

University Learning in Schools

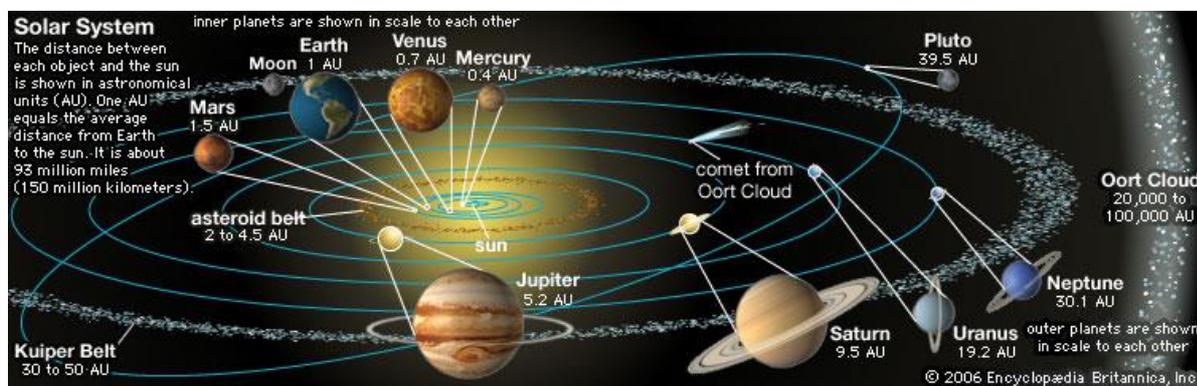
Physics

Exoplanet: Explore Activity

Lesson 2



Introduction



[Encyclopædia Britannica, Inc.](#)

As the [Sun](#) rushes through space at a speed of roughly 150 miles (240 kilometers) per second, it takes many smaller objects along with it. These include the [planets](#) and [dwarf planets](#); their moons; and small bodies such as [asteroids](#), [comets](#), and [meteoroids](#). All these objects orbit, or revolve around, the Sun. Together, the Sun and all its smaller companions are known as the solar system. The solar system itself orbits the center of the [Milky Way galaxy](#), completing one revolution about every 225 million years.

Earth is one of the larger bodies of the solar system. It is quite small, however, compared to the Sun or the planet Jupiter, which are the largest members of the solar system. The solar system's smallest members are the microscopic particles of dust and the even smaller atoms and molecules of gas of the interplanetary medium. This dust and gas is very thinly scattered in the huge expanses between the planets and other bodies in the solar system. (See also [the solar system at a glance](#).)

The Solar System in Space

Astronomers do not know exactly how far out the solar system extends. Earth orbits the Sun at an average distance of about 93 million miles (150 million kilometers).

Astronomers use this distance as a basic unit of length in describing the vast distances of the solar system. One astronomical unit (AU) is defined as the average distance between Earth and the Sun.

There are eight planets in the solar system. Neptune, the outermost planet, orbits the Sun from about 30 AU, or 2.8 billion miles (4.5 billion kilometers), away. Many comets have orbits that take them thousands of times farther out than Neptune. Most comets are thought to originate in the outermost parts of the solar system, the Kuiper belt and the much more distant Oort cloud. Each of these consists of countless small icy bodies that orbit the Sun. The farthest reaches of the Oort cloud extend perhaps to 100,000 AU, or some 9.3 trillion miles (15 trillion kilometers), from the Sun.



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The solar system is, of course, not alone in space. The Sun is a [star](#) like countless others, and other stars also have [planets circling them](#). The Sun is part of the Milky Way galaxy, a huge group of stars swirling around in a pinwheel shape. The galaxy contains hundreds of billions of stars. To

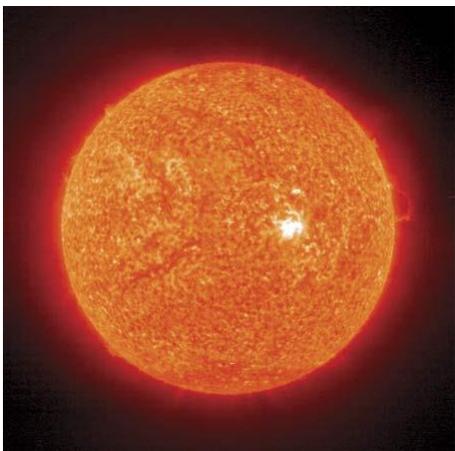
measure the enormous distances in space, astronomers often use the light-year as a unit of length. One light-year is equal to the distance light travels in a vacuum in one year, about 5.88 trillion miles (9.46 trillion kilometers). The Milky Way galaxy is roughly 150,000 light-years across. The Sun's nearest neighbor in the galaxy is the star Proxima Centauri (part of the triple-star system named [Alpha Centauri](#)). This stellar "neighbor" lies some 4.2 light-years, or more than 25 million miles (40 trillion kilometers), away from the Sun. Outside the Milky Way galaxy there are billions more galaxies stretching out through space. Astronomers cannot see to the end of the universe, but they have detected galaxies and other objects that are several billion light-years away from the Sun. Compared with such distances, the space that the solar system occupies seems tiny.

Parts of the Solar System

The Sun is the central and dominant member of the solar system. Its [gravitational](#) force holds the other members in orbit and governs their motions. The largest members of the solar system after the Sun are the planets and the dwarf planets and their moons. The other natural bodies in the solar system are called small bodies. They include asteroids, meteoroids, comets, and the billions of icy objects in the Kuiper belt and Oort cloud. The small bodies and the smaller moons can be quite irregularly shaped. The planets, the dwarf planets, and the larger moons are nearly spherical in shape. They are large enough so that their own gravity squeezes them into about the shape of a ball. The shapes of the planets and dwarf planets that rotate especially rapidly are distorted to various degrees. Instead of being perfect spheres, such bodies have some flattening at the poles, which makes them appear squashed.

Most objects in the solar system have elliptical, or oval-shaped, orbits around the Sun. These objects include the planets, dwarf planets, asteroids, comets, and Kuiper belt objects. The planets orbit the Sun in nearly circular orbits, while the small bodies tend to have much more eccentric, or elongated, orbits. The planets also orbit in very nearly the same plane, that of the Sun's equator. The small bodies again differ, generally orbiting in planes that are more inclined, or tilted, relative to the plane of the Sun's equator. Comets whose orbits take them very far from the Sun tend to have especially eccentric and inclined orbits.

Many of those comets also orbit in a different direction than most other objects in the solar system. The Sun rotates in a counterclockwise direction as viewed from a vantage



point above Earth's North Pole. All the planets, dwarf planets, asteroids, and Kuiper belt objects and many comets orbit the Sun in the same direction that the Sun rotates. This is called prograde, or direct, motion. The comets with large orbits and the icy bodies of the Oort cloud are thought to be distributed randomly in all directions of the sky. Many of these objects orbit the Sun in retrograde motion, or the direction opposite to that of the Sun's rotation.

The Sun

The Sun far outweighs all other components of the solar system combined. In fact, the Sun contains more than 99 percent of the mass of the entire solar system. Nevertheless, the Sun is a fairly average-sized star. From Earth it looks so much larger and brighter than other stars only because it is so much nearer to Earth than any other star. If the Sun were much farther away, it would look pretty much like many other stars in the night sky. But if this were so, life as we know it could not exist on Earth. The Sun provides nearly all the heat, light, and other forms of [energy](#) necessary for life on Earth. In fact, the Sun provides the great majority of the energy of the solar system. (See also [Sun](#).)

The Planets and Dwarf Planets

The largest and most massive members of the solar system after the Sun are the planets. Even so, their combined mass is less than 0.2 percent of the total mass of the solar system, and Jupiter accounts for a very large share of that percentage. From nearest to farthest from the Sun, the eight planets are [Mercury](#), [Venus](#), [Earth](#), [Mars](#), [Jupiter](#), [Saturn](#), [Uranus](#), and [Neptune](#). [Pluto](#) had been considered the solar system's ninth planet from the time of its discovery in 1930 until 2006, when the International Astronomical Union (the organization that approves the names of astronomical objects for the scientific community) changed its designation. The organization created a new category of object called [dwarf planet](#) and made Pluto, [Eris](#), and Ceres the first members of the group. Pluto and Eris are also considered Kuiper belt objects, and Ceres is also the largest [asteroid](#). As their name suggests, dwarf planets are similar to the eight major planets but are smaller. (For a fuller discussion of the reclassification of Pluto and of the definitions of "planet" and "dwarf planet," see [planet](#).)

The eight planets can be divided into two groups, the inner planets and the outer planets, according to their nearness to the Sun and their physical properties. The four inner planets—Mercury, Venus, Earth, and Mars—are composed mostly of silicate rock and iron and other metals in varying proportions. They all have solid surfaces and are more than three times as dense as water. These rocky planets are also known as the terrestrial, or Earth-like, planets.

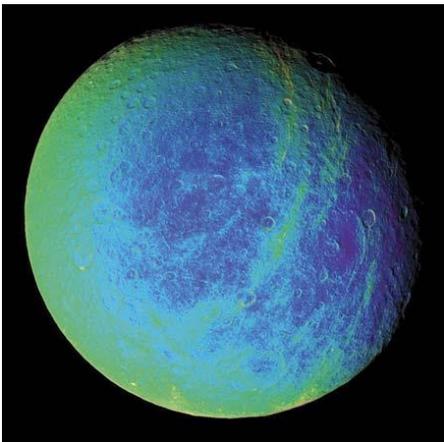
In sharp contrast, the four outer planets—Jupiter, Saturn, Uranus, and Neptune—have no solid surfaces. Jupiter and Saturn consist mainly of liquid and gaseous hydrogen and helium; Uranus and Neptune have melted ices and molten rock as well as hydrogen and helium. All the outer planets are less than twice as dense as water. In fact, Saturn’s density is so low that it would float if put in water. The outer planets are also much larger than the inner planets, and they have deep gaseous atmospheres. Because of this, these planets are sometimes nicknamed the gas giants. Since Jupiter is the outstanding representative of this group, the four outer planets are also known as the Jovian, or Jupiter-like, planets.

The eight planets are not distributed evenly in space. The four inner planets are much closer to each other than the four outer planets are to one another.



Moons and Rings

Six of the eight planets have smaller bodies—their natural satellites, or moons—circling them. All the outer planets have numerous moons: Jupiter and Saturn have more than 60 known moons each, Uranus has more than 25, and Neptune has more than 10. The inner planets have few or none: Mars has two moons, Earth of course has [only one](#), and Venus and Mercury lack moons. Many asteroids and Kuiper belt objects, including the dwarf planets Pluto, Eris, and Haumea, also have moons.



The largest natural satellite in the solar system is Jupiter's moon Ganymede. Next in size are Saturn's moon Titan, Jupiter's Callisto and Io, Earth's Moon, and Jupiter's Europa. Both Ganymede and Titan are larger than the planet Mercury. Earth's Moon is so large with respect to Earth that the two bodies have sometimes been considered a double-planet system. The solar system's smallest moons, most of which orbit Jupiter and Saturn, are only a few miles in diameter.

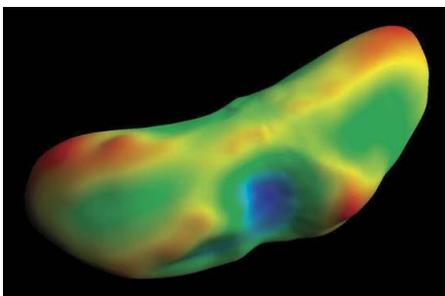
Most of the solar system's larger moons, including Earth's, orbit their planet in the same direction in which the planets orbit the Sun. A notable exception is Triton, which is Neptune's largest moon. It orbits in retrograde motion, as do many of the small, outer moons of the gas giants. Most of the solar system's moons also orbit their planet in the plane of the planet's equator. Again, Triton and many of the small, outer moons of the outer planets are exceptions, having highly inclined orbits. Moons that orbit in retrograde motion or that have inclined orbits or both are called irregular moons.

Saturn's spectacular rings are well known, but all the other outer planets also have systems of thin, flat rings. Each of the rings is composed of countless small pieces of matter orbiting the planet like tiny satellites. None of the inner planets has rings. (See also [planet](#); [dwarf planet](#).)



Asteroids

[Photo NASA/JPL/Caltech](#)



Numerous rocky small bodies are called asteroids or minor planets. Their orbits lie, for the most part, in a doughnut-shaped zone between the orbits of Mars and Jupiter. This zone is known as the main asteroid belt. The asteroids are not distributed evenly in the main belt. Rather there are several gaps in their orbits, owing to the influence of Jupiter's gravitational force. The asteroids outside the main belt include the near-Earth asteroids, which come within at least about 28 million miles (45 million kilometers) of Earth's orbit. The orbits of some of these asteroids even cross Earth's orbit. Ceres is the largest asteroid, with a diameter of roughly 585 miles (940 kilometers). The asteroids Pallas and Vesta each have a diameter greater than 300 miles (485 kilometers). Few asteroids, however, are larger than 100 miles (160 kilometers) across, and the numbers of

asteroids increase dramatically at smaller sizes. It is estimated that millions of asteroids of boulder size exist in the solar system.

Astronomers think that the asteroids are chunks of material left over from the process that created the inner planets. The huge pull of Jupiter's gravity prevented these rocky chunks from clumping together into a large planet. Many of the smaller asteroids are thought to be fragments caused by collisions between the larger asteroids. Some of these fragments collide with Earth as [meteorites](#).

The three main types of asteroids seem to be rich in organic compounds, stony materials, and iron and other metals, respectively. Some asteroids are thought to contain samples of the first materials to coalesce out of the great cloud of gas and dust from which the solar system itself is believed to have formed. (See also [asteroid](#).)

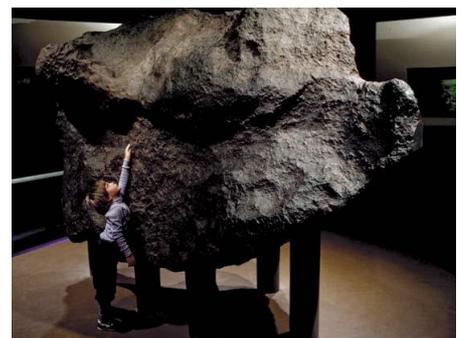
Meteoroids

[Jonathan Blair/Corbis](#)

Meteoroids are small chunks of rock, metal, or other material in interplanetary space. The vast majority of meteoroids are small fragments of asteroids. Other meteoroids are fragments from the Moon or Mars, while some may be rocky debris shed by comets.

[D. Nunuk/Photo Researchers, Inc.](#)

When a meteoroid collides with Earth's [atmosphere](#), it is usually vaporized by heat from friction with the air



molecules. The bright streak of light that occurs while the particle vaporizes is called a meteor. Occasionally, a large chunk of rock and metal survives the journey to the ground. Such remnants are called meteorites. Meteorites have also been identified on Mars, and pieces of meteorites were found in rock samples collected by astronauts on the Moon. (See also [meteor and meteorite](#).)



Comets, the Kuiper Belt, and the Oort Cloud

[NASA/Space Telescope Science Institute](#)

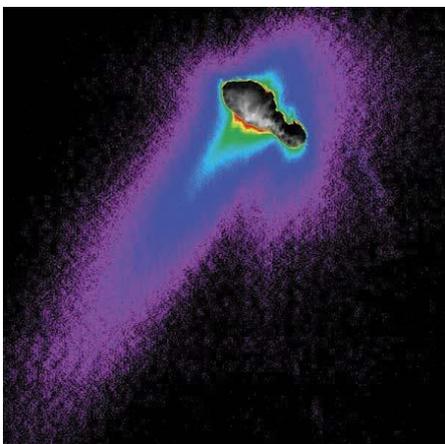
At times, a fuzzy spot of light, perhaps with a tail streaming away from it, appears in the sky. Such appearances of the small icy bodies called comets are spectacular but infrequent. Comets are only easily visible from Earth when they pass close to the Sun. Most comets that are detected from Earth are visible only with a telescope. Occasionally, one can be seen with the unaided eye, and several times a century a comet will

appear that can be seen even in the daytime.

[NASA/JPL](#)



Just as the asteroids are the rocky remnants of the process that formed the inner planets, the comets are thought to be leftover icy material from the formation of the outermost planets, Uranus and Neptune. Comets contain particles of rock dust and organic compounds, water ice, and ices of various substances that are normally gases on Earth. As a comet approaches the Sun, the ices turn to vapor, forming a hazy, gaseous atmosphere, or coma, around a core of solid particles, the nucleus. As the comet moves even closer to the Sun, even more material is vaporized. Radiation and high-energy particles streaming out from the Sun may push material away from the comet into one or more long, glowing tails, which point generally away from the Sun. A comet may disintegrate completely, ending up as a swarm of tiny particles, or continues along its orbital path. As a comet moves away from the Sun, it loses its coma and tail. The only permanent part of the comet is its solid nucleus. Eventually, it may end up as a dormant, or dead, comet, after all its ices have vaporized away from near its surface. Dormant comets resemble asteroids.



A comet may exist as a nucleus for thousands of years or more in the cold outer reaches of the solar system before its orbit takes it near the Sun again. The billions of distant icy objects in the Kuiper belt and the Oort cloud are, in fact, comet nuclei. These objects are thought to have orbited as nuclei for eons, without ever having approached the Sun. Sometimes the orbit of one of the objects in the Kuiper belt or the Oort cloud is disturbed by the gravity of another body so that the object is sent on a path that takes it closer to the Sun. This process is thought to be the source of most comets. For instance, one way the orbits of Oort cloud objects might be altered is by the gravity of passing stars.

The Kuiper belt and the Oort cloud, then, can be considered vast reservoirs of comets. The Kuiper belt is a doughnut-shaped zone of several millions of comet nuclei. They orbit the Sun from beyond the orbit of Neptune, mainly between about 30 and 50 AU from the Sun. The region for the most part lies fairly close to the plane of the Sun's equator (the plane in which the planets orbit). Some Kuiper belt objects have almost circular orbits that



fall near this plane. Others have very elongated, highly inclined orbits. Among the latter group are Eris and Pluto, the largest known members of the Kuiper belt.

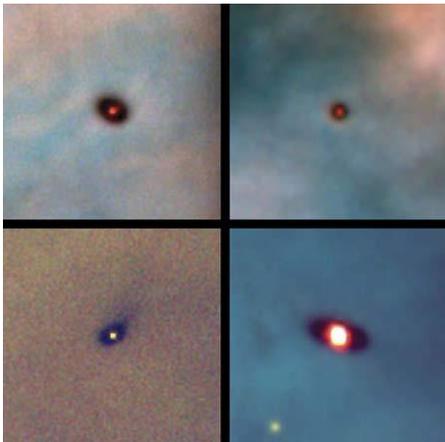
The Kuiper belt is thought to be the source of most of the short-period comets, or those that complete an orbit around the Sun in less than 200 years, and especially those that take less than 20 years to circle the Sun once. The comet nuclei called Centaur objects are also believed to have originated in the Kuiper belt. This group of icy objects is found mainly between the orbits of the outer planets, or about 5 to 30 AU from the Sun.

Most of the long-period comets, those that take more than 200 years to orbit the Sun, are thought to come from the Oort cloud. Most of these comets have very long orbital periods, with some taking many millions of years to circle the Sun once. The Oort cloud lies much farther from the Sun than the Kuiper belt does, extending from perhaps 20,000 to 100,000 AU from the Sun. It is not a flat ring but a roughly spherical shell of probably many billions of icy small bodies orbiting in all directions.

In the middle of the 20th century, astronomers first postulated that the Kuiper belt and the Oort cloud must exist. However, because of their great distance from Earth, Kuiper belt objects were not directly detected until the 1990s, when sensitive enough light detectors and telescopes became available. The first object in the belt to be detected was discovered in 1992, and many more large objects have since been found. (Astronomers did not begin to consider Pluto a Kuiper belt object until several other similar objects were found in the belt.) However, none of the much more distant small bodies in the Oort cloud has been seen directly. (See also [comet](#); [astronomy](#), "[Comets, the Oort Cloud, and the Kuiper Belt](#).)

Interplanetary Medium

In the spaces between the planets and other bodies lie vast stretches of extremely thinly distributed matter called the interplanetary medium. The matter includes tiny particles called interplanetary dust or micrometeorites, along with electrically charged particles, tiny amounts of hydrogen gas, and cosmic rays.



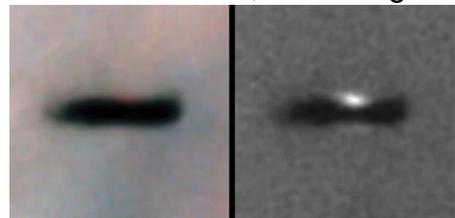
The relatively small amounts of interplanetary dust appear to be orbiting the Sun in a disk that extends throughout the solar system in or near the plane of the planets' orbit. On a clear night a faint glow is visible in the sky along the line of the zodiac, following the setting Sun or preceding the rising Sun. This glow can be almost as bright as the Milky Way. It is caused by sunlight reflected by the interplanetary dust.

Astronomers estimate that about 30,000 tons of the dust enter Earth's upper atmosphere each year.

Spacecraft have detected such dust particles in space nearly as far as the orbit of Uranus. Most of the interplanetary dust is thought to come from the collisions of asteroids and from comets, which lose matter when they approach the Sun.

[NASA/Johnson Space Center/Earth Sciences and Image Analysis Laboratory](http://www.nasa.gov/jsc/esa/earth_sciences/image_analysis_laboratory)

The Sun itself contributes much material to the vast spaces between the planets and other bodies. Along with the radiation that continuously leaves its surface, the Sun gives off a stream of electrically charged particles—mostly electrons and protons (plasma). This flow of particles is the solar wind. The solar wind spreads beyond the planets to the heliopause, which is the boundary between the interplanetary medium and the interstellar medium, the diffuse matter between the stars.



The part of the solar wind that encounters Earth causes the [auroras](#), or the northern and southern lights. The solar wind causes auroras on other planets, too. The interplanetary medium also includes cosmic rays, which are high-speed, high-energy particles (nuclei and electrons). Some of the cosmic rays come from the Sun, but most originate outside the solar system. (See also [Sun](#).)

Formation and Future of the Solar System

Astronomers believe that the solar system formed as a by-product of the formation of the Sun itself some 4.6 billion years ago. According to the prevailing theory, the Sun and its many satellites condensed out of the solar nebula, a huge interstellar cloud of gas and dust. The solar system began forming when the gravity of this interstellar cloud caused the cloud to start contracting and slowly spinning. This could have been caused by random fluctuations in the density of the cloud or by an external disturbance, such as the shock wave from an exploding star.

As the interstellar cloud squeezed inward, more and more matter became packed into the center, which became the protosun (the material that later developed into the Sun). The contraction caused the cloud to spin faster and faster and to flatten into a disk.

Eventually, the center of the cloud collapsed so much that it became dense enough and hot enough for nuclear reactions to begin, and the Sun was born.

Meanwhile, away from the center the gas and dust in the spinning disk cooled. Solid grains of silicates and other minerals, the basis of rocks, condensed out of the gaseous material in the disk. Farther from the center, where temperatures were lower, ices of water, methane, ammonia, and other gases began to form. The spinning material in the disk collided and began to stick together, forming larger and larger objects. Ultimately, some of the clumped-together objects grew huge and developed into planets. The inner planets formed mostly from chunks of silicate rock and metal, while the outer planets developed mainly from ices. Smaller chunks of matter and debris that did not get incorporated into the planets became asteroids, in the inner part of the solar nebula, and comet nuclei, in the outer part of the nebula. At some point after matter in the nebula had condensed and clumped into objects, the intensity of the solar wind seems to have suddenly increased. This blew much of the rest of gas and dust off into space.

This general formation process is thought not to be unique to the solar system but rather to be how stars and planets throughout the universe develop. Astronomers have detected disks of matter surrounding newly formed stars.

The future of the solar system probably depends on the behavior of the Sun. If current theories of stellar evolution are correct, the Sun will have much the same size and temperature for about 5 billion more years. By then, all of the hydrogen in its core will have been used up. Other nuclear reactions will begin in a shell around the core. Then the Sun will grow much brighter and larger, turning into a red giant and expanding beyond the orbit of Venus, perhaps even engulfing Earth. Much later, when all its nuclear energy sources are exhausted, the Sun will cool down, evolving into a white dwarf star. Around it will orbit the remaining planets. They will have turned into frozen chunks, orbiting their shrunken star. (See also [cosmology](#).)