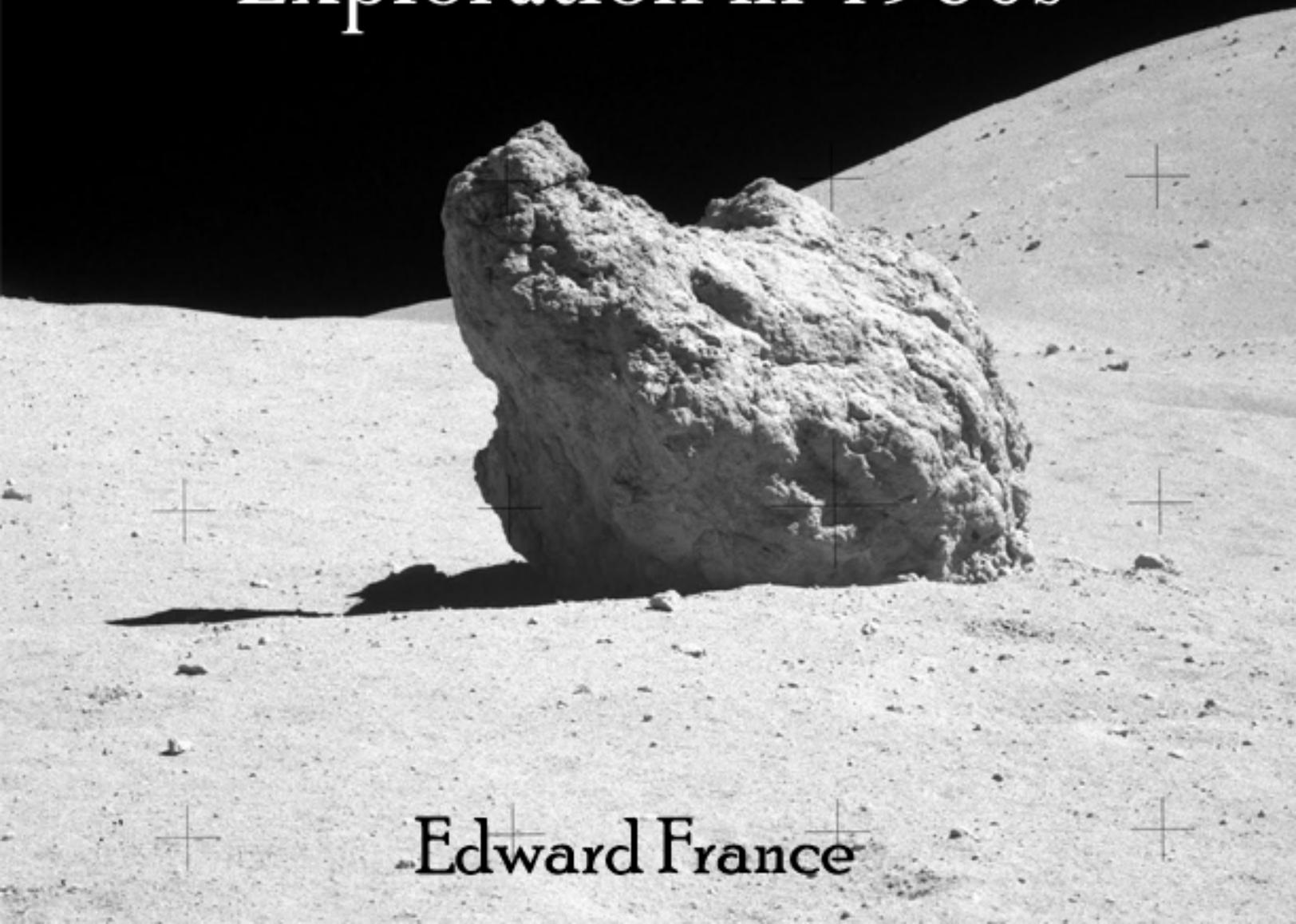


Handbook of  
Space and Solar System  
Exploration in 1980s



Edward France

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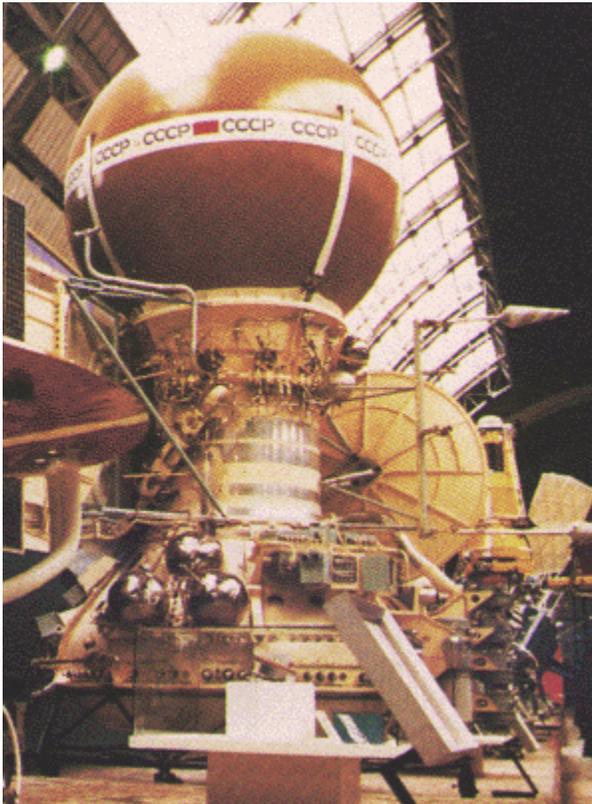
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## Chapter- 1

# Space and Solar System Exploration in 1981

## Venera 13

Venera 13



Venera 13 orbiter

<b>Operator</b>	USSR
<b>Mission type</b>	Flyby and Lander
<b>Flyby date</b>	March 1, 1982

<b>Satellite of</b>	Venus
<b>Launch date</b>	1981-10-30 at 06:04:00 UTC
<b>Launch vehicle</b>	Proton Booster Plus Upper Stage and Escape Stages
<b>COSPAR ID</b>	1981-106A
<b>Mass</b>	760 kg

**Venera 13** (Russian: Венера-13) was a probe in the Soviet Venera program for the exploration of Venus.

Venera 13 and 14 were identical spacecraft built to take advantage of the 1981 Venus launch opportunity and launched 5 days apart, Venera 13 on 1981-10-30 at 06:04:00 UTC and Venera 14 on 1981-11-04 at 05:31:00 UTC, both with an on-orbit dry mass of 760 kg.

## Design



Venera 13 lander

Each mission consisted of a bus and an attached descent craft. The descent craft/lander was a hermetically sealed pressure vessel, which contained most of the instrumentation and electronics, mounted on a ring-shaped landing platform and topped by an antenna. The design was similar to the earlier Venera 9–12 landers. It carried instruments to take chemical and isotopic measurements, monitor the spectrum of scattered sunlight, and record electric discharges during its descent phase through the Venusian atmosphere. The spacecraft utilized a camera system, an X-ray fluorescence spectrometer, a screw drill and surface sampler, a dynamic penetrometer, and a seismometer to conduct investigations on the surface.

List of lander experiments and instruments:

- Accelerometer, Impact Analysis - Bison-M
- Thermometers, Barometers - ITD
- Spectrometer / Directional Photometer - IOAV-2
- Ultraviolet Photometer
- Mass Spectrometer - MKh-6411
- Penetrometer / Soil Ohmmeter - PrOP-V
- Chemical Redox Indicator - Kontrast
- 2 Color Telephotometer Cameras - TFZL-077
- Gas Chromatograph - Sigma-2
- Radio / Seismometer - Groza-2
- Nephelometer - MNV-78-2
- Hydrometer - VM-3R
- X-Ray Fluorescence Spectrometer (Aerosol) - BDRA-1V
- X-Ray Fluorescence Spectrometer (Soil) - Arakhis-2
- Soil Drilling Apparatus - GZU VB-02
- Stabilized Oscillator / Doppler Radio
- Small solar batteries - MSB

## Landing

After launch and a four month cruise to Venus the descent vehicle separated from the bus and plunged into the Venusian atmosphere on March 1, 1982. After entering the atmosphere a parachute was deployed. At an altitude of about 50 km the parachute was released and simple airbraking was used the rest of the way to the surface.

Venera 13 landed at 7°30'S 303°00'E / 7.5°S 303°E, about 950 km northeast of Venera 14, just east of the eastern extension of an elevated region known as Phoebe Regio.

The lander had cameras to take pictures of the ground and spring-loaded arms to measure the compressibility of the soil. The quartz camera windows were covered by lens caps which popped off after descent.

The area was composed of bedrock outcrops surrounded by dark, fine-grained soil. After landing an imaging panorama was started and a mechanical drilling arm reached to the

surface and obtained a sample, which was deposited in a hermetically sealed chamber, maintained at 30 °C and a pressure of about 0.05 atmosphere (5 kPa). The composition of the sample determined by the X-ray fluorescence spectrometer put it in the class of weakly differentiated melanocratic alkaline gabbroids.

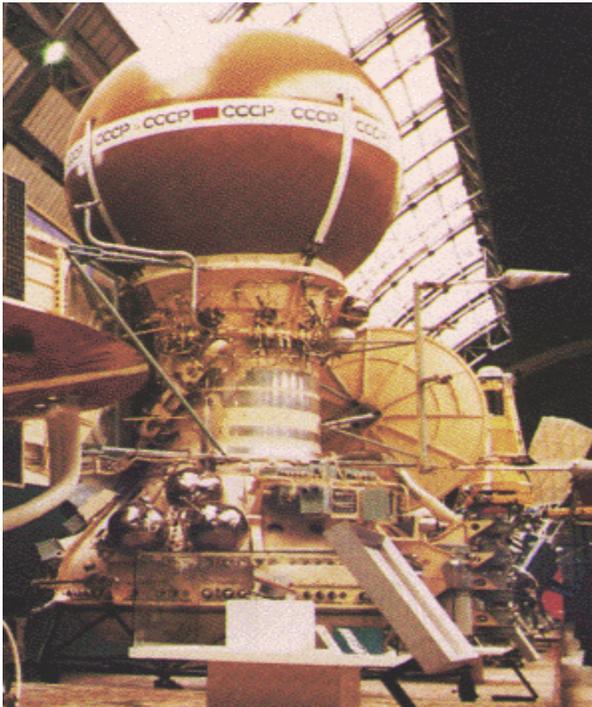
The lander survived for 127 minutes (the planned design life was 32 minutes) in an environment with a temperature of 457 °C (855 °F) and a pressure of 89 Earth atmospheres (9.0 MPa). The descent vehicle transmitted data to the bus, which acted as a data relay as it flew by Venus. It is probable that the probe or its remains have been severely degraded by the high surface temperature and pressure and the presence of corrosive supercritical carbon dioxide in the Venusian atmosphere.

## Image processing

American researcher Don P. Mitchell has processed the color images from Venera 13 and 14 using the original digital telemetry data. The new images are based on a more accurate linearization of the original 9-bit logarithmic pixel encoding.

## Venera 14

Venera 14



## Venera 14 orbiter

<b>Operator</b>	USSR
<b>Mission type</b>	Flyby
<b>Satellite of</b>	Venus
<b>Launch date</b>	1981-11-04 at 05:31:00 UTC
<b>Launch vehicle</b>	Proton Booster Plus Upper Stage and Escape Stages
<b>COSPAR ID</b>	1981-110A

**Venera 14** (Russian: Венера-14) was a probe in the Soviet Venera program for the exploration of Venus.

Venera 14 was identical to the Venera 13 spacecraft and built to take advantage of the 1981 Venus launch opportunity and launched 5 days apart. It was launched on 4 November 1981 at 05:31:00 UTC and Venera 13 on 30 October 1981 at 06:04:00 UTC, both with an on-orbit dry mass of 760 kg.

## Design

Each mission consisted of a bus and an attached descent craft.

As it flew by Venus the bus acted as a data relay for the lander and then continued on into a heliocentric orbit. It was equipped with a gamma-ray spectrometer, UV grating monochromator, electron and proton spectrometers, gamma-ray burst detectors, solar wind plasma detectors, and two-frequency transmitters which made measurements before, during, and after the Venus flyby.

The descent lander was a hermetically sealed pressure vessel, which contained most of the instrumentation and electronics, mounted on a ring-shaped landing platform and topped by an antenna. The design was similar to the earlier Venera 9–12 landers. It carried instruments to take chemical and isotopic measurements, monitor the spectrum of scattered sunlight, and record electric discharges during its descent phase through the Venusian atmosphere. The spacecraft utilized a camera system, an X-ray fluorescence spectrometer, a screw drill and surface sampler, a dynamic penetrometer, and a seismometer to conduct investigations on the surface.

List of lander experiments and instruments:

- Accelerometer, Impact Analysis - Bison-M
- Thermometers, Barometers - ITD
- Spectrometer / Directional Photometer - IOAV-2

- Ultraviolet Photometer
- Mass Spectrometer - MKh-6411
- Penetrometer / Soil Ohmmeter - PrOP-V
- Chemical Redox Indicator - Kontrast
- 2 Color Telephotometer Cameras - TFZL-077
- Gas Chromatograph - Sigma-2
- Radio / Microphone / Seismometer - Groza-2
- Nephelometer - MNV-78-2
- Hydrometer - VM-3R
- X-Ray Fluorescence Spectrometer (Aerosol) - BDRA-1V
- X-Ray Fluorescence Spectrometer (Soil) - Arakhis-2
- Soil Drilling Apparatus - GZU VB-02
- Stabilized Oscillator / Doppler Radio
- Small solar batteries - MSB

## Landing

Venera 14 lander



The Venera 14 lander was identical to Venera 13

<b>Operator</b>	USSR
<b>Mission type</b>	Venus Lander
<b>Launch vehicle</b>	Venera 14 bus
<b>COSPAR ID</b>	1981-110D
<b>Mass</b>	760 kg

After launch and a four month cruise to Venus the descent vehicle separated from the bus and plunged into the Venusian atmosphere on March 5, 1982. After entering the

atmosphere a parachute was deployed. At an altitude of about 50 km the parachute was released and simple airbraking was used the rest of the way to the surface.

Venera 14 landed at 13°15'S 310°00'E / 13.25°S 310°E (about 950 km southwest of Venera 13) near the eastern flank of Phoebe Regio on a basaltic plain.

The lander had cameras to take pictures of the ground and spring-loaded arms to measure the compressibility of the soil. The quartz camera windows were covered by lens caps which popped off after descent. Venera 14, however, ended up measuring the compressibility of the lens cap, which landed right where the probe was to measure the soil.

The composition of the surface samples was determined by the X-ray fluorescence spectrometer, showing it to be similar to oceanic tholeiitic basalts.

The lander survived for 57 minutes (the planned design life was 32 minutes) in an environment with a temperature of 465 °C and a pressure of 94 Earth atmospheres (9.5 MPa). It is probable that the probe or its remains have been severely degraded by the high surface temperature and pressure and the presence of corrosive supercritical carbon dioxide in the Venusian atmosphere.

## **Image processing**

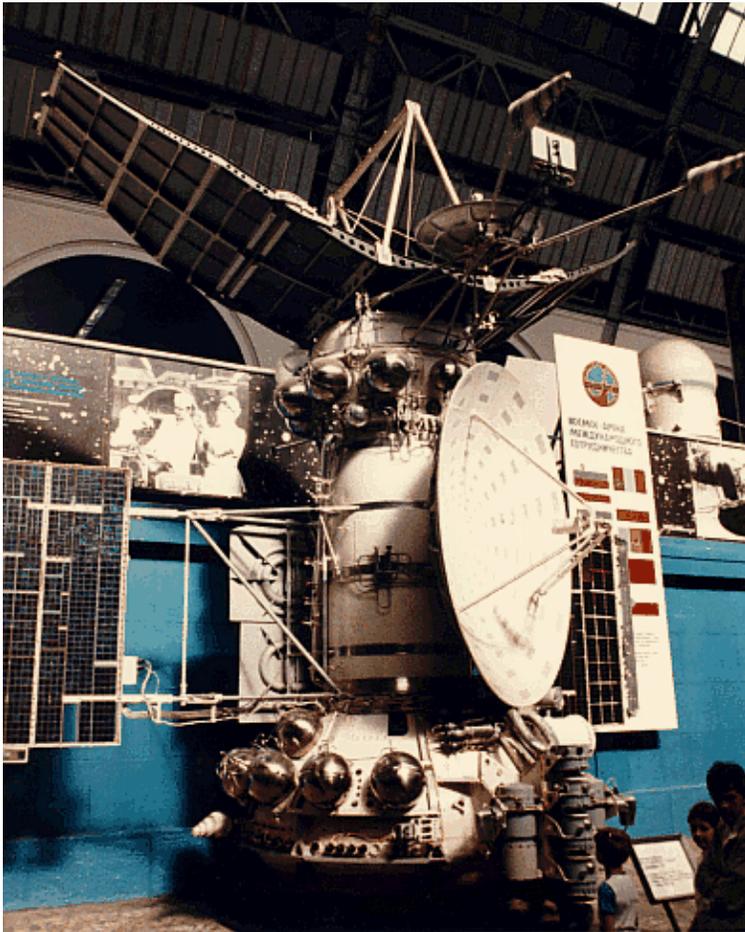
American researcher Don P. Mitchell has processed the color images from Venera 13 and 14 using the raw original data. The new images are based on a more accurate linearization of the original 9-bit logarithmic pixel encoding.

## Chapter- 2

# Space and Solar System Exploration in 1983

## Venera 15

Venera 15



Venera 15 orbiter

**Operator**

USSR

<b>Mission type</b>	Orbiter
<b>Satellite of</b>	Venus
<b>Orbital insertion date</b>	October 10, 1983
<b>Launch date</b>	June 2, 1983
<b>Mission duration</b>	June 2, 1983 to ~July 1984
<b>COSPAR ID</b>	1983-053A
<b>Mass</b>	4000 kg

#### **Orbital elements**

<b>Eccentricity</b>	.8211
<b>Inclination</b>	92.5°
<b>Apoapsis</b>	11.91 RV
<b>Periapsis</b>	1.17 RV
<b>Orbital period</b>	24 h

**Venera 15** (Russian: Венера-15) was a spacecraft sent to Venus by the Soviet Union. This unmanned orbiter was to map the surface of Venus using high resolution imaging systems. The spacecraft was identical to Venera 16 and based on modifications to the earlier Venera space probes.

## **Mission profile**

Venera 15 was launched on June 2, 1983 at 02:38:39 UTC and reached Venus' orbit on October 10, 1983.

The spacecraft was inserted into Venus orbit a day apart from Venera 16, with its orbital plane shifted by an angle of approximately 4° relative to one another probe. This made it possible to reimage an area if necessary. The spacecraft was in a nearly polar orbit with a periapsis ~1000 km, at 62°N latitude, and apoapsis ~65000 km, with an inclination ~90°, the orbital period being ~24 hours.

Together with Venera 16, the spacecraft imaged the area from the north pole down to about 30°N latitude (i.e. approx. 25% of Venus surface) over the 8 months of mapping operations.

## Spacecraft structure

The Venera 15 and 16 spacecraft were identical and were based on modifications to the orbiter portions of the Venera 9 and Venera 14 probes. Each spacecraft consisted of a 5 m long cylinder with a 0.6 m diameter, 1.4 m tall parabolic dish antenna for the synthetic aperture radar (SAR) at one end. A 1 meter diameter parabolic dish antenna for the radio altimeter was also located at this end. The electrical axis of the radio altimeter antenna was lined up with the axis of the cylinder. The electrical axis of the SAR deviated from the spacecraft axis by 10 degrees. During imaging, the radio altimeter would be lined up with the center of the planet (local vertical) and the SAR would be looking off to the side at 10 degrees. A bulge at the opposite end of the cylinder held fuel tanks and propulsion units. Two square solar arrays extended like wings from the sides of the cylinder. A 2.6 m radio dish antenna for communications was also attached to the side of the cylinder. The spacecraft each massed 4000 kg.

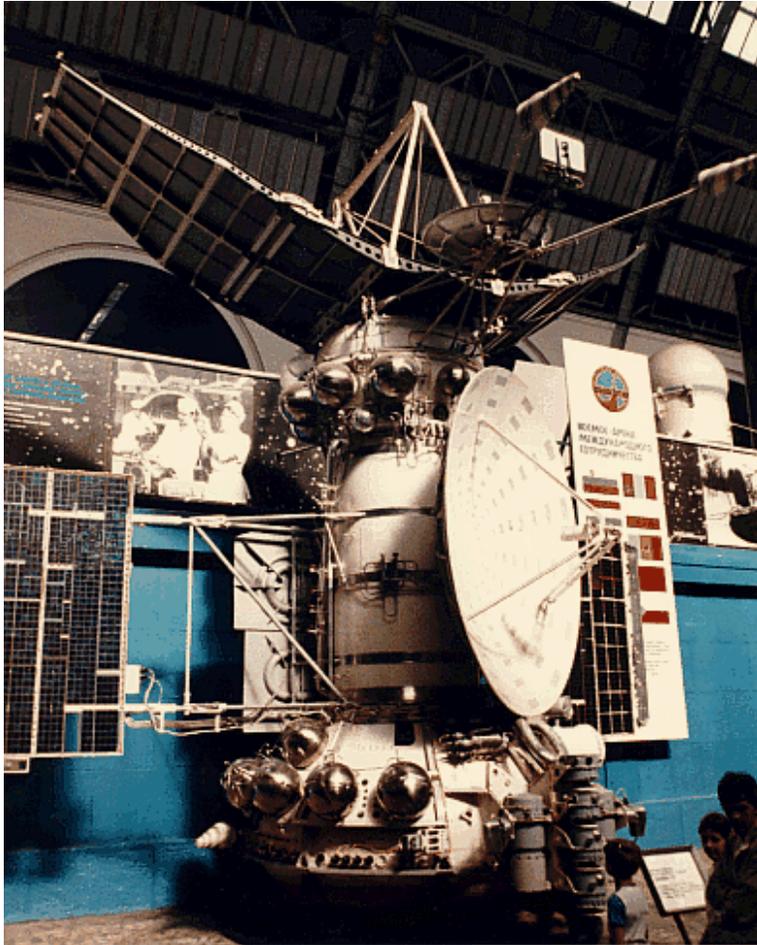
Both Venera 15 and 16 were equipped with a Synthetic Aperture Radar (SAR). A radar was necessary in this mission because nothing else would be able to penetrate the dense clouds of Venus. The probes were equipped with on board computers that saved the images until the entire image was complete.

List of spacecraft instruments and experiments:

- Polyus-V Synthetic Aperture Radar
- Omega Radar Altimeter
- Infrared Fourier Spectrometer
- Cosmic-Ray Detectors (6 sensors)
- Solar-Plasma Detectors

# Venera 16

## Venera 16



Venera 16 orbiter

<b>Operator</b>	USSR
<b>Mission type</b>	Orbiter
<b>Satellite of</b>	Venus
<b>Orbital insertion date</b>	October 11, 1983
<b>Launch date</b>	June 7, 1983
<b>Mission duration</b>	June 7, 1983 to ~July 1984
<b>COSPAR ID</b>	1983-054A
<b>Mass</b>	4000 kg

### Orbital elements

<b>Inclination</b>	92.5°
<b>Apoapsis</b>	11.91 RV
<b>Periapsis</b>	1.17 RV
<b>Orbital period</b>	24 h

**Venera 16** (Russian: Венера-16) was a spacecraft sent to Venus by the Soviet Union. This unmanned orbiter was to map the surface of Venus using high resolution imaging systems. The spacecraft was identical to Venera 15 and based on modifications to the earlier Venera space probes.

## Mission profile

Venera 16 was launched on June 7, 1983 at 02:32:00 UTC and reached Venus' orbit on October 11, 1983.

The spacecraft was inserted into Venus orbit a day apart from Venera 15, with its orbital plane shifted by an angle of approximately 4° relative to one another probe. This made it possible to reimage an area if necessary. The spacecraft was in a nearly polar orbit with a periapsis ~1000 km, at 62°N latitude, and apoapsis ~65000 km, with an inclination ~90°, the orbital period being ~24 hours.

Together with Venera 15, the spacecraft imaged the area from the north pole down to about 30°N latitude (i.e. approx. 25% of Venus surface) over the 8 months of mapping operations.

## Spacecraft structure

The Venera 15 and 16 spacecraft were identical and were based on modifications to the orbiter portions of the Venera 9 and Venera 14 probes. Each spacecraft consisted of a 5 m long cylinder with a 0.6 m diameter, 1.4 m tall parabolic dish antenna for the synthetic aperture radar (SAR) at one end. A 1 meter diameter parabolic dish antenna for the radio altimeter was also located at this end. The electrical axis of the radio altimeter antenna was lined up with the axis of the cylinder. The electrical axis of the SAR deviated from the spacecraft axis by 10 degrees. During imaging, the radio altimeter would be lined up with the center of the planet (local vertical) and the SAR would be looking off to the side at 10 degrees. A bulge at the opposite end of the cylinder held fuel tanks and propulsion units. Two square solar arrays extended like wings from the sides of the cylinder. A 2.6 m radio dish antenna for communications was also attached to the side of the cylinder. The spacecraft each massed 4000 kg.

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List of spacecraft instruments and experiments:

- Polyus-V Synthetic Aperture Radar
- Omega Radar Altimeter
- Infrared Fourier Spectrometer
- Cosmic-Ray Detectors (6 sensors)
- Solar-Plasma Detectors

## Chapter- 3

# Space and Solar System Exploration in 1984

## Vega 1

### Vega 1 spacecraft

<b>Operator</b>	USSR
<b>Mission type</b>	Flyby, balloon and lander
<b>Flyby of</b>	Venus, Halley
<b>Flyby date</b>	June 11, 1985 (Venus) and March 6, 1986 (Halley)
<b>Launch date</b>	1984-12-15 at 09:16:24 UTC
<b>Launch vehicle</b>	Proton 8K82K rocket
<b>COSPAR ID</b>	1984-125A
<b>Mass</b>	4920 kg

**Vega 1** (along with its twin Vega 2) is a Soviet space probe part of the Vega program. The spacecraft was a development of the earlier *Venera* craft. They were designed by Babakin Space Center and constructed as 5VK by Lavochkin at Khimki.

The craft was powered by twin large solar panels and instruments included an antenna dish, cameras, spectrometer, infrared sounder, magnetometers (MISCHA), and plasma probes. The 4,920 kg craft was launched by a Proton 8K82K rocket from Baikonur Cosmodrome, Tyuratam, Kazakh SSR. Both Vega 1 and 2 were three-axis stabilized spacecraft. The spacecraft were equipped with a dual bumper shield for dust protection from Halley's comet.

# The Venus mission

Vega 1 arrived at Venus on June 11, 1985 delivering a 1500 kg, 240 cm diameter spherical descent unit. The units were released some days before each arrived at Venus and entered the atmosphere without active inclination changes. Each contained a lander and a balloon explorer.

## Descent craft

### Vega 1 Descent Craft

<b>Operator</b>	USSR
<b>Mission type</b>	Venus Lander
<b>Launch vehicle</b>	Vega 1
<b>COSPAR ID</b>	1984-125E

The landers were identical to that of the previous five *Venera* missions and were to study the atmosphere and surface, each had instruments to study temperature, pressure, a UV spectrometer, a water concentration meter, a gas-phase chromatograph, an X-ray spectrometer, a mass spectrometer and a surface sampling device.

The Vega 1 lander's surface experiments were inadvertently activated at 20 km from the surface by an especially hard wind jolt and so failed to provide results. It landed at 7°12'N 177°48'E / 7.2°N 177.8°E in the Mermaid Plain north of Aphrodite Terra.

## Balloon

### Vega 1 Balloon

<b>Operator</b>	USSR
<b>Mission type</b>	Venus balloon
<b>Launch vehicle</b>	Vega 1 Descent Craft
<b>Mission duration</b>	11 June to 13 June 1985
<b>COSPAR ID</b>	1984-125F
<b>Mass</b>	21.5 kg

The Vega 1 Lander/Balloon capsule entered the Venus atmosphere (125 km altitude) at 2:06:10 UT (Earth received time; Moscow time 5:06:10 a.m.) on 11 June 1985 at roughly 11 km/s. At approximately 2:06:25 UT the parachute attached to the landing craft cap opened at an altitude of 64 km. The cap and parachute were released 15 seconds later at 63 km altitude. The balloon package was pulled out of its compartment by parachute 40

seconds later at 61 km altitude, at 8.1 degrees N, 176.9 degrees east. A second parachute opened at an altitude of 55 km, 200 seconds after entry, extracting the furled balloon. The balloon was inflated 100 seconds later at 54 km and the parachute and inflation system were jettisoned. The ballast was jettisoned when the balloon reached roughly 50 km and the balloon floated back to a stable height between 53 and 54 km some 15 to 25 minutes after entry. The mean stable height was 53.6 km, with a pressure of 535 mbar and a temperature of 300-310 K in the middle, most active layer of the Venus three-tiered cloud system. The balloon drifted westward in the zonal wind flow with an average speed of about 69 m/s at nearly constant latitude. The probe crossed the terminator from night to day at 12:20 UT on 12 June after traversing 8500 km. The probe continued to operate in the daytime until the final transmission was received at 00:38 UT on 13 June from 8.1 N, 68.8 E after a total traverse distance of 11,600 km. It is not known how much farther the balloon travelled after the final communication.

## **The Halley mission**

Images started to be returned on March 4, 1986, and were used to help pinpoint Giotto's upcoming close flyby of the comet. The early images from Vega that showed two bright areas on the comet, which were initially interpreted as a double nucleus. The bright areas would later turn out to be two jets emitting from the comet. The images also showed the nucleus to be dark, and the infrared spectrometer readings measured a nucleus temperature of 300 K to 400 K, much warmer than expected for an ice body. The conclusion was that the comet had a thin layer on its surface covering an icy body.

Vega 1 made its closest approach on March 6 at around 8,889 kilometers (at 07:20:06 UT) of the nucleus. It took more than 500 pictures via different filters as it flew through the gas cloud around the coma. Although the spacecraft was battered by dust, none of the instruments were disabled during the encounter.

The data intensive examination of the comet covered only the three hours around closest approach. They were intended to measure the physical parameters of the nucleus, such as dimensions, shape, temperature and surface properties, as well as to study the structure and dynamics of the coma, the gas composition close to the nucleus, the dust particles' composition and mass distribution as functions of distance to the nucleus and the cometary-solar wind interaction.

The Vega images showed the nucleus to be about 14 km long with a rotation period of about 53 hours. The dust mass spectrometer detected material similar to the composition of carbonaceous chondrites meteorites and also detected clathrate ice.

After subsequent imaging sessions on 7 and 8 March 1986, Vega 1 headed out to deep space. In total Vega 1 and Vega 2 returned about 1500 images of Comet Halley. Vega 1 ran out of attitude control propellant on 30 January 1987, and contact with Vega 2 continued until 24 March 1987.

Vega 1 and Vega 2 are currently in heliocentric orbits.

# Vega 2

## Vega 2 spacecraft

<b>Operator</b>	USSR
<b>Mission type</b>	Flyby, balloon and lander
<b>Flyby of</b>	Venus, Halley
<b>Flyby date</b>	June 15, 1985 (Venus) and March 9, 1986 (Halley)
<b>Launch date</b>	1984-12-21 at 09:13:52 UTC
<b>Launch vehicle</b>	Proton 8K82K rocket
<b>COSPAR ID</b>	1984-128A
<b>Mass</b>	4920 kg

**Vega 2** (along with Vega 1) is a Soviet space probe part of the Vega program. The spacecraft was a development of the earlier *Venera* craft. They were designed by Babakin Space Center and constructed as 5VK by Lavochkin at Khimki. The craft was powered by twin large solar panels and instruments included an antenna dish, cameras, spectrometer, infrared sounder, magnetometers (MISCHA), and plasma probes. The 4,920 kg craft was launched by a Proton 8K82K rocket from Baikonur Cosmodrome, Tyuratam, Kazakh SSR. Both Vega 1 and 2 were three-axis stabilized spacecraft. The spacecraft were equipped with a dual bumper shield for dust protection from Halley's Comet.

## The Venus mission

Vega 2 arrived at Venus on June 15, 1985. Its 1500 kg, 240 cm diameter spherical descent unit was released some days before arrival and entered the atmosphere without active inclination changes. It contained a lander and a balloon explorer.

### Descent craft

#### Vega 2 Descent craft

<b>Operator</b>	USSR
<b>Mission type</b>	Venus lander
<b>Launch vehicle</b>	Vega 2

**COSPAR ID**

1984-128E

The Vega 2 lander touched down at 03:00:50 UT on 15 June 1985 at around 7°08'S 177°40'E / 7.14°S 177.67°E, in the northern region of Aphrodite Terra. The altitude of the touchdown site was 0.1 km above the planetary mean radius. The measured pressure at the landing site was 91 atm and the temperature was 736 K. The surface sample was found to be an anorthosite-troctolite rock, rarely found on Earth, but present in the lunar highlands, leading to the conclusion that the area was probably the oldest explored by any Venera vehicle. It transmitted data from the surface for 56 minutes.

## **Balloon**

### **Vega 2 Balloon**

<b>Operator</b>	USSR
<b>Mission type</b>	Venus ballon
<b>Launch vehicle</b>	Vega 2 Descent craft
<b>Mission duration</b>	15 June to 17 June 1985
<b>COSPAR ID</b>	1984-128F
<b>Mass</b>	21.5 kg

The Vega 2 Lander/Balloon capsule entered the Venus atmosphere (125 km altitude) at 2:06:04 UT (Earth received time; Moscow time 5:06:04 a.m.) on 15 June 1985 at roughly 11 km/s. At approximately 2:06:19 UT the parachute attached to the landing craft cap opened at an altitude of 64 km. The cap and parachute were released 15 seconds later at 63 km altitude. The balloon package was pulled out of its compartment by parachute 40 seconds later at 61 km altitude, at 7.45 degrees S, 179.8 degrees east. A second parachute opened at an altitude of 55 km, 200 seconds after entry, extracting the furled balloon. The balloon was inflated 100 seconds later at 54 km and the parachute and inflation system were jettisoned. The ballast was jettisoned when the balloon reached roughly 50 km and the balloon floated back to a stable height between 53 and 54 km some 15 to 25 minutes after entry. The mean stable height was 53.6 km, with a pressure of 535 mbar and a temperature of 308-316 K in the middle, most active layer of the Venus three-tiered cloud system. The balloon drifted westward in the zonal wind flow with an average speed of about 66 m/s at nearly constant latitude. The probe crossed the terminator from night to day at 9:10 UT on 16 June after traversing 7400 km. The probe continued to operate in the daytime until the final transmission was received at 00:38 UT on 17 June from 7.5 S, 76.3 E after a total traverse distance of 11,100 km. It is not known how much further the balloon traveled after the final communication.

## **The Halley mission**

After their encounters, the Vegas' motherships were redirected by Venus' gravity to intercept Halley's Comet.

The spacecraft initiated its encounter on March 7, 1986 by taking 100 photos of the comet from a distance of 14 million kilometers.

Vega 2 made its closest approach at 07:20 UT on March 9, 1986 at 8,030 km. The data intensive examination of the comet covered only the three hours around closest approach. They were intended to measure the physical parameters of the nucleus, such as dimensions, shape, temperature and surface properties, as well as to study the structure and dynamics of the coma, the gas composition close to the nucleus, the dust particles' composition and mass distribution as functions of distance to the nucleus and the cometary-solar wind interaction.

During the encounter, Vega 2 took 700 images of the comet, with better resolution than those from the twin Vega 1, partly due to the presence of less dust outside of the coma at the time. Yet Vega 2 recorded an 80% power loss during the encounter as compared to Vega 1's 40%.

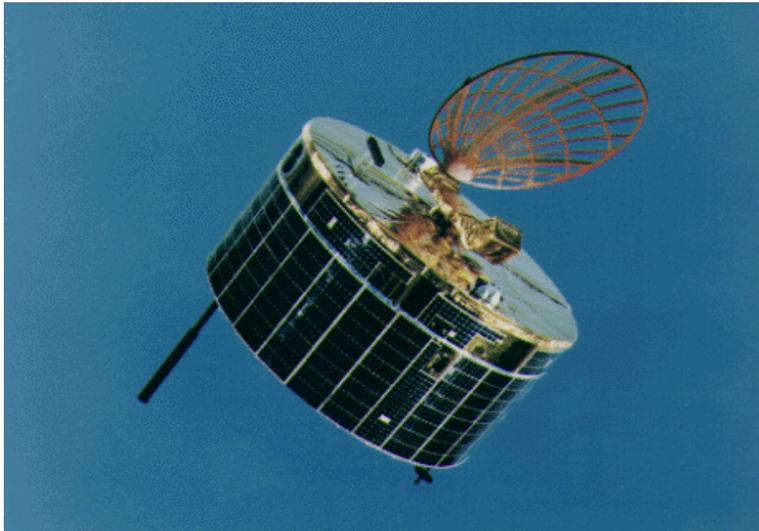
After further imaging sessions on 10 and 11 March 1986, Vega 2 finished its primary mission. Vega 1 ran out of attitude control propellant on 30 January 1987, and contact with Vega 2 continued until 24 March 1987.

## Chapter- 4

# Space and Solar System Exploration in 1985

## Sakigake

Sakigake



Spacecraft Sakigake

<b>Operator</b>	ISAS (now part of JAXA).
<b>Mission type</b>	Flyby
<b>Flyby of</b>	Comet Halley
<b>Launch date</b>	January 7, 1985 from Kagoshima Space Center
<b>Launch vehicle</b>	M-3SII-1
<b>Mission duration</b>	November 15, 1995
<b>COSPAR ID</b>	1985-001A
<b>Homepage</b>	SAKIGAKE

**Mass** 138.1 kg

**Orbital elements**

**Inclination** .07°

**Apoapsis** 1.15 AU

**Periapsis** .92 AU

**Orbital period** 382.8 d

**Sakigake** (translating to "pioneer"), pre-launch codename **MS-T5**, was Japan's first interplanetary spacecraft, and the first deep space probe to be launched by any country other than the USA or the Soviet Union. It aimed to demonstrate the performance of the new launch vehicle, test the schemes of the first escape from the Earth gravitation for Japan on engineering basis, observing space plasma and magnetic field in interplanetary space. Sakigake was also supposed to get references for scientists. Early measurements would be used to improve the mission of the Suisei probe several months later.

Sakigake developed by the Institute of Space and Astronautical Science for the National Space Development Agency (both of which are now part of the Japanese Aerospace Exploration Agency, or JAXA). It became a part of the Halley Armada together with Suisei, the Soviet/French Vega probes, the ESA Giotto and the NASA International Cometary Explorer, to explore Halley's Comet during its 1986 sojourn through the inner solar system.

## Design

Unlike its twin Suisei, it carried no imaging instruments in its instrument payload.

## Launch

Sakigake was launched January 7, 1985 from Kagoshima Space Center by M-3SII-1 launch vehicle.

## Halley encounter

It carried out a flyby of Halley's Comet on March 11, 1986 at a distance of 6.99 million km.

## Giacobini-Zinner encounter

There were plans for the spacecraft to go on to an encounter with 21P/Giacobini-Zinner in 1998 but they had to be abandoned due to lack of propellant.

## End of mission

Telemetry contact was lost on 15 November 1995, though a beacon signal continued to be received until 7 January 1999.

## Giotto

### Giotto



Artist's concept of Giotto spacecraft

<b>Operator</b>	European Space Agency
<b>Mission type</b>	Fly-by
<b>Flyby of</b>	Comet Halley, Comet Grigg-Skjellerup, Earth
<b>Flyby date</b>	(Halley) 14 March 1986, (Grigg- Skjellerup) 10 July 1992
<b>Launch date</b>	2 July 1985
<b>Launch vehicle</b>	Ariane 1 rocket
<b>Launch site</b>	Guiana Space Centre Kourou, French Guiana
<b>Mission duration</b>	Ended on 23 July 1992

**COSPAR ID** 1985-056A

**Homepage** Official site

**Mass** 582.7 kg

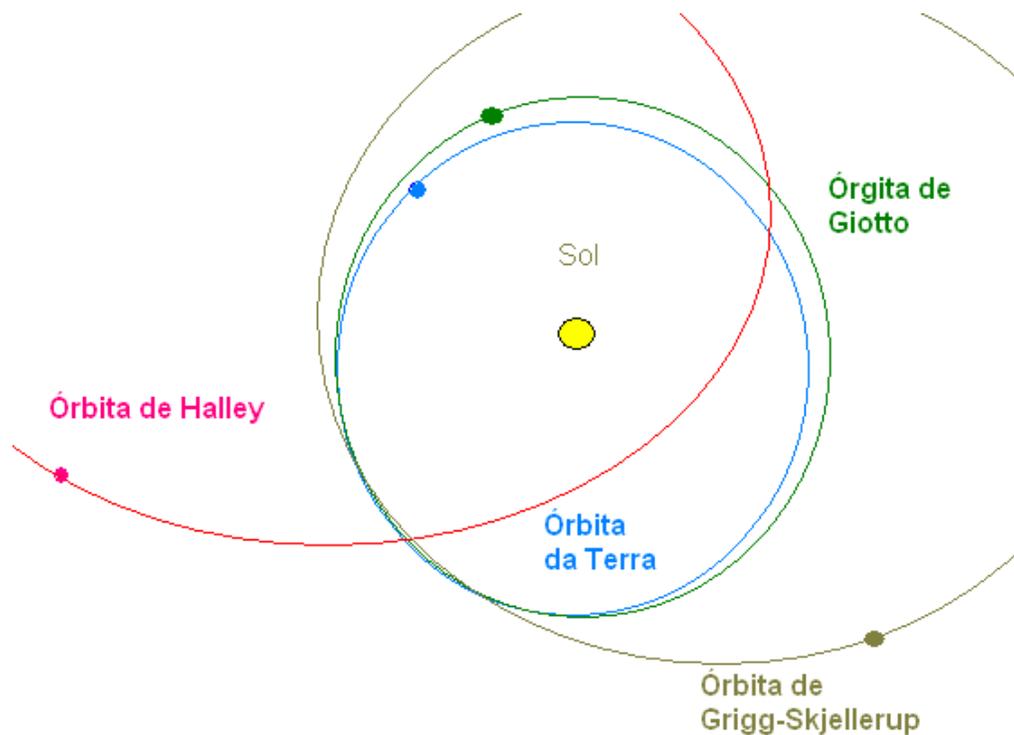
**Power** 196 W

**Orbital elements**

**Periapsis** 596 km (Halley), 200 km (Grigg-Skjellerup)

**Giotto** was a European robotic spacecraft mission from the European Space Agency, intended to fly by and study Halley's Comet. On 13 March 1986, the mission succeeded in approaching Halley's nucleus at a distance of 596 kilometers. The spacecraft was named after the Early Italian Renaissance painter Giotto di Bondone. He had observed Halley's Comet in 1301 and was inspired to depict it as the star of Bethlehem in his painting Adoration of the Magi.

## Mission



Giotto trajectory

Originally a United States partner probe was planned that would accompany Giotto, but this fell through due to budget cuts at NASA. There were plans to have observation equipment on-board a Space Shuttle in low-Earth orbit around the time of Giotto's fly-by, but they in turn fell through with the Challenger disaster.

The plan then became a cooperative armada of five spaceprobes including Giotto, two from the Soviet Union's Vega program and two from Japan: the Sakigake and Suisei probes. The idea was for Japanese probes and the pre-existing American probe International Cometary Explorer to make long distance measurements, followed by the Russian Vegas which would locate the nucleus, and the resulting information sent back would allow Giotto to precisely target very close to the nucleus. Because Giotto would pass so very close to the nucleus ESA was mostly convinced it would not survive the encounter due to bombardment from the many high speed cometary particles. The coordinated group of probes became known as the Halley Armada.

## **The craft**

The spacecraft was derived from the GEOS research satellite built by British Aerospace, and modified with the addition of a dust shield as proposed by Fred Whipple which comprised a thin (1 mm) aluminium sheet separated by a space and a thicker Kevlar sheet. The later Stardust spacecraft would use a similar Whipple shield. A mock up of the spacecraft resides at the Bristol Aero Collection hanger, at Kemble Airport, UK.

## **Timeline**

### **Launch**

The mission was given the go-ahead by ESA in 1980, and launched on an Ariane 1 rocket (flight V14) on 2 July 1985 from Kourou. The craft was controlled from the European Space Agency ESOC facilities in Darmstadt (then West Germany) initially in Geostationary Transfer Orbit (GTO) then in the Near Earth Phase (NEP) before the longer Cruise Phase through to the encounter. While in GTO a number of slew and spin-up manoeuvres (to 90 RPM) were carried out in preparation for the firing of the Apogee Boost Motor (ABM), although unlike orbit circularisations for geostationary orbit, the ABM for Giotto was fired at perigee. Attitude determination and control used sun pulse and IR earth sensor data in the telemetry to determine the spacecraft orientation.

### **Halley encounter**

The Soviet Vega 1 started returning images of Halley on 1986 4 March, and the first ever of its nucleus, and made its flyby on 6 March, followed by Vega 2 making its flyby on 9 March.

Giotto passed Halley successfully on 14 March 1986 at 600 km distance, and surprisingly survived despite being hit by some small particles. One impact sent it spinning off its

stabilized spin axis so that its antenna no longer always pointed at the Earth, and importantly, its dust shield no longer protected its instruments. After 32 minutes Giotto re-stabilized itself and continued gathering science data.

Another impact destroyed the Halley Multicolor Camera, but not before it took spectacular pictures of the nucleus at closest approach.

### **First Earth flyby**

Giotto's trajectory was adjusted for an Earth flyby and its science instruments were turned off on 1986 15 March at 02:00 UT.

### **Grigg-Skjellerup encounter**

Giotto was commanded to wake up on 2 July 1990 when it flew by Earth in order to sling shot to its next cometary encounter.

The probe then flew by the Comet Grigg-Skjellerup in 10 July 1992 which it approached to a distance of about 200 kilometres. Afterwards, Giotto was again switched off on 23 July 1992.

### **Second Earth flyby**

In 1999 Giotto made another Earth flyby but was not reactivated.

## **Results**

### **Scientific results**

Images showed Halley's nucleus to be a dark peanut-shaped body, 15 km long, 7 to 10 km wide. Only 10% of the surface was active, with at least three outgassing jets seen on the sunlit side. Analysis showed the comet formed 4.5 billion years ago from volatiles (mainly ice) that had condensed onto interstellar dust particles. It had remained practically unaltered since its formation.

Measured volume of material ejected by Halley:

- 80% water,
- 10% carbon monoxide
- 2.5% A mix of methane and ammonia.
- Other hydrocarbons, iron, and sodium were detected in trace amounts.

Giotto found Halley's nucleus was blacker than coal, which suggested a thick covering of dust.

The nucleus's surface was rough and of a porous quality, with the density of the whole nucleus as low as 0.3 gram per cubic centimetre ( $\text{g/cm}^3$ ). Sagdeev's team estimated a density of  $0.6 \text{ g/cm}^3$ , but S. J. Peale warned that all estimates had error bars too large to be informative.

The quantity of material ejected was found to be 3 tonnes per second for seven jets, and these caused the comet to wobble over long time periods.

The dust ejected was mostly only the size of cigarette smoke particles, with masses ranging from  $10^{-20} \text{ kg}$  to  $40 \times 10^{-5} \text{ kg}$  (10 attograms to 40 milligrams). Although the one particle impact that sent Giotto spinning was not measured, from its effects - it also probably broke off a piece of Giotto - its mass has been estimated to lie between 0.1 and 1 gram.

Two kinds of dust were seen: one with carbon, hydrogen, nitrogen and oxygen; the other with calcium, iron, magnesium, silicon and sodium.

The ratio of abundances of the comet's light elements excluding nitrogen (i.e. hydrogen, carbon, oxygen) were the same as the Sun's. The implication is that the constituents of Halley are among the most primitive in the solar system.

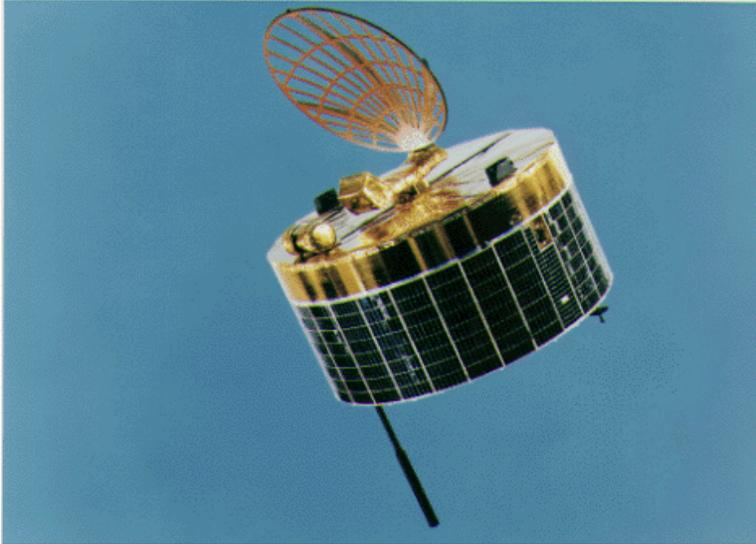
The plasma and ion mass spectrometer instruments showed Halley has a carbon-rich surface.

## **Spacecraft achievements**

- Giotto made the closest approach to Halley comet and provided the best data for this comet.
- Giotto was the first spacecraft to provide pictures of a cometary nucleus.
- Giotto was the first spacecraft to do a close flyby of two comets. Young and active comet Halley could be compared to old Grigg-Skjellerup.
- Giotto was the first spacecraft to return from interplanetary space and perform an Earth swing by.
- Giotto was the first spacecraft to be re-activated from hibernation mode.

# Suisei

## Suisei



Spacecraft Suisei

<b>Operator</b>	ISAS (now part of Japanese Aerospace Exploration Agency)
<b>Mission type</b>	Flyby
<b>Satellite of</b>	<b>Comet Halley</b>
<b>Launch date</b>	1985-08-18, Uchinoura Space Center
<b>Launch vehicle</b>	M-3SII-2
<b>Mission duration</b>	August 20, 1992
<b>COSPAR ID</b>	1985-073A
<b>Homepage</b>	Suisei
<b>Mass</b>	139.5 kg

### Orbital elements

<b>Periapsis</b>	151000 km (Comet Halley)
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**Suisei** (すいせい; Japanese for *Comet*), originally known as **Planet-A**, was an unmanned space probe developed by the Institute of Space and Astronautical Science (now part of the Japanese Aerospace Exploration Agency, or JAXA).

It constituted a part of the Halley Armada together with Sakigake, the Soviet/French Vega probes, the ESA Giotto and the NASA International Cometary Explorer, to explore Halley's Comet during its 1986 sojourn through the inner solar system.

## **Spacecraft**

Suisei was identical in construction and shape to Sakigake, but carried a different payload: a CCD UV imaging system and a solar wind instrument.

The main objective of the mission was to take UV images of the hydrogen corona for about 30 days before and after Comet Halley's descending crossing of the ecliptic plane. Solar wind parameters were measured for a much longer time period. The spacecraft is spin-stabilized at two different rates (5 and 0.2 rpm). Hydrazine thrusters are used for attitude and velocity control; star and sun sensors are for attitude control; and a mechanically despun off-set parabolic dish is used for long range communication.

## **Launch**

Suisei was launched on August 18, 1985 by M-3SII-2 launch vehicle from Kagoshima Space Center. It was sent on an intercept course with Comet Halley, after which it would remain in a heliocentric orbit for later use as long as it was viable.

## **Halley encounter**

Suisei began UV observations in November 1985, generating up to 6 images/day.

The spacecraft encountered Comet Halley at 151,000 km on sunward side during March 8, 1986, suffering only 2 dust impacts.

## **Earth flyby**

Fifteen burns of Suisei's 3 N motors during the period of April 5–10, 1987, yielded a 65 m/s velocity increase for a 60,000 km Earth gravity assist swingby on August 20, 1992, although the craft was then lost behind the Sun for the summer.

The hydrazine fuel was depleted on February 22, 1991. Preliminary tracking indicated a 900,000 km flyby had been achieved.

## **Other planned encounters**

ISAS had decided during 1987 to guide Suisei to a November 24, 1998, encounter with 21P/Giacobini-Zinner, but due to depletion of the hydrazine, this, as well as plans to fly within several million kilometers of Comet 55P/Tempel-Tuttle on February 28, 1998, were cancelled.

# STS-51-B

## STS-51-B

### Mission insignia



### Mission statistics

<b>Mission name</b>	STS-51-B
<b>Space shuttle</b>	<i>Challenger</i>
<b>Launch pad</b>	39-A
<b>Launch date</b>	29 April 1985, 16:02:18 UTC
<b>Landing</b>	6 May 1985, 16:11:04 UTC Edwards AFB, Runway 17
<b>Mission duration</b>	7d/00:08:46
<b>Number of orbits</b>	111
<b>Orbital altitude</b>	222 nautical miles (411 km)
<b>Orbital inclination</b>	57.0°
<b>Distance traveled</b>	2,890,383 miles (4,651,621 km)

### Crew photo



L-R: (sitting): Overmyer, Gregory  
 (standing): Lind, Wang, Thagard, Thornton, van den Berg

**Related missions**

Previous mission	Subsequent mission
STS-51-D 	STS-51-G 

**STS 51-B** was the seventeenth flight of a Space Shuttle and the seventh flight of *Challenger*. The launch of *Challenger* was delayed 2 minutes 18 seconds due to a launch processing failure. *Challenger* was initially rolled out to the pad to launch on the STS-51E mission. The shuttle was rolled back when there was a timing issue with the TDRS-B satellite. When STS-51E was canceled *Challenger* was remanifested with the STS-51B payloads.

**Crew**

Position	Astronaut
<b>Commander</b>	Robert F. Overmyer Second spaceflight
<b>Pilot</b>	Frederick D. Gregory First spaceflight
<b>Mission Specialist 1 Payload Commander</b>	Don L. Lind Only spaceflight
<b>Mission Specialist 2</b>	Norman E. Thagard Second spaceflight

<b>Mission Specialist 3</b>	William E. Thornton Second spaceflight
<b>Payload Specialist 1</b>	Lodewijk van den Berg Only spaceflight
<b>Payload Specialist 2</b>	Taylor G. Wang Only spaceflight

## Backup crew

<b>Position</b>	<b>Astronaut</b>
<b>Payload Specialist 1</b>	Mary Johnston
<b>Payload Specialist 2</b>	Eugene H. Trinh

## Mission parameters

- **Mass:**
  - *Orbiter liftoff:* 246,880 pounds (111,980 kg)
  - *Orbiter landing:* 212,465 pounds (96,373 kg)
  - *Payload:* 34,415 pounds (15,610 kg)
- **Perigee:** 215 miles (346 km)
- **Apogee:** 219 miles (352 km)
- **Inclination:** 57.0°
- **Period:** 91.5 min

## Mission highlights

The Orbiter *Challenger* lifted off from Pad A, Launch Complex 39, KSC, at 12:02 p.m. EDT on 29 April 1985. This was the second flight of the European Space Agency's Spacelab, the first in a fully operational configuration. Spacelab capabilities for multi-disciplinary research in microgravity were successfully demonstrated. The gravity gradient attitude of the orbiter proved quite stable, allowing the delicate experiments in materials processing and fluid mechanics to proceed normally. The crew operated around the clock in two 12-hour shifts. Two monkeys and 24 rodents were flown in special cages, the second time American astronauts flew live non-human mammals aboard the shuttle. The crew members in orbit were supported 24 hours a day by a temporary Payload Operations Control Center, located at the Johnson Space Center. *Challenger* landed at Edwards AFB. Wheel motion stopped at 12:11 p.m. EDT on 6 May 1985, after a mission duration of 7 days, 0 hours and 8 minutes.

The crew members were Robert F. Overmyer, commander; Frederick D. Gregory, pilot; Don L. Lind, Norman E. Thagard and William E. Thornton, mission specialists; and Lodewijk van den Berg, of EG&G Energy Management, Inc., and Taylor G. Wang, of Jet Propulsion Laboratory, payload specialists. Payload and Experiments. Five basic discipline areas: materials sciences, life sciences, fluid mechanics, atmospheric physics. and astronomy main mission objective with Spacelab-3 was to provide high quality

microgravity environment for delicate materials processing and fluid experiments. Spacelab 3 carried a large number of experiments, including 15 primary ones, of which 14 were successfully performed. There were five basic discipline areas: materials sciences, life sciences, fluid mechanics, atmospheric physics, and astronomy—with numerous experiments in each. Two Getaway Special experiments required that they be deployed from their canisters, a "first" in this program. These were NUSAT (Northern Utah Satellite) and GLOMR (Global Low Orbiting Message Relay Satellite). NUSAT deployed successfully, but GLOMR did not deploy and was returned to Earth.

## Connection to *Challenger* accident

Overmyer discovered while serving on the *Challenger* accident investigation team that 51-B had had a similar problem with its O-rings during the launch. Morton Thiokol engineers told Lind that "you came within three-tenths of one second of dying."

# STS-51-C

## STS-51-C

### Mission insignia



### Mission statistics

<b>Mission name</b>	STS-51-C
<b>Space shuttle</b>	<i>Discovery</i>
<b>Launch pad</b>	39-A
<b>Launch date</b>	24 January 1985, 19:50:00 UTC
<b>Landing</b>	27 January 1985, 21:23:23 UTC KSC, Runway 15

<b>Mission duration</b>	3d/01:33:23
<b>Number of orbits</b>	49
<b>Orbital altitude</b>	220 nautical miles (410 km)
<b>Orbital inclination</b>	28.5°
<b>Distance traveled</b>	1,250,000 miles (2,010,000 km)

**Crew photo**



Back row: L-R: Payton, Buchli, Onizuka  
 Front row L-R: Shriver, Mattingly

**Related missions**

**Previous mission**

STS-51-A 

**Subsequent mission**

STS-51-D 

**STS 51-C** was the 15th flight of a space shuttle, the third flight of Space Shuttle *Discovery*, and the first United States Department of Defense mission. It made the fourth landing at Kennedy Space Center, Florida.

**Crew**

<b>Position</b>	<b>Astronaut</b>
<b>Commander</b>	T. Kenneth Mattingly, II Third spaceflight

<b>Pilot</b>	Loren Shriver First spaceflight
<b>Mission Specialist 1</b>	Ellison S. Onizuka First spaceflight
<b>Mission Specialist 2</b>	James Buchli First spaceflight
<b>Payload Specialist 1</b>	Gary Payton, MSE First spaceflight

## Backup crew

<b>Position</b>	<b>Astronaut</b>
<b>Payload Specialist 1</b>	Keith C. Wright

## Mission parameters

- **Mass:**
  - *Orbiter Liftoff:* 250,891 pounds (113,802 kg)
  - *Orbiter Landing* weight is classified
- **Perigee:** 206 miles (332 km)
- **Apogee:** 212 miles (341 km)
- **Inclination:** 28.4°
- **Period:** 91.3 min

## Mission highlights

First mission dedicated to Department of Defense. U.S. Air Force Inertial Upper Stage (IUS) booster deployed and met mission objectives. This mission's accomplishments are classified due to the nature of the work done. The shuttle deployed a single satellite, 1985-010B (USA-8).

According to *Aviation Week & Space Technology*, STS-51-C launched a secret, Magnum ELINT (ELectronic INTelligence) gathering satellite into geosynchronous orbit. Identical satellites were also launched by STS-33 and STS-38.

Also according to *Aviation Week*, the shuttle initially entered a 204 kilometres (127 mi) x 519 kilometres (322 mi) orbit at an inclination of 28.45 deg to the equator. It then executed three OMS (orbital maneuvering system) burns, the last on orbit #4. The first burn is to circularize the orbit at 519 kilometres (322 mi).

The satellite was deployed on the 7th orbit and then ignited its IUS rocket at the ascending node of the 8th orbit, to place it in a geo-synchronous transfer orbit.

The classified payload was deployed successfully and boosted into its operating orbit by an Inertial Upper Stage (IUS) booster according to an Air Force announcement.

## Connection to the *Challenger* disaster

As a precursor to the *Challenger's* destruction almost exactly a year later, it was reported to the Rogers Commission that during the launch of STS-51-C, the worst solid rocket booster (SRB) blow-by effects of any mission prior to STS-51-L occurred, indicating conclusively that the Viton O-rings were not sufficiently sealing the hot gases inside the combustion chamber of the SRBs while firing. After they were recovered post-flight, the O-rings in both the right and left SRBs showed some degree of charring, but analysis of the center field joint of the right SRB showed an unprecedented penetration of the primary O-ring and heavily charred effects on the secondary O-ring.

This is significant to the established consensus that low air temperature was a major factor in *Challenger's* destruction because the temperature at STS-51-C's launch was also, up to its time, the coldest recorded at only 53 degrees Fahrenheit.

## Mission statement

*Discovery* was to make its third flight in January 1985 to conduct the first mission totally dedicated to the Department of Defense. The classified payload was deployed successfully and boosted into its operating orbit by an Inertial Upper Stage (IUS) booster according to an Air Force announcement.

The launch occurred on 24 January 1985, at 14:40 EST and was the first of 9 Shuttle missions that year. It was originally scheduled for 23 January 1985 but was delayed because of freezing weather conditions. *Challenger* had been scheduled for this flight, but *Discovery* was substituted when thermal tile problems were encountered with *Challenger*.

The mission's duration was 3 days, 1 hour, and 33 minutes. *Discovery* touched down on Runway 15 at Kennedy Space Center on 27 January 1985 at 16:23 EST.

STS-51C marked the 100th human spaceflight to achieve orbit.

# STS-51-D

## STS-51-D

### Mission insignia



### Mission statistics

<b>Mission name</b>	STS-51-D
<b>Space shuttle</b>	<i>Discovery</i>
<b>Launch pad</b>	39-A
<b>Launch date</b>	12 April 1985, 13:59:05 UTC
<b>Landing</b>	19 April 1985, 13:54:28 UTC KSC, Runway 33
<b>Mission duration</b>	6d/23:55:23
<b>Number of orbits</b>	110
<b>Orbital altitude</b>	285 nautical miles (528 km)
<b>Orbital inclination</b>	28.5°
<b>Distance traveled</b>	2,889,785 miles (4,650,658 km)

### Crew photo



Back row L-R: Griggs, Walker, Garn

Front row: L-R: Bobko, Williams, Seddon, Hoffman.

#### Related missions

##### Previous mission

STS-51-C



##### Subsequent mission

STS-51-B



**STS-51D** was the sixteenth flight of a space shuttle and the fourth flight of *Discovery*. It conducted the fifth landing at Kennedy Space Center, Florida. The launch of *Discovery* on STS-51D was delayed by 55 minutes when a boat strayed into the restricted SRB recovery zone. STS-51D was the third mission to be extended in the shuttle program. *Discovery* suffered extensive brake damage and a blown tire during landing. This forced all landings to be done at Edwards Air Force Base in California until the development and implementation of nose wheel steering.

## Crew

Position	Astronaut
<b>Commander</b>	Karol J. Bobko Second spaceflight
<b>Pilot</b>	Donald E. Williams First spaceflight
<b>Mission Specialist 1</b>	M. Rhea Seddon First spaceflight
<b>Mission Specialist 2</b>	Jeffrey A. Hoffman

	First spaceflight
<b>Mission Specialist 3</b>	S. David Griggs First spaceflight
<b>Payload Specialist 1</b>	Charles D. Walker Second spaceflight
<b>Payload Specialist 2</b>	Jake Garn Only spaceflight

Garn was a Republican senator from Utah.  
He was the first sitting member of Congress in space.

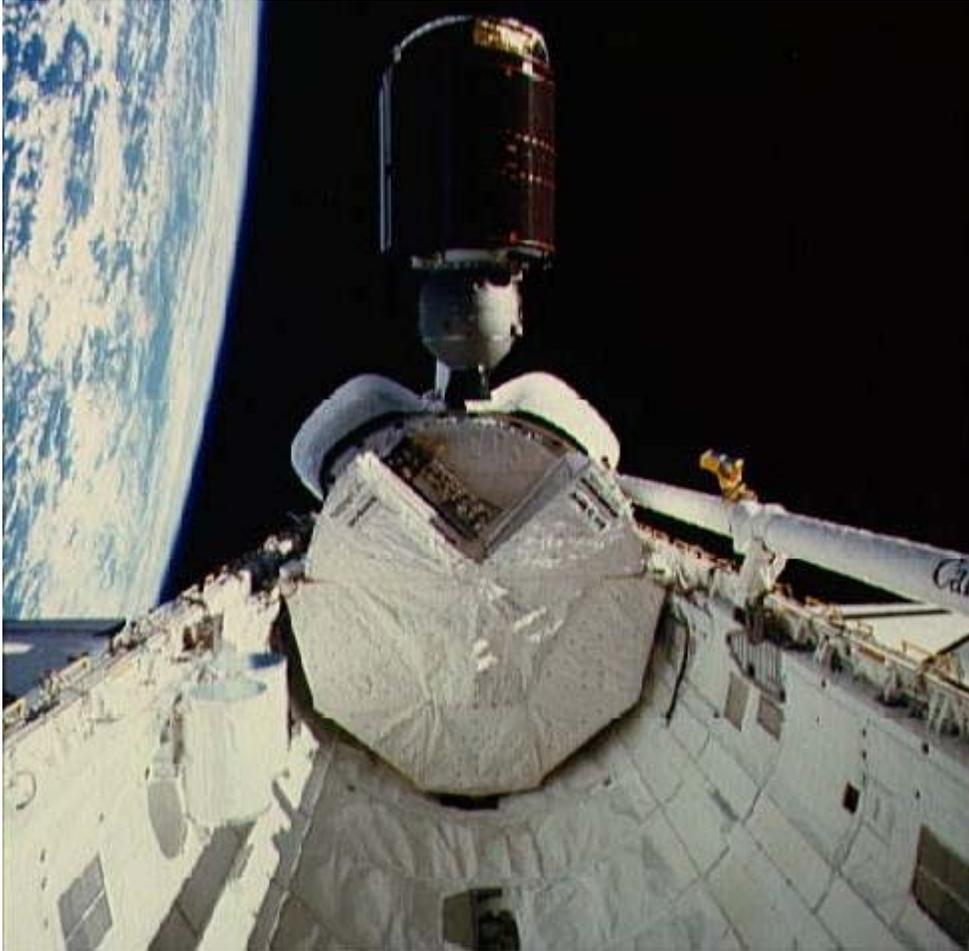
## Mission parameters

- **Mass:**
  - *Orbiter Liftoff:* 250,891 pounds (113,802 kg)
  - *Orbiter Landing:* 198,014 pounds (89,818 kg)
  - *Payload:* 28,747 pounds (13,039 kg)
- **Orbit:**
  - Syncom release
    - **Perigee:** 166 nautical miles (307 km)
    - **Apogee:** 244 nautical miles (452 km)
  - Telesat release
    - **Perigee:** 160 nautical miles (300 km)
    - **Apogee:** 244 nautical miles (452 km)
- **Inclination:** 28.5°
- **Period:** 94.4 min

## Space walk

- *Hoffman and Griggs* - EVA 1
- **EVA 1 Start:** 16 April 1985
- **EVA 1 End:** 16 April 1985
- **Duration:** 3 hours, 06 minutes

## Mission highlights



Telesat-1 during deployment

TELESAT-1 (ANIK C-1) communications satellite deployed, attached to Payload Assist Module (PAM-D) motor. SYNCOM IV-3 (also known as LEASAT-3) deployed, but the spacecraft sequencer failed to initiate antenna deployment, spin-up, and ignite the perigee kick motor. Mission extended two days to make certain sequencer start lever in proper position. Griggs and Hoffman performed space walk to attach Flyswatter devices to remote manipulator system. Seddon engaged LEASAT lever using remote manipulator system but post deployment sequence did not begin. Other payloads: Continuous Flow Electrophoresis System (CFES) III, flying for sixth time; two Shuttle Student Involvement Program (SSIP) experiments; American Flight Echo-cardiograph (AFE); two Getaway Specials; Phase Partitioning Experiments (PPE); astronomy Photography verification test; medical experiments and "toys in space," an informal study of the behavior of simple toys in weightless environment, with results to be made available to school students. Extensive brake damage and blown tire during landing prompted landing of future flights at Edwards Air Force Base until implementation of nose wheel steering.

## Wake-up calls

NASA began a tradition of playing music to astronauts during the Gemini program, which was first used to wake up a flight crew during Apollo 15. Each track is specially chosen, often by their families, and usually has a special meaning to an individual member of the crew, or is applicable to their daily activities.

Flight Day	Song	Artist/Composer
Day 2	<i>Top of the World</i>	The Carpenters
Day 3	<i>Rescue Aid Society</i>	from the Disney film, <i>The Rescuers</i>

## STS-51-F

### STS-51-F

#### Mission insignia



#### Mission statistics

<b>Mission name</b>	STS-51-F
<b>Space shuttle</b>	<i>Challenger</i>
<b>Launch pad</b>	39A
<b>Launch date</b>	29 July 1985, 21:00:00 UTC
<b>Landing</b>	6 August 1985, 19:45:26 UTC Edwards AFB, Runway 23
<b>Mission duration</b>	7d/22:45:26
<b>Number of orbits</b>	127
<b>Orbital altitude</b>	173 nautical miles (320 km)

**Orbital inclination** 49.5°  
**Distance traveled** 3,283,543 miles (5,284,350 km)

**Crew photo**



Front row (seated) L-R: Fullerton, Bridges, Back row (standing)  
L-R: England, Henize, Musgrave, Acton, Bartoe

**Related missions**

**Previous mission**

STS-51-G 

**Subsequent mission**

STS-51-I 

**STS-51-F** (Spacelab 2) was the eighth flight of Space Shuttle *Challenger*, and the nineteenth shuttle flight.

While the primary payload was Spacelab-2, the payload with most publicity was the *Carbonated Beverage Dispenser Evaluation*, which was an experiment where both Coca-Cola and Pepsi tried to make their drinks available to astronauts.

## Crew

<b>Position</b>	<b>Crew Member</b>
<b>Commander</b>	C. Gordon Fullerton Second spaceflight
<b>Pilot</b>	Roy D. Bridges, Jr. Only spaceflight
<b>Mission Specialist 1</b>	F. Story Musgrave

	Second spaceflight
<b>Mission Specialist 2</b>	Anthony W. England Only spaceflight
<b>Mission Specialist 3</b>	Karl G. Henize Only spaceflight
<b>Payload Specialist 1</b>	Loren W. Acton Only spaceflight
<b>Payload Specialist 2</b>	John-David F. Bartoe Only spaceflight

### **Backup crew**

<b>Position</b>	<b>Astronaut</b>
<b>Payload Specialist</b>	George W. Simon
<b>Payload Specialist</b>	Diane K. Prinz

### **Mission parameters**

- **Mass:**
  - *Orbiter Liftoff:* 252,855 pounds (114,693 kg)
  - *Orbiter Landing:* 216,735 pounds (98,309 kg)
  - *Payload:* 35,955 pounds (16,309 kg)
- **Perigee:** 193.9 miles (312.1 km)
- **Apogee:** 199.5 miles (321.1 km)
- **Inclination:** 49.5°
- **Period:** 90.9 min

## Mission highlights



View of experiments in the payload bay



The Plasma Diagnostics Package (PDP) grappled by the Remote Manipulator System (RMS).



Coke and Pepsi cans flown aboard STS-51-F on display at the National Air and Space Museum

Primary payload was Spacelab-2. Despite an abort to orbit, which required mission replanning, the mission was declared a success. A special part of the modular Spacelab system, the igloo, located at head of a three-pallet train, provided on-site support to instruments mounted on pallets. The main mission objective was to verify performance of Spacelab systems, determine the interface capability of the orbiter, and measure the environment created by the spacecraft. Experiments covered life sciences, plasma physics, astronomy, high-energy astrophysics, solar physics, atmospheric physics and technology research.

The flight marked the first time the ESA Instrument Pointing System (IPS) was tested in orbit. This unique pointing instrument was designed with an accuracy of one arcsecond. Initially, some problems were experienced when it was commanded to track the Sun, but a series of software fixes were made and the problem was corrected.

In addition, Tony England became the second amateur radio operator to transmit from space during the mission.

## **Launch**

A launch attempt on 12 July 1985 was halted with the countdown at T-3 seconds after main engine ignition when a malfunction of the number two Space Shuttle Main Engine (SSME) coolant valve caused shutdown of all three main engines.

Launch took place at 29 July 1985, 17:00 EDT, after a delay of one hour, 37 minutes due to a problem with the table maintenance block update uplink.

Three minutes and 31 seconds into the ascent, one of two high pressure fuel turbopump turbine discharge temperature sensors for the center engine failed. Two minutes and 12 seconds later, the second sensor failed, causing the shutdown of the center engine. To date, this has been the only in-flight main engine failure of the shuttle program. Approximately 8 minutes into the flight, one of the same temperature sensors in the right engine failed and the remaining right engine temperature sensor displayed readings near the redline for engine shutdown. Booster Systems Engineer Jenny M. Howard acted quickly to command the crew to inhibit any further automatic SSME shutdowns based on readings from the remaining sensors, preventing the potential shutdown of a second engine and a possible abort mode that may have resulted in the loss of the vehicle and crew.

The failed SSME resulted in an Abort To Orbit (ATO) trajectory, whereby the shuttle achieves a lower than planned orbital altitude.

## **Carbonated beverages**

Astronauts aboard STS-51-F enjoyed carbonated beverages from specially designed cans provided by competitors Coca-Cola and Pepsi.

## **Landing**

On 6 August 1985, at 12:45:26 p.m. PDT, *Challenger* landed at Edwards Air Force Base, California. Rollout distance was 8,569 feet (2,612 m). The mission was extended 17 orbits for additional payload activities due to the abort-to-orbit. The orbiter arrived back at Kennedy Space Center on 11 August 1985.

## **Mission insignia**

The mission insignia was designed by Houston artist Skip Bradley. The Space Shuttle Challenger is depicted ascending toward the heavens in search of new knowledge in the field of solar and stellar astronomy, with its Spacelab 2 payload. The constellations Leo and Orion are in the positions they were in, relative to the Sun during the flight. The nineteen stars signify that this will be the 19th STS flight.

# STS-51-G

## STS-51-G

### Mission insignia



### Mission statistics

<b>Mission name</b>	STS-51-G
<b>Space shuttle</b>	<i>Discovery</i>
<b>Launch pad</b>	LC-39A, Kennedy Space Center
<b>Launch date</b>	17 June 1985, 11:33:00 UTC
<b>Landing</b>	24 June 1985, 13:11:52 UTC Runway 23, Edwards AFB
<b>Mission duration</b>	7d/01:38:52
<b>Number of orbits</b>	112
<b>Orbital altitude</b>	209 nautical miles (387 km)
<b>Orbital inclination</b>	28.45°
<b>Distance traveled</b>	2,916,127 miles (4,693,051 km)

### Crew photo



Back L-R: Nagel, Lucid, Baudry, Al-Saud

Front L-R: Creighton, Brandenstein, Fabian

#### Related missions

##### Previous mission

STS-51-B



##### Subsequent mission

STS-51-F



**STS 51-G** was the eighteenth flight of a space shuttle, and the fifth flight of *Discovery*. The mission launched from Kennedy Space Center, Florida, on 17 June 1985. Sultan Salman Al Saud of Saudi Arabia was on board as a payload specialist.

## Crew

Position	Astronaut
<b>Commander</b>	Daniel C. Brandenstein Second spaceflight
<b>Pilot</b>	John O. Creighton First spaceflight
<b>Mission Specialist 1</b>	Shannon W. Lucid First spaceflight
<b>Mission Specialist 2</b>	John M. Fabian Second spaceflight
<b>Mission Specialist 3</b>	Steven R. Nagel First spaceflight

<b>Payload Specialist 1</b>	Patrick Baudry, CNES Only spaceflight
<b>Payload Specialist 2</b>	Sultan Salman Al Saud,  Saudi Arabia Only spaceflight

Al Saud became the first member of royalty to fly in space

## Backup crew

Position	Astronaut
<b>Payload Specialist 1</b>	Jean-Loup Chrétien, CNES
<b>Payload Specialist 2</b>	Abdalmohsen Al-Bassam,  Saudi Arabia

## Mission parameters

- **Mass:**
  - *Orbiter Liftoff:* 256,524 pounds (116,357 kg)
  - *Orbiter Landing:* 204,169 pounds (92,610 kg)
  - *Payload:* 38,096 pounds (17,280 kg)
- **Perigee:** 219.5 miles (353.3 km)
- **Apogee:** 220.5 miles (354.9 km)
- **Inclination:** 28.5°
- **Period:** 91.8 min

## Mission highlights

The Orbiter *Discovery* lifted off from Pad A, Launch Complex 39, KSC, at 7:33 a.m. EDT on 17 June 1985. The largest items of cargo were three communications satellites. Also flown were the deployable/retrievable Spartan 1, six Getaway Special canisters, a High Precision Tracking Experiment (HPTE) for the Strategic Defense Initiative ("Star Wars"), a materials processing furnace, and French biomedical experiments. All three communications satellites were successfully deployed and turned over to their owner-operators. Their PAM-D perigee booster motors fired and all three reached geosynchronous orbit, where they entered checkout operations. Spartan 1 was deployed and recovered. All the experiments were successfully accomplished. *Discovery* landed at Edwards AFB at 9:12 a.m. EDT on 24 June 1985, after a mission duration of 7 days, one hour, 38 minutes and 52 seconds.

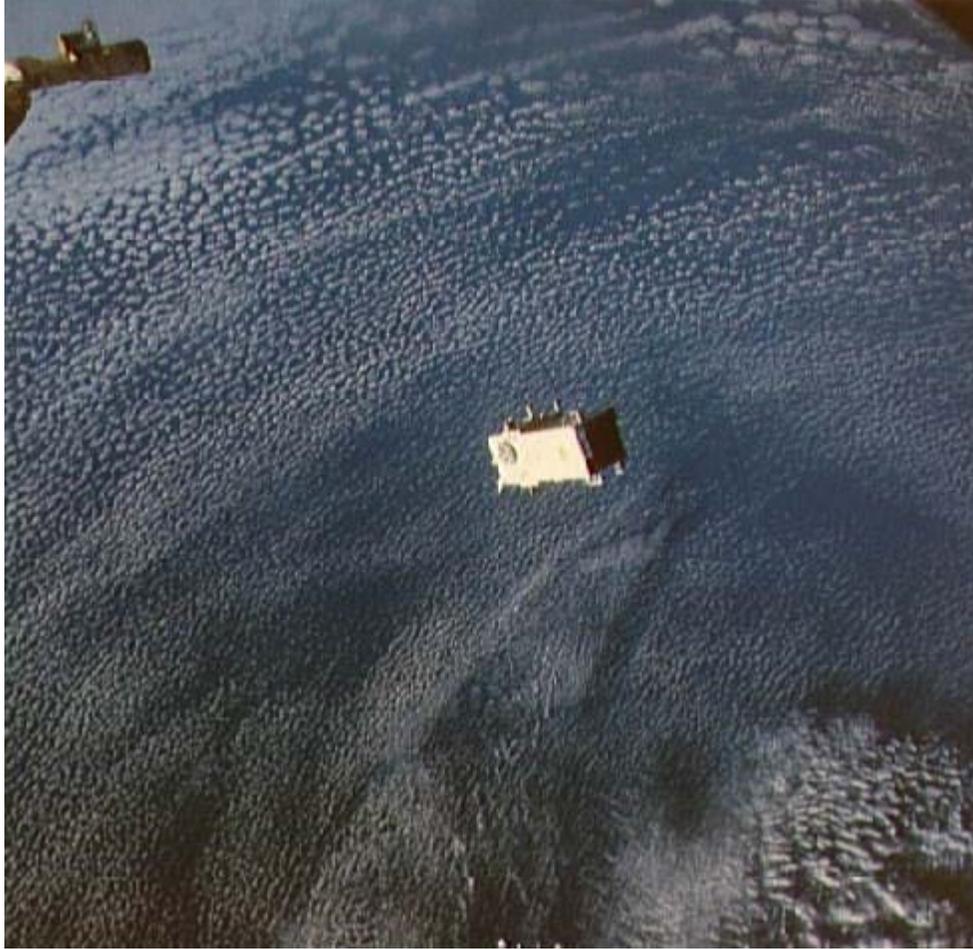
The crew members were Daniel C. Brandenstein, commander; John O. Creighton, pilot; Shannon W. Lucid, Steven R. Nagel, and John M. Fabian, mission specialists; and Patrick Baudry, France, and Prince Sultan Salman Al Saud, Saudi Arabia, payload specialists. Deployed were the Arabsat 1-B (Arab Satellite Communications Organization); Morelos I (Mexico); and Telstar 3-D (AT&T). All three utilized PAM-D booster stages to achieve geosynchronous transfer orbits after deployment from the *Discovery*. The latter two spacecraft are variants of the Hughes-built HS-376 series of spin-stabilized satellites. Both use the Morton Thiokol Star 48 motor to circularize the

orbit and align it with the equator at apogee. Morelos I provides 12 channels operating in the C-band and 6 channels operating in the K<sub>u</sub> band. It can provide educational and commercial television programs, telephone and facsimile services, and data and business transmission services to even the most remote parts of Mexico. Telstar 3-D operates in the C-band only, and has 24 working channels. Using single sideband technology, a Telstar can relay up to 86,400 two-way telephone calls. Both spacecraft are about 22 feet (6.7 m) high and 7 feet (2.1 m) wide when deployed, and have a mass of around 1,300 pounds (590 kg) when operational.



Arabsat 1-B deployment

Arabsat 1 satellites are built by an international team led by Aerospatiale of France. It is a three-axis stabilized spacecraft with two deployable solar array wings, making it almost 68 feet (21 m) long and over 18 feet (5.5 m) wide when deployed in orbit. It weighs about 2,800 pounds (1,300 kg) in its initial orbit, but some 1,490 pounds (680 kg) of this is propellant. It has an onboard low-thrust motor that utilizes hydrazine and nitrogen tetroxide, and transfers from an initial elliptical to geosynchronous orbit by firing this motor. The remaining propellant is then used for station-keeping or moving over the life of the satellite.



Spartan 1

Spartan 1 measured 126 inches (3.2 m) by 42 inches (1.1 m) by 48 inches (1.2 m) inches, and weighed 2,223 pounds (1,008 kg). The Spartan is a carrier, designed to be deployed from the orbiter and fly free in space before being retrieved. Spartan 1 included 300 pounds (140 kg) of experiments in the field of astronomy. It was deployed and operated successfully, independent of the orbiter, before being retrieved.

The materials furnace, French biomedical experiments, and six Getaway Special experiments were all successfully performed, although the GO34 Getaway Special shut down prematurely. The Strategic Defense Initiative failed during its first try on orbit 37 because the orbiter was not at the correct attitude. It was successfully completed on orbit 64.

Three communications satellites, all attached to Payload Assist Module-D (PAM-D) motors, were deployed: MORELOS-A, for Mexico; ARABSAT-1B, for Arab Satellite Communications Organization; and TELSTAR-3D, for AT&T. Also flown: deployable/retrievable Shuttle Pointed Autonomous Research Tool for Astronomy (SPARTAN-1); six Get Away Special canisters; Strategic Defense Initiative experiment

called the High Precision Tracking Experiment (HPTE); a materials processing furnace called Automated Directional Solidification Furnace (ADSF); and two French biomedical experiments.

## Wake-up calls

NASA began a tradition of playing music to astronauts during the Gemini program, which was first used to wake up a flight crew during Apollo 15. Each track is specially chosen, often by their families, and usually has a special meaning to an individual member of the crew, or is applicable to their daily activities.

Flight Day	Song	Artist/Composer
Day 2	<i>I Feel the Earth Move</i>	Carole King
Day 3	<i>Proud Mary</i>	Creedence Clearwater Revival
Day 4	<i>Sailing</i>	Christopher Cross
Day 5	<i>Jonathan Livingston Seagull</i>	Neil Diamond
Day 6	<i>Wedding March</i>	Felix Mendelssohn

## STS-51-I

### STS-51-I

#### Mission insignia



#### Mission statistics

<b>Mission name</b>	STS-51-I
<b>Space shuttle</b>	<i>Discovery</i>

<b>Launch pad</b>	39-A
<b>Launch date</b>	27 August 1985, 10:58:01 UTC
<b>Landing</b>	3 September 1985, 13:15:43 UTC EAFB, Runway 23
<b>Mission duration</b>	7d/02:17:42
<b>Number of orbits</b>	112
<b>Orbital altitude</b>	242 nautical miles (448 km)
<b>Orbital inclination</b>	28.45°
<b>Distance traveled</b>	2,919,576 miles (4,698,602 km)

**Crew photo**



Back row L-R: van Hoften, Lounge, Fisher

Front row L-R: Engle, Covey

**Related missions**

**Previous mission**



**Subsequent mission**



**STS-51-I** was a Space Shuttle *Discovery* mission that deployed three communications satellites. The mission launched from Kennedy Space Center, Florida on 27 August 1985.

## Crew

Position	Astronaut
<b>Commander</b>	Joseph H. Engle Fifth and last spaceflight
<b>Pilot</b>	Richard O. Covey First spaceflight
<b>Mission Specialist 1</b>	James D. A. van Hoften Second spaceflight
<b>Mission Specialist 2</b>	John M. Lounge First spaceflight
<b>Mission Specialist 3</b>	William F. Fisher Only spaceflight

## Mission parameters

- **Mass:**
  - *Orbiter Liftoff:* 262,309 pounds (118,981 kg)
  - *Orbiter Landing:* 196,674 pounds (89,210 kg)
  - *Payload:* 65,635 pounds (29,772 kg)
- **Perigee:** 220 miles (350 km)
- **Apogee:** 289 miles (465 km)
- **Inclination:** 28.5°
- **Period:** 92 min

## Space walks

- ***Fisher and van Hoften*** - EVA 1
- **EVA 1 Start:** 31 August 1985
- **EVA 1 End:** 31 August 1985
- **Duration:** 7 hours, 20 minutes
  
- ***Fisher and van Hoften*** - EVA 2
- **EVA 2 Start:** 1 September 1985
- **EVA 2 End:** 1 September 1985
- **Duration:** 4 hours, 26 minutes

## Mission highlights

The orbiter *Discovery* flew the 20th space shuttle mission starting with its launch at 6:58 a.m. EDT, 27 August 1985. Two earlier launch attempts, one on 24 August and another on 25 August were scrubbed — the first because of poor weather and the second because the backup orbiter computer failed and had to be replaced. The successful 27 August launch took place just as an approaching storm front reached the launch pad area.

The five-man STS 51-I crew included Joe H. Engle, commander; Richard O. Covey, pilot; and three mission specialists James van Hoften, John M. Lounge and William F. Fisher. Their primary mission was to deploy three commercial communications satellites and retrieve and repair SYNCOM IV-3 which was deployed during the STS 51-D mission in April 1985 and had malfunctioned. In addition, a middeck materials processing experiment was flown.

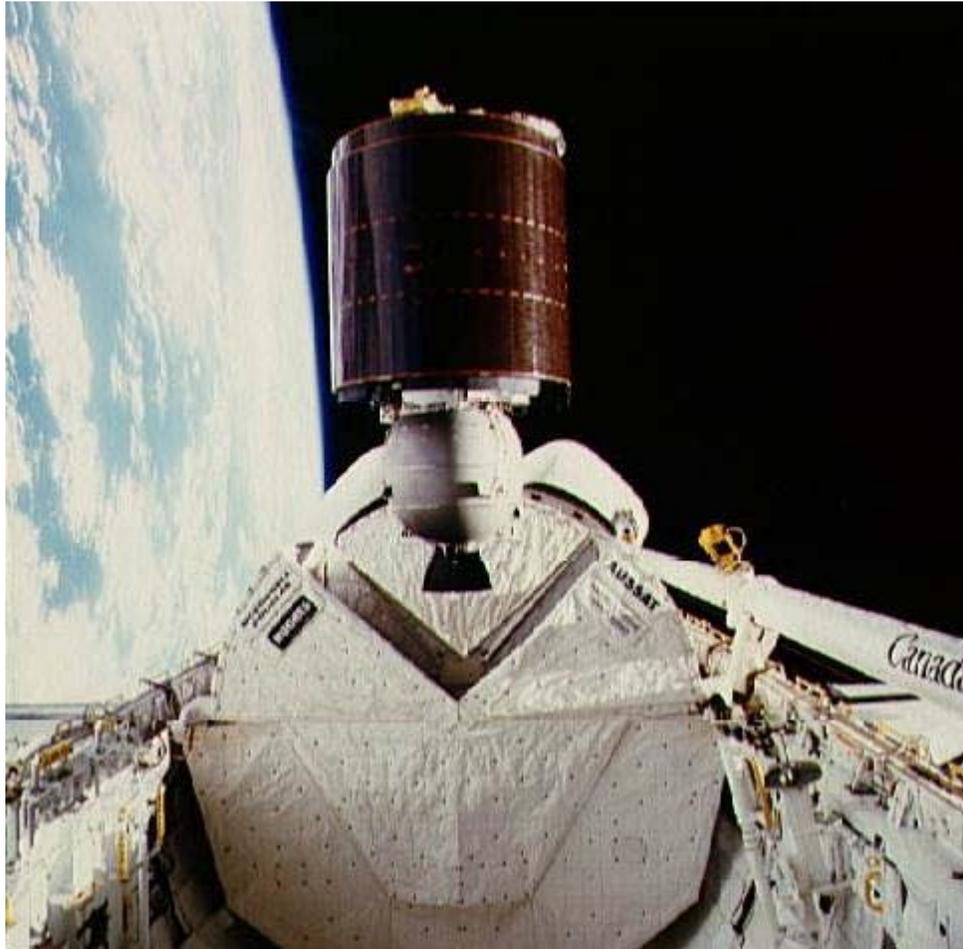
The three communications satellites included AUSSAT-1, a multi-purpose spacecraft owned by Australia; the ASC-1 owned and operated by the American Satellite Co.; and SYNCOM IV-4 leased to the Department of Defense by its builder, the Hughes Co. Both AUSSAT-1 and ASC-1 were deployed on launch day, 27 August. IV-4, was deployed two days later. All three achieved proper geosynchronous orbits and became operational.

On the fifth day of the mission, astronauts Fisher and van Hoften began repair efforts on the malfunctioning IV-3 following a successful rendezvous maneuver with *Discovery*. The effort was slowed because of a problem in the RMS elbow joint. In any event, after a second EVA by Fisher and van Hoften, the lever was repaired, permitting commands from the ground to activate the spacecraft's systems and eventually sending it into its proper geosynchronous orbit. The two EVAs took 11 hours and 27 minutes.

*Discovery* landed on Runway 23 at Edwards AFB at 6:16 a.m. PDT on 3 September 1985. The flight took 7 days, 2 hours, 18 minutes, 42 seconds, completing 111 orbits of the Earth.

The three communications satellites deployed were: ASC-1, for American Satellite Company; AUSSAT-1, an Australian Communications Satellite; and SYNCOM IV-4, the Synchronous Communications Satellite. ASC-1 and AUSSAT-1 both attached to Payload Assist Module-D (PAM-D) motors. SYNCOM IV-4 (also known as LEASAT-4) failed to function after reaching correct geosynchronous orbit. Fisher and van Hoften performed 11 hours, 27 minutes of space walk. Part of time spent retrieving, repairing and redeploying LEASAT-3, deployed on Mission 51-D. Middeck Payload: Physical Vapor Transport Organic Solid Experiment (PVTOS).

## Additional image



Deployment of AUSSAT-1



Deployment of ASC-1



Deployment Syncom IV-4



van Hoften works on Syncom IV-3

## Wake-up calls

NASA began a tradition of playing music to astronauts during the Gemini program, which was first used to wake up a flight crew during Apollo 15. Each track is specially chosen, often by their families, and usually has a special meaning to an individual member of the crew, or is applicable to their daily activities.

Flight Day	Song	Artist/Composer
Day 2	<i>Waltzing Matilda</i>	
Day 3	<i>Over the Rainbow</i>	Judy Garland
Day 4	<i>I Saw the Light</i>	Willie Nelson
Day 5	<i>I Get Around</i>	Beach Boys
Day 6	<i>Lucky Old Sun</i>	Willie Nelson
Day 7	<i>Stormy Weather</i>	Willie Nelson
Day 8	<i>Living in the USA</i>	Linda Ronstadt

# STS-61-A

## STS-61-A

### Mission insignia



### Mission statistics

<b>Mission name</b>	STS-61-A
<b>Space shuttle</b>	<i>Challenger</i>
<b>Launch pad</b>	39A
<b>Launch date</b>	October 30, 1985, 17:00:00 UTC
<b>Landing</b>	November 6, 1985, 17:44:51 UTC
<b>Mission duration</b>	7d/00:44:51
<b>Number of orbits</b>	112
<b>Orbital altitude</b>	207 nautical miles
<b>Orbital inclination</b>	57°
<b>Distance traveled</b>	4,682,148 kilometres (2,909,352 mi)

### Crew photo



Back L-R: Nagel, Bluford, Messerschmid, Ockels

Front L-R: Furrer, Dunbar, Buchli, Hartsfield

#### Related missions

##### Previous mission



STS-51-J

##### Subsequent mission



STS-61-B

**STS-61-A** (also known as **D-1**) was the 22nd Space Shuttle mission. It was a scientific Spacelab mission funded and controlled by West Germany - hence the non-NASA name of D-1 (for *Deutschland 1*). It was also the last successful mission of the Space Shuttle *Challenger*. STS-61-A holds the record for the largest crew, eight people, aboard any single spacecraft for the entire period from launch to landing.

The Space Shuttle mission carried the NASA/ESA Spacelab module with 76 experiments, and was declared a success. Payload operations were controlled from the German Space Operations Center in Oberpfaffenhofen, Germany instead of the regular NASA centers.

## Crew

Position	Astronaut
Commander	Henry W. Hartsfield Third spaceflight

<b>Pilot</b>	Steven R. Nagel Second spaceflight
<b>Mission Specialist 1</b>	Bonnie J. Dunbar First spaceflight
<b>Mission Specialist 2</b>	James F. Buchli Second spaceflight
<b>Mission Specialist 3</b>	Guion S. Bluford Second spaceflight
<b>Payload Specialist 1</b>	Reinhard Furrer, DLR Only spaceflight
<b>Payload Specialist 2</b>	Ernst Messerschmid, DLR Only spaceflight
<b>Payload Specialist 3</b>	Wubbo Ockels, ESA Only spaceflight

### **Backup crew**

<b>Position</b>	<b>Astronaut</b>
<b>Payload Specialist 3</b>	Ulf Merbold, ESA

## **Mission parameters**

- **Mass:**
  - *Orbiter liftoff:* 110,568 kilograms (243,760 lb)
  - *Orbiter landing:* 97,144 kilograms (214,170 lb)
  - *Payload:* 14,451 kilograms (31,860 lb)
- **Perigee:** 319 kilometres (198 mi)
- **Apogee:** 331 kilometres (206 mi)
- **Inclination:** 57.0°
- **Period:** 91.0 min

## **Mission highlights**

The Orbiter *Challenger* lifted off from Pad A, Launch Complex 39, KSC, at noon EST on October 30, 1985. This was the first Space Shuttle mission largely financed and operated by another nation, West Germany. It was also the only Space Shuttle flight to launch with a crew of eight. The primary mission was to operate a series of experiments, almost all related to functions in microgravity, in Spacelab D-1, the fourth flight of a Spacelab. Two other mission assignments were to deploy the Global Low Orbiting Message Relay Satellite (GLOMR) out of a Getaway Special canister in the cargo bay, and operate five materials processing experiments mounted in the cargo bay on a separate device called the German Unique Support Structure.



The crew works in Spacelab

NASA operated the Space Shuttle, and was responsible for overall safety and control functions throughout the flight. West Germany was responsible for the scientific research carried out during the seven-day mission. To fulfill this function German scientific controllers on the ground worked closely with the personnel in orbit, operating out of the German Space Operations Center at Oberpfaffenhofen, near Munich, West Germany. The orbiting crew divided into two teams, and operated 24-h a day. Communications were very good throughout the mission and the ground and orbital crews were able to interact regularly. The overall system of one Center controlling spacecraft operations and a second controlling experiment functions worked very smoothly in practice.

The GLOMR satellite was successfully deployed during the mission. The five experiments mounted on the separate structure behind the Spacelab module obtained good data. Orbiter *Challenger* landed on Runway 17 at Edwards AFB on November 6, 1985. The wheels stopped rolling at 12:45 p.m. EST, after a mission duration of 7 days, 0 h, and 45 min. The crew members were Henry W. Hartsfield, Jr., commander; Steven R. Nagel, pilot; Bonnie J. Dunbar, James F. Buchli and Guion S. Bluford, mission specialists; and Ernst Messerschmid and Reinhard Furrer, West Germany, along with Wubbo Ockels, European Space Agency, payload specialists, encompassed some 75 numbered experiments, most of which were performed more than once. Some of these experiments had predecessors which had returned data obtained on earlier flights. This made it possible to prepare experiment regimens that were 'second generation' with

respect to technical concept and experiment installation. Almost all of them took advantage of the microgravity environment to perform work not possible, or very much more difficult to do, on Earth. The major area of concentration was materials science, in which West Germany has a well developed expertise.

The primary areas of experiment concentration were: fluid physics, with experiments in capillarity, Marangoni convection, diffusion phenomena, and critical point; solidification experiments; single crystal growth; composites; biological, including cell functions, developmental processes, and the ability of plants to perceive gravity; medical, including the gravitational perceptions of humans, and their adaptation processes in space; and speed-time interaction studies of people working in space.

One equipment item of unusual interest was the Vestibular Sled, an ESA contribution consisting of a seat for a test subject that could be moved backward and forward with precisely controlled accelerations and stops, along rails fixed to the floor of the Spacelab aisle. By taking detailed measurements on a human strapped into the seat, scientists gained data on the functional organization of the human vestibular and orientation systems, and the vestibular adaptation processes under microgravity. The acceleration experiments by the sled riders were combined with thermal stimulations of the inner ear and optokinetic stimulations of the eye.

Overall, this was the most comprehensive series of experiments to date on materials processing in space and associated human activities, adding a rich store to humanity's knowledge. The data that was gained required years of analysis.

This dedicated German Spacelab mission was conducted in long module configuration, which featured Vestibular Sled designed to give scientists data on functional organization of human vestibular and orientation systems. Spacelab D-1 encompassed 75 numbered experiments, most performed more than once. Mission included basic and applied microgravity research in fields of materials science, life sciences and technology, and communications and navigation. Though orbiter controlled from Johnson Space Center, scientific operations controlled from the German Space Operations Center at Oberpfaffenhofen, near Munich. Other objectives: Global Low Orbiting Message Relay (GLOMR) satellite deployed from Get Away Special canister.

## Chapter- 5

# Space and Solar System Exploration in 1988

## Phobos program

### Phobos 2



Illustration of the Phobos spacecraft

<b>Operator</b>	IKI
<b>Mission type</b>	Orbiter
<b>Satellite of</b>	Mars
<b>Orbital insertion date</b>	January 29, 1989
<b>Launch date</b>	July 12, 1988

<b>Launch vehicle</b>	Proton-K rocket
<b>COSPAR ID</b>	1988-059A
<b>Homepage</b>	
<b>Mass</b>	2600 kg (6220 kg with orbital insertion hardware attached)

The **Phobos** (Russian: Фобос, Fobos) **program** was an unmanned space mission consisting of two probes launched by the Soviet Union to study Mars and its moons Phobos and Deimos. Phobos 2 became a Mars orbiter and returned 38 images with a resolution of up to 40 meters. Both probes suffered from critical failures.

Phobos 1 and 2 were of a new spacecraft design, succeeding the type used in the Venera planetary missions of 1975-1985, last used during the Vega 1 and Vega 2 missions to comet Halley.

Phobos 1 was launched on July 7, 1988 and Phobos 2 on July 12, 1988, each aboard a Proton-K rocket. They each had a mass of 2600 kg (6220 kg with orbital insertion hardware attached).

The program featured co-operation from 14 other nations including Sweden, Switzerland, Austria, France, West Germany, and the United States (who contributed the use of its Deep Space Network for tracking the twin spacecraft).

## Objectives

The objectives of the Phobos missions were to:

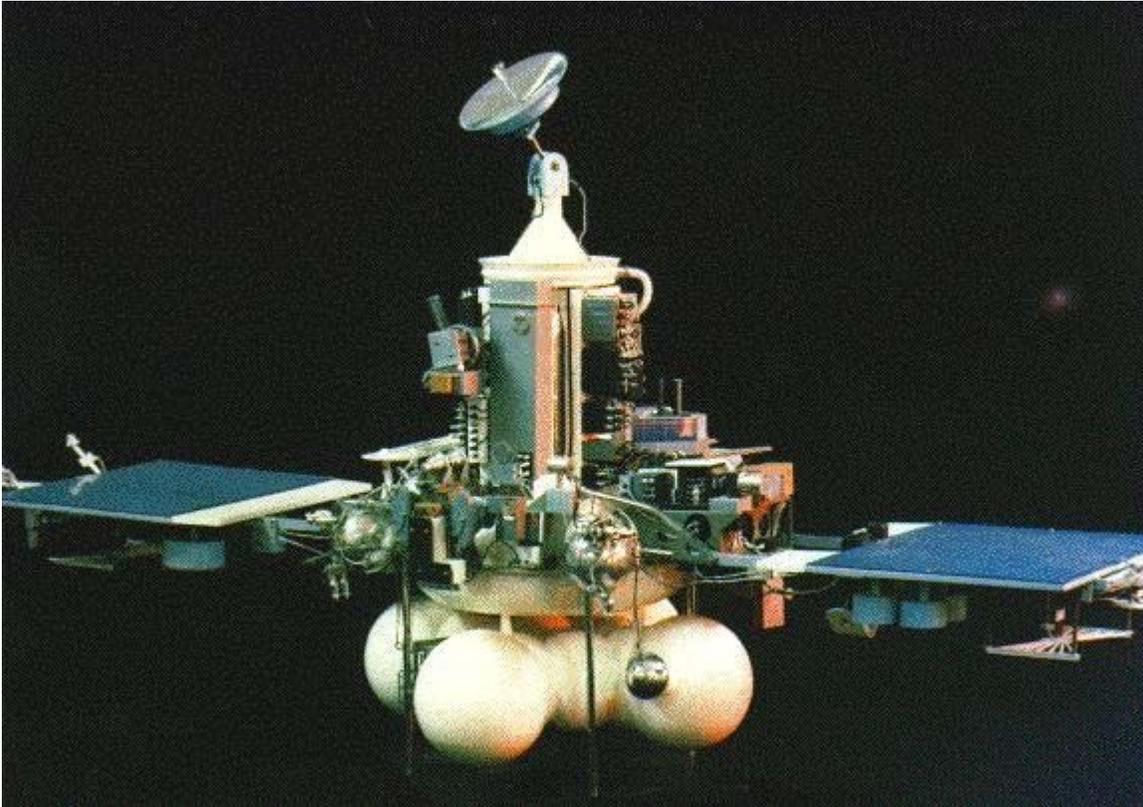
- conduct studies of the interplanetary environment;
- perform observations of the Sun;
- characterize the plasma environment in the Martian vicinity;
- conduct surface and atmospheric studies of Mars; and,
- study the surface composition of the Martian satellite Phobos.

## Spacecraft design

The main section of the spacecraft consisted of a pressurized toroidal electronics section, surrounding a modular cylindrical experiment section. Below these were mounted four spherical tanks (the Fregat vehicle) containing hydrazine for attitude control and, after the main propulsion module was to be jettisoned, orbit adjustment. A total of 28 thrusters (twenty-four 50 N thrusters and four 10 N thrusters) were mounted on the spherical tanks, with additional thrusters mounted on the spacecraft body and solar panels. Attitude was

maintained through the use of a three-axis control system, with pointing maintained with Sun and star sensors.

## Phobos 1



Phobos spacecraft

**Phobos 1** operated nominally until an expected communications session on September 2, 1988 failed to occur. The failure of controllers to regain contact with the spacecraft was traced to an error in the software uploaded on August 29/August 30, which had deactivated the attitude thrusters. By losing its lock on the Sun, the spacecraft could no longer properly orient its solar arrays, thus depleting its batteries.

A natural question is "Why would a spacecraft have instructions that turn off the attitude control, normally a fatal operation?" In this case, these instructions were part of a routine used when testing the spacecraft on the ground. Normally this routine would be removed before launch. However, the software was coded in PROMs, and so removing the test code would have required removing and replacing the entire computer. Because of time pressure from the impending launch, engineers decided to leave the command sequence in, though it should never be used. However, a single character error in constructing an upload sequence resulted in the command executing, with subsequent loss of the spacecraft.

## Phobos 2

**Phobos 2** operated nominally throughout its cruise and Mars orbital insertion phases on January 29, 1989, gathering data on the Sun, interplanetary medium, Mars, and Phobos. Shortly before the final phase of the mission, during which the spacecraft was to approach within 50 m of Phobos' surface and release two landers, one a mobile "hopper", the other a stationary platform, contact with Phobos 2 was lost. The mission ended when the spacecraft signal failed to be successfully reacquired on March 27, 1989. The cause of the failure was determined to be a malfunction of the on-board computer.

The Phobos design was used again for the long delayed Mars 96 mission which ended in failure when the launch vehicle's fourth stage misfired.

### Controversial "last photo"

In 1989 several photographs were published, which were made shortly before *Phobos 2* failure. They lead to speculations of large UFO with 20-25km size which supposedly prevented *Phobos 2* from completing its mission. Shortly, these speculations were publicly dismissed by Glavcosmos expert M.Naraeva, who attributed artifacts on images to a distorted image of shadow of Phobos on surface of Mars.

## Systems and sensors

Phobos probes carried several instruments: solar x-ray and ultraviolet telescopes, a neutron spectrometer and the Grunt radar experiment designed to study the surface relief of Phobos. The lander had an x-ray/alpha spectrometer to provide information on the chemical element composition of the surface of Phobos, a seismometer to determine the internal structure of Phobos, and the "Razrez" penetrator with temperature sensors and an accelerometer for testing the physical and mechanical properties of the surface.

The Phobos 2 infrared spectrometer (ISM) obtained 30 000 spectra in the near infrared (from 0.75 to 3.2  $\mu\text{m}$ ) in the equatorial areas of Mars, with a spatial resolution ranging from 7 to 25 km, and 400 spectra of Phobos at 700 m resolution. These observations made it possible to retrieve the first mineralogical maps of the planet and its satellite, and to study the atmosphere of Mars. ISM was developed at IAS and DESPA (Paris Observatory) with support from CNES.

List of instruments:

- "VSK" TV imaging system
- PROP-F "hopping" lander. Only carried by Phobos 2.
  - ARS-FP automatic X-ray fluorescence spectrometer
  - ferroprobe magnetometer
  - Kappameter magnetic permeability / susceptibility sensor
  - gravimeter

- temperature sensors
  - BISIN conductometer / tiltmeter
  - mechanical sensors (penetrometer, UIU accelerometer, sensors on hopping mechanism)
- "DAS" (long-lived autonomous station) lander
  - TV camera
  - ALPHA-X Alpha-Proton-X-Ray Spectrometer
  - LIBRATION sun sensor (also known as STENOPEE)
  - Seismometer
  - RAZREZ anchor penetrometer
  - Celestial mechanics experiment
- "ISM" thermal infrared spectrometer/radiometer - 1–2 km resolution
- near-infrared imaging spectrometer
- thermal imaging camera; magnetometers
- gamma-ray spectrometers
- X-ray telescope
- radiation detectors
- radar and laser altimeters
- Lima-D laser experiment - designed to vaporise material from the Phobos surface for chemical analysis by a mass spectrometer
- "Grunt" imaging radar - Only carried by Phobos 1

## Chapter- 6

# Space and Solar System Exploration in 1989

## Magellan

### Magellan



Artist depiction of Magellan at Venus.

<b>Operator</b>	NASA / CNES
<b>Mission type</b>	Orbiter
<b>Satellite of</b>	Venus
<b>Orbital insertion date</b>	1990-08-10 17:00:00 UTC

<b>Launch date</b>	1989-05-04 18:47:00 UTC (21 years, 8 months, and 11 days ago)
<b>Launch vehicle</b>	Space Shuttle Atlantis (STS-30) Inertial Upper Stage
<b>Launch site</b>	Launch Complex 39B, Kennedy Space Center
<b>Mission duration</b>	August 10, 1990 - October 12, 1994 (deorbited 1994-10-12)
<b>COSPAR ID</b>	1989-033B
<b>Homepage</b>	Magellan Mission to Venus
<b>Mass</b>	1,035 kg (2,282 lb)
<b>Power</b>	1029 W (Solar array / NiCad)



The **Magellan spacecraft** was an American space probe sent to the planet Venus, the first unmanned interplanetary spacecraft to be launched by NASA since its successful *Pioneer Orbiter*, also to Venus, in 1978. It was also the first of three deep-space probes to be launched on the Space Shuttle (the others being the Ulysses Sun probe and the Galileo

spacecraft to Jupiter) until the launching of the failed Mars Observer spacecraft on a Titan III rocket in 1992, and the first spacecraft to employ aerobraking techniques to circularize its orbit, a technique used on the current series of orbiters around Mars that allows fuel to be conserved.

Magellan created the first (and currently the best) near-photographic quality, high resolution radar mapping of the planet's surface features. Prior Venus missions had created low resolution radar globes of general, continent-sized formations. Magellan, however, finally allowed detailed imaging and analysis of craters, hills, ridges, and other geologic formations, to a degree comparable to the visible-light photographic mapping of other planets. Magellan's global radar map will remain the most detailed Venus map in existence for the foreseeable future, although the planned Russian Venera-D may carry a radar that can achieve the same, if not better resolution as the radar used by Magellan.

It was named after the sixteenth-century Portuguese explorer Ferdinand Magellan. Magellan was the first planetary spacecraft to be launched by a Space Shuttle when it was carried aloft by the Orbiter *Atlantis* from Kennedy Space Center in Florida on May 4, 1989, on the STS-30 mission. *Atlantis* took Magellan into low Earth orbit, where it was released from the shuttle's cargo bay. A solid-fuel motor, the Inertial Upper Stage (IUS) then fired, sending Magellan on a 15-month cruise looping around the Sun 1-1/2 times before it arrived at its orbit around Venus on August 10, 1990. In 1994 it plunged to the surface as planned and partly vaporized; some sections are thought to have hit the planet's surface.

## **Mission overview**

Magellan's initial orbit was highly elliptical, taking it as close as 294 kilometers (182 miles) from Venus and as far away as 8,543 km (5,296 mi). The orbit was a polar one, meaning that the spacecraft moved from south to north or vice versa during each looping pass, flying over Venus' north and south poles. Magellan completed one orbit every 3 hours, 15 minutes.

During the part of its orbit closest to Venus, Magellan's radar mapper imaged a swath of the planet's surface approximately 17 to 28 km (10 to 17 mi) wide. At the end of each orbit, the spacecraft radioed back to Earth a map of a long ribbon-like strip of the planet's surface captured on that orbit. Venus itself rotates once every 243 Earth days. As the planet rotated under the spacecraft, Magellan collected strip after strip of radar image data, eventually covering the entire globe at the end of the 243-day orbital cycle.

By the end of its first such eight-month orbital cycle between September 1990 and May 1991, Magellan had sent to Earth detailed images of 84 percent of Venus' surface. The spacecraft then conducted radar mapping on two more eight-month cycles from May 1991 to September 1992. This allowed it to capture detailed maps of 98 percent of the planet's surface. The follow-on cycles also allowed scientists to look for any changes in the surface from one year to the next. In addition, because the "look angle" of the radar

was slightly different from one cycle to the next, scientists could construct three-dimensional views of Venus' surface.

During Magellan's fourth eight-month orbital cycle at Venus from September 1992 to May 1993, the spacecraft collected data on the planet's gravity field. During this cycle, Magellan did not use its radar mapper but instead transmitted a constant radio signal to Earth. If it passed over an area of Venus with higher than normal gravity, the spacecraft would slightly speed up in its orbit. This would cause the frequency of Magellan's radio signal to change very slightly due to the Doppler effect – much like the pitch of a siren changes as an ambulance passes. Thanks to the ability of radio receivers in the NASA/JPL Deep Space Network to measure frequencies extremely accurately, scientists could build up a detailed gravity map of Venus.

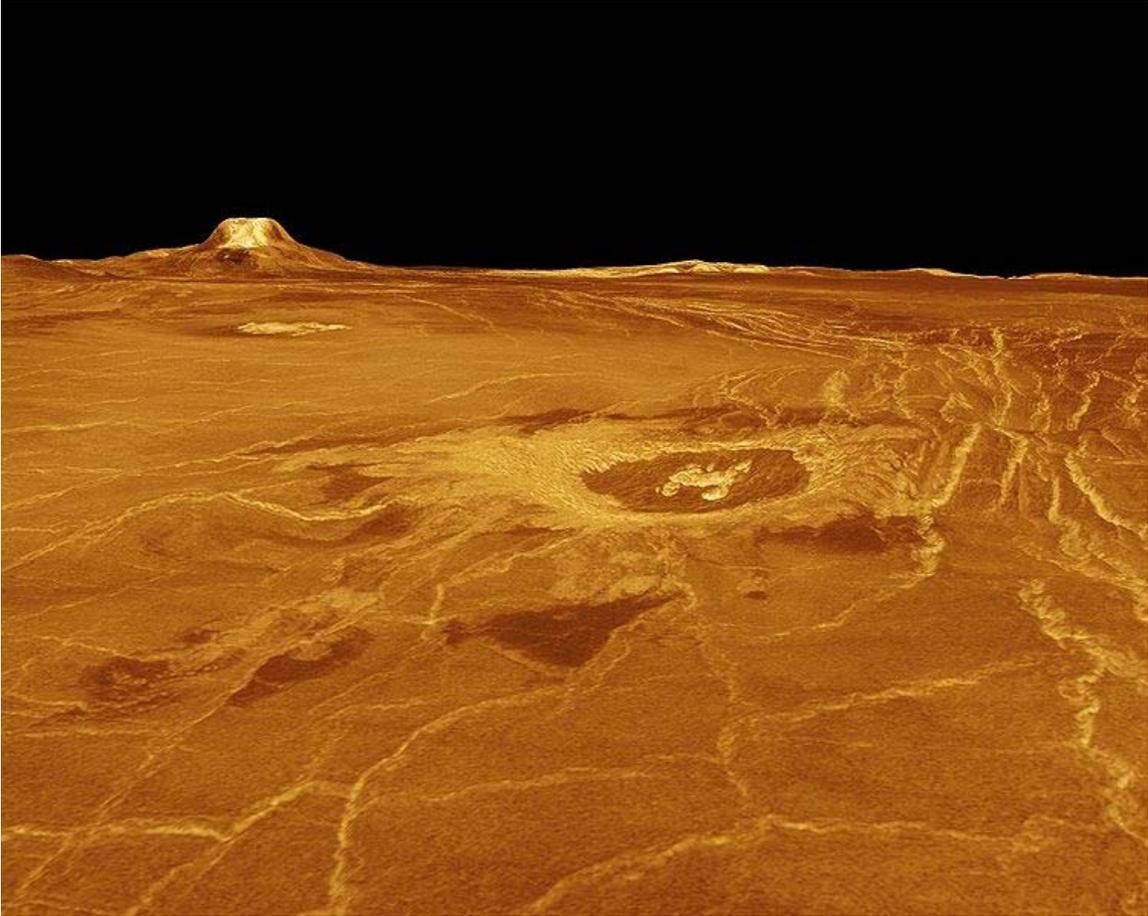
At the end of Magellan's fourth orbital cycle in May 1993, flight controllers circularized the spacecraft's orbit using a then-untried technique called aerobraking. This maneuver sent Magellan dipping into Venus' atmosphere once every orbit; the atmospheric drag on the spacecraft slowed down Magellan and lowered its periapsis. After the aerobraking was completed between May 25 and August 3, 1993, Magellan's orbit then took it as close as 180 km (112 mi) from Venus and as far away as 541 km (336 mi). Magellan also circled Venus more quickly, completing an orbit once every 94 minutes (roughly the same amount of time it takes the Space Shuttle or the International Space Station to complete a single orbit around Earth). This new, more circularized orbit allowed Magellan to collect better gravity data in the higher northern and southern latitudes near Venus' poles.

After the end of that fifth orbital cycle in April 1994, Magellan began a sixth and final orbital cycle, collecting more gravity data and conducting radar and radio science experiments. By the end of the mission, Magellan had captured high-resolution gravity data for an estimated 95 percent of the planet's surface.

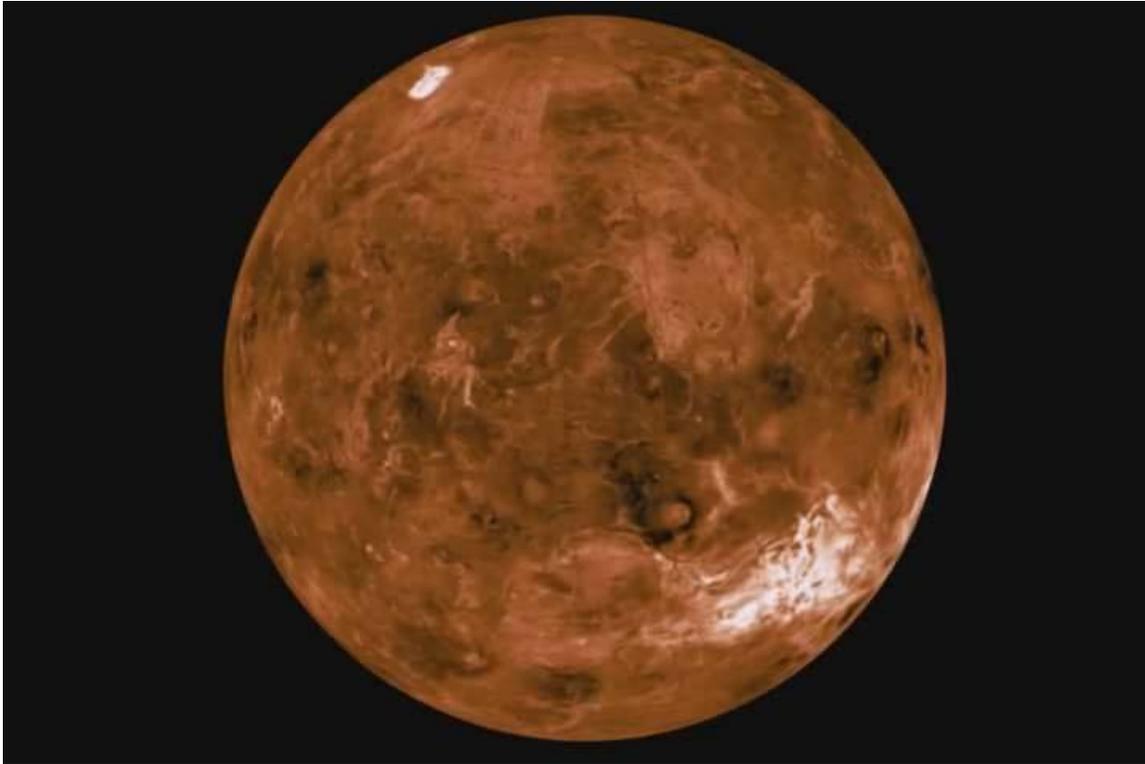
In September 1994, Magellan's orbit was lowered once more in another test called a "windmill experiment". In this test, the spacecraft's solar panels were turned to a configuration resembling the blades of a windmill, and Magellan's orbit was lowered into the thin outer reaches of Venus' dense atmosphere. Flight controllers then measured the amount of torque control required to maintain Magellan's orientation and keep it from spinning. This experiment gave scientists data on the behaviour of molecules in Venus' upper atmosphere, and led engineers new information useful in designing spacecraft.

On October 11, 1994, Magellan's orbit was lowered a final time and radio contact was lost the next day. Within two days after that maneuver, the spacecraft became caught in the atmosphere and plunged to the surface. Although much of Magellan was vaporized, some sections are thought to have hit the planet's surface intact.

## Imaging cycles



3D view of Venus's Eistla Regio produced from *Magellan* radar data



Rendered image of Venus rotating using data gathered by Magellan

From its arrival in August, 1990 until its demise in 1994, the Magellan spacecraft's primary mission was divided into "imaging cycles," each lasting 243 days total (the time it takes Venus to complete a single rotation on its axis). During each of the early cycles, the probe would complete a total of 7.3 orbits for each Earth day, imaging strips approximately 17 to 28 km. (11 to 17 mi.) wide and 70,000 km. (43,486 mi.) long. It took a total of 1,800 strips to cover the entire planet, which were then combined into a single mosaic image.

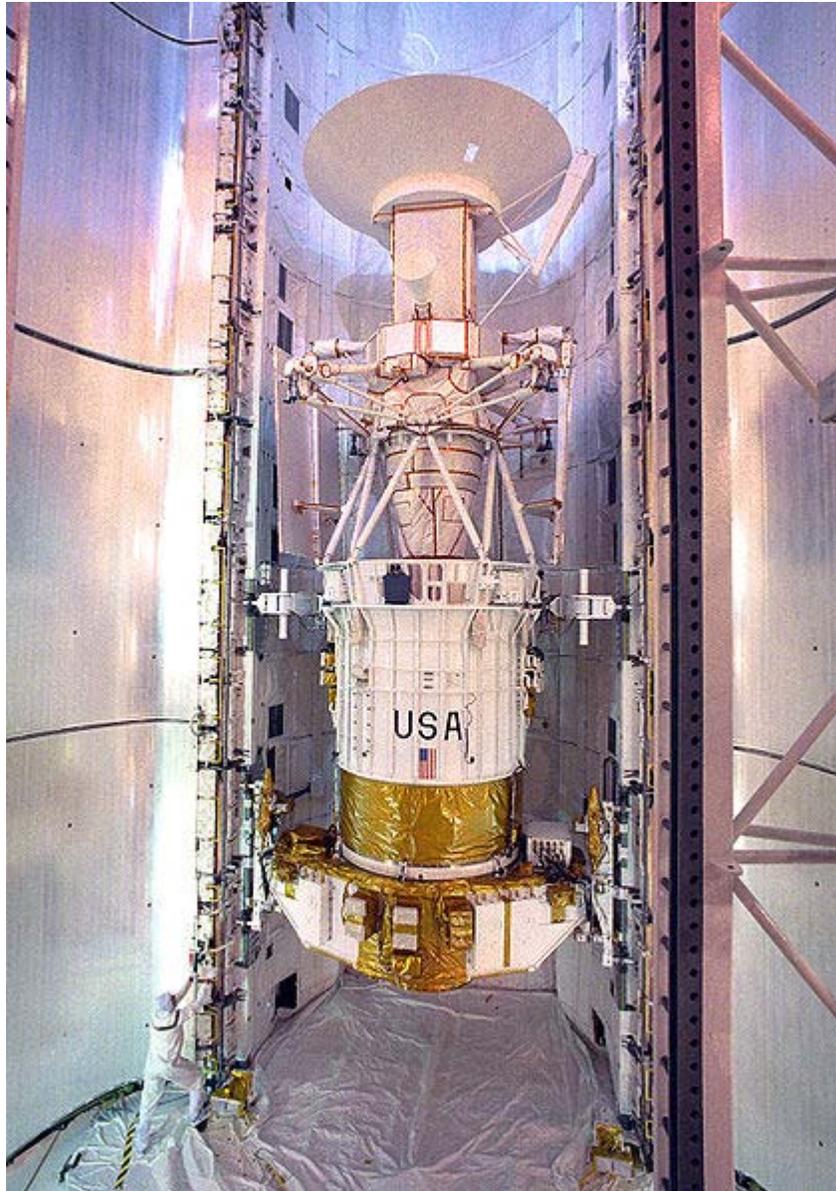
The first images of Venus were received on August 16, 1990, and routine mapping operations began on September 15, 1990. The first mapping cycle (Cycle 1) was completed successfully on May 15, 1991, mapping 84% of the Venusian surface.

Cycle 2 began immediately afterwards and lasted until January 15, 1992. In each cycle, the probe was inclined at a different "look angle", producing stereoscopic data which enabled scientists to compile a three-dimensional map of the surface—a technique known as interferometric synthetic aperture radar.

Cycle 3 was due to finish on September 14, 1992, but was terminated a day early due to problems with onboard equipment. In total, radar coverage of 98% of the surface of Venus was obtained, with 22% of the images in stereo. *Magellan* produced surface images of unprecedented clarity and coverage, which are still unsurpassed.

Cycles 4, 5 and 6 were devoted to collecting gravimetric data, for which *Magellan* was aerobraked to its lowest possible stable orbit, with a periapsis or closest approach of 180 kilometers (112 mi). At the end of Cycle 6 its orbit was reduced further, entering the outer reaches of the atmosphere. After carrying out a few final experiments, *Magellan* successfully completed its mission on October 11, 1994, and was de-orbited to burn up in Venus's atmosphere.

## Spacecraft design



The Magellan spacecraft being fixed into position inside the Space Shuttle Atlantis payload bay prior to launch.

Built largely from spare parts from both the *Voyager* and *Galileo* missions, the Magellan spacecraft was 4.6 meters (15.4 feet) long, topped with a 3.7 m (12 ft) parabolic antenna. Mated to its solid rocket motor (which was jettisoned after orbital insertion) and fully tanked with propellants, the spacecraft weighed a total of 3,460 kilograms (7,612 pounds) at launch.

The high-gain antenna, used for both communication and radar imaging, was a spare from the Voyager Program to the outer planets, as were Magellan's 10-sided main bus section and a set of thrusters. On board computer systems and power distribution units are spares from the Galileo mission to Jupiter and its medium-gain antenna is from the NASA/JPL Mariner 9 project. Martin Marietta Astronautics (Now Lockheed Martin) was the prime contractor for the Magellan spacecraft, while Hughes Space & Communications was the prime contractor for the radar system.

Magellan was powered by two square solar panels, each measuring 2.5 m (8.2 ft) on a side; together they supplied 1,200 watts of power (100 watt per m<sup>2</sup>). Over the course of the mission the solar panels gradually degraded, as expected; by the end of the mission in the fall of 1994 it was necessary to manage power usage carefully to keep the spacecraft operating.

Because Venus was shrouded by a dense, opaque atmosphere, conventional optical cameras could not be used to image its surface. Instead, Magellan's imaging radar used bursts of microwave energy somewhat like a camera flash to illuminate the planet's surface.

Magellan's high-gain antenna sent out thousands of pulses each second toward the planet; the antenna then collected the echoes returned to the spacecraft when the radar pulses bounce off Venus' surface. Because the radar pulses were not sent directly downward but rather at a slight angle to the side of the spacecraft, the radar is thus sometimes called "side-looking radar". In addition, special processing techniques were used on the radar data to result in higher resolution as if the radar had a larger antenna, or "aperture"; the technique is thus often called "synthetic aperture radar", or SAR. Magellan's maps had an ultimate resolution of about 120m; the published maps are oversampled at 75m.

Synthetic aperture radar was first used by NASA on JPL's Seasat oceanographic satellite in 1978; it was later developed more extensively on the Spaceborne Imaging Radar (SIR) missions on the space shuttle in 1981, 1984 and 1994. An imaging radar was also used as part of the NASA/JPL Cassini mission to Saturn in 1997 to map the surface of the ringed planet's major moon Titan.

Besides its use in imaging, Magellan's radar system was also used to collect altimetry data showing the elevations of various surface features. In this mode, pulses were sent directly downward and Magellan measured the time it took a radar pulse to reach Venus and return in order to determine the distance between the spacecraft and the planet.

## Mission results

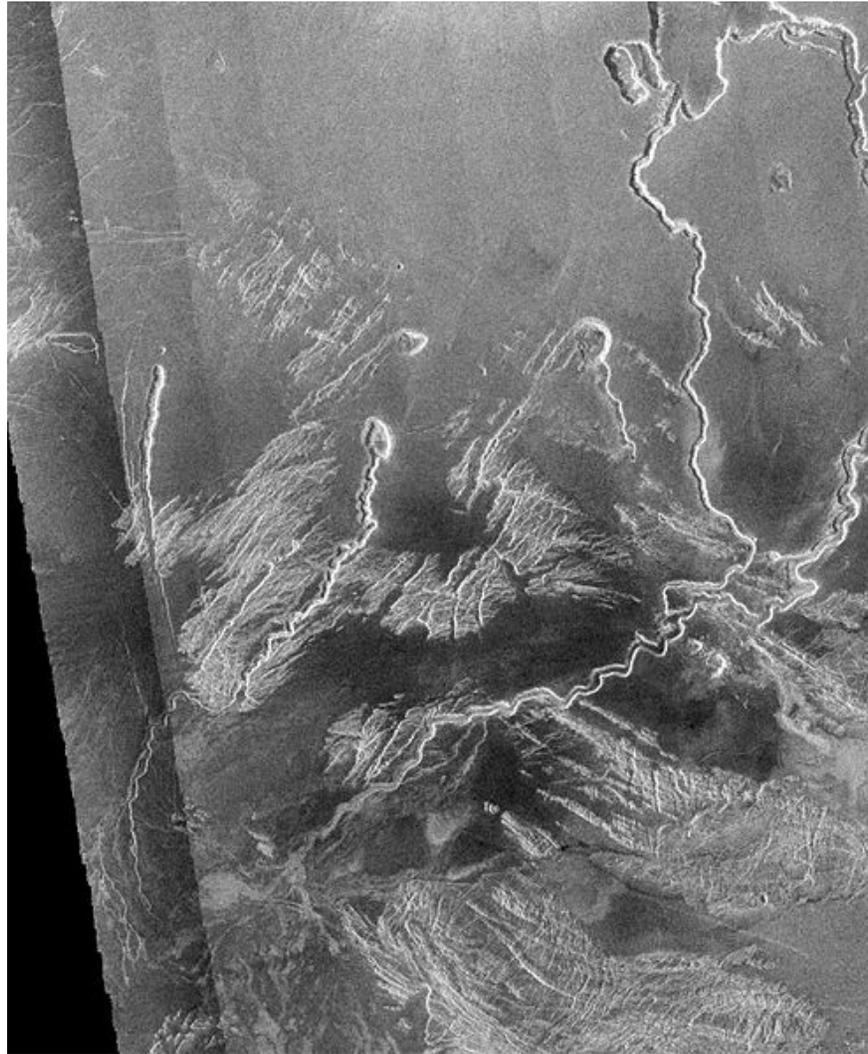


Image of the surface of Venus taken by the Magellan spacecraft

Study of the Magellan high-resolution global images is providing evidence to better understand Venusian geology and the role of impacts, volcanism, and tectonism in the formation of Venusian surface structures. 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 in evidence 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.

## Galileo (spacecraft)

### *Galileo Orbiter*



*Galileo* is prepared for mating with the IUS booster

<b>Operator</b>	NASA
<b>Mission type</b>	Orbiter, Fly-by
<b>Flyby of</b>	Venus, Earth, 951 Gaspra, 243 Ida
<b>Satellite of</b>	<b>Jupiter</b>
<b>Orbital insertion date</b>	1995-12-08 01:20:00 UTC
<b>Launch date</b>	1989-10-18 16:53:00 UTC
<b>Launch vehicle</b>	Space Shuttle Atlantis Inertial Upper Stage
<b>Launch site</b>	KSC Launch Complex 39B Kennedy Space Center
<b>Mission duration</b>	December 8, 1995 - September 21, 2003  (deorbited 2003-09-21 18:57:00 UTC)
<b>COSPAR ID</b>	1989-084B
<b>Homepage</b>	<i>Galileo</i> Project Home Page
<b>Mass</b>	2,380 kg (5,200 lb)
<b>Power</b>	570 W (2 RTGs)





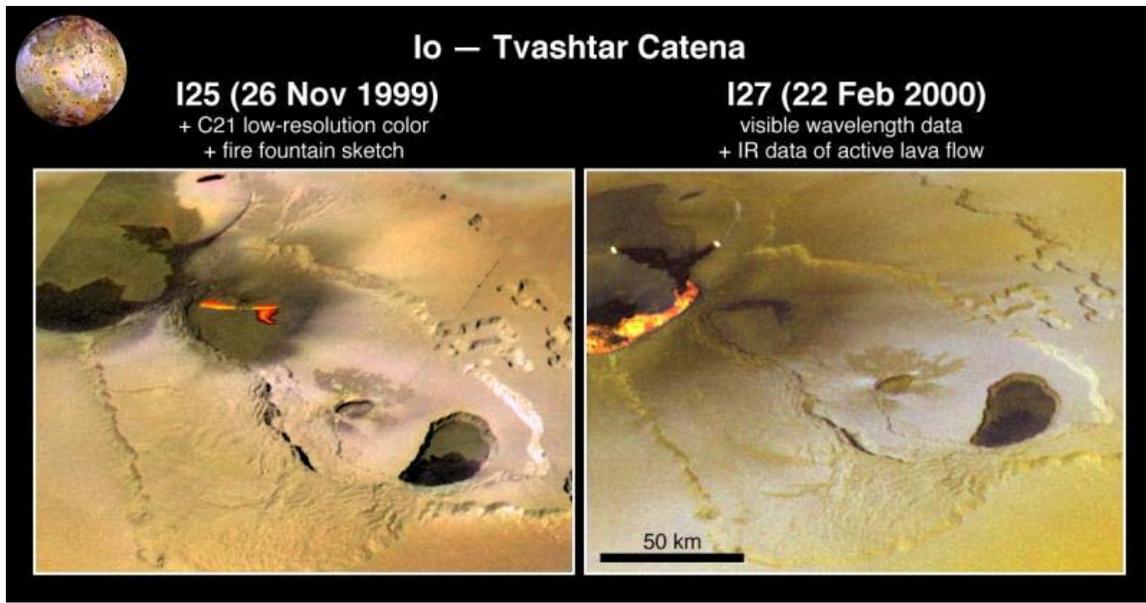
*Galileo* and Inertial Upper Stage being deployed after being launched by the Space Shuttle Atlantis on the STS-34 mission



*Galileo* and Inertial Upper Stage in space



The four largest moons of Jupiter photographed by *Galileo*



*Galileo* captures a dynamic eruption at Tvashtar Catena, a chain of volcanic bowls on Jupiter's moon Io

**Galileo** was an unmanned spacecraft sent by NASA to study the planet Jupiter and its moons. Named after the astronomer and Renaissance pioneer Galileo Galilei, it was launched on October 18, 1989 by the Space Shuttle *Atlantis* on the STS-34 mission. It arrived at Jupiter on December 7, 1995, a little more than six years later, via gravitational assist flybys of Venus and Earth.

Despite antenna problems, *Galileo* conducted the first asteroid flyby near 951 Gaspra, discovered the first asteroid moon Dactyl around asteroid 243 Ida, was the first spacecraft to orbit Jupiter, and launched the first probe into Jupiter's atmosphere.

The spacecraft measured atmospheric composition of Jupiter and directly observed ammonia clouds, which seems to be created from an outflow from lower depths. It also registered Io's volcanism and plasma interactions between the atmosphere with currents from Jupiter's atmosphere. Other studies gave support for the popular theory of liquid oceans under the icy surface of Europa. There was also indications of similar liquid-saltwater layers under the surfaces of Ganymede and Callisto, while Ganymede was shown to possess a magnetic field. New evidence was also found for existence of exospheres around Europa, Ganymede, and Callisto.

It was discovered that Jupiter's faint ring system is formed by dust from impacts on the four small inner moons. The extent and structure of Jupiter's magnetosphere was also mapped.

*Galileo* was the only direct observation point of comet Shoemaker-Levy 9's impact into the atmosphere of Jupiter.

On September 21, 2003, after 14 years in space and 8 years of service in the Jovian system, *Galileo's* mission was terminated by sending the orbiter into Jupiter's atmosphere at a speed of nearly 50 kilometres per second to avoid any chance of it contaminating local moons with bacteria from Earth. Of particular concern was the ice-crust moon Europa, which, thanks to *Galileo*, scientists now suspect harbors a salt water ocean beneath its surface.

## **Mission overview**

*Galileo's* launch had been significantly delayed by the hiatus in Space Shuttle launches that occurred after the *Challenger* space shuttle disaster. New safety protocols introduced as a result of the Challenger accident forced *Galileo* to use a lower-powered upper stage booster rocket, instead of a Centaur booster rocket, to send it from Earth orbit to Jupiter. Several gravitational slingshots, called a "VEEGA" or Venus Earth Earth Gravity Assist maneuver, provided the additional velocity required to reach its destination: Venus was flown by on February 10, 1990, and Earth twice, on December 8, 1990, and again on December 8, 1992. Along the way *Galileo* performed close observation of the asteroids 951 Gaspra (October 29, 1991) and 243 Ida (August 28, 1993), and discovered Ida's moon Dactyl. In 1994 *Galileo* was perfectly positioned to watch the fragments of comet Shoemaker-Levy 9 crash into Jupiter. Terrestrial telescopes had to wait to see the impact sites as they rotated into view.

*Galileo's* prime mission was a two-year study of the Jovian system. The spacecraft traveled around Jupiter in elongated ellipses, each orbit lasting about two months. The differing distances from Jupiter afforded by these orbits allowed *Galileo* to sample different parts of the planet's extensive magnetosphere. The orbits were designed for close up flybys of Jupiter's largest moons. Once *Galileo's* prime mission was concluded, an extended mission followed starting on December 7, 1997; the spacecraft made a number of daring close flybys of Jupiter's moons Europa and Io. The closest approach was 180 km (112 mi) on October 15, 2001. The radiation environment near Io in particular was very unhealthy for *Galileo's* systems, and so these flybys were saved for the extended mission when loss of the spacecraft would be more acceptable.

*Galileo's* cameras were deactivated on January 17, 2002 after they had sustained irrecoverable radiation damage. NASA engineers were able to recover the damaged tape recorder electronics, and once more *Galileo* continued to return other scientific data until it was deorbited in 2003 as described above, performing one last scientific experiment — a measurement of Amalthea's mass as *Galileo* swung by.

## **The *Galileo* spacecraft**

The Jet Propulsion Laboratory built the *Galileo* spacecraft and managed the *Galileo* mission for NASA. Germany supplied the propulsion module. NASA's Ames Research Center managed the probe, which was built by Hughes Aircraft Company.

At launch, the orbiter and probe together had a mass of 2,564 kilograms (5,653 pounds) and was seven metres tall. One section of the spacecraft rotated at 3 rpm, keeping *Galileo* stable and holding six instruments that gathered data from many different directions, including the fields and particles instruments. The other section of the spacecraft was an antenna, and data were periodically transmitted to it. Back on the ground the mission operations team used software containing 650,000 lines of programming code in the orbit sequence design process; 1,615,000 lines in the telemetry interpretation; and 550,000 lines of code in navigation.

## **Command and data handling**

The CDH was actively redundant, with two parallel strings running at all times. It was composed of multiplexers (MUX), high-level modules (HLM), low-level modules (LLM), power converters (PC), bulk memory (BUM), data management subsystem bulk memory (DBUM), timing chains (TC), phase lock loops (PLL), Golay coders (GC), and hardware command decodes (HCD).

The spacecraft was controlled by six RCA 1802 Cosmac microprocessor CPUs: four on the spun side and two on the despun side. Each CPU was clocked at about 1.6 MHz, and fabricated on sapphire (Silicon on sapphire) which is a radiation-and static-hardened material ideal for spacecraft operation. This microprocessor was the first low-power CMOS processor chip, quite on a par with the 8-bit 6502 that was being built into the Apple II desktop computer at that time. *Galileo's* attitude control system software was written in the HAL/S programming language, also used in the Space Shuttle program. Memory capacity provided by each BUM was 16K of RAM while the DBUMs each provided 8K of RAM. The BUMs and DBUMs provided storage for sequences and contain various buffers for telemetry data and interbus communication.

Every HLM and LLM was built up around a single 1802 microprocessor and 32K of RAM (for HLMs) or 16K of RAM (for LLMs). Two HLMs and two LLMs resided on the spun side while two LLMs were on the despun side.

Each HLM was responsible for the following functions: 1.) uplink command processing, 2.) maintenance of the spacecraft clock, 3.) movement of data over the data system bus, 4.) execution of stored sequences (time-event tables), 5.) telemetry control, and 6.) error recovery including system fault-protection monitoring and response.

Each LLM was responsible for the following functions: 1.) collect and format engineering data from the subsystems, 2.) provide the capability to issue coded and discrete commands to spacecraft users, 3.) recognize out-of-tolerance conditions on status inputs, and 4.) perform some system fault-protection functions.

## **Propulsion**

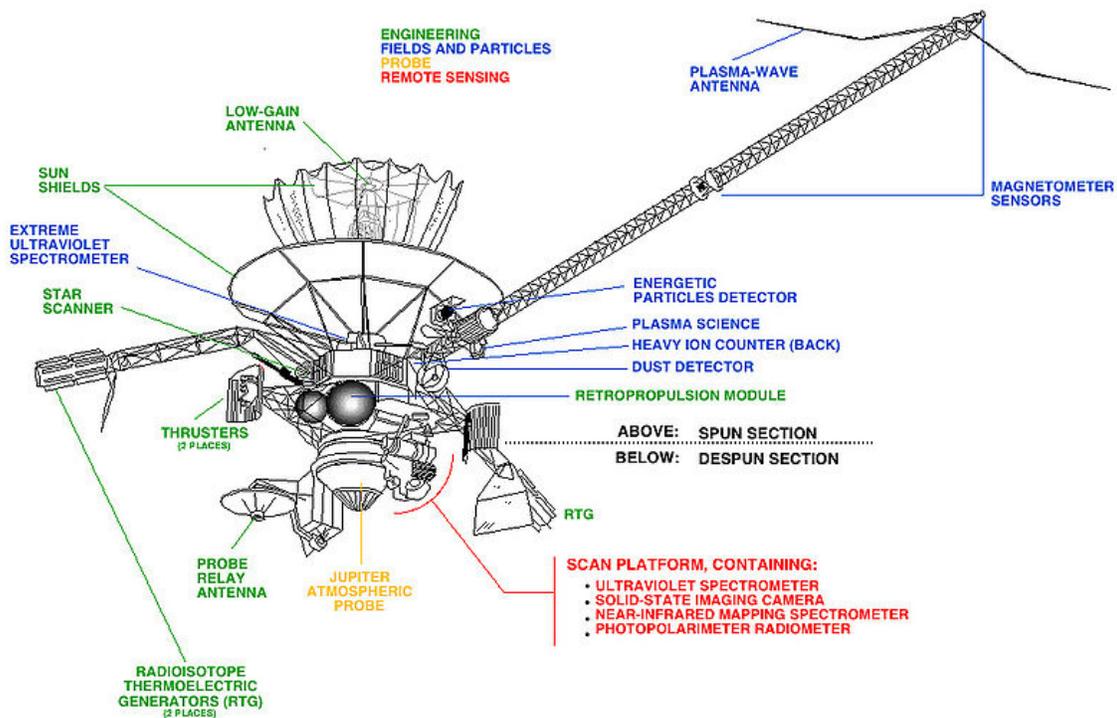
The Propulsion Subsystem consisted of a 400 N main engine and twelve 10 N thrusters together with propellant, storage and pressurizing tanks, and associated plumbing. The 10

N thrusters were mounted in groups of six on two 2-meter booms. The fuel for the system was 925 kg of monomethylhydrazine and nitrogen tetroxide. Two separate tanks held another 7 kg of helium pressurant. The Propulsion Subsystem was developed and built by Daimler Benz Aero Space AG (DASA) (formerly Messerschmitt-Bölkow-Blohm (MBB)) and provided by Germany, the major international partner in Project *Galileo*.

## **Electrical power**

Solar panels were not a practical solution for *Galileo*'s power needs at Jupiter's distance from the Sun (it would have needed a *minimum* of 65 square metres (700 ft<sup>2</sup>) of solar panels); as for batteries, they would have been prohibitively massive. The solution adopted consisted of two radioisotope thermoelectric generators (RTGs). The RTGs powered the spacecraft through the radioactive decay of plutonium-238. The heat emitted by this decay was converted into electricity for the spacecraft through the solid-state Seebeck effect. This provided a reliable and long-lasting source of electricity unaffected by the cold space environment and high radiation fields such as those encountered in Jupiter's magnetosphere.

Each GPHS-RTG, mounted on a 5-meter long boom, carried 7.8 kilograms (17.2 lb) of <sup>238</sup>Pu. Each RTG contained 18 separate heat source modules, and each module encased four pellets of plutonium dioxide, a ceramic material resistant to fracturing. The modules were designed to survive a range of hypothetical accidents: launch vehicle explosion or fire, re-entry into the atmosphere followed by land or water impact, and post-impact situations. An outer covering of graphite provided protection against the structural, thermal, and eroding environments of a potential re-entry. Additional graphite components provided impact protection, while iridium cladding of the fuel cells provided post-impact containment. The RTGs produced about 570 watts at launch. The power output initially decreased at the rate of 0.6 watts per month and was 493 watts when *Galileo* arrived at Jupiter.



Overview of *Galileo's* components

As the launch of *Galileo* neared, anti-nuclear groups, concerned over what they perceived as an unacceptable risk to the public's safety from *Galileo's* RTGs, sought a court injunction prohibiting *Galileo's* launch. RTGs had been used for years in planetary exploration without mishap: the Lincoln Experimental Satellites 8/9, launched by the U.S. Department of Defense, had 7% more plutonium on board than *Galileo*, and the two Voyager spacecraft each carried 80% as much plutonium as *Galileo* did. However, activists remembered the messy crash of the Soviet Union's nuclear-powered Cosmos 954 satellite in Canada in 1978, and the 1986 Challenger accident had raised public awareness of the possibility of explosive spacecraft failures. Also, no RTGs had ever been made to swing past the Earth at close range and high speed, as *Galileo's* Venus-Earth-Earth Gravity Assist trajectory required it to do. This created a novel mission failure modality that might plausibly have entailed total dispersal of *Galileo's* plutonium in the Earth's atmosphere. Scientist Carl Sagan, for example, a strong supporter of the *Galileo* mission, said in 1989 that "there is nothing absurd about either side of this argument."

After the Challenger accident, a study considered additional shielding and eventually rejected it, in part because such a design significantly increased the overall risk of mission failure and only shifted the other risks around (for example, if a failure on orbit had occurred, additional shielding would have significantly increased the consequences of a ground impact).

## **Instrumentation overview**

Scientific instruments to measure fields and particles were mounted on the spinning section of the spacecraft, together with the main antenna, power supply, the propulsion module and most of the *Galileo* computers and control electronics. The sixteen instruments, weighing 118 kg altogether, included magnetometer sensors mounted on an 11 m boom to minimize interference from the spacecraft; a plasma instrument for detecting low energy charged particles and a plasma wave detector to study waves generated by the particles; a high energy particle detector; and a detector of cosmic and Jovian dust. It also carried the Heavy Ion Counter, an engineering experiment added to assess the potentially hazardous charged particle environments the spacecraft flew through, and an added Extreme Ultraviolet detector associated with the UV spectrometer on the scan platform.

The despun section's instruments included the camera system; the near infrared mapping spectrometer to make multi-spectral images for atmospheric and moon surface chemical analysis; ultraviolet spectrometer to study gases; and photo-polarimeter radiometer to measure radiant and reflected energy. The camera system was designed to obtain images of Jupiter's satellites at resolutions from 20 to 1,000 times better than *Voyager's* best, because *Galileo* flew closer to the planet and its inner moons and because the CCD sensor in *Galileo's* camera was more sensitive and had a broader color detection band than the vidicons of *Voyager*.

## **Instrumentation details**

The following information was taken directly from NASA's *Galileo* legacy site.

# Despun section

## The Galileo Spacecraft

Science experiments are described in Italian, and have blue connecting lines. Engineering components are shown as red connecting lines.

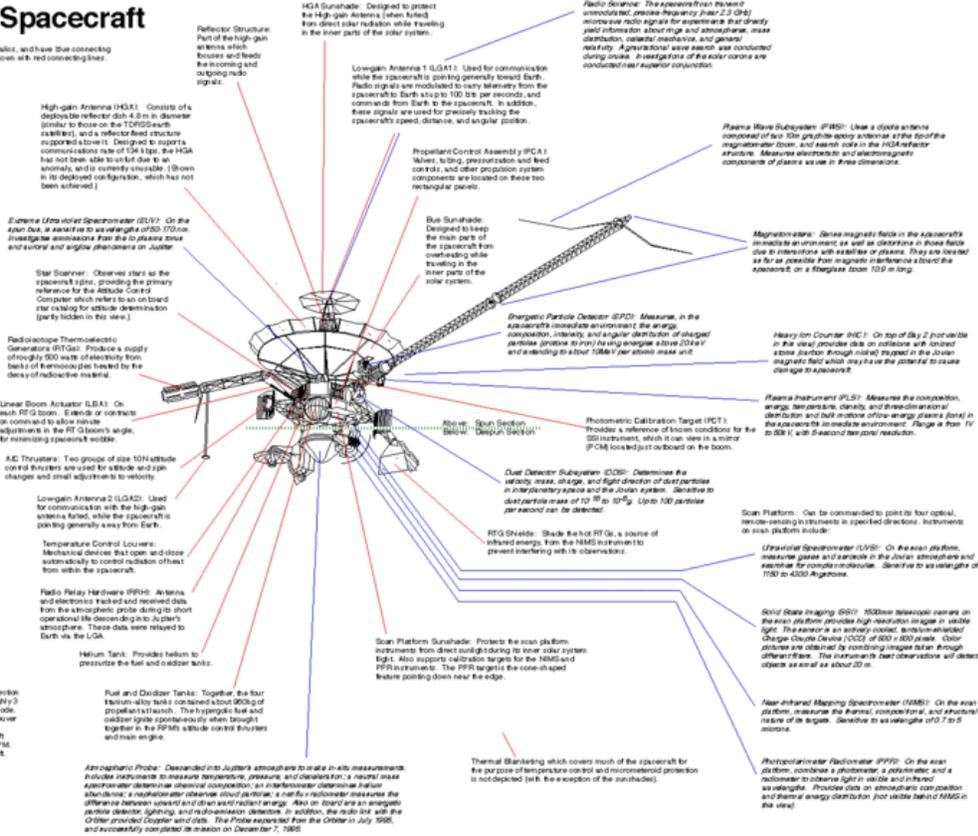
**Spacecraft Spin Section:** The spin bus houses electronics and computers for attitude control, command processing, and flight science data processing. Also houses components such as radio, data storage tape recorder, and magnetometers.

**Pero Propulsion Module (PPM):** The entire propulsion system is a single module provided by the Federal Republic of Germany. It consists of twelve 10N attitude control thrusters on two A/C thruster booms, one control A/C thruster, four tanks of fuel and oxidizer, and two tanks of helium pressurant. The HGA, RTG, and Science Booms are also part of the spin section.

**Spin Bearing Assembly (SBA):** Connects the spin and the despun sections of the spacecraft. In addition to mechanical coupling, slip rings provide transfer of power and science data, and rotary transformers provide a coupling for high rate data. An optical encoder provides relative position information.

**Spacecraft Despun Section:** The main platform and its optical instruments and the probe release hardware are despun via the SBA so they can be pointed at their target. The atmospheric probe is carried as part of the despun section.

**Spacecraft Spin:** The spin section spins about the roll axis at roughly 3 RPM in its normal, dual-spin mode. During the probe release maneuver and the Jupiter orbit insertion maneuver, the entire spacecraft spins together at about 10 RPM. Spin direction is indicated at left.



## Highly detailed diagram of Galileo instruments and subsystems



Solid-State Imaging camera of the Galileo spacecraft

### **Solid State Imager (SSI)**

The SSI is an 800 by 800 pixel solid state camera consisting of an array of silicon sensors called a "charge coupled device" (CCD). The optical portion of the camera is built as a Cassegrain telescope. Light is collected by the primary mirror and directed to a smaller secondary mirror that channels it through a hole in the center of the primary mirror and onto the CCD. The CCD sensor is shielded from radiation, a particular problem within the harsh Jovian magnetosphere. The shielding is accomplished by means of a 10 mm thick layer of tantalum surrounding the CCD except where the light enters the system. An eight position filter wheel is used to obtain images at specific wavelengths. The images are then combined electronically on Earth to produce color images. The spectral response of the SSI ranges from about 0.4 to 1.1 micrometres. The SSI weighs 29.7 kilograms and consumes, on average, 15 watts of power.

### **Near-Infrared Mapping Spectrometer (NIMS)**

The NIMS instrument is sensitive from 0.7 to 5.2 micrometre wavelength IR light, overlapping the wavelength range of SSI. The telescope associated with NIMS is all reflective (uses mirrors and no lenses) with an aperture of 229 mm. The spectrometer of NIMS uses a grating to disperse the light collected by the telescope. The dispersed spectrum of light is focused on detectors of indium antimonide and silicon. The NIMS weighs 18 kilograms and uses 12 watts of power on average.

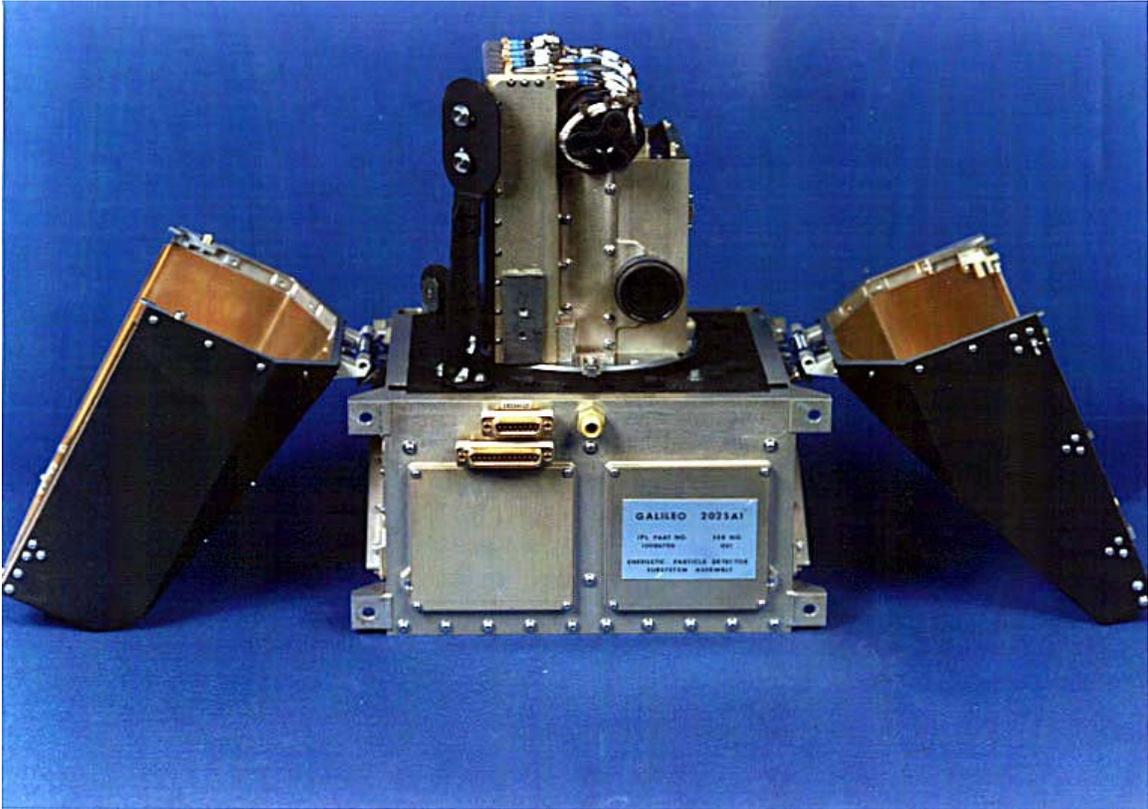
### **Ultraviolet Spectrometer / Extreme Ultraviolet Spectrometer (UVS/EUV)**

The Cassegrain telescope of the UVS has a 250 mm aperture and collects light from the observation target. Both the UVS and EUV instruments use a ruled grating to disperse this light for spectral analysis. This light then passes through an exit slit into photomultiplier tubes that produce pulses or "sprays" of electrons. These electron pulses are counted, and these count numbers are the data that are sent to Earth. The UVS is mounted on the scan platform and can be pointed to an object in inertial space. The EUV is mounted on the spun section of the spacecraft. As *Galileo* spins, the EUV observes a narrow ribbon of space perpendicular to the spin axis. The two instruments combined weigh about 9.7 kilograms and use 5.9 watts of power.

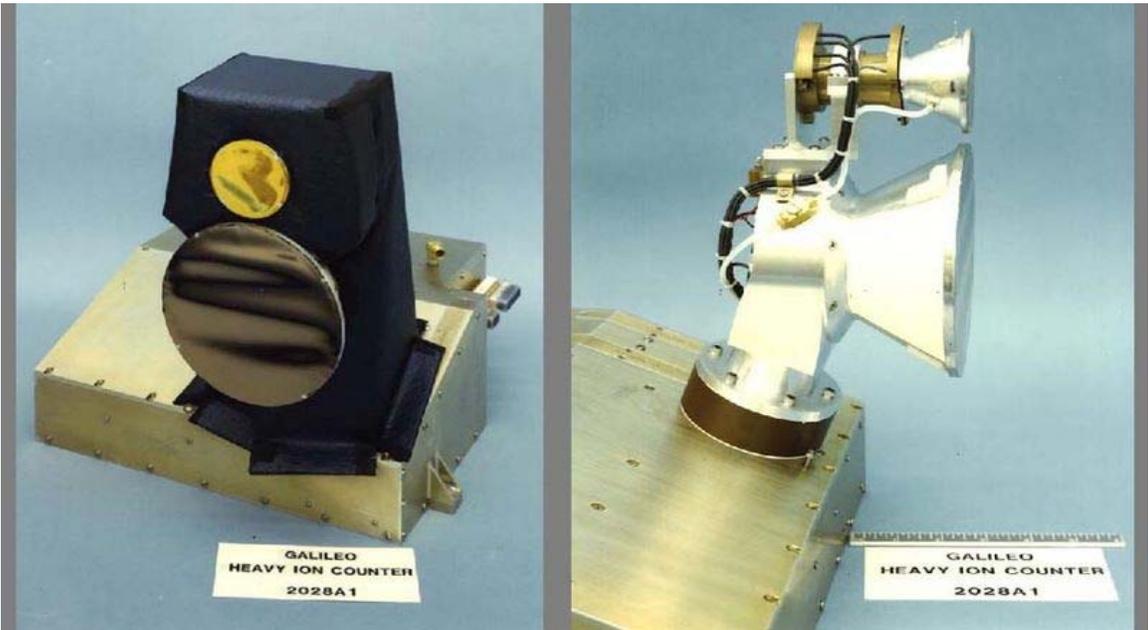
### **Photopolarimeter-Radiometer (PPR)**

The PPR has seven radiometry bands. One of these uses no filters and observes all the radiation, both solar and thermal. Another band lets only solar radiation through. The difference between the solar- plus-thermal and the solar-only channels gives the total thermal radiation emitted. The PPR also measured in five broadband channels that span the spectral range from 17 to 110 micrometres. The radiometer provides data on the temperatures of the Jovian satellites and Jupiter's atmosphere. The design of the instrument is based on that of an instrument flown on the Pioneer Venus spacecraft. A 100 mm aperture reflecting telescope collects light, directs it to a series of filters, and, from there, measurements are performed by the detectors of the PPR. The PPR weighs 5.0 kilograms and consumes about 5 watts of power.

**Spun section**



Energetic Particles Detector of the Galileo spacecraft



Heavy Ion Counter of the Galileo spacecraft

### **Dust Detector Subsystem (DDS)**

The Dust Detector Subsystem (DDS) was used to measure the mass, electric charge, and velocity of incoming particles. The masses of dust particles that the DDS can detect go from  $10^{-16}$  to  $10^{-7}$  grams. The speed of these small particles can be measured over the range of 1 to 70 kilometers per second. The instrument can measure impact rates from 1 particle per 115 days (10 megaseconds) to 100 particles per second. These particles will help determine dust origin and dynamics within the magnetosphere. The DDS weighs 4.2 kilograms and uses an average of 5.4 watts of power.

### **Energetic Particles Detector (EPD)**

The energetic particles detector (EPD) is designed to measure the numbers and energies of ions and electrons whose energies exceed about 20 keV (3.2 fJ). The EPD can also measure the direction of travel of such particles and, in the case of ions, can determine their composition (whether the ion is oxygen or sulfur, for example). The EPD uses silicon solid state detectors and a time-of-flight detector system to measure changes in the energetic particle population at Jupiter as a function of position and time. These measurements will tell us how the particles get their energy and how they are transported through Jupiter's magnetosphere. The EPD weighs 10.5 kilograms and uses 10.1 watts of power on average.

### **Heavy Ion Counter (HIC)**

The HIC is really a repackaged and updated version of some parts of the flight spare of the Voyager Cosmic Ray System. The HIC detects heavy ions using stacks of single crystal silicon wafers. The HIC can measure heavy ions with energies as low as 6 MeV (1 pJ) and as high as 200 MeV (32 pJ) per nucleon. This range includes all atomic substances between carbon and nickel. The HIC and the EUV share a communications link and, therefore, must share observing time. The HIC weighs 8 kilograms and uses an average of 2.8 watts of power.

### **Magnetometer (MAG)**

The magnetometer (MAG) uses two sets of three sensors. The three sensors allow the three orthogonal components of the magnetic field section to be measured. One set is located at the end of the magnetometer boom and, in this position, is about 11 m from the spin axis of the spacecraft. The second set, designed to detect stronger fields, is 6.7 m from the spin axis. The boom is used to remove the MAG from the immediate vicinity of the spacecraft to minimize magnetic effects from the spacecraft. However, not all these effects can be eliminated by distancing the instrument. The rotation of the spacecraft is used to separate natural magnetic fields from engineering induced fields. Another source of potential error in measurement comes from bending and twisting of the long magnetometer boom. To account for these motions, a calibration coil is mounted rigidly on the spacecraft and puts out a reference magnetic field during calibrations. The magnetic field at the surface of the Earth has a strength of about 50,000 nT. At Jupiter, the outboard (11 m) set of sensors can measure magnetic field strengths in the range from

$\pm 32$  to  $\pm 512$  nT while the inboard (6.7 m) set is active in the range from  $\pm 512$  to  $\pm 16,384$  nT. The MAG experiment weighs 7 kilograms and uses 3.9 watts of power.

#### **Plasma Subsystem (PLS)**

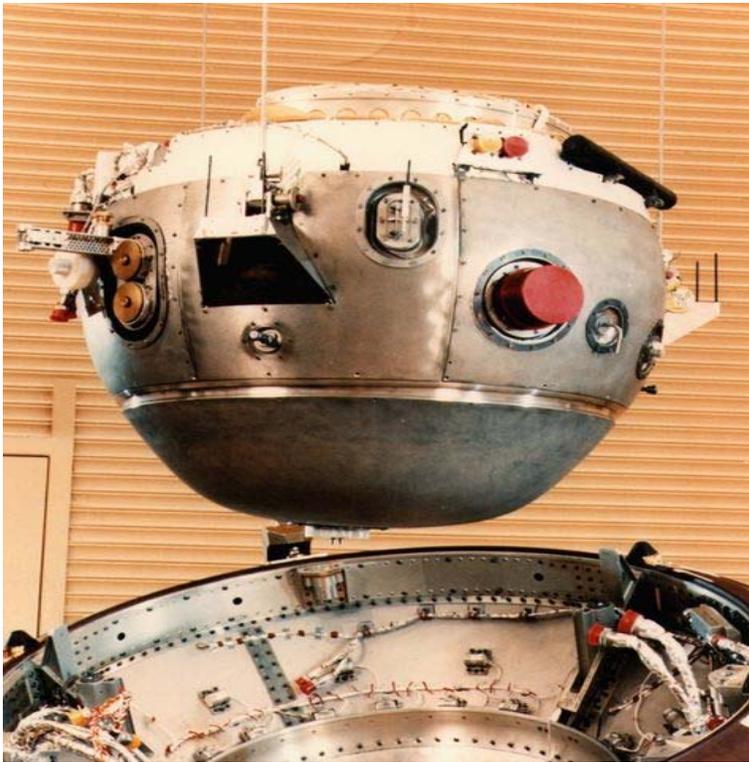
The PLS uses seven fields of view to collect charged particles for energy and mass analysis. These fields of view cover most angles from 0 to 180 degrees, fanning out from the spin axis. The rotation of the spacecraft carries each field of view through a full circle. The PLS will measure particles in the energy range from 0.9 eV to 52 keV (0.1 aJ to 8.3 fJ). The PLS weighs 13.2 kilograms and uses an average of 10.7 watts of power.

#### **Plasma Wave Subsystem (PWS)**

An electric dipole antenna is used to study the electric fields of plasmas, while two search coil magnetic antennas studied the magnetic fields. The electric dipole antenna is mounted at the tip of the magnetometer boom. The search coil magnetic antennas are mounted on the high-gain antenna feed. Nearly simultaneous measurements of the electric and magnetic field spectrum allowed electrostatic waves to be distinguished from electromagnetic waves. The PWS weighs 7.1 kilograms and uses an average of 9.8 watts.

## **Galileo's atmospheric entry probe**

### ***Galileo Probe***

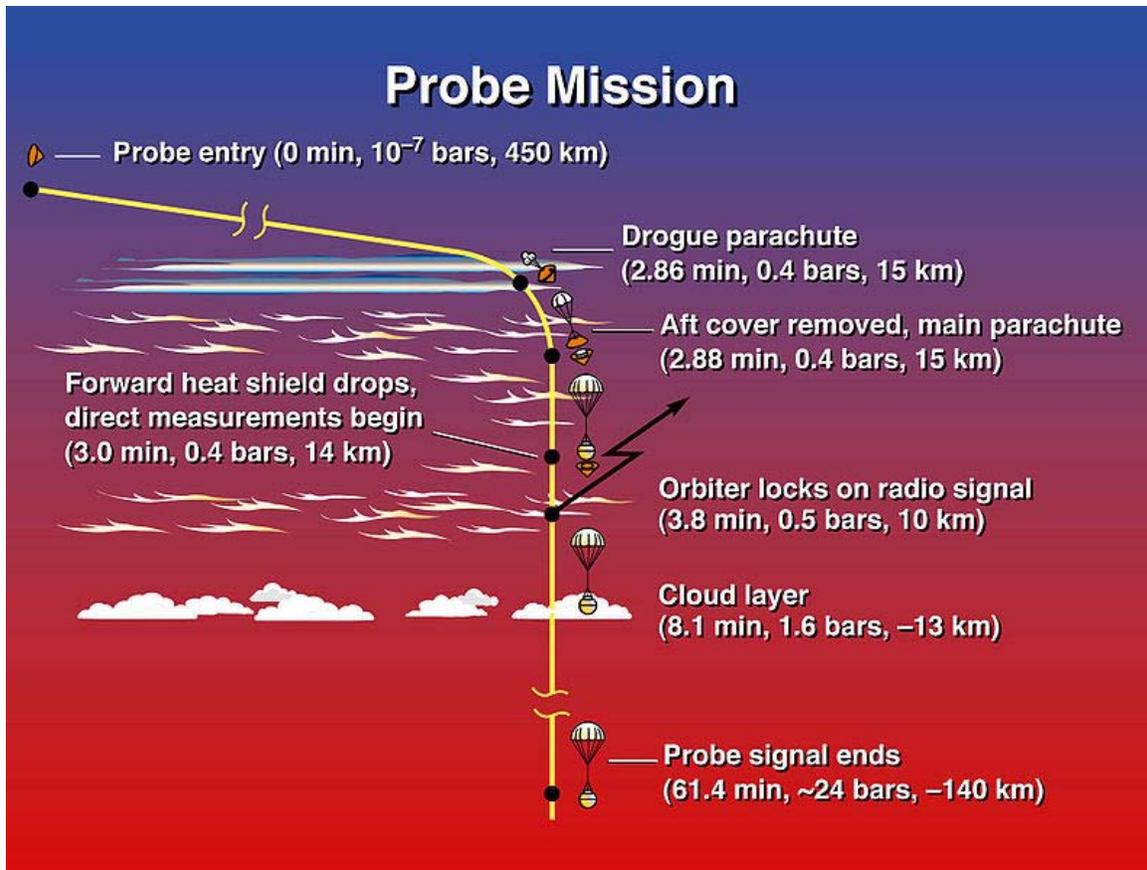


The *Galileo* Probe Descent Module

<b>Operator</b>	NASA
<b>Mission type</b>	Atmospheric probe
<b>Launch date</b>	July 13, 1995
<b>Launch vehicle</b>	Space Shuttle Atlantis Inertial Upper Stage Galileo Orbiter
<b>Launch site</b>	KSC Launch Complex 39B Kennedy Space Center
<b>Mission duration</b>	December 7, 1995 (57.6 minutes)
<b>COSPAR ID</b>	1989-084E
<b>Homepage</b>	<i>Galileo</i> Project Home Page
<b>Mass</b>	339 kg (750 lb)
<b>Power</b>	580 W (LiSO <sub>2</sub> battery)

**Orbital elements**

<b>Eccentricity</b>	1.03116
<b>Inclination</b>	8.151°
<b>Periapsis</b>	0.9928 RJ



Timeline of probe atmospheric entry

The 339 kilogram atmospheric probe, built by Hughes Aircraft Company at its El Segundo, California plant, measured about 1.3 meters across. Inside the heat shield, the scientific instruments were protected from ferocious heat during entry. The probe had to withstand extreme heat and pressure on its high speed journey at 47.8 km/s.

The probe was released from the main spacecraft in July 1995, five months before reaching Jupiter, and entered Jupiter's atmosphere with no braking beforehand. It was slowed from the probe's arrival speed of about 47 kilometers per second to subsonic speed in less than two minutes.

This was by far the most difficult atmospheric entry ever attempted; the probe had to withstand 230 g and the probe's 152 kg heat shield made up almost half of the probe's total mass, and lost 80 kg during the entry. NASA built a special laboratory, the Giant Planet Facility to simulate the heat load, which was similar to that of an ICBM-style straight-down reentry through a thermonuclear fireball. It then deployed its 2.5-meter (8 ft) parachute, and dropped its heat shield.

As the probe descended through 150 kilometers of the top layers of the atmosphere, it collected 58 minutes of data on the local weather. It only stopped transmitting when ambient pressure exceeded 23 atmospheres and temperature reached 153 °C (307 °F).

The data was sent to the spacecraft overhead, then transmitted back to Earth. Each of 2 L-band transmitters operated at 128 bits per second and sent nearly identical streams of scientific data to the orbiter. All the probe's electronics were powered by lithium sulfur dioxide (LiSO<sub>2</sub>) batteries that provided a nominal power output of about 580 watts with an estimated capacity of about 21 ampere-hours on arrival at Jupiter.

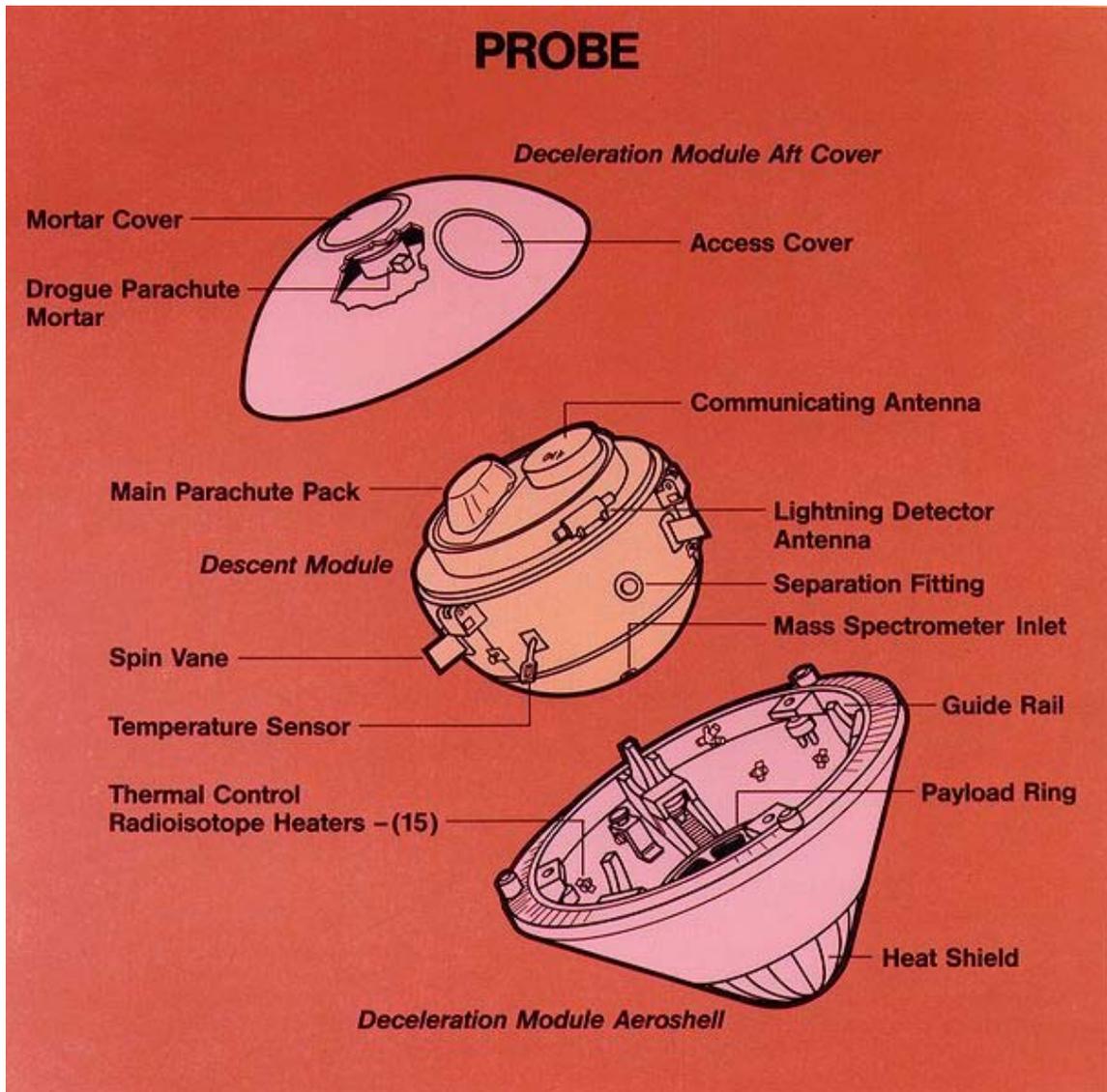


Diagram of *Galileo* atmospheric entry probe instruments and subsystems

The probe included six instruments for taking data on its plunge into Jupiter:

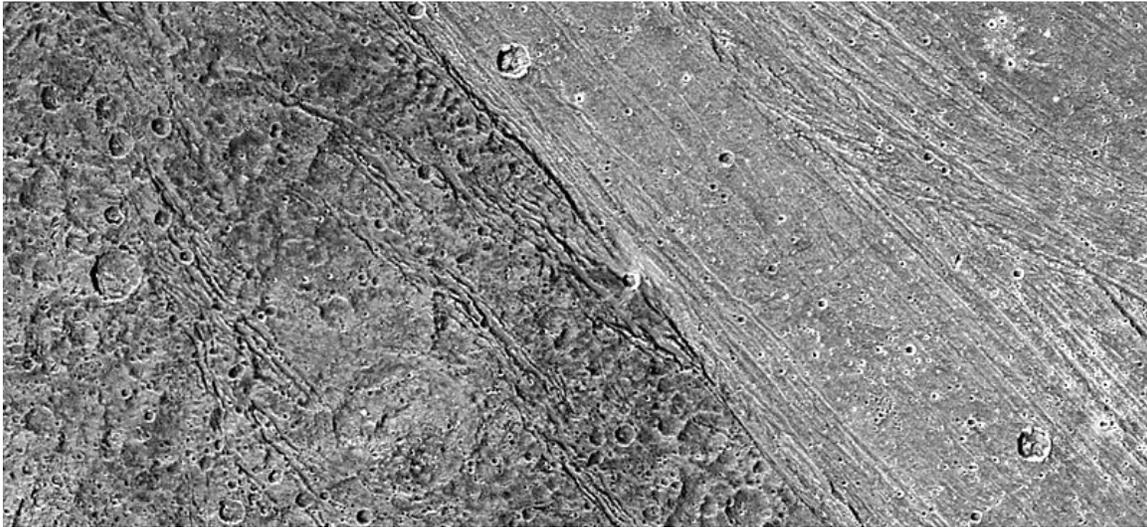
- an *atmospheric structure instrument group* measuring temperature, pressure and deceleration,
- a *neutral mass spectrometer* and
- a *helium-abundance interferometer* supporting atmospheric composition studies,
- a *nephelometer* for cloud location and cloud-particle observations,

- a *net-flux radiometer* measuring the difference between upward and downward radiant flux at each altitude, and
- a *lightning/radio-emission instrument* with an energetic-particle detector that measured light and radio emissions associated with lightning and energetic particles in Jupiter's radiation belts.

Total data returned from the probe was about 3.5 megabits (~458752 bytes). The probe stopped transmitting before the line of sight link with the orbiter was cut. The likely proximal cause of the final probe failure was overheating, which sensors indicated before signal loss.

The atmosphere through which the probe descended was somewhat more turbulent and hotter than expected. The probe was eventually completely destroyed as it continued to descend. The parachute would have melted first, roughly 30 minutes later, then the aluminum components after another 40 minutes of free fall. The titanium structure would have lasted 6.5 hours more before disintegrating. Due to the high pressure, the droplets of metals from the probe would finally have vaporised once their critical temperature had been reached, and mixed with Jupiter's liquid metallic hydrogen interior.

## Science performed by the *Galileo* Orbiter at Jupiter



Terrain on Ganymede



Pwyll crater on Europa

After arriving on December 7, 1995 and completing 35 orbits around Jupiter throughout a nearly eight year mission, the *Galileo* Orbiter was destroyed during a controlled impact with Jupiter on September 21, 2003. During that intervening time, *Galileo* forever changed the way scientists saw Jupiter and provided a wealth of information on the moons orbiting the planet which will be studied for years to come. Culled from NASA's press kit, the top orbiter science results were:

- *Galileo* made the first observation of ammonia clouds in another planet's atmosphere. The atmosphere creates ammonia ice particles from material coming up from lower depths.

- The moon Io was confirmed to have extensive volcanic activity that is 100 times greater than that found on Earth. The heat and frequency of eruptions are reminiscent of early Earth.
- Complex plasma interactions in Io's atmosphere create immense electrical currents which couple to Jupiter's atmosphere.
- Several lines of evidence from *Galileo* support the theory that liquid oceans exist under Europa's icy surface.
- Ganymede possesses its own, substantial magnetic field - the first satellite known to have one.
- *Galileo* magnetic data provide evidence that Europa, Ganymede and Callisto have a liquid-saltwater layer under the visible surface.
- Evidence exists that Europa, Ganymede, and Callisto all have a thin atmospheric layer known as a 'surface-bound exosphere'.
- Jupiter's ring system is formed by dust kicked up as interplanetary meteoroids smash into the planet's four small inner moons. The outermost ring is actually two rings, one embedded with the other. There is probably a separate ring along Amalthea's orbit, as well.
- The *Galileo* spacecraft identified the global structure and dynamics of a giant planet's magnetosphere.

## Other science conducted with *Galileo*

### The *Galileo* star scanner

The star scanner was a small optical telescope used to provide the spacecraft with an absolute attitude reference. It was also able serendipitously to make scientific discoveries. In the prime mission, it was found that the star scanner was able to detect high energy particles as a noise signal. These data were eventually calibrated to show the particles were predominantly  $> 2$  MeV electrons that were trapped in the Jovian magnetic belts.

A second discovery occurred in 2000. The star scanner was observing a set of stars which included the second magnitude star Delta Velorum. At one point, this star dimmed for 8 hours below the star scanner's detection threshold. Subsequent analysis of *Galileo* data and work by amateur and professional astronomers showed that Delta Velorum is the brightest known eclipsing binary, brighter at maximum than even Algol. It has a primary period of 45 days and the dimming is just visible with the naked eye.

A final discovery occurred during the last two orbits of the mission. When the spacecraft passed the orbit of Jupiter's moon Amalthea, the star scanner detected unexpected flashes of light that were reflections from moonlets. None of the individual moonlets were sighted twice, hence no orbits were determined and the moonlets did not meet the International Astronomical Union requirements to receive designations. It is believed that these moonlets most likely are debris ejected from Amalthea and form a tenuous, and perhaps temporary, ring.



Image taken by *Galileo* of Earth during GOPEX test clearly showing bright laser pulses coming from a transmitting telescope on the night side. *Galileo's* imager was panned downward during the exposure to separate the pulses, thus blurring earth's image on the right.

### **Remote detection of life**

The late Carl Sagan, pondering the question of whether life on Earth could be easily detected from space, devised a set of experiments in the late 1980s using *Galileo's* remote sensing instruments to determine if life indeed could be detected during the first Earth flyby of the mission in December 1990. After data acquisition and processing, Sagan et al. published a paper in *Nature* in 1993 detailing the results of the experiment. *Galileo* had found what are now referred to as the "Sagan criteria for life"; these were: strong absorption of light at the red end of the visible spectrum (especially over continents) which was caused by absorption by chlorophyll in photosynthesizing plants, absorption bands of molecular oxygen which is also a result of plant activity, infrared absorption

bands caused by the  $\sim 1$  micromole per mole ( $\mu\text{mol/mol}$ ) of methane in Earth's atmosphere (a gas which must be replenished by either volcanic or biological activity) and modulated narrowband radio wave transmissions uncharacteristic of any known natural source. *Galileo's* experiments were thus the first ever controls in the newborn science of astrobiological remote sensing.

### **The *Galileo* optical experiment**

In December 1992 during *Galileo's* second gravity assist flyby of Earth, another groundbreaking yet almost entirely unpublicized experiment was done using *Galileo* to assess the possibility of optical communication with spacecraft by detecting pulses of light from powerful lasers which were to be directly imaged by *Galileo's* CCD. The experiment, dubbed Galileo OPTical EXperiment or GOPEX, used two separate sites to beam laser pulses to the spacecraft, one at Table Mountain Observatory in California and the other at the Starfire Optical Range in New Mexico. The Table Mountain site used a frequency doubled Neodymium-Yttrium-Aluminium Garnet (Nd:YAG) laser operating at 532 nm with a repetition rate of  $\sim 15$  to 30 Hz and a pulse power (FWHM) in the tens of megawatts range, which was coupled to a 0.6 meter Cassegrain telescope for transmission to *Galileo*; the Starfire range site used a similar setup with a larger transmitting telescope (1.5 m). Long exposure ( $\sim 0.1$  to 0.8 s) images using *Galileo's* 560 nm centered green filter produced images of Earth clearly showing the laser pulses even at distances of up to 6,000,000 km. Adverse weather conditions, restrictions placed on laser transmissions by the U.S. Space Defense Operations Center (SPADOC) and a pointing error caused by the scan platform acceleration on the spacecraft being slower than expected (which prevented laser detection on all frames with less than 400 ms exposure times) all contributed to the reduction of the number of successful detections of the laser transmission to 48 of the total 159 frames taken. Nonetheless, the experiment was considered a resounding success and the data acquired will likely be used in the future to design laser "downlinks" which will send large volumes of data very quickly, from spacecraft to Earth. The scheme is already being studied (as of 2004) for a data link to a future Mars orbiting spacecraft.

## Asteroid encounters



NASA image of 951 Gaspra

### **First asteroid encounter: 951 Gaspra**

On October 29, 1991, two months after entering the asteroid belt, *Galileo* performed the first ever asteroid encounter by passing about 1,600 kilometers (1,000 miles) from 951 Gaspra at a relative speed of about 8 kilometers per second (18,000 mph). Several pictures of Gaspra were taken along with measurements using the NIMS instrument to indicate composition and physical properties. The last (and best) two images were played back to Earth in November 1991 and June 1992. The imagery revealed a cratered and very irregular body about 19 by 12 by 11 kilometers (12 by 7.5 by 7 miles). The remainder of data taken, including low resolution images of more of the surface, were transmitted in late November 1992.

## Second asteroid encounter: 243 Ida and Dactyl

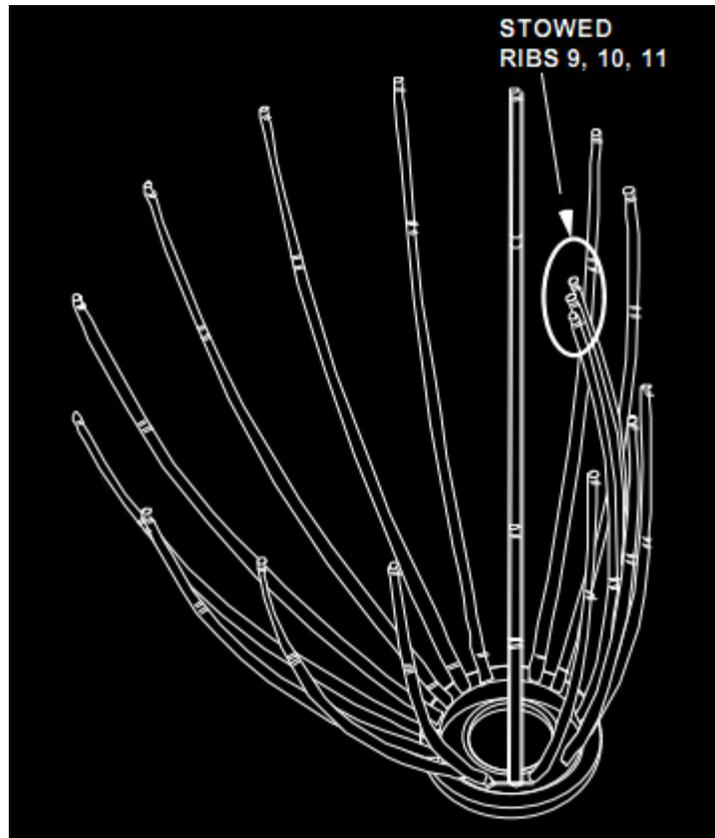


NASA image of 243 Ida. The tiny dot to the right is its moon, Dactyl.

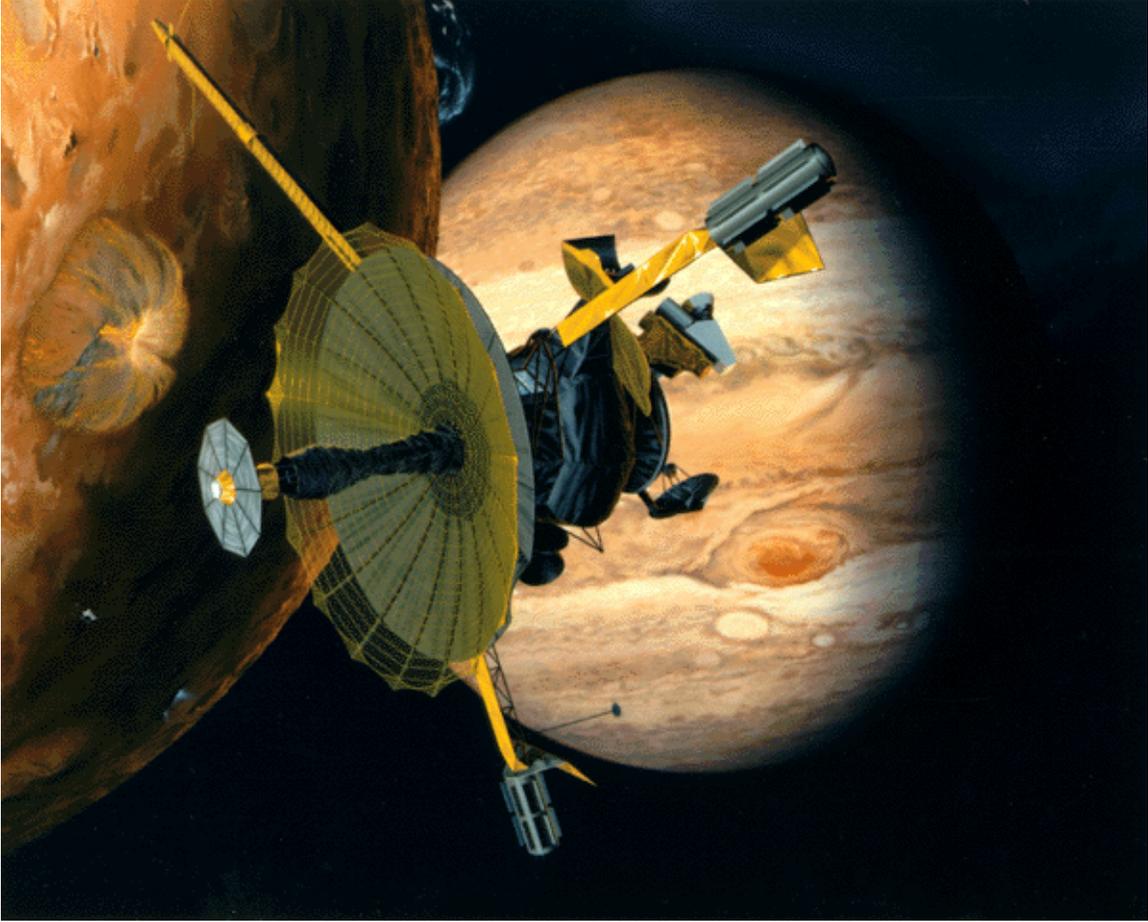
Twenty-two months after the Gasptra encounter, on August 28, 1993, *Galileo* flew within 2,400 kilometers (1,500 miles) of asteroid 243 Ida. The probe discovered that Ida had a small moon, dubbed Dactyl, only 1.4 km in diameter which was the first asteroid moon discovered. Measurements using *Galileo's* solid state imager, magnetometer and NIMS instrument were taken. From subsequent analysis of data, Dactyl appears to be an SII subtype S type asteroid and is spectrally different from 243 Ida. It is hypothesized that Dactyl may have been produced by partial melting within a Koronis parent body (Ida belongs to the "Koronis" family of asteroids that travels in the main Asteroid Belt between Mars and Jupiter) while the 243 Ida region escaped such igneous processing.

# Spacecraft malfunctions

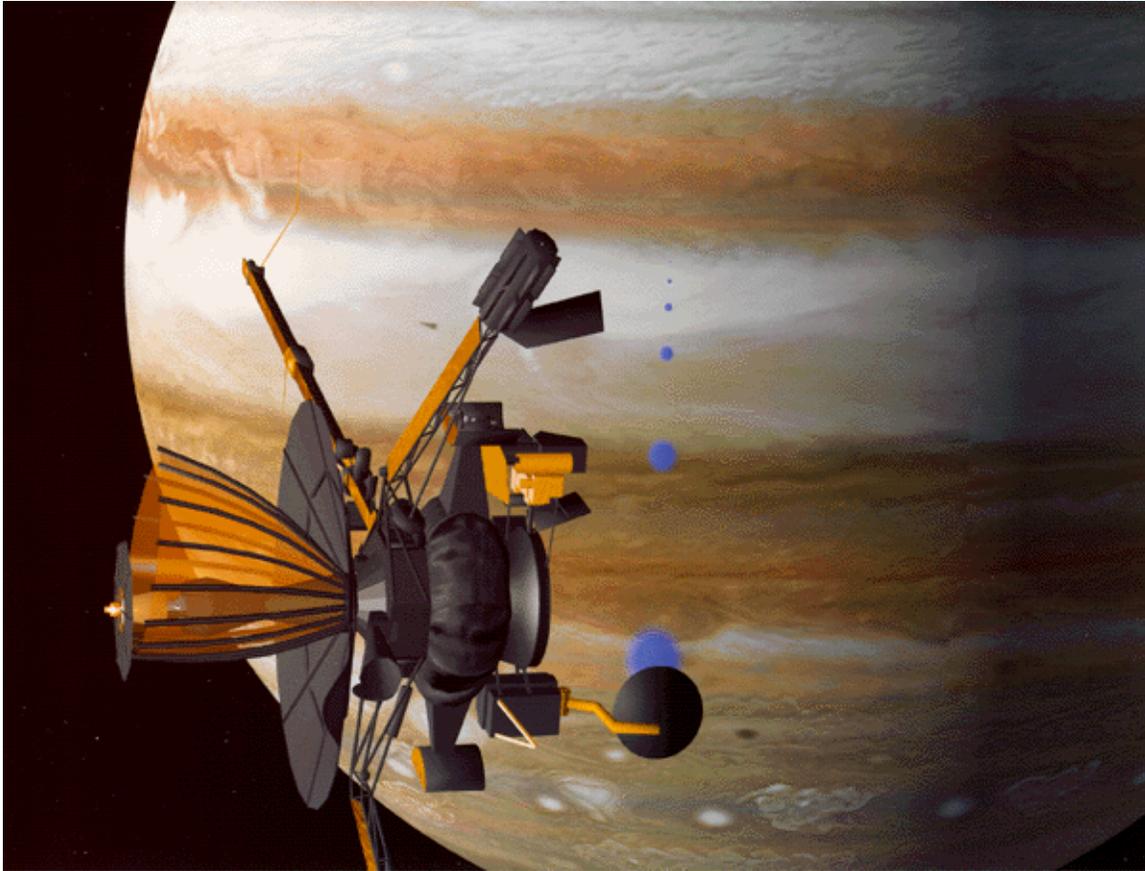
## Main antenna failure



Laboratory tests verified that holding ribs 9, 10, and 11 in the stowed position most nearly modeled the spacecraft telemetry.



Artist's concept of *Galileo* at Io. Note the fully deployed high-gain antenna. Compare with below image.



Artist's concept of *Galileo* at Jupiter with only a partially deployed high-gain antenna

For reasons which are not currently known, and in all likelihood will never be known with certainty, *Galileo's* high-gain antenna failed to fully deploy after its first flyby of Earth. Investigators speculate that during the time that *Galileo* spent in storage after the *Challenger* disaster, the lubricants evaporated, or the system was otherwise damaged. Engineers tried thermal cycling the antenna, rotating the spacecraft up to its maximum spin rate of 10.5 rpm, and "hammering" the antenna deployment motors - turning them on and off repeatedly - over 13,000 times; all attempts failed to open the high-gain antenna. Fortunately *Galileo* had an additional low-gain antenna that was capable of transmitting information back to Earth, though since it transmitted a signal isotropically, the low-gain antenna's bandwidth was significantly less than the high-gain antenna's would have been; the high-gain antenna was to have transmitted at 134 kilobits per second whereas the low-gain antenna was only intended to transmit at about 8 to 16 bits per second. *Galileo's* low-gain antenna transmitted with a power of about 15 to 20 watts, which, by the time it reached Earth, and had been collected by one of the large aperture (70 m) DSN antennas, had a total power of about -170 dBm or 10 zeptowatts ( $10 \times 10^{-21}$  watts). Through implementation of sophisticated data compression techniques, arraying of several Deep Space Network antennas and sensitivity upgrades of receivers used to listen to *Galileo's* signal, data throughput was increased to a maximum of 160 bits per second. The data collected on Jupiter and its moons was stored in the on board tape recorder, and transmitted back to Earth during the long apozyne portion of the probe's orbit using the

low-gain antenna. At the same time, measurements were made of Jupiter's magnetosphere and transmitted back to Earth. The reduction in available bandwidth reduced the total amount of data transmitted throughout the mission to about 30 gigabytes and reduced the number of pictures that were transmitted significantly; in all, only around 14,000 images were returned.

### **Tape recorder anomalies and remote repair**

Since *Galileo's* high-gain antenna failed to open in 1991 the mission was forced to use the low-gain antenna for all communication to Earth. This meant that data storage to *Galileo's* tape recorder for later compression and playback was absolutely crucial in order to obtain any substantial information from the planned Jupiter and moon flybys. In October 1995, *Galileo's* 114 megabyte (914,489,344 bits), four-track digital tape recorder which was manufactured by Odetics Corporation, remained stuck in rewind mode for 15 hours before engineers learned what happened and sent commands to shut it off, after recording an image of Jupiter. Though the recorder itself was still in working order the malfunction possibly damaged a length of tape at the end of the reel. This section of tape was subsequently declared "off limits" to any future data recording and was covered with 25 more turns of tape to secure the section and reduce any further stresses, which could tear it. Because it happened only weeks before Jupiter Orbit Insertion, the anomaly prompted engineers to sacrifice data acquisition of almost all of the Io and Europa observations during Jupiter Orbit Insertion in order to focus solely on recording data sent from the Jupiter probe descent.

In November 2002, after completion of the mission's only encounter of Jupiter's moon Amalthea, problems with playback of the tape recorder would again plague the spacecraft. About 10 minutes after closest approach of the flyby *Galileo* stopped collecting data, shut down all of its instruments, and went into safe mode; apparently as a result of exposure to Jupiter's extremely high radiation environment. Though most of the Amalthea data was already written to tape, it was found that the recorder refused to respond to commands telling it to play back data. Through careful analysis after weeks of troubleshooting of an identical flight spare of the recorder on the ground, it was determined that the cause of the malfunction was a reduction of light output in three infrared Optek OP133 light emitting diodes located in the drive electronics of the recorder's motor encoder wheel. The GaAs LEDs had been particularly sensitive to proton irradiation induced atomic lattice displacement defects, which greatly decreased their effective light output and caused the drive motor's electronics to falsely believe the motor encoder wheel was incorrectly positioned. *Galileo's* flight team then began a series of "annealing" sessions, where current was passed through the LEDs for hours at a time to heat them to a point where some of the crystalline lattice defects would be shifted back into place, thus increasing the LED's light output. After about 100 hours of annealing and playback cycles, the recorder was able to operate for up to an hour at a time. After many subsequent playback and cooling cycles, the complete transmission back to Earth of all recorded Amalthea flyby data was successful.

## **Other radiation related anomalies**

The uniquely harsh radiation environment at Jupiter caused over 20 anomalies in addition to the incidents expanded upon above. Despite exceeding its radiation design limit by at least a factor of three, the spacecraft survived all the anomalies. Several of the science instruments suffered increased noise while within about 700,000 km of Jupiter. The quartz crystal used as the frequency reference for the radio suffered permanent frequency shifts with each Jupiter approach. A spin detector failed and the spacecraft gyro output was biased by the radiation environment. The SSI camera began producing totally white images when the spacecraft was hit by the exceptional 'Bastille Day' coronal mass ejection in 2000 and subsequently on close approaches to Jupiter. The most severe effect was a reset of the computers (a CDS despun bus reset) that occurred when the spacecraft was either close to Jupiter or in the region of space magnetically downstream of the Earth. Work-arounds were found for all of these problems.

## **Near failure of atmospheric probe parachute**

The atmospheric probe deployed its first parachute about one minute later than anticipated, resulting in a small loss of upper atmospheric readings. Through review of records, the problem was later determined to likely be faulty wiring in the parachute control system. The fact that the chute opened at all was attributed to luck.

It is believed today that the accelerometer controlling the parachute's pyrotechnics was installed backwards. The same thing happened to the *Genesis* probe's sample return capsule when it returned to Earth in 2004. In that case, the parachute never opened, and the probe crashed in the desert of Utah.

## ***Galileo's end***

Once its fuel supply was nearly depleted, *Galileo* was intentionally commanded to crash into Jupiter to eliminate any chance of a future impact with Europa that could contaminate the icy moon. At the completion of its 35th and final circuit around the Jovian system, *Galileo* impacted the gas giant in darkness just south of the equator on September 21, 2003, at 18:57 GMT, at a speed of approximately 48.26 kilometers per second (nearly 108,000 mph). In order to crash into Jupiter, *Galileo* was flown by Amalthea on November 5, 2002, during its 34<sup>th</sup> orbit, allowing a measurement of the moon's mass as it passed within  $163.0 \pm 11.7$  kilometres (100 mi) of its surface. *Galileo* then reached its greatest distance from Jupiter for the entire mission, some 26 million kilometers on April 14, 2003, before plunging back into the gas giant, taking a little less than nine months to do so.