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The *Magellan* Spacecraft at Venus

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"Having finally penetrated below the clouds of Venus, we find its surface to be naked [not hidden], revealing the history of hundreds of millions of years of geological activity. Venus is a geologist's dream planet.'' —Astronomer David Morrison

This fall, the brightest star-like object you can see in the eastern skies before dawn isn't a star at all — it's Venus, the second closest planet to the Sun. Because Venus is so similar in diameter and mass to our world, and also has a gaseous atmosphere, it has been called the Earth's "sister planet''. Many years ago, scientists expected its surface, which is perpetually hidden beneath a thick cloud layer, to look like Earth's as well. Earlier this century, some people even imagined that Venus was a hot, humid, swampy world populated by prehistoric creatures! But we now know Venus is very, very different.

New radar images of Venus, just returned from NASA's *Magellan* spacecraft orbiting the planet, have provided astronomers the clearest view ever of its surface, revealing unique geological features, meteor impact craters, and evidence of volcanic eruptions different from any others found in the solar system. This issue of The Universe in the Classroom is devoted to what *Magellan* is teaching us today about our nearest neighbor, Venus.

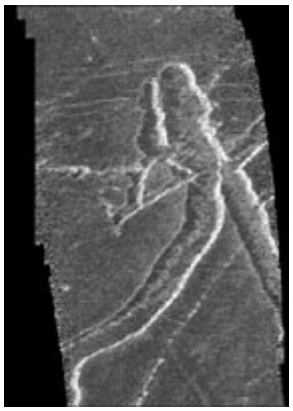
Where is Venus, and what is it like?

Venus orbits the Sun in a nearly circular path between Mercury and the Earth, about 3/4 as far from our star as the Earth is. Venus takes about 7 and one-half months to go around the Sun once, but it turns so slowly on its axis that one complete rotation lasts 243 Earth days! Astronomers have learned that Venus's surface is hotter than any other planet in the solar system, including Mercury (which orbits much closer to the Sun). The average ground temperature is around 900 degrees Fahrenheit — much hotter than a typical oven broiler, and hot enough to melt metals like lead and zinc. Venus' atmosphere is 97 percent carbon dioxide, and is over 90 times heavier than the Earth's. Most of the intense heat on Venus is due to this thick blanket of carbon dioxide, which traps heat very well. (See the box on back page). And astronomers have determined

that Venus' clouds are made of — at least in part — corrosive sulfuric acid droplets. Venus is truly an inhospitable place!

Spacecraft exploration of Venus's surface

Before *Magellan*, more than 20 spacecraft from the U.S. and the U.S.S.R. had already probed Venus' surface and atmosphere. No other planet has received so many terrestrial visitors and yet managed to remain so elusive. The Soviets' early *Venera* craft were crushed by the high pressure of Venus' atmosphere, but later models survived to land on the surface, and sent back the first pictures ever taken on another planet. In the late 1970s and early 1980s, American and Soviet orbiters made the first global radar maps of Venus, but their instruments could only "see'' features larger than a kilometer or more. About 75 percent of Venus seemed to be covered by lava plains, resembling the dark lunar *maria* we see on our Moon. There were two continent-sized land masses visible on Venus, as well as some large mountains, possibly volcanic. And there were indications of meteor impact craters.



This 80-kilometer (50-mile) long trough (dubbed "gumby" by project scientists because of its resemblance to the pliable toy) is at least one kilometer deep. It probably formed when lava channels beneath the surface collapsed after the lava had drained out through vents at the surface.

These tantalizing early observations of Venus told us that the planet had some features similar to our Earth, but the pictures and maps were too coarse to answer many of our questions. Thus astronomers built a new spacecraft, *Magellan*, that would use modern radar technology to make images of the surface much sharper than ever before.

Magellan — a "recycled'' spacecraft

The *Magellan* mission was originally approved in 1980, but had to be simplified due to budget pressures. The modified spacecraft was based on existing designs, and its construction included spare parts left over from other space missions. For example, *Magellan*'s medium-sized antenna comes from the *Mariner* 9 project, and its main 3.7-meter (12-foot) mapping and communications antenna is a spare from *Voyager*.

Magellan was launched from Cape Canaveral on May 4, 1989, aboard the space shuttle *Atlantis*. The spacecraft arrived at Venus on August 10, 1990, after traveling more than 1.3 billion kilometers (806 million miles) in a path that took the probe around the Sun one and one-half times.

How does *Magellan* take pictures through the clouds?

Although visible light will not penetrate Venus' thick atmosphere, longer wavelength radio waves easily pass through the clouds and reflect off the ground, revealing surface elevations and details such as craters, canyons, cliffs, lava flows, and volcanoes. Different types of terrain reflect more or less radio energy, allowing scientists on Earth to determine not only the shape of the Venusian surface, but its approximate composition, roughness, and the size of its irregularities as well. Electronic systems that use radio waves to measure distances and heights are called *radar*, short for *radio detection and ranging*.

Most typical forms of radar systems — called *real aperture radar* — send out one signal at a time, and process each echo by itself, before sending out another pulse of radio energy. The *Magellan* spacecraft uses a special technique called *Synthetic Aperture Radar* to gather extremely detailed pictures of the Venusian terrain. *Magellan* sends out several thousand radar pulses each second, and its SAR system uses fast computers to accumulate multiple echoes, received from many locations simultaneously, as the spacecraft flies over the surface. *Magellan* stores the data, and transmits it back to Earth at the end of each 3 hour, 9 minute orbit. Scientists then process the data, factor in how fast *Magellan* was moving as it received the echoes, and create wonderfully detailed images. In a sense, using SAR is like taking many pictures, from many different angles, of every feature along a path, creating a very precise, almost three-dimensional image. *Magellan* can see features on Venus more than 10 times sharper than any previous radar images taken from Earth or orbiting spacecraft.

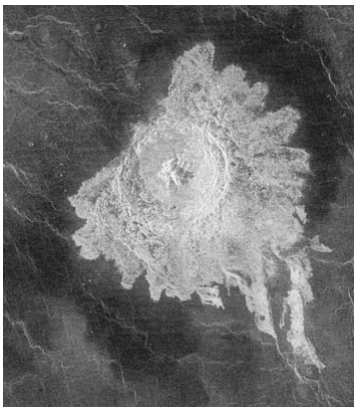
Magellan's Synthetic Aperture Radar allows the spacecraft to photograph details as small as 120 meters across. *Magellan*'s computers can take in 36 million bits of data each second. In fact, the spacecraft has already sent back more data on Venus alone than had been acquired in total from all previous space missions, to all of the planets.

What has *Magellan* revealed about Venus?

Magellan has photographed a remarkable assortment of new features and terrain on Venus; some have never before been seen in the solar system. Unlike Earth, Venus' heavy atmosphere and lack of liquid water or ice keep the planet's surface from eroding substantially. Many of these unique surface features are hundreds of millions of years old — far older than much of our planet's surface, but still much, much younger than the heavily cratered ancient surfaces of Mercury.

Unique kinds of impact craters

Magellan has sent back beautiful images of impact craters on Venus, formed when large meteors plummeted through the planet's atmosphere and struck the ground. Smaller meteors burn up completely in the thick Venusian air. Colliding with Venus at about 20 kilometers per second (12 miles per second, which is over 43,000 miles per hour!), the surviving meteors release a tremendous amount of energy. The collision utterly vaporizes the incoming object and the surrounding ground. Surface material is blasted out, forming a crater, and lava trapped miles below the ground can be released. On Venus, the atmosphere is so thick that the material thrown out by the impact doesn't fly very far, but the surface temperature is so hot that it stays molten, and oozes away from the crater. Thus the craters on Venus look different from those on any other planet.

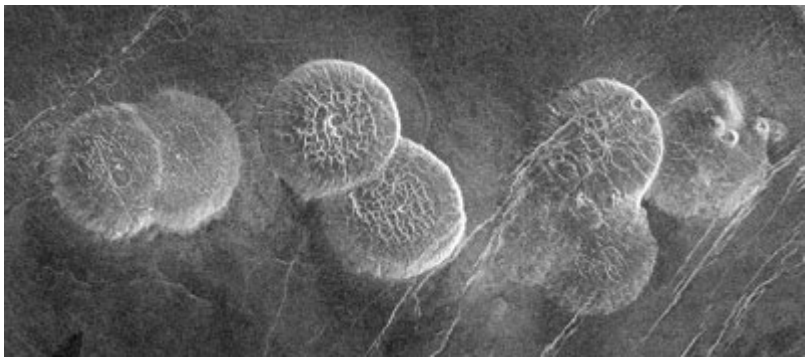


The impact crater Aurelia, about 20 miles across, is surrounded by a thick blanket of ejected material. A small "tail" of melted rock flowed away from the crater to the lower right. Aurelia was Julius Caesar's mother.

One way to tell the age of Venus' surface is to count the number of impact craters. On the plains we see only about 15 percent of the number of craters on the Moon's lava plains; these results tell planetary geologists that lava must have covered many of the craters in the "recent'' past, and that Venus was geologically active. *Magellan* also revealed multiple craters in a tight grouping, formed when the dense atmosphere broke up an incoming meteor into pieces that struck near each other. And still other craters were surrounded by streaks of dark material blown by a slow wind. In the extremely thick, 900 degree Venusian air, a "wind'' of 3-4 miles per hour is really more like a slow current at the bottom of the Pacific Ocean.

Volcanoes, Pancakes, and Coronae

Venus is literally covered with volcanoes, but *Magellan* has not yet observed any actively erupting. Hundreds of thousands of small domes 2 — 3 kilometers across, and perhaps one hundred meters high, dot the plains. These are *shield volcanoes*, similar to those that formed our planet's Hawaiian Islands, and they form over hot spots in Venus' crust. In other locations, volcanoes appear where thick, sticky lava oozed into 25- kilometer wide pancake-like puddles, typically less than a mile high. As the pancake dome of lava cools, the hot material underneath pushes and cracks the surface. On Earth, geologists have identified similar kinds of features near Mono Lake in California, but those on Venus are much larger. And *Magellan* has revealed hundreds of broad circular features called *coronae*, which appear to be blobs of hot lava that rose, created a large bulge or dome in the surface, and then sank, collapsing the dome and leaving a ring that looks like a "fallen souffle.'' These are also unique, never before seen on any other planet or satellite in the solar system. Other new volcanic features seen by *Magellan* included what some astronomers have dubbed "arachnoids'', because they look like spider bodies connected by a web of fractures.



Pancake domes.

Venus also has some very large volcanoes. One of the largest, called Sif Mons (named after the Scandinavian Grain Goddess Sif, whose long golden hair is the autumn grass), is about 500 km across, but only 3 km high;

Sif Mons is broader but lower than the Hawaiian volcano Mauna Loa. The lava flows from Sif are up to 500 km (more than 300 miles) long — longer than any on Earth.

How does Venus' surface compare with Earth's?

On our planet, the crust is really a set of lighter "plates'' floating on heavier molten lava. Where the plates buckle or collide, mountain ranges can form; where they rub together, zones of earthquakes and volcanoes occur. We use the term "plate tectonics'' to describe these motions of our surface. But Venus does not appear to have plates like Earth. Instead, *Magellan* has shown us that the geology of Venus seems dominated by hot currents and hot spots beneath the crust, which push and stretch the surface. In the process, blobs of hot lava bubble up to form large land masses, mountains, and the volcanic pancakes and coronae mentioned earlier. Scientists have called the unique geology of Venus "blob tectonics.''

What is the next step in *Magellan's* mission?

Magellan has successfully concluded its primary mission, and has mapped 84 percent of the surface of Venus over 243 days (one complete rotation of the planet). The probe is now continuing to map Venus, filling in the gaps from the first pass. The spacecraft will look for changes in terrain that might indicate large-scale winds or active volcanoes. Scientists will also try to measure the slight changes in the planet's gravity as the probe flies over areas of high density. *Magellan* speeds up and rises a few meters as it passes over high density areas (which have more gravity), and it slows down and falls closer to Venus as it flies over a lower-density region. Data can be analyzed to help us determine the large-scale composition of Venus' crust. Eventually, scientists will change *Magellan*'s orbit to make it follow a close circle above Venus' atmosphere, allowing even more sensitive gravitational measurements to be made.

If Venus is such an uninviting place, why are we interested in it?

True, Venus is not likely to be a place for people to colonize — or even visit on vacation — since its surface conditions are so uninviting. But *Magellan* is helping us to understand our own planet's history by providing a glimpse of Venus' very different terrain. Without Earth's effective weathering processes of wind and rain, Venus maintains its tectonic and volcanic features for long periods. Scientists can study the planet's carefully preserved history, and learn more about volcanoes and lava flows. *Magellan*'s observations are also teaching us about the movement of a planet's crust as heat escapes from the interior. Furthermore, if — as some scientists suspect — human activity and pollution on Earth is loading our atmosphere with material that could slowly increase our own global temperature, studying the extreme conditions on Venus may help us understand our own future. And, of course, Venus is the closest example of another world — and another global arena in which to exercise our curiosity about where we live, and how we got here.

Reading List

- Beatty, K., "Venus in the Radar Spotlight'', *Sky & Telescope*, July 1991, p. 24
- Burnham, R., "Venus: Planet of Fire'', *Astronomy*, Sept. 1991, p. 32. (See also "Update on *Magellan*'', *Astronomy*, Feb., 1991, p. 44.)
- Saunders, S., "The Exploration of Venus: A *Magellan* Progress Report'' in *Mercury*, Sept/Oct. 1991.
- Saunders, S., et. al., "*Magellan* at Venus'', *Science*, Vol. 252, pp. 247 — 297, 12 April 1991. (Technical)

Why is it so hot on Venus?

Soviet and American unmanned probes that landed on the surface of Venus reported temperatures around 900 degrees Fahrenheit, day or night. Part of the reason for the high temperature is that Venus is closer to the Sun than we are — but that's by no means the whole story! Most of the heat on Venus is due to the peculiar heat-trap its atmosphere provides, caused by the *greenhouse effect*.

Venus' massive atmosphere is made mostly of *carbon dioxide*, a gas that is transparent to visible light from the Sun but which almost completely blocks *infrared* light (sometimes called heat radiation). On Venus, sunlight filters through the clouds and heats up the rocky surface. The rocks then "glow'', and re-radiate infrared heat, but the carbon dioxide atmosphere doesn't allow that infrared light to get out into space. Instead, its energy is trapped in the atmosphere, adding to the heat provided by sunlight, and turning Venus into a gigantic furnace.

Ordinary window glass behaves in much the same way on Earth as carbon dioxide does on Venus. Imagine a car parked in a sunny parking lot with the windows rolled up. Sunlight gets through the windows, and warms up the car's interior. The seats then radiate that heat as infrared light, which is trapped by the windows; glass doesn't allow the heat radiation to escape easily. Heat builds up inside the car, and when you open the door . . . Whew! It's *hot*. In a way, Venus can be thought of as a car that's been left in a sunny parking lot for four billion years with the windows rolled up!