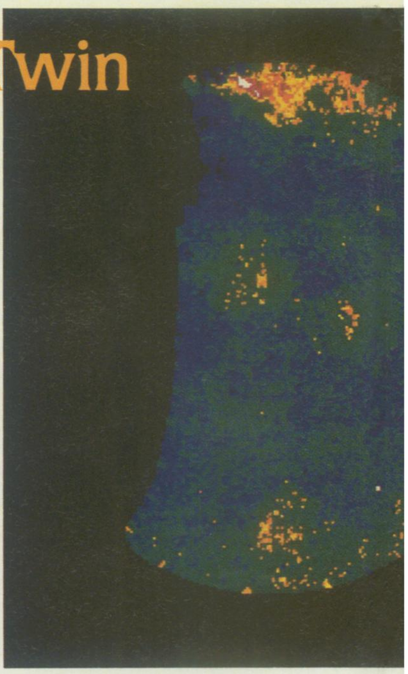
Taking the Temperature of Earth's Twin



Galileo Imaging Team/JPL

Galileo measures the heat of Venus

By RON COWEN

When the Galileo spacecraft swung by Venus in February 1990, it was just for kicks. The encounter gave the craft part of the gravitational boost it needed to keep a future appointment, a 1995 rendezvous with Jupiter. But the Venus flyby had an additional bonus. It marked the first time any spacecraft had imaged the cloud-shrouded surface of Venus in the infrared, recording the heat emitted by the surface.

For two 45-minute intervals near the craft's closest approach to the planet, an imaging spectrometer designed to study the atmosphere of Jupiter and its large satellites sampled the temperature of regions on the nightside of Venus. Just as on Earth, higher elevations on Venus are colder than low-lying regions. Thus, the temperatures measured by Galileo's Near-Infrared Mapping Spectrometer (NIMS) indicate the altitude of different parts of the planet's surface.

While the Magellan spacecraft recently used radar to compile a far more detailed topographic map of Venus, Galileo's infrared measurements may provide new information to help determine the surface composition. Also, notes Kevin H. Baines of NASA's Jet Propulsion Laboratory (JPL) in Pasadena, Calif., the thermal mapping of Venus previews studies that Galileo will do when it arrives at Jupiter. The measurements also foreshadow studies with a newer generation spectrometer, now scheduled to fly on the Cassini mission to Saturn's methane-cloaked moon, Titan.

"The Venus study is proof that we can use spectrometers to get to the surface of any solar system object hidden beneath a thin, cloudy atmosphere – including Titan," says Baines.

He and his collaborators, including team leader Robert W. Carlson and imaging specialist Lucas W. Kamp of JPL, first presented the near-infrared images in March at the annual Lunar and Planetary Science Conference in Houston.

As recently as a decade ago, no one envisioned detecting near-infrared radiation from the face of Venus. To reach an orbiting telescope, for example, heat radiated from the surface must pass through dense layers of carbon dioxide – a gas that absorbs most near-infrared light. The radiation must also penetrate several layers of tenuous clouds, made of concentrated sulfuric acid, that further obscure the hot surface. Thus it seemed certain that the heat-absorbing upper layers of Venus' atmosphere would wipe out near-infrared emissions from the surface.

Indeed, that's just what David A. Allen thought when he pointed a new infrared camera at the nightside of the planet in 1983. The astronomer, who works at the Anglo-Australian Observatory in Epping, Australia, had intended to calibrate his camera by recording the dark, featureless blur of Venus at the near-infrared wavelength of 2.2 microns. Instead, he found a puzzling pattern of light and dark patches that varied over time. Allen figured his camera had broken.

But he later realized that the wavelength at which he observed the unexpected pattern is part of a narrow band of infrared radiation that carbon dioxide doesn't absorb. In other words, certain wavelengths of infrared radiation produced at the surface or in the lower depths of the Venusian atmosphere can pass unimpeded through this "window" in the absorption spectra of the carbon dioxide layer. But while that would explain why Venus didn't appear entirely dark at 2.2 microns, it alone couldn't account for the patchy pattern Allen had observed.

With the help of David Crisp at JPL and Boris Ragent of NASA's Ames Research Center in Mountain View, Calif., Allen concluded that Venus' sulfuric acid clouds, particularly those highest in the atmosphere, obscure near-infrared radiation much less effectively than previously believed. In fact, the topmost clouds, which have the lowest density, are nearly transparent, more like a gauzy curtain than an opaque blanket. The lower clouds are patchy: Denser parts scatter and obscure near-infrared emissions from below; more transparent parts permit the radiation to pass through without being absorbed.

This structure could explain the patchy radiation pattern. A telescope observing Venus at 2.2 microns would thus see dark spots where the clouds obscure the most radiation and light spots where the clouds are virtually clear.

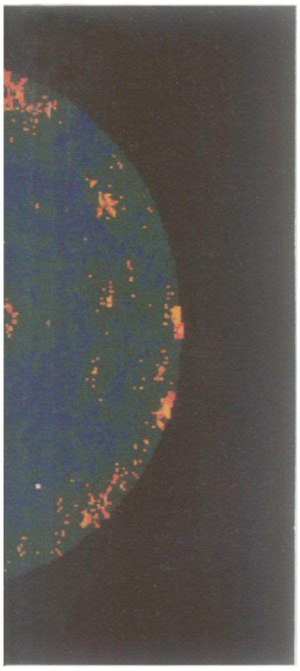
Allen publicized this analysis of his findings in the October 1987 SKY AND TELESCOPE, where it caught the eye of JPL astronomers then putting together a flight plan for Galileo's encounter with Venus. "We were happy as clams that Allen decided to write about his work," recalls Baines. "Our instrument [NIMS] is set up beautifully to do exactly the kind of studies from space that he had done from the ground."

So for some 90 minutes on Feb. 10, 1990, NIMS recorded near-infrared emissions from the nightside of Venus at 17 different wavelengths. (Near-infrared emissions from Venus' brilliantly lit dayside would have overwhelmed most of the NIMS detectors.) Three of the wavelengths observed with NIMS proved particularly useful in taking the temperature of the planet's surface, notes Baines.

All three pass relatively unimpeded through Venus' atmosphere of carbon dioxide, and one of the wavelengths, 1.18 microns, is the thermal emission from the hot, lower atmosphere and surface. But because the patchy sulfuric acid clouds in the upper atmosphere slightly but significantly scatter this light, studying that wavelength alone doesn't accurately measure the surface temperature.

To "decloud" the surface image, astronomers used NIMS to examine infrared radiation at two slightly longer wavelengths, 1.7 and 2.3 microns. These two wavelengths also sample thermal emissions from beneath the cloud layers. However, these emissions come not from the surface but from higher altitudes: radiation at 1.7 microns originates at about 24 kilometers above the surface of Venus; 2.3 microns originates at 34 km.

These emissions act like flashlights, passing through and backlighting the clouds above them. In recording the intensity of light at 1.7 and 2.3 microns,



Map shows altitude of features on Venus' nightside, derived from infrared emissions recorded by the Galileo spacecraft. Blue depicts lowest elevations, red and white the highest.

Baines and his colleagues calculated the amount by which clouds obscure the radiation and how that dimming changes with wavelength. Extrapolating from these measurements, the researchers determined the clouds' dimming influence on emissions at the all-important wavelength of 1.18 microns to get the true near-infrared radiation from Venus' surface.

The team confirmed that the lowlands on Venus are about 100 kelvins hotter than its highlands and that the surface temperature drops with altitude at the rate of 8 kelvins per kilometer. The Magellan mission produced a topographic map with far greater spatial resolution than NIMS. Nonetheless, the spectrometer identified such highland features as Maxwell Montes (at 11 km the tallest mountain on Venus), Bell Regio (at an elevation of 2 to 3 km), and the western edge of Aphrodite Terra (2 to 2.5 km tall).

If Baines and his colleagues can further improve the accuracy of the thermal map generated by Galileo, they hope to use it to identify the chemical composition of Venus' surface. Because different minerals emit different intensities of infrared light, the map may provide an additional set of fingerprints to determine how the surface of Venus may have been chemically altered by the planet's high temperatures and atmospheric pressures.

According to Baines, changes in the concentration of these minerals over time could reveal chemical processes associated with recent volcanic eruptions. The thermal maps might also indicate whether Venus' more mountainous parts have a different surface composition, as some Magellan data suggest. But Baines remains cautious about such applications: "The data [are] mostly fun at this point; the big breakthrough is that we're seeing the surface and lower atmosphere."

He adds that the Venus study suggests NIMS will have similar success examining Jupiter and its four largest moons, including volcanically active Io. However, because Galileo's main antenna remains stuck, the craft can only transmit data to Earth at about one-thousandth the planned rate (SN: 6/20/92, p.406). An onboard tape recorder can store data, but its capacity is limited. For these reasons, NIMS will primarily conduct studies with 10 to 12 key wavelengths, rather than all 408 possible wavelengths it could sample between 0.7 and 5 microns. The Jovian study will mark the first time any spacecraft has taken near-infrared spectral readings of one of the outer planets, Baines notes.

Like Venus, Titan lies hidden behind clouds. But because Titan is so much colder than Venus, researchers can't hope to image its icy surface by measuring thermal emissions.

Nonetheless, the Cassini mission, scheduled for launch in 1997 and arrival at Titan in 2004, will employ a combination infrared and visible-light imaging spectrometer to probe Titan's obscured surface. By measuring the intensity of sunlight at wavelengths that can pierce Titan's methane-rich atmosphere and bounce off the moon's surface, the spectrometer will map the composition of the surface. The instrument – informally known as "Son of NIMS" – should effectively peel away like an onion skin the cloud layers that obscure Titan's surface. Such studies may settle the long-standing debate over whether Titan contains lakes or oceans of liquid methane. □