Introduction – What is the Solar System?

The Solar System[c] is the gravitationally bound system of the Sun and the objects that orbit it. The Solar System formed 4.6 billion years ago from the gravitational collapse of a giant interstellar molecular cloud. The vast majority (99.86%) of the system's mass is in the Sun, with most of the remaining mass contained in the planet Jupiter. The four inner system planets—Mercury, Venus, Earth and Mars—are terrestrial planets, being composed primarily of rock and metal. The four giant planets of the outer system are substantially larger and more massive than the terrestrials. The two largest, Jupiter and Saturn, are gas giants, being composed mainly of hydrogen and helium; the next two, Uranus and Neptune, are ice giants, being composed mostly of volatile substances with relatively high melting points compared with hydrogen and helium, such as water, ammonia, and methane. All eight planets have nearly circular orbits that lie near the plane of Earth's orbit, called the ecliptic.

There are an unknown number of smaller dwarf planets and innumerable small Solar System bodies orbiting the Sun.[d] Six of the major planets, the six largest possible dwarf planets, and many of the smaller bodies are orbited by natural satellites, commonly called "moons" after the Moon. Two natural satellites, Jupiter's moon Ganymede and Saturn's moon Titan, are larger but not more massive than Mercury, the smallest terrestrial planet, and Jupiter's moon Callisto is nearly as large. Each of the giant planets and some smaller bodies are encircled by planetary rings of ice, dust and moonlets. The asteroid belt, which lies between the orbits of Mars and Jupiter, contains objects composed of rock, metal and ice. Beyond Neptune's orbit lie the Kuiper belt and scattered disc, which are populations of objects composed mostly of ice and rock.

In the outer reaches of the Solar System lies a class of minor planets called detached objects. There is considerable debate as to how many such objects there will prove to be.[9] Some of these objects are large enough to have rounded under their own gravity and thus to be categorized as dwarf planets. Astronomers generally accept about nine objects as dwarf planets: the asteroid Ceres, the Kuiper-belt objects Pluto, Orcus, Haumea, Quaoar and Makemake, and the scattered-disk objects Gonggong and Eris, and Sedna.[d] Various small-body populations, including comets, centaurs and interplanetary dust clouds, freely travel between the regions of the Solar System.

The solar wind, a stream of charged particles flowing outwards from the Sun, creates a bubble-like region of interplanetary medium 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 26,000 light-years from the center of the Milky Way galaxy in the Orion Arm, which contains most of the visible stars in the night sky. The nearest stars are within the so-called Local Bubble, with the closest, Proxima Centauri, at 4.2441 light-years.

Structure and composition

The word solar means "pertaining to the Sun", which is derived from the Latin word sol, meaning Sun.[10] The Sun is the dominant gravitational member of the Solar System, and its planetary system is maintained in a relatively stable, slowly evolving state by following isolated, gravitationally bound orbits around the Sun.[11]

Orbits

Animations of the Solar System's inner planets and outer planets orbiting; the latter animation is 100 times faster than the former. Jupiter is three times as far from the Sun as Mars.

The planets and other large objects in orbit around the Sun lie near the plane of Earth's orbit, known as the ecliptic. Smaller icy objects such as comets frequently orbit at significantly greater angles to this plane.[12][13] Most of the planets in the Solar System have secondary systems of their own, being orbited by natural satellites called moons. Many of the largest natural satellites are in synchronous rotation, with one face permanently turned toward their parent. The four giant planets have planetary rings, thin bands of tiny particles that orbit them in unison.[14]

As a result of the formation of the Solar System, planets and most other objects orbit the Sun in the same direction that the Sun is rotating. That is, counter-clockwise, as viewed from above Earth's north pole.[15] There are exceptions, such as Halley's Comet.[16] Most of the larger moons orbit their planets in prograde direction, matching the planetary rotation; Neptune's moon Triton is the largest to orbit in the opposite, retrograde manner.[17] Most larger objects rotate around their own axes in the prograde direction relative to their orbit, though the rotation of Venus is retrograde.[18]

To a good first approximation, Kepler's laws of planetary motion describe the orbits of objects about the Sun.[19]: 433–437  These laws stipulate that each object travels along an ellipse with the Sun at one focus, which causes the body's distance from the Sun to vary over the course of its year. A body's closest approach to the Sun is called its perihelion, whereas its most distant point from the Sun is called its aphelion.[20]: 9-6  The orbits of the planets are nearly circular, but many comets, asteroids, and Kuiper belt objects follow highly elliptical orbits. Kepler's laws only account for the influence of the Sun's gravity upon an orbiting body, not the gravitational pulls of different bodies upon each other. On a human time scale, these additional perturbations can be accounted for using numerical models,[20]: 9-6  but the planetary system can change chaotically over billions of years.[21]

The angular momentum of the Solar System is a measure of the total amount of orbital and rotational momentum possessed by all its moving components.[22] Although the Sun dominates the system by mass, it accounts for only about 2% of the angular momentum.[23][24] The planets, dominated by Jupiter, account for most of the rest of the angular momentum due to the combination of their mass, orbit, and distance from the Sun, with a possibly significant contribution from comets.[23]

Composition

The overall structure of the charted regions of the Solar System consists of the Sun, four smaller inner planets surrounded by a belt of mostly rocky asteroids, and four giant planets surrounded by the Kuiper belt of mostly icy objects. Astronomers sometimes informally divide this structure into separate regions. The inner Solar System includes the four terrestrial planets and the asteroid belt. The outer Solar System is beyond the asteroids, including the four giant planets.[25] Since the discovery of the Kuiper belt, the outermost parts of the Solar System are considered a distinct region consisting of the objects beyond Neptune.[26]

The principal component of the Solar System is the Sun, a low-mass star that contains 99.86% of the system's known mass and dominates it gravitationally.[27] The Sun's four largest orbiting bodies, the giant planets, account for 99% of the remaining mass, with Jupiter and Saturn together comprising more than 90%. The remaining objects of the Solar System (including the four terrestrial planets, the dwarf planets, moons, asteroids, and comets) together comprise less than 0.002% of the Solar System's total mass.[e]

The Sun is composed of roughly 98% hydrogen and helium,[31] as are Jupiter and Saturn.[32][33] A composition gradient exists in the Solar System, created by heat and light pressure from the early Sun; those objects closer to the Sun, which are more affected by heat and light pressure, are composed of elements with high melting points. Objects farther from the Sun are composed largely of materials with lower melting points.[34] The boundary in the Solar System beyond which those volatile substances could coalesce is known as the frost line, and it lies at roughly five times the Earth's distance from the Sun.[3]

The objects of the inner Solar System are composed mostly of rocky materials,[35] such as silicates, iron or nickel.[36] Jupiter and Saturn are composed mainly of gases with extremely low melting points and high vapour pressure, such as hydrogen, helium, and neon.[36] Ices, like water, methane, ammonia, hydrogen sulfide, and carbon dioxide,[35] have melting points up to a few hundred kelvins.[36] They can be found as ices, liquids, or gases in various places in the Solar System.[36] Icy substances comprise the majority of the satellites of the giant planets, as well as most of Uranus and Neptune (the so-called "ice giants") and the numerous small objects that lie beyond Neptune's orbit.[35][37] Together, gases and ices are referred to as volatiles.[38]

Distances and scales

The astronomical unit [AU] (150,000,000 km; 93,000,000 mi) would be the distance from the Earth to the Sun if the planet's orbit were perfectly circular.[39] For comparison, the radius of the Sun is 0.0047 AU (700,000 km; 400,000 mi).[40] Thus, the Sun occupies 0.00001% (10−5 %) of the volume of a sphere with a radius the size of Earth's orbit, whereas Earth's volume is roughly one millionth (10−6) that of the Sun. Jupiter, the largest planet, is 5.2 astronomical units (780,000,000 km; 480,000,000 mi) from the Sun and has a radius of 71,000 km (0.00047 AU; 44,000 mi), whereas the most distant planet, Neptune, is 30 AU (4.5×109 km; 2.8×109 mi) from the Sun.[33][41]

With a few exceptions, the farther a planet or belt is from the Sun, the larger the distance between its orbit and the orbit of the next nearer object to the Sun. For example, Venus is approximately 0.33 AU farther out from the Sun than Mercury, whereas Saturn is 4.3 AU out from Jupiter, and Neptune lies 10.5 AU out from Uranus. Attempts have been made to determine a relationship between these orbital distances, like the Titius–Bode law[42] and Johannes Kepler's model based on the Platonic solids,[43] but ongoing discoveries have invalidated these hypotheses.[44]

Some Solar System models attempt to convey the relative scales involved in the Solar System on human terms. Some are small in scale (and may be mechanical—called orreries)—whereas others extend across cities or regional areas.[45] The largest such scale model, the Sweden Solar System, uses the 110-metre (361 ft) Ericsson Globe in Stockholm as its substitute Sun, and, following the scale, Jupiter is a 7.5-metre (25-foot) sphere at Stockholm Arlanda Airport, 40 km (25 mi) away, whereas the farthest current object, Sedna, is a 10 cm (4 in) sphere in Luleå, 912 km (567 mi) away.[46][47]

If the Sun–Neptune distance is scaled to 100 metres (330 ft), then the Sun would be about 3 cm (1.2 in) in diameter (roughly two-thirds the diameter of a golf ball), the giant planets would be all smaller than about 3 mm (0.12 in), and Earth's diameter along with that of the other terrestrial planets would be smaller than a flea (0.3 mm or 0.012 in) at this scale.[48]

Formation and evolution

The Solar System formed 4.568 billion years ago from the gravitational collapse of a region within a large molecular cloud.[f] This initial cloud was likely several light-years across and probably birthed several stars.[50] As is typical of molecular clouds, this one consisted mostly of hydrogen, with some helium, and small amounts of heavier elements fused by previous generations of stars. As the region that would become the Solar System, known as the pre-solar nebula,[51] collapsed, conservation of angular momentum caused it to rotate faster. The centre, where most of the mass collected, became increasingly hotter than the surrounding disc.[50] As the contracting nebula rotated faster, it began to flatten into a protoplanetary disc with a diameter of roughly 200 AU (30 billion km; 19 billion mi)[50] and a hot, dense protostar at the centre.[52][53] The planets formed by accretion from this disc,[54] in which dust and gas gravitationally attracted each other, coalescing to form ever larger bodies. Hundreds of protoplanets may have existed in the early Solar System, but they either merged or were destroyed or ejected, leaving the planets, dwarf planets, and leftover minor bodies.[55][56]

Due to their higher boiling points, only metals and silicates could exist in solid form in the warm inner Solar System close to the Sun, and these would eventually form the rocky planets of Mercury, Venus, Earth, and Mars. Because metallic elements only comprised a very small fraction of the solar nebula, the terrestrial planets could not grow very large. The giant planets (Jupiter, Saturn, Uranus, and Neptune) formed further out, beyond the frost line, the point between the orbits of Mars and Jupiter where material is cool enough for volatile icy compounds to remain solid. The ices that formed these planets were more plentiful than the metals and silicates that formed the terrestrial inner planets, allowing them to grow massive enough to capture large atmospheres of hydrogen and helium, the lightest and most abundant elements. Leftover debris that never became planets congregated in regions such as the asteroid belt, Kuiper belt, and Oort cloud.[55] The Nice model is an explanation for the creation of these regions and how the outer planets could have formed in different positions and migrated to their current orbits through various gravitational interactions.[57]

Colorful shell which has an almost eye like appearance. The center shows the small central star with a blue circular area that could represent the iris. This is surrounded by an iris like area of concentric orange bands. This is surrounded by an eyelid shaped red area before the edge where plain space is shown. Background stars dot the whole image.

The Helix Nebula, a planetary nebula similar to what the Sun will create when it enters its white dwarf stage.

Within 50 million years, the pressure and density of hydrogen in the centre of the protostar became great enough for it to begin thermonuclear fusion.[58] The temperature, reaction rate, pressure, and density increased until hydrostatic equilibrium was achieved: the thermal pressure counterbalancing the force of gravity. At this point, the Sun became a main-sequence star.[59] The main-sequence phase, from beginning to end, will last about 10 billion years for the Sun compared to around two billion years for all other phases of the Sun's pre-remnant life combined.[60] Solar wind from the Sun created the heliosphere and swept away the remaining gas and dust from the protoplanetary disc into interstellar space. As helium accumulates at its core the Sun is growing brighter;[61] early in its main-sequence life its brightness was 70% that of what it is today.[62]

The Solar System will remain roughly as it is known today until the hydrogen in the core of the Sun has been entirely converted to helium, which will occur roughly 5 billion years from now. This will mark the end of the Sun's main-sequence life. At that time, the core of the Sun will contract with hydrogen fusion occurring along a shell surrounding the inert helium, and the energy output will be greater than at present. The outer layers of the Sun will expand to roughly 260 times its current diameter, and the Sun will become a red giant. Because of its increased surface area, the surface of the Sun will be cooler (2,600 K (2,330 °C; 4,220 °F) at its coolest) than it is on the main sequence.[60]

The expanding Sun is expected to vaporize Mercury and render Earth uninhabitable. Eventually, the core will be hot enough for helium fusion; the Sun will burn helium for a fraction of the time it burned hydrogen in the core. The Sun is not massive enough to commence the fusion of heavier elements, and nuclear reactions in the core will dwindle. Its outer layers will be ejected into space, leaving behind a dense white dwarf, half the original mass of the Sun but only the size of Earth.[63] The ejected outer layers will form what is known as a planetary nebula, returning some of the material that formed the Sun—but now enriched with heavier elements like carbon—to the interstellar medium.[64]

Sun

The Sun is the Solar System's star and by far its most massive component. Its large mass (332,900 Earth masses),[65] which comprises 99.86% of all the mass in the Solar System,[66] produces temperatures and densities in its core high enough to sustain nuclear fusion of hydrogen into helium.[67] This releases an enormous amount of energy, mostly radiated into space as electromagnetic radiation peaking in visible light.[68][69]

Because the Sun fuses hydrogen into helium at its core, it is a main-sequence star. More specifically, it is a G2-type main-sequence star, where the type designation refers to its effective temperature. Hotter main-sequence stars are more luminous. The Sun's temperature is intermediate between that of the hottest stars and that of the coolest stars. Stars brighter and hotter than the Sun are rare, whereas substantially dimmer and cooler stars, known as red dwarfs, make up about 75% of the stars in the Milky Way.[70][71]

The Sun is a population I star; it has a higher abundance of elements heavier than hydrogen and helium ("metals" in astronomical parlance) than the older population II stars.[72] Elements heavier than hydrogen and helium were formed in the cores of ancient and exploding stars, so the first generation of stars had to die before the universe could be enriched with these atoms. The oldest stars contain few metals, whereas stars born later have more. This higher metallicity is thought to have been crucial to the Sun's development of a planetary system because the planets form from the accretion of "metals".[73]

Inner Solar System

Overview of the Inner Solar System up to the Jovian System.

The inner Solar System is the region comprising the terrestrial planets and the asteroid belt.[86] Composed mainly of silicates and metals,[87] the objects of the inner Solar System are relatively close to the Sun; the radius of this entire region is less than the distance between the orbits of Jupiter and Saturn. This region is also within the frost line, which is a little less than 5 AU (750 million km; 460 million mi) from the Sun.[12]

Inner planets

The terrestrial planets of the Solar System: Mercury, Venus, Earth and Mars, sized to scale

The four terrestrial or inner planets have dense, rocky compositions, few or no moons, and no ring systems. They are composed largely of refractory minerals such as the silicates—which form their crusts and mantles—and metals such as iron and nickel which form their cores. Three of the four inner planets (Venus, Earth and Mars) have atmospheres substantial enough to generate weather; all have impact craters and tectonic surface features, such as rift valleys and volcanoes. The term inner planet should not be confused with inferior planet, which designates those planets that are closer to the Sun than Earth is (i.e. Mercury and Venus).[88]

Mercury

Mercury (0.4 AU (60 million km; 37 million mi) from the Sun) is the closest planet to the Sun. The smallest planet in the Solar System (0.055 MEarth), Mercury has no natural satellites. The dominant geological features are impact craters or basins with ejecta blankets, the remains of early volcanic activity including magma flows, and lobed ridges or rupes that were probably produced by a period of contraction early in the planet's history.[89] Mercury's very tenuous atmosphere consists of solar-wind particles trapped by Mercury's magnetic field, as well as atoms blasted off its surface by the solar wind.[90][91] Its relatively large iron core and thin mantle have not yet been adequately explained. Hypotheses include that its outer layers were stripped off by a giant impact, or that it was prevented from fully accreting by the young Sun's energy.[92][93]

There have been searches for "Vulcanoids", asteroids in stable orbits between Mercury and the Sun, but none have been discovered.[94][95]

Venus

Venus (0.7 AU (100 million km; 65 million mi) from the Sun) is close in size to Earth (0.815 MEarth) and, like Earth, has a thick silicate mantle around an iron core, a substantial atmosphere, and evidence of internal geological activity. It is much drier than Earth, and its atmosphere is ninety times as dense. Venus has no natural satellites. It is the hottest planet, with surface temperatures over 400 °C (752 °F), mainly due to the amount of greenhouse gases in the atmosphere.[96] The planet has no magnetic field that would prevent depletion of its substantial atmosphere, which suggests that its atmosphere is being replenished by volcanic eruptions.[97] A relatively young planetary surface displays extensive evidence of volcanic activity, but is devoid of plate tectonics. It may undergo resurfacing episodes on a time scale of 700 million years.[98]

Earth

Earth (1 AU (150 million km; 93 million mi) from the Sun) is the largest and densest of the inner planets, the only one known to have current geological activity, and the only place where life is known to exist.[99] Its liquid hydrosphere is unique among the terrestrial planets, and it is the only planet where plate tectonics has been observed.[100] Earth's atmosphere is radically different from those of the other planets, having been altered by the presence of life to contain 21% free oxygen.[101][102] The planetary magnetosphere shields the surface from solar and cosmic radiation, limiting atmospheric stripping and maintaining habitability.[103] It has one natural satellite, the Moon, the only large satellite of a terrestrial planet in the Solar System.

Mars

Mars (1.5 AU (220 million km; 140 million mi) from the Sun) is smaller than Earth and Venus (0.107 MEarth). It has an atmosphere of mostly carbon dioxide with a surface pressure of 6.1 millibars (0.088 psi; 0.18 inHg); roughly 0.6% of that of Earth but sufficient to support weather phenomena.[104] Its surface, peppered with volcanoes, such as Olympus Mons, and rift valleys, such as Valles Marineris, shows geological activity that may have persisted until as recently as 2 million years ago.[105] Its red colour comes from iron oxide (rust) in its soil.[106] Mars has two tiny natural satellites (Deimos and Phobos) thought to be either captured asteroids,[107] or ejected debris from a massive impact early in Mars's history.[108]

Asteroid belt

Linear map of the inner Solar System, showing many asteroid populations

Asteroids except for the largest, Ceres, are classified as small Solar System bodies[d] and are composed mainly of refractory rocky and metallic minerals, with some ice.[109][110] They range from a few metres to hundreds of kilometres in size. Asteroids smaller than one meter are usually called meteoroids and micrometeoroids (grain-sized), with the exact division between the two categories being debated over the years.[111] As of 2017, the IAU designates asteroids having diameter between about 30 micrometres and 1 metre as micrometeroids, and terms smaller particles "dust".[112]

The asteroid belt occupies the orbit between Mars and Jupiter, between 2.3 and 3.3 AU (340 and 490 million km; 210 and 310 million mi) from the Sun. It is thought to be remnants from the Solar System's formation that failed to coalesce because of the gravitational interference of Jupiter.[113] The asteroid belt contains tens of thousands, possibly millions, of objects over one kilometre in diameter.[114] Despite this, the total mass of the asteroid belt is unlikely to be more than a thousandth of that of Earth.[30] The asteroid belt is very sparsely populated; spacecraft routinely pass through without incident.[115]

Ceres

Ceres (2.77 AU (414 million km; 257 million mi) from the Sun) is the largest asteroid, a protoplanet, and a dwarf planet.[d] It has a diameter of slightly under 1,000 km (620 mi), and a mass large enough for its own gravity to pull it into a spherical shape. Ceres was considered a planet when it was discovered in 1801, but as further observations revealed additional asteroids, it became common to consider it as one of the minor rather than major planets.[116] It was then reclassified again as a dwarf planet in 2006 when the IAU definition of planet was established.[117]: 218

Pallas and Vesta

Pallas (2.77 AU from the Sun) and Vesta (2.36 AU from the Sun) are the largest asteroids in the asteroid belt, after Ceres. They are the other two protoplanets that survive more or less intact. At about 520 km (320 mi) in diameter, they were large enough to have developed planetary geology in the past, but both have suffered large impacts and been battered out of being round.[118][119][120] Fragments from impacts upon these two bodies survive elsewhere in the asteroid belt, as the Pallas family and Vesta family. Both were considered planets upon their discoveries in 1802 and 1807 respectively, and then like Ceres generally considered as minor planets with the discovery of more asteroids. Some authors today have begun to consider Pallas and Vesta as planets again, along with Ceres, under geophysical definitions of the term.[5]

Asteroid groups

Asteroids in the asteroid belt are divided into asteroid groups and families based on their orbital characteristics. Kirkwood gaps are sharp dips in the distribution of asteroid orbits that correspond to orbital resonances with Jupiter.[121] Asteroid moons are asteroids that orbit larger asteroids. They are not as clearly distinguished as planetary moons, sometimes being almost as large as their partners (e.g. that of 90 Antiope). The asteroid belt includes main-belt comets, which may have been the source of Earth's water.[122]

Jupiter trojans are located in either of Jupiter's L4 or L5 points (gravitationally stable regions leading and trailing a planet in its orbit); the term trojan is also used for small bodies in any other planetary or satellite Lagrange point. Hilda asteroids are in a 2:3 resonance with Jupiter; that is, they go around the Sun three times for every two Jupiter orbits.[123] The inner Solar System contains near-Earth asteroids, many of which cross the orbits of the inner planets.[124] Some of them are potentially hazardous objects.[125]

Outer Solar System

Plot of objects around the Kuiper belt and other asteroid populations, the J, S, U and N denotes Jupiter, Saturn, Uranus and Neptune

The outer region of the Solar System is home to the giant planets and their large moons. The centaurs and many short-period comets also orbit in this region. Due to their greater distance from the Sun, the solid objects in the outer Solar System contain a higher proportion of volatiles, such as water, ammonia, and methane than those of the inner Solar System because the lower temperatures allow these compounds to remain solid.[55]

Outer planets

The outer planets Jupiter, Saturn, Uranus and Neptune, compared to the inner planets Earth, Venus, Mars and Mercury at the bottom right

The four outer planets, also called giant planets or Jovian planets, collectively make up 99% of the mass known to orbit the Sun.[e] Jupiter and Saturn are together more than 400 times the mass of Earth and consist overwhelmingly of the gases hydrogen and helium, hence their designation as gas giants.[126] Uranus and Neptune are far less massive—less than 20 Earth masses (MEarth) each—and are composed primarily of ices. For these reasons, some astronomers suggest they belong in their own category, ice giants.[127] All four giant planets have rings, although only Saturn's ring system is easily observed from Earth. The term superior planet designates planets outside Earth's orbit and thus includes both the outer planets and Mars.[88]

The ring–moon systems of Jupiter, Saturn, and Uranus are like miniature versions of the Solar System; that of Neptune is significantly different, having been disrupted by the capture of its largest moon Triton.[128]

Jupiter

Jupiter (5.2 AU (780 million km; 480 million mi) from the Sun), at 318 MEarth, is 2.5 times the mass of all the other planets put together. It is composed largely of hydrogen and helium. Jupiter's strong internal heat creates semi-permanent features in its atmosphere, such as cloud bands and the Great Red Spot. The planet possesses a 4.2–14 Gauss strength magnetosphere that spans 22–29 million km, making it, in certain respects, the largest object in the Solar System.[129] Jupiter has 80 known satellites. The four largest, Ganymede, Callisto, Io, and Europa, are called the Galilean moons: they show similarities to the terrestrial planets, such as volcanism and internal heating.[130] Ganymede, the largest satellite in the Solar System, is larger than Mercury; Callisto is almost as large.[131]

Saturn

Saturn (9.5 AU (1.42 billion km; 880 million mi) from the Sun), distinguished by its extensive ring system, has several similarities to Jupiter, such as its atmospheric composition and magnetosphere. Although Saturn has 60% of Jupiter's volume, it is less than a third as massive, at 95 MEarth. Saturn is the only planet of the Solar System that is less dense than water. The rings of Saturn are made up of small ice and rock particles.[132] Saturn has 83 confirmed satellites composed largely of ice. Two of these, Titan and Enceladus, show signs of geological activity;[133] they, as well as five other Saturnian moons (Iapetus, Rhea, Dione, Tethys, and Mimas), are large enough to be round. Titan, the second-largest moon in the Solar System, is bigger than Mercury and the only satellite in the Solar System to have a substantial atmosphere.[134][135]

Uranus

Uranus (19.2 AU (2.87 billion km; 1.78 billion mi) from the Sun), at 14 MEarth, has the lowest mass of the outer planets. Uniquely among the planets, it orbits the Sun on its side; its axial tilt is over ninety degrees to the ecliptic. This gives the planet extreme seasonal variation as each pole points toward and then away from the Sun.[136] It has a much colder core than the other giant planets and radiates very little heat into space.[137] As a consequence, it has the coldest planetary atmosphere in the Solar System.[138] Uranus has 27 known satellites, the largest ones being Titania, Oberon, Umbriel, Ariel, and Miranda.[139] Like the other giant planets, it possesses a ring system and magnetosphere.[140]

Neptune

Neptune (30.1 AU (4.50 billion km; 2.80 billion mi) from the Sun), though slightly smaller than Uranus, is more massive (17 MEarth) and hence more dense. It radiates more internal heat than Uranus, but not as much as Jupiter or Saturn.[141] Neptune has 14 known satellites. The largest, Triton, is geologically active, with geysers of liquid nitrogen.[142] Triton is the only large satellite with a retrograde orbit, which indicates that it did not form with Neptune, but was probably captured from the Kuiper belt.[143] Neptune is accompanied in its orbit by several minor planets, termed Neptune trojans, that either lead or trail the planet by about one-sixth of the way around the Sun, positions known as Lagrange points.[144]