

# Probing the Atmosphere of Venus using Infrared Spectroscopy

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**Summary:** The surface and lower atmosphere of Venus is hidden from direct view by dense sulfuric acid clouds that extend up to 70 km altitude. It is possible to see through these clouds by observing the night-side of the planet at infrared wavelength. Through “windows” at certain infrared wavelengths we can see thermal radiation from the lower atmosphere, and surface. This makes it possible to study the atmospheric composition and properties in regions that would be hard to reach using in-situ probes because of the extreme temperatures and pressures. These Australian-developed techniques are now being used by the European Space Agency’s Venus Express spacecraft. We are also using this technique for continued studies of Venus from the Anglo-Australian Telescope using its new infrared spectrometer IRIS2. The data can be used to study the composition of the atmosphere near the surface, to study the composition and circulation of the cloud layers, and to follow the highly variable oxygen airglow emission, which provides a probe of upper atmosphere chemistry and dynamics.

**Keywords:** Venus, Planetary Atmospheres, Infrared Spectroscopy.

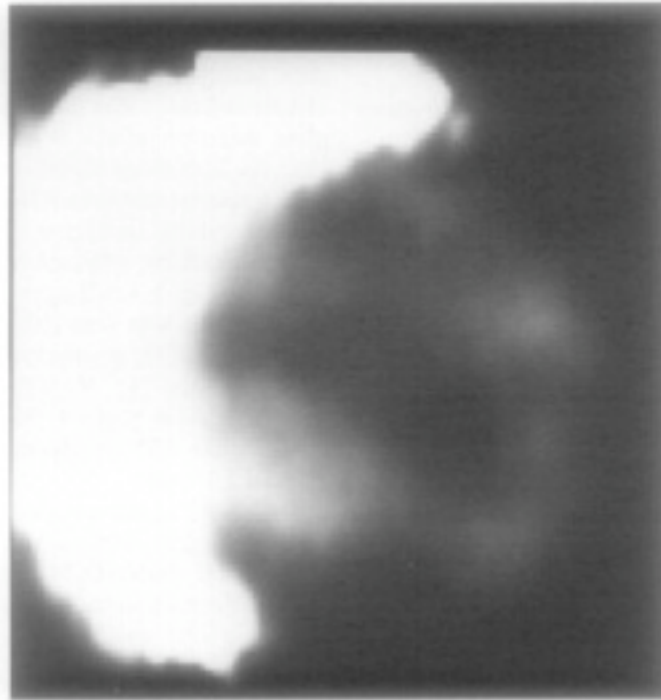
## Introduction

Venus is almost the Earth’s twin in terms of its mass and radius. However, Venus has an atmosphere very different from that of the Earth. With a surface pressure more than 90 times that of the Earth and a composition of more than 95% carbon dioxide, an extreme greenhouse effect heats the surface of the planet to temperatures of 730 K — hot enough to melt lead. The planet is completely enshrouded with clouds, composed of concentrated sulfuric acid droplets that extend up to 70 km altitude.

But Venus wasn’t always like that. It is quite likely that early in its history, when the Sun was 30% less luminous than it is today, Venus would have had liquid water on its surface and have had conditions suitable for life. In fact early Venus is in many ways a more promising location for life than early Mars. But these conditions didn’t last. Understanding why Venus “went bad” may be crucial to understanding the future of our own planet, and the evolution of terrestrial planets in general.

The best current model for the evolution of Venus suggests that a runaway or moist greenhouse process [1,2] led to Venus losing most of its water (through photodissociation, and escape of the hydrogen to space). With no surface water, carbon cycles, such as those we have on Earth, could not operate to remove CO<sub>2</sub> from the atmosphere, while volcanic processes continued to return CO<sub>2</sub> to the atmosphere. The end result was a planet with most of its carbon in the atmosphere in the form of CO<sub>2</sub>, whereas most of Earth’s carbon is buried in carbonate rocks. The same processes could occur on the Earth in about a billion years time when the solar luminosity increases by another 10%. The atmosphere of Venus is not easy to study. The extreme surface conditions make it impossible to

use surface landers as weather stations (as was done with Viking on Mars) as they can only survive for an hour or so. The global cloud cover also makes it difficult to study the atmosphere from orbit. When observing the sunlit side of the planet all we normally see is light scattered off the upper cloud layer. A solution to this problem was found in the 1980's by an Australian astronomer, the late Dr David Allen. Allen observed Venus at Infrared (IR) wavelengths using the Anglo-Australian telescope at Siding Spring in NSW and discovered structure on the night-side of the planet [3 ,4] which he interpreted as being thermal radiation from the lower atmosphere. In certain wavelength "windows" between strong lines of CO<sub>2</sub> and H<sub>2</sub>O it is possible to see the glow of the hot surface and lower atmosphere. Further IR windows at shorter wavelengths were then discovered [5], and in some of these it is possible to see the planet's surface [6]. By taking spectra in these windows we can study the structure and composition of the lower atmosphere.



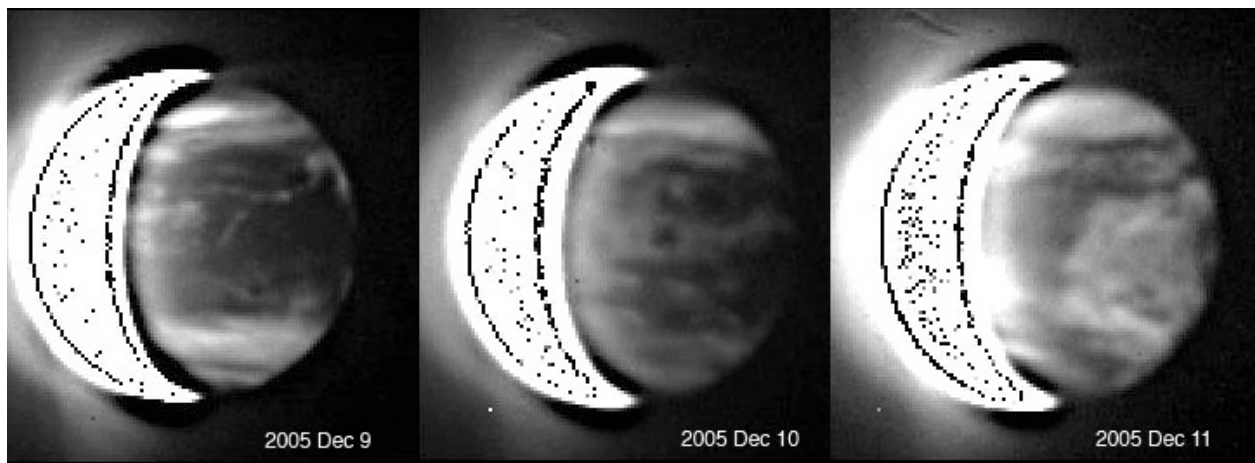
*Fig 1: Image of the Venus night-side obtained in 1985 by David Allen [2] at a wavelength of 2.41  $\mu\text{m}$ . The image was obtained by scanning a single element detector across the planet in a raster pattern. Compare with the images obtainable with a modern IR camera employing a 2D array detector (Fig 2).*

The European Space Agency Venus Express mission is the first spacecraft to study Venus for many years, and is aimed in particular at understanding the atmosphere. Venus Express builds heavily on the infrared techniques developed in Australia. Three of the spacecraft's instruments (VIRTIS, an infrared imaging spectrometer; PFS, a fourier transform spectrometer; and SPICAV) work at infrared wavelengths. They will be used to probe the atmosphere at various levels, and study such issues as the origin of the planet's atmospheric super-rotation (the upper atmosphere rotates in periods of a few days, while the planet rotates very slowly), the composition and chemistry of the atmosphere, and the past and future evolution of the atmosphere.

## **Recent Observations**

When Allen carried out his pioneering observations of Venus, the only way to construct an image at infrared wavelengths was to laboriously scan a single element detector across the planet in a raster pattern by moving the telescope. The recent rapid development of infrared array detectors means that such images can now be obtained in short exposures. At the AAT, the IRIS infrared camera with

a 128 x 128 pixel array detector was used for such observations in the 1990s, and in the last few years a new instrument IRIS2, with a 1024 x 1024 pixel array detector has become available [7].



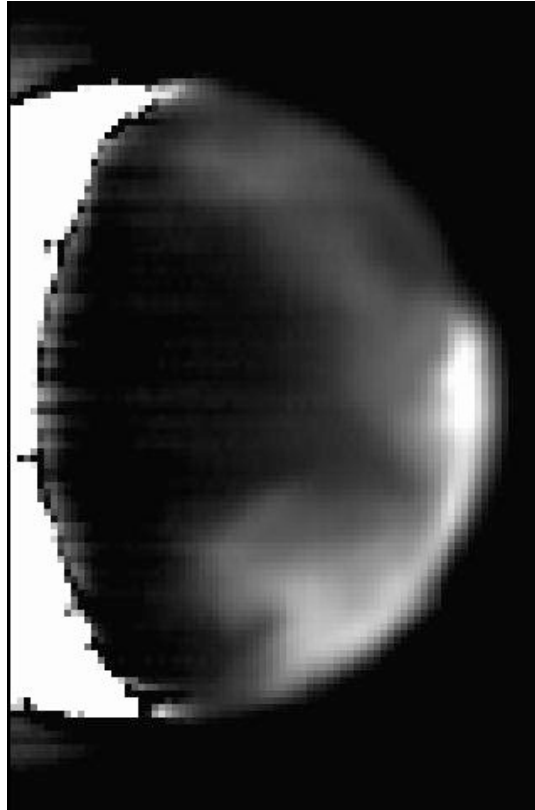
*Fig 2: Images of the Venus night-side obtained in December 2005 using the Anglo-Australian Telescope and IRIS2 infrared camera at a wavelength of  $2.3 \mu\text{m}$ . At this wavelength we see the cloud structure silhouetted against the glow of the hot lower atmosphere. The changes in cloud patterns from night to night are due to the rapid super-rotation of the upper atmosphere.*

These new instruments also make it possible to obtain spectroscopic observations of the Venus night-side. The instruments can be used as slit spectrometers, and by scanning the slit across the disk of the planet it is possible to make three dimensional spectral image cubes, from which we can extract spectra at any point on the planet, or images in any spectral feature.

The spectroscopic images can be used to study the atmosphere of Venus at a range of levels. In the short wavelength windows at  $1.0$ ,  $1.1$  and  $1.18 \mu\text{m}$ , radiation from the surface is seen. By looking at the absorption lines of water above surface topography of different heights it has been possible to determine the abundance of water in the lower few km of the atmosphere [6]. In this way ground-based observations can be used to study a region of the atmosphere that is extremely difficult to study using in-situ probes because of the extreme temperatures and pressures.

At wavelengths around  $2.3 \mu\text{m}$ , the Venus lower clouds are seen with high contrast, silhouetted against the hot lower atmosphere. By imaging Venus at these wavelengths it is possible to study the motion of the clouds and hence the Venus atmospheric circulation at altitudes near  $50\text{km}$  [8,9]. These regions are found to rotate with periods of around 5-7 days, very much faster than the rotation period of the planet of 243 days. The origin of this atmospheric super-rotation is still not well understood. Observations such as these can provide important data to constrain general circulation models of the atmosphere.

At wavelengths of  $1.27 \mu\text{m}$  we see airglow emission from oxygen molecules in the upper atmosphere at altitudes of around  $100\text{km}$  [10,11]. This emission is believed to arise when the atmospheric  $\text{CO}_2$  is photolysed by solar UV radiation on the day-side of the planet. The resulting oxygen atoms cannot immediately recombine as two-body recombinations are spin forbidden, and three-body reactions are rare at the high altitudes (low densities) where this photolysis occurs. Thus the atoms are carried by the upper atmosphere circulation to the night-side, where they can descend to higher density regions at which they can recombine to  $\text{O}_2$  in excited states. This then gives rise to the airglow emission.



*Fig 3: Image of the Venus oxygen airglow at  $1.27\mu\text{m}$  obtained from a spectral scan with IRIS2 on the AAT on December 9 2005. The airglow is brightest around the anti-solar point but shows structure extending a considerable distance across the planet. The sunlit crescent is on the left.*

This airglow emission is found to be highly variable in intensity and structure. Typically it is brightest near the anti-solar point, consistent with a tidal circulation from the day-side to the night-side descending near the anti-solar point. The airglow provides a probe of the chemistry and circulation of the upper atmosphere.

## **Conclusions**

Infrared spectroscopic imaging provides a powerful method of studying the atmosphere of Venus at a range of levels from the surface to the high-altitude airglow. These techniques are being used both by the ESA Venus express spacecraft now in orbit around Venus, and by new ground-based instruments such as IRIS2 on the Anglo-Australian Telescope. Over the next few years this Australian-developed technique should help us to better understand the structure and evolution of the Venus atmosphere.

## **Acknowledgments**

Thanks to Vikki Meadows, Sarah Chamberlain and Andrew Simpson for their help in obtaining the observations shown here. Thanks to the Anglo-Australian Observatory for support during the observations.

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