Planetary science's rebirth: Magellan goes to Venus

A remarkable mission to the nearby planet will teach us more about it than all previous U.S. and Soviet missions combined. Marsha Freeman reports.

On May 4, space history was made when the first planetary probe was deployed by a Space Shuttle crew and started on its way through space. For the next 15 months, the Magellan spacecraft will go around the Sun one and a half times and then head back toward its target—Venus. It will be the most technically sophisticated planetary probe in operation, as all of the others operating U.S. planetary probes such as Voyager and Pioneer were launched more than a decade ago.

NASA has sent Magellan on this unusually long journey to nearby Venus in order for the space agency to be able to also launch the Galileo probe to Jupiter this year. Actually, when Galileo is launched from the Shuttle in October, it will spend its first four months in space going to Venus, passing close by and picking up a gravitational assist which will accelerate it toward Jupiter.

In addition to being the first U.S. planetary probe to incorporate 1980s technology, Magellan will also be the first of recent planetary missions to be comprised of only a single spacecraft. The Viking missions to Mars, Voyager to the outer solar system, and even the interplanetary Pioneers were done with two spacecraft, in case one failed.

This new single-spacecraft mission design evolved more from the fact of limited funding available for the space program than 100% confidence that there can be no failures. But unlike the recent and past Soviet planetary disappointments, in which, in the case of the Phobos mission, *both* spacecraft failed, the ability to thoroughly check out the spacecraft while it is still within the reach of the astronauts on the Shuttle does increase the chance of success.

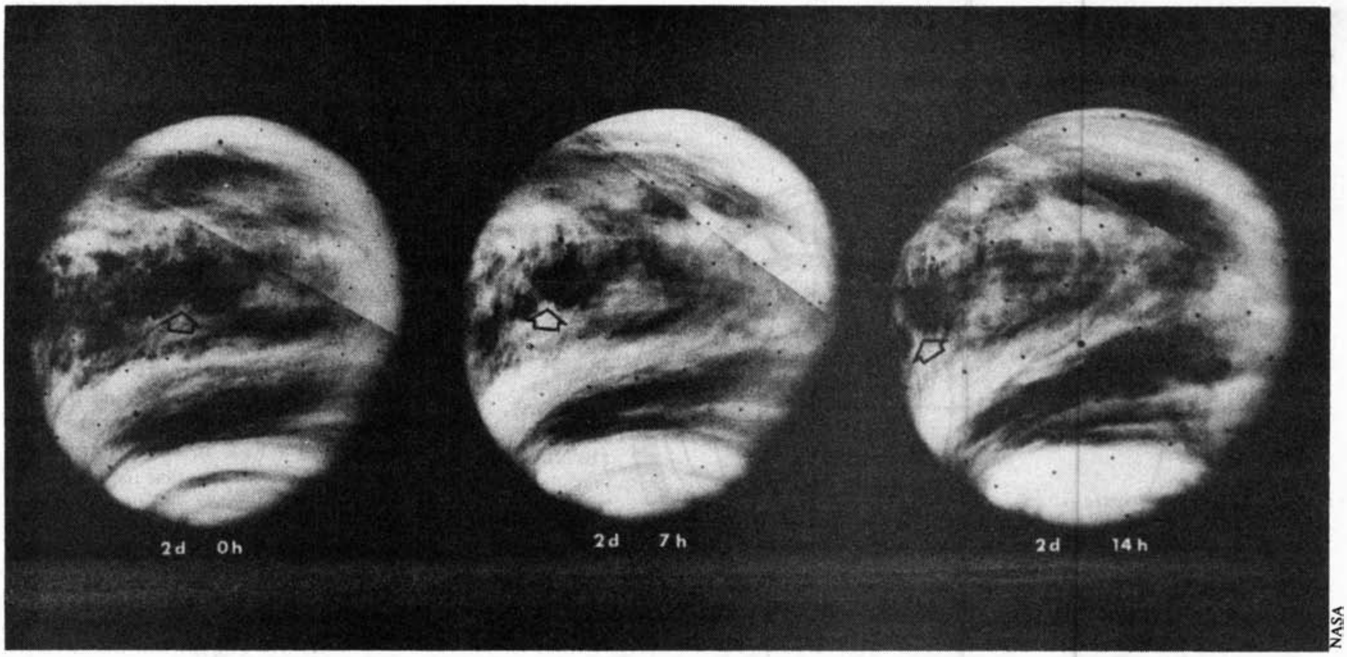
Commenting on the Soviet Phobos failures, in which a faulty computer command from ground control was responsible for one of them, U.S. space managers made the point during the Magellan Shuttle deployment, that ground controllers cannot command the spacecraft into a state "we can't recover from." Magellan can detect some faults on its own and correct them. If it cannot, it "calls home for help."

Venus has been the most difficult planet in the inner solar system to explore because it is shrouded in clouds. Radar imaging spacecraft did finally reveal some surface features of the planet in the 1970s, showing mountains higher than Everest, volcanoes that may still be active, and craters that are older than those on Earth, but younger than those on the Moon and Mars.

For many years, Venus was considered the "sister planet" to Earth due to their apparent similarities. But previous space missions and ground-based radar observations have shown a planet with a surface temperature over 850°F, hot enough to melt lead; the only body in the solar system rotating in a retrograde motion, from east to west; and the only planet to have a longer period of rotation on its axis (its day) than its revolution around the Sun (its year).

When it was confirmed that the differences between the two planets are more striking than the similarities, missions like Magellan were put on the drawing board. Scientists are anxious to take a look at a place that is similar to the Earth in size, distance from the Sun, density, and gravitational field, yet so strikingly different.

In the middle of August 1990, scientists will start to receive data from the Synthetic Aperture Radar which is the primary science instrument on Magellan. For 243 Earth days, or one Venus day, the 7,604 pound spacecraft will collect radar data and transmit it to Earth, showing surface features as small as 300 feet near the equator. We will learn more about Venus from Magellan than from all 20 of the previous



These three photomosaics of Venus were taken at seven-hour intervals two days after Mariner 10 flew past Venus in February 1974. The pictures, taken through ultraviolet filters, show how rapidly the thick clouds covering Venus rotate. Over this 14-hour period, the clouds evidently rotate almost a quarter of the way around the circumference of the planet, yet it takes the planet 243 days to rotate once on its axis.

U.S. and Soviet Venus missions combined.

Looking at the second planet from the Sun with cameras only produces pictures of clouds. To distinguish features on the surface, long-wavelength radar that can penetrate clouds is required. The Synthetic Aperture Radar (SAR) carried by Magellan sends hundreds of speed-of-light radio pulses per second toward Venus below it, and collects back the echo of the signal.

The synthetic aperture creates images with a clarity characteristic not of the 11.8-foot-diameter high-gain antenna on the spacecraft, but of an antenna hundreds of feet in diameter. This is created by using highly sophisticated computer processing on Earth. The computer takes into account precise changes in the position and motion of the spacecraft itself by measuring the shift in frequency (or pitch) of the signal.

The computer will measure the strength of the signal (brightness) that is received back as the echo to the spacecraft, and how long the signal takes to make the round-trip from target and back (the range). The resolution possible using the SAR on Magellan varies with the altitude of Magellan from Venus and its speed. The size of features and objects resolved from the radar data will vary from 300-900 feet.

The Synthetic Aperture Radar will collect data at a much higher rate than it can be transmitted to Earth. This, even though Magellan will transmit data two orders of magnitude faster than the Mars Viking orbiters.

In order to send the information to scientists in as close to real-time as possible, and also because of budget cuts in the beginning of the program, Magellan will engage in an extraordinary repeated series of maneuvers while in the orbit of Venus.

The mapping mission

Magellan will arrive at Venus in August 1990, where it will fire a small solid-fueled rocket to place it into a highly elliptical orbit around the planet. For the next 18 days or so, it will check out its instruments and adjust its position. It will then begin its unusual mapping mission.

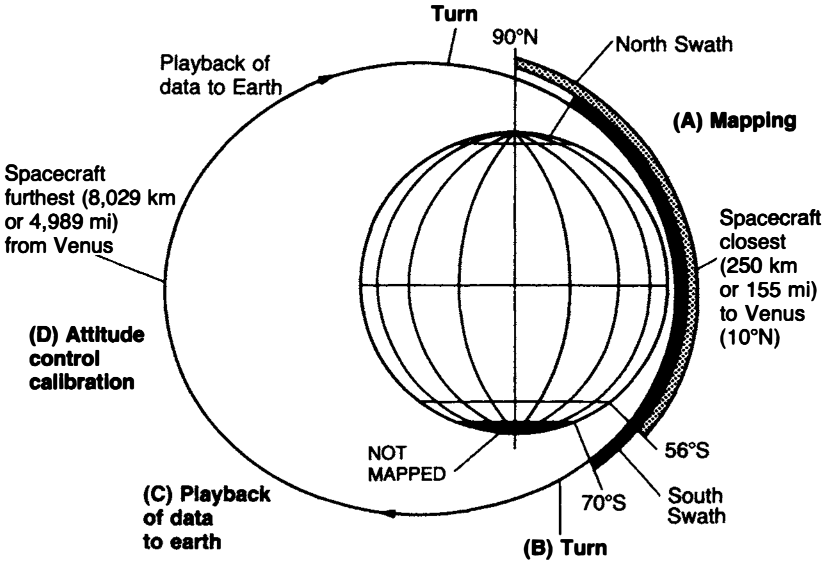
As shown in **Figure 1,** Magellan will orbit Venus pole-to-pole and not around the equator. It will complete this highly elliptical polar orbit every 3 hours and 9 minutes. The spacecraft will be about 155 miles from the planet's surface during its periapsis or closest approach, and 4,977 miles at its apoapsis, or furthest point.

For 37 minutes on each orbit, during periapsis, the SAR antenna will be oriented toward Venus, sending down signals and gathering back echos. During the period of apoapsis, or farthest point from the planet, the entire spacecraft will be turned around and the high-gain antenna will be pointed toward Earth, to transmit the data just collected.

In the middle of this period of apoapsis, data transmission to Earth will be interrupted to allow Magellan's navigational system to make star calibrations to confirm its position. The craft looks at the position of two stars and compares their position at the time to the map in its computer. If need be,

FIGURE 1

Magellan Venus orbital operations



Magellan will start its radar mapping of Venus over the north pole, when the radar is activated at the point labeled North Swatch. During its closest orbit around the planet, denoted by the heavy black line, the SAR will be pointed toward Venus. Then, at point B, the spacecraft will turn, and in the wide swing out toward the left of this diagram, will transmit its data to Earth. At point D, it will do an attitude control calibration to fix its position. and then turn again near the north pole to once again map the planet. The extreme north and south poles will be difficult to map, but Magellan should be able to image 90% of Venus.

Source: NASA

Magellan can slightly adjust its position, to make sure it will be in the right place when it goes back into periapsis.

The data that are transmitted from Venus will be gathered by the 70-foot-diameter radio tracking station antenna at Goldstone, California; one near Madrid, Spain; and in Canberra, Australia. These facilities comprise NASA's Deep Space Tracking Network.

During its mission, Magellan will take a total of 1,852 swaths of Venus. Each swath will be 9,600 miles long by 12 miles wide. Each swath of Venus will be done by moving alternately north and south so that up to 90% of the planet will be covered (Figure 1). Because it takes Venus 243 days to rotate once on its axis, it will take Magellan 243 days to complete a Venus day's worth of mapping.

During its 243-day primary mission, Magellan will make over 7,000 major attitude changes as it turns from the planet toward the Earth on each orbit. If these changes had to be made by firing small thrusters on the spacecraft, it would require 14,800 firings, to cover the three directional axes of pitch, roll, and yaw. Instead, Magellan has gyroscopic momentum reaction wheels which spin, and impart a portion of their rotational momentum when it is needed. Small thrusters are fired only one time per orbit, to restore any lost momentum to the spinning wheels.

While Magellan's high-gain antenna is pointed toward Earth, there are passive radar experiments that can be done with SAR. Variations in the speed of Magellan will be measured every few seconds, and the Earth-based radio tracking system will measure the Doppler shift, or change in frequency due to motion, of the SAR's radio signal. It is assumed that such variations will reflect irregularities due to the planet's density and resulting gravitational field.

The medium-gain antenna on Magellan receives commands by and sends engineering data from Magellan during its 15 month transit through space, and the low-gain antenna is an alternate means of commanding the spacecraft in case of emergency or failure.

Mounted on the side of the spacecraft is the altimeter antenna, which is pointed down at the surface of Venus (see **Figure 2**). This instrument should be able to measure the height of surface features to an accuracy of about 100 feet.

Two solar panels will provide Magellan with 1,200 watts

TABLE 1

Characteristics of Venus

Radius	3,630 miles, 95% of Earth
Rotational Period	243 Earth days
Period of Revolution	225 Earth days
Distance from the Sun	64.92 million miles
Density	5.2×water, Earth is 5.5 times
Surface gravity	.9×Earth
Atmospheric pressure	90×Earth
Surface temperature	at least 850°F
Atmosphere	96% carbon dioxide, 3% nitrogen

of electrical power. Unlike the two Voyager craft, which are journeying further and further away from the Sun and require nuclear power sources, since Venus is a little less than 65 million miles from the Sun, Magellan can use solar panels.

What the scientists hope to find

For the past few years, space quack Carl Sagan has looked forward to the further exploration of Venus in order to prove his questionable "greenhouse effect" theory. This posits that the Earth will suffer a global warming as carbon dioxide and other "greenhouse" gases accumulate in the atmosphere. Sagan has not yet found out who is burning so much coal on Venus to have raised the surface temperature to over 850°F.

Regardless of such nonsensical linear extrapolations from one planet to another, it has been proposed that volcanoes may have played a part in transporting heat from the interior of the planet through the atmosphere of Venus. The evidence of volcanoes has been seen from images taken by the Soviet Venera 15 and 16 probes in 1983, and also from Earth-based images.

Like Mars, which also has an atmosphere, there are signs of "weathering" of the surface of Venus. Mars's thin atmosphere is hardly a whisper, however, and that of Venus is 90 times the atmospheric pressure of Earth's atmosphere. Scientists hope to find evidence of wind erosion, landslides, dune fields, or other indications of the relationship between the lithosphere (land mass) and atmosphere of Venus.

Although Venus is drier than any desert on Earth, the ratio of deuterium to hydrogen in the current atmosphere indicates, according to scientists, that Venus had relatively large amounts of water in the past. Scientists will analyze the Magellan radar data to look for fluvial activity like natural drainage systems, lakebeds, and coastal signatures.

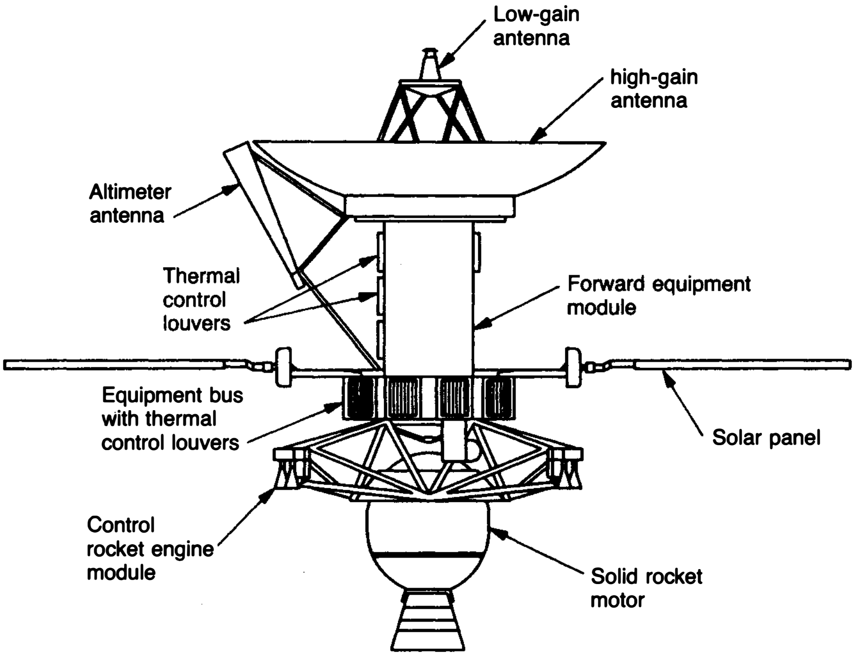
Mission scientists hope to be able to extend Magellan's mission past April 1991, to collect data it would otherwise miss, and to do more precise gravity mapping of the planet.

Due to the relative and changing position of the planets and the Sun vis-à-vis each other and Magellan, though the spacecraft will be in orbit for a full Venus day, there will be a gap in the data when the Sun is between Venus and the Earth, and when Venus is between Magellan and the Earth (see **Figure 3**). On an extended mission, those missing areas could be mapped.

Between 1978 and 1982, the Pioneer Venus Orbiter laid the basis for further gravity studies of Venus, by finding a significant correlation between the gravity field and topography of Venus. This correlation between assumed areas of higher mass and corresponding surface features was found to be different than the Earth, the Moon, or Mars.

On Venus, the amplitude of the gravity anomalies are comparable to the amplitude on Earth, but are much smaller than the Moon or Mars. Scientists expect that the gravity data alone will tell them the mass distribution within the interior of Venus.

FIGURE 2
Magellan spacecraft



The Magellan spacecraft is a compact, high-technology robotic explorer. The high-gain antenna, almost 12 feet in diameter, dominates the configuration of the craft. The solid rocket motor on the bottom is fired to slow Magellan into Venus orbit and is then jettisoned. The thermal control louvers, along with thermal blankets, passive coatings, and heat-dissipating elements keep the spacecraft's temperature between the range of 25-104°F. The two solar panels are extended parallel to the plane of the antenna.

Source: NASA

An extended mission, to continue to process the data Magellan will able to collect, would cost up to $30 million per year for data processing and ground support. Considering that the cost of the mission is over $500 million, to shut off the spacecraft after less than a year for no other reason than money seems hardly defensible.

TABLE 2
Previous missions to Venus

Spacecraft	Arrival	Data
Venera 1	May 1961	Lost contact
Mariner 2	Dec. 1962	First successful planetary flight; approached at 20,000 miles, verified temperature above 800 degrees; saw no magnetic field; no radiation belts.
Venera 2	Dec. 1966	Failed to transmit data
Venera 3	March, 1966	Failed to return data
Venera 4	Oct. 1967	Transmitted data for 94 minutes during entry
Mariner 5	Oct. 1967	Closest approach at 2,480 miles
Venera 5	May 1969	Entered atmosphere deeper than Venera 4
Venera 6	May 1969	Presumed impact
Venera 7	Dec. 1970	Landed and survived 23 minutes
Venera 8	July, 1972	Landed and transmitted data for 50 minutes
Mariner 10	Feb. 1974	En route to Mercury, came within 3, 186 miles; took more than 4,000 photos of clouds
Venera 9	Oct. 1975	Lander and orbiter; saw surface features for an hour, including mountains and canyons
Venera 10	Oct. 1975	Lander and orbiter
PioneerOrbiter	Dec. 1978	Detected atmospheric lightening mapped 93% of planet with radar, saw canyons and continent-sized plateaus,possible volcanoes
Pioneer Probe	Dec. 1978	Multiprobe spacecraft which separated into 5 atmospheric probes; one transmitted for 67 minutes on the surface
Venera 11	Dec. 1978	Landed; detected lightening and sounds like thunder
Venera 12	Dec. 1978	Similar to Venera 11
Venera 15	Oct. 1983	Mapped 25% surface to .7-1.4miles resolution
Venera 16	Oct. 1983	Similar to Venera 15
Vega 1 and 2	June 1985	Sent balloons into atmosphere, and landers

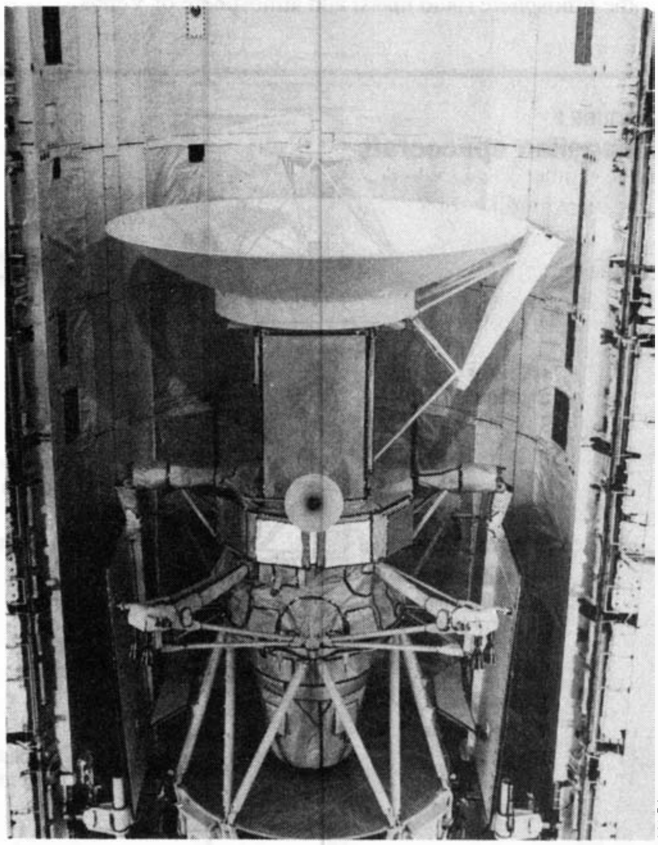
A mission almost canceled

The history of this marvelous Magellan mission represents the rocky road space and planetary science has traveled during the Reagan years. In the early 1970s, the science team at the Jet Propulsion Laboratory (JPL) in California was already planning an advanced radar mapping Venus mission.

In a 1978 pamphlet, JPL stated it was studying the Venus Orbiting Imaging Radar mission (VOIR), which if approved, could be launched in 1983 on the Space Shuttle. The Synthetic Aperture Radar, JPL stated, would be the same developed for Seasat, using microwaves.

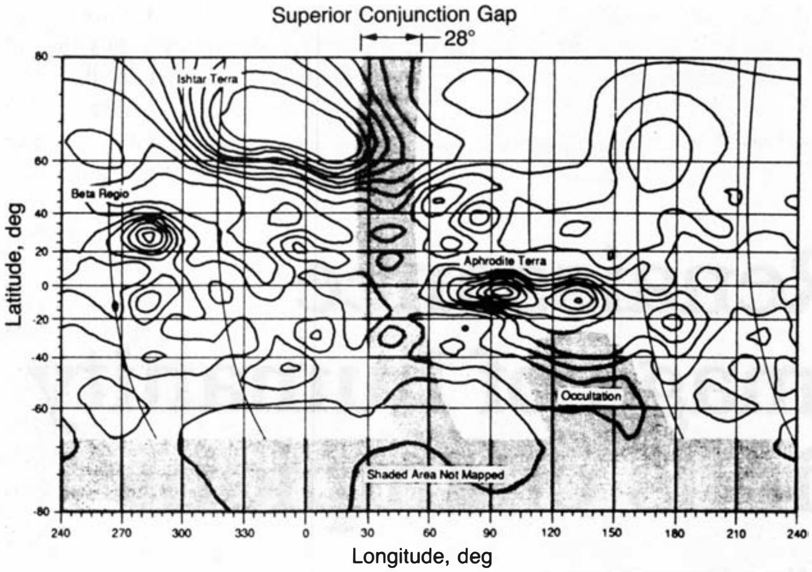
A year and half later, a press release from JPL announced that the Martin Marietta and Hughes companies had been selected to do studies on the VOIR mission spacecraft. They assumed a five-month trip for the craft, which would spend two months in a 185 by 11,800-mile elliptical orbit for a gravity study, and then circularize its orbit at 185 miles for 120 days of radar mapping. They hoped to cover nearly the entire surface of Venus at a six-tenths of a mile, or 2,000 foot resolution, and about 2% of the surface at a high resolution of 328 feet.

A half year later, a new start had not yet been approved, and NASA proposed a May 1986 launch from the Shuttle, a six-month cruise to Venus, and the use of aerobraking to trim


NASA

The Magellan spacecraft.

FIGURE 3
The Magellan data gap



Due to the relationship of the Earth, Venus, the Sun, and Magellan during the Magellan day (243 Earth days) there will be a gap in data collected, shown by the grey shading north to south in this drawing. Extending the mission past the 243 days will allow these gaps in data to be filled in.

Source: NASA

the spacecraft's orbit at Venus. Aerobraking is a way of taking advantage of the friction of the atmosphere of the planet to slow down the speeding spacecraft. It avoids the necessity of carrying along the fuel that retro-fired rockets would need.

As the Carter administration was winding down in early November 1980, NASA announced that Carter was going to request funding for VOIR in fiscal year 1981 to be a new start in the space budget. The estimated cost of the mission at that time was $500-600 million.

But as the Reagan administration came to Washington, all of the space science projects were reviewed. The consensus from the Office of Management and Budget and George Keyworth, the President's science adviser, was that too much money had been projected for solar system exploration programs.

At the end of December 1981, White House budget cutters were on the verge of eliminating everything but the Voyager fly-bys. Hatcheted from the budget was the U.S. half of the International Solar Polar Mission, now called Ulysses.

As the space science community rallied for its very existence, a Solar System Exploration Committee was established to advise NASA on space science missions, and developed a "core program" which began with the Venus radar mapping mission.

The FY84 NASA budget which was sent to the Congress in January 1983, included $29 million for a new start of the newly-named Venus Radar Mapper, (VRM) which now had a price tag of $300 million, or less than half of what JPL had hoped they could spend.

VRM was now scheduled for an April 1988 Shuttle launch, and the costs were to be cut by using already-available hardware. The high-gain antenna was the spare from Voyager, which was flight quality hardware that had been used for testing. An instrument to measure the composition of Venus's atmosphere was eliminated, and the circular orbit was changed to a highly elliptical one to reduce propulsion and aerobraking costs.

But the technology for planetary missions was advancing all the time, and John H. Gerpheide, the VRM program manager at JPL commented at the time that the primary science data gathering of the old VOIR missions had been retained, but the secondary objectives had been eliminated.

In 1986, after a two-year review, the Venus Radar Mapper became Magellan. Due to the Challenger explosion and hiatus in the Shuttle program, Magellan was delayed. That it was launched only a year after planned is a tribute to the creativity of the mission planners and experts in orbital mechanics, and the commitment of the entire space community—both civilian and military—to get planetary science back on track.

Each one of the planets in our solar system is unique. As far as we know, only the Earth supports life. Venus is not one of the planets that will be easily terraformed, but it should teach us a great deal about the formation of the other terrestrial planets around us, and may well shed light on the dynamics and history of our own planet.