Venus

This article is about the planet. For other uses, see Venus (disambiguation).

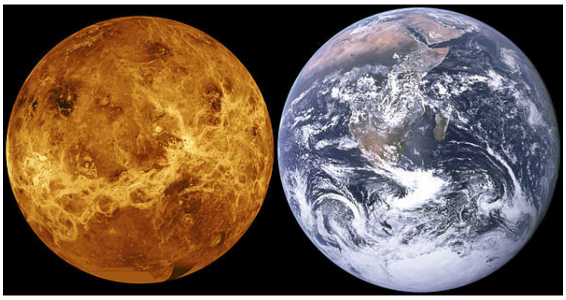
Venus is the second planet from the Sun, orbiting it every 224.7 Earth days.*[12] It has the longest rotation period (243 days) of any planet in the Solar System and rotates in the opposite direction to most other planets. It has no natural satellite. It is named after the Roman goddess of love and beauty. It is the second-brightest natural object in the night sky after the Moon, reaching an apparent magnitude of −4.6, bright enough to cast shadows.*[13] Because Venus orbits within Earth's orbit it is an inferior planet and never appears to venture far from the Sun; its maximum angular distance from the Sun (elongation) is 47.8°.

Venus is a terrestrial planet and is sometimes called Earth's "sister planet" because of their similar size, mass, proximity to the Sun, and bulk composition. It is radically different from Earth in other respects. It has the densest atmosphere of the four terrestrial planets, consisting of more than 96% carbon dioxide. The atmospheric pressure at the planet's surface is 92 times that of Earth, or roughly the pressure found 900 m (3,000 ft) underwater on Earth. Venus is by far the hottest planet in the Solar System, with a mean surface temperature of 735 K (462 °C; 863 °F), even though Mercury is closer to the Sun. Venus is shrouded by an opaque layer of highly reflective clouds of sulfuric acid, preventing its surface from being seen from space in visible light. It may have had water oceans in the past,*[14]*[15] but these would have vaporized as the temperature rose due to a runaway greenhouse effect.*[16] The water has probably photodissociated, and the free hydrogen has been swept into interplanetary space by the solar wind because of the lack of a planetary magnetic field.*[17] Venus's surface is a dry desertscape interspersed with slab-like rocks and is periodically resurfaced by volcanism.

As one of the brightest objects in the sky, Venus has been a major fixture in human culture for as long as records have existed. It has been made sacred to gods of many cultures, and has been a prime inspiration for writers and poets as the "morning star" and "evening star". Venus was the first planet to have its motions plotted across the sky, as early as the second millennium BC.*[18]

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

1 Physical characteristics



Size comparison with Earth

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".*[19] The diameter of Venus is 12,092 km (7,514 mi)—only 650 km (404 mi) less than Earth's—and its mass is 81.5% of Earth's. 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.*[20]

1.1 Geography

Main article: Mapping of Venus

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.*[21] The surface was mapped in detail by *Magellan* in 1990–91. The ground shows evidence of extensive volcanism, and the sulfur in the atmosphere may indicate that there have been some recent eruptions.*[22]*[23]

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.*[24] 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 above the Venusian average surface elevation. The southern continent is called Aphrodite Terra, after the Greek 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.*[25]

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, approximately 300–600 million years old.*[26]*[27] 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.*[28]

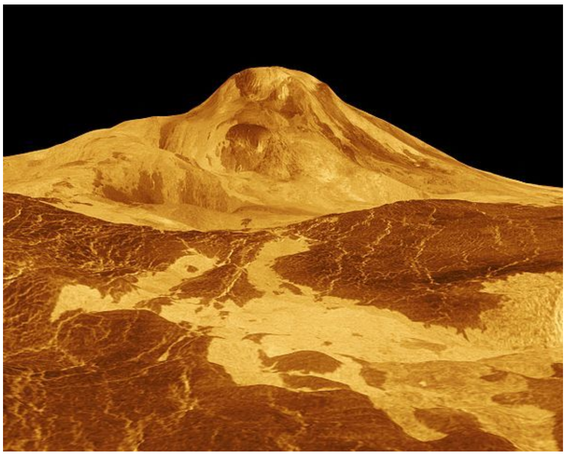
Most Venusian surface features are named after historical and mythological women.*[29] Exceptions are Maxwell Montes, named after James Clerk Maxwell, and highland regions Alpha Regio, Beta Regio, and Ovda Regio. The latter three features were named before the current system was adopted by the International Astronomical Union, the body which oversees planetary nomenclature.*[30]

The longitudes of physical features on Venus are 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.*[31] After the Venera missions were completed, the prime meridian was redefined to pass through the central peak in the crater Ariadne.*[32]*[33]

1.2 Surface geology

Main articles: Geology of Venus and Volcanology of Venus

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 (62 mi) across. The only volcanic complex of this size on Earth is the Big Island of Hawaii.*[28]*:154 This is not because Venus is more volcanically active than Earth, but because its crust is older. 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,*[34] whereas



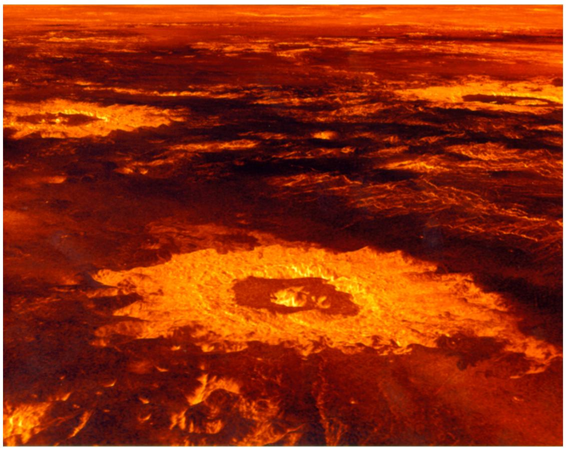
False-colour image of Maat Mons with a vertical exaggeration of 22.5

the Venusian surface is estimated to be 300–600 million years old.*[26]*[28]

Several lines of evidence point to ongoing volcanic activity on Venus. During the Soviet Venera program, the *Venera 9* orbiter obtained spectroscopic evidence of lightning on Venus,*[35] and the *Venera 12* descent probe obtained additional evidence of lightning and thunder.*[36]*[37] The European Space Agency's *Venus Express* in 2007 detected whistler waves further confirming the occurrence of lightning on Venus.*[38]*[39] One possibility is that ash from a volcanic eruption was generating the lightning. Another piece of evidence comes from measurements of sulfur dioxide concentrations in the atmosphere, which dropped by a factor of 10 between 1978 and 1986, jumped in 2006, and again declined 10-fold.*[40] This may mean that levels had been boosted several times by large volcanic eruptions.*[41]*[42]

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,*[43]*[n 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.*[44]*[45] 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).*[46]

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 about 300–600 mil-



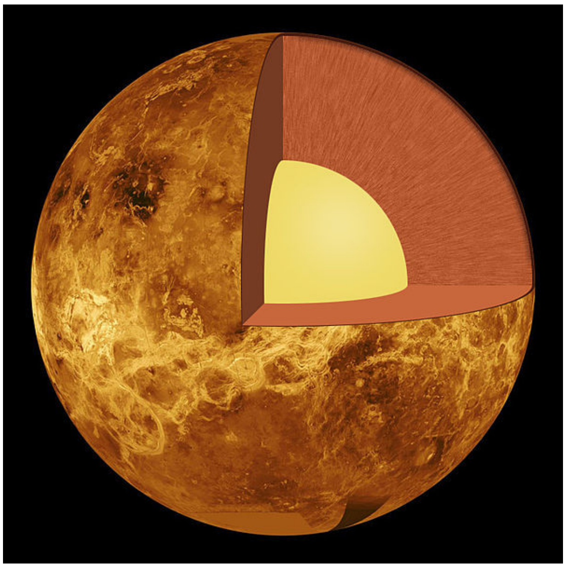
Impact craters on the surface of Venus (false-colour image reconstructed from radar data)

lion years ago,*[26]*[27] followed by a decay in volcanism.*[47] 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.*[28]

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 down so much by the atmosphere that they do not create an impact crater.*[48] Incoming projectiles less than 50 m (160 ft) in diameter will fragment and burn up in the atmosphere before reaching the ground.*[49]

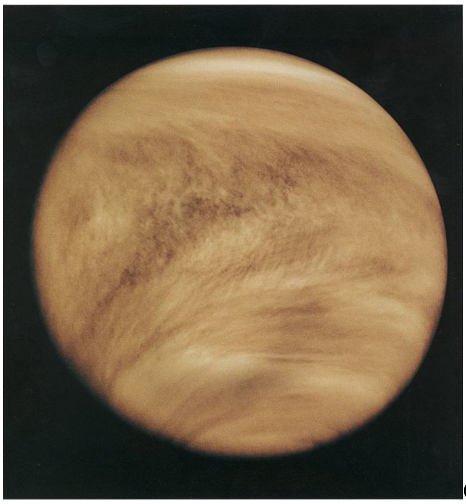
1.3 Internal structure

Without seismic data or knowledge of its moment of inertia, little direct information is available about the internal structure and geochemistry of Venus.*[50] The similarity in size and density between Venus and Earth suggests they share a similar internal structure: a core, mantle, and crust. Like that of Earth, the Venusian core is at least partially liquid because the two planets have been cooling at about the same rate.*[51] The slightly smaller size of Venus means pressures are 24% lower in its deep interior than Earth's.*[52] 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.*[53] Instead, Venus may lose its internal heat in periodic major resurfacing events.*[26]

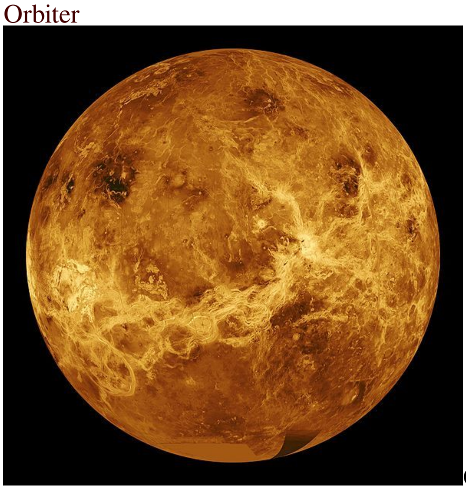


The internal structure of Venus – the crust (outer layer), the mantle (middle layer) and the core (yellow inner layer)

1.4 Atmosphere and climate



Cloud structure in the Venusian atmosphere in 1979, revealed by observations in the ultraviolet band by Pioneer Venus Orbiter



Global radar view of Venus (without the clouds) from *Magellan*

between 1990 and 1994
Main article: Atmosphere of Venus

Venus has an extremely dense atmosphere composed of 96.5% carbon dioxide, 3.5% nitrogen, and traces of other gases, most notably sulfur dioxide.*[54] The mass of its atmosphere is 93 times that of Earth's, whereas the pressure at its surface is about 92 times that at Earth's—a pressure equivalent to that at a depth of nearly 1 kilometre (0.62 mi) under Earth's oceans. The density at the surface is 65 kg/m^3, 6.5% that of water 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).*[12]*[55] This makes Venus's surface hotter than Mercury's, which has a minimum surface temperature of 53 K (−220 °C; −364 °F) and maximum surface temperature of 693 K (420 °C; 788 °F),*[56] even though Venus is nearly twice Mercury's distance from the Sun and thus receives only 25% of Mercury's solar irradiance. This temperature is higher than that used for sterilization. The surface of Venus is often said to resemble traditional accounts of Hell.*[57]*[58]

Studies have suggested that billions of years ago Venus's atmosphere was much more like Earth's than it is now, and that there may have been substantial quantities of liquid water on the surface, but after a period of 600 million to several billion years,*[59] a runaway greenhouse effect was caused by the evaporation of that original water, which generated a critical level of greenhouse gases in its atmosphere.*[60] Although the surface conditions on Venus are no longer hospitable to any Earthlike 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 (31 mi) up from the surface, where the temperature ranges between 303 and 353 K (30 and 80 °C; 86 and 176 °F) but the environment is acidic.*[61]*[62]*[63]

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 night and day sides, despite Venus's extremely 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 if the heat, pressure, and lack of oxygen were not a problem.*[64]

Above the dense CO
2 layer are thick clouds consisting mainly of sulfuric acid droplets. The clouds also contain sulfur aerosol, about 1% ferric chloride*[65] and some water.*[66]*[67] 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.*[65] These clouds reflect and scatter about 90% of the sunlight that falls on them back into space, and 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. Strong 300 km/h (185 mph) winds at the cloud tops go around Venus about every four to five Earth days.*[68] 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.*[69]

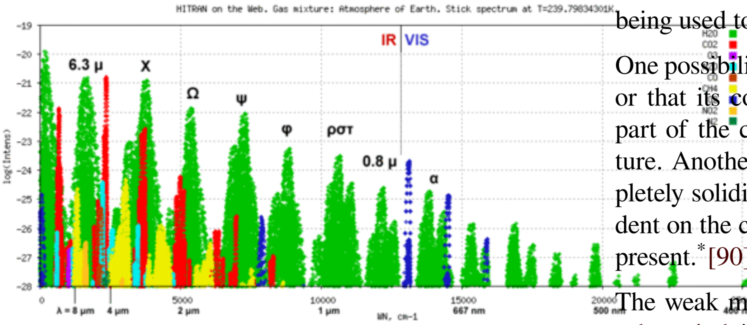
The surface of Venus is effectively isothermal; it retains a constant temperature not only between day and night sides but between the equator and the poles.*[1]*[70] Venus's minute axial tilt—less than 3°, compared to 23° on Earth—also minimises seasonal temperature variation.*[71] The only appreciable variation in temperature occurs with altitude. 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).*[72]*[73] In 1995, the *Magellan* spacecraft imaged a highly reflective substance at the tops of the highest mountain peaks 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).*[74]

The clouds of Venus may be capable of producing lightning.*[75] The existence of lightning in the atmosphere of Venus has been controversial since the first suspected bursts were detected by the Soviet Venera probes. 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 of that on Earth.*[38] In 2007, *Venus Express* discovered that a huge double atmospheric vortex exists at the south pole.*[76]*[77]

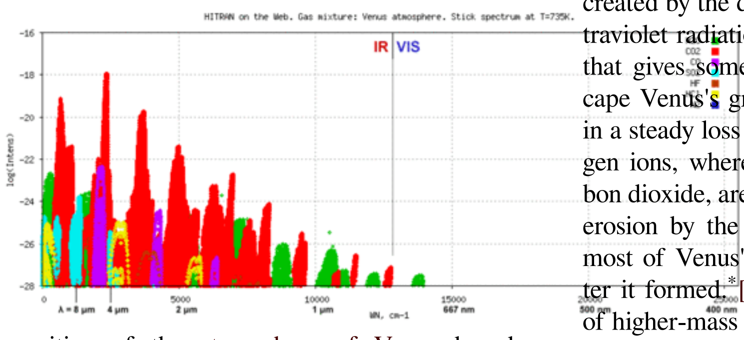
Venus Express also discovered, in 2011, that an ozone layer exists high in the atmosphere of Venus.*[78] On 29 January 2013, ESA scientists reported that the ionosphere of Venus streams outwards in a manner similar to "the ion tail seen streaming from a comet under similar conditions." *[79]*[80]

In December 2015 and to a lesser extent in April and May 2016, researchers working on Japan's *Akatsuki* mission observed bow shapes in the atmosphere of Venus. This was considered direct evidence of the existence of perhaps the largest stationary gravity waves in the solar system.*[81]*[82]*[83]

Atmospheric composition



Absorption spectrum of a simple gas mixture corresponding to Earth's atmosphere



The composition of the atmosphere of Venus based on HITRAN data*[84] created using HITRAN on the Web system.*[85]
Green colour – water vapour, red – carbon dioxide, WN – wavenumber (other colours have different meanings, lower wavelengths on the right, higher on the left).

1.5 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,*[86]*[87] rather than by an internal dynamo as in the Earth's core. Venus's small induced magnetosphere provides negligible protection to the atmosphere against cosmic radiation.

The lack of an intrinsic magnetic field at Venus was surprising, given that it is similar to Earth in size, and was expected also 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.*[88]*[89] 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 hotter 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 caused 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 being used to reheat the crust.*[90]

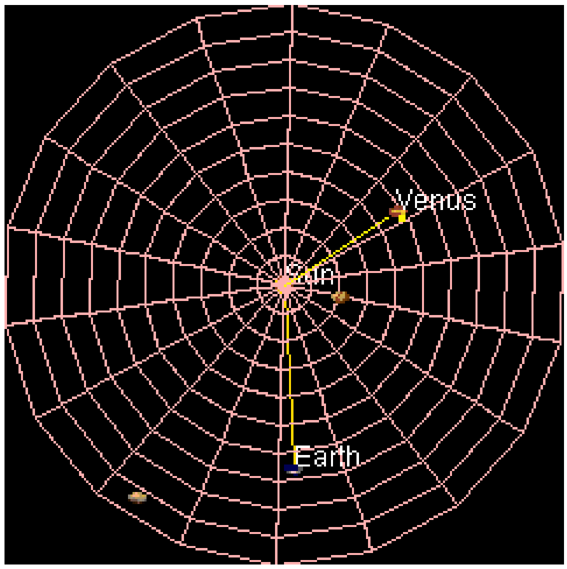
One possibility is that Venus has no solid inner core,*[91] or that its core is not cooling, so that the entire liquid part of the core is at approximately the same temperature. Another possibility is that its core has already completely solidified. The state of the core is highly dependent on the concentration of sulfur, which is unknown at present.*[90]

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 neutral 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 probably led to the loss of most of Venus's water during the first billion years after it formed.*[92] 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.*[93]

2 Orbit and rotation

Main article: Orbit of Venus

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 or-



Venus orbits the Sun at an average distance of about 108 million kilometres (about 0.7 AU) and completes an orbit every 224.7 days. Venus is the second planet from the Sun and orbits the Sun approximately 1.6 times (yellow trail) in Earth's 365 days (blue trail) bits are elliptical, Venus's orbit is the closest to circular, with an eccentricity of less than 0.01.*[1] 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).*[1] The planet reaches inferior conjunction every 584 days, on average.*[1] 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; then there are none for about 60,158 years.*[94]

All the planets in the Solar System orbit the Sun in an anti-clockwise direction as viewed from above Earth's north pole. Most planets also rotate on their axes in an anti-clockwise direction, but Venus rotates clockwise in retrograde rotation once every 243 Earth days—the slowest rotation of any planet. Because its rotation is so slow, Venus is very close to spherical.*[95] A Venusian sidereal day thus lasts longer than a Venusian year (243 versus 224.7 Earth days). Venus's equator rotates at 6.5 km/h (4.0 mph), whereas Earth's is approximately 1,670 km/h (1,040 mph).*[96] Venus's rotation has slowed down by 6.5 min per Venusian sidereal day in the 16 years between the *Magellan* spacecraft and *Venus Express* visits.*[97] 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).*[98] One Venusian year is about 1.92 Venusian solar days.*[99] To an observer on the surface of Venus, the Sun would rise in the west and set in the east,*[99] although Venus's opaque clouds prevent observing the Sun from the planet's surface.*[100]

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.*[101]*[102] The 584-day average interval between successive close approaches to Earth is almost exactly equal to 5 Venusian solar days,*[103] but the hypothesis of a spin–orbit resonance with Earth has been discounted.*[104]

Venus has no natural satellites.*[105] It has several trojan asteroids: the quasi-satellite 2002 VE68*[106]*[107] and two other temporary trojans, 2001 CK$_{32}$ and 2012 XE133.*[108] 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.*[109] About 10 million years later, according to the study, another impact reversed the planet's spin direction and caused the Venusian moon gradually to spiral inward until it collided with Venus.*[110] 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.*[105]

3 Observation

Venus is always brighter than all other planets or stars as seen from Earth. The second brightest object on the image is Jupiter.

The phases of Venus and evolution of its apparent diameter

To the naked eye, Venus appears as a white point of light brighter than any other planet or star (apart from the Sun).*[111] Its brightest apparent magnitude, −4.9,*[10] occurs during crescent phase, only 36 days before or after inferior conjunction*[112]. Venus will be brightest on 30 April 2017, then grow dimmer for nearly a year. Venus fades to about magnitude −3 when it is backlit by the Sun.*[9] The planet is bright enough to be seen in a clear midday sky*[113] and is easily visible when the Sun is low on the horizon. As an inferior planet, it always lies within about 47° of the Sun.*[11]

Venus "overtakes" Earth every 584 days as it orbits the Sun.*[1] 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". U.S. President Jimmy Carter reported having seen a UFO in 1969, which later analysis suggested was probably Venus.

As it moves around its orbit, Venus displays phases like those of the Moon in a telescopic view. The planet presents a small "full" image when it is on the opposite side of the Sun. It shows a larger "quarter phase" when it is at its maximum elongations from the Sun, and is at its brightest in the night sky, and presents a much larger "thin crescent" in telescopic views as it comes around to the near side between Earth and the Sun. Venus is at its largest and presents its "new phase" when it is between Earth and the Sun. Its atmosphere can be seen in a telescope by the halo of light refracted around it.*[11]

3.1 Transits

2004 transit of Venus

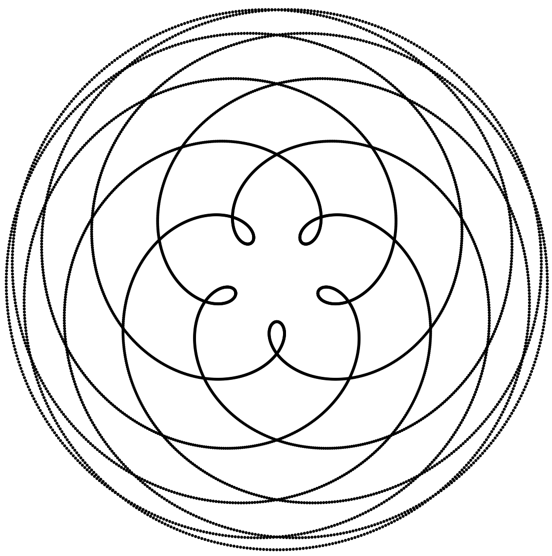
Main articles: Transit of Venus and Transit of Venus, 2012

The Venusian orbit is slightly inclined relative to Earth's orbit; thus, when the planet passes between Earth and the Sun, it usually does not cross the face of the Sun. Transits of Venus occur when the planet's inferior conjunction coincides with its presence in the plane of Earth's orbit. Transits of Venus occur in cycles of 243 years with the current pattern of transits being pairs of transits separated by eight years, at intervals of about 105.5 years or 121.5 years—a pattern first discovered in 1639 by the English astronomer Jeremiah Horrocks.*[114]

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.*[115]

The preceding pair of transits occurred in December 1874 and December 1882; the following pair will occur in December 2117 and December 2125.*[116] The oldest film known is the 1874 *Passage de Venus*, showing the 1874 Venus transit of the sun. 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 Horrocks in 1639.*[117] Captain Cook's exploration of the east coast of Australia came after he had sailed to Tahiti in 1768 to observe a transit of Venus.*[118]*[119]

3.2 Pentagram of Venus



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

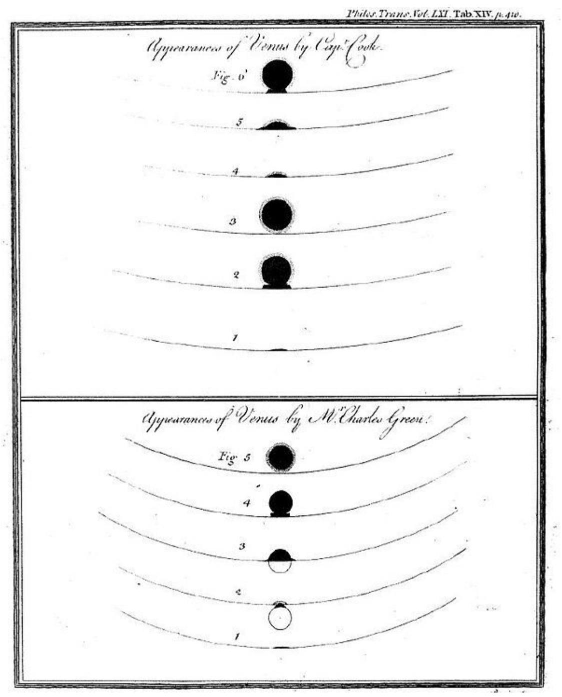
The pentagram of Venus is the path that Venus makes as observed from Earth. Successive inferior conjunctions of Venus repeat very near a 13:8 orbital resonance (Earth orbits 8 times for every 13 orbits of Venus), shifting 144° upon sequential inferior conjunctions. The resonance 13:8 ratio is approximate. 8/13 is approximately 0.615385 while Venus orbits the Sun in 0.615187 years.*[120]

3.3 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.*[121]*[36]

4 Studies

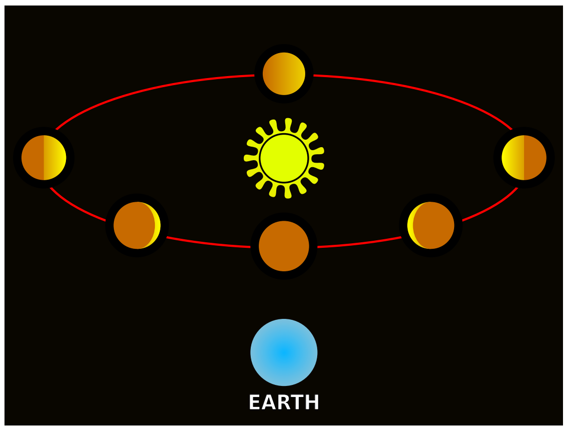
4.1 Early studies



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

Venus was known to ancient civilizations both as the "morning star" and as the "evening star", names that reflect the early assumption that these were two separate objects. The Venus tablet of Ammisaduqa, believed to have been compiled around the mid-seventeenth century BCE,*[122] shows the Babylonians understood the two were a single object, referred to in the tablet as the "bright queen of the sky", and could support this view with detailed observations.*[123] The Ancient Greeks thought of the two as separate stars, Phosphorus and Hesperus. Pliny the Elder credited the realization that they were a single object to Pythagoras in the sixth century BCE,*[124] while Diogenes Laertius argued that Parmenides was probably responsible.*[125] The ancient Chinese referred to the morning Venus as "the Great White" (*Tai-bai* 太白) or "the Opener (Starter) of Brightness" (*Qi-ming* 啓明), and the evening Venus as "the Excellent West One" (*Chang-geng* 長庚). The Romans designated the morning aspect of Venus as Lucifer, literally "Light-Bringer", and the evening aspect as Vesper, both literal translations of the respective Greek names.

In the second century, in his astronomical treatise *Almagest*, Ptolemy theorized that both Mercury and Venus are located between the Sun and the Earth. The 11th century Persian astronomer Avicenna claimed to have observed the transit of Venus,*[126] which later astronomers took as confirmation of Ptolemy's theory.*[127] In the 12th century, the Andalusian astronomer Ibn Bajjah observed "two planets as black spots on the face of the Sun", which were later identified as the transits of Venus and Mercury by the Maragha astronomer Qotb al-Din Shirazi in the 13th century.*[128]*[n 2]



Galileo's discovery that Venus showed phases (although remaining near the Sun in Earth's sky) proved that it orbits the Sun and not Earth

When the Italian physicist Galileo Galilei first observed the planet 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.*[131]*[132]

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).*[133]

The atmosphere of Venus was discovered in 1761 by Russian polymath Mikhail Lomonosov.*[134]*[135] 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 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.*[136] 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.*[137]

4.2 Ground-based research

Modern telescopic view of Venus from Earth's surface

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, radar and ultraviolet observations that more of its secrets were revealed. 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.*[138]

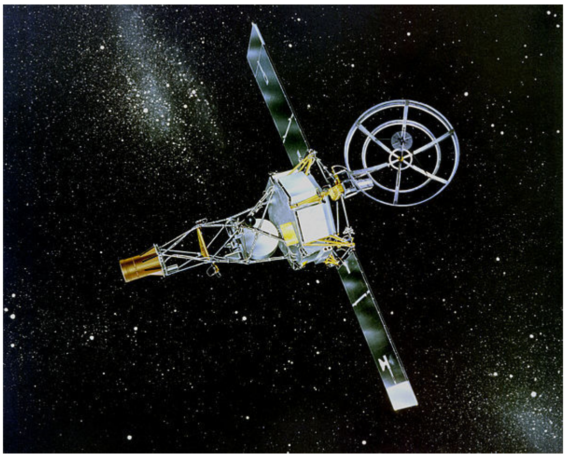
Spectroscopic observations in the 1900s gave the first clues about the Venusian rotation. Vesto Slipher tried to measure the Doppler shift of light from Venus, but found he could not detect any rotation. He surmised the planet must have a much longer rotation period than had previously been thought.*[139] Later work in the 1950s showed the rotation was retrograde. 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 modern value.*[140]

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 (980 ft) radio telescope at Arecibo Observatory, and the echoes revealed two highly reflective regions, designated the Alpha and Beta regions. The observations also revealed a bright region attributed to mountains, which was called Maxwell Montes.*[141] These three features are now the only ones on Venus that do not have female names.*[30]

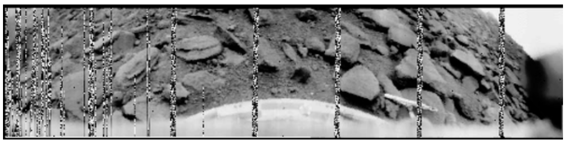
4.3 Exploration

Main article: Observations and explorations of Venus

The first robotic space probe mission to Venus, and the first to any planet, began with the Soviet Venera program in 1961.*[142] The United States' exploration of Venus had its first success with the Mariner 2 mission on 14 December 1962, becoming the world's first successful interplanetary mission, passing 34,833 km (21,644 mi) above the surface of Venus, and gathering data on the planet's atmosphere.*[143]*[144]



Artist's impression of Mariner 2, launched in 1962, a skeletal, bottle-shaped spacecraft with a large radio dish on top



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. Several lines are missing due to a simultaneous transmission of the scientific data

On 18 October 1967, the Soviet *Venera 4* successfully entered the atmosphere and deployed science experiments. *Venera 4* showed the surface temperature was hotter than *Mariner 2* had calculated, at almost 500 °C, determined that the atmosphere is 95% carbon dioxide (CO_2), and discovered that Venus's atmosphere was considerably denser than *Venera 4*'s designers had anticipated.*[145] The joint *Venera 4*–*Mariner 5* data were analysed by a combined Soviet–American science team in a series of colloquia over the following year,*[146] in an early example of space cooperation.*[147]

In 1975 the Soviet *Venera 9* and *10* landers transmitted the first images from the surface of Venus, which were in black and white. In 1982 the first colour images of the surface were obtained with the Soviet *Venera 13* and *14* landers.

NASA obtained additional data in 1978 with the Pioneer Venus project that consisted of two separate missions:[148] Pioneer Venus Orbiter and Pioneer Venus Multiprobe.[149] The successful Soviet Venera program came to a close in October 1983, when *Venera 15* and *16* were placed in orbit to conduct detailed mapping of 25% of Venus's terrain (from the north pole to 30°N latitude)[150]

Several other Venus flybys took place in the 1980s and 1990s that increased the understanding of Venus, including *Vega 1* (1985), *Vega 2* (1985), *Galileo* (1990), *Magellan* (1994), *Cassini–Huygens* (1998), and *MESSENGER* (2006). Then, *Venus Express* by the European Space Agency (ESA) entered orbit around Venus in April 2006. Equipped with seven scientific instruments, *Venus Express* provided unprecedented long-term observation of Venus's atmosphere. ESA concluded that mission in December 2014.

As of 2016, Japan's *Akatsuki* is in a highly elliptical orbit around Venus since 7 December 2015, and there are several probing proposals under study by Roscosmos, NASA, and India's ISRO.

5 In culture

See also: Venus in fiction and Observations and explorations of Venus § Historical observations and impact

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. Classical poets such as Homer, Sappho, Ovid and Virgil spoke of the star and its light.[151] Romantic poets such as William Blake, Robert Frost, Alfred Lord Tennyson and William Wordsworth wrote odes to it.[152] With the invention of the telescope, the idea that Venus was a physical world and possible destination began to take form.

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 frequently depicted as warmer, but still habitable by humans.[153] 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 the reality to be quite different, and brought this particular genre to an end.[154] As scientific knowledge of Venus advanced, so science fiction authors tried to keep pace, particularly by conjecturing human attempts to terraform Venus.[155]

5.1 Symbol

Main article: Venus symbol

♀ The astronomical symbol for Venus is the same as that used in biology for the female sex: a circle with a small cross beneath.[156] The Venus symbol also represents femininity, and in Western alchemy stood for the metal copper.[156] Polished copper has been used for mirrors from antiquity, and the symbol for Venus has sometimes been understood to stand for the mirror of the goddess.[156]

6 Habitability

Main article: Life on Venus
See also: Colonization of Venus

The speculation of the existence of life on Venus decreased significantly since the early 1960s, when spacecraft began studying Venus and it became clear that the conditions on Venus are extreme compared to those on Earth.

The fact that Venus is located closer to the Sun than Earth, raising temperatures on the surface to nearly 735 K (462 °C; 863 °F), the atmospheric pressure is ninety times that of Earth, and the extreme impact of the greenhouse effect, make water-based life as we know it unlikely. However, a few scientists have speculated that thermoacidophilic extremophile microorganisms might exist in the lower-temperature, acidic upper layers of the Venusian atmosphere.[157][158][159] The atmospheric pressure and temperature approximately fifty kilometres above the surface are similar to those at Earth's surface. This has led to proposals to use aerostats (lighter-than-air balloons) for initial exploration and ultimately for permanent "floating cities" in the Venusian atmosphere.[160] Among the many engineering challenges are the dangerous amounts of sulfuric acid at these heights.[160]

7 See also

- Outline of Venus
- Aspects of Venus
- Geodynamics of Venus

- Venus zone

8 Notes

[1] Misstated as “Ganiki Chasma” in the press release and scientific publication.*[44]

[2] Several claims of transit observations made by medieval Islamic astronomers have been shown to be sunspots.*[129] 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.*[130]

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10 External links

- Venus profile at NASA's Solar System Exploration site
- Missions to Venus and Image catalog at the National Space Science Data Center

- Soviet Exploration of Venus and Image catalog at Mentallandscape.com
- Venus page at *The Nine Planets*
- Transits of Venus at NASA.gov
- Geody Venus, a search engine for surface features

10.1 Cartographic resources

- Map-a-Planet: Venus by the U.S. Geological Survey
- Gazetteer of Planetary Nomenclature: Venus by the International Astronomical Union
- Venus crater database by the Lunar and Planetary Institute
- Map of Venus by Eötvös Loránd University

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