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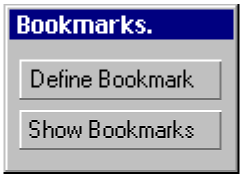
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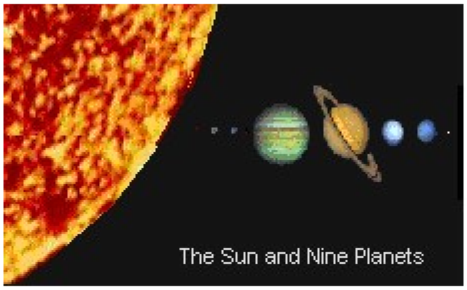
Our Solar System



From our small world we have gazed upon the cosmic ocean for untold thousands of years. Ancient astronomers observed points of light that appeared to move among the stars. They called these objects planets, meaning wanderers, and named them after Roman deities Jupiter, king of the gods; Mars, the god of war; Mercury, messenger of the gods; Venus, the god of love and beauty, and Saturn, father of Jupiter and god of agriculture. The stargazers also observed comets with sparkling tails, and meteors or shooting stars apparently falling from the sky. Science flourished during the European Renaissance. Fundamental physical laws governing planetary motion were discovered, and the orbits of the planets round the Sun were calculated. In the 17th century, astronomers pointed a new device called the telescope at the heavens and made startling discoveries. But the years since 1959 have amounted to a golden age of solar system exploration. Advancements in rocketry after World War II enabled our machines to break the grip of Earth's gravity and travel to the Moon and to other planets.

The United States has sent automated spacecraft, then human-crewed expeditions, to explore the Moon. Our automated machines have orbited and landed on Venus and Mars; explored the Sun's environment; observed comets, and made close-range surveys while flying past Mercury, Jupiter, Saturn, Uranus and Neptune. These travellers brought a quantum leap in our knowledge and understanding of the solar system. Through the electronic sight and other senses of our automated spacecraft, colour and complexion have been given to worlds that for centuries appeared to Earth-bound eyes as fuzzy disks or indistinct points of light. And dozens of previously unknown objects have been discovered. Future historians will likely view these pioneering flights through the solar system as some of the most remarkable achievements of the 20th century.

Automated Spacecraft

The National Aeronautics and Space Administration's (NASA's) automated spacecraft for solar system exploration come in many shapes and sizes. While they are designed to fulfil separate and specific mission objectives, the craft share much in common.

Each spacecraft consists of various scientific instruments selected for a particular mission, supported by basic subsystems for electrical power, trajectory and orientation control, as well as for processing data and communicating with Earth. Electrical power is required to operate the spacecraft instruments and systems. NASA uses both solar energy from arrays of photo-voltaic cells and small nuclear generators to power its solar system missions. Rechargeable batteries are employed for backup and supplemental power. Imagine that a spacecraft has successfully journeyed millions of miles through space to fly but one time near a planet, only to have its cameras and other sensing instruments pointed the wrong way as it speeds past the target

To help prevent such a mishap, a subsystem of small thrusters is used to control spacecraft. The thrusters are linked with devices that maintain a constant gaze at selected stars. Just as Earth's early seafarers used the stars to navigate the oceans, spacecraft use stars to maintain their bearings in space. With the sub-system locked onto fixed points of reference, flight controllers can keep a spacecraft's scientific instruments pointed at the target body and the craft's communications antennas pointed toward Earth. The thrusters can also be used to fine-tune the flight path and speed of the spacecraft to ensure that a target body is encountered at the planned distance and on the proper trajectory.

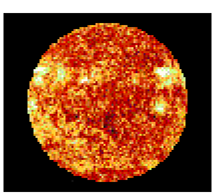
Between 1959 and 1971, NASA spacecraft were dispatched to study the Moon and the solar environment; they also scanned the inner planets other than Earth -- Mercury, Venus and Mars. These three worlds, and our own, are known as the terrestrial planets because they share a solid-rock composition. For the early planetary reconnaissance missions, NASA employed a highly successful series of spacecraft called the Mariners. Their flights helped shape the planning of later missions. Between 1962 and 1975, seven Mariner missions conducted the first surveys of our planetary neighbours in space. All of the Mariners used solar panels as their primary power source. The first and the final versions of the spacecraft had two wings covered with photo-voltaic cells.

Other Mariners were equipped with four solar panels extending from their octagonal bodies. Although the Mariners ranged from the Mariner 2 Venus spacecraft, weighing in at 203 kilograms (447 pounds), to the Mariner 9 Mars Orbiter, weighing in at 974 kilograms (2,147 pounds), their basic design remained quite similar through-out the program. The Mariner 5 Venus spacecraft, for example, had originally been a backup for the Mariner 4 Mars flyby. The Mariner 10 spacecraft sent to Venus and Mercury used components left over from the Mariner 9 Mars Orbiter program.

In 1972, NASA launched Pioneer 10, a Jupiter spacecraft. Interest was shifting to four of the outer planets -- Jupiter, Saturn, Uranus and Neptune -- giant balls of dense gas quite different from the terrestrial worlds we had already surveyed. Four NASA spacecraft in all -- two Pioneers and two Voyagers -- were sent in the 1970s to tour the outer regions of our solar system. Because of the distances involved, these travellers took anywhere from 20 months to 12 years to reach their destinations. Barring faster spacecraft, they will eventually become the first human artefacts to journey to distant stars. Because the Sun's light becomes so faint in the outer solar system, these travellers do not use solar power but instead operate on electricity generated by heat from the decay of radioisotopes.

NASA also developed highly specialised spacecraft to revisit our neighbours Mars and Venus in the middle and late 1970s. Twin Viking Landers were equipped to serve as seismic and weather stations and as biology laboratories. Two advanced orbiters -- descendants of the Mariner craft -- carried the Viking Landers from Earth and then studied Martian features from above. Two drum-shaped Pioneer spacecraft visited Venus in 1978. The Pioneer Venus Orbiter was equipped with a radar instrument that allowed it to "see" through the planet's dense cloud cover to study surface features. The Pioneer Venus Multiprobe carried four probes that were dropped through the clouds. The probes and the main body -- all of which contained scientific instruments -- radioed information about the planet's atmosphere during their descent toward the surface. A new generation of automated spacecraft -- including Magellan, Galileo, Ulysses, and Cassini -- is being developed and sent out into the solar system to make detailed examinations that will increase our understanding of our neighbour-hood and our own planet.

THE SUN



A discussion of the objects in the solar system must start with the Sun. The Sun dwarfs the other bodies, representing approximately 99.86 percent of all the mass in the solar system; all of the planets, moons, asteroids, comets, dust and gas add up to only about 0.14 percent. This 0.14 percent represents the material left over from the Sun's formation. One hundred and nine Earth's would be required to fit across the Sun's disk, and its interior could hold over 1.3 million Earth's. As a star, the Sun generates energy through the process of fusion. The temperature at the Sun's core is 15 million degrees Celsius (27 million degrees Fahrenheit), and the pressure there is 340 billion times Earth's air pressure at sea level. The Sun's surface temperature of 5,500 degrees Celsius (10,000 degrees Fahrenheit) seems almost chilly compared to its core-temperature. At the solar core, hydrogen can fuse into helium, producing energy. The Sun also produces a strong magnetic field and streams of charged particles, both extending far beyond the planets. The Sun appears to have been active for 4.6 billion years and has enough fuel to go on for another five billion years or so.

At the end of its life, the Sun will start to fuse helium into heavier elements and begin to swell up, ultimately growing so large that it will swallow Earth. After a billion years as a "red giant," it will suddenly collapse into a "white dwarf"-- the final end product of a star like ours. It may take a trillion years to cool off completely.

Many spacecraft have explored the Sun's environment, but none have got any closer to its surface than approximately two thirds of the distance from Earth to the Sun. Pioneers 5-11, the Pioneer Venus Orbiter, Voyagers 1 and 2 and other spacecraft have all sampled the solar environment. The Ulysses spacecraft, launched on October 6, 1990, is a joint solar mission of NASA and the European Space Agency. On February 8, 1992, Ulysses flew close to Jupiter and used Jupiter's gravity to hurl it down below the plane of the planets. Although it will still be at great distance from the Sun, Ulysses will fly over the Sun's polar regions during 1994 and 1995 and will perform a wide range of studies using nine onboard scientific instruments. We are fortunate that the Sun is exactly the way it is. If it were different in almost any way, life would almost certainly never have developed on Earth.

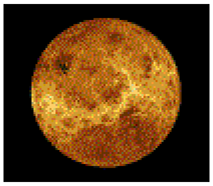
MERCURY

Obtaining the first close-up views of Mercury was the primary objective of the Mariner 10 spacecraft, launched on November 3, 1973, from Kennedy Space Center in Florida. After a journey of nearly five months, which included a flyby of Venus, the spacecraft passed within 703 kilometres (437 miles) of the solar system's innermost planet on March 29, 1974. Until Mariner 10, little was known about Mercury. Even the best telescopic views from Earth showed Mercury as an indistinct object lacking any surface detail. The planet is so close to the Sun that it is usually lost in solar glare. When the planet is visible on Earth's horizon just after sunset or before dawn, it is obscured by the haze and dust in our atmosphere. Only radar telescopes gave any hint of Mercury's surface conditions prior to the voyage of Mariner 10. The photographs Mariner 10 radioed back to Earth revealed an ancient, heavily cratered surface, closely resembling our own Moon. The pictures also showed huge cliffs criss-crossing the planet. These apparently were created when Mercury's interior cooled and shrank, buckling the planet's crust. The cliffs are as high as 3 kilometres (2 miles) and as long as 500 kilometres (310 miles). Instruments on Mariner 10 discovered that Mercury has a weak magnetic field and a trace of atmosphere -- a trillionth the density of Earth's atmosphere and composed chiefly of argon, neon and helium. When the planet's orbit takes it closest to the Sun, surface temperatures range from 467 degrees Celsius (872 degrees Fahrenheit) on Mercury's sunlit side to -183 degrees Celsius (-298 degrees Fahrenheit) on the dark side. This range in surface temperature -- 650 degrees Celsius (1,170 degrees Fahrenheit) -- is the largest for a single body in the solar system. Mercury literally bakes and freezes at the same time.

Days and nights are long on Mercury. The combination of a slow rotation relative to the stars (59 Earth days) and a rapid revolution around the Sun (88 Earth days) means that one Mercury solar day takes 176 Earth days or two Mercury years -- the time it takes the inner-most planet to complete two orbits around the Sun Mercury appears to have a crust of light silicate rock like that of Earth. Scientists believe

Mercury has a heavy iron-rich core making up slightly less than half of its volume. That would make Mercury's core larger, proportionally, than the Moon's core or those of any of the planets. After the initial Mercury encounter, Mariner 10 made two additional flybys -- on September 21, 1974, and March 16, 1975 -- before control gas used to orient the spacecraft was exhausted and the mission was concluded. Each flyby took place at the same local Mercury time when the identical half of the planet was illuminated; as a result, we still have not seen one-half of the planet's surface.

VENUS



Veiled by dense cloud cover, Venus -- our nearest planetary neighbour -- was the first planet to be explored. The Mariner 2 spacecraft, launched on August 27, 1962, was the first of more than a dozen successful American and Soviet missions to study the mysterious planet. As spacecraft flew by or orbited Venus, plunged into the atmosphere or gently landed on Venus' surface, romantic myths and speculations about our neighbour were laid to rest. On December 14, 1962, Mariner 2 passed within 34,839 kilometres (21,648 miles) of Venus and became the first spacecraft to scan another planet; onboard instruments measured Venus for 42 minutes. Mariner 5, launched in June 1967, flew much closer to the planet. Passing within 4,094 kilo-metres (2,544 miles) of Venus on the second American flyby, Mariner 5's instruments measured the planet's magnetic field, ionosphere, radiation belts and temperatures. On its way to Mercury, Mariner 10 flew by Venus and transmitted ultraviolet pictures to Earth showing cloud circulation patterns in the Venusian atmosphere.

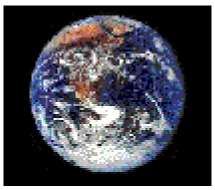
In the spring and summer of 1978, two spacecraft were launched to further unravel the mysteries of Venus. On December 4 of the same year, the Pioneer Venus Orbiter became the first spacecraft placed in orbit around the planet. Five days later, the five separate components making up the second spacecraft -- the Pioneer Venus Multiprobe entered the Venusian atmosphere at different locations above the planet. The four small, independent probes and the main body radioed atmospheric data back to Earth during their descent toward the surface. Although designed to examine the atmosphere, one of the probes survived its impact with the surface and continued to transmit data for another hour. Venus resembles Earth in size, physical composition and density more closely than any other known planet. However, spacecraft have discovered significant differences as well. For example, Venus' rotation (west to east) is retrograde (backward) compared to the east-to-west spin of Earth and most of the other planets.

Approximately 96.5 percent of Venus' atmosphere (95 times as dense as Earth's) is carbon dioxide. The principal constituent of Earth's atmosphere is nitrogen. Venus' atmosphere acts like a greenhouse, permitting solar radiation to reach the surface but trapping the heat that would ordinarily be radiated back into space. As a result, the planet's average surface temperature is 482 degrees Celsius (900 degrees Fahrenheit), hot enough to melt lead. A radio altimeter on the Pioneer Venus Orbiter provided the first means of seeing through the planet's dense cloud cover and deter-mining surface features over almost the entire planet. NASA's Magellan spacecraft, launched on May 5, 1989, has been in orbit around Venus since August 10, 1990. The spacecraft used radar-mapping techniques to provide high-resolution images of 98 percent of the surface.

Magellan's radar revealed a landscape dominated by volcanic features, faults and impact craters. Huge areas of the surface show evidence of multiple periods of lava flooding with flows lying on top of previous ones. An elevated region named Ishtar Terra is a lava-filled basin as large as the United States. At one end of this plateau sits Maxwell Montes, a mountain the size of Mount Everest. Scarring the mountain's flank is a 100-kilometre (62-miles) wide, 2.5-kilometre (1.5-miles) deep impact crater named Cleopatra. (Almost all features on Venus are named for women; Maxwell Montes, Alpha Regio and Beta Regioare the exceptions.) Craters survive on Venus for perhaps 400 million years because there is no water and very little wind erosion.

Extensive fault-line networks cover the planet, probably the result of the same crustal flexing that produces plate tectonics on Earth. But on Venus the surface temperature is sufficient to weaken the rock, which cracks just about everywhere, preventing the formation of major plates and large earth quake faults like the San Andreas Fault in California. Venus' predominant weather pattern is a high-altitude, high-speed circulation of clouds that contain sulphuric acid. At speeds reaching as high as 360 kilometres (225 miles) per hour, the clouds circle the planet in only four Earth days. The circulation is in the same direction -- west to east -- as Venus' slow rotation of 243 Earth days, whereas Earth's winds blow in both directions -- west to east and east to west -- in six alternating bands. Venus' atmosphere serves as a simplified laboratory for the study of our weather.

EARTH



As viewed from space, our world's distinguishing characteristics are its blue waters, brown and green land masses and white clouds. We are enveloped by an ocean of air consisting of 78 percent nitrogen, 21 percent oxygen and 1 percent other constituents. The only planet in the solar system known to harbour life, Earth orbits the Sun at an average distance of 150 million kilometres (93 million miles). Earth is the third planet from the Sun and the fifth largest in the solar system, with a diameter just a few hundred kilometres larger than that of Venus. Our planet's rapid spin and molten nickel-iron core give rise to an extensive magnetic field, which, along with the atmosphere, shields us from nearly all of the harmful radiation coming from the Sun and other stars. Earth's atmosphere protects us from meteors as well, most of which burn up before they can strike the surface. Active geological processes have left no evidence of the pelting Earth almost certainly received soon after it formed - about 4.6 billion years ago. Along with the other newly formed planets, it was showered by space debris in the early days of the solar system.

From our journeys into space, we have learned much about our home planet. The first American satellite -- Explorer 1 -- was launched from Cape Canaveral in Florida on January 31, 1958, and discovered an intense radiation zone, now called the Van Allen radiation belts, surrounding Earth. Since then, other research satellites have revealed that our planet's magnetic field is distorted into a teardrop shape by the solar wind -- the stream if charged particles continuously ejected from the Sun. We've learned that the magnetic field does not fade off into space but has definite boundaries. And we now know that our wispy upper atmosphere, once believed calm and uneventful, seethes with activity -- swelling by day and contracting by night. Affected by changes in solar activity, the upper atmosphere contributes to weather and climate on Earth.

Besides affecting Earth's weather, solar activity gives rise to a dramatic visual phenomenon in our atmosphere. When charged particles from the solar wind become trapped in Earth's magnetic field, they collide with air molecules above our planet's magnetic poles. These air molecules then begin to glow and are known as the auroras or the northern and southern lights. Satellites about 35,789 kilometres (22,238 miles) out in space play a major role in daily local weather forecasting. These watchful electronic eyes warn us of dangerous storms. Continuous global monitoring provides a vast amount of useful data and contributes to a better understanding of Earth's complex weather systems. From their unique vantage points, satellites can survey Earth's oceans, land use and resources, and monitor the planet's health. These eyes in space have saved countless lives, provided tremendous conveniences and shown us that we may be altering our planet in dangerous ways.

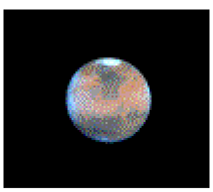
THE MOON

The Moon is Earth's single natural satellite. The first human foot-steps on an alien world were made by American astronauts on the dusty surface of our airless, lifeless companion. In preparation for the human-crewed Apollo expeditions, NASA dispatched the automated Ranger, Surveyor and Lunar Orbiter spacecraft to study the Moon between 1964 and 1968. NASA's Apollo program left a large legacy of lunar materials and data. Six two-astronaut crews landed on and explored the lunar surface between 1969 and 1972, carrying back a collection of rocks and soil weighing a total of 382 kilograms (842 pounds) and consisting of more than 2,000 separate samples. From this material and other studies, scientists have constructed a history of the Moon that includes its infancy. Rocks collected from the lunar highlands date to about 4.0-4.3 billion years old. The first few million years of the Moon's existence were so violent that few traces of this period remain. As a molten outer layer gradually cooled and solidified into different kinds of rock, the Moon was bombarded by huge asteroids and smaller objects, and their collisions with the Moon created basins hundreds of kilometres across.

This catastrophic bombardment tapered off approximately four billion years ago, leaving the lunar highlands covered with huge, overlapping craters and a deep layer of shattered and broken rock. Heat produced by the decay of radioactive elements began to melt the interior of the Moon at depths of about 200 kilometres (125 miles) below the surface. Then, for the next 700 million years -- from about 3.8 to 3.1 billion years ago -- lava rose from inside the Moon. The lava gradually spread out over the surface, flooding the large impact basins to form the dark areas that Galileo Galilei, an astronomer of the Italian Renaissance, called maria, meaning seas. As far as we can tell, there has been no significant volcanic activity on the Moon for more than three billion years. Since then, the lunar surface has been altered only by micro-meteorites, by the atomic particles from the Sun and stars, by the rare impacts of large meteorites and by spacecraft and astronauts. If our astronauts had landed on the Moon a billion years ago, they would have seen a landscape very similar to the one today. Thousands of years from now, the footsteps left by the Apollo crews will remain sharp and clear.

The origin of the Moon is still a mystery. Four theories attempt an explanation: the Moon formed near Earth as a separate body; it was torn from Earth; it formed somewhere else and was captured by our planet's gravity, or it was the result of a collision between Earth and an asteroid about the size of Mars. The last theory has some good support but is far from certain.

MARS



Of all the planets, Mars has long been considered the solar system's prime candidate for harbouring extraterrestrial life. Astronomers studying the red planet through telescopes saw what appeared to be straight lines criss-crossing its surface. These observations -- later determined to be optical illusions -- led to the popular notion that intelligent beings had constructed a system of irrigation canals on the planet. In 1938, when Orson Welles broadcast a radio drama based on the science fiction classic War of the Worlds by H.G. Wells, enough people believed in the tale of invading Martians to cause a near panic. Another reason for scientists to expect life on Mars had to do with the apparent seasonal colour changes on the planet's surface. This phenomenon led to speculation that conditions might support a bloom of Martian vegetation during the warmer months and cause plant life to become dormant during colder periods. So far, six American missions to Mars have been carried out. Four Mariner spacecraft -- three flying by the planet and one placed into Martian orbit -- surveyed the planet extensively before the Viking Orbiters and Landers arrived.

Mariner 4, launched in late 1964, flew past Mars on July 14, 1965, coming within 9,846 kilometres (6,118 miles) of the surface. Transmitting to Earth 22 close-up pictures of the planet, the spacecraft found many craters and naturally occurring channels but no evidence of artificial canals or flowing water. Mariners 6 and 7 followed with their flybys during the summer of 1969 and returned 201 pictures. Mariners 4, 6 and 7 showed a diversity of surface conditions as well as a thin, cold, dry atmosphere of carbon dioxide. On May 30, 1971, the Mariner 9 Orbiter was launched on a mission to make a year-long study of the Martian surface. The spacecraft arrived five and a half months after lift-off, only to find Mars in the midst of a planet-wide dust storm that made surface photography impossible for several weeks. But after the storm cleared, Mariner 9 began returning the first of 7,329 pictures; these revealed previously unknown Martian features, including evidence that large amounts of water once flowed across the surface, etching river valleys and flood plains.

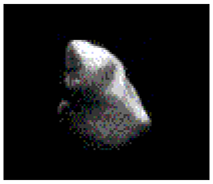
In August and September 1975, the Viking 1 and 2 spacecraft -- each consisting of an orbiter and a lander -- lifted off from Kennedy Space Center. The mission was designed to answer several questions about the red planet, including, Is there life there? Nobody expected the spacecraft to spot Martian cities, but it was hoped that the biology experiments on the Viking Landers would at least find evidence of primitive life -- past or present. Viking Lander 1 became the first spacecraft to successfully touch down on another planet when it landed on July 20, 1976, while the United States was celebrating its Bicentennial. Photos sent back from the Chryse Planitia ("Plains of Gold") showed a bleak, rusty-red landscape. Panoramic images returned by the lander revealed a rolling plain, littered with rocks and marked by rippled sand dunes. Fine red dust from the Martian soil gives the sky a salmon hue. When Viking Lander 2 touched down on Utopia Planitia on September 3, 1976, it viewed a more rolling landscape than the one seen by its predecessor -- one without visible dunes.

The results sent back by the laboratory on each Viking Lander were inconclusive. Small samples of the red Martian soil were tested in three different experiments designed to detect biological processes. While some of the test results seemed to indicate biological activity, later analysis confirmed that this activity was inorganic in nature and related to the planet's soil chemistry. Is there life on Mars? No one knows for sure, but the Viking mission found no evidence that organic molecules exist there. The Viking Landers became weather stations, recording wind velocity and direction as well as atmospheric temperature and pressure. Few weather changes were observed. The highest temperature recorded by either craft was - 14 degrees Celsius (7 degrees Fahrenheit) at the Viking Lander 1 site in midsummer. The lowest temperature, -120 degrees Celsius (-184 degrees Fahrenheit), was recorded at the more northerly Viking Lander 2 site during winter. Near-hurricane wind speeds were measured at the two Martian weather stations during global dust storms, but because the atmosphere is so thin, wind force is minimal. Viking Lander 2 photographed light patches of frost -- probably water-ice.

The Martian atmosphere, like that of Venus, is primarily carbon dioxide. Nitrogen and oxygen are present only in small percentages. Martian air contains only about 1/1,000 as much water as our air, but even this small amount can condense out, forming clouds that ride high in the atmosphere or swirl around the slopes of towering volcanoes. Local patches of early morning fog can form in valleys. There is evidence that in the past a denser Martian atmosphere may have allowed water to flow on the planet. Physical features closely resembling shorelines, gorges, river-beds and islands suggest that great rivers once marked the planet. Mars has two moons, Phobos and Deimos. They are small and irregularly shaped and possess ancient, cratered surfaces. It is possible the moons were originally asteroids that ventured too close to Mars and were captured by its gravity.

The Viking Orbiters and Landers exceeded by large margins their design lifetimes of 120 and 90 days, respectively. The first to fail was Viking Orbiter 2, which stopped operating on July 24, 1978, when a leak depleted its altitude-control gas. Viking Lander 2 operated until April 12, 1980, when it was shut down because of battery degeneration. Viking orbiter 1 quit on August 7, 1980, when the last of its attitudecontrol gas was used up. Viking Lander1 ceased functioning on November 13, 1983. Despite the inconclusive results of the Viking biology experiments, we know more about Mars than any other planet except Earth.

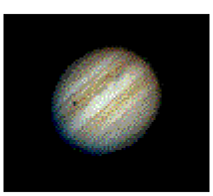
THE ASTEROIDS



The solar system has a large number of rocky and metallic objects that are in orbit around the Sun but are too small to be considered full-fledged planets. These objects are known as asteroids or minor planets. Most, but not all, are found in a band or belt between the orbits of Mars and Jupiter. Some have orbits that cross Earth's path, and there is evidence that Earth has been hit by asteroids in the past. One of the least eroded, best preserved examples is the Barringer Meteor Crater near Winslow, Arizona. Asteroids are material left over from the formation of the solar system. One theory suggests that they are the remains of a planet that was destroyed in a massive collision long ago. More likely, asteroids are material that never coalesced into a planet. In fact, if the estimated total mass of all asteroids was gathered into a single object, the object would be less than 1,500 kilometres (932 miles) across -- less than half the diameter of our Moon. Thousands of asteroids have been identified from Earth. It is estimated that 100,000 are bright enough to eventually be photographed through Earth-based telescopes.

Much of our understanding about asteroids comes from examining pieces of space debris that fall to the surface of Earth. Asteroids that are on a collision course with Earth are called meteoroids. When a meteoroid strikes our atmosphere at high velocity, friction causes this chunk of space matter to incinerate in a streak of light known as a meteor. If the meteoroid does not burn up completely, what's left strikes Earth's surface and is called a meteorite. One of the best places to look for meteorites is the ice cap of Antarctica. Of all the meteorites examined, 92.8 percent are composed of silicate (stone), and 5.7 percent are composed of iron and nickel; the rest are a mixture of the three materials. Stony meteorites are the hardest to identify since they look very much like terrestrial rocks. Since asteroids are material from the very early solar system, scientists are interested in their composition. Spacecraft that have flown through the asteroid belt have found that the belt is really quite empty and that asteroids are separated by very large distances. Current and future missions will fly by selected asteroids for closer examination. The Galileo spacecraft, launched by NASA in October 1989, investigated the main-belt asteroid Gaspra on October 29, 1991 and will encounter Ida on August 28, 1993 on its way to Jupiter. One day, space factories will mine the asteroids for raw materials.

JUPITER



Beyond Mars and the asteroid belt, in the outer regions of our solar system, lie the giant planets of Jupiter, Saturn, Uranus and Neptune. In 1972, NASA dispatched the first of four spacecraft slated to conduct the initial surveys of these colossal worlds of gas and their moons of ice and rock. Jupiter was the first port of call. Pioneer 10, which lifted off from Kennedy Space Center in March 1972, was the first spacecraft to penetrate the asteroid belt and travel to the outer regions of the solar system. In December 1973, it returned the first close-up images of Jupiter, flying within 132,252 kilometres (82,178 miles) of the planet's banded cloud tops. Pioneer 11 followed a year later. Voyagers

1 and 2 were launched in the summer of 1977 and returned spectacular photographs of Jupiter and its family of satellites during flybys in 1979. These travellers found Jupiter to be a whirling ball of liquid hydrogen and helium, topped with a colourful atmosphere composed mostly of gaseous hydrogen and helium. Ammonia ice crystals form white Jovian clouds. Sulphur compounds (and perhaps phosphorus) may produce the brown and orange hues that characterise Jupiter's atmosphere. It is likely that methane, ammonia, water and other gases react to form organic molecules in the regions between the planet's frigid cloud tops and the warmer hydrogen ocean lying below. because of Jupiter's atmospheric dynamics, however, these organic compounds -- if they exist -- are probably short-lived.

The Great Red Spot has been observed for centuries through telescopes on Earth. This hurricane-like storm in Jupiter's atmosphere is more than twice the size of our planet. As a high- pressure region, the Great Red Spot spins in a direction opposite to that of low-pressure storms on Jupiter; it is surrounded by swirling currents that rotate around the spot and are sometimes consumed by it. The Great Red Spot might be a million years old. Our spacecraft detected lightning in Jupiter's upper atmosphere and observed auroral emissions similar to Earth's northern lights at the Jovian polar regions. Voyager 1 returned the first images of a faint, narrow ring encircling Jupiter. Largest of the solar system's planets, Jupiter rotates at a dizzying pace -- once every 9 hours 55 minutes 30 seconds. The massive planet takes almost 12 Earth years to complete a journey around the Sun. With 16 known moons, Jupiter is something of a miniature solar system. A new mission to Jupiter -- the Galileo Project -- is under way. On December 7, 1995, after a six year cruise that takes the Galileo Orbiter once past Venus, twice past Earth and the Moon and once past two asteroids, the spacecraft will drop an atmospheric probe into Jupiter's cloud layers and relay data back to Earth. The Galileo Orbiter will spend two years circling the planet and flying close to Jupiter's large moons, exploring in detail what the two Pioneers and two Voyagers revealed.

Galilean Satellites

In 1610, Galileo Galilei aimed his telescope at Jupiter and spotted four points of light orbiting the planet. For the first time, humans had seen the moons of another world. In honour of their discoverer, these four bodies would become known as the Galilean satellites or moons. But Galileo might have happily traded this honour for one look at the dazzling photographs returned by the Voyager spacecraft as they flew past these planet sized satellites.

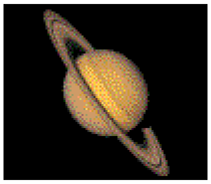
One of the most remarkable findings of the Voyager mission was the presence of active volcanoes on the Galilean moon Io. Volcanic eruptions had never before been observed on a world other than Earth. The Voyager cameras identified at least nine active volcanoes on Io, with plumes of ejected material extending as far as 280 kilometres (175 miles) above the moon's surface. Io's pizza-coloured terrain, marked by orange and yellow hues, is probably the result of sulphur-rich materials brought to the surface by volcanic activity. Volcanic activity on this satellite is the result of tidal flexing caused by the gravitational tug-of-war between Io, Jupiter and the other three Galilean moons.

Europa, approximately the same size as our Moon, is the brightest Galilean satellite. The moon's surface displays a complex array of streaks, indicating the crust has been fractured. Caught in a gravitational tug-of-war like Io, Europa has been heated enough to cause its interior ice to melt -- apparently producing a liquid-water ocean. This ocean is covered by an ice crust that has formed where water is exposed to the cold of space. Europa's core is made of rock that sank to its centre. Like Europa, the other two Galilean moons -- Ganymede and Callisto --are worlds of ice and rock. Ganymede is the largest satellite in the solar system -- larger than the planets Mercury and Pluto. The satellite is composed of about 50 percent ice or slush and the rest rock. Ganymede's surface has areas of different brightness, indicating that, in the past, material oozed out of the moon's interior and was deposited at various locations on the surface

Callisto, only slightly smaller than Ganymede, has the lowest density of any Galilean satellite, suggesting that large amounts of water are part of its composition. Callisto is the most heavily cratered object in the solar system; no activity during its history has erased old craters except more impacts.

Detailed studies of all the Galilean satellites will be performed by the Galileo Orbiter.

SATURN



No planet in the solar system is adorned like Saturn. Its exquisite ring system is unrivalled. Like Jupiter, Saturn is composed mostly of hydrogen. But in contrast to the vivid colours and wild turbulence found in Jovian clouds, Saturn's atmosphere has a more subtle, butter-scotch hue, and its markings are muted by high-altitude haze. Given Saturn's somewhat placid-looking appearance, scientists were surprised at the high-velocity equatorial jet stream that blows some 1,770 kilometres (1,100 miles) per hour. Three American space-craft have visited Saturn. Pioneer 11 sped by the planet and its moon Titan in September 1979, returning the first close-up images. Voyager 1 followed in November 1980, sending back breathtaking photographs that revealed for the first time the complexities of Saturn's ring system and moons. Voyager 2 flew by the planet and its moons in August 1981. The rings are composed of countless low-density particles orbiting individually around Saturn's equator at progressive distances from the cloud tops. Analysis of spacecraft radio waves passing through the rings showed that the particles vary widely in size, ranging from dust to house-sized boulders. The rings are bright because they are mostly ice and frosted rock. The rings might have resulted when a moon or a passing body ventured too close to Saturn. The unlucky object would have been torn apart by great tidal forces on its surface and in its interior. Or the object may not have been fully formed to begin with and disintegrated under the influence of Saturn's gravity. A third possibility is that the object was shattered by collisions with larger objects orbiting the planet.

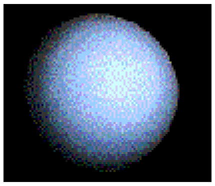
Unable either to form into a moon or to drift away from each other, individual ring particles appear to be held in place by the gravitational pull of Saturn and its satellites. These complex gravitational interactions form the thousands of ringlets that make up the major rings. Radio emissions quite similar to the static heard on an AM car radio during an electrical storm were detected by the Voyager spacecraft. These emissions are typical of lightning but are believed to be coming from Saturn's ring system rather than its atmosphere, where no lightning was observed. As they had at Jupiter, the Voyagers saw a version of Earth's auroras near Saturn's poles. The Voyagers discovered new moons and found several satellites that share the same orbit. We learned that some moons shepherd ring particles, maintaining Saturn's rings and the gaps in the rings. Saturn's 18th moon was discovered in 1990 from images taken by Voyager 2 in 1981.

Voyager 1 determined that Titan has a nitrogen-based atmosphere with methane and argon -- one more like Earth's in composition than the carbon dioxide atmospheres of Mars and Venus. Titan's surface temperature of -179 degrees Celsius (-290 degrees Fahrenheit) implies that there might be water-ice islands rising above oceans of ethane-methane liquid or sludge. Unfortunately, Voyager's cameras could not penetrate the moon's dense clouds. Continuing photochemistry from solar radiation may be converting Titan's methane to ethane, acetylene and -- in combination with nitrogen -- hydrogen cyanide. The latter compound is a building block of amino acids. These conditions may be similar to the atmospheric conditions of primeval Earth between three and four billion years ago. However, Titan's atmospheric temperature is believed to be too low to permit progress beyond this stage of organic chemistry.

The exploration of Saturn will continue with the Cassini mission. Scheduled for launch in the latter part of the 1990s, the Cassini mission is a collaborative project of NASA, the European Space Agency and the federal space agencies of Italy and Germany, as well as the United States Air Force and the Department of Energy. Cassini will orbit the planet and will also deploy a probe called Huygens, which will be dropped into Titan's atmosphere and fall to the surface. Cassini will use radar to peer through

Titan's clouds and will spend years examining the Saturnian system.

URANUS

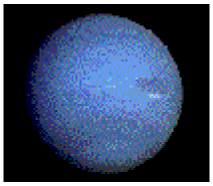
 In January 1986, four and a half years after visiting Saturn, Voyager 2 completed the first close-up survey of the Uranian system. The brief flyby revealed more information about Uranus and its retinue of icy moons than had been gleaned from ground observations since the planet's discovery over two centuries ago by the English astronomer William Herschel. Uranus, third largest of the planets, is an oddball of the solar system. Unlike the other planets (with the exception of Pluto), this giant lies tipped on its side with its north and south poles alternately facing the sun during an 84-year swing around the solar system. During Voyager 2's flyby, the south pole faced the Sun. Uranus might have been knocked over when an Earth sized object collided with it early in the life of the solar system. Voyager 2 found that Uranus' magnetic field does not follow the usual north-south axis found on the other planets. Instead, the field is tilted 60 degrees and offset from the planet's centre, a phenomenon that on Earth would be like having one magnetic pole in New York City and the other in the city of Djakarta, on the island of Java in Indonesia.

Uranus' atmosphere consists mainly of hydrogen, with some 12 percent helium and small amounts of ammonia, methane and water vapour. The planet's blue colour occurs because methane in its atmosphere absorbs all other colours. Wind speeds range up to 580 kilometres (360 miles) per hour, and temperatures near the cloud tops average -221 degrees Celsius (-366 degrees Fahrenheit). Uranus' sunlit south pole is shrouded in a kind of photochemical "smog" believed to be a combination of acetylene, ethane and other sunlight-generated chemicals. Surrounding the planet's atmosphere and extending thousands of kilometres into space is a mysterious ultraviolet sheen known as electroglow." Approximately 8,000 kilometres (5,000 miles) below Uranus' cloud tops, there is thought to be a scalding ocean of water and dissolved ammonia some 10,000 kilometres (6,200 miles) deep. Beneath this ocean is an Earth-sized core of heavier materials.

Voyager 2 discovered 10 new moons, 16-169 kilometres (10- 105 miles) in diameter, orbiting Uranus. The five previously known -- Miranda, Ariel, Umbriel, Titania and Oberon -- range in size from 520 to 1,610 kilometres (323 to 1,000 miles) across. Representing a geological showcase, these five moons are half-ice, half-rock spheres that are cold and dark and show evidence of past activity, including faulting and ice flows.

The most remarkable of Uranus' moons is Miranda. Its surface features high cliffs as well as canyons, crater-pocked plains and winding valleys. The sharp variations in terrain suggest that, after the moon formed, it was smashed apart by a collision with another body -- an event not unusual in our solar system, which contains many objects that have impact craters or are fragments from large impacts. What is extraordinary is that Miranda apparently reformed with some of the material that had been in its interior exposed on its surface. Uranus was thought to have nine dark rings; Voyager 2 imaged 11. In contrast to Saturn's rings, which are composed of bright particles, Uranus' rings are primarily made up of dark, boulder sized chunks.

NEPTUNE

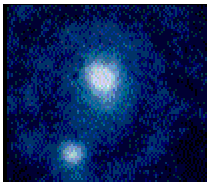
 Voyager 2 completed its 12-year tour of the solar system with an investigation of Neptune and the planet's moons. On August 25, 1989, the spacecraft swept to within 4,850 kilometres (3,010 miles) of Neptune and then flew on to the moon Triton. During the Neptune encounter it became clear that the planet's atmosphere was more active than Uranus'. Voyager 2 observed the Great Dark Spot, a circular storm the size of Earth, in Neptune's atmosphere. Resembling Jupiter's Great Red Spot, the storm spins counter clockwise and moves westward at almost 1,200 kilometres (745 miles) per hour. Voyager 2 also noted a smaller dark spot and a fast moving cloud dubbed the "Scooter," as well as high-altitude clouds over the main hydrogen and helium cloud deck. The highest wind speeds of any planet were observed, up to 2,400 kilometres (1,500 miles) per hour. Like the other giant planets, Neptune has a gaseous hydrogen and helium upper layer over a liquid interior. The planet's core contains a higher percentage of rock and metal than those of the other gas giants. Neptune's distinctive blue appearance, like Uranus' blue colour, is due to atmospheric methane. Neptune's magnetic field is tilted relative to the planet's spin axis and is not centred at the core. This phenomenon is similar to Uranus' magnetic field and suggests that the fields of the two giants are being generated in an area above the cores, where the pressure is so great that liquid hydrogen assumes the electrical properties of a metal. Earth's magnetic field, on the other hand, is produced by its spinning metallic core and is only slightly tilted and offset relative to its centre.

Voyager 2 also shed light on the mystery of Neptune's rings. Observations from Earth indicated that there were arcs of material in orbit around the giant planet. It was not clear how Neptune could have arcs and ho these could be kept from spreading out into even, unclumped rings. Voyager 2 detected these arcs, but they were, in fact, part of thin, complete rings. A number of small moons could explain the arcs, but such bodies were not spotted. Astronomers had identified the Neptunian moons Triton in 1846 and Nereid in 1949. Voyager 2 found six more. One of the new moons -- Proteus is actually larger than Nereid, but since Proteus orbits close to Neptune, it was lost in the planet's glare for observers on Earth.

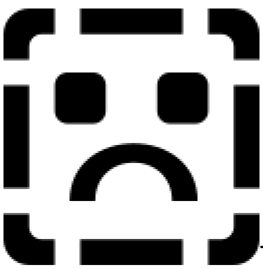
Triton circles Neptune in a retrograde orbit in under six days. Tidal forces on Triton are causing it to spiral slowly towards the planet. In 10 to 100 million years (a short time in astronomical terms), the moon will be so close that Neptunian gravity will tear it apart, forming a spectacular ring to accompany the planet's modest current rings. Triton's landscape is as strange and unexpected as those of Io and Miranda. The moon has more rock than its counterparts at Saturn and Uranus. Triton's mantle is probably composed of water ice, but the moon's crust is a thin veneer of nitrogen and methane. The moon shows two dramatically different types of terrain: the so-called "cantaloupe" terrain and a receding ice cap.

Dark streaks appear on the ice cap. These streaks are the fallout from geyser-like volcanic vents that shoot nitrogen gas and dark, fine-grained particles to heights of 2 to 8 kilometres (1 to 5 miles). Triton's thin atmosphere, only 1/70,000th as thick as Earth's, has winds that carry the dark particles and deposit them as streaks on the ice cap -- the coldest surface yet found in the solar system (-235 degrees Celsius, -391 degrees Fahrenheit). Triton might be more like Pluto than any other object spacecraft have so far visited.

PLUTO

 Pluto is the most distant of the planets, yet the eccentricity of its orbit periodically carries it inside Neptune's orbit, where it has been since 1979 and where it will remain until March 1999. Pluto's orbit is also highly inclined -- tilted 17 degrees to the orbital plane of the other planets. Discovered in 1930, Pluto appears to be little more than a celestial snowball. The planet's diameter is calculated to be approximately 2,300 kilometres (1,430 miles), only two-thirds the size of our Moon. Ground-based observations indicate that Pluto's surface is covered with methane ice and that there is a thin atmosphere that may freeze and fall to the surface as the planet moves away from the Sun. Observations also show that Pluto's spin axis is tipped by 122 degrees. The planet has one known satellite, Charon, discovered in 1978. Charon's surface composition is different from Pluto's: the moon appears to be covered with water-ice rather than methane ice. Its orbit is gravitationally locked with Pluto, so both bodies always keep the same hemisphere facing each other. Pluto's and Charon's rotational period and Charon's period of revolution are all 6.4 Earth days. Although no spacecraft have ever visited Pluto, NASA is currently exploring the possibility of such a mission.

COMETS

The outermost members of the solar system occasionally pay a visit to the inner planets. As asteroids are the rocky and metallic remnants of the formation of the solar system, comets are the icy debris from that dim beginning and can survive only far from the Sun. Most comet nuclei reside in the Oort Cloud, a loose swarm of objects in a halo beyond the planets and reaching perhaps halfway to the nearest star. Comet nuclei orbit in this frozen abyss until they are gravitationally perturbed into new orbits that carry them close to the Sun. As a nucleus falls inside the orbits of the outer planets, the volatile elements of which it is made gradually warm; by the time the nucleus enters the region of the inner planets, these volatile elements are boiling. The nucleus itself is irregular and only a few miles across, and is made principally of water-ice with carbon monoxide, carbon dioxide, methane and ammonia -- materials very similar to those composing the moons of the giant planets As these materials boil off of the nucleus, they form a coma or cloud-like "head" that can measure tens of thousands of kilometres across. The coma grows as the comet gets closer to the Sun. Solar charged particles push on gas molecules and the pressure of sunlight pushes on the cloud of dust particles, blowing them back like flags in the wind and giving rise to the comet's "tails." Gases and ions are blown directly back from the nucleus, but dust particles are pushed more slowly. As the nucleus continues in its orbit, the dust particles are left behind in a curved arc.

Both the gas and dust tails are blown away from the Sun; in effect, the comet chases its tails as it recedes from the Sun. The tails can reach 150 million kilometres (93 million miles) in length, but the total amount of material contained in this dramatic display would fit in an ordinary suitcase. Comets -- from the Latin cometa, meaning "long-haired" -- are essentially dramatic light shows. Some comets pass through the solar system only once, but others have their orbits gravitationally modified by a close encounter with one of the giant outer planets. These latter visitors can enter closed elliptical orbits and repeatedly return to the inner solar system.

Halley's Comet is the most famous example of a relatively short period comet, returning on an average of once every 76 years and orbiting from beyond Neptune to within Venus' orbit. Confirmed sightings of the comet go back to 240 B.C. This regular visitor to our solar system is named for Sir Edmond Halley, because he plotted the comet's orbit and predicted its return, based on earlier sightings and Newtonian laws of motion. His name became part of astronomical lore when, in 1759, the comet returned on schedule. Unfortunately, Sir Edmond did not live to see it. A comet can be very prominent in the sky if it passes comparatively close to Earth. Unfortunately, on its most recent appearance, Halley's Comet passed no closer than 62.4 million kilometres (38.8 million miles) from our world. The comet was visible to the naked eye, especially for viewers in the southern hemisphere, but it was not spectacular. Comets have been so bright, on rare occasions, that they were visible during day-time. Historically, comet sightings have been interpreted as bad omens and have been artistically rendered as daggers in the sky. Several spacecraft have flown by comets at high speed; the first was NASA's International Cometary Explorer in 1985. An armada of five spacecraft (two Japanese, two Soviet and the Giotto spacecraft from the European Space Agency) flew by Halley's Comet in 1986. Additional comet missions are being examined in the United States and abroad.

Conclusion

Despite their efforts to peer across the vast distances of space through an obscuring atmosphere, scientists of the past had only one body they could study closely -- Earth. But since 1959, space flight through the solar system has lifted the veil on our neighbours in space. We have learned more about our solar system and its members than anyone had in the previous thousands of years. Our automated spacecraft have travelled to the Moon and to all the planets beyond our world except Pluto; they have observed moons as large as small planets, flown by comets and sampled the solar environment. Astronomy books now include detailed pictures of bodies that were only smudges in the largest telescopes for generations. We are lucky to be alive now to see these strange and beautiful places and objects.

The knowledge gained from our journeys through the solar system has redefined traditional Earth sciences like geology and meteorology and spawned an entirely new discipline called comparative planetology. By studying the geology of planets, moons, asteroids and comets, and comparing differences and similarities, we are learning more about the origin and history of these bodies and the solar system as a whole. We are also gaining insight into Earth's complex weather systems. By seeing how weather is shaped on other worlds and by investigating the Sun's activity and its influence throughout the solar system, we can better understand climatic conditions and processes on Earth.

We will continue to learn and benefit as our automated spacecraft explore our neighbourhood in space. Missions to each type of body in the solar system are in flight or under development or study. We can also look forward to the time when humans will once again set foot on an alien world. Although astronauts have not been back to the Moon since December 1972, plans are being formulated for our return to the lunar landscape and for the human exploration of Mars and even the establishment of Martian outposts. One day, taking a holiday may mean spending a week at a lunar base or a Martian colony

THE ORIGIN OF THE SOLAR SYSTEM

The earliest accounts of how the Sun, the Earth and the rest of the Solar System were formed are to be found in early myths, legends and religious texts. None of these can be considered a serious scientific account. The earliest scientific attempts to explain the origin of the solar system invoked collisions or condensations from a gas cloud. The discovery of `island universes', which we now know to be galaxies, was thought to confirm this latter theory.

During this century Jeans proposed the idea that material had been dragged out of the Sun by a passing star and that this material had then condensed to form the planets. There are serious flaws to this explanation but recent developments have been made suggesting that a filament was drawn out of a passing protostar at a time when the Sun was a member of a loose cluster of stars but the most favoured theories still involve the gravitational collapse of a gas and dust cloud. The problems to be faced by any theory for the formation of the Solar System Any theory has to account for certain rather tricky facts about the Solar System. These are in addition to the obvious facts that the Sun is at the centre with the planets in orbit around it. There are 5 of these problem areas.

1. The Sun spins slowly and only has 1 percent of the angular momentum of the Solar System but 99.9 percent of its mass. The planets carry the rest of the angular momentum.

2. The formation of the terrestrial planets with solid cores.

3. The formation of the gaseous giant planets.

4. The formation of planetary satellites.

5. An explanation of Bode's law which states that the distances of the planets from the Sun follow a simple arithmetic progression.

(Bode's `law' takes the form of a series in which the first term is 0, the second is 3 and each term is then double the previous one, to each term add 4 and divide the result by 10. This yields the series of numbers, 0.4, 0.7, 1.0, 1.6, 2.8, 5.2, 10.0, 19.6, 38.8; which may be compared to the mean distances of the planets from the Sun in AU, 0.39, 0.72, 1.0, 1.52, 5.2, 9.52, 19.26, 30.1, 39.8. The agreement for all but Neptune and Pluto is remarkable. The lack of a planet at 2.8 led to the discovery of the asteroids.) There are 5 theories which are still considered to be `reasonable' in that they explain many (but not all) of the phenomena exhibited by the solar system.

The Accretion theory

This assumes that the Sun passed through a dense interstellar cloud and emerged surrounded by a dusty, gaseous envelope. It thus separates the formation of the Sun from that of the planets thus losing problem 1. The problem which remains is that of getting the cloud to form the planets. The terrestrial planets can form in a reasonable time but the gaseous planets take far too long to form. The theory does not explain satellites or Bode's law and must be considered the weakest of those described here.

The Protoplanet theory

This assumes that initially there is a dense interstellar cloud which will eventually produce a cluster of stars. Dense regions in the cloud form and coalesce; as the small blobs have random spins the resulting stars will have a low rotation rates. The planets are smaller blobs captured by the star. The small blobs would have higher rotation than is seen in the planets but the theory accounts for this by having the `planetary blobs' split to give a planet and satellites. Thus many of the problem areas are covered but it is not clear how the planets came to be confined to a plane or why their rotations are in the same sense.

The Capture theory

This theory is a version of Jeans's theory in which the Sun interacts with a nearby protostar dragging a filament of material from the protostar. The low rotation speed of the Sun is explained as being due to its formation before the planets, the terrestrial planets are explained by collisions between the protoplanets close to the Sun and the giant planets and their satellites are explained as condensations in the drawn out filament.

The Modern Laplacian theory

Laplace in 1796 first suggested that the Sun and the planets formed in a rotating nebula which cooled and collapsed. It condensed into rings which eventually formed the planets and a central mass which became the Sun. The slow spin of the Sun could not be explained. The modern version assumes that the central condensation contains solid dust grains which create drag in the gas as the centre condenses. Eventually, after the core has been slowed its temperature rises and the dust is evaporated. The slowly rotating core becomes the Sun. The planets form from the faster rotating cloud.

The Modern Nebula theory

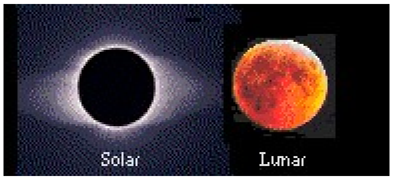
Observations of very young stars indicate that they are surrounded by dense dusty disks. While there are still difficulties in explaining some of the problem areas outlined above, in particular ways to slow down the rotation of the Sun, it is believed that the planets originated in a dense disk which formed from material in the gas and dust cloud which collapsed to give the Sun. The density of this disk has to be sufficient to allow the formation of the planets and yet be thin enough for the residual matter to be blown away by the Sun as its energy output increased.

Conclusion

There have been many attempts to develop theories for the origin of the Solar System. None of them can be described as totally satisfactory and it is possible that there will further developments which may better explain the known facts. We do believe, however, that we understand the overall mechanism which is that the Sun and the planets formed from the contraction of part of a gas/dust cloud under its own gravitational pull and that the small net rotation of the cloud was responsible for the formation of a disk around the central condensation. The central condensation eventually formed the Sun while small condensations in the disk formed the planets and their satellites. The energy from the young Sun blew away the remaining gas and dust leaving the solar system as we see it today.

Further Reading

ECLIPSES



We generally talk of eclipses of the Sun and Moon but other bodies inside and outside the Solar System exhibit eclipses and are very important in astronomy. Eclipses of the moons of Jupiter were used in one of the first measures of the speed of light and eclipsing binary stars give us fundamental data on the masses of stars. An eclipse occurs when a body cuts off the light from a light source so that we can no longer see it shining. An eclipse can be due either to a dark body coming between us and a light emitter, so that we can no longer see the source, or it can be a body coming between a light source and the body that the light is illuminating, so that we no longer see the illuminated body. Let us first consider eclipses of the Sun and Moon.

Eclipses of the Sun and Moon.

An eclipse of the Sun occurs when the Moon comes directly between the Sun and the Earth so that the Earth lies in the shadow of the Moon. An eclipse of the Moon occurs when the Earth lies directly between the Sun and the Moon and the Moon lies in the shadow of the Earth. If the orbit of the Moon about the Earth lay in the same plane as the orbit of the Earth about the Sun then there would be eclipses of the Sun and Moon at every New and Full Moon respectively. The orbits are inclined, however, and eclipses can only occur when the Moon is close to the nodes of its orbit (when it is near to the places where the orbital planes cross).

Lunar Eclipses.

The amount of the Moon's disk that is eclipsed depends on how close the Moon is to the node of its orbit at Full Moon. Like all shadows of light from an extended source the shadow produced by the Earth has an umbra, where all the light from the Sun is shadowed, and a penumbra, where only some of it is. Penumbral eclipses of the Moon occur when the Moon passes only through the Earth's penumbral shadow. Although these are catalogued they are inconspicuous events and are not noteworthy.

When the Moon passes through the Earth's umbral shadow we can either see a Partial Eclipse, when only part of the Moon is obscured, or a Total Eclipse. The Earth's shadow is much larger than the Moon and so eclipses can last up to 3 hrs 40 mins, with totality lasting up to 1 hr 40 mins. They can be seen from anywhere on the side of the Earth which faces the Moon. During a Total Eclipse, the Moon does not, as might be expected, disappear entirely but turns a deep, dark red. The brightness and colour depend on the state of the Earth's atmosphere for the Moon, during eclipse, is illuminated by light that has passed through the Earth's atmosphere and has been bent towards the Moon by refraction.

Solar Eclipses

These, like Lunar Eclipses, can only occur when the Moon is near the nodes of its orbit but in this case at New Moon. The shadow of the Moon can then pass over the surface of the Earth. Because the Moon is much smaller than the Earth its shadow only covers a small part of the Earth's surface and a solar eclipse can only be seen from a restricted area. Like the Earth's shadow, the Moon's has an umbra and a penumbra. Viewed from the Earth a person in the umbra sees the whole of the Sun eclipsed while someone in the penumbra sees only part of the Sun obscured. These are called a Total and a Partial Eclipse respectively.

Quite by chance the apparent sizes if the Sun and Moon are very nearly the same. The apparent angular size of the Sun does not change very much due to the Earth's non-circular orbit but the Moon's apparent size varies quite a lot. For most solar eclipses the Moon's apparent diameter is less than the Sun's and so the whole solar disk is nowhere totally obscured. It is only when the Moon is close to the Earth that, at some places, the whole disk is obscured and a Total Eclipse is seen. The track of the small area on the Earth's surface where a total eclipse can be seen is several thousand miles long but only up to 160 miles wide. Outside this track and outside the short time of totality, maximum about 7 minutes, a Partial Eclipse is seen.

When the Moon is not at its closest to the Earth its apparent diameter is less than that of the Sun and even where the Moon's disk obscures the Sun centrally the outer ring of the Sun's disk is still visible. This is called an Annular Eclipse. Total eclipses of the Sun are much more spectacular than Partial eclipses as virtually all the light from the Sun is blocked out by the Moon and it becomes as dark as night and stars can be seen. The solar chromosphere and corona can be seen. The former as a reddish rim around the eclipsing Moon and the latter as a whitish glow surrounding the eclipsed Sun. The length of totality depends on how close the Moon is to the Earth. The 1991 total eclipse was the longest for 140 years. The next total solar eclipse to be visible in Britain will be in August 1999. It will only be visible from parts of Cornwall and Devon.

WARNING Never look at the Sun with any kind of telescope or binoculars. You could easily blind yourself. It is even dangerous to look at the fully bright Sun with the naked-eye.

Other Eclipses.

The eclipse of an apparently small object by one which appears much larger is generally called an occultation. Thus the Moon occults many stars as it moves across the sky. Observations of occultation's by the Moon were used for a long time to get the most accurate positions for the Moon and have been used to determine the position and size of such strange objects as radio stars. Eclipses of the satellites of Jupiter by the planet, and also by one another, were used in one of the first determinations of the speed of light. And occultation's of stars by the planets have allowed analyses of the planetary atmospheres. Eclipsing binary stars, in which two stars are in orbit about each other and each passes in front of the other as seen from the Earth, have given us most of our knowledge of the masses of different kinds of stars.

Further Reading

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Apollo Program

Author/s	Title
N.A.S.A	Apollo Expeditions to the Moon
Murray. C & Bly Cox .C	Apollo: Race the Moon
Irwin. J	Destination Moon
Wilford. J	We Reach the Moon

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Ponnamperuma. C .	Cosmochemistry and the Origin of Life
Herbst, E., and others	Organic Geo- and Cosmochemistry

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Mutch. T . A	Geology of the Moon
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Short, Nicholas M	Planetary Geology

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Mueller. I and Kolaczek. B	Developments in Astrometry and Their Impact on Astrophysics and Geodynamics.
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Atlasas & Catalogues

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Beazley . M	Atlas of the oceans
Henry, R.C., and others	Atlas of the Ultraviolet Sky
Hunt, G and Moore. P	Atlas of Uranus
Cambridge University	Cambridge Atlas of Astronomy
Audouze / Israel	Cambridge atlas of astronomy
Tirion . W & Others	Deep-sky field guide-Uranometria 2000
Ridpath . I	Norton's Star Atlas 2000 18th ed.
Norton . A. P	Norton's Star Atlas and Reference Handbook
Karkoschka . E	Observers Sky Atlas.
Cox. J	Philips Color Star Atlas
Tirion . W	Sky Atlas 2000-Deluxe Edition
Strong. R A	Sky Atlas 2000.0 Companion
Hirschfield. A and Sinnott. R	Sky Catalogue 2000.0, 2 vols
Sinnott	Sky catalogue 2000.00 V1 P/B
Sinnott	Sky catalogue 2000.00 V2 P/B
Yenne . B	The Atlas of the Solar System
Wray . J . D	The Color Atlas of Galaxies
Cragin. M	The Deep Sky Field Guide to Uranometria 2000.0
Warner. D. J.	The Sky Explored: Celestial Cartography
Tirion - Rappport & Lovi	Uranometria 2000.00 Star Atlas V1
Tirion - Rappport & Lovi	Uranometria 2000.00 Star Atlas V2

Books Indexed By Subject.

Indexed By Title. Indexed By Author.

Author/s Title

Astronomy (General)

Moore . P	1996 Yearbook of Astronomy
Sherrod Clay . P	A Complete Manual of amateur Astronomy
Fix . J	Astronomy
Fuller . J	Astronomy
Graham . I	Astronomy
Hartmann . W	Astronomy
Kaler . J . B	Astronomy
Mitton . J	Astronomy
Muiren . J	Astronomy

Pasachoff . J . M	Astronomy
Peacock . G	Astronomy
Robbins . R	Astronomy
Zolg . C	Astronomy
Roth G . D	Astronomy - A Handbook
Roy . A	Astronomy : Principles & Practice
Roy . A	Astronomy : Structure of the Universe
Burkhardt . G	Astronomy and Astrophysics
Schatzman . E . I	Astronomy and Astrophysics
Open University	Astronomy and Planetary Science
Press . F	Astronomy and Planetary Science
Wood . W. R	Astronomy and Space Science
British Museum Press	Astronomy before the Telescope
Hansson . A	Astronomy for all ages
Harrinton . P	Astronomy for all ages
Moore . P	Astronomy for G.C.S.E
Moore . P	Astronomy for the beginner
Davis . J . K	Astronomy from Space
Scagell . R	Astronomy from Towns and Suburbs
Aiton . E . J	Astronomy in Harriot's Time
Shaikh . A	Astronomy in the UK
Moore . P	Astronomy in the UK.
Pasachoff . J . M	Astronomy Now
Montenbruck . O	Astronomy on the Personal Computer
Eicher . D . J	Astronomy through Time and Space
Engelbrektson . S	Astronomy through Time and Space
Duffett / Smith	Astronomy with personal computers
Carroll . B	Beginner's Guide to Amateur Astronomy
Herrmann . D . B	Conceptual Astronomy
Engelbrektson . S	General History of Astronomy
Carroll . B	Introduction to modern Astronomy
Harrinton . P	New Astronomy
Garfinkle. R	Star-Hopping (beginners)
Richarson, R . S.	The Fascinating World of Astronomy
Mitton . J	Young Oxford book of Astronomy
Moore . P	Astronomy with Patrick Moore
Zeilik . M	Astronomy: The Evolving Universe
Mcclelland . D . E	Desktop Publishing in Astronomy

Astronomy (History)

Author/s	Title
Burtt, E. A	A Critical and Comparative Analysis of Copernicus, Kepler, Galileo, and Descartes.
Dreyer, John L.	A History of Astronomy from Thales to Kepler
Donnelly, M . C	A Short History of Observatories
British Museum Press	Astronomy before the Telescope
Lattis . J . M	Between Copernicus and Galileo
Al Tusi Nasir Al	Early Astronomy
Pederson . O	Early Physics and Astronomy
Pederson . O	Early Physics and Astronomy H/B
North . J	Fontana History of Astronomy
Reston . J . Jr	Galileo
Engelbrektson . S	General History of Astronomy
Hansson . A	General History of Astronomy
Moore . P	General History of Astronomy
Saliba . G	History of Arabic Astronomy
Leverington . D	History of Astronomy

Pannekoek . A	History of Astronomy
Malphrus . B	History of Radio Astronomy and ....
Sesti . G	The Glorious Constellations: History and Mythology.
Henbest . N	The History of Astronomy
Herrmann . D . B	The History of Astronomy
King . H . C	The History of the Telescope

Astrophotography & CCD

Wallis & Provin	A Manual of Advanced Celestial Photography
Gordon. B	Astrophotography
Corington, M. A	Astrophotography for the Amateur
Buil.C	CCD Astronomy
Berry, Kanto and Munger	CCD Camera Cookbook
Berry.R	Choosing and Using a CCD Camera
Berry . R	Choosing and Using a CCD Camera
Dragesco . J	High Resolution Astrophotographer.
Berry.R	Introduction to Astronomical Image Processing
Dobbins,Parker and Capen	Observing and photographing the Solar System
Mayall / Mayall	Sky shooting-Photography for the amateur astronomer

Atmosphere

Durrant . C . J	Atmosphere of the sun
Cox, Arthur, and others	Solar Interior and Atmosphere
Anthes. R, and others	The Atmosphere
Lutgens. F. and Tarbuck E	The Atmosphere: An Introduction to Meteorology
Gribben. J	The Breathing Planet
Wayne. R	The Chemistry of Atmospheres

Aurora Borealis

Bone . N	Aurora
Davis . N	Aurora watchers handbook
Eather, R. H	Majestic Lights
Akasofu. S. and Kamide. Y	The Solar Wind and the Earth
Raychaudhuri. A . K	Urban Sky Glow

Big Bang

Hawking . S	A Brief History of Time
Sharov . S	Bang Universe
Sharov . S	Edwin Hubble : Discoverer of the Big Bang
Gribben . J	In search of the Big Bang P/B
Trefil . J	Space, Time, Infinity
Silk . J	The Big Bang
Gribbin. J	The Omega Point

Black Holes

Luminet . J . P	Black holes
Hawking . S	Black holes & baby universes
Novikov . I	Black holes and the universe.
Chaisson. E	Relatively Speaking
Wald. R	Space, Time, and Gravity
Kafatas. M	Supermassive Black Holes
Melton . P	Will Black Holes Devour the Universe

Celestial Coordinates

Norton . A. P	Norton's Star Atlas and Reference Handbook
Warner . D	The Sky Explored: Celestial Cartography.

Celestial Mechanics

Szebehely, V. G	Adventures in Celestial Mechanics
Szebehely. V	Adventures in Celestial Mechanics.
Moullon, F	An Introduction to Celestial Mechanics.
Pollard, H	Celestial Mechanics
Van De Kamp, Peter	Elements of Astromechanics
Danby. J	Fundamentals of Celestial Mechanics.
Skinner, R	Mechanics
Madonna, Richard	Orbital Mechanics
Collins, G. W., II	The Foundations of Celestial Mechanics.

Comets & Asteroids

Kowal . C . T	Asteroids
Binzel, R. P and others	Asteroids II
Kowel . C . T	Asteroids: Their Nature and U....
Wiley J & Sons (Pub)	Comet Halley
Wiley J & Sons (Pub)	Comet Halley Investigations
Sagan / Druyan	Comet.
Moore . P	Comets and Shooting Stars
Yeomans . D . K	Comets: A Chronological History
Cunningham, C.	Introduction to Asteroids
Brandt / Chapman	Introduction to comets.
Edberg . S	Observing Comets, Asteroids.
Calder, Nigel.	The Comet is Coming
Whipple . F	The Mystery of Comets.

Constellations

Sanford . J	Observing the Constellations
Motz, Lloyd, and Nathanson	The Constellations: An Enthusiast's Guide
Sesti . G	The Glorious Constellations: History and Mythology.

Convection

Kennel . C. F	Convection and Substorms

Burmeister . L. . G	Convective Heat Transfer
Rohsenow, Warren, Hartnett	Handbook of Heat Transfer Fundamentals.
Baker . M	Heat Transfer
Jaluria . U	Natural Convection Heat and Mass Transfer

Copernicus, Galileo, Kepler

Burtt, E. A	A Critical and Comparative Analysis of Copernicus, Kepler, Galileo, and Descartes.
Dreyer, John L.	A History of Astronomy from Thales to Kepler
Lattis . J . M	Between Copernicus and Galileo
Rosen, E	Copernicus and the Scientific Revolution.
Reston . J . Jr	Galileo
Gingerich . O	Great Copernicus Chase
Pannekoek . A	Johannes Kepler ' New Astronomy
Stephenson . B	Kepler's Physical Astronomy
Westman . R . S	The Copernican Achievement.

Cosmology (Universe)

Hawking . S	A Brief History of Time.
David Malin	A view of the universe
Roy . A	Astronomy : Structure of the Universe
Roy . A	Astronomy : Structure of the Universe
Wright . A & H	At the edge of the universe
Wright A & H	At the Edge of the Universe.
Sutton . C	Building the universe
Edberg . S	Cosmology
Robinson . R	Cosmology
Rowan . R . M	Cosmology
Sagan . C	Cosmos
Kaufmann, W.,	Discovering the Universe.
Evans . A	Dusty Universe
Wright . H	Explorer of the Universe
Combes . F	Galaxies and Cosmology
Mcclelland . D . E	Gamma Ray and Neutrino Cosmology
Tayler . R . J	Hidden Universe H\B
Couper. H and Henbest. N	How the Universe Works
Tauber, G.E. .	Man and the Cosmos
De Grasse Tyson . N	Merlins tour of the Universe
Sciama D . W	Modern Cosmology
Manly P. L	Modern Cosmology and the Darwin Theory
Henbest Nigel	Observing the Universe
Longair . M	Our Evolving Universe
Oxford	Ox Illustrated Encyclopaedia of the Universe V8
Linde. A . D	Particle Physics and Inflationary Cosmology.
Osserman . R	Poetry of the Universe
Abell . G . O	Realm of the Universe
Friedman . H	The Amazing Universe
Silk . J	The Big Bang.
Trinh Xuan Thuan	The Changing Universe
Asimov, Isaac	The Collapsing Universe
Davies . P	The Cosmic Blueprint.
Henbest. N	The Exploding Universe
Ronan . C	The Natural History of the Universe
Longair. G	The Origins of the Universe
Hey & Walters	The Quantum Universe

Mallove, E. F	The Quickening Universe.
Greenstein . G	The Symbiotic Universe
Parker, B	The Universe in Turmoil
Clark . S	Towards the edge of the Universe
Kaufman, W. J., III	Universe
Robinson . R	Universe
Ronan . C	Universe Explained
Newton . J	Vanishing Universe
Narlikar, J V.	Violent Phenomena in the Universe.

Earth (Planet)

Rocha . R & Roth . O	Blue & Beautiful Planet Earth Our Home
Cartermill Publishing	Earth and Astronomical Science
England . N	Earth and Space
Tarbuck . E . J	Earth Science
Robinson . A	Earthshock
Stevens / Kelley	Embracing Earth
Asimov Isaac	Exploring the earth & the cosmos
Moore. P	Exploring the Earth and Moon
Strain . P & Engle . F	Looking at Earth
Akasofu. S. and Kamide. Y	The Solar Wind and the Earth
Cattermole / Moore	The Story of the Earth
Dunning F . W. & Others	The Story of the Earth
Melchior, P. J	The Tides of the Planet Earth
Press . F	Understanding Earth

Eclipses

Espenak . F	50 Year Canon of Lunar Eclipses
Espenak . F	50 Year Canon of Solar Eclipses
Link. F	Eclipse Phenomena in Astronomy

Electromagnetic Radiation

Jackson . J . D	Classical Electrodynamics
Lorrain. P and others	Electromagnetic Fields and Waves
Ekefi .G	Electromagnetic Vibrations, Waves, and Radiation
Kraus J. D	Electromagnetics
Condon . V. and Shortley G. H	The Theory of Atomic Spectra

Extragalactic Systems

Miller . J . P	Astrophysics of Active Galaxies and Quasi-Stellar Objects
Wright A & H	At the Edge of the Universe.
Mardirossian . F , and others	Clusters and Groups of Galaxies
Hodge . P	Galaxies
Wray . J . D	The Color Atlas of Galaxies
Kaufman, W. J., III	Universe

Extraterrestrial Life

Bova, Ben, and Preiss, Byron	First Contact
Shklovskii . I and Sagan . C	Intelligent Life in the Universe
Dick . S	Plurality of Worlds
Ashpole . E	Search for Extra-Terrestrial Intelligence
Papagiannis . M	The Search for Extraterrestrial Life

Galaxies\ Milky Way

Miller, J	Astrophysics of Active Galaxies and Quasi-Stellar Objects
Mardirossian, F., and others	Clusters and Groups of Galaxies
Ferris . T	Coming of age in the Milky Way
Vorontsov-Velyaminov, B	Extragalactic Astronomy
Hodge, P	Galaxies
Combes . F	Galaxies and Cosmology
Editors of Deep Sky magazine	Galaxies and the Universe
Boccaletti . D	Galaxies in the Young Universe
Springer Verlag (Pub)	Galaxies in the Young Universe
Shuter, W. L	Kinematics, Dynamics and Structure of the Milky Way
Hansson . A	Milky Way Galaxy and Statistics
Moore . P	Milky Way Galaxy and Statistics
Springer Verlag (Pub)	Spiral Galaxies
Osterbrock. E	Stars and Galaxies
Eicher . D . J	Stars and Galaxies: Astronomy's Guide to Exploring the Cosmos
Wray, J. D	The Color Atlas of Galaxies
Bok, Bart J and Priscilla F	The Milky Way
Corwin and Bottinelli	The World of Galaxies
Hodge . P	Universe of Galaxies

Gamma Ray Astronomy

Chen Joseph	Gamma Ray and Neutrino Cosmology
Mcclelland . D . E	Gamma Ray and Neutrino Cosmology
Edberg . S . J	Gamma Ray Astronomy
Elsevier Science (Pub)	Gamma Ray Astronomy
Hillier . R	Gamma Ray Astronomy
Massey, H. S., and others	Gamma Ray Astronomy
Wood . W. R	Gamma Ray Astronomy
Ramana. M and Wolfendale. A	Gamma-Ray Astronomy
Sopka . K . R	High Energy Gamma-Ray Astronomy
Henbest, N and Marten, M	The New Astronomy
Turner . K . E	Very High Energy Gamma Ray Astronomy

Interstellar Matter

Duley, W. W., and Williams, D	Interstellar Chemistry
Verschuur, G. L	Interstellar Matters
Carrington, A., and Ramsey, D	Molecules in Interstellar Space
Kichin. C	Stars, Nebulae and the Interstellar Medium

Jupiter (Planet)

Burgess. E	By Jupiter : Odysseys to a Giant
Washburn. M	Distant Encounters: The Exploration of Jupiter and Saturn
Jones . B	Exploring the Planets
Rogers . J . H	Giant Planet Jupiter
Hughes. D	Jupiter
Shurkin . J	Jupiter: The star that failed
Morrison. D	Satellites of Jupiter
Beatty, J. Kelly, and others	The New Solar System

Laws of Motion

Sorabji. R	Matter, Space, and Motion
McMullin. E	Newton on Matter and Activity
Tippens. P	Physics

Mars (Planet)

Murray, Bruce and others	Earth like Planets.
Jones . B	Exploring the Planets
Hoyt, W. G	Lowell and Mars
Kieffer, H. H., and others	Mars
Votg . G	Mars and the Inner Planets
Wilford, John Noble	Mars Beckons : The Mysteries, the Challenges, the Expectations of Our Next Great Adventure in Space
Chapman . C . R	Planets of Rock and Ice
Allaby . M	The Greening of Mars
Carr, M	The Surface of Mars

Mercury (Planet)

Murray, Bruce and others	Earth like Planets
Jones . B	Exploring the Planets
Vilas, Faith, and others	Mercury
Strom, R. G	Mercury: The Elusive Planet
Chapman . C . R	Planets of Rock and Ice.
Yenne. B	The Atlas of the Solar System
Time-Life Books Editors	The Inner Planets
Time-Life Books Editors	The Near Planets

Meteors & Meteorites

Burke, J. G	Cosmic Debris
Wasson, J. T	Meteorites, 2 vols.
Kerridge, J., and Matthews, M.	Meteorites and the Early Solar System
McSween, H. Y., Jr	Meteorites and Their Parent Planets
Graham . A	Meteorites-The key to our existence
Bone . N	Meteors (Philip's)
Bagnall. M. P	The Meteorite and Tektite Collectors Handbook

Meteor Showers

Burke, J. G	Cosmic Debris
Kronk, G. W	Meteor Showers.

Moon (the)

Rükl R	Atlas of the Moon
Moore. P	Exploring the Earth and Moon
Cherrington . E . JR	Exploring the Moon through binoculars & telescopes
Mutch. T . A	Geology of the Moon
B.A.A.	Guide for observers of the Moon
Hartmann, W. K., and others	Origin of the Moon.
Kopal. Z	Physics and Astronomy of the Moon
Davis. D and Hughes. D	The Moon
Price. F. W	The Moon Observer's Handbook
Kitt .T.M	The Moon: An Observing Guide for Backyard Telescopes

Nebula

Osterbrock. E	Astrophysics of Gaseous Nebulae and Active Galactic Nuclei
Jones, Kenneth Glyn	Messier's Nebulae and Star Clusters
Steven J. H	Planetary Nebulae: A Practical Guide and Handbook.
Kichin. C	Stars, Nebulae and the Interstellar Medium
Kaufman, W. J., III	Stars and Nebulas
Kreimer, Evered, and Mallas	The Messier Album

Neptune (Planet)

Jones . B	Exploring the Planets
Asimov, Isaac	Neptune
Moore . P	Planet Neptune
Littman, M	Planets Beyond
Rothery, D. A	Satellites of the Outer Planets
Grosser, M	The Discovery of Neptune
Burgess, E	Uranus and Neptune.

Observatories

Donnelly, M . C	A Short History of Observatories
Marx. S and Pfau. W	Observatories of the World
Tayler . R . J	Robotic Observatories
Springer Verlag Pub	Small Astronomical Observatories
Kirby-Smith, Henry T	US. Observatories: A Directory and Travel Guide

Orbits

Roy, A . E	Orbital Motion

Photometry

Golay, M	Introduction to Astronomical Photometry
Genet, K . A. and others	Photoelectric Photometry Handbook

Planets (General)

Ridpath . I	Atlas of stars and planets
Murray, Bruce and others	Earth like Planets
Jones . B	Exploring the Planets.
Moore . P	Guide to stars and planets (Philip's)
Votg . G	Mars and the Inner Planets
Jaki, S. L.	Planets and Planetarians : A History of Theories of the Origin of Planetary Systems.
LittmanI . M	Planets Beyond-Discovering the outer Sol\Sys
Chapman . C . R	Planets of Rock and Ice
Rothery, D. A	Satellites of the Outer Planets
Frazier, K	Solar System
Time-Life Books Editors	The Inner Planets
Time-Life Books Editors	The Near Planets
Owen. T and Morrison. D	The Planetary System
Duncombe, R. L., and others	The Stability of Planetary Systems

Plasma

Casini. A. R., and Sudan, R. N	Basic Plasma Physics II
Boenig. H . V	Fundamentals of Plasma Chemistry and Technology
Nicholson. D . R.	Introduction to Plasma Theory

Pluto (planet)

Levy . D	Clyde Tombaugh : Discoverer of planet Pluto
Jones . B	Exploring the Planets
Tombaugh, C., and Moore, P	Out of the Darkness
Litmann, M.	Planets Beyond
Chapman . C . R	Planets of Rock and Ice
Beatty, J. K	The New Solar System

Pricipia

Cohen, I. B	Introduction to Newton's Principia
King-Hele, D.G., and Hall, A.R	Newton's Principia and Its Legacy
Cohen, I. B	The Newtonian Revolution

Pulsars & Quasars

Manchester. N., and Taylor . J	Pulsars
Smith, F. G	Pulsars
Aubrecht . G	Quarks, Quasars, and Quandaries
Weedman Daniel	Quasar Astronomy

Arp, Halton B	Quasars, Redshifts and Controversies
Worvill, R	The Radio Universe: An Introduction to Radio Astronomy and Outer Space.

Radio Astronomy

Malphrus . B	History of Radio Astronomy and ....
Goldsmith, P	Instrumentation and Techniques for Radio Astronomy
Burke . B	Introduction to Radio Astronomy
Christiansen, W & Hogbom, J	Radio telescopes
Worvill, R	The Radio Universe: An Introduction to Radio Astronomy and Outer Space.
Rohlfs, K	Tools of Radio Astronomy

Relativity

Angel, R. B	Relativity
Tauber, G. E	Relativity
Russell, B	The A B C of Relativity
Einstein, Albert	The Meaning of Relativity
Gibilisco, S	Understanding Einstein's Theories of Relativity

Satellites (artificial)

Payne. S	International Satellite Directory
King-Hele, D. G	Observing Earth Satellites
Davis . J . K	Satellite Astronomy
Chetty, P. R	Satellite Technology and Its Applications

Saturn (Planet)

Washburn, Mark	Distant Encounters: The Exploration of Jupiter and Saturn
Jones . B	Exploring the Planets
Gehrels, Tom, and Matthews	Saturn
Hunt, Garry, and Moore . P	Saturn

Solar System

Dobbins,Parker and Capen	Observing and photographing the Solar System
Encrenaz . T	Solar System
Frazier, K	Solar System
Baugher J . F	Space Age Solar System
Yenne. B	The Atlas of the Solar System
Beatty / Chaikin	The New Solar System
Reidy. D and Wallace . K	The Solar System: A Practical Guide

Stars and Stellar Evolution

Lipunov . V . M	Astrophysics of Neutron Stars
Burnham . R . J	Burnham's celestial handbook V1,2 & 3
Malin & Murdin	Colours of the stars
Berry . R	Discover the stars
Berry.R	Discover the Stars (beginner)
Heintz, W	Double Stars
Cohen, M	In Darkness Born: The Story of Star Formation
Cambridge University	Molecular Clouds
Chen Joseph	Molecular Clouds and Star Formation
Carrington, A., & Ramsey	Molecules in Interstellar Space
Levy . D	Observing Variable Stars
Cox. J	Philips Color Star Atlas
Cornelius . G	Secret Language of the Stars
Richard H A	Star Names: Their Lore and Meaning
Osterbrock. E	Stars and Galaxies
Eicher . D . J	Stars and Galaxies: Astronomy's Guide to Exploring the Cosmos
Kippenhahn, Rudolf, and Weigert	Stellar Structure and Evolution
Cooke. E	The Life and Death of Stars.
Lada, C. J., and Kylafis, N. D	The Physics of Star Formation and Early Stellar Evolution
Ottewell .G	To Know the Stars (for children & beginners)
Percy, J., and others.	Variable Star Research
Hoffmeister, C., and others	Variable Stars
Petit, Michel	Variable Stars

Sun & Sunspots

Espenak . F	50 year canon of solar eclipses
Durrant . C . J	Atmosphere of the sun
Hendrickson . L . N	Beginners Guide to the Sun
Hufbauer, K	Exploring the Sun
Phillips, K	Guide to the Sun
Taylor . P . O	Observing the Sun
Giovanelli . R	Secrets of the Sun
Foukal, P	Solar Astrophysics
Cox, Arthur, and others	Solar Interior and Atmosphere
J. H., and Weiss, N. O	Sunspots: Theory and Observations
Stix, M	The Sun
Time-Life Books Editors	The Sun

Sundials

Mayall,R. Newton & Margaret W	Sundials: How to Know, Use, and Make Them
Rohr, Rene R. J	Sundials: History, Theory, and Practice
Waugh, Albert E	Sundials: Their Theory and Construction

Supernova

Schneider . P	Supernovae
Murdin, Paul and Leslie	Supernovae
Petschek, A., and others.	Supernovae
Branley, F. M	Superstar: The Supernova of 1987
Marschall, Laurence A	The Supernova Story

Telescopes & Binoculars

Kluwer Academic Pub	Adaptive Optics for Astronomy
Crossen.C	Binocular Astronomy
Berry. R	Build Your Own Telescope
Cherrington . E . JR	Exploring the Moon through binoculars & telescopes
Moore . P	Exploring the night sky with Binoculars
Texereau . J	How to make a telescope
Muriden . J	How to use an astronomical telescope P/B
Cohen, Martin	In Quest of Telescopes
Thompson . A	Making your own telescope
Trueblood. M and Genet .R	Microcomputer Control of Telescopes
Christiansen and Hogbom	Radio telescopes
Ruten / Venrooij . V	Telescope Optics-Evaluation and Design
Peltier. L	The Binocular Stargazer
King, H. C	The History of the Telescope
King . H . C	The History of the Telescope
Bell, Louis	The Telescope
Harrington. P	Touring the Universe Through Binoculars
Manly, P. L	Unusual Telescopes.

Tides & Time

Marchuk, G. I., and Kagan, B. A	Dynamics of Ocean Tides
Howse, D	Greenwich Time and the Discovery of the Longitude
Kopczynski, W., and Trautman, A	Space, Time and Gravitation
Coveney, P., and Highfield, R	The Arrow of Time
Toulmin, S. V., and Goodfield, J	The Discovery of Time
Fraser, J. T	The Genesis and Evolution of Time
Whitrow, G. J	The Natural Philosophy of Time
Flood, R., and Lockwood, M	The Nature of Time
Melchior, P. J	The Tides of the Planet Earth
Wylie, F. E	Tides and the Pull of the Moon

Uranus (Planet)

Hunt, G and Moore. P	Atlas of Uranus
Jones . B	Exploring the Planets
Rothery, D. A	Satellites of the Outer Planets.
Bergstralh, Jay T., and others	Uranus
Miner, E. D	Uranus
Miner, E. D	Uranus : The Planet's Rings and ....
Burgess, Eric	Uranus and Neptune

Venus (Planet)

Murray, Bruce and others	Earth like Planets
Jones . B	Exploring the Planets
Vogt, G	Magellan and the Radar Mapping of Venus
Chapman . C . R	Planets of Rock and Ice
Time-Life Books Editors	The Inner Planets
Hunten, D. M., and others	Venus
Russell, C. T	Venus Aeronomy

Burgess, Eric	Venus: An Errant Twin

X-Ray Astronomy

International Astronomical Union	High Resolution X-ray Spectroscopy of Cosmic Plasmas
Elvis, M	Imaging X-Ray Astronomy: Two Decades of Einstein Observatory Achievements
Tucker, W., and Giacconi, R	The X-Ray Universe.
Fraser, G. W	X-Ray Detectors in Astronomy

Observing

British Astronomical Assoc.	Guide for observers of the Moon
Birney . D . S	Observational Astronomy
Hill . H	Observational Astronomy
Bruck . M .T	Observational Astrophysics
Martinez . P	Observers Guide to Astronomy
Karkoschka . E	Observers Sky Atlas
Dobbins,Parker and Capen	Observing and photographing the Solar System
Mcclelland . D . E	Observing at a Distance
Edberg . S . J	Observing Comets, Asteroids..
King-Hele, D. G	Observing Earth Satellites
Sanford . J	Observing the Constellations
Stott . C	Observing the Sky
Taylor . P . O	Observing the Sun
Henbest . N	Observing the Universe
Levy . D	Observing Variable Stars
Sidgwick . J . B	Observational Astronomy for amateurs
Schaaf . F	Seeing the Deep Sky
Schaaf . F	Seeing the Sky
Levy . D	Sky A User's Guide
J. H., and Weiss, N. O	Sunspots: Theory and Observations
Price . F. W	The Moon Observer's Hand Book
Kitt.T.M	The Moon: An Observing Guide for Backyard Telescopes

Note: Hints on observing and an "Observers Log" are provided in the WDA tables section.

Astrophysics

Burkhardt . G	Astronomy and Astrophysics
Schatzman . E . I	Astronomy and Astrophysics
Springer Verlag (Pub)	Astrophysical Concepts
Kitchin . C . R	Astrophysical techniques
Miller J	Astrophysics of Active Galaxies and Quasi-Stellar Objects
Osterbrock. E	Astrophysics of Gaseous Nebulae and Active Galactic Nuclei
Lipunov . V . M	Astrophysics of Neutron Stars
Bruck . M .T	Observational Astrophysics
Kirk . J . G	Plasma Astrophysics
Foukal, P	Solar Astrophysics
Bruck . M .T	Stellar Astrophysics
Bohm-Vitense	Stellar Astrophysics V1
Bohm-Vitense	Stellar Astrophysics V2
Cambridge	The Astronomy & Astrophysics Encyclopaedia

Beginners

Moullon, F	An Introduction to Celestial Mechanics.
Moore . P	Comets and Shooting Stars
Berry . R	Discover the Stars (beginners)
Cunningham, C.	Introduction to Asteroids
Berry . R	Introduction to Astronomical Image Processing
Golay, M	Introduction to Astronomical Photometry
Brandt / Chapman	Introduction to comets
Carroll . B	Introduction to modern Astronomy
Cohen, I. B	Introduction to Newton's Principia
Glass. B . P	Introduction to Planetary Geology
Nicholson. D . R.	Introduction to Plasma Theory
Burke . B	Introduction to Radio Astronomy
Furguson . D	Introductory Astronomy Exercises
Moore . P	Planets
Moore . P	Stars
Lutgens. F. and Tarbuck E	The Atmosphere: An Introduction to Meteorology
Worvill, R	The Radio Universe: An Introduction to Radio Astronomy and Outer Space.

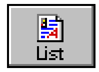
WDA Read File & Further Reading Help.

The WDA Read File Viewer has been added with the inclusion of several articles designed to enhance your understanding of the many areas of astronomy and to offer suggestions for further reading. We know of no other astronomical dictionary, paper based or electronic that includes this much information (apart from encyclopaedia costing much more). For the benefit of this demonstration version we have enabled two Read Files entitled "Our Solar System" and "Eclipses". All Read Files are enabled in the full version. The Further Reading Index by Subject section has also been enabled for demonstration purposes.

See also:
Printing Read Files
Read File Viewer Toolbar Functions
Further Reading Section

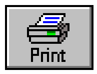
Printing Read Files

To print an article from the Read File Viewer.

1) If its not already displayed, click on the Read List icon 

and select an article from the list by clicking on the title you wish to view.

2) Check your printer setup from the file menu and make sure you have the right printer selected.

3) Click on the print icon 

to send the displayed article to the printer.

Note: Some read files are quite large, so make sure you have plenty of paper in the printer.

Read File Viewer Toolbar Functions

Copy selected text to the clipboard.
Send selected article to the printer.
Display list of Articles.
Display Bookmark menu.
Append Notes to Article.
Go-Back \ Display the previous topic
Display the help contents.

Please note: If you came to the read file viewer via the dictionary main button bar, the Go-Back button will be inactive. In this case you should close the read file viewer by selecting exit from the file menu. If you came via a link within the dictionary, use the Go-Back button as normal.

Further Reading Help

The further reading section available from the read file viewer has been added to offer suggestions for enhancing your understanding of astronomy in general. Most topics in astronomy are covered here and most are available, by order, from W H Smith or your local book shop. With over **600 titles** indexed by **Author, Title** and **Subject,** you are sure to find a title covering your particular field of interest. Links to further reading are provided where appropriate at the end of terms from the dictionary, on the end of most read files as well as from the Read file list. Look out for the book Icon and click on the words Further Reading to display a list covering the particular subject on view.

Titles with International Standard Book Numbers (ISBN) are courtesy of W H Smith Bookfinder database. If you would like to order any of these books call in at your nearest W H Smith store and they will be happy to raise an order for you. **Please Note**: ISBN numbers are displayed only in further reading sections indexed by Author and Title.