

The goddess of love and beauty hides her face behind a thick veil of clouds. Researchers thus have to use special instruments to tackle Venus - like the *Venus Monitoring Camera* (see page 28), for example.



# The Blazing Hell Behind the Veil

The first European Venus probe has been orbiting our neighbor in the solar system for more than three years: *Venus Express* has a bizarre inferno in its sights. **Dmitriy Titov** from the **Max Planck Institute for Solar System Research** in Katlenburg-Lindau coordinates the mission planning and data analysis.

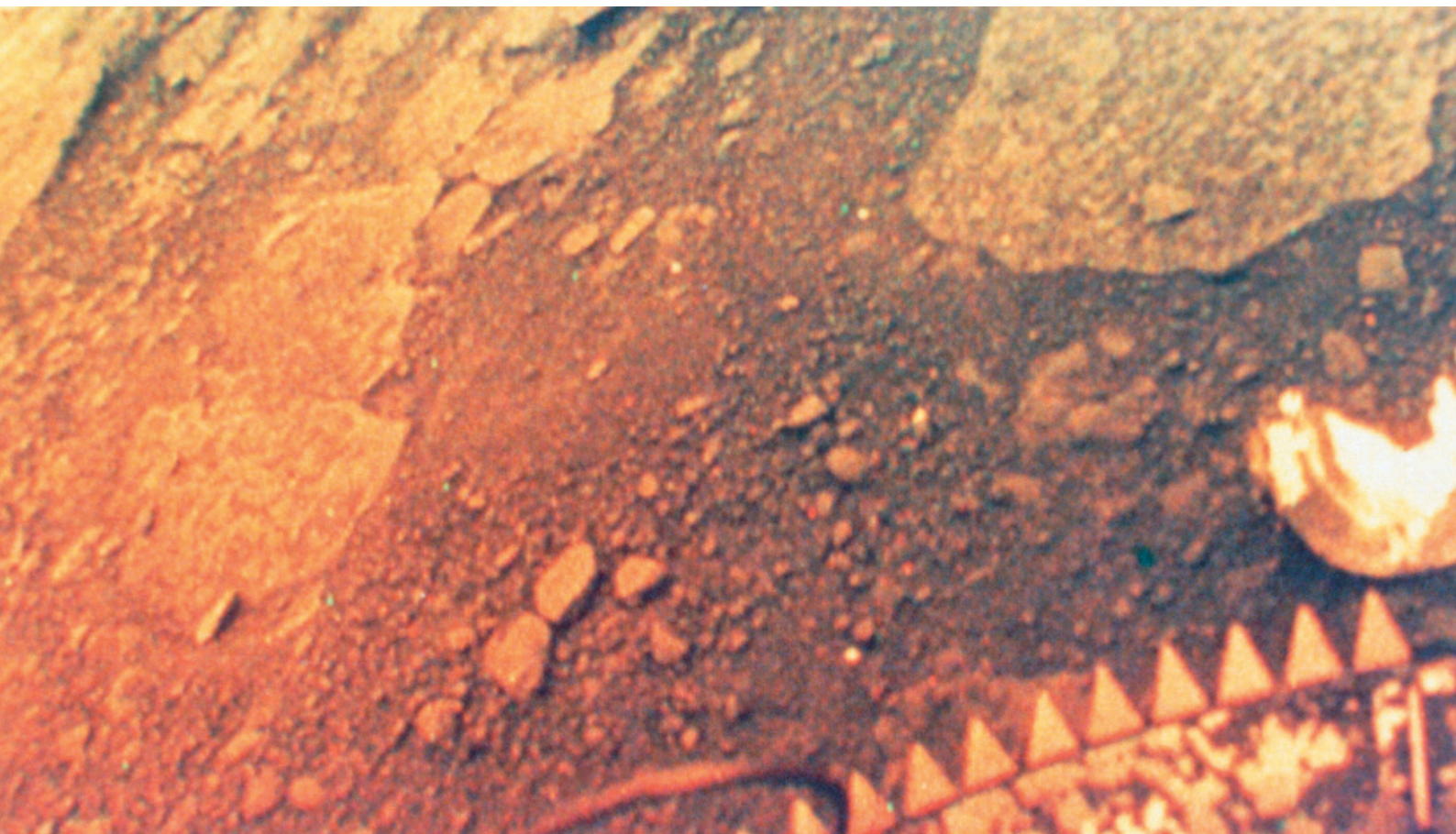
TEXT **THORSTEN DAMBECK**

If we look at the bare numbers, Venus should really be something like Earth's twin. Its diameter measures 12,100 kilometers, which is 95 percent of that of our planet. The same applies to its mean density (94 percent) and its mass (82 percent). Yet the planet, which is 108 million kilometers from the Sun (Earth: 150 million kilometers) is completely different. Corrosive clouds of sulfuric acid hang in the air on Venus – an almost impenetrable veil behind which our neighbor hides from the far too inquisitive eyes of science.

This explains why astronomers were long unable to detect anything with their telescopes in the featureless yellow of the planet's disk. This dearth of information stimulated researchers' imaginations: does it have any deserts, similar to the Sahara, or even tropical rain forests? The first space probes put an early end to such speculations. In a flyby in 1962, *Mariner 2* already made two important findings that put the supposedly twin planet in sharp contrast with Earth. First, *Mariner* detected almost no water in the air surrounding

Venus, and second, the US probe reported lethal temperatures on the surface. The hypothesis of the Venusian jungle quickly died.

In 1967, *Venera 4* sent a weather report directly from the hot gaseous envelope. The Soviet probe confirmed the existence of an atmosphere rich in carbon dioxide. From the 1970s onward, several Soviet landers even sent panorama photos from the surface and increased the accuracy of the weather data. The air pressure at the surface is 92 bar – on Earth, one would



## A MONITOR FOR VENUS

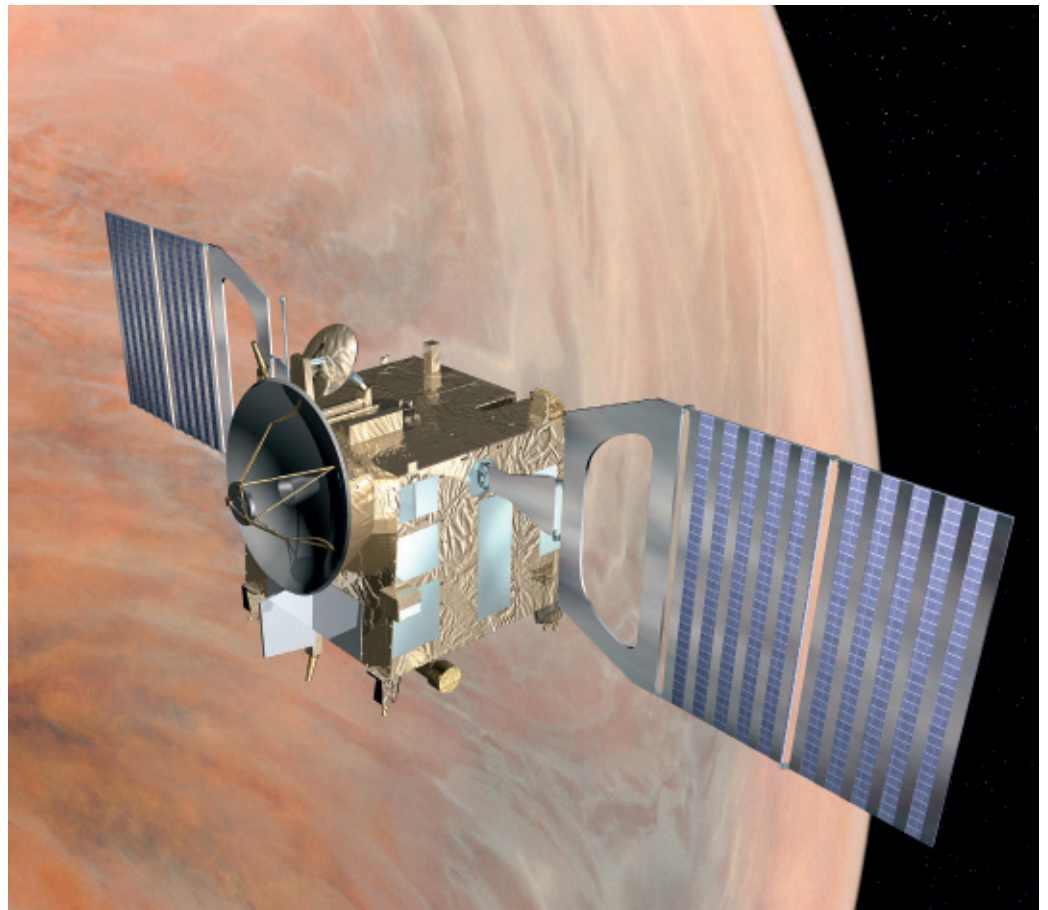


The project to build the *Venus Monitoring Camera* (VMC) was spearheaded by the Max Planck Institute for Solar System Research in collaboration with the Institute for Planetary Exploration (DLR) in Berlin and the Institute of Computer and Network Engineering at the Technical University in Braunschweig. The compact camera with a weight of less than 1.8 kilograms has a field of view of 17.5 degrees; at the most remote point of its elliptical orbit,

A treasure chest for planetologists: The *Venus Monitoring Camera* provides pictures of Earth's neighbor in the ultraviolet up to the near infrared spectral range.

Venus fills just about the entire image. The parts of the orbit close to Venus are intended for detailed studies. The resolution varies between 200 meters and 50 kilometers, depending on the distance.

Moving parts such as filter wheels were largely avoided in order to keep the design simple and unsusceptible to technical problems. Images of Venus in four different wavelengths, from UV and visible light to infrared, are simultaneously projected onto the same CCD sensor. Each wavelength uses a certain quadrant of the detector. Even before the photos are transmitted to the board computer, the image data is subjected to initial image processing in the camera.



left | Temperatures of around 460 degrees Celsius and the same pressure that occurs 900 meters below sea level make survival difficult even for a robot. That's why views of Venus's surface are rare. The picture on the left was taken by the *Venera 13* Russian space probe.  
 right | Max Planck researchers play a crucial role in analyzing the data from the European scout *Venus Express*.

have to dive to sea depths of more than 900 meters to encounter such pressures. In the stony Venusian desert, the temperatures reach 457° Celsius on average – lead would immediately melt here. And Venusian clouds race at Formula 1 speeds across the overcast sky.

**HOW DID EARTH'S NEIGHBOR COME TO BE A HOTHOUSE?**

Although more than 30 probes have already reached Venus, many questions remain unanswered: What drives the stormy Venus atmosphere? Why does the atmosphere rotate 60 times faster than the planet itself? Are there active volcanoes still hidden under the dense clouds? And the key question is still

open: Why did Venus follow its strange development path to become the hothouse it is today?

*Venus Express*, the first scout of the European Space Agency (ESA), has been orbiting Earth's neighbor since April 2006. Six instruments including cameras are in action on board to find answers to these questions; they bear witness to the truly European nature of the mission. The Italo-French *VIRTIS* is an imaging spectrometer – in other words, it also works as a camera. It studies the lower atmosphere and the surface. The chemical composition of the gaseous envelope is analyzed by the *SpicaV/Soir* spectrometer under the direction of French and Belgian researchers with strong Russian participation. It uses the

light of the Sun and individual stars as it travels through the Venusian atmosphere to probe its structure and composition.

**93 KILOS OF EXPERIMENTS**

Researchers from Germany probe the ionosphere, atmosphere and surface with the VeRa radio experiment. The Swedish experiment *ASPERA* studies the interactions between the upper atmosphere and the solar wind. Two new developments are also included: the Austrian magnetometer *MAG* and the German wide-angle camera *VMC*, which was developed under the leadership of the Max Planck Institute for Solar System Research (see page 28). The payload totals 93 kilograms. >

Computer graphics: ESA

This mission has advanced the institute in Katlenburg-Lindau to a center for research into our sister planet. Pictures and measurement data land on Dmitriy Titov's desk on a daily basis. The Russian physicist coordinates the mission planning and the analysis of the scientific data.

*Venus Express* orbits the planet on a strongly elliptical orbit once every 24 hours, its altitude varying between 250 and 66,000 kilometers. "The elongated orbit means that the instruments and cameras look especially at Venus's southern hemisphere," says Titov. The observation of the atmosphere is facilitated by the fact that the planet shows many details in the ultraviolet (UV), which is not the case in visible light.

Although this has been known for a long time, the planetologists still puzzle over which substance causes this uneven absorption of UV radiation. "The unknown substance is probably hidden in the sulfuric acid droplets of the clouds," explains Dmitriy Titov. In any case, the presence of mysterious material is also a great help, because "it makes it easy to follow the dynamic processes in the Venusian atmosphere in UV light."

How is Venus's gaseous envelope structured on a large scale? What changes are occurring there? The *Venus*

*Monitoring Camera* from Katlenburg-Lindau provides the answers. Its photos of the southern hemisphere show three very distinct zones in the Venusian cloud cover. Insolation is strongest near the equator; this is where turbulent convection currents transport the dark UV absorber from lower layers of the atmosphere upward. The images of these latitudes are thus dominated by dark markings in the UV.

### CLOUDS REFLECT A LARGE FRACTION OF SOLAR RADIATION

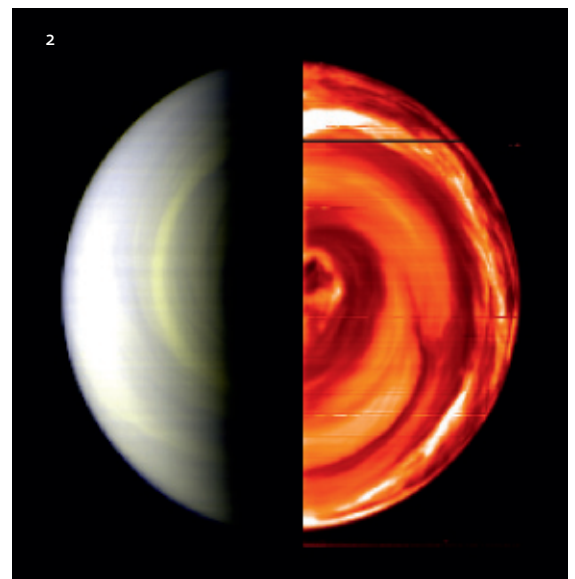
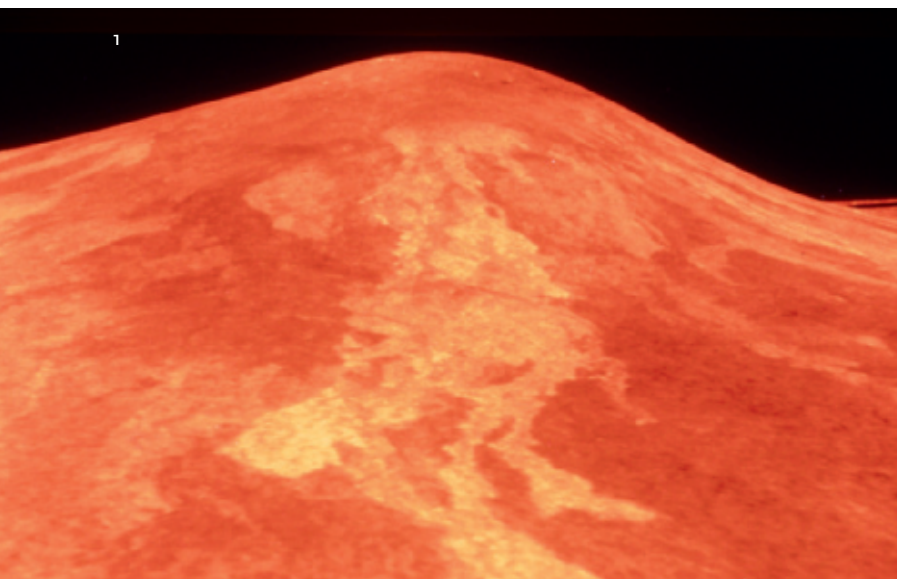
Things are different further south, beyond 40 degrees south latitude. There, the UV "eyes" of *Venus Express* see elongated, streaky cloud formations that suggest a more ordered, more laminar atmospheric current. They turn into a ring of bright, almost unstructured clouds that encircle the entire planet between 50 and 70 degrees south latitude. Aerosols presumably reflect a large fraction of the sunlight here before it reaches the UV absorber. This zone can be visualized as a stream of relatively cool Venusian air that circles the polar area.

The polar region itself has been offering the researchers an impressive spectacle since the beginning of the

mission. A huge vortex of clouds rages there that rotates around the south pole in two and a half days and was discovered by the predecessors of *Venus Express*. Never before have scientists been able to study it in so much detail. Sometimes it resembles a hurricane on Earth. Sometimes it seems to have two centers, so that earlier Venus researchers had nicknamed it a "polar dipole." "Within a short time, the eye of the hurricane changes its appearance to such an extent that it is sometimes no longer possible to make out a dipole," says Max Planck researcher Titov.

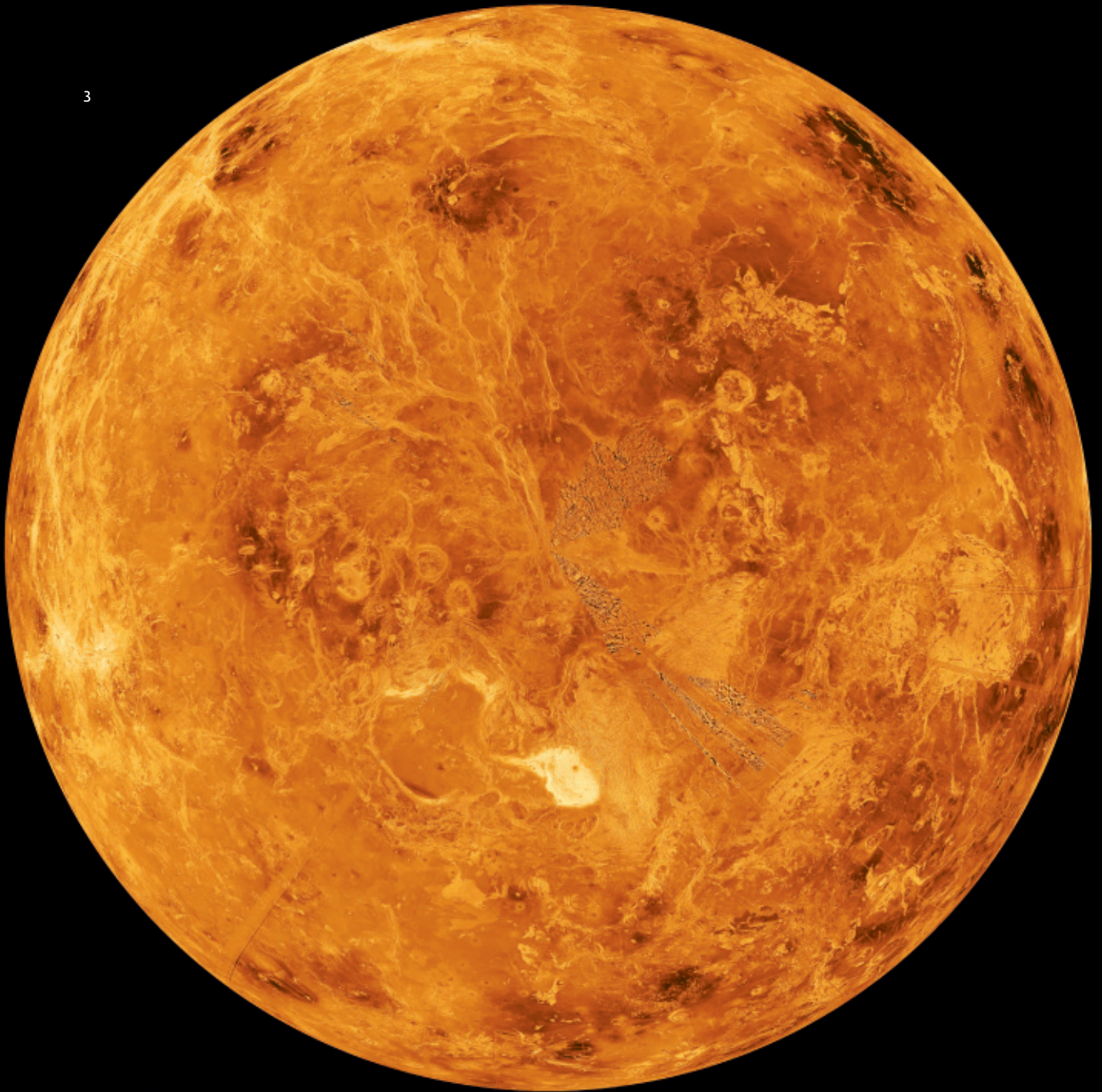
The large-scale structure of the gaseous envelope over the southern hemisphere is typical of the whole planet, because the atmosphere in the north has a similar structure. The special orbit of the satellite makes the northern hemisphere suitable for detailed studies. For example, Katlenburg's camera was able to take pictures of wave trains – wave-like cloud structures that exist in a similar form on Earth. Little by little, even the mysterious UV absorber is now being forced to surrender its secret.

"By comparing the UV and infrared photos of such clouds, we were able to confirm with our cameras several times that the unknown UV absorber is also slightly absorbent in the near infrared,"

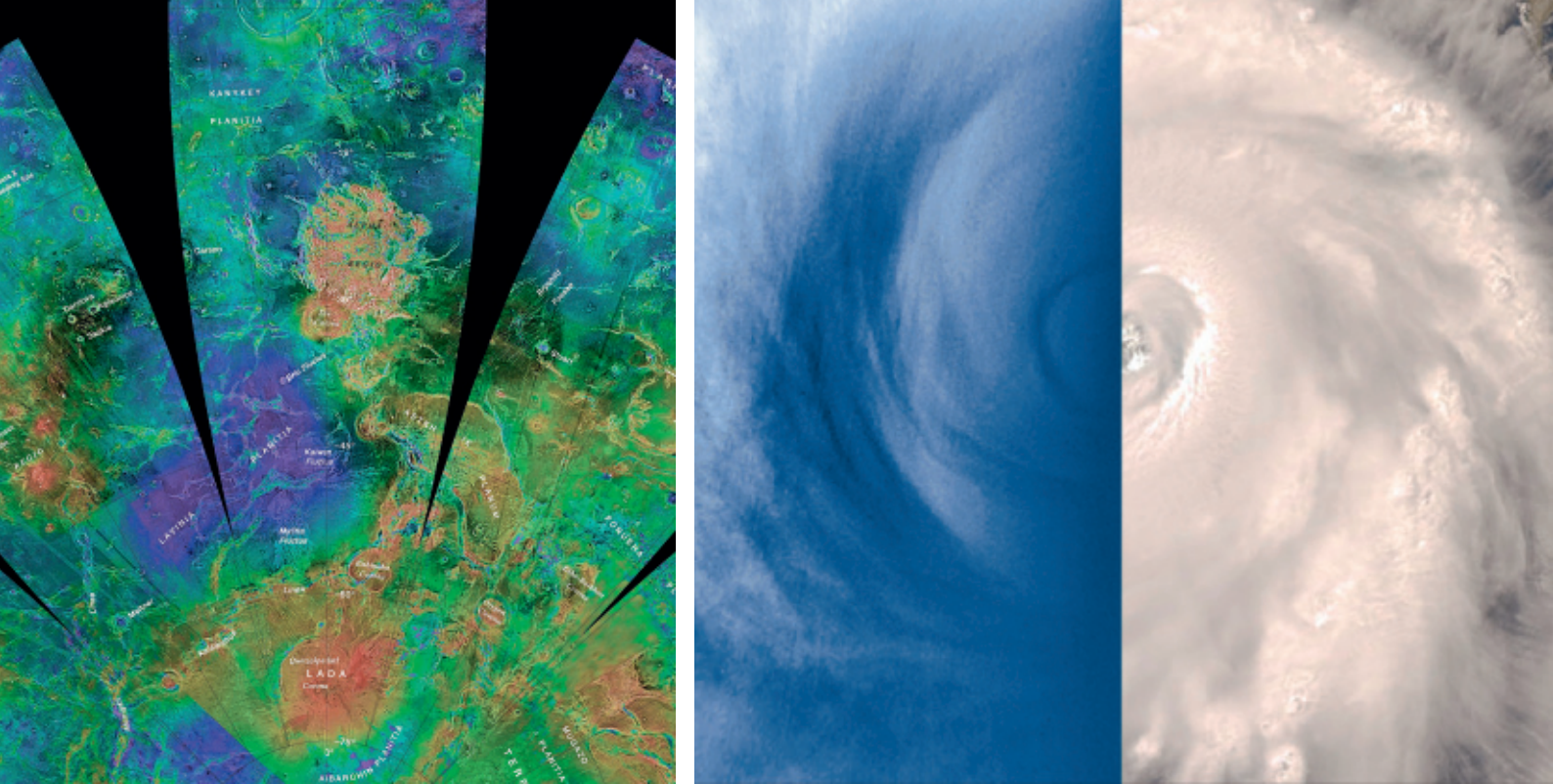


Photos: Magellan Project/JPL/NASA (left), ESA/MPS

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- 1 | The Venusian landscape was formed by volcanoes, such as the approximately 2,000-meter-high Sif Mons. Planetologists are now studying the geological history.
- 2 | Two views of Venus's cloud-covered south pole. The left part of the image shows the gaseous envelope during the day in reflected sunlight, while the part on the right reveals it at night in thermal radiation. Both views show traces of a huge whirlwind.
- 3 | Venus without its veil: Such views of the naked planetary globe are possible only with radar instruments.



left | Part of the southern hemisphere. The color scheme is based on altitude measurements: blue areas indicate the low-lying regions of Venus, green areas the central regions, and the highest areas are shown in ochre and brown to orange shades.

right | Sisters in turmoil: The image on the left shows a whirlwind on Venus, the one on the right, for comparison, Hurricane Frances on Earth. The latter was enlarged by about a factor of 5 to make both to scale.

explains Wojciech Markiewicz, the man in charge of the camera experiment at the Max Planck Institute for Solar System Research. His colleague Titov adds: “Although many substances are being discussed as the cause of the UV absorption, it may simply be a special modification of sulfur.”

Although the approximately 25-kilometer-thick blanket of cloud obstructs the view to the surface in the visible wavelengths of the spectrum, the camera can still pick up details on the ground on the nightside. This happens as follows: Even on its nightside, the surface of Venus has a temperature of over 400°C, which means that the surface rocks emit heat radiation in the invisible infrared. Part of this radiation can get through the cloud cover in narrow spectral intervals called transparency windows. “Although the resolution of the photos is severely limited by

multiple scattering in the clouds, we can nevertheless learn a lot about the surface,” explains Markiewicz.

### GLOBAL VOLCANIC ERUPTIONS POSE A MYSTERY

These photographic mosaics composed of more than 1,000 individual images show the temperature variations in Venus’s landscapes. Just like on Earth, the valleys are warmer than the mountains, which rise to heights of up to 12 kilometers. The temperatures on a 5-kilometer summit are 40 degrees below those in the plain, for example. The planetologists also want to use such studies to learn more about the minerals in Venus’s crust. According to conventional theories, the surface was created by planet-wide volcanic eruptions. This mysterious global catastrophe ravaged Venus some 500 to 600 million years ago.

The Magellan probe, which charted around 98 percent of Venus’s surface, discovered large-scale volcanism back in the 1990s. The researchers counted about 1,000 volcanoes on its radar images. If Venus’s volcanoes are still belching out fire, the VMC camera and the Visible and Infrared Thermal Imaging Spectrometer (*VIRTIS*) will be able to find them. The search continues.

But back to the sky above Venus, the real subject of the research mission. The planetologists use photos of individual cloud formations taken by VMC and *VIRTIS* to measure wind conditions in the stormy atmosphere. Movements occurring at different altitudes of the multilayered cloud system can thus be detected in the different wavelengths. This made it possible to carry out the first comprehensive 3D studies of Venus’s storms: at an altitude of 66 kilometers, the clouds race at up to 370

kilometers per hour, or as much as three times faster than hurricanes on Earth. Lower down, between 45 and 47 kilometers above the surface, speeds of 210 kilometers per hour can still be measured.

The researchers want to use such studies to find out what drives the “super-rotation” of the Venusian atmosphere. This rapid movement causes the higher gaseous envelope to circle the entire planet in just four Earth days. It moves in the same direction as Venus itself rotates. A Venusian day, on the other hand, is unusually long: the unequal sister planet takes 243 Earth days to rotate about its own axis – nearly 19 Earth days longer than it takes to complete an orbit of the Sun. A Venusian day thus lasts longer than a Venusian year.

The snail’s pace of Venus’s rotation about its own axis is probably one of the reasons for another important difference between this planet and the Earth: Venus has no global magnetic field. This fact probably also influenced the history of its climate, in particular the fate of the water, which the young Venus received as a dowry at the time of planet formation in the same way as Earth and Mars. Nor, incidentally, are there any plate tectonics on Venus.

In contrast to these two terrestrial planets, Venus is now extremely dry. Although water is present as a trace gas in the Venusian atmosphere, it makes up only 30 ppm (parts per million). If all of the water currently present on Venus were to collect on the ground and spread across the surface, the resulting “ocean” would be a mere three centimeters deep. The comparison value for Earth is nearly three kilometers.

An indication of Venus’s wetter younger years was already provided by the American *Pioneer-Venus* probe, which reached its destination three decades ago. Its mass spectrometer investigated the isotopes of hydrogen in the droplets of the acidic Venusian clouds. In addition to the normal hydrogen (chemical symbol: H), *Pioneer* also measured the concentration of deuterium (D), known as heavy hydro-

gen. Deuterium accounts for only 0.015 percent of the hydrogen fixed in the water of Earth’s oceans.

However, the measurements of *Pioneer-Venus* showed that the ratio of D to H on Venus is shifted by about a factor of 120 toward deuterium. This is because, since its formation, Venus has disproportionately lost the lighter H atoms into space. The heavier deuterium preferentially remained trapped in the gravitational field – a gradual enrichment in favor of this isotope. The D surplus, which *Venus Express* confirmed, thus points to a higher quantity of water when Venus was young.

#### ULTRAVIOLET LIGHT RAGES IN THE UPPER ATMOSPHERE

The loss of atmospheric gases continues to this day. With the *ASPERA* instrument (Analyzer of Space Plasma and Energetic Atoms), *Venus Express* has been able to prove the loss of hydrogen and oxygen, two H atoms being lost for every O atom – the same ratio as in the water molecule. Markus Fränz, who analyzes the *ASPERA* data at the institute in Katlenburg, does not believe in a coincidence: “Physical models explain that H<sub>2</sub>O is broken up and ionized in the upper atmosphere by ultraviolet sunlight. The H ions and O ions can escape into space. This loss occurs primarily on the nightside of the planet.”

Escaping H ions have since been measured on the dayside, as well. The researchers still have to discover which processes in the past and present have been driving the atoms out of the planets’ gaseous envelopes. The main suspect is the solar wind, a stream of charged particles that are emitted by the Sun and that can accelerate atoms and ions so strongly that they leave the gravitational field. Fränz says: “At the moment, the Sun’s activity is at its low point, and this also applies to the solar wind. But both change in an 11-year cycle. We want to study the erosion of the atmosphere in the coming years as the Sun’s activity increases.”

It is still too early to give certain answers to the key questions in the research into Venus. Nevertheless, Dmitry Titov risks a provisional answer: Venus is not as mysterious as it appeared in the early years of planetary research. “In the beginning, it was similar to Earth. But its stock of carbon was not bound in carbonaceous rock by the action of the oceans, as it was on Earth. The carbon remained in the atmosphere as CO<sub>2</sub>. This set in motion a self-amplifying greenhouse effect.”

In the rising heat, all the water evaporated and was lost in space. Similar processes are also known on Earth, but on Venus they have amplified to a bizarre level. Corroborating this idea with long-term measurements is the task for the coming years – a great deal of work for *Venus Express* and its successor probes, which are already in the planning stages. ◀

#### GLOSSARY

##### Isotope

Atoms whose nuclei have the same number of protons (and therefore identical nuclear charges) but a different number of neutrons.

##### Plate tectonics

The visible expression of the Earth’s plate tectonics is the movement of the lithospheric plates, commonly referred to as continental drift. Plate tectonics causes the formation of folded mountains and such phenomena as volcanism and earthquakes.

##### Greenhouse effect

Energy-rich UV and visible radiation from the Sun passes through a planet’s atmosphere while long-wavelength heat radiation from the lower atmosphere, which is supposed to cool it, remains trapped due to the presence of absorbing gases and clouds. On Earth, it is primarily water vapor and clouds in the atmosphere that prevent the heat from escaping into space, resulting in a surface temperature increase by around 40 degrees Celsius. On Venus, the greenhouse effect is much stronger.