Air and Space this Week

Item of the Week

MAGELLAN VENUS ORBITER

Originally appeared April 29, 2024

KEY WORDS: Magellan Venus SAR

The Magellan *spacecraft was launched on board Space Shuttle* Atlantis *(STS-30) 35 years ago this May 4. Its data are still among the best available to help us understand Venus, an important, but enigmatic, planet.*

WHY IS VENUS IMPORTANT?

Venus is often referred to as "Earth's Fraternal Twin," and rightly so. It is about the same size and mass as the Earth, meaning it has about the same bulk density, which implies that the two planets are made of the same "stuff," more or less. Yet, Venus' surface temperature is enough to melt lead, and its atmosphere's density is about 90x that of Earth's and is almost all carbon dioxide. Venus being somewhat closer to the Sun would cause one to expect Venus to be hotter than Earth, but this is ridiculous. Unless you realized the cause of the difference.

A huge amount of carbon in Earth's surface environment resides in biological materials, plant and animal, and in the buried and altered versions of plant (coal), animal (oil), and geological (limestone) material. Think about it; plants create energy from sunlight, and animals eat plants, therefore, coal, oil, and some natural gas are all ultimately stored solar energy!

If all of Earth's surficial carbon were taken from its present location and dumped into the atmosphere, it would be 90x denser, too, and mostly carbon dioxide, just like Venus. CO_2 molecules absorb longer infrared energy but are transparent to visible light. Venus' atmosphere behaves like the glass in a greenhouse; sunlight heats the surface with visible light, and the surface can't re-emit that energy as infrared because the atmosphere blocks it.

For more on Venus and its importance in understanding Earth, see this archived Item of the Week here.

Venus is also different from Earth in other respects. Venus has such a slow rotation rate that its "day" is actually longer than its "year," and to top that, its rotation is retrograde (opposite of the direction of its orbit), unlike Earth's.

Three related and very important questions arise from the characteristics of Venus. First, was Venus ever more Earth-like in its past; second, what made Venus' surface environment like it is today; and third, are there "tipping points" in Earth's climate that could cause a shift to fatal, Venus-like conditions!?!

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After all, we are conducting a large-scale unconstrained experiment in the only "Petri Dish" in which we can live …!

PREVIOUS MISSIONS TO VENUS

Venus has been a target of many spacecraft missions since the dawn of planetary exploration in early 1960s. Orbital mechanics limit launch windows for spacecraft traveling to Venus to about every two years. Twelve missions were flown in the period 1962-1967; eight of them failed because of their rocket booster (common in the early days); three more suffered communications failures (also common). Only one was successful, *Mariner 2*, which was launched on August 27, 1962, and flew by Venus on December 14, 1962 (which is, coincidentally, ten years to the very day before the last Apollo Moonwalker's footprint was made!). Rockets and electronics got better quickly in the mid-60s, and both Spacefaring countries began scoring mission successes. The Soviets had bigger rockets than the U.S., and could launch much heavier payloads, so the focused more on successes at Venus rather than elsewhere, because their heavier landers could survive the harsh surface conditions long enough to make some measurements and send the data, and pictures, back to Earth.

Both the U.S. and the U.S.S.R. were concentrating on publicity-worthy "firsts" with their early Space programs. The Soviets, in particular, wanted to be the first nation to land on Venus, or at least hit its surface. Their first attempt was a launch failure (4 February 1961); the spacecraft involved did not survive long enough to get an "official" name. Their second attempt, *Venera 1*, was intended as an impactor, but missed; it actually flew-by Venus on 19 May 1961, but long after its communication system had failed. Both countries made attempts during the 1962 launch window. Our *Mariner 1* was destroyed by the Range Safety Officer after its booster went haywire (22 July 1962). Their third landing attempt launch failed (25 August 1962), but our *Mariner 2* worked as planned. Two more Soviet attempts in 1962 failed to leave Earth orbit, as did three of the four attempts during the 1964 launch window; the fourth flew by Venus on 14 July 1964, but its communication system had failed beforehand.

The Soviets went 0-for-3 in the 1965 launch window. Two missions were designed as fly-bys. *Venera 2* did fly-by, but with a dead communications system, and *Kosmos 96* blew up when it attempted to leave its parking orbit. The third mission, *Venera 3*, was designed to land on the surface and it actually did so, giving the Soviets a "first," however, the communications system failed during atmospheric entry and no data were returned. The U.S. was focusing on Mars and its manned program, and may no attempt to go to Venus in this launch window.

Both nations did a bit better in the 1967 launch opportunity. The Soviets sent two spacecraft, one, *Venera 4,* to make measurement of the venusian atmosphere but not return data from the surface; it succeeded. The other, *Kosmos 167*, failed to leave Earth orbit. The U.S.' effort, *Mariner 5*, successfully flew by Venus on 19 October 1967.

The Soviets had the 1969 launch window all to themselves; our attention was on Neil and Buzz. The Soviets launched two atmospheric probes to Venus, *Venera 5* and *6*, and both were successful.

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Everyone's rocket and electronic technology had improved by the time the 1970 launch window rolled around, and the litany of failures began to abate somewhat. The Soviets launched two landers to Venus in August of that year. One failed to leave Earth orbit, but the other, *Venera 7*, actually landed on Venus and was able to send enough of a message to know that it landed mostly intact. It had rolled over upon landing, but was able to send a small signal, making it the first spacecraft to soft-land on another planet.

The Soviet hit their stride during the rest of the 1970s, with three fully-successful missions (*Veneras 8, 9, 10*), three partially-successful missions (*Veneras 7, 11, 12*), and only three total failures that at most made and stayed in Earth orbit (*Kosmos 167, 359, 482*). The United States flew past Venus on 5 February 1974 with *Mariner 10 en route* to three fly-bys of Mercury (not counted here as a Venus mission), then two fully-successful *Pioneer Venus* missions launched in 1978, one an orbiter and the other an atmospheric probe.

Changes in the Soviet Union ended their Venus exploration effort in the mid-1980s. But their Venera landers had given us images and other data from the venusian surface.

THE MAGELLAN MISSION

Soviet successes extended through the 1980s up to the launch of *Magellan* on **May 4, 1989, thirty-five years ago this week**. The Soviets launched in pairs during all three launch windows of the first half of the decade. *Veneras 13* and *14*, launched in 1981, were a fly-by with a lander combination. *Veneras 15* and *16*, both orbiters, were launched in 1983. All four of these missions were successful. *Vegas 1* and *2*, launched in 1984, were more complex missions, both comprising a fly-by of Venus and dropping an atmospheric probe as they received a gravity assist and redirection to Comet Halley. *Vega 2* was fully successful, and *Vega 1* mostly so. NASA did not even try to mount a mission to Comet Halley…

Part of the problem was budgetary, part of it was target prioritization, and part of it was celestial mechanics. The U.S. was also planning a complicated major mission to Jupiter called "Galileo." Its launch window was small and isolated, and making sure *Galileo* launched then required some rescheduling of *Magellan*'s launch; there was no time or money to go for Halley.

Venus has an extremely thick cloud cover that blocks all visible wavelengths, making imaging of the surface from orbit impossible, at least in the visible part of the spectrum. However(!), venusian clouds are transparent to radar. Radar geology on Earth was being developed at this time, and NASA planned a mission to fly a radar imager in Venus orbit. Called (imaginatively) the *Venus Orbiting Imaging Radar* (*VOIR*), but it was cancelled due to budgetary constraints. The science was so important that the mission was resurrected, but downsized significantly. The new mission was at first called the *Venus Radar Mapper*, but the name was upgraded to "Magellan" after the great explorer. The result was much more than a mapper of the surface; the radar could operate as an altimeter, allowing a near-global topographic map of Venus to be made. *Magellan* also included a sensitive gravimeter to measure variations in Venus' gravity field.

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Magellan had a very tight budget, and NASA had to resort to cannibalizing a number of back-up spacecraft originally built to support previous missions. For example, *Magellan*'s main bus, high- and low-gain antennas, and thrusters were back-ups for the *Voyager* spacecraft; its attitude control system, power distribution unit, and pyrotechnic controls came from the back-up for the *Galileo* Jupiter spacecraft; its medium-gain antenna had been the back-up for *Mariner 9*; other communication system components had been back-ups for the *Ulysses* solar mission; and its solid rocket motor and propellant tank came from the Shuttle program. Only the radar systems, gravitometer, and a few other sundry components were new.

Would you believe that the construction manager for *Magellan* was named Frankenstein?

The radar system was state-of-the-art. It operated in three modes: surface imaging, altimeter, and radiometer. The imaging component produced an image of the surface at much greater spatial resolution (1 km) of its transmitting antenna would otherwise bring, using a tactic called "synthetic aperture radar (SAR)." The SAR images took a little getting used to, because the radar system was sensitive to surface roughness, not the wavelengths of the reflected radar beam. A surface rough on the same size scale as the wavelength of the radar would produce a very bright return; a smoother surface would send almost no radar back to the antenna, which served as both transmitter and receiver. When the SAR image was digitally combined with the data from the radar altimeter, a good 3-D rendition of the surface was possible (for examples, see here and here). The radar's radiometer mode was passive; it measured radio-thermal information, useful in characterizing surface temperatures and their variations.

The radio communications team even pulled the same trick that was developed for *Mariner 4*, garnering atmosphere structure data from the attenuation of radio signals when *Magellan* passed behind Venus.

DISCOVERIES AND IMPLICATIONS

The pre-mission objectives of the Magellan mission were to:

- Obtain near-global radar images of the Venusian surface with a resolution equivalent to optical imaging of 1.0 kilometer (0.62 mi) per line pair.
- Obtain data to allow the creation of a near-global topographic map with 50 kilometers (31 mi) spatial and 100 meters (330 ft) vertical resolution.
- Obtain near-global gravity field data with 700 kilometers (430 mi) resolution and two to three milligals of accuracy.
- Obtain data to help the development of an understanding of the geological structure of the planet, including its density distribution and dynamics.

Magellan's radar system produced the best radar/altimetry map of the almost entire planet, nothing tops it even today over thirty-five years later. The results for the patchwork-collection spacecraft were very impressive, outstripping scientists' most optimistic projections. Here's a list of results (from here):

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- The *Magellan* high-resolution global images provided evidence to better understand Venusian geology and the role of impacts, volcanism, and tectonics in the formation of Venusian surface structures.
- The discovery that the surface of Venus is mostly covered by volcanic materials. Volcanic surface features, such as vast lava plains, fields of small lava domes, and large shield volcanoes are common.
- There are few impact craters on Venus, suggesting that the surface is, in general, geologically young - less than 800 million years old.
- The presence of lava channels over 6,000 kilometers long suggests river-like flows of extremely low-viscosity lava that probably erupted at a high rate.
- Large pancake-shaped volcanic domes suggest the presence of a type of lava produced by extensive evolution of crustal rocks.
- The typical signs of terrestrial plate tectonics - continental drift and basin floor spreading - are not evident on Venus. The planet's tectonics is dominated by a system of global rift zones and numerous broad, low domical structures called coronae, produced by the upwelling and subsidence of magma from the mantle.
- Although Venus has a dense atmosphere, the surface reveals no evidence of substantial wind erosion, and only evidence of limited wind transport of dust and sand. This contrasts with Mars, where there is a thin atmosphere, but substantial evidence of wind erosion and transport of dust and sand.

The Magellan mission was a rousing success, but age was catching up with the busy orbiter by the start of the 1990s. Its solar cells were producing less power, and other minor glitches were occurring. Mission controllers decided to deorbit the spacecraft, but to do it in such a way so the tracking its motions could provide information about Venus' upper atmosphere.

The success of the Magellan mission was made possible by the excellent efforts of many people, but I'd like to mention a few of them: R. Stephen Saunders was the Project Scientist, he's retired now but was a lot of fun doing field work on radar-imaged surfaces in the Mojave; Ellen Stofan was the Deputy Project Scientist, today she's the Smithsonian Institution's Under-secretary for Science and Research (after a stint as Director of the National Air and Space Museum); my good friend a fellow Pe-Te lover Tim Parker, an early observer of ancient shorelines on Mars, and fellow ASUer Greg Michaels.

POST-MAGELLAN

Neither NASA nor Russia have mounted a Venus-only mission during the last 30+ years. ESA's *Venus Express* mission, launched on 9 November 2005 on a Russian booster, was a five-year success in Venus orbit. Japan's *Akatsuki* spacecraft, designed as an orbiter and launched on 20 May 2010, failed to enter orbit on 6 December 2010, but was successfully inserted into Venus orbit on 7 December 2015. The Venus Express mission ended on 28 November 2018, and *Akatsuki*, at the time of this writing, is still operational.

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Several other missions used Venus fly-by(s) to go elsewhere in the Solar system, often using it as a target to test instrumentation. Some data of value were obtained, but Venus was not their primary objective.

A number of Venus missions have been proposed and some are under development. At this time, the only two approved and funded mission to Venus are NASA's DAVINCI and VERITAS.

***Deep Atmosphere Venus Investigation of Nobel gases, Chemistry, and Imaging* (*DAVINCI*)**

DAVINCI is a combined orbiter/atmospheric probe was accepted as part of NASA's Discovery Program on 2 June 2021. Data it is designed to produce will help scientists explore how Venus' atmosphere formed and then changed over time, and the history of water that Venus should have at least once contained. The descent probe will determine atmospheric content in detail and take images all the way to the surface, but it is not designed to operate on the surface itself. These measurements are crucial to understanding why Venus' surface conditions are so different from Earth's. The target launch date for *DAVINCI* is June, 2029.

***Venus Emissivity, Radio science, InSAR, Togography, and Spectroscopy* (*VERITAS*)**

The other approved mission is *VERITAS*, which had a rockier road to approval than did *DAVINCI*. Originally proposed in 2015 to be the 13th entry in NASA's Discovery Program, it was in competition with *Lucy*, a mission to a number of asteroids, and *Psyche*, a mission to the metal-rich asteroid of that name. The latter two became part of the Discovery Program and are underway to their objectives, launching on 16 October 2021 and 13 October 2023, respectively. For more about NASA's Discovery Program, see here.

VERITAS was again proposed for the Discovery Program in 2019, and was funded for further development. It was selected at the same time as *DAVINCI*, but problems with *Psyche* pushed its potential launch date to 2031 at the earliest. A cut in the FY 2024 budget puts *VERITAS*' future in doubt. *VERITAS*' scientific potential is not in doubt, only its funding is.

Magellan's SAR system had a spatial resolution of 1km, which was excellent by 1980 standards. But many important surface features are much smaller than that. The Interferometric SAR system proposed for *VERITAS* has a 30m spatial resolution, more than 30x better. Magellan data were good enough for us to see the larger-scale surface features, but only could hint at the landforms diagnostic of other surface processes. To get a better understanding of how the improvement in resolution means for understanding the venusian surface features, see this diagram from here.

VERITAS would be a logical extension of *Magellan*'s success. IF it flies… And that's the Truth!

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NASA: https:science.nasa.gov/venus

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Previous Missions to Venus

NOTE: Spacecraft that flew by Venus for a gravity assist to Mercury or those testing proof-of-concepts are not included in this Item of the Week.

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Planetary Society: https://www.planetary.org/space-missions/every-venus-mission

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Your absolutely best resource on past planetary missions, to Venus or elsewhere, is Asif A. Siddiqi's fabulous book, *Beyond Earth: A Chronicle of Deep Space Exploration*. You can find it at: https://www.nasa.gov/connect/ebooks/beyond_earth_detail.html.

The Magellan Mission

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Last Edited on 28 April 2024

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