Voyage through the Solar System

albedo - fraction of solar energy reflected from an object back into space; ranges from 0.0 to 1.0; the higher the number the greater the reflected energy

angular diameter - angle subtended by a diameter of a distant spherical body which is perpendicular to the line between the observer and the center of the body, usually measured in arcseconds

angular momentum - the quantity of rotation of a body, which is the product of its moment of inertia and its angular velocity

anorthosite – a plutonic rock composed largely of calcic plagioclase

aphelion – the location in an object's orbit when it is farthest from the Sun

apparent magnitude – measure of the brightness of an object as seen from Earth; the lower the number, the brighter the object

arcsecond – an angle measurement of 1/3600th of a degree; designated by the symbol "

asteroid – a small rocky body orbiting the Sun

asteroid belt – the circumstellar disc in the solar system located roughly between the orbits of the planets Mars and Jupiter; occupied by numerous irregularly shaped bodies called asteroids or minor planets

asthenosphere – the upper layer of the Earth's mantle, below the lithosphere, there is low resistance to plastic flow and convection occurs

astronomical unit (AU) – the mean distance between the Earth and the Sun, approximately 149,600,000 km

atmosphere – the envelope of gases surrounding the Earth or another planet or moon

bar – a metric unit of pressure equal to 100,000 pascals (Pa), slightly less than the average atmospheric pressure on Earth at sea level

belt – dark, linear, low altitude, downdrafting pressure band in Jupiter's atmosphere

biosignature – any substance, such as an element, isotope, molecule, or phenomenon, that provides scientific evidence of past or present life

carbon dioxide – naturally occurring chemical compound consisting of a carbon atom covalently double bonded to two oxygen atoms

carbonaceous chondrite – a member of the class of primitive meteorites composed mainly of silicates, oxides and sulfides, with the minerals olivine and serpentine

celestial sphere – an imaginary sphere of which the observer is the center and on which all celestial objects are considered to lie

Celsius (^{0}C) - the scale of temperature in which water freezes at 0° and boils at 100° under standard conditions

centaur – a minor planet with a semi-major axis between those of the outer planets; has an unstable orbit that crosses the orbits of one or more of the giant planets

chromosphere – a reddish gaseous layer immediately above the photosphere of the Sun or another star; constitutes the star's outer atmosphere

comet - a small, icy object made of ice, dust, and small pieces of rock, that orbits the sun and has a long "tail" of gas

comparative planetology – a branch of planetary science in which different natural processes and systems are studied by their effects and phenomena on and between multiple bodies

convection – the movement caused within a fluid by the tendency of hotter, less dense material to rise, and colder, denser material to sink under the influence of gravity, which results in transfer of heat

convective zone – a region of turbulent plasma between a star's core and its visible photosphere at the surface, through which energy is transferred by convection; hot plasma rises, cools as it nears the surface, and falls to be heated and rise again

core – the center of a star, planet, or other celestial body

corona – the rarefied gaseous envelope of the Sun and other stars; normally visible only during a total solar eclipse when it is seen as an irregularly shaped pearly glow surrounding the darkened disk of the moon

cosmic radiation – radiation consisting of cosmic rays

cubewano - a Kuiper belt object that orbits beyond Neptune and is not controlled by an orbital resonance with the giant planet

differentiation – process in which a mixture of materials separates out into its constituent parts based on density; denser materials sink and lighter materials rise

dwarf planet - a celestial body orbiting the Sun that is massive enough to be rounded by its own gravity but has not cleared its neighboring region of planetesimals and is not a satellite; has to have sufficient mass to overcome rigid body forces and achieve hydrostatic equilibrium

ecliptic - a great circle on the celestial sphere representing the Sun's apparent path during the year; lunar and solar eclipses can occur only when the Moon crosses it

escape velocity – the speed needed to "break free" of the gravity of a celestial object

exoplanet – a planet that orbits a star other than the Sun

felsic - relating to or denoting a group of light-colored minerals including feldspar, feldspathoids, quartz, and muscovite

frost line - the location in the solar system where volatiles become ices, instead of remaining in gaseous or liquid states

galactocentric – relative to the center of the galaxy

galaxy – a system of millions or billions of stars, together with gas and dust, held together by gravitational attraction

gas giant - a large planet that is not primarily composed of rock or other solid matter which may have a liquid metallic core

geocentric – relative to the center of the Earth

granule – one of the small, transient, luminous markings in the photosphere of the sun

great circle – a circle on the surface of a sphere that lies in a plane passing through the sphere's center; it represents the shortest distance between any two points on a sphere

greenhouse gas – a gas that contributes to the greenhouse effect by absorbing infrared radiation

habitable zone – the range of orbits around a star within which a planetary surface can support liquid water given sufficient atmospheric pressure

heliocentric – relative to the center of the Sun

helium – the second most common element in the universe

heteropolymer – a compound formed from subunits that are not all the same

hydrogen – the most common element in the universe

hydrosphere – all the waters on the surface of a celestial body, including lakes, rivers, seas, and clouds

hydrostatic equilibrium - when compression due to gravity is balanced by a pressure in the opposite direction; in celestial bodies it is frequently the result of gravity pulling inward and pressure pushing outward

ice dwarf - larger than the nucleus of a normal comet and icier than a typical asteroid

ice giant – a large planet composed mostly of hydrogen and helium as well as water, ammonia, and methane ices which may have a liquid metallic core

infrared radiation – refers to energy in the region of the electromagnetic radiation spectrum at wavelengths longer than those of visible light, but shorter than those of radio waves

jovian planet – a large planet composed mostly of hydrogen and helium, lacking a visible solid surface, and which may have a liquid metallic core; categories include gas giant and ice giant

Kelvin (K) – temperature used in science, where absolute zero is 0 K, the freezing point of water is 273 K, and the boiling point of water is 373 K

Kuiper belt – a region of the solar system beyond the planets extending from the orbit of Neptune, at 30 AU, to approximately 55 AU from the Sun

libration – an oscillation of the Moon, by which parts near the edge that are often not visible from the Earth sometimes come into view

lithosphere – the rigid outer part of the Earth, consisting of the crust and upper mantle

luminosity - the intrinsic brightness of a celestial object

lunar – referring to the Moon

lunar eclipse – occurs at full moon, when the Sun, Earth, and Moon are in a straight line

mafic – relating to, denoting, or containing a group of dark-colored, mainly ferromagnesian minerals such as pyroxene and olivine

magnetic field – a region around a magnetic material or a moving electric charge within which the force of magnetism acts

main sequence - a series of star types to which most stars belong, represented on a Hertzsprung–Russell diagram as a continuous band extending from the upper left (hot, bright stars) to the lower right (cool, dim stars)

mantle – the region of the interior of the Earth between the core (on its inner surface) and the crust (on its outer)

maria – dark and relatively featureless lunar plains

mascon - large positive gravitational anomaly associated with giant impact basins on the Moon

maximum elongation – location in an orbit where a planet appears to have its largest angular separation from the Sun

methane – a colorless, odorless, flammable gas that is the simplest hydrocarbon

minor planet – an astronomical object in direct orbit around the Sun that is neither a planet nor exclusively classified as a comet; can be dwarf planets, asteroids, trojans, centaurs, Kuiper belt objects, and other trans-Neptunian objects

molten – melted by intense heat

moon – a natural satellite of a planet

nanotesla – a unit of magnetic flux density equal to 10^{-9} tesla

natural satellite - celestial body, usually referred to simply as a moon, that orbits a planet or smaller body, which is called the primary

nebula - an interstellar cloud of dust, hydrogen gas and plasma

nucleosynthesis – the cosmic formation of atoms more complex than the hydrogen atom

Oort cloud – a spherical shell of cometary bodies believed to surround the Sun far beyond the orbits of the outermost planets and from which some are dislodged when perturbed to fall toward the Sun

ophiolite – an igneous rock consisting largely of serpentine; believed to have been formed from the submarine eruption of oceanic crustal and upper mantle material

orbital resonance – occurs when two orbiting bodies exert a regular, periodic gravitational influence on each other, usually because their orbital periods are related by a ratio of two small integers

pascal (Pa) - unit of pressure, equal to one newton per square meter (approximately 0.000145 pounds per square inch, or 9.9×10^{-6} atmospheres)

perihelion – the location in an object's orbit when it is closest to the Sun

perturbation – a deviation of a system, moving object, or process from its regular or normal state of path, caused by an outside influence

photosphere – the luminous visible surface of the Sun, where there is a shallow layer of strongly ionized gases

planet - an object in orbit around the Sun, has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a nearly round shape, and has cleared the neighborhood around its orbit

planetary nebula – an emission nebula consisting of an expanding, glowing shell of ionized gas ejected from old red giant stars late in their lives

planetesimal - solid objects in protoplanetary discs in the process of becoming planets

plasma – an ionized gas consisting of positive ions and free electrons in proportions resulting in more or less no overall electric charge, typically at very high temperatures found in stellar interiors

plutino - a trans-Neptunian object in 2:3 mean motion resonance with Neptune

protoplanet – a large body of matter in orbit around the Sun or a star and thought to be developing into a planet

protoplanetary disc - a rotating circumstellar disc of dense gas and dust surrounding a young newly formed star

protostar - a contracting mass of gas that represents an early stage in the formation of a star, before nucleosynthesis has begun

radiative diffusion – random, heat-driven motions of photons

radiative zone – a layer of a star's interior where energy is primarily transported toward the exterior by means of radiative diffusion and thermal conduction

retrograde motion – apparent backward motion of a celestial object, especially a planet, as a result of Earth overtaking it in its orbit

Roche limit - mimimum distance within which a small object, held together by its own gravity, can get to a more massive object before it is pulled apart by the tidal stresses caused by the massive object, which is approximately 2.5 times the radius of the more massive object

saros cycle – the period of time, just under 19 years, between successive lunar or solar eclipses occurring when the Sun, Earth, and Moon are in the same positions relative to one another

scattered disc object – an object in the distant circumstellar disc in the solar system that is sparsely populated by icy minor planets; a subset of the broader family of trans-Neptunian objects; has high orbital eccentricity and orbital inclination, and a perihelion greater than 30 AU

semimajor axis – one half of the major axis, and thus runs from the center, through a focus, and to the perimeter

sidereal rotation period - rotation of a celestial object observed relative to a fixed point outside the solar system; Earth’s sidereal rotation period is 23 h 56 m 4.1 s

silicate - any of the many minerals consisting primarily of SiO_4^{2-} combined with metal ions, forming a major part of Earth's crust

solar – referring to the Sun

solar eclipse – occurs at new moon, when the Sun, Moon, and Earth are in a straight line

spectrum - the range of wavelengths or frequencies over which electromagnetic radiation extends

star - massive, luminous ball of plasma that shines due to thermonuclear fusion in its cores, which release energy that radiates into outer space; almost all elements heavier than hydrogen and helium were created by fusion processes in stars

subduction - the sideways and downward movement of the edge of a plate of the Earth's crust into the mantle beneath another plate

sunspot – temporary phenomenon on the photosphere of the Sun that appears as a dark spot compared to surrounding regions; an area of reduced surface temperature caused by concentrations of magnetic field flux that inhibit convection; usually appear in pairs of opposite magnetic polarity

surface gravity – gravitational acceleration at the surface of an object; on Earth it is approximately 9.81 m/s^2

synchronous rotation – the result of tidal forces that over time slow the rotation of the smaller body until it is synchronized with its period of revolution around the larger body

synodic period - time for an object to reappear at the same point in the sky, relative to the Sun, as observed from Earth

tachocline – the transition region of the Sun between the radiative interior and the differentially rotating outer convective zone

terrae – lunar highlands

terrestrial planet - composed primarily of silicate rocks and having a solid surface

tholin - heteropolymer molecule formed by solar ultraviolet irradiation of simple organic compounds

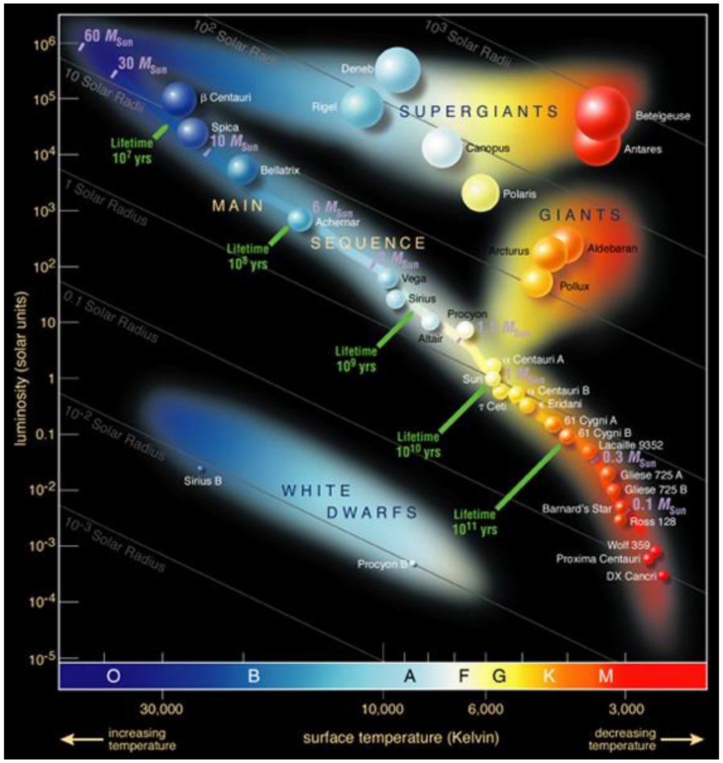
trans-Neptunian object (TNO) - any minor planet in the solar system that orbits the Sun at a greater average distance (semi-major axis) than Neptune, 30 astronomical units (AU)

ultraviolet radiation – electromagnetic radiation having a wavelength longer than that of x-rays but shorter than that of visible light

volatile – a substance that evaporates easily at normal temperatures

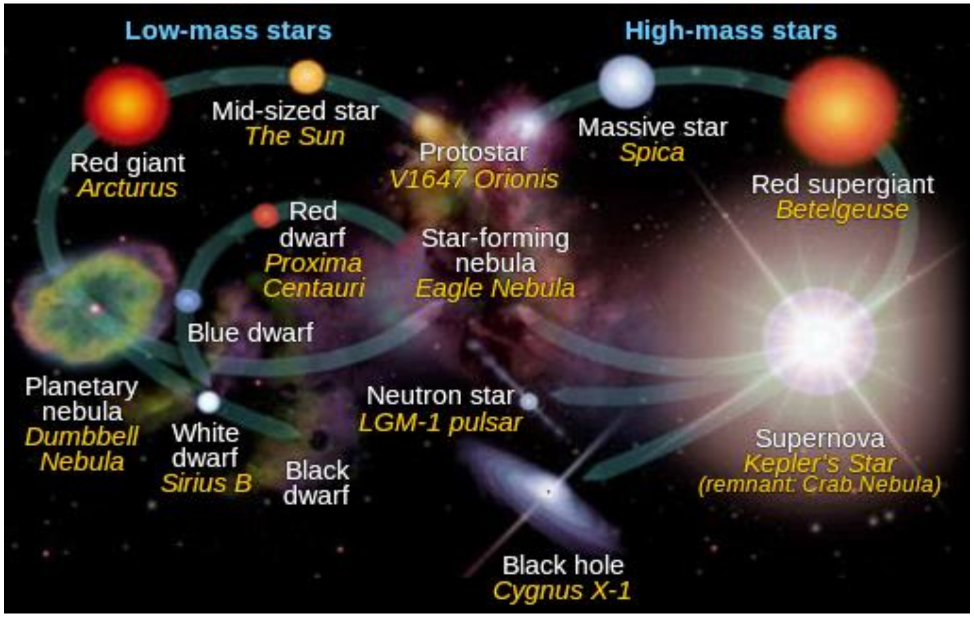
zone – light, linear, high altitude, updrafting high pressure band in Jupiter's atmosphere

Stars



Astronomers can determine the mass, age, chemical composition and many other properties of a star by observing its spectrum, luminosity, and motion through space. A star's total mass is the principal determinant in its evolution and eventual fate. Other characteristics are determined by its evolutionary history, including diameter, rotation, movement and temperature. A plot of the temperature of many stars against their luminosities, known as a Hertzsprung-Russell diagram, or H–R diagram, allows the age and evolutionary state of a star to be determined.

Stars spend about 90% of their lifetime fusing hydrogen to produce helium in high-temperature and high-pressure reactions near the core as main sequence stars. The Sun is estimated to have increased in luminosity by about 40% since it reached the main sequence 4.6 billion years ago.



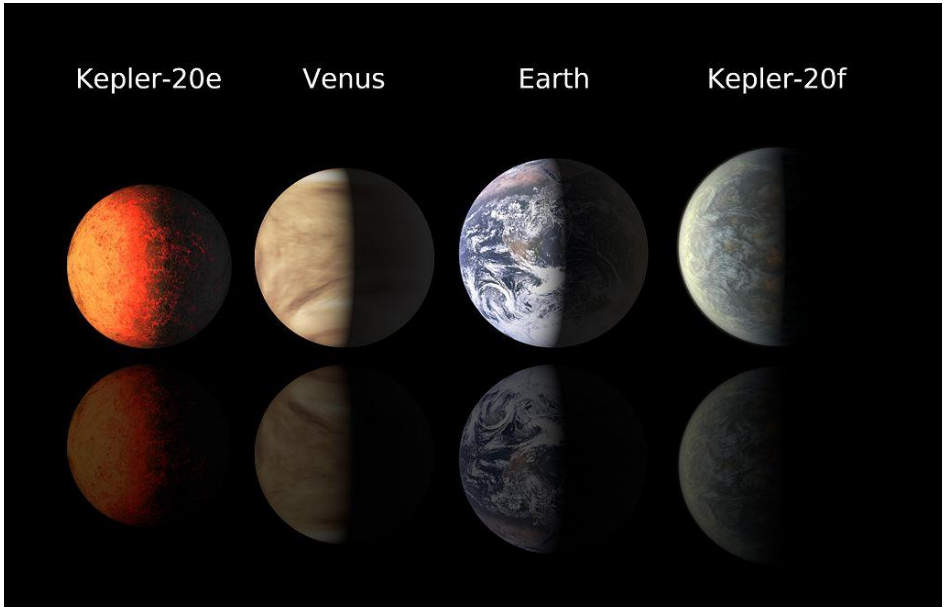
A star's lifetime on the main sequence depends primarily on the amount of fuel it has and the rate at which it burns that fuel. The lifetime of our Sun is estimated to be about 10^{10} years since it is a fairly average star. Large stars burn their fuel more rapidly and have much shorter lives. Small stars, called red dwarfs, burn their fuel very slowly and last tens to hundreds of billions of years, ending their lives as small, dim stars.

(Information: https://en.wikipedia.org/wiki/Star; H-R diagram: https://en.wikipedia.org/wiki/Hertzsprung%E2%80%93Russell_diagram#/media/File:Hertzsprung-Russel_StarData.png, European Space Agency, CC BY 4.0; Star lifetime diagram: http://scioly.org/wiki/index.php/Astronomy/Stellar_Evolution, Cmglee, NASA Spaceflight Center, CC BY-SA 4.0;)

Planets

1. A "planet" is a celestial body that:
    a. is in orbit around the Sun,
    b. has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a nearly round shape, and
    c. has cleared the neighborhood around its orbit.
2. A "dwarf planet" is a celestial body that:
    a. is in orbit around the Sun,
    b. has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a nearly round shape,
    c. has not cleared the neighborhood around its orbit, and
    d. is not a satellite.
3. All other objects except satellites orbiting the Sun shall be referred to collectively as "Small Solar System Bodies."

Planets are generally divided into two main types: large low-density giant planets, and smaller rocky terrestrial planets. The eight planets in our solar system are the four terrestrials, Mercury, Venus, Earth, and Mars, and the four giant planets, Jupiter, Saturn, Uranus, and Neptune. Six of these have at least one or more natural satellites.



More than two thousand planets around other stars, called exoplanets, have been discovered in our Milky Way galaxy. As of January, 2017, 3,565 known extrasolar planets in 2,675 planetary systems, including 602 multiple planetary systems, ranging in size from slightly larger than the Moon to gas giants, about twice as large as Jupiter, have been discovered. About 100 are about the same size as Earth, nine of which are at the same relative distance from their star as Earth from the Sun, in the 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 estimated that there is an average of at least 1.6 bound planets for every star in the Milky Way. Around one in five Sun-like stars may have an Earth-sized planet in its habitable zone.

(Information: https://en.wikipedia.org/wiki/Planet; Planet comparison diagram: https://en.wikipedia.org/wiki/Kepler-20e#/media/File:Kepler_20_-_planet_lineup.jpg, NASA/Ames/JPL/Caltech, public domain)

Solar System Formation

Solar system formation began 4.6 billion years ago with the gravitational collapse of a small part of a giant molecular cloud. The collapsing mass collected at the center formed the Sun, while the rest flattened into a protoplanetary disc out of which the planets, moons, asteroids, and other small solar system bodies formed. The oldest inclusions of this material, found in meteorites, are 4.568 billion years old, which helps astronomers determine the age of the solar system.

As the material within the nebula collapsed and condensed, its atoms collided with increasing frequency, converting their kinetic energy into heat. The center became hotter than the surrounding disc. Over about 100,000 years, the competing forces of gravity, gas pressure, magnetic fields, and rotation caused the contracting nebula to flatten into a spinning protoplanetary disc with a diameter of about 200 AU. A hot, dense protostar, a star in which hydrogen fusion has not yet begun, formed at the center.

At that point, the Sun was considered to be a T Tauri star, a star often accompanied by a disc of pre-planetary matter, with masses of 0.001–0.1 times the mass of the Sun. Within 50 million years, the temperature and pressure at the core of the Sun became so great that its hydrogen began to fuse, creating an internal source of energy that countered gravitational contraction until hydrostatic equilibrium was achieved, and the Sun became a main sequence star.

The inner solar system, inside 4 AU, was too warm for volatile molecules like water and methane to condense, so planetesimals that formed there could only form from compounds with high melting points, such as metals, including iron, nickel, and aluminium, and rocky silicates. These rocky bodies became the terrestrial planets Mercury, Venus, Earth, and Mars.

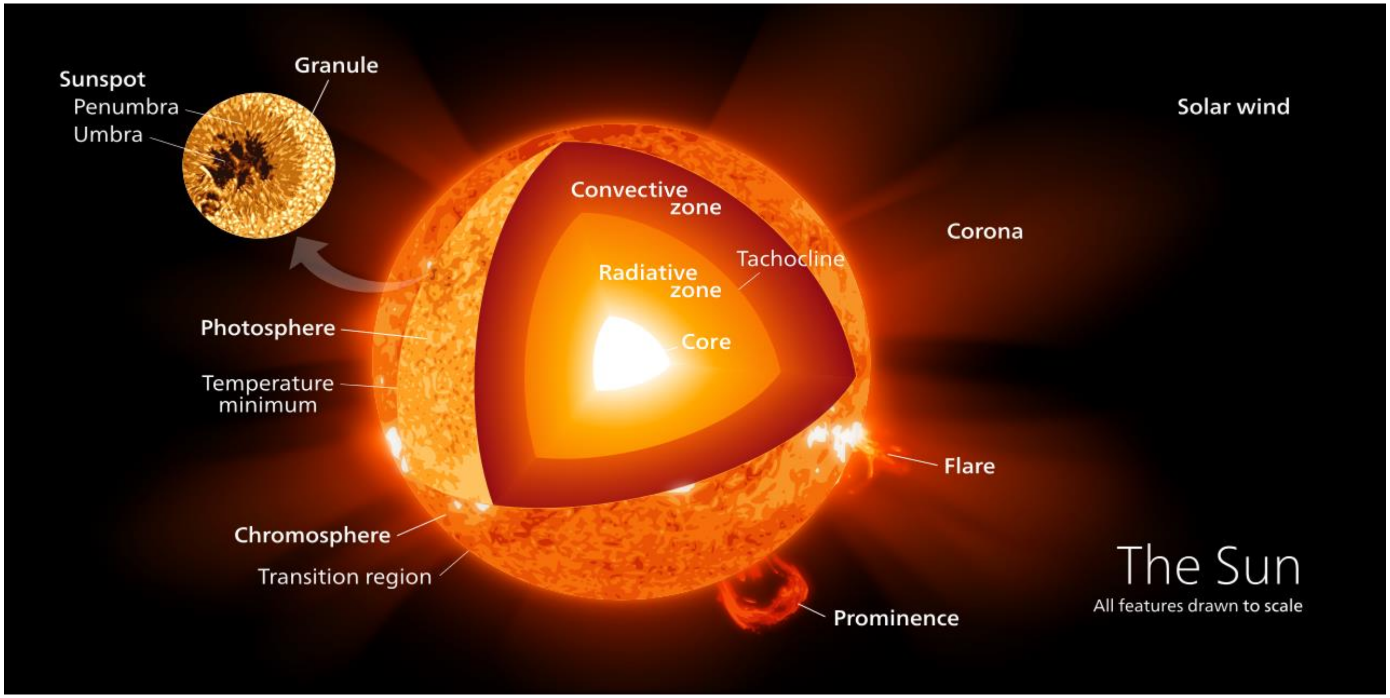
The outer edge of the terrestrial region, between 2 and 4 AU from the Sun, is the asteroid belt. Many planetesimals formed there, later coalesced, and formed 20–30 Moon- to Mars-sized planetary sized bodies. Orbital resonances with Jupiter and Saturn are strong in the asteroid belt, and gravitational interactions scattered many of them into those resonances. Jupiter's gravity increased their velocity, so many of them collided and shattered.

The giant planets, Jupiter, Saturn, Uranus, and Neptune, formed out beyond the frost line, the point between the orbits of Mars and Jupiter where the material is cool enough for volatile icy compounds to remain solid. The ices that formed the Jovian planets were more abundant than the metals and silicates that formed the terrestrial planets, allowing the giant planets to grow massive enough to capture hydrogen and helium, the lightest and most abundant elements. The four giant planets comprise just under 99% of all the mass orbiting the Sun

The Sun is currently a G-type main-sequence star (G2V). In about 5 billion years, the Sun will cool and expand outward to become a red giant, before casting off its outer layers to become a planetary nebula and leaving behind a stellar remnant known as a white dwarf. In the far distant future, the gravity of passing stars will gradually reduce the Sun's planets. Some will be destroyed, others ejected into interstellar space.

(Information: https://en.wikipedia.org/wiki/Formation_and_evolution_of_the_Solar_System)

Structure of the Sun



The core of the Sun extends from the center to about 0.2 solar radii. It has a density of up to 150 gm/cm³, 150 times the density of water on Earth, and a temperature of close to 13,600,000 K. Its surface temperature is about 5,800 K.

From about 0.2 to about 0.7 solar radii, solar material is hot and dense enough that thermal radiation is sufficient to transfer the intense heat of the core outward. Heat is transferred by radiation. Ions of hydrogen and helium emit photons, which travel a brief distance before being reabsorbed by other ions. In this way energy makes its way very slowly outward.

Between the radiative zone and the convective zone is a transition layer called the tachocline. This is a region where there is a sharp change between the uniform rotation of the radiative zone and the differential rotation of the convective zone, resulting in a large shear, meaning successive vertical layers slide past one another.

In the Sun's outer layer, down to approximately 70% of the solar radius, solar plasma is not dense or hot enough to transfer the heat energy of the interior outward via radiation. Thermal convection occurs as thermal columns carry hot material to the photosphere of the Sun. Once the material cools off at the surface, it plunges back down to the base of the convection zone, to receive more heat from the top of the radiative zone.

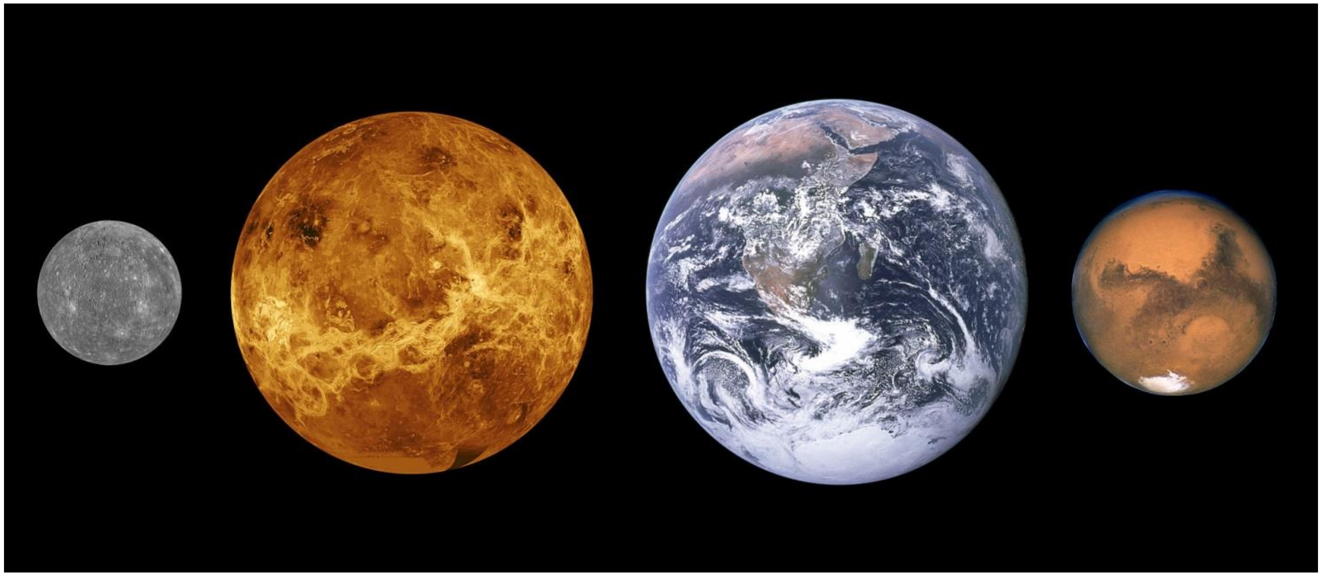
The thermal columns in the convection zone form an imprint on the surface of the Sun, in the form of the solar granulation and supergranulation. Turbulent convection of this outer part of the solar interior gives rise to a "small-scale" dynamo that produces magnetic north and south poles all over the surface of the Sun resulting in sunspots.

The visible surface of the Sun, the photosphere, is the layer below which the Sun becomes opaque to visible light. Above the photosphere visible sunlight is free to propagate into space, and its energy escapes the Sun entirely. The layers above are the chromosphere and the corona, visible only during a solar eclipse.

(Information: https://en.wikipedia.org/wiki/Sun#Structure; Solar interior diagram: https://en.wikipedia.org/wiki/Sun#/media/File:Sun_poster.svg, Kelvinsong, CC BY-SA 3.0)

Terrestrial Planets

Terrestrial planets all have roughly the same structure: a central metallic core, mostly iron, with a surrounding silicate mantle. The Moon is similar, but lacks an iron core. Terrestrial planets have canyons, craters, mountains, and volcanoes, and possess secondary atmospheres generated through internal volcanism or comet impacts, as opposed to the gas giants, which possess primary atmospheres captured directly from the original solar nebula.



Terrestrial planets

Theoretically, there are two types of terrestrial or rocky planets, one dominated by silicon compounds and another dominated by carbon compounds, like carbonaceous chondrite asteroids. Earth's solar system has four terrestrial planets: Mercury, Venus, Earth and Mars.

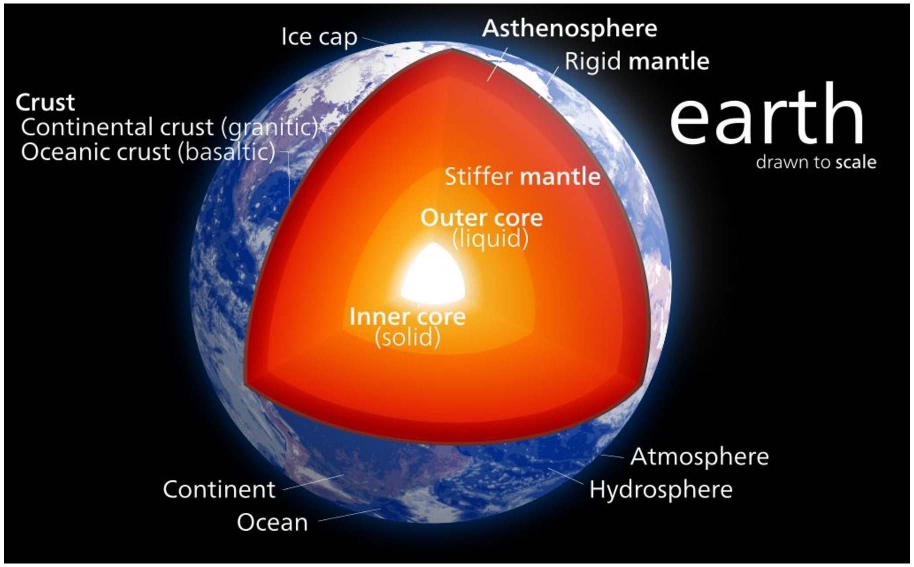
Dwarf planets, such as Ceres and Pluto, and large small solar system bodies are similar to terrestrial planets in the fact that they do have a solid surface, but are composed of more icy materials.

During the formation of the solar system, there were probably many more planetesimals, but they have all merged with or been destroyed by the remaining planets in the solar nebula. Only one terrestrial planet, Earth, is known to have an active hydrosphere.

Earth's moon, Jupiter's satellites Io and Europa, and Saturn’s moon Titan can also be regarded as terrestrial worlds, though since they orbit planets they cannot be considered planets. Io and Europa have mainly rocky compositions despite forming beyond the frost line. Titan has a solid surface and is covered by thick nitrogen smog. The region of the circum-Jovian disc in which they formed was kept too warm by radiation from the proto-Jupiter to contain large quantities of icy material.

(Information: https://en.wikipedia.org/wiki/Terrestrial_planet; Terrestrial planets: https://en.wikipedia.org/wiki/Terrestrial_planet#/media/File:Terrestrial_planet_sizes.jpg, NASA, Mercury image: JHUAPL, Venus image: JPL, Mars image: HST, public domain)

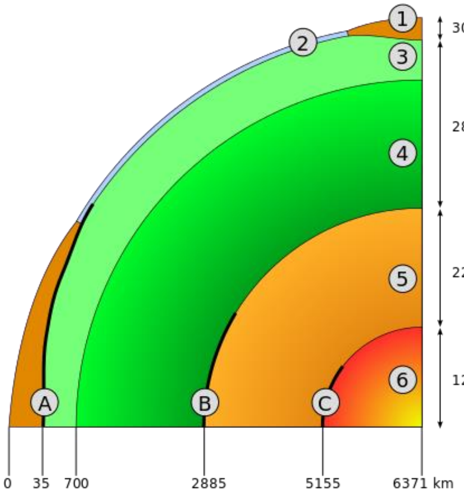
Structure of Earth



In early stages of Earth's formation about four and a half billion years ago, melting would have caused denser substances to sink toward the center in a process called planetary differentiation while less-dense materials migrated to the crust. The core is likely composed of iron (80%), along with nickel and one or more light elements.

The crust ranges from 5 to 70 km in depth. The thin parts are oceanic crust composed of dense (mafic) iron magnesium silicate rocks, like basalt. The thicker crust is continental crust, which is less dense and composed of (felsic) sodium potassium aluminium silicate rocks, like granite. The crust-mantle boundary occurs as two physically different events.

First, there is a discontinuity in the seismic velocity, which is known as the Mohorovičić discontinuity likely caused by a change in rock composition from rocks containing plagioclase feldspar (above) to rocks that contain no feldspars (below). Second, there is a chemical discontinuity between ultramafic cumulates and tectonized harzburgites (ultramafic rock), which has been observed from deep parts of the oceanic crust that have been subducted into the continental crust and preserved as ophiolite (uplifted oceanic crust) sequences.



The core-mantle boundary or Gutenberg discontinuity lies between the Earth's silicate mantle and its liquid iron-nickel outer core. This boundary is located at approximately 2,900 km beneath the surface.

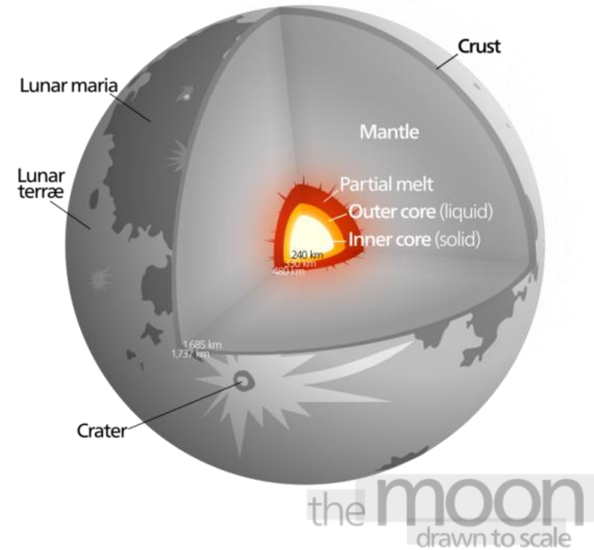
Earth's mantle extends to a depth of 2,890 km, making it the largest layer of Earth. The mantle is composed of silicate rocks that are rich in iron and magnesium relative to the overlying crust.

Seismic measurements show that the core is divided into two parts, a solid inner core with a radius of ~1,220 km and a liquid outer core extending beyond it to a radius of ~3400 km. The solid inner core was discovered in 1936 by Inge Lehmann and is generally believed to be composed primarily of iron and some nickel.

1. continental crust; 2. oceanic crust; 3. upper mantle; 4. lower mantle; 5. outer core; 6. inner core; A: Mohorovičić discontinuity; B: Gutenberg Discontinuity; C: Lehmann–Bullen discontinuity.

(Information: https://en.wikipedia.org/wiki/Structure_of_the_Earth; Earth diagram: https://en.wikipedia.org/wiki/Structure_of_the_Earth#/media/File:Earth_poster.svg, Kelvinsong, CC BY-SA 3.0; Earth structure diagram: https://en.wikipedia.org/wiki/Structure_of_the_Earth#/media/File:Slice_earth.svg, Dake, CC BY-SA 2.5)

More About the Moon



The crust is anorthositic, composed primarily of oxygen, silicon, magnesium, iron, calcium, and aluminium. Its thickness is estimated to be about 50 km. The dark and relatively featureless lunar plains are called maria, Latin for seas, since they were believed by ancient astronomers to be filled with water, but are now known to be solidified pools of ancient basaltic lava. Maria are found almost exclusively on the near side of the Moon, with the far side having only a few scattered patches.

The lighter-colored regions of the Moon are called terrae, or highlands. Mountain ranges on the near side are found along the periphery of the giant impact basins, many of which have been filled by mare basalt. These are believed to be the surviving remnants of the impact basin's outer rims.

Eclipses can occur only when the Sun, Earth, and Moon are all in a straight line. Solar eclipses occur near a new moon, when the Moon is between the Sun and Earth. Lunar eclipses occur near a full moon, when the Earth is between the Sun and Moon.

Because the Moon's orbit around the Earth is inclined by about 5° with respect to the orbit of the Earth around the Sun, eclipses do not occur at every full and new moon. For an eclipse to occur, the Moon must be near the intersection of the two orbital planes. The periodicity and recurrence of eclipses of the Sun by the Moon, and of the Moon by the Earth, is described by the saros cycle, which has a period of approximately 18 years 11 days 8 hours.

The Moon appears larger when close to the horizon. This is an optical illusion.

The major characteristic of the Moon's gravitational field is the presence of mascons, large positive gravitational anomalies associated with some of the giant impact basins. These anomalies greatly influence the orbit of spacecraft about the Moon, and an accurate gravitational model is necessary in the planning of both manned and unmanned missions. The Moon has an external magnetic field of the order of one to a hundred nanotesla, less than one hundredth that of the Earth, and an atmosphere so thin as to be almost negligible.

Neil Armstrong became the first person to walk on the Moon as the commander of Apollo 11 by first setting foot on the Moon at 02:56 UTC on July 21, 1969. Eugene Cernan and Harrison Schmitt, as part of the mission Apollo 17, left the surface of the Moon on December 14, 1972 and no one has set foot on it since.

Although many American, Soviet, and Russian unmanned spacecraft have landed on the Moon, no nation currently claims ownership of any part of the Moon's surface. Russia and the U.S. are party to the Outer Space Treaty, which places the Moon under the same jurisdiction as international waters. This treaty also restricts the use of the Moon to peaceful purposes, explicitly banning military installations and weapons of mass destruction.

(Information: https://en.wikipedia.org/wiki/Moon; The Moon diagram: https://en.wikipedia.org/wiki/Moon#/media/File:Moon_diagram.svg, Kelvinsong, CC BY 3.0)

Runaway Greenhouse Effect

Earth and Venus are similar in size, density, and composition. Their atmospheres, however, are very different.

Sunlight falling on a planet's surface is primarily in the visible part of the spectrum, and when reflected, produces light of longer wavelength called infrared radiation, also known as radiant heat. Because of their molecular structures, gases like carbon dioxide, water vapor, and others, are transparent to visible light but absorb infrared radiation. These compounds are called greenhouse gases. In a planetary atmosphere, they absorb the scattered infrared radiation and raise the temperature of the atmosphere by trapping solar energy.

The greenhouse effect occurs in all atmospheres containing greenhouse gases, and is responsible for higher temperatures than would otherwise occur. Under certain conditions the greenhouse effect can "run away."

On Earth there are large amounts of water vapor and carbon dioxide. Most of the water is in the oceans, and the carbon dioxide is primarily bound chemically in rocks made from carbonates, such as limestone. If we increased the effectiveness of greenhouse heating of Earth's atmosphere by increasing the concentration of greenhouse gases by burning fossil fuels, which produce water vapor and carbon dioxide as byproducts of burning, we would expect the atmospheric temperature to rise, causing a greenhouse effect.

It becomes a runaway greenhouse effect if the rising temperature approaches the boiling point of water. Oceans would begin to convert to water vapor, trapping even more heat, accelerating the greenhouse effect, causing the temperature to rise and the oceans to evaporate faster, in what is called a "positive feedback loop." Once the oceans were gone the atmosphere would finally stabilize at a much higher temperature and at much higher density, because all the water would now be in the atmosphere.

Suppose the runaway raised the temperature to a few hundred degrees Celsius, so high that chemical reactions begin to occur that drive the carbon dioxide from the rocks into the atmosphere, a process called sublimation. Another runaway would then occur as the carbon dioxide feeding into the atmosphere accelerated the heating, which would accelerate the transfer of carbon dioxide from the rocks to the atmosphere. The atmosphere would stabilize at a higher temperature and pressure after all the carbon dioxide had been driven from the rocks. On Earth the resulting temperature and pressure of the atmosphere would probably be similar to that on present-day Venus

On Venus, initial solar heating kept oceans from forming, or kept them from staying around if they did form. Absence of rainfall and plant life kept carbon dioxide in the atmosphere, rather than binding it in the rocks as on Earth. Venus has an environmental disaster for an atmosphere, thus Venus may provide a warning of what could happen to our atmosphere if we don't care for it now.

(Information: https://en.wikipedia.org/wiki/Runaway_greenhouse_effect)

Exploring Mars

By studying the similarities and differences between Earth and Mars, a process called comparative planetology, we can learn more about our own planet as well as Mars.

Goal 1: Determine if Life ever arose on Mars.
On Earth, we find life in many places where sunlight never reaches: at dark ocean depths, inside rocks, and deep below the surface. Chemical and geothermal energy are also energy sources used by life forms on Earth, and could be used by tiny, subsurface microbes on Mars. NASA will also look for life on Mars by searching for biosignatures, of current and past life, including carbon, carbonate minerals, dried waterways, and fossils, however, it is possible that Martian life, if it exists, could possess different chemistry and form.

Goal 2: Characterize the Climate of Mars.
The Martian climate is regulated by seasonal changes of the carbon dioxide ice caps, the movement of large amounts of dust by the atmosphere, and the exchange of water vapor between the surface and the atmosphere. Dust storms generally occur in the southern spring and summer, and can cover the entire planet.

Goal 3: Characterize the Geology of Mars.
Mars once had a magnetic field, as Earth does today. Magnetic fields shield planets from cosmic radiation, so this discovery has important implications for the prospects for finding evidence of past Martian life. Studying the magnetic field provides important information about the interior structure, temperature and composition of Mars in the past, and the age and composition of different types of rocks on the Martian surface can help geologists determine the sequence of events in its history.

Goal 4: Prepare for Human Exploration of Mars.
Mars lacks an ozone layer, which shields us from lethal doses of solar ultraviolet radiation. A more detailed understanding of the Martian radiation environment will provide information to assess the effects of UV radiation on astronauts, and help engineers design protective space suits and habitats.

There have been several unmanned missions to Mars since the 1960s. Curiosity, launched in 2011, is a car-sized robotic rover exploring Gale Crater on Mars as part of NASA's Mars Science Laboratory mission (MSL). As of January 2017, Curiosity has been on Mars for nearly 1600 sols (Mars days) since landing on August 6, 2012. The rover's goals include: investigation of the Martian climate and geology; assessment of whether the selected field site inside Gale Crater has ever offered environmental conditions favorable for microbial life, including investigation of the role of water; and planetary habitability studies in preparation for future human exploration. In December 2012, Curiosity's two-year mission was extended indefinitely.

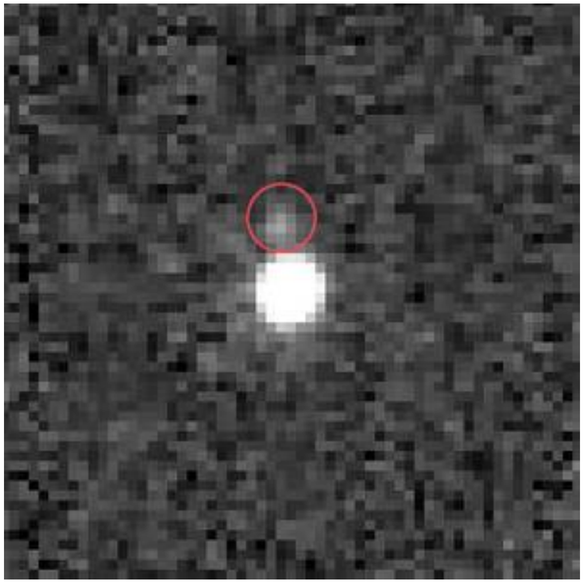
Curiosity selfie

(Information: https://en.wikipedia.org/wiki/Mars_Exploration_Program, https://en.wikipedia.org/wiki/Curiosity_(rover); Curiosity selfie: https://en.wikipedia.org/wiki/Curiosity_(rover)#/media/File:Curiosity_Self-Portrait_at_%27Big_Sky%27_Drilling_Site.jpg, NASA, public domain)

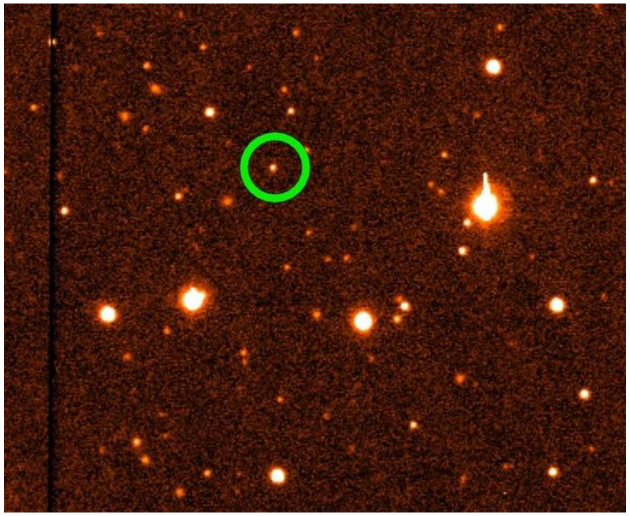
Dwarf Planets

The term dwarf planet was adopted in 2006 as part of a three-way categorization of bodies orbiting the Sun, brought about by an increase in discoveries of transNeptunian (TNO) objects that rivaled Pluto in size, and finally resulted in the discovery of an even larger object, Eris. The International Astronomical Union (IAU) currently recognizes five dwarf planets: Ceres, Pluto, Haumea, Makemake, an Eris

It is suspected that another hundred or so known objects in the solar system are dwarf planets. Estimates are that up to 200 dwarf planets may be found when the entire Kuiper belt is explored, and that the number may exceed 10,000 when objects scattered outside the Kuiper belt are considered.



2007 OR10 and its moon



90482 Orcus

Astronomer Mike Brown identified ten known trans-Neptunian objects, the four accepted by the IAU plus 2007 OR10, Quaoar, Sedna, 90482 Orcus, (307261) 2002 MS4 and Salacia as "virtually certain," with another twenty highly likely.

"Ice dwarf" is not an IAU classification, and it overlaps with the official cubewano (a Kuiper belt object that orbits beyond Neptune and is not controlled by an orbital resonance with the giant planet) and plutino (a trans-Neptunian object in 2:3 mean motion resonance with Neptune) classifications. One attempted definition is that an ice dwarf "is larger than the nucleus of a normal comet and icier than a typical asteroid." There are large numbers of such objects in the Oort cloud and the Kuiper belt. It is not clear that all ice dwarfs are actually icier than icy asteroids such as Ceres, now considered a dwarf planet. Ceres is sometimes called a terrestrial dwarf to distinguish it from Pluto and Eris.

Information: http://en.wikipedia.org/wiki/Dwarf_planet, http://en.wikipedia.org/wiki/Ice_dwarf, http://en.wikipedia.org/wiki/Plutino, http://en.wikipedia.org/wiki/Cubewano; 2007 OR10: https://en.wikipedia.org/wiki/(225088)_2007_OR10#/media/File:2007_OR10_and_its_moon.png, NASA, public domain; 90482 Orcus: https://en.wikipedia.org/wiki/90482_Orcus#/media/File:Orcus_nasa.jpg, NASA, public domain)

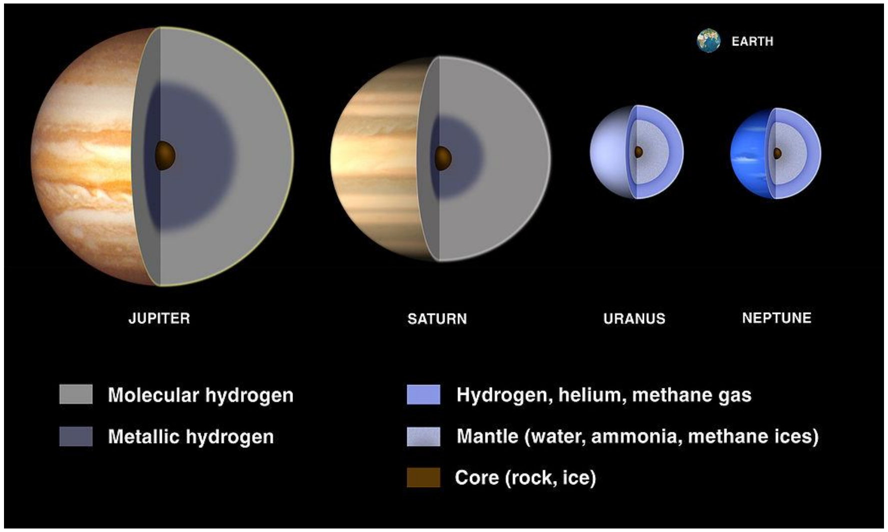
Jovian Planets

A jovian planet is a large planet that is not primarily composed of rock or other solid matter. Jovian planets can be subdivided into different types: gas giants and ice giants.

A gas giant is composed mainly of hydrogen and helium. Jupiter and Saturn are the gas giants of the solar system. In the 1990s it became known that Uranus and Neptune are really a distinct class of giant planet, being composed mainly of heavier volatile substances, referred to as "ices." Uranus and Neptune are now classified in the separate category of ice giants.

Jupiter and Saturn are both more than 90% hydrogen and helium by mass, with heavier elements making up between 3 and 13 percent of the mass. They consist of an outer layer of molecular hydrogen surrounding a layer of liquid metallic hydrogen, and probably have a molten rocky core. The outermost part of their hydrogen atmosphere is characterized by many layers of visible clouds composed mostly of water and ammonia. The layer of metallic hydrogen makes up the bulk of each planet, and is referred to as "metallic" because large pressure turns hydrogen into an electrical conductor. The gas giants' cores may consist of heavier elements at such high temperatures (20,000 K).

An ice giant is a giant planet composed mainly of elements heavier than hydrogen and helium, such as oxygen, carbon, nitrogen, and sulfur. Ice giants consist of only about 20% hydrogen and helium by mass. A jovian planet is an ice giant if its compounds were ices when they were primarily incorporated into the planet during its formation, either directly in the form of ices or trapped in water ice. The amount of solid volatiles within the ice giants today is very small.



All four planets rotate relatively rapidly, which causes wind patterns to break up into east-west bands or stripes. These bands are prominent on Jupiter, muted on Saturn and Neptune, and barely detectable on Uranus. The bands seen in the jovian atmosphere are due to counter-circulating streams of material called zones and belts, encircling the planet parallel to its equator. The zones are the lighter bands, and are at higher altitudes. They have internal updraft, and are high-pressure regions.

The belts are the darker bands. They are lower in the atmosphere, and have internal downdraft. They are low-pressure regions. These structures are somewhat analogous to high- and low-pressure cells in Earth's atmosphere, but have a much different structure as latitudinal bands that circle the entire planet, as opposed to small confined cells of pressure. This appears to be a result of the rapid rotation and underlying symmetry of the planet.

(Information: http://en.wikipedia.org/wiki/Jovian_planet, https://en.wikipedia.org/wiki/Gas_giant, https://en.wikipedia.org/wiki/Ice_giant; Gas giant diagram: https://en.wikipedia.org/wiki/Giant_planet#/media/File:Gas_Giant_Interiors.jpg, NASA, public domain)

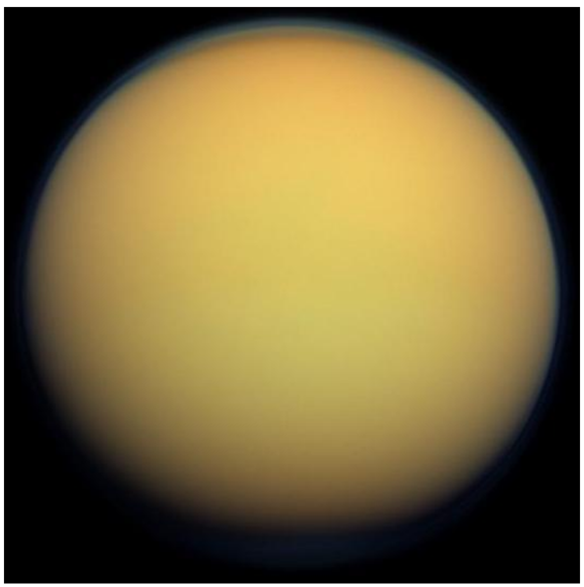
Moons

The jovian planets have extensive systems of moons, including half a dozen comparable in size to Earth's moon: the four Galilean moons Io, Europa, Ganymede, and Callisto, Saturn's Titan, and Neptune's Triton. Of the inner planets, Mercury and Venus have no moons at all, Earth has one, and Mars has two tiny moons, Phobos and Deimos, which may be captured asteroids.

Jupiter's moons Io, Europa, Ganymede, and Callisto

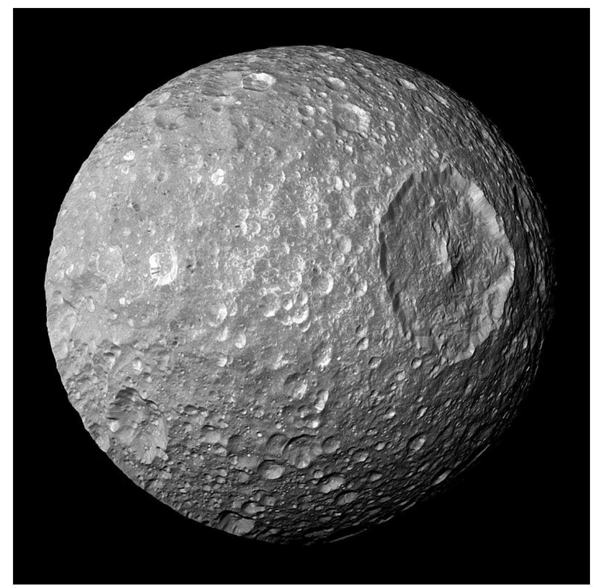
Large planets have many moons in orbit around them because of their high masses and substantial gravitational pull on smaller objects, including asteroids, passing comets, and dust and ice particles. Although the jovian planets have several planet-sized moons, most of their moons are small, many between 100 km and 300 km in diameter, and smaller.

Saturn's moon Titan is the only moon with a substantial atmosphere, composed mostly of nitrogen. Minor atmospheric components lead to the formation of methane and ethane clouds and nitrogen-rich organic smog. The climate includes wind and rain, and creates surface features similar to those on Earth, including dunes, deltas, rivers, lakes, and seas composed of liquid methane and ethane. Titan has seasonal weather patterns, and a methane cycle is analogous to Earth's water cycle, although at the much lower temperature of about 94 K (−179.2°C).



Saturn's moon Titan

(Information: https://en.wikipedia.org/wiki/Moons_of_Jupiter, https://en.wikipedia.org/wiki/Titan_(moon); Jupiter's moons: https://en.wikipedia.org/wiki/Moons_of_Jupiter#/media/File:The_Galilean_satellites_(the_four_largest_moons_of_Jupiter).tif, NASA/JPL/DLR, public domain; Titan: https://en.wikipedia.org/wiki/Titan_(moon)#/media/File:Titan_in_true_color.jpg, NASA, public domain; Mimas: https://en.wikipedia.org/wiki/Mimas_(moon)#/media/File:Mimas_Cassini.jpg, NASA/JPL/Cal Tech/Space Science Institute, public domain)



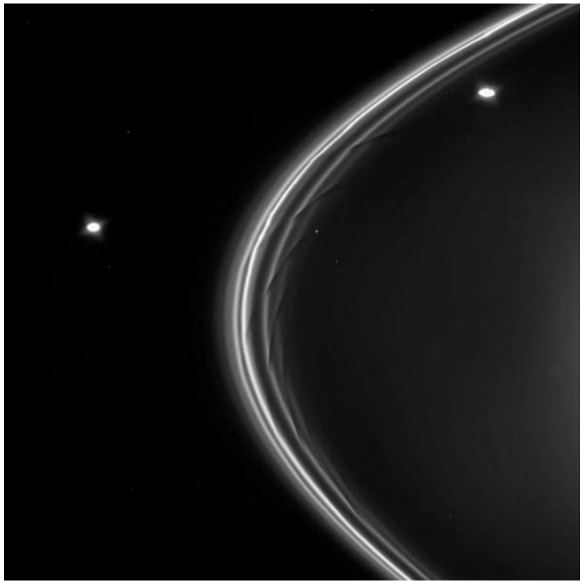
Saturn's moon Mimas and Herschel Crater

Rings

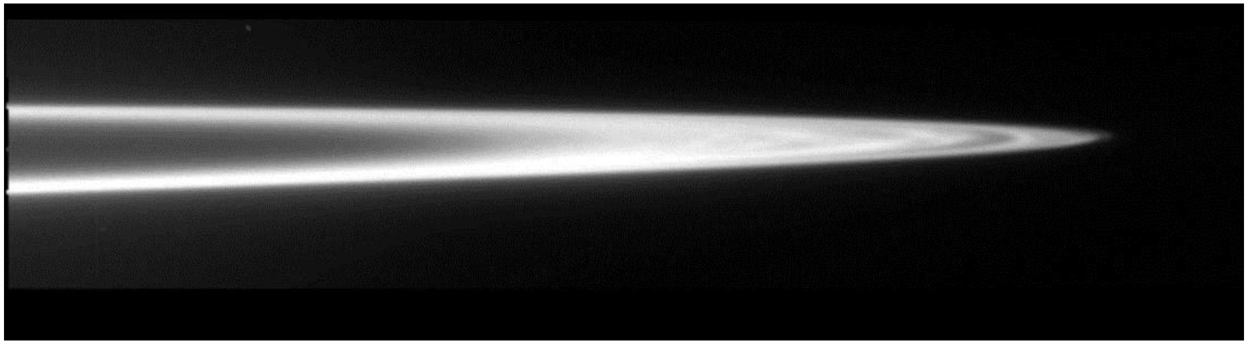
A planetary ring consists of dust and other small particles orbiting around a planet in a flat disc-shaped region. The most famous planetary rings are those around Saturn, but the other three gas giants, Jupiter, Uranus and Neptune, possess faint ring or incomplete ring systems.

Planetary rings can form from material from the protoplanetary disc material that was within the Roche limit of the planet that could not coalesce to form moons, from the debris of a moon that was disrupted by a large impact, or from the debris of a moon that was disrupted by tidal stresses when it passed within the planet's Roche limit.

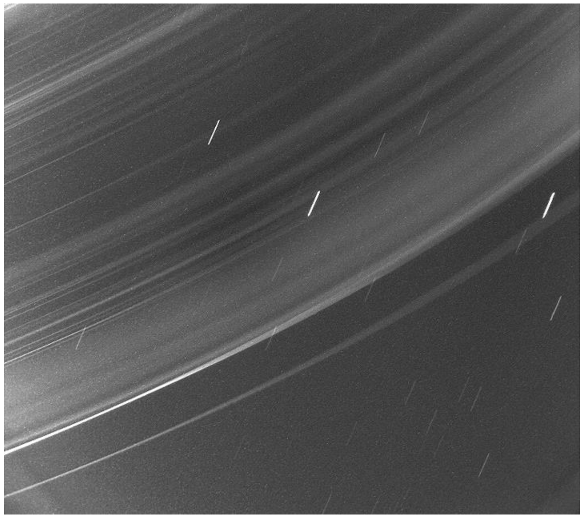
Saturn's rings might be quite old, dating to the early days of the solar system. Sometimes rings will have "shepherd" moons that orbit near the outer edges of rings or within gaps in the rings, which maintain a sharply defined ring edge.



Shepherd moons Prometheus and Pandora near Saturn's F-ring



Jupiter's main ring



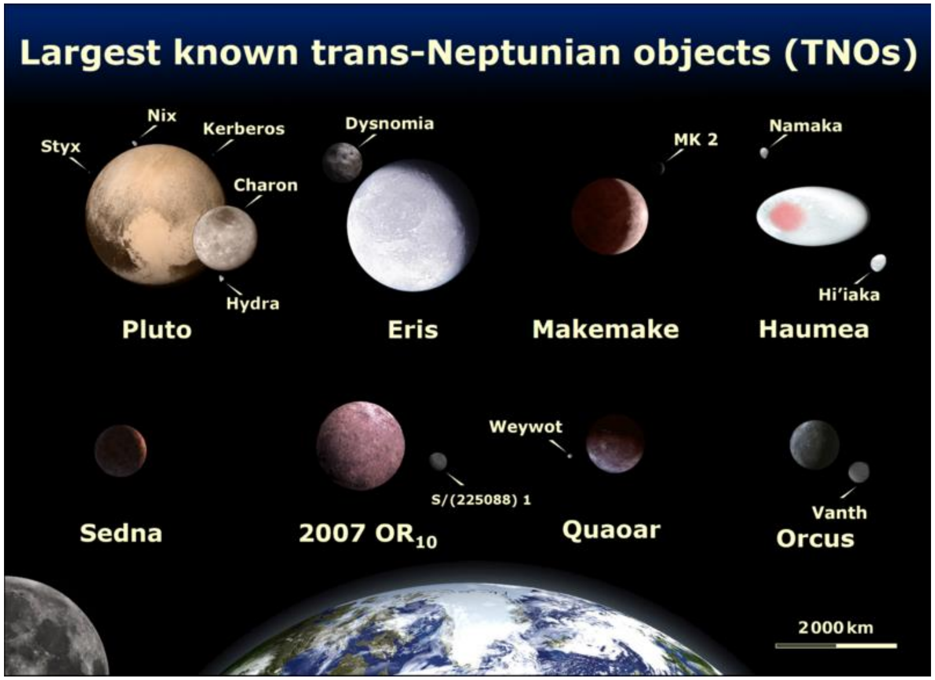
Rings of Uranus

(Information: http://en.wikipedia.org/wiki/Planetary_ring; Shepherd ring image: https://en.wikipedia.org/wiki/File:PIA07712_-_F_ring_animation_videoquality_6_framerate_5.ogv, NASA/JPL/Space Science Institute, public domain; Jupiter's main ring: https://en.wikipedia.org/wiki/Ring_system#/media/File:Main_Ring_Galeleo_forward_PIA00538.jpg, NASA/JPL, public domain; Rings of Uranus: https://en.wikipedia.org/wiki/Ring_system#/media/File:FDS_26852.19_Rings_of_Uranus.png, NASA/JPL/Cal Tech/University of Arizona/Texas A & M, public domain)

Kuiper Belt

The Kuiper belt is a region beyond the planets, extending from the orbit of Neptune, at 30 AU, to approximately 55 AU from the Sun. It is 20 times as wide and 20–200 times as massive as the asteroid belt. Asteroid belt objects are composed primarily of rock and metal, but Kuiper belt objects are composed largely of frozen volatiles, or "ices," such as methane, ammonia and water.

Since its discovery in 1992, the number of known KBOs has increased to over 1,000, and more than 70,000 KBOs over 100 km in diameter are believed to reside there. Scattered disc objects such as Eris are KBOlike bodies with extremely large orbits that take them as far as 100 AU from the Sun. The centaurs, comet-like bodies that orbit among the gas giants, are believed to originate there. Neptune's moon Triton is believed to be a captured KBO. Pluto, a dwarf planet, is similar to many other objects of the Kuiper belt, and its orbital period is identical to that of the KBOs known as "plutinos."



The Kuiper belt should not be confused with the hypothesized Oort cloud, which is a thousand times more distant. The objects within the Kuiper belt, together with the members of the scattered disc and any potential Oort cloud objects, are collectively referred to as trans-Neptunian objects (TNOs).

In a 1951 article for the journal *Astrophysics*, Gerard Kuiper speculated on a similar disc having formed early in the solar system's evolution, however, he did not believe that such a belt still existed. He assumed that Pluto was the size of the Earth, and that it scattered these bodies out toward the Oort cloud or out of the solar system.

In 1962, physicist Al G.W. Cameron postulated the existence of "a tremendous mass of small material on the outskirts of the solar system," and in 1964, Fred Whipple, who popularized the famous "dirty snowball" hypothesis for cometary structure, thought that a "comet belt" might be massive enough to cause the discrepancies in the orbit of Uranus that had sparked the search for Planet X, and to affect the orbits of known comets.

In 1977, Charles Kowal discovered 2060 Chiron, an icy planetoid with an orbit between Saturn and Uranus. In 1992, another object, 5145 Pholus, was discovered in a similar orbit. Today, an entire population of comet-like bodies, the centaurs, is known to exist in the region between Jupiter and Neptune. In 1987, astronomers David Jewitt and Jane Luu began searching for objects beyond Pluto using telescopes at the Kitt Peak National Observatory in Arizona and the Cerro Tololo Inter-American Observatory in Chile. After five years of searching, on August 30, 1992, Jewitt and Luu announced the "Discovery of the candidate Kuiper belt object" (15760) 1992 QB1. Six months later, they discovered a second object in the region, 1993 FW.

(Information: http://en.wikipedia.org/wiki/Kuiper_belt; Largest known trans-Neptunian objects: https://en.wikipedia.org/wiki/File:EightTNOs.png, Lexicon/NASA, public domain)

Learning About the Solar System and the Universe

Astronomy expands our horizons both figuratively and literally. It encourages us to view the universe around us in new ways and opens our eyes to the spectacular celestial objects imaged by the Hubble Space Telescope, many of which were viewed for the first time for the last three decades.

Astronomy attempts to explain everything that we observe in the Universe, from the Big Bang and quasars of 13 billion years ago to the current search for ice on Mars and the oceans of Europa. By studying the cosmos beyond planet Earth, we can learn more about ourselves, our origins and destiny, and how to care for our own planet.

Astronomy is the synthesis of physics, geology, mathematics, chemistry, and history. The Mesopotamians, Egyptians, Chinese, Greeks, Mayans, Indians, and Arabs were some of the first to make systematic observations of the heavens. Islamic astronomers provided many of the names for stars still used today. Copernicus, Galileo, Brahe, Kepler, and Newton extended their work, providing a mathematical basis to explain the movements of celestial bodies, including planets and comets.

Charles A. Young, 1834-1908, was a prominent solar spectroscopist. In *Elements of Astronomy* he explained:

NGC 2174

"Astronomy is the oldest of the natural sciences: nearly the earliest records that we find in the annals of China and upon the inscribed 'library bricks' of Assyria and Babylon relate to astronomical subjects, such as eclipses and the positions of the planets. Obviously in the infancy of the race the rising and setting of the sun, the progress of the seasons, and the phases of the moon must have compelled the attention of even the most unobservant…No other science so operates to give us on the one hand just views of our real insignificance in the universe of space, matter, and time, or to teach us on the other hand the dignity of the human intellect as the offspring. The study of the science cultivates nearly every faculty of the mind; the memory, the reasoning power, and the imagination all receive from it special exercise and development. By the precise and mathematical character of many of its discussions it enforces exactness of thought and expression, and corrects that vague indefiniteness which is apt to be the result of pure literary training. On the other hand, by the beauty and grandeur of the subjects it presents, it stimulates the imagination and gratifies the poetic sense. In every way it well deserves the place which has long been assigned to it in education." (Young, 1889, http://www.physics.csbsju.edu/astro/CAYoung.html)

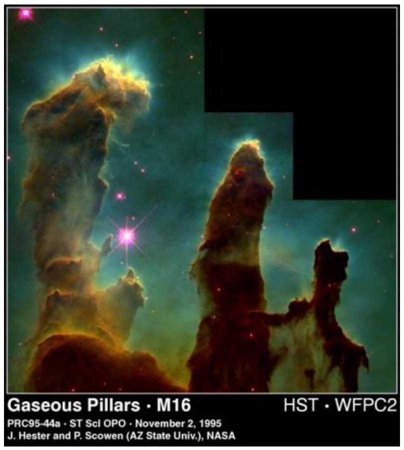
(Information: http://en.wikipedia.org/wiki/History_of_astronomy; NGC 2174: http://hubblesite.org/image/3336/news/3-nebulae, Space Telescope Science Institute, public domain)

The Future

Andromeda Galaxy

Once upon a time humanity believed that we were the center of the universe and that the stars in the heavens were attached to crystalline spheres. The motions of celestial objects were explained by calling on the powers of gods and goddesses whose benevolence or spite were the result of our good and bad behavior. Comets and aurorae were seen as portents of fortune or evil, depending on whims of their interpreters and the mood of the times. And Ptolemy explained the motions of the planets with a complicated system of epicycles.

Ancient astronomers built temples to worship the Sun and Moon, to determine when to celebrate religious occasions, and when to plant crops. In the 16th century Nicholas Copernicus published *De revolutionibus orbium coelestium*, removing us forever from the center of the solar system, placing us, and later the other planets, dwarf planets, asteroids, and comets in orbit around the Sun, which then became the center of our universe.



Eagle Nebula

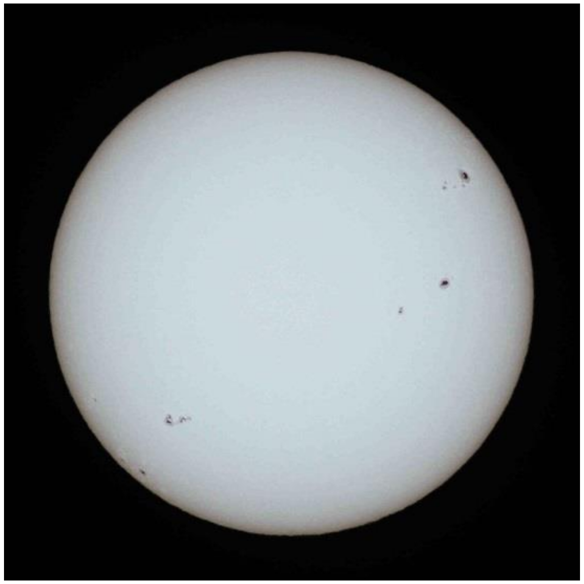
The 16th, 17th, and 18th centuries expanded our astronomical horizons. Tycho Brahe observed the orbit of Mars; Johannes Kepler used those observations to find the true elliptical shape of planetary orbits and formulated the laws of planetary motion; Galileo Galilei promoted Copernicus' ideas in Italian so that they were accessible to everyone and was condemned by the Church for doing so; and Isaac Newton explained why planets and moons orbited under the influence of gravity.

In the 20th century Edwin Hubble demonstrated that we were not the only galaxy in the universe and that our closest large neighbor, the Andromeda galaxy was 2.5 million light years away. Albert Einstein showed us that our ability to travel through our greatly expanded, now four dimensional universe, was limited by the astronomical speed limit, the speed of light. Twenty first century cosmologists Stephen Hawking and Kip Thorne theorize about the origins of our universe, the Big Bang, black holes, wormholes, time travel, and ways to get around the cosmological speed limit. The Hubble Space Telescope looks back in time at objects more than 13 billion light years away. Brian Greene and Ed Witten think about ten dimensional string theory, not really a theory at all, since it can't be tested. Yet it has the potential to explain how the four forces in the universe, the weak and strong atomic, electromagnetic, and gravitational, can work and play well together within a set of simple, elegant mathematical postulates.

We have lived in egocentric, geocentric, heliocentric, and galactocentric universes, all of which have been shown to be false representations of our space and time. There is no center to the universe at all and our current observations show that space is expanding. But into what and when? We don't yet have the answers, but we have come a long way in our understanding of the universe around us and will continue to explore and to dream about what lies beyond the edge of our cosmological horizon.

(Images source: http://hubblesite.org/gallery/; Space Telescope Science Institute, public domain)

The Sun



Orbital period:	**225 – 250 million years around the center of the galaxy**
Average orbital speed:	**251 km/s around the center of the galaxy**
Sidereal rotation period (solar day):	**25.4 Earth days**
Equatorial radius:	**6.96×10^5 km (109 x Earth)**
Surface area:	**6.09×10^{12} km^2 (12,000 x Earth)**
Volume:	**1.41×10^{18} km^3 (1,300,000 x Earth)**
Mass:	**1.99×10^{30} kg (333,000 x Earth)**
Mean density:	**1.41 gm/cm^3 (0.26 x Earth)**
Center density:	**162.2 gm/cm^3 (29.4 x Earth)**
Surface gravity:	**274 m/s^2 (27.9 x Earth)**
Escape velocity:	**617.7 km/s**
Apparent magnitude:	**-26.74**
Angular diameter:	**30’ (0.5 degrees)**
Temperature:	**5,778 K photosphere, 1.57×10^7 K in the core**
Luminosity:	**3.828×10^{26} W**
Atmospheric composition:	**73.5% hydrogen, 24.6% helium, trace amounts of oxygen, carbon, iron, neon, nitrogen, silicon, magnesium, and sulfur**

The Sun accounts for about 99.8% of the solar system’s mass. It consists of about 74% hydrogen, about 24% helium, and trace quantities of other elements, including iron, nickel, oxygen, silicon, sulfur, magnesium, carbon, neon, calcium, and chromium. The Sun has a spectral class of G2V, which means that it has a surface temperature of approximately 5,780 K, giving it a white color that, because of atmospheric scattering, appears yellow when seen from the surface of the Earth. It is this scattering of light at the blue end of the spectrum that gives the surrounding sky its color. When the Sun is low in the sky, even more light is scattered so that the Sun appears orange or red.

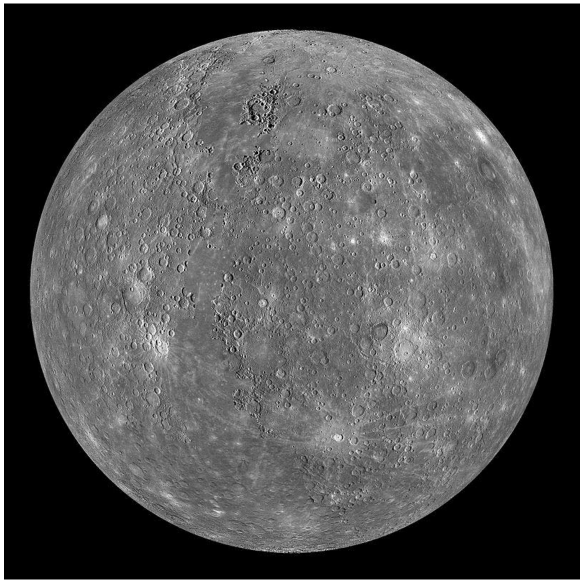
V in the spectral class indicates that the Sun is a main sequence star. It generates its energy by nuclear fusion of hydrogen nuclei into helium. The Sun is now known to be brighter than 85% of the stars in the galaxy, most of which are red dwarfs.

The Sun orbits the center of the Milky Way galaxy at a distance of approximately 26,000 light-years from the galactic center, completing one revolution in about 225 to 250 million years. Its orbital speed is about 251 km/s, equivalent to about one light-year every 1,190 years, and about one AU every 7 days. The Sun is currently traveling in the inner rim of the Orion Arm of the Milky Way Galaxy, between the larger Perseus and Sagittarius arms of the galaxy, in a galactic habitable zone.

The Sun is a heavy element-rich star. Its formation may have been triggered by shockwaves from one or more nearby supernovae.

(Information: https://en.wikipedia.org/wiki/Sun; Sun: https://en.wikipedia.org/wiki/Sun#/media/File:Sun_white.jpg, Geoff Elston, CC BY 4.0)

Mercury –Terrestrial Planet, Closest Planet to the Sun, Planet Size Rank: 8



Discovery date:	**ancient**
Semimajor axis:	**5.79×10^7 km (0.387 AU)**
Orbital period:	**0.24 years (88.0 days)**
Synodic period:	**0.32 years (115.9 days)**
Average orbital speed:	**47.4 km/s**
Sidereal rotation period (Mercury day):	**58.7 Earth days**
Mean radius:	**2,439.7 km (0.38 x Earth)**
Surface area:	**7.48×10^7 km^2 (0.15 x Earth)**
Volume:	**6.08×10^{10} km^3 (0.056 x Earth)**
Mass:	**3.30×10^{23} kg (0.055 x Earth)**
Mean density:	**5.43 gm/cm^3 (0.98 x Earth)**
Surface gravity:	**3.70 m/s^2 (0.38 x Earth)**
Escape velocity:	**4.25 km/s (0.38 x Earth)**
Apparent magnitude:	**+5.7 to -2.6**
Angular diameter:	**4.5" to 13"**
Albedo:	**0.12**
Temperature:	**340 K mean, 100 K minimum, 700 K maximum**
Number of satellites:	**0**
Surface pressure:	**trace**
Atmospheric composition:	**42% molecular oxygen, 29% sodium, 22% hydrogen, 6% helium, and traces of other elements**

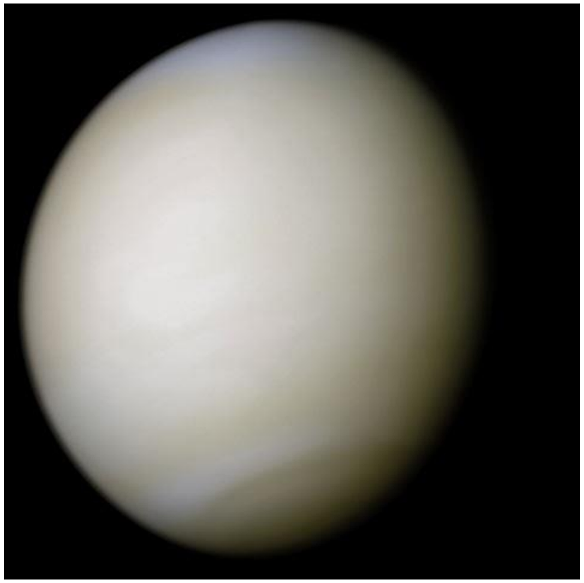
Mercury is the smallest planet in the solar system. Its greatest angular separation from the Sun is only 28.3°, so it is difficult to see here on Earth when it is visible, either just before sunset or before sunrise. Mercury's axis has the smallest tilt of any of the solar system's planets (about 1⁄30 degree), and its orbital eccentricity is the largest of all known planets in the solar system. At aphelion, Mercury is about 1.5 times as far from the Sun as it is at perihelion.

Mercury is similar in appearance to the Moon, is heavily cratered, and has no substantial atmosphere. Unlike the moon, it has a large iron core, which generates a magnetic field about 1% as strong as Earth's. It is very dense due to the relatively large size of its core.

Mercury is tidally or gravitationally locked with the Sun in a 3:2 resonance, and rotates in a way that is unique in the solar system. As seen relative to the fixed stars, it rotates on its axis exactly three times for every two revolutions it makes around the Sun.

(Information: https://en.wikipedia.org/wiki/Mercury_(planet); MESSENGER Mercury: https://en.wikipedia.org/wiki/Mercury_(planet)#/media/File:Mercury_Globe-MESSENGER_mosaic_centered_at_0degN-0degE.jpg, NASA/APL, public domain)

Venus –Terrestrial Planet, Second Planet from the Sun, Planet Size Rank: 6



Discovery date:	ancient
Semimajor axis:	1.08×10^8 km (0.723 AU)
Orbital period:	0.615 years (224.7 days, 1.92 Venus solar day)
Synodic period:	1.60 years (583.9 days)
Average orbital speed:	35.0 km/s
Sidereal rotation period (Venus day):	-243.0 Earth days (retrograde)
Mean radius:	6,051.8 km (0.95 x Earth)
Surface area:	4.60×10^8 km^2 (0.90 x Earth)
Volume:	9.28×10^{11} km^3 (0.87 x Earth)
Mass:	4.87×10^{24} kg (0.82 x Earth)
Mean density:	5.24 gm/cm^3 (0.95 x Earth)
Surface gravity:	8.87 m/s^2 (0.90 x Earth)
Escape velocity:	10.36 km/s (0.93 x Earth)
Apparent magnitude:	-4.9 to -3.8
Angular diameter:	9.7" to 66.0"
Albedo:	0.69
Temperature:	737 K
Number of satellites:	0
Surface pressure:	9.2 MPa (92 x Earth)
Atmospheric composition:	96.5% carbon dioxide, 3.5% nitrogen, 0.015% sulfur dioxide, 0.007% argon, 0.002% water vapor, 0.0017% carbon monoxide, 0.0012% helium, 0.0007% neon

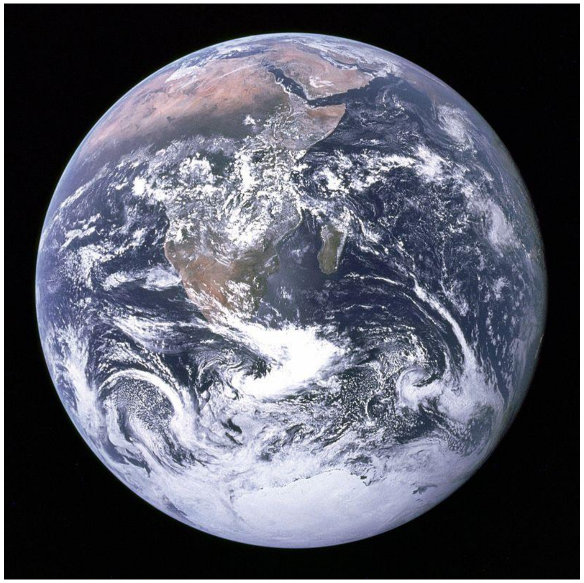
Venus is sometimes called Earth's "sister planet," because the two are similar in size, gravity, and bulk composition. It is covered with an opaque layer of highly reflective clouds of sulfuric acid, preventing its surface from being seen in visible light. It has the densest atmosphere of all the terrestrial planets, consisting mostly of carbon dioxide, as it has no carbon cycle to lock carbon back into rocks and surface features, nor organic life to absorb it in biomass.

It is so hot that the earth-like oceans that the young Venus may have had totally evaporated, leaving a dry desertscape. The lack of a planetary magnetic field resulted in hydrogen being swept into interplanetary space by the solar wind.

It has few impact craters, demonstrating that the surface is relatively young, approximately half a billion years old. There is no evidence for plate tectonics, possibly because its crust is too strong to subduct without water to make it less viscous, and some suggest that instead Venus loses its internal heat in periodic massive resurfacing events.

(Information: https://en.wikipedia.org/wiki/Venus; Mariner 10 Venus: https://en.wikipedia.org/wiki/Venus#/media/File:Venus-real_color.jpg, NASA/Ricardo Nunes, public domain)

Earth – Largest Terrestrial Planet, Third Planet from the Sun, Planet Size Rank: 5



Semimajor axis:	**1.50×10^8 km (1.000 AU)**
Orbital period:	**1.000 year (365.26 days)**
Average orbital speed:	**29.8 km/s**
Sidereal rotation period:	**23 h 56 m 4.1 s (0.997 days)**
Mean radius:	**6,371.0 km**
Surface area:	**5.10×10^8 km^2 (1.49×10^8 km^2 land, 3.61×10^8 km^2 water)**
Volume:	**1.08×10^{12} km^3**
Mass:	**5.97×10^{24} kg**
Mean density:	**5.51 gm/cm^3**
Surface gravity:	**9.81 m/s^2**
Escape velocity:	**11.19 km/s**
Albedo:	**0.367**
Temperature:	**288 K mean, 184 K minimum, 330 K maximum**
Number of satellites:	**1**
Surface pressure:	**101.325 kPa**
Atmospheric composition:	**78.08% nitrogen, 20.95% oxygen, 0.930% argon, 0.0402% carbon dioxide, ~1% water vapor**

Earth is the largest terrestrial planet in diameter, mass and density. Life appeared on its surface within a billion years, and outgassing and volcanic activity produced the primordial atmosphere.

About 71% of the surface is covered with oceans, the remaining 29% consists of continents and islands. Only about 1/8 of the surface of the Earth is suitable for humans to live on. Half the land area is either desert, high mountains, or other less suitable terrain.

Earth is composed mostly of iron, oxygen, silicon, magnesium, sulfur, nickel, calcium, and aluminum, and trace amounts of other elements. The core region, likely composed of iron, is responsible, in part, for Earth's magnetic field, which reverses at irregular intervals a few times every million years. The most recent reversal occurred approximately 700,000 years ago.

Water is a unique feature that distinguishes the "Blue Planet" from others in the solar system. Condensing water vapor, augmented by ice and liquid water delivered by asteroids and the larger protoplanets, comets, and transNeptunian objects produced the oceans. Earth's hydrosphere consists chiefly of the oceans, but includes all water surfaces in the world, including inland seas, lakes, rivers, and underground water.

Earth's seasons are the result of its 23.50 axial tilt. The four seasons are determined by the solstices, the point in the orbit of maximum axial tilt toward or away from the Sun, and the equinoxes, when the direction of the tilt and the direction to the Sun are perpendicular.

(Information: https://en.wikipedia.org/wiki/Earth; Earth Apollo 17: https://en.wikipedia.org/wiki/Earth#/media/File:The_Earth_seen_from_Apollo_17.jpg, Harrison Schmitt, public domain)

The Moon

Semimajor axis:	3.85×10^5 km (0.00257 AU)
Orbital period:	27 d 7 h 43 min 11.5 s (27.321 days)
Synodic period:	29 d 12 h 44 m 2.9 s (29.530 days)
Average orbital speed:	1.022 km/s
Sidereal rotation period (Moon day):	27.322 Earth days
Mean radius:	1,737.1 km (0.27 x Earth)
Surface area:	3.79×10^7 km^2 (0.074 x Earth)
Volume:	2.20×10^{10} km^3 (0.020 x Earth)
Mass:	7.34×10^{22} kg (0.012 x Earth)
Mean density:	3.34 gm/cm^3 (0.61 x Earth)
Surface gravity:	1.62 m/s^2 (0.17 x Earth)
Escape velocity:	2.38 km/s (0.21 x Earth)
Apparent magnitude:	-2.5 to -12.9, -12.4 at full moon
Angular diameter:	29.3” to 34.1”
Albedo:	0.136
Temperature:	220 K mean, 100 K minimum, 390 K maximum
Surface pressure:	10^{-7} Pa day, 10^{-10} Pa night
Atmospheric composition:	trace

The Moon is the fifth largest natural satellite in the solar system. It is in synchronous rotation, keeping nearly the same face turned toward Earth. Its rotation slowed early in its history, and became locked in this configuration as a result of frictional effects associated with tidal deformations caused by Earth. Small variations, called libration, allow about 59% of its surface to be viewed from Earth. Unlike most satellites of other planets, the Moon orbits near the ecliptic and not the Earth's equatorial plane.

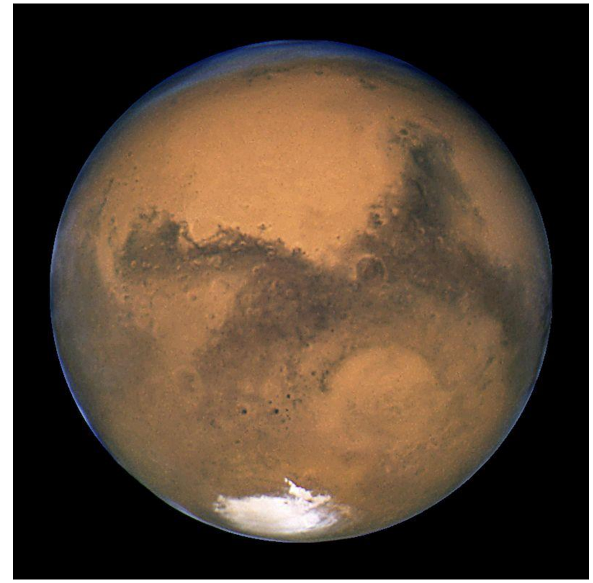
The side facing Earth is called the near side, and the opposite side the far side, inaccurately called the "dark side.” It is illuminated exactly as often as the near side, once per lunar day, during the new moon phase we observe on Earth when the near side is dark. The far side of the Moon was first photographed by the Soviet probe Luna 3 in 1959.

The prevailing hypothesis for the formation of the Moon is that it formed as a result of a giant impact. A Mars-size body called “Theia” is believed to have hit proto-Earth, blasting material into orbit, forming the Moon through accretion.

Tidal effects result in an increase of the mean Earth-Moon distance of about 3.8 m per century.

(Information: https://en.wikipedia.org/wiki/Moon; Full Moon: https://en.wikipedia.org/wiki/Moon#/media/File:FullMoon2010.jpg, Gregory H. Revera, CC BY-SA 3.0)

Mars –Terrestrial Planet, Fourth Planet from the Sun, Planet Size Rank: 7



Discovery date:	**ancient**
Semimajor axis:	**2.28×10^5 km (1.523 AU)**
Orbital period:	**1.88 years (686.7 days)**
Synodic period:	**2.13 years (778.0 days)**
Average orbital speed:	**24.1 km/s**
Sidereal rotation period (Mars day):	**1.03 Earth days**
Mean radius:	**3,389.5 km (0.53 x Earth)**
Surface area:	**1.45×10^8 km^2 (0.28 x Earth)**
Volume:	**1.63×10^{11} km^3 (0.15 x Earth)**
Mass:	**6.42×10^{23} kg (0.11 x Earth)**
Mean density:	**3.93 gm/cm^3 (0.71 x Earth)**
Surface gravity:	**3.71 m/s^2 (0.38 x Earth)**
Escape velocity:	**5.03 km/s (0.45 x Earth)**
Apparent magnitude:	**+1.8 to -2.9**
Angular diameter:	**3.5" to 25.1"**
Albedo:	**0.17**
Temperature:	**210 K mean, 130 K minimum, 308 K maximum**
Number of satellites:	**2**
Satellites:	**Phobos, Deimos**
Surface pressure:	**0.636 kPa**
Atmospheric composition:	**95.97% carbon dioxide, 1.93% argon, 1.89% nitrogen, 0.146% oxygen, 0.0577% carbon monoxide**

Mars is named after Mars, the Roman god of war. It is also referred to as the "Red Planet" because of its reddish appearance.

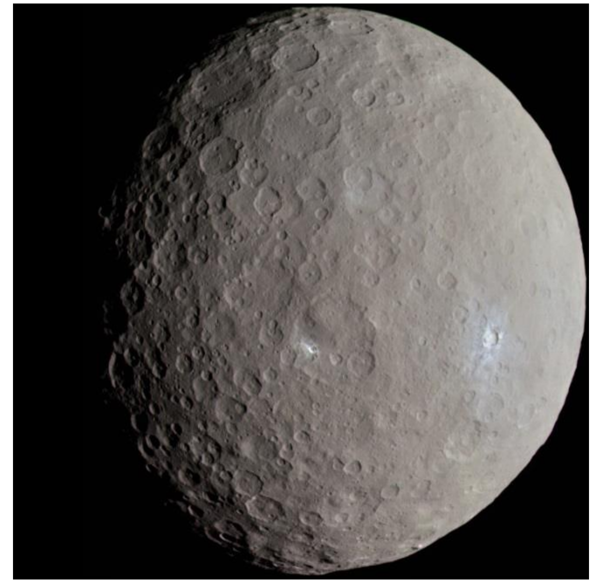
It has impact craters similar to those on the Moon and volcanoes, valleys, deserts and polar ice caps similar to those on Earth. It is the site of Olympus Mons, the highest known mountain, and of Valles Marineris, the largest canyon. Mars' rotational period and seasonal cycles are similar to Earth's.

Geological evidence gathered by these and preceding missions suggests that Mars may have been partially covered by large bodies of water, and observations show that small geyser-like water flows have occurred during the past decade.

Mars has two moons, Phobos and Deimos, which are small and irregularly shaped, and may be captured asteroids. Mars can be seen from Earth with the naked eye fairly easily. Its apparent magnitude reaches −2.9, a brightness surpassed only by Venus, the Moon, and the Sun, though most of the time Jupiter will appear brighter to the naked eye than Mars.

(Information: http://en.wikipedia.org/wiki/Mars; Hubble Mars : https://en.wikipedia.org/wiki/Mars#/media/File:Mars_23_aug_2003_hubble.jpg, Hubble Space Telescope, public domain)

Ceres – Dwarf Terrestrial Planet



Discovery date:	**January 1, 1801 by Guiseppi Piazzi**
Semimajor axis:	**4.14×10^8 km (2.768 AU)**
Orbital period:	**4.60 years (1,680 days)**
Synodic period:	**1.23 years (449 days)**
Average orbital speed:	**17.905 km/s**
Sidereal rotation period (Ceres day):	**9.12 Earth hours**
Mean radius:	**473 km (0.0742 x Earth)**
Surface area:	**2.77×10^6 km^2 (0.0054 x Earth)**
Volume:	**8.26×10^8 km^3 (0.00076 x Earth)**
Mass:	**9.39×10^{20} kg (0.00016 x Earth)**
Mean density:	**2.16 gm/cm^3 (0.392 x Earth)**
Surface gravity:	**0.28 m/s^2 (0.0285 x Earth)**
Escape velocity:	**0.51 km/s**
Apparent magnitude:	**+6.7 to +9.3**
Angular diameter:	**0.84” to 0.33”**
Albedo:	**0.09**
Temperature:	**167 K**
Number of satellites:	**0**

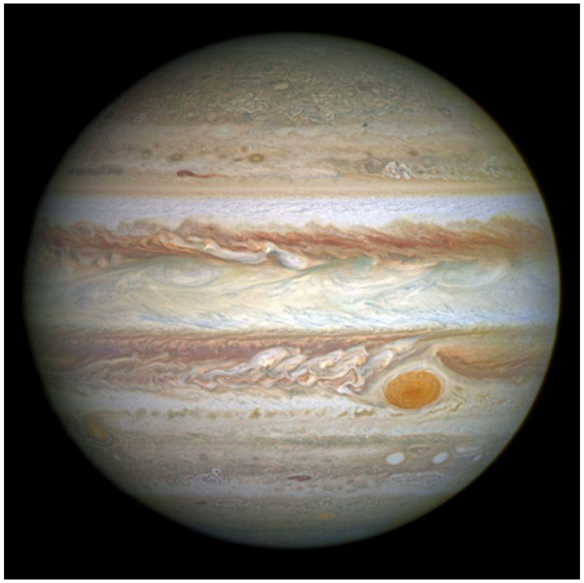
Ceres is the smallest identified dwarf planet in the solar system and the only one in the asteroid belt. It was discovered on January 1, 1801, by Giuseppe Piazzi, and is named after the Roman goddess Ceres, the goddess of growing plants, the harvest, and of motherly love.

Ceres is the largest and most massive body in the asteroid belt, and contains approximately a third of the belt's total mass. It is nearly spherical, unlike the irregular shapes of smaller bodies with lower gravity and its surface is probably made of a mixture of water ice and various hydrated minerals like carbonates and clays. It likely has a rocky core and ice mantle, and may have an ocean of liquid water below its surface, and may be surrounded by a tenuous atmosphere containing water vapor.

Ceres’ may have significant amounts of water in its interior. Surface constituents include iron-rich clays and carbonates, which are common minerals in carbonaceous chondrite meteorites. It may also have a tenuous atmosphere and water frost on the surface. High resolution ultraviolet Hubble Space Telescope images taken in 1995 showed a dark spot on its surface which was nicknamed "Piazzi" in honor of its discoverer.

(Information: https://en.wikipedia.org/wiki/Ceres_(dwarf_planet); Ceres: https://en.wikipedia.org/wiki/Ceres_(dwarf_planet)#/media/File:Ceres_-_RC3_-_Haulani_Crater_(22381131691)_(cropped).jpg, Justin Cowart, CC BY 2.0)

Jupiter – Jovian Gas Giant Planet, Fifth Planet from the Sun, Planet Size Rank: 1



Discovery date:	ancient
Semimajor axis:	7.78×10^8 km (5.202 AU)
Orbital period:	11.86 years (4,332 days)
Synodic period:	1.09 years (398.9 days)
Average orbital speed:	13.1 km/s
Sidereal rotation period (Jupiter day):	9.93 Earth hours
Mean radius:	69,911 km (10.97 x Earth)
Surface area:	6.14×10^{10} km^2 (121.9 x Earth)
Volume:	1.43×10^{15} km^3 (1,321 x Earth)
Mass:	1.90×10^{27} kg (317.8 x Earth, 1/1047 of the Sun)
Mean density:	1.326 gm/cm^3 (0.24 x Earth)
Surface gravity:	24.8 m/s^2 (2.53 x Earth)
Escape velocity:	59.5 km/s (5.31 x Earth)
Apparent magnitude:	-1.6 to -2.9
Angular diameter:	29.8” to 50.1”
Albedo:	0.34
Temperature:	165 K
Number of satellites:	at least 67
Large satellites:	Ganymede, Callisto, Io, Europa
Ring system:	faint, three main segments made of dust
Atmospheric composition:	89.8% hydrogen, 10.2% helium, ~0.3% methane, ~0.026% ammonia, ~0.003% hydrogen deuteride, 0.0006% ethane, 0.0004% water, including ammonia ice, water ice, ammonium hydrosulfide ice

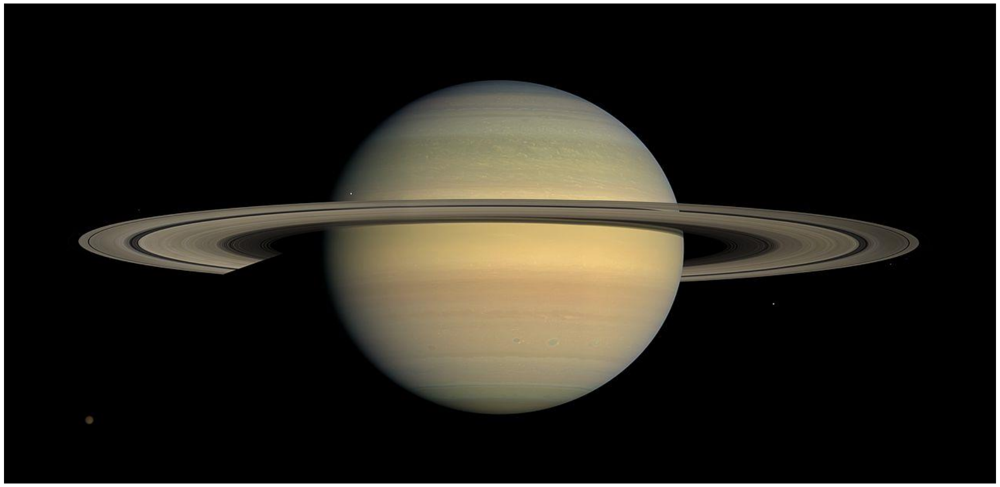
Jupiter is 2½ times as massive as all of the other planets combined. The planet was associated with the mythology and religious beliefs of many cultures. The Romans named the planet after the Roman god Jupiter.

Jupiter’s Great Red Spot, is a giant storm that is known to have existed since at least the 17th century, when Galileo saw it through his telescope. Jupiter’s windspeeds have been measured at more than 644 km/h (> 400 mph).

Jupiter has been explored on several occasions by robotic spacecraft, including the early Pioneer and Voyager flyby missions and later by the Galileo orbiter. 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 potentially ice-covered liquid ocean of its moon Europa.

(Information: https://en.wikipedia.org/wiki/Jupiter; Jupiter: https://en.wikipedia.org/wiki/Jupiter#/media/File:Jupiter_and_its_shrunken_Great_Red_Spot.jpg, NASA/ESA and A. Simon, public domain)

Saturn – Jovian Gas Giant Planet, Sixth Planet from the Sun, Planet Size Rank: 2



Discovery date:	ancient
Semimajor axis:	1.43×10^9 km (9.554 AU)
Orbital period:	29.46 years (10,759 days)
Synodic period:	1.04 years (378.1 days)
Average orbital speed:	9.69 km/s
Sidereal rotation period (Saturn day):	10.66 Earth hours
Mean radius:	58,232 km (9.14 x Earth)
Surface area:	4.27×10^{10} km^2 (83.7 x Earth)
Volume:	8.27×10^{14} km^3 (764 x Earth)
Mass:	5.68×10^{26} kg (95.1 x Earth)
Mean density:	0.69 gm/cm^3 (0.13 x Earth)
Surface gravity:	8.96 m/s^2 (0.91 x Earth)
Escape velocity:	35.5 km/s (3.17 x Earth)
Apparent magnitude:	+1.2 to -0.24
Angular diameter:	14.5" to 20.1"
Albedo:	0.30
Temperature:	88 K to 151 K
Number of satellites:	at least 62 with regular orbits
Largest satellites:	Titan, Rhea, Iapetus, Dione, Tethys, Enceladus, Mimas
Ring system:	extensive, consisting of water ice and trace amounts of rock, particles from micrometer to meter sizes
Atmospheric composition:	~96% hydrogen, 3% helium, ~0.4% methane, ~0.01% ammonia, ~0.01% hydrogen deuteride, 0.0007% ethane, with ammonia, water, and ammonium hydrosulfide ices

Saturn is named after the Roman god Saturnus, equated to the Greek Kronos, the Titan father of Zeus, and the Babylonian Ninurta.

In 1990, the Hubble Space Telescope observed an enormous white cloud near Saturn's equator, not present during the Voyager encounters, and, in 1994, another smaller storm was observed. The 1990 storm was an example of a Great White Spot, a unique, short-lived phenomenon which occurs once every Saturnian year, or roughly every 30 Earth years, around the time of the northern hemisphere's summer solstice. Another storm should occur in about 2020. Wind speeds on Saturn can reach 1,800 km/h (1,120 mph), higher than Jupiter's, but slower than Neptune's.

A persisting hexagonal wave pattern around the north polar vortex in the atmosphere at about 78°N was discovered in the Voyager images. The sides of the hexagon are each about 13,800 km (8,600 mi) long, longer than Earth's diameter. Most scientists think it is a standing wave pattern in the atmosphere.

(Information: https://en.wikipedia.org/wiki/Saturn; Saturn: https://en.wikipedia.org/wiki/Saturn#/media/File:Saturn_during_Equinox.jpg, NASA/JPL/Space Science Institute, public domain)

Uranus – Jovian Ice Giant Planet, Seventh Planet from the Sun, Planet Size Rank: 3

Discovery date:	March 13, 1781 by William Herschel
Semimajor axis:	2.88×10^9 km (19.218 AU)
Orbital period:	84.32 years (30,798 days)
Synodic period:	1.01 years (369.7 days)
Average orbital speed:	6.81 km/s
Sidereal rotation period (Uranus day):	-17.24 Earth hours (retrograde)
Mean radius:	25,362 km (3.98 x Earth)
Surface area:	8.12×10^9 km^2 (15.9 x Earth)
Volume:	6.83×10^{13} km^3 (63 x Earth)
Mass:	8.68×10^{25} kg (14.8 x Earth)
Mean density:	1.27 gm/cm^3 (0.23 x Earth)
Surface gravity:	8.69 m/s^2 (0.89 x Earth)
Escape velocity:	21.3 km/s (1.90 x Earth)
Apparent magnitude:	+5.9 to +5.32
Angular diameter:	3.3" to 4.1"
Albedo:	0.30
Temperature:	53 K mean, 47 K minimum, 57 K maximum
Number of satellites:	at least 27, many named after Shakespearean characters
Largest satellites:	Miranda, Ariel, Umbriel, Titania, Oberon
Ring system:	thirteen narrow rings, may have been part of a moon
Atmospheric composition:	83% hydrogen, 15% helium, 2.3% methane, 0.009% hydrogen deuteride, with ammonia, water, ammonium sulfide, and methane hydrate ices

Uranus is the only planet whose name is derived from a figure from Greek mythology, from the Latinized version of the Greek god of the sky Ouranos.

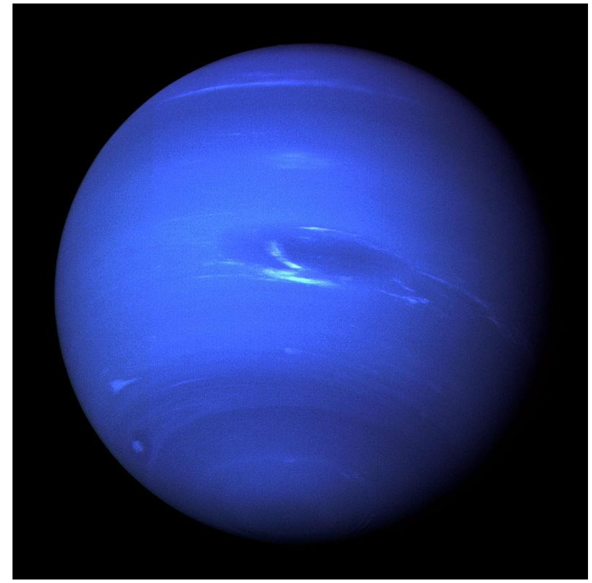
Sir William Herschel decided to name Uranus Georgium Sidus (George's Star), or the "Georgian Planet" in honor of his new patron, King George III. The name was not popular and it later was named Uranus.

The intensity of sunlight on Uranus is about 1/400 that of Earth. It has very strong winds and its axis of rotation lies on its side with respect to the plane of the solar system, resulting in extreme seasons. Wind speeds can reach 900 km/h, (560 mph).

Uranus' atmosphere is bland. When Voyager 2 flew by Uranus in 1986, it observed a total of ten cloud features across the entire planet. Uranus' internal heat appears markedly lower than that of the other giant planets. Uranus is the coldest planet in the solar system.

(Information: http://en.wikipedia.org/wiki/Uranus; Uranus: https://en.wikipedia.org/wiki/Uranus#/media/File:Uranus2.jpg, NASA/JPL/Cal Tech, public domain)

Neptune – Jovian Ice Giant Planet, Eighth Planet from the Sun, Planet Size Rank: 4



Discovery date:	**September 23, 1846 by Le Verrier, Adams, and Couch**
Semimajor axis:	**4.50×10^9 km (30.110 AU)**
Orbital period:	**164.79 years (60,190 days)**
Synodic period:	**1.01 years (367.5 days)**
Average orbital speed:	**5.43 km/s**
Sidereal rotation period (Neptune day):	**16.1 Earth hours**
Mean radius:	**24,622 km (3.86 x Earth)**
Surface area:	**7.62×10^9 km^2 (14.9 x Earth)**
Volume:	**6.25×10^{13} km^3 (58 x Earth)**
Mass:	**1.02×10^{26} kg (17.1 x Earth)**
Mean density:	**1.64 gm/cm^3 (0.30 x Earth)**
Surface gravity:	**11.15 m/s^2 (1.14 x Earth)**
Escape velocity:	**23.5 km/s (2.10 x Earth)**
Apparent magnitude:	**+8.0 to +7.78**
Angular diameter:	**2.2" to 2.4"**
Albedo:	**0.29**
Temperature:	**55 K – 72 K**
Number of satellites:	**14**
Largest satellites:	**Triton, Proteus, Nereid, Larissa, Galatea, Despina**
Ring system:	**three main, faint, fragmented ring arcs discovered in 1968**
Atmospheric composition:	**80% hydrogen, 19% helium, 1.5% methane, ~0.019% hydrogen deuteride, with ammonia, water, ammonium hydrosulfide, and methane ice**

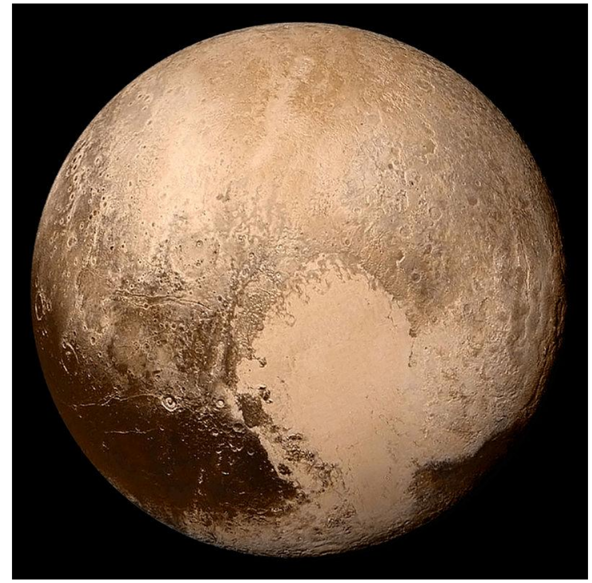
Neptune was the first planet found by mathematical prediction rather than regular observation. Unexpected changes in the orbit of Uranus led astronomers to deduce the gravitational perturbation of an unknown planet. Neptune was found within a degree of the predicted position.

Neptune's atmosphere has active and visible weather patterns, and it has the strongest winds of any planet in the solar system, measured as high as 2,100 km/h (1,300 mph). At the time of the 1989 Voyager 2 flyby, its southern hemisphere possessed a Great Dark Spot comparable to the Great Red Spot on Jupiter.

The rings may consist of ice particles coated with silicates or carbon-based material, which most likely gives them a reddish hue. The first ring was discovered in 1968.

(Information: https://en.wikipedia.org/wiki/Neptune; Neptune: https://en.wikipedia.org/wiki/Neptune#/media/File:Neptune_Full.jpg, NASA/JPL, public domain)

Pluto – Ice Dwarf Planet



Discovery date:	February 18, 1930 by Clyde Tombaugh
Semimajor axis:	5.91×10^9 km (39.48 AU)
Orbital period:	248 years (90,560 days)
Synodic period:	1.004 years (366.7 days)
Average orbital speed:	4.67 km/s
Sidereal rotation period (Pluto day):	-6.38 Earth days (retrograde)
Mean radius:	1,187 km (0.19 x Earth)
Surface area:	1.77×10^7 km^2 (0.034 x Earth)
Volume:	7.15×10^9 km^3 (0.007 x Earth)
Mass:	1.30×10^{22} kg (0.002 x Earth)
Mean density:	2.03 gm/cm^3 (0.39 x Earth)
Surface gravity:	0.62 m/s^2 (0.063 x Earth)
Escape velocity:	1.21 km/s (0.11 x Earth)
Apparent magnitude:	+13.65
Angular diameter:	0.06” to 0.11”
Albedo:	0.49 to 0.66
Temperature:	44 K mean, 33 K minimum, 55 K maximum
Number of satellites:	5
Satellites:	Charon, Styx, Nix, Kerberos, Hydra
Surface pressure:	1.0 Pa
Atmospheric composition:	nitrogen, methane, carbon monoxide

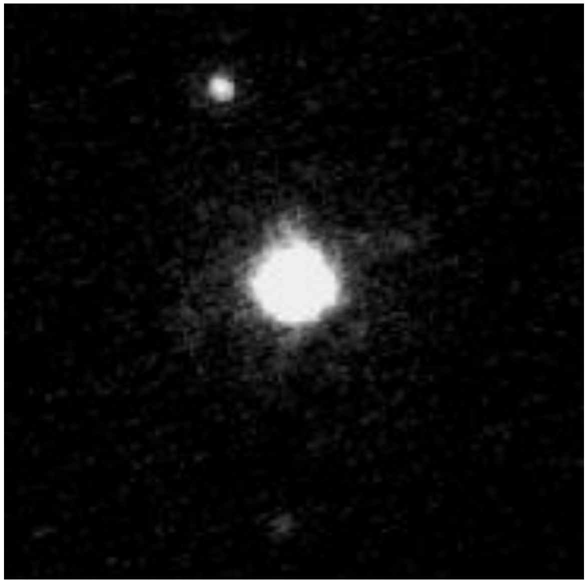
In 1906, Percival Lowell, founder of the Lowell Observatory in Flagstaff, Arizona, started searching for a ninth planet. Later, the job of finding this planet was given to Clyde Tombaugh whose task was to systematically image the night sky and examine pairs of photographs. On February 18, 1930, after nearly a year of searching, Tombaugh discovered Pluto on photographic plates.

Pluto has a highly eccentric and highly inclined orbit. Pluto and its largest moon, Charon, are often treated together as a binary system because the barycentre of their orbits does not lie within either body. Pluto's eccentricity takes it from 30 to 49 AU from the Sun, causing it to occasionally come closer to the Sun than Neptune. Despite Pluto's orbit apparently crossing that of Neptune when viewed from directly above the ecliptic, the two objects cannot collide because their orbits are aligned so that Pluto and Neptune can never approach closely.

On July 14, 2015, the New Horizons spacecraft became the first spacecraft to fly by Pluto. During its brief flyby, New Horizons made detailed measurements and observations of Pluto and its moons.

(Information: https://en.wikipedia.org/wiki/Pluto; Pluto: http://en.wikipedia.org/wiki/Pluto , NASA/Johns Hopkins/APL/Southwest Research Institute, public domain)

Haumea – Ice Dwarf Planet



Discovery date:	December 28, 2004 by Brown, Trujillo, and Rabinowitz
Semimajor axis:	6.47×10^9 km (43.35 AU)
Orbital period:	285 years (104,096 days)
Synodic period:	1.0035 years (366.5 days)
Average orbital speed:	4.53 km/s
Sidereal rotation period (Haumea day):	3.91 Earth hours
Mean radius:	620 km
Surface area:	6.8×10^6 km^2 (0.013 x Earth)
Mass:	4.0×10^{21} kg (0.0007 x Earth)
Mean density:	2.6 – 3.3 gm/cm^3 (0.47 to 0.60 x Earth)
Surface gravity:	0.63 m/s^2 (0.064 x Earth)
Escape velocity:	0.91 km/s
Apparent magnitude:	17.3
Albedo:	0.80
Temperature:	< 50K
Number of satellites:	2
Satellites:	Hi'iaka, Namaka

Haumea is a dwarf planet in the Kuiper belt, one-third the mass of Pluto. It was discovered in 2004 by a team headed by Mike Brown at Caltech and the Mauna Kea Observatory in Hawai'i. On September 17, 2008, it was classified as a dwarf planet by the International Astronomical Union.

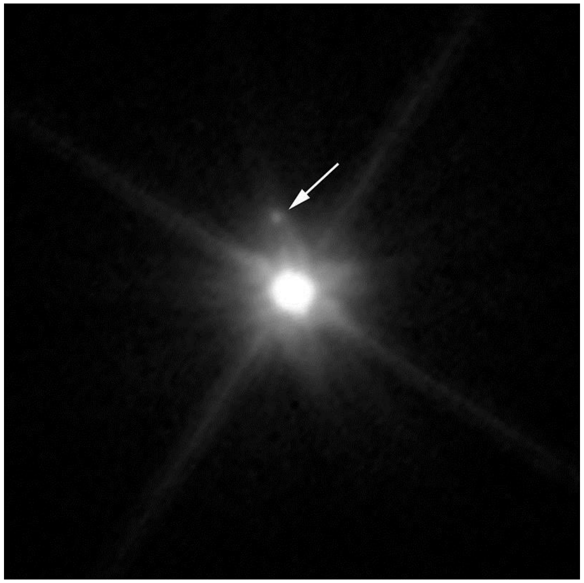
Its name and that of its moons were proposed by David Rabinowitz of the Caltech discovery team. *Haumea* is the matron goddess of the island of Hawaiʻi,. She is identified with Papa, the goddess of the earth and wife of Wākea (space). Haumea is thought to be composed almost entirely of solid rock, without the thick ice mantle over a small rocky core, typical of other known Kuiper belt objects. Haumea is the goddess of fertility and childbirth, with many children who sprang from different parts of her body, corresponding to the swarm of icy bodies thought to have broken off the dwarf planet during an ancient collision. The two known moons, also believed to have formed in this manner, are thus named after two of Haumea's daughters, Hiʻiaka and Nāmaka.

Haumea's elongated shape together with its rapid rotation, high density, and high albedo (from a surface of crystalline water ice), are thought to be the consequences of a giant collision, which left Haumea the largest member of a collisional family that includes several large trans-Neptunian objects (TNOs) and its two known moons.

(Information: http://en.wikipedia.org/wiki/Haumea_(dwarf_planet); Haumea and its moons: https://en.wikipedia.org/wiki/Haumea#/media/File:2003_EL61_Haumea,_with_moons.jpg, Mike Brown, Cal Tech, Keck Telescope, fair use)

Makemake – Ice Dwarf Planet

Discovery date:	March 31, 2005 by Brown, Trujillo, and Rabinowitz
Semimajor axis:	6.84 x 10^9 km (45.72 AU)
Orbital period:	309 years (112,895 days)
Synodic period:	1.0032 years (366.4 days)
Average orbital speed:	4.42 km/s
Sidereal rotation period (Makemake day):	7.77 Earth hours
Mean radius:	715 km (0.11 x Earth)
Surface area:	6.90 x 10^6 km^2 (0.014 x Earth)
Volume:	1.70 x 10^9 km^3 (0.002 x Earth)
Mass:	44 x 10^{21} kg (0.0007 x Earth)
Mean density:	3.05 gm/cm^3 (0.55 x Earth)
Surface gravity:	0.47 m/s^2 (0.048 x Earth)
Escape velocity:	0.84 km/s (0.075 x Earth)
Apparent magnitude:	17.0
Albedo:	0.81
Temperature:	32 K – 44 K
Number of satellites:	1
Satellite:	MK 2
Surface pressure:	4 – 12 nanobars
Atmosphere:	proposed nitrogen, methane, and ethane



Makemake's moon indicated by the arrow

Makemake was discovered on March 31, 2005, by a team at the Palomar Observatory, led by Michael E. Brown. In July 2008, in accordance with IAU rules for classical Kuiper belt objects, it was given the name of a creator deity. Makemake is the creator of humanity and god of fertility in the mythos of the Rapanui, the native people of Easter Island.

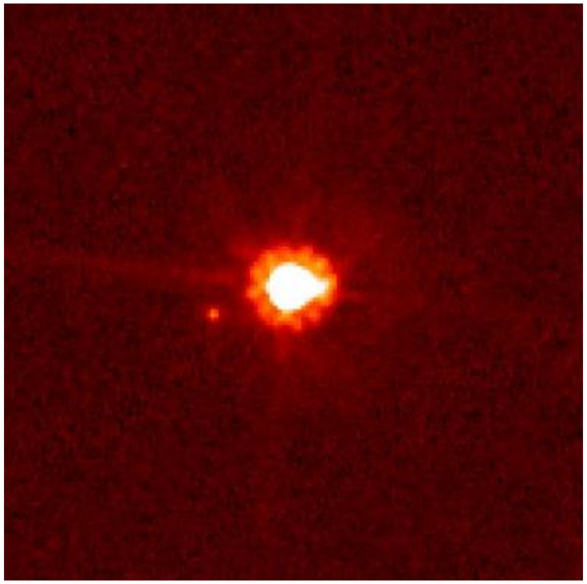
Spectral analysis of Makemake revealed that its surface is covered in methane, ethane and tholins (heteropolymer molecules formed by solar ultraviolet irradiation of simple organic compounds), which are probably responsible for its red color. Although evidence exists for the presence of nitrogen ice on its surface, at least mixed with other ices, there is nowhere near the same level of nitrogen as on Pluto and Triton. The presence of methane and possibly nitrogen suggests that Makemake could have a transient atmosphere similar to that of Pluto near its perihelion.

It was calculated that a flyby mission to Makemake could take just over 16 years using a Jupiter gravity assist.

(Information: http://en.wikipedia.org/wiki/Makemake_(dwarf_planet); Makemake: https://en.wikipedia.org/wiki/Makemake#/media/File:Makemake_moon_Hubble_image_with_legend_(cropped).jpg, NASA/ESA/A. Parker and M. Buie (Southwest Research Institute), W. Grundy (Lowell Observatory), and K. Noll (NASA GSFC), public domain)

Eris – Ice Dwarf Planet

Discovery date:	January 6, 2005 by Brown, Trujillo, and Rabinowitz
Semimajor axis:	1.02×10^{10} km (67.67 AU)
Orbital period:	558 years (203,810 days)
Synodic period:	1.0018 years (365.9 days)
Average orbital speed:	3.43 km/s
Sidereal rotation period (Eris day):	25.9 Earth hours
Mean radius:	1,163 km (0.18 x Earth)
Surface area:	1.70×10^7 km^2 (0.033 x Earth)
Volume:	6.59×10^9 km^3 (0.006 x Earth)
Mass:	1.66×10^{22} kg (0.0028 x Earth)
Mean density:	2.52 gm/cm^3 (0.46 x Earth)
Surface gravity:	0.82 m/s^2 (0.084 of Earth)
Escape velocity:	1.38 km/s
Apparent magnitude:	18.7
Albedo:	0.96
Temperature:	42.5K, min 30K, max 55K
Number of satellites:	1
Satellite:	Dysnomia



Eris and Dysnomia

Eris was discovered by the team of Mike Brown, Chad Trujillo, and David Rabinowitz on January 5, 2005. The discovery was announced on July 29, 2005, the same day as Makemake and two days after Haumea. Eris is named after the Greek goddess Eris, a personification of strife and discord.

It is approximately three times farther from the Sun than Pluto, and with the exception of some comets, the pair are the most distant known natural objects in the Solar System. Its aphelion distance is 97.65 AU, and its perihelion distance is 37.91 AU. It came to perihelion between 1698 and 1699, to aphelion around 1977, and will return to perihelion around 2256 to 2258. It was calculated that a flyby mission to Eris could take 24.66 years using a Jupiter gravity assist.

Eris appears almost white. It is far enough from the Sun that methane can condense onto its surface. The condensation of methane uniformly over the surface reduces any albedo contrasts and would cover up any deposits of red tholins. Even though Eris can be up to three times farther from the Sun than Pluto, it approaches close enough that some of the ices on the surface might warm enough to sublime. Because methane is highly volatile, its presence shows either that Eris has always resided in the distant reaches of the solar system, where it is cold enough for methane ice to persist, or that the celestial body has an internal source of methane to replenish gas that escapes from its atmosphere.

(Information: http://en.wikipedia.org/wiki/Eris_(dwarf_planet); Eris: https://en.wikipedia.org/wiki/Eris_(dwarf_planet)#/media/File:Eris_and_dysnomia2.jpg, NASA/ESA and Mike Brown, public domain)