a Full Moon (5). In between, it passes through crescent (2), quarter (3) and gibbous (4) phases, and back again (6-8).

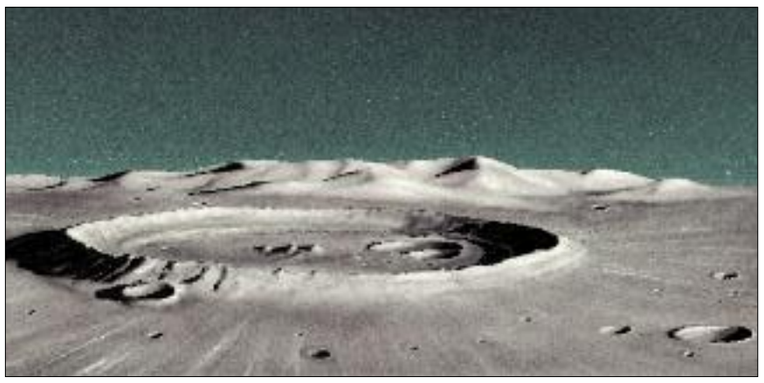


A completely barren world, the Moon's surface consists of cratered highlands and wide plains.

The Moon's internal structure is similar to Earth's, its crust is thicker and not divided into tectonic plates.

FACTFILE

Diameter: 3476 km
Average distance from Earth: 384,600 km
Day: 27.3 days
Surface temperature: -155 to 105°C
Atmosphere: none



With neither air nor liquid water, it is impossible for plants or animals to live on the Moon. The barren lunar landscape is pitted with craters, blasted out by meteorites crashing to its surface. Scattered debris has left streaks radiating from some craters. The Moon also has wide, smooth lava plains. Early astronomers thought these were seas. They are still called by the Latin name for sea, *mare*.

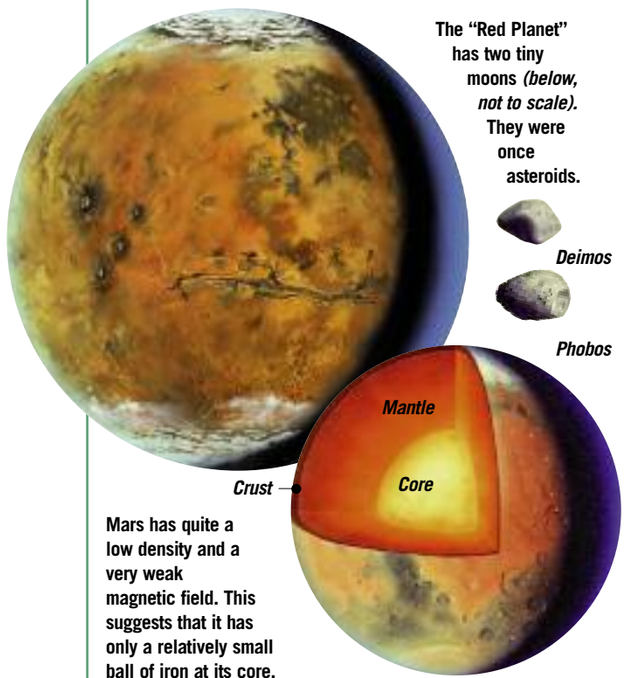
MARS

ALTHOUGH Mars is much smaller than Earth, the two planets have a number of similarities. The Martian day is only a little longer than ours and its angle of tilt means that Mars has four seasons, just as we do on Earth. Daytime temperatures at the equator in midsummer can sometimes reach 25°C. Thin clouds of water vapour or early morning surface frosts can also sometimes be seen. Like Earth, Mars has volcanoes, mountains, dried-up river beds, canyons, deserts and polar icecaps.

Mars' four massive volcanoes stand on the Tharsis bulge. Olympus Mons, which rises 20 km, is seen here compared to Mauna Kea, Hawaii (green summit, at far right) the tallest mountain on Earth measured from base to summit (10,205 m).

For these reasons, Mars is thought to be the only other planet where life may once have existed. However, analysis of the Martian soil by space probes Viking 1 and 2, which touched down on the planet in 1976, and Pathfinder in 1997, failed to find any sign of past or present life.

Mars is a barren planet. Its reddish colour comes from iron oxide dust (similar to rust). From time to time, large dark regions appear on the surface. These are areas of bare rock, exposed when storms remove the dusty covering. The Martian landscape features some dramatic landforms. The Solar System's highest mountains and its deepest canyon, Valles Marineris, are found on Mars.



The "Red Planet" has two tiny moons *(below, not to scale).* They were once asteroids.

Mars has quite a low density and a very weak magnetic field. This suggests that it has only a relatively small ball of iron at its core.

FACTFILE

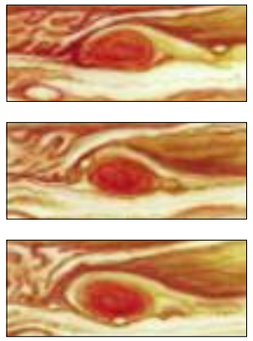
Diameter: 6797 km
Day: 24.6 hours
Year: 687 days
Average distance from the Sun: 228 million km
Surface temperature: -120 to +25°C
Atmosphere: carbon dioxide, nitrogen
Moons: 2

A number of valleys and channels have been carved into the Martian plains. From the evidence of sediments—muds and silts deposited by water—it seems likely that there were once rivers, lakes and even seas on Mars. The only water left on the surface today is frozen in the polar icecaps. The rest may have been lost to space due to Mars' weak gravity, or hidden from view as a deep-frozen layer beneath the surface.

JUPITER

JUPITER is the largest planet in the Solar System. Large enough to contain more than 1300 Earths inside it, Jupiter is more massive than all the other planets combined. Along with Saturn, Uranus and Neptune, Jupiter is known as a "gas giant", because it is mostly made of gas with no solid surface at all.

The colourful patterns of red, brown, yellow and white on Jupiter's surface are produced by the chemicals sulphur and phosphorus in the swirling atmosphere. Jupiter's extremely quick rotation is probably responsible both for separating the clouds into different colour "zones" (the lighter bands) and "belts" (the darker bands), and for the continual storms. The Great Red Spot, its most famous feature, is such a storm. The quick rotation also causes Jupiter to bulge at its equator, so that it measures 7500 kilometres less from pole to pole.



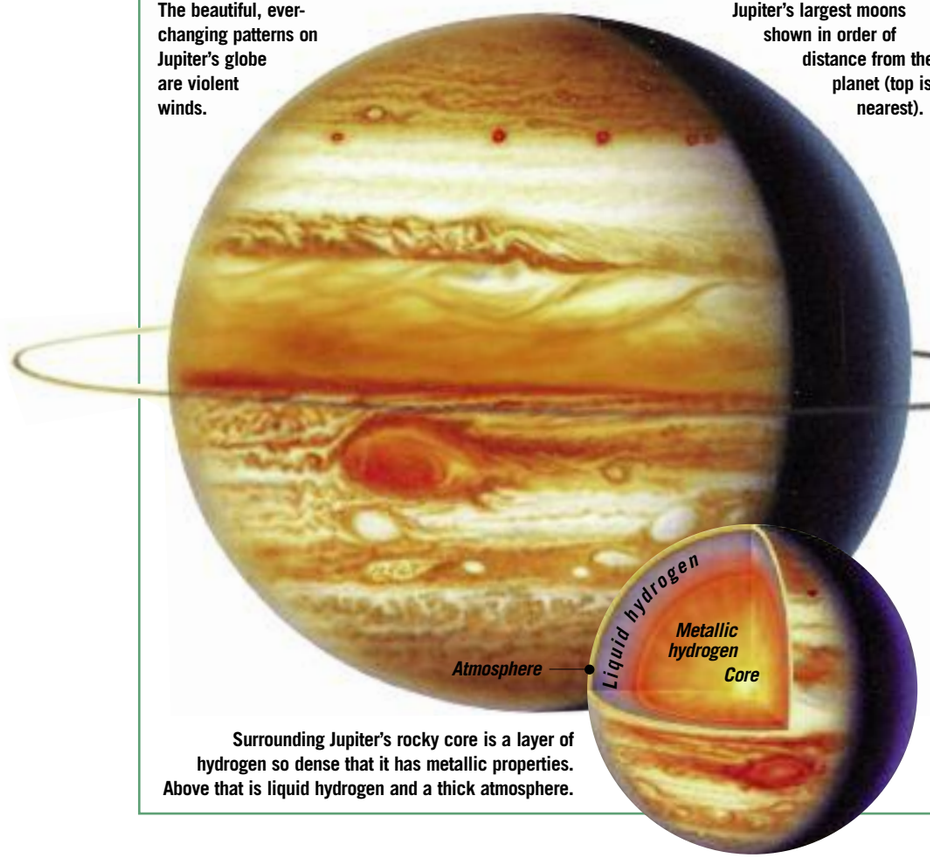
Large enough to contain two Earths, the Great Red Spot is actually a giant storm that has been raging for at least 300 years. Its topmost clouds rotate in an anticlockwise direction, taking about six days to make a complete turn. This sequence shows smaller storms (the white ovals) and turbulent air currents flowing past the Spot.

Jupiter has a system of rings consisting of dark grains of dust. The four largest of its moons are bigger than Pluto.

FACTFILE

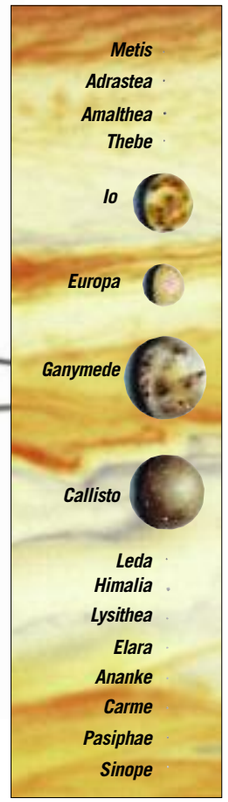
Diameter: 143,884 km
Day: 9.8 hours
Year: 11.8 years
Average distance from the Sun: 778 million km
Surface temperature: -150°C
Atmosphere: hydrogen, helium
Number of moons: 63

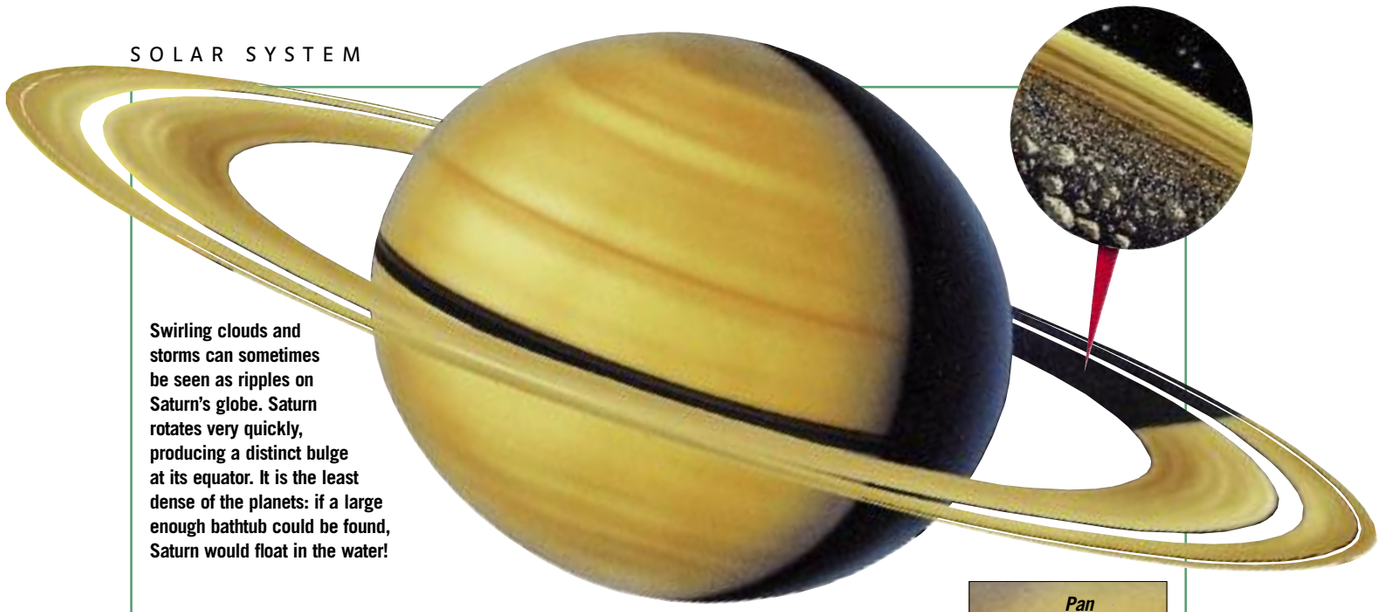
The beautiful, ever-changing patterns on Jupiter's globe are violent winds.



Surrounding Jupiter's rocky core is a layer of hydrogen so dense that it has metallic properties. Above that is liquid hydrogen and a thick atmosphere.

Jupiter's largest moons shown in order of distance from the planet (top is nearest).





Swirling clouds and storms can sometimes be seen as ripples on Saturn's globe. Saturn rotates very quickly, producing a distinct bulge at its equator. It is the least dense of the planets: if a large enough bathtub could be found, Saturn would float in the water!

SATURN

ALL FOUR gas giants have rings, but Saturn's, visible from Earth through even a small telescope, are broad, bright and magnificent. As detailed photographs taken by Voyager 2 show, the rings are made up of billions of blocks of ice and rock, ranging in size from boulders as large as houses down to tiny fragments the size of snowflakes *(top right)*. They are only a few tens of metres thick. Some astronomers think that the rings are the fragmented remains of a moon that was smashed apart by a passing comet.

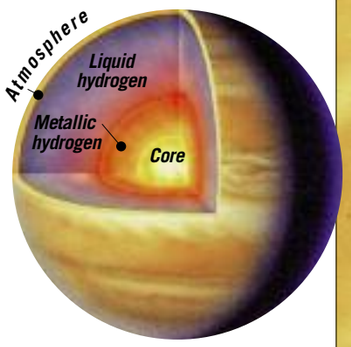
Three rings can be made out from Earth. The outer ring (A ring) is separated from the other two lying inside it (B and C) by a gap called the Cassini Division. Voyager 2 spotted fainter rings beyond A ring. It also revealed that each ring was, itself, divided into thousands of ringlets.

Saturn has a large family of moons, many of which are small, irregularly shaped bodies with some even sharing the same orbits.

FACTFILE

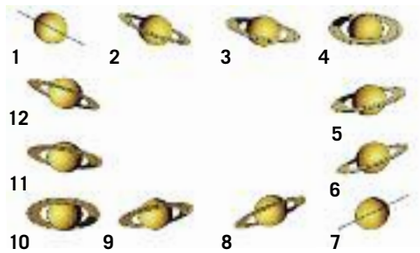
Diameter: 120,514 km
Day: 10.2 hours
Year: 29.5 years
Average distance from Sun: 1427 million km
Surface temperature: -180˚C
Atmosphere: hydrogen, helium
Number of moons: 60

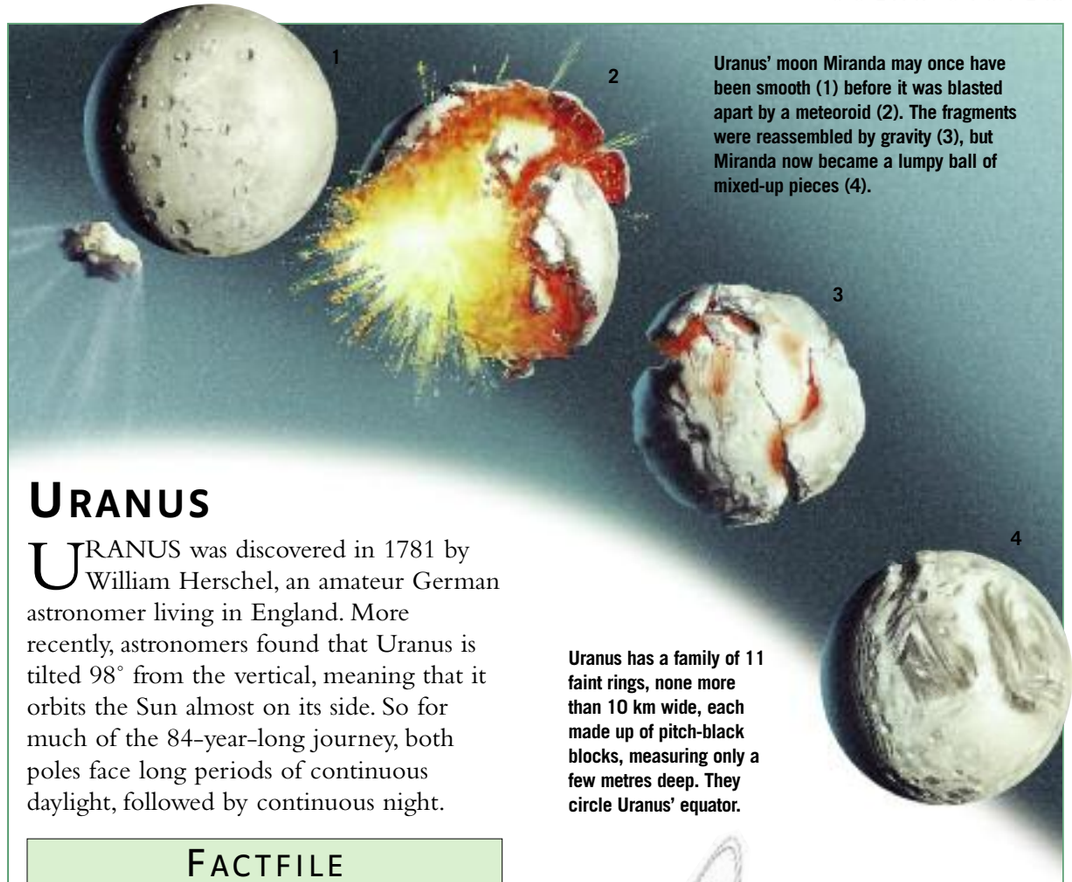
Eighteen of Saturn's moons, in order of distance from the planet (top is nearest). They are drawn to scale, relative to one another.



Saturn's internal structure *(above)* is similar to Jupiter's.

Saturn's spinning axis is tilted so our view of its rings alters as it orbits the Sun *(below)*. At stages 1 and 7 they are invisible. At 4 and 10 they are at their widest angles.





Uranus' moon Miranda may once have been smooth (1) before it was blasted apart by a meteoroid (2). The fragments were reassembled by gravity (3), but Miranda now became a lumpy ball of mixed-up pieces (4).

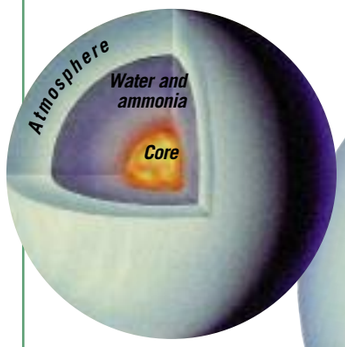
URANUS

URANUS was discovered in 1781 by William Herschel, an amateur German astronomer living in England. More recently, astronomers found that Uranus is tilted 98˚ from the vertical, meaning that it orbits the Sun almost on its side. So for much of the 84-year-long journey, both poles face long periods of continuous daylight, followed by continuous night.

Uranus has a family of 11 faint rings, none more than 10 km wide, each made up of pitch-black blocks, measuring only a few metres deep. They circle Uranus' equator.

FACTFILE

Diameter: 51,118 km
Day: 17.2 hours
Year: 84 years
Average distance from the Sun: 2869 million km
Surface temperature: -210˚C
Atmosphere: hydrogen, helium, methane
Number of moons: 27



Uranus' relatively small, rocky core is surrounded by a slushy ocean of water with some ammonia. Its thick atmosphere is composed mainly of hydrogen.

Uranus' moons, in order of distance from the planet (top is nearest). Twelve more moons have recently been discovered.

NEPTUNE

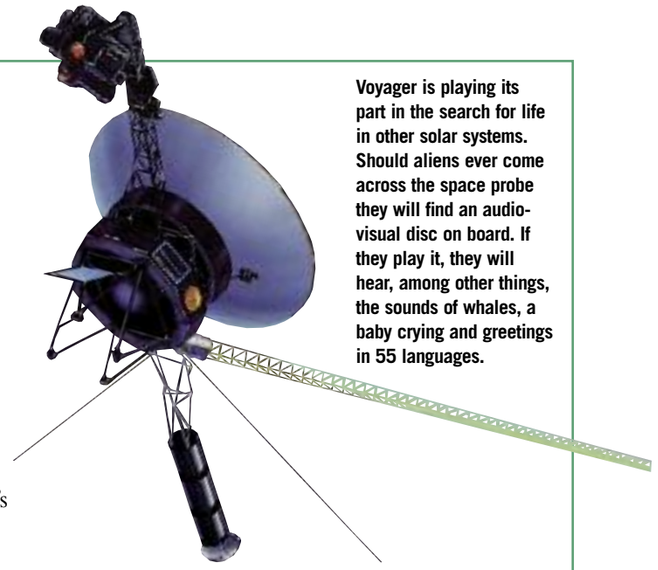
NEPTUNE was discovered by German astronomer Johann Galle in 1846. Its largest moon, Triton, was recorded a few days later. Besides that, very little was known about Neptune until the space probe Voyager 2 visited it in 1989.

A bright blue globe, Neptune almost completely lacks surface features. At the time it was photographed by Voyager, a storm system, called the Great Dark Spot (which later disappeared), could be seen racing in a direction opposite to the planet's rotation. Winds on Neptune blow at more than 2000 kilometres per hour.

Like the other gas giants, Neptune has a system of rings. There are four extremely faint rings, composed of dark, icy fragments.

FACTFILE

Diameter: **50,538 km**
Day: **16.1 hours**
Year: **164.8 years**
Average distance from the Sun: **4496 million km**
Surface temperature: **-220°C**
Atmosphere: **hydrogen, helium, methane**
Moons: **13**



Voyager is playing its part in the search for life in other solar systems. Should aliens ever come across the space probe they will find an audio-visual disc on board. If they play it, they will hear, among other things, the sounds of whales, a baby crying and greetings in 55 languages.

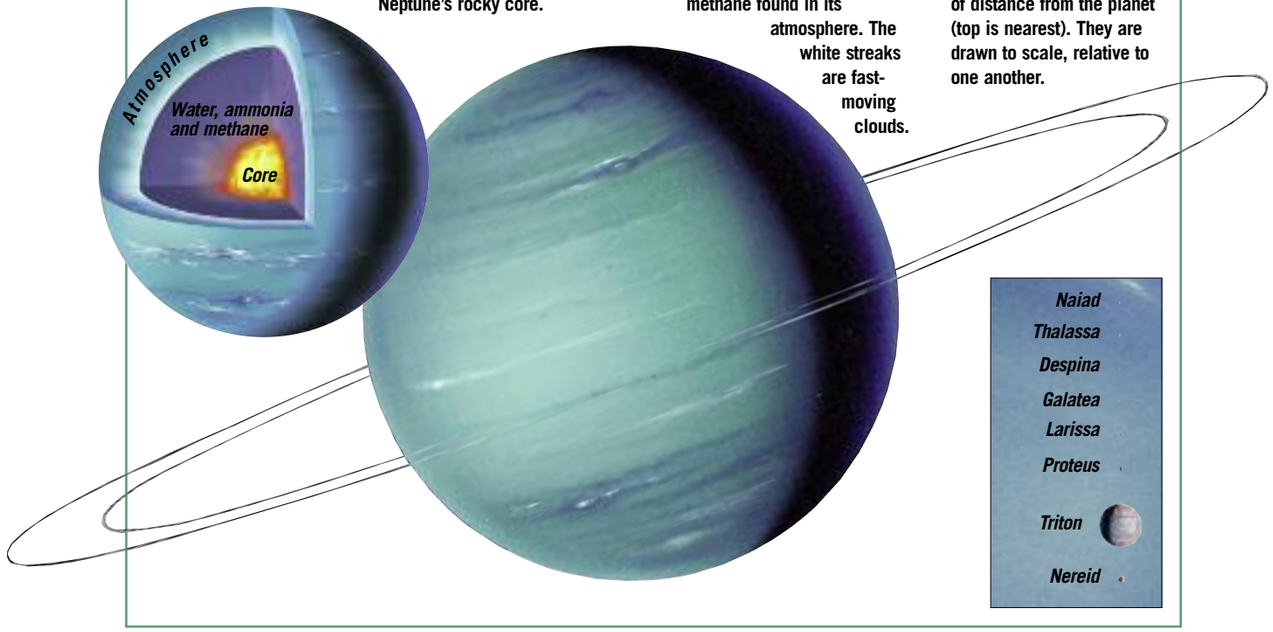
VOYAGER 2

The greatest journey by a space probe so far undertaken was made by Voyager 2. Between 1979 and 1989, it flew close by Jupiter, Saturn, Uranus and Neptune, transmitting superbly clear pictures of the planets and their moons. Voyager has since sped away from the Solar System, although it continues to send back signals—20 billion times weaker than those of a watch battery!

A layer of warm water, with some ammonia and methane, surrounds Neptune's rocky core.

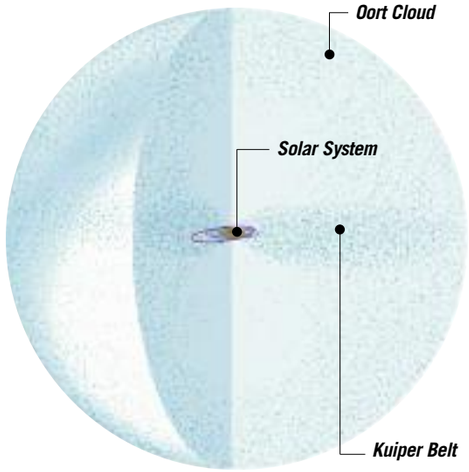
Neptune's blueness arises from the small amounts of methane found in its atmosphere. The white streaks are fast-moving clouds.

***(Bottom)* Eight of Neptune's moons are shown in order of distance from the planet (top is nearest). They are drawn to scale, relative to one another.**



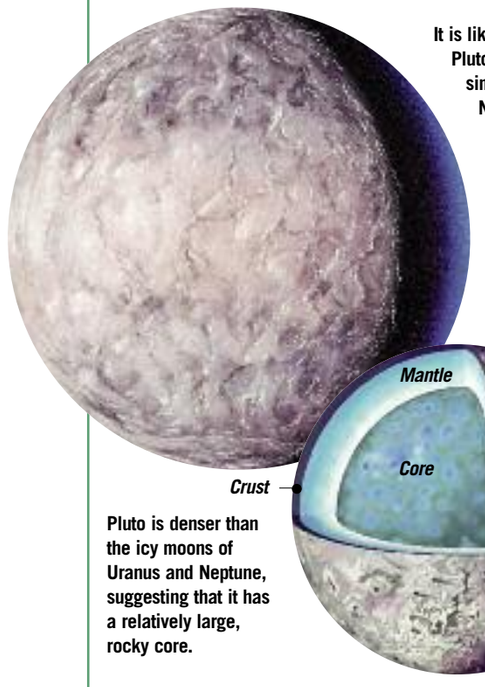
PLUTO

PLUTO was first identified in 1930 by the American astronomer Clyde Tombaugh. He compared photographs of part of the sky taken six days apart and noticed that a pinprick of light had moved slightly against the background of stars. In recent years, many objects similar to Pluto have been discovered in the outer Solar System, notably Eris. In 2006, Pluto was placed in the new category of "dwarf planets", along with Eris and the asteroid Ceres. Pluto has three moons, Charon, Hydra and Nix.



Thousands of icy objects may exist in the outer reaches of the Solar System. They may form either a belt (the Kuiper Belt) or a cloud (the Oort Cloud). This could be the birthplace of comets *(see page 30).*

Pluto has a very elongated orbit, ranging between 7400 and 4400 million kilometres from the Sun, bringing it inside the orbit of Neptune for part of the journey. Pluto's largest moon, Charon, is just over half its size and lies only 19,640 kilometres away from it. Both spin in a direction opposite to that of all the true planets except Venus.



It is likely that Pluto looks quite similar to Neptune's moon, Triton.

Pluto is denser than the icy moons of Uranus and Neptune, suggesting that it has a relatively large, rocky core.

FACTFILE

Diameter: **2300 km**
Day: **6.4 days**
Year: **248 years**
Average distance from the Sun: **5914 million km**
Surface temperature: **-220°C**
Atmosphere: **probably nitrogen and methane**
Number of moons: **3**

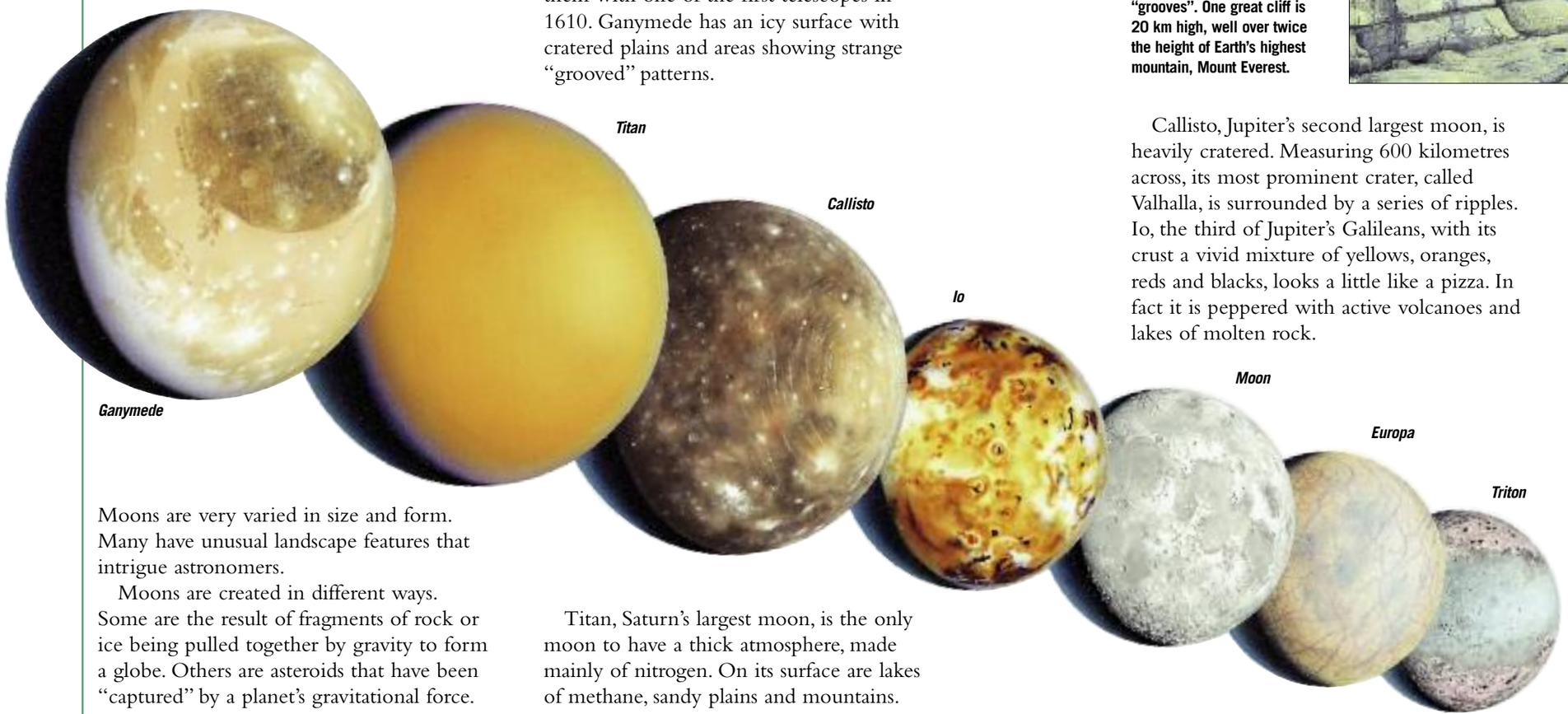
Pluto's surface is probably an "icescape" of frozen nitrogen, carbon monoxide and methane. There may be craters made by collisions with rock and ice fragments. Seen from Pluto, the Sun looks no more than a bright, distant star. It still provides just enough heat to evaporate some of the surface frost and create an extremely thin atmosphere. Charon, Pluto's largest moon, features prominently in the sky.

SOLAR SYSTEM

Moons

MOONS, also known as satellites, are relatively small worlds that orbit the planets of the Solar System. Earth has one moon, known simply as the Moon *(see page 21)*, but other planets have many more—Saturn, for example, has at least 60 moons.

All seven of the moons illustrated here *(below)* are larger than the dwarf planet Pluto, while the largest moons, Ganymede and Titan, are even bigger than Mercury, the smallest true planet. Jupiter's four largest moons are all in the top seven. They are called the "Galileans" after the Italian scientist Galileo Galilei who first discovered them with one of the first telescopes in 1610. Ganymede has an icy surface with cratered plains and areas showing strange "grooved" patterns.

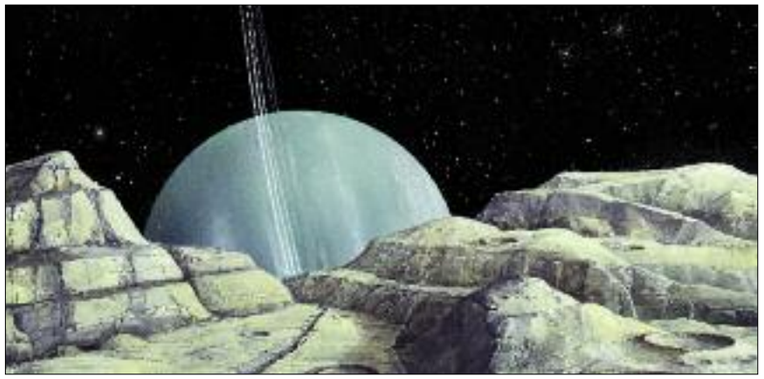


Moons are very varied in size and form. Many have unusual landscape features that intrigue astronomers.

Moons are created in different ways. Some are the result of fragments of rock or ice being pulled together by gravity to form a globe. Others are asteroids that have been "captured" by a planet's gravitational force.

Titan, Saturn's largest moon, is the only moon to have a thick atmosphere, made mainly of nitrogen. On its surface are lakes of methane, sandy plains and mountains.

The surface of Jupiter's moon Io may look like this. There are volcanoes everywhere. When they erupt, plumes of sulphur dioxide gas burst through from Io's rocky interior, jetting some 300 km into space. Astronomers think it is likely that Io is being affected by the enormous gravitational pull of Jupiter (and nearby moon Europa), which tugs at the moon, creating sufficient heat inside it to cause the eruptions.



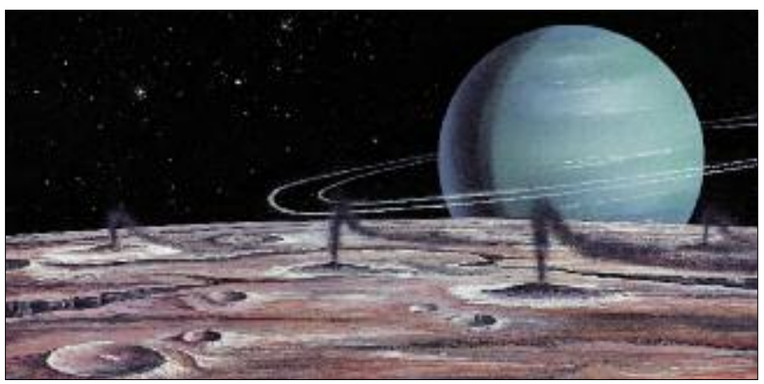
The blue-green globe of Uranus, about 129,000 km away, dominates the skies of one of its moons, Miranda. The landscape of this moon, a jumble of cliffs, canyons and craters, looks as if it has been patched together from many different landscapes *(see page 25).* There is a distinctly V-shaped zone of "grooves". One great cliff is 20 km high, well over twice the height of Earth's highest mountain, Mount Everest.

Callisto, Jupiter's second largest moon, is heavily cratered. Measuring 600 kilometres across, its most prominent crater, called Valhalla, is surrounded by a series of ripples. Io, the third of Jupiter's Galileans, with its crust a vivid mixture of yellows, oranges, reds and blacks, looks a little like a pizza. In fact it is peppered with active volcanoes and lakes of molten rock.

Our own Moon is the fifth largest moon in the Solar System, although it would take 81 Moons to make up a world the size of Earth. The Moon's lava plains indicate past volcanic activity, but there are no active volcanoes there today.

Next in order of size comes Europa, the fourth Galilean and an object of great interest amongst astronomers. Looking like a cracked egg, its surface consists of ice sheets that are continually melting and re-solidifying. It is by no means impossible that, beneath those ice sheets, there is a warm ocean of liquid water. Could it be that life has also evolved on Europa and that there are life-forms swimming in its oceans? Future space probe missions may find out.

Triton is Neptune's largest moon. Its surface is the coldest place known in the Solar System. At -235°C, the temperature is low enough to freeze nitrogen. Triton was photographed in stunning detail by Voyager 2, the last of its close encounters, in 1989.

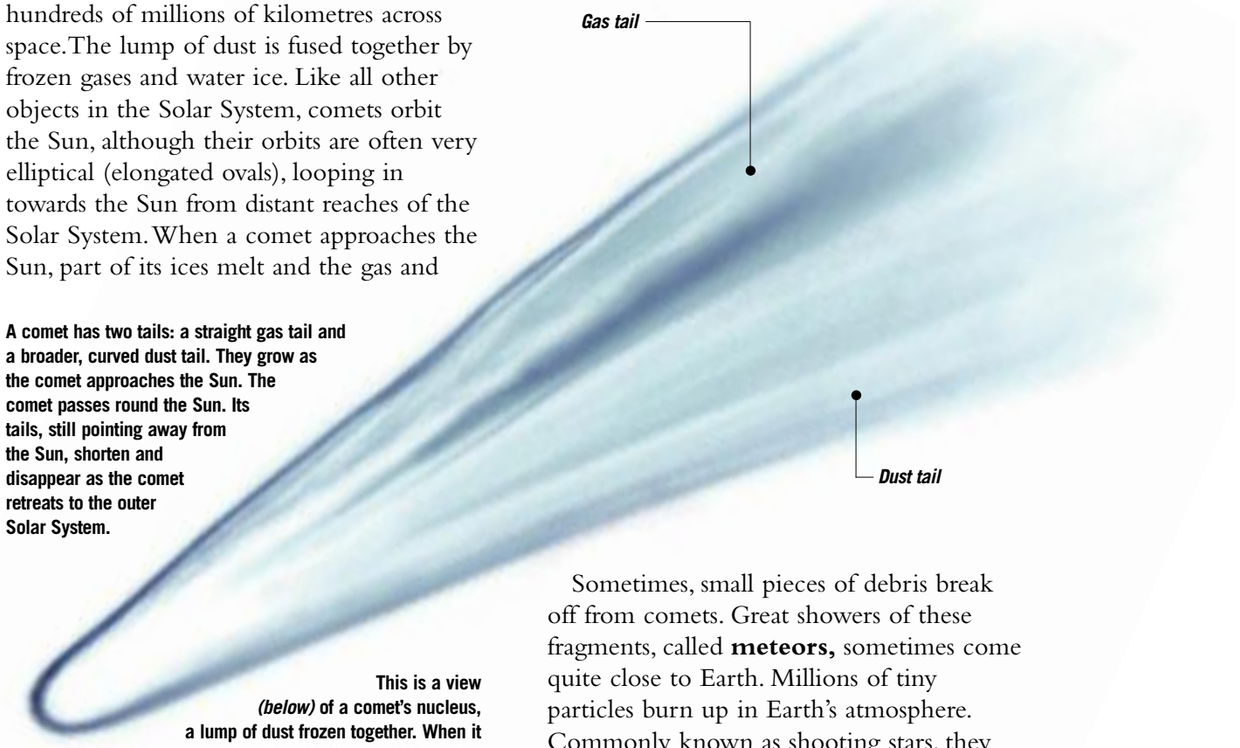


The surface of Triton, Neptune's major moon, is made up of a deep layer of mainly granite-hard nitrogen ice. Sometimes the ice melts to a slush before quickly refreezing, producing ridges and cracks. Nitrogen in its gaseous form collects beneath the solid ice crust. The pressure builds up and eventually the nitrogen gas erupts through weak points in the crust. Gas and dust are spurted up to 8 km high.

SOLAR SYSTEM

COMETS

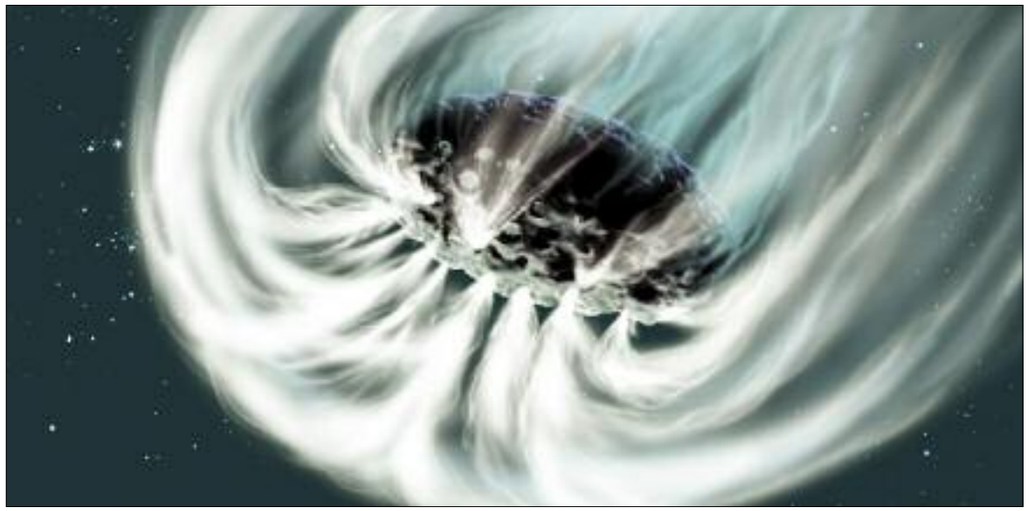
COMETS are potato-shaped lumps of dust measuring only a few kilometres across, but accompanied by (when near the Sun) tails of gas or dust that stretch for hundreds of millions of kilometres across space. The lump of dust is fused together by frozen gases and water ice. Like all other objects in the Solar System, comets orbit the Sun, although their orbits are often very elliptical (elongated ovals), looping in towards the Sun from distant reaches of the Solar System. When a comet approaches the Sun, part of its ices melt and the gas and dust escape, forming a surrounding cloud, or coma. As it rounds the Sun, the coma is swept back into two tails, a straight gas tail and a broader, curved dust tail, always pointing away from the Sun.



A comet has two tails: a straight gas tail and a broader, curved dust tail. They grow as the comet approaches the Sun. The comet passes round the Sun. Its tails, still pointing away from the Sun, shorten and disappear as the comet retreats to the outer Solar System.

This is a view *(below)* of a comet's nucleus, a lump of dust frozen together. When it comes near to the Sun, the ices melt, the outer crust of the nucleus cracks open and jets of dust and gas gush out to form a cloud called a coma.

Sometimes, small pieces of debris break off from comets. Great showers of these fragments, called **meteors,** sometimes come quite close to Earth. Millions of tiny particles burn up in Earth's atmosphere. Commonly known as shooting stars, they appear to us as split-second streaks of light in the night sky.



On 30th June 1908 there was a huge explosion in the Tunguska region of Siberia, Russia. Trees in an area about 100 km across were felled by the blast, but no crater was found. The Tunguska fireball may have been a comet exploding at an altitude of about 6 km.

FAMOUS COMETS

The English astronomer Edmund Halley (1656-1742) was the first to realise that comets were orbiting objects. He once made a famous prediction: a comet that he observed in 1682 would return to the skies in 1758. Halley believed that comets recorded in 1531 and 1607 were simply earlier sightings of the one he saw in 1682. Halley did not live to see his prediction come true. Halley's Comet, as it has been known ever since, was duly sighted on Christmas Day 1758 and has reappeared every 75 to 76 years. When Halley's Comet appeared in March 1986, the space probe Giotto flew within 600 kilometres of it, sending back pictures and sampling the gases and dust particles given off by it.

Comet sightings are always big events. Comet Hale-Bopp in 1997 and McNaught in 2007 were the most spectacular of recent years. Comets can also be destructive if they pass too close to a planet. In July 1994, drawn in by gravity, fragments of Comet Shoemaker-Levy smashed into Jupiter, creating fireballs on impact.

ASTEROIDS

ASTEROIDS are small, mostly rocky, irregular-shaped bodies. They are found orbiting the Sun in a band filling the 550-million-kilometre gap between Mars and Jupiter. The largest, Ceres, measures just under 1000 kilometres across, but only a handful have diameters greater than 100 kilometres. About 4000 have been recorded, but there are many thousands more too small to be identified.

Astronomers believe that, during the formation of the Solar System *(see page 17)*, Jupiter's strong gravitational pull caused nearby planetesimals to smash into one another rather than build up into another planet. This left the belt of fragments we call the asteroids.

Most asteroids are rocky, indicating they come from the outer layers of a former minor planet. But some are metallic—they come from the core of such a planet.

The asteroids have continued to collide with one another since their formation, producing smaller fragments called **meteoroids.** These have occasionally crashed on to Earth's surface (when they are known as **meteorites**). It is feared that one day a large meteorite may devastate Earth, causing climatic change sufficient to wipe out many life-forms.

A close-up view of the irregular shaped objects that make up the asteroid belt between Mars and Jupiter. From study of asteroid fragments that have fallen to Earth, scientists have dated the age of the Solar System to 4.6 million years ago.

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