

A Tour of Space

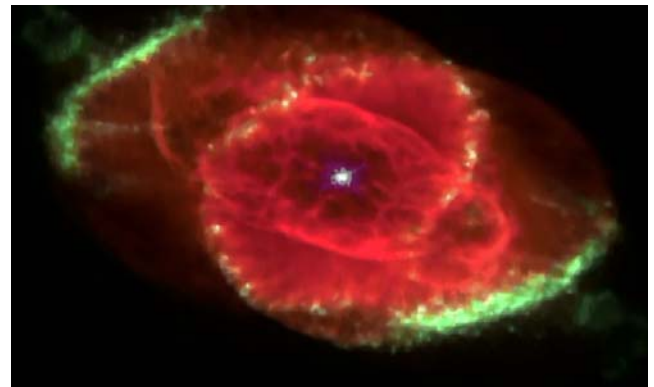
This tour of space offers a glimpse of the awesome majesty of the Universe, but with little technical detail. Although we have learned much, we really know very little of its countless mysteries.

The Universe is Nature on the grand scale, and the distances involved are way beyond human comprehension. To give an idea, if the Earth was the size of a pea, the Sun would be a beach ball about 3km or 2 miles away. On this scale, the nearest star would be about 905,000 km or 560,000 miles away.

Within the Solar System, spacecraft have produced stunning close-up images of the planets and many of their moons. The Hubble Space Telescope and other powerful instruments have brought us breathtaking images of the staggering beauty of distant nebulae (right lower centre), and galaxies (right bottom).

Gazing up at a clear night sky can be a mind-expanding experience, with the glorious vista of stars carpeting a backdrop of black velvet.

Starting with the Sun and working outwards, we can travel through space to far-away galaxies.



Contents

The Solar System	2
The Stars	9
The Galaxies	11

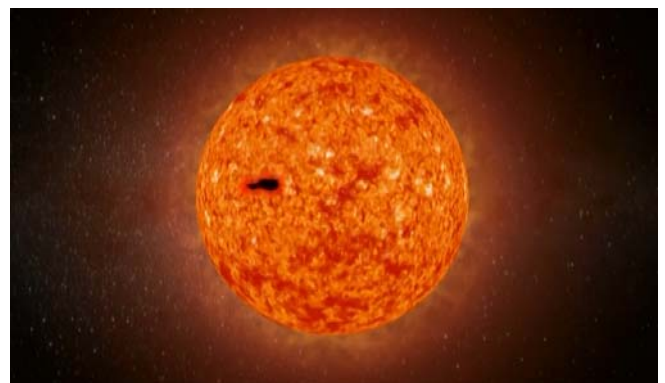
The Solar System

The Sun

The Sun formed some 4.7 billion years ago from a cloud of gas and dust, which contained all the chemical elements ejected during a supernova explosion. As the cloud began collapsing due to gravity, a central body (the early Sun) and a planetary disc (see opposite) of surplus material developed as the young Sun began to cool. The disc then broke down into a series of concentric rings which would later form the planets. Dust particles in these rings collided and stayed together through static attraction. More collisions built up larger bodies which became increasingly large until, by gravitational attraction, they formed the early planets (accretion). Planets are a natural by-product of star birth and are common in the Galaxy. Planetary discs have been seen by the Hubble Space Telescope around young stars such as those in the Orion nebula, but it has been found that the discs risk being evaporated by the radiation from nearby hot stars before planets have a chance to develop. The Solar System is about 4.6 billion years old.

The Sun is 1,392,000 km in diameter and is energised by nuclear fusion reactions within the core which is at a temperature of some 15 million °C. Hot gases percolate through the radiative and convective layers up to the surface layer, the photosphere, whose temperature is some 5,500 °C. The more tenuous gas layer above the photosphere is the chromosphere; beyond that lies the corona which is an irregularly shaped halo of plasma extending outwards into interplanetary space. Sunspots are regions on the photosphere that are at lower temperatures than their surroundings and are regions of intense magnetic activity. They have an eleven year cycle between

maximum and minimum activity; 2006 was a year of minimum sunspot activity. Sunspots can be many times the Earth's diameter in size. They are often related to coronal activity such as solar flares, which are violent explosions in the corona and travel at about 1,000,000 km/hour. Sunspot activity can lead to interference with computers and disrupt communications equipment.



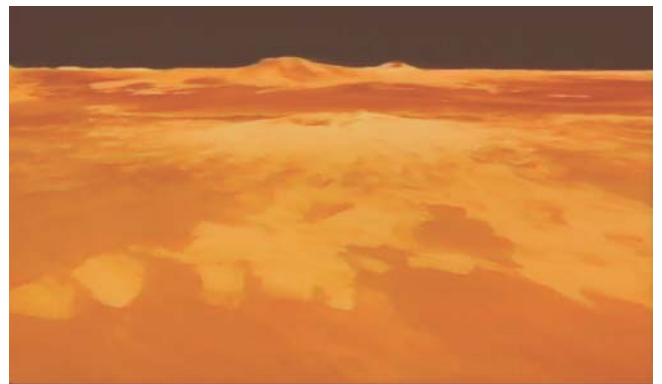
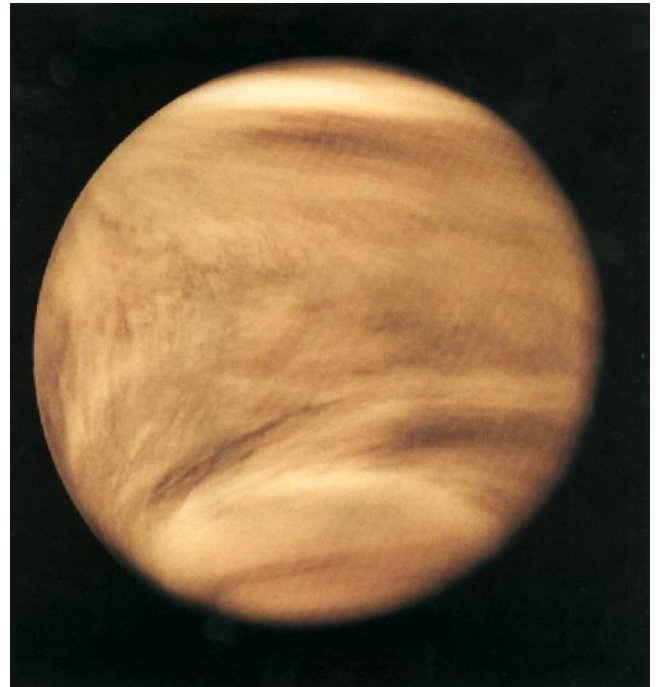
Mercury

Mercury (opposite) is the smallest planet in the solar system with a diameter of 4880 km (Pluto is smaller, but lost its planetary status in 2006). In the mid 1970's the Mariner 10 space probe photographed some 40% of its surface. This showed a landscape covered with impact craters (from meteors rather than volcanic activity), similar to those on the Moon, and many huge faults with steep cliffs up to 300 metres in height. On the dayside, temperatures rise to about 400°C , while during the long night fall below -180°C . The relatively high density of the planet suggests it has a large iron core. There are no moons.



Venus

Venus (diameter 12,100 km), has an atmosphere of about 95% carbon dioxide topped with clouds composed of sulphuric acid droplets. The atmospheric pressure is some 90 times that of Earth. The dense atmosphere traps heat in an extreme greenhouse effect, resulting in surface temperatures of up to 450°C , hot enough to melt lead. The visually impenetrable atmosphere was penetrated by the Magellan probe during the early 1990's using radar. The planet's surface (opposite) was mapped and found to be dotted with volcanoes and impact craters with some upland areas and high mountains. Venus has no moons.



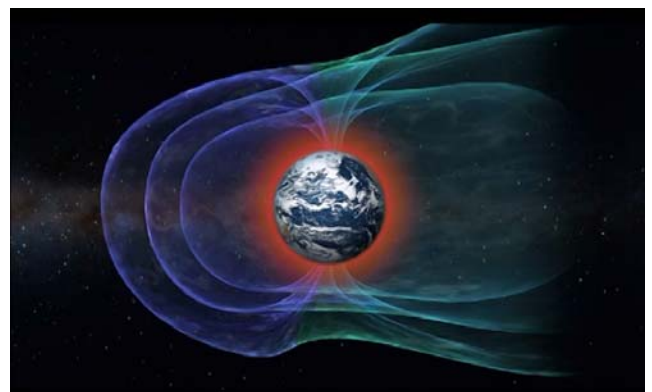
The Earth

Our beautiful home planet has a diameter of 12,575 km, and is about 150 million km (93 million miles) from the Sun. The oceans cover just over two thirds of the surface. Earth was born from the accumulation of rocks (accretion) during the birth of the Solar System, and gradually formed as a molten ball of rock before slowly cooling down (top). The innermost of Earth's layers is a hot metallic core, consisting mainly of iron, which is solid as it is under great pressure. Beyond this there is a mushy transition layer surrounded by the liquid outer core. Above the outer core lie the lower and upper mantles respectively, which make up about 70% of the Earth's volume. The crust is a thin outer layer of relatively low density rock, the depth of which varies from a few km under some areas of the oceans to a maximum of some 80 km under some mountain ranges

Up to about 80 km altitude, near its upper extremities, the Earth's atmosphere consists of about 78% nitrogen, 21% oxygen and 1% carbon dioxide, argon and other trace elements. The far more rarified ionosphere lies from 80 km to 600 km and the composition begins to change, having a greater proportion of lighter gases and also charged particles.

The Earth's magnetic field (bottom) extends several tens of thousands of kilometres into space as the magnetosphere. The magnetosphere is a region which surrounds the Earth and largely prevents the charged particles of the solar wind from entering the atmosphere by deflecting them, protecting life on the Earth's surface. The magnetosphere is compressed on the day side of Earth due to the force of the particles and extends outwards on the night side. The solar wind can cause phenomena such as the aurora, or Northern Lights, visible in the Arctic and Antarctic regions.

The dynamics of Earth's orbit are very complex, largely due to the gravitational influences of the Sun, Moon, Jupiter and Saturn. The variations in orbit and movements of Earth's rotational axis have had considerable influence on the climate, particularly the ice ages, and the evolution of life and the environment. It is believed that the Moon's gravitational field has stabilised the tilt of the Earth's axis, which gives us the seasons. This has moderated extremes in Earth's climate over the ages.



The Moon

The Moon is about 384,400 km (240,000 miles) from Earth and 3,476 km in diameter. It consists of an iron-nickel core some 200-300 km in diameter; the remainder being made up of various types of rock aged between 3.1 and 4.6 billion years. There is strong evidence that indicates that the Moon was the result of a massive oblique impact with a smaller planet soon after the initial formation of the Earth. The planet disintegrated on impact and a large quantity of pulverised rock was propelled into space, orbited the Earth and later accreted to form the Moon. It is thought that the tilt of the Earth's axis is a result of this impact.

The Moon rotates such that the same face is always presented to the Earth. The lunar day from phase to phase (synodic period) is 29 days, 12 hours and 44 minutes. With respect to the stars (sidereal period), the Moon takes 27 days, 7 hours and 43 minutes to orbit the Earth.



Mars

Mars is 6780 km in diameter and has a mean surface temperature of -150°C . Its atmosphere is about a hundredth as dense as that of Earth at the surface and is composed of carbon dioxide and traces of other gases. In spite of the thin atmosphere, extensive and violent dust storms can arise on the planet's surface. Even at its warmest the surface temperature rarely rises above 0°C . Mars has polar ice -caps of water ice and frozen carbon dioxide.

The early atmosphere of Mars, coupled with the presence of water, could have been suitable for the emergence of microscopic life forms. Mars has two very small potato-shaped moons, Phobos and Deimos, which may have been captured from the asteroid belt.



The surface of Mars (below) comprises some impact craters, uplands, deep valleys, high mountains, sand dunes, volcanic craters and ancient river systems. The presence of river systems, and other geological evidence, show there was once flowing water on Mars.



has been present for over 200 years. There are smaller white oval features which are also storms, on a background of banded, multicoloured, swirling clouds. The Galileo spacecraft released a probe into Jupiter's atmosphere. Buffeted by winds of up to 720 km/hour the descending probe failed through the effects of 150 °C in temperature and a pressure of 22 times Earth's atmosphere nearly 200 km below the visible surface.

Jupiter has 67 known moons. From the planet outwards the four largest, discovered by Galileo, are volcanically active Io, Europa (believed to have an icy crust with liquid water below), Ganymede and Callisto. Their diameters range from 3,100 to 5,300 km.

The Asteroid Belt

Between the orbits of Mars and Jupiter lies the asteroid belt, a belt of rocks 150,000 to 300,000 km wide, largely ranging in size from pebbles to mountains. Meteorites are asteroids, rocks, etc, which fall on Earth at an average of 550 each year. The largest meteors are capable of creating large craters such as Meteor Crater in Arizona, USA. This crater, 180 m deep and 1200 m diameter, was made some 50,000 years ago by an iron meteorite some 30 m across and weighing about 110 million kg.

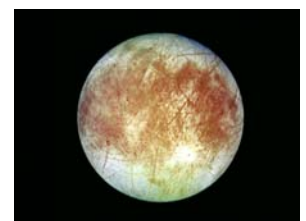


Jupiter

Jupiter is the largest planet in the Solar System with a diameter of 142,980 km and a mass 318 times that of Earth. It has a very dense solid metallic core surrounded by a thick mantle of hydrogen in the metallic state, because of the high pressure. Above this is a layer of liquid hydrogen topped with helium and hydrogen, with some methane and ammonia. To the south of the equator lies the Great Red Spot, a 15,000 by 30,000 km oval vortex of rising warm gases which



IO



EUROPA



GANYMEDE



CALLISTO

Saturn

Saturn, with a diameter of 120,535 km has 62 known moons, the largest being Titan with a diameter of 3,300 km. The Huygens probe, delivered by the Cassini spacecraft, landed on Titan in 2004. Titan is the only moon in the Solar System to have a thick atmosphere; methane lakes and precipitation have been discovered. Titan has rugged, variable terrain. The moon Enceladus is icy, and water is present. Along with Jupiter's Europa, there is a possibility of microscopic life. Saturn has a beautiful ring system comprising several concentric rings separated by gaps which extends from 7,000 to 42,000 km from the equator. The rings are up to one hundred metres thick and are made of dust and ice particles. They may originate from passing comets captured by Saturn and disrupted, or original material that did not accrete into a moon.

Saturn's surface features are more subtly banded than those of Jupiter, with occasional temporary white storm spots. The atmosphere has windspeeds up to 1600 km/hour and is colder than that of Jupiter. The Voyager space probes, the later Cassini Saturn orbiter and Hubble Space Telescope have produced detailed images and new information on Saturn, its larger satellites and ring system.



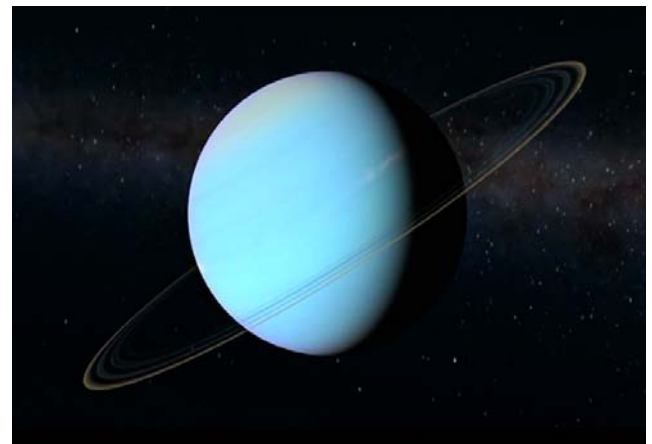
TITAN



ENCELADUS

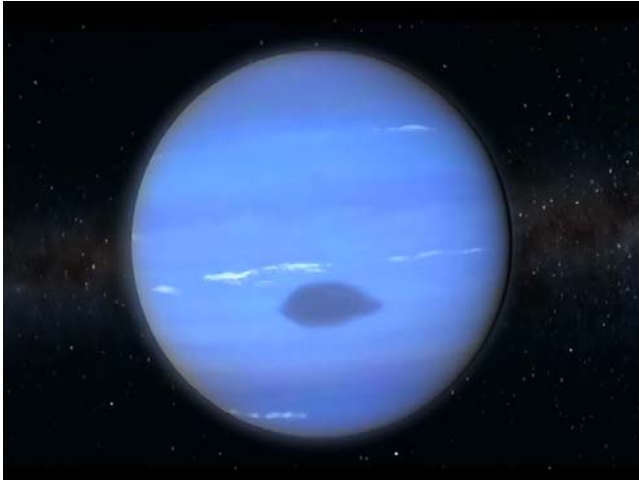
Uranus

Uranus (opposite) contains proportionally more methane and ammonia than Jupiter and Saturn, but much less hydrogen and helium. The planet is basically a sphere of liquid and gas whose bland, greenish surface shows few visible cloud features. Uranus has a diameter of 51,120 km, over 29 small to medium moons of up to 1,600 km diameter and a system of eleven tenuous rings.



Neptune

Neptune (below) was discovered because of perturbations of Uranus' orbit as Uranus was not quite keeping to the orbit calculated for it. Mathematicians calculated the position of a possible planet beyond Uranus and this led to the first observation of Neptune by telescope. Neptune, diameter 49,530 km, is the furthest planet from the Sun, at a distance of 4.5 billion km. The planet is blue in appearance as there is more methane in the atmosphere than Uranus. Neptune was seen close up by the Voyager 2 spacecraft (as was Uranus), and distinct cloud features were seen. Neptune has 14 known moons, the largest being Triton with a diameter of 2,700 km, and a very tenuous system of four rings.



the Solar System. Short term comets with periods less than about 200 years lie within the EKB; some 150 are known. Halley's Comet (shown below) which returns every 75 to 76 years is an example. If any of these bodies has an orbit in the same direction as the planets and is close to the planetary plane, it may be deflected gravitationally by one of the outer planets and thrown into a new orbit taking it close to the inner planets.

Beyond the EKB lies the sparse Oort Cloud comprising millions of icy bodies, which forms a rough sphere around the Solar System at a distance of many times that of Neptune from the Sun and well outside the EKB. Here roam the long-period comets which may take up to 1 million years to reappear.

When a comet comes within the orbit of Mars, it is close enough to the Sun for the frozen gases to start vapourising. A bright, expanded head and a long, tenuous tail which points away from the Sun are formed, caused by the solar wind. When the orbiting Earth crosses one of the cometary trails, small fragments are captured and burn up as they enter the atmosphere, leaving the luminous trails known as shooting stars. There are a number of meteor showers throughout the year - examples in order of richness are:- the Perseids (Aug 11-13), Quadrantids (Jan 3) and the Geminids (Dec 13).

Comets

Beyond Neptune is a doughnut-shaped belt of bodies known as the Edgeworth-Kuiper belt (EKB), which extends from about 6 to 12 billion km from the Sun. These bodies (known as Kuiper Belt Objects) include Pluto and consist of frozen gas, water ice, dust and rock.

Comet cores (nuclei) are made of ice and dust, are typically 1 to 30 km across and tend to be irregular in shape. Comets consist of the primordial matter that originally formed



The Stars

A star is a body that has enough mass for its centre to reach a temperature high enough for nuclear fusion to take place (over 10 million °C). The mass of a star largely determines its power output and longevity.

The birthplaces of stars are swirling clouds of gas and dust (nebulae), consisting mainly of hydrogen and helium. Within these interstellar nebulae, denser knots of gas begin to collapse under their own gravity. As these contract, temperature and gravitational pressure rise until they become high enough to trigger nuclear fusion reactions that convert hydrogen into more helium. The heat released in this reaction, which is like a controlled hydrogen bomb explosion, is what makes a star shine, releasing vast amounts of energy. As the hydrogen is fused into helium atoms, the released energy does two things. First, most of it provides an outward explosive pressure to counterbalance the inward pressure of gravity in the emerging star. This enables a star to remain stable for up to billions of years, as a balance is maintained. Second, some of the energy not involved in this balancing act escapes the star, radiating outwards as heat and light energy. Today stars are being born in nebulae such as "The Pillars of Creation" in the Eagle nebula (top) and the nebula in Orion (bottom). When looking at today's nebulae, we are effectively seeing how the Sun was born.

Low output stars are the most economical, lasting tens of billions of years, whereas large stars may only last a few tens of millions of years because of their relatively high power output. The Sun is a medium sized star with an expected total life of nine to ten billion years; it was born some 4.6 billion years ago.

There is still enough hydrogen to fuel the Sun for some 5 billion years. After this time the hydrogen will be almost depleted and the



predominant element will be helium. Then the helium atoms will start fusing together to form atoms of the next heaviest chemical element. This process will continue with successive elements becoming dominant in the star. With small and medium stars there is not enough mass to generate the extremely high temperatures and pressures to start the fusion process for elements denser than carbon. The star will contain a quantity of all the lighter elements prior to its final demise.

The Sun will expand many times in size into a red giant large enough to engulf Venus. At its largest the Sun will be too distended to be held in check by its own gravity and its outer layers will disperse into space, surrounding the star with picturesque loops and shells of gas. These are known as planetary nebulae



because 18th century observers thought they were of planetary origin. The Helix nebula is shown opposite. Stripped of its overlying gas, the white hot core will be exposed as a white dwarf little larger than the Earth but with much of the mass of the Sun.

Nuclear reactions have ceased in white dwarfs. Since they are no longer generating energy, there is nothing to prevent the pressure of gravity from packing the atomic particles within them as closely together as is physically possible. As a result, white dwarfs are far denser than any material on Earth - a spoonful of matter from one would weigh several thousand kg. Over billions of years, the white dwarf will cool and fade.

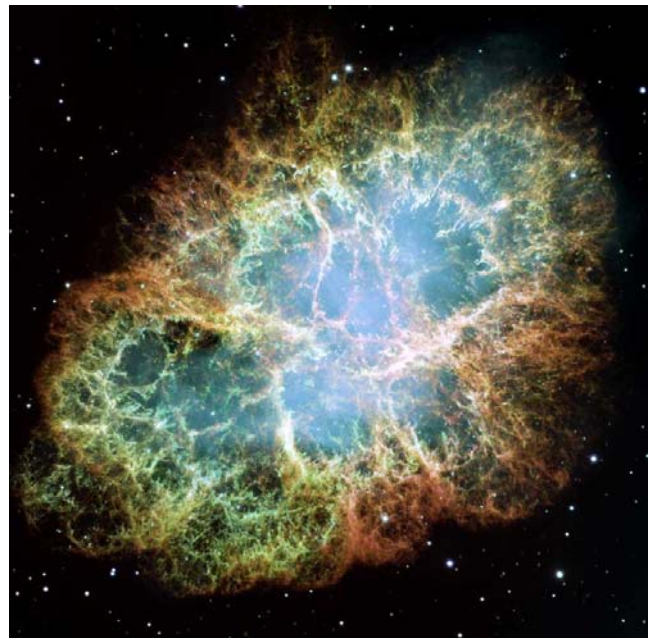
Stars several times the mass of the Sun burn their hydrogen at a far higher rate than smaller stars, and only last from tens to hundreds of millions of years. Towards the end of their lives they expand into supergiants and explode as huge supernovae.

All the chemical elements in Nature are forged in a supernova and are blown into space by the explosion. (The Crab Nebula is shown opposite.) They mix with the interstellar dust and gas of nebulae, later to form new stars and planets, completing a cycle of stellar life and death. We all contain atoms that were created in supernova explosions which occurred long before the Sun was born.

The central core remaining from a supernova is known as a neutron star and is around a million times denser than a white dwarf. A typical neutron star has the mass of one or two Suns and a diameter of 10 to 30 km. The matter is so dense that a spoonful weighs billions of kg. As they are small, neutron stars can spin rapidly, typically a few times a second to once every few seconds. A beam of radiation radiates from their magnetic poles and should this intercept the Earth the neutron star is observed as a rapidly oscillating radio source known as a pulsar.



Should the core created in the supernova have a mass greater than about three Suns it will collapse beyond the stage of a neutron star. The tremendous gravitational field causes the core to shrink ever smaller and denser, becoming a black hole. At the centre of the black hole the remains of the former star are crushed to a point of infinite density known as a singularity.



The Galaxies

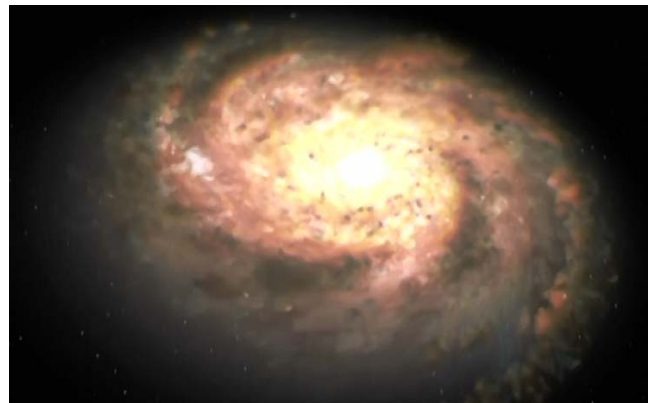
Matter in the Universe is concentrated in gas clouds, stars with their planetary systems, neutron stars, dark matter, black holes and possibly other material, known or unknown, which in turn is concentrated in the galaxies. The galaxies are grouped in galactic clusters and these clusters in superclusters. Matter is distributed throughout the Universe in an irregular lace-like network. Thus, the Universe looks like 3D gossamer; each string being known as a filament (top).

There are three basic galaxy types, with variations - elliptical, spiral and irregular.

Interstellar and intergalactic distances are measured in light years, as the distances involved are so vast. As light travels at about 271,000 km/second (186,000 miles/second) a single light year is a huge distance.

Our home Galaxy, the Milky Way (artist's impression upper centre), is a spiral galaxy over 100,000 light years in diameter and containing some 200 to 400 billion stars, possibly many more if the dead stars known as brown dwarfs are included. The Milky Way and Andromeda, a spiral galaxy about twice the size of ours and about 2.2 million light years away, are accompanied by about 45 smaller satellite galaxies. Far smaller than the Milky Way, two of these are the glorious Large and Small Magellanic Clouds (lower centre and bottom), which are irregular satellite galaxies. Together these form the galactic cluster known as the Local Group.

The Milky Way slowly turns on its axis, but not as a solid wheel; its rotational speed varies across the galactic disc. The Sun, around 30,000 light years from the centre, travels around the centre at about 800,000 km/hour and completes one turn in about 220 million years.



Astronomers believe that in the centre of the Milky Way there is a supermassive black hole with a mass of a few million Suns, in common with most galaxies. A black hole is a region in space-time from which nothing, including light, can escape if it comes too close, because of its immense gravitational field.

The largest members of our Local Group, the Andromeda galaxy and the Milky Way, are approaching each other at a speed of some 820,000 km/hour owing to gravitational influence. In about 3 billion years' time, the night sky as seen from Earth will be filled by the Andromeda galaxy, which will first pass by before falling back to merge about a billion years later.

Observations with the Hubble Space Telescope have confirmed that quasars lie at the heart of some distant galaxies several billion light years away, when galaxies were first forming. The most distant quasar yet observed is moving away from us at about 94.5% light-speed and is some 13.5 billion light years distant. For something so far away to have the appearance of a nearby star, a phenomenal amount of heat and light radiation must be emitted. We see the nearer galaxies as they were much more recently and these rarely have quasars. This suggests that the nearer galaxies have generally evolved beyond the stage of having quasars at their centre and that the very high energies of quasars were integral to the formation of early galaxies.

Huge black holes, between a million and a billion times the Sun's mass form the centre of quasars (see opposite). Although a black hole cannot be observed directly, it resides in the centre of an orbiting disc of dust and gas clouds attracted from nearby nebulae and stars that have been shredded by its immense gravitational field. This indicates the presence of a black hole. Any gas not swallowed by the black hole is ejected at near light speed along or close to the rotational axis of the disc.



THE WHIRLPOOL GALAXY



THE SOMBRERO GALAXY



Credits

Credits are due to NASA, the ESA (European Space Agency), other astronomical and astronomically related institutions, and the talented artists who produce impressions of astronomical bodies and phenomena, for producing all the images shown in this article. The text is my own, derived from many sources over the years.