Venus

Venus is the second planet from the Sun. It is a terrestrial planet and is the closest in mass and size to its orbital neighbour Earth. Venus is notable for having the densest atmosphere of the terrestrial planets, composed mostly of carbon dioxide with a thick, global sulfuric acid cloud cover. At the surface it has a mean temperature of 737 K (464 °C; 867 °F) and a pressure of 92 times that of Earth's at sea level. These conditions are extreme enough to compress carbon dioxide into a supercritical state close to Venus's surface.

Internally, Venus has a core, mantle, and crust. Venus lacks an internal dynamo, and its weak induced magnetosphere is instead caused by atmospheric interactions with the solar wind. Internal heat escapes through active volcanism, resulting in resurfacing instead of plate tectonics. Venus is one of two planets in the Solar System that have no moons.[20] Conditions perhaps favourable for life on Venus have been identified at its cloud layers. Venus may have had liquid surface water early in its history with a habitable environment,[21][22] before a runaway greenhouse effect evaporated any water and turned Venus into its present state.[23][24][25]

The rotation of Venus has been slowed and turned against its orbital direction (retrograde) by the strong currents and drag of its atmosphere. It takes 224.7 Earth days for Venus to complete an orbit around the Sun, and a Venusian solar year is just under two Venusian days long. The orbits of Venus and Earth are the closest between any two Solar System planets, approaching each other in synodic periods of 1.6 years. Venus and Earth have the lowest difference in gravitational potential of any pair of Solar System planets. This allows Venus to be the most accessible destination and a useful gravity assist waypoint for interplanetary flights from Earth.

Venus has historically been a common and important object for humans, in both their cultures and astronomy. Orbiting inferiorly (inside of Earth's orbit), it always appears close to the Sun in Earth's sky, as either a

Venus

True colour image of Venus, as captured by *MESSENGER*. A global layer of bright sulfuric acid clouds permanently obscures the Venusian surface.

Designations	
Pronunciation	/ˈviːnəs/
Named after	Roman goddess of love (see goddess Venus)
Adjectives	Venusian /vɪˈnjuːziən, -ʒən/,[1] rarely Cytherean /sɪθəˈriːən/[2] or Venerean / Venerian /vɪˈnɪəriən/[3]
Symbol	♀
Orbital characteristics[4][5]	
Epoch J2000	
Aphelion	0.728213 AU (108.94 million km)
Perihelion	0.718440 AU (107.48 million km)
Semi-major axis	0.723332 AU (108.21 million km)
Eccentricity	0.006772[6]

"morning star" or an "evening star". While this is also true for Mercury, Venus appears more prominent, since it is the third brightest object in Earth's sky after the Moon and the Sun.[26][27]

In 1961, Venus became the target of the first interplanetary flight, Venera 1, followed by many essential interplanetary firsts, such as the first soft landing on another planet by Venera 7 in 1970. These probes demonstrated the extreme surface conditions, an insight that has informed predictions about global warming on Earth.[28][29] This finding ended the theories and then popular science fiction about Venus being a habitable or inhabited planet.

Physical characteristics

Venus to scale among the terrestrial planets of the Solar System, which are arranged by the order of their Inner Solar System orbits outward from the Sun (from left: Mercury, Venus, Earth and Mars)

Venus is one of the four terrestrial planets in the Solar System, meaning that it is a rocky body like Earth. It is similar to Earth in size and mass and is often described as Earth's "sister" or "twin".[30] Venus is close to spherical due to its slow rotation.[31] Venus has a diameter of 12,103.6 km (7,520.8 mi)—only 638.4 km (396.7 mi) less than Earth's—and its mass is 81.5% of Earth's, making it the third-smallest planet in the Solar System. Conditions on the Venusian surface differ radically from those on Earth because its dense atmosphere is 96.5% carbon dioxide, with most of the remaining 3.5% being nitrogen.[32] The surface pressure is 9.3 megapascals (93 bars), and the average surface temperature is 737 K (464 °C; 867 °F), above the critical points of both major

Orbital period (sidereal)	224.701 d[4] 0.615 198 yr 1.92 Venus solar day
Orbital period (synodic)	583.92 days[4]
Average orbital speed	35.02 km/s
Mean anomaly	50.115°
Inclination	3.394 58° to ecliptic 3.86° to Sun's equator 2.15° to invariable plane[7]
Longitude of ascending node	76.680°[6]
Argument of perihelion	54.884°
Satellites	None
Physical characteristics	
Mean radius	6,051.8 ± 1.0 km[8] 0.9499 Earths
Flattening	0[8]
Surface area	4.6023×10^{8} km^2 0.902 Earths
Volume	9.2843×10^{11} km^3 0.857 Earths
Mass	4.8675×10^{24} kg[9] 0.815 Earths
Mean density	5.243 g/cm^3
Surface gravity	8.87 m/s^2 0.904 *g*
Escape velocity	10.36 km/s (6.44 mi/s)[10]
Synodic rotation period	−116.75 d (retrograde)[11] 1 Venus solar day
Sidereal rotation period	−243.0226 d (retrograde)[12]
Equatorial rotation velocity	6.52 km/h (1.81 m/s)
Axial tilt	2.64° (for retrograde rotation) 177.36° (to orbit)[4][note 1]

constituents and making the surface atmosphere a supercritical fluid out of mainly supercritical carbon dioxide and some supercritical nitrogen.

Atmosphere and climate

Venus has a dense atmosphere composed of 96.5% carbon dioxide, 3.5% nitrogen—both exist as supercritical fluids at the planet's surface with a density 6.5% that of water[33]—and traces of other gases including sulphur dioxide.[34] The mass of its atmosphere is 92 times that of Earth's, whereas the pressure at its surface is about 93 times that at Earth's—a pressure equivalent to that at a depth of nearly 1 km ($5⁄8$ mi) under Earth's ocean surfaces. The density at the surface is 65 kg/m^3 (4.1 lb/cu ft), 6.5% that of water[33] or 50 times as dense as Earth's atmosphere at 293 K (20 °C; 68 °F) at sea level. The CO_2-rich atmosphere generates the strongest greenhouse effect in the Solar System, creating surface temperatures of at least 735 K (462 °C; 864 °F).[35][36] This makes the Venusian surface hotter than Mercury's, which has a minimum surface temperature of 53 K (−220 °C; −364 °F) and maximum surface temperature of 700 K (427 °C; 801 °F),[37][38] even though Venus is nearly twice Mercury's distance from the Sun and thus receives only 25% of Mercury's solar irradiance. Because of its runaway greenhouse effect, Venus has been identified by scientists such as Carl Sagan as a warning and research object linked to climate change on Earth.[28][29]

Venus's atmosphere is rich in primordial noble gases compared to that of Earth.[40] This enrichment indicates an early divergence from Earth in evolution. An unusually large comet impact[41] or accretion of a more massive primary atmosphere from solar nebula[42] have been proposed to explain the enrichment. However, the atmosphere is depleted of radiogenic argon, a proxy for mantle degassing, suggesting an early shutdown of major magmatism.[43][44]

Studies have suggested that billions of years ago, Venus's atmosphere could have been much more like the one surrounding the early Earth, and that there may have been substantial quantities of liquid water on the surface.[45][46][47] After a period of 600 million to several billion years,[48] solar forcing from rising

North pole right ascension	$18^h\ 11^m\ 2^s$ 272.76°[13]
North pole declination	67.16°
Albedo	0.689 (geometric)[14] 0.76 (Bond)[15]
Temperature	232 K (−41 °C) (blackbody temperature)[16]

Surface temp.	min	mean	max
Kelvin		737 K[4]	
Celsius		464 °C	
Fahrenheit		867 °F	

Surface absorbed dose rate	2.1×10^{-6} μGy/h[17]
Surface equivalent dose rate	2.2×10^{-6} μSv/h 0.092–22 μSv/h at cloud level[17]
Apparent magnitude	−4.92 to −2.98[18]
Absolute magnitude *(H)*	−4.4[19]
Angular diameter	9.7″–66.0″[4]
Atmosphere[4]	
Surface pressure	93 bar (9.3 MPa) 92 atm
Composition by volume	96.5% carbon dioxide 3.5% nitrogen 0.015% sulphur dioxide 0.0070% argon 0.0020% water vapour 0.0017% carbon monoxide 0.0012% helium 0.0007% neon Trace carbonyl sulfide Trace hydrogen chloride Trace hydrogen fluoride

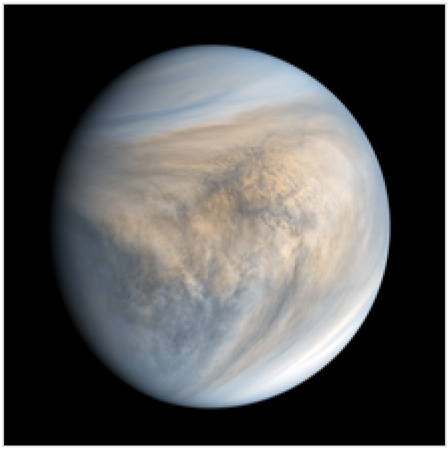
1. Defining the rotation as retrograde, as done by NASA space missions and the

luminosity of the Sun and possibly large volcanic resurfacing caused the evaporation of the original water and the current atmosphere.[49] A runaway greenhouse effect was created once a critical level of greenhouse gases (including water) was added to its atmosphere.[50] Although the surface conditions on Venus are no longer hospitable to any Earth-like life that may have formed before this event, there is speculation on the possibility that life exists in the upper cloud layers of Venus, 50 km (30 mi) up from the surface, where the atmospheric conditions are the most Earth-like in the Solar System,[51] with temperatures ranging between 303 and 353 K (30 and 80 °C; 86 and 176 °F), and the pressure and radiation being about the same as at Earth's surface, but with acidic clouds and the carbon dioxide air.[52][53][54] The putative detection of an absorption line of phosphine in Venus's atmosphere, with no known pathway for abiotic production, led to speculation in September 2020 that there could be extant life currently present in the atmosphere.[55][56] Later research attributed the spectroscopic signal that was interpreted as phosphine to sulphur dioxide,[57] or found that in fact there was no absorption line.[58][59]

USGS, puts Ishtar Terra in the northern hemisphere and makes the axial tilt 2.64°. Following the right-hand rule for prograde rotation puts Ishtar Terra in the negative hemisphere and makes the axial tilt 177.36°.

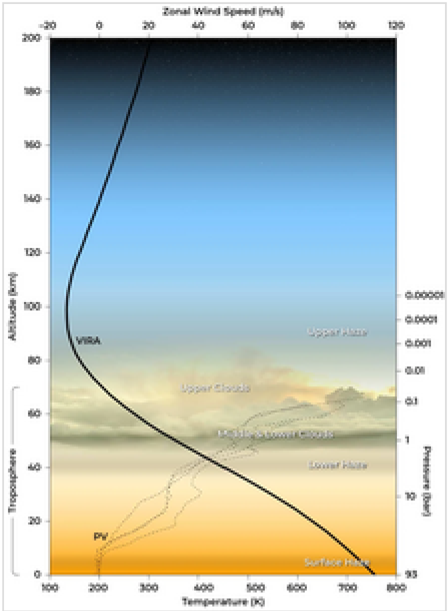
Venus temperature[39]

Type	Surface temperature
Maximum	900 °F (482 °C)
Normal	847 °F (453 °C)
Minimum	820 °F (438 °C)



Cloud structure of the Venusian atmosphere, made visible through ultraviolet imaging

Thermal inertia and the transfer of heat by winds in the lower atmosphere mean that the temperature of Venus's surface does not vary significantly between the planet's two hemispheres, those facing and not facing the Sun, despite Venus's slow rotation. Winds at the surface are slow, moving at a few kilometres per hour, but because of the high density of the atmosphere at the surface, they exert a significant amount of force against obstructions, and transport dust and small stones across the surface. This alone would make it difficult for a human to walk through, even without the heat, pressure, and lack of oxygen.[60]



Types of cloud layers, as well as temperature and pressure change by altitude in the atmosphere

Above the dense CO_2 layer are thick clouds, consisting mainly of sulfuric acid, which is formed by sulphur dioxide and water through a chemical reaction resulting in sulfuric acid hydrate. Additionally, the clouds consist of approximately 1% ferric chloride.[61][62] Other possible constituents of the cloud particles are ferric sulfate, aluminium chloride and phosphoric anhydride. Clouds at different levels have different compositions and particle size distributions.[61] These clouds reflect, similar to thick cloud cover on Earth,[63] about 70% of the sunlight that falls on them back into space,[64] and since they cover the whole planet they prevent visual observation of Venus's surface. The permanent cloud cover means that although Venus is closer than Earth to the Sun, it receives less sunlight on the ground, with only 10% of the received sunlight reaching the surface,[65] resulting in average daytime levels of illumination at the surface of 14,000 lux, comparable to that on Earth "in the daytime with overcast clouds".[66] Strong 300 km/h (185 mph) winds at the cloud tops go around Venus about every four to five Earth days.[67] Winds on Venus move at up to 60 times the speed of its rotation, whereas Earth's fastest winds are only 10–20% rotation speed.[68]

The surface of Venus is effectively isothermal; it retains a constant temperature not only between the two hemispheres but between the equator and the poles.[4][69] Venus's minute axial tilt—less than 3°, compared to 23° on Earth—also minimises seasonal temperature variation.[70] Altitude is one of the few factors that affect Venusian temperatures. The highest point on Venus, Maxwell Montes, is therefore the coolest point on Venus, with a temperature of about 655 K (380 °C; 715 °F) and an atmospheric pressure of about 4.5 MPa (45 bar).[71][72] In 1995, the *Magellan* spacecraft imaged a highly reflective substance at the tops of the highest mountain peaks, a "Venus snow" that bore a strong resemblance to terrestrial snow. This substance likely formed from a similar process to snow, albeit at a far higher temperature. Too volatile to condense on the surface, it rose in gaseous form to higher elevations, where it is cooler and could precipitate. The identity of this substance is not known with certainty, but speculation has ranged from elemental tellurium to lead sulfide (galena).[73]

Although Venus has no seasons, in 2019 astronomers identified a cyclical variation in sunlight absorption by the atmosphere, possibly caused by opaque, absorbing particles suspended in the upper clouds. The variation causes observed changes in the speed of Venus's zonal winds and appears to rise and fall in time with the Sun's 11-year sunspot cycle.[74]

The existence of lightning in the atmosphere of Venus has been controversial[75] since the first suspected bursts were detected by the Soviet Venera probes.[76][77][78] In 2006–07, *Venus Express* clearly detected whistler mode waves, the signatures of lightning. Their intermittent appearance indicates a pattern associated with weather activity. According to these measurements, the lightning rate is at least half that on Earth,[79] however other instruments have not detected lightning at all.[75] The origin of any lightning remains unclear, but could originate from clouds or Venusian volcanoes.

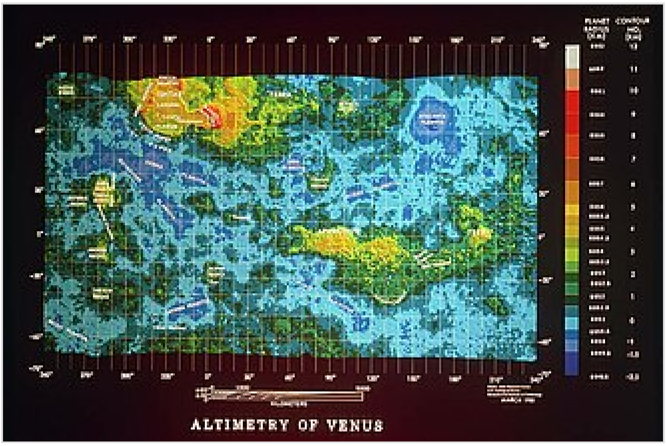
In 2007, *Venus Express* discovered that a huge double atmospheric polar vortex exists at the south pole.[80][81] *Venus Express* discovered, in 2011, that an ozone layer exists high in the atmosphere of Venus.[82] On 29 January 2013, ESA scientists reported that the ionosphere of Venus streams outwards in a manner similar to "the ion tail seen streaming from a comet under similar conditions."[83][84]

In December 2015, and to a lesser extent in April and May 2016, researchers working on Japan's *Akatsuki* mission observed bow-shaped objects in the atmosphere of Venus. This was considered direct evidence of the existence of perhaps the largest stationary gravity waves in the solar system.[85][86][87]

Geography

The Venusian surface was a subject of speculation until some of its secrets were revealed by planetary science in the 20th century. *Venera* landers in 1975 and 1982 returned images of a surface covered in sediment and relatively angular rocks.[88] The surface was mapped in detail by *Magellan* in 1990–91. The ground shows evidence of extensive volcanism, and the sulphur in the atmosphere may indicate that there have been recent eruptions.[89][90]

About 80% of the Venusian surface is covered by smooth, volcanic plains, consisting of 70% plains with wrinkle ridges and 10% smooth or lobate plains.[91] Two highland "continents" make up the rest of its surface area, one lying in the planet's northern hemisphere and the other just south of the equator. The northern continent is called Ishtar Terra after Ishtar, the Babylonian goddess of love, and is about the size of Australia. Maxwell Montes, the highest mountain on Venus, lies on Ishtar Terra. Its peak is 11 km (7 mi) above the Venusian average surface elevation.[92] The southern continent is called Aphrodite Terra, after the Greek mythological goddess of love, and is the larger of the two highland regions at roughly the size of South America. A network of fractures and faults covers much of this area.[93]



Color-coded elevation map, showing the elevated terrae "continents" in yellow and minor features of Venus.

The absence of evidence of lava flow accompanying any of the visible calderas remains an enigma. The planet has few impact craters, demonstrating that the surface is relatively young, at 300–600 million years old.[94][95] Venus has some unique surface features in addition to the impact craters, mountains, and valleys commonly found on rocky planets. Among these are flat-topped volcanic features called "farra", which look somewhat like pancakes and range in size from 20 to 50 km (12 to 31 mi) across, and from 100 to 1,000 m (330 to 3,280 ft) high; radial, star-like fracture systems called "novae"; features with both radial and concentric fractures resembling spider webs, known as "arachnoids"; and "coronae", circular rings of fractures sometimes surrounded by a depression. These features are volcanic in origin.[96]

Most Venusian surface features are named after historical and mythological women.[97] Exceptions are Maxwell Montes, named after James Clerk Maxwell, and highland regions Alpha Regio, Beta Regio, and Ovda Regio. The last three features were named before the current system was adopted by the International Astronomical Union, the body which oversees planetary nomenclature.[98]

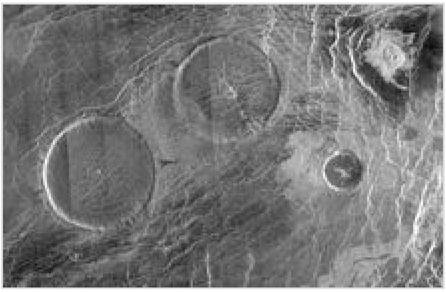
The longitude of physical features on Venus is expressed relative to its prime meridian. The original prime meridian passed through the radar-bright spot at the centre of the oval feature Eve, located south of Alpha Regio.[99] After the Venera missions were completed, the prime meridian was redefined to pass through the central peak in the crater Ariadne on Sedna Planitia.[100][101]

The stratigraphically oldest tessera terrains have consistently lower thermal emissivity than the surrounding basaltic plains measured by *Venus Express* and *Magellan*, indicating a different, possibly a more felsic, mineral assemblage.[24][102] The mechanism to generate a large amount of felsic crust usually requires the presence of water ocean and plate tectonics, implying that habitable condition had existed on early Venus with large bodies of water at some point.[103] However, the nature of tessera terrains is far from certain.[104]

Studies reported on 26 October 2023 suggest for the first time that Venus may have had plate tectonics during ancient times and, as a result, may have had a more habitable environment, possibly one capable of sustaining life.[21][22] Venus has gained interest as a case for research into the development of Earth-like planets and their habitability.

180-degree panorama of Venus's surface from the Soviet *Venera 9* lander, 1975. Black-and-white image of barren, black, slate-like rocks against a flat sky. The ground and the probe are the focus.

Volcanism



Radar mosaic of two 65 km (40 mi) wide (and less than 1 km (0.62 mi) high) pancake domes in Venus's Eistla region

Much of the Venusian surface appears to have been shaped by volcanic activity. Venus has several times as many volcanoes as Earth, and it has 167 large volcanoes that are over 100 km (60 mi) across. The only volcanic complex of this size on Earth is the Big Island of Hawaii.[96]: 154 More than 85,000 volcanoes on Venus were identified and mapped.[105][106] This is not because Venus is more volcanically active than Earth, but because its crust is older and is not subject to the same erosion process. Earth's oceanic crust is continually recycled by subduction at the boundaries of tectonic plates, and has an average age of about 100 million years,[107] whereas the Venusian surface is estimated to be 300–600 million years old.[94][96]

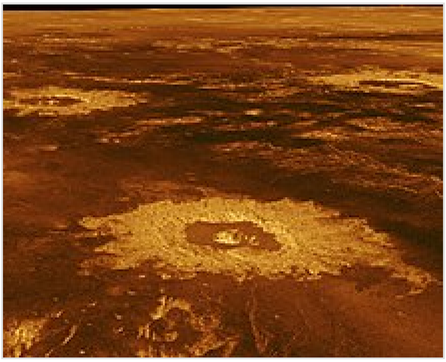
Several lines of evidence point to ongoing volcanic activity on Venus. Sulfur dioxide concentrations in the upper atmosphere dropped by a factor of 10 between 1978 and 1986, jumped in 2006, and again declined 10-fold.[108] This may mean that levels had been boosted several times by large volcanic eruptions.[109][110] It has been suggested that Venusian lightning (discussed below) could originate from volcanic activity (i.e. volcanic lightning). In January 2020, astronomers reported evidence that suggests that Venus is currently volcanically active, specifically the detection of olivine, a volcanic product that would weather quickly on the planet's surface.[111][112]

This massive volcanic activity is fuelled by a superheated interior, which models say could be explained by energetic collisions from when the planet was young. Impacts would have had significantly higher velocity than on Earth, both because Venus's orbit is faster due to its closer proximity to the Sun and because objects would require higher orbital eccentricities to collide with the planet.[113]

In 2008 and 2009, the first direct evidence for ongoing volcanism was observed by *Venus Express*, in the form of four transient localized infrared hot spots within the rift zone Ganis Chasma,[114][note 1] near the shield volcano Maat Mons. Three of the spots were observed in more than one successive orbit. These spots are thought to represent lava freshly released by volcanic eruptions.[115][116] The actual temperatures are not known, because the size of the hot spots could not be measured, but are likely to have been in the 800–1,100 K (527–827 °C; 980–1,520 °F) range, relative to a normal temperature of 740 K (467 °C;

872 °F).[117] In 2023, scientists reexamined topographical images of the Maat Mons region taken by the *Magellan* orbiter. Using computer simulations, they determined that the topography had changed during an 8-month interval, and concluded that active volcanism was the cause.[118]

Craters

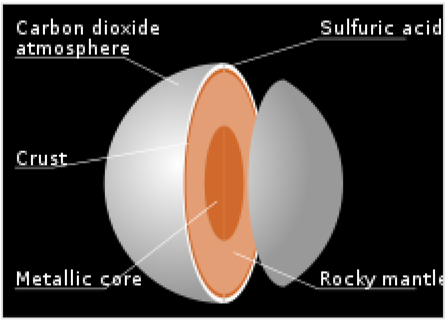


Impact craters on the surface of Venus (false-colour image reconstructed from radar data)

Almost a thousand impact craters on Venus are evenly distributed across its surface. On other cratered bodies, such as Earth and the Moon, craters show a range of states of degradation. On the Moon, degradation is caused by subsequent impacts, whereas on Earth it is caused by wind and rain erosion. On Venus, about 85% of the craters are in pristine condition. The number of craters, together with their well-preserved condition, indicates the planet underwent a global resurfacing event 300–600 million years ago,[94][95] followed by a decay in volcanism.[119] Whereas Earth's crust is in continuous motion, Venus is thought to be unable to sustain such a process. Without plate tectonics to dissipate heat from its mantle, Venus instead undergoes a cyclical process in which mantle temperatures rise until they reach a critical level that weakens the crust. Then, over a period of about 100 million years, subduction occurs on an enormous scale, completely recycling the crust.[96]

Venusian craters range from 3 to 280 km (2 to 174 mi) in diameter. No craters are smaller than 3 km, because of the effects of the dense atmosphere on incoming objects. Objects with less than a certain kinetic energy are slowed so much by the atmosphere that they do not create an impact crater.[120] Incoming projectiles less than 50 m (160 ft) in diameter will fragment and burn up in the atmosphere before reaching the ground.[121]

Internal structure



The differentiated structure of Venus

Without data from reflection seismology or knowledge of its moment of inertia, little direct information is available about the internal structure and geochemistry of Venus.[122] The similarity in size and density between Venus and Earth suggests that they share a similar internal structure: a core, mantle, and crust. Like that of Earth, the Venusian core is most likely at least partially liquid because the two planets have been cooling at about the same rate,[123] although a completely solid core cannot be ruled out.[124] The slightly smaller size of Venus means pressures are 24% lower in its deep interior than Earth's.[125] The predicted values for the moment of inertia based on planetary models suggest a core radius of 2,900–3,450 km.[124] This is in line with the first observation-based estimate of 3,500 km.[126]

The principal difference between the two planets is the lack of evidence for plate tectonics on Venus, possibly because its crust is too strong to subduct without water to make it less viscous. This results in reduced heat loss from the planet, preventing it from cooling and providing a likely explanation for its lack of an internally generated magnetic field.[127] Instead, Venus may lose its internal heat in periodic major resurfacing events.[94]

Magnetic field and core

In 1967, *Venera 4* found Venus's magnetic field to be much weaker than that of Earth. This magnetic field is induced by an interaction between the ionosphere and the solar wind,[128][129] rather than by an internal dynamo as in the Earth's core. Venus's small induced magnetosphere provides negligible protection to the atmosphere against solar and cosmic radiation, reaching at elevations of 54 to 48 km Earth-like levels.[130][131]

The lack of an intrinsic magnetic field on Venus was surprising, given that it is similar to Earth in size and was expected to contain a dynamo at its core. A dynamo requires three things: a conducting liquid, rotation, and convection. The core is thought to be electrically conductive and, although its rotation is often thought to be too slow, simulations show it is adequate to produce a dynamo.[132][133] This implies that the dynamo is missing because of a lack of convection in Venus's core. On Earth, convection occurs in the liquid outer layer of the core because the bottom of the liquid layer is much higher in temperature than the top. On Venus, a global resurfacing event may have shut down plate tectonics and led to a reduced heat flux through the crust. This insulating effect would cause the mantle temperature to increase, thereby reducing the heat flux out of the core. As a result, no internal geodynamo is available to drive a magnetic field. Instead, the heat from the core is reheating the crust.[134]

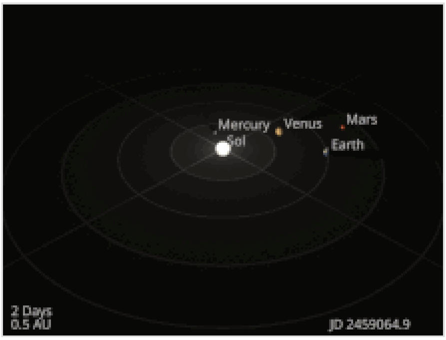
One possibility is that Venus has no solid inner core,[135] or that its core is not cooling, so that the entire liquid part of the core is at approximately the same temperature. Another possibility is that its core has already been completely solidified. The state of the core is highly dependent on the concentration of sulphur, which is unknown at present.[134]

Another possibility is that the absence of a late, large impact on Venus (*contra* the Earth's "Moon-forming" impact) left the core of Venus stratified from the core's incremental formation, and without the forces to initiate/sustain convection, and thus a "geodynamo".[136]

The weak magnetosphere around Venus means that the solar wind is interacting directly with its outer atmosphere. Here, ions of hydrogen and oxygen are being created by the dissociation of water molecules from ultraviolet radiation. The solar wind then supplies energy that gives some of these ions sufficient velocity to escape Venus's gravity field. This erosion process results in a steady loss of low-mass hydrogen, helium, and oxygen ions, whereas higher-mass molecules, such as carbon dioxide, are more likely to be retained. Atmospheric erosion by the solar wind could have led to the loss of most of Venus's water during the first billion years after it formed.[137] However, the planet may have retained a dynamo for its first 2–3 billion years, so the water loss may have occurred more recently.[138] The erosion has increased the ratio of higher-mass deuterium to lower-mass hydrogen in the atmosphere 100 times compared to the rest of the solar system.[139]

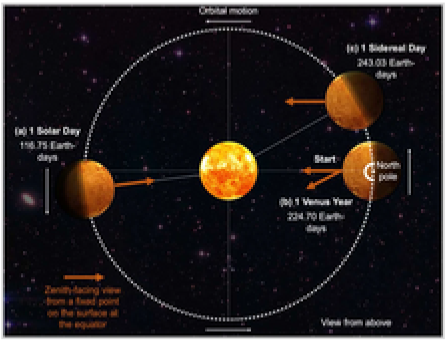
Orbit and rotation

Venus orbits the Sun at an average distance of about 0.72 AU (108 million km; 67 million mi), and completes an orbit every 224.7 days. Although all planetary orbits are elliptical, Venus's orbit is currently the closest to circular, with an eccentricity of less than 0.01.[4] Simulations of the early solar system orbital dynamics have shown that the eccentricity of the Venus orbit may have been substantially larger in the past, reaching values as high as 0.31 and possibly impacting early climate evolution.[140]



Venus is the second planet from the Sun, making a full orbit in about 224 days

All planets in the Solar System orbit the Sun in an anticlockwise direction as viewed from above Earth's north pole. Most planets rotate on their axes in an anticlockwise direction, but Venus rotates clockwise in retrograde rotation once every 243 Earth days—the slowest rotation of any planet. This Venusian sidereal day lasts therefore longer than a Venusian year (243 versus 224.7 Earth days). Slowed by its strong atmospheric current the length of the day also fluctuates by up to 20 minutes.[141] Venus's equator rotates at 6.52 km/h (4.05 mph), whereas Earth's rotates at 1,674.4 km/h (1,040.4 mph).[note 2][145] Venus's rotation period measured with *Magellan* spacecraft data over a 500-day period is smaller than the rotation period measured during the 16-year period between the Magellan spacecraft and *Venus Express* visits, with a difference of about 6.5 minutes.[146] Because of the retrograde rotation, the length of a solar day on Venus is significantly shorter than the sidereal day, at 116.75 Earth days (making the Venusian solar day shorter than Mercury's 176 Earth days — the 116-day figure is close to the average number of days it takes Mercury to slip underneath the Earth in its orbit [the number of days of Mercury's synodic orbital period]).[11] One Venusian year is about 1.92 Venusian solar days.[147] To an observer on the surface of Venus, the Sun would rise in the west and set in the east,[147] although Venus's opaque clouds prevent observing the Sun from the planet's surface.[148]



Venus and its rotation in respect to its revolution.

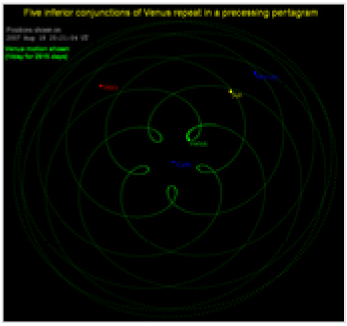
Venus may have formed from the solar nebula with a different rotation period and obliquity, reaching its current state because of chaotic spin changes caused by planetary perturbations and tidal effects on its dense atmosphere, a change that would have occurred over the course of billions of years. The rotation period of Venus may represent an equilibrium state between tidal locking to the Sun's gravitation, which tends to slow rotation, and an atmospheric tide created by solar heating of the thick Venusian atmosphere.[149][150] The 584-day average interval between successive close approaches to Earth is almost exactly equal to 5 Venusian solar days (5.001444 to be precise),[151] but the hypothesis of a spin-orbit resonance with Earth has been discounted.[152]

Venus has no natural satellites.[153] It has several trojan asteroids: the quasi-satellite 524522 Zoozve[154][155] and two other temporary trojans, 2001 CK_{32} and 2012 XE_{133}.[156] In the 17th century, Giovanni Cassini reported a moon orbiting Venus, which was named Neith and numerous sightings were reported over the following 200 years, but most were determined to be stars in the vicinity. Alex Alemi's and David Stevenson's 2006 study of models of the early Solar System at the California Institute of Technology shows Venus likely had at least one moon created by a huge impact event billions of years ago.[157] About 10 million years later, according to the study, another impact reversed the planet's spin direction and the resulting tidal deceleration caused the Venusian moon gradually to spiral inward until it collided with Venus.[158] If later impacts created moons, these were removed in the same way. An alternative explanation for the lack of satellites is the effect of strong solar tides, which can destabilize large satellites orbiting the inner terrestrial planets.[153]

The orbital space of Venus has a dust ring-cloud,[159] with a suspected origin either from Venus–trailing asteroids,[160] interplanetary dust migrating in waves, or the remains of the Solar System's original circumstellar disc that formed the planetary system.[161]

Orbit in respect to Earth

Earth and Venus have a near orbital resonance of 13:8 (Earth orbits eight times for every 13 orbits of Venus).[162] Therefore, they approach each other and reach inferior conjunction in synodic periods of 584 days, on average.[4] The path that Venus makes in relation to Earth viewed geocentrically draws a pentagram over five synodic periods, shifting every period by 144°. This pentagram of Venus is sometimes referred to as the petals of Venus due to the path's visual similarity to a flower.[163]



Earth is positioned at the centre of the diagram, and the curve represents the direction and distance of Venus as a function of time.

When Venus lies between Earth and the Sun in inferior conjunction, it makes the closest approach to Earth of any planet at an average distance of 41 million km (25 million mi).[4][note 3][164] Because of the decreasing eccentricity of Earth's orbit, the minimum distances will become greater over tens of thousands of years. From the year 1 to 5383, there are 526 approaches less than 40 million km (25 million mi); then, there are none for about 60,158 years.[165]

While Venus approaches Earth the closest, Mercury is more often the closest to Earth of all planets.[166][167] Venus has the lowest gravitational potential difference to Earth than any other planet, needing the lowest delta-v to transfer between them.[168][169]

Tidally Venus exerts the third strongest tidal force on Earth, after the Moon and the Sun, though significantly less.[170]

Observability

To the naked eye, Venus appears as a white point of light brighter than any other planet or star (apart from the Sun).[171] The planet's mean apparent magnitude is −4.14 with a standard deviation of 0.31.[18] The brightest magnitude occurs during the crescent phase about one month before or after an inferior conjunction. Venus fades to about magnitude −3 when it is backlit by the Sun.[172] The planet is bright enough to be seen in broad daylight,[173] but is more easily visible when the Sun is low on the horizon or setting. As an inferior planet, it always lies within about 47° of the Sun.[174]

Venus, pictured centre-right, is always brighter than all other planets or stars at their maximal brightness, as seen from Earth. Jupiter is visible at the top of the image.

Venus "overtakes" Earth every 584 days as it orbits the Sun.[4] As it does so, it changes from the "Evening Star", visible after sunset, to the "Morning Star", visible before sunrise. Although Mercury, the other inferior planet, reaches a maximum elongation of only 28° and is often difficult to discern in twilight, Venus is hard to miss when it is at its brightest. Its greater maximum elongation means it is visible in dark skies long after sunset. As the brightest point-like object in the sky, Venus is a commonly misreported "unidentified flying object".[175]

Phases

As it orbits the Sun, Venus displays phases like those of the Moon in a telescopic view. The planet appears as a small and "full" disc when it is on the opposite side of the Sun (at superior conjunction). Venus shows a larger disc and "quarter phase" at its maximum elongations from the Sun, and appears at its brightest in the night sky. The planet presents a much larger thin "crescent" in telescopic views as it passes along the near side between Earth and the Sun. Venus displays its largest size and "new phase" when it is between Earth and the Sun (at inferior conjunction). Its atmosphere is visible through telescopes by the halo of sunlight refracted around it.[174] The phases are clearly visible in a 4" telescope. Although naked eye visibility of Venus's phases is disputed, records exist of observations of its crescent.[176]

The phases of Venus and evolution of its apparent diameter

Daylight apparitions

When Venus is sufficiently bright with enough angular distance from the sun, it is easily observed in a clear daytime sky with the naked eye, though most people do not know to look for it.[177] Astronomer Edmund Halley calculated its maximum naked eye brightness in 1716, when many Londoners were alarmed by its appearance in the daytime. French emperor Napoleon Bonaparte once witnessed a daytime apparition of the planet while at a reception in Luxembourg.[178] Another historical daytime observation of the planet took place during the inauguration of the American president Abraham Lincoln in Washington, D.C., on 4 March 1865.[179]


Venus is often visible to the naked eye in daytime, as seen just prior to the lunar occultation of December 7th, 2015

Transits

A transit of Venus is the appearance of Venus in front of the Sun, during inferior conjunction. Since the orbit of Venus is slightly inclined relative to Earth's orbit, most inferior conjunctions with Earth, which occur every synodic period of 1.6 years, do not produce a transit of Venus above Earth. Consequently, Venus transits above Earth only occur when an inferior conjunction takes place during some days of June or December, the time where the orbits of Venus and Earth cross a straight line with the Sun.[180] This results in Venus transiting above Earth in a sequence of currently 8 years, 105.5 years, 8 years and 121.5 years, forming cycles of 243 years.

2012 transit of Venus, projected to a white card by a telescope

Historically, transits of Venus were important, because they allowed astronomers to determine the size of the astronomical unit, and hence the size of the Solar System as shown by Jeremiah Horrocks in 1639 with the first known observation of a Venus transit (after history's first observed planetary transit in 1631, of Mercury).[181]

Only seven Venus transits have been observed so far, since their occurrences were calculated in the 1621 by Johannes Kepler. Captain Cook sailed to Tahiti in 1768 to record the third observed transit of Venus, which subsequently resulted in the exploration of the east coast of Australia.[182][183]

The latest pair was June 8, 2004 and June 5–6, 2012. The transit could be watched live from many online outlets or observed locally with the right equipment and conditions.[184] The preceding pair of transits occurred in December 1874 and December 1882.

The next transit will occur in December 2117 and December 2125.[185]

Ashen light

A long-standing mystery of Venus observations is the so-called ashen light—an apparent weak illumination of its dark side, seen when the planet is in the crescent phase. The first claimed observation of ashen light was made in 1643, but the existence of the illumination has never been reliably confirmed. Observers have speculated it may result from electrical activity in the Venusian atmosphere, but it could be illusory, resulting from the physiological effect of observing a bright, crescent-shaped object.[186][77] The ashen light has often been sighted when Venus is in the evening sky, when the evening terminator of the planet is towards Earth.

Observation and exploration history

Early observation

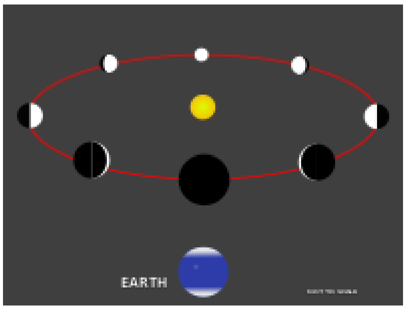
Venus is in Earth's sky bright enough to be visible without aid, making it one of the star-like classical planets that human cultures have known and identified throughout history, particularly for being the third brightest object in Earth's sky after the Sun and the Moon. Because the movements of Venus appear to be discontinuous (it disappears due to its proximity to the sun, for many days at a time, and then reappears on the other horizon), some cultures did not recognise Venus as a single entity;[187] instead, they assumed it to be two separate stars on each horizon: the morning and evening star.[187] Nonetheless, a cylinder seal from the Jemdet Nasr period and the Venus tablet of Ammisaduqa from the First Babylonian dynasty indicate that the ancient Sumerians already knew that the morning and evening stars were the same celestial object.[188][187][189] In the Old Babylonian period, the planet Venus was known as Ninsi'anna, and later as Dilbat.[190] The name "Ninsi'anna" translates to "divine lady, illumination of heaven", which refers to Venus as the brightest visible "star". Earlier spellings of the name were written with the cuneiform sign si4 (= SU, meaning "to be red"), and the original meaning may have been "divine lady of the redness of heaven", in reference to the colour of the morning and evening sky.[191]

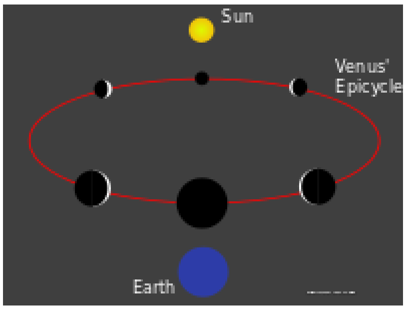
The Chinese historically referred to the morning Venus as "the Great White" (*Tàibái* 太白) or "the Opener (Starter) of Brightness" (*Qǐmíng* 啟明), and the evening Venus as "the Excellent West One" (*Chánggēng* 長庚).[192]

The ancient Greeks initially believed Venus to be two separate stars: Phosphorus, the morning star, and Hesperus, the evening star. Pliny the Elder credited the realization that they were a single object to Pythagoras in the sixth century BC,[193] while Diogenes Laërtius argued that Parmenides (early fifth century) was probably responsible for this discovery.[194] Though they recognized Venus as a single object, the ancient Romans continued to designate the morning aspect of Venus as Lucifer, literally "Light-Bringer", and the evening aspect as Vesper,[195] both of which are literal translations of their traditional Greek names.

In the second century, in his astronomical treatise *Almagest*, Ptolemy theorized that both Mercury and Venus were located between the Sun and the Earth. The 11th-century Persian astronomer Avicenna claimed to have observed a transit of Venus (although there is some doubt about it),[196] which later astronomers took as confirmation of Ptolemy's theory.[197] In the 12th century, the Andalusian astronomer Ibn Bajjah observed "two planets as black spots on the face of the Sun"; these were thought to be the transits of Venus and Mercury by 13th-century Maragha astronomer Qotb al-Din Shirazi, though this cannot be true as there were no Venus transits in Ibn Bajjah's lifetime.[198][note 4]

Venus and early modern astronomy



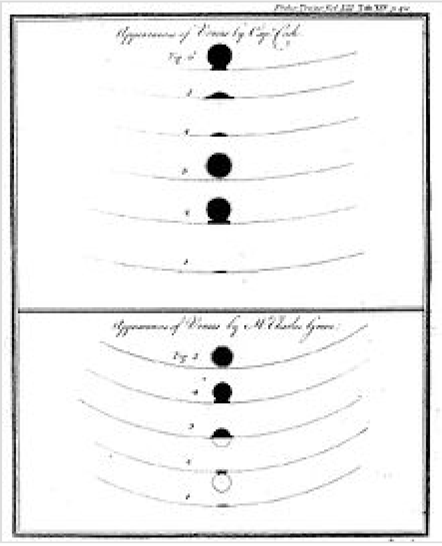


In 1610 Galileo Galilei observed with his telescope that Venus showed phases, despite remaining near the Sun in Earth's sky (first image). This proved that it orbits the Sun and not Earth, as predicted by Copernicus's heliocentric model and disproved Ptolemy's geocentric model (second image).

When the Italian physicist Galileo Galilei first observed the planet with a telescope in the early 17th century, he found it showed phases like the Moon, varying from crescent to gibbous to full and vice versa. When Venus is furthest from the Sun in the sky, it shows a half-lit phase, and when it is closest to the Sun in the sky, it shows as a crescent or full phase. This could be possible only if Venus orbited the Sun, and this was among the first observations to clearly contradict the Ptolemaic geocentric model that the Solar System was concentric and centred on Earth.[201][202]

The 1639 transit of Venus was accurately predicted by Jeremiah Horrocks and observed by him and his friend, William Crabtree, at each of their respective homes, on 4 December 1639 (24 November under the Julian calendar in use at that time).[203]

The atmosphere of Venus was discovered in 1761 by Russian polymath Mikhail Lomonosov.[204][205] Venus's atmosphere was observed in 1790 by German astronomer Johann Schröter. Schröter found when the planet was a thin crescent, the cusps extended through more than 180°. He correctly surmised this was



The "black drop effect" as recorded during the 1769 transit

due to scattering of sunlight in a dense atmosphere. Later, American astronomer Chester Smith Lyman observed a complete ring around the dark side of the planet when it was at inferior conjunction, providing further evidence for an atmosphere.[206] The atmosphere complicated efforts to determine a rotation period for the planet, and observers such as Italian-born astronomer Giovanni Cassini and Schröter incorrectly estimated periods of about 24 h from the motions of markings on the planet's apparent surface.[207]

Early 20th century advances

Little more was discovered about Venus until the 20th century. Its almost featureless disc gave no hint what its surface might be like, and it was only with the development of spectroscopic and ultraviolet observations that more of its secrets were revealed.

Spectroscopic observations in the 1900s gave the first clues about the Venusian rotation. Vesto Slipher tried to measure the Doppler shift of light from Venus, but found he could not detect any rotation. He surmised the planet must have a much longer rotation period than had previously been thought.[208]

The first ultraviolet observations were carried out in the 1920s, when Frank E. Ross found that ultraviolet photographs revealed considerable detail that was absent in visible and infrared radiation. He suggested this was due to a dense, yellow lower atmosphere with high cirrus clouds above it.[209]

It had been noted that Venus had no discernible oblateness in its disk, suggesting a slow rotation, and some astronomers concluded based on this that it was tidally locked like Mercury was believed to be at the time; but other researchers had detected a significant quantity of heat coming from the planet's nightside, suggesting a quick rotation (a high surface temperature was not suspected at the time), confusing the issue.[210] Later work in the 1950s showed the rotation was retrograde.

Space age

Humanity's first interplanetary spaceflight was achieved in 1961 with the robotic space probe *Venera 1* of the Soviet Venera programme flying to Venus, though it lost contact en route.[211]

Therefore, the first successful interplanetary mission was the *Mariner 2* mission to Venus of the United States' Mariner programme, passing on 14 December 1962 at 34,833 km (21,644 mi) above the surface of Venus and gathering data on the planet's atmosphere.[212][213]

Additionally radar observations of Venus were first carried out in the 1960s, and provided the first measurements of the rotation period, which were close to the actual value.[214]

Venera 3, launched in 1966, became humanity's first probe and lander to reach and impact another celestial body other than the Moon, but could not return data as it crashed into the surface of Venus. In 1967, *Venera 4* was launched and successfully deployed science experiments in the Venusian atmosphere before impacting. *Venera 4* showed the surface temperature was hotter than *Mariner 2* had calculated, at almost 500 °C (932 °F), determined that the atmosphere was 95% carbon dioxide (CO_2), and discovered that Venus's atmosphere was considerably denser than *Venera 4*'s designers had anticipated.[215]

In an early example of space cooperation the data of *Venera 4* was joined with the 1967 *Mariner 5* data, analysed by a combined Soviet–American science team in a series of colloquia over the following year.[216]

On 15 December 1970, *Venera 7* became the first spacecraft to soft land on another planet and the first to transmit data from there back to Earth.[217]

In 1974, *Mariner 10* swung by Venus to bend its path towards Mercury and took ultraviolet photographs of the clouds, revealing the extraordinarily high wind speeds in the Venusian atmosphere. This was the first interplanetary gravity assist ever used, a technique which would be used by later probes.

Radar observations in the 1970s revealed details of the Venusian surface for the first time. Pulses of radio waves were beamed at the planet using the 300 m (1,000 ft) radio telescope at Arecibo Observatory, and the echoes revealed two highly reflective regions, designated the Alpha and Beta regions. The observations revealed a bright region attributed to mountains, which was called Maxwell Montes.[218] These three features are now the only ones on Venus that do not have female names.[98]

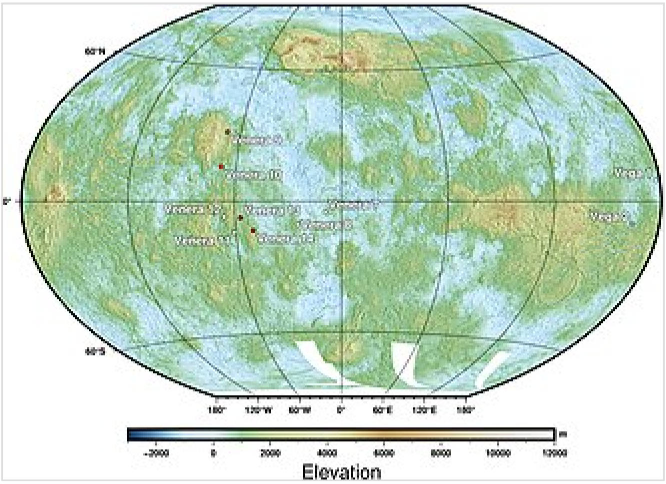
First view and first clear 180-degree panorama of Venus's surface as well as any other planet than Earth (1975, Soviet *Venera 9* lander). Black-and-white image of barren, black, slate-like rocks against a flat sky. The ground and the probe are the focus.

In 1975, the Soviet *Venera 9* and *10* landers transmitted the first images from the surface of Venus, which were in black and white. NASA obtained additional data with the Pioneer Venus project that consisted of two separate missions:[219] the Pioneer Venus Multiprobe and Pioneer Venus Orbiter, orbiting Venus between 1978 and 1992.[220] In 1982 the first colour images of the surface were obtained with the Soviet *Venera 13* and *14* landers. After *Venera 15* and *16* operated between 1983 and 1984 in orbit, conducting detailed mapping of 25% of Venus's terrain (from the north pole to 30°N latitude), the successful Soviet Venera programme came to a close.[221]

In 1985 the Vega programme with its *Vega 1* and *Vega 2* missions carried the last entry probes and carried the first ever extraterrestrial aerobots for the first time achieving atmospheric flight outside Earth by employing inflatable balloons.

Between 1990 and 1994, *Magellan* operated in orbit until deorbiting, mapping the surface of Venus. Furthermore, probes like *Galileo* (1990),[222] *Cassini–Huygens* (1998/1999), and *MESSENGER* (2006/2007) visited Venus with flybys flying to other destinations. In April 2006, *Venus Express*, the first dedicated Venus mission by the European Space Agency (ESA), entered orbit around Venus. *Venus Express* provided unprecedented observation of Venus's atmosphere. ESA concluded the *Venus Express* mission in December 2014 deorbiting it in January 2015.[223]

In 2010, the first successful interplanetary solar sail spacecraft IKAROS travelled to Venus for a flyby.

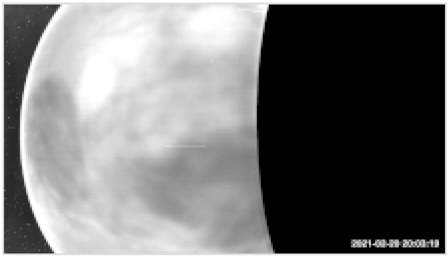


Global topographic map of Venus, with all probe landings marked

Active and future missions

As of 2023, the only active mission at Venus is Japan's *Akatsuki*, having achieved orbital insertion on 7 December 2015. Additionally, several flybys by other probes have been performed and studied Venus on their way, including NASA's Parker Solar Probe, and ESA's Solar Orbiter and BepiColombo.

There are currently several probes under development as well as multiple proposed missions still in their early conceptual stages.


WISPR visible light footage (2021) of the nightside, showing the hot faintly glowing surface, and its Aphrodite Terra as large dark patch, through the clouds, which prohibit such observations on the dayside when they are illuminated.[224][225]

Venus has been identified for future research as an important case for understanding:

- the origins of the solar system and Earth, and if systems and planets like ours are common or rare in the universe.
- how planetary bodies evolve from their primordial states to today's diverse objects.
- the development of conditions leading to habitable environments and life.[226]

Search for life

Speculation on the possibility of life on Venus's surface decreased significantly after the early 1960s when it became clear that conditions were extreme compared to those on Earth. Venus's extreme temperatures and atmospheric pressure make water-based life, as currently known, unlikely.

Some scientists have speculated that thermoacidophilic extremophile microorganisms might exist in the cooler, acidic upper layers of the Venusian atmosphere.[227][228][229] Such speculations go back to 1967, when Carl Sagan and Harold J. Morowitz suggested in a *Nature* article that tiny objects detected in Venus's clouds might be organisms similar to Earth's bacteria (which are of approximately the same size):

> While the surface conditions of Venus make the hypothesis of life there implausible, the clouds of Venus are a different story altogether. As was pointed out some years ago, water, carbon dioxide and sunlight—the prerequisites for photosynthesis—are plentiful in the vicinity of the clouds.[230]

In August 2019, astronomers led by Yeon Joo Lee reported that long-term pattern of absorbance and albedo changes in the atmosphere of the planet Venus caused by "unknown absorbers", which may be chemicals or even large colonies of microorganisms high up in the atmosphere of the planet, affect the climate.[74]

Their light absorbance is almost identical to that of micro-organisms in Earth's clouds. Similar conclusions have been reached by other studies.[231]

In September 2020, a team of astronomers led by Jane Greaves from Cardiff University announced the likely detection of phosphine, a gas not known to be produced by any known chemical processes on the Venusian surface or atmosphere, in the upper levels of the planet's clouds.[232][56][55][233][234] One proposed source for this phosphine is living organisms.[235] The phosphine was detected at heights of at least 30 miles (48 km) above the surface, and primarily at mid-latitudes with none detected at the poles. The discovery prompted NASA administrator Jim Bridenstine to publicly call for a new focus on the study of Venus, describing the phosphine find as "the most significant development yet in building the case for life off Earth".[236][237]

Subsequent analysis of the data-processing used to identify phosphine in the atmosphere of Venus has raised concerns that the detection-line may be an artefact. The use of a 12th-order polynomial fit may have amplified noise and generated a false reading (see Runge's phenomenon). Observations of the atmosphere of Venus at other parts of the electromagnetic spectrum in which a phosphine absorption line would be expected did not detect phosphine.[238] By late October 2020, re-analysis of data with a proper subtraction of background did not show a statistically significant detection of phosphine.[239][240][241]

Members of the team around Greaves, are working as part of a project by the MIT to send with the rocket company Rocket Lab the first private interplanetary space craft, to look for organics by entering the atmosphere of Venus with a probe, set to launch in January 2025.[242]

Planetary protection

The Committee on Space Research is a scientific organisation established by the International Council for Science. Among their responsibilities is the development of recommendations for avoiding interplanetary contamination. For this purpose, space missions are categorized into five groups. Due to the harsh surface environment of Venus, Venus has been under the planetary protection category two.[243] This indicates that there is only a remote chance that spacecraft-borne contamination could compromise investigations.

Human presence

Venus is the place of the first interplanetary human presence, mediated through robotic missions, with the first successful landings on another planet and extraterrestrial body other than the Moon. Currently in orbit is Akatsuki, and other probes routinely use Venus for gravity assist manoeuvres capturing some data about Venus on the way.[244]

The only nation that has sent lander probes to the surface of Venus has been the Soviet Union,[note 5] which has been used by Russian officials to call Venus a "Russian planet".[245][246]

Crewed flight

Studies of routes for crewed missions to Mars have since the 1960s proposed opposition missions instead of direct conjunction missions with Venus gravity assist flybys, demonstrating that they should be quicker and safer missions to Mars, with better return or abort flight windows, and less or the same amount of radiation exposure from the flight as direct Mars flights.[247][248]

Early in the space age the Soviet Union and the United States proposed the TMK-MAVR and Manned Venus flyby crewed flyby missions to Venus, though they were never realized.

Habitation

Artist's rendering of a NASA High Altitude Venus Operational Concept (HAVOC) crewed floating outpost on Venus

While the surface conditions of Venus are inhospitable, the atmospheric pressure, temperature, and solar and cosmic radiation 50 km above the surface are similar to those at Earth's surface.[131][130] With this in mind, Soviet engineer Sergey Zhitomirskiy (Сергей Житомирский, 1929–2004) in 1971[249][250] and NASA aerospace engineer Geoffrey A. Landis in 2003[251] suggested the use of aerostats for crewed exploration and possibly for permanent "floating cities" in the Venusian atmosphere, an alternative to the popular idea of living on planetary surfaces such as Mars.[252][253] Among the many engineering challenges for any human presence in the atmosphere of Venus are the corrosive amounts of sulfuric acid in the atmosphere.[251]

NASA's High Altitude Venus Operational Concept is a mission concept that proposed a crewed aerostat design.

In culture

Venus is portrayed just to the right of the large cypress tree in Vincent van Gogh's 1889 painting *The Starry Night*.[254][255]

Venus is a primary feature of the night sky, and so has been of remarkable importance in mythology, astrology and fiction throughout history and in different cultures.

The English name of Venus was originally the ancient Roman name for it. Romans named Venus after their goddess of love, who in turn was based on the ancient Greek goddess of love Aphrodite,[256] who was herself based on the similar Sumerian religion goddess Inanna (which is Ishtar in Akkadian religion), all of whom were associated with the planet.[257][258] The weekday of the planet and these goddesses is Friday, named after the Germanic goddess Frigg, who has been associated with the Roman goddess Venus.

Several hymns praise Inanna in her role as the goddess of the planet Venus.[187][258][257] Theology professor Jeffrey Cooley has argued that, in many myths, Inanna's movements may correspond with the movements of the planet Venus in the sky.[187] The discontinuous movements of Venus relate to both mythology as well as Inanna's dual nature.[187] In *Inanna's Descent to the Underworld*, unlike any other deity, Inanna is able to descend into the netherworld and return to the heavens. The planet Venus appears to make a similar descent, setting in the West and then rising again in the East.[187] An introductory hymn describes Inanna leaving the heavens and heading for *Kur*, what could be presumed to be, the mountains, replicating the rising and setting of Inanna to the West.[187] In *Inanna and Shukaletuda* and *Inanna's Descent into the Underworld* appear to parallel the motion of the planet Venus.[187] In *Inanna and Shukaletuda*, Shukaletuda is described as scanning the heavens in search of Inanna, possibly searching the eastern and western horizons.[259] In the same myth, while searching for her attacker, Inanna herself makes several movements that correspond with the movements of Venus in the sky.[187]

The eight-pointed star a symbol used in some cultures for Venus, and sometimes combined into a star and crescent arrangement. Here the eight pointed star is the Star of Ishtar, the Babylonian Venus goddess, alongside the solar disk of her brother Shamash and the crescent moon of their father Sin on a boundary stone of Meli-Shipak II, dating to the twelfth century BC.

The Ancient Egyptians and ancient Greeks possibly knew by the second millennium BC or at the latest by the Late Period, under mesopotamian influence that the morning star and an evening star were one and the same.[260][261] The Egyptians knew the morning star as *Tioumoutiri* and the evening star as *Ouaiti*.[262] They depicted Venus at first as a phoenix or heron (see Bennu),[260] calling it "the crosser" or "star with crosses",[260] associating it with Osiris, and later depicting it two-headed with human or falco heads, and associated it with Horus,[261] son of Isis (which during the even later Hellenistic period was together with Hathor identified with Aphrodite). The Greeks used the names *Phōsphoros* (Φωσφόρος), meaning "light-bringer" (whence the element phosphorus; alternately *Ēōsphoros* (Ἠωσφόρος), meaning "dawn-bringer"), for the morning star, and *Hesperos* (Ἕσπερος), meaning "Western one", for the evening star,[263] both children of dawn Eos and therefore grandchildren of Aphrodite. Though by the Roman era they were recognized as one celestial object, known as "the star of Venus", the traditional two Greek names continued to be used, though usually translated to Latin as *Lūcifer* and *Vesper*.[263][264]

Classical poets such as Homer, Sappho, Ovid and Virgil spoke of the star and its light.[265] Poets such as William Blake, Robert Frost, Letitia Elizabeth Landon, Alfred Lord Tennyson and William Wordsworth wrote odes to it.[266]

In India, Shukra Graha ("the planet Shukra") is named after the powerful saint Shukra. *Shukra* which is used in Indian Vedic astrology[267] means "clear, pure" or "brightness, clearness" in Sanskrit. One of the nine Navagraha, it is held to affect wealth, pleasure and reproduction; it was the son of Bhrgu, preceptor of the Daityas, and guru of the Asuras.[268] The word *Shukra* is also associated with semen, or generation.

Venus is known as Kejora in Indonesian and Malaysian Malay.

In Chinese the planet is called Jīn-xīng (金星), the golden planet of the metal element. Modern Chinese, Japanese, Korean and Vietnamese cultures refer to the planet literally as the "metal star" (金星), based on the Five elements.[269][270][271][272]

The Maya considered Venus to be the most important celestial body after the Sun and Moon. They called it *Chac ek*,[273] or *Noh Ek*', "the Great Star".[274] The cycles of Venus were important to their calendar and were described in some of their books such as *Maya Codex of Mexico* and *Dresden Codex*.

Modern culture

The impenetrable Venusian cloud cover gave science fiction writers free rein to speculate on conditions at its surface; all the more so when early observations showed that not only was it similar in size to Earth, it possessed a substantial atmosphere. Closer to the Sun than Earth, the planet was often depicted as warmer, but still habitable by humans.[275] The genre reached its peak between the 1930s and 1950s, at a time when science had revealed some aspects of Venus, but not yet the harsh reality of its surface conditions. Findings from the first missions to Venus showed reality to be quite different and brought this particular genre to an end.[276] As scientific knowledge of Venus advanced, science fiction authors tried to keep pace, particularly by conjecturing human attempts to terraform Venus.[277]

Symbols

The symbol of a circle with a small cross beneath is the so-called Venus symbol, gaining its name for being used as the astronomical symbol for Venus. The symbol is of ancient Greek origin, and represents more generally femininity, adopted by biology as gender symbol for female,[278][279][280] like the Mars symbol for male and sometimes the Mercury symbol for hermaphrodite. This gendered association of Venus and Mars has been used to pair them heteronormatively, describing women and men stereotypically as being so different that they can be understood as coming from different planets, an understanding popularized in 1992 by the book titled *Men Are from Mars, Women Are from Venus*.[281][282]

The Venus symbol was also used in Western alchemy representing the element copper (like the symbol of Mercury is also the symbol of the element mercury),[279][280] and since polished copper has been used for mirrors from antiquity the symbol for Venus has sometimes been called Venus mirror, representing the mirror of the goddess, although this origin has been discredited as an unlikely origin.[279][280]

Besides the Venus symbol, many other symbols have been associated with Venus, other common ones are the crescent or particularly the star, as with the Star of Ishtar.

See also

Solar System portal
Outer space portal
Astronomy portal

- Outline of Venus
- Physical properties of planets in the Solar System
- Venus zone

Notes

1. Misstated as "Ganiki Chasma" in the press release and scientific publication.[115]
2. The equatorial speed of Earth is given as both about 1674.4 km/h and 1669.8 km/h by reliable sources. The simplest way to determine the correct figure is to multiply Earth's radius of 6 378 137 m (WGS84) and Earth's angular speed, 7.292 1150 $\times 10^{-5}$ rad/s,[142] yielding 465.1011 m/s = 1674.364 km/h. The incorrect figure of 1669.8 km/h is obtained by dividing Earth's equatorial circumference by 24 h. But the correct speed must be relative to inertial

space, so the stellar day of 86 164.098 903 691 s/3600 = 23.934 472 h (23 h 56 m 4.0989 s) must be used.[143] Thus $\frac{2\pi(6378.137\text{ km})}{23.934472\text{ h}}$ = 1674.364 km/h.[144]

3. It is important to be clear about the meaning of "closeness". In the astronomical literature, the term "closest planets" often refers to the two planets that approach each other the most closely. In other words, the orbits of the two planets approach each other most closely. However, this does not mean that the two planets are closest over time. Essentially because Mercury is closer to the Sun than Venus, Mercury spends more time in proximity to Earth; it could, therefore, be said that Mercury is the planet that is "closest to Earth when averaged over time". However, using this time-average definition of "closeness", it turns out that Mercury is the closest planet to *all* other planets in the solar system. For that reason, arguably, the proximity-definition is not particularly helpful. An episode of the BBC Radio 4 programme "More or Less" explains the different notions of proximity well.[164]
4. Several claims of transit observations made by mediaeval Islamic astronomers have been shown to be sunspots.[199] Avicenna did not record the date of his observation. There was a transit of Venus within his lifetime, on 24 May 1032, although it is questionable whether it would have been visible from his location.[200]
5. The American Pioneer Venus Multiprobe has brought the only non-Soviet probes to enter the atmosphere, as atmospheric entry probes only briefly signals were received from the surface.

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External links

- Venus profile (https://web.archive.org/web/20150906034051/http://solarsystem.nasa.gov/planets/venus) at NASA's Solar System Exploration site
- Missions to Venus (http://nssdc.gsfc.nasa.gov/planetary/planets/venuspage.html) and Image catalogue (http://nssdc.gsfc.nasa.gov/imgcat/thumbnail_pages/venus_thumbnails.html) at the National Space Science Data Center
- Soviet Exploration of Venus (http://www.mentallandscape.com/V_Venus.htm) and Image catalogue (http://www.mentallandscape.com/C_CatalogVenus.htm) at Mentallandscape.com
- Image catalogue from the Venera missions (https://web.archive.org/web/20151015045714/http://www.strykfoto.org/venera.htm)

- Venus page (http://www.nineplanets.org/venus.html) at *The Nine Planets*
- Transits of Venus (http://eclipse.gsfc.nasa.gov/transit/catalogue/VenusCatalog.html) at NASA.gov
- Geody Venus (http://www.geody.com/?world=venus), a search engine for surface features
- Interactive 3D gravity simulation of the pentagram that the orbit of Venus traces when Earth is held fixed at the centre of the coordinate system (https://gravitysimulator.org/solar-system/pentagram-of-venus)

Cartographic resources

- Map-a-Planet: Venus (https://web.archive.org/web/20071005184007/http://www.mapaplanet.org/explorer/venus.html) by the U.S. Geological Survey
- Gazetteer of Planetary Nomenclature: Venus (https://web.archive.org/web/20160112001040/http://planetarynames.wr.usgs.gov/Page/VENUS/target) by the International Astronomical Union
- Venus crater database (http://www.lpi.usra.edu/resources/vc/vchome.shtml) by the Lunar and Planetary Institute
- Map of Venus (http://planetologia.elte.hu/venusz-terkep-elte-ttk-kavucs.pdf) by Eötvös Loránd University
- Google Venus 3D (https://www.google.com/maps/space/venus/@33.5623476,-46.1493481,7057278m/data=!3m1!1e3), interactive map of the planet

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