Chapter 25 OUR SOLAR SYSTEM

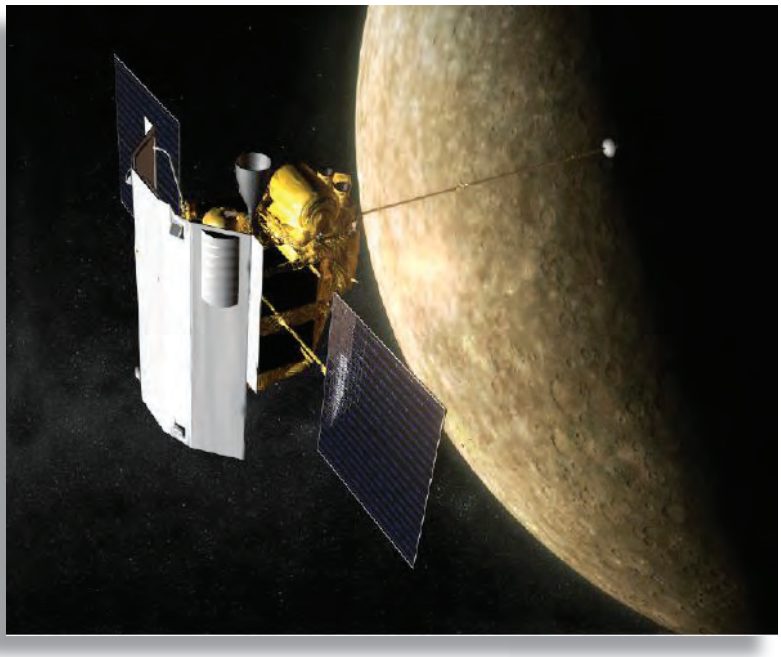
This chapter discusses the planets of our solar system. It is not an in-depth look, but it should give you a better understanding of some of the characteristics of the planets.

This chapter also takes into account moons of the planets and other bodies like asteroids, comets, meteoroids, nebula and novas. We discuss the planets in the order of their distance from the Sun, beginning with the planet that is closest to the Sun, Mercury.

Objectives

Describe the characteristics of Mercury.
Describe the characteristics of Venus.
Identify the different programs that sent spacecraft to observe Venus.
Describe some of Earth's characteristics.
State basic moon facts.
Describe the physical features of the moon.
Describe the basic types of moon rocks.
Describe the results of the *Mariner* probes of Mars.
Describe the results of the *Viking* probes of Mars.
Describe the characteristics of the planet Jupiter.
Explain the results of the *Pioneer* probes of Jupiter.
Describe the results of the *Voyager* probes of Jupiter.
Describe the characteristics of the planet Saturn.
Describe the ring system around Saturn.
Describe the characteristics of the planet Uranus.
Explain the results of the *Voyager* 2 probe of Uranus.
Describe the characteristics of the planet Neptune.
State the characteristics of the planet Pluto.
Describe the location of the asteroid belt.
Explain the characteristics of an asteroid.
Describe the characteristics of a comet.
Identify the results of the probes of Comet Halley.
Describe the characteristics of the Milky Way.
Define nova, supernova, pulsar, black hole phenomenon, nebulae, light year and parsec.
Describe the scientific objectives of Messenger.
Describe the timeline of The Venus Express.
Explain why we are returning to the moon.
Describe Saturn.
Describe Sedna.

Mercury



The *Messenger* satellite entering orbit around Mercury.
(Illustration Courtesy of NASA)

Mercury is the planet closest to the Sun, yet it is difficult to see because of the Sun's glare on its surface. Mercury is slightly larger than our Moon, and it is the second smallest of the nine original planets.

Mercury is only 36 million miles from the Sun and orbits it every 88 days. It has a very elliptical orbit and moves approximately 30 miles per second. Mercury rotates very slowly and its "day" is 59 Earth days.

Mercury has a rocky, crust surface with many craters. This gives it the appearance much like our Moon. Many of these craters were formed when space objects crashed into its surface.

Within the solar system there are four planets that are categorized as "terrestrial" (or rocky). They are: Venus, Earth, Mars and Mercury. Everything about this planet is extreme and a new satellite, launched from Earth, has been sent to gather data on Mercury's density, geological history, core structure, atmosphere, surface chemistry, and its extremely dynamic magnetic field. The probe is all part of a program designated MESSENGER.

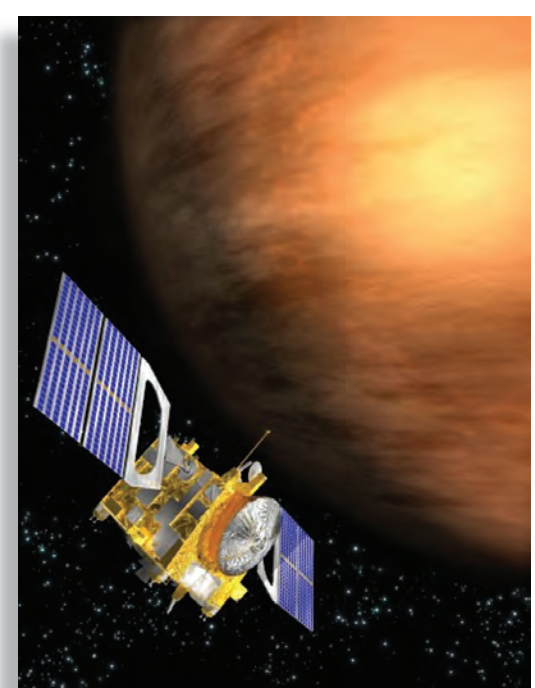
Messenger is the first spacecraft to orbit Mercury. It was launched on August 2, 2004, and is set to flyby the planet on January 14, 2008. Pictures of Mercury were first taken by *Mariner* 10, in a flyby in 1974. Sensors on board the *Mariner* transmitted information that described Mercury as very hot with a loosely porous soil. It also gave indications that ice existed at its poles, in deep craters, where the Sun could not melt it. In the three *Mariner* 10 flybys, it was discovered that both a thin atmosphere and magnetic field existed.

***Mariner* 10 was the first satellite to fly past Mercury.**
(Illustration courtesy of NASA)

The four innermost planets compared, Mercury, Venus, Earth and Mars. *(Illustration courtesy of NASA)*

Venus

Moonless Venus is the second planet from the Sun and is nearest to the Earth in both distance and size. This is why it is often referred to as Earth's "sister" planet. The two are similar in size, gravity and bulk. Venus is covered with an opaque layer that has a highly reflective atmosphere with clouds of sulfuric acid and sulfur dioxide. This keeps its surface from being seen from space in normal visible light. The Venusian atmosphere also has a pressure that is about 90 times greater than that of Earth. The CO2-rich environment creates a very strong greenhouse effect and this raises the surface temperature to over 400º Celsius, or 752º Fahrenheit. Venus has the most dense atmosphere of all the terrestrial planets. It has become so hot that any ancient water ocean would have totally evaporated.



The probe *Venus Express* in orbit around the planet. *(NASA Illustration)*

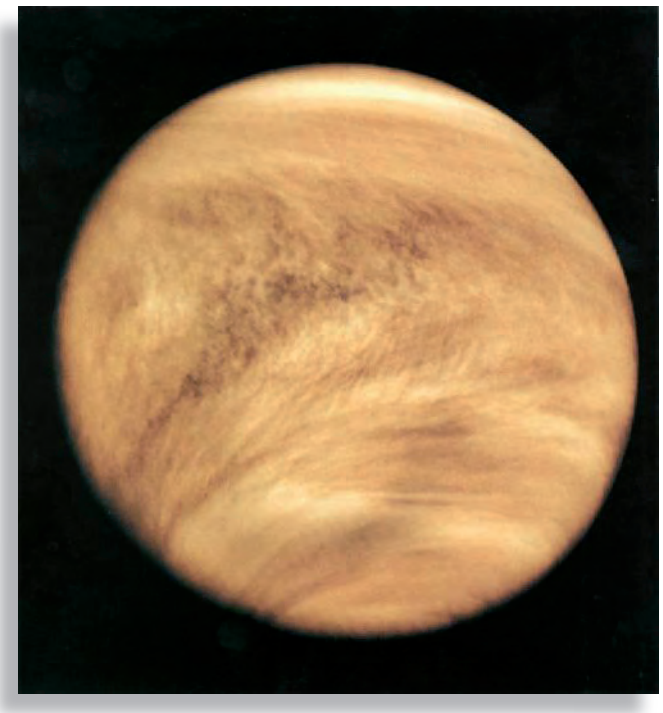
Venus' surface has been mapped in detail by the *Magellan* probe and shows only about 1,000 meteor craters, which is a very low number compared to the Earth or our Moon. It is a rocky body and the diameter is only 650 kilometers less than the Earth. About 80% of Venus' surface consists of smooth plains. There are two highland continents, which make up the rest of the surface. One is located in the northern hemisphere and the other is located south of its equator.

Since Venus is the closest planet to Earth, it has also

A globe of Venus from an image produced by the *Magellan* probe.
(NASA Photo)

been the most visited by our spacecraft. The following list summarizes the missions to Venus and some of the highlights of information collected:

- *Venera* 1 – (1961) launched by the USSR on a direct impact trajectory. Contact was lost seven days into the mission.
- *Mariner* 2 – (1962) confirmed the high surface temperature. This was the world's first successful interplanetary mission.
- *Venera* 3 – Soviet probe that crash-landed on the surface of Venus in 1966. Its communication system failed before it was able to return data.
- *Mariner* 5 – (1967) discovered a carbon dioxide-rich atmosphere and a surface pressure much greater than Earth's.
- *Mariner* 10 – (1969) determined the direction and speed (225 mph) of cloud movement. This probe used Venus as a slingshot to give it enough energy to continue on to Mercury. It passed to within 5790 Km of Venus, returning over 4,000 images as it made its flyby.
- *Veneras* 9 & 10 – (USSR) revealed through radar images of the surface, that many large craters existed. This probe also showed surface wind speeds of only 1-3 mph.
- *Pioneer* 1 – identified, through radar mapping of the surface, tall mountains, plateaus and canyons.
- *Pioneer* 2 – discovered 4 distinct cloud and haze layers.
- *Magellan* – (1989) mapped 99% of the surface with a resolution down to 300 meters.



The Venus atmosphere as seen by ultraviolet imagery.
(NASA Photo)

- *Galileo* – (1989) orbiter and atmospheric probe
- *Venus Express* – (2005) European Space Agency

Venus is currently being explored by the European Space Agency. The mission was scheduled to get underway in October of 2005; however, problems with the Fregat upper stage delayed this plan. It was finally launched on the 9th of November, 2005. It arrived at Venus on April 11, 2006. The *Venus Express* will study the atmosphere, clouds and its environment. Because of the success of the mission, it has been extended to May of 2009.

Earth

In the previous chapter, we discussed earth's relationship to the solar system. We looked at how the earth was influenced by the affects of space. In this section, we will discuss some of the earth's characteristics and how they compare to the other planets within our solar system.

The Planet Earth

As far as we know, earth is the only planet that sustains life. Therefore, earth is a unique planet. Our atmosphere contains 78% nitrogen and 21% oxygen, with small amounts of argon, carbon dioxide, neon, helium, ozone and hydrogen. Our atmosphere contains clouds, and these clouds, along with the chemical composition of the atmosphere, help absorb some of the sun's radiation.

The surface of our planet is covered with over 70% water, with the Pacific Ocean accounting for over 50% all by itself. This water, in liquid form, is vital to life on earth.

Also, we have anywhere from smooth green pastures to hot dry desserts. Or, we have plateaus and small hills, to tremendous mountain ranges. We have acres of lush forests or areas with no trees anywhere in sight.

The earth revolves around the sun in 365¼ days. It rotates on its axis every 24 hours.

Earth's Moon

Basic Moon Facts

The earth has one moon. In the earth/moon relationship, the moon is situated in an elliptical orbit about earth. Because it is elliptical and not circular, the moon's distance from earth changes slightly. The distance varies from approximately 252,000 miles at its farthest point to 221,000 at its nearest point.

The moon's period of orbit around earth is 27 days 7 hours 43 minutes. Because the moon rotates about its axis in the same length of time as it takes to complete an orbit, it presents the same side toward earth at all times.

Between 1969 and 1972, six Apollo missions sent 12 astronauts to the moon's surface. They collected lunar rocks and soil to be brought back to earth to be analyzed.

The moon is less dense than earth (there is more matter in a given volume of earth than the same volume of the moon). Its gravitational pull is about one-sixth that of the earth's, and it does not have an atmosphere to protect it. Solar radiation, cosmic rays, meteoroids, and interplanetary dust bombard its surface without any interference. The surface temperature reaches 270° F during the 14 earth days that equal one moon day. During the lunar night, the surface temperature drops to -250° F.

From the earth, we always see the same side of the moon. The same force that causes the tides in the oceans–(gravity), causes this "synchronous rotation." The moon's gravity pulls on earth and earth's gravity pulls on the moon. This mutual attraction is strong enough to pull the water in the oceans slightly towards to the Moon, creating the tides. In return, the earth's gravity has slowed the moon's rotation on its axis. Therefore, the moon completes one turn on its axis in the same time it completes one orbit around the earth. Hence, the same side of the moon always faces the earth.

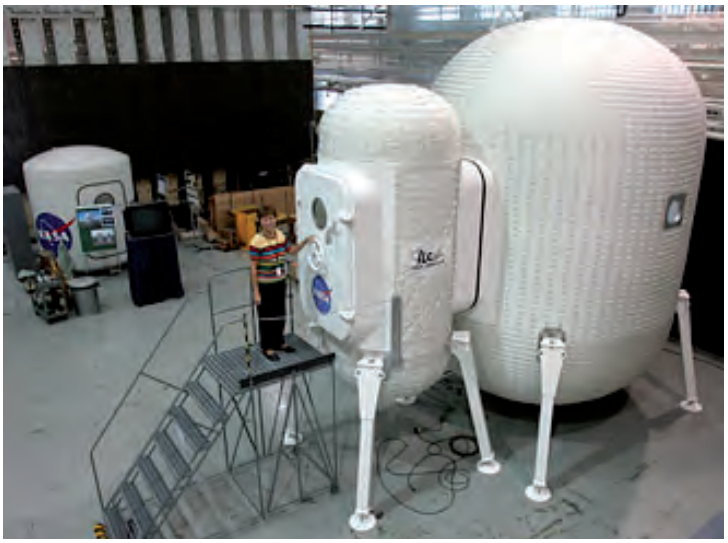
Physical Features

The Moon

The entire surface is pockmarked by impact craters made by meteoroids. The size of craters ranges from very tiny to a 150-mile-diameter giant. These larger craters have walls that may average 8,000 feet above the surrounding terrain.

As is true with almost all other features of the moon, an explanation of the origin of the craters is unsettled. It is agreed that most of them are impact craters, but some are believed to be the result of volcanic action since they closely resemble volcanic craters found on earth.

Other features of the moon include very rugged ridges and mountains. Most of the mountains are less than 10,000 feet above the surface, but a mountain named Leibnitz rises to 30,000 feet above the surrounding terrain. In contrast to the mountains are the rilles, which are long irregular depressions similar to streambeds on earth. Most of these rilles are fairly shallow and narrow. The exception is called the Hadley Rille; it measures 1,200 feet deep and is 1 mile wide. What caused these rilles is still a mystery. The larger ones may have been caused by flows of lava many years ago and the smaller ones possibly were caused by large stones rolling across the surface after being blasted out by meteoroid impact.



NASA refers to this as the planetary surface habitat and airlock unit.

Living on the Moon – Lunar Habitats

This new project has been delivered to the NASA Langley facility for ground-based evaluation of a study of yet-to-be-discovered emerging technologies.

Development of a lunar structure has to serve two purposes: It must be extremely versatile when astronauts and visitors are on location. Conversely, it has to be made of materials that can withstand long periods of abandonment when technicians and scientists are working elsewhere on the surface of the planet or in space.

One of the technologies being sought with long term facilities is the possibility of "living off the land." This also means that a habitat such as the one shown would allow a study of materials that could possibly be used on journeys to distant places such as Mars. If the moon does have usable materials, this means they wouldn't have to be transported from the earth. From an economic standpoint, this could amount to huge savings in payload costs and program funding.

The scientists working from the habitat are hoping to develop inflatable buildings that can withstand an environment that has no protection against incoming space debris and severe radiation from the sun.

Another reason that this research is receiving considerable attention is the development of a technology that would help make the moon a stepping-stone for further trips to Mars.

The planetary surface habitat and airlock structure is being carefully studied so that buildings can be linked together to accommodate scientific teams working on multiple projects simultaneously.

Moon Dust

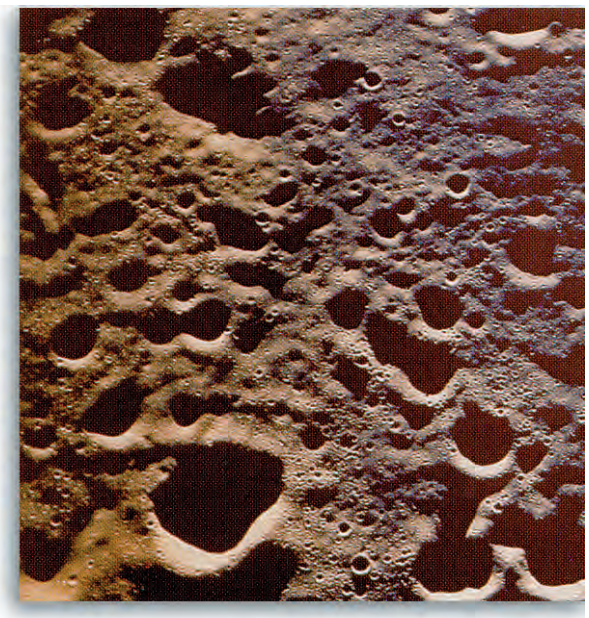
A fine dust covers the entire surface of the moon. On earth, sand, soil and dust deposits are the result of the erosion effect of wind and water, plus the transport of such particles by the movement of wind and water. The lunar environment apparently has never had a significant atmosphere, so how did so much dust get there? There are two theories—the explosive impact of meteoroids striking the surface pulverizes lunar matter into dust, which settles to the surface slowly and evenly, and other dust (cosmic dust) is picked up from space as it comes within the moon's gravitational influence.

Experiments with moon-dust samples produced some surprises. Tests on subsurface dust showed it had a sterilizing antibacterial effect almost as strong as that of a typical mouthwash. However, no other samples have produced this effect since then. Thus, scientists have one of many new moon mysteries to add to the old.

Moon Rocks

Certain dating techniques reveal lunar rocks may range in age from 3.0 billion to 4.6 billion years; thus, the older ones are older than any rocks on earth. Lunar rocks have remained exposed on the lunar surface for periods as long as 500 million years without being destroyed.

One discovery made during the Apollo lunar landings is that there are actually many different kinds of rocks on the moon. At first, it was believed that the surface of the moon would consist largely of primitive material. Although moon rocks have not gone through the weathering that earth rocks have and do not show as many variations, they do show evidence of melting and change.



Moon Craters Taken by *Apollo* 8

Basalt. The moon basalt is a dark gray rock with tiny holes from which gas has escaped. It closely resembles earth basalt, but contains different mineral combinations. On the moon, basaltic lava makes up the dark, smooth surfaces of the lunar plains, which cover about half of the visible side of the moon. These plains can be seen from earth without a telescope and are popularly identified as the features of "the man in the moon".

Anorthosite. Probably the most common rock on the moon is known as anorthosite. This rock is composed almost entirely of one mineral, feldspar. Anorthosite makes up the highlands of the moon, and they are seen from earth as the light areas. The highlands form the larger portion of the moon, thus comprising about half of the visible side and nearly all of the far side. Although anorthosite is common on the moon, it is rarer on the earth. It has been found in Greenland and is believed to be an ancient rock.

Other Rocks. Besides the two basic kinds of rocks described, a variety of other kinds and combinations of kinds of rocks were found on the moon. One of these, breccia, is a combination rock formed when meteorites broke up the surface and the pieces were welded together by the heat and pressure of impact processes.

The astronauts observed an abundance of natural glass, a substance also extremely rare on the earth. Among the moon samples, scientists identified a rock they called KREEP, which has not been found on earth. Astronauts and scientists also identified deposits of quartz, granite and other rocks that are also found on the earth. Three new minerals were also discovered in the moon rocks that have never been found on earth—tranquillityite, armalcolite and pyroxferroite.

Mars

Mars is the fourth planet in our solar system. Also called the Red Planet, Mars appears as a small reddish light when viewed with the naked eye. When viewed in the telescope, it shows up as a predominantly reddish-colored disk with distinct markings. This color is due to the rock and dust covering the surface of Mars. It has been analyzed and found to have a high iron content, so it has a rusty look.

The surface of Mars is dry and rocky, and is covered with this reddish dust. The atmosphere is very thin and is composed mainly of carbon dioxide. Mars has about half of the gravity of Earth, so when the wind blows, the dust from the surface rises and gives the atmosphere a reddish pink appearance.

The surface of Mars is covered with deserts, high mountains, deep craters and huge volcanoes. One of Mars' volcanoes is the highest known mountain in our solar system. It is over 400 miles across and 17 miles high (about 90,000 feet high).

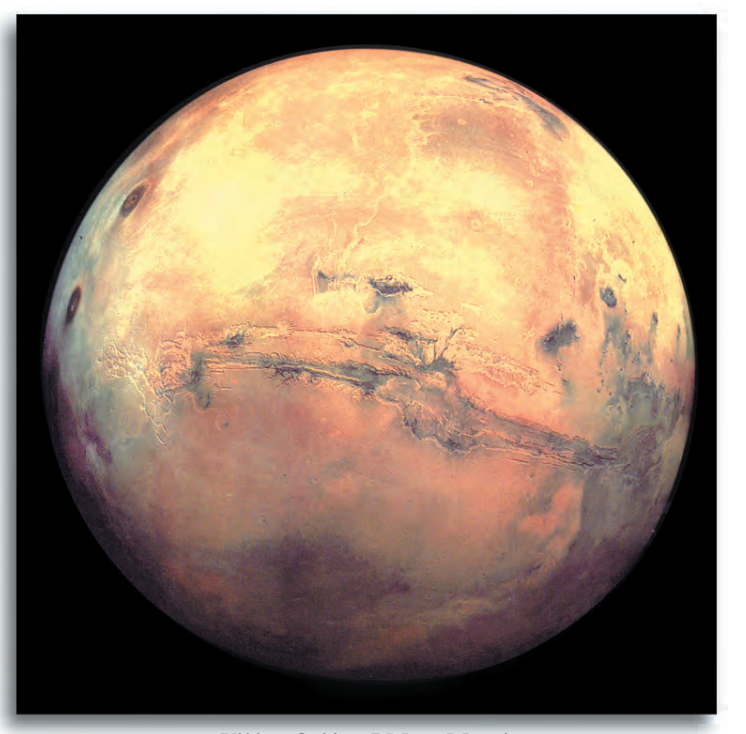
One day on Mars lasts slightly longer than earth's, at 24 hours 37 minutes. A Martian year is almost twice as long as an Earth year—about 687 Earth days. Mars has two moons, which are called Deimos (Terror) and Phobos (Fear), appropriate names for moons orbiting a planet named for the god of war. Both of the Martian moons are known to be extremely small.

It is possible that Mars once had an atmosphere, rivers, lakes and small seas. Scientists think that some pools of frozen or liquid water may be hidden underground. The north and south poles of Mars are covered with a frost that is made mostly of carbon dioxide (dry ice). Air pressure varies with the seasons on Mars. Winters are so cold that 20 to 30 percent of the entire atmosphere freezes out at the poles, forming a huge pile of carbon dioxide.

The Mariner Probe of Mars

***Mariner* 4.** *Mariner* 4, launched in November 1964, made a flyby of Mars in July 1965 and took 21 photos of the planet. Scientists were surprised when the pictures revealed a surface more like the earth's moon than the earth's. The pictures covered only a very small part of the planet, but they caused much excitement at the time because they were the first close-up photos returned to earth of another planet.

***Mariners* 6 and 7.** The second and third probes of Mars, *Mariners* 6 and 7 launched as a pair of probes in 1969, were much more advanced. Together, these two spacecraft took over 200 photos. Pictures



***Viking Orbitor* I Mars Mosaic**

returned by *Mariners* 6 and 7 still gave no clues to the identity of the dark-line markings on Mars or of other puzzling features observed in the telescope.

***Mariner* 9.** Since the flybys only photographed a portion of the planet at a particular time, *Mariner* 9 was designed to take pictures of the entire surface of the planet over a period of time. *Mariner* 9 revealed that at one time almost half the surface of Mars was affected by volcanic activity and extensive lava flows.

The Viking Probes of Mars

The most spectacular photographs yet received from any of the many planetary probes came from the *Vikings* 1 and 2. These craft consisted of orbiters and landers. The orbiters' role was to survey the planet on a global scale, and at the same time, serve as relayers of data and pictures gathered by the landers on the surface below.

The *Viking* 1 lander touched down July 26, 1976, and was followed by *Viking* 2 lander, which touched down on September 3, 1976. One of the primary missions of both landers was to determine if life—on a microscopic scale—existed on Mars. Unfortunately, the elaborate and automated experiments were not conclusive.

Considerably more water was found on Mars than had been expected. Analyses from orbit show the north polar cap to consist primarily of water ice; of course, carbon dioxide in frozen form is there too. Within some of the volcanic cones, water ice and carbon dioxide ice also exists. These frozen forms in the volcanic cones give way to clouds of condensate and vapor when heated by the sun. They return to ice when the sun sets.

Mars is cold. The daily temperature range measured at the *Viking* 1 lander site went from a high of -18° F to a low of -130° F (-191° F at *Viking* 2 site). The analysis of surface material near the lander showed a high content of silicon and iron, plus smaller amounts of aluminum, magnesium, calcium and sulfur. As mentioned earlier, the iron provides the red color of the Martian landscape.

The Mars Pathfinder Mission

On July 4, 1997, the *Mars Pathfinder* landed on Mars. The Pathfinder mission included a small exploration rover called *Sojourner* that moved around the surface of the planet to investigate the atmosphere and the composition of the Martian rocks and soil. The rocks analyzed by *Pathfinder* may be volcanic. Their pitted surface texture, presumably formed when gases trapped during cooling left small holes in the rock, suggests a volcanic origin. However, their silicon content classifies them as andesites.

Mars Sojourner

One way that andesites can form is when a basaltic melt from the mantle intrudes deep within the crust of the planet. Crystals rich in iron and magnesium form and are separated from the melt, leaving a more silicon-rich melt that erupts on to the surface. The finding of these andesites was a great surprise to the scientists. Not all of the rocks on Mars are volcanic in origin, however, and there is evidence that liquid water was once stable and that the climate of the planet, therefore, was warmer and wetter than at present.

The Mars Global Surveyor

The *Mars Global Surveyor* was launched on November 7, 1996, and entered orbit around Mars September 11, 1997. Designed to study climate and geology, the Surveyor's Mars Orbiter Laser Altimeter instrument collected exciting new observations of the north polar regions during the Science Phasing Orbit activities of the mission. These observations show the height of the Martian surface increases sharply by about 0.5 miles above the surrounding terrain at the edge of the polar cap. The elevation of the cap increases toward the pole and is 1.25-1.5 miles above the surroundings at the highest latitude sampled. A striking surface topography is composed of canyons and spiral troughs cutting through the upper portions of the northern polar cap to depths as great as 3600 feet below the ice surface. Vast dune fields surrounding the polar cap are similar to some forms of terrestrial sand dunes.

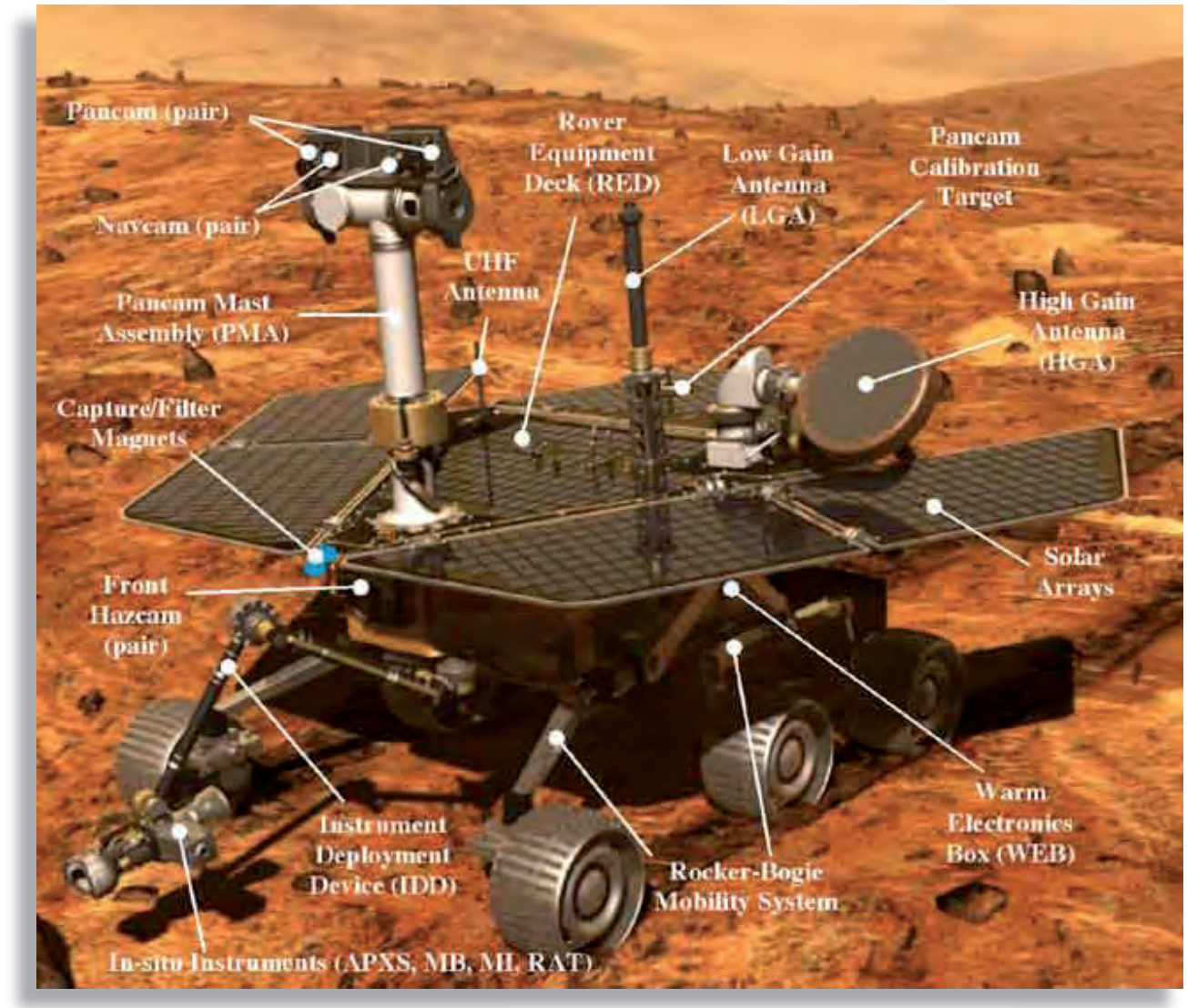
Partly because of the success of these missions, several other explorations of Mars are scheduled in the next few years.

Further Exploration of the Surface of Mars

On its way for a 263 million kilometer flight to Mars.

Earlier successes with the Global Surveyor missions prompted NASA to launch the Martian probes. Five of these were very successful and there are now two American Mars Rovers at work on the surface of the red planet. The rover *Spirit* landed on Mars on January 4, 2004, at a place known as the Gusev Crater. Another rover called *Opportunity* landed January 25, 2004. Its point of contact was on the Meridiani Planum. There was great excitement when, on March 2, 2004, NASA confirmed that liquid water once flowed on the surface.

The rover *Spirit* and its twin, *Opportunity*, are still doing their job after almost 4 years. These scientific marvels move about 44 yards a day and the rover *Opportunity* has already

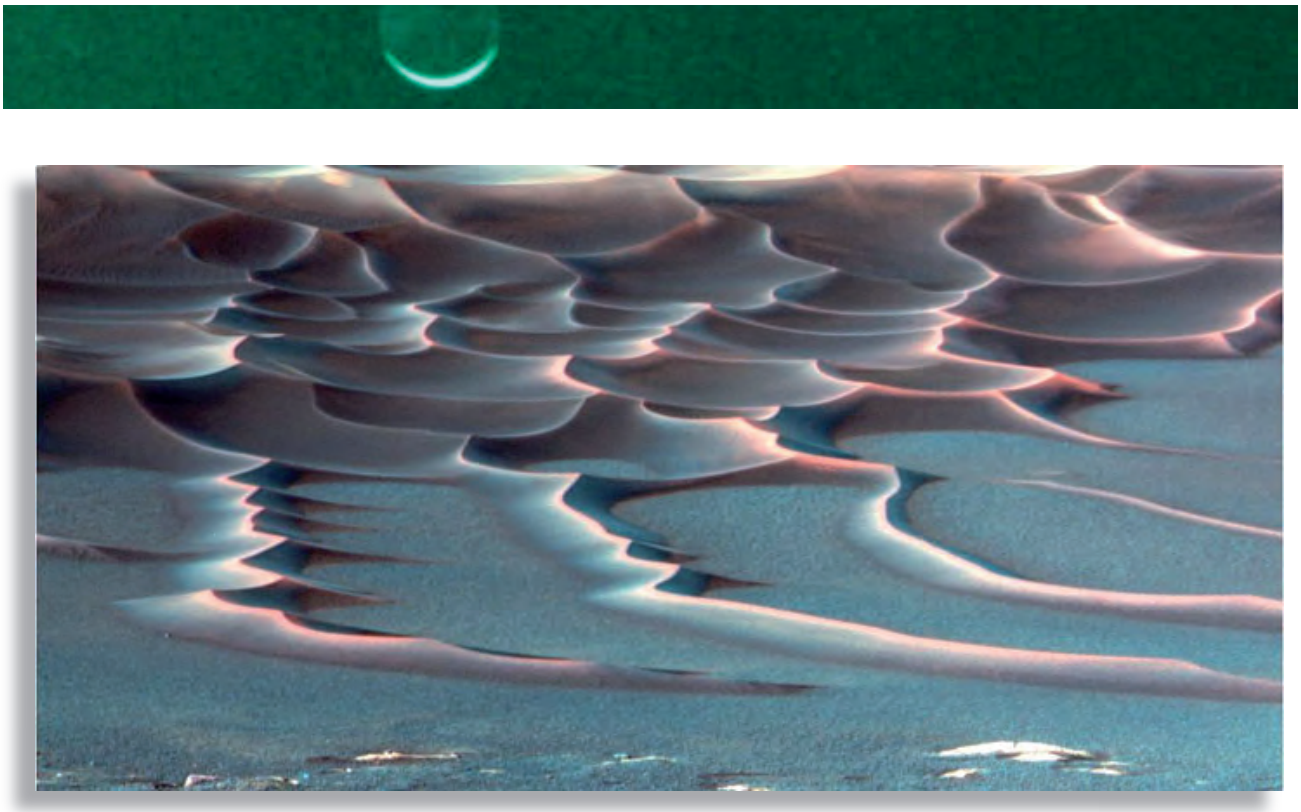


An artist conception of the Rover's Components. *(NASA)*

traveled more than 6 miles.

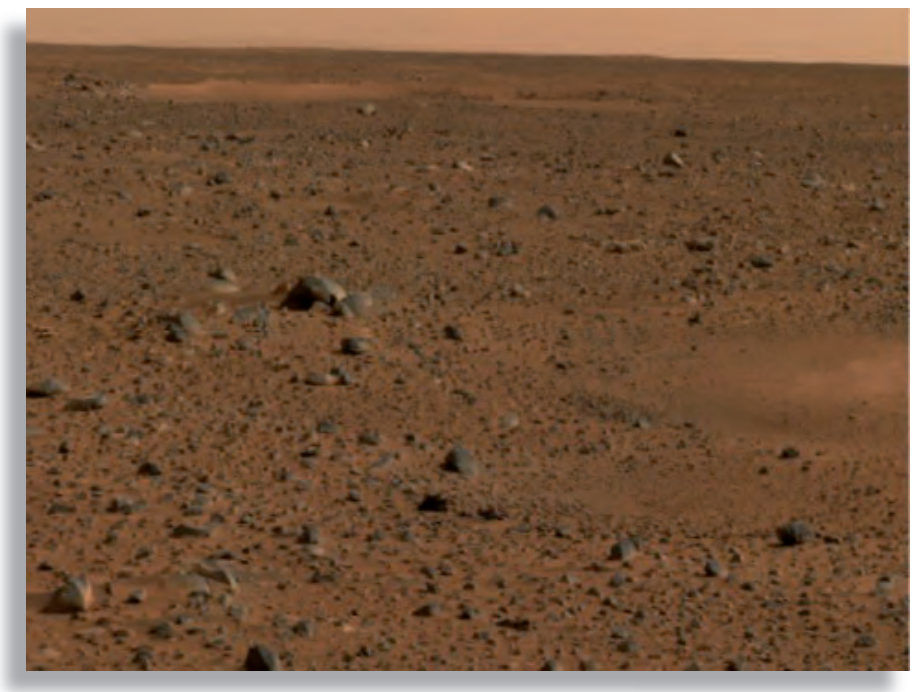
The unexpected longevity of *Spirit* and *Opportunity* is giving NASA a chance to field test some unexpected new capabilities. These tests will benefit current and future rovers. They are currently testing four new skills included in revised flight software uploaded to their onboard computers. One of the capabilities enables spacecraft to examine images and recognize certain features. It is based on software developed for NASA's Space Technology 6 "thinking spacecraft."

Spirit has photographed dozens of dusty whirlwinds in action and both rovers have photographed clouds. Until now, however, scientists on Earth had to sift through many transmitted images from Mars to find those few. With the new intelligence boost, the rovers can recognize dust devils or clouds and select only the relevant parts of the images to send back to earth. The increased efficiency will free up more communication time for additional scientific investigations.



The Great Endurance Dunes of Mars. *(NASA)*

Another new feature, called "visual target tracking," enables a rover to keep recognizing a designated landscape feature as the rover moves. Khaled Ali, of NASA's JPL Division and flight software team leader for *Spirit* and *Opportunity,* said, "The rover keeps updating its template of what the feature looks like. It may be a rock that looks bigger as the rover approaches it, or maybe the shape looks different from other angles. Fortunately the rover still knows it's the same rock."



The First Images of Mars as seen by the Spirit Rover. *(NASA)*

The combination of visual target tracking and the intelligence boost gives *Spirit* and *Opportunity* a capability called "go and touch." So far in the mission, whenever a rover has driven to a new location, the crew on earth has had to evaluate images of the new location to decide where the rover could place its contact instruments on a subsequent day. After the new

Photo confirmation of frozen liquid on Mars.

Mars Recon Orbiter

software has been tested and validated, the crew will have the option of letting a rover choose a target.

Spirit and *Opportunity* have worked on Mars for almost 12 times as long as NASA originally had planned. *Spirit* has traveled almost 4.3 miles and *Opportunity* has traveled more than 6.1 miles. *Spirit* has returned more than 88,500 images and *Opportunity* more than 80,700 images. Visit http://marsrovers.jpl.nasa.gov for more about the available technology and to view more raw images from both of the rovers.

As of May 2007, scientists and engineers were still deciding on when and if *Opportunity* would enter the Victoria Crater. In the meantime, *Opportunity* has a lot to accomplish, such as driving back to the area of its original arrival, which is approximately 600 meters away.

In addition, *Opportunity* must complete checkouts of its new technologies such as the D-star hazard avoidance path planner, visual target tracking and the IDD robotic arm. Also, on its way to Duck Bay, several imaging campaigns required it to arrive at the Cape of Good Hope and Cape St. Mary. Brisk winds have helped clean the solar arrays and the result is that these winds have given the rover 75 watt-hours more energy!

(Spirit update 13 APRIL 2007)

Spirit is healthy and recently completed a campaign of scientific studies on rock outcroppings known as the "Elizabeth Mahon." *Spirit* is now proceeding to another outcropping nicknamed "Madeline English." The route forced *Spirit* to drive backwards, turn around, back up, and parallel-park between two large rocks flanking the target.It then pivoted clockwise on the stuck right-front wheel, and moved in a "crabbing" motion forward to the target. *Spirit* performs crabbing by steering the two rear wheels toward the stuck right front wheel. And the opposing resistance from the right-front wheel helps to keep the yaw to a minimum.

***Opportunity* discovered the first meteorite ever seen on Mars.** *(NASA)*

As of May, 2007, there are two small rovers moving about the planet Mars gathering an invaluable amount of scientific information for scientists here on Earth. The dedicated personnel of NASA, JPL and the California Institute of Technology are to be congratulated on the phenomenal success of these exploratory missions.

Jupiter

Jupiter, the fifth planet from the Sun, is by far the largest planet in the solar system. It has three times the mass of all of the other eight planets put together. This equates to Jupiter being about 11 times larger than Earth.

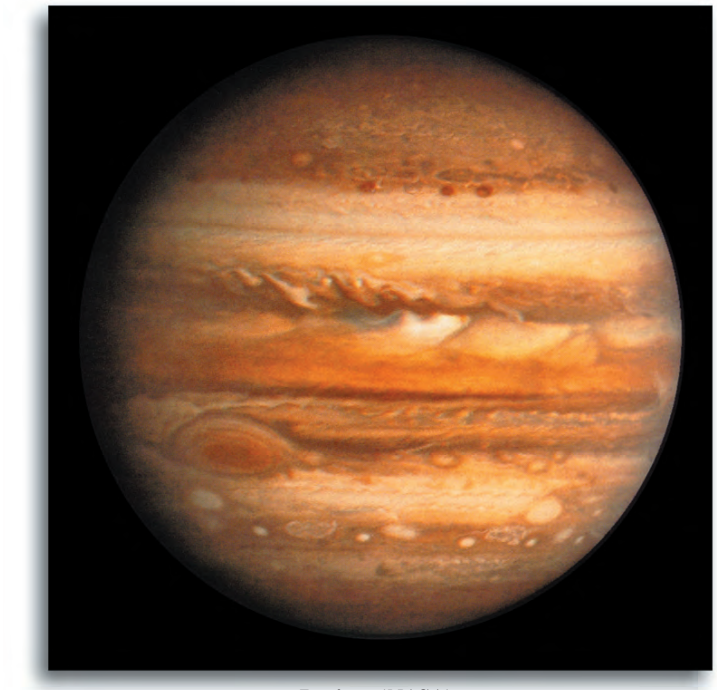
Even though Jupiter is huge, it rotates very quickly, about every 10 hours. This causes a flattening effect at the poles and a bulging effect at the equator. This fast rotation also enhances the weather patterns on Jupiter. It creates high winds and giant storms.

Jupiter is a gas giant. Hydrogen is the most prominent gas, followed by helium, methane and ammonia. The outer core of Jupiter is composed of liquid hydrogen and helium, and these mix with the gaseous atmosphere to form belts of clouds.

These belts are very colorful, but change rapidly due to the high winds associated with the quick rotation of the planet. These belts make Jupiter look like a striped ball with a giant red spot in the lower half. This red spot is a distinguishing feature of Jupiter and is called the Giant Red Spot. This spot is a giant hurricane-like storm that is 30,000 miles long and 10,000 miles wide.

Another feature of Jupiter is the moons. There are 16 known moons, with four that are much larger than the rest. These four are called the Galilean moons, named after their discoverer, Galileo. One of these moons has active volcanoes.

Jupiter has a diameter of about 88,700 miles, and it revolves in about 11 Earth years. Its temperature



Jupiter *(NASA)*

ranges from over 60,000° F at its center, to -220° F at the upper cloud layers. Except for Earth, Jupiter is the only planet known to have a strong magnetic field and radiation belts.

The *Pioneers* 10 and 11 spacecraft were the first investigations of the planet. Launched in the early 1970s, they made very significant contributions to our knowledge of the Jovian (Jupiter) atmosphere, magnetism and radiation, and satellites of the giant planet.

Atmosphere. The *Pioneers* discovered that the generally banded structure of the Jovian atmosphere is not present near the poles where oval circulation patterns develop. At the poles, a thick, particle-free (or blue-sky) atmosphere was found. The bright zones were found to consist of rising cloud masses at higher altitudes, while the belts are descending masses that allow a deeper view into the atmosphere. Detailed study showed rapid motions among the clouds and changes in the wind speeds. Between 1973 and 1974, changes in the flow patterns of the Giant Red Spot were also observed.

A great deal of atmospheric activity on Jupiter is similar to that of Earth. However, Jupiter's storms seem to be powered by the planet itself rather than by the Sun as they are on Earth. Jupiter's core still retains heat from the planet's original formation by collapse and compression and its storms develop from this internal heat source. Jupiter's heat reservoir of highly compressed hydrogen at its center causes the planet to emit almost 70 percent more heat than it absorbs from the Sun. This leads scientists to speculate that the source of Jupiter's stormy turbulence is the planet itself.

Magnetism and Radiation. The *Pioneers* detected a huge magnetic field on Jupiter. If the Jovian magnetosphere were visible in the sky from Earth, it would appear larger than our Sun or Moon. The *Pioneers* also revealed the fact that the Jovian magnetic field is 10 times stronger than Earth's and contains 20,000 times as much energy. However, the Jovian magnetic field is opposite to that of Earth—north magnetic pole is at the south pole of Jupiter.

The *Voyager* Spacecraft. On January 4, 1979, the first of two *Voyager* spacecraft was launched on a long mission to study the outer planets. These spacecraft were sent out to investigate the planets Jupiter, Saturn and Uranus as well as their moons. Besides sending back many superbly detailed photographs of Jupiter, these probes confirmed many observations from telescopes.

Satellites. Before the flights of the *Voyagers*, Jupiter had 13 known satellites, or moons. Four of these moons are large and bright enough to be seen through the higher-powered binoculars. Their sizes approximate those of the Earth's Moon and that of the planet Mercury. The four outermost small

moons revolve around Jupiter in a clockwise direction. This is opposite to the inner nine moons in that they behave as they are supposed to; that is, they revolve in a counterclockwise direction like the moons of Mars, and Earth and other planets.

The flights of the *Voyagers* revealed additional information about the Jovian satellites. First, three additional moons were discovered, raising the total to 16 moons orbiting Jupiter. Volcanic eruptions were discovered in Io, the first evidence of active volcanism found outside the Earth.

Jupiter's atmosphere is very deep, perhaps comprising the entire planet and in some ways is similar to the Sun. Composed mainly of hydrogen and helium, with small amounts of methane, ammonia, water vapor, and other compounds. At great depths within the planet, the pressure is so great that the hydrogen atoms are broken up and the electrons are freed so that the resulting atoms consist of bare protons. This produces a state in which the hydrogen becomes metallic.

Like all of the gas giant planets in our solar system, Jupiter has a ring system. However, it is a simple one in comparison to Saturn's intricate and complex ring patterns. The Jovian rings are tenuous and composed of dust particles kicked up as interplanetary meteoroids smash into the planet's four small inner moons. Many of these particles are microscopic in size.

These rings, which are not visible from Earth, and the Jovian moons exist within an intense radiation belt of electrons and ions trapped in the planet's magnetic field. These fields and particles make up the magnetosphere, which extends from 1.9 to 4.3 million miles toward the Sun and stretches at least as far as Saturn's orbit — a distance of 466 million miles.

Saturn

Saturn is the second largest planet in the solar system and the sixth from the Sun. It is the famous "ringed planet." The rings are easily the most recognizable features of Saturn. Through a telescope, the rings are spectacular! They are made of icy chunks of rock ranging from tiny particles to large boulders. The main rings are made of hundreds of narrow ringlets. The entire ring system is about 1 mile thick and extends about 250,000 miles from the planet.

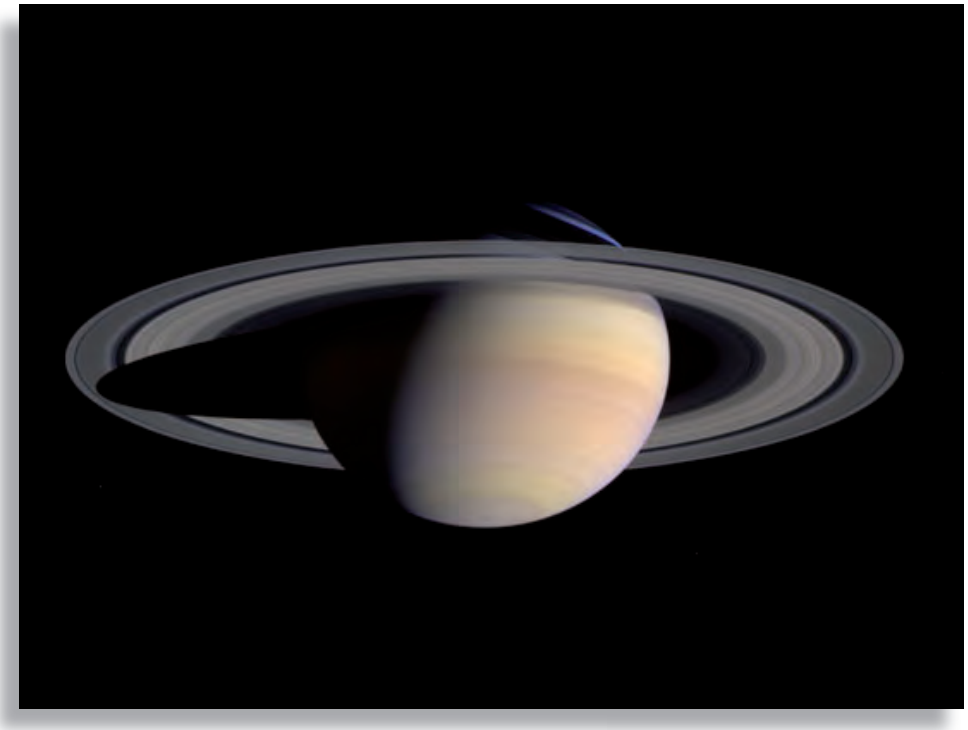
Saturn's rings intrigue scientists and lay persons alike. There are seven distinct rings around Saturn. The rings are designated by the letters A

Saturn *(NASA)*

SATURN — *Cassini* has produced some of the most spectacular images of any spacecraft to date.
Cassini *is a large spacecraft weighing in at six tons and stands approximately two stories tall. It was launched on October 15, 1997, and its flight covered a distance of 2.2 billion miles. A Titan IVB/Centaur rocket launched the* Cassini *(and the Huygens investigation probe equipment) from Cape Canaveral.* Cassini *entered the new millennium and returned some of the most incredible images ever seen of a solar body beyond the moon.* Cassini *was scheduled to study Saturn and its moons for a period of four years and the project was managed by the Jet Propulsion Laboratory in Pasadena, California.*

through G. The first five rings were discovered by Galileo in 1610 and the final two by the *Pioneer* spacecraft.

The planet itself has an icy rock core surrounded by metallic hydrogen with an outer layer of hydrogen and helium. The hydrogen and helium are mainly liquid and turn to gas as they get to the outer surface.



In this image, dark regions represent areas where *Cassini* is seeing into deeper levels in Saturn's atmosphere. The dark regions are relatively free of high clouds and the light at these particular near-infrared wavelenghts penetrates into the gaseous cloud-free atmosphere and is absorbed by methane. The image was taken with the *Cassini* spacecraft narrow angle camera on May 15, 2004, from a distance of 24.7 million kilometers (15.4 million miles) from Saturn.

Saturn is a large planet, though not nearly as large as Jupiter. Like Jupiter, Saturn rotates at a very fast 10 hours. However, it takes over 29 years to revolve around the Sun. Also like Jupiter, the combination of fast rotation and gaseous and liquid atmosphere create very strong winds, clouds and storms. The winds of Saturn have been known to reach 1,100 miles per hour.

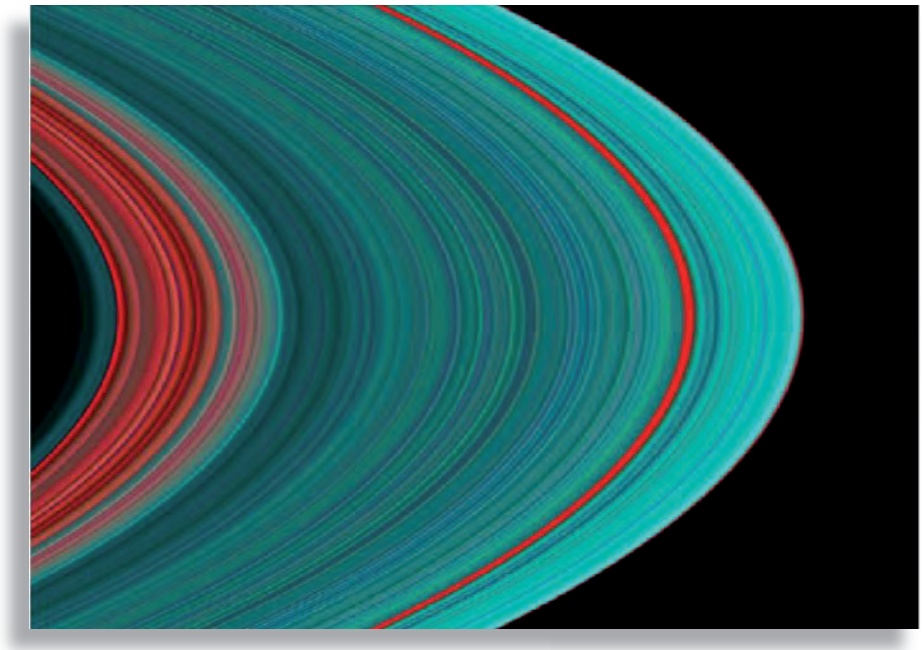
The temperatures of Saturn do not vary as much as many of the other planets. During the day the temperature gets up to 130°F and at night down to -330°F. Saturn is about 900 million miles from the Sun.

Saturn has 18 known moons, all but one of which are covered with craters and icy surfaces. The one exception is Titan, which has an atmosphere of nitrogen and methane. It is the only moon in the solar system to have its own atmosphere.

***Pioneer* and *Voyager* Missions.** The passage of these spacecraft past Saturn in the late 1970's and early 1980's has produced much information about the planet.

The planet's outermost region contains Saturn's atmosphere and cloud layers. The atmosphere has weak bands rather than the conspicuous belts and zones seen on Jupiter. Saturn's three main cloud layers are thought to consist respectively (from the top down) of ammonia ice, ammonia hydrosulfide ice, and water ice. Unusual atmospheric features discovered include a ribbon-like wave feature, large and small clouds, and a red oval similar to, but smaller than, Jupiter's Great Red Spot. *Pioneer* also discovered a magnetic field around Saturn that is larger than the Earth is but smaller than that of Jupiter.

Saturn has 18 known moons, some detected from Earth, others found during *Pioneer* and *Voyager*



Icy Rings of Saturn *(NASA)*

missions. In 1995, scientists using the *Hubble Space Telescope* sighted four objects, which might also be moons.

Titan, the largest of Saturn's moons and the second largest moon in the solar system, is the only moon known to have a dense atmosphere. The density of the moon appears to be about twice that of water ice and may be composed of nearly equal amounts of rock and ice. As with Earth, nitrogen is the most prevalent gas in the Titan atmosphere. Methane is the next most abundant gas. The thickness of the atmosphere is about ten times that of Earth.

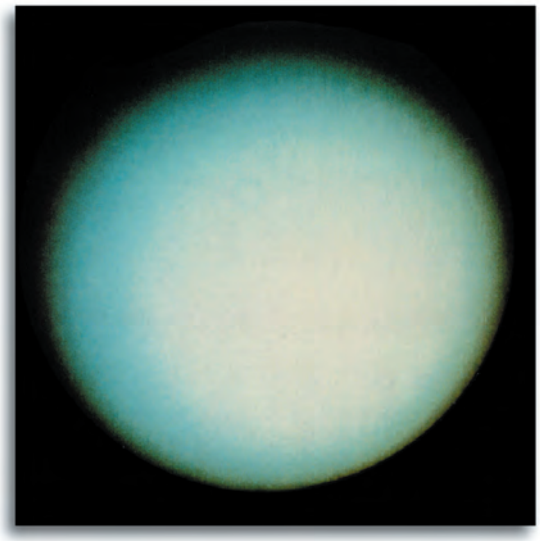
Phoebe, one of the known 18 moons of Saturn, orbits the planet in a plane much closer to the ecliptic than to Saturn's equatorial plane. It is quite red, roughly circular in shape, and reflects about six percent of the sunlight. It rotates on its axis about once in nine hours; thus, it does not always show the same face to the planet. Scientists believe that Phoebe, the only satellite of the planet to travel in a retrograde orbit, may in fact be a captured asteroid with its composition unmodified since its formation in the outer solar system. If so, Phoebe is the first such object that has been photographed at close enough range to show shape and surface brightness.

Saturn's magnetic field, unlike those of all other planets whose magnetic fields have been measured, is tipped less than one degree relative to the rotation poles. This rare alignment was first measured by *Pioneer II* in 1979 and confirmed by the missions of *Voyagers* 1 and 2.

Saturn is the only planet in our solar system that is less dense than water (about thirty percent less). This means that Saturn would float if placed in a large enough ocean of water. The planet has a volume 764 times that of Earth, but weighs only about 95 times as much.

Uranus

Uranus is the third largest planet in the solar system. Like Jupiter and Saturn, it is a gas-giant world. Uranus has a rocky core surrounded by water, ammonia and methane, in both ice and liquid forms. The outer layer consists of hydrogen and helium gases. There is also methane in the upper atmosphere, and this gives Uranus a bluish greenish color.



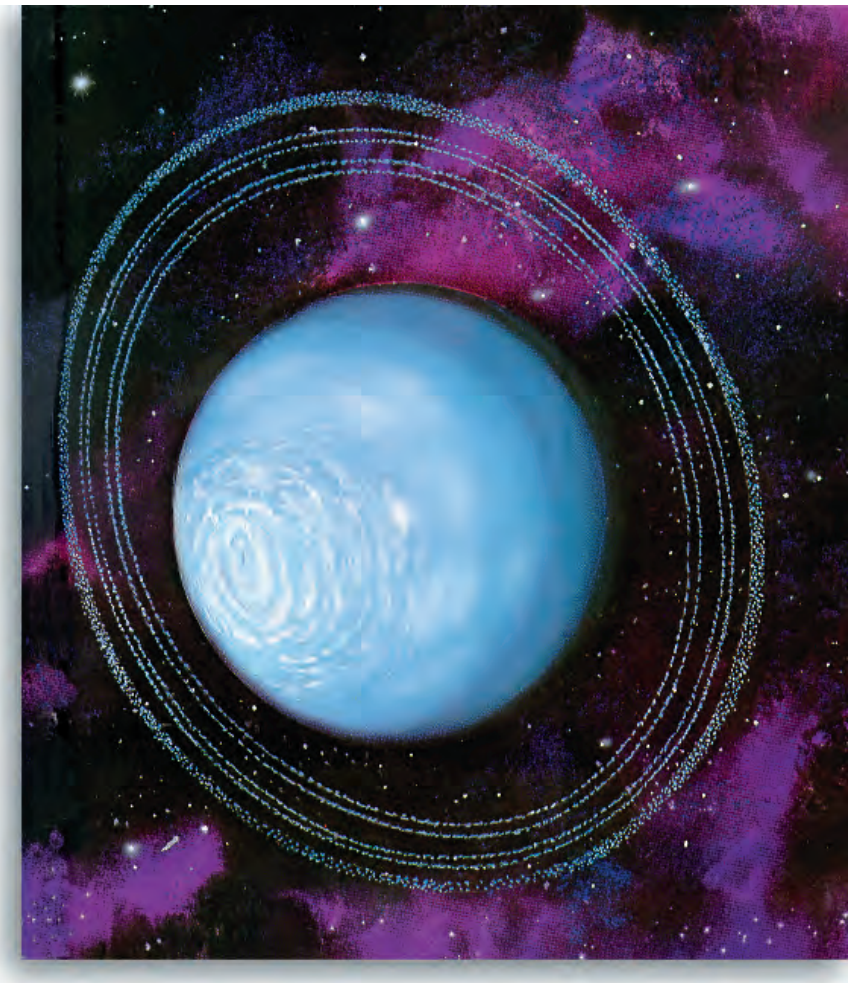
Color Image of Uranus Produced in 1986 *(NASA)*

Uranus rotates once every 18 hours, but unlike the other planets, it spins sideways. The unusual position of the planet is thought to be the result of a collision with a planet-sized body early in the solar system's history.

Taking 84 years to orbit the sun, when the sun rises on the north pole, it stays up for 42 years and then is in darkness for 42 years. The sunlit hemisphere radiates large amounts of ultraviolet light. Voyager scientists have dubbed this phenomenon "dayglow."

The orbit of Uranus is nearly 2 billion miles from the Sun, about twice as far as Saturn. The temperature is about -340° F on Uranus.

Its environment is super cold because the amount of solar radiation reaching it is negligible. The *Voyager* 2 probe discovered Uranus' magnetic field is not in the usual north-south alignment, but is tilted 60 degrees and offset from the center of the planet. Astronomers initially discovered nine rings and five moons around Uranus. *Voyager* revealed the existence of 2 more rings and 10 more moons.



An Artist's Conception of the Rings of Uranus *(NASA)*

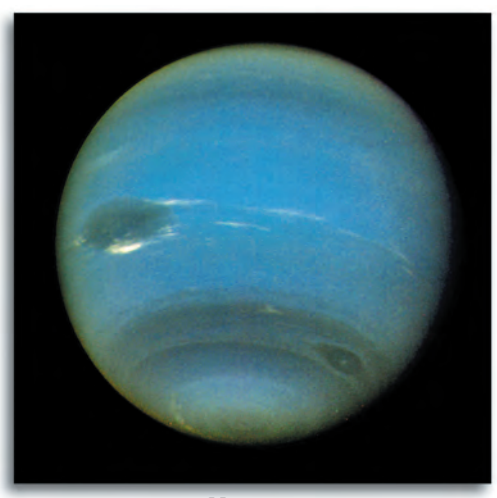
Neptune

Neptune, the outermost of the gas planets, is the fourth largest planet in the solar system. It was discovered in 1846 when scientists determined that something was affecting the orbit of Uranus. Neptune and Uranus are so similar they are sometimes called twins.

Neptune is about 3 billion miles from the Sun and it takes 165 Earth years to complete an orbit. A Neptune day lasts about 19 hours. The planet has a rocky core surrounded by water, ammonia and methane. The atmosphere consists of hydrogen, helium and methane. The methane gives Neptune a bluish color.

Pictures of the planet show that bright clouds of methane ice crystals are present. Pictures also indicate that Neptune has a very thin, faint ring system, which is hard to detect.

Neptune is a windy planet, the most windy in the solar system. Most of the winds blow in a westward direction, retrograde to the rotation of the planet. Storms similar to those on Jupiter were found during the *Voyager* missions. Several large dark spots were found during the mission; the largest of these storms, the Great Dark Spot, is about the size of the Earth and appears to be an anticyclone similar to Jupiter's Great Red Spot. Retrograde winds blowing up to 1,500 miles per hour, the strongest winds measured on any planet in the solar system, are found around the Great Dark Spot.



Neptune

The ring system around the planet is narrow and very faint. The rings are composed of dust particles that scientists believe were made by tiny meteorites smashing into Neptune's moons. From ground based telescopes the rings appear to be arcs, but *Voyager* revealed the arcs to be bright spots or clumps in the ring system itself.

Neptune has eight moons, the largest of which is Triton. Triton differs from all other icy satellites studied by the *Voyages*. It is approximately three-fourths the size of Earth's Moon and circles Neptune in a tilted, circular, retrograde orbit every 5.875 days.

The moon shows evidence of a remarkable geologic history, and *Voyager* 2 images show active geyser-like eruptions spewing invisible nitrogen gas and dark dust particles several kilometers into space. The density of the moon is about 2.066 grams per cubic centimeter indicating Triton contains more rock in its interior than the icy satellites of Saturn and Uranus do. (For comparison, the density of water is 1.0 gram per cubic centimeter.) This relatively high density and the retrograde orbit of the satellite offer strong evidence that Triton did not originate near Neptune, but is a captured object.

If that is the case, tidal heating could have melted Triton in its originally eccentric orbit, and the satellite might even have been liquid for a long as one billion years after its capture by Neptune. While scientists are unsure of the history of Triton, icy volcanism is undoubtedly an important ingredient.

Pluto

After 7 months of painstaking work, astronomer Clyde W. Tombaugh discovered Pluto on February 18, 1930. Less is known about Pluto than the other planets, but that is about to change with the launch of *New Horizons* space probe in 2006. It is a yellowish-gold in color and about the size of Mars. It rotates on its axis in about 6.5 Earth days. The planet's orbit is inclined to the plane of an elliptic 17 degrees, bringing the planet inside the orbit of Neptune for 20 of its 249-year orbit.

Artist's Illustration of New Horizons as it arrives at Pluto
(Courtesy of NASA)

Pluto reaches its maximum distance from the elliptic, due to the 17° inclination, as it approaches perihelion (its closest approach to the Sun). This means it remains far above or below the plane of Neptune's orbit and there is no danger of the planets colliding. Pluto last crossed Neptune's orbit on January 21, 1979, made its closest approach on September 5, 1989, and remained within the orbit of Neptune until February 11, 1999. This will not occur again until September 2226.

Scientists believe that Pluto is 50-75% rock mixed with ice. Temperatures vary widely, since Pluto can be as close to the Sun as 2,939 million miles or as far away as 4,583 million miles. The planet has a thin atmosphere that freezes and falls to the surface as it moves away from the sun.

An Artist's Conception of the Pluto-Charon Binary Planet
(NASA Artwork by Pat Rawlings)

Pluto's rotation period is 6.387 Earth days. Recent discoveries indicate there are millions of small rocky objects orbiting in the Kuiper Belt, a vast region that extends beyond Neptune. The Edgeworth-Kuiper Disk of "ice dwarfs," or minor planets, lies beyond Pluto.

Latest Developments

Pluto-The Great Controversy

From the time of its discovery in 1930, until 2006, Pluto was considered the solar system's ninth planet. In the late 20th and early 21st centuries, however, many objects similar to Pluto were discovered in the outer solar system, most notably the trans-Neptunian object Eris, which is slightly larger than Pluto. On August 24, 2006, the IAU (International Astronomical Union) defined the term "planet" for the first time. This definition excluded Pluto and it was reclassified under the category of "Dwarf Planet." The definition of a planet by the IAU is: (1) a body that orbits the sun, (2) is large enough for its own gravity to make it round, and (3) has cleared its neighborhood of smaller objects. The new definition of "dwarf planet" includes Pluto, Eris and Ceres. There is much controversy over the new definition and as a result, it has been put on the agenda of the IAU's next meeting (2009) in Rio de Janeiro.

By the current definition, Pluto is now the second-largest known dwarf planet in the solar system and the tenth-largest body orbiting the Sun. It is officially designated "134340 Pluto." Once the IAU reaches a decision on the name, the "134340" will be dropped.

The composition of tiny Pluto is mostly rock and ice and is estimated to be 1,440 miles in diameter, or about 70% that of our moon. Pluto takes 249 years to make an orbit around our Sun and the distance of that journey is 3.67 billion miles.

Scientists have described the orbit as a "squashed loop." Its orbit tilts up at a 17 degree angle whereas the other planets in the solar system rotate in a flat plane about the sun. Because of the inclination, Pluto's orbit will sometimes bring it closer to the Sun than the orbit of Neptune. As recent as 1999, Pluto crossed Neptunes path where it momentarily became the solar system's eighth planet from the Sun. Pluto and Neptune will, however, never collide.

***NEW HORIZONS* AT LIFT OFF ON JANUARY 19, 2006.**
(Image by Pat Corkery, Courtesy of Lockheed Martin)

Why Go There?

Pluto is moving farther away from planet Earth and because of deep space temperatures, its atmosphere will become completely frozen and will eventually fall to the surface. Once frozen, it won't

thaw until early in the 23rd century. As a result, the astronomical scientific community of this century wanted to see "up close" the results of their hard work before their passing. Because of the relative urgency, an unmanned space probe was launched toward Pluto in 2006. It was called *New Horizons*. The image shown is an artist's rendition depicting the *New Horizons'* interplanetary spacecraft passing Jupiter.

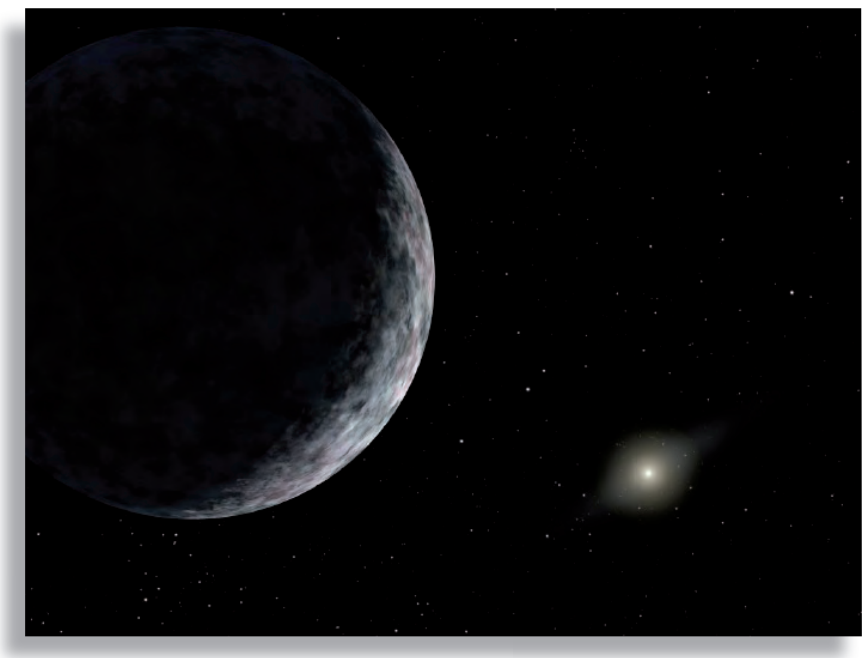
Pluto is recognized as the largest member of a region known as the Kuiper Belt and we now know that it has three known natural satellites, the largest being Charon, first identified in 1978 by astronomer James Christy. In 2005, astronomers working with the Hubble Space Telescope discovered that Pluto also has two smaller moons. In 2006, their names, Nix and Hydra became official. These moons orbit Pluto at approximately 2-3 times the distance of Charon.

The Kuiper Belt

Our solar system is a magnificent collection of beautiful planets and various other bodies of lesser magnitude. There is a ring of bodies that exists billions of miles beyond the orbit of Neptune. This ring is called the Kuiper Belt and most of its inhabitants are small, icy bodies that are so far away, and dim, only the most sophisticated optical equipment is capable of capturing the reflected light. The majority of bodies within this Belt are smaller than Pluto, yet many have names and have been cataloged by astronomers. As of this writing, over 84 objects have been catalogued and 19 have names. The greatest source of data has been gathered by the Hubble Space Telescope.

Another Space Telescope

The Hubble Space Telescope has had a few problems and a delicate, but successful "operation" brought it into usable operation. It continues to provide science with very important information about near and deep space. Another space telescope exists and collects its information in the infrared range. It is called the Spitzer Space Telescope and was launched into earth orbit in 2003. It has become extremely valuable for the collection of data of bodies within the Kuiper Belt.

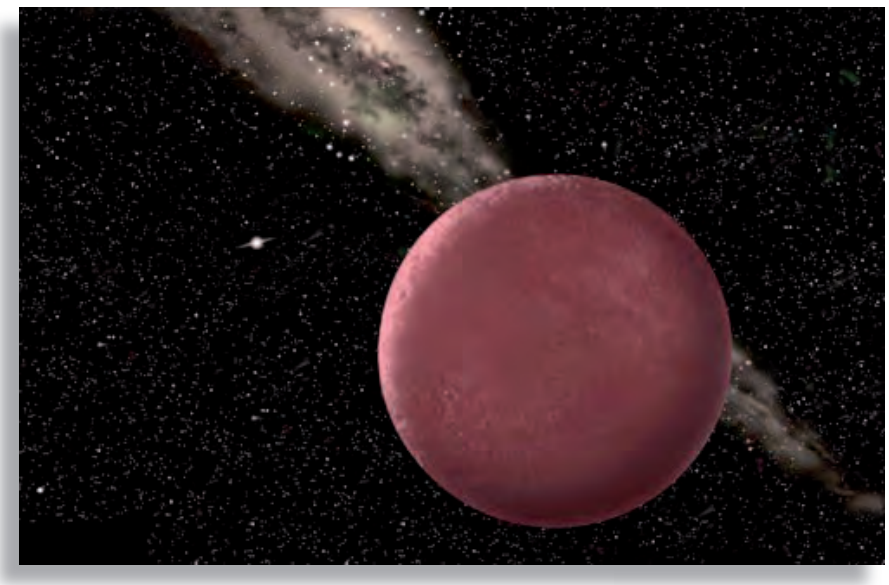


Artist's concept of Eris with the Sun far away in the distance.
(Courtesy NASA)

Another Mystery – The Tenth Planet

Scientist Michael Brown of the California Institute of Technology found what is believed to be the 10th planet in our solar system. The new body, designated 2003-UB 313, has been named Eris. This body has been classified as a dwarf and it has also been found to have a moon. This moon has been given the name Dysnomia.

Eris is approximately 1.5 times larger than Pluto and is located almost 10 billion miles from the Sun.



Bright red Sedna with the sun dimly seen in the distance.
(Courtesy NASA)

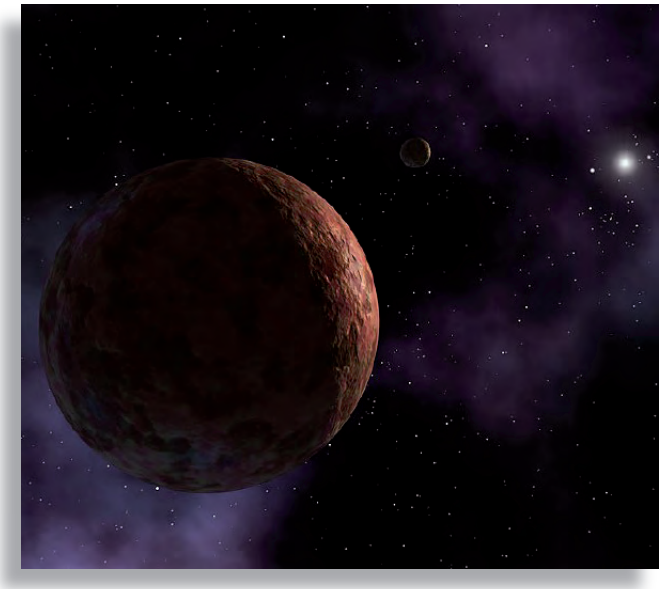
Michael Brown and Chad Trujillo of the Gemini Observatory and David Rabinowitz of Yale, used the Mt. Palomar Observatory near San Diego to photograph Eris on October 21, 2003. Another photograph, on January 8, 2005, spotted the planet. The astronomers calculated that it takes Eris 560 years to orbit the Sun. Approximately 280 years from this decade, it will be as close as the planet Neptune. Like Pluto, the surface is mostly made up of methane ice. Astronomer Trujillo made a spectrum analysis of the surface on January 25, 2005, and concluded that the surface had been in this state since the formation of the solar system. The planet's interior is most likely the same as Pluto's, i.e., rock and ice.

The Mystery Continues–The Discovery of Sedna

Located approximately 8 billion miles from Earth, approximately 84 billion miles from our sun, is yet another body that may someday be classified as either a dwarf or an actual planet. It is Sedna and is the most distant body yet recorded—it is an astounding 2.5 billion miles beyond Pluto. Sedna has a very unusual orbit that forms a long path about the Sun. Another astonishing fact is the body takes 10,500 years to make just one orbit around the sun.

Sedna has an unusual shiny red color. Astronomical calculations put the surface temperature at -400 degrees F. This means the temperature is just about 60 degrees away from being absolute zero (-459.69 degrees F). Scientists also found the size to be approximately 995 miles in diameter.

The name Sedna comes from the a mythical goddess of the sea. The connection comes from the story of how she was thrown into the icy Arctic waters by her father. Observations have concluded that the body Sedna is the coldest object in the solar system and that is how its name was connected to the mythical goddess.

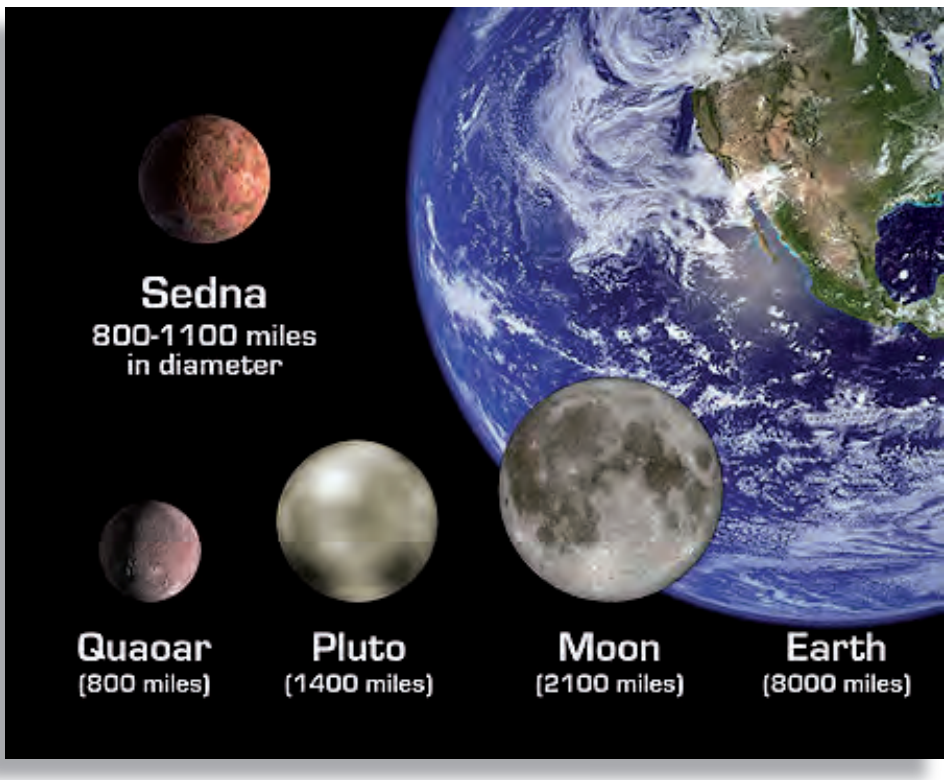


An Artist's Rendition Showing Sedna located in the Kuiper Belt.
(Courtesy of NASA)

The Mystery – Is There an Eleventh?

In the year 2002, astronomers Brown and Trujillo found yet another large body in the Kuiper Belt. They called it Quaoar (pronounced kwa war) a name taken from a Native American legend for their god of creation. The official designation is 2002LM60 and it resides at the edge of the Kuiper Belt in a field of icy bodies. The astronomers are not sure about the object, but they know it is a desolate, icy body that is larger than most asteroids with a diameter of approximately 800 miles.

Several other bodies have been discovered by the team of Brown, Trujillo and Rabinowitz. All totaled, more than 35 have been added to the "possibles." As the New Horizons approaches the Kuiper Belt and with extremely sophisticated optical equipment become available, there is no end to what they may find in and beyond the far reaching edge of our solar system.



An artist's rendition comparing the size of the Earth, Moon, Pluto, Sedna and Quaoar.
(Illustration Courtesy of NASA)

CREDIT: The source for much of the information in this section was provided by the outstanding web site, SPACE TODAY ONLINE.

Other Bodies

The Asteroids

Asteroids are rocky and metallic objects orbiting the sun, too small to be considered planets. Known as minor planets, they range in size from Ceres, with a diameter of about 623 miles, to the size of pebbles. Sixteen asteroids found in an area ranging from inside Earth's orbit to beyond Saturn's orbit are known to have a diameter of 150 miles or greater; however, the main belt of asteroids lies between the orbits of Mars and Jupiter.

Italian astronomer Guiseppe Piazi discovered the first asteroid in 1801. Since that time, more than 15,000 asteroids have been found and catalogued. Scientists speculate, however, that there are probably millions more asteroids in our solar system.

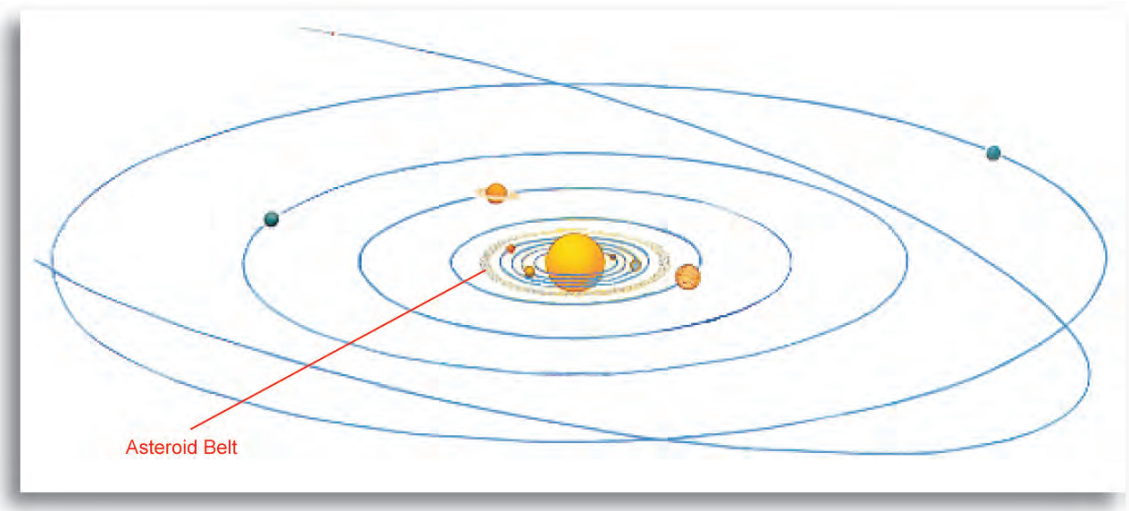
Asteroids are material left over from the formation of the solar system. There are several theories regarding their origin; one suggests that they are the remains of a planet that was destroyed in a massive collision during the formation of the solar system. More likely, they are materials that never coalesced into a planet. Scientists estimate that if the total mass of all asteroids was gathered together into a single object, the object would be less than 932 miles across—less than half the diameter of earth's moon.

Since asteroids are materials from the very early solar system, scientists are interested in their composition. Many of the asteroids have been studied through earth-based observations. Spacecraft that have flown through the asteroid belt have found that the asteroids are separated by very large distances. In October 1991, Gaspra was visited by the *Galileo* spacecraft, becoming the first asteroid to have high-resolution images taken of it. *Galileo* went on to a close encounter with Ida in 1993. Both Gaspra and Ida have been classified as S-type asteroids composed of metal-rich silicates. Photographs show them to be lumpy, potato-shaped rocks.

The Asteroid Gaspra

In 1997, the spacecraft *Near Earth Asteroid Rendezvous (NEAR)* made a high-speed, close encounter with the asteroid Mathilde, giving scientists their first close-up look of a carbon rich C-type asteroid. *NEAR* went on to an encounter with asteroid Eros in 1999 - 2000, discovering the existence of numerous boulders protruding above the surrounding surface. While some of these boulders are angular, others appear rounded, suggesting various origins or histories. Their non-uniform distribution seems not to correlate with any large craters or with gravitational laws on the asteroid.

Earth-based observation of the asteroids continues. In May 2000, scientists observed Kleopatra with the 1,000 foot telescope of the Arecibo Observatory. They collected the first-ever radar images of a main belt asteroid and discovered that Kleopatra was a metallic, dog bone-shaped rock the size of the state of New Jersey. Apparently a leftover from an ancient, violent cosmic collision, the scientists



theorize that Kleopatra is the remnant of an incredibly violent collision between two asteroids that did not completely shatter and disperse all the fragments. Radar observations indicated the surface of the asteroid is porous and loosely consolidated, much like the surface of earth's moon. Its interior arrangement and components are unknown. However, scientists believe its collision history to be extremely unusual.

Comets

A comet is a small, irregularly shaped body whose tiny nucleus is composed of water, ice, rock and frozen gases. Comets travel in highly elliptical orbits that take them very close to the Sun and swing them into deep space, often beyond the orbit of the planet Pluto. Comet structures are diverse, but all develop a coma (diffuse material surrounding the nucleus) that usually grows in size and brightness as the comet approaches the sun. Usually a small, bright nucleus will be visible in the middle of the coma; these two structures (the nucleus and the coma) form the head of the comet.

As a comet moves closer to the sun, it develops an enormous tail that can extend for millions of miles from the head, away from the sun. Far from the sun, the nucleus is cold and its material is frozen solid. It is this state that leads to comets being referred to as "dirty snowballs" since more than half of the material composing the comet is ice. But as the comet approaches the sun, the surface of the nucleus begins to warm and the volatiles evaporate.

The evaporated molecules boil off, carrying small solid particles with them. This is what forms the comet's coma of gas and dust. This cloud of dust and gas spreads out from the nucleus and reflects the sunlight. Thus a previously unnoticed, tiny speck suddenly becomes visible. As it continues to approach the sun, the stream of particles and radiation from the sun sweep the gas and dust away from the nucleus, forming a hazy head (the coma) and sometimes a tail as well. Some of the largest comets have had tails 100 million miles long—more than the distance from the sun to the earth.

Each time a comet visits the sun, it loses some of its volatiles. Eventually, it becomes just another rocky object in the solar system; therefore, comets are said to be short-lived, cosmologically speaking. Many scientists believe that some asteroids are comet nuclei that have lost all of their volatiles.

Comet West as Seen Above Table Mountain in California
(*NASA Courtesy of the Jet Propulsion Laboratory)*

English astronomer Sir Edmund Halley first suggested that comets were members of our solar system. After studying historical writings of sightings of bright objects in the sky, he predicted the appearance of a comet in 1758. When it appeared right on schedule, it proved his theory and the comet was named after him. Halley's Comet continues to make regular appearances in our skies; it last approached the sun in 1996 and will return in 2061.

Comets originate at the very edge of the solar system and are probably simply icy material mixed with dust that failed to come together to form true planets. The Oort Cloud is the source of long-period comets and possibly higher-inclination intermediate comets that were pulled into shorter period orbits by the planets, such as Halley and Swift-Tuttle. Comets can also shift their orbits as a result of jets of gas and dust that rocket from their icy surfaces as they approach the sun.

Although they can change their course, comets have initial orbits with widely different ranges. Long-period comets come from the Oort Cloud; Hyakutake and Hale-Bopp are two recent examples. The Oort Cloud itself is an immense spherical cloud surrounding the planetary system and extending approximately three light years from the sun. This distance is considered to be the edge of the sun's range of physical, gravitational, and dynamic influence.

The cloud structure is believed to be a relatively dense core that lies near the ecliptic plane and slowly replenishes the outer boundaries. One sixth of an estimated six trillion icy objects are in the outer region of the cloud; the remainder are found in the core. The total mass of the Oort Cloud is estimated

to be forty times that of earth. Scientists believe this matter originated at different distances (and thus at different temperatures) from the sun, thus explaining the compositional diversity in comets.

Many comets have probably slammed into the earth, causing widespread destruction (such as the extinction of the dinosaurs.) In 1994, Comet Shoemaker-Levy, broken up by Jupiter's massive gravity, impacted the planet. The *Galileo* spacecraft, about 150 million miles from the planet, recorded eight separate impact events. Preliminary spectroscopic data implies that the comet fragments did not penetrate very deeply into the planet — little or no water was splashed up into the stratosphere. Scientists presume that each comet fragment was vaporized in the impact and its constituent molecules were dissociated (broken apart) as was a considerable amount of the Jovian atmosphere along the explosion path.

Meteoroids

A Micrometeorite

Bits and clumps of matter orbit the sun and cross, or exist within, the path swept by cislunar space as the earth/moon system revolves around the sun. The very small, dust-particle size bits of matter are called **micrometeorites.** From this size upward, **meteoroid** is the name applied to clumps of matter in space.

Where do these meteoroids come from, and if they enter cislunar space what happens to them? No one is positive of the origin of meteoroids. The best evidence so far suggests they are parts of comets after the sun melted away some of the ice that bound them to the comet. Other meteoroids have a definite solar orbit because the earth/moon system keeps running into them on a very regular and frequent basis.

Then there are the random encounters with meteoroids, the origin of which can only be guessed. Those, which cannot be associated with the comet theory, may very well be parts left over from the formation of the earth, other planets or asteroids.

When a meteoroid is drawn toward earth by gravitational attraction or when the two bodies collide and the meteoroid enters the outer fringes of earth's atmosphere, the meteoroid becomes a **meteor.** Friction causes the body to heat and glow, and begin to disintegrate leaving a trail of luminous matter.

Meteor showers occur when a great many meteors are seen in the sky within a span of an hour. The distinctive fiery trail left in the sky by the meteor as it burns up in the atmosphere is the reason for meteors being referred to as "shooting stars." Typical meteor tracks look like a streak in the sky. They fade away almost as soon as they are made. The particle making the meteor generally is about the size of a pea. As it travels through earth's atmosphere it quickly heats up and crumbles, causing a flare of light. Larger meteors can cause spectacular glowing tracks that last for longer periods of time.

Meteorites are the matter that remains when debris does not burn up completely as it passes through the atmosphere and lands on the surface of the planet. Scientists believe that many meteorites hit the surface of our planet each year, but it is rare to actually see it happen. Most meteorites are basketball-size or smaller, but larger pieces can and do impact the surface of the earth. Some meteorites are small pieces of asteroid; others have proved to be material blasted off the surface of the moon following an impact on its surface. Other meteorites have been determined to originate on Mars.

The recent recovery of a carbonaceous chondrite meteorite from the Yukon has excited scientists

A Meteor Shower

who say that its very primitive composition and pristine condition may tell us what the initial materials were like that went into making up the earth, the moon and the sun. Only about two percent of meteorites are carbonaceous chondrites containing many forms of carbon and organics, the basic building blocks of life. This type of meteorite is easily broken down during entry into the earth's atmosphere and during weathering on the ground; therefore, recovery is quite rare.

A resident of the area over which the meteorite exploded retrieved fallen fragments from the snow-covered ground, placed them in clean plastic bags, and kept them frozen. They are the only freshly fallen meteorite fragments ever recovered and transferred to a laboratory without thawing. (Keeping the meteorite fragments frozen minimizes the potential loss of organic materials and other volatile compounds contained in the fragments.) The 4.5 billion-year-old meteorite may help scientists understand the original composition of the entire solar system before planets formed.

Periodically, earth encounters a swarm of meteoroids called the Perseids. The diameter of this swarm exceeds fifty million miles. However, the density of meteoroids is said to be only one for each million cubic miles. Yet when earth encounters the Perseids, the high-speed collision makes the meteor shower look as if the meteoroids are closely packed. This phenomenon, however, should not cause you to believe that cislunar space is crowded with meteors and other materials.

According to astronauts who have been there, space looks very much like the void it has been called. William Anders (Apollo 8) reported, "The sky is very, very stark. The sky is pitch black and the moon is quite light. The contrast between the sky and the moon is a vivid dark line."

The Milky Way and Beyond

On nights free of clouds and air pollution, the Milky Way is visible. This is the common name for the galaxy in which we live, along with about 100 billion other solar systems and stars.

The Milky Way galaxy is an enormous collection of stars arranged in a spiral shape. The Milky Way has a dense central bulge with four arms spiraling outward. The center of our galaxy contains older red and yellow stars, while the arms have mostly hot, younger blue stars.

Distance between the stars and/or solar systems varies and involves such high numbers of miles that the imagination is staggered. In this case, distance is thought of in light years and parsecs instead of astronomical units. A light year is the distance a photon can travel in one of earth's calendar years. This amounts to 5 trillion 878 billion-statute miles (5,878,000,000,000 miles). When the number of light years gets very large, parsecs are used; one parsec is 3.26 light years, or 19.2 trillion miles.

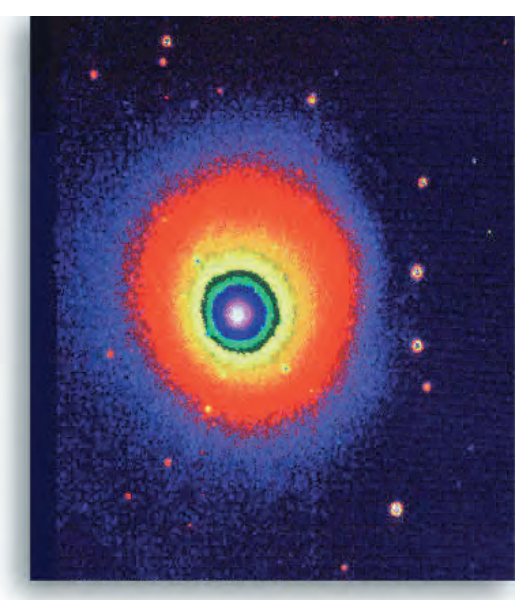
The Milky Way Galaxy

An extended halo of gas surrounding the Milky Way was generated by thousands of exploding stars as the galaxy evolved. Roughly football-shaped, this hot gas halo extends between five thousand and ten thousand light years above and below the galactic plain, thinning out with distance. Although the half-million-degree gas halo has been known for some time, scientists were not certain how it came to be there or remained hot.

Observations made with NASA's *Far Ultraviolet Spectroscopic Explorer (FUSE)* spacecraft revealed an extensive amount of oxygen VI in the halo. Oxygen six — oxygen atoms that have had five of their eight surrounding electrons stripped away — could only have been created through collision with the blast waves from exploding stars. Such star explosions are actually a record of star formation, and comparison of these supernovae-generated halos among galaxies may allow scientists to compare the star formation histories of the galaxies.

Nova and Supernova

Novas are stars that are not stable; they flare, subside and flare again. This type of existence has been observed just before the star "dies." It is not known if this is part of the normal life cycle of a star. A supernova occurs when a star gives up great mass in one giant explosion of light and energy.



Nova

Supernova

Supernovae are the source of the heavier elements in the universe. The last-known supernova in the Milky Way was in the 1700s and astronomers believe the next Milky Way supernova is overdue. Long-term supernova sequences obtained from SN1993J are helping astronomers understand supernovae in general as well as the remnants of ancient supernovae in our own galaxy. Detailed study of the stellar explosion twelve million light-years away showed a massive, morphing shock wave and provided scientists with a case study in the structure and evolution of the events in a stellar explosion.

Another supernova of particular interest to astronomers is SN1987A, located in a galaxy 169,000 light years away. A ring of gas believed to have been ejected by the star 20,000 years ago (long before the star exploded) surrounds the supernova. This gas ring is being impacted by a never-before-seen violent collision of the fastest moving debris from the stellar explosion, causing the gases in the ring to glow as they are heated to millions of degrees and compressed by the blow of the forty million miles-per-hour blast wave. In 1997, astronomers observed the first impact between the shock wave and the ring. It appeared as a single knot in the ring shining like a bright diamond. The *Hubble Space Telescope* has been used by astronomers in the monitoring of SN1987A since it was launched in 1990.

Quasars and the Formation of the Universe

Quasars, extremely luminous bodies, were much more prevalent in the early universe. In a volume roughly equivalent to our solar system, a quasar emits up to 10,000 times the energy of the entire Milky Way galaxy. Scientists believe quasars are fueled by gases such as remnants of stars spiraling into super massive black holes at the center of galaxies; black holes that eject enormous amounts of energy as they consume surrounding matter. A recently discovered quasar in the constellation Cetus is among the earliest known structures ever to form in the universe.

In images, quasars look very much like stars, but a spectral analysis of the light reveals the true nature of the quasar. The quasar's redshift measures how fast it is moving away from us as the universe expands, and it is a good indicator of cosmic distances. The faster it moves away, the more its light shifts toward the longer wavelengths in the red part of the spectrum. That means the faster an object appears to move, the farther away it actually is.

Light from the Cetus constellation quasar, with a redshift of 5.5, takes about 13 billion years to travel to earth. Thus the ancient quasar in the Cetus constellation, in existence at a time when the universe was less than eight percent of its current age, is one of the universe's first structures. High redshift quasars are extremely important to understanding how the universe developed. The young universe is believed to have begun in a hot, dense state shortly after the Big Bang. Matter was ionized (electrons were not bound to protons) and over time matter cooled enough for electrons and protons to combine and become neutral. The formation of the first stars and galaxies reheated matter between galaxies and created the ionized intergalactic medium of today's local universe.

As a quasar's light travels toward earth, the light is absorbed by any matter lying in its path. Clouds of neutral hydrogen absorb more than half of a quasar's light at high redshift in the early universe, a finding essential to the understanding how and when super massive black holes, quasars, and other structures condensed from large, high-density clouds of hydrogen soon after the Big Bang.

The Cetus constellation quasar will also help astronomers determine how matter was distributed at earlier stages of cosmic history. Since quasars are more luminous than distant galaxies at the same

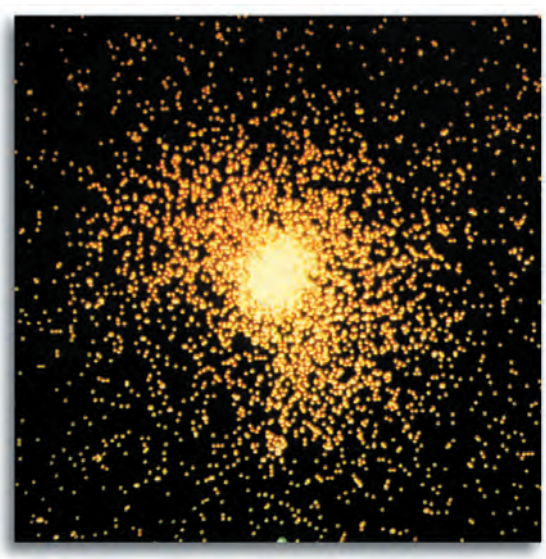
redshift, they allow astronomers to study everything that has ever developed between us and the quasar. Continuing missions such as the International Space Very Long Base Interferometry Space Observatory Program (Space VBLI), combine satellite- and earth-based radio antennas to create a telescope more than two-and-a-half times the diameter of the earth. This provides one of the sharpest views yet of the universe and the most detailed images of quasars ever seen.

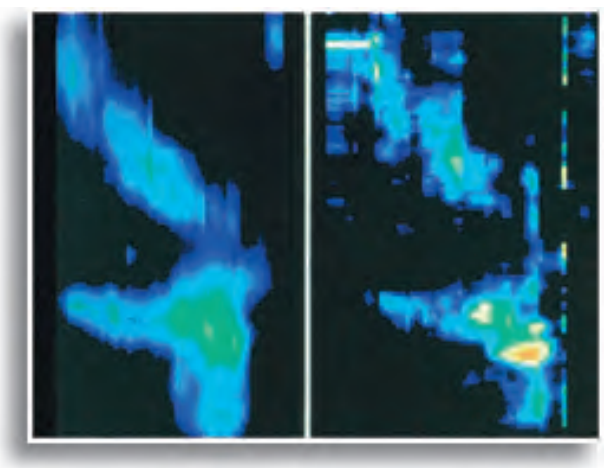
Common in galaxies and much more luminous and massive than our sun, tightly packed groups of hundreds to thousands of stars are known as star clusters. The Very Large Array (VLA) radio telescope has afforded astronomers a glimpse of what may be the youngest massive star clusters ever observed. Providing astronomers with a look inside the stellar nursery, massive star clusters estimated to be as young as 500,000 years and in their very earliest stages of development, are seen in their infancy. These observations may show astronomers the types of environments where globular clusters form.

For years, astronomers have searched for vast amounts of hydrogen that were cooked up in the Big Bang but somehow managed to disappear into space. The *Hubble Space Telescope* uncovered the long-sought hydrogen, which accounts for nearly half of all the "normal" matter in the universe, while the remainder is locked up in myriad galaxies. Astronomers believe that at least ninety percent of the matter in the universe is in dark form and has not yet been seen directly.

Pulsar

A pulsar is also known as a pulsating star because it flashes electromagnetic emissions (radio or other waves) in a set pattern. The astronomers who first discovered a pulsar first thought earth was being sent signals from intelligent life in another solar system. Today astronomers believe the phenomenon occurs in a manner similar to that in the pictures below. The body's magnetic poles are located at its equator. Its magnetic field keeps powerful radiation from escaping except at the holes created at each of the magnetic poles. As the star rotates about its axis, electromagnetic emissions stream out from the holes like the beams of light from a double-light beacon.





Pulsars

Hundreds of pulsars, found in supernovae nebulae, are now known. After a supernova explosion, stars more than 1.4 times the size of our sun leave behind a large core of solid iron. The absence of fusion reactions allows the core of the star to collapse and presses the remaining star matter into a smaller space where it continues to degenerate until only neutrons remain. The result is a dense neutron star, about twenty miles across, in which matter is extremely dense (one centimeter of matter would weigh one billion tons).

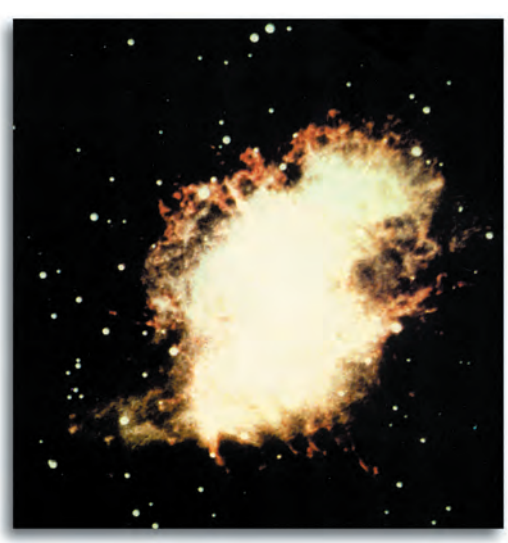
Spinning neutron stars have an axis of rotation that does not coincide with the axis of the magnetic field of the star. This causes its radio beams to sweep across the sky and deliver short pulses of radio waves to any receiver in its path.

Nebulae

Nebula is the Latin word for cloud and there are many dark and bright nebulae within our own galaxy, the Milky Way. The dark nebulae simply are vast clouds of matter which have not yet formed into stars. The bright nebulae may be studded with stars, and thus, send forth brilliant arrays of color. Some bright nebulae are the remnants of supernova; one such example is the Crab Nebula seen below left. Perhaps the best example of a dark nebula is also shown below right.

Several types of nebulae exist within the universe. In dark nebulae, both visible and ultraviolet light are almost totally absorbed by dust within the nebula itself, making the nebula appear as a dark smudge against the background. The dust within reflection nebulae reflects and scatters sufficient starlight to make the nebula visible and causes it to glow faintly. The most visible nebulae, emission or glowing nebulae, are three-fourths hydrogen (and nearly all the rest helium) heated by ultraviolet radiation from nearby hot stars; energy is re-emitted in the form of visible light.

After a star has evolved into a red giant, it enters a brief phase in which the outer layers are blown off. Eventually these layers become visible as a thin shell of gas around the star. Early astronomers



The Crab Nubula

The Horsehead Nebula in Orion

observed that some of these shells of gas were the shape and color of the planets Uranus and Neptune, and so called them planetary nebulae. The nebulae, however, have nothing to do with planets. Many, but not all, nebulae are the places where stars are born.

Formed out of gas clouds, stars are large gaseous balls of hydrogen and helium along with a few other elements. As gravity pulls the star's materials inward, the pressure of it's hot gas drives it outward, resulting in an equilibrium that exists in all main sequence stars. Deep in the core, hydrogen atoms fuse together to create helium, a process that continues for billions of years as the star exists in the prime of its life.

Black Holes

A black hole probably began as a large star that exhausted its nuclear fuel and collapsed inward upon itself. The theory is that if gravitational force builds at the proper rate, the force itself keeps an explosion from occurring. So much matter is compressed into such small volumes that everything is together and nothing is allowed to leave because the resulting gravity is so strong. There are no x-rays, ultraviolet rays, radio waves, or visible light–nothing is coming from this dense body. If it can't emit some type of radiation, it is known as a black hole.

Mounting circumstantial evidence suggests black holes occupy the center of most galaxies and astronomers have used the *Hubble Space Telescope* and innovative imaging techniques to investigate swirling masses of interstellar dust believed to feed super massive black holes as it spirals into the center of nearby galaxies.

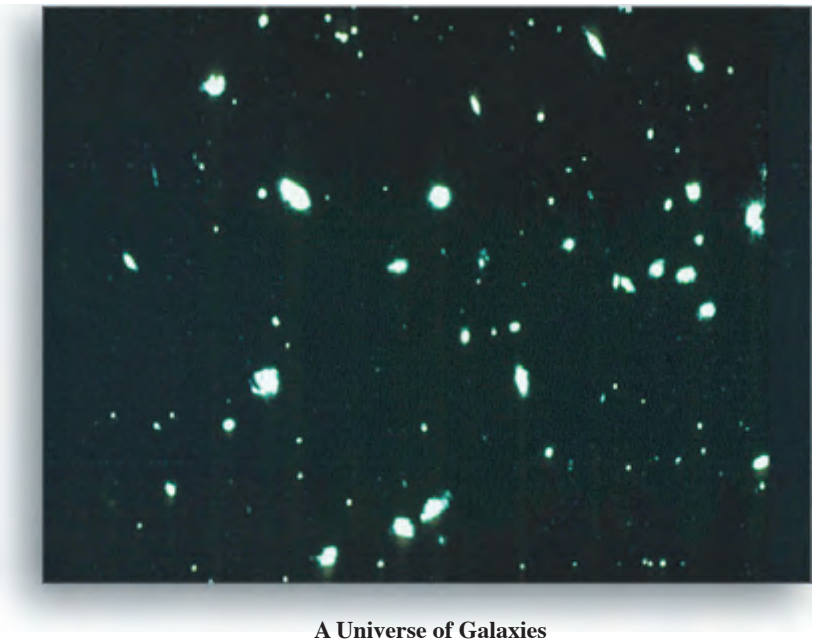
Black Hole

Black holes are considered active when their powerful gravity tears material apart, releasing radiation and brightening the galaxy's center. Only about one percent of galaxies that should contain super massive black holes appear to be in an active state. Astronomers calculate that black holes must consume stars, gas, or dust in amounts up to the mass of our sun every year to remain active.

Some astronomers and scientists doubt that these mystery stars even exist. If energy cannot escape from a black hole, how is one detected? Astronomers can detect gaseous matter being pulled into a black hole from a nearby star. Just before the matter disappears, it sends out strong bursts of x-rays that can be measured.

Black holes are perplexing to scientists because everything about them must be guessed. Anything sent to investigate could not send its messages back to earth because the black hole would absorb the radio transmissions.

Other Galaxies



A Universe of Galaxies

Beyond our system of stars or galaxy, there seems to be an endless number of other galaxies. Each time our scientists develop techniques of seeing farther into space, they find other galaxies beyond the range limit of previous instruments.

Even the galaxy-to-galaxy relationship is in motion. In general, all of these individual galaxies and groups of galaxies seem to be moving away from each other. This movement also seems to be moving away from a common point. However, when the movement began is not certain, and the outermost extent of this expanding universe is not yet known. At one time, the edge was thought to be 14 billion light-years out, but where it really is and how it all started are two things about which scientists can only speculate and theorize.

According to astronomer Douglas Richstone, "The formation and evolution of galaxies are intimately connected to the presence of a central massive black hole. Radiation and high-energy particles released by the formation and growth of black holes are the dominant sources of heat and kinetic energy for star-forming gas in protogalaxies."

Researchers have noted that nearly all galaxies with spheroidal distributions of stars (that is, bulges in spirals) seem to have massive black holes that appear to correlate with the mass of the central part of the host galaxy, pointing to a connection between the massive black hole and the galaxy. Additionally, comparisons of the history of star formation in the universe with the history of quasars reveals that quasars developed well before most star formation in galaxies. Astronomers believe the massive black holes now seen in the centers of galaxies are relics of these quasars, indicating that the black holes must have been present at the height of the quasar epoch when the universe was about one billion years old.

Astronomers theorize that as galaxies formed in the early universe, powerful gravitational attraction pulled huge amounts of gas together at their center to create a black hole. Gas and any close stars were sucked in and converted to gas in the process. As the gas swirled into the black hole in a huge vortex, it became hotter and hotter and glowed more and more brightly. Just before plunging into oblivion,

it became a quasar, emitting a burst of radiation, including massive flashes of x-ray and ultraviolet radiation.

Although the universe is still expanding, the combined gravity of its dark matter may be sufficient to halt the expansion. If this happens, then gravity may pull all the galaxies together again in a massive Big Crunch. The more we explore, the more we discover we have yet to learn.

Key Terms and Concepts

- moon
- crater
- rille
- moon dust
- moon rocks
- basalt
- anorthosite
- KREEP
- Mars
- *Mariner* and *Viking* probes
- asteroids
- Jupiter
- Saturn
- Uranus
- Neptune
- Pluto
- *Pioneer* and *Voyager* probes
- comets
- galaxy
- Milky Way
- interstellar space vs. intragalactic space
- nova and supernova
- pulsar
- black hole
- nebulae
- Hubble Space Telescope
- Eris, Sedna and Quaoar
- Rovers Opportunity and Spirit

? Test Your Knowledge ?

MATCHING

1. *older than rocks on the earth*
2. *found mainly on the moon's plains*
3. *composed mostly of feldspar*
4. *abundant on the moon; rare on earth*
5. *can't find on earth*
6. *three new minerals discovered*
7. *makes up the highlands of the moon*

a. lunar rocks
b. anorthosite
c. basalt
d. pyroxferroite
e. natural glass
f. armalcolite
g. KREEP
h. tranquillityite

MATCHING

8. *means starlike*
9. *first to be discovered*
10. *small, irregular shaped body composed of water, ice, rock and frozen gases*

a. comet
b. asteroids
c. Ceres

MATCHING

11. *refers to the space within galaxies*
12. *unstable stars; their action makes them appear to be winking*
13. *exploding star*
14. *flashes electromagnetic emissions*
15. *the ultimate star, which cannot radiate anything*
16. *clouds of matter not yet stars*
17. *a spiral-shaped galaxy of which the earth is a part*

a. black hole
b. intragalactic space
c. nebulae
d. supernova
e. nova
f. pulsar
g. the Milky Way

FILL IN THE BLANKS

18. *It takes _____ days for the moon to _____ the earth.*
19. *Since the moon is less dense than the earth, its _____ is only one-sixth that of earth's.*
20. *Day and night on the moon can have a difference of _____ °F.*
21. *From earth we see only _____ side of the moon and it's always the _____ side.*
22. *Besides having mountains, plains, and craters, the moon has _____, which are long irregular depressions.*
23. *The Martian day is _____ to a day on earth.*
24. *The reddish areas on Mars were thought to be _____.*
25. Mariner *4 took the first _____ of another planet.*

MULTIPLE CHOICE

26. *Saturn's rings contain mostly*
    - *a. rock.*
    - *b. gases.*
    - *c. ice.*
    - *d. a and c above.*

27. *The exact number of Saturn moons is*
    a. *17*
    b *15*
    c. *11*
    d. *we're still not sure*
28. *The orbits of most comets are*
    a. *erratic.*
    b. *circular.*
    c. *consistent.*
    d. *none of these.*
29. *Comets have been observed*
    a. *since 1910.*
    b. *only recently.*
    c. *since ancient times.*
    d. *in the last 200 years.*
30. *The comet's tail forms as it nears*
    a. *the sun.*
    b. *the moon.*
    c. *the earth.*
    d. *Uranus.*

TRUE OR FALSE

31. Vikings *1 and 2 consisted of orbiters and landers.*
32. *The existence of water was found in liquid form on Mars.*
33. *The highest content of surface material on Mars is silicon and iron.*
34. *Iron provides the red color of the Martian landscape.*
35. *By virtue of its size, Jupiter makes up about 70 percent of the mass of all the planets.*
36. *Due to its size, Jupiter rotates very slowly.*
37. *Of all the planets, Jupiter has the most intense radiation belts.*
38. *Nine rings encircle Uranus.*
39. *Neptune and Uranus are very similar.*
40. *In 2004, two rovers landed on Mars; their names are Spirit and Faith.*
41. *Some scientists have reclassified Pluto as a dwarf planet.*
42. *The Kuiper Belt is a ring of celestial bodies that exists billions of miles beyond the orbit of Neptune.*