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Saturn

Saturn is the sixth planet from the Sun and the second-largest in the Solar System, after Jupiter. It is a gas giant with an average radius of about nine times that of Earth.[20][21] It only has one-eighth the average density of Earth; however, with its larger volume, Saturn is over 95 times more massive.[22][23][24] Saturn is named after the Roman god of wealth and agriculture; its astronomical symbol (♄) represents the god's sickle.

Saturn's interior is most likely composed of a core of iron–nickel and rock (silicon and oxygen compounds). Its core is surrounded by a deep layer of metallic hydrogen, an intermediate layer of liquid hydrogen and liquid helium, and finally a gaseous outer layer. Saturn has a pale yellow hue due to ammonia crystals in its upper atmosphere. An electrical current within the metallic hydrogen layer is thought to give rise to Saturn's planetary magnetic field, which is weaker than the Earth's, but has a magnetic moment 580 times that of Earth due to Saturn's larger size. Saturn's magnetic field strength is around one-twentieth of Jupiter's.[25] The outer atmosphere is generally bland and lacking in contrast, although long-lived features can appear. Wind speeds on Saturn can reach 1,800 km/h (1,100 mph; 500 m/s), higher than on Jupiter, but not as high as those on Neptune.[26] In January 2019, astronomers reported that a day on the planet Saturn has been determined to be$10^{h}\ 33^{m}\ 38^{s}\ {}^{+\,1^{m}\,52^{s}}_{-\,1^{m}\,19^{s}}$, based on studies of the planet's C Ring.[14][15]

The planet's most famous feature is its prominent ring system, which is composed mostly of ice particles, with a smaller amount of rocky debris and dust. At least 82 moons[27] are known to orbit Saturn, of which 53 are officially named; this does not include the hundreds of moonlets in its rings. Titan, Saturn's largest moon, and the second-largest in the Solar System, is larger than the planet Mercury, although less massive, and is the only moon in the Solar System to have a substantial atmosphere.[28]

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Notes

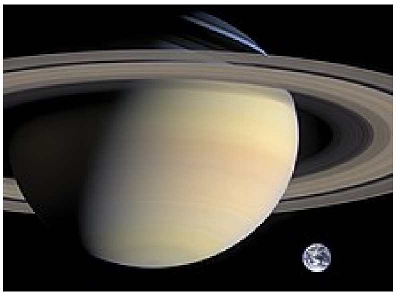
Saturn ♄

Pictured in natural color approaching equinox, photographed by *Cassini* in July 2008; the dot in the bottom left corner is Titan

Designations	
Pronunciation	/ˈsætərn/ (listen)[1]
Named after	Saturn
Adjectives	Saturnian /səˈtɜːrniən/,[2] Cronian[3] / Kronian[4] /ˈkroʊniən/[5]
Orbital characteristics[10]	
Epoch J2000.0	
Aphelion	1,514.50 million km (10.1238 AU)
Perihelion	1,352.55 million km (9.0412 AU)
Semi-major axis	1,433.53 million km (9.5826 AU)
Eccentricity	0.0565
Orbital period	29.4571 yr 10,759.22 d 24,491.07 Saturnian solar days[6]
Synodic period	378.09 days
Average orbital speed	9.68 km/s (6.01 mi/s)
Mean anomaly	317.020°[7]
Inclination	2.485° to ecliptic[7] 5.51° to Sun's equator[7] 0.93° to invariable plane[8]
Longitude of ascending node	113.665°
Time of perihelion	2032-Nov-29[9]
Argument of perihelion	339.392°[7]
Known satellites	82 with formal designations; innumerable additional moonlets.[10]
Physical characteristics[10]	
Mean radius	58,232 km (36,184 mi)[a]
Equatorial radius	60,268 km (37,449 mi)[a]

References
Further reading
External links

Physical characteristics



Composite image comparing the sizes of Saturn and Earth

Saturn is a gas giant because it is predominantly composed of hydrogen and helium. It lacks a definite surface, though it may have a solid core.[29] Saturn's rotation causes it to have the shape of an oblate spheroid; that is, it is flattened at the poles and bulges at its equator. Its equatorial and polar radii differ by almost 10%: 60,268 km versus 54,364 km.[10] Jupiter, Uranus, and Neptune, the other giant planets in the Solar System, are also oblate but to a lesser extent. The combination of the bulge and rotation rate means that the effective surface gravity along the equator, 8.96 m/s^2, is 74% that at the poles and is lower than the surface gravity of Earth. However, the equatorial escape velocity of nearly 36 km/s is much higher than that for Earth.[30]

Saturn is the only planet of the Solar System that is less dense than water—about 30% less.[31] Although Saturn's core is considerably denser than water, the average specific density of the planet is 0.69 g/cm^3 due to the atmosphere. Jupiter has 318 times Earth's mass,[32] and Saturn is 95 times Earth's mass.[10] Together, Jupiter and Saturn hold 92% of the total planetary mass in the Solar System.[33]

Internal structure

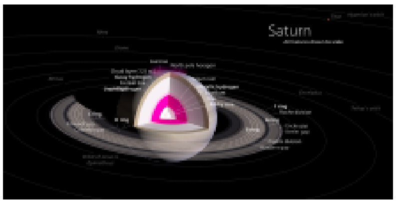


Diagram of Saturn, to scale

Despite consisting mostly of hydrogen and helium, most of Saturn's mass is not in the gas phase, because hydrogen becomes a non-ideal liquid when the density is above 0.01 g/cm^3, which is reached at a radius containing 99.9% of Saturn's mass. The temperature, pressure, and density inside Saturn all rise steadily toward the core, which causes hydrogen to be a metal in the deeper layers.[33]

Standard planetary models suggest that the interior of Saturn is similar to that of Jupiter, having a small rocky core surrounded by hydrogen and helium, with trace amounts of various volatiles.[34] This core is similar in composition to Earth, but is more dense. The examination of Saturn's gravitational moment, in combination with physical models of the interior, has allowed constraints to be placed on the mass of Saturn's core. In 2004, scientists estimated that the core must be 9–22 times the mass of Earth,[35][36] which corresponds to a diameter of about 25,000 km.[37] This is

	9.449 Earths
Polar radius	54,364 km (33,780 mi)[a] 8.552 Earths
Flattening	0.097 96
Circumference	365 882.4 km equatorial (227 348.8 mi)[11]
Surface area	4.27×10^{10} km^2 (1.65×10^{10} sq mi)[12][a] 83.703 Earths
Volume	8.2713×10^{14} km^3 (1.9844×10^{14} cu mi)[a] 763.59 Earths
Mass	5.6834×10^{26} kg 95.159 Earths
Mean density	0.687 g/cm^3 (0.0248 lb/cu in)[b] (less than water)
Surface gravity	10.44 m/s^2 (34.3 ft/s^2)[a] 1.065 *g*
Moment of inertia factor	0.22[13]
Escape velocity	35.5 km/s (22.1 mi/s)[a]
Sidereal rotation period	$10^h\,33^m\,38^s\ {}^{+\,1^m\,52^s}_{-\,1^m\,19^s}$ [14][15]
Equatorial rotation velocity	9.87 km/s (6.13 mi/s; 35,500 km/h)[a]
Axial tilt	26.73° (to orbit)
North pole right ascension	40.589°; $2^h\,42^m\,21^s$
North pole declination	83.537°
Albedo	0.342 (Bond)[16] 0.499 (geometric)[17]

Surface temp.	min	mean	max
1 bar		134 K (−139 °C)	
0.1 bar		84 K (−189 °C)	

Apparent magnitude	−0.55[18] to +1.17[18]
Angular diameter	14.5″ to 20.1″ (excludes rings)
Atmosphere[10]	
Surface pressure	140 kPa[19]
Scale height	59.5 km (37.0 mi)

Composition by volume		
	96.3% ± 2.4%	hydrogen (H_2)
	3.25% ± 2.4%	helium (He)
	0.45% ± 0.2%	methane (CH_4)
	0.0125% ± 0.0075%	ammonia (NH_3)
	0.0110% ± 0.0058%	hydrogen deuteride (HD)

surrounded by a thicker liquid metallic hydrogen layer, followed by a liquid layer of helium-saturated molecular hydrogen that gradually transitions to a gas with increasing altitude. The outermost layer spans 1,000 km and consists of gas.[38][39][40]

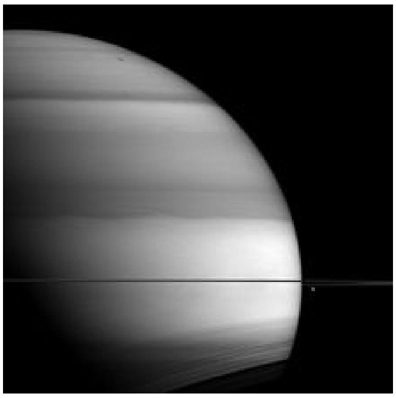
0.0007% ± 0.00015% ethane (C_2H_6)

Ices:

- ammonia (NH_3)
- water (H_2O)
- ammonium hydrosulfide (NH_4SH)

Saturn has a hot interior, reaching 11,700 °C at its core, and it radiates 2.5 times more energy into space than it receives from the Sun. Jupiter's thermal energy is generated by the Kelvin–Helmholtz mechanism of slow gravitational compression, but such a process alone may not be sufficient to explain heat production for Saturn, because it is less massive. An alternative or additional mechanism may be generation of heat through the "raining out" of droplets of helium deep in Saturn's interior. As the droplets descend through the lower-density hydrogen, the process releases heat by friction and leaves Saturn's outer layers depleted of helium.[41][42] These descending droplets may have accumulated into a helium shell surrounding the core.[34] Rainfalls of diamonds have been suggested to occur within Saturn, as well as in Jupiter[43] and ice giants Uranus and Neptune.[44]

Atmosphere



Methane bands circle Saturn. The moon Dione hangs below the rings to the right.

The outer atmosphere of Saturn contains 96.3% molecular hydrogen and 3.25% helium by volume.[45] The proportion of helium is significantly deficient compared to the abundance of this element in the Sun.[34] The quantity of elements heavier than helium (metallicity) is not known precisely, but the proportions are assumed to match the primordial abundances from the formation of the Solar System. The total mass of these heavier elements is estimated to be 19–31 times the mass of the Earth, with a significant fraction located in Saturn's core region.[46]

Trace amounts of ammonia, acetylene, ethane, propane, phosphine, and methane have been detected in Saturn's atmosphere.[47][48][49] The upper clouds are composed of ammonia crystals, while the lower level clouds appear to consist of either ammonium hydrosulfide (NH_4SH) or water.[50] Ultraviolet radiation from the Sun causes methane photolysis in the upper atmosphere, leading to a series of hydrocarbon chemical reactions with the resulting products being carried downward by eddies and diffusion. This photochemical cycle is modulated by Saturn's annual seasonal cycle.[49]

Cloud layers

A global storm girdles the planet in 2011. The storm passes around the planet, such that the storm's head (bright area) passes its tail.

Saturn's atmosphere exhibits a banded pattern similar to Jupiter's, but Saturn's bands are much fainter and are much wider near the equator. The nomenclature used to describe these bands is the same as on Jupiter. Saturn's finer cloud patterns were not observed until the flybys of the *Voyager* spacecraft during the 1980s. Since then, Earth-based telescopy has improved to the point where regular observations can be made.[51]

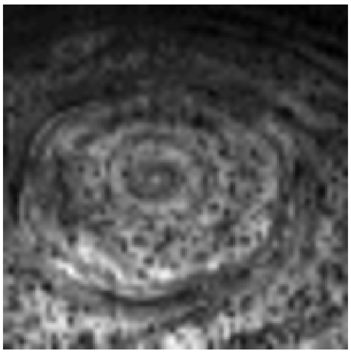
The composition of the clouds varies with depth and increasing pressure. In the upper cloud layers, with the temperature in the range 100–160 K and pressures extending between 0.5–2 bar, the clouds consist of ammonia ice. Water ice clouds begin at a level where the pressure is about 2.5 bar and extend down to 9.5 bar, where temperatures range from 185–270 K. Intermixed in this layer is a band of ammonium hydrosulfide ice, lying in the pressure range 3–6 bar with temperatures of 190–235 K. Finally, the lower layers, where pressures are between 10–20 bar and temperatures are 270–330 K, contains a region of water droplets with ammonia in aqueous solution.[52]

Saturn's usually bland atmosphere occasionally exhibits long-lived ovals and other features common on Jupiter. In 1990, the Hubble Space Telescope imaged an enormous white cloud near Saturn's equator that was 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 but short-lived phenomenon that occurs once every Saturnian year, roughly every 30 Earth years, around the time of the northern hemisphere's summer solstice.[53] Previous Great White Spots were observed in 1876, 1903, 1933 and 1960, with the 1933 storm being the most famous. If the periodicity is maintained, another storm will occur in about 2020.[54]

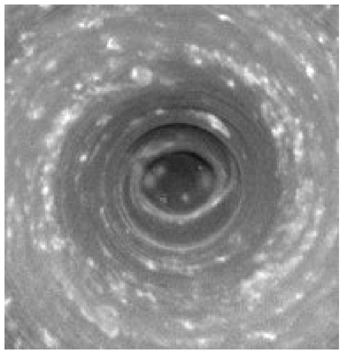
The winds on Saturn are the second fastest among the Solar System's planets, after Neptune's. *Voyager* data indicate peak easterly winds of 500 m/s (1,800 km/h).[55] In images from the *Cassini* spacecraft during 2007, Saturn's northern hemisphere displayed a bright blue hue, similar to Uranus. The color was most likely caused by Rayleigh scattering.[56] Thermography has shown that Saturn's south pole has a warm polar vortex, the only known example of such a phenomenon in the Solar System.[57] Whereas temperatures on Saturn are normally −185 °C, temperatures on the vortex often reach as high as −122 °C, suspected to be the warmest spot on Saturn.[57]

North pole hexagonal cloud pattern

A persisting hexagonal wave pattern around the north polar vortex in the atmosphere at about 78°N was first noted in the *Voyager* images.[58][59][60] The sides of the hexagon are each about 13,800 km (8,600 mi) long, which is longer than the diameter of the Earth.[61] The entire structure rotates with a period of 10^{h} 39^{m} 24^{s} (the same period as that of the planet's radio emissions) which is assumed to be equal to the period of rotation of Saturn's interior.[62] The hexagonal feature does not shift in longitude like the other clouds in the visible atmosphere.[63] The pattern's origin is a matter of much speculation. Most scientists think it is a standing wave pattern in the atmosphere. Polygonal shapes have been replicated in the laboratory through differential rotation of fluids.[64][65]



Saturn's north pole (IR animation)



Saturn's south pole

South pole vortex

HST imaging of the south polar region indicates the presence of a jet stream, but no strong polar vortex nor any hexagonal standing wave.[66] NASA reported in November 2006 that *Cassini* had observed a "hurricane-like" storm locked to the south pole that had a clearly defined eyewall.[67][68] Eyewall clouds had not previously been seen on any planet other than Earth. For example, images from the *Galileo* spacecraft did not show an eyewall in the Great Red Spot of Jupiter.[69]

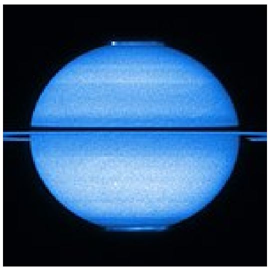
The south pole storm may have been present for billions of years.[70] This vortex is comparable to the size of Earth, and it has winds of 550 km/h.[70]

Other features

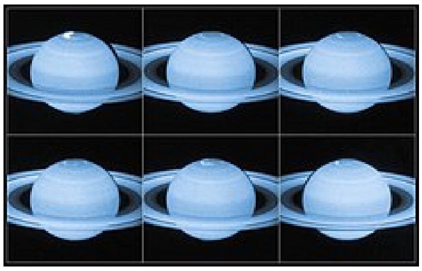
Cassini observed a series of cloud features found in northern latitudes, nicknamed the "String of Pearls". These features are cloud clearings that reside in deeper cloud layers.[71]

Magnetosphere

Saturn has an intrinsic magnetic field that has a simple, symmetric shape – a magnetic dipole. Its strength at the equator – 0.2 gauss (20 µT) – is approximately one twentieth of that of the field around Jupiter and slightly weaker than Earth's magnetic field.[25] As a result, Saturn's magnetosphere is much smaller than Jupiter's.[73] When *Voyager 2* entered the magnetosphere, the solar wind pressure was high and the magnetosphere extended only 19 Saturn radii, or 1.1 million km (712,000 mi),[74] although it enlarged within several hours, and remained so for about three days.[75] Most probably, the magnetic field is generated similarly to that of Jupiter – by currents in the liquid metallic-hydrogen layer called a metallic-hydrogen dynamo.[73] This magnetosphere is efficient at deflecting the solar wind particles from the Sun. The moon Titan orbits within the outer part of Saturn's magnetosphere and contributes plasma from the ionized particles in Titan's outer atmosphere.[25] Saturn's magnetosphere, like Earth's, produces aurorae.[76]



Polar aurorae on Saturn



Auroral lights at Saturn's north pole[72]

0:00 MENU

Radio emissions detected by *Cassini*

Orbit and rotation

Saturn and rings as viewed by the *Cassini* spacecraft (28 October 2016)

The average distance between Saturn and the Sun is over 1.4 billion kilometers (9 AU). With an average orbital speed of 9.68 km/s,[10] it takes Saturn 10,759 Earth days (or about 29½ years)[77] to finish one revolution around the Sun.[10] As a consequence, it forms a near 5:2 mean-motion resonance with Jupiter.[78] The elliptical orbit of Saturn is inclined 2.48° relative to the orbital plane of the Earth.[10] The perihelion and aphelion distances are, respectively, 9.195 and 9.957 AU, on average.[10][79] The visible features on Saturn rotate at different rates depending on latitude and multiple rotation periods have been assigned to various regions (as in Jupiter's case).

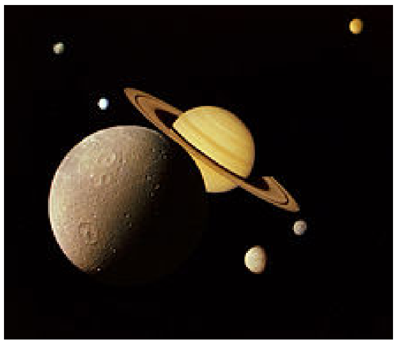
Astronomers use three different systems for specifying the rotation rate of Saturn. *System I* has a period of $10^h\ 14^m\ 00^s$ (844.3°/d) and encompasses the Equatorial Zone, the South Equatorial Belt, and the North Equatorial Belt. The polar regions are considered to have rotation rates similar to *System I*. All other Saturnian latitudes, excluding the north and south polar regions, are indicated as *System II* and have been assigned a rotation period of $10^h\ 38^m\ 25.4^s$ (810.76°/d). *System III* refers to Saturn's internal rotation rate. Based on radio emissions from the planet detected by *Voyager 1* and *Voyager 2*,[80] System III has a rotation period of $10^h\ 39^m\ 22.4^s$ (810.8°/d). System III has largely superseded System II.[81]

A precise value for the rotation period of the interior remains elusive. While approaching Saturn in 2004, *Cassini* found that the radio rotation period of Saturn had increased appreciably, to approximately $10^h\ 45^m\ 45^s \pm 36^s$.[82][83] The latest estimate of Saturn's rotation (as an indicated rotation rate for Saturn as a whole) based on a compilation of various measurements from the *Cassini*, *Voyager* and *Pioneer* probes was reported in September 2007 is $10^h\ 32^m\ 35^s$.[84]

In March 2007, it was found that the variation of radio emissions from the planet did not match Saturn's rotation rate. This variance may be caused by geyser activity on Saturn's moon Enceladus. The water vapor emitted into Saturn's orbit by this activity becomes charged and creates a drag upon Saturn's magnetic field, slowing its rotation slightly relative to the rotation of the planet.[85][86][87]

An apparent oddity for Saturn is that it does not have any known trojan asteroids. These are minor planets that orbit the Sun at the stable Lagrangian points, designated L_4 and L_5, located at 60° angles to the planet along its orbit. Trojan asteroids have been discovered for Mars, Jupiter, Uranus, and Neptune. Orbital resonance mechanisms, including secular resonance, are believed to be the cause of the missing Saturnian trojans.[88]

Natural satellites



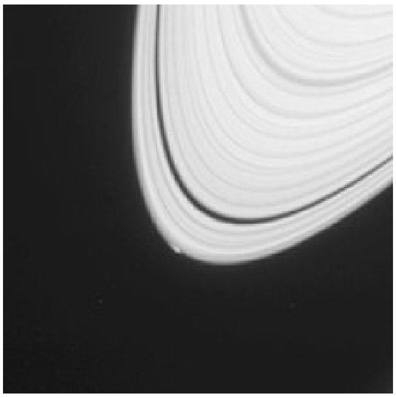
A montage of Saturn and its principal moons (Dione, Tethys, Mimas, Enceladus, Rhea and Titan; Iapetus not shown). This image was created from photographs taken in November 1980 by the *Voyager 1* spacecraft.

Saturn has 82 known moons,[27] 53 of which have formal names.[89][90] In addition, there is evidence of dozens to hundreds of moonlets with diameters of 40–500 meters in Saturn's rings,[91] which are not considered to be true moons. Titan, the largest moon, comprises more than 90% of the mass in orbit around Saturn, including the rings.[92] Saturn's second-largest moon, Rhea, may have a tenuous ring system of its own,[93] along with a tenuous atmosphere.[94][95][96]

Many of the other moons are small: 34 are less than 10 km in diameter and another 14 between 10 and 50 km in diameter.[97] Traditionally, most of Saturn's moons have been named after Titans of Greek mythology. Titan is the only satellite in the Solar System with a major atmosphere,[98][99] in which a complex organic chemistry occurs. It is the only satellite with hydrocarbon lakes.[100][101]

On 6 June 2013, scientists at the IAA-CSIC reported the detection of polycyclic aromatic hydrocarbons in the upper atmosphere of Titan, a possible precursor for life.[102] On 23 June 2014, NASA claimed to have strong evidence that nitrogen in the atmosphere of Titan came from materials in the Oort cloud, associated with comets, and not from the materials that formed Saturn in earlier times.[103]

Saturn's moon Enceladus, which seems similar in chemical makeup to comets,[104] has often been regarded as a potential habitat for microbial life.[105][106][107][108] Evidence of this possibility includes the satellite's salt-rich particles having an "ocean-like" composition that indicates most of Enceladus's expelled ice comes from the evaporation of liquid salt



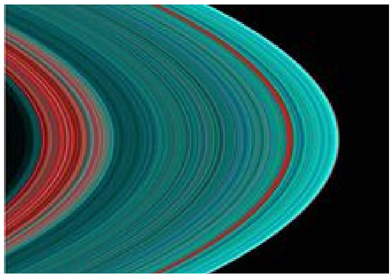
Possible beginning of a new moon (white dot) of Saturn (image taken by *Cassini* on 15 April 2013)

water.[109][110][111] A 2015 flyby by *Cassini* through a plume on Enceladus found most of the ingredients to sustain life forms that live by methanogenesis.[112]

In April 2014, NASA scientists reported the possible beginning of a new moon within the A Ring, which was imaged by *Cassini* on 15 April 2013.[113]

Planetary rings

The rings of Saturn (imaged here by *Cassini* in 2007) are the most massive and conspicuous in the Solar System.[39]



False-color UV image of Saturn's outer B and A rings; dirtier ringlets in the Cassini Division and Encke Gap show up red.

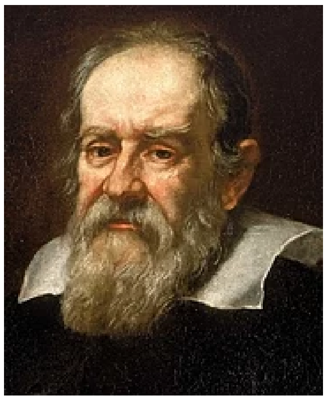
Saturn is probably best known for the system of planetary rings that makes it visually unique.[39] The rings extend from 6,630 to 120,700 kilometers (4,120 to 75,000 mi) outward from Saturn's equator and average approximately 20 meters (66 ft) in thickness. They are composed predominantly of water ice, with trace amounts of tholin impurities and a peppered coating of approximately 7% amorphous carbon.[114] The particles that make up the rings range in size from specks of dust up to 10 m.[115] While the other gas giants also have ring systems, Saturn's is the largest and most visible.

There are two main hypotheses regarding the origin of the rings. One hypothesis is that the rings are remnants of a destroyed moon of Saturn. The second hypothesis is that the rings are left over from the original nebular material from which Saturn was formed. Some ice in the E ring comes from the moon Enceladus's geysers.[116][117][118][119] The water abundance of the rings varies radially, with the outermost ring A being the most pure in ice water. This abundance variance may be explained by meteor bombardment.[120]

Beyond the main rings, at a distance of 12 million km from the planet is the sparse Phoebe ring. It is tilted at an angle of 27° to the other rings and, like Phoebe, orbits in retrograde fashion.[121]

Some of the moons of Saturn, including Pandora and Prometheus, act as shepherd moons to confine the rings and prevent them from spreading out.[122] Pan and Atlas cause weak, linear density waves in Saturn's rings that have yielded more reliable calculations of their masses.[123]

History of observation and exploration



Galileo Galilei first observed the rings of Saturn in 1610

The observation and exploration of Saturn can be divided into three phases. The first phase is ancient observations (such as with the naked eye), before the invention of modern telescopes. The second phase began in the 17th century, with telescopic observations from Earth, which improved over time. The third phase is visitation by space probes, in orbit or on flyby. In the 21st century, telescopic observations continue from Earth (including Earth-orbiting observatories like the Hubble Space Telescope) and, until its 2017 retirement, from the *Cassini* orbiter around Saturn.

Ancient observations

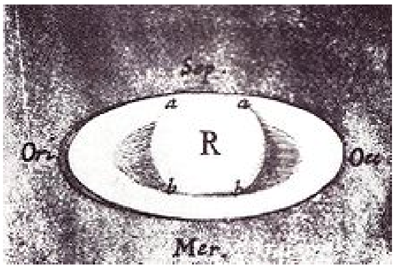
Saturn has been known since prehistoric times,[124] and in early recorded history it was a major character in various mythologies. Babylonian astronomers systematically observed and recorded the movements of Saturn.[125] In ancient Greek, the planet was known as Φαίνων ***Phainon***,[126] and in Roman times it was known as the "star of Saturn".[127] In ancient Roman mythology, the planet Phainon was sacred to this agricultural god, from which the planet takes its modern name.[128] The Romans considered the god Saturnus the equivalent of the Greek god Cronus; in modern Greek, the planet retains the name *Cronus*—Κρόνος: *Kronos*.[129]

The Greek scientist Ptolemy based his calculations of Saturn's orbit on observations he made while it was in opposition.[130] In Hindu astrology, there are nine astrological objects, known as Navagrahas. Saturn is known as "Shani" and judges everyone based on the good and bad deeds performed in life.[128][130] Ancient Chinese and Japanese culture designated the planet Saturn as the "earth star" (土星). This was based on Five Elements which were traditionally used to classify natural elements.[131][132][133]

In ancient Hebrew, Saturn is called 'Shabbathai'.[134] Its angel is Cassiel. Its intelligence or beneficial spirit is 'Agȋêl (Hebrew: אגיאל, romanized: *ʿAgyal*),[135] and its darker spirit (demon) is Zȃzȇl (Hebrew: זאזל, romanized: *Zazl*).[135][136][137] Zazel has been described as a great angel, invoked in Solomonic magic, who is "effective in love conjurations".[138][139] In Ottoman Turkish, Urdu and Malay, the name of Zazel is 'Zuhal', derived from the Arabic language (Arabic: زحل, romanized: *Zuhal*).[136]

European observations (17th–19th centuries)

Saturn's rings require at least a 15-mm-diameter telescope[140] to resolve and thus were not known to exist until Christiaan Huygens saw them in 1659. Galileo, with his primitive telescope in 1610,[141][142] incorrectly thought of Saturn's appearing not quite round as two moons on Saturn's sides.[143][144] It was not until Huygens used greater telescopic magnification that this notion was refuted, and the rings were truly seen for the first time. Huygens also discovered Saturn's moon Titan; Giovanni Domenico Cassini later discovered four other moons: Iapetus, Rhea, Tethys and Dione. In 1675, Cassini discovered the gap now known as the Cassini Division.[145]



Robert Hooke noted the shadows (*a* and *b*) cast by both the globe and the rings on each other in this drawing of Saturn in 1666.

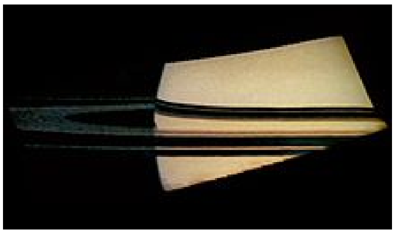
No further discoveries of significance were made until 1789 when William Herschel discovered two further moons, Mimas and Enceladus. The irregularly shaped satellite Hyperion, which has a resonance with Titan, was discovered in 1848 by a British team.[146]

In 1899 William Henry Pickering discovered Phoebe, a highly irregular satellite that does not rotate synchronously with Saturn as the larger moons do.[146] Phoebe was the first such satellite found and it takes more than a year to orbit Saturn in a retrograde orbit. During the early 20th century, research on Titan led to the confirmation in 1944 that it had a thick atmosphere – a feature unique among the Solar System's moons.[147]

Modern NASA and ESA probes

Pioneer 11 flyby

Pioneer 11 made the first flyby of Saturn in September 1979, when it passed within 20,000 km of the planet's cloud tops. Images were taken of the planet and a few of its moons, although their resolution was too low to discern surface detail. The spacecraft also studied Saturn's rings, revealing the thin F-ring and the fact that dark gaps in the rings are bright when viewed at high phase angle (towards the Sun), meaning that they contain fine light-scattering material. In addition, *Pioneer 11* measured the temperature of Titan.[148]



Pioneer 11 image of Saturn

Voyager flybys

In November 1980, the *Voyager 1* probe visited the Saturn system. It sent back the first high-resolution images of the planet, its rings and satellites. Surface features of various moons were seen for the first time. *Voyager 1* performed a close flyby of Titan, increasing knowledge of the atmosphere of the moon. It proved that Titan's atmosphere is impenetrable in visible wavelengths; therefore no surface details were seen. The flyby changed the spacecraft's trajectory out from the plane of the Solar System.[149]

Almost a year later, in August 1981, *Voyager 2* continued the study of the Saturn system. More close-up images of Saturn's moons were acquired, as well as evidence of changes in the atmosphere and the rings. Unfortunately, during the flyby, the probe's turnable camera platform stuck for a couple of days and some planned imaging was lost. Saturn's gravity was used to direct the spacecraft's trajectory towards Uranus.[149]

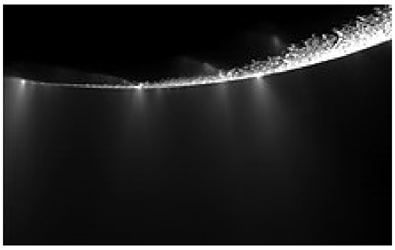
The probes discovered and confirmed several new satellites orbiting near or within the planet's rings, as well as the small Maxwell Gap (a gap within the C Ring) and Keeler gap (a 42 km-wide gap in the A Ring).

Cassini–Huygens spacecraft

The *Cassini–Huygens* space probe entered orbit around Saturn on 1 July 2004. In June 2004, it conducted a close flyby of Phoebe, sending back high-resolution images and data. *Cassini*'s flyby of Saturn's largest moon, Titan, captured radar images of large lakes and their coastlines with numerous islands and mountains. The orbiter completed two Titan flybys before releasing the *Huygens* probe on 25 December 2004. *Huygens* descended onto the surface of Titan on 14 January 2005.[150]

Starting in early 2005, scientists used *Cassini* to track lightning on Saturn. The power of the lightning is approximately 1,000 times that of lightning on Earth.[151]

In 2006, NASA reported that *Cassini* had found evidence of liquid water reservoirs no more than tens of meters below the surface that erupt in geysers on Saturn's moon Enceladus. These jets of icy particles are emitted into orbit around Saturn from vents in the moon's south polar region.[153] Over 100 geysers have been identified on Enceladus.[152] In May 2011, NASA scientists reported that Enceladus "is emerging as the most habitable spot beyond Earth in the Solar System for life as we know it".[154][155]



At Enceladus's south pole geysers spray water from many locations along the tiger stripes.[152]

Cassini photographs have revealed a previously undiscovered planetary ring, outside the brighter main rings of Saturn and inside the G and E rings. The source of this ring is hypothesized to be the crashing of a meteoroid off Janus and Epimetheus.[156] In July 2006, images were returned of hydrocarbon lakes near Titan's north pole, the presence of which were confirmed in January 2007. In March 2007, hydrocarbon seas were found near the North pole, the largest of which is almost the size of the Caspian Sea.[157] In October 2006, the probe detected an 8,000 km diameter cyclone-like storm with an eyewall at Saturn's south pole.[158]

From 2004 to 2 November 2009, the probe discovered and confirmed eight new satellites.[159] In April 2013 *Cassini* sent back images of a hurricane at the planet's north pole 20 times larger than those found on Earth, with winds faster than 530 km/h (330 mph).[160] On 15 September 2017, the *Cassini-Huygens* spacecraft performed the "Grand Finale" of its mission: a number of passes through gaps between Saturn and Saturn's inner rings.[161][162] The atmospheric entry of *Cassini* ended the mission.

Possible future missions

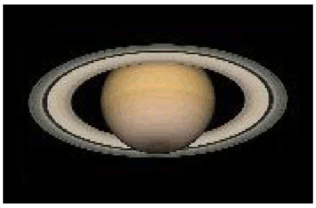
The continued exploration of Saturn is still considered to be a viable option for NASA as part of their ongoing New Frontiers program of missions. NASA previously requested for plans to be put forward for a mission to Saturn that included the Saturn Atmospheric Entry Probe, and possible investigations into the habitability and possible discovery of life on Saturn's moons Titan and Enceladus by *Dragonfly*.[163][164]

Observation

Saturn is the most distant of the five planets easily visible to the naked eye from Earth, the other four being Mercury, Venus, Mars and Jupiter. (Uranus, and occasionally 4 Vesta, are visible to the naked eye in dark skies.) Saturn appears to the naked eye in the night sky as a bright, yellowish point of light. The mean apparent magnitude of Saturn is 0.46 with a standard deviation of 0.34.[18] Most of the magnitude variation is due to the inclination of the ring system relative to the Sun and Earth. The brightest magnitude, −0.55, occurs near in time to when the plane of the rings is inclined most highly, and the faintest magnitude, 1.17, occurs around the time when they are least inclined.[18] It takes approximately 29.5 years for the planet to complete an entire circuit of the ecliptic against the background constellations of the zodiac. Most people will require an optical aid (very large binoculars or a small telescope) that magnifies at least 30 times to achieve an image of Saturn's rings in which clear resolution is present.[39][140] When Earth passes through the ring plane, which occurs twice every Saturnian year (roughly every 15 Earth years), the rings briefly disappear from view because they are so thin. Such a "disappearance" will next occur in 2025, but Saturn will be too close to the Sun for observations.[165]

Amateur telescopic view of Saturn

Saturn and its rings are best seen when the planet is at, or near, opposition, the configuration of a planet when it is at an elongation of 180°, and thus appears opposite the Sun in the sky. A Saturnian opposition occurs every year—approximately every 378 days—and results in the planet appearing at its brightest. Both the Earth and Saturn orbit the Sun on eccentric orbits, which means their distances from the Sun vary over time, and therefore so do their distances from each other, hence



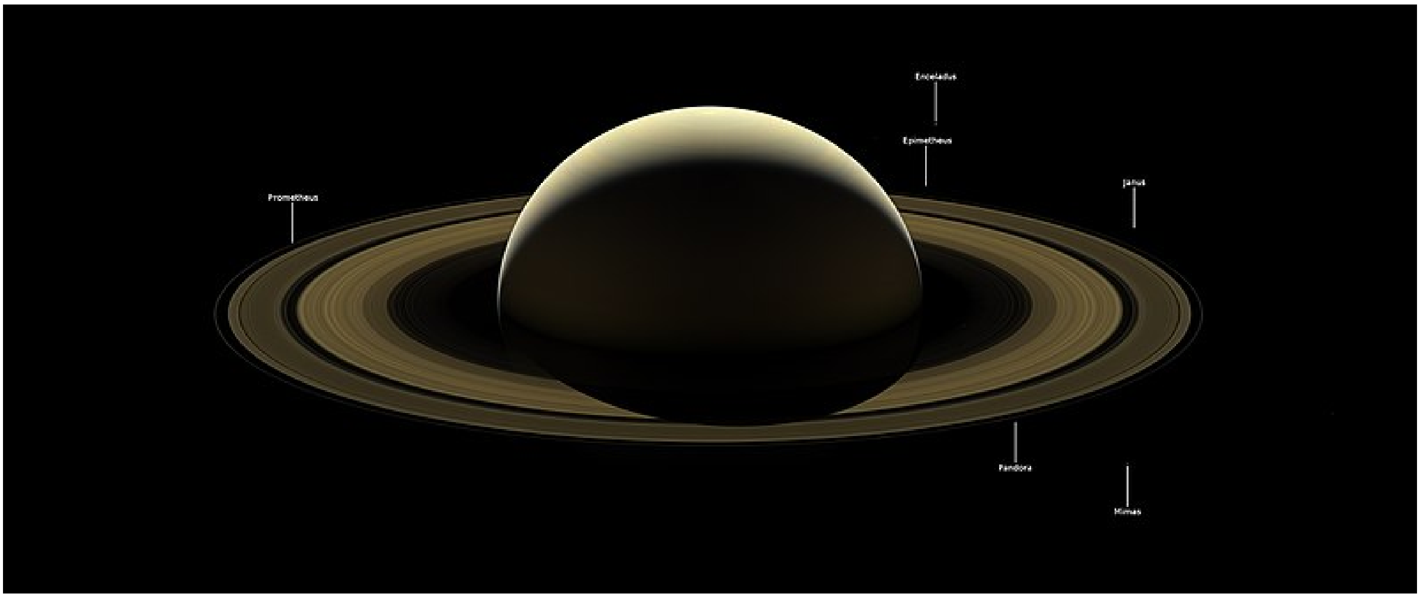
Simulated appearance of Saturn as seen from Earth (at opposition) during an orbit of Saturn, 2001–2029

varying the brightness of Saturn from one opposition to the next. Saturn also appears brighter when the rings are angled such that they are more visible. For example, during the opposition of 17 December 2002, Saturn appeared at its brightest due to a favorable orientation of its rings relative to the Earth,[166] even though Saturn was closer to the Earth and Sun in late 2003.[166]

From time to time, Saturn is occulted by the Moon (that is, the Moon covers up Saturn in the sky). As with all the planets in the Solar System, occultations of Saturn occur in "seasons". Saturnian occultations will take place monthly for about a 12-month period, followed by about a five-year period in which no such activity is registered. The Moon's orbit is inclined by several degrees relative to Saturn's, so occultations will only occur when Saturn is near one of the points in the sky where the two planes intersect (both the length of Saturn's year and the 18.6-Earth year nodal precession period of the Moon's orbit influence the periodicity).[167]

Saturn eclipses the Sun, as seen from *Cassini*. The rings are visible, including the F Ring.

HST Saturn portrait from 20 June 2019



Farewell to Saturn and moons (Enceladus, Epimetheus, Janus, Mimas, Pandora and Prometheus), by *Cassini* (21 November 2017).

Notes

a. Refers to the level of 1 bar atmospheric pressure
b. Based on the volume within the level of 1 bar atmospheric pressure

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External links

- Saturn overview (https://solarsystem.nasa.gov/planets/saturn/overview/) by NASA's Science Mission Directorate
- Saturn fact sheet (https://nssdc.gsfc.nasa.gov/planetary/factsheet/saturnfact.html) at the NASA Space Science Data Coordinated Archive
- Saturnian System terminology (https://web.archive.org/web/20180219090345/https://planetarynames.wr.usgs.gov/Page/SATURN/system) by the IAU Gazetteer of Planetary Nomenclature
- *Cassini-Huygens* legacy website (https://saturn.jpl.nasa.gov/) by the Jet Propulsion Laboratory
- Saturn (http://solarviews.com/eng/saturn.htm) at SolarViews.com
- Interactive 3D gravity simulation of the Cronian system (https://gravitysimulator.org/solar-system/the-cronian-system)