



PIONEER VENUS

ORBITER AND MULTIPROBE MISSIONS

an essay by
HAMISH LINDSAY





"Abandon hope all ye who enter here."

Dante – The Inferno

PIONEER VENUS

ORBITER AND MULTIPROBE MISSIONS

Extracted from content available on the
Honeysuckle Creek Tracking Station
website, developed by Colin Mackellar
www.honeysucklecreek.net

Click or scan the QR code below to see the website:



Cover illustration: Original illustration by NASA. Expanded for cover by Glen Nagle.

Mission Facts

Pioneer Venus Orbiter

AKA: Pioneer 12 / Pioneer Venus 1

Launch date: 20 May 1978

Launch time: 0913:00 US EDT / 1313:00 UTC

Launch site: Launch Complex 36A, Cape Canaveral

Launch vehicle: Atlas SLV-3D Centaur-D1AR (AC-50)

Spacecraft Bus: HS-507 / Hughes Aircraft Co.

Spacecraft mass: 582 kilograms / 517 kg dry mass

Spacecraft power: 312 watts (solar array)

Mission duration: 13 years, 10 months, 4 days

Last contact: 8 October 1992

Orbital parameters

Orbital insertion: 4 December 1978

Pericytherion: 181.6 kilometres

Apocytherion: 66,630 kilometres

Inclination: 105°

Period: 24 hours

Orbit decay: 22 October 1992

Pioneer Venus Multiprobe

AKA: Pioneer 13 / Pioneer Venus 2

Launch date: 8 August 1978

Launch time: 0333:00 US EDT / 0733:00 UTC

Launch site: Launch Complex 36A, Cape Canaveral

Launch vehicle: Atlas SLV-3D Centaur-D1AR (AC-51)

Spacecraft Bus: HS-507 / Hughes Aircraft Co.

Spacecraft power: 241 watts (solar array)

Spacecraft mass: 904 kilograms

Bus mass: 290 kilograms dry mass

Large probe mass: 315 kilograms

Small probe mass: 3x 90 kilograms

Mission duration: 4 months, 1 days

Last contact: 9 December 1978

2022:55 UTC (Bus)

2055:34 UTC (Day probe)

Orbital parameters

Heliocentric reference system

Semi-major axis: 0.9 AU / 130,000,000 kilometres

Perihelion: 0.69 AU / 103,000,000 kilometres

Aphelion: 1.01 AU / 151,000,000 kilometres

Inclination: 2.3°

Period: 284 days

Atmospheric entry: 8 December 1978 (Bus/Probes)

Main Bus: 2021:52 UTC

Large Probe: 1845:32 UTC

Small Probes: 1849:40 UTC (North)

1852:18 UTC (Day)

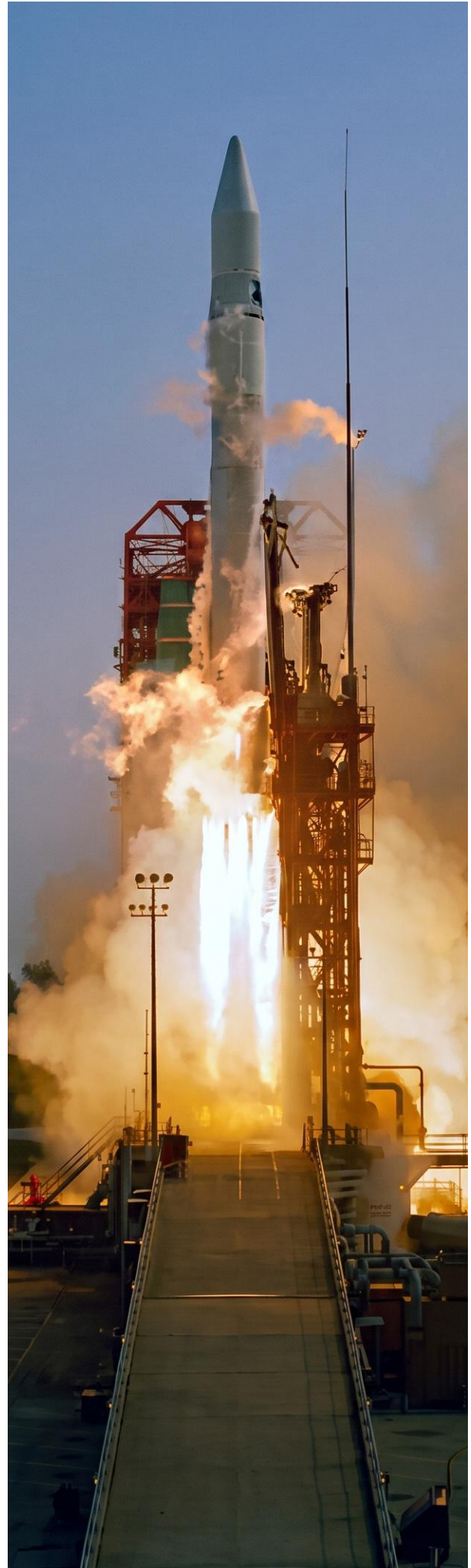
1856:13 UTC (Night)

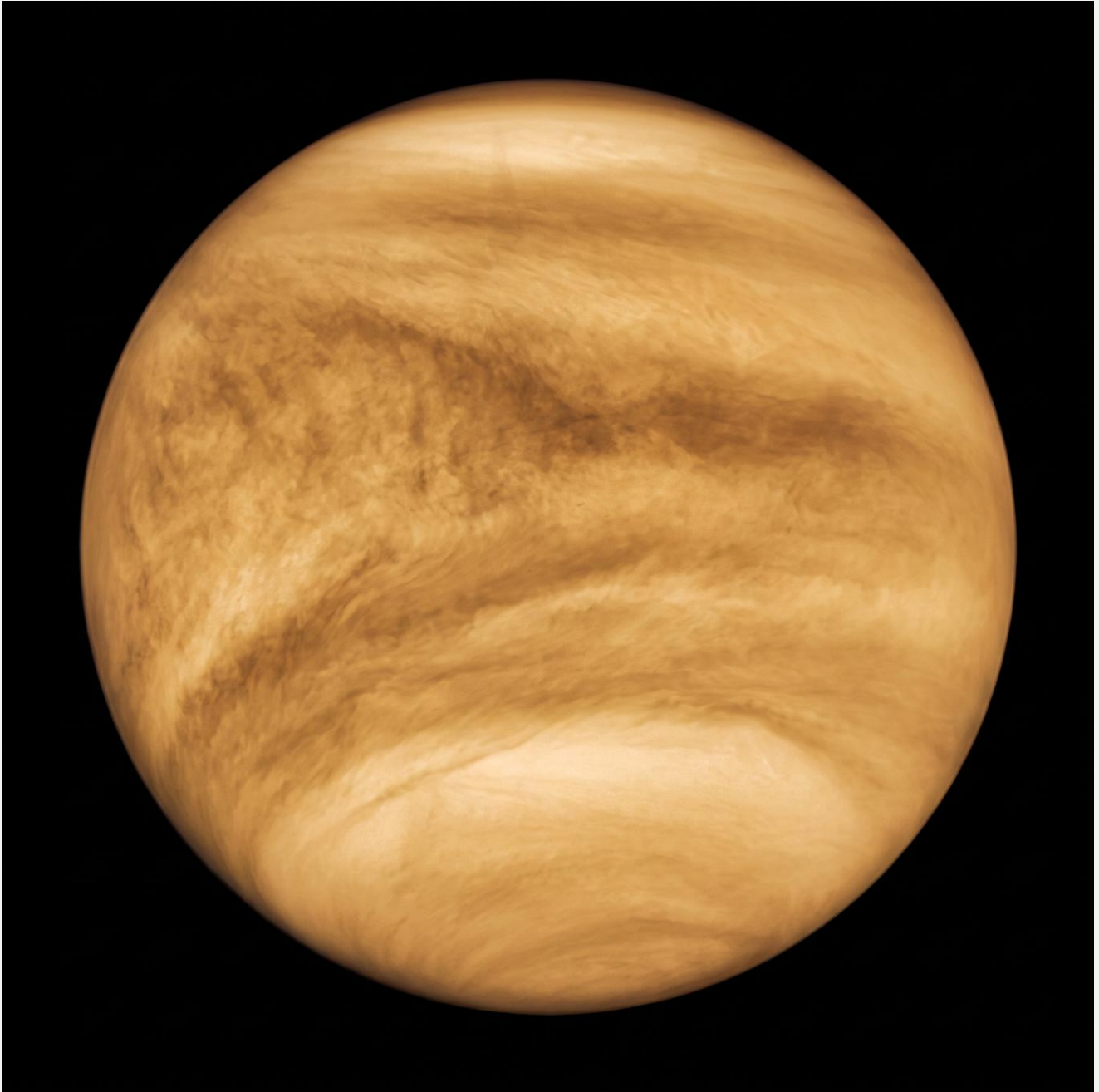
Launch vehicle

Version: Atlas SLV-3D Centaur-D1AR

Stage one: Atlas-SLV3D / MA5

Stage two: Centaur-D1AR / 2 × RL10A-3-3





An ultraviolet image of Venus by Pioneer Venus Orbiter, taken on 11 February 1979 on orbit 68/69 from a distance of 65,000 kilometres. Image: NASA

THE PLANET VENUS

THE SHEPHERD'S STAR

Venus – the third brightest object in our sky after the Sun and Moon was named after the Roman Goddess of Love and Beauty.

It is the only planet with a female name in the Solar System, so the international scientific community involved agreed it would be preferable for all the names of its surface features should follow the female theme.

It is the Morning and Evening Star that glitters so brightly in the dusk.

Sadly, these romantic names and settings belie the world that lies behind the swirling clouds that cover the planet, hiding its secrets from inquisitive eyes behind prying telescopes on planet Earth.

Little was known about Venus before the arrival of spacecraft, as telescopes could never penetrate the opaque clouds always covering the surface.

Because of its brightness, observations of Venus go back to at least 3000 BC.



Mariner 2 was built by JPL and final assembly at the Atlantic Missile Range, Cape Canaveral. Image: NASA/JPL

Homer celebrated it in the twenty second book of the Iliad; as a Morning Star it was named Lucifer, the Bearer of Light; as an Evening Star as Vesper; and in primitive times lovers associated it with the feeling in their hearts.

In 361 AD the Chinese recorded an occultation of Venus by the Moon. In 1639 Horrox and Crabtree were the first to observe a transit of Venus across the face of the Sun, which was followed by the famous voyage of Captain Cook in 1769 when he sailed to Tahiti to observe a transit.

As late as the 1950s people toured the world giving lectures about their meetings with Venusians in their flying saucers.

As no reliable feature could be seen through telescopes to figure out the rotation, many wild guesstimations were put forward until Schiaparelli (1890) and Lowell (1907) both worked out that the planet rotates once in 225 days, which was pretty close. Price made the first radar soundings of the surface by radar in 1956.

Then Venus made history when it became the first planet in the solar system to receive a visitor from Earth.

The American Mariner 2 spacecraft arrived on 14 December 1962 to fly past at a height of 34,833 kilometres, and the secrets hidden beneath the clouds began to unfold.

Before Pioneers 12 and 13 arrived, 3 American and 10 Russian spacecraft had visited the planet – 5 fly-bys and 8 landers. Some of the early Russian landers were crushed by the high pressures and temperatures before reaching the surface.

Artist's view of Venera spacecraft.





Taken on 1 March 1982, this colour image was taken by the Russian Venera 13 lander.
Image: Russian Academy of Sciences. Modern processing: Ted Stryk

VENUS

CHARACTERISTICS

With a mean distance from the Sun of 108,200,000 kilometres, Venus lies at an inclination of 3.39° to the plane of the ecliptic and takes 224.7 Earth days to orbit the Sun, while a sidereal day (the rotation period of the planet relative to inertial space) lasts 243.1 Earth days – longer than a Venusian year! Still more confusing to an Earthling would be the reverse spin means the Sun rises in the West and sets in the East.

Gravity on the surface is 0.9 of Earth's while the optically clear lower atmosphere consists of 96% carbon dioxide and 3% nitrogen.

Conditions are so harsh that no spacecraft, using the toughest materials known on Earth, has lasted more than a few minutes, the longest to date is the Russian spacecraft Venera 13 which landed on 1 March 1982 and kept transmitting for 127 minutes before succumbing to the heat and pressure.

Venus is quite spherical, unusual for our planets, and slightly smaller than Earth in size, mass and density, but its other characteristics are a veritable 'Hell' to us – no life as we know it could possibly survive in the conditions.

The density of the predominantly carbon dioxide atmosphere is 92 times that of Earth, laced with sulphuric acid rain. This sulphuric acid rain never reaches the surface, as the intense heat converts it back to a gas to rise up into the clouds again.

The temperature at the surface is 480°C, hot enough to melt lead. It is evenly distributed around the planet, on both day and night sides.

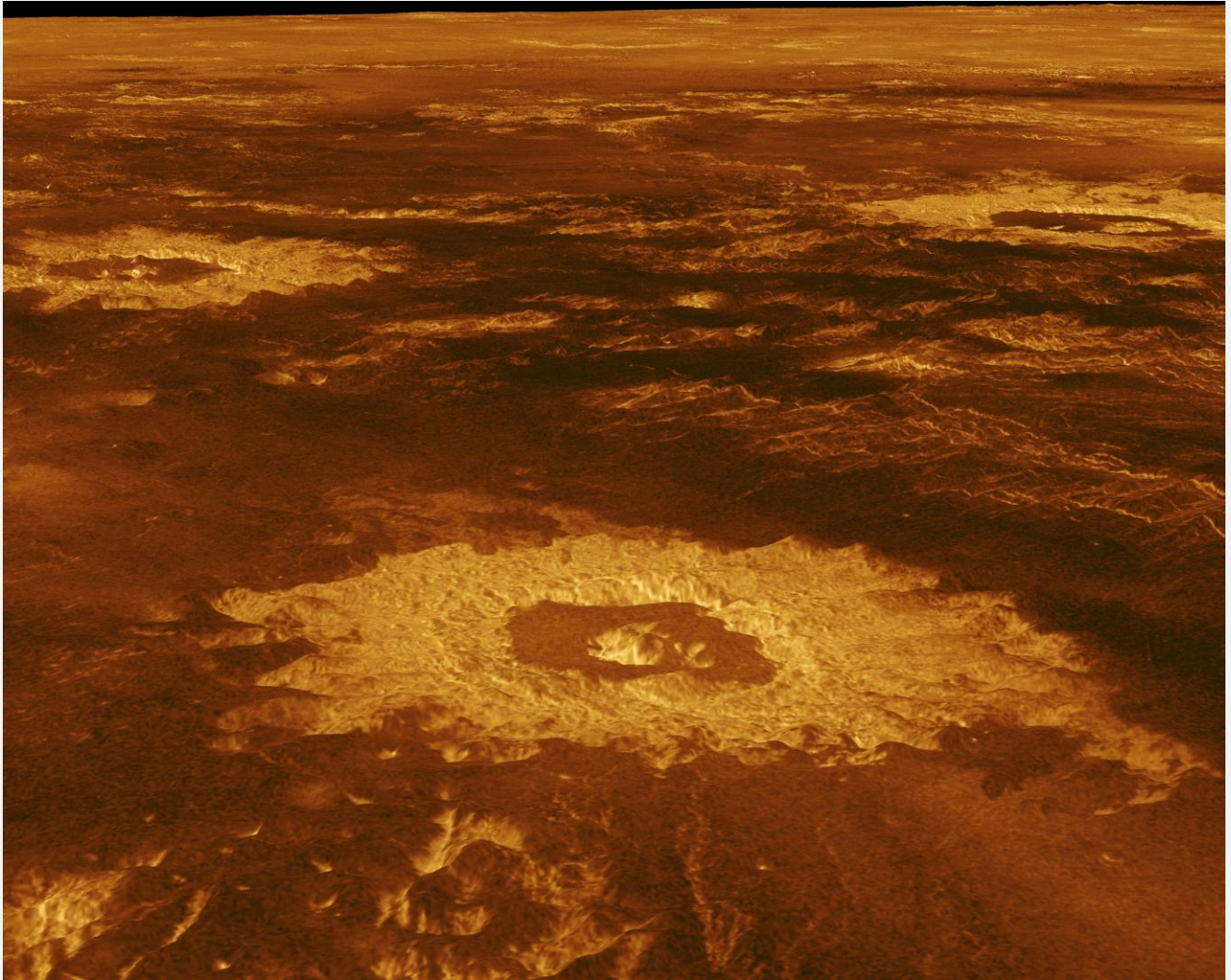
The yellowish clouds, more like hazes, that swathe the planet travel at 350 kilometres per hour, circling the planet in four days. Eighteen kilometres thick, they spread 40 kilometres above the surface, creating a classic greenhouse effect by trapping the Sun's radiant heat and making it hotter than the planet Mercury. Westerly winds blow consistently in the upper atmosphere but gradually slow down until at the surface it is relatively calm, measured at around 3 to 4 kilometres per hour.

Electrical signals inferring lightning, cloud to cloud rather than cloud to ground, were detected by Venera's 11 and 12 and Pioneer Venus, the first seen in December 1978 when the Orbiter's periapsis moved from sunlight into darkness.

NASA has observed,

"The atmosphere continues to recover from an intense shower of sulphuric acid rain triggered by the suspected eruption of a volcano in the late 1970s.

This is similar to what happens on Earth when sulphur dioxide emissions from coal power plants are broken apart in the atmosphere to make acid rain. On Venus, this effect takes place on a planetary scale."



Perspective view of impact features on Venus obtained from the Magellan spacecraft's synthetic aperture radar data combined with radar altimetry. Image: JPL Multi-mission Image Processing Laboratory

This three-dimensional perspective of the surface shows three impact craters. At the bottom is Howe crater with a diameter of 37 kilometres. Danilova, a crater with a diameter of 47.6 kilometres, appears above and to the left. Aglaonice, a crater with a diameter of 62.7 kilometres, is shown to the upper right of Danilova. The simulated hues are based on colour images recorded by the Soviet Venera 13 and 14 spacecraft. The image was released on 29 May 1991.

Venus' surface is relatively young geologically speaking. It appears to have been completely resurfaced 300 to 500 million years ago. The Venusian topography consists of vast plains covered by lava flows and mountain or highland regions deformed by geological activity.

Maxwell Montes in Ishtar Terra is the highest peak on Venus, 10.8 kilometres above the mean level. Ishtar is the mythical Babylonian goddess of love. The Aphrodite Terra highlands extend almost half way around the equator. Aphrodite is the Greek goddess of love.

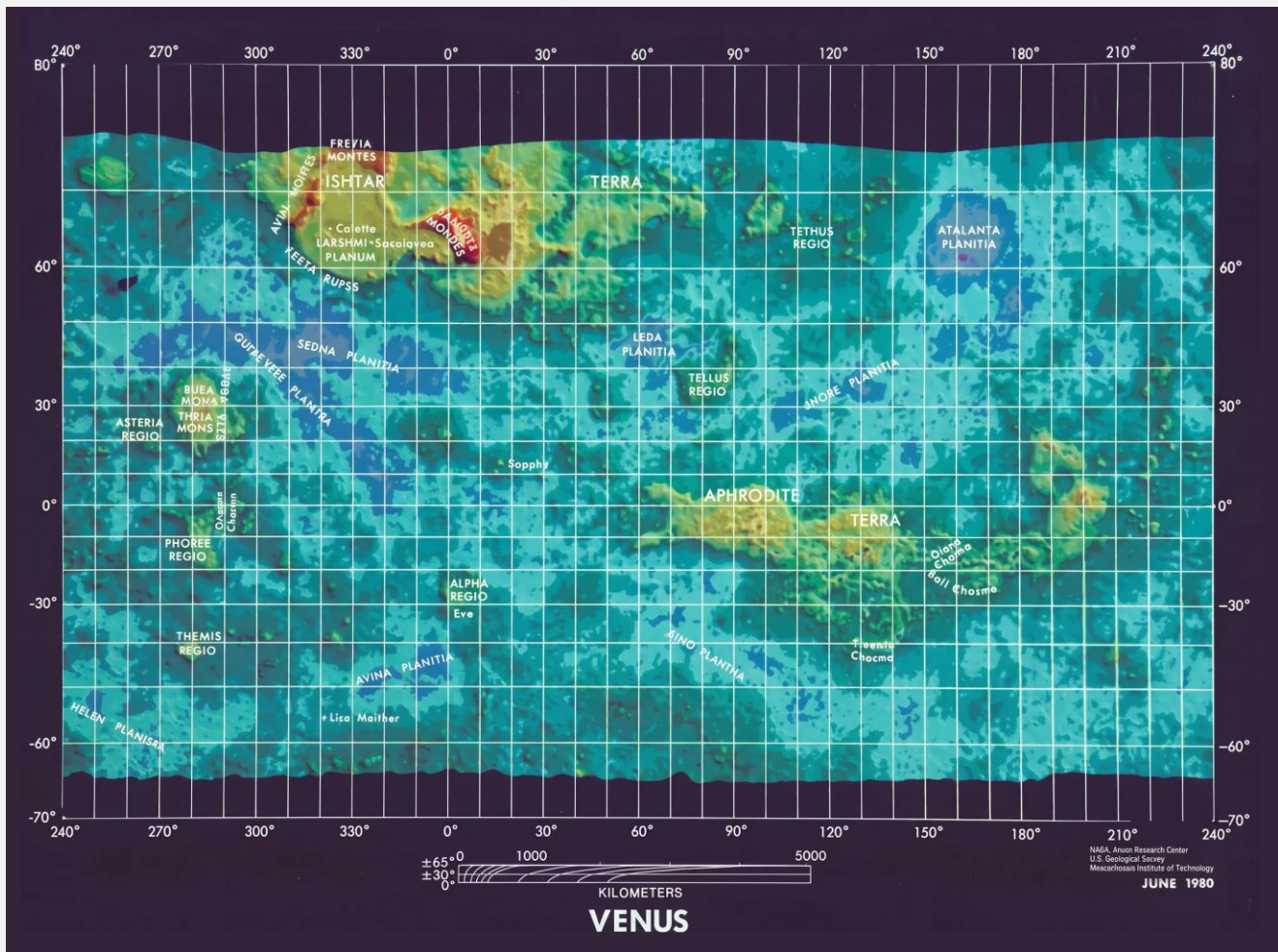
The lowest point is 2.9 kilometres below the mean level in a rift valley at 156° East longitude and 14° South Latitude.

Magellan spacecraft images of highland regions above 2.5 kilometres are unusually bright, characteristic of moist soil. However, liquid water does not exist on the surface so cannot account for the bright highlands.

One theory suggests that the bright material might be composed of metallic compounds. Studies have shown the material might be iron pyrite (also known as "fool's gold").

The material could also be some type of exotic material which would give the same results but at lower concentrations.

Venus is scarred by numerous impact craters distributed randomly over its surface.



Global topographic map produced from Pioneer Venus Orbiter radar data. Image: NASA Ames/USGS

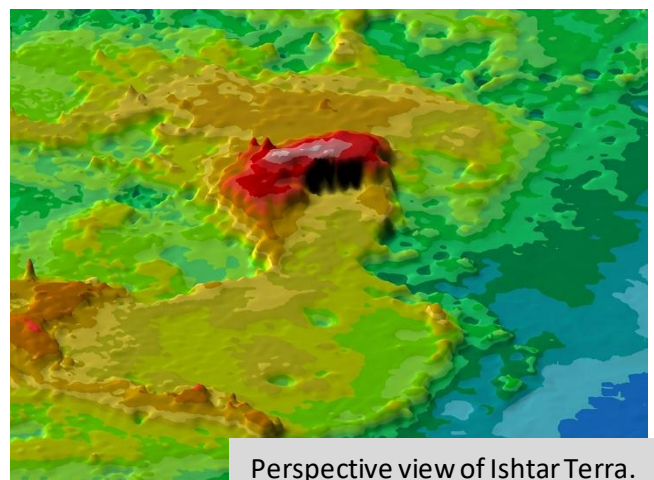
Small craters less than 2 kilometres are almost non-existent due to the heavy Venusian atmosphere. The exception occurs when large meteorites shatter just before impact, creating crater clusters.

Volcanoes and volcanic features are even more numerous. At least 85% of the Venusian surface is covered with volcanic rock. Huge lava flows, extending for hundreds of kilometres, have flooded the lowlands creating vast plains. More than 100,000 small shield volcanoes dot the surface along with hundreds of large volcanos. Flows from volcanos have produced long sinuous channels extending for hundreds of kilometres, with one extending nearly 7,000 kilometres.

Giant calderas more than 100 kilometres in diameter have been found on Venus. Terrestrial calderas are usually only several kilometres in diameter. Several features unique to Venus include coronae and arachnoids. Coronae are large circular to oval features, encircled with cliffs and are hundreds of kilometres across.

They are thought to be the result of mantle upwelling. Arachnoids are circular to elongated features similar to coronae. They may have been caused by molten rock seeping into surface fractures and producing systems of radiating dykes and fractures.

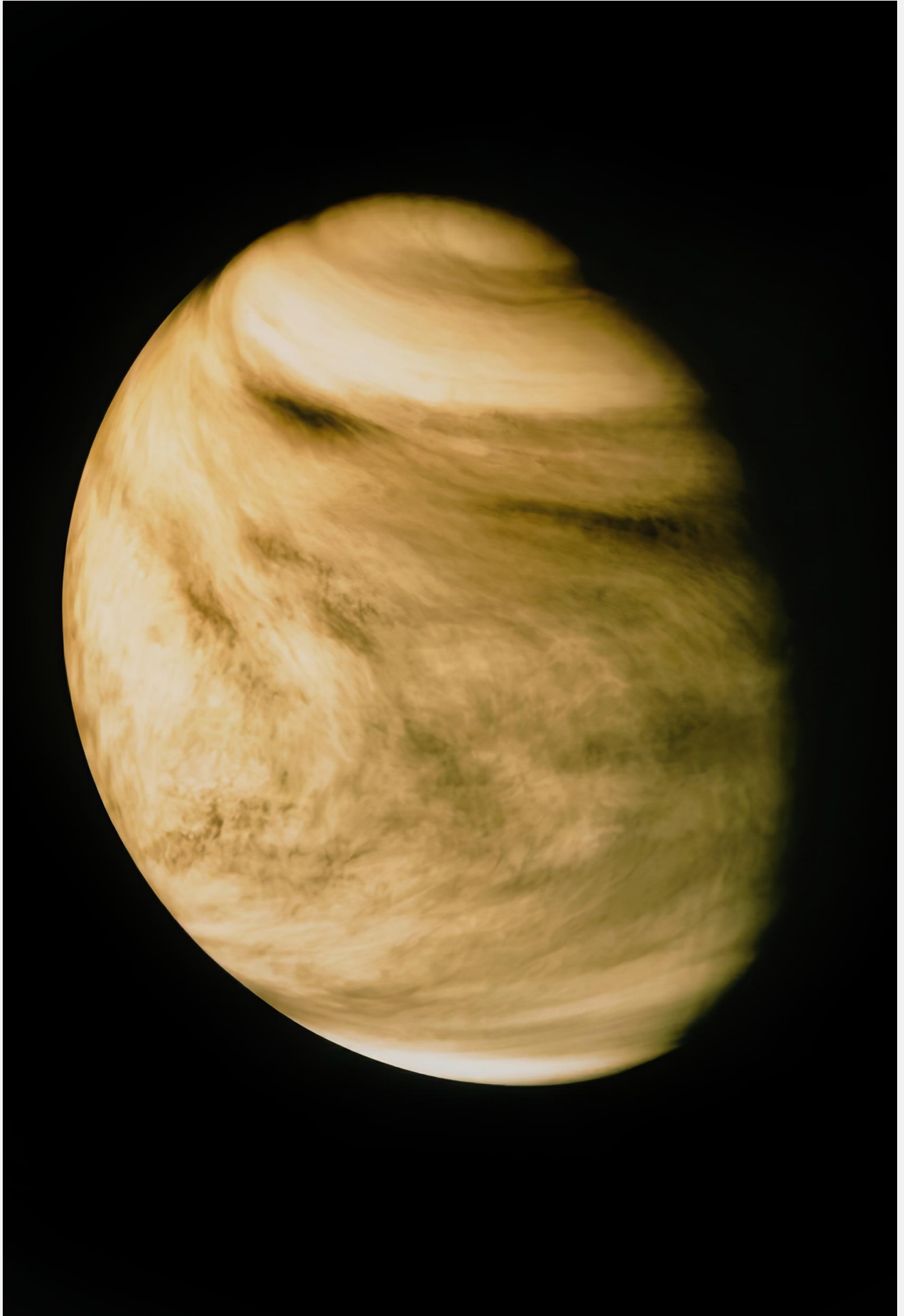
Even though Pioneer Venus probed with sensitive instruments, it could not find any signs of a magnetic field, so Venus has a very different interaction with the solar wind to Earth.



Perspective view of Ishtar Terra.



Pioneer Venus Orbiter false-colour image made at ultraviolet wavelengths. Image: NASA



Pioneer Venus Orbiter false-colour image of Venus made at ultraviolet wavelengths. Image: NASA

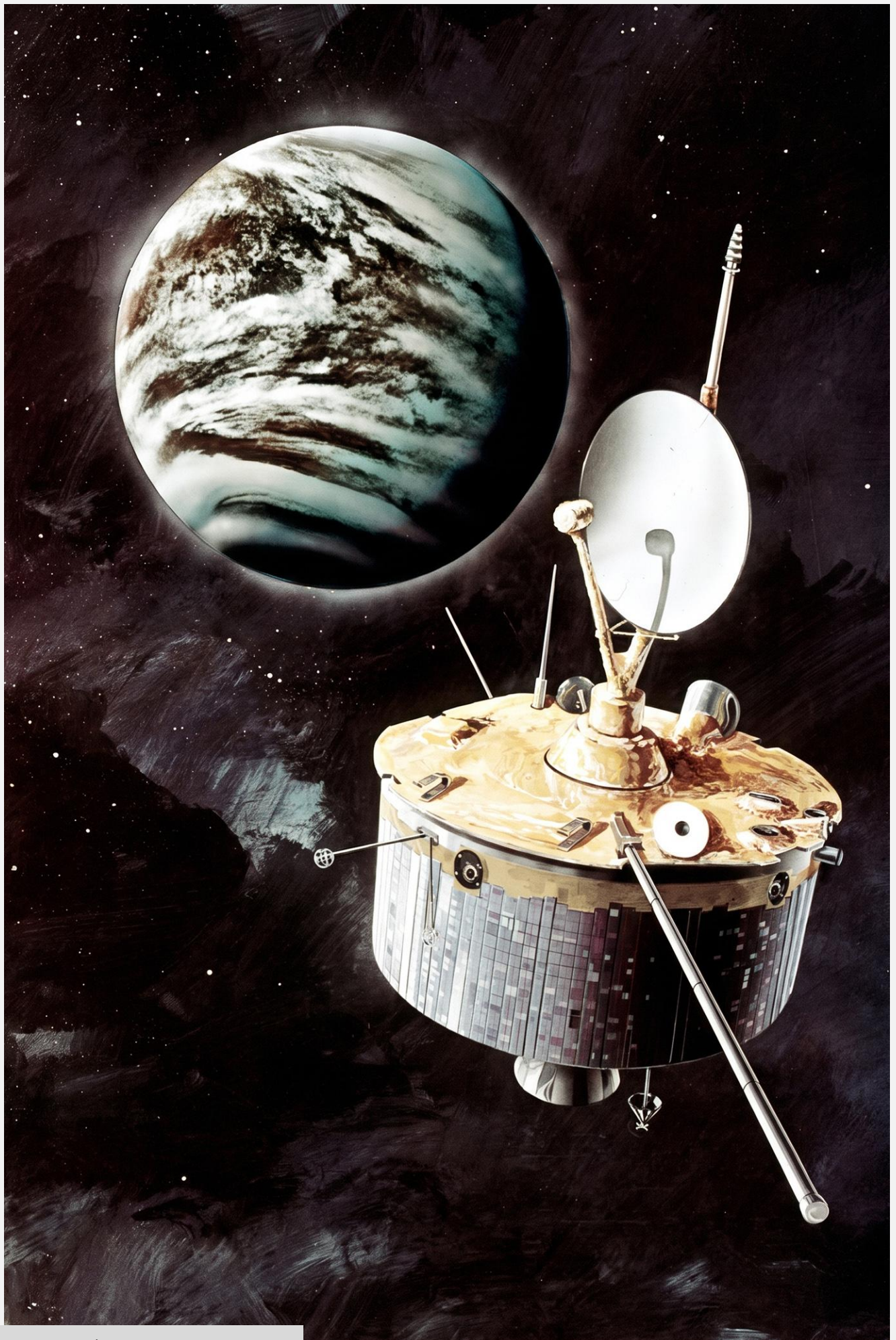
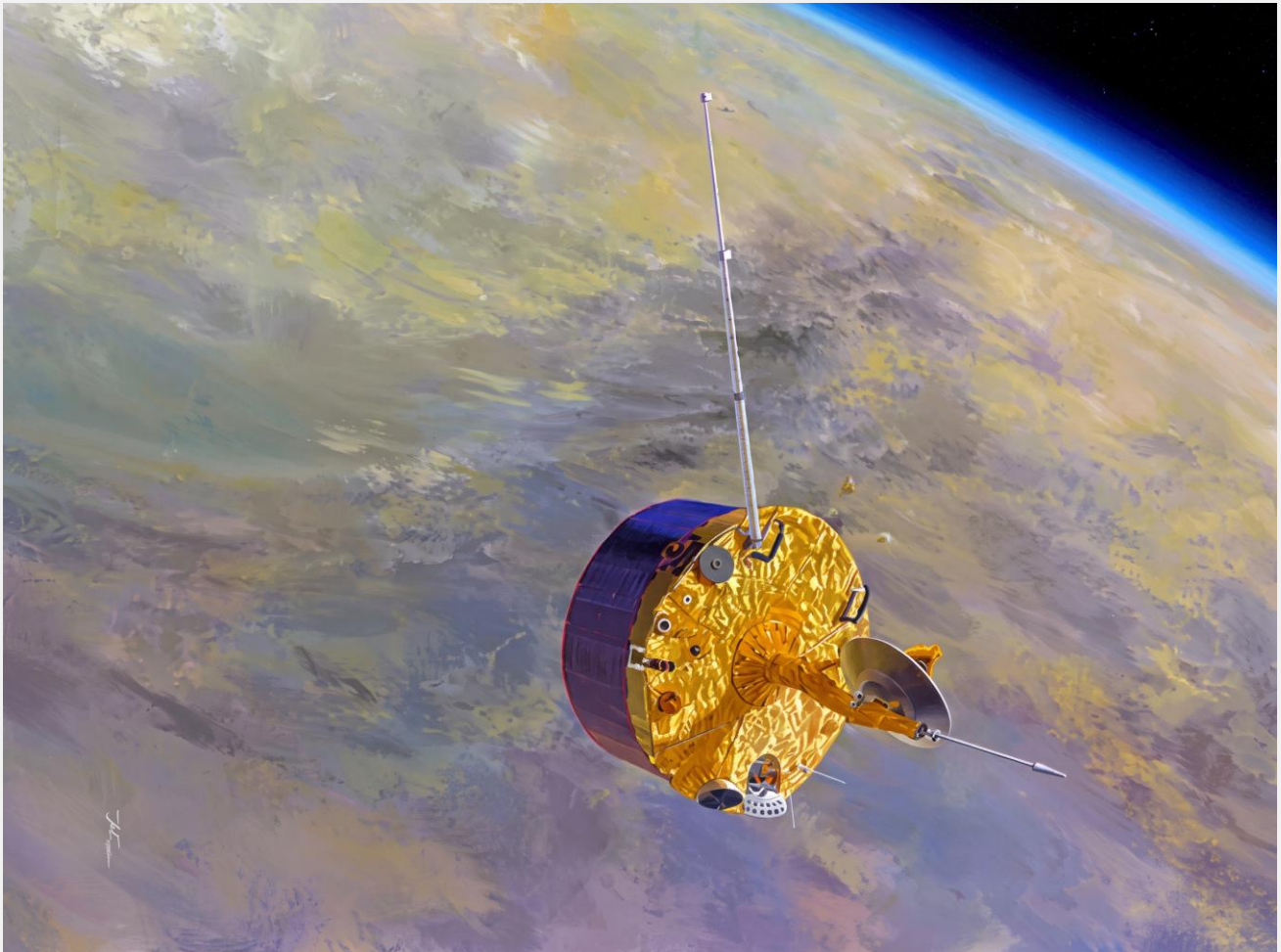


Image: NASA/Ames. Artist: Paul Hudson



An artist's impression of the Pioneer Venus Orbiter cruising above the clouds.
Original artwork by Paul Hudson, December 1981.

PIONEER 12

VENUS ORBITER

The Mission

1978 – 1981 (HSK) – 1992 (Mission end)

DSS44 Honeysuckle Creek began tracking Pioneer Venus from the beginning, and was there at the end when the Pioneer 13 probes plunged into the Venusian atmosphere.

Unfortunately, the station had already closed down in 1981 when the Pioneer 12 Orbiter fell off the perch in 1992.

Mission Controllers had to remotely control two spacecraft simultaneously as the Pioneer spacecraft were not automated spacecraft (one way of minimising costs), so had to provide round the clock support from Earth. Two teams were needed for the two spacecraft.

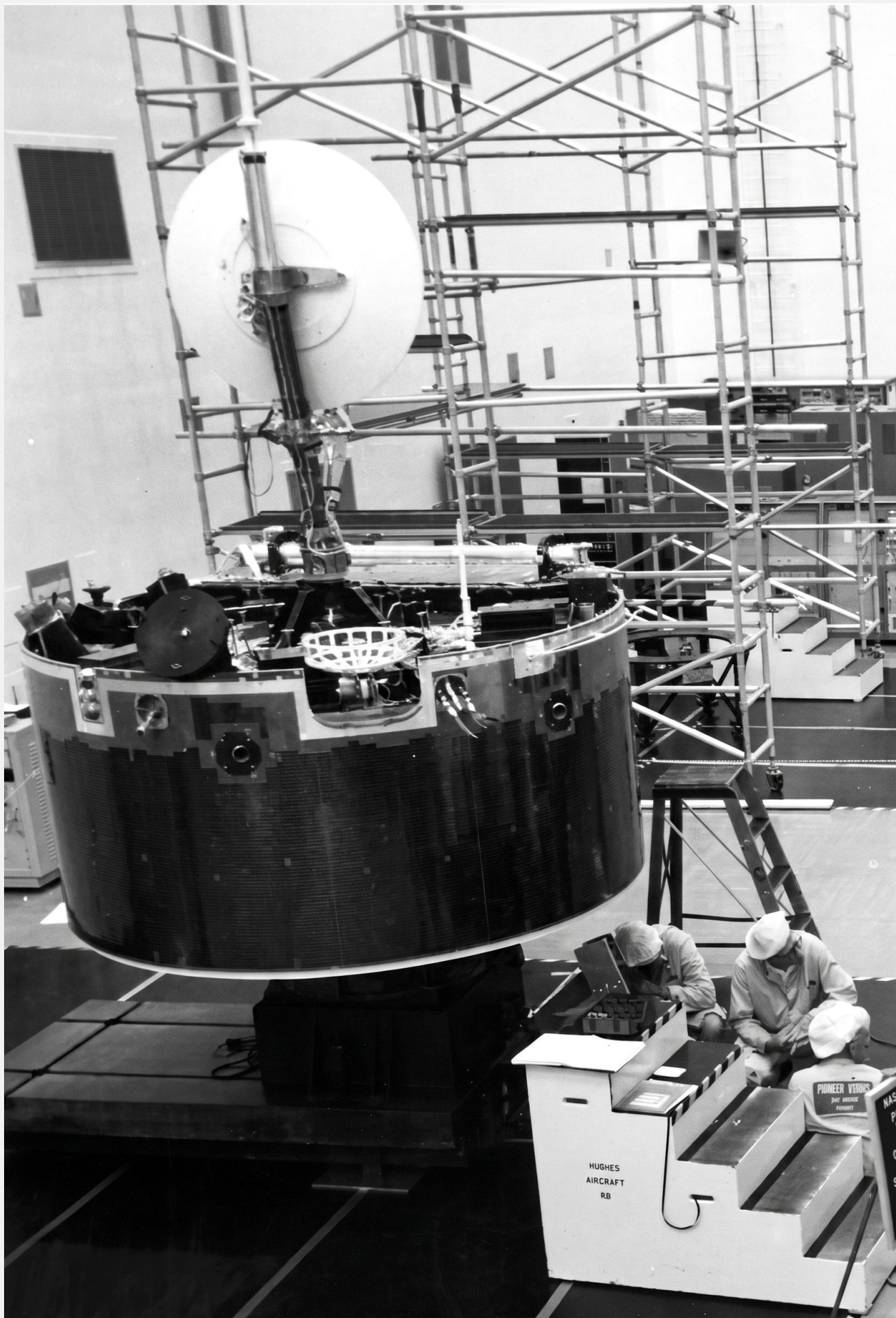
Our data from DSS44 was transmitted over the high speed lines of the NASCOM system to the Pioneer Mission Computing Center at Ames Research Center in California.

Our incoming commands were generated at this Center, verified by the Ames computers, and sent to us for transmitting to the spacecraft. JPL provided the necessary navigation data and trajectory computations.

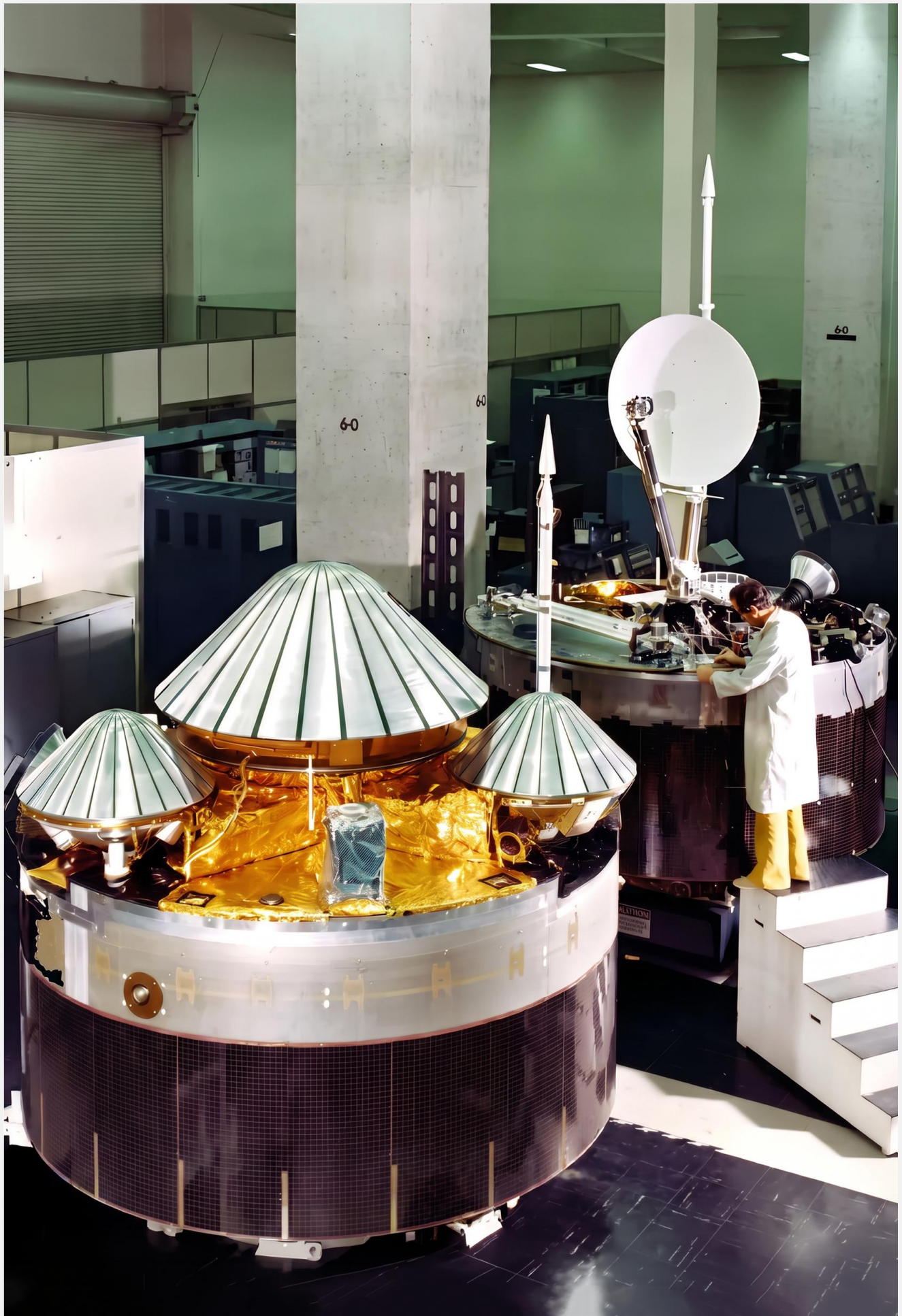
For the Venus mission at the tracking stations, we had special receivers to handle the five data streams and new wideband recorders were required to cope with large frequency shifts caused by changes in probe velocity and expected atmospheric effects on signal propagation when they entered the atmosphere.

To make sure no data was lost as the probes dived through the atmosphere, special equipment to tune the receivers to the signals being received from each probe was installed.

The data had to be recorded in unsynchronised form for special off-line processing.



The Pioneer Venus Orbiter at the Kennedy Space Center. Image: NASA/KSC



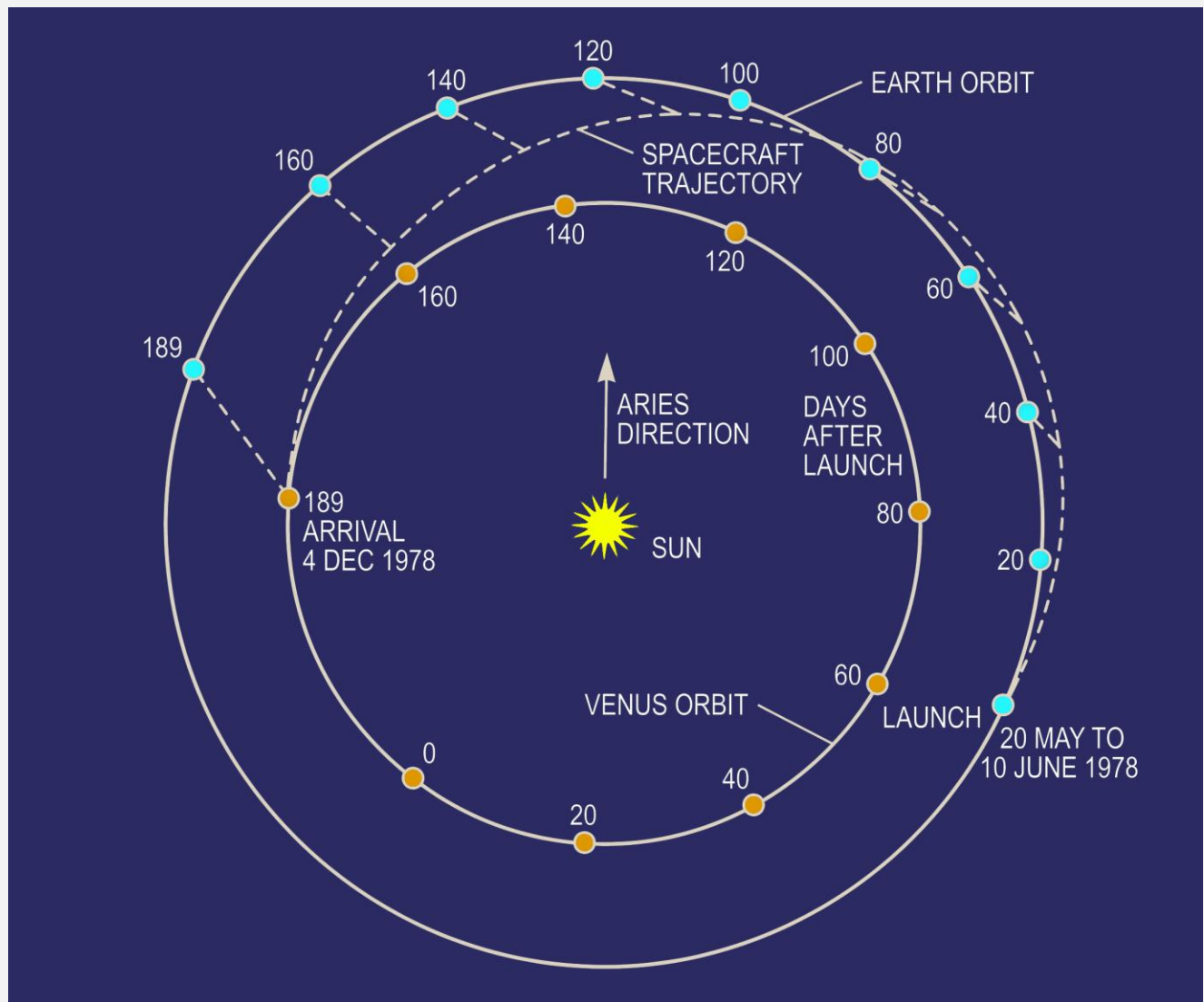
The Pioneer Venus Multiprobe and Orbiter at the Hughes Aircraft Company. Image: NASA/Hughes



The NASA Atlas-Centaur '50' rocket sits of the pad with the Pioneer Venus Orbiter. Image: NASA/KSC



Lift-off of the Atlas-Centaur rocket from Launch Complex 36A. Image: NASA/KSC



Flight trajectory for the Pioneer (12) Venus (A) Orbiter mission. Graphic: NASA

Launch and voyage to Venus

December 1978 saw an invasion of Venus by Earth. In September the Russians launched two spacecraft, Venera 11 and Venera 12, to arrive at Venus late in December, the same month as America's Pioneer Venus arrived.

Both Russian spacecraft consisted of two vehicles, a fly-by and a lander, looking for similar data as Pioneer Venus.

Pioneer 12 was launched from Cape Canaveral on 20 May 1978 by an Atlas-Centaur launch vehicle. Soon after launch the long magnetometer boom thrust out to full extension and the high-gain antenna was despun to face Earth for tracking. The instrumentation was checked out, the imaging system taking pictures of a crescent Earth. All systems were Go.

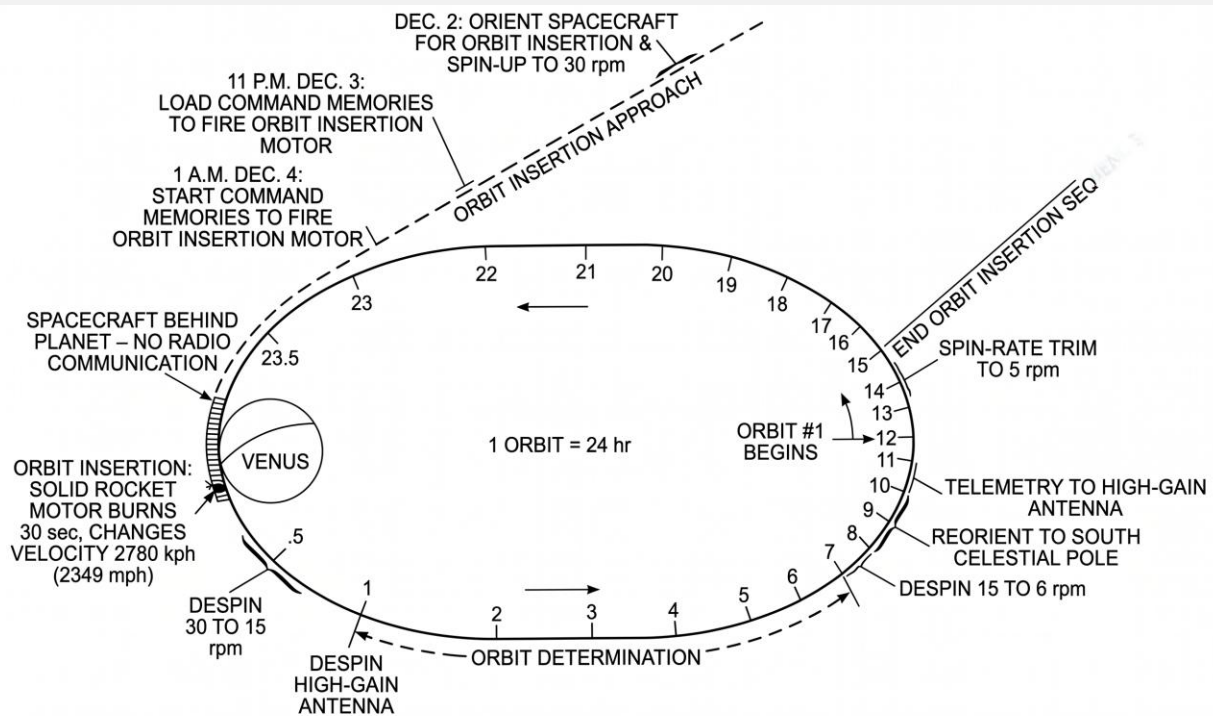
The path of the Orbiter from Earth to Venus carried the spacecraft more than half way around

the Sun on its 7 month journey to Venus. At first the spacecraft was sent outside the Earth's orbit, crossing back over behind the Earth to spiral in towards Venus about 90 days after launch.

For the first 82 days, or nearly half the journey, the Orbiter arced outside the Earth's orbit before crossing back to spiral in towards the Sun, and Venus. This trajectory saved the weight and space of 92 kilograms of fuel needed to enter orbit at Venus.

Flight Controllers at JPL sent a mid-course correction command on 1 June to aim the spacecraft more accurately for the Venus orbit insertion point.

It was aborted when part of the structure deflected the gas from the thrusters and caused the spacecraft to change the roll-rate too harshly, driving the servo-mechanism too hard and shutting it down.



To overcome the problem the Controllers had to send commands to disable the automatic cut-off circuit, but it took 8 hours to successfully complete the manoeuvre, increasing the speed of the spacecraft by 12 kilometres per hour so it would arrive 6 hours earlier. As a result, the original target in the southern hemisphere changed to a point 348 kilometres above the equator in planet's northern hemisphere.

Another problem which taxed the controllers were bit/flip errors in the spacecraft memories caused by high energy solar cosmic rays – randomly swapping its “1’s” and “0’s”. This meant that every command had to be checked before execution.

In early June the Orbiter detected a powerful burst of gamma radiation from the galaxy, confirmed by two other spacecraft, Vela circling the Earth, and our friend Helios 2, circling the Sun. Six bursts were detected during the trip, two the most powerful ever recorded at the time. By triangulation scientists were able to locate the origin of these bursts, one originating from the Large Magellanic Cloud.

By mid-November both Pioneer 12 and Pioneer 13 were converging on Venus, which had passed its closest approach to Earth. Rising as the Morning Star, it was just emerging from the Sun's

glare as seen from Earth. Although it had been launched more than two and a half months earlier, the Multiprobe was now following closely behind the Orbiter, and was getting ready for the separation of the first probe.

Arrival at Venus

On 2 December 1978 Pioneer 12 aligned itself for orbit insertion and the telemetry bit rate was dropped from 1024 to 64 bits per second to maintain contact on the omni-directional low-gain antenna. The high-gain antenna was released and spun up to match the spin rate of the spacecraft, which was increased to 30 revs per minute. After the manoeuvres the high-gain antenna was despun and the bit rate was reset to 1024 bits per second.

On 4 December at 1700 AEDT the sequence commands were loaded for orbit insertion, planned to precede the arrival of the Multiprobe spacecraft. At 0251 AEDT on 5 December, Pioneer 12 passed behind Venus and the rocket motor fired for 30 seconds to slow the spacecraft by 2,780 kilometres per hour to inject it into a highly elliptical orbit inclined at 75° to the Venusian equator. The apoapsis, or highest orbital point, was 66,900 kilometres, while the periapsis, or low point, varied between 150 and 200 kilometres above the surface of the planet giving an orbital period of 23h 11m 26s.

As this was the first time a solid propellant motor had been fired after being stored in space for 7 months and JPL had never lit a rocket behind a planet before so as a precaution the Flight Controllers sent a command to fire the motor after emergence to stop the spacecraft going off into solar orbit.

If ignition had occurred on time behind the planet, then the carrier signal doppler frequency would have changed. So, the ground tracking stations had one receiver set on the expected doppler and a second receiver set on the frequency expected if the rockets had not fired.

The Orbiter enters orbit around Venus

The spacecraft appeared from behind the planet at 0317 AEDT on 5 December – Project Manager Charles Hall remembers, “When it was clear that the right receiver had locked onto the signal there was a big cheer because we knew the spacecraft had gone into orbit.”

The back-up emergence command wasn’t necessary because the retro rocket performed better than its specifications to slow the spacecraft. Thus Pioneer 12 ended up in a lower orbit than planned and correcting burns had to be executed later in the day.

At 0330 AEDT on 5 December the Orbiter’s spin rate was dropped from 30 to 15 revs per minute and the high-gain antenna despun and aligned to point at Earth ready for an intensive period of spacecraft data analysis. After 6 hours, at 1000 AEDT, the spin rate was reduced to 6 revs per minute, and the spin axis was adjusted to point to the celestial poles.

At this point the infrared radiometer, neutral mass spectrometer and temperature probe were activated and calibrated, and the radar antenna was unlocked. At apoapsis the magnetometer and retarding potential analyser were activated and the first orbital data gathering sequence began. The high-gain antenna was aligned to Earth and the signal switched from the omni antennas.

The shorter orbital period caused the time of periapsis to occur earlier than planned each Earth day, which affected the assignments of the two prime tracking stations (Goldstone and Tidbinbilla, which included DSS42, DSS43, and Honeysuckle Creek DSS44).

The scientists wanted these key stations to receive signals from the spacecraft at a preselected part of its daily orbit around Venus, so on 6 December the orbital period was increased to 24 hours and the mission settled down to observing the planet over a period of several Venusian sidereal days.

The 24-hour orbit was divided into two segments reflecting the type of measurements being taken. The periapsis segment was 4 hours long, using 5 data formats designed to allow changing the emphasis for part or all of a periapsis period. The remaining 20 hour segment used 2 data formats for measurements during apoapsis periods, one of which obtained images of the whole disk of the planet in ultraviolet light for cloud features.

The science experiments consisted of:

- global mapping of the clouds, atmosphere and ionosphere;
- measurement of upper atmosphere, ionosphere, and solar wind-ionosphere interaction; and
- mapping of the planet’s surface by radar.

Unfortunately, the radar mapper failed after the first 24 orbits but recovered after turning it off. Apparently it failed if used for periods longer than 10 hours, an electrical charge suspected of accumulating in the logic circuitry. For the rest of the mission, it could only be used for short periods. A month of data was lost, but the missing data was covered during the extended mission.

A big disappointment was the failure of the Infrared Radiometer during the 70th orbit on 13 February 1979. All attempts to resuscitate it failed. It was suspected the unit’s power supply had developed a fault.



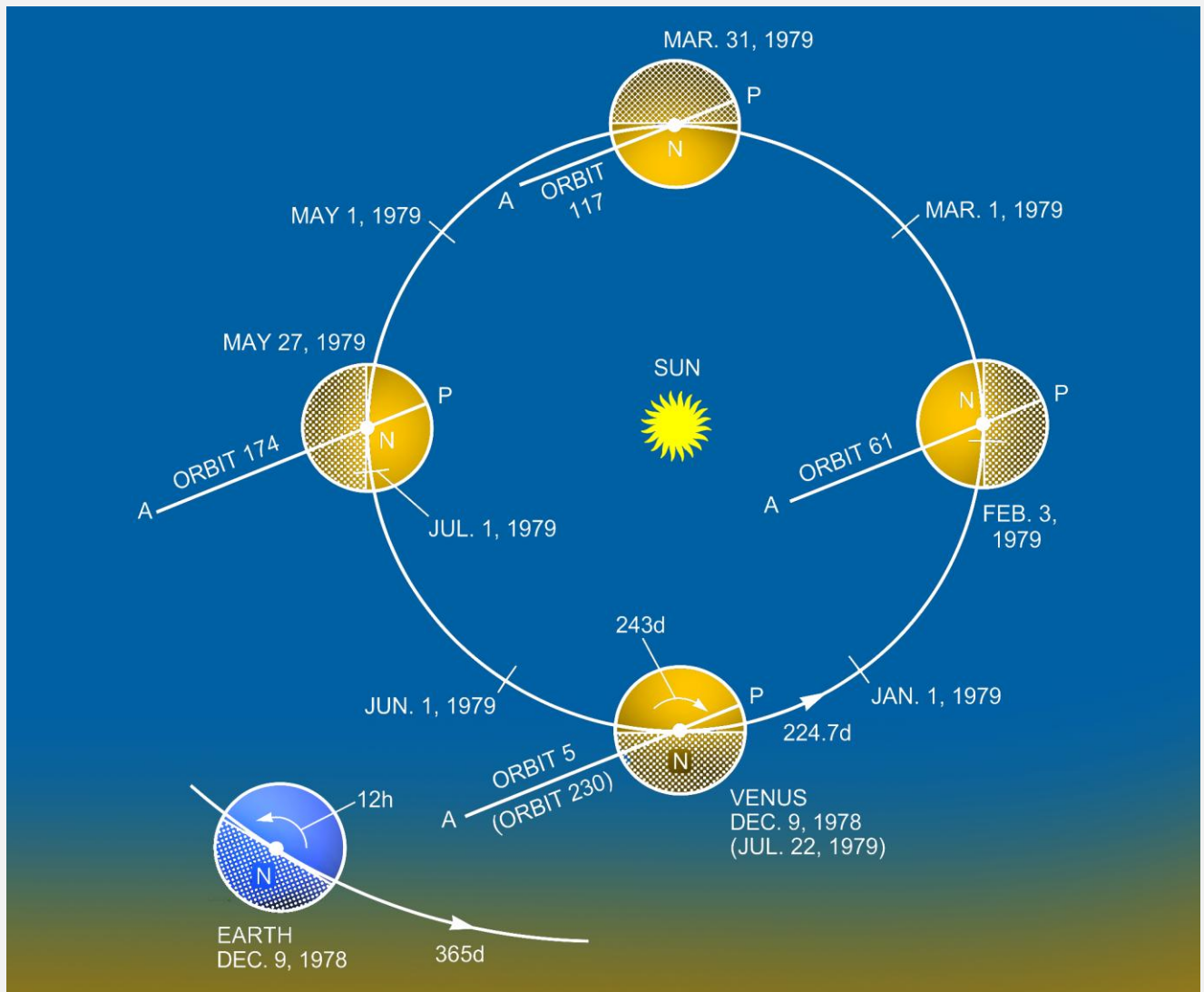


Diagram of the Sun/Venus/Orbiter geometry. Graphic: NASA

Illustrates how the Orbiter periapsis moves around the planet during a Venusian sidereal year to observe the day and night hemispheres. Because the planet rotates in a retrograde direction it takes more than one Venusian sidereal year for the periapsis to move over all the longitudes of the planet.

Primary mission completed - Extended mission commenced

By 4 August 1979 the primary mission was completed, and with the tanks still almost half full of Hydrazine, the Extended Mission began and was expected to go for another 480 days. The scientists planned to cover two operational phases during the extended mission.

They decided to continue the basic periodic control of the orbit until orbit 600 on 27 July 1980 and then allow the periapsis altitude to rise slowly at a rate of 400 kilometres per 243 days, then at a rate of 225 kilometres until 1984 to a maximum of 2290 kilometres.

The apoapsis descended at the same rate so the period of the orbit remained constant at 24 hours.

During the first phase periapsis was controlled to remain in the Venusian atmosphere for measurements, then during the second phase large regions of the dayside bow shock and the night ionosphere were observed. This phase also provided an opportunity to track the spacecraft for better estimates of the low-order gravity field of Venus.

On Friday 21 August 1981 Honeysuckle was tracking the Orbiter two-way.

To those old Deep Space tracking hands here is a typical pass acq. message.... just for nostalgia.

PIONEER 12 – VENUS ORBITER

After hand-over from DSS11 (Goldstone)

Times: Zulu (GMT/UTC)

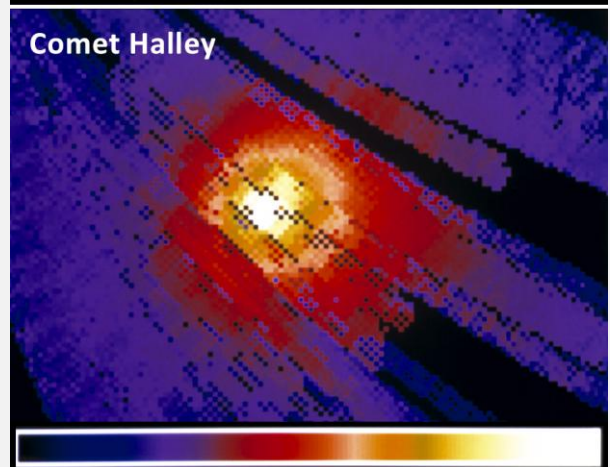
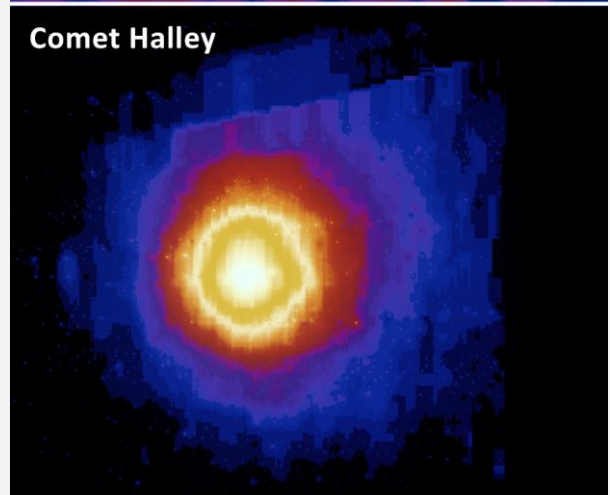
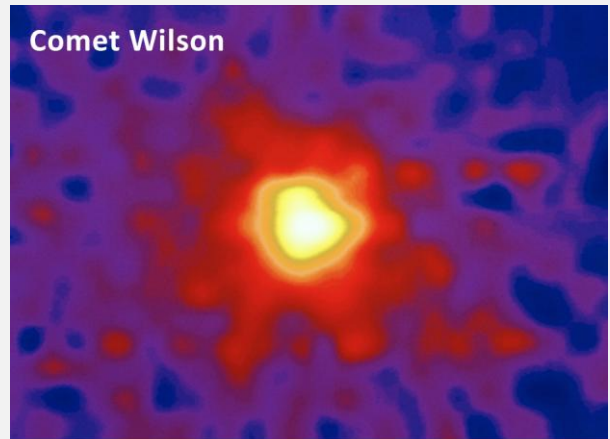
Track Syn Frequency (TSF): 44.004660
Round Trip Light Time (RTLT): 20 m 57.7788 s

EVENT	TIME
MDA 1/5	0010:00 0310:00
MOD OFF	0135:00
TUNING	0135:58
On XA	0143:45
DRIVE OFF	0144:30
TUNING	0145:30
On TSF	0153:17
BAD DATA (Tuning plus RTLT)	0156:56
TUNING	0201:26
LOS (Loss of Signal)	0203:34
1-WAY	0210:54
ON XA	0215:15
512c	0215:54
DRIVE ON	0216:00
AOS (Acquisition of Signal)	0225:51
Exit Occultation 1-way	0225:51
341.1C	0229:54
2-WAY	0240:54
GOOD DATA	0251:47

During the Orbiter's mission, opportunities arose to make systematic observations of several comets (all after DSS44 had closed) with the Ultraviolet Spectrometer.

The comets and their date of observation were:

- Encke 13 – 16 April 1984
- Giacobini-Zinner, 8 – 15 September 1985
- Halley, 27 December 1985 to 9 March 1986
- Wilson, 13 March to 2 May 1987
- NTT, 8 April 1987; and
- McNaught, 19 – 24 November 1987.



In 1991 the Radar Mapper was reactivated to investigate previously inaccessible southern portions of the planet before the final phase of the mission began in May 1992.

Starting in September 1992, controllers used the remaining fuel in a series of manoeuvres to keep the periapsis between 150 and 250 kilometres.

The Pioneer Orbiter's mission ended on 8 October 1992 when the fuel ran out, and it burned up in the Venusian atmosphere like a meteor with a glowing tail. It eventually drifted down towards the surface, to become lost in that hellish world as a fine dust.



Technicians performing system tests on the Pioneer Venus Orbiter. Image: NASA/Hughes

PIONEER 12

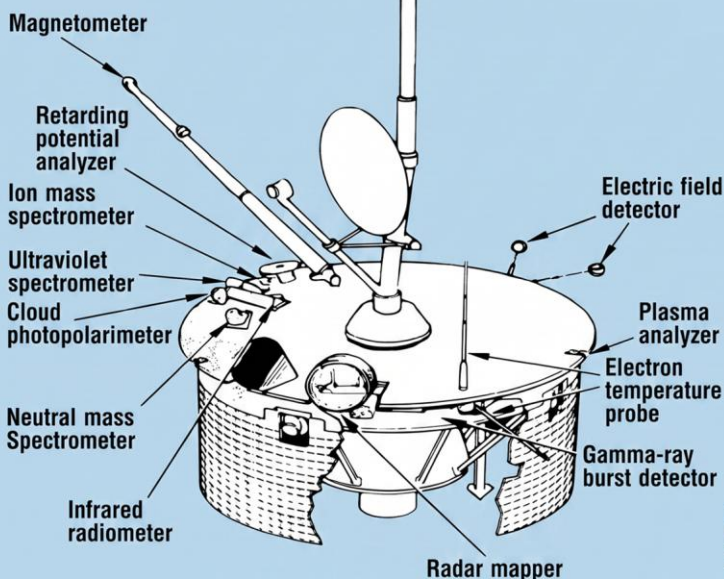
ORBITER SPACECRAFT

Built by Hughes Aircraft Co., the Pioneer Venus Orbiter was designed to last for 8 months, and investigate Venus in four important ways:

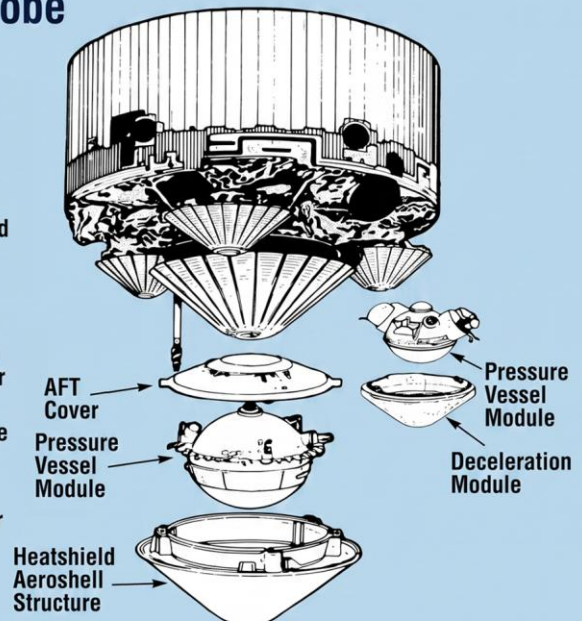
1. Investigate the clouds of the whole planet.
2. Measure the characteristics of the upper atmosphere and ionosphere and detect how the solar wind interacts with the ionosphere.
3. Use radar to penetrate the upper cloud layers to map the planet's surface.
4. Determine the general shape of the gravitational field and detect anomalies in the field by measuring how the field affected the orbit of the spacecraft.

Pioneer Venus Spacecraft

Orbiter



Multiprobe



Despite their very different roles, the Orbiter and Multiprobe were very similar in design. The use of identical systems (including flight hardware, flight software, and ground test equipment) and incorporation of existing designs from previous missions (including OSO and Intelsat) allowed the mission to meet its objectives at minimum cost.

After entering orbit, the spacecraft returned global maps of the planet's clouds, atmosphere and ionosphere, measurements of the atmosphere-solar wind interaction, and radar maps of 93 percent of the planet's surface.

Additionally, the spacecraft made use of several opportunities to make systematic UV observations of several comets. Data from the Orbiter was correlated with data from its sister vehicle (Pioneer 13 Venus Multiprobe and its atmospheric probes) to relate specific local measurements to the general state of the planet and its environment as observed from orbit.

The Orbiter spacecraft provided a 2.5 metre diameter, spin-stabilized platform for the 17 experiments. Body mounted solar panels provided 312 watts of power at 28 volts dc, backed up by two 7.5 Ah NiCad batteries for when the spacecraft is hidden from the sun by Venus.

A 1.09 metre dish high-gain antenna provided high rate S-band communication with Earth, with 2 low-gain omni antennas for non-critical communication times.

The up-link carrier frequency was 2.115 GHz while the telemetry down link was 2.295 GHz.

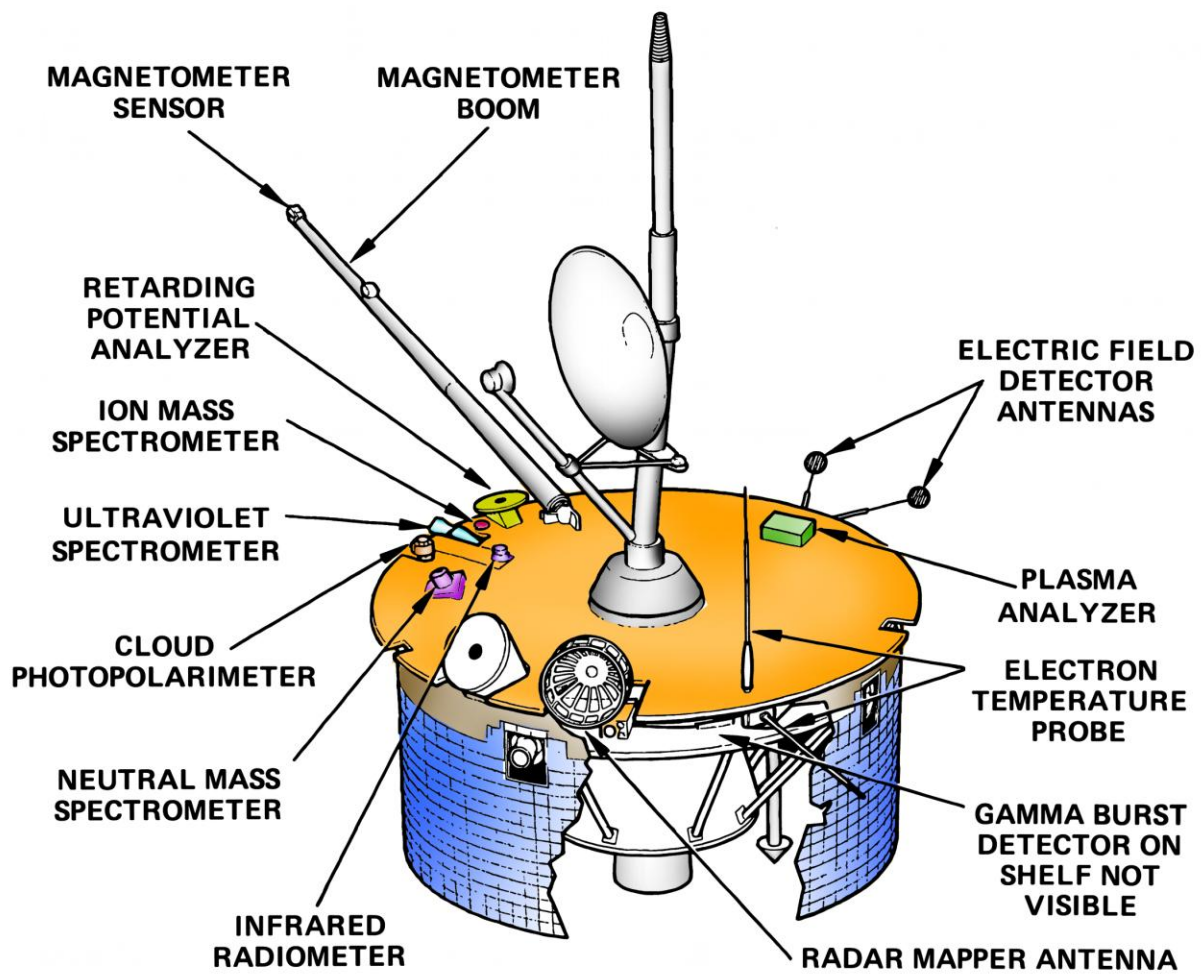
For radio propagation experiments during occultation, an X-Band transmitter also used the high-gain dish antenna.

The telemetry system could accommodate twelve data rates between 8 and 2048 bits per second with data storage of 524,288 bits, or 1024 frames of data, enough to cover the Earth occultation periods.

The X-band transmitter was also used for occultation measurements.

Attitude determination was provided by sun and star sensors. Nutation damping was with a partially filled tube of liquid Freon.

A Hydrazine propellant system with 7 thrusters was used for attitude control and orbit adjustment. A solid rocket motor provided 18,000 N of thrust used for Venus orbit insertion.



Pioneer Venus Orbiter instruments. Graphic: NASA

The Experiments

Pioneer Venus Orbiter carried 12 scientific instruments with a total mass of 45 kilograms.

Using the spacecraft signal, a further five experiments were conducted. Most of the instruments were still operating when the spacecraft burned up in the atmosphere 14 years later.

It is interesting to note that the ion mass spectrometer on Pioneer Venus used the first microprocessor in space, an Intel 4004. By using a microprocessor, a full spectrum of atmospheric data could be taken every kilometre instead of every 10 kilometres.

Cloud photopolarimeter – to measure the vertical distribution of the Venusian clouds and haze particles.

Surface radar mapper – provided the only direct observations of the surface of Venus from the Orbiter. It mapped planetary topography and surface characteristics to an accuracy of 100

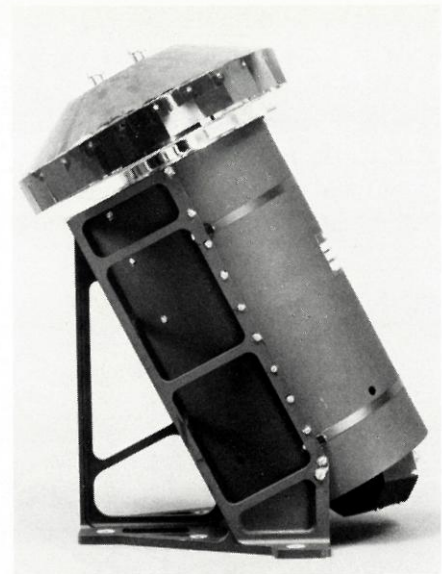
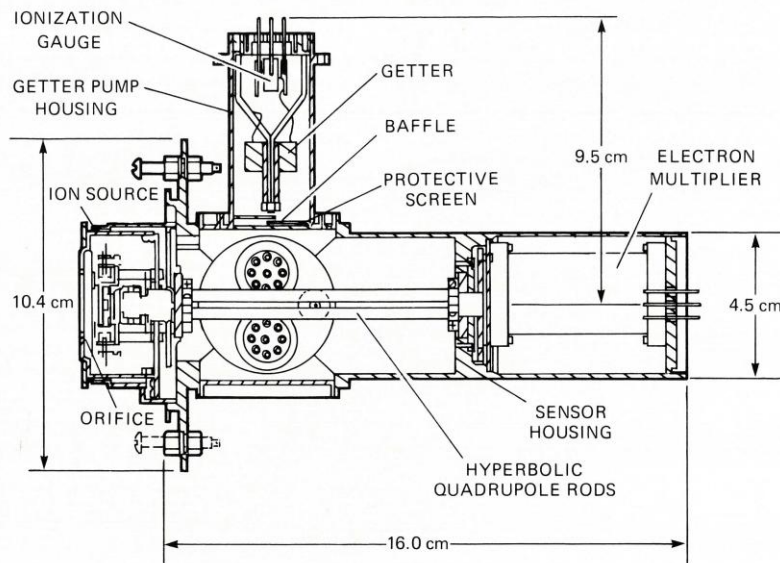
metres as well as measured the intensity and polarisation of light reflected from the clouds.

Infrared radiometer – to monitor infrared emissions from the Venusian atmosphere to determine the emitted temperature of the atmosphere at various levels, and map the distribution of water vapour and reflected solar radiation.

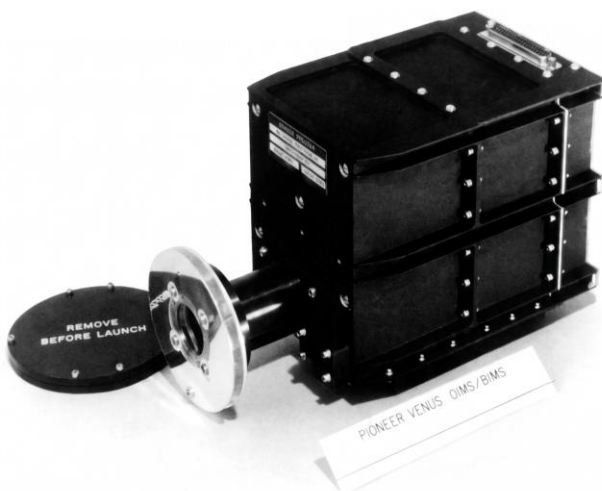
Airglow ultraviolet spectrometer – to measure temperature, energy balance, and the scattered and emitted UV radiation to check how sunlight is reflected and scattered from the clouds and haze layers. Also used to detect day and night glows in the upper atmosphere.

Neutral particle mass spectrometer – to evaluate the composition of the upper atmosphere when passing through it during periapsis from an altitude of 150 kilometres up to 500 kilometres.

Solar wind plasma analyser – to measure the velocity, density, flow direction, and temperature of the solar wind.



Above: Neutral Mass Spectrometer. Image: NASA



- (1) SENSOR AT REST
RELATIVE TO PLASMA:

$$M = \frac{K|V_a|}{S^2 F^2}$$

- (2) SENSOR MOVING
RELATIVE TO PLASMA:

$$M = \frac{K(|V_a| - 1/2 mv^2 + \phi_{sc})}{S^2 F^2}$$

WHERE:

M = MASS OF ION (AMU)

V_a = ACCELERATING VOLTAGE

m = MASS OF ION

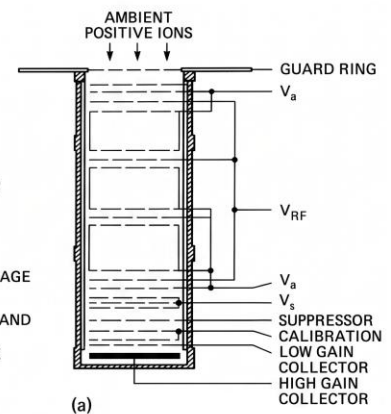
v = SUM OF SPACECRAFT AND
ION VELOCITIES

ϕ_{sc} = SPACECRAFT CHARGE

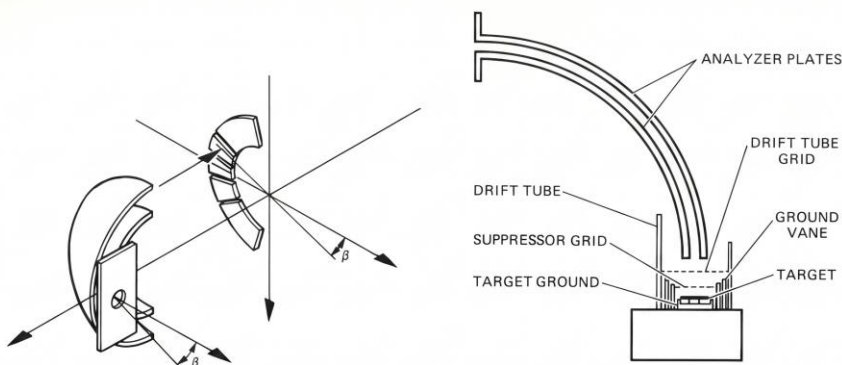
S = INTER-GRID SPACING

F = RF FREQUENCY

K = CONSTANT



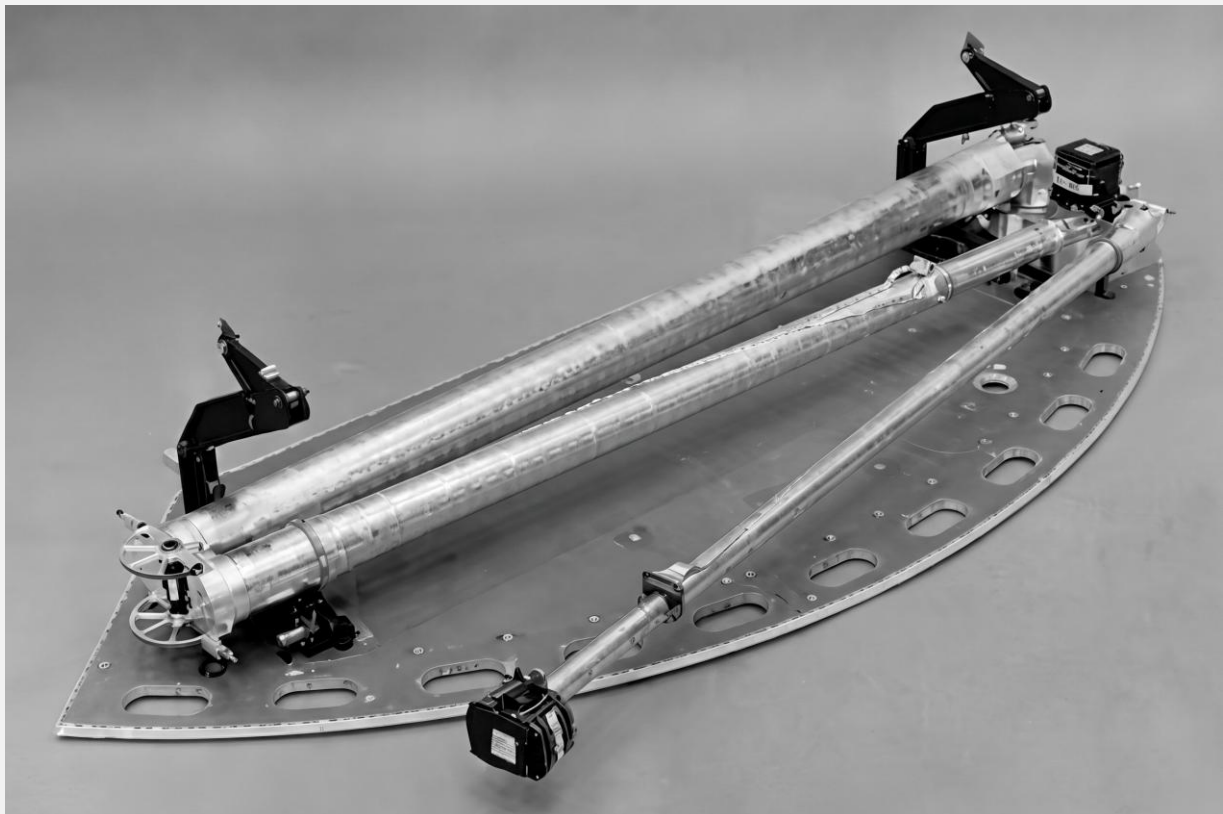
Above: Ion Mass Spectrometer. Image: NASA

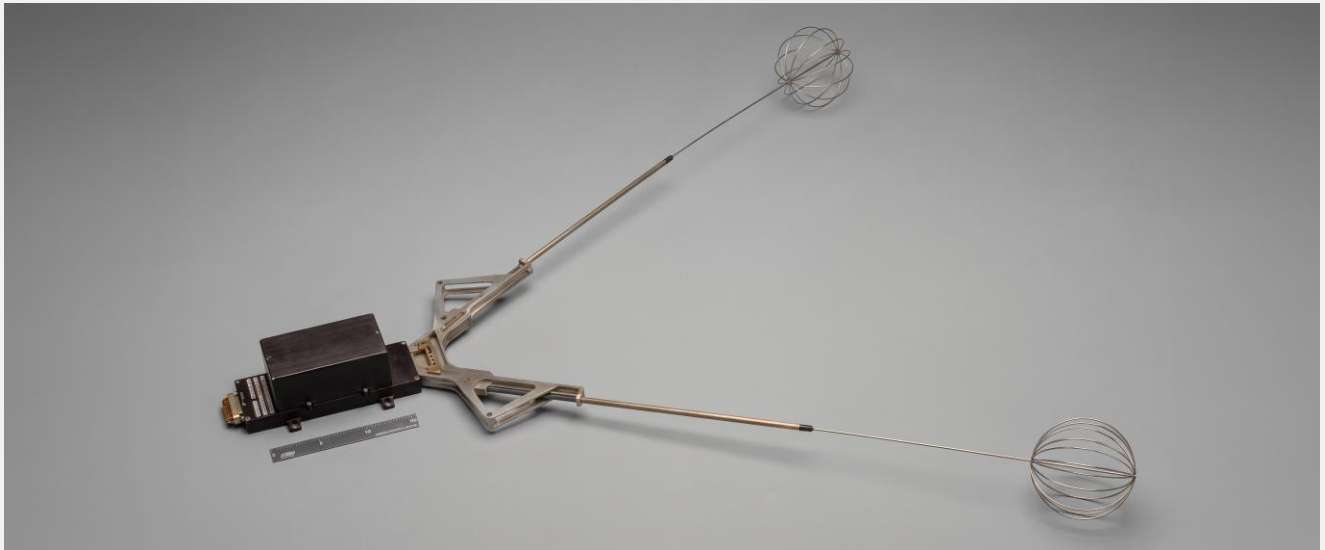


Above: Solar Wind Plasma Analyser. Image: NASA



Above: Electron Temperature Probe. Image: NASA/Goddard
Below: Magnetometer boom arm (folded) . Image: NASA





Pioneer Venus Orbiter's Electric Field Detector. Image: NASA

Flux gate Magnetometer – to measure Venus' magnetic field and the location and strength of ionospheric current systems, and to investigate the solar wind interaction with Venus.

Electric field detector – to measure electric fields and study the solar wind and its interactions with the Venusian atmosphere. It was also searching for 'whistlers', electromagnetic disturbances that travel along magnetic field lines in 100 Hz channels.

Electron temperature probe – to examine the thermal properties of Venus' ionosphere.

Ion mass spectrometer – to measure the positively charged ions in the atmosphere above 150 kilometres to better understand the atmosphere of Venus and its interaction with the solar wind.

Charged particle retarding potential analyser – to study the temperature, concentration, and velocity of the most abundant ions in the ionosphere. To determine the main sources of energy input to the ionosphere and the solar wind – ionosphere interaction process.

Gamma ray burst detector – to monitor bursts of gamma rays coming from outside the solar system. In association with other spacecraft to triangulate the source of these rays to accuracies of less than 1 arc minute.

Radio Science Experiments

These experiments evaluated the signal received from the spacecraft by the various tracking stations on Earth.

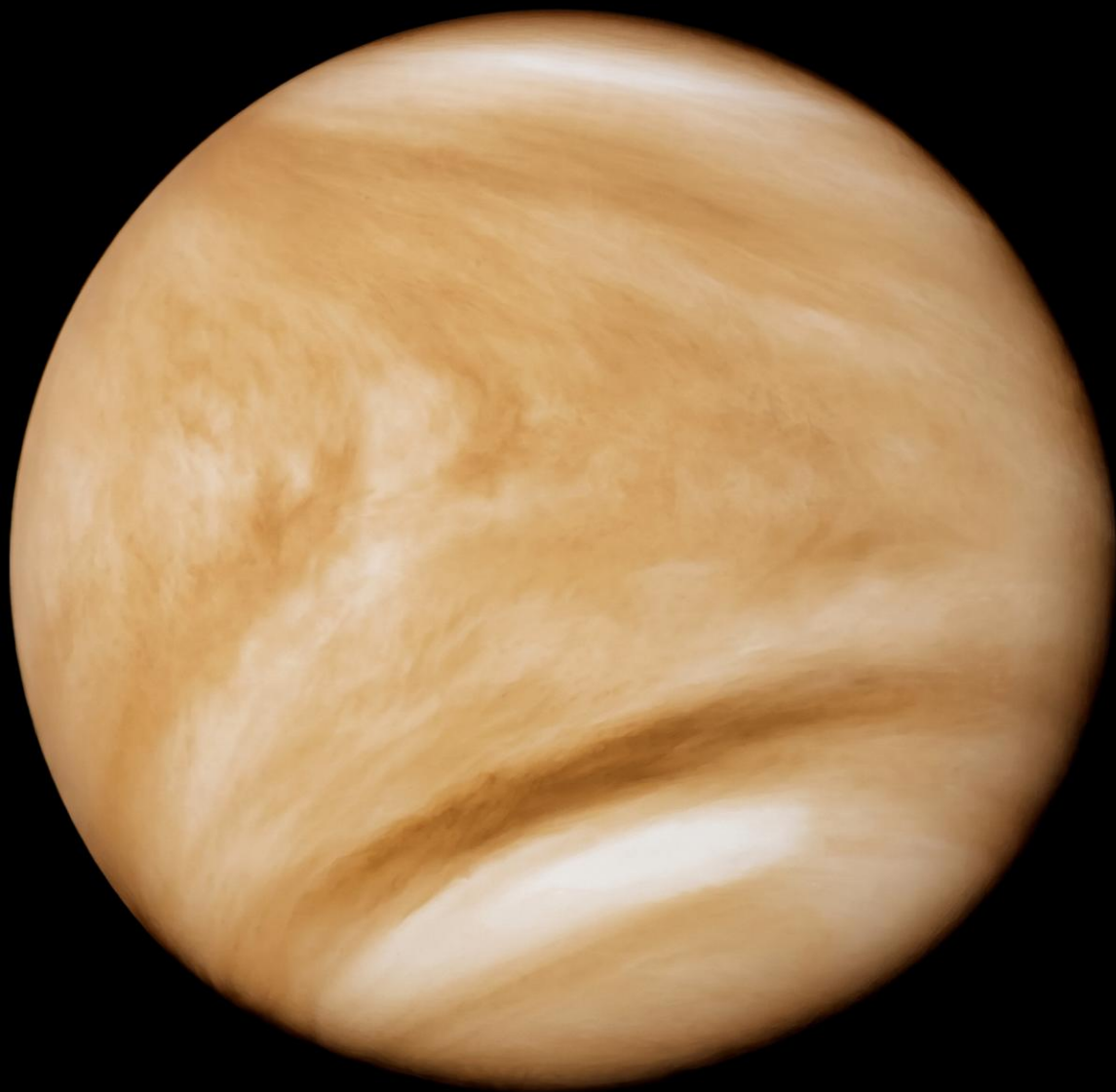
Internal density distribution experiment – the shape of Venus and gravitational perturbations of the spacecraft were used to study the relationship between the surface features of the planet and internal densities.

Celestial mechanics experiment – used the Doppler tracking data to develop a high resolution map of the gravitational potential of Venus, showing the irregularities in the vertical component of gravity at the surface of the planet.

Dual frequency radio occultation experiment – provided information about the atmosphere of Venus by observing phase perturbations of the S-Band and X-Band signals from the Orbiter penetrating the ionosphere and atmosphere during occultations. These profiles yield temperatures, pressures, and densities in the neutral atmosphere above 35 kilometres. Each occultation provided a record of Doppler frequency shift and changes in signal strength caused by the refraction and absorption by the planet's atmosphere.

Atmospheric and solar wind turbulence experiment - to determine the global distribution of turbulence in the atmosphere, as well as fluctuations in its electron density.

Atmospheric drag experiment – to model the behaviour of the upper atmosphere and search for variations in upper atmosphere density that correlate with solar wind activity and changes in ultraviolet radiation.

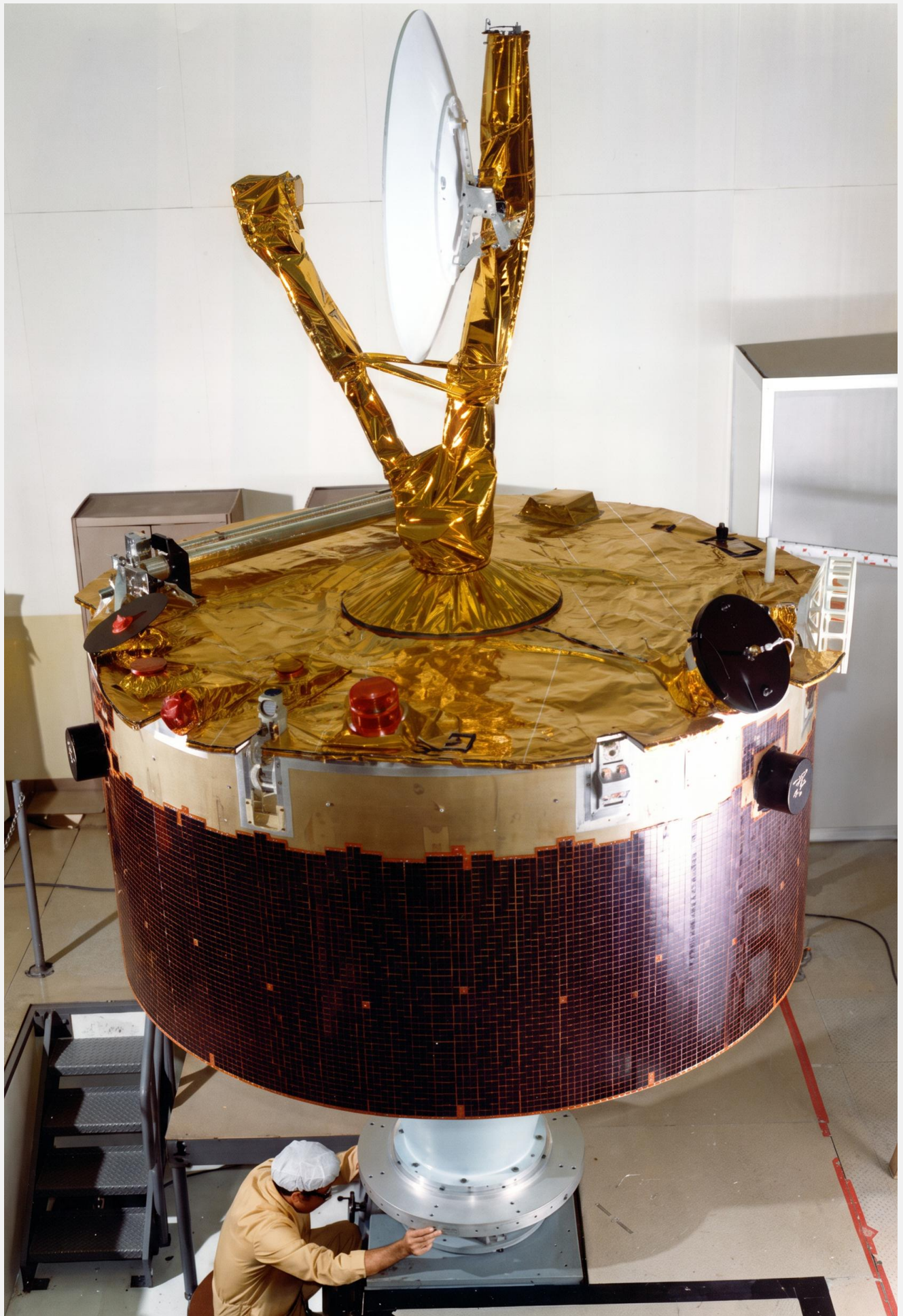


Pioneer Venus Orbiter false-colour image of Venus made at ultraviolet wavelengths. Image: NASA



(From left): H.E. Revercomb, L.A. Sromovsky, and V.E. Suomi (considered the 'father of satellite meteorology') study data from the Net Flux Radiometer observations from the Pioneer Venus mission.

Photo: University of Wisconsin-Madison Communications



The Hughes-built Pioneer Venus Orbiter being prepared for flight. Image: NASA/Hughes

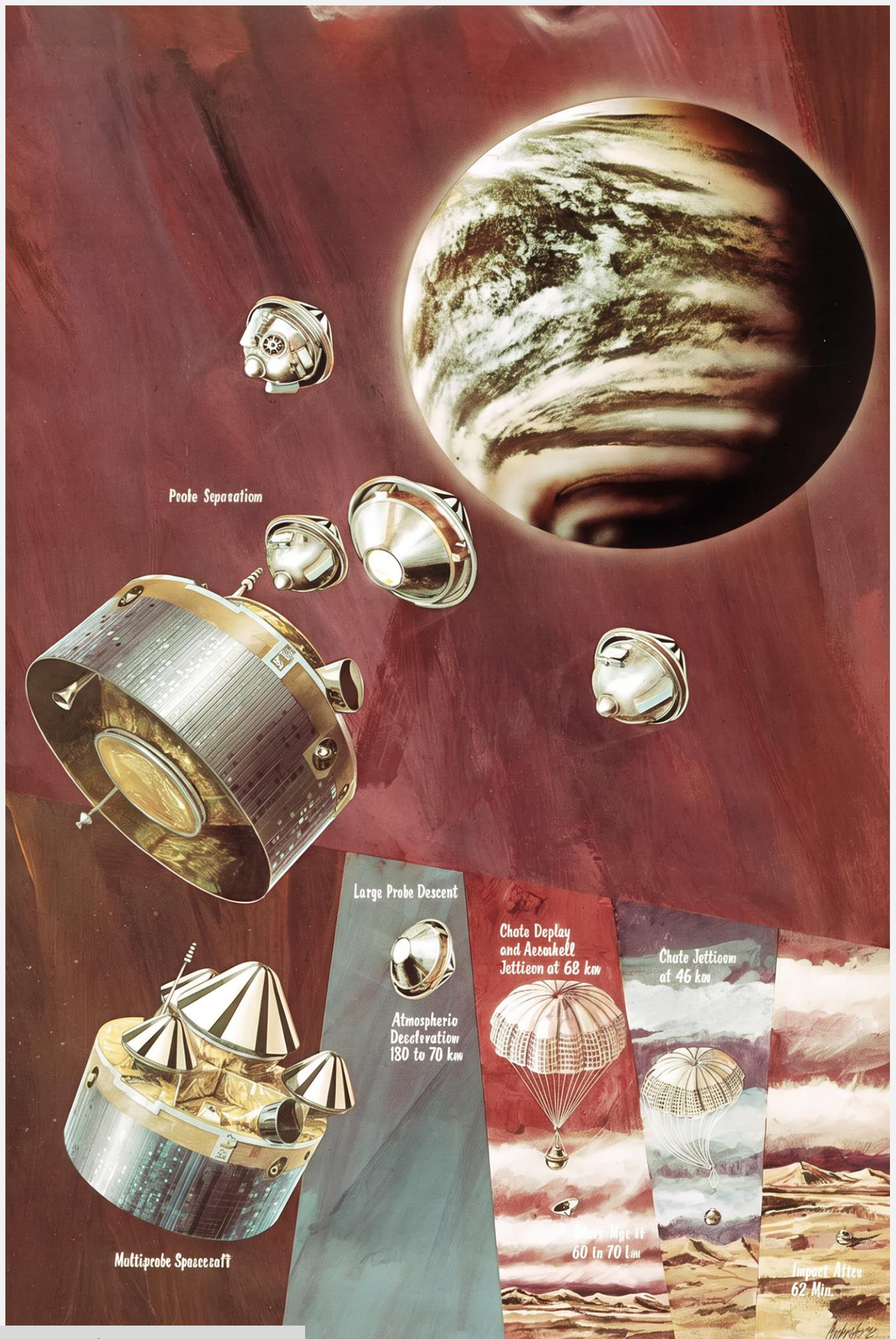
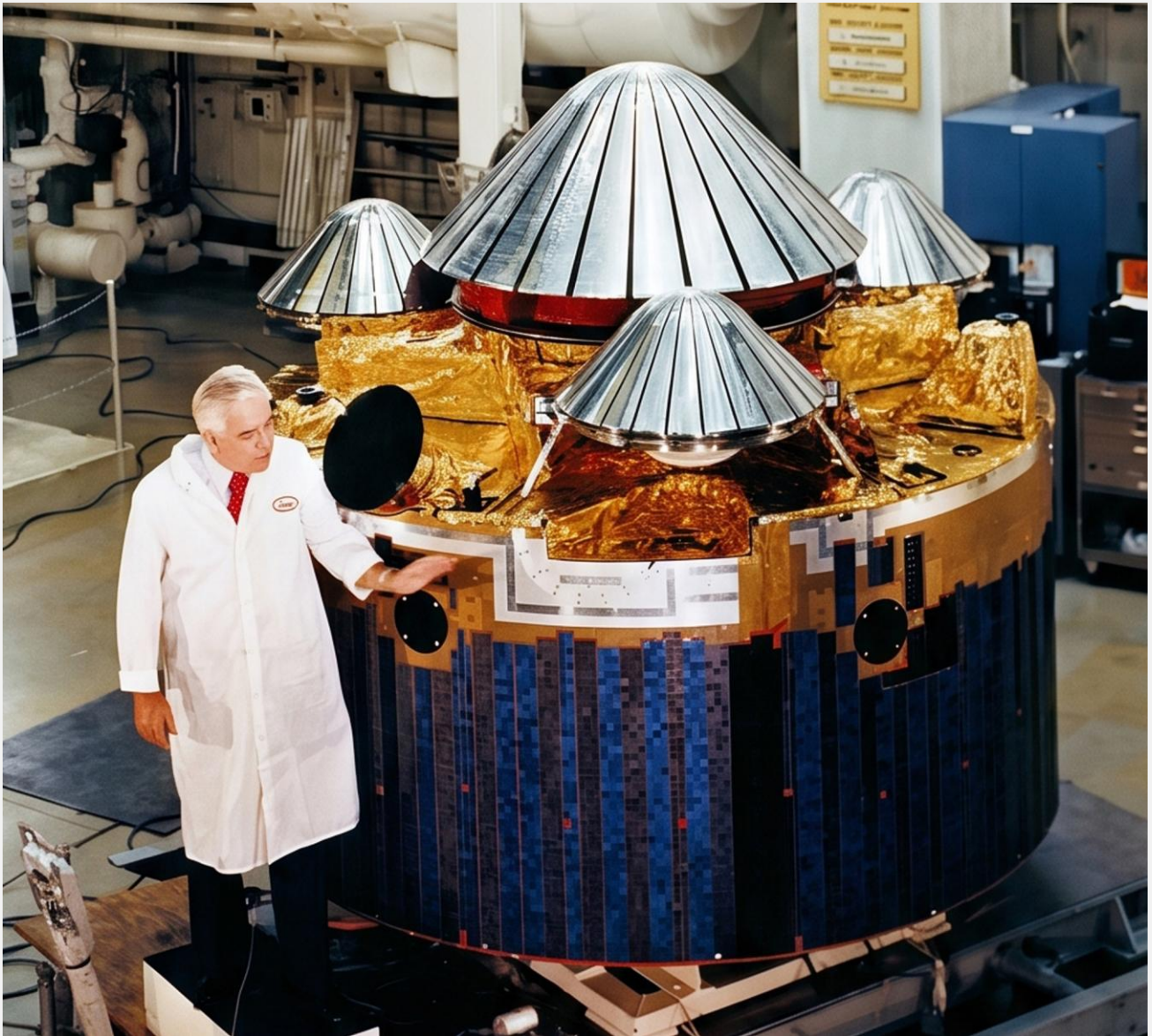


Image: NASA/Ames. Artist: Paul Hudson



The Pioneer Venus Multiprobe Bus with the Large Probe and three Small Probes. Image: NASA/Ames

PIONEER 13

VENUS MULTIPROBE

The Mission

August 1978 – November 1978

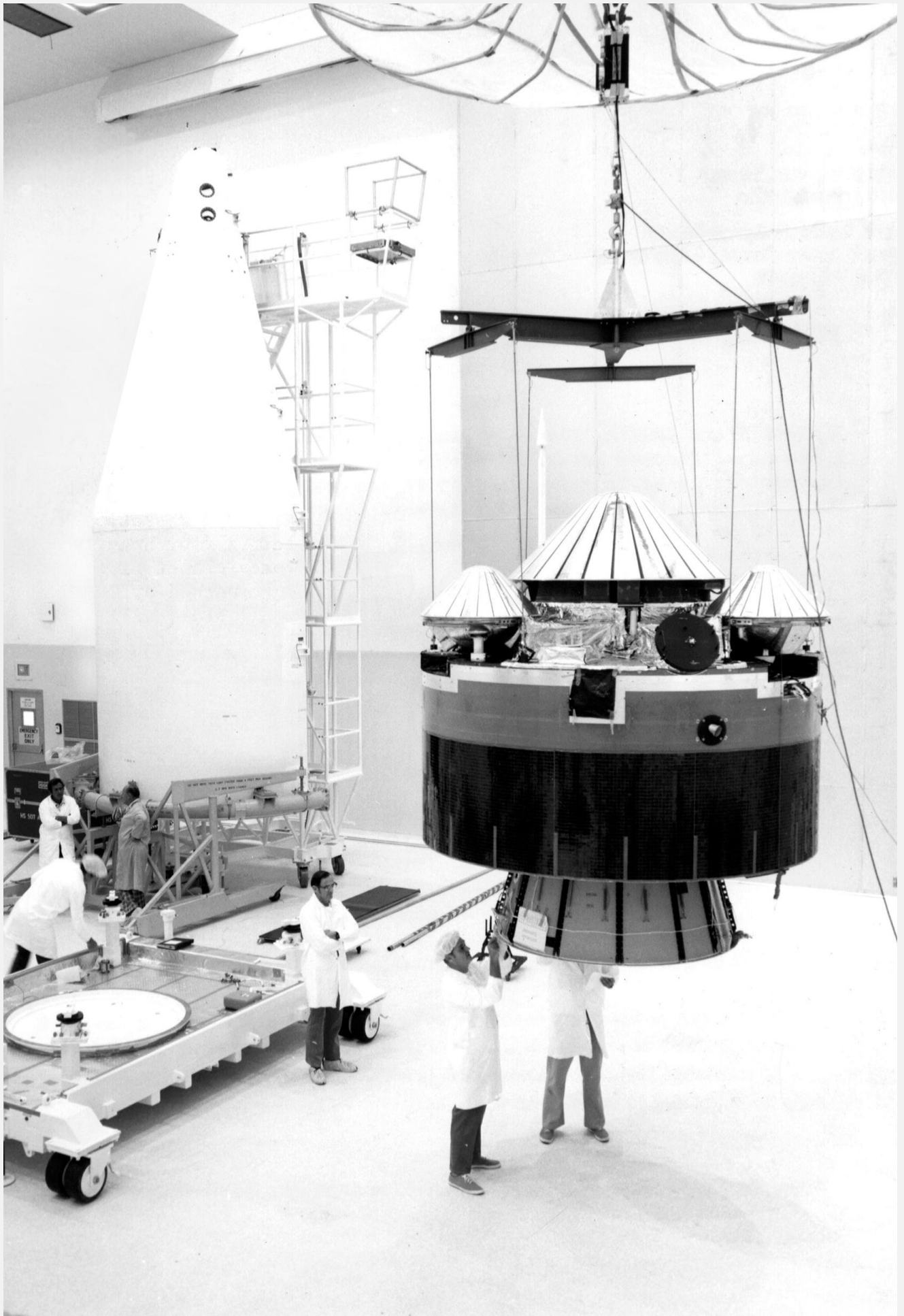
Pioneer 13 was a stablemate of Pioneer 12, the Venus Orbiter. It was also built by Hughes for the NASA Ames Research Center. It was launched from Cape Canaveral on 8 August 1978 with an Atlas Centaur. The first course change was initiated on 16 August, or it would have missed Venus by 14,000 kilometres. It took a day to execute and increased the speed of the spacecraft by 8 kilometres per hour.

The only problem during the trip to Venus was a prime receiver failure, so the back-up receiver was switched on line, and used throughout the remainder of the mission.

At 13 million kilometres from Venus the spin axis of the Bus was aligned so the heat shield of the Large Probe would be facing forward, but from the data received from the tracking stations the scientists could not be sure which direction the Bus was pointing.

One problem was the Doppler differences between the tracking stations located in the northern and southern hemispheres on Earth created slight residuals which did not agree with the model.

This generated a lot of book-keeping to keep track of what had been done to a spacecraft's velocity vector as well as the direction it was approaching the planet.



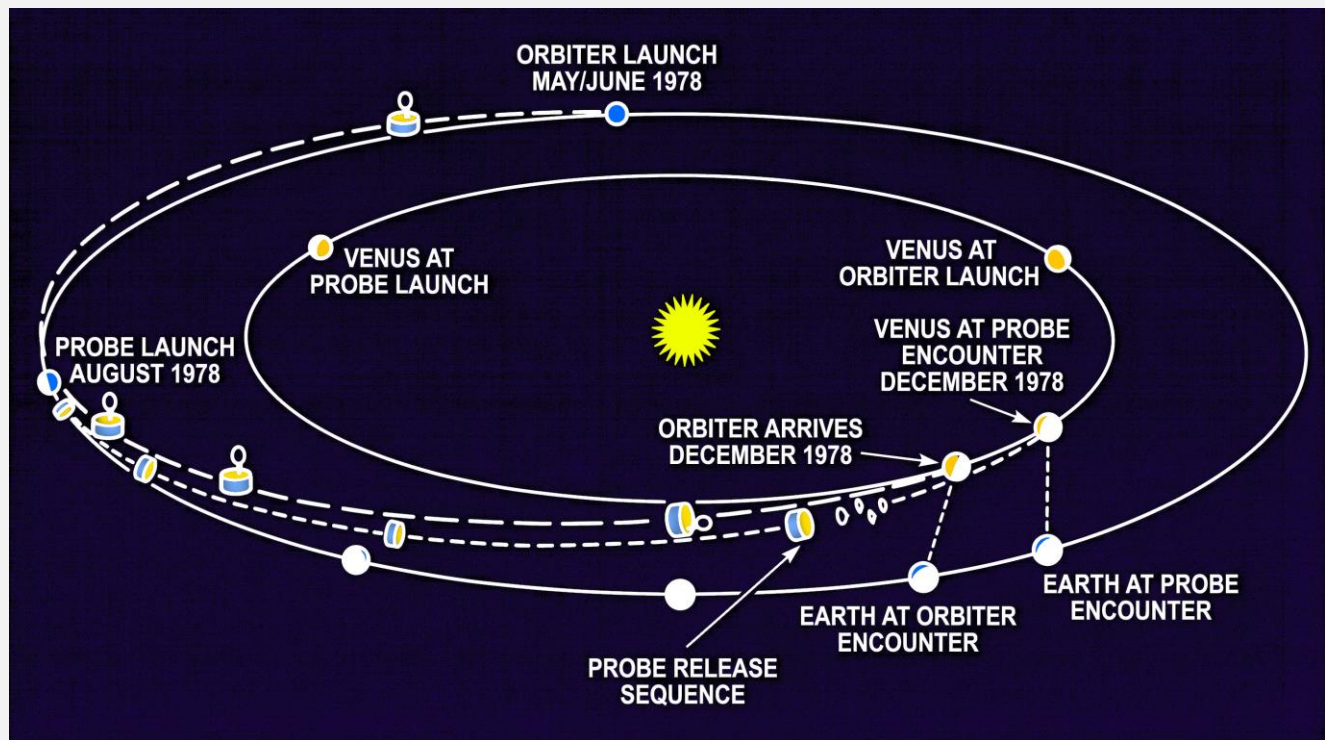
The Pioneer Venus Multiprobe craft is prepared for encapsulation in the rocket shroud. Image: NASA/KSC



Atlas-Centaur '51' sits on the pad at Launch Complex 36A at Cape Canaveral. Image: NASA/KSC



Lift-off of the Pioneer Venus Multiprobe mission on 8 August 1978. Image: NASA/KSC



Trajectories of the Pioneer Orbiter and Multiprobe spacecraft. Graphic: NASA/JPL

The scientists model the trajectory, then compare the real-time tracking data with the model and measure frequency shifts resulting from the Doppler effects they call residuals. These residuals are continually measured, evaluated, and used to update the mathematical model. Accuracies within a fraction of a thousandth of a metre per second are achieved.

Before any spacecraft manoeuvre is performed, the anticipated Doppler is calculated. After the manoeuvre is executed, any differences are attributed to a directional error in the new flight path, or the performance of the firing thruster was not to specification.

During the four days prior to the launch of the Small Probes, the Doppler uncertainty problem was found to be an unexpected solar radiation problem. When the aspect angle of the spacecraft was changed during the pre-release manoeuvre, the force of the solar radiation was different to the mathematical model, which explained the discrepancy.

The Multiprobe Bus

To launch the Small Probes, the Bus first spun up to 45 rpm, then at 0006:29 AEDT on 21 November explosive nuts fired to open the clamps on their hinges. This sequence allowed the probes to spin off tangentially within a millisecond of each other

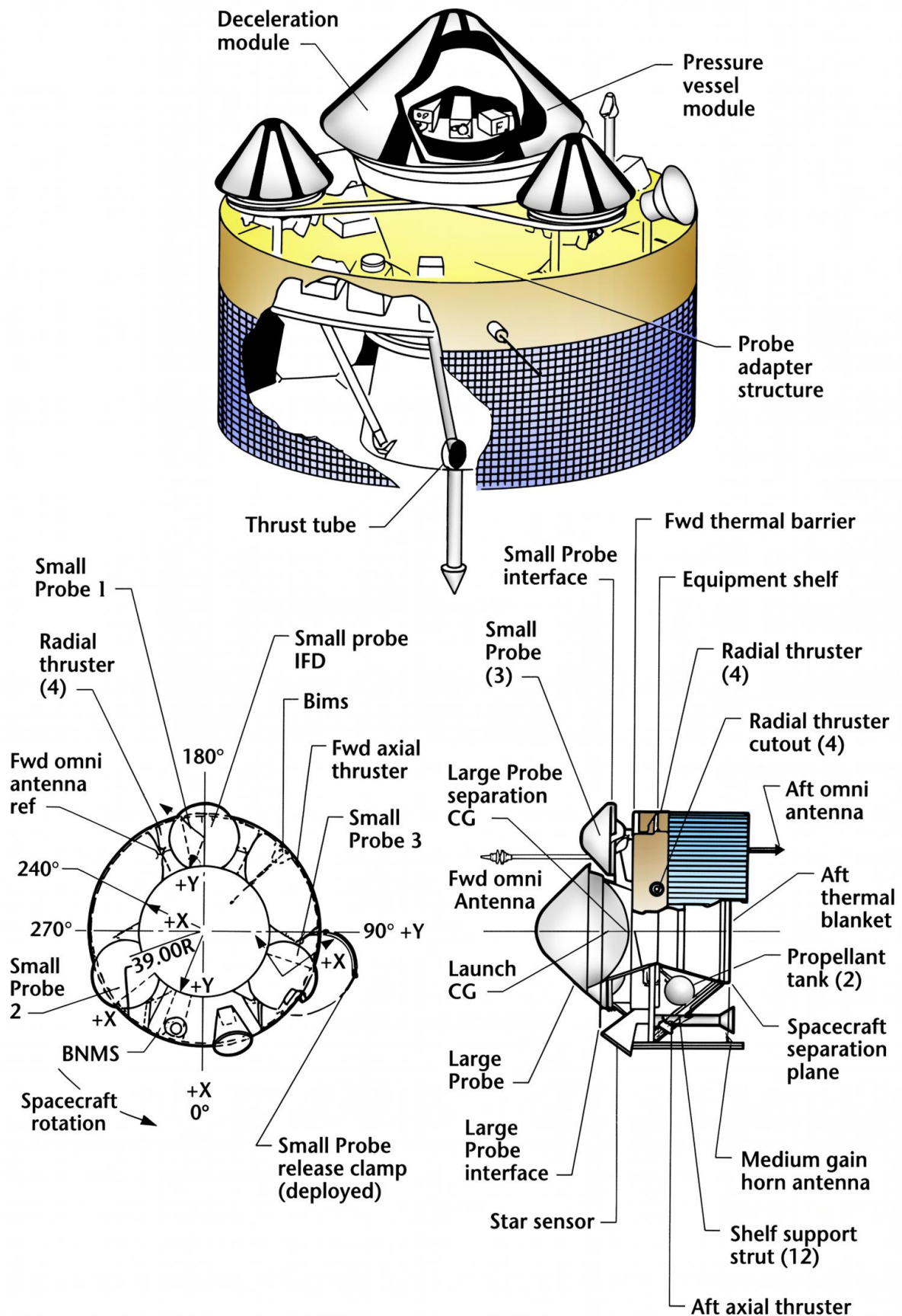
at a pre-determined point in the spin cycle. The timers began counting the seconds down to the calculated atmospheric entry. The spin of the spacecraft and the precise timing of release directed the probes into the trajectories required.

After the probes separated from the Bus, their power was shut down because they did not have sufficient on-board battery power for the whole trip to the Venusian surface, and the spacecraft coasted on their single active count-down timers.

These timers were scheduled to bring each probe into operation again three hours before the probes began their descent through the Venusian atmosphere.

The trickiest part of the whole Multiprobe mission was splitting the Bus into five independent units and aiming them at their targets. It would only take small errors to make the probes miss their targets or ruin the experiments.

After separation from the four probes, 20 days before reaching Venus, the Bus was slowed to make sure it was following the probes, and became a probe itself, seeking information on the density and composition of the upper atmosphere in the region of 150 to 130 kilometres above the surface. It had two mass spectrometers to measure the components such as atoms and molecules and their vertical distribution from



Note: Star sensor, thrusters, aft omni antenna, propellant tanks, and horn antenna rotated for clarity

Diagram of the Multiprobe showing the major components. Graphic: NASA/Hughes

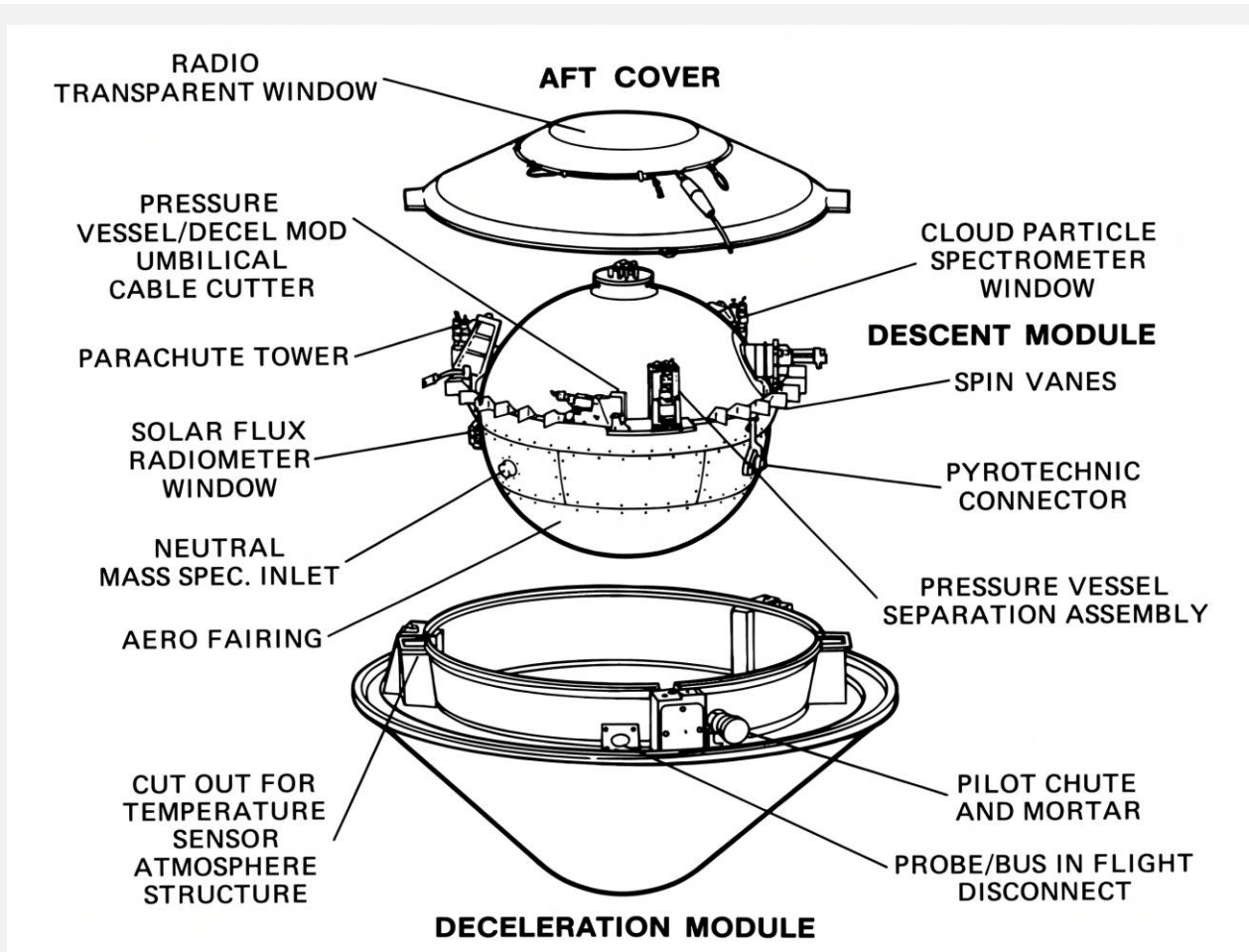


Diagram of the components of the Large Probe. Graphic: NASA/Hughes

an altitude of 700 kilometres until destruction. It had no heat shield or parachute.

Since the Bus could be targeted over a large area of Venus as it was only sampling the upper atmosphere, the precise aiming point was not so critical, but the timer setting and angle of entry was. The challenge was to angle the entry so the Bus gained the maximum time to gather data, but not so shallow that the Bus would skip off back into space.

Ideally they would have liked to skip off and enter again for more data gathering, but they decided this manoeuvre was too critical, so chose an angle of 9 degrees below the local horizontal at 200 kilometres above the surface.

The Large Probe

Before the Large Probe could be separated from the Bus on 15 November (US time) the Bus had to be oriented to send it off in the right direction.

The spin axis of the Bus was kept perpendicular to the plane of the ecliptic on the journey from Earth until 9 November when the spin axis was moved through 90° so the medium-gain horn antenna

could be used to communicate with Earth, as the omnis were no longer sensitive enough for checking out the probes before release.

The Doppler differences from the tracking stations (referred to above) had caused concern among the scientists, who even wondered if there was a propellant leak driving the spacecraft off its commanded orientation.

Project Manager Charles Hall explained,

"There were so many unknowns at that time that I decided we had better not separate until we had a better handle on the problem."

After an all-night session in his office the scientists decided that as the target was not so critical for the Large Probe they would not attempt another correcting manoeuvre but chose a timer setting to overcome the problem.

Before separation the Bus was oriented so the Large Probe would separate in the right direction. Then it was launched by a pyrotechnical spring mechanism at 1337 AEDT on 16 November and entered the Venusian atmosphere at 0545:32 AEDT on 10 December near the planet's equator in daylight.

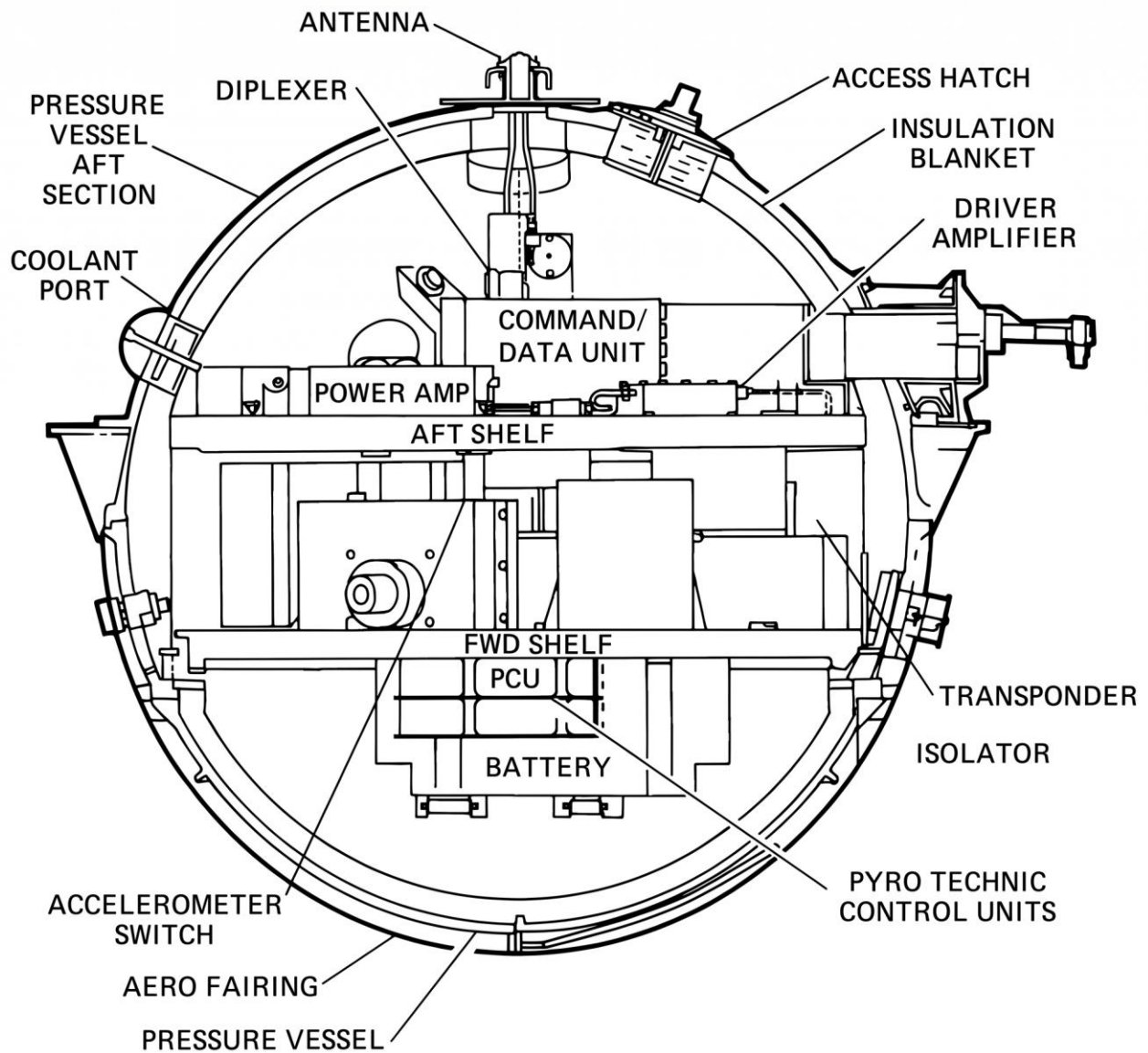


Diagram of the spherical Pressure Vessel, or Descent Module. Graphic: NASA/Hughes

The Pressure Vessel was machined from titanium and filled with Nitrogen gas under a pressure of 102 kPa. A bottle of extra gas increased the internal pressure to 143 kPa for the descent. The experiment instruments were mounted on two heat-absorbing Beryllium shelves, and the interior of the vessel was also protected from external heat by a thick blanket of multilayered Kapton lining.

The aerodynamically designed Deceleration Module (diagram on previous page), made of aluminium, enveloped the Pressure Vessel to keep the spacecraft stable during flight and provide protection from the heat of atmospheric entry. For high-speed entry a heat shield of ablative carbon phenolic material was bonded to the outer forward-facing surface of the aeroshell. The rest of the shell was covered with a heat-resisting, low density, elastomeric material.

Just 18 minutes before entering the rarefied upper atmosphere, the Large Probe began to transmit radio signals to Earth.

At 0527 AEDT on 10 December the first signal arrived at Goldstone, Tidbinbilla and Honeysuckle Creek from one of the small probes, followed by the rest, then 17 minutes later the Bus began sending data.

After deceleration from initial atmospheric entry at about 41,400 kilometres per hour near the equator on the Venus night side, a pilot parachute was mortar-fired from a small compartment in the side of the Descent Module.

The pilot chute dragged the aft cover clear which in turn yanked the main parachute from its compartment.

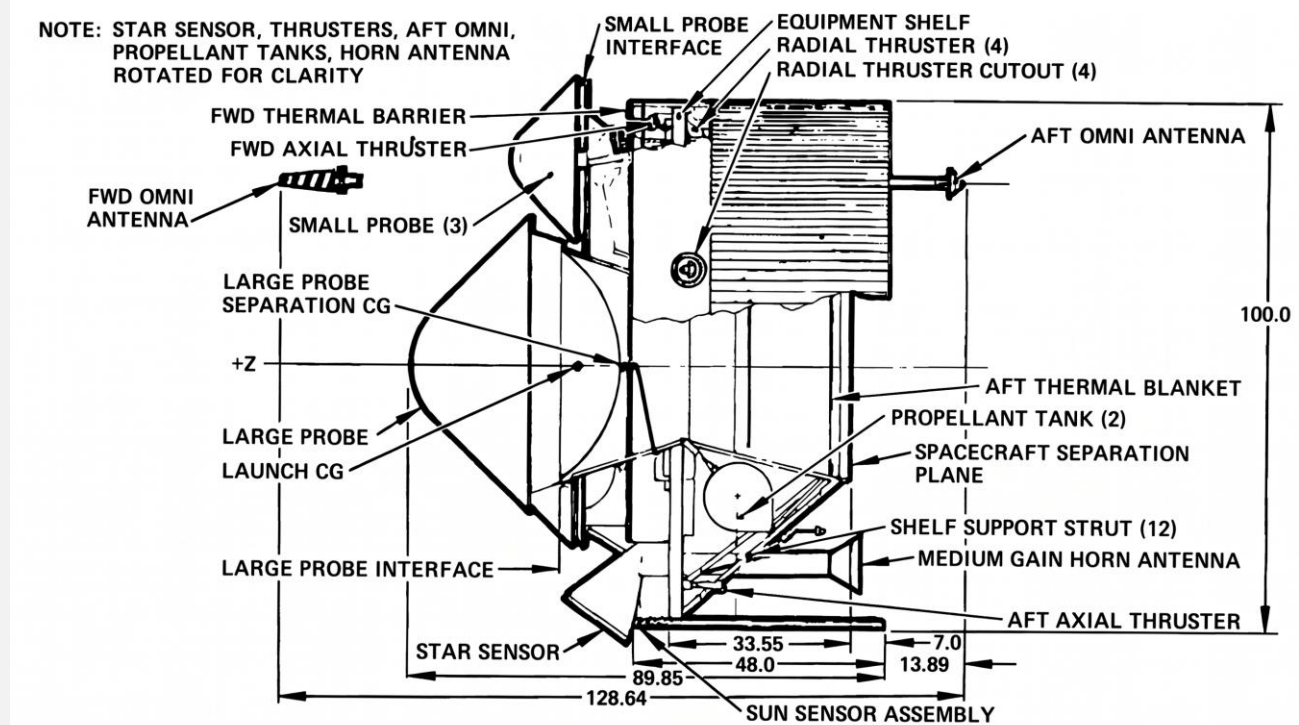


Diagram of the major components of the Multiprobe bus (measurements in inches). Graphic: NASA/Hughes

As soon as the spacecraft stabilised, mechanical and electrical connections were severed by explosive devices and cutters, and the main chute pulled the Pressure Vessel free of the Deceleration Module.

The heat shield was jettisoned at 67 kilometres altitude, the parachute released at 47 kilometres, and the spherical Descent Module had a free-fall drop to the surface, spinning slowly at less than 1 rev per minute, smashing into the ground 55 minutes later.

The Large Probe received a 2.1 GHz carrier with no command modulation from Earth, and its 40 watt transmitter sent a 2.3 GHz signal back to Earth with telemetry at 256 bits per second. There was a radio blackout period on entry, when the data collected was stored in a 3072 bit memory, for later transmission to Earth.

The Small Probes

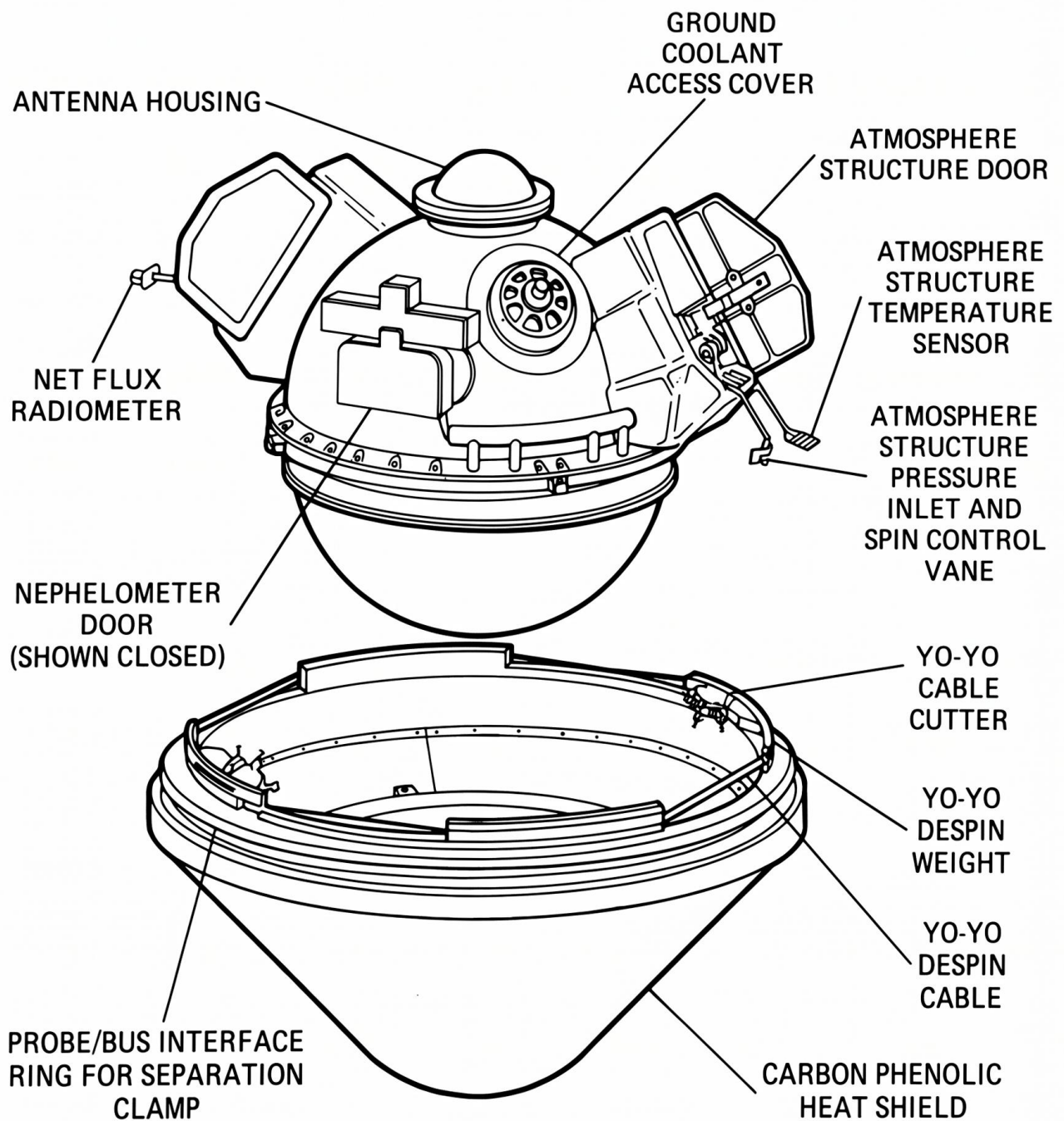
The Small Probes were checked out 22 days before entry, and all passed the tests. They had to be ejected within a few hours of the preselected time and within a fraction of a degree of roll.

To beat human error in the critical calculations, three people, working independently, were assigned to calculate each result. These precisely calculated numbers had to be lodged in the timers

of each probe, each number representing millions of seconds between the release of the probe and the times when the various experiments would commence operating. This timing was critical because if the timers were set too early the probe would run out of battery power before reaching the bottom and if set too late would have missed important data in the upper atmosphere. The Probes were not designed to receive commands from Earth once they were launched, so the timer instructions had to be loaded and verified before separation.

The Small Probes were sent to three different targets – one to the night side high-latitude northern hemisphere, and one each to the day and night sides of the planet.

As for the Large Probe, the sequence of events began 22 minutes before entry. Five minutes before entry two weights were cut loose by a pyrotechnic cable cutter allowing them to swing out like a yo-yo on 2.4 metre cables, reducing the spin rate of each probe from 48 revs per minute to 17. All three probes then entered the atmosphere at 42,000 kilometres per hour, when the yo-yos were jettisoned. At 70 kilometres altitude three doors opened to allow the Venusian atmosphere to access the instruments for sampling.



DECELERATION MODULE

The Small Probes fell through the atmosphere in times varying from 53 to 55 minutes, transmitting telemetry data with only 10 watt transmitters.

Though weak, the signals were capable of being received by the 64 metre antennas of the Deep Space Network at a rate of 64 bits per second. Once they reached a height of 30 kilometres the data rate dropped to 16 bits per second.

The probes had to face a number of tremendous challenges – apart from the initial high entry speed, they had to contend with high pressures in

the lower regions of Venus' atmosphere, which is 92 times greater than the pressure on Earth and the high temperature of about 480°C at the surface as well as highly corrosive constituents of the clouds, such as sulphuric acid.

At 0527 AEDT on 10 December the first signal arrived at Goldstone, Tidbinbilla and Honeysuckle from one of the small probes, followed by the rest, then 17 minutes later the Bus began sending data.

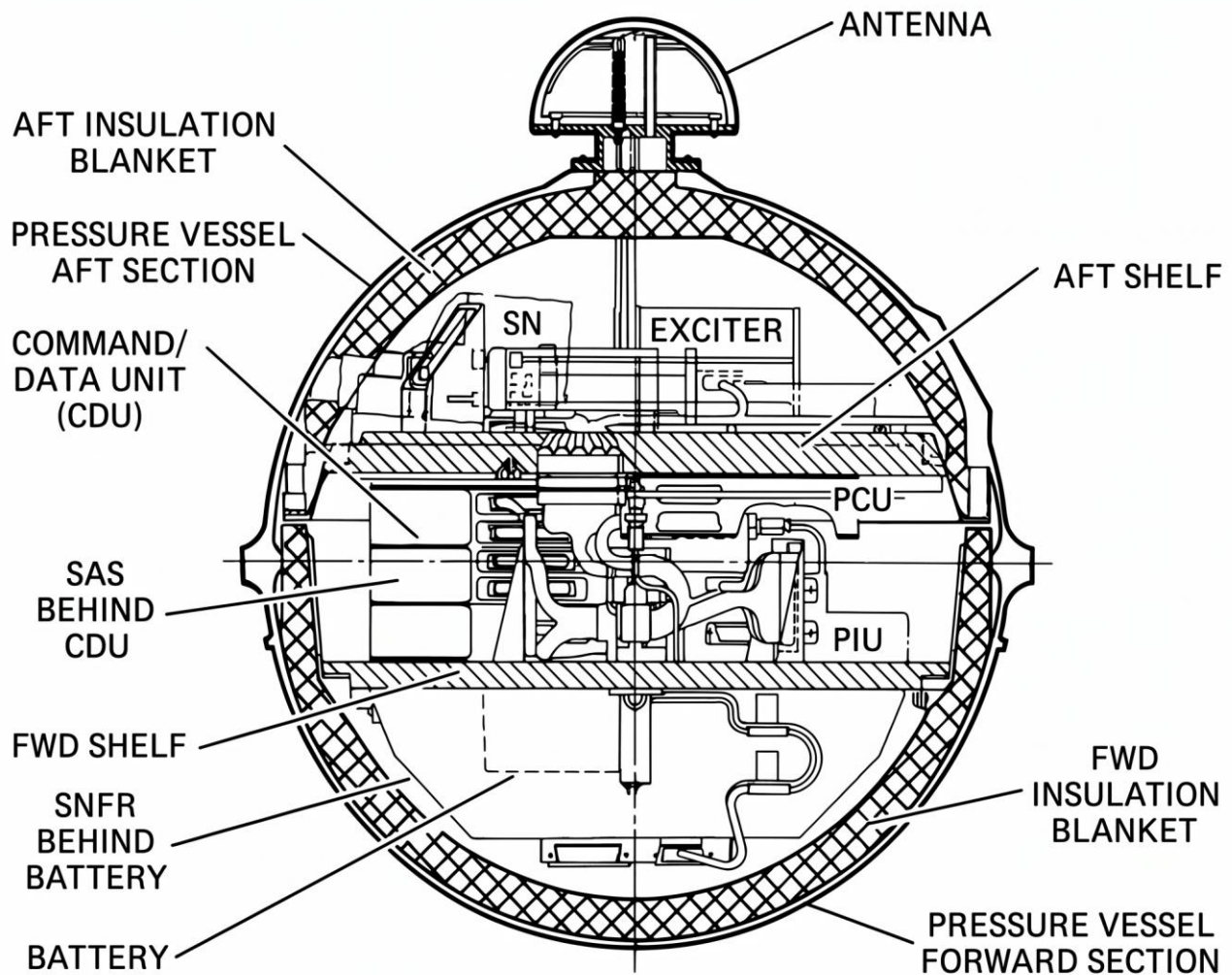


Diagram of a Small Probe's spherical Pressure Vessel. Graphic: NASA/Hughes

The Pressure Vessel was machined from Titanium filled with Xenon gas under 102 kPa pressure to reduce the flow of heat from the walls to the instruments, which were mounted on heat-absorbing Beryllium shelves. The interior of the vessel was protected from external heat by a thick blanket of multilayered Kapton lining.

The aerodynamically designed Deceleration Module (diagram on previous page) enveloped the Pressure Vessel to keep the spacecraft stable during flight and provide protection from the heat of atmospheric entry. Unlike the Large Probe they did not carry a parachute but were slowed down by aerodynamic braking. Also, unlike the Large Probe the shell was fabricated of Titanium instead of Aluminium, with a heat shield of bonded carbon to combat the heat all the way down to the surface.

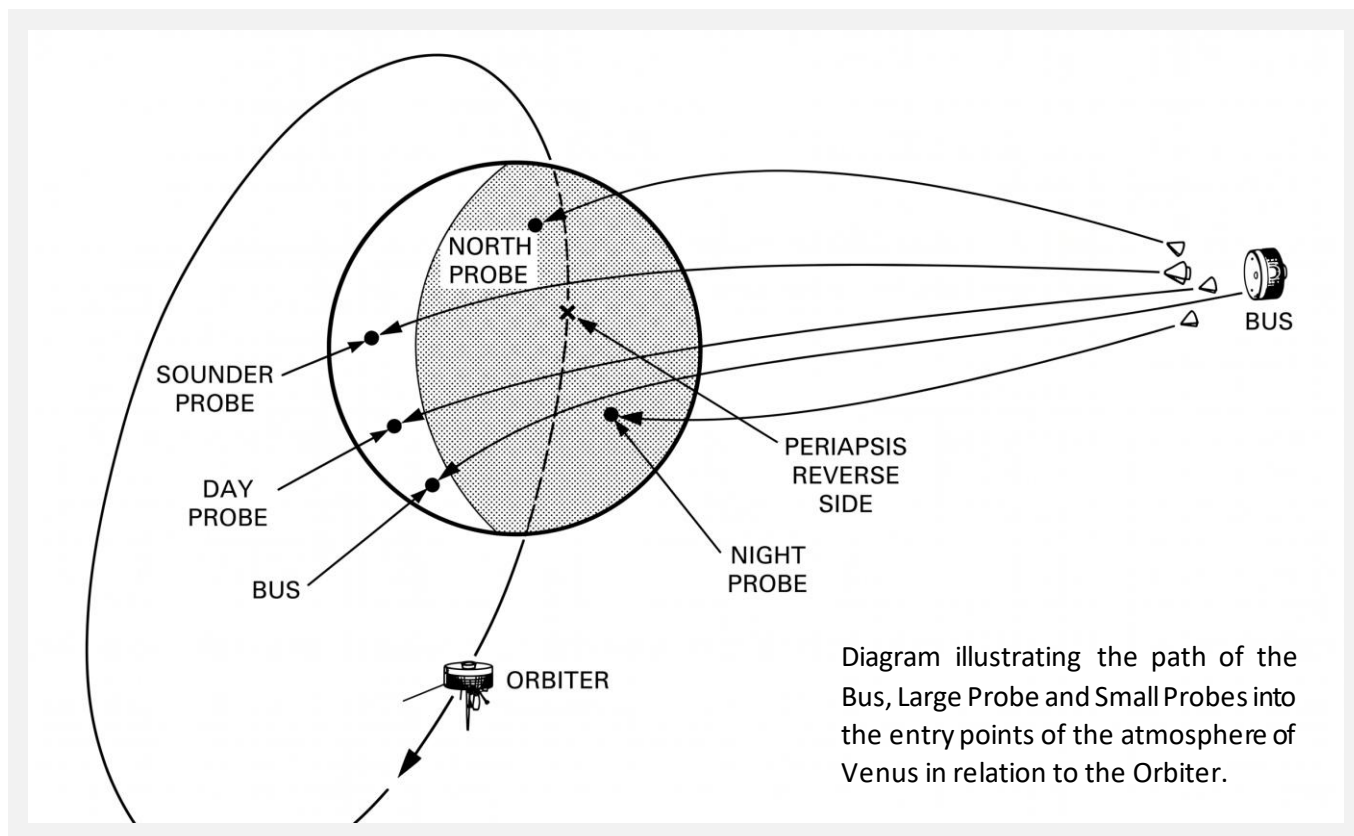
Some unexpected problems arose. All the temperature probes failed when sulphuric acid blocked the inlet. When it boiled off its constituents entered the instruments.

The sensors did not physically break. Acid films on the sensors were indicated from partial shorting of insulation while in the clouds, but this cleared as the probes descended into higher temps.

These anomalous events entered the engineering and science data at the same altitude in all four probes. Anomalies included power variations,

changes in the Large Probe's transponder static phase error and receiver AGC, jumps in internal pressure and temperature readings were probably due to static discharges inside or outside the probe.

One explanation suggested there was a reaction between the atmospheric sulphur and probe materials. Because each probe was always colder than the atmosphere, sulphur condensed on the outside of the probe pressure vessels and was carried down into the regions of higher temperatures.



This generated an electrical charge. Each probe then acted as a large capacitor because parts of the probe had not been electrically bonded to avoid heat transfer. Also, titanium, though a tough material, is a poor conductor, so would act as an insulator and stop electrical charges from dissipating. One conclusion was that most of the anomalies could be explained by these unexpected electrical interactions.

Despite these widespread anomalies a wealth of new data was gathered and technology developed for future exploration of hostile atmospheres of other planets.

The nephelometer showed a clear atmosphere below 40 kilometres.

All four probes were designed for a descent time of approximately 55 minutes before impacting the surface. None were designed to withstand the impact.

However, the Small Day Probe did survive and sent data from the surface for an extra 67 minutes. Engineering data radioed back from the Day Probe showed that its internal temperature climbed steadily to a high of 126°C. Then the batteries went flat and its signal disappeared.

PROBE ENTRY DATA

Event times are UTC, 9 December 1978, and Australian Eastern Daylight Time at tracking stations.

	Large Probe	North Probe	Day Probe	Night Probe	Bus
Entry time (200km)	1845:32	1849:40	1852:18	1856:13	2021:82
AEDT (10 December)	0545:32	0549:40	0552:18	0556:13	0721:82
Impact time	1939:53	1942:40	1947:59	1952:05	*
AEDT (10 December)	0639:53	0642:40	0647:59	0652:05	*
Loss of Signal	1939:53	1942:40	2055:34	1952:07	2022:55
AEDT (10 December)	0639:53	0642:40	0755:34	0652:07	0722:55
Impact Latitude	4.4° N	59.3° N	31.3° N	28.7° N	(37.9° S)
Impact Longitude	304.0° E	4.8° E	317.0° E	56.7° E	(290.9° E)
Local Venus time	0738:--	0335:--	0646:--	0007:--	0830:--

* Unknown, due to Bus' Loss of Signal at 110 kilometres altitude.

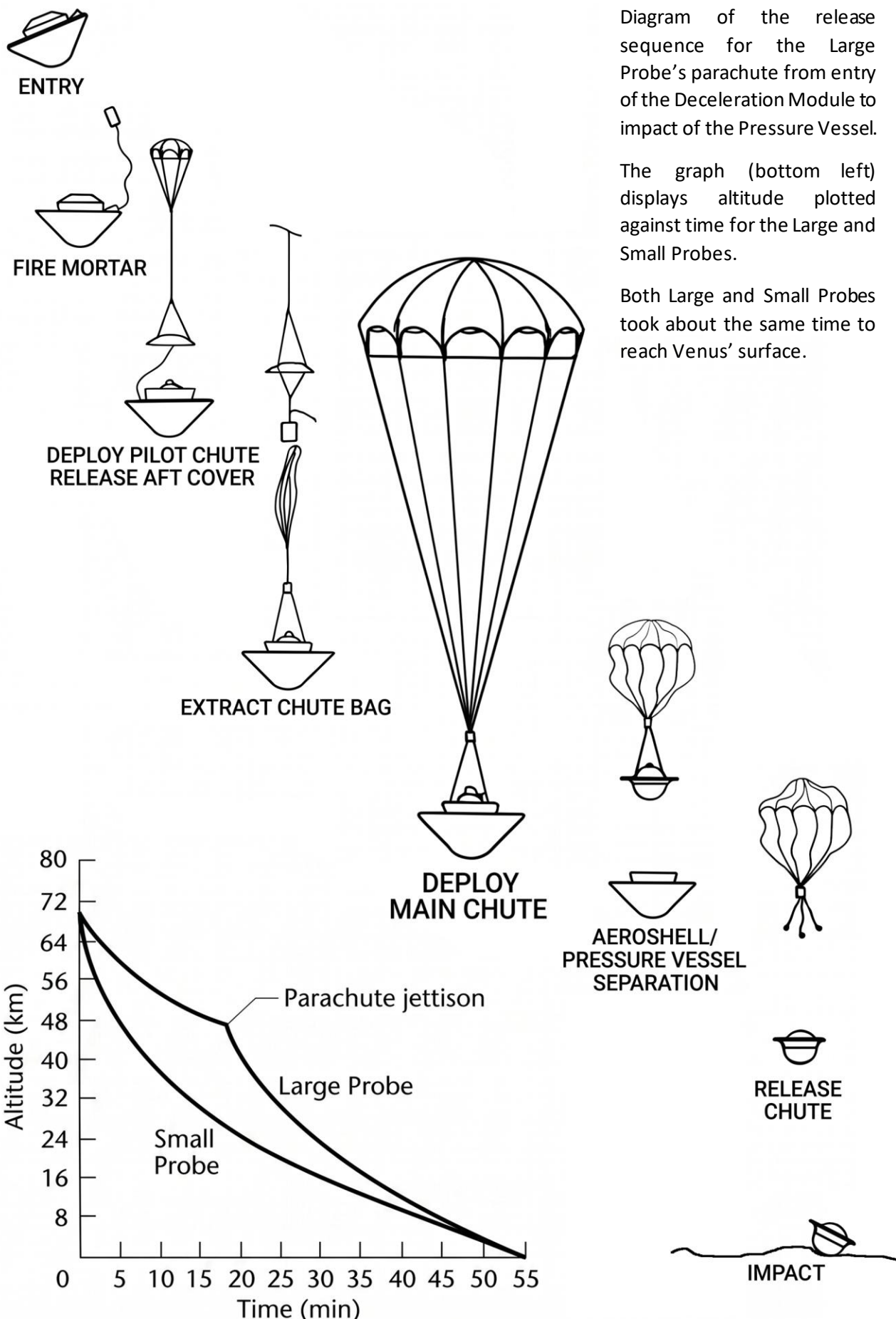


Diagram of the entry and descent of the Large Probe. Graphic: NASA/JPL
The Small Probes did not use a parachute, relying on aerodynamic forces.



A Hughes technician performs checks on the Pioneer Venus Multiprobe spacecraft. Image: NASA/Hughes

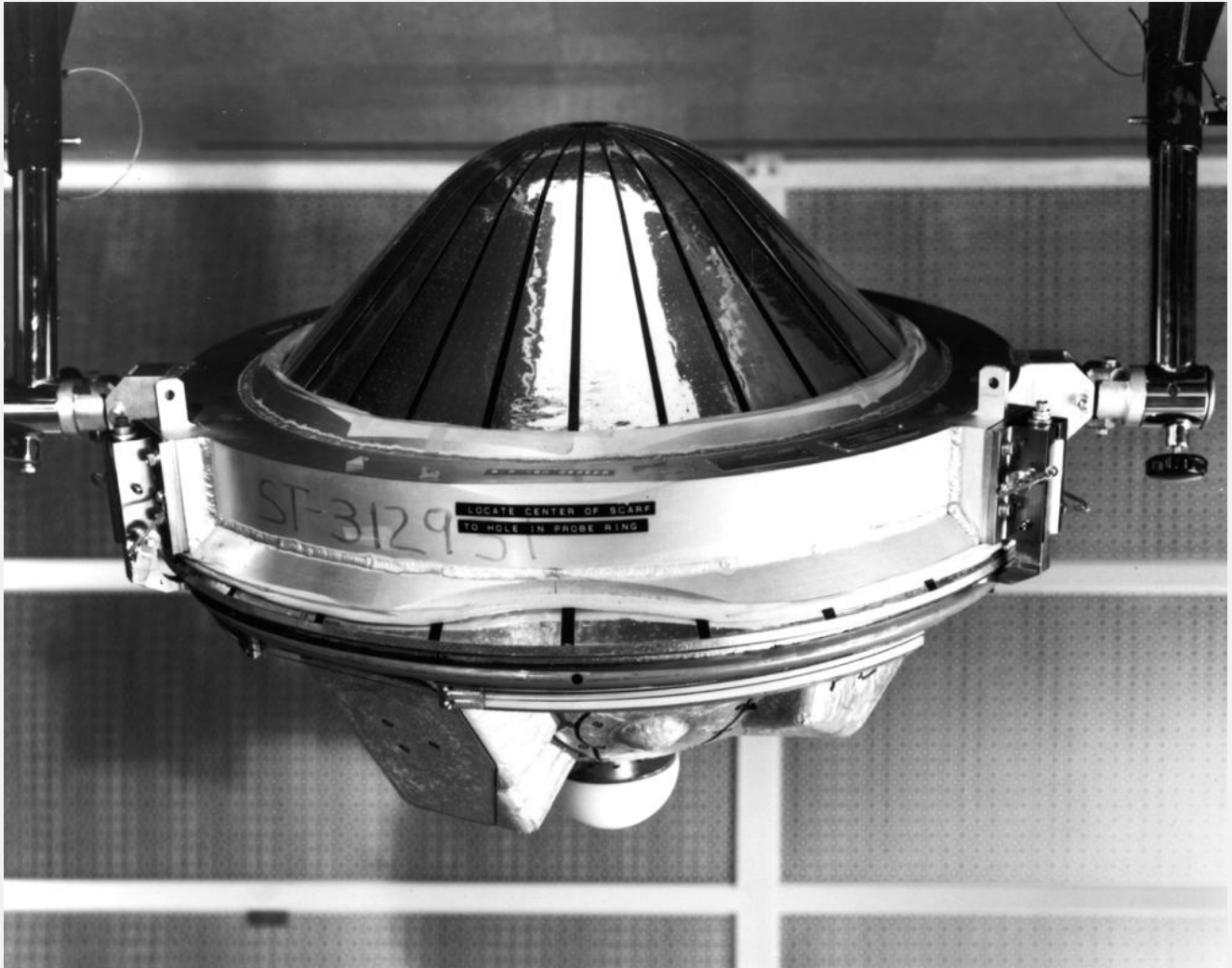


The Spacecraft

The Multiprobe was also designed to investigate Venus in four important ways:

1. To study the nature and composition of the clouds by direct sampling
2. To determine the composition, structure, and thermal balance of the planet's atmosphere
3. To determine how the atmosphere circulates about the planet
4. To investigate how the planet interacts with the solar wind.

from high altitudes down to the surface by direct sampling and measurements of radiation



Close-up of one of the Pioneer Venus' Small Probes. Image: NASA
Three identical probes named 'North, Day and Night' entered the atmosphere of Venus on 9 December 1978.

The Bus

The 2.5 metre diameter, 290 kilogram Pioneer 13 Bus carried two experiments:

1. A neutral mass spectrometer to measure the atoms and molecules of the atmosphere and their vertical distribution from about 700 kilometres to the 130 kilometres when the Bus was destroyed.
2. An ion mass spectrometer, identical to the one on the Orbiter, to measure the distribution and concentration of the positively charged ions in the upper atmosphere above 120 kilometres.

With no heat shield or parachute, the bus only made measurements to about 110 km altitude before burning up.

The bus afforded us our only direct observation of the upper Venus atmosphere, as the probes did not begin making direct measurements until they had decelerated lower in the atmosphere.

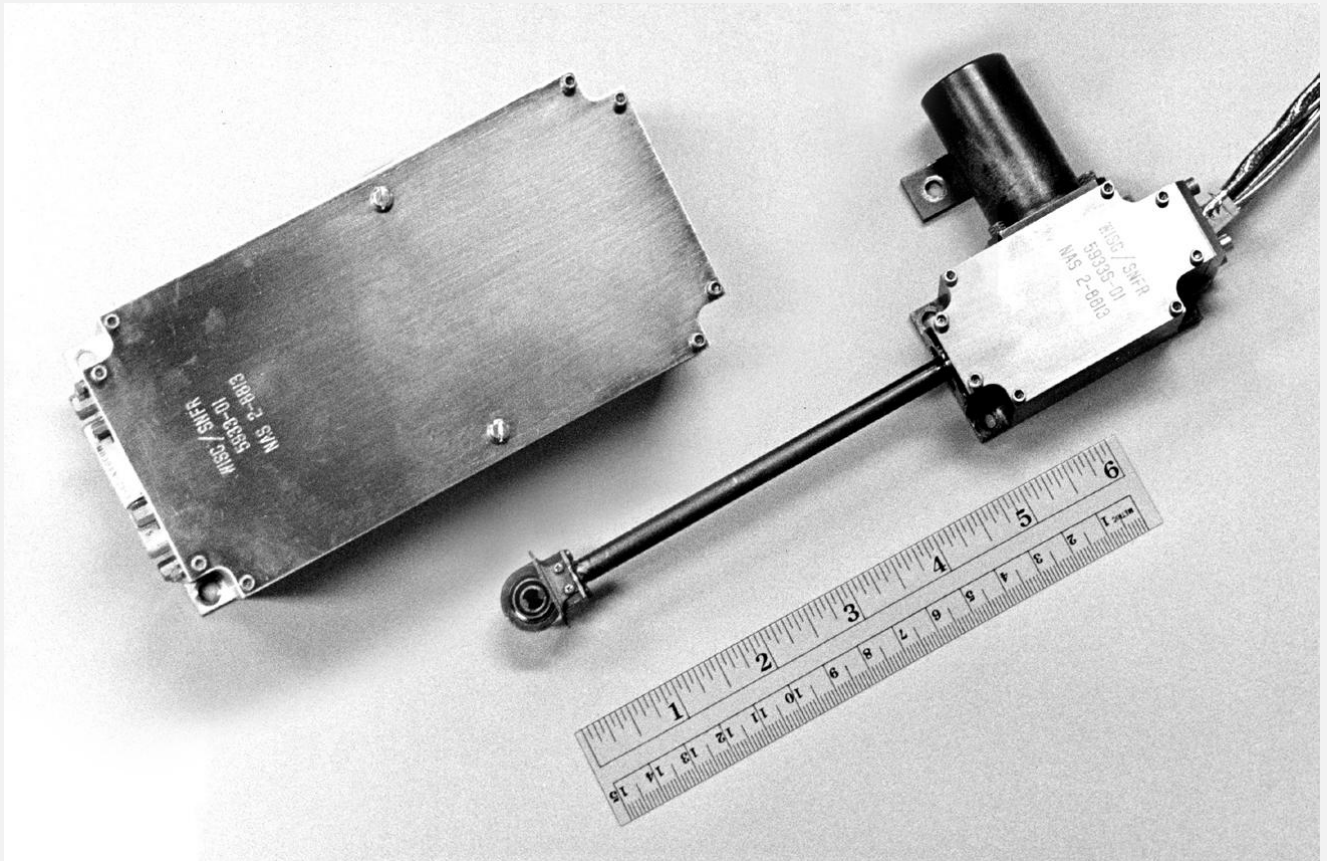
The Large Probe

With a mass of 315 kg, the large probe was about 1.5 m in diameter and the pressure vessel itself was 73.2 cm in diameter.

It was equipped with 7 science experiments, contained within a sealed spherical pressure vessel machined from titanium.

A conical aeroshell deceleration module and heat shield protected the probes from the heat of high speed atmospheric entry. This pressure vessel was encased in a nose cone and aft protective cover. Three pressure vessel penetrations were also provided as inlets for direct atmospheric sampling.

Nine observation windows (8 sapphire and 1 diamond) were required for the Large Probe instrument observations. Sapphire was used for ultraviolet light, but the only material that could withstand the high temperatures and pressures and still transmit infrared light was diamond.



A Net Flux Radiometer carried by the Small Probes. Image: NASA

Suitable diamonds were not easy to obtain. They had to go to the only people in the world who deal with the South African diamond producers in London, and wait for a large enough diamond to come from South Africa.

The 13.5 carat stone was then cut up into several windows, one with 32 facets and another with 16 facets for the Infrared radiometer and the Net Flux radiometers.

Using a data rate of 256 bits per second, the science experiments were:

Temperature, pressure, and acceleration sensors.

A neutral mass spectrometer – to measure the composition of the lower 62 kilometres of the atmosphere.

A gas chromatograph – to measure the gaseous composition of the lower atmosphere.

A solar flux radiometer – to measure solar flux penetration in the atmosphere – how much sunlight was absorbed by the clouds and how much reached the surface.

An infrared radiometer – to measure the vertical distribution of infrared radiation

A cloud particle size spectrometer – to measure particle size and shape

A nephelometer – to search for cloud particles

The Small Probes

The three small probes were identical to each other, 80 centimetres in diameter with a mass of 90 kilograms.

These probes also consisted of spherical pressure vessels surrounded by an aeroshell, but unlike the large probe, they had no parachutes and the aeroshells did not separate from the probe.

The heat shield and protective cover remained attached to the pressure vessel, and no parachutes were used.

The Small Probes were equipped with a mechanism that deployed two 2.4 metre cables and weights as a yo-yo de-spinning system five minutes before atmospheric entry.

The cables and weights reduced the spin rate of the probes from 48 to 15 rpm. The weights and cables were then jettisoned.

Using data rates of 16 to 64 bits per second, each small probe carried:



Artist illustration of the Pioneer Venus Multiprobe bus and probes, and the Orbiter. Image: NASA/Rick Guidice

A nephelometer – to measure the intensity of the light backscattered by atmospheric particles at 3500 Angstroms and 5300 Angstroms to better than a vertical spatial resolution of 150 metres.

Temperature sensors – recording temperature gradient during descent.

Pressure sensors – operated from 30 millibars to 100 bars.

Acceleration sensors – one on each probe, measured from 0.4 microgravity to 600 gravities in four ranges for entry and two ranges for descent.

Net flux radiometer – experiment to map the distribution of sources and sinks of radiative energy in the atmosphere at the surface and relate these results to observed atmospheric motions, temperature structures and cloud characteristics.

The radio signals from all four probes were also used to measure the winds, turbulence, and propagation in the atmosphere.

The small probes were each targeted at different parts of the planet and were named accordingly.

The North probe entered the atmosphere at about 60 degrees north latitude on the day side.

The night probe plunged into the darkness on the night side.

The day probe entered well into the day side, and was the only one of the four probes which continued to send radio signals back after impact. It kept transmitting for over an hour.

Essay by Hamish Lindsay, 2012-2014
 With content from honeysucklecreek.net
 created and developed by Colin Mackellar.
 Unless specified, illustrations and captions by
 Hamish Lindsay, Colin Mackellar, and Glen Nagle.
 Most images in this booklet have been digitally
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 PDF formatted by Glen Nagle.

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Artist's illustration of the Large Probe descending through a turbulent atmosphere. Image: NASA



ABOUT THE AUTHOR



Hamish Lindsay (1937-2022) worked at the Muchea, Carnarvon and Honeysuckle Creek space tracking stations between 1963 and 1981.

He wrote many essays on the history of human spaceflight and was the author of the book, *Tracking Apollo to the Moon*.