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VENUS EXPRESS

Welcome to the Cryptic Planet

European Space Agency
Agence spatiale européenne

About ESA

The European Space Agency (ESA) was formed on 31 May 1975. It currently has 15 Member States: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

The ESA Science Programme has launched a series of innovative and successful missions. Highlights of the programme include:

Cassini-Huygens is one of the most ambitious planetary exploration efforts ever attempted. After a seven-year journey, the Cassini orbiter began studying the Saturnian system in great detail, and the Huygens probe descended onto Saturn's giant moon Titan, unveiling an amazing cold but Earth-like world.

Cluster, which is a four-spacecraft mission to investigate in unprecedented detail the interaction between the Sun and the Earth's magnetosphere.

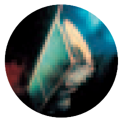
Double Star, following in the footsteps of the Cluster mission, with its two spacecraft it studies the effects of the Sun on the Earth's environment.

Giotto, which took the first close-up pictures of a comet nucleus (Halley) and completed flybys of Comets Halley and Grigg-Skjellerup.

Hipparcos, which fixed the positions of the stars far more accurately than ever before and changed astronomers' ideas about the scale of the Universe.

Hubble Space Telescope, a collaboration with NASA on the world's most important and successful orbital observatory.

Integral, which is the first space observatory that can simultaneously observe celestial objects in gamma rays, X-rays and visible light.



ISO, which studied cool gas clouds and planetary atmospheres. Everywhere it looked, it found water in surprising abundance.

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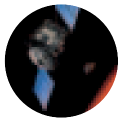


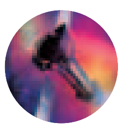
Mars Express, Europe's first mission to Mars, which consists of an orbiter and a lander looking for signs of water and life on the Red Planet.

Rosetta, Europe's comet chaser, will be the first mission to fly alongside and land on a comet, probing the building blocks of the Solar System in unprecedented detail.

SMART-1, Europe's first mission to the Moon, which will test solar-electric propulsion in flight, a key technology for future deep-space missions.

SOHO, which is providing new views of the Sun's atmosphere and interior, revealing solar tornadoes and the probable cause of the supersonic solar wind.

Ulysses, the first spacecraft to fly over the Sun's poles.



XMM-Newton, with its powerful mirrors, is helping to solve many cosmic mysteries of the violent X-ray Universe, from enigmatic black holes to the formation of galaxies.

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Venus Express

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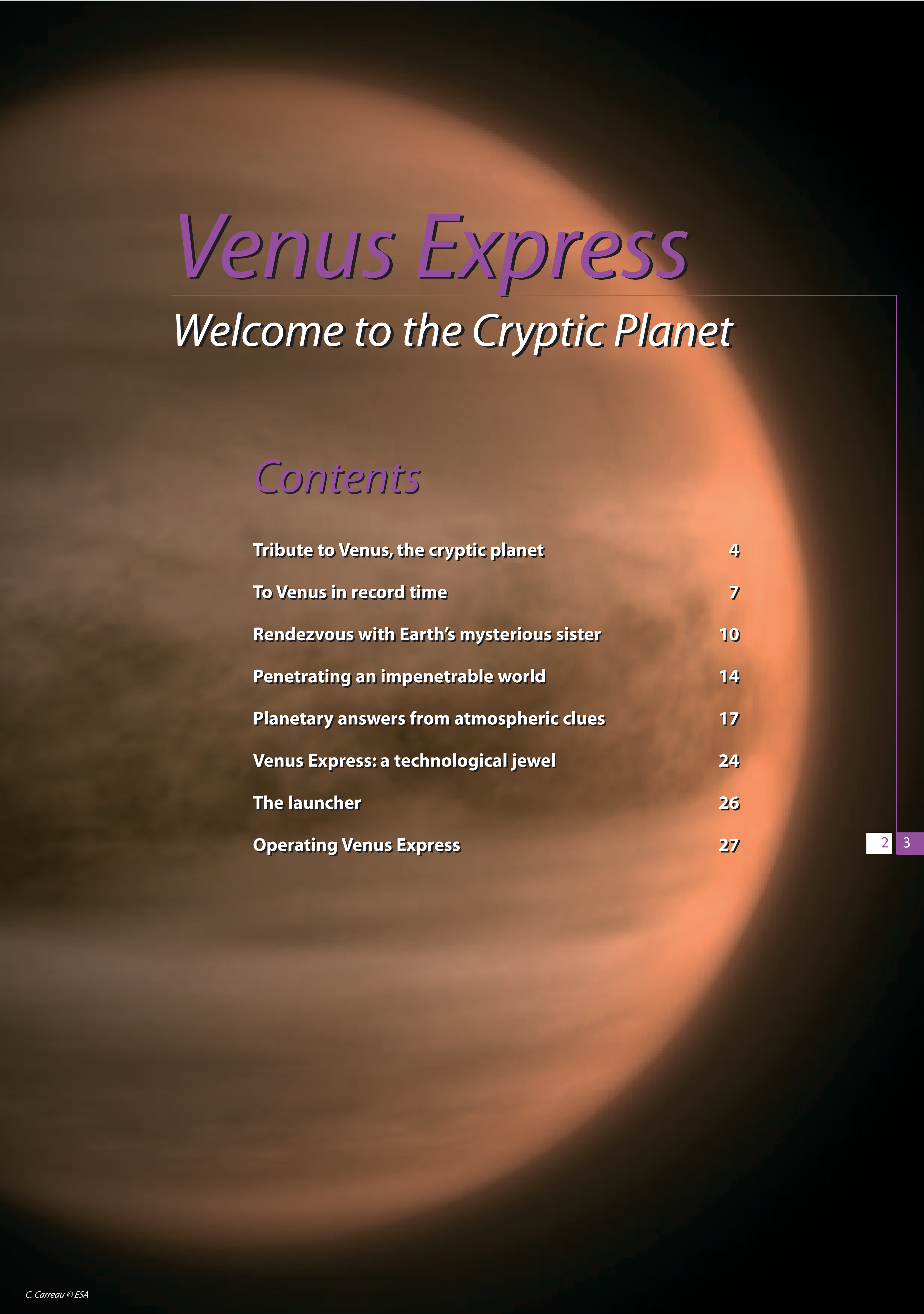


C. Carreau © ESA

Tribute to Venus, the cryptic planet

Venus, the 'Morning Star', the second closest planet to the Sun after Mercury and our closest planetary neighbour, has fascinated mankind from the earliest times. Named after the Roman goddess of love and beauty, it is the third brightest object in the sky after the Sun and the Moon.

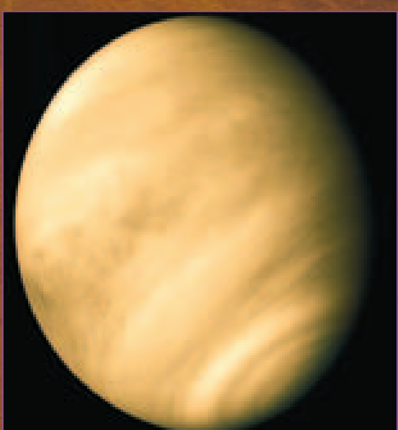
Since the beginning of the space era, Venus has been an attractive subject for planetary science and it was one of the first natural targets to explore, due to its proximity to Earth – half as far as Mars at closest approach. Very similar to Earth in size and mass, Venus was expected to be very like to our own planet when the first Russian and American space probes approached it in the early 1960s and started returning the first data about its atmosphere.

Observers soon realised that Venus is an entirely different, exotic and inhospitable world, hidden behind a curtain of dense clouds of noxious gases. It has an atmosphere composed mainly of carbon dioxide, with a crushing surface pressure and burning-hot temperatures. The question then arose: Why did a planet apparently so similar to Earth evolve in such a radically different way over the last four thousand million years?

By the mid-1990s, many ground observatories and more than twenty spacecraft had attempted to explore Venus. A set of orbiters and descent probes - the Soviet Venera series and the Vega balloons and landers, the US Mariner, Pioneer Venus and Magellan missions - tried to penetrate this hostile world to add pieces to the big jigsaw that Venus represented for scientists.

Many missions were lost, many landers were destroyed by the high pressure and temperature of the Venusian atmosphere while trying to gather the first information about the planet. For years, the dense atmosphere with its thick cloud cover prevented scientists from seeing what lay below and from understanding the nature of the Venusian surface. Only when modern radar imaging systems became operational on space probes and at ground observatories did the first glimpses of the real face of Venus start to emerge.

NASA's Pioneer Venus mission (1978), the Soviet Union's Venera 15 and 16 missions



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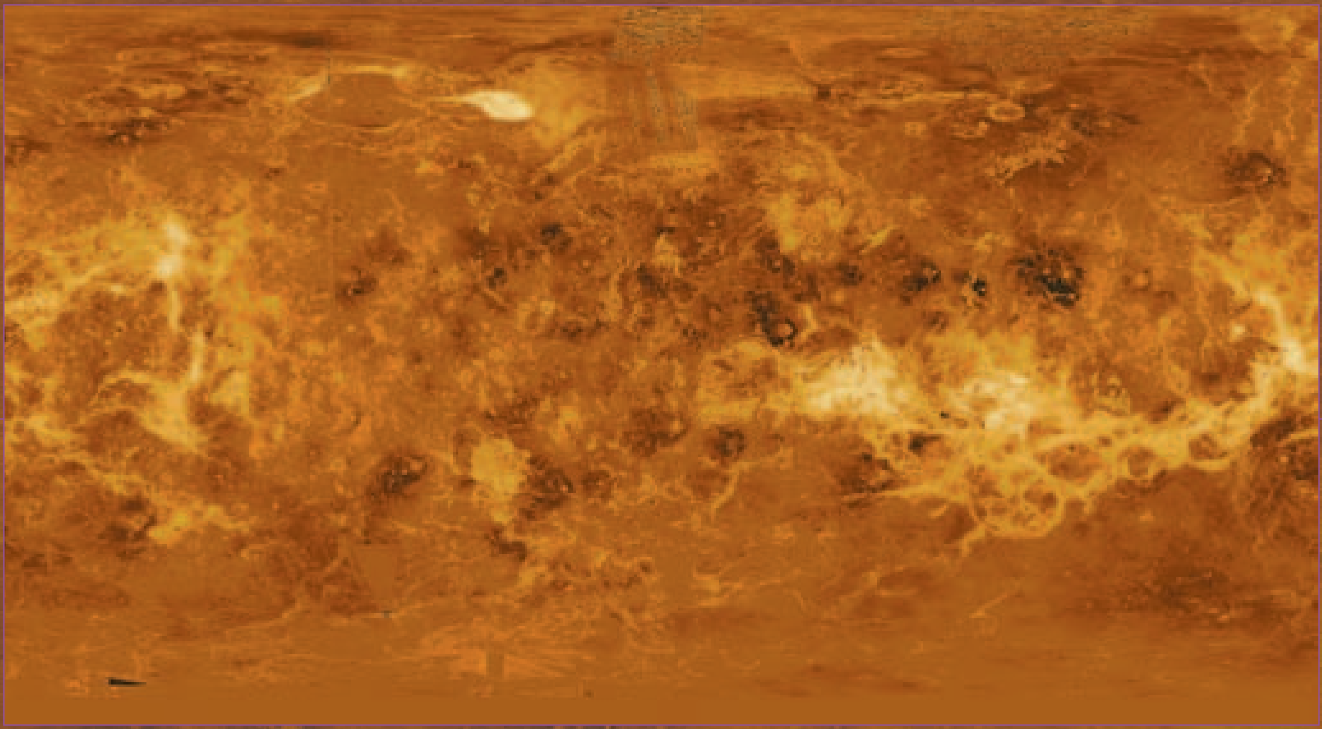
Thick cloud coverage as shown by this Mariner 10 mosaic image, taken in February 1974.

© NASA

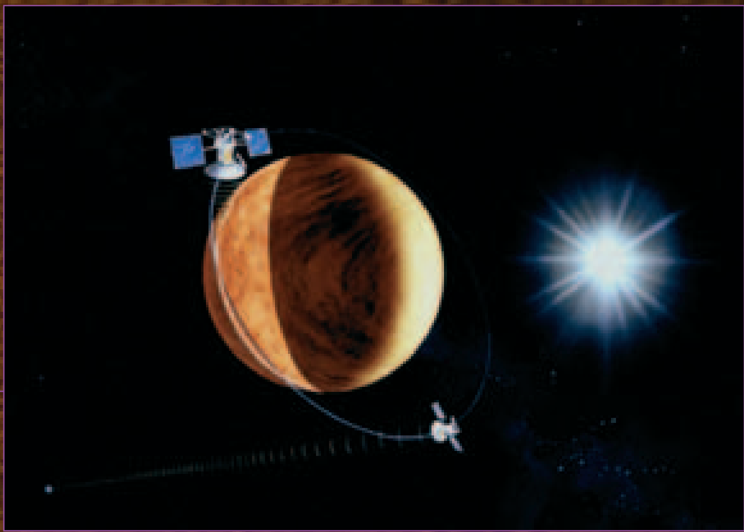
Venera 14 lander images of the surface of Venus taken in March 1982. The lander survived for 60 minutes.



Composite radar image obtained by the Magellan mission, displaying the whole Venusian surface. At the top, left of centre, the bright region is Maxwell Montes, the highest mountain range on Venus. Extending along the equator to the right of centre is Aphrodite Terra, a large highland region on Venus.

Major Historical Missions to Venus

Mariner 2 (USA, 1962)	Fly-by	First spacecraft at Venus. Closest distance 35 000 km. No magnetic field detected.
Venera 4 (USSR, 1967)	Atmospheric probe	First probe to return data about atmospheric composition (90-95% carbon dioxide), surface temperature (500°C) and pressure (75 bar). It was crushed by the pressure before it reached the surface.
Venera 5 & 6 (USSR, 1969)	Atmospheric probes	It detected the presence of atmospheric nitrogen (2.5%) and oxygen (~4 %). It was crushed by atmospheric pressure a few kilometres before reaching the surface.
Venera 7 (USSR, 1970)	Lander	The first successful soft landing of a spacecraft on another planet. It measured a surface temperature of 475°C and a surface pressure of 90 bar.
Venera 8 (USSR, 1972)	Lander	The first to measure wind speeds as it descended through the atmosphere (from 100 m/s above 48 kilometres to 1 m/s below 10 kilometres). Surface composition measured by gamma-ray spectrometer.
Mariner 10 (USA, 1974)	Fly-by spacecraft	Flew by Venus in 1974 on its way to Mercury. It was the first spacecraft to have an imaging system, recording circulation in the Venusian atmosphere and the temperature of the cloud tops to be -23°C.
Venera 9 & 10 (USSR, 1975)	2 orbiters with 1 lander each	First spacecraft in orbit around Venus. They photographed the clouds and looked at the upper atmosphere, while the landers returned the first black and white panoramic images of the surface.
Pioneer Venus 1 & 2 (USA, 1978-1992)	1 orbiter and 4 atmospheric probes	Longest mission in orbit around Venus (14 years). First orbiter to conduct radar mapping of the surface. Radio bursts possibly caused by lightning were detected. No magnetic field was detected. Over a decade, it recorded a 90% decrease in sulphur dioxide, possibly indicating a large volcanic eruption just before the orbiter's arrival. The probes measured structure, composition and cloud properties down to 12 km altitude.
Venera 11 & 12 (USSR, 1978)	Fly-by, 2 landers	During the descent, the landers investigated the structure and composition of the atmosphere and clouds, measured scattered solar radiation. Atmospheric dynamics were studied by Doppler tracking.
Venera 13 & 14 (USSR, 1982)	Fly-by, 2 landers	The landers returned the first colour panoramic views of the surface. They conducted soil analysis and found leucite basalt, a rock type rare on Earth, and tholeiitic basalt similar to that found at mid-ocean ridges on Earth.
Venera 15 & 16 (USSR, 1983)	2 orbiters	Radar mapping of the surface. Detailed study of the mesosphere and cloud tops in the morning and evening sectors by high-spectral-resolution thermal emission spectroscopy.
Vega 1 & 2 (USSR, 1985)	Fly-by spacecraft en route to Comet Halley, carrying 1 lander and 1 balloon each	First balloons in the atmosphere of another planet recorded winds running at 240 km/h. Landers provided precise temperature profiles down to the surface and *in situ* measurements of cloud composition.
Magellan (USA, 1990-1994)	Orbiter	First almost-global radar mapping of the surface (300 m/pixel resolution).
Galileo (USA, 1990)	Fly-by en route to Jupiter	Spectral imaging of the night-side near-infrared emissions. Detection of radio waves possibly emitted by lightning.
Cassini-Huygens (USA, ESA, I, 1998, 1999)	Fly-by en route to Saturn	Spectral imaging of the night-side near-infrared emissions.



The Venera 15 spacecraft.

The Magellan radar mapping mission.

(1983-1984), and NASA's Magellan radar-mapping mission (1990-1994) together provided a comprehensive picture of an arid world, with landscapes shaped by intense volcanic and geological activity. There were vast plains marked by lava flows, bordered by highlands and mountains. The later discovery of the night-side thermal emissions from deep inside the atmosphere of Venus provided an effective tool with which to peek through the dense clouds and study the lower atmospheric layers. The Galileo and Cassini spacecraft were the first to use this approach during their short fly-bys en route to Jupiter and Saturn.

Despite this past intensive exploration of the planet, our knowledge of Venus is still very limited. Almost all of the planet's peculiar features remain unexplained, and so a new phase of exploration is long overdue. This important scientific call has been picked up by Europe and, after being forsaken for a decade, the 'Morning Star' will receive a new visitor in the form of Venus Express, an orbiter mission developed by the ESA and due for launch in October 2005.

The Pioneer Venus mission.

Thanks to a set of state-of-the-art instruments for planetary investigations, Venus Express will delve into the secrets of the Venusian atmosphere. It will study its complex dynamics and chemistry, and the interactions between the atmosphere and the surface, which will provide clues about the surface's characteristics. It will also study the interactions between the atmosphere and the interplanetary environment (solar wind) to improve our understanding of the planet's evolution.
In the most comprehensive study ever of the Venusian atmosphere, Venus Express will address many unanswered questions:

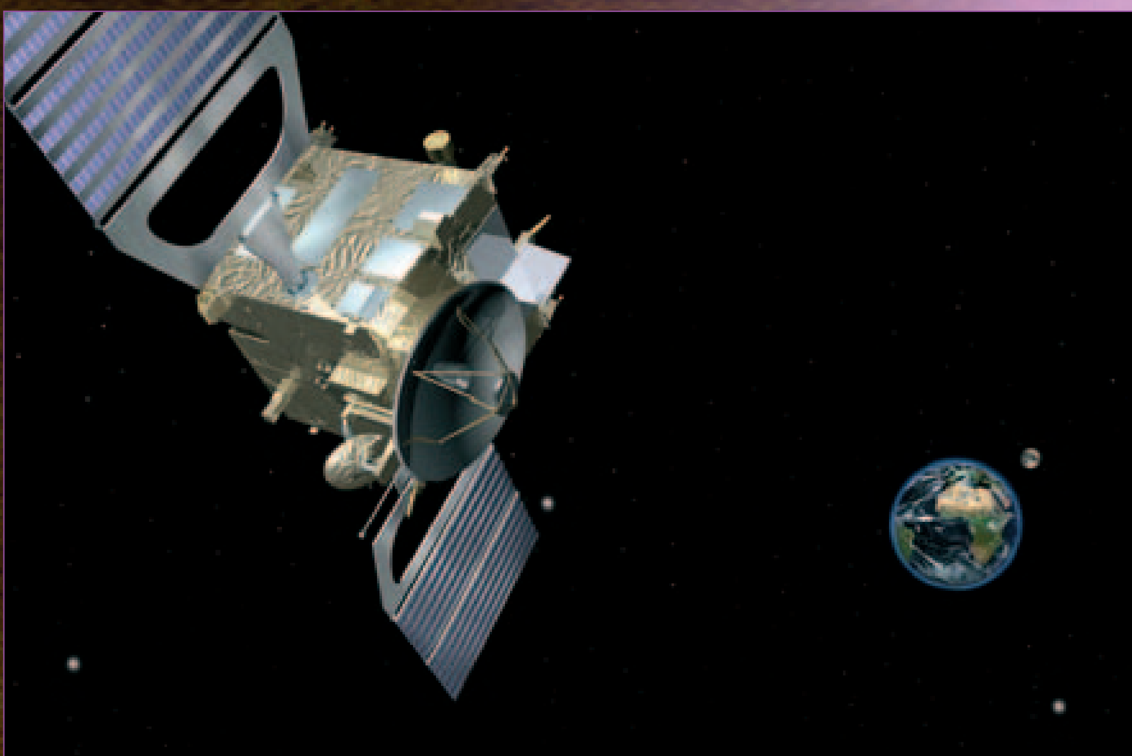
- **How do the complex global dynamics of the planet work?**
  What causes the super-fast atmospheric rotation and the hurricane-force winds?
  What maintains the double atmospheric vortex at the poles?
- **How does the cloud system work?**
  How do clouds and haze form and evolve at different altitudes?
  What is at the origin of mysterious ultraviolet markers at the cloud tops?
- **What processes govern the chemical state of the atmosphere?**
- **What role does the 'greenhouse effect' play in the global evolution of the Venusian climate?**
- **What governs the escape processes of the atmosphere?**
- **Are there water, carbon-dioxide or sulphuric-acid cycles on Venus?**
- **What caused the global volcanic resurfacing of Venus 500 thousand million years ago?**
- **Why are some areas on the surface so reflective to radar?**
- **Is there currently volcanic or seismic activity on the planet?**

To Venus in record time

In the sidereal dance of the planets, Venus reaches its closest point to Earth every nineteen months. At the next approach, ESA will be ready to launch Venus Express to the star-bright planet. The launch window will open on 26 October 2005, and close one month later on 24 November. Everything has been planned to exploit the planet's proximity to make the journey as short as possible.

A Russian Soyuz-Fregat launcher will boost Venus Express into space from the Baikonur Cosmodrome in Kazakhstan. The Soyuz rocket will lift the autonomous upper stage 'Fregat', with Venus Express mounted on top, into a sub-orbital trajectory. Then, with two consecutive burns, Fregat will inject the spacecraft onto an interplanetary or 'escape' trajectory that, with few corrections, will take it directly to Venus.

For about five months (162 days), Venus Express will cruise in the peace of space. Once at Venus, in April 2006, it will fire its main engine to slow down and counteract the predominant pull of the Sun and of Venus, to be captured into orbit around the planet. A large velocity change is required for the initial capture manoeuvre, which will require the engine to burn for 53 minutes. Starting about five days later, a two-week-long series of manoeuvres will put the spacecraft into its final operating orbit, circling the poles of the planet once every 24 hours. At its closest, the spacecraft's orbit will drop to 250 kilometres altitude over northern latitudes, and at its furthest it will be 66 000 kilometres from the planet's surface.



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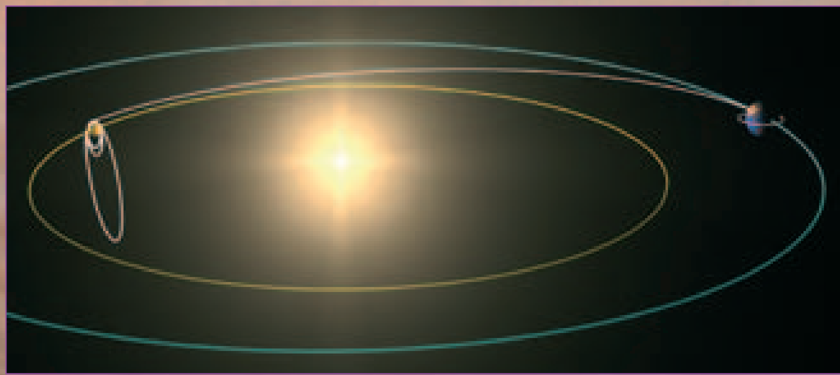
Venus Express leaves Earth

HST © L. Esposito (Univ. Colorado)/NASA



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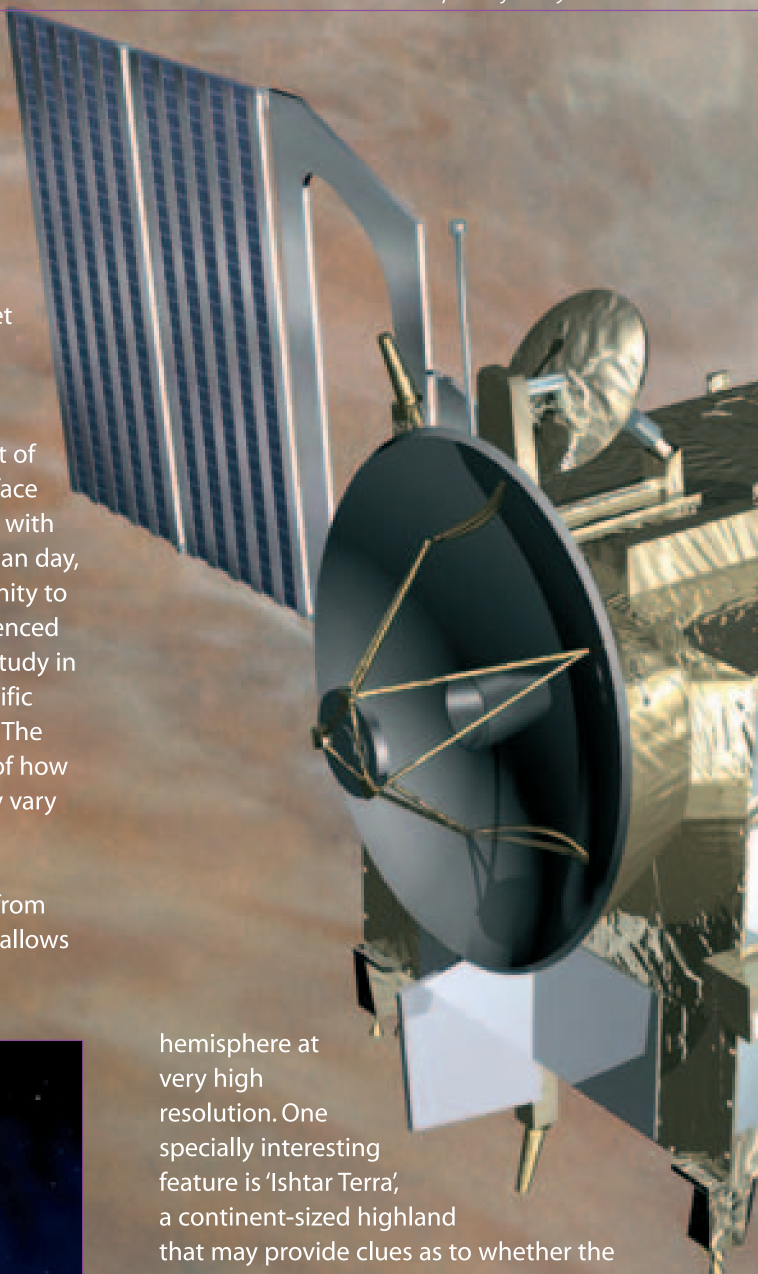
Venus Express's journey to Venus.



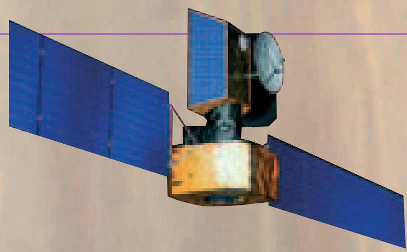
The orbit of Venus Express has been specifically chosen to learn as much as possible about the planet and to maximise the scientific return from the mission. It prescribes an ellipse which is 'locked' in space with respect to fixed stars, while the planet slowly rotates below it. During the course of the first full Venusian day (243 Earth days), the spacecraft will make a global observation from orbit of the Venusian atmosphere, of the surface characteristics and of the interaction with the solar wind. On the second Venusian day, Venus Express will have the opportunity to fill possible observation gaps experienced in the course of the first day and to study in more detail items of particular scientific interest selected during the first day. The second day also allows observation of how the phenomena seen on the first day vary with time.

The spacecraft's very short distance from Venus at pericentre (250 kilometres) allows in particular study of the northern hemisphere at very high resolution. One specially interesting feature is 'Ishtar Terra', a continent-sized highland that may provide clues as to whether the surface of Venus is actually 'moving' on geological time scales. The greater distance of Venus Express from the planet around apocentre (66 000 kilometres) will allow good global coverage of the atmospheric conditions in the southern hemisphere, including the tracking of cloud features.

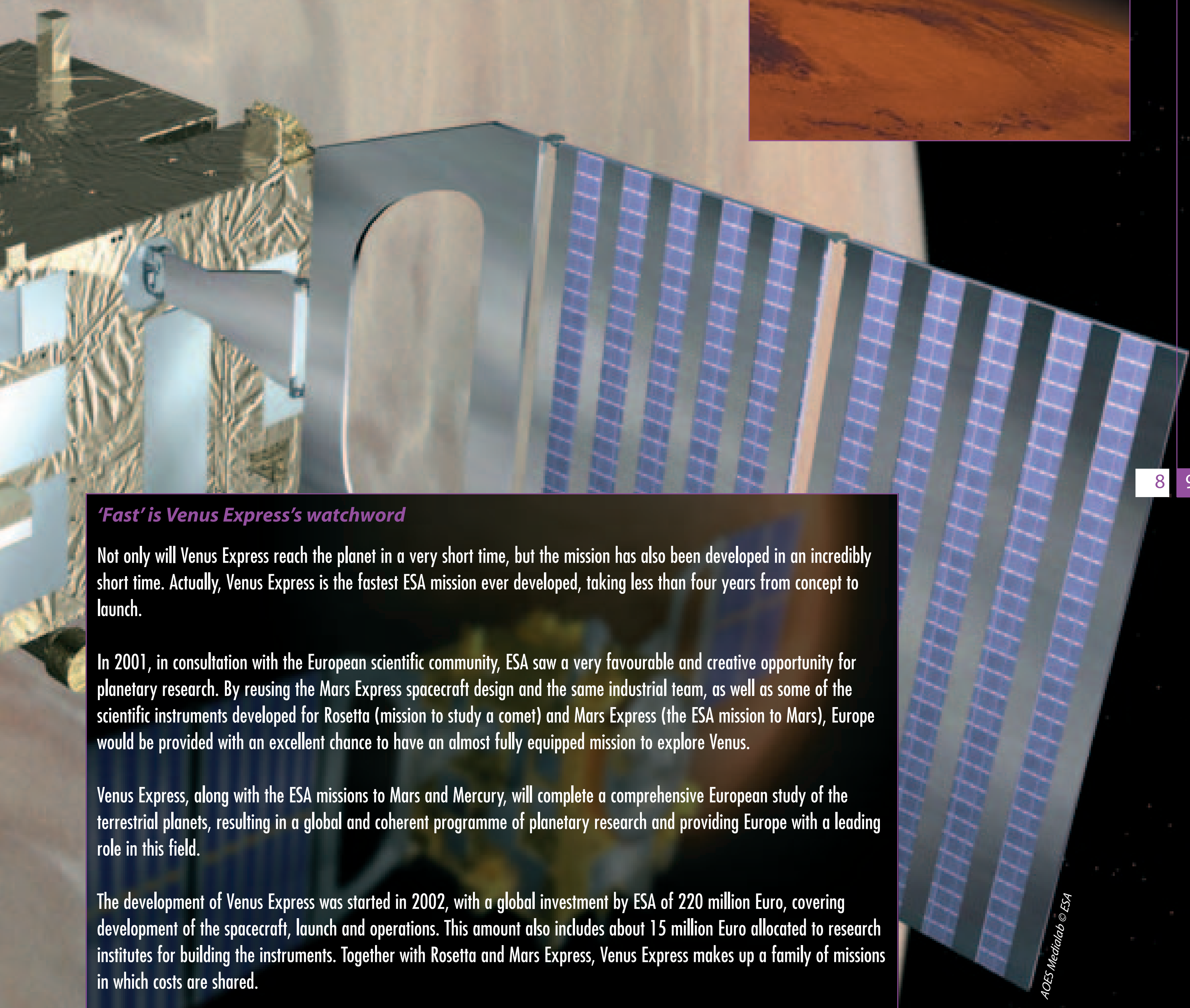
AOES Medialab © ESA

Venus Express re-uses some of Mars Express's and Rosetta's instrumentation.

Orbit	Highly elliptical
Orbit inclination	90° over Venusian equator (polar orbit)
Pericentre (min. distance from the planet's surface)	250 km
Apocentre (max. distance from the planet's surface)	66 000 km
Pericentre latitude	~80 to 90°N
Period	24 hours
Planned mission lifetime	2 Venusian sidereal days (486 Earth days). It is possible to extend the mission by another two Venusian days.



With Venus Express, Mars Express orbiting Mars and BepiColombo to reach Mercury, ESA will complete the study of terrestrial planets.



'Fast' is Venus Express's watchword

Not only will Venus Express reach the planet in a very short time, but the mission has also been developed in an incredibly short time. Actually, Venus Express is the fastest ESA mission ever developed, taking less than four years from concept to launch.

In 2001, in consultation with the European scientific community, ESA saw a very favourable and creative opportunity for planetary research. By reusing the Mars Express spacecraft design and the same industrial team, as well as some of the scientific instruments developed for Rosetta (mission to study a comet) and Mars Express (the ESA mission to Mars), Europe would be provided with an excellent chance to have an almost fully equipped mission to explore Venus.

Venus Express, along with the ESA missions to Mars and Mercury, will complete a comprehensive European study of the terrestrial planets, resulting in a global and coherent programme of planetary research and providing Europe with a leading role in this field.

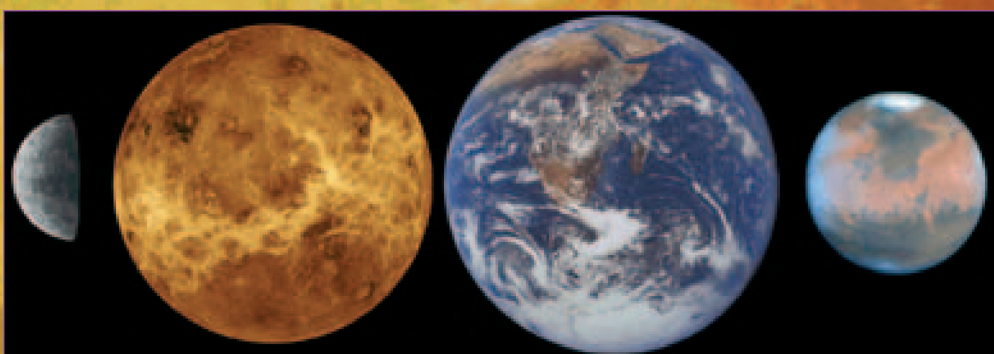
The development of Venus Express was started in 2002, with a global investment by ESA of 220 million Euro, covering development of the spacecraft, launch and operations. This amount also includes about 15 million Euro allocated to research institutes for building the instruments. Together with Rosetta and Mars Express, Venus Express makes up a family of missions in which costs are shared.

Rendezvous with Earth's mysterious sister

Venus, Mars and Earth, which constitute three of the four inner or 'rocky' planets of the Solar System, have a lot in common – a solid surface you could walk on, a comparable surface composition, an atmosphere, and a weather system. If you are looking for a twin sister to Earth, that would be Venus. Or so it seems!

basaltic, the result of intense volcanism and of a similar solidification process, initiated at about the same time, four and a half thousand million years ago, when the planets of the Solar System first started to form from the solar 'proto-planetary nebula'.

However, looking more closely, Venus and Earth are truly worlds apart in many major respects. Walking on Venus's surface would be difficult, like walking under water at a depth of 900 metres - the atmospheric pressure on Venus is 90 times greater than on Earth at sea level - and as uncomfortable as sitting in an oven at 465°C ! Venus's surface is the hottest in the Solar System. Despite only 10% of



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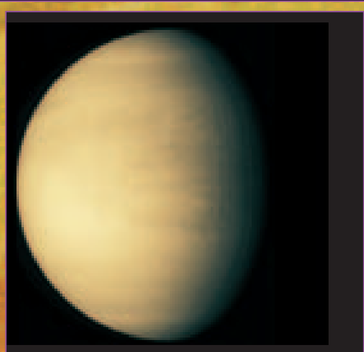
Mariner 10, Apollo 17 and Viking images showing the relative dimensions of Venus, Earth and the terrestrial planets.



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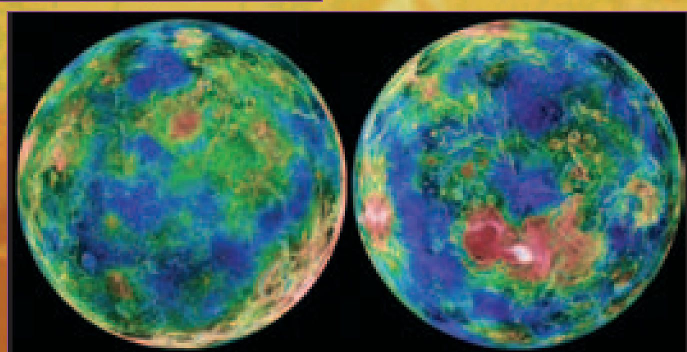
Only thick cloud cover could be seen from this image taken in February 1990 by NASA's Galileo spacecraft.



Magellan © NASA/USGS Flagstaff

Venus Express will orbit over Venus's poles. It will map the North Pole in high resolution.

It is amazing to compare some of the planetary features of Venus with those of Earth. Their masses are basically the same, and their densities also. Their radii seem just to be copied from one planet to the other. Their distances from the Sun are not so different – Venus is about 108 million kilometres away and Earth 150 million kilometres. Their rocks are both largely

the solar flux reaching the surface, enough energy is trapped by gases and particles present in the lower atmosphere to raise the surface temperature dramatically. A catastrophic 'greenhouse effect' is taking place.

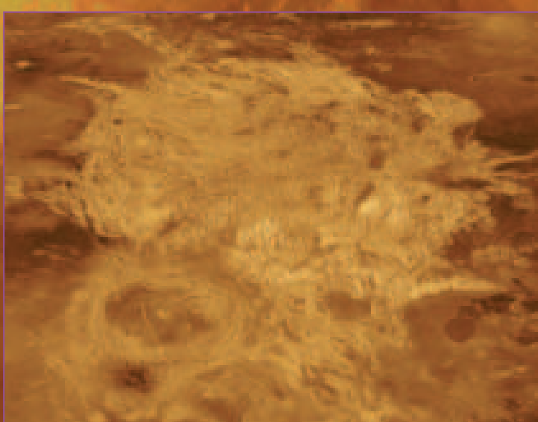
Venus's atmosphere is composed almost entirely of carbon dioxide, with very little

	Venus	Earth
Mass	4.87×10^{24} kg	5.98×10^{24} kg
Equatorial radius	6052 kilometres	6378 kilometres
Density (mean)	5250 kilograms per cubic metre	5520 kilograms per cubic metre
Average distance from the Sun	108 million km (0.7 Astronomical Unit)	150 million km (1 Astronomical Unit)
Rotation period	243 Earth days (retrograde)	23 hours 56 minutes
Year length (orbital period)	224.7 (Earth) days	365.2 days
Surface temperature (mean)	465 °C	15 °C
Atmospheric pressure on the surface	90 bars	1 bar (sea level)
Visual albedo (reflectivity)	0.76	0.37
Highest point on the surface	Maxwell Montes (17 kilometres)	Mount Everest (8.8 kilometres)
Major atmospheric components	96% carbon dioxide, 3% nitrogen	78% nitrogen, 21% oxygen, 1% argon
Surface materials	Basaltic rock and altered materials	Basaltic and granitic rock and altered materials
Orbit inclination	3.4 °	0 ° (per definition)
Obliquity of rotation axis	178 °	23.5 °
Surface gravity (at equator)	8.9 m/s^2	9.8 m/s^2

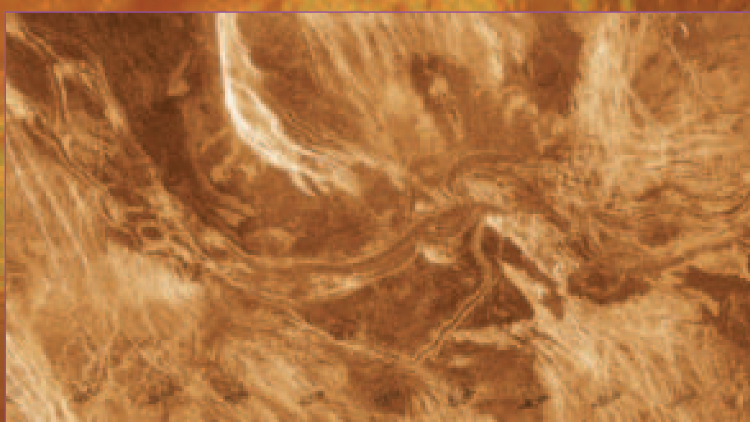
water vapour. It contains significant amounts of corrosive sulphur-bearing gases and rapidly moving clouds of sulphuric-acid droplets. The dense clouds scatter back to space about 80% of the radiation received from the Sun. Scientists translate this concept by saying that Venus has a very high *albedo*. This is the reason why it is so easy to see with the naked eye and was long considered to be a star rather than a planet.

Venus is almost 70% covered by gently rolling uplands, about 20% by very flat lowlands called 'planitia', and 10% by continent-size highlands, rising above the lowland regions, called 'tesserae'. On Earth, continents are associated with the borders of tectonic plates, which drift and collide over time, giving birth to mountains and causing earthquakes. On Venus there does not seem to be any tectonic-plate activity to move and shape the surface. On the

Magellan © NASA/JPL

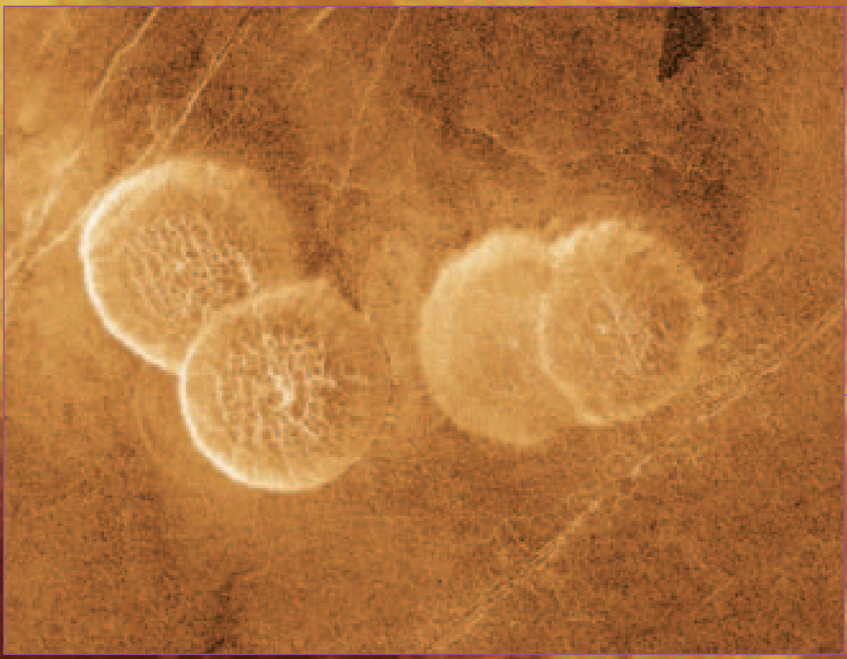


Three-dimensional view of Alpha Regio, one of Venus's highlands. It is 1300 kilometres across and it was the first feature on Venus to be identified from Earth-based radar.



Magellan © Calvin J. Hamilton

Rolling uplands, showing signs of lava flows.



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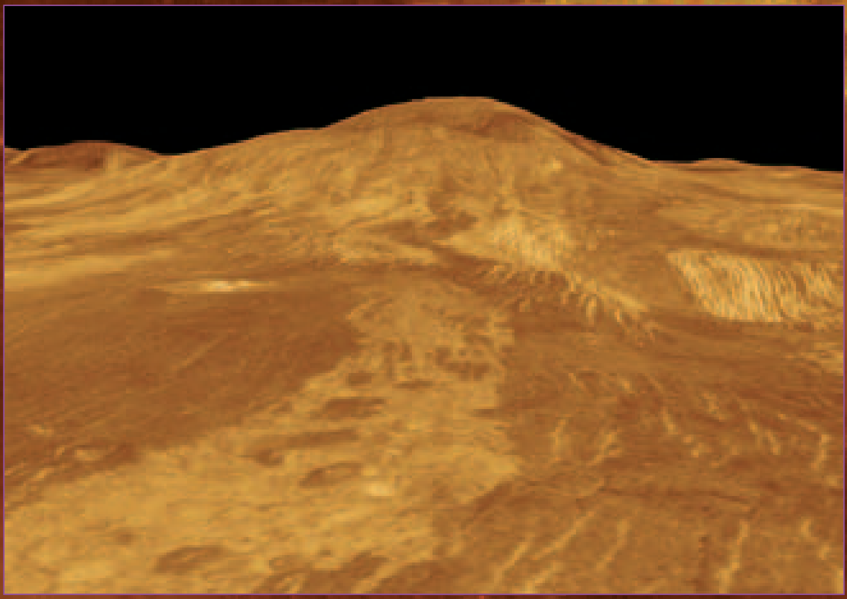

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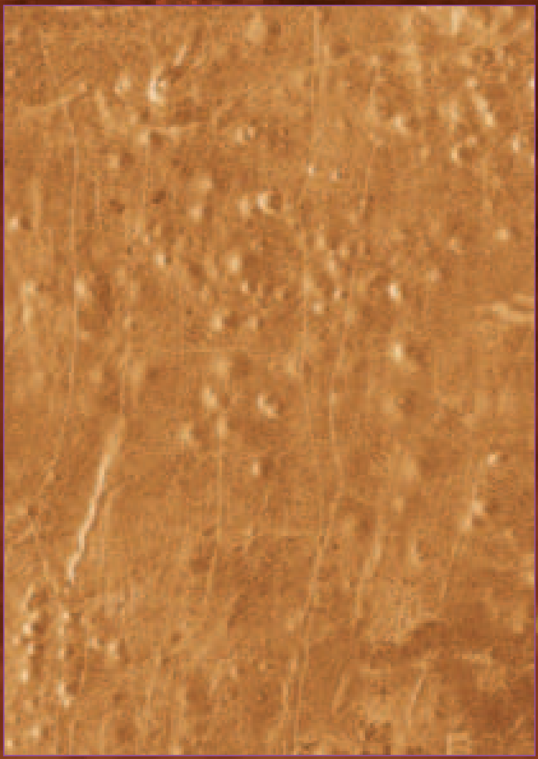

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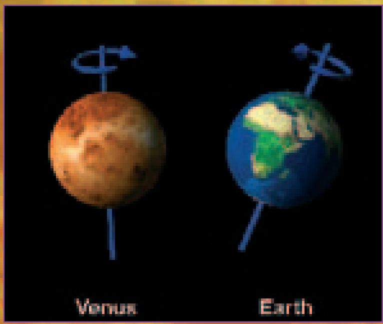
Magellan images showing different kinds of volcanism at Venus: group of four overlapping domes at the edge of Alpha Regio, showing possible viscous eruptions (top); Sif Mons volcano (centre); cluster of small volcanic cones overlying a fracture network in Niobe Planitia (bottom).

contrary, it seems that there is a single plate covering the whole planet. Whether this crust is thick or thin, and whether it still moves, no one yet knows.

It is sure that the surface of Venus is shaped by deformation of the crust and by volcanism. Lava flows extend hundreds miles across the surface. Volcanism indicates that, at least in the past, the crust has been lying on a liquid mantle, like on Earth. However, on Venus there are signs of many different kinds of volcanism, such as volcanic plains and volcanic rises, besides the classic cones we find on Earth. So are volcanoes still active on Venus?

High mountains and many impact craters pepper the surface. Unlike other worlds, however, it is almost impossible to find craters less than two kilometres across. This is possibly due to the high density of the planet's atmosphere, which pulverizes smaller meteorites before they hit the ground.

The oldest craters seem not to be older than 500 million years, which may indicate that the planet behaves like a volcanic 'pressure cooker'. On Earth, the constant, steady eruption of volcanoes and the shifting of the surface ensures that the energy released is dissipated gradually. Instead, on Venus pressure builds up inside the planet until the whole world is engulfed in a global eruption, resurfacing the planet and destroying many craters that have formed.

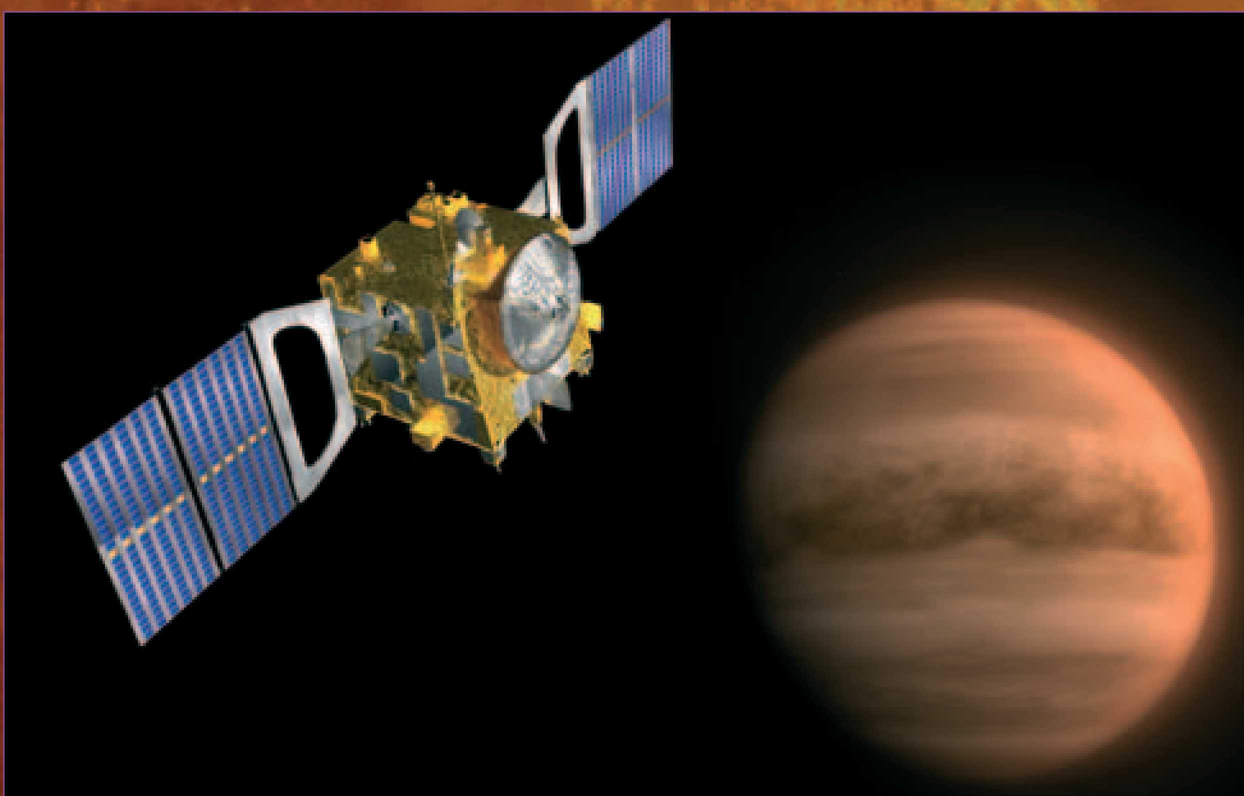


Venus rotates in the opposite direction to Earth.

Venus rotates in the opposite direction to Earth, so the Sun appears to rise in the west. It also rotates very slowly, with one rotation, or sidereal day, taking 243 Earth days. This is longer than the Venusian year (orbital period), which is 225 Earth days long. Its winds, however, are so fast that they can circumnavigate the planet in only four Earth days: it is still not known why this happens.

Venus does not have its own planetary magnetic field to protect it from the solar wind. On Earth, the magnetic field is generated by movements in the metallic core coupled with the planet's relatively fast rotation. On Venus, the core may be solid and the rotation of the planet is very slow, which may explain the lack of a magnetic field, but scientists are still debating the reasons.

In studying Venus, we are trying to understand not only how the Solar System formed and evolved, but also the complex set of forces and mechanisms that have caused such dramatic differences between the internal structures, surfaces and atmospheres of Venus and Earth. An understanding of Venus can therefore lead eventually to a better understanding of our own planet, and especially the long-term evolution of Earth's climate.



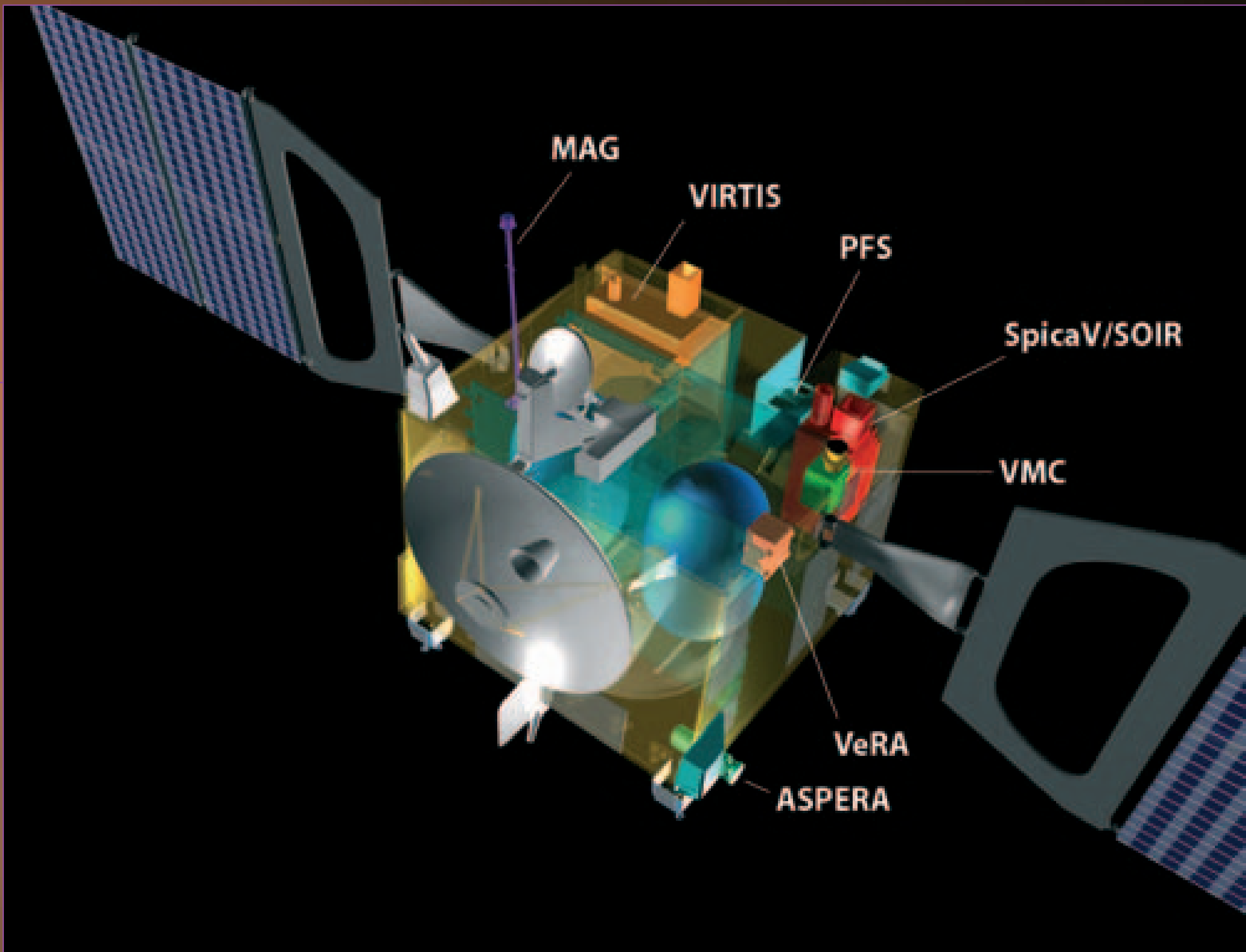
The Venus Express spacecraft.

Penetrating an impenetrable world

Probing the mysteries of Venus with a precision never before achieved is the goal of Venus Express.

Compared with previous missions, the scientific instrumentation onboard Venus Express is enormously improved. This will allow us to study Venus's atmosphere in great detail, to understand its complex dynamics and its close relationship with the surface and with the planetary space environment around it. Venus Express data will answer many of the unresolved questions about Venus and will allow the definition of new objectives for future missions to the planet. This will be achieved using mainly instruments inherited from the scientific packages already developed for the Mars Express and Rosetta missions. The 'eyes' of Venus Express are extremely

Instrument	Purpose	Heritage
ASPERA (led by Institute of Space Physics, Kiruna, Sweden)	The Analyser of Space Plasma and Energetic Atoms will investigate the interaction between the solar wind and the atmosphere of Venus by measuring outflowing particles from the planet's atmosphere and the particles making up the solar wind. It will study how the molecules and ions escape from the planet.	Mars Express
MAG (led by IWF, Graz, Austria)	Venus has no detectable internal magnetic field, and the field that exists around the planet is entirely due to the interaction between the solar wind and the atmosphere. The MAG magnetometer will study this process and will help in understanding the effect this has on Venus's atmosphere, for instance the atmospheric escape process.	Newly developed for Venus Express (but re-using sensor design from the Rosetta lander)
PFS (led by IFSI-INAF, Rome, Italy)	The Planetary Fourier Spectrometer will be able to measure the temperature of the atmosphere at altitudes of 55–100 kilometres and 0–10 kilometres at very high resolutions. It will also be able to measure the surface temperature and therefore be able to search for volcanic activity. In addition to its temperature measurements, PFS will be able to make composition measurements of the atmosphere.	Mars Express
SpicaV/SOIR (led by Service d'Aeronomie du CNRS, Verrieres, France; Institute for Space Aeronomy, Belgium; IKI, Russia)	The Ultraviolet and Infrared atmospheric spectrometer for stellar and solar occultation assists in the analysis of Venus's atmosphere. In particular, it will search for the small quantities of water expected to exist in the Venusian atmosphere. It will also look for sulphur compounds and molecular oxygen in the atmosphere. It will determine the density and temperature of the atmosphere at 80–180 kilometres altitude.	SpicaV inherited from Mars Express, new development for SOIR
VeRa (led by Univ. der Bunderswehr, Munich, Germany)	The Venus Radio Science experiment uses the powerful radio link between the spacecraft and Earth to investigate the conditions prevalent in the ionosphere of Venus. Scientists will also use it to study the density, temperature, and pressure of the atmosphere from 35–40 km up to 100 km from the surface, and to determine roughness and electrical properties of the surface. It will also allow investigations of the conditions of the solar wind in the inner part of the Solar System.	Rosetta
VIRTIS (led by CNR-IASF, Rome, Italy, Observatoire de Paris, France;)	The Ultraviolet/Visible/Near-Infrared mapping spectrometer will be able to study the composition of the lower atmosphere between 40 kilometres altitude and the surface. It will track the clouds at both ultraviolet and infrared wavelengths and allow scientists to study atmospheric dynamics at different altitudes.	Rosetta
VMC (led by MPS, Katlenburg-Lindau, Germany)	The Venus Monitoring Camera is a wide-angle multi-channel camera that will be able to take images of the planet at near-infrared, ultraviolet and visible wavelengths. VMC will be able to make global images and will study the cloud dynamics and image the surface. In addition, it will assist in the identification of phenomena seen by other instruments.	Newly developed for Venus Express (reusing parts of Mars Express's High Resolution Stereo Camera)



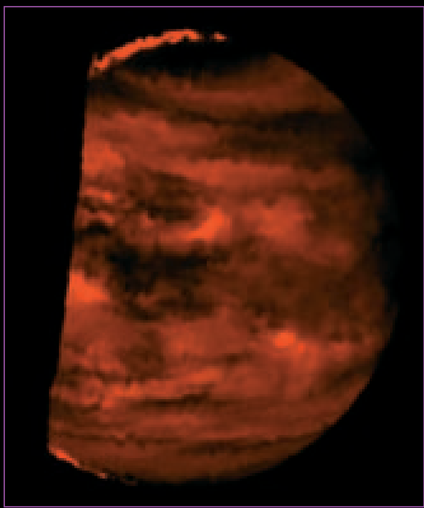
C.Carreau © ESA

sensitive to a wide range of electromagnetic wavelengths, from the ultraviolet to the infrared. They will be able to peer down through the atmosphere by exploiting for the first time the so-called 'spectroscopic windows', discovered in the late 1980s thanks to ground observations. The radiation leaking from the deep atmosphere through these 'windows' can be observed on Venus's night side. Surprisingly, infrared radiation from the lower atmosphere and even the surface can escape to space here, carrying precious information that Venus Express will collect from orbit. In this way, many phenomena previously hidden below the thick clouds will be seen by Venus Express.

Venus Express 'firsts'

- First global monitoring of the composition of the lower atmosphere via near-infrared transparency 'windows'.
- First coherent study of atmospheric temperature and dynamics at different levels of the atmosphere, from the surface up to ~200 km.
- First measurements from orbit of global surface-temperature distribution.
- First study of middle- and upper-atmosphere dynamics from oxygen (atomic and molecular) and nitrogen-oxide emissions.
- First measurements of non-thermal atmospheric escape.
- First coherent observations of Venus in the ultraviolet to thermal-infrared spectral range.
- First application of the solar/stellar occultation* technique at Venus.
- First use of a 3D ion mass analyser, high-energy resolution electron spectrometer and energetic neutral atom imager.
- First sounding of Venusian top-side ionospheric structure.

* *Occultation: looking at an object like the Sun, Earth or a star through the atmosphere from a limb perspective allows us to analyse how the light emitted by this object is absorbed by the atmosphere, and this tells us about the characteristics of the atmosphere itself.*



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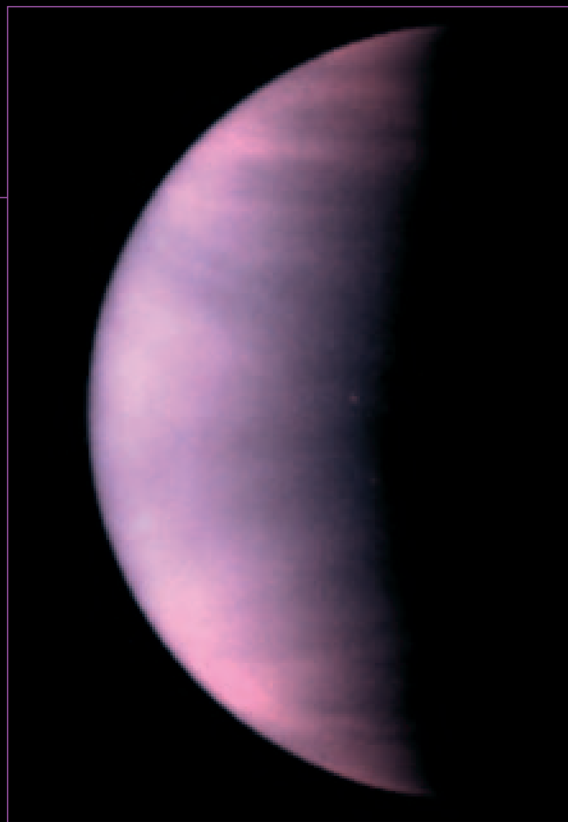
Infrared view of Venus, as imaged by the NIMS experiment on board NASA's Galileo mission.



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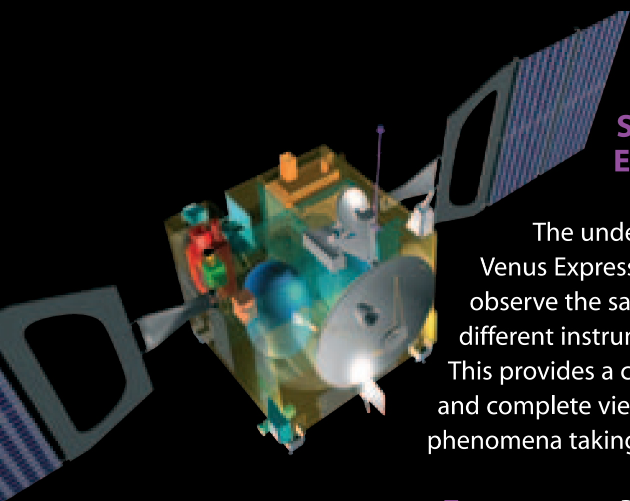
Ultraviolet image of Venus from the NASA/ESA Hubble Space Telescope, taken in January 1995, showing mysterious dark atmospheric features.



Synergy is Venus Express's strength

The underlying philosophy of the Venus Express investigations is to observe the same target with several different instruments at the same time. This provides a comprehensive, versatile and complete view of the different phenomena taking place on Venus:

- **Temperatures:** PFS, VIRTIS, VeRa and SPICAV
- **Chemical composition:** VIRTIS, SPICAV and PFS
- **Climate, weather and global atmospheric dynamics:** VIRTIS and VMC, complemented by temperatures retrieved by PFS, VeRa and VIRTIS
- **Atmospheric escape into space:** ASPERA, in combination with SPICAV to assess how this process evolves over time
- **Interaction of solar wind with atmosphere:** ASPERA, MAG and VeRa.
- **Surface roughness, temperature and other properties:** VeRa, together with VIRTIS, PFS and SPICAV
- **Volcanic activity:** VIRTIS, PFS and VMC.
- **Signs of seismic activity:** VIRTIS and PFS.

Planetary answers from atmospheric clues

Venus's atmosphere is so dense and so strictly 'coupled' to the planet's surface that studying it will provide information about the nature of the whole planet. Not only will the study of the atmosphere allow us to understand the complex Venusian environment and climate system, and the way it evolved, but it can also provide an enormous amount of information about the surface, its geology and, indirectly, about the interior of the planet. Are there gaseous emissions from the surface that could tell us whether there are active volcanoes? Is there a carbon dioxide (or even water) cycle similar to the water cycle on Earth? Or it is completely replaced by the cycle of sulphuric acid and other sulphur compounds? Is there any similarity between the ocean-atmosphere relationship on Earth and the surface-atmosphere relationship on Venus? Can mechanical waves propagating through the dense atmosphere reveal the presence of seismic activity?

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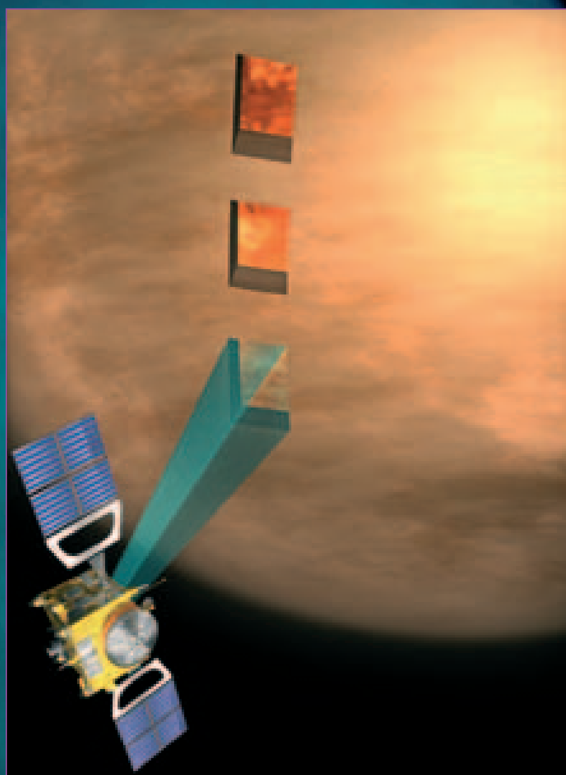
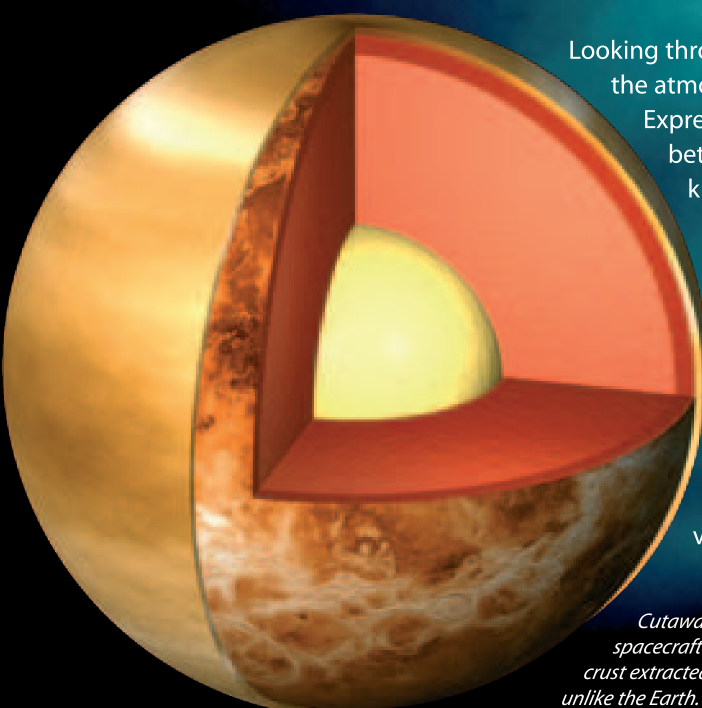


By digging into the atmosphere, Venus Express will provide clues about the whole planet.

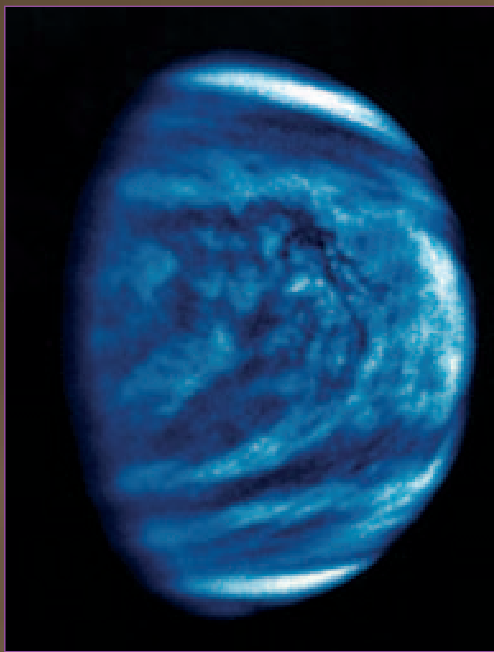
Deeper than ever before

Looking through the infrared 'windows' in the atmosphere will allow Venus Express to study its lower layers – between the surface and 60 kilometres altitude – whose physics is virtually unknown. Venus Express will be able to determine the surface temperature as a function of altitude at all planetary latitudes and longitudes. Measuring a local increase in surface temperature may indicate the presence of volcanic activity. These

Mariner 10/Magellan images © Calvin J. Hamilton



Cutaway view of the possible internal structure of Venus. Previous spacecraft data suggest that Venus is differentiated with a basaltic crust extracted from the mantle, and that it has a single tectonic plate, unlike the Earth.



© Galileo/NASA

Clouds moving to the west (left) at about 100 m/s at the equator are visible in this Galileo image of Venus. The bright spot on the right shows the local noon. The evening terminator is on the left.

measurements will also allow us to better understand the local weather, including for instance the mechanisms that cause turbulences close to the surface. Furthermore, Venus Express will be able to gather information about the surface topography, allowing us to understand why some regions are particularly reflective to radio waves: is it due to the presence of particular materials in a specific state, like snow or ice on Earth?

We do not know anything about the nature of the chemistry in the lower atmospheric layers. Indeed, from the little data available from previous missions, we know only that the thermal decomposition of sulphuric acid, caused by the high surface temperature (465°C), is the dominant process in these layers. Chemical cycles involving sulphur, carbon monoxide and water vapour are also at work. These are gases that are especially important for understanding the greenhouse effect on Venus. In addition, they can also be markers for volcanic activity and global atmospheric dynamics. Venus Express will make an unprecedented global map of the composition of the planet's lower atmosphere, telling us exactly what gases exist, in what quantity, and how their concentrations may vary in space and time.

Acid clouds and lightning

At around 60 kilometres altitude is a very thick cloud layer – a 20 kilometre-deep

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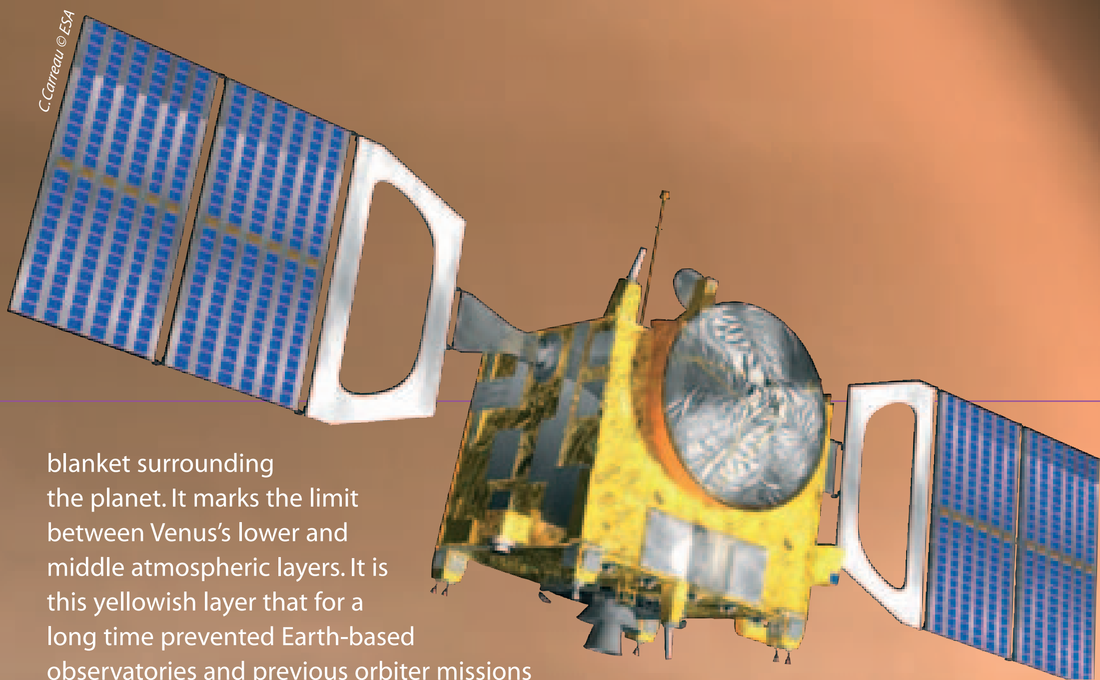
Are the radio flashes recorded at Venus due to lightning ?

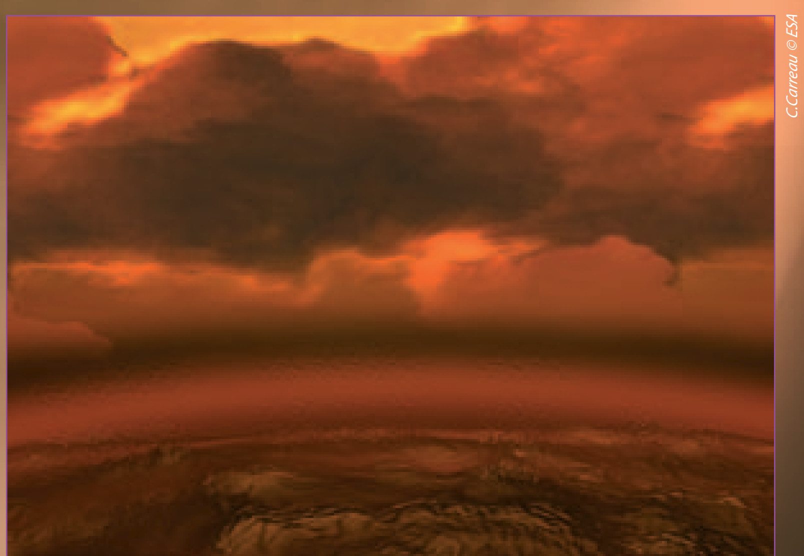


blanket surrounding the planet. It marks the limit between Venus's lower and middle atmospheric layers. It is this yellowish layer that for a long time prevented Earth-based observatories and previous orbiter missions from seeing the surface. Today it is known that the upper part of this layer is mostly composed of tiny droplets of sulphuric acid, but what is happening chemically in the lower clouds is still unknown. For instance, what is the origin of the large solid particles floating in the lower clouds observed by Pioneer-Venus? The Venus Express remote-sensing instruments will be able to see how the clouds are shaped and structured, how they form and evolve with time, how their opacity varies and what molecules they are made of. Local and global weather patterns will keep no secrets from Venus Express.

During previous ground and satellite observations, visible flashes in the atmosphere have been observed, and localised emissions of radio waves have also been reported. Are they due to lightning? The sulphuric-acid droplets can be electrically highly charged, and so they offer the potential for lightning. It is very important not only to learn whether it is possible that lightning has an influence on Venus's atmospheric chemistry, but also to understand how the atmospheres of all terrestrial planets become electrified and then discharge. Venus Express has the ability to address these still unanswered questions.

Greenhouse effect

On the global scale, Venus's climate is strongly driven by the most powerful greenhouse effect found in the Solar System. The agents sustaining it are water vapour, carbon dioxide and sulphuric-acid aerosols. About 80% of the incoming solar radiation is reflected back to space by the cloud layer, and only 10% manages to get through it and heat the surface. However, the thermal radiation emitted by the surface gets trapped by the same atmosphere. The result is an amazing 500°C difference between the surface and cloud-top temperatures. Are there other gases sustaining such an efficient planetary greenhouse? How is the heat transported from the surface to the cloud layer: through radiation or dynamic mechanisms such as turbulence? Answering these questions is one of the primary goals of Venus Express.



A dramatic greenhouse effect is in place at Venus.

C. Carreau © ESA

Looking at
ultraviolet

Mysterious ultraviolet markings on the clouds

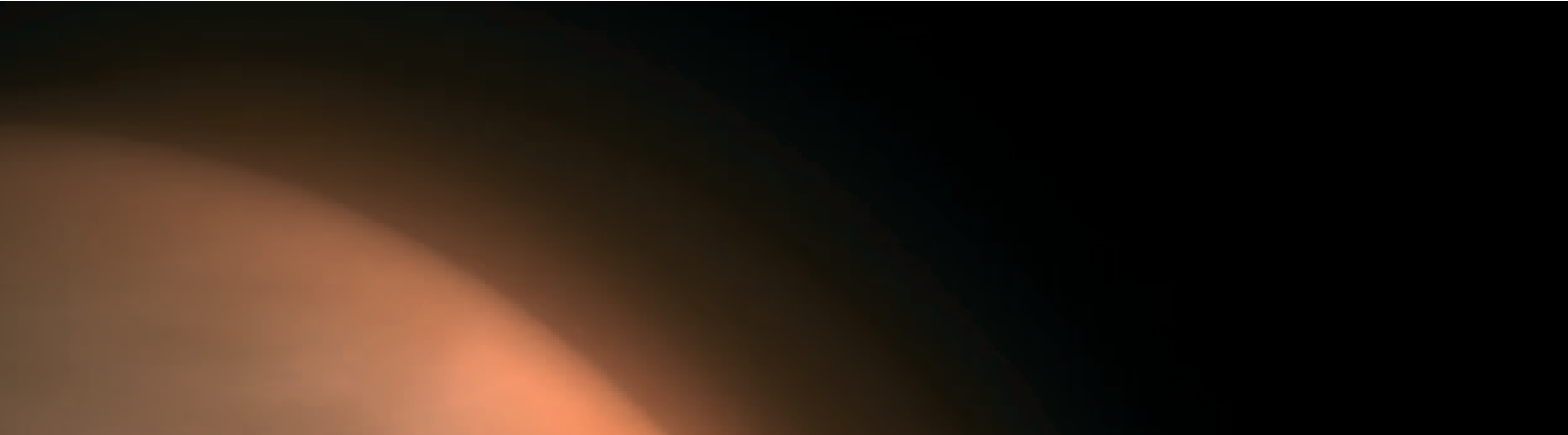
Looking at Venus's thick cloud layer by optical means would not reveal much. However, by looking at the clouds in other wavelengths, such as the infrared and ultraviolet, a very different world appears. The clouds on Venus are very inhomogeneous in all directions, due possibly to the formation of enormous cumulus-type clouds. Furthermore, the upper clouds are marked by areas visible in the ultraviolet that mysteriously absorb half of all the solar energy received by the planet. What is the origin of these ultraviolet markings? What makes their absorbing power so high? By revealing the temperature and the chemical composition of these regions, Venus Express will help to provide the answers.

Hurricane-force winds and huge atmospheric vortexes

The lower atmosphere of Venus has a dramatic and peculiar behaviour pattern. At the level of the cloud tops, the atmosphere rotates at a formidable velocity, with wind speeds of up to 360 kilometres per hour. The speed of the winds then progressively decreases to almost zero at the planet's surface, where it becomes a gentle breeze, barely able to kick up dust. What mechanisms cause this 'zonal super-rotation'? Furthermore, two enormous vortices, with very complex shapes and behaviours, rotate vertically over the poles, recycling the atmosphere downwards. The vortex at the north pole, the only one previously observed in some detail, has a peculiar 'double-eye' shape, surrounded by a collar of cool air. It completes a full rotation in only three Earth days. How are the super-rotation and the polar vortices linked? How does the global atmospheric circulation on Venus work? No model is so far able to simulate the dynamics of Venus's atmosphere as too few data are available. Venus Express observations will finally fill the gaps.

Where the sulphuric acid forms

The higher layers of the atmosphere, between 60 and 200 kilometres altitude, are also still relatively unknown. We know that in the middle atmosphere (60 to 110 kilometres), above the cloud tops, carbon monoxide is in great abundance among the minor species. It is formed by dissociation of carbon dioxide by ultraviolet radiation coming from the Sun. Photo-dissociation of sulphur dioxide leads to the formation of sulphuric-acid molecules that eventually form the cloud aerosols. Limited amounts of oxygen and water vapour are also present in the middle atmosphere. Study of the chemical cycles of these elements is important in order to understand the formation of the clouds below.



nus's atmosphere in different wavelengths shows very inhomogeneous clouds, and mysterious rks at the cloud tops.

Higher in the atmosphere, above 110 kilometres, the mysteries continue. Why, in the higher atmosphere of a planet as close to the Sun as Venus, do we measure temperatures as low as 30°C on the day side, and even –160°C on the night side? And why do such differences between the day and night sides not cause the strong winds we would expect? This behaviour is unique in the Solar System.

Venus Express will study the global circulation, chemistry, temperature and dynamics of the upper atmospheric layers in great detail.

A planet with no magnetic shelter

It is very likely that Venus and Earth, which are similar in mass and density, initially contained the same amount of 'volatile' substances. However, they have become two worlds apart. The secret must lie in the way their atmospheres evolved. How much of the atmosphere of Venus escaped under the bombardment of the solar wind and how much did it combine with the surface material?

Venus is a planet with no intrinsic magnetic field, and so it has no shield to protect it from the continuous attack of the capricious and violent solar wind. The planet is embedded only in a local magnetic field induced by the solar wind

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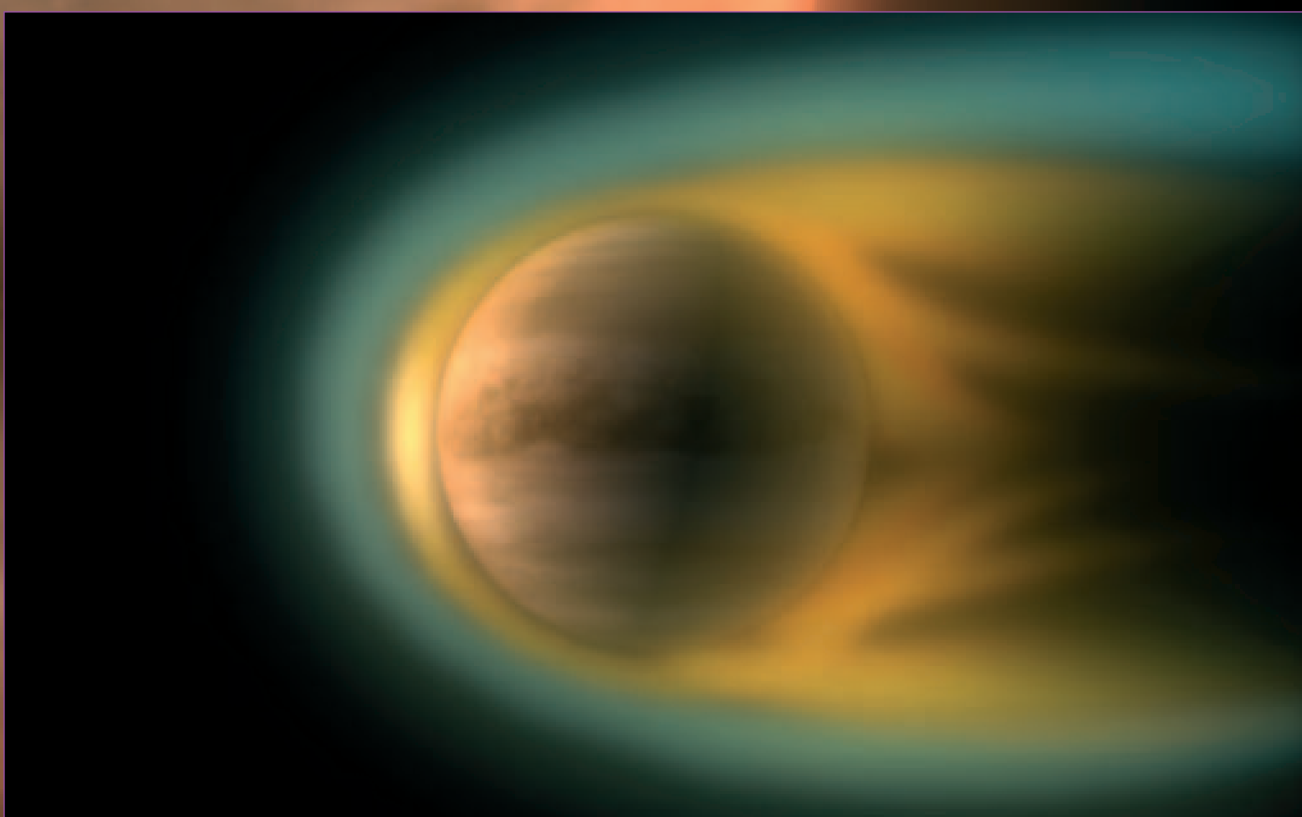


By observing the ionosphere, Venus Express will make the first global study of the atmospheric escape processes at Venus.

Artist's impression of the Venusian surface, the hottest in the Solar System.

C.Carreau © ESA

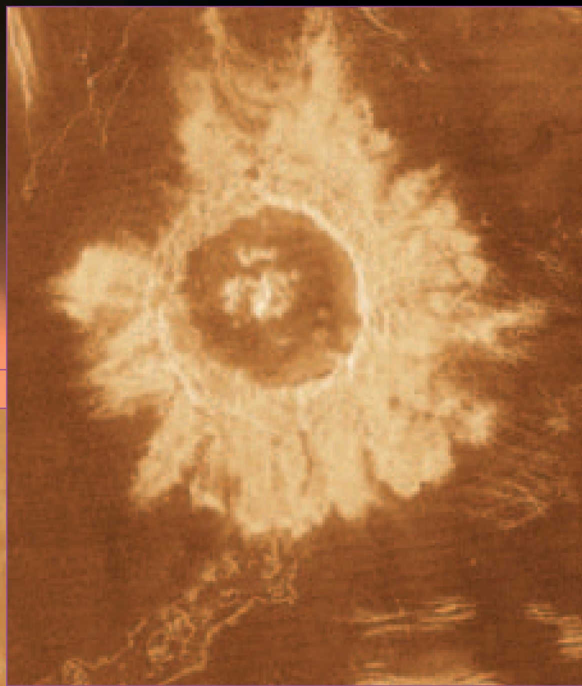
itself and perhaps by local magnetism derived from the surface. This peculiar situation gives birth to a complex set of mechanisms through which atmospheric gases are lost to space, including water vapour. This may well have had effects on Venus's climate on geological time scales and driven the evolution of the two planets' atmospheres in different directions.

Very little water vapour can presently be found in the Venusian atmosphere. It is possible that hydrogen escaped from it in large quantities during early epochs. Equally, the same may have happened with the oxygen, or it may have been involved in huge oxidation processes with surface materials. Maybe a primordial ocean was vapourised at a certain point in Venus's history. Otherwise, we could conclude that the little water vapour present was just supplied by comets or volcanism. Venus Express will make the first global study of how the atmosphere's escape processes work, which is fundamental to under-standing its evolution and, indirectly, that of Earth's atmosphere.

Alien volcanoes and 'Venus-quakes'

Venus, as seen by previous space missions, appears to be among the most geologically active planets in the Solar System. Its surface doesn't record signs of its past history earlier than 500 million years ago - it is as if the planet was completely resurfaced not so long ago by some massive planetary-crust phenomenon. Moreover, it also seems that some of its surface features have only recently been formed, which suggests that the planet may still be active internally.

Venus Express will address this question from several perspectives. First of all, it will analyse the gases in the lower atmosphere, where a certain abundance of sulphuric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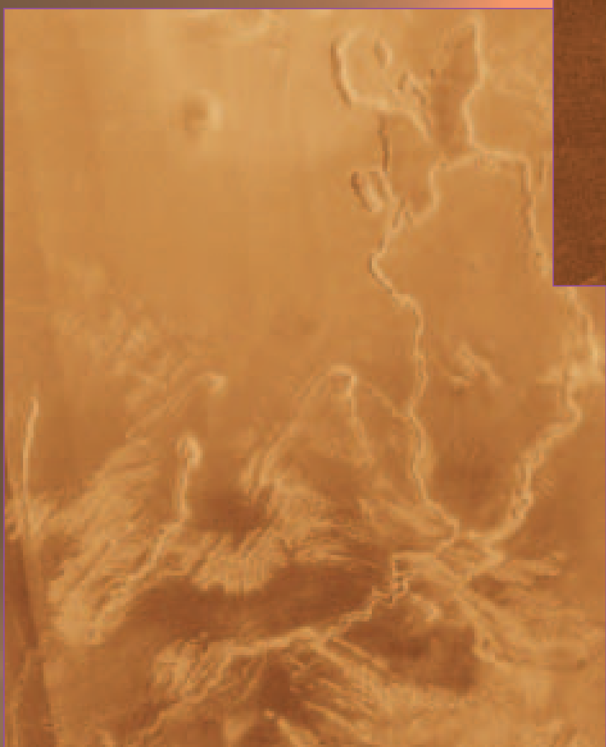
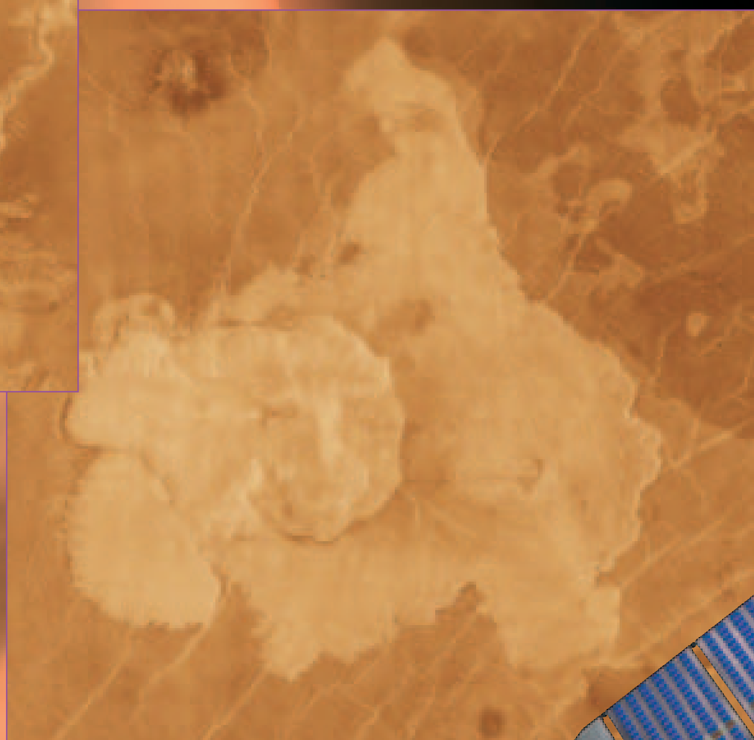
Danilova crater is an example of Venusian impact crater, as seen by the Magellan spacecraft.

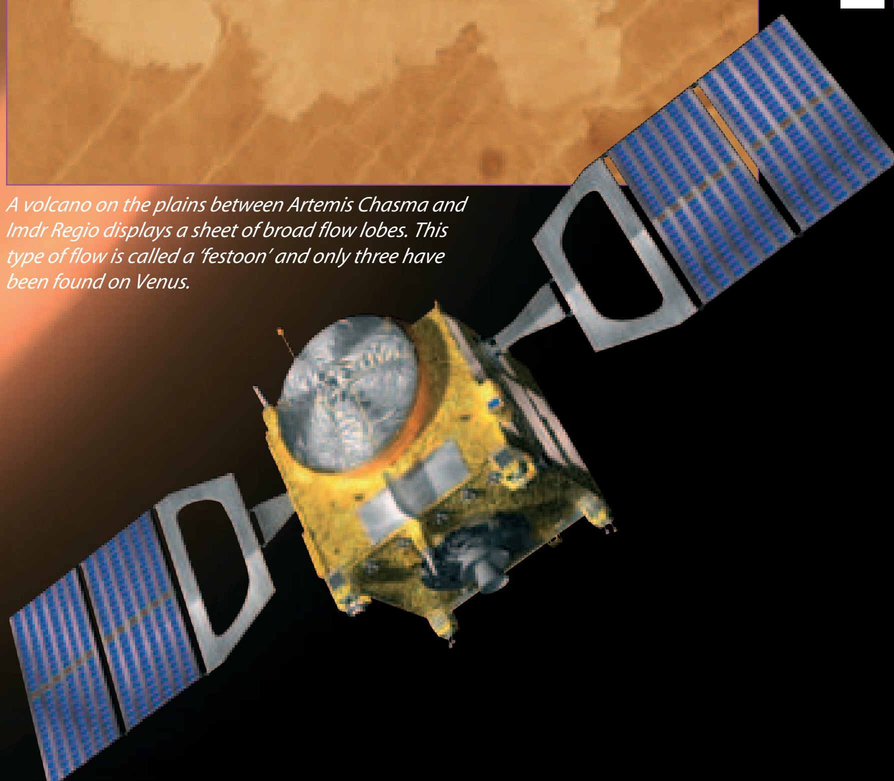

Magellan © Calvin J. Hamilton.

Smooth features may show that the planet could have been resurfaced by intense geological activity not long ago.

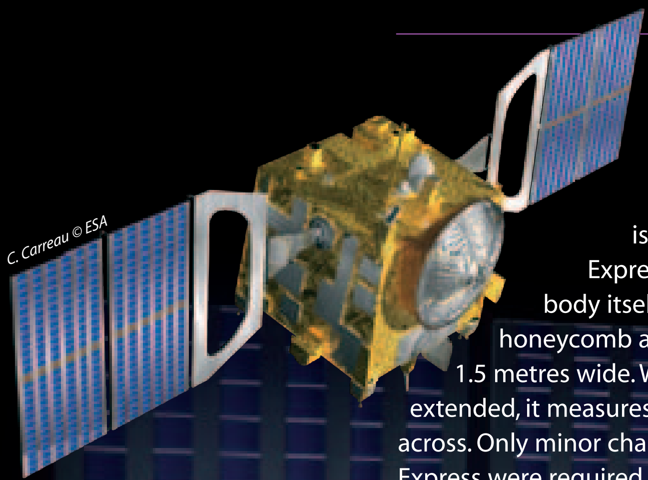
acid and sulphur dioxide may, for instance, indicate the presence of volcanic activity. This can also be revealed by possible temperature variations at corresponding latitudes. Venus Express is also able to observe local variations in the temperature and pressure that may indicate the propagation of seismic waves through the atmosphere. Signatures of 'Venus-quakes' may be observed at the top of the planet's atmosphere, which is so dense that its ability to transmit waves is thirty times greater than on Earth. Venus Express could identify the most active parts of the planet, determine the rate of this activity, and even the positions and magnitudes of the strongest quakes.


Magellan. © Calvin J. Hamilton.

A volcano on the plains between Artemis Chasma and Imdr Regio displays a sheet of broad flow lobes. This type of flow is called a 'festoon' and only three have been found on Venus.



Venus Express: a technological jewel



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The Venus Express spacecraft is a virtual twin of Mars Express. The spacecraft body itself, termed a 'bus', is a honeycomb aluminium box about 1.5 metres wide. With its solar arrays extended, it measures about 8 metres across. Only minor changes from Mars Express were required to accommodate the revised instrument payload, which is concentrated on three sides of the spacecraft bus.

However, the fact that the environment of Venus is very different from that of Mars required some design changes to make Venus Express more suited to operating around this particular planet.

Venus: hot and harsh

Flying to an inner Solar System planet like Venus, at half the distance to the Sun as compared to Mars, means that the effects of solar illumination and ionising radiation on the spacecraft are much higher. In fact, the heating of the spacecraft is four times greater at Venus than at Mars. To keep Venus Express at safe temperatures, the radiators on its surfaces have therefore been increased in both area and efficiency. The spacecraft's protective jacket, known as 'multi-layer insulation' or MLI, is composed of 23 layers, packaged differently from those on Mars Express. Moreover, the MLI on Venus Express is gold instead of black in colour, which allows it to reflect more radiation. In general, Mars Express was designed to keep warm, while Venus Express needs to stay cool.

Plenty of electrical power

The Sun is twice as strong at Venus as on Earth, so there is plentiful solar radiation to power the spacecraft. Venus Express's solar arrays could therefore be made smaller (almost half the size) than those on Mars Express. The two symmetric solar arrays, with a total area of about six square metres, are based on a 'triple-junction' gallium arsenide (GaAs) technology, rather than the silicon-based technology used for Mars Express. The solar cells, each composed of four layers of gallium arsenide, are more tolerant to high temperatures (up to around 120°C), as well as being able to exploit a wider spectrum of solar radiation. The solar cells are separated by aluminium strips that help to reject heat. Altogether, these aluminium strips account for half of the solar array's total surface area.

When the spacecraft is in shadow (eclipse) or when its power demand exceeds the capacity of the solar arrays, electrical power is supplied by three lithium-ion batteries, which are charged by the solar generated power.

More propellant to catch Venus

The gravity of Venus, which is almost the same as Earth's, is about eight times stronger than that of Mars. This, plus the fact that the gravitational pull of the Sun is stronger at Venus, means that Venus Express needs more energy to brake and be captured into orbit around Venus. This energy is provided by part of the 570 kilograms of propellant onboard (about 20% more than for Mars Express), which constitutes almost half of the spacecraft's launch weight!

Profile of Venus Express

Spacecraft dimensions	1.5 x 1.8 x 1.4 m (excluding solar panels)
Spacecraft mass	1270 kg (including 93 kg of payload and 570 kg of fuel)
Main engine	400 Newton (N) thrust
Thrusters	10 Newton (N) thrust
Solar arrays	Two triple-junction gallium arsenide; 5.7 square metres in total; generating 800 Watts in the vicinity of Earth and 1100 Watts at Venus
Power storage	3 lithium-ion batteries
Antennas	2 high-gain antenna dishes (HGA1 = 1.3 m diameter; HGA2 = 0.3 m diameter); 2 low-gain antennas
Prime Contractor	Astrium, Toulouse (France), leading an industrial consortium of several European companies

Major spacecraft manoeuvres, such as its injection into orbit around Venus, are performed by firing the main engine located at the base of the spacecraft, while minor manoeuvres are effected using four pairs of thrusters located at its four bottom corners. The thrusters are used for small trajectory corrections, for spacecraft attitude changes, and to correct the altitude of the orbit's pericentre approximately once every 50 days. In fact, due to the gravitational pull of the Sun while the spacecraft is further away from the planet, the pericentre naturally drifts upwards at a rate of about 1.5 kilometres per day.

Two antenna dishes

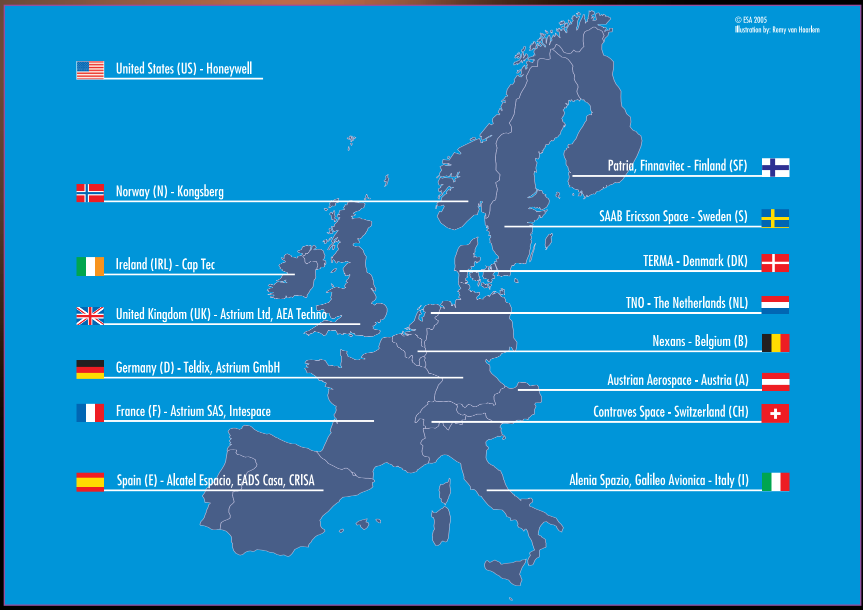
For a spacecraft in orbit around Venus, it is not always possible to point a single antenna dish at Earth while always keeping the cold face of the spacecraft, hosting delicate instruments, away from the Sun. To overcome this pointing constraint, Venus Express has two high-gain antennas mounted on different spacecraft faces. The main high-gain antenna, used for most of the communications with Earth, is a 1.3 metre-diameter dish. The second, smaller high-gain antenna (30 centimetres diameter) is used when the spacecraft is in the part of its orbit closest to Earth (less than 0.78 AU* away). There are also two low-gain antennas onboard, which are used to communicate with Earth during launch, during the first days of the cruise phase and, should the need occur, during severe 'safe modes'.

Navigation and attitude control

Venus Express is a three-axis-stabilised spacecraft. Three different onboard systems can acquire data about its position and attitude (orientation) in space, and any change in its velocity. They include two star trackers, two Sun sensors, and a set of three laser gyroscopes and three accelerometers, which provide the data for re-orienting the spacecraft and the solar arrays when necessary. The actual spacecraft re-orientation manoeuvre or trajectory correction is performed by means of so-called 'reaction wheels' or by firing the thrusters.

Storing data on board

Venus Express's onboard computer is responsible for supervising and managing the overall functioning of the spacecraft, for handling all data acquired by its instruments and sensors, and for distributing commands throughout the whole spacecraft. The computer's Solid State Mass Memory has a capacity of 12 Gigabits and it stores all scientific data collected by the instruments until they can be transmitted to Earth during the appropriate orbital phase.



**One Astronomical Unit (AU) is defined as the mean distance between the Sun and Earth, which is about 150 million kilometres*

The launcher

A Soyuz-Fregat launcher will set Venus Express on its course to Venus from the Russian Baikonur Cosmodrome in Kazakhstan. Soyuz, first launched in 1963, has made more than 1600 flights, and its 98% success rate makes it one of the most reliable launchers in the World. The Soyuz-Fregat is being procured through the European-Russian company Starsem.

The Soyuz vehicle itself has three lower stages, to which the Fregat upper stage and its fairing which houses Venus Express are attached via a conically shaped adapter. Venus Express will use an upgraded version of Fregat, which is both lighter and more powerful than the previous one.

Fregat will be ignited twice. The first firing will move the Fregat - Venus Express composite into an almost circular 'parking orbit' from the sub-orbital trajectory into which it is to be delivered by the Soyuz third stage. The second ignition will put Venus Express onto its interplanetary flight trajectory.

ESA/STARSEM-S.Corvaja

Souyz-Fregat on the launch pad.

Operating Venus Express

From 23:00 hours to 01:00 hours	High (spatial) resolution observations of atmosphere and surface in the Northern Hemisphere (near pericentre)
From 01:00 hours to 09:00 hours	Communication with Earth and transmission of the scientific data
From 11:00 hours to 13:00 hours	Global mapping and study of large-scale phenomena in the Southern Hemisphere (around apocentre)
From 15:00 hours to 23:00 hours	Study of the dynamics of the atmosphere and the cloud systems
Various orbital phases	High (vertical) resolution studies of the atmosphere, through solar, stellar and Earth occultation
N.B. 00:00 hours corresponds to the passage over the pericentre	

All communications to and from Venus Express will be controlled from a single centre, namely the Venus Express Mission Control Centre (VMOC), located at ESA's European Space Operations Centre (ESOC) in Darmstadt, Germany. Immediately after launch, the antennas at ESA's deep-space ground stations at Villafranca, Spain (15 m), New Norcia, Australia (35 m) and Kourou, French Guiana (15 m) will be used for communication and orbit determination. Once the spacecraft is in orbit around Venus, all communications will be routed via the 35 m antenna at the new ESA ground station at Cebreros near Madrid, Spain, and the New Norcia antenna will be used to support the Venus Radio Science experiment (VeRa).

Once in orbit around the planet, Venus Express essentially follows the 'look-store-downlink' mission scenario already implemented for the Mars Express and Rosetta missions. The spacecraft will collect most of its scientific data during a one and a half hour passage through the orbit's pericentre, when it is closest to the surface of the planet. The part of the orbit where the spacecraft is further from the planet will be shared between remote-sensing observations, in-situ observations and periods of data transmission. All data collected are to be transmitted to Earth for about eight hours a day (one orbit around Venus lasts 24 hours). Eight hours of transmission correspond to the downlinking of between 100 and 800 Megabytes of data, depending on the actual distance between Earth and Venus. Throughout the mission, ESOC will provide the Venus Express Principal Investigators with the complete sets of raw data acquired from their instruments, together with any other spacecraft data needed, for further processing and analysis.

The ESA Venus Express Science Operations Centre (VSOC), which is located at ESTEC, ESA's Space Research and Technology Centre in Noordwijk, The Netherlands, is collecting and co-ordinating all observation requests from the Principal Investigators. It also generates and cross-checks the instrument command files that are then passed to ESOC for uploading to the spacecraft. The VSOC is also managing the Planetary Science Archive, where all data will be stored and made available to the wide scientific community once the six-month period during which the Principal Investigators have proprietary rights has elapsed. The data will be archived in the same standardised format that is now applied for all new ESA planetary missions, including Mars Express and Rosetta.

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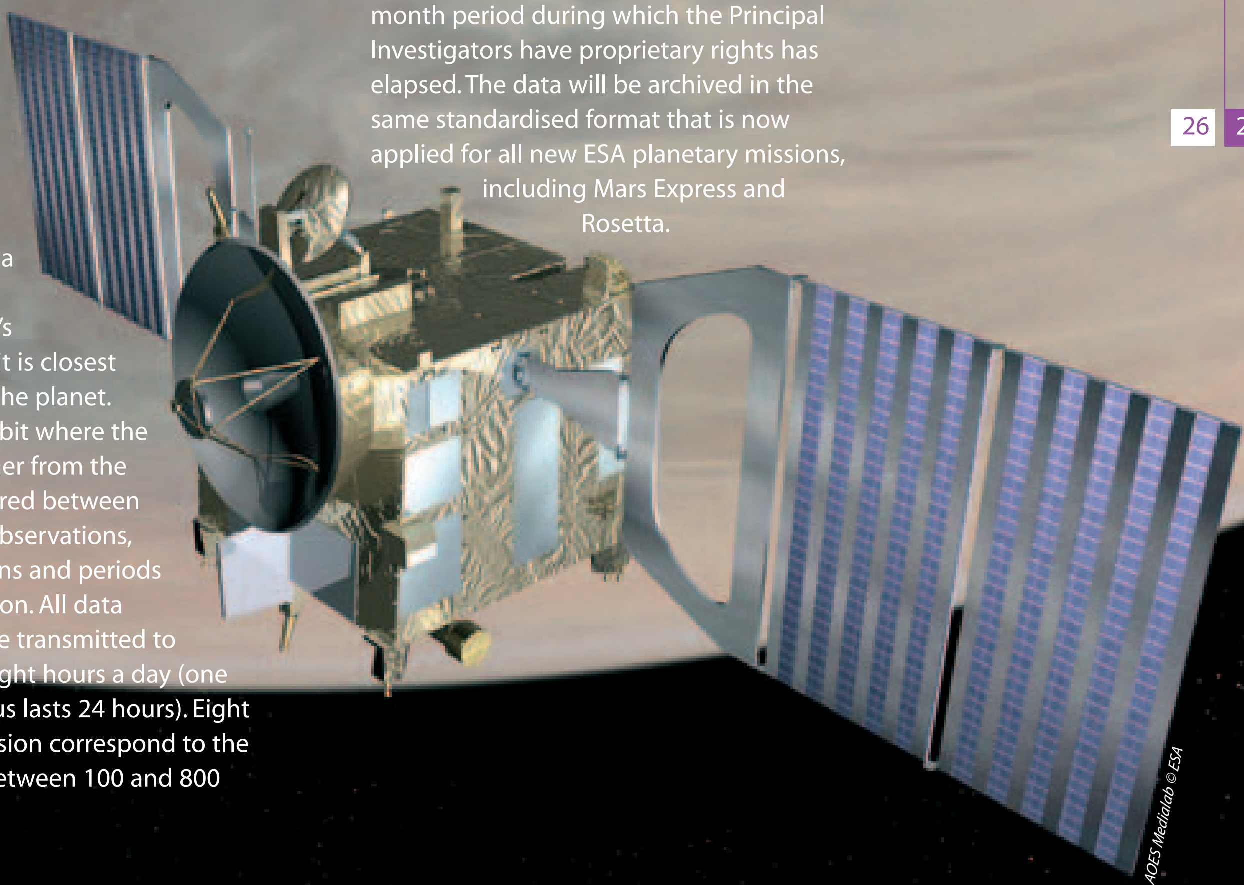
ESA's New Norcia antenna in Australia



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