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The UK’s Strategic Science Investment Agency

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ESA’s mission to the Morning Star
Venus is the brightest ‘star’ in the sky. It is our nearest planetary neighbour, but ever veiled in mystery by a dense, opaque atmosphere. Planetary scientists hope to find out much more when Europe’s first mission to our sister planet sets out in Autumn 2005.

The European Space Agency’s Venus Express spacecraft will be launched from Baikonur Cosmodrome in Kazakhstan aboard a Soyuz-Fregat rocket. After a 5-month journey, it will go into orbit around the second planet from the Sun, while its seven instruments will investigate its local environment and peer beneath the deep layers of clouds for at least 500 Earth days. The aim is to discover more about Venus’s bizarre atmospheric chemistry and complex weather with its furious winds. The mission will map temperatures going down to the surface, where they reach those of molten metals, and look for signs of volcanic activity. It will also study how the energetic stream of charged particles (plasma) from the Sun, called the solar wind, gnaws away at the fringes of the atmosphere.

Scientists hope that learning more about the fearsome forces that govern the Venetian climate will shed light on the dynamics of Earth’s more clement environment. Overheated Venus is very different from Earth. It is the ultimate ‘greenhouse’ planet and may help us to understand the possible future of our own planetary home. Studying the second innermost planet will also give us a better understanding of how the Solar System evolved and why all the rocky planets are so different.

Previous missions

Venus Express is the first mission to the second planet for more than 10 years. In all, more than 20 spacecraft have visited it, the first as long ago as 1962 when the American Mariner 2 successfully flew by Venus, confirming ground temperatures as high as 460°C. In the 1970s and 1980s, a series of American and Soviet spacecraft reached the planet, sending back information about the thickness and chemical composition of the cloud layers as well as surface conditions.

The Russian Venera 7 was the first to land, surviving briefly for 20 minutes or so before succumbing to the crushing pressure and searing heat. A later Russian probe Venera 9 returned the first photos of the planetary surface. In 1978, the NASA mission Pioneer Venus 1 managed to map nearly all of the surface using radar, with further maps produced by Veneras 15 and 16 in 1983. The last mission dedicated to taking a close look at Venus was the US Magellan mission.
which orbited the planet between 1990 and 1994, making detailed radar maps that revealed an arid landscape of highlands, plains and large volcano-like mountains.

Venus Express will be able to build on data from all these missions.

**Recycling space parts**

The European Space Agency (ESA), of which the UK is a member, has a vigorous and ambitious programme of planetary exploration. One cost-effective way to make the most of the huge effort that member countries put into developing technology for each project is to re-use instruments and spare parts designed for one mission in another (each instrument is usually built with a back-up spare). Venus Express was unusual in that, in 2001, ESA asked the European space community for suggestions on how best to re-use its Mars Express spacecraft design quickly while the teams of scientists and engineers responsible for the recent Mars mission were still in place. The new mission would have to be ready to fly by 2005.

ESA selected Venus Express. Not only does the choice offer a complementary scientific challenge but it also satisfactorily employs testing facilities and spare instruments from both the Mars Express project and Rosetta – the 10-year mission ESA sent in 2004 to meet with Comet 67P/Churyumov-Gerasimenko.

A few changes had to be made. Some instruments were dropped and new ones added. And because Venus is twice as close to the Sun as is Mars, the spacecraft would get four times as hot. The spacecraft design therefore had to be adapted to cope with the harsher thermal and radiation environment around the planet. Venus’s gravity is also considerably greater than that of Mars so more fuel is needed to get into a suitable orbit.

Venus Express was developed in a record 3 years, after final agreement, in collaboration with the Italian Space Agency and Russia. It has cost about 200M euros – about the same as a blockbuster movie.

UK teams are participating in the mission, drawing on expertise in planetary atmospheres and plasma environments, and using instruments developed for Mars Express and Rosetta.
Venus is the Earth’s double, having a similar size and mass, and was born out of the same cloud of condensing stellar gas. But its seductive name is a deception. It is a prodigal twin with a hellish climate. The suffocatingly dense carbon-dioxide atmosphere generates surface pressures similar to those found a kilometre down in terrestrial oceans. Layers of sulphur-laden acidic clouds, 35 kilometres deep, enshroud the sluggishly rotating globe. The planet has no surface water; in fact, it may be the driest planet in the Solar System. The surface shows evidence of recent volcanism everywhere suggesting a potential for sudden geological violence. Signs are that Venus’s chemistry is of the brimstone variety.

Bizarre behaviour
Being one-third closer to the Sun than the Earth, you would expect Venus to be a little warmer. However, surface temperatures are, in fact, higher than on Mercury which is half as close again to the Sun, making Venus the hottest planetary body in the Solar System. This is despite the fact that Venus’s dense cloud cover reflects 76 per cent of the incident solar radiation back into space so that the surface actually gets less sunlight than the Earth.

Venus is an enigma. It is a Solar System rebel, rotating backwards compared to the other planets, so that sitting on the planet’s surface you would see the Sun rising in the west and setting in the east. And the day would take a long while to dawn, as the solid planet takes longer to turn on its axis than it does to orbit the Sun. There are likely no seasons, since the planet’s axis of rotation is hardly tilted with respect to its nearly circular orbit.

 Weird weather
Measurements so far indicate that the Venusian atmosphere is far from a placid blanket of gases. It has a puzzling weather system that rages across the planet. High zonal winds rip through the cloud tops reaching speeds of 200 miles an hour at the equator, making the whole atmosphere sweep around the planet, or ‘super-rotate’, in 4 Earth days. Two giant whirlpools of air at the poles suck cold air down towards the hot planet surface. They are surrounded by collars of even colder air. At lower latitudes, huge convective systems, possibly resembling terrestrial thunderstorms, stir up the atmosphere, creating highly complex weather patterns.

Corrosive chemistry
The Venusian atmosphere consists largely of carbon dioxide and smaller amounts of other gases such as carbon monoxide and sulphur dioxide. Interestingly, because Venus has 100 times more atmosphere than Earth, it actually contains the same amount of nitrogen, even though the proportion is small. The thick layers of clouds, which lie between altitudes of 45 and 70 kilometres, are made up of fine droplets of concentrated sulphuric acid.
The solar wind is not deflected and impacts directly with the upper atmosphere which is continually eroded away.

**Why is Venus so different?**

Much about Venus’s wayward behaviour is puzzling. Why is its rotation slow and backward? Perhaps the massive atmosphere has acted as a dragging force. The Venusian weather systems are certainly very different from those on Earth. We don’t understand the superrotation process and why the winds are so strong, and we don’t understand the complex polar structures.

One thing we are pretty sure about is that once absorbed, the solar energy is trapped by the excessive amounts of carbon dioxide, leading to a catastrophic greenhouse effect exacerbated by the sulphurous clouds. But perhaps there is also present-day volcanic activity to contribute to heating.

Venus clearly has some fascinating chemistry both at its surface and in the atmosphere. Mysterious patches exist above the clouds that absorb UV light. Some have even suggested that microbes could be responsible – although it seems unlikely in what is probably the most inhospitable environment in the Solar System.

An obvious difference is that Venus has no oceans, although there is evidence that it may have done in the past. Perhaps water was lost in a similar way as on Mars: the solar wind gradually ate away the primordial atmosphere and water from a planet with a hotter surface than the Earth’s and unprotected by a magnetic field.

The terrestrial climate models we have just don’t work for Venus. Finding out more about the atmospheric dynamics will give us a better understanding of how our own climate behaves. We need to know more about the effects of growing levels of carbon dioxide emissions, which on Earth have increased by 30 per cent since the Industrial Revolution. Information on how clouds on Venus affect the energy balance between the incoming and reflected solar radiation, and how the absorbed energy is transported in the atmosphere, will illuminate mechanisms of global warming.

Probing the dynamic interactions between the surface and the atmosphere, and between the upper atmosphere and the solar wind, will give us clues as to why Venus and Earth took such different evolutionary paths. In this way we will learn more about the origin and evolution of the inner planets, and why life on Earth is so special.

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**A prodigal twin with a hellish climate.**

This infrared image taken by Galileo reveals Venus’s vast weather systems.
Venus Express is due to be launched in mid-October, 2005, although the launch window extends to late November. The launcher is provided by Starsem, which is jointly owned by Arianespace, Aerospatiale, the Russian Aviation and Space Agency, and the Samara Space Centre. Although the Fregat upper stage is fairly new, the Russian Soyuz rocket has successfully launched into space more than 1000 times over the past 30 years.

A polar orbit
When it has reached the transfer orbit, Venus Express will be released from the upper stage and immediately head towards Venus. It will arrive in 153 days. Once captured by Venusian gravity, the 1270-kilogramme spacecraft will take 5 Earth days to manoeuvre into its operational orbit. Because Venus's spin axis is almost perpendicular to the plane of its orbit, it has not been possible to see the poles properly from ground-based telescopes or from spacecraft orbiting the equator, so a highly elliptical orbit has been chosen that will take the spacecraft over the poles. This is particularly important because of the interesting atmospheric dynamics in those regions. At its closest, Venus Express will reach an altitude of 250 kilometres over the north pole and at its furthest, it will be 66,000 kilometres away from the planet at the south pole.

The mapping mission is designed to last for 2 Venusian days, with the first day devoted to covering all latitudes and longitudes at all local times. The second day will be used to fill in any gaps in observations, investigate in more detail any interesting phenomena found in the first day's data, and to monitor any changes.

Experiments and instruments
The payload of the mission comprises a set of instruments designed to study Venus and its planetary environment in detail. They include spectrometers, and imagers covering wavelengths from ultraviolet (UV) to infrared, a plasma analyser and a magnetometer.

The Venus Monitoring Camera (VMC) will image the planet's atmosphere and surface at UV, visible and infrared wavelengths. It will probe the unknown UV absorber at the cloud tops and search for volcanic activity.

The Planetary Fourier Spectrometer (PFS) will monitor atmospheric temperatures and analyse atmospheric composition across the globe, investigating the dynamics and energetics including the radiation balance and surface-to-atmosphere exchange processes.

Two imaging spectrometers, one working in the ultraviolet and infrared (SPICAV), and one operating in the near ultraviolet, visible and infrared (VIRTIS), will also analyse the atmosphere and map temperatures.

A radio sounding experiment (VeRa) will examine the ionosphere, atmosphere and surface of Venus using radio waves transmitted from the spacecraft and received on the Earth.

ASPERA-4 will study the interaction between the solar wind and the atmosphere, while a magnetometer (MAG) is designed to make complementary measurements of magnetic field strengths and direction.

Ground operations
The Venus Express Mission Operations Centre (VMOC) at the European Space Operations Centre (ESOC) in Darmstadt, Germany will monitor and control the spacecraft throughout the mission. Communications with the spacecraft will be via ESA ground stations around the world, especially the newly-commissioned station at Cebreros near Madrid in Spain. One of two high-gain antennas, depending on time of year, will relay scientific data back to the Venus Express Science Operations Centre (VSOC) at ESA's technical centre, ESTEC in the Netherlands.

The mission

Venus Express's different observation modes

The UK has considerable expertise in planetary science
The UK is participating in Venus Express in several ways. Scientists from Oxford University, Imperial College, the Mullard Space Science Laboratory-University College London (MSSL-UCL) and the CCLRC Rutherford Appleton Laboratory (RAL) will be involved in analysing the returned data. The teams have also provided elements of two experiments, MAG and ASPERA 4. Two UK companies, EADS Astrium (Stevenage), and SciSys are also playing central roles in the mission.

Strengths in planetary science

UK has considerable expertise in planetary science and space technology.

Professor Fred Taylor, Halley Professor of Physics at the University of Oxford, was one of the three scientists who designed the mission and proposed it to ESA. Professor Taylor now works with the Venus Express Project Scientist and experiment teams as a Science Coordinator. He is an expert in planetary atmospheres, and says that Venus is his favourite planet (next to the Earth!).

Teams led by Dr Andrew Coates, Head of Planetary Science at MSSL-UCL and Professor Manuel Grande, Head of the Planetary and Magnetospheric Physics Group at RAL, have provided key components of ASPERA-4, which is the flight spare of the ASPERA-3 instrument on Mars Express. It consists of four sensors: two to image the solar wind/planet interaction (the neutral particle detector and imager, NPD and NPI) and two to measure directly the solar wind interaction (the electron spectrometer, ELS, and ion mass analyser, IMA). RAL is providing the microchannel plate detectors used in the NPD, and MSSL leads the ELS experiment.

Professor André Balogh, Head of Space Physics at Imperial College London, leads a team that has built magnetometers for several missions, Ulysses, Cluster, Cassini and Double Star, plus the data-processing unit for the Rosetta magnetometer and four other sensors. They have built part of the Venus Express magnetometer experiment which has a new design. It consists of two triaxial fluxgate sensors similar to those on Rosetta, which will map the magnetic field around Venus in three dimensions. One of them is mounted on the end of a metre-long deployable boom. Between them, the two sensors can distinguish between stray magnetic fields due to the spacecraft and the background field in space.

At Venus, the magnetometer and plasma instrument teams will work closely together, to measure the magnetic field and plasma characteristics at the unmagnetised planet’s boundary with the solar wind, with the aim of quantifying atmospheric loss, and comparing the results with those from Mars Express.

Industrial contributions

EADS Astrium in Toulouse in France is the prime contractor for the spacecraft. The propulsion system was designed, built and tested at the company’s UK site in Stevenage. The system controlling the temperature of the chemical propulsion system was also built and fitted in the UK. EADS Astrium is the European leader in planetary exploration, and many of the technologies developed go on to be deployed in other areas, such as civil and military telecommunications, Earth observation and avionics.

SciSys, a leading European software house based in Chippenham, is responsible for the mission-control system. The company was one of the original developers of ESA’s SCOS Mission Control System (also used on Rosetta and Mars Express). SciSys is also part of the team responsible for training the mission controllers – in particular, preparing them for the crucial orbit-insertion manoeuvre around Venus in April 2006. The company recently won an ‘Innovator of the Year’ award for its work in space programmes.