DOI: 10.46299/979-8-89814-227-8.1

1. The main astronomical and physical characteristics of Venus and their comparison with Earth

Introduction

Because of its similarity in size, mass, and average density, Venus is often called Earth's "sister." However, this planet is a world with a very different geological history and surface conditions. The surface of Venus is hidden under a dense layer of clouds (Fig. 1.1) of sulfuric acid. And the temperature on it reaches 737 K at a pressure that is 92 times higher than on the Earth's surface.

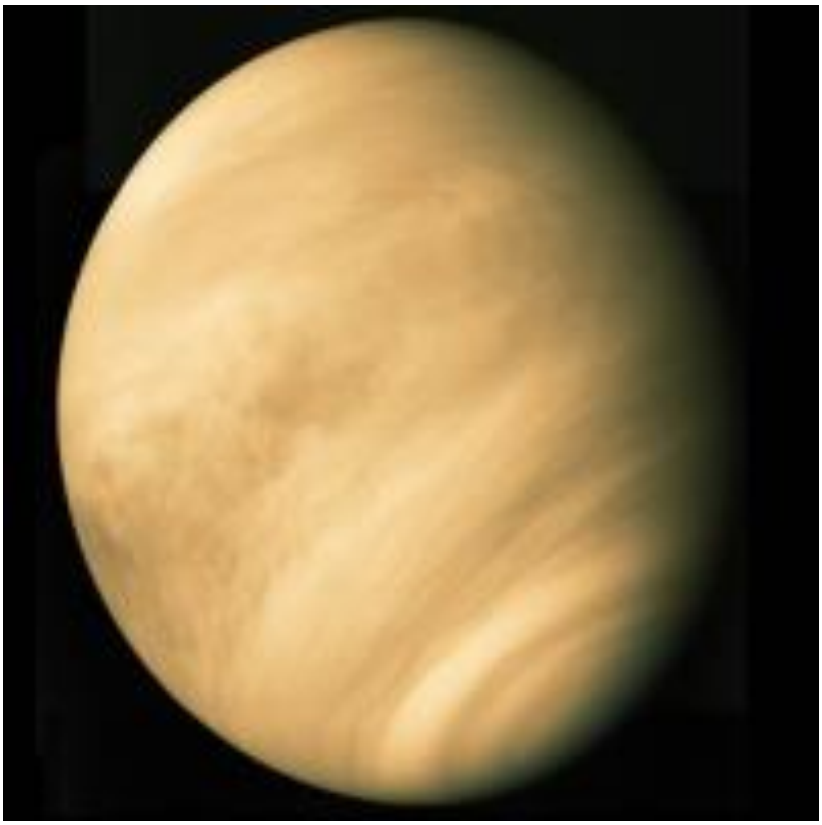


Fig. 1.1. Photograph of Venus taken by the Mariner 10 spacecraft (https://sci.esa.int/sci-images/40/ACFKIA.kay8r.jpg).

Both planets belong to the so-called terrestrial group [30]. They formed in approximately the same part of the Solar System and should have a similar overall chemical composition, similar metallic cores and silicate mantle. However, the list of similarities practically ends there. Venus represents a rather paradoxical case of

planetary evolution, demonstrating a radically different path of further development from Earth. After all, its surface turned out to be red-hot to temperatures at which some metals can melt.

In terms of its size and mass, Venus is very similar to Earth. Its average radius is 6051.8 km, which is approximately 95% of the Earth's radius. The mass of Venus is estimated at $4.8685 \cdot 10^{24}$ kg, or about 0.815 times the mass of Earth. Its average density is 5.24 g/cm³, only slightly less than the average density of Earth (5.514 g/cm³). This high density indicates a significant proportion of metals (mainly iron and nickel) in its core and a silicate composition of the mantle and crust [29].

The gravitational force at the equator of Venus is about 8.87 m/s², which is approximately 91% of Earth's gravity. Venus orbits the Sun at an average distance of 0.723 AU and completes one orbit in 224.7 Earth days [1, 3]. The plane of Venus's orbit is only slightly inclined to the plane of the ecliptic: about 3.4°. Venus's orbit is almost perfectly circular, with a very low eccentricity of only 0.0067. This means that Venus's distance from the Sun varies very little during its orbital motion: from 107.5 million km at perihelion to 108.9 million km at aphelion. Due to the peculiarities of its orbit, located inside the Earth's, Venus is the closest planet to Earth, sometimes approaching a distance of less than 40 million km.

One of the most striking characteristics of Venus is its very slow and, moreover, retrograde (from east to west) rotation. Moreover, the sidereal period of the planet's rotation is 243.02 Earth days. This combination of slow retrograde rotation and relatively fast orbital motion leads to a very long solar day, which is the period between two consecutive noons. Its axial tilt is 177.36°, which is almost inverted compared to the tilt of the Earth's axis.

It is also important to note that Venus does not have a significant global magnetic dipole field [22], and there are no satellites around it; and its geological activity manifests itself in forms that are significantly different from the Earth's plate tectonics. Such significant contrasts between two seemingly very similar celestial bodies raise a fundamental question regarding the list of factors that determine the evolutionary paths of these nearby terrestrial planets [23].

1.1. The significance of Venus research

The above characteristics show that the study of Venus is of key importance for planetology. After all, the study of extreme conditions on its surface and in the atmosphere [9], in particular the powerful greenhouse effect, should help to better understand climate processes and their possible consequences on planet Earth [15]. Analysis of the geological history of Venus, which is characterized by large-scale volcanism [7, 24, 33] and the absence of plate tectonics [10] of the terrestrial type, provides a unique opportunity to study alternative paths of evolution of rocky planets and mechanisms of loss of internal heat by these bodies. And a comparison of Venus with our planet Earth will also reveal a list of critical factors that determine the suitability of a particular planet for life, and understand why Earth became an oasis of life, and its "sister" – a hellish world (Fig. 1.2). In addition, Venus can serve as a natural laboratory for studying processes that could occur on the early Earth before the establishment of modern plate tectonics.

1.2. Exploration of Venus by Space Missions

Our modern understanding of Venus is largely based on data obtained by spacecraft (SC). Since the first successful flyby of Mariner 2 in 1962, a series of subsequent space missions have revealed the planet's secrets. The Soviet "Venera" program made the first surface landings and analyzed its rocks and atmosphere. The American Pioneer Venus missions (an orbiter and atmospheric probes) provided detailed data on the atmosphere and allowed the first global topographic maps of the surface.

A revolutionary step was the high-resolution radar mapping carried out by the "Venera-15", "Venera-16" and, especially, the American Magellan (1990-1994) spacecraft, which was able to map about 98% of the surface of Venus [18, 20]. The result of their work was the discovery of a complex world of surface structures such as volcanoes, plains, mountain ranges and unique tectonic structures [2, 11].

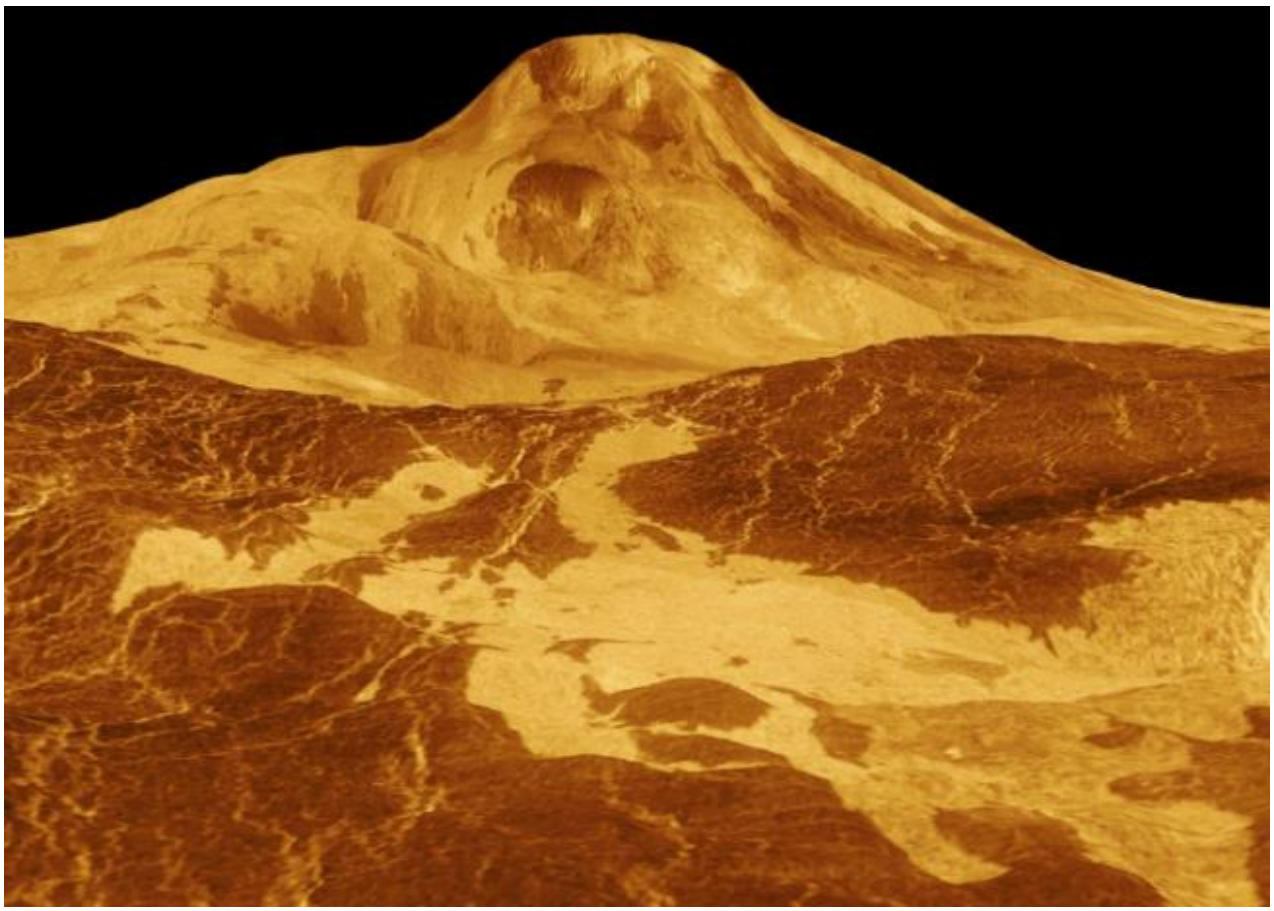


Fig. 1.2. Perspective view of Maat Mons on the surface of Venus, 1700 m above the terrain. Lava flows extend for hundreds of kilometers across fractured plains. Maat Mons is a volcano 8 km above mean surface level. Vertical scale increased by 22.5 times. Simulated shades are based on color images obtained by the “Venera-13” and “Venera-14” spacecraft (https://studfile.net/html/2706/829/html_hByup0TCgQ.cNvD/img-b7teeL.jpg).

The European mission Venus Express (2006-2014) focused on studying the atmosphere [8]. However, it was also able to provide important observational data indicating possible modern volcanic activity [32, 34]. The Japanese spacecraft “Akatsuki” continues to study the atmosphere of Venus. And future missions to Venus, such as VERITAS (NASA), DAVINCI (NASA), and “EnVision” (ESA), promise to delve even deeper into the secrets of this planet, using the latest technologies to map its surface, analyze the composition of the atmosphere and crust, and to further search for definitive evidence of modern geological activity.

Below we provide a fairly detailed list of various spacecrafts that have explored

Venus. In this, the planet is second only to the Moon and Mars. In doing so, we will use the data published in the book [30], prepared with our participation.

02/12/1961 the spacecraft “Venera-1” (USSR) was first sent to Venus. The device was equipped with a magnetometer, radiation sensors, etc. At that time, it was assumed that after landing on the planet, it would float in a vast ocean. However, a week after launch, contact with this spacecraft was lost, and the device flew 100 thousand km from the planet. On July 22, 1962, the United States launched the “Mariner 1” spacecraft. But after the rocket deviated from its intended course, an accident occurred 293 seconds after launch.

On August 25, 1962, the USSR launched another spacecraft of the “Venera” type. But when it entered Earth's orbit, problems occurred and it became “Sputnik 19”. On August 27, 1962, the United States launched a backup spacecraft “Mariner 2”. But due to problems, this spacecraft flew 34,773 km from Venus. However, its instruments were able to record thick clouds, high temperature and high pressure near the surface, the planet's very slow rotation, and the absence of a noticeable magnetic field.

On September 1, 1962, the USSR launched another spacecraft to Venus. But due to problems in Earth's orbit, it became “Sputnik 20”. On September 12, 1962, the USSR launched “Sputnik-21”, which was intended to fly by Venus; however, an accident occurred. On November 11, 1963, the USSR launched “Kosmos-21” to test the capabilities of various technologies for flying to Venus, and this spacecraft remained in Earth orbit.

On February 19, 1964, the USSR launched unsuccessfully, first “Venera-1964A”, and after half a month, on March 1, 1964, the “Venera-1964B” spacecraft. On March 27, 1964, the USSR launched “Kosmos-27” in the direction of Venus (it remained in Earth orbit). It should be noted that since 1962, the name “Kosmos” began to be given to all spacecraft that, regardless of their original purpose, remained in Earth orbit. On April 2, 1964, the USSR launched the spacecraft “Zond-1”; it also missed Venus, flying 100 thousand km from it. On November 12, 1965, the USSR launched the spacecraft “Venera-2”. It was equipped with a television system, equipment for studying cosmic rays, the magnetic field, solar plasma flows and flows of low energy

charged particles and micrometeorites.

But on February 27, 1966, this spacecraft also flew 24 thousand km from Venus. On November 16, 1965, the USSR launched the spacecraft “Venera-3” with the aim of lowering it to the surface with a significant list of scientific instruments and a radio communication system. Although it was able to reach Venus in the spring of 1966, the lander was unable to transmit any information. 11/23/1965 The USSR launched the spacecraft “Kosmos-96” due to an accident in orbit.

06/12/1967 The USSR launched the spacecraft “Venera-4”, designed to study Venus and Mars both from a flight path and using a lander. 10/18/1967 this device was able to enter the atmosphere and for more than an hour and a half it descended to the night side of Venus using a parachute system; it transmitted data on the pressure, composition of the atmosphere and temperature up to an altitude of 25 km; and already there it was crushed by the atmosphere. It was able to obtain information that at an altitude of 25 km the temperature of the Venusian atmosphere was 544 K with a pressure of about 20 bars. It was also possible to establish that the atmosphere of Venus consists of 96% carbon dioxide CO_2.

On June 14, 1967, the United States launched the “Mariner 5” spacecraft, which was a backup spacecraft for “Mariner 4”. After the successful operation of its predecessor, the spacecraft was modified. The television cameras were removed, the solar panels were changed, and thermal insulation was added. On October 19, 1967, this spacecraft flew within 4,000 km of Venus. The updated equipment was able to determine the very high surface temperature [16] and that its atmosphere was much denser than previously expected.

On June 17, 1967, the USSR launched the “Cosmos 167” spacecraft, which again remained in Earth orbit. On January 5, 1969, the USSR launched the “Venera 5” spacecraft. A specially upgraded capsule was also parachuted into the nighttime atmosphere. But it was only able to operate there for 53 minutes and was crushed by atmospheric pressure. Sensors on the descent vehicle were able to measure atmospheric pressure in the range from 0.13 to 40 bars; gas analyzers were also able to determine the chemical composition of the components in the atmosphere, other devices

determined the illumination in the atmosphere, density, and temperature in the atmosphere [26].

10.01.1969 the USSR launched the spacecraft "Venera-6"; since it was a copy of the spacecraft "Venera-4 and -5", the atmosphere also crushed this descent vehicle. But it was still possible to obtain updated results on the structure of the solar wind near Venus and it was obtained that the front of the change in plasma flows was observed at a distance of 28 thousand km from the surface of the planet.

17.08.1970 the USSR launched the spacecraft "Venera-7". The descent vehicle entered the planet's atmosphere on 15.12.1970 and first began to brake aerodynamically, and then – with the help of parachutes. He was the first to reach the planetary surface and work there for 23 minutes. Data were obtained on the chemical composition of the atmosphere, on temperature changes at different altitudes and on the surface itself, and on pressure changes with altitude.

The atmospheric pressure near the surface of Venus was found to be 90±15 bar at a temperature of 748±20 K. On 03/27/1972, the USSR launched the “Venera-8” spacecraft. Entry into the atmosphere took place on 07/22/1972. At an altitude of 60 km above the surface, a parachute with a diameter of 2.5 m was opened, and as a result, a landing was made on the day side of the planet for the first time. At altitudes of 35-30 km, a sharp decrease in illumination was registered. On 03/31/1972, the USSR launched the “Kosmos-482” interplanetary station, which did not leave Earth's orbit. On November 4, 1973, the United States launched the “Mariner 10” spacecraft, which used Venus' gravity to accelerate it to its final destination, Mercury. The closest approach to Venus was 5,770 km. The spacecraft transmitted almost 3,000 images of Venus to Earth in the ultraviolet (UV) range and visible light with a maximum resolution of up to 18 m. On June 8, 1975, the USSR launched the “Venera 9” spacecraft, and on June 14, 1975, “Venera 10”. The first landed on October 22, 1975, on the illuminated part of the planet, and the second on October 25, 1975, 2,200 km from it.

Due to its cooling system, the “Venera 9” probe was able to operate on the surface for about 53 minutes. Both spacecraft were able to transmit color panoramas

of the surface to Earth for the first time. On 20.05.1978 the USA launched the spacecraft “Pioneer-Venus-1”, which on 4.12.1978 was launched into the orbit of Venus. With the help of radar equipment, certain features of the relief were obtained on a significant part of the surface of Venus [25]. This made it possible to compile maps with the presence of mountain ranges, large plateaus and lowlands. With the help of magnetometers, the absence of a magnetic field on Venus was confirmed. It was also possible to detect the presence of permanent lightning discharges, which were concentrated only in certain regions of the planet.

On 08/08/1978, the United States launched the “Pioneer Venus-2” spacecraft, which on 16/11/1978 dropped one large (with a diameter of about 1.5 m and a mass of 316 kg), and on 20/11/1978 three smaller (with a diameter of 0.7 m and a mass of 96.6 kg) descent vehicles onto the night side, the day side, and the area near the planet's North Pole. All four modules entered the atmosphere on 9 December and descended for almost an hour. One of the smaller vehicles was able to work on the surface for over an hour, although it was not designed for this. The results of this experiment confirmed the already known atmospheric chemical composition, and a thin layer of dust was detected on the surface itself. Below the cloud level, water vapor [12] and a fairly high concentration of molecular oxygen [5] were detected.

Droplets of concentrated sulfuric acid were recorded in the upper layer of clouds at an altitude of 65-70 km. In the middle layer of clouds, in addition to sulfuric acid, a large number of solid and liquid sulfur particles were found. Slightly larger sulfur particles were in the lower layer of clouds at an altitude of about 50 km. Below 30 km, the atmosphere of Venus turned out to be relatively transparent. On September 9, 1978, the USSR launched the “Venera-11” spacecraft. Its entry into the atmosphere occurred on December 25, 1978, and the landing lasted about 1 hour. The instruments of this station registered electrical discharges in the atmosphere, up to 25 lightning flashes per second. One of the thunderclaps lasted as long as 15 minutes. The occurrence of such discharges may be facilitated by the high content of sulfuric acid in these clouds.

The amount of sulfur dioxide, sulfur itself, nitrogen, carbon monoxide, water vapor, neon, argon, and their isotopic ratios in cloud particles were determined using

mass spectrometry, gas chromatography, X-ray and optical spectrometry methods. To study the thermal regime of the planet, the results of the absorption and re-emission of sunlight at different altitudes in the atmosphere were refined [4].

In the upper layers of the atmosphere, about 96% of carbon dioxide and up to 4% of nitrogen were found; traces of SO_2 and carbon monoxide were also found; oxygen was practically absent, and the water vapor content under the cloud layer was within 0.1-0.4%, and above the clouds it reached 15-30%. The temperature near the surface was 735 K at a pressure of about 90 bars. 09/14/1978 the USSR launched the spacecraft "Venera-12". It descended to the surface 800 km from the “Venera-11” spacecraft and was able to register up to 1 thousand lightning flashes. On 10/30/1981, the USSR launched the “Venera-1”3 spacecraft, and 4 days later, on 11/4/1981, the almost identical “Venera-14” spacecraft.

Their landings on the surface were carried out on March 1 and 5 at a distance of 950 km between them. Color images of the landscapes were obtained at the landing sites, and soil analysis was performed on the surface of Venus (Fig. 1.3). Drilling, sampling, and chemical analysis of the soil composition were carried out at a temperature of 740 K and a pressure of 93 bars. Oxides of iron, silicon, aluminum, magnesium, calcium, potassium, and titanium were found in the soil. The measured mechanical strength of the soil and electrical conductivity were similar to terrestrial basalts present in the ocean basins on Earth.

02.06.1983 the USSR launched the spacecraft "Venera-15", and 5 days later – 07.06.1983 – "Venera-16". Their orbital modules were equipped with radar systems that transmitted images of the surface of individual parts of the planet in the northern hemisphere and the results of measurements of the height of the relief [13]. The materials obtained allowed to compile an atlas of the surface of Venus, maps of its relief, geological [18] and other special maps with a resolution of 1-2 km. These images show craters, large faults, hills, ranges and mountain ranges.

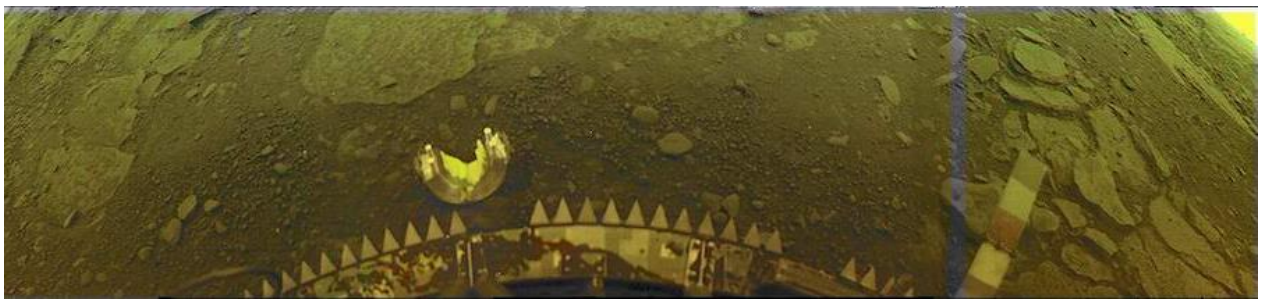


Fig. 1.3. Panoramas of the surface of Venus at the landing site of the “Venera-13” spacecraft (the second of two 180° sectors) [27].

On 15.12.1984 and 21.12.1984, the USSR launched the “Vega-1” and “Vega-2” spacecraft. Their main task was to study Halley's Comet. But the descent vehicles to the surface of Venus were also designed and manufactured using a new method. They consisted of a landing module and also had aerodynamic probes. These probes drifted for almost two days at an altitude of about 54 km and transmitted the results obtained on the studies of the atmosphere and surface of the planet. The landing modules were first equipped with UV spectrometers, with which they determined small atmospheric components and the concentration of water vapor. The balloon probes drifted for almost 9 thousand km, and when they reached the day side of Venus, they collapsed.

04.05.1989 The USA launched the Magellan spacecraft. On August 10, 1990, it reached Venus and entered a polar orbit with a rotation period of 195 minutes. Over the course of two years, the spacecraft was able to image about 98% of the surface; it operated until October 12, 1994, when communication with the spacecraft was lost. Bistatic radar provided detailed data on the relief of almost the entire surface of Venus with a resolution of better than 100 m.

At the same time, it was possible to record the absence of plate tectonics [19] and the fact that about 85% of the planet's surface is covered by volcanic lava flows [2, 6], and the remaining 15% by mountains.

A very slow erosion process was also noted and the average age of rocks on the surface was up to 500 million years. Measurements of gravitational anomalies on the planet allowed maps of the state of its interior to be constructed. 09.11.2005 The European Space Agency launched the interplanetary probe "Venus Express". Its main

goal was to study in detail the environment around Venus and its interaction with the solar wind flows. Studies were also carried out on the properties of the surface, its structure and geology of the surface layer, changes in the composition and chemistry of the atmosphere, the cloud layer and fog above it. On 12.04.2006, it was possible to obtain the first image of the planet's north pole (Fig. 1.4).



Fig. 1.3. Image of two vortices in the atmosphere above the north pole of Venus obtained by the “Venus Express” spacecraft (http://www.esa.int/SPECIALS/Venus_Express/).

On August 3, 2004, the “Messenger” spacecraft was launched to study Mercury. To enter orbit around the planet closest to the Sun, the probe had to perform a series of maneuvers, which included one orbit around the Earth, two orbits near Venus, 15 orbits around the Sun, and then another 3 orbits near Mercury. During the second approach to Venus, the spacecraft transmitted a series of images to Earth and established

communication with the then artificial satellite of Venus, the “Venus Express” spacecraft.

The interplanetary station of the Japanese Aerospace Exploration Agency “Akatsuki”, or “PLANET-C”, was launched on May 21, 2010. On December 7, 2010, this device unsuccessfully approached Venus and failed to enter orbit around the planet. The probe's engines were retested several times. But only on 7.12.2015 the spacecraft was able to enter the planned elliptical orbit around Venus. On 4 April this probe was able to transmit the first images of the planet in the IR range to Earth.

The spacecraft with a solar sail “IKAROS” was also created by the Japanese Aerospace Agency. It was launched on 21.05.2010; and from 3 to 10 June the solar sail with a total area of 200 m2 was successfully deployed. On 8.12.2010 “IKAROS” passed at a distance of about 81 thousand km from Venus, successfully completing the planned mission.

1.3. Briefly about the atmosphere of Venus

The atmosphere of Venus is its most prominent feature, which radically distinguishes it from the Earth. It is the densest among the terrestrial planets [23, 28] in the Solar System, and its mass is about $4.8 \cdot 10^{20}$ kg. The pressure at the average surface level reaches as much as 92-95 bar, which is almost a hundred times higher than the atmospheric pressure at sea level on Earth. The atmosphere consists mainly of carbon dioxide (CO_2), the proportion of which exceeds 96.5%.

The second most abundant gas is nitrogen (N_2), which is about 3.5%. All other components, such as sulfur dioxide (SO_2), argon (Ar), water vapor (H2O), carbon monoxide (CO), helium (He), neon (Ne), halides (HF, HCl) and various sulfur compounds (SO_2, SO, OCS, H_2S), are present only in trace amounts. Atomic oxygen (O) has been detected only in a thin layer high above the surface. Therefore, there is no significant amount of molecular oxygen (O_2) in the atmosphere of Venus. This may indicate the absence of large-scale biological processes and a different atmospheric evolution compared to the early Earth.

The dominance of CO_2 in the atmosphere leads to a powerful greenhouse effect.

After all, such an atmosphere freely transmits visible sunlight, but effectively absorbs infrared radiation in the thermal range, which comes from the heated surface. Therefore, this heat retention and heats the surface to extremely high temperatures; the average temperature on the surface of Venus is about 737 K.

This makes it the hottest planet in the Solar System; hotter even than Mercury, which is closer to the Sun. The temperature on the surface of Venus is sufficient to melt metals such as lead and zinc. At the same time, daily fluctuations in temperature on the surface are insignificant due to the enormous heat capacity of such a dense atmosphere.

Venus is completely covered with a dense multilayer cloud cover, located at an altitude of 45 to 70 km above the surface. These clouds consist mainly of small droplets of concentrated sulfuric acid (H_2SO_4).

These clouds also contain small amounts of solid sulfur, nitrosyl sulfuric acid and phosphoric acid. These components are highly reflective; therefore, Venus's albedo is one of the highest in the Solar System, about 0.77. This makes Venus a very bright celestial object in the sky, but completely obscures the planet's surface from visible light observations. Therefore, the surface can only be studied with radar or landers.

Thin aerosol hazes lie at altitudes of 30 to 90 km. And it is sulfur-containing compounds that are crucial for understanding cloud formation. Polysulfur (forms of pure sulfur, such as S_2, S_4, S_8) is suspected of forming very small particles on which sulfuric acid droplets condense.

These polysulfur molecules are formed as a result of the photochemical destruction of sulfur dioxide (SO_2) in the atmosphere; and recent studies have revealed new photochemical pathways for their formation.

The upper part of Venus atmosphere is in a state of extremely rapid global circulation, known as “superrotation”. This superrotation begins at an altitude of about 10 km and increases steadily with altitude. The upper layers of the clouds rotate around the planet from east to west with a period of about 4 Earth days. This value is much faster than the rotation of the planet itself.

The wind speed at the cloud top at an altitude of about 65 km reaches 100 m/s.

Higher up, the wind speed decreases significantly with altitude. And near the surface, the wind speed is only a fraction of m/s.

The mechanism of superrotation is quite complex, but the interaction of thermal tides with planetary Rossby waves is thought to contribute significantly to these fast winds. This phenomenon also plays a role in the uniform distribution of heat across the planet's surface. Superrotation, driven by atmospheric waves, is the primary mechanism for efficient global heat redistribution, and explains why the surface temperature remains nearly constant day and night, despite the planet's slow rotation.

This warm layer further emphasizes that the atmosphere of Venus is a highly dynamic system with significant vertical and horizontal circulation, rather than simply a static blanket for the surface layers. This complex atmospheric circulation is crucial for understanding the planet's energy balance and the stability of the global climate.

In the upper cloud layer at altitudes of about 60 km, temperatures are relatively constant, close to 230 K. Above this level, the temperature decreases, reaching about 165 K at an altitude of 95 km, where the mesopause begins. Recent observations from the Venus Express spacecraft have revealed an unexpected warm layer on the night side of the planet at altitudes of 90-120 km, in a region considered to be the cryosphere of Venus (Fig. 1.4).

Measurements have shown that this “temperature inversion” shows a temperature increase of 30-70 K, reaching a peak at an altitude of about 100 km. It is believed that such an increase may be caused by the descent of peculiar gas “pockets” from higher altitudes in the atmosphere and their heating due to compression.

This region of the Venusian atmosphere also contains light hazes of various aerosol particles, which consist mainly of sulfuric acid and water. They are very variable and can be seen from a distance as bright areas in the planet's clouds. But so far, they are poorly studied areas of the planet, as previous space probes that descended through Venus' atmosphere only began their measurements at altitudes of 60 km and below. The historical evolution of Venus involves the evaporation of its primordial oceans, which led to the release of water vapor into the atmosphere.

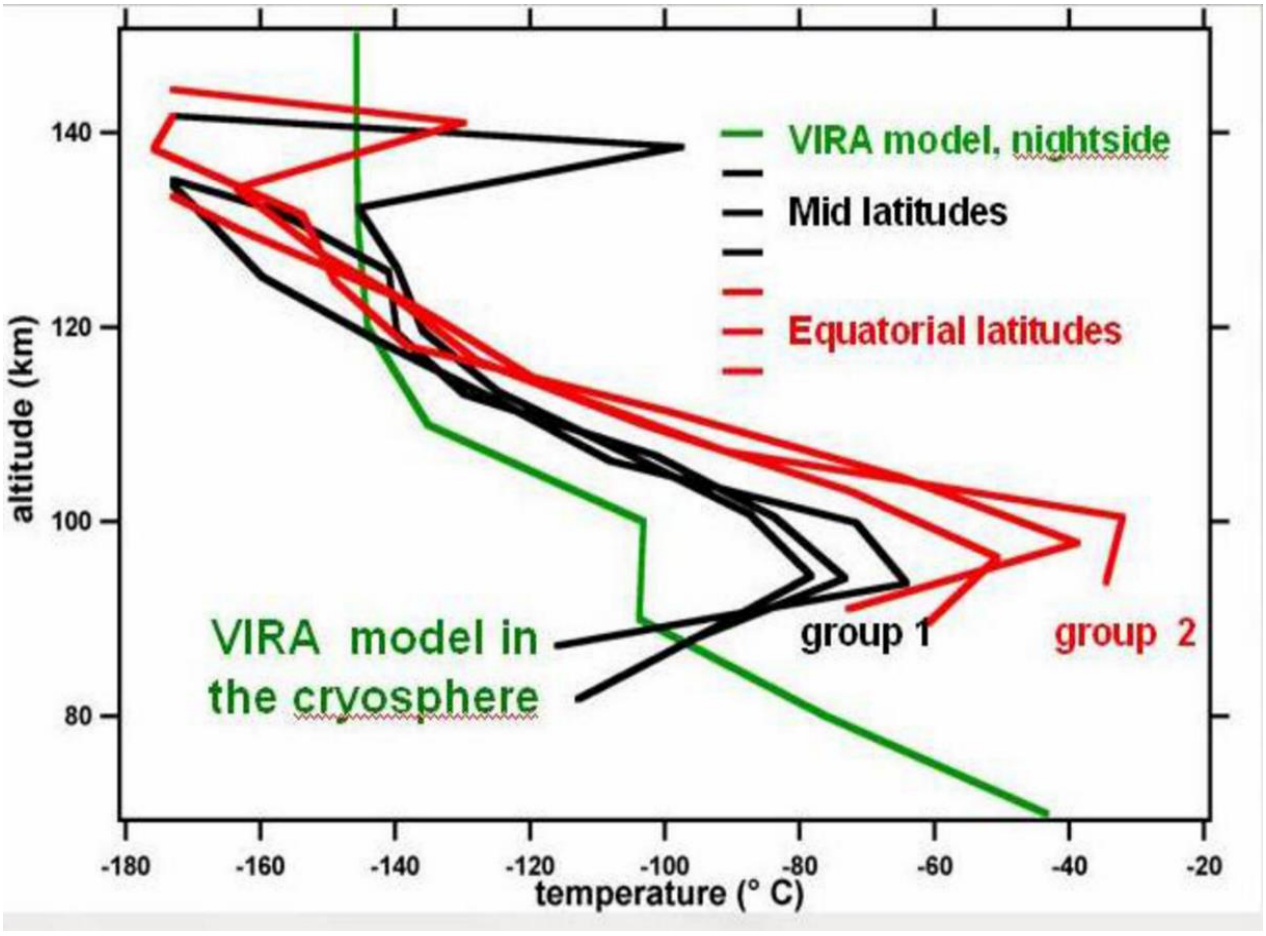


Fig. 1.4. Nighttime temperatures in the atmosphere of Venus (https://www.esa.int/var/esa/storage/images/esa_multimedia/images/2007/11/venus_-_night-time_temperatures_in_the_atmosphere/9260274-5-eng-GB/Venus_-_night-time_temperatures_in_the_atmosphere_pillars.jpg). Venus - night-time temperatures in the atmosphere.

This, in turn, accelerated the greenhouse effect. Eventually, hydrogen, after photodissociation, escaped into space, and carbon trapped in rocks sublimed into the atmosphere; its subsequent combination with oxygen led to the formation of increasing amounts of CO_2, and to the formation of the increasingly dense, heat-trapping atmosphere observed today. Venus is a prime example of what happens when the greenhouse effect goes unchecked.

Earth's atmosphere contains only a tiny fraction of CO_2 compared to Venus, but anthropogenic emissions have increased its concentration by about 30% since pre-industrial times, amplifying Earth's greenhouse effect. Studying Venus therefore

allows us to understand the consequences of extreme greenhouse effects. Venus is therefore a critical natural laboratory and a powerful warning sign for the habitability of planets and their climatic evolution.

It demonstrates how seemingly small initial differences in orbital position and internal dynamics can lead to radically divergent evolutionary paths, transforming a potentially habitable world into a hostile one. This highlights the delicate balance of planetary systems and the profound influence of atmospheric composition on surface conditions.

1.4. Comparative analysis with Earth

A comparison of Venus and Earth reveals both some similarities and fundamental differences. This makes them ideal objects for studying the factors that determine planetary evolution. As already noted, the main similarities lie in the global physical parameters: size, mass, average density and, consequently, the force of gravity. Both planets are rocky bodies with a differentiated internal structure, which includes a metallic core and a silicate mantle.

The differences are more numerous and profound. The most striking difference concerns the atmosphere and climate: Venus's extremely dense, hot, dry atmosphere, dominated by CO_2 and clouds of H_2SO_4, contrasts with Earth's moderate-pressure, nitrogen- and oxygen-rich atmosphere, with water clouds and the presence of liquid water on the surface.

Venus rotates slowly and retrogradely, while Earth rotates relatively quickly and in a direct direction. Venus has no satellites and no global magnetic field [17], unlike Earth. Geological activity on Venus also manifests itself differently: there is no terrestrial-type plate tectonics, and processes associated with mantle plumes and large-scale volcanism dominate [31, 33].

Table 1.1 below summarizes the key comparative characteristics. These tables clearly demonstrate that although Venus and Earth are very similar in size and mass, their evolutionary paths have led to the formation of very different celestial objects.

Table 1.1.

Comparative characteristics of Venus and Earth

Parameter	**Venus**	**Earth**	**Ratio (Venus/Earth)**
Average radius (km)	6051.8	6371.0	0.950
Mass (10^{24} kg)	4.869	5.972	0.815
Volume (10^{10} km³)	92.843	108.321	0.857
Average density (kg/m³)	5238	5514	0.951
Surface gravity (m/s²)	8.87	9.82 (average)	0.903
Orbital period (Earth day)	224.7	365.26	0.615
Rotation period (Earth day)	243.02 (retrograde)	0.997 (23.93 год)	~243.7
Axis inclination to orbit (deg.)	177.36 (or 2.64)	23.44	-
Average surface temperature (°C)	464	15	-
Atmospheric pressure (bar)	92 - 95	~1	~92-95
Main atmospheric components	CO_2 (>96.5%), N_2 (~3.5%)	N_2 (~78%), O_2 (~21%), Ar (~0.9%)	-
Presence of satellites	0	1 (Moon)	-
Global magnetic field	Practically no	There is (dynamo effect)	-

1.5. Relationships between the characteristics of Venus

Some key characteristics of Venus are closely related. For example, the lack of a significant global magnetic field is likely a consequence of the planet's extremely slow rotation. Even if Venus had a liquid metallic core similar to Earth's, the slow rotation would not provide a sufficiently intense dynamo effect to generate a strong field. The lack of a magnetosphere, in turn, makes Venus's atmosphere more vulnerable to interaction with the solar wind, which may have played a crucial role in the planet's loss of water during its history.

Another important relationship exists between the composition of its atmosphere and its surface temperature. Although Venus receives about twice as much solar energy

as Earth, its high albedo, due to its dense clouds, means that it absorbs less energy. However, its surface is much hotter due to the dominance of carbon dioxide (over 96%) in the atmosphere. CO_2 is a potent greenhouse gas that effectively traps thermal radiation from the surface, creating a runaway greenhouse effect. This demonstrates the critical role of atmospheric composition in determining the planet's climate and serves as an important example for understanding the greenhouse effect on Earth [14].

References:

1. Carpenter R.L. (1970) A radar determination of the rotation of Venus. Astron. J. 75(1), p. 61-66.
2. Crumpler L.S., Head J.W., Aubele J.C. (1993) Relation of major volcanic center concentration on Venus to global tectonic patterns. Science. 261(5121) p. 591-595.
3. Dyce R.B., Pettengill G.H., Shapiro I.I. (1967) Radar determination of the rotations of Venus and Mercury. Astron. J. 72(3), p. 351-359.
4. Encrenaz T., Greathouse T.K., Richter M.J., DeWitt C., Widemann T., Bézard B., Fouchet T., Atreya S.K., Sagawa H. (2016) HDO and SO2 thermal mapping on Venus. III. Short-term and long-term variations between 2012 and 2016. Astronomy & Astrophysics. 595(A74), 15 p.
5. Grinspoon D. H.; Bullock M. A. (2005) The history of water on Venus. Geochimica et Cosmochimica Acta Supplement. 69(10), p. 750.
6. Hansen V.L. (2000) Geologic mapping of tectonic planets. Earth and Planetary Science Letters. 176(3-4), p. 527-542.
7. Head J.W., Campbell D.B., Elachi Ch., et al. (1991) Venus vulcanism: initial analysis from Magellan data. Science. 252(5003), p. 276-288.
8. Hueso R., Peralta J., Garate-Lopez I., Bandos T.V., Sánchez-Lavega A. (2015) Six years of Venus winds at the upper cloud level from UV, visible and near infrared observations from VIRTIS on Venus Express. Planetary and Space Science. 113, p. 78-99.
9. Jenkins V.M., Steffes P.G., Hinson D.P. (1994) Radio occultation of the Venus atmosphere with the Magellan spacecraft. 2. Results from the October 1991

experiment. Icarus. 111(1), p. 79.

10. Komatsu G., Baker V.R. (1994) Plains tectonics on Venus: Inferences from canali longitudinal profiles. Icarus. 110(2), p. 275-286.

11. Komatsu G., Baker V.R., Gulick V.C. (1993) Venusian Channels and Valley: Distribution and volcanological implications. Icarus. 102(1), p. 1-25.

12. Kurosawa K. (2015) Impact-driven planetary desiccation: The origin of the dry Venus. Earth and Planetary Science Letters. 429, p. 181-190.

13. Masursky H., Eliason E., Ford P.G., et al. (1980) Pioneer Venus radar results: geology from images and altimetry. J. Geophys. Res. 85(A13), p. 8232-8260.

14. Morozhenko A. V., Vidmachenko A. P., Nevodovskiy P. V. (2013) Aerosol in the upper layer of earth's atmosphere. Kinematics and Physics of Celestial Bodies. 29(5), p. 243-246.

15. Morozhenko A. V., Vidmachenko A. P., Nevodovskiy P. V., Kostogryz N. M. (2014) On the Efficiency of Polarization Measurements while Studying Aerosols in the Terrestrial Atmosphere. Kinematics and Physics of Celestial Bodies. 30(1), p. 11-21.

16. Pettengill G.H., Ford P.H., Wilt R.J. (1992) Venus surface radiothermal emission as observed by Magellan. J. Geophys. Res. 97(E8), p. 13091-13102.

17. Russell C.T., Elphic R.C., Slavin J.A. (1980) Limits on the possible intrinsic magnetic field of Venus. J. Geophys. Res. 85(A13), p. 8319-8332.

18. Saunders R.S., Advidson R.E., Head III J.W. (1991) An overview of Venus geology. Science. 252(5003), p. 249-252.

19. Saunders R.S., Pettengill G.H. (1991) Magellan: Mission Summary. Science. 252(5003), p. 247-249.

20. Saunders R.S., Spear A.J., Allin P.C., et al. (1992) Magellan mission summery. J. Geophys. Res. 96(A4), p. 5457-5468.

21. Solomon S.C., Head J.W., Kaula W.M., et al. (1991) Venus tectonics: Initial analysis from Magellan. Science. 252(5003), p. 297-312.

22. Vidmachenko A. P. (2012) The magnetic field of planets, satellites and asteroids. Astronomical School's Report. 8(2), p. 136-148.

23. Vidmachenko A. P. (2014) Study of Earth-like planets. 16 International scientific

conference Astronomical School of Young Scientists, held May 29-31, 2015 in Kirovograd, Ukraine. The program and abstracts. P. 12-13.

24. Vidmachenko A. P. (2018) Modern volcanic activity on the Moon. 20 International scientific conference Astronomical School of Young Scientists. May 23-24, 2018. Uman, Ukraine, p. 5-7.

25. Vidmachenko A. P. (2023) Methods of obtaining information about the relief of Venusian surface. Proceedings of VI International Scientific and Practical Conference. Science and technology: problems, prospects and innovations. (March 16-18, 2023). Chapter 34. CPN Publishing Group, Osaka, Japan, p. 205-214.

26. Vidmachenko A. P. (2023) Thermal properties of the surface of Mars. Proceedings of VII International Scientific and Practical Conference. Progressive research in the modern world (March 29-31, 2023). Chapter 42. P. 243-252.

27. Vidmachenko A. P., Morozhenko O. V. (2013) Textbook Comparative Planetology. Main Astronomical Observatory of NAS of Ukraine Press, Kyiv, Ltd. Dia, -552 p.

28. Vidmachenko A.P., Morozhenko O.V. (2014) The study Earth-like planets using spacecraft. Astronomical School's Report. 10(1), p. 6-19.

29. Vidmachenko A. P., Morozhenko O. V. (2014) The physical characteristics of surface Earth-like planets, dwarf and small (asteroids) planets, and their companions, according to distance studies. Main Astronomical Observatory NAS of Ukraine, National University of Life and Environmental Sciences of Ukraine. Kyiv, Publishing House "Profi". - 388 p.

30. Vidmachenko A. P., Morozhenko O. V. (2019) Physical parameters of terrestrial planets and their satellites. Kyiv, Editorial and Publishing Department of NULES of Ukraine. -468 p.

31. Vidmachenko A. P., Steklov A. F. (2022) Features of volcanic structures on Venus. Proceedings of the 9th International scientific and practical conference. Modern directions of scientific research development. BoScience Publisher. Chicago, USA. 23-25.02.2022. P. 195-204.

32. Vidmachenko A. P., Steklov A. F. (2022) Modern volcanism on Venus.

Proceedings of the 7th International scientific and practical conference. Innovations and prospects of world science. (March 2-4, 2022). Chapter 19. Perfect Publishing. Vancouver, Canada. P. 119-129.

33. Vidmachenko A. P., Steklov O. F. (2023) Features of volcanic activity on the surface of Venus. Basics of learning the latest theories and methods. Proceedings of the IX International Scientific and Practical Conference. (March 07 – 10, 2023). Chapter 7. Boston, USA. International Science Group, p. 39-46.

34. Vidmachenko A. P., Steklov A. F. (2023) Signs of modern volcanism on Venus. Proceedings of II International Scientific and Practical Conference. European scientific congress. (March 20-22, 2023). Chapter 37. Barca Academy Publishing, Madrid, Spain, p. 161-167.