

Solar System

The Solar System is the gravitationally bound system of the Sun and the objects that orbit it, either directly or indirectly. Of the objects that orbit the Sun directly, the largest are the eight planets, with the remainder being smaller objects, the dwarf planets and small Solar System bodies. Of the objects that orbit the Sun indirectly—the moons—two are larger than the smallest planet, Mercury.

Solar System formed 4.6 billion years ago from the gravitational collapse of a giant interstellar molecular cloud. The vast majority of the system's mass is in the Sun, with the majority of the remaining mass contained in Jupiter. The four smaller inner planets, Mercury, Venus, Earth and Mars, are terrestrial planets, being primarily composed of rock and metal. The four outer planets are giant planets, being substantially more massive than the terrestrials. The two largest planets, Jupiter and Saturn, are gas giants, being composed mainly of hydrogen and helium; the two outermost planets, Uranus and Neptune, are ice giants, being composed mostly of substances with relatively high melting points compared with hydrogen and helium, called volatiles, such as water, ammonia and methane. All eight planets have almost circular orbits that lie within a nearly flat disc called the ecliptic.

The Solar System also contains smaller objects. The asteroid belt, which lies between the orbits of Mars and Jupiter, mostly contains objects composed, like the terrestrial planets, of rock and metal. Beyond Neptune's orbit lie the Kuiper belt and scattered disc, which are populations of trans-Neptunian objects composed mostly of ices, and beyond them a newly discovered population of sednoids. Within these populations, some objects are large enough to have rounded under their own gravity, though there is considerable debate as to how many there will prove to be. Such objects are categorized as dwarf planets. The only certain dwarf planet is Pluto, with another trans-Neptunian object, Eris, expected to be, and the asteroid Ceres at least close to being a dwarf planet. In addition to these two regions, various other small-body populations, including comets, centaurs and interplanetary

dust clouds, freely travel between regions. Six of the planets, the six largest possible dwarf planets, and many of the smaller bodies are orbited by natural satellites, usually termed "moons" after the Moon. Each of the outer planets is encircled by planetary rings of dust and other small objects.

The solar wind, a stream of charged particles flowing outwards from the Sun, creates a bubble-like region in the interstellar medium known as the heliosphere. The heliopause is the point at which pressure from the solar wind is equal to the opposing pressure of the interstellar medium; it extends out to the edge of the scattered disc. The Oort cloud, which is thought to be the source for long-period comets, may also exist at a distance roughly a thousand times further than the heliosphere. The Solar System is located in the Orion Arm, 26,000 light-years from the center of the Milky Way galaxy.

Planets

A planet is an astronomical body orbiting a star or stellar remnant that is massive enough to be rounded by its own gravity, is not massive enough to cause thermonuclear fusion, and – according to the International Astronomical Union but not all planetary scientists – has cleared its neighbouring region of planetesimals. The term planet is ancient, with ties to history, astrology, science, mythology, and religion. Apart from Earth itself, five planets in the Solar System are often visible to the naked eye. These were regarded by many early cultures as divine, or as emissaries of deities. As scientific knowledge advanced, human perception of the planets changed, incorporating a number of disparate objects. In 2006, the International Astronomical Union (IAU) officially adopted a resolution defining planets within the Solar System. This definition is controversial because it excludes many objects of planetary mass based on where or what they orbit. Although eight of the planetary bodies discovered before 1950 remain "planets" under the current definition, some celestial bodies, such as Ceres, Pallas, Juno and Vesta (each an object in the solar asteroid belt), and Pluto (the first trans-Neptunian object discovered), that were

once considered planets by the scientific community, are no longer viewed as planets under the current definition of planet.

The planets were thought by Ptolemy to orbit Earth in deferent and epicycle motions. Although the idea that the planets orbited the Sun had been suggested many times, it was not until the 17th century that this view was supported by evidence from the first telescopic astronomical observations, performed by Galileo Galilei. About the same time, by careful analysis of pre-telescopic observational data collected by Tycho Brahe, Johannes Kepler found the planets' orbits were elliptical rather than circular. As observational tools improved, astronomers saw that, like Earth, each of the planets rotated around an axis tilted with respect to its orbital pole, and some shared such features as ice caps and seasons. Since the dawn of the Space Age, close observation by space probes has found that Earth and the other planets share characteristics such as volcanism, hurricanes, tectonics, and even hydrology.

Planets in the Solar System are divided into two main types: large low-density giant planets, and smaller rocky terrestrials. There are eight planets in the Solar System according to the IAU definition. In order of increasing distance from the Sun, they are the four terrestrials, Mercury, Venus, Earth, and Mars, then the four giant planets, Jupiter, Saturn, Uranus, and Neptune. Six of the planets are orbited by one or more natural satellites.

Several thousands of planets around other stars ("extrasolar planets" or "exoplanets") have been discovered in the Milky Way. As of 1 November 2020, 4,370 known extrasolar planets in 3,230 planetary systems (including 715 multiple planetary systems), ranging in size from just above the size of the Moon to gas giants about twice as large as Jupiter have been discovered, out of which more than 100 planets are the same size as Earth, nine of which are at the same relative distance from their star as Earth from the Sun, i.e. in the circumstellar habitable zone. On December 20, 2011, the Kepler Space Telescope team reported the discovery of the first Earth-sized extrasolar planets, Kepler-20e and Kepler-20f, orbiting a Sun-like star, Kepler-20. A 2012 study, analyzing gravitational microlensing data, estimates an average of at least 1.6 bound planets for every star in the Milky Way. Around one in

five Sun-like stars is thought to have an Earth-sized planet in its habitable zone.

Mercury

Mercury is the smallest and innermost planet in the Solar System. Its orbit around the Sun takes 87.97 Earth days, the shortest of all the planets in the Solar System. It is named after the Greek god Hermes (Ερμής), translated into Latin Mercurius Mercury, god of commerce, messenger of the gods, mediator between gods and mortals.

Like Venus, Mercury orbits the Sun within Earth's orbit as an inferior planet, and its apparent distance from the Sun as viewed from Earth never exceeds 28° . This proximity to the Sun means the planet can only be seen near the western horizon after sunset or eastern horizon before sunrise, usually in twilight. At this time, it may appear as a bright star-like object, but is often far more difficult to observe than Venus. The planet telescopically displays the complete range of phases, similar to Venus and the Moon, as it moves in its inner orbit relative to Earth, which recurs over its synodic period of approximately 116 days.

Mercury rotates in a way that is unique in the Solar System. It is tidally locked with the Sun in a 3:2 spin-orbit resonance, meaning that relative to the fixed stars, it rotates on its axis exactly three times for every two revolutions it makes around the Sun. As seen from the Sun, in a frame of reference that rotates with the orbital motion, it appears to rotate only once every two Mercurian years. An observer on Mercury would therefore see only one day every two Mercurian years.

Mercury's axis has the smallest tilt of any of the Solar System's planets (about 1/30 degree). Its orbital eccentricity is the largest of all known planets in the Solar System; at perihelion, Mercury's distance from the Sun is only about two-thirds (or 66%) of its distance at aphelion. Mercury's surface appears heavily cratered and is similar in appearance to the Moon's, indicating that it has been geologically inactive for billions of years. Having almost no atmosphere to retain heat, it has surface temperatures that vary diurnally more than on any other planet in the Solar System, ranging from 100 K (−173 °C; −280 °F) at night to 700 K (427 °C; 800 °F) during the day across the equatorial regions. The polar regions are constantly below 180 K (−93 °C; −136 °F). The planet has no known natural satellites.

Two spacecraft have visited Mercury: Mariner 10 flew by in 1974 and 1975; and MESSENGER, launched in 2004, orbited Mercury over 4,000 times in four years before exhausting its fuel and crashing into the planet's surface on April 30, 2015. The BepiColombo spacecraft is planned to arrive at Mercury in 2025.

Venus

Venus is the second planet from the Sun. It is named after the Roman goddess of love and beauty. As the second-brightest natural object in the night sky after the Moon, Venus can cast shadows and can be, on rare occasion, visible to the naked eye in broad daylight. Venus lies within Earth's orbit, and so never appears to venture far from the Sun, either setting in the west just after dusk or rising in the east a bit before dawn. Venus orbits the Sun every 224.7 Earth days. With a rotation period of 243 Earth days, it takes longer to rotate about its axis than any other planet in the Solar System by far, and does so in the opposite direction to all but Uranus (meaning the Sun rises in the west and sets in the east). Venus does not have any

moons, a distinction it shares only with Mercury among the planets in the Solar System.

Venus is a terrestrial planet and is sometimes called Earth's "sister planet" because of their similar size, mass, proximity to the Sun, and bulk composition. It is radically different from Earth in other respects. It has the densest atmosphere of the four terrestrial planets, consisting of more than 96% carbon dioxide. The atmospheric pressure at the planet's surface is about 92 times the sea level pressure of Earth, or roughly the pressure at 900 m (3,000 ft) underwater on Earth. Venus has, by far, the hottest surface of any planet in the Solar System, with a mean temperature of 737 K (464 °C; 867 °F), even though Mercury is closer to the Sun. Venus is shrouded by an opaque layer of highly reflective clouds of sulfuric acid, preventing its surface from being seen from space in visible light. It may have had water oceans in the past, but these would have vaporized as the temperature rose due to a runaway greenhouse effect. The water has probably photodissociated, and the free hydrogen has been swept into interplanetary space by the solar wind because of the lack of a planetary magnetic field. Venus' surface is a dry desertscape interspersed with slab-like rocks and is periodically resurfaced by volcanism.

As one of the brightest objects in the sky, Venus has been a major fixture in human culture for as long as records have existed. It has been made sacred to gods of many cultures, and has been a prime inspiration for writers and poets as the "morning star" and "evening star". Venus was the first planet to have its motions plotted across the sky, as early as the second millennium BC.

Due to its proximity to Earth, Venus has been a prime target for early interplanetary exploration. It was the first planet beyond Earth visited by a spacecraft (Mariner 2 in 1962), and the first to be successfully landed on (by Venera 7 in 1970). Venus' thick clouds render observation of its surface impossible in visible light, and the first detailed maps did not emerge until the arrival of the Magellan orbiter in 1991. Plans have been proposed for rovers or more complex missions, but they are hindered by Venus' hostile surface conditions.

The possibility of life on Venus has long been a topic of speculation, and in recent years has received active research. Following a 2019 observation that the light absorbance of the upper cloud layers was consistent with the presence of microorganisms, a September 2020 article in *Nature Astronomy* announced the detection of phosphine gas, a biomarker, in concentrations higher than can be explained by any known abiotic source. However, doubts have been cast on these observations due to the failure to detect phosphine at other wavelengths and data-processing issues.

Earth

Earth is the third planet from the Sun and the only astronomical object known to harbor life. About 29% of Earth's surface is land consisting of continents and islands. The remaining 71% is covered with water, mostly by oceans but also lakes, rivers and other fresh water, which together constitute the hydrosphere. Much of Earth's polar regions are covered in ice, including the Antarctic ice sheet and the sea ice of the Arctic ice pack. Earth's outer layer is divided into several rigid tectonic plates that migrate across the surface over many millions of years. Earth's

interior remains active with a solid iron inner core, a liquid outer core that generates Earth's magnetic field, and a convecting mantle that drives plate tectonics.

According to radiometric dating estimation and other evidence, Earth formed over 4.5 billion years ago. Within the first billion years of Earth's history, life appeared in the oceans and began to affect Earth's atmosphere and surface, leading to the proliferation of anaerobic and, later, aerobic organisms. Some geological evidence indicates that life may have arisen as early as 4.1 billion years ago. Since then, the combination of Earth's distance from the Sun, physical properties and geological history have allowed life to evolve and thrive. In the history of life on Earth, biodiversity has gone through long periods of expansion, occasionally punctuated by mass extinctions. Over 99% of all species that ever lived on Earth are extinct. Almost 8 billion humans live on Earth and depend on its biosphere and natural resources for their survival. Humans increasingly impact Earth's hydrology, atmospheric processes and other life.

Earth's atmosphere consists mostly of nitrogen and oxygen. Tropical regions receive more energy from the Sun than polar regions, which is redistributed by atmospheric and ocean circulation. Greenhouse gases also play an important role in regulating the surface temperature. A region's climate is not only determined by latitude, but also by its proximity to moderating oceans and height among other factors. Extreme weather, such as tropical cyclones and heat waves, occurs in most areas and has a large impact on life.

Earth's gravity interacts with other objects in space, especially the Sun and the Moon, which is Earth's only natural satellite. Earth orbits around the Sun in about 365.25 days. Earth's axis of rotation is tilted with respect to its orbital plane, producing seasons on Earth. The gravitational interaction between Earth and the Moon causes tides, stabilizes Earth's orientation on its axis, and gradually slows its rotation. Earth is the densest planet in the Solar System and the largest and most massive of the four rocky planets.

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Mars

Mars is the fourth planet from the Sun and the second-smallest planet in the Solar System, being larger than only Mercury. In English, Mars carries the name of the Roman god of war and is often referred to as the "Red Planet". The latter refers to the effect of the iron oxide prevalent on Mars's surface, which gives it a reddish appearance distinctive among the astronomical bodies visible to the naked eye. Mars is a terrestrial planet with a thin atmosphere, with surface features reminiscent of the impact craters of the Moon and the valleys, deserts and polar ice caps of Earth.

The days and seasons are comparable to those of Earth, because the rotational period as well as the tilt of the rotational axis relative to the ecliptic plane are similar. Mars is the site of Olympus Mons, the largest volcano and highest known mountain on any planet in the Solar System, and of Valles Marineris, one of the largest canyons in the Solar System. The smooth Borealis basin in the northern hemisphere covers 40% of the planet and may be a giant impact feature. Mars has two moons, Phobos and Deimos, which

are small and irregularly shaped. These may be captured asteroids, similar to 5261 Eureka, a Mars trojan.

Mars has been explored by several uncrewed spacecraft. Mariner 4 was the first spacecraft to visit Mars; launched by NASA on 28 November 1964, it made its closest approach to the planet on 15 July 1965. Mariner 4 detected the weak Martian radiation belt, measured at about 0.1% that of Earth, and captured the first images of another planet from deep space. The Soviet Mars 3 mission included a lander, which achieved a soft landing in December 1971; however, contact was lost seconds after touchdown. On 20 July 1976, Viking 1 performed the first successful landing on the Martian surface. On 4 July 1997, the Mars Pathfinder spacecraft landed on Mars and on 5 July released its rover, Sojourner, the first robotic rover to operate on Mars. The Mars Express orbiter, the first European Space Agency (ESA) spacecraft to visit Mars, arrived in orbit on 25 December 2003. In January 2004, the Mars Exploration Rovers, named Spirit and Opportunity, both landed on Mars. Spirit operated until 22 March 2010 and Opportunity lasted until 10 June 2018. On 24 September 2014, the Indian Space Research Organisation (ISRO) became the fourth space agency to visit Mars when its maiden interplanetary mission, the Mars Orbiter Mission spacecraft, arrived in orbit.

There are investigations assessing the past habitability of Mars, as well as the possibility of extant life. Astrobiology missions are planned, including the Perseverance and Rosalind Franklin rovers. Liquid water on the surface of Mars cannot exist due to low atmospheric pressure, which is less than 1% of the atmospheric pressure on Earth, except at the lowest elevations for short periods. The two polar ice caps appear to be made largely of water. The volume of water ice in the south polar ice cap, if melted, would be sufficient to cover the planetary surface to a depth of 11 metres (36 ft). In November 2016, NASA reported finding a large amount of underground ice in the Utopia Planitia region. The

volume of water detected has been estimated to be equivalent to the volume of water in Lake Superior.

Mars can easily be seen from Earth with the naked eye, as can its reddish coloring. Its apparent magnitude reaches -2.94 , which is surpassed only by Venus, the Moon and the Sun. Optical ground-based telescopes are typically limited to resolving features about 300 kilometres (190 mi) across when Earth and Mars are closest because of Earth's atmosphere.

Jupiter

Jupiter is the fifth planet from the Sun and the largest in the Solar System. It is a gas giant with a mass one-thousandth that of the Sun, but two-and-a-half times that of all the other planets in the Solar System combined. Jupiter is one of the brightest objects visible to the naked eye in the night sky, and has been known to ancient civilizations since before recorded history. It is named after the Roman god Jupiter. When viewed from Earth, Jupiter can be bright enough for its reflected light to cast visible shadows, and is on average the third-brightest natural object in the night sky after the Moon and Venus.

Jupiter is primarily composed of hydrogen with a quarter of its mass being helium, though helium comprises only about a tenth of the number of molecules. It may also have a rocky core of heavier elements, but like the other giant planets, Jupiter lacks a well-defined solid surface. Because of its rapid rotation, the planet's shape is that of an oblate spheroid (it has a slight but noticeable bulge around the equator). The outer atmosphere is visibly segregated into several bands at different latitudes, resulting in turbulence and storms along their interacting boundaries. A prominent result is the Great Red Spot, a giant storm that is known to have existed since at least the 17th century when it was first seen

by telescope. Surrounding Jupiter is a faint planetary ring system and a powerful magnetosphere. Jupiter has 79 known moons, including the four large Galilean moons discovered by Galileo Galilei in 1610. Ganymede, the largest of these, has a diameter greater than that of the planet Mercury.

Pioneer 10 was the first spacecraft to visit Jupiter, making its closest approach to the planet on December 4, 1973; Pioneer 10 identified plasma in Jupiter's magnetic field and also found that Jupiter's magnetic tail was nearly 800 million kilometers long, covering the entire distance to Saturn. Jupiter has been explored on a number of occasions by robotic spacecraft, beginning with the Pioneer and Voyager flyby missions from 1973 to 1979, and later by the Galileo orbiter, which arrived at Jupiter in 1995. In late February 2007, Jupiter was visited by the New Horizons probe, which used Jupiter's gravity to increase its speed and bend its trajectory en route to Pluto. The latest probe to visit the planet is Juno, which entered into orbit around Jupiter on July 4, 2016. Future targets for exploration in the Jupiter system include the probable ice-covered liquid ocean of its moon Europa.

Saturn

Saturn is the sixth planet from the Sun and the second-largest in the Solar System, after Jupiter. It is a gas giant with an average radius of about nine times that of Earth. It only has one-eighth the average density of Earth; however, with its larger volume, Saturn is over 95 times more massive. Saturn is named after the Roman god of wealth and agriculture; its astronomical symbol (♄) represents the god's sickle.

Saturn's interior is most likely composed of a core of iron–nickel and rock (silicon and oxygen compounds). Its core is surrounded

by a deep layer of metallic hydrogen, an intermediate layer of liquid hydrogen and liquid helium, and finally a gaseous outer layer. Saturn has a pale yellow hue due to ammonia crystals in its upper atmosphere. An electrical current within the metallic hydrogen layer is thought to give rise to Saturn's planetary magnetic field, which is weaker than the Earth's, but has a magnetic moment 580 times that of Earth due to Saturn's larger size. Saturn's magnetic field strength is around one-twentieth of Jupiter's. The outer atmosphere is generally bland and lacking in contrast, although long-lived features can appear. Wind speeds on Saturn can reach 1,800 km/h (1,100 mph; 500 m/s), higher than on Jupiter, but not as high as those on Neptune. In January 2019, astronomers reported that a day on the planet Saturn has been determined to be 10h 33m 38s + 1m 52s– 1m 19s, based on studies of the planet's C Ring.

The planet's most famous feature is its prominent ring system, which is composed mostly of ice particles, with a smaller amount of rocky debris and dust. At least 82 moons are known to orbit Saturn, of which 53 are officially named; this does not include the hundreds of moonlets in its rings. Titan, Saturn's largest moon, and the second-largest in the Solar System, is larger than the planet Mercury, although less massive, and is the only moon in the Solar System to have a substantial atmosphere.

Uranus

Uranus is the seventh planet from the Sun. Its name is a reference to the Greek god of the sky, Uranus, who, according to Greek mythology, was the grandfather of Zeus (Jupiter) and father of Cronus (Saturn). It has the third-largest planetary radius and fourth-largest planetary mass in the Solar System. Uranus is similar in composition to Neptune, and both have bulk chemical compositions which differ from that of the larger gas giants Jupiter and Saturn. For this reason, scientists often classify Uranus and

Neptune as "ice giants" to distinguish them from the other gas giants. Uranus's atmosphere is similar to Jupiter's and Saturn's in its primary composition of hydrogen and helium, but it contains more "ices" such as water, ammonia, and methane, along with traces of other hydrocarbons. It has the coldest planetary atmosphere in the Solar System, with a minimum temperature of 49 K (−224 °C; −371 °F), and has a complex, layered cloud structure with water thought to make up the lowest clouds and methane the uppermost layer of clouds. The interior of Uranus is mainly composed of ices and rock.

Like the other giant planets, Uranus has a ring system, a magnetosphere, and numerous moons. The Uranian system has a unique configuration because its axis of rotation is tilted sideways, nearly into the plane of its solar orbit. Its north and south poles, therefore, lie where most other planets have their equators. In 1986, images from Voyager 2 showed Uranus as an almost featureless planet in visible light, without the cloud bands or storms associated with the other giant planets. Voyager 2 remains the only spacecraft to visit the planet. Observations from Earth have shown seasonal change and increased weather activity as Uranus approached its equinox in 2007. Wind speeds can reach 250 metres per second (900 km/h; 560 mph).

Neptune

Neptune is the eighth and farthest-known Solar planet from the Sun. In the Solar System, it is the fourth-largest planet by diameter, the third-most-massive planet, and the densest giant planet. It is 17 times the mass of Earth, slightly more massive than its near-twin Uranus. Neptune is denser and physically smaller than Uranus because its greater mass causes more gravitational compression of its atmosphere. The planet orbits the Sun once every 164.8 years at an average distance of 30.1 AU (4.5 billion km; 2.8 billion mi). It is named after the Roman god of the sea and has the

astronomical symbol Ψ , a stylised version of the god Neptune's trident.

Neptune is not visible to the unaided eye and is the only planet in the Solar System found by mathematical prediction rather than by empirical observation. Unexpected changes in the orbit of Uranus led Alexis Bouvard to deduce that its orbit was subject to gravitational perturbation by an unknown planet. After Bouvard's death, the position of Neptune was predicted from his observations, independently, by John Couch Adams and Urbain Le Verrier. Neptune was subsequently observed with a telescope on 23 September 1846 by Johann Galle within a degree of the position predicted by Le Verrier. Its largest moon, Triton, was discovered shortly thereafter, though none of the planet's remaining 13 known moons were located telescopically until the 20th century. The planet's distance from Earth gives it a very small apparent size, making it challenging to study with Earth-based telescopes. Neptune was visited by Voyager 2, when it flew by the planet on 25 August 1989; Voyager 2 remains the only spacecraft to visit Neptune. The advent of the Hubble Space Telescope and large ground-based telescopes with adaptive optics has recently allowed for additional detailed observations from afar.

Like Jupiter and Saturn, Neptune's atmosphere is composed primarily of hydrogen and helium, along with traces of hydrocarbons and possibly nitrogen, though it contains a higher proportion of "ices" such as water, ammonia and methane. However, similar to Uranus, its interior is primarily composed of ices and rock; Uranus and Neptune are normally considered "ice giants" to emphasise this distinction. Traces of methane in the outermost regions in part account for the planet's blue appearance.

In contrast to the hazy, relatively featureless atmosphere of Uranus, Neptune's atmosphere has active and visible weather patterns. For example, at the time of the Voyager 2 flyby in 1989, the planet's southern hemisphere had a Great Dark Spot comparable to the Great Red Spot on Jupiter. These weather patterns are driven by the strongest sustained winds of any planet in the Solar System, with recorded wind speeds as high as 2,100 km/h (580 m/s; 1,300 mph). Because of its great distance from the Sun, Neptune's outer atmosphere is one of the coldest places in the Solar System, with temperatures at its cloud tops approaching 55 K (−218 °C; −361 °F). Temperatures at the planet's centre are approximately 5,400 K (5,100 °C; 9,300 °F). Neptune has a faint and fragmented ring system (labelled "arcs"), which was discovered in 1984, then later confirmed by Voyager 2.

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