Spacecraft Missions to Jupiter

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Chapter- 1

Juno (Spacecraft)

Juno

An artist's concept of *Juno* at Jupiter

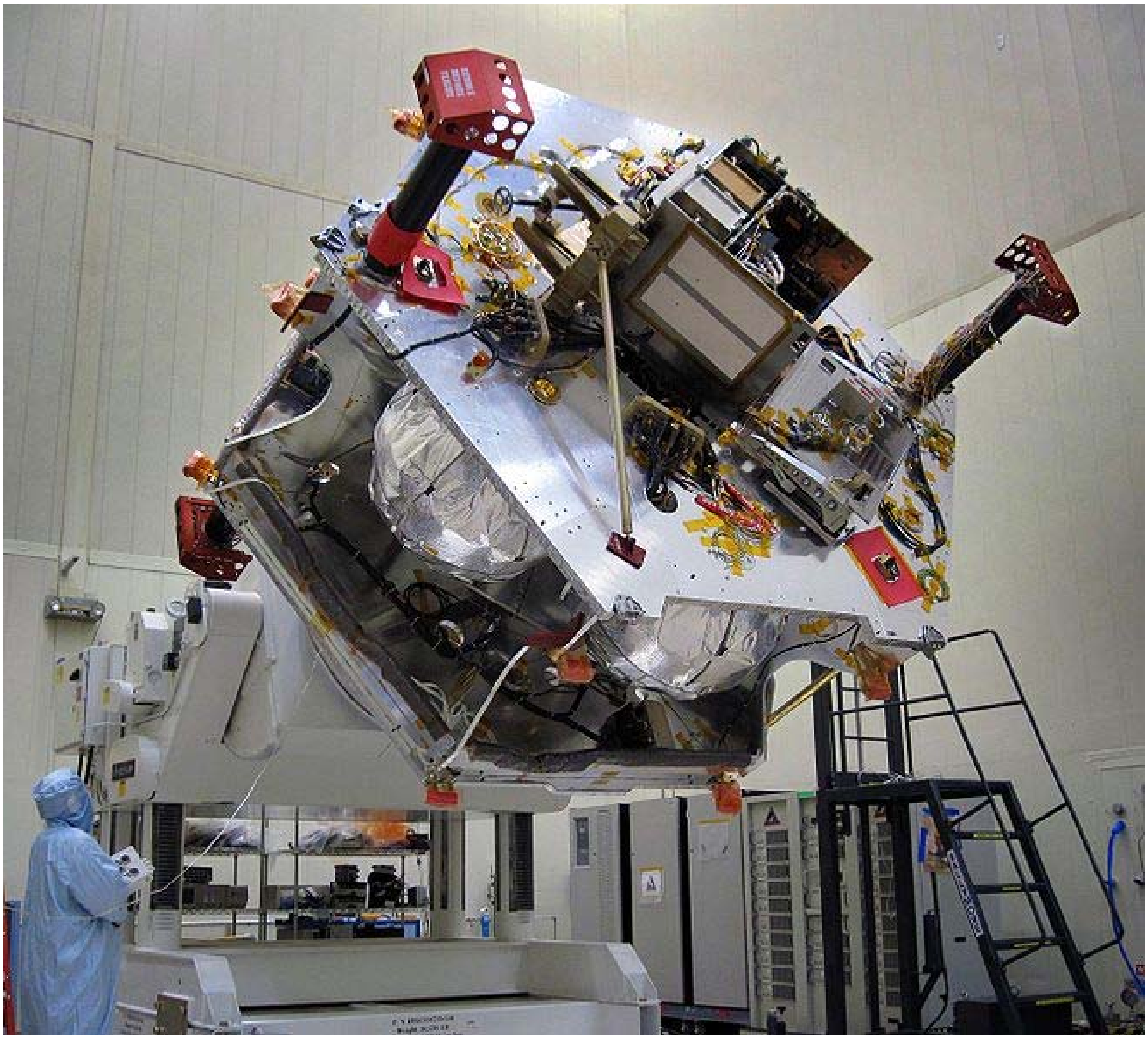
Operator	NASA
Major contractors	Lockheed Martin Corporation
Mission type	Orbiter
Flyby of	Earth
Satellite of	**Jupiter**
Orbital insertion date	2016
Orbits	32
Launch date	August 2011

Launch vehicle	Atlas V 551
Mission duration	1 Earth year
Homepage	Mission home NASA page
Power	Solar power
Orbital elements	
Regime	Polar
Periapsis	4300 km (2671 miles)

Juno is a NASA New Frontiers mission to the planet Jupiter. It was originally proposed at a cost of approximately US$700 million (FY03) for a June 2009 launch. NASA budgetary restrictions resulted in Juno being re-scheduled to an August 2011 launch. The Atlas V rocket has been chosen to launch Juno in the Atlas V-551 configuration.

The spacecraft will be placed in a polar orbit to study the planet's composition, gravity field, magnetic field, and polar magnetosphere. Juno will also search for clues about how Jupiter formed, including whether the planet has a rocky core, the amount of water present within the deep atmosphere, and how the mass is distributed within the planet. Juno will also study Jupiter's deep winds, which can reach speeds of 600 km/h.

Mission summary



Juno during construction phase, mounted on a rotating fixture

Juno's trajectory will use a gravity assist speed boost from Earth, accomplished through an Earth flyby two years after its 2011 launch, scheduled for 5 August. In 2016, the spacecraft will perform an orbit insertion burn to slow the spacecraft enough to allow capture into an 11-day polar orbit. Once Juno enters into its orbit, infrared and microwave instruments will begin to measure the thermal radiation emanating from deep within Jupiter's atmosphere. These observations will complement previous studies of the planet's composition by assessing the abundance and distribution of water, and therefore oxygen. While filling missing pieces of the puzzle of Jupiter's composition, this data also provides insight into the planet's origins. Juno will also investigate the convection that drives general circulation patterns in Jupiter's atmosphere. Meanwhile, other instruments aboard Juno will gather data about the planet's gravitational field and polar magnetosphere.

The Juno mission will conclude in 2018, after 32 orbits around Jupiter. Data analysis may continue beyond 2018.

Scientific objectives

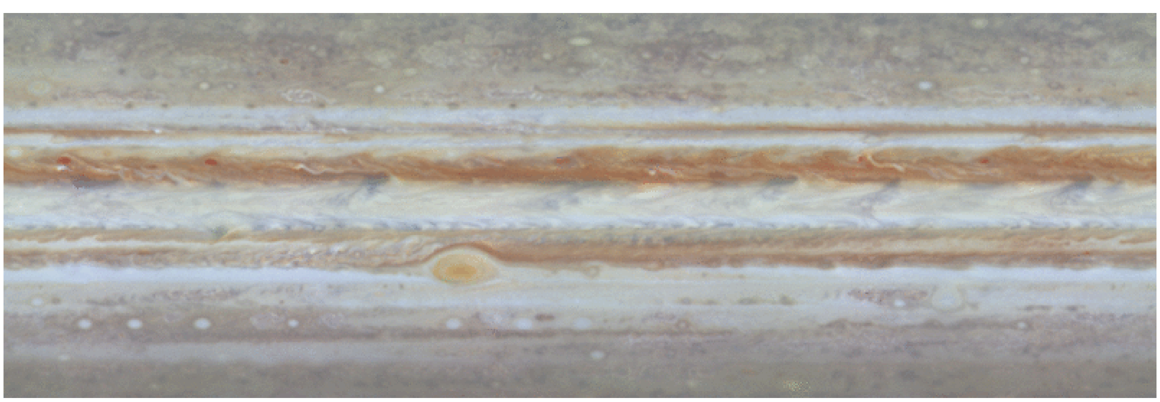
The Juno spacecraft's suite of seven science instruments will determine:

- The ratio of oxygen to hydrogen, effectively measuring the abundance of water in Jupiter, which will help distinguish among prevailing theories linking the gas giant's formation to the solar system.
- Obtain a better estimate of Jupiter's core mass, which will also help distinguish among prevailing theories linking the gas giant's formation to the solar system.
- Precisely map Jupiter's gravity to assess the distribution of mass in Jupiter's interior, including properties of the planet's structure and dynamics.
- Precisely map Jupiter's magnetic field to assess the origin and structure of the field and how deep in Jupiter the magnetic field is created. This experiment also will help scientists understand the fundamental physics of dynamo theory.
- Map the variation in atmospheric composition, temperature, structure, cloud opacity and dynamics to depths far greater than 100 bars at all latitudes.
- Characterize and explore the three dimensional structure of Jupiter's polar magnetosphere and its auroras.

The team

Scott Bolton of the Southwest Research Institute in San Antonio, Texas is the Principal Investigator and is responsible for all aspects of the mission. The Jet Propulsion Laboratory in California manages the mission and Lockheed Martin Corporation is responsible for the spacecraft development. The mission is being carried out with the participation of several institutional partners.

Scientific instruments



Zones, belts and vortices on Jupiter.

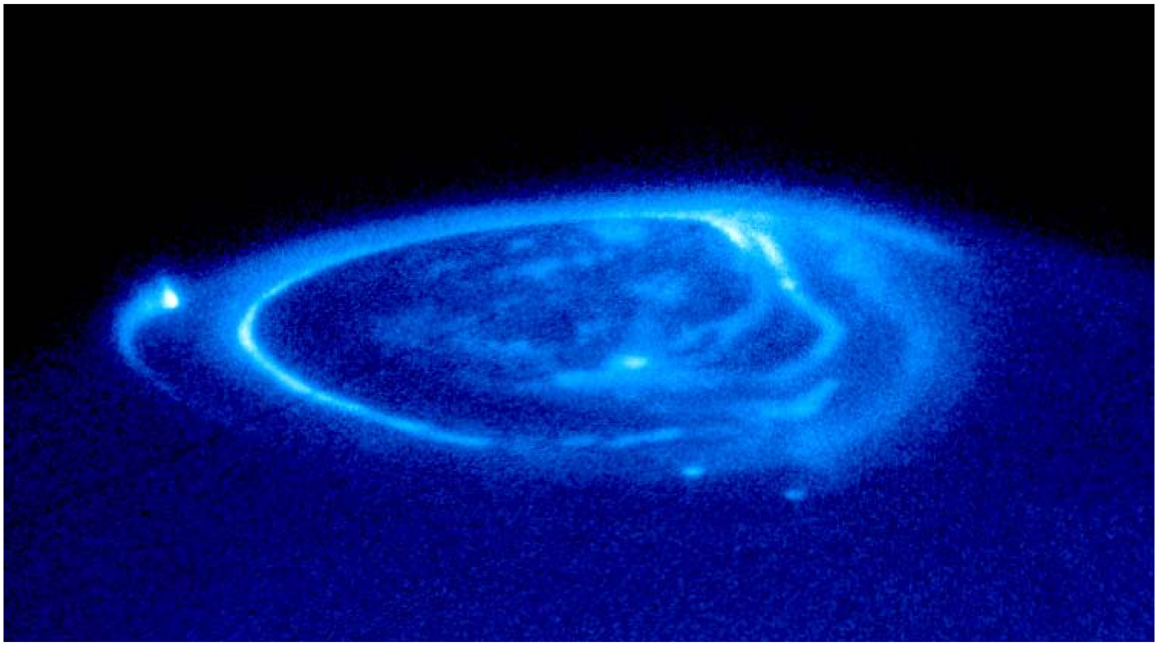


Image of Jupiter aurora in UV by the Hubble Space Telescope. Bright streaks and dots are caused by magnetic flux tubes connecting Jupiter to its largest moons: Io: bright streak on the far left . Ganymede: bright dot below center, Europa: dot on the right.

The Juno mission's science objectives will be achieved with a payload of eight instruments onboard the spacecraft:,

- Microwave radiometer (MWR)

  Jet Propulsion Laboratory, PI: Mike Janssen

- Jovian Infrared Auroral Mapper (JIRAM)

  Italian National Institute for Astrophysics

- Fluxgate Magnetometer (FGM) and Advanced Stellar Compass (ASC)

  NASA's Goddard Space Flight Center

- Jovian Auroral Distribution Experiment (JADE)

  Southwest Research Institute, PI: David McComas

- Jovian Energetic Particle Detector Instrument (JEDI)

  Applied Physics Laboratory

- Radio and Plasma Wave Sensor (WAVES)

University of Iowa

- Ultraviolet Imaging Spectrograph (UVS)

  Southwest Research Institute, PI: G. Randall Gladstone

- JunoCam (JCM)

  Malin Space Science Systems

Solar panels

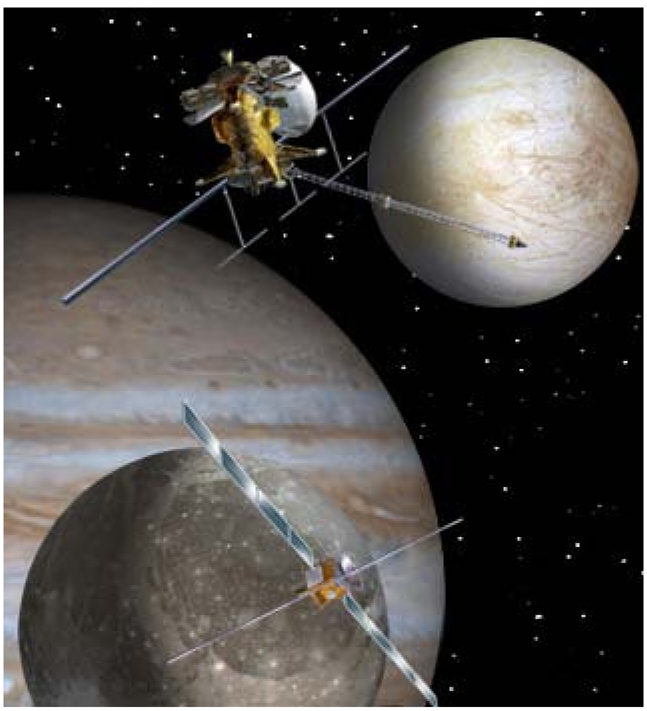
Juno will be the first mission to Jupiter using solar panels instead of the radioisotope thermoelectric generators (RTGs) used by Pioneer 10, Pioneer 11, the Voyager program, Cassini–Huygens, and the Galileo orbiter. Advances made in both solar cell technology and efficiency over the past several decades makes it economically feasible to use solar panels of practical size to provide power 5 Astronomical units from the Sun. In addition, RTGs are in short supply, limiting their availability for space missions. NASA plans several more projects involving RTGs, and the decision to use alternate technology on this mission is more practical and economical than political.

The Juno spacecraft uses three solar arrays symmetrically arranged around the spacecraft, which are stowed against the sides of the spacecraft for launch. Immediately after launch the arrays deploy. Two of the arrays have 4 panels each, and the third array has 3 panels with a magnetometer experiment in place of the fourth panel. The total area of the arrays is over 60 square metres (650 sq ft). This is enough to produce about 15 kilowatts (20 hp) while in Earth orbit, but only 486 watts (0.652 hp) when Juno arrives at Jupiter, declining to 420 watts (0.56 hp) as the radiation degrades the cells. The solar panels will remain in sunlight continuously from launch through to the end of the mission, except for short periods during the operation of the main engine.

Chapter- 2

Europa Jupiter System Mission

Europa Jupiter System Mission



Artist concept of the Europa Jupiter System Mission: Jupiter Europa Orbiter (top) and Jupiter Ganymede Orbiter (bottom)

Operator	Proposed joint ESA/NASA
Mission type	Multiple orbiters and lander
Launch date	2020 (if funded)
Mission duration	Undefined

The **Europa Jupiter System Mission** (**EJSM**, ESA-working title: **Laplace**) is a proposed joint NASA/ESA unmanned space mission slated to launch around 2020 for the in-depth exploration of Jupiter's moons with a focus on Europa, Ganymede and Jupiter's magnetosphere. In February 2009 it was announced that NASA/ESA had given this mission priority ahead of the Titan Saturn System Mission (TSSM). The ESA contribution still faces funding competition from two other missions, the Laser Interferometer Space Antenna (LISA) and the International X-ray Observatory (IXO). In 2013 ESA will choose only one of these three missions for further funding, which is why NASA keeps a contingency plan of sending its part of the mission as a stand-alone project.

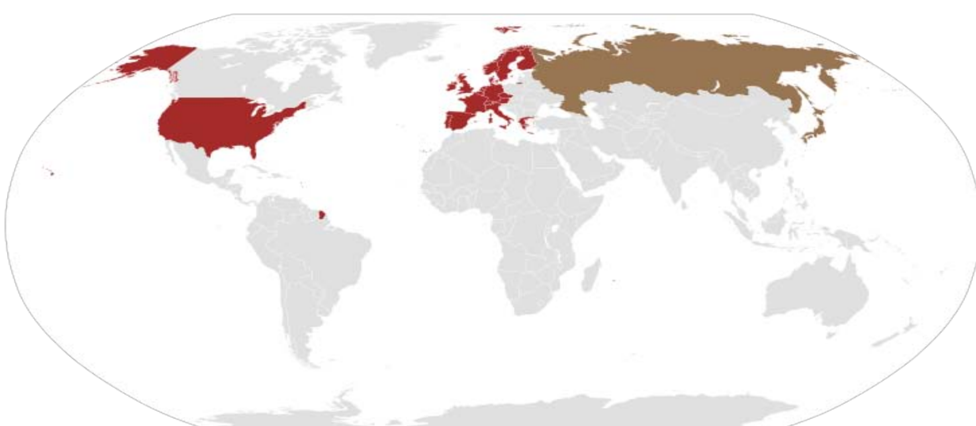
The Japan Aerospace Exploration Agency (JAXA) and the Russian Federal Space Agency (Roscosmos) have expressed their interest in contributing, although no deals have been finalized. Like the TSSM, the EJSM (considering an orbiter-only scenario and without a participation by Japan or Russia) is estimated to cost $4.45 billion, of which NASA contributes $3.8 billion (85%) and ESA $650 million (15%).

Origins

In February 2008, NASA and ESA began joint investigations into sending a probe to study the icy satellites of the outer solar system under the title Outer Planet Flagship Mission. Two primary candidate missions were considered under the study: EJSM and TSSM, also known under the ESA designation TandEM.

On February 18, 2009 NASA and ESA jointly announced that both missions can proceed forward, but the EJSM is to be the first, departing Earth in 2020 and arriving at the Jupiter in 2026. The Titan mission is to be launched at later date.

Mission architecture



A map showing all the nations which are either currently part of (red) or interested in becoming a part of (brown) the EJSM.

The most distinctive feature of the EJSM/Laplace-study, are its proposed two, possibly three, or even four separate orbiters/landers.

- **NASA**: Jupiter Europa Orbiter (JEO), planned to study Europa and Io.
- **ESA**: Jupiter Ganymede Orbiter (JGO), planned to study Ganymede and Callisto
- **JAXA**: Jupiter Magnetospheric Orbiter (JMO), planned to study Jupiter's magnetosphere.
- **Roscosmos**: Europa Lander, planned to land on Europa's surface for *in situ* studies.

The baseline EJSM architecture consists of JEO and JGO, which are proposed to be launched in 2020 and will execute an intricately choreographed exploration of the Jupiter System before settling into orbit around Europa and Ganymede, respectively. The JEO and JGO are separate and independent spacecraft developed, launched and operated by their respective organizations to work together. Their launch dates and interplanetary trajectories are not dependent on each other. While each flight system will focus on two of the four Galilean satellites, by operating together they allow full system coverage including Jupiter, its magnetosphere, and its rings.

Both satellites are to monitor dynamic phenomena such as Io’s volcanoes and Jupiter’s atmosphere, map the Jovian magnetosphere and its interactions with the Galilean satellites, and confirm the hypothesized water oceans beneath the ice shells of Europa and Ganymede. Should Japan (JAXA) join the project, JMO will explore the Jovian magnetosphere *in situ* as a template for an astrophysical magnetised disk and affording the opportunity for "3-point" investigations of the Jupiter system via synergistic observations with JGO and JEO.

Objective

The objective is to determine whether the Jupiter system harbors habitable environments. The fundamental theme for EJSM can be further focused into science objectives relating to habitability (focusing on Europa and Ganymede). The main science objectives supporting this goal are:

- Characterize sub-surface oceans
- Characterize the ice shells and any subsurface water
- Characterize the deep internal structure for Ganymede and the intrinsic magnetic field
- Compare the exospheres, plasma environments, and magnetospheric interactions.
- Determine global surface compositions and chemistry
- Understand the formation of surface features, including sites of recent or current activity, and identify and characterize candidate sites for future *in situ* exploration.

Possible addition of a Russian Europa lander

The Russian Federal Space Agency (Roscosmos) and the Russian Academy of Sciences are considering an independent Russian segment of the mission with the objective of delivering a lander to Europa, called Europa Lander. It would be separately launched by a Soyuz-class launcher relying on the ESA and/or NASA-orbiters to relay its data to Earth. A broad international involvement in the science payload and exploration tools of the descent module is envisaged. Depending on the available resources, a combination of a grinder on a robotic arm, or even a drill/thermal penetration system is envisaged in order to determine the characteristics of Europa's surface ice. Other landing scenarios suggest the use of high-velocity impactors which penetrate through the irradiated surface material to reach pristine ice. Once impacted, the probe can release a melting system to explore the shallow subsurface of Europa.

Chapter- 3

Galileo (Spacecraft)

***Galileo* Orbiter**

Galileo is prepared for mating with the IUS booster

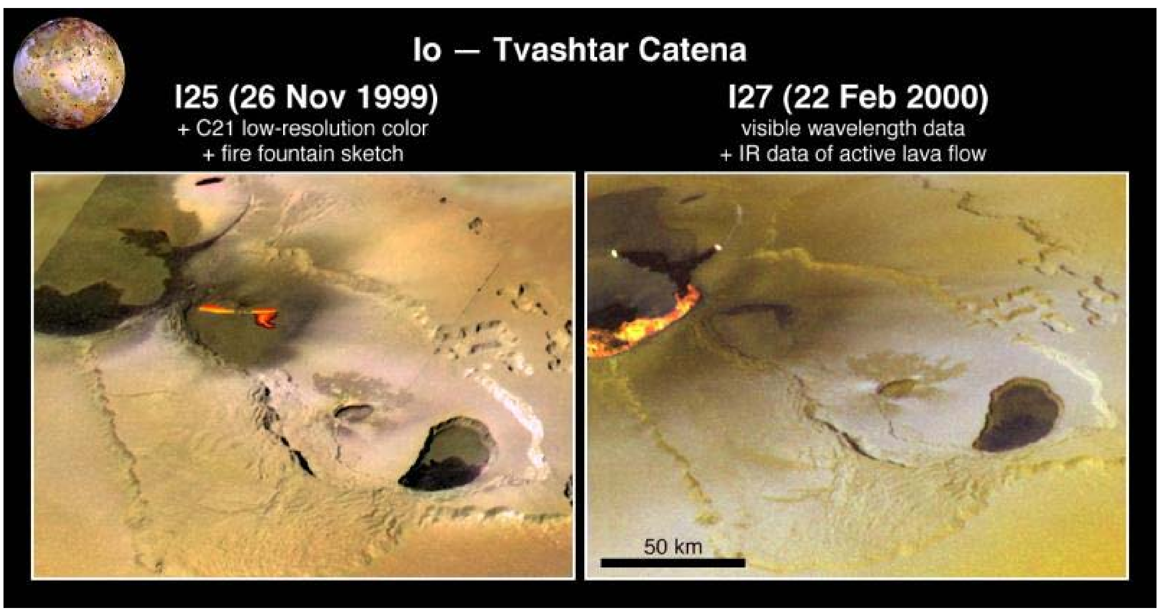
Operator	NASA
Mission type	Orbiter, Fly-by
Flyby of	Venus, Earth, 951 Gaspra, 243 Ida
Satellite of	**Jupiter**
Orbital insertion date	1995-12-08 01:20:00 UTC
Launch date	1989-10-18 16:53:00 UTC
Launch vehicle	Space Shuttle Atlantis Inertial Upper Stage
Launch site	KSC Launch Complex 39B Kennedy Space Center
Mission duration	December 8, 1995 - September 21, 2003 (deorbited 2003-09-21 18:57:00

	UTC)
COSPAR ID	1989-084B
Homepage	*Galileo* Project Home Page
Mass	2,380 kg (5,200 lb)
Power	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-crusted 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.

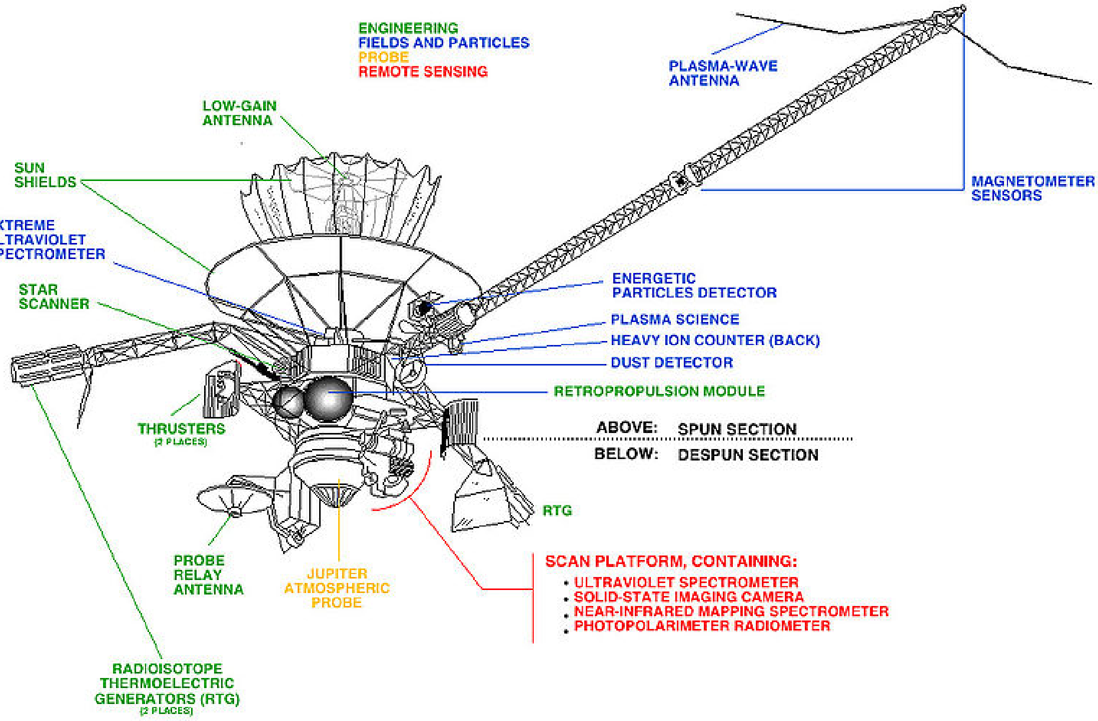
Propulsion

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^2) 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 ^{238}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

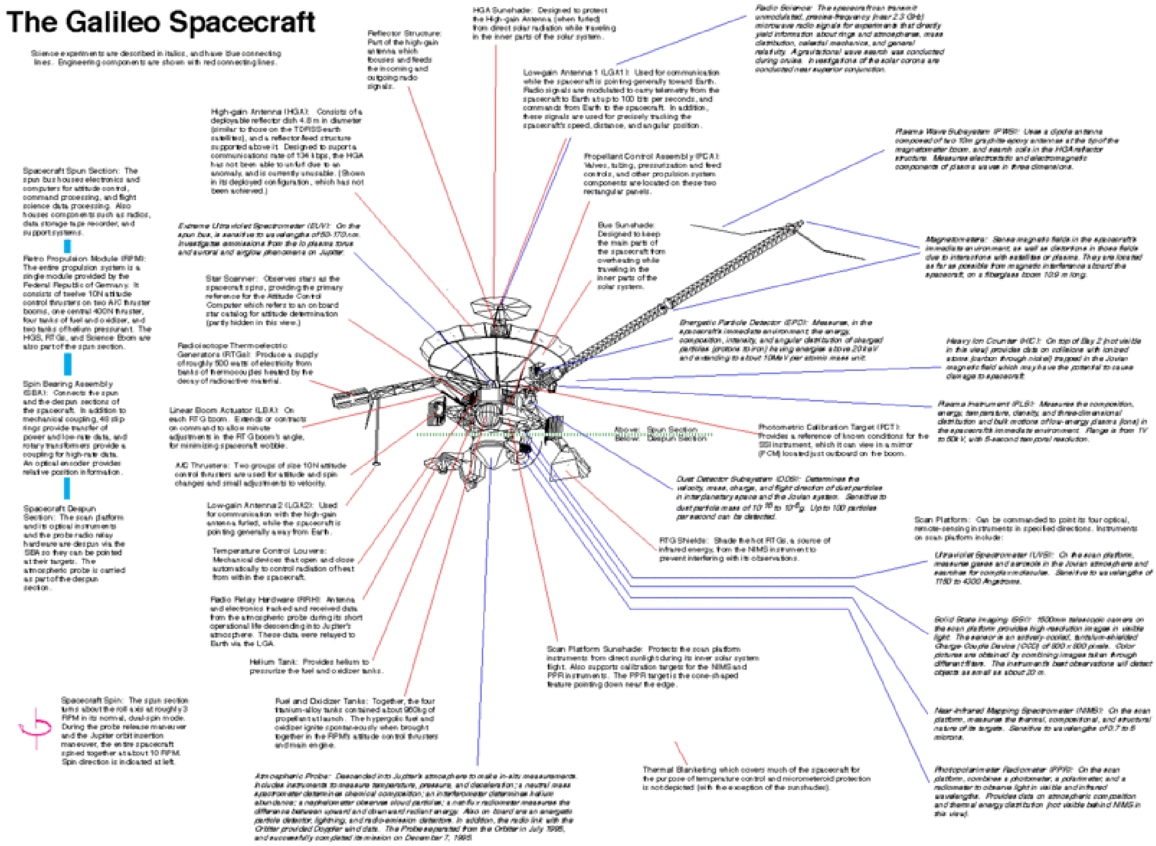
Scientific instruments to measure fields and particles were mounted on the spinning section of the spacecraft, together with the main antenna, power supply, the propulsion module and most of the *Galileo* computers and control electronics. The sixteen instruments, weighing 118 kg altogether, included 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



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). Galileo was one of the first spacecraft to be equipped with CCD camera. 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.

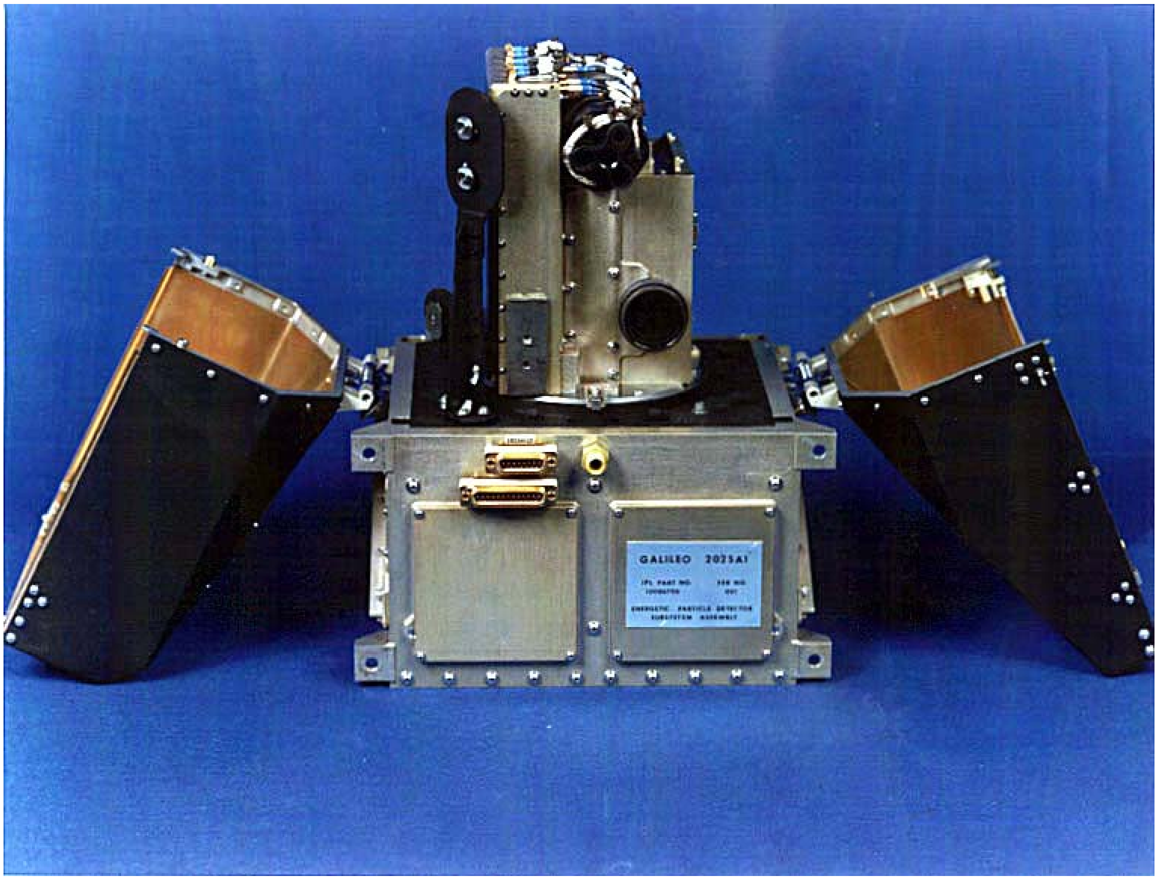
Ultraviolet Spectrometer / Extreme Ultraviolet Spectrometer (UVS/EUV)

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.

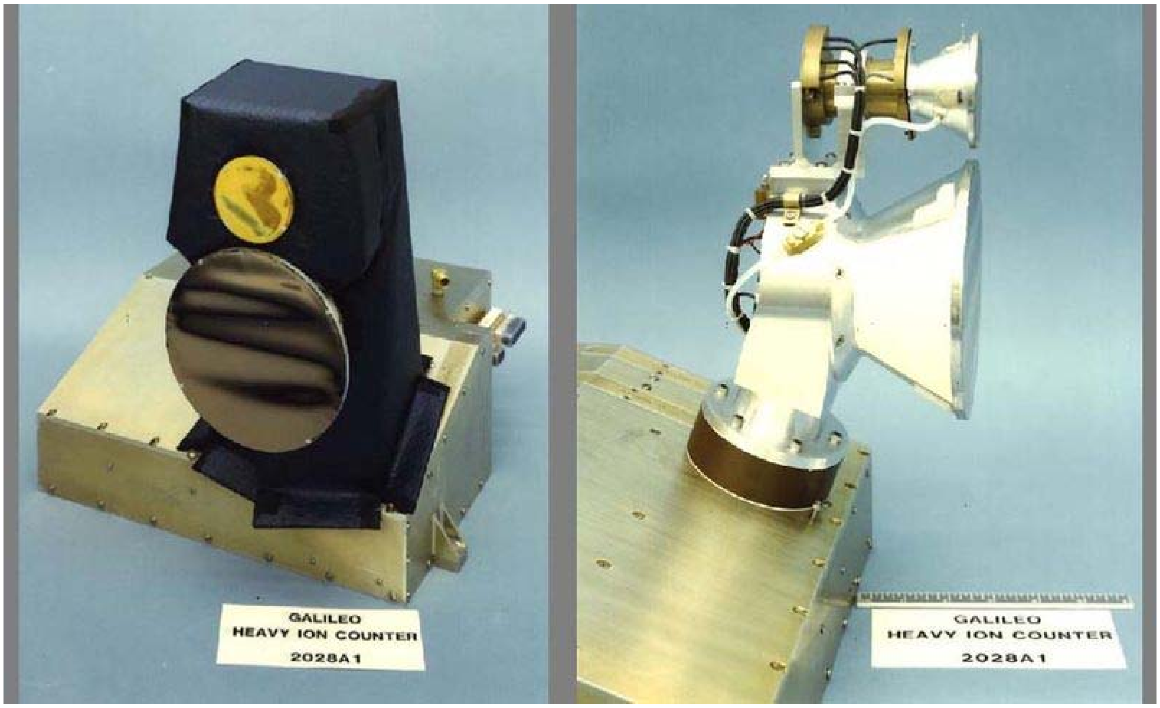
Photopolarimeter-Radiometer (PPR)

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

Plasma Subsystem (PLS)

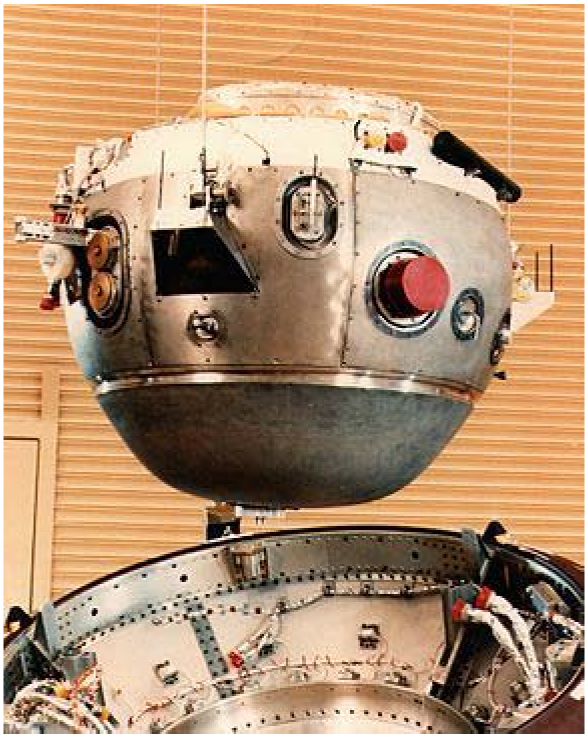
The PLS uses seven fields of view to collect charged particles for energy and mass analysis. These fields of view cover most angles from 0 to 180 degrees, fanning out from the spin axis. The rotation of the spacecraft carries each field of view through a full circle. The PLS will measure particles in 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



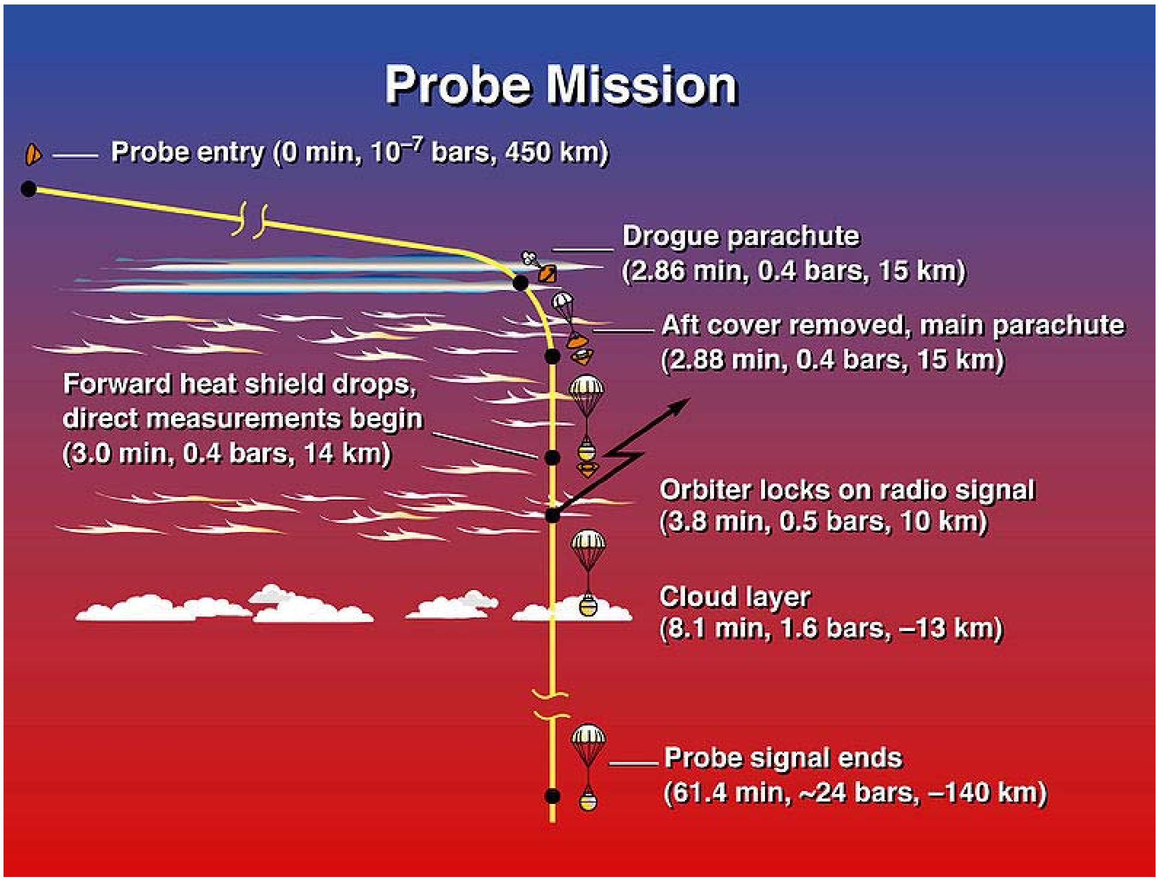
The *Galileo* Probe Descent Module

Operator	NASA
Mission type	Atmospheric probe
Launch date	July 13, 1995
Launch vehicle	Space Shuttle Atlantis Inertial Upper Stage Galileo Orbiter
Launch site	KSC Launch Complex 39B Kennedy Space Center
Mission duration	December 7, 1995 (57.6 minutes)
COSPAR ID	1989-084E
Homepage	*Galileo* Project Home Page
Mass	339 kg (750 lb)

Power	580 W ($LiSO_2$ battery)

Orbital elements

Eccentricity	1.03116
Inclination	8.151°
Periapsis	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 ($LiSO_2$) batteries that provided a nominal power output of about 580 watts with an estimated capacity of about 21 ampere-hours on arrival at Jupiter.

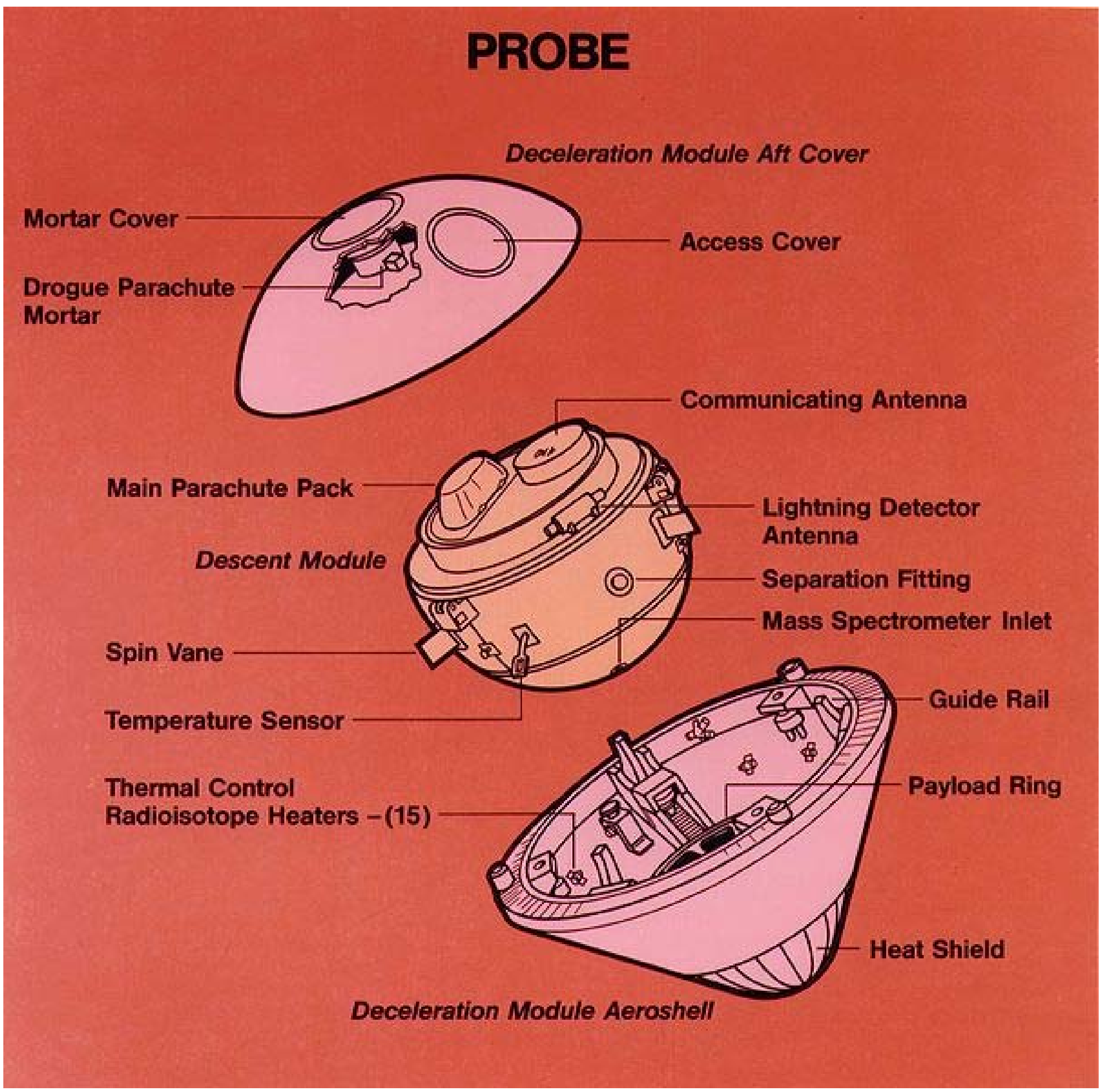


Diagram of *Galileo* atmospheric entry probe instruments and subsystems.

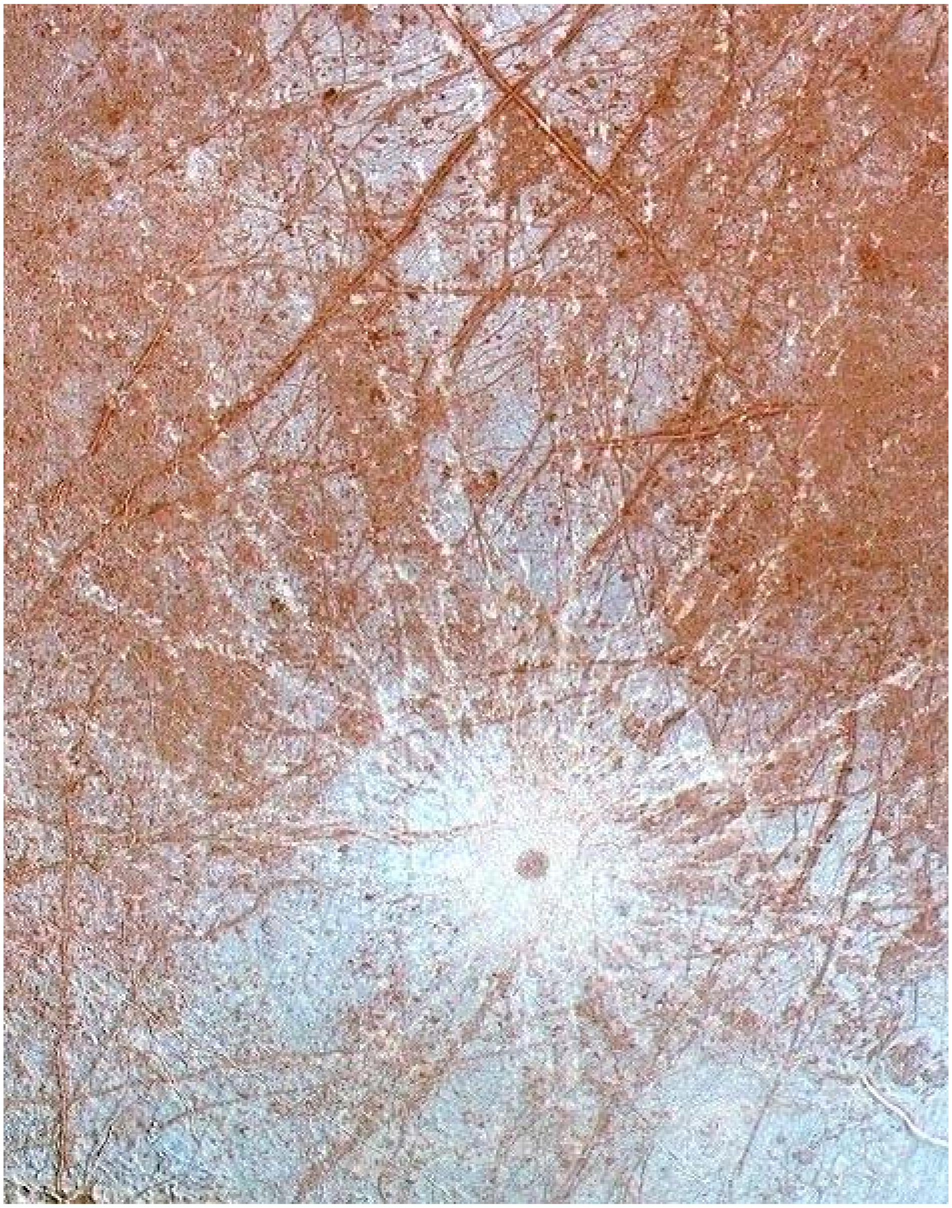
The probe included six instruments for taking data on its plunge into Jupiter:

- 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.

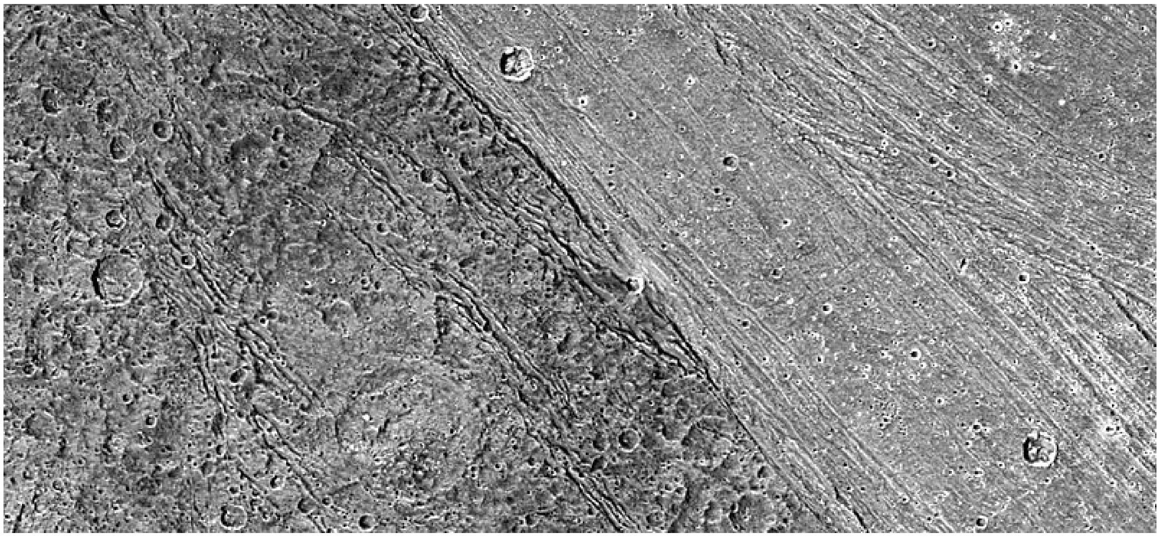
Total data returned from the probe was about 3.5 megabits (~458752 bytes). The probe stopped transmitting before the line of sight link with the orbiter was cut. The likely proximal cause of the final probe failure was overheating, which sensors indicated before signal loss.

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



Pwyll crater on Europa



Terrain on Ganymede

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 ~1 micromole per mole (μmol/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 ~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 (~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.

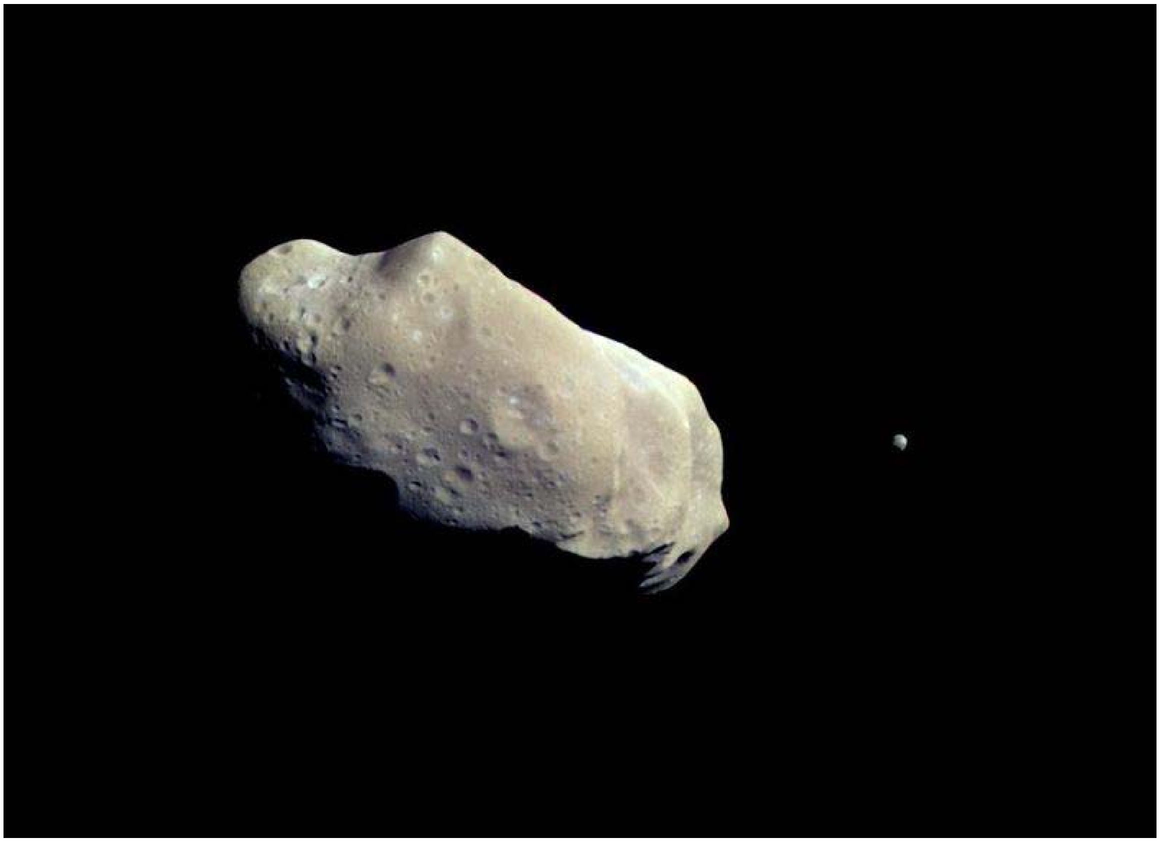
Asteroid encounters

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

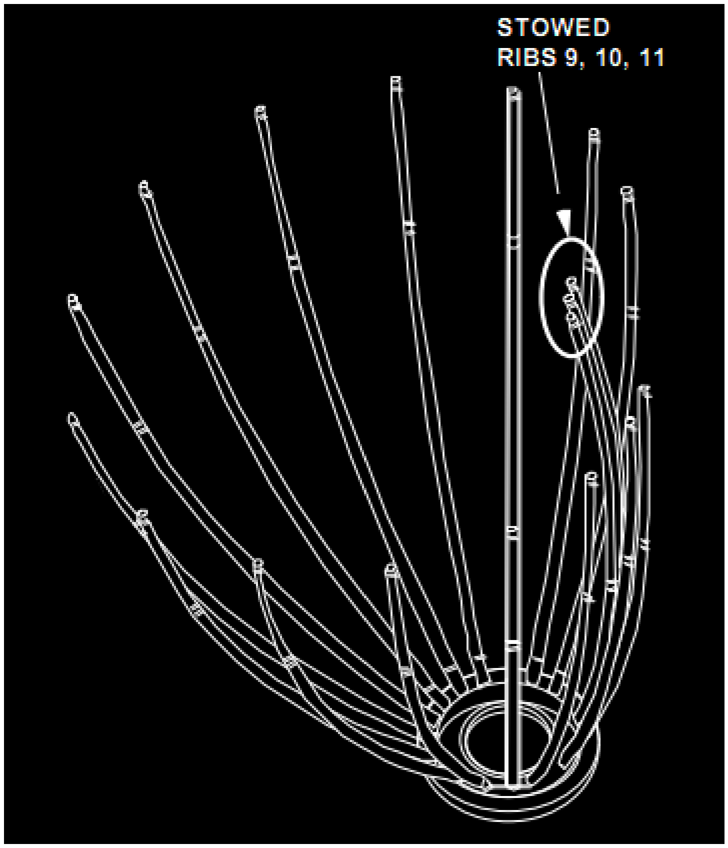


NASA image of 243 Ida. The tiny dot to the right is its moon, Dactyl.

Twenty-two months after the Gaspra 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.

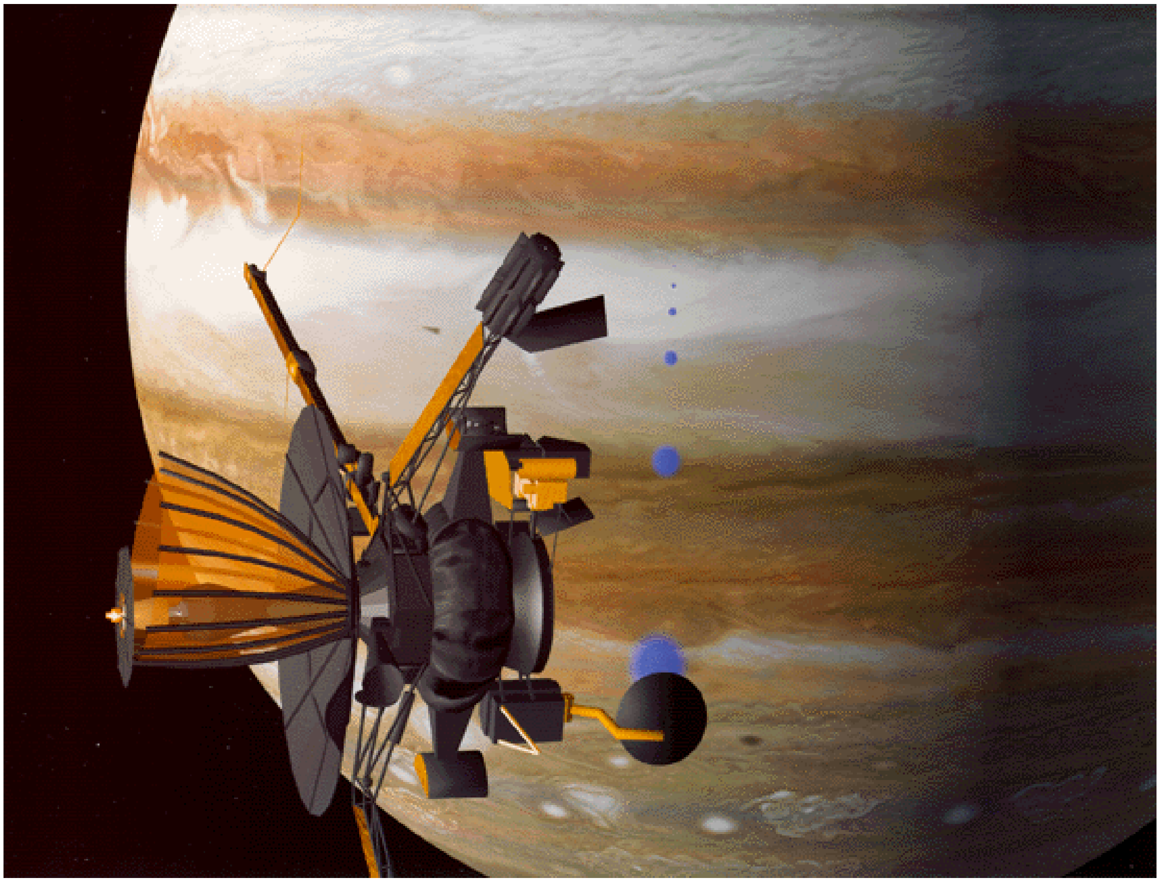
Spacecraft malfunctions

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 (10×10^{-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 apozene 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.

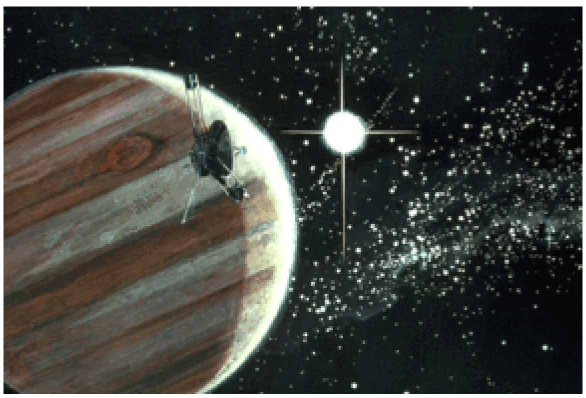
Galileo's end

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 34th orbit, allowing a measurement of the moon's mass as it passed within 163.0 ± 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.

Chapter- 4

Pioneer 10

Pioneer 10



An artist's concept of the Pioneer 10 Jupiter encounter

Operator	ARC / NASA
Major contractors	TRW
Mission type	Flyby
Flyby of	Jupiter
Launch date	1972-03-02 01:49:00 UTC (38 years, 11 months, and 21 days ago)
Launch vehicle	Atlas/Centaur/TE364-4
Launch site	Space Launch Complex 36A Cape Canaveral Air Force Station
Mission duration	Mar 2, 1972 - Jan 23, 2003 (30 years, 10 months, 22 days) (lost communication) Jupiter flyby *(completed 1974-01-01)*

	Interstellar mission *(completed 1997-03-31)*
COSPAR ID	1972-012A
Homepage	Pioneer Project website(archived) NASA Archive page
Mass	258 kg (569 lb)
Power	165.0 W (4 SNAP-19 RTGs)

Pioneer 10 (also known as *Pioneer F*) was a 258-kilogram robotic space probe launched by NASA on March 2, 1972 to study the asteroid belt, the environment around Jupiter, solar wind, cosmic rays, and eventually the far reaches of the solar system and heliosphere. It was the first spacecraft to traverse the asteroid belt and the first to encounter Jupiter. Due to power constraints and the vast distance of the probe, communication has been lost since January 23, 2003.

Mission background

History

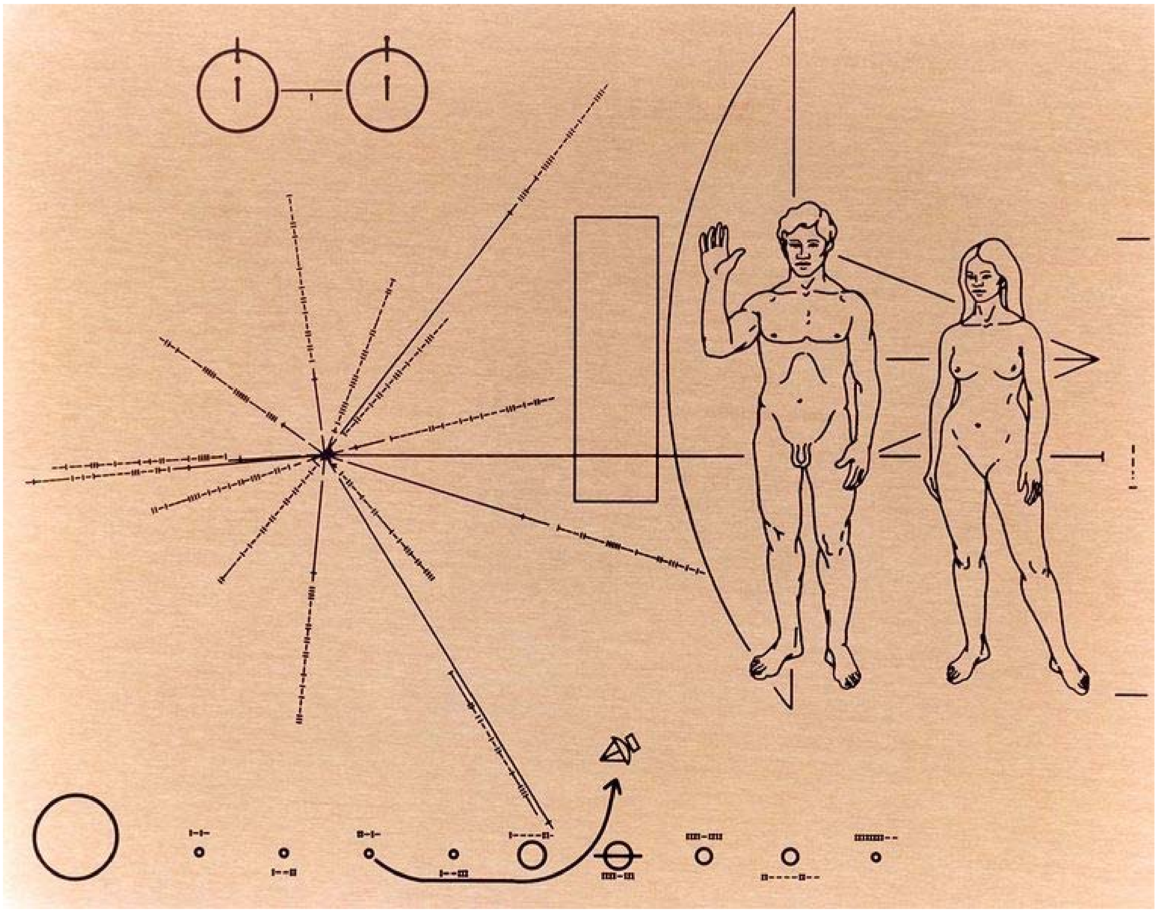
Approved in February 1969, *Pioneer 10* and twin probe *Pioneer 11*, were the first to be designed for exploring the outer solar system. Yielding to multiple proposals throughout the 1960s, early mission objectives were defined as:

- Explore the interplanetary medium beyond the orbit of Mars
- Investigate the nature of the asteroid belt from the scientific standpoint and assess the belt's possible hazard to missions to the outer planets.
- Explore the environment of Jupiter.

Later development-stage objectives also included the probe closely approaching Jupiter to provide data on the effect the environmental radiation surrounding Jupiter would have to the instruments on the spacecraft.

Pioneer 10 was built by TRW and managed as part of the Pioneer program by NASA Ames Research Center. A backup unit, Pioneer H, is currently on display in the "Milestones of Flight" exhibit at the National Air and Space Museum in Washington, D.C.. Many elements of the mission proved to be critical in the planning of the Voyager Program.

Pioneer plaque

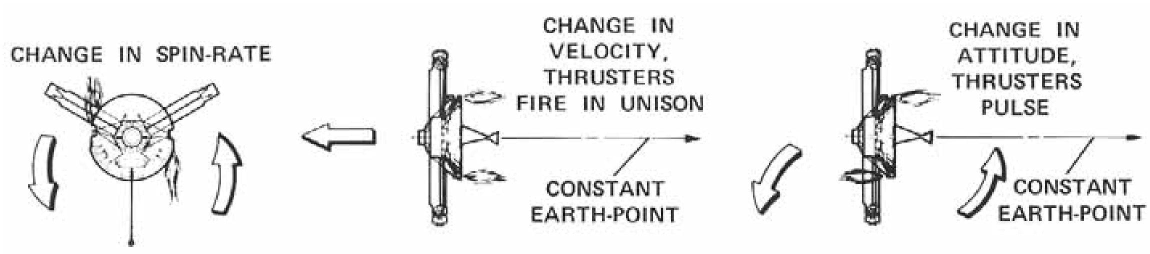


Pioneer 10 and Pioneer 11 carry a gold-anodized aluminium plaque in the event that either spacecraft is ever found by intelligent life-forms from other planetary systems. The plaques feature the nude figures of a human male and female along with several symbols that are designed to provide information about the origin of the spacecraft.

Spacecraft design

The *Pioneer 10* bus measures 36-centimeters deep and with six 76-centimeters long panels forming the hexagonal structure. The bus houses propellant to control the orientation of the probe and eight of the eleven scientific instruments. The spacecraft had a mass of 260-kilograms.

Attitude control and propulsion

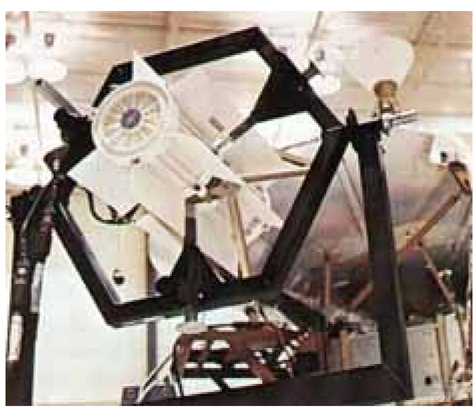


Orientation of the spacecraft was maintained with six 4.5 N, hydrazine monopropellant thrusters: pair one maintained a constant spin-rate of 4.8-rpm, pair two controlled the forward thrust, pair three controlled attitude. Information for the orientation was provided by a star sensor able to reference Canopus, and two sun sensors.

Communications

The space probe included a redundant system of transceivers, one attached to the high-gain antenna, the other to an omni-antenna and medium-gain antenna. Each transceiver is 8 watts and transmits data across the S-band using 2110 MHz for the uplink from Earth and 2292 MHz for the downlink to Earth with the Deep Space Network tracking the signal. Prior to transmitting data, used a convolutional encoder, a form of error correction, to avoid sending corrupted data.

Power



Pioneer 10 used 4 SNAP-19 radioisotope thermoelectric generators (RTG) (***see diagram***). They were positioned on 2 three-rod trusses, each 3 meters (10 feet) in length and 120 degrees apart. This was expected to be a safe distance from the sensitive scientific experiments carried on board. Combined, the RTGs provided 155 watts at launch, and decayed to 140w in transit to Jupiter. The spacecraft required 100w to power all systems.

Computer

Much of the computation for the mission was performed on Earth and transmitted to the probe, where it was able to retain in memory, up to five commands of the 222 possible entries by ground controllers. The spacecraft included two command decoders and a command distribution unit, a very limited form of processor, to direct operations on the spacecraft. This system required that mission operators prepare commands long in advance of transmitting them to the probe. A data storage unit was included to record up to 6,144-bytes of information gathered by the instruments. The digital telemetry unit would then be used to prepare the collected data in one of the thirteen possible formats before transmitting it back to Earth.

Scientific instruments

Helium Vector Magnetometer (**HVM**)

Measures the fine structure of the interplanetary magnetic field, maps the Jovian magnetic field, and provides magnetic field measurements to evaluate solar wind interaction with Jupiter.

- **Principal investigator:** Edward Smith / JPL
- **Data:** PDS/PPI data catalog, NSSDC data archive

Quadrispherical Plasma Analyzer

Peers through a hole in the large dish-shaped antenna to detect particles of the solar wind originating from the Sun.

- **Principal investigator:** Aaron Barnes / NASA Ames Research Center (archived website)
- **Data:** PDS/PPI data catalog, NSSDC data archive

Charged Particle Instrument (**CPI**)

Detects cosmic rays in the Solar System.

- **Principal investigator:** John Simpson / University of Chicago
- **Data:** NSSDC data archive

Cosmic Ray Telescope (**CRT**)

Collects data on the composition of the cosmic ray particles and their energy ranges.

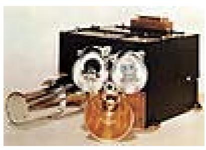
- **Principal investigator:** Frank McDonald / NASA Goddard Space Flight Center
- **Data:** PDS/PPI data catalog, NSSDC data archive

Geiger Tube Telescope (**GTT**)

Surveys the intensities, energy spectra, and angular distributions of electrons and protons along the spacecraft's path through the radiation belts of Jupiter.

- **Principal investigator:** James Van Allen / University of Iowa (website)
- **Data:** PDS/PPI data catalog, NSSDC data archive

Trapped Radiation Detector (**TRD**)



Includes an *unfocused Cerenkov counter* that detects the light emitted in a particular direction as particles pass through it recording electrons of energy, 0.5 to 12 MeV, an *electron scatter detector* for electrons of energy, 100 to 400 keV, and a *minimum ionizing detector* consisting of a solid-state diode that measures minimum ionizing particles (<3 MeV) and protons in the range of 50 to 350 MeV.

- **Principal investigator:** R. Fillius / University of California San Diego
- **Data:** NSSDC data archive

Meteoroid Detectors

Twelve panels of pressurized cell detectors mounted on the back of the main dish antenna record penetrating impacts of small meteoroids.

- **Principal investigator:** William Kinard / NASA Langley Research Center
- **Data:** NSSDC data archive list

Asteroid/Meteoroid Detector (**AMD**)

Meteoroid-asteroid detector looks into space with four non-imaging telescopes to track particles ranging from close-by bits of dust to distant large asteroids.

- **Principal investigator:** Robert Soberman / General Electric Company
- **Data:** NSSDC data archive

Ultraviolet Photometer

Ultraviolet light is sensed to determine the quantities of hydrogen and helium in space and on Jupiter.

- **Principal investigator:** Darrell Judge / University of Southern California
- **Data:** PDS/PPI data catalog, NSSDC data archive

Imaging Photopolarimeter (**IPP**)

The imaging experiment relies upon the spin of the spacecraft to sweep a small telescope across the planet in narrow strips only 0.03 degrees wide, looking at the planet in red and blue light. These strips were then processed to build up a visual image of the planet.

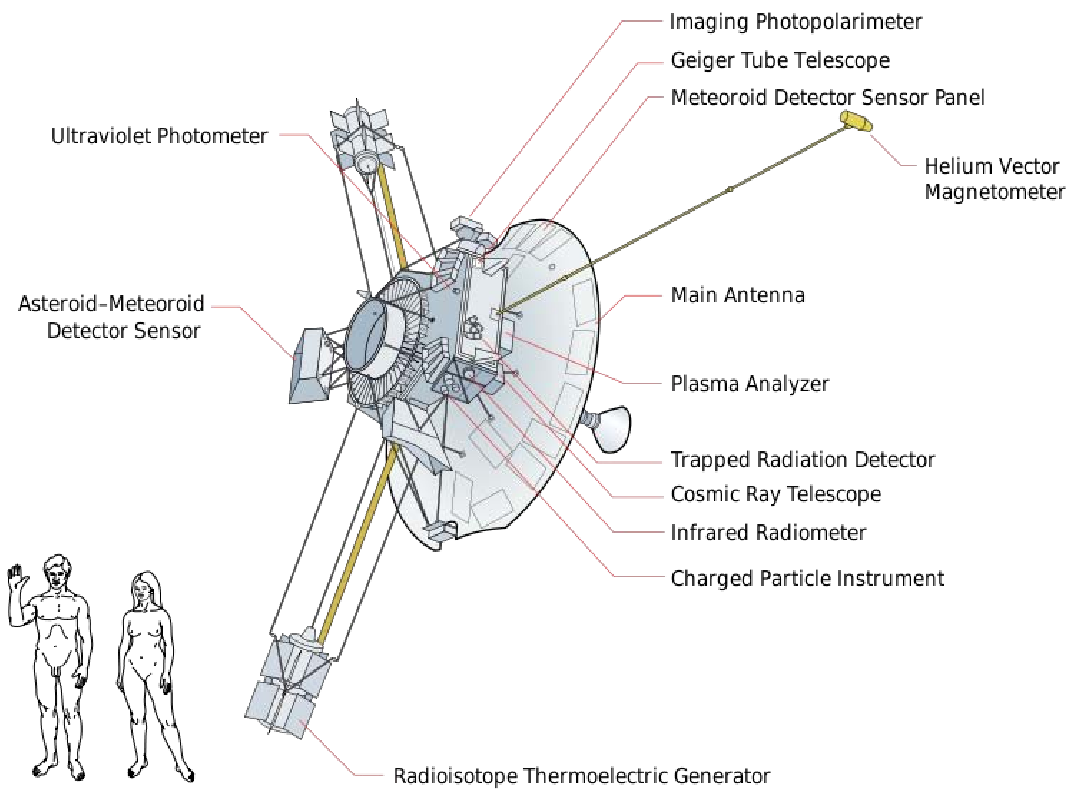
- **Principal investigator:** Tom Gehrels / University of Arizona
- **Data:** NSSDC data archive list

Infrared Radiometer

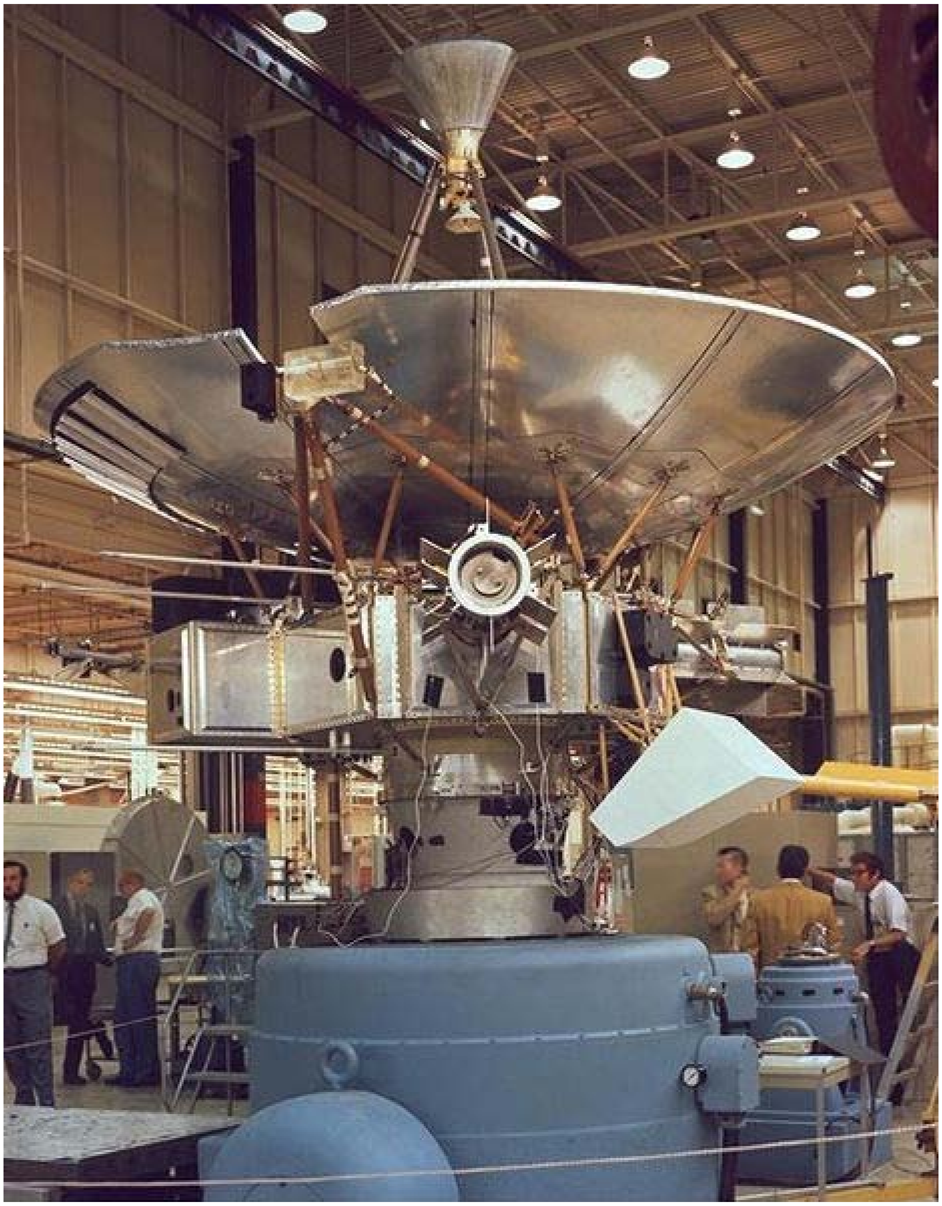
Provides information on cloud temperature and the output of heat from Jupiter.

- **Principal investigator:** Andrew Ingersoll / California Institute of Technology

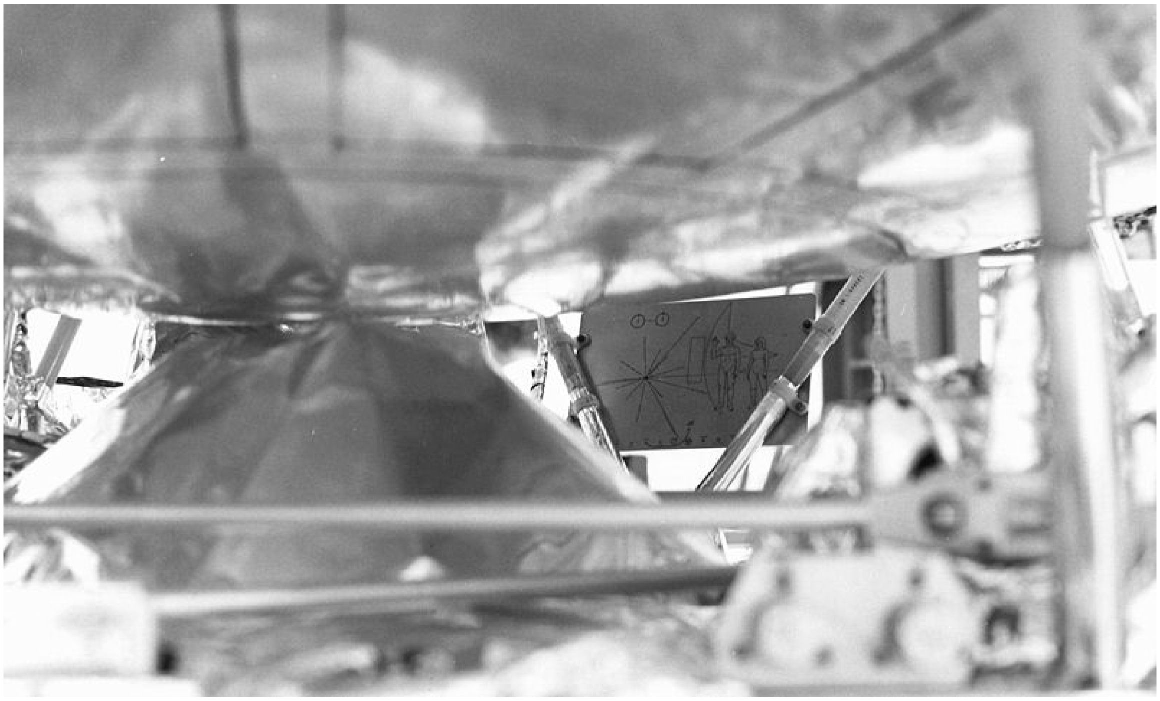
Images of the spacecraft



Pioneer 10 and Pioneer 11 spacecraft diagram.



Pioneer 10 in the final stages of construction.



The Pioneer plaque fixed to the space probe.

Pioneer 10 on a kick motor just prior to be encapsulated for launch.

Mission profile

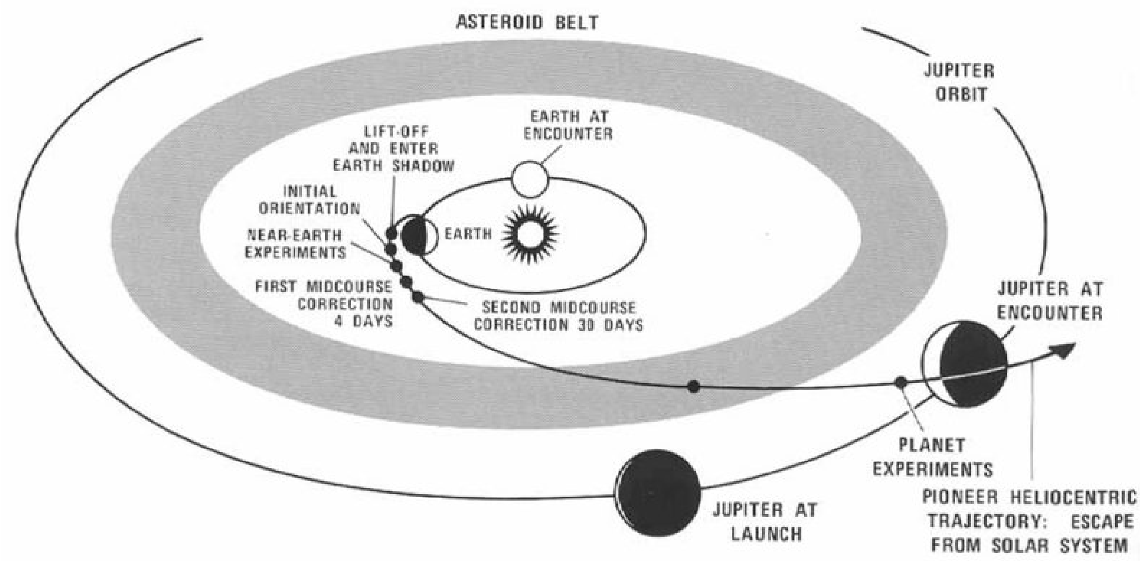
Timeline of travel

Date	Event
1972-03-03	Spacecraft launched
1972-06-	Crossed orbit of Mars.
1972-07-15	Entered the asteroid belt.
1972-07-15	Start Jupiter observation phase. **Time** **Event**
1974-01-01	Begin Pioneer Interstellar Mission.

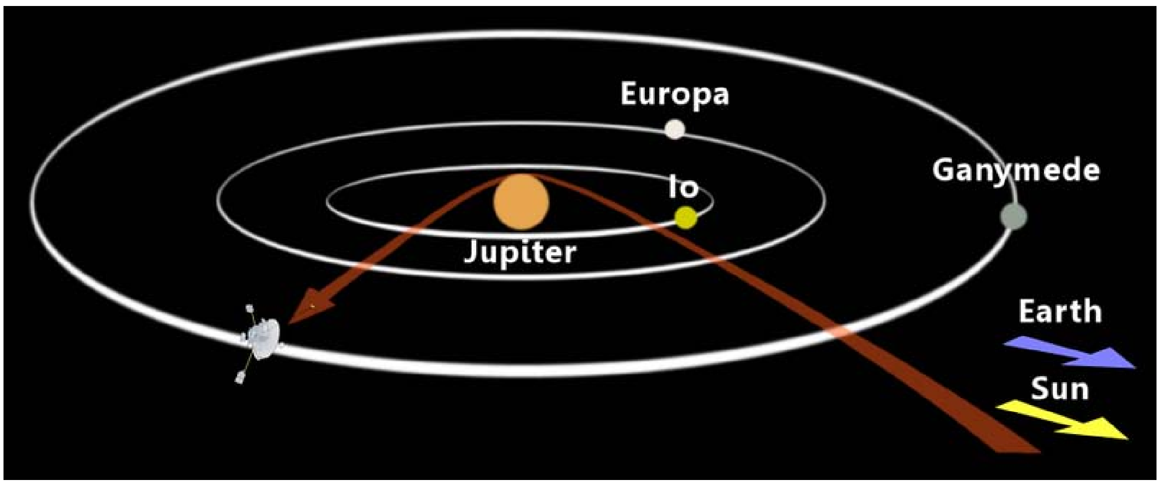
Launch and trajectory

The *Pioneer 10* probe was launched on March 3, 1972 at 01:49:00 UTC by the National Aeronautics and Space Administration from Space Launch Complex 36A at Cape Canaveral, Florida aboard an Atlas/Centaur launch vehicle. The launch vehicle accelerated the probe for 17 minutes, reaching a velocity of 51,682 kilometers/hour (32,114 miles/hour) passing by the moon in 11 hours and becoming the fastest man-made object at that time. Twin probe, Pioneer 11, would launch a year later on April 4, 1973.

Pioneer 10 launching from Space Launch Complex 36A



Pioneer 10 interplanetary trajectory



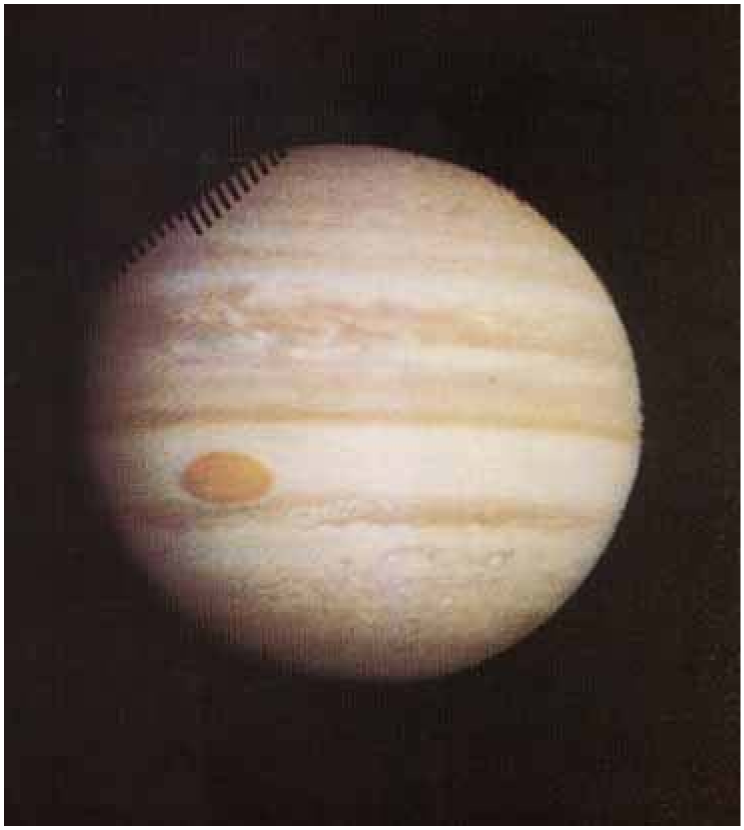
Pioneer 10 trajectory through the Jovian system

Encounter with Jupiter

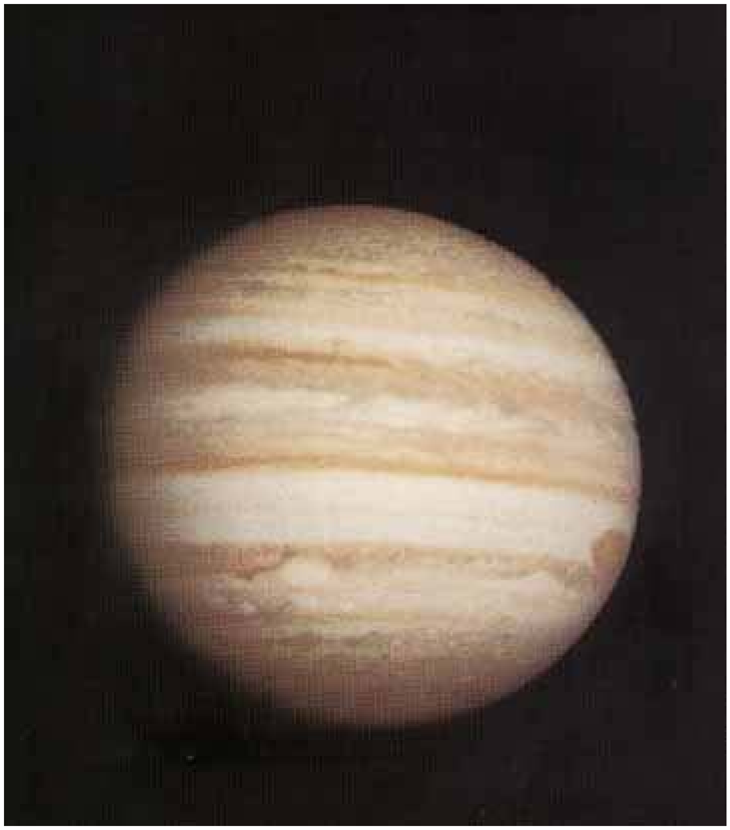
In November and December 1973, *Pioneer 10* began transmitting images of Jupiter back to Earth. 500 images of Jupiter had been received by December 2, 1973, revealing little detail. However, within the 48 hours prior to closest approach, the probe exceeded the resolution of Earth based observations, revealing many previously unseen details.

On December 4, 1973, *Pioneer 10* reached closest approach to Jupiter, passing 200,000 kilometers (124,274 miles) above the cloud tops.

Jupiter encounter (frame 1)



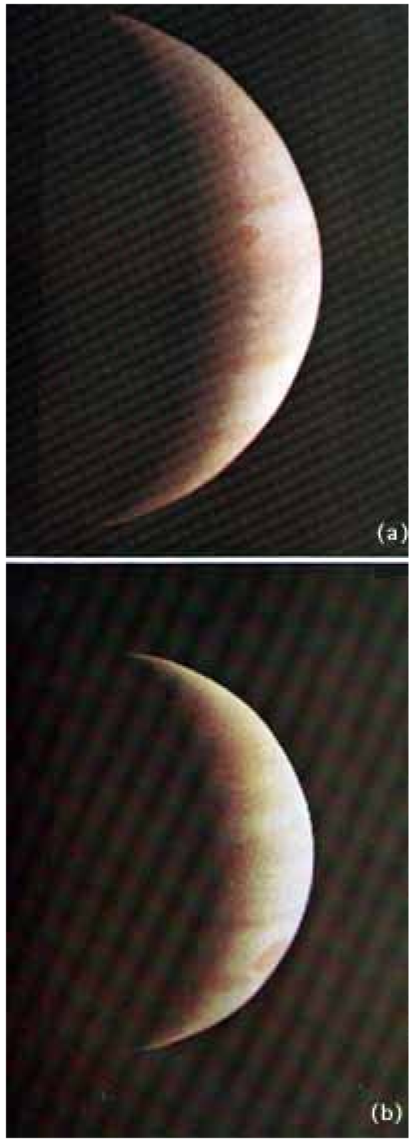
Jupiter encounter (frame 2)



Jupiter encounter (frame 3)

Jupiter encounter (frame 4)

Highest detailed image of the *Pioneer 10* encounter of Jupiter.



Sunrise on a crescent-shaped Jupiter.

Ganymede as seen from *Pioneer 10*.

Europa as seen by Pioneer 10

Interstellar mission

Pioneer anomaly

Analysis of the radio tracking data from the *Pioneer 10* and *11* spacecraft at distances between 20–70 AU from the Sun has consistently indicated the presence of a small but anomalous Doppler frequency drift. The drift can be interpreted as due to a constant acceleration of $(8.74 \pm 1.33) \times 10^{-10}$ m/s^2 directed towards the Sun. Although it is suspected that there is a systematic origin to the effect, none has been found. As a result, there is growing interest in the nature of this anomaly.

Current status

An artist's depiction of Pioneer 10 in the outer solar system

After March 31, 1997, *Pioneer 10*'s weak signal continued to be tracked by the Deep Space Network to aid the training of flight controllers in the process of acquiring deep space radio signals. There was an Advanced Concepts study applying chaos theory to extract coherent data from the fading signal.

On **April 27, 2002**, the last successful reception of telemetry was received from *Pioneer 10*; subsequent signals were barely strong enough to detect and provided no usable data.

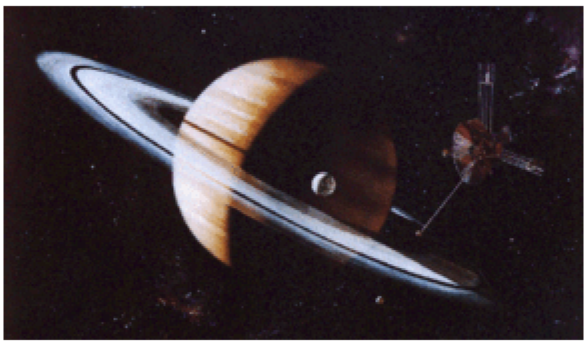
On **January 23, 2003**, the last, very weak signal from *Pioneer 10* was received when it was 12 billion-kilometers (80 AU) from Earth. Further attempts to contact the spacecraft were unsuccessful. The final attempt was made on the evening of March 4, 2006, the last time the antenna would be correctly aligned with Earth. No response was received from *Pioneer 10*. Loss of contact was probably due to a combination of increasing distance and the steadily weakening power source on the spacecraft.

Pioneer 10 is heading in the direction of the star Aldebaran in the constellation Taurus at approximately 2.6 AU per year. If Aldebaran had zero relative velocity, it would take *Pioneer 10* approximately 2 million years to reach the star.

Chapter- 5

Pioneer 11

Pioneer 11



Pioneer 11 at Saturn (artist's impression)

Operator	ARC / NASA
Major contractors	TRW
Mission type	Flyby
Flyby of	Jupiter, Saturn
Launch date	1973-04-06 02:11:00 UTC (37 years, 10 months, and 18 days ago)
Launch vehicle	Atlas/Centaur/TE364-4
Launch site	Space Launch Complex 36A Cape Canaveral Air Force Station
Mission duration	Apr 6, 1973 - Sep 30, 1995 (22 years, 5 months, 25 days) (lost communication) Jupiter flyby *(completed 1975-01-01)* Saturn flyby *(completed 1979-10-05)*

	Interstellar mission *(completed 1995-09-30)*
COSPAR ID	1973-019A
Homepage	Pioneer Project website(archived) NASA Archive
Mass	259 kg (571 lb)
Power	165.0 W (4 SNAP-19 RTGs)

Pioneer 11 (also known as *Pioneer G*) was a 259-kilogram (569 lb) robotic space probe launched by NASA on April 6, 1973 to study the asteroid belt, the environment around Jupiter and Saturn, solar wind, cosmic rays, and eventually the far reaches of the solar system and heliosphere. It was the first probe to encounter Saturn and the second to fly through the asteroid belt and by Jupiter. Due to power constraints and the vast distance of the probe, communication has been lost since November 30, 1995.

Mission background

History

Approved in February 1969, *Pioneer 11* and twin probe *Pioneer 10*, were the first to be designed for exploring the outer solar system. Yielding to multiple proposals throughout the 1960s, early mission objectives were defined as:

- Explore the interplanetary medium beyond the orbit of Mars
- Investigate the nature of the asteroid belt from the scientific standpoint and assess the belt's possible hazard to missions to the outer planets.
- Explore the environment of Jupiter.

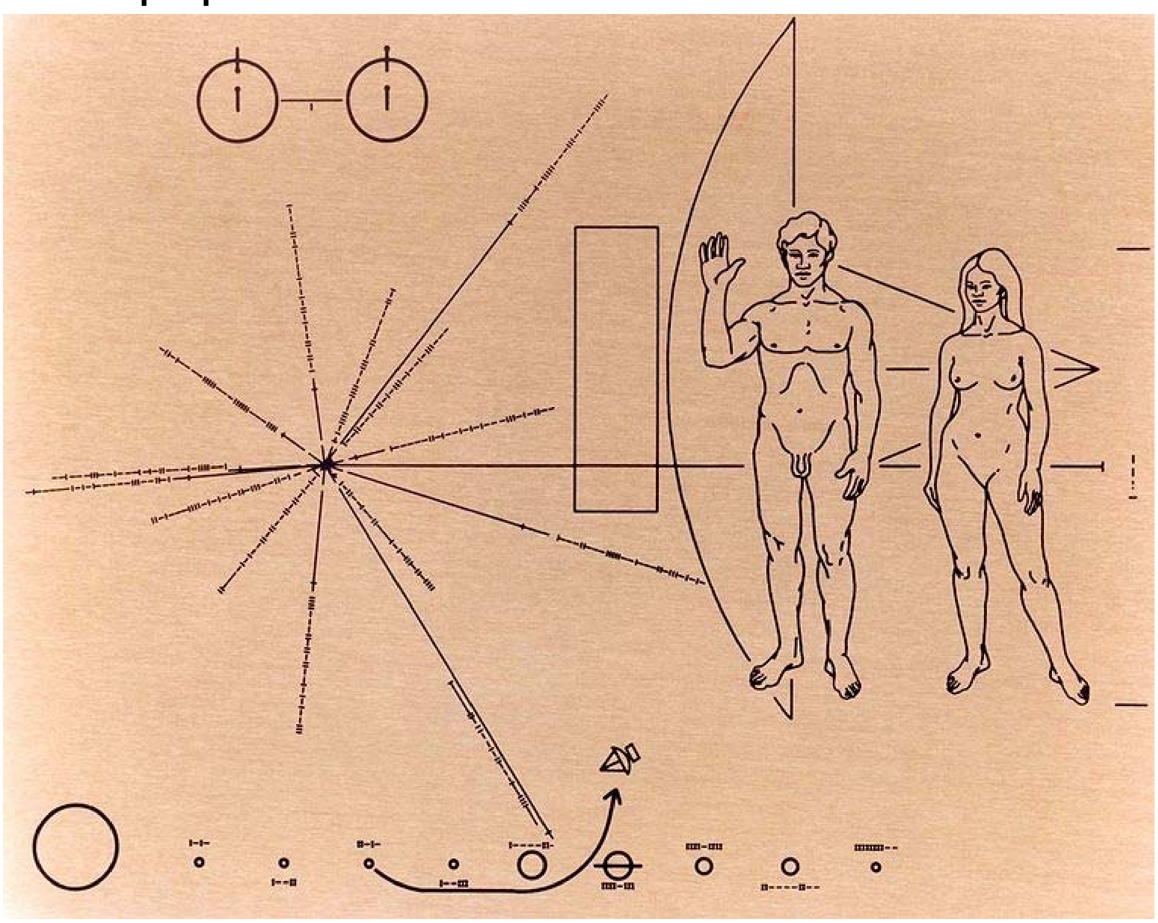
Subsequent planning for an encounter with Saturn added many more goals:

- Map the magnetic field of Saturn and determine its intensity, direction, and structure.
- Determine how many electrons and protons of various energies are distributed along the trajectory of the spacecraft through the Saturn system.
- Map the interaction of the Saturn system with the solar wind.
- Measure the temperature of Saturn's atmosphere and that of Titan, the large satellite of Saturn.
- Determine the structure of the upper atmosphere of Saturn where molecules are expected to be electrically charged and form an ionosphere.
- Map the thermal structure of Saturn's atmosphere by infrared observations coupled with radio occultation data.

- Obtain spin-scan images of the Saturnian system in two colors during the encounter sequence and polarimetry measurements of the planet.
- Probe the ring system and the atmosphere of Saturn with S-band radio waves at occultation.
- Determine more precisely the masses of Saturn and its larger satellites by accurate observations of the effects of their gravitational fields on the motion of the spacecraft.
- As a precursor to the Mariner Jupiter/Saturn mission, verify the environment of the ring plane to find out where it may be safely crossed by the Mariner spacecraft without serious damage.

Pioneer 11 was built by TRW and managed as part of the Pioneer program by NASA Ames Research Center. A backup unit, Pioneer H, is currently on display in the "Milestones of Flight" exhibit at the National Air and Space Museum in Washington, D.C.. Many elements of the mission proved to be critical in the planning of the Voyager Program.

Pioneer plaque

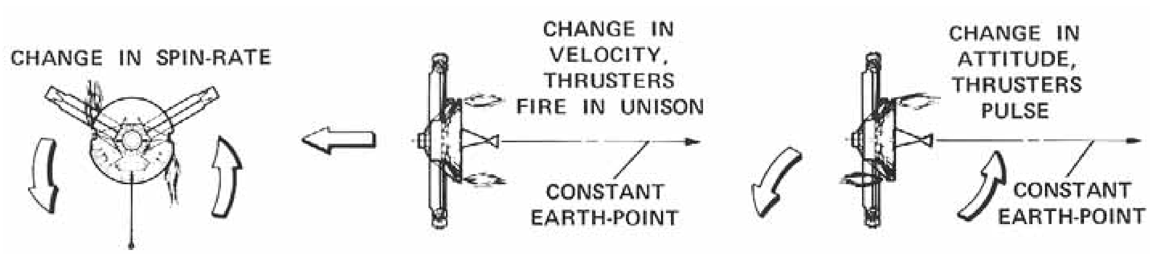


Pioneer 10 and Pioneer 11 carry a gold-anodized aluminium plaque in the event that either spacecraft is ever found by intelligent life-forms from other planetary systems. The plaques feature the nude figures of a human male and female along with several symbols that are designed to provide information about the origin of the spacecraft.

Spacecraft design

The *Pioneer 11* bus measures 36-centimeters deep and with six 76-centimeters long panels forming the hexagonal structure. The bus houses propellant to control the orientation of the probe and eight of the eleven scientific instruments. The spacecraft had a mass of 260-kilograms.

Attitude control and propulsion



Orientation of the spacecraft was maintained with six 4.5 N, hydrazine monopropellant thrusters: pair one maintained a constant spin-rate of 4.8-rpm, pair two controlled the forward thrust, pair three controlled attitude. Information for the orientation was provided by a star sensor able to reference Canopus, and two sun sensors.

Communications

The space probe included a redundant system of transceivers, one attached to the high-gain antenna, the other to an omni-antenna and medium-gain antenna. Each transceiver is 8 watts and transmits data across the S-band using 2110 MHz for the uplink from Earth and 2292 MHz for the downlink to Earth with the Deep Space Network tracking the signal. Prior to transmitting data, used a convolutional encoder, a form of error correction, to avoid sending corrupted data.

Power

Pioneer 10 used 4 SNAP-19 radioisotope thermoelectric generators (RTG) (***see diagram***). They were positioned on 2 three-rod trusses, each 3 meters (10 feet) in length and 120 degrees apart. This was expected to be a safe distance from the sensitive scientific experiments carried on board. Combined, the RTGs provided 155 watts at launch, and decayed to 140w in transit to Jupiter. The spacecraft required 100w to power all systems.

Computer

Much of the computation for the mission was performed on Earth and transmitted to the probe, where it was able to retain in memory, up to five commands of the 222 possible entries by ground controllers. The spacecraft included two command decoders and a command distribution unit, a very limited form of processor, to direct operations on the spacecraft. This system required that mission operators prepare commands long in advance of transmitting them to the probe. A data storage unit was included to record up to 6,144-bytes of information gathered by the instruments. The digital telemetry unit would then be used to prepare the collected data in one of the thirteen possible formats before transmitting it back to Earth.

Scientific instruments

Helium Vector Magnetometer (**HVM**)

Measures the fine structure of the interplanetary magnetic field, maps the Jovian magnetic field, and provides magnetic field measurements to evaluate solar wind interaction with Jupiter.

- **Principal investigator:** Edward Smith / JPL
- **Data:** PDS/PPI data catalog, NSSDC data archive

Quadrispherical Plasma Analyzer

Peers through a hole in the large dish-shaped antenna to detect particles of the solar wind originating from the Sun.

- **Principal investigator:** Aaron Barnes / NASA Ames Research Center (archived website)
- **Data:** PDS/PPI data catalog, NSSDC data archive

Charged Particle Instrument (**CPI**)

Detects cosmic rays in the Solar System.

- **Principal investigator:** John Simpson / University of Chicago
- **Data:** NSSDC data archive

Cosmic Ray Telescope (**CRT**)

Collects data on the composition of the cosmic ray particles and their energy ranges.

- **Principal investigator:** Frank McDonald / NASA Goddard Space Flight Center
- **Data:** PDS/PPI data catalog, NSSDC data archive

Geiger Tube Telescope (**GTT**)

Surveys the intensities, energy spectra, and angular distributions of electrons and protons along the spacecraft's path through the radiation belts of Jupiter.

- **Principal investigator:** James Van Allen / University of Iowa (website)
- **Data:** PDS/PPI data catalog, NSSDC data archive, NSSDC Jupiter data archive

Trapped Radiation Detector (**TRD**)

Includes an *unfocused Cerenkov counter* that detects the light emitted in a particular direction as particles pass through it recording electrons of energy, 0.5 to 12 MeV, an *electron scatter detector* for electrons of energy, 100 to 400 keV, and a *minimum ionizing detector* consisting of a solid-state diode that measures minimum ionizing particles (<3 MeV) and protons in the range of 50 to 350 MeV.

- **Principal investigator:** R. Fillius / University of California San Diego
- **Data:** NSSDC hourly data archive, NSSDC Saturn data archive

Meteoroid Detectors

Twelve panels of pressurized cell detectors mounted on the back of the main dish antenna record penetrating impacts of small meteoroids.

- **Principal investigator:** William Kinard / NASA Langley Research Center

- **Data:** NSSDC data archive list

Asteroid/Meteoroid Detector (**AMD**)

Meteoroid-asteroid detector looks into space with four non-imaging telescopes to track particles ranging from close-by bits of dust to distant large asteroids.

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Ultraviolet Photometer

Ultraviolet light is sensed to determine the quantities of hydrogen and helium in space and on Jupiter.

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Imaging Photopolarimeter (**IPP**)

The imaging experiment relies upon the spin of the spacecraft to sweep a small telescope across the planet in narrow strips only 0.03 degrees wide, looking at the planet in red and blue light. These strips were then processed to build up a visual image of the planet.

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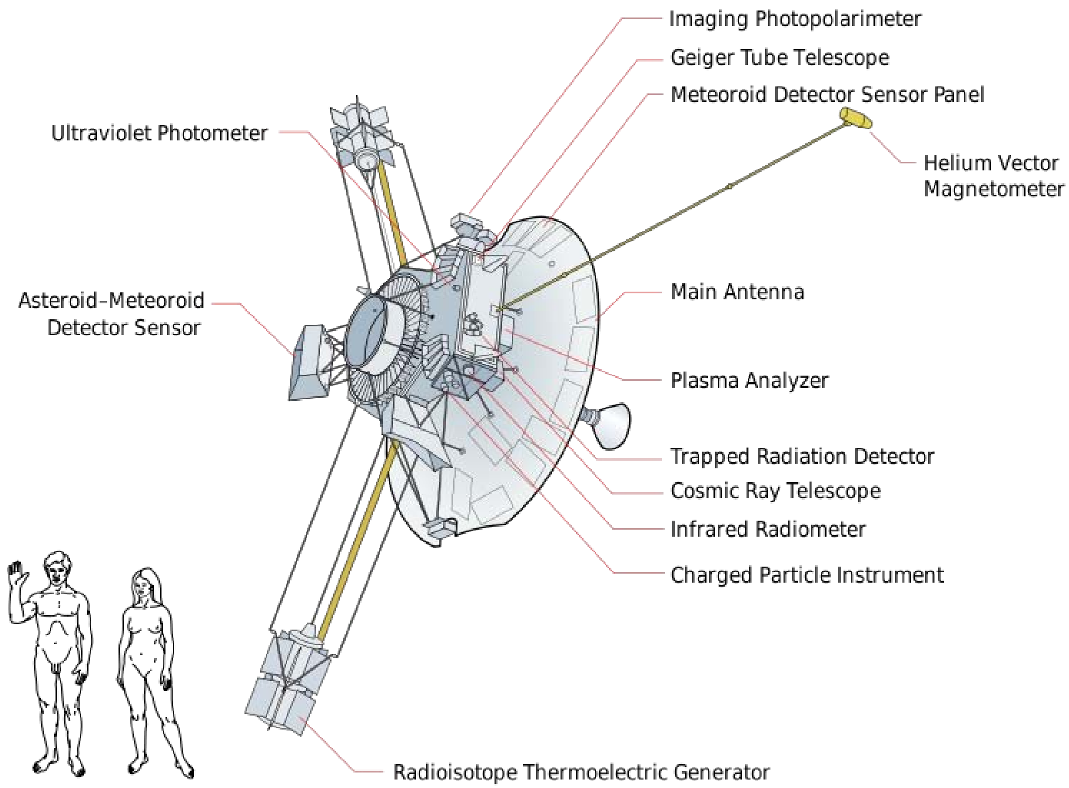
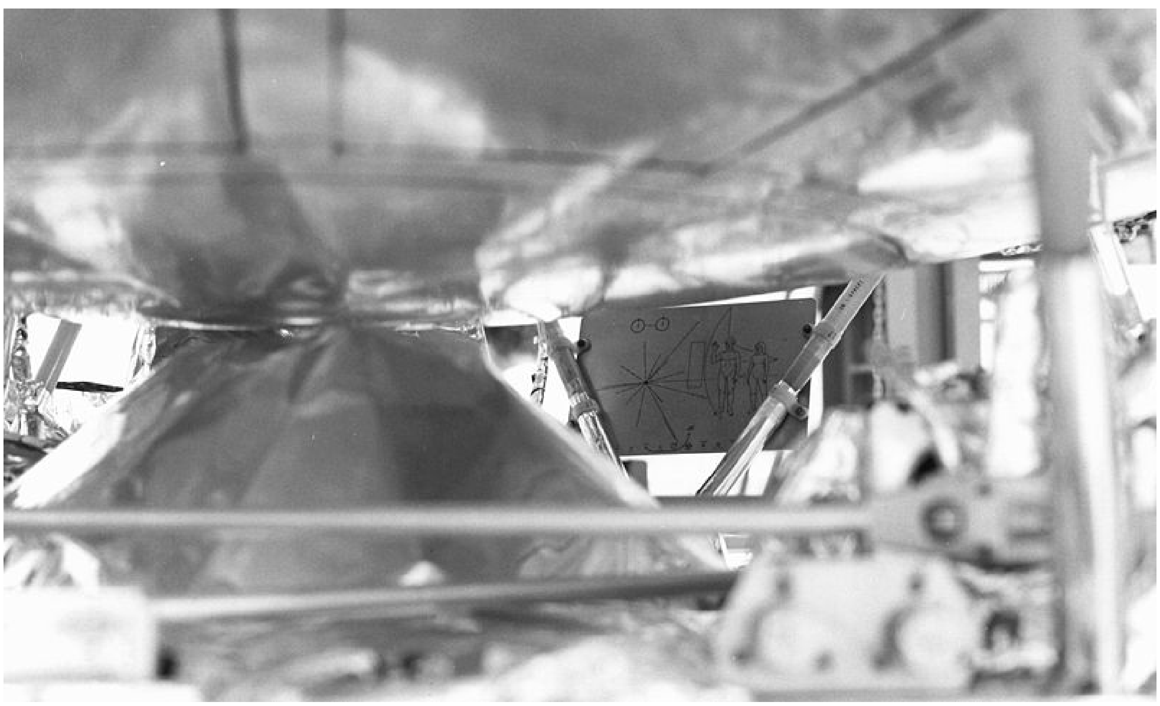
Images of the spacecraft



Pioneer 11 spacecraft design.

Pioneer 11 spin stabilization testing.



The Pioneer plaque fixed to the space probe.

Pioneer 11 being encapsulated for launch.

Mission profile

Launch and trajectory

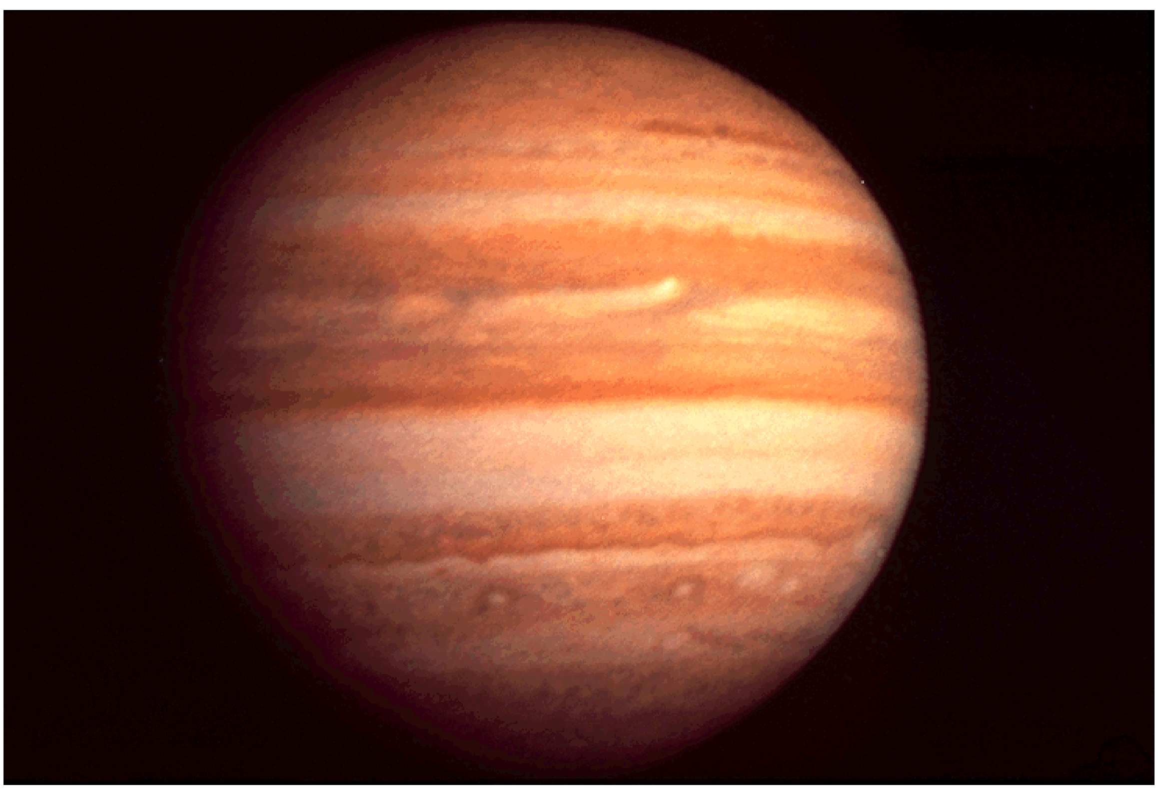
The *Pioneer 11* probe was launched on April 6, 1973 at 02:11:00 UTC, by the National Aeronautics and Space Administration from Space Launch Complex 36A at Cape Canaveral, Florida aboard an Atlas/Centaur launch vehicle. Twin probe, Pioneer 10, had previously launched a year before on March 3, 1972.

Pioneer 11 launching from Space Launch Complex 36A.

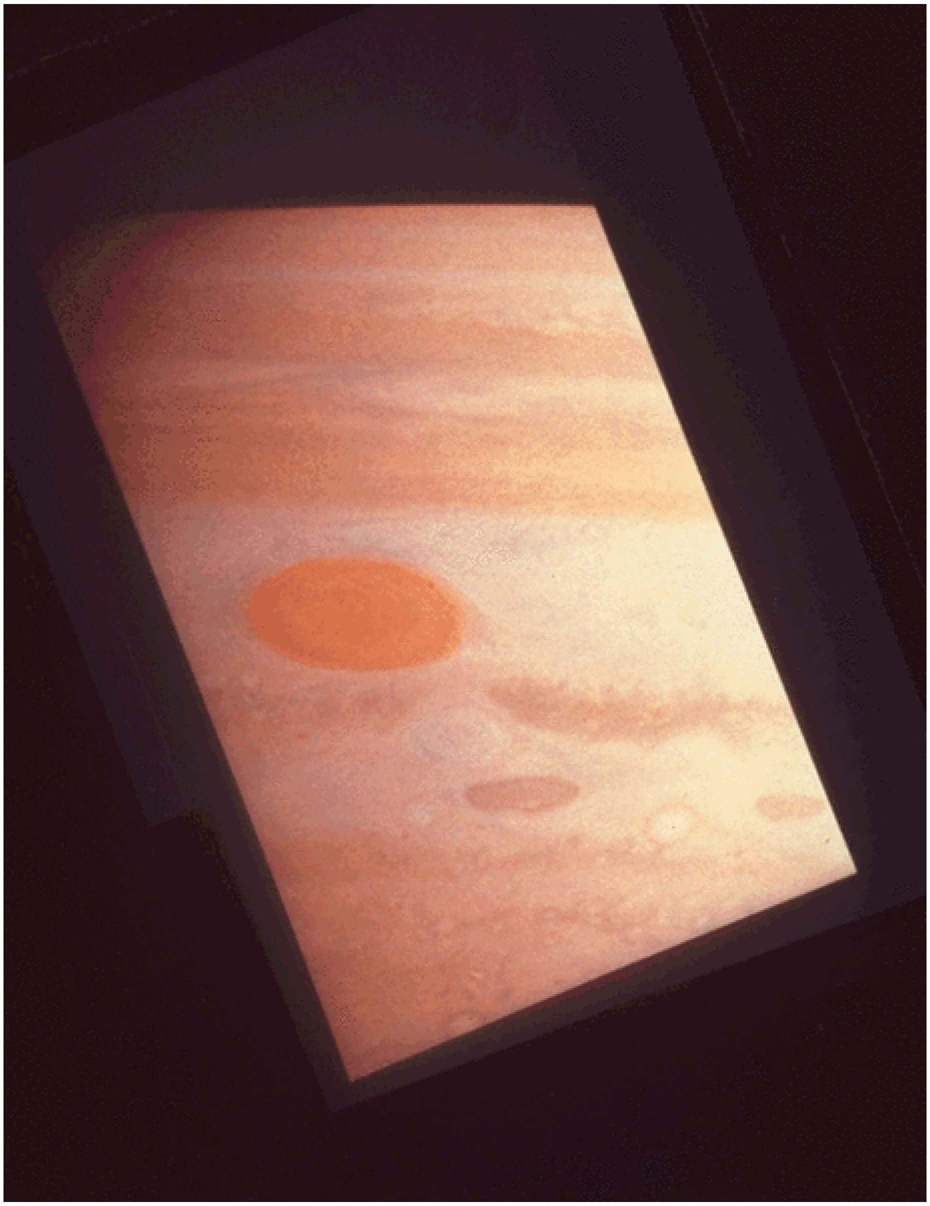
Encounter with Jupiter

In November and December 1974, During its closest approach, December 2, 1974, *Pioneer 11* reached closest approach to Jupiter, passing 42,828 kilometers (26,612 miles) above the cloud tops. The probe obtained detailed images of the Great Red Spot, transmitted the first images of the immense polar regions, and determined the mass of Jupiter's moon Callisto. Utilizing the gravitational pull of Jupiter, a gravity assist was used to alter the trajectory of the probe, towards Saturn.

Pioneer 11 Jupiter encounter.

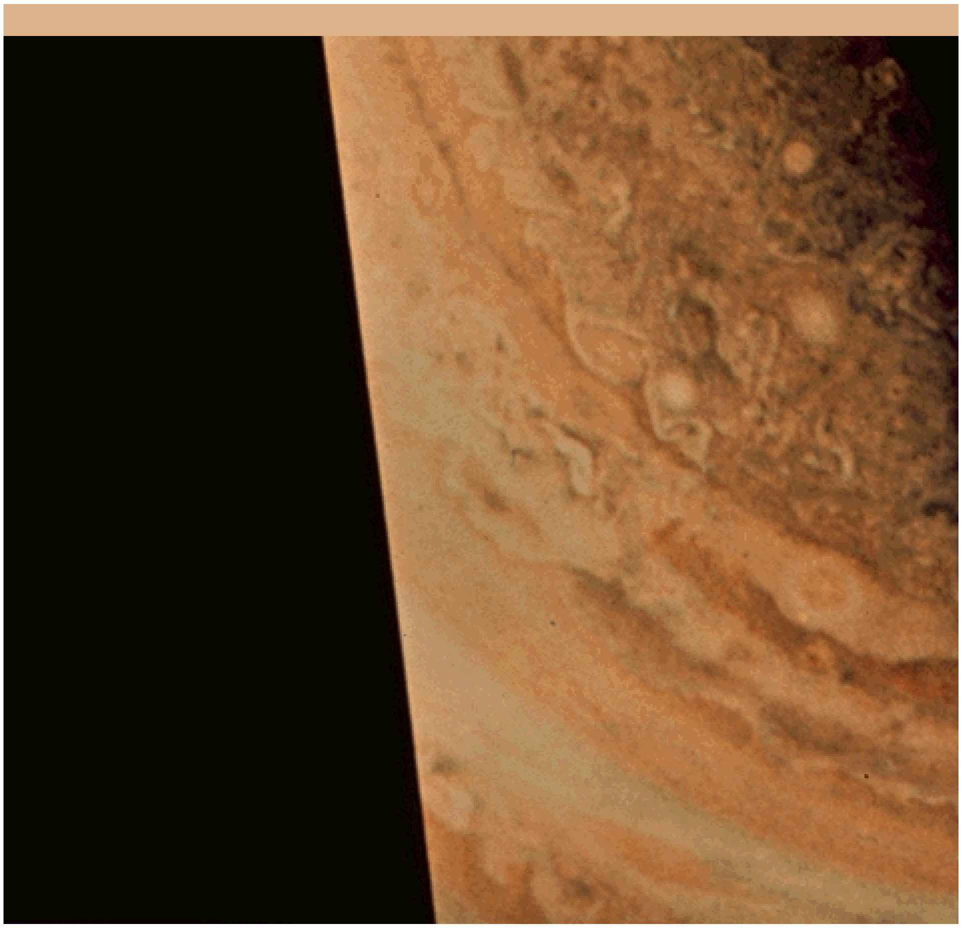


Approach on Jupiter.

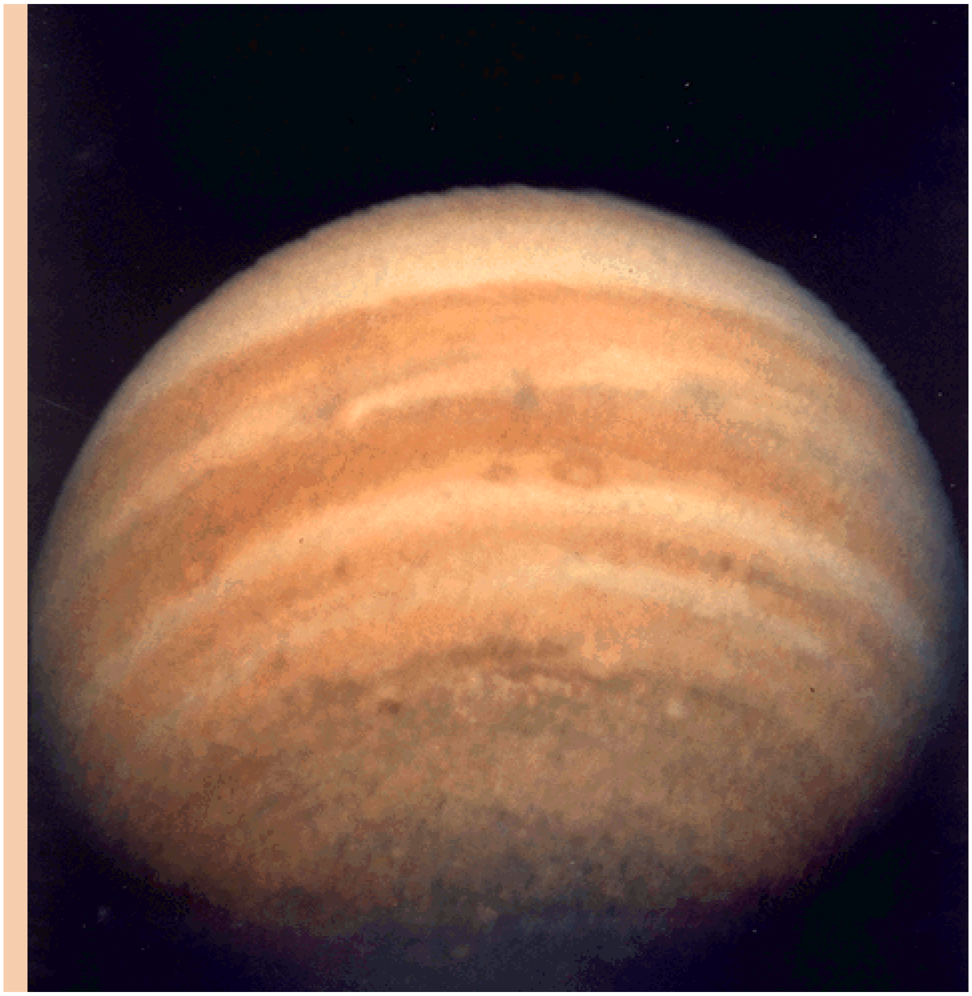


The Great Red Spot imaged by *Pioneer 11*.

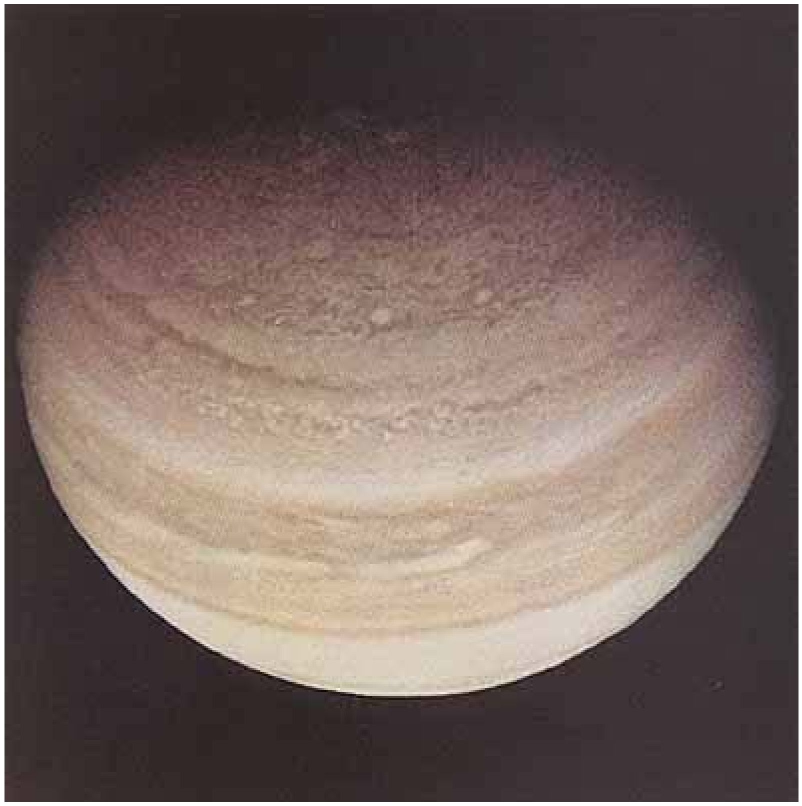
The Great Red Spot prior to closest approach.



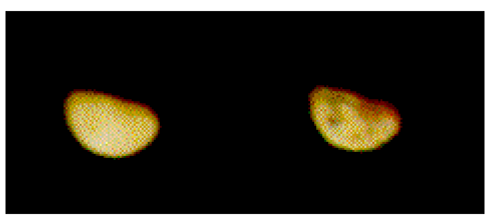
Cloud bands along the edge of Jupiter.



Beginning polar gravity assist



Jupiter polar region from 1,079,000 km.



Io imaged from 756,000 km.

Saturn encounter

Pioneer 11 and Saturn rings on September 1, 1979 (artist's impression)

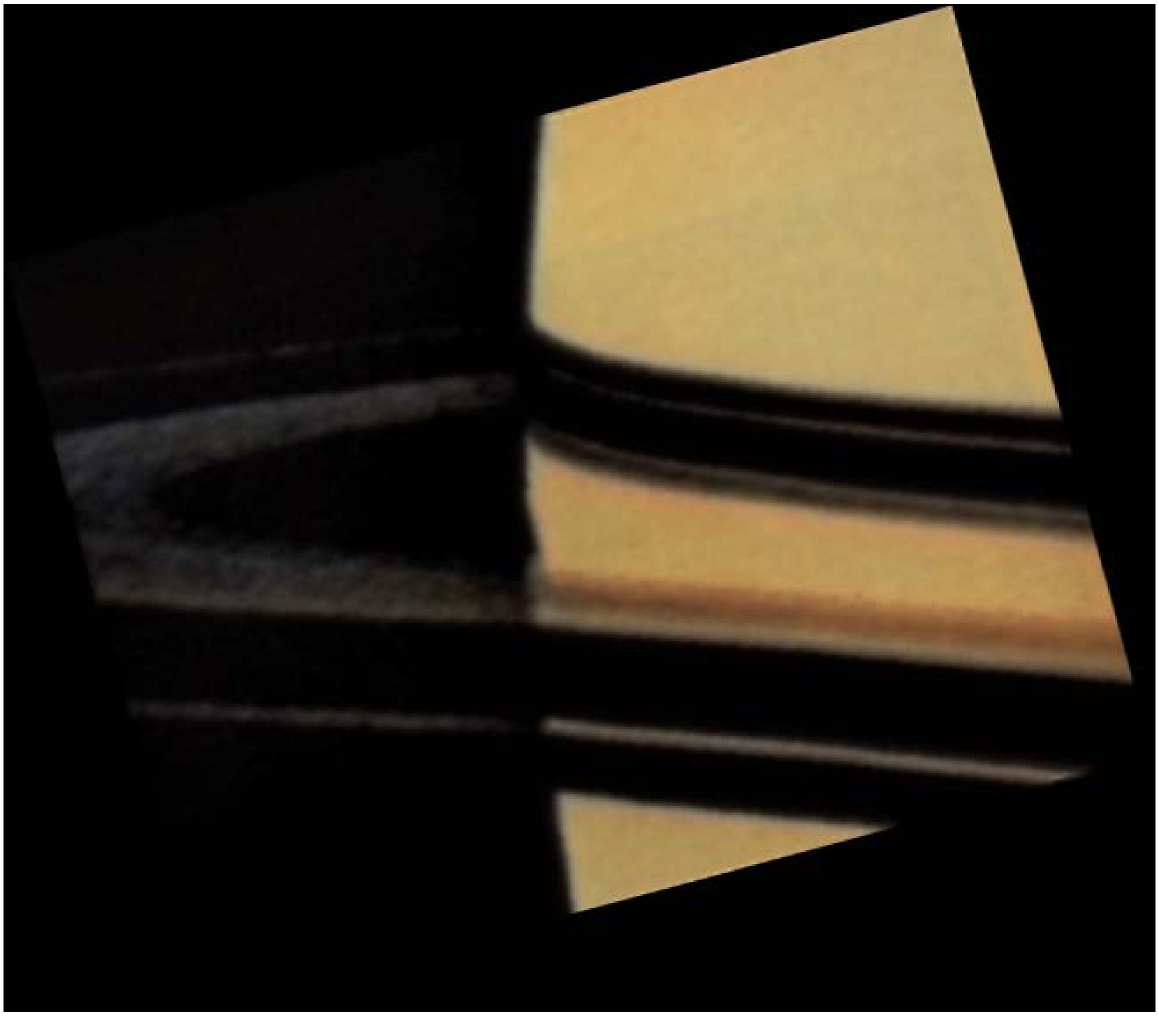
Pioneer 11 passed by Saturn on September 1, 1979, at a distance of 21,000 km from Saturn's cloud tops.

By this time Voyager 1 and Voyager 2 had already passed Jupiter and were also en route to Saturn, so it was decided to target Pioneer 11 to pass through the Saturn ring plane at the same position that the soon-to-come Voyager probe would use in order to test the route before Voyager arrived. If there were faint ring particles that could damage a probe in that area, mission planners felt it was better to learn about it via Pioneer. Thus, Pioneer 11 was acting as a "pioneer" in a true sense of the word; if danger was detected, then the Voyager probes could be rerouted further away from the rings, but missing the opportunity to visit Uranus and Neptune in the process.

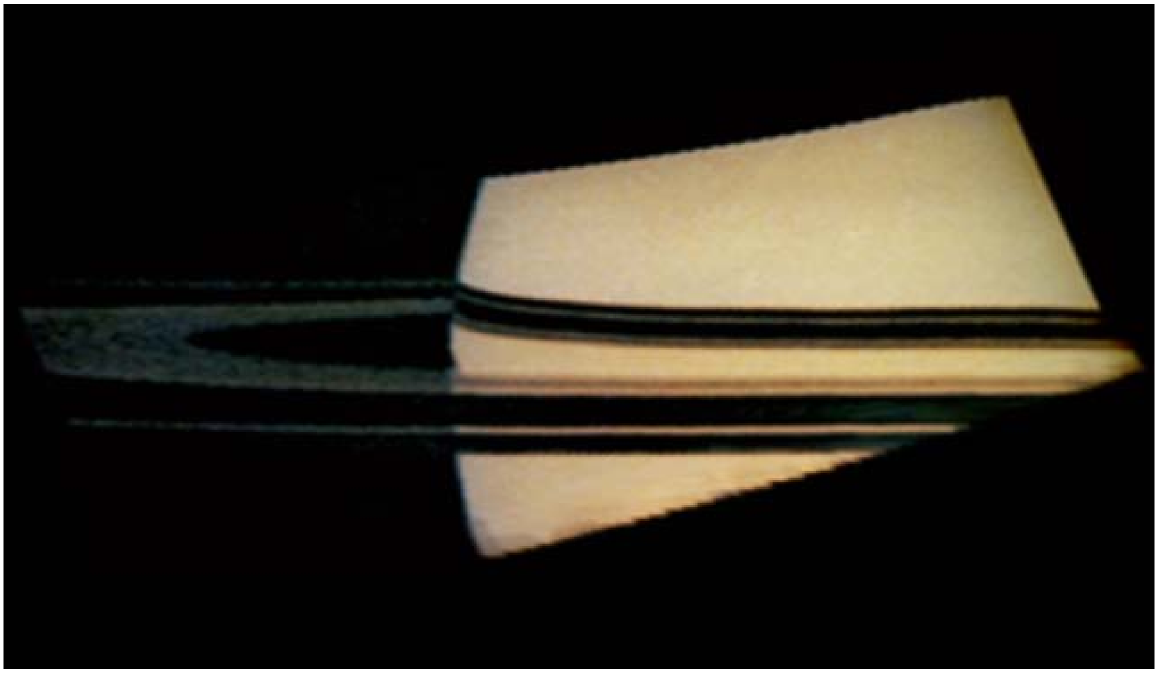
Pioneer 11 imaged and nearly collided with one of Saturn's small moons, passing at a distance of no more than 2500 miles. The object was tentatively identified as Epimetheus, a moon discovered the previous day from Pioneer's imaging, and suspected from earlier observations by Earth-based telescopes. After the Voyager flybys, it became known that there are two similarly-sized moons (Epimetheus and Janus) in the same orbit, so there is some uncertainty about which one was the object of Pioneer's near-miss. Pioneer 11 encountered Janus on September 1, 1979 at 14:52 UTC at a distance of 2500 km and Mimas at 16:20 UTC the same day at 103000 km.

Besides Epimetheus, instruments located another previously undiscovered small moon and an additional ring, charted Saturn's magnetosphere and magnetic field and found its planet-size moon, Titan, to be too cold for life. Hurtling underneath the ring plane, Pioneer 11 sent back amazing pictures of Saturn's rings. The rings, which normally seem bright when observed from Earth, appeared dark in the Pioneer pictures, and the dark gaps in the rings seen from Earth appeared as bright rings.

Pioneer 11 image of Saturn taken on 1979/08/26.



Pioneer 11 image of Saturn taken on 1979/09/01.



Pioneer 11 image of Saturn taken on 1979/09/01.

Outgoing Pioneer 11 image of Saturn taken on 1979/09/03.

Interstellar mission

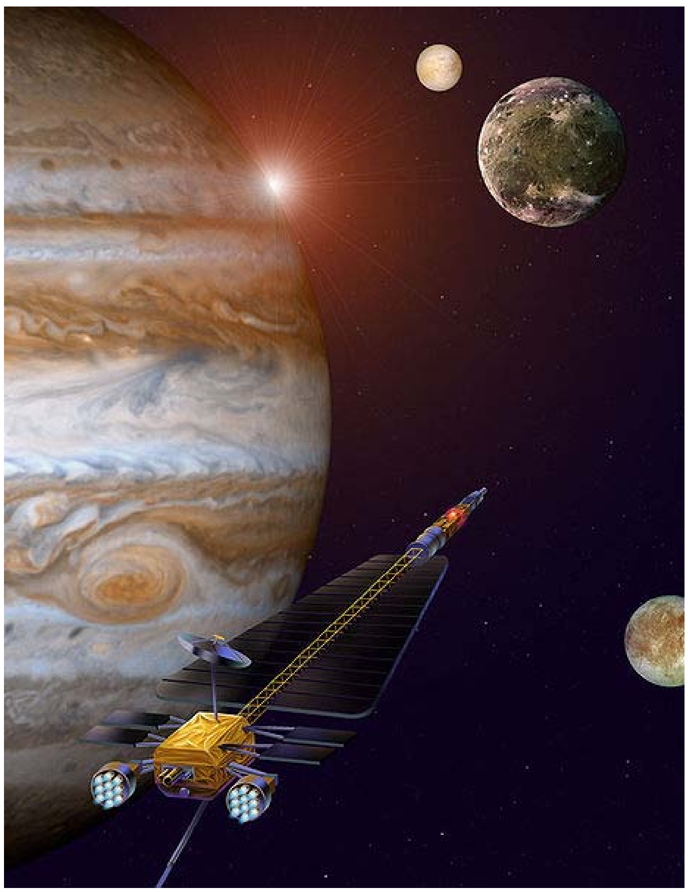
Pioneer anomaly

Analysis of the radio tracking data from the Pioneer 10 and 11 spacecraft at distances between 20–70 AU from the Sun has consistently indicated the presence of an anomalous, small Doppler frequency drift. The drift can be interpreted as being due to a constant acceleration of $(8.74 \pm 1.33) \times 10^{-10}$ m/s² directed towards the Sun. Although it is suspected that there is a systematic origin to the effect, none has been found. As a result, the nature of this anomaly has become of growing interest.

Chapter- 6

Cancelled Spacecraft Missions to Jupiter

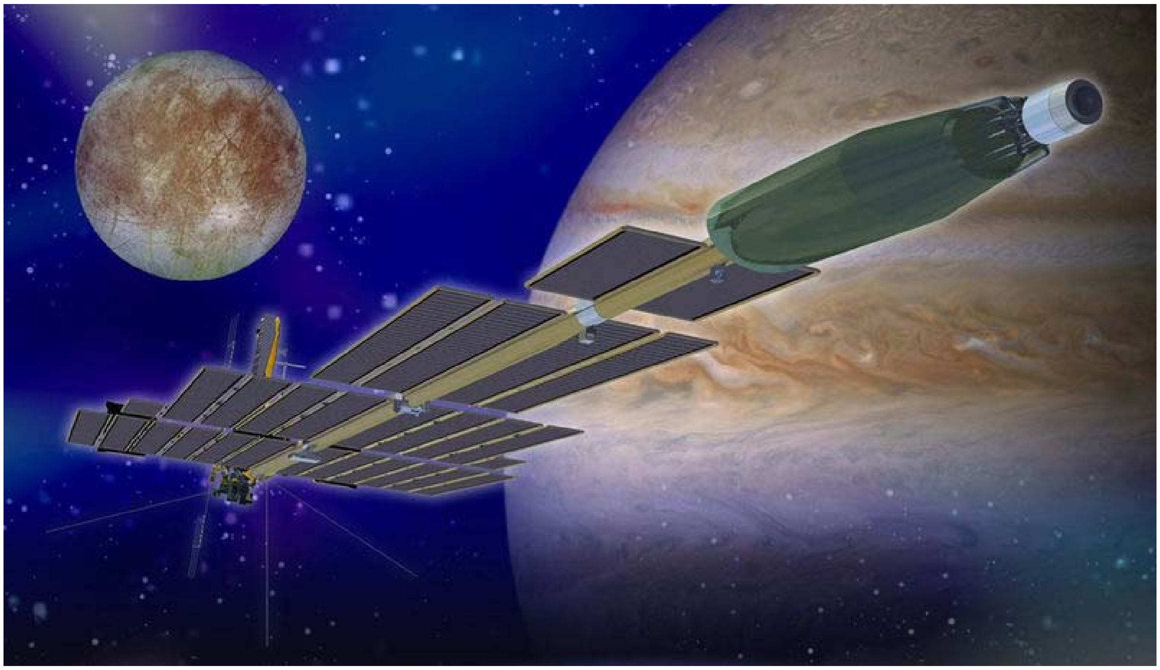
Jupiter Icy Moons Orbiter



Artists's Conception of Jupiter Icy Moons Orbiter

The **Jupiter Icy Moons Orbiter** (**JIMO**) was a proposed spacecraft designed to explore the icy moons of Jupiter. The main target was Europa, the suspected ocean of which is one of the places where simple alien life is a possibility in our solar system. Ganymede and Callisto, which are now thought to have liquid, salty oceans beneath their icy surfaces, were also targets of interest for the probe.

The JIMO spacecraft



Forward view of JIMO.

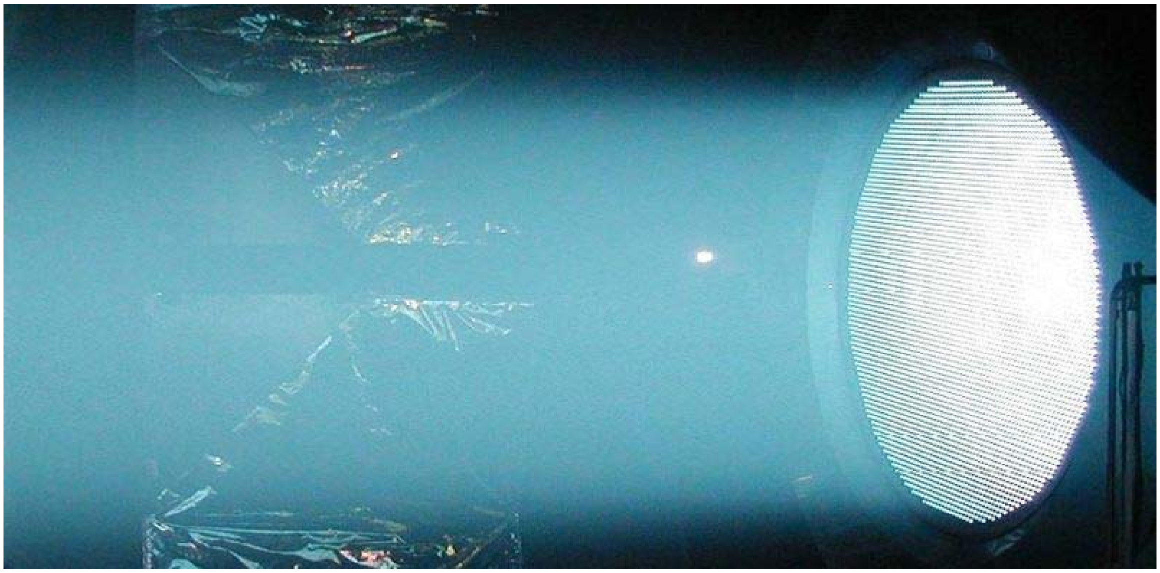
JIMO was to have a large number of revolutionary features. Throughout its main voyage to the Jupiter moons, it was to be propelled by an ion propulsion system via either the HiPEP or NEXIS engine, and powered by a small fission reactor. A Brayton power conversion system would convert reactor heat into electricity. Providing a thousand times the electrical output of conventional solar or RTG based power system, the reactor was expected to open up opportunities like flying a full scale ice-penetrating radar system and providing a strong, high-bandwidth data transmitter.

Using electric propulsion (8 ion engines, plus Hall thrusters of varying sizes) would make it possible to go into and leave orbits around the moons of Jupiter, creating more thorough observation and mapping windows than exist for current spacecraft, which must make short fly-by maneuvers because of limited fuel for maneuvering.

The design called for the reactor to be positioned in the tip of the spacecraft behind a strong radiation shield protecting sensitive spacecraft equipment. The reactor would only be powered up once the probe was well out of Earth orbit, so that the amount of radionuclides that must be launched into orbit is minimized. This configuration is thought to be less risky than the radioisotope thermoelectric generators (RTGs) used on previous missions to the outer solar system.

Northrop Grumman was selected on September 20, 2004 for a $400 million preliminary design contract, beating Lockheed Martin and Boeing IDS. The contract was to have run through to 2008. Separate contracts, covering construction and individual instruments, were to be awarded at a later date.

Preliminary design specifications



JIMO/NEXIS ion engine test (2005)

- Science payload mass: 1,500 kg
- Electric turboalternators: multiple 104 kW (440 V AC)
- Deployable radiator: 422 m² surface area
- Electric Herakles ion thrusters: multiple 30 kW high efficiency, specific impulse 7,000 s (69 kN·s/kg)
- Hall thrusters: high power, higher thrust
- Telecommunications link: 10 Mbit/s (4×250 watt TWTA)
- Deployed size: 58.4 m long × 15.7 m wide
- Stowed size: 19.7 m long × 4.57 m wide
- Mission design life: 20 years
- Launch date: 2017
- Launch Vehicle: Delta 4H

Cancellation

Due to a shift in priorities at NASA that favored manned space missions, the project lost funding in 2005, effectively cancelling the JIMO mission. Among other issues, the proposed nuclear technology was deemed too ambitious, as was the multiple-launch and in-orbit assembly mission architecture. Engineers at the Jet Propulsion Laboratory with JIMO were laid off or reassigned during the spring and summer of 2005.

As a result of the budget changes, NASA is instead considering a demonstration mission to a target closer to Earth to test out the reactor and heat rejection systems. The spacecraft would possibly be scaled down from its original size as well.

When it was cancelled, the JIMO mission was in its early planning stage and launch wasn't expected before 2017. It was to be the first proposed mission of NASA's Project Prometheus, a program for developing nuclear fission into a viable means of spacecraft propulsion.

Europa Jupiter System Mission is a currently planned NASA/ESA mission to Jupiter's moons.

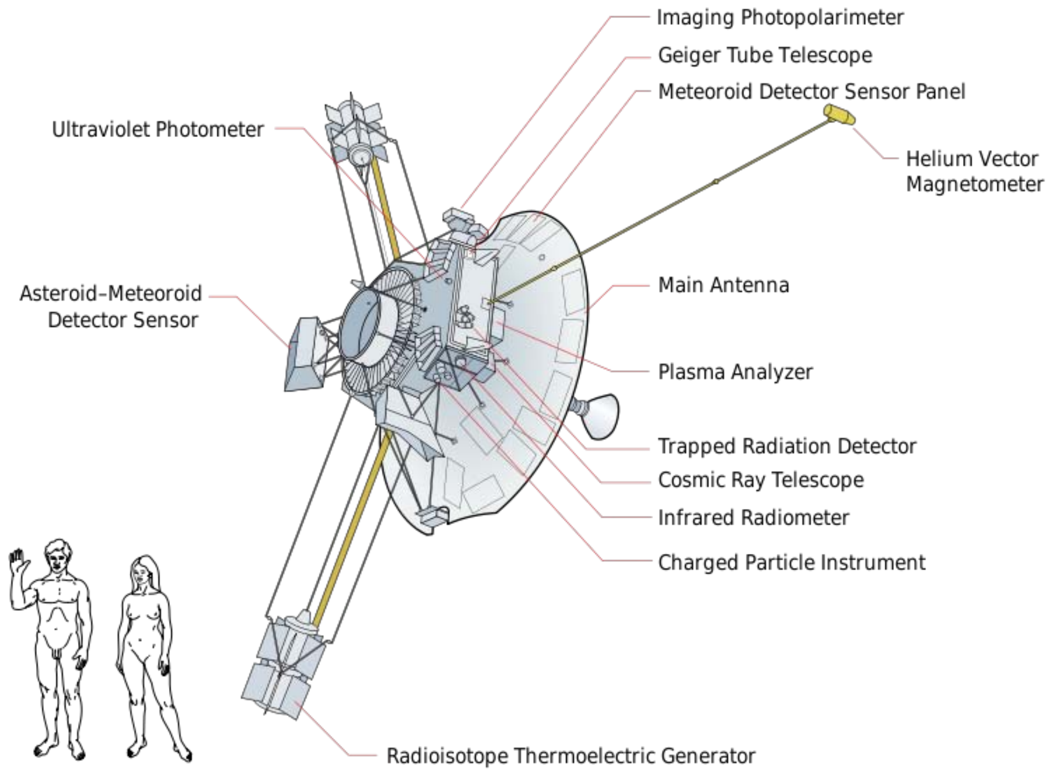
Europa Orbiter

The **Europa Orbiter** was a planned NASA mission to Jupiter's Moon Europa, that was cancelled in 2002. Its main objectives included determining the presence or absence of a subsurface ocean and identifying candidate sites for future lander misions.

The results of the studies on the Europa Orbiter have been conducive to the Jupiter Europa Orbiter, NASA's contribution to the planned international Europa Jupiter System Mission (EJSM) slated for launch in 2020.

The Europa Orbiter-concept should not be confused with the Jovian Europa Orbiter, a feasibility study conducted by the European Space Agency which was finally superseded by the EJSM, too.

Pioneer H



Pioneer H (diagram), uses same design as Pioneer 10 and 11

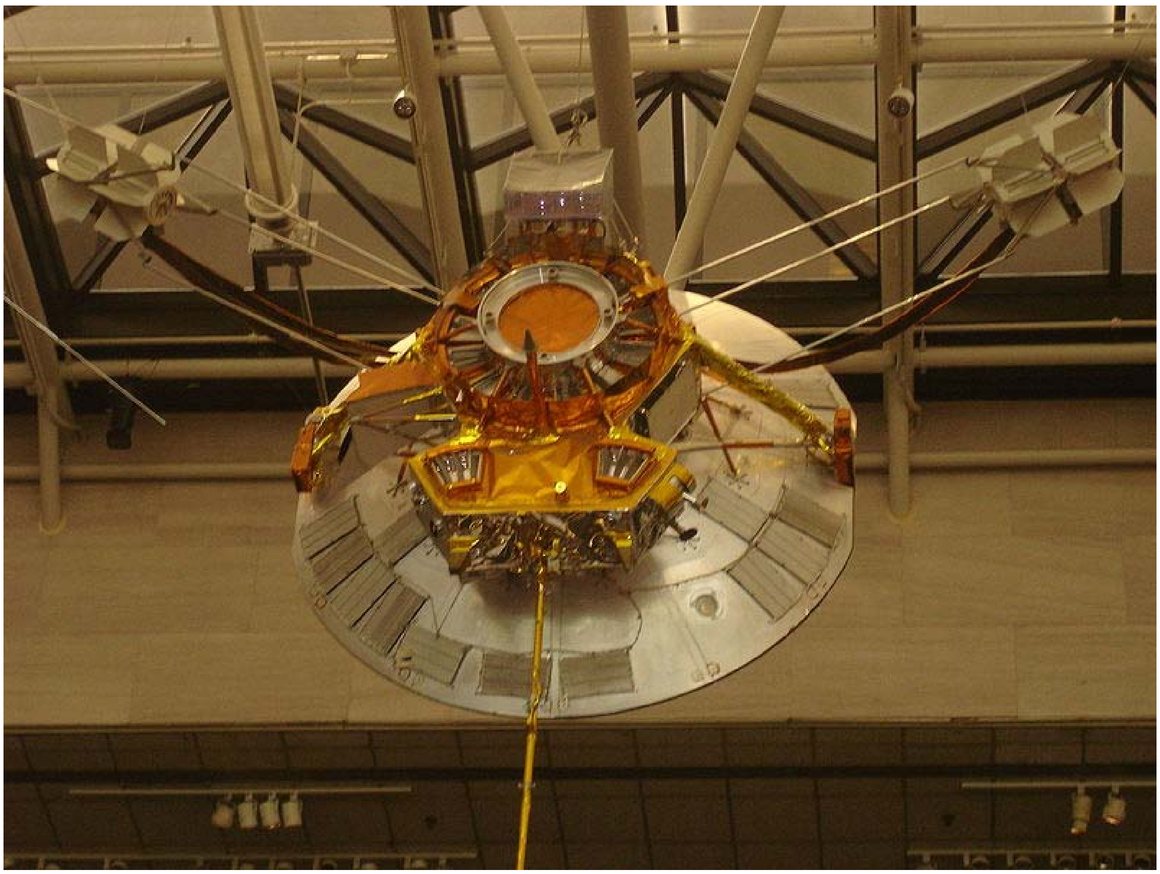
Pioneer H is an unlaunched unmanned space mission that was part of the US Pioneer program for a planned 1974 launch. Had this mission and spacecraft been launched, it would have been designated Pioneer 12; that designation was later applied to the Pioneer Venus Orbiter.

The probe would have been constructed from flight-qualified spare components intended for the Pioneer F and G probes (designated Pioneer 10 and Pioneer 11 after launch) by NASA contractor TRW.

As planning for the Pioneer 10 and 11 missions progressed, mission scientists found themselves desiring a third probe. They proposed a 1974 launch, using a spacecraft assembled from the unused spare parts. The mission would take the craft to Jupiter, where it would use the gas giant as a gravitational slingshot to travel outside the ecliptic. However, NASA management did not approve the mission, and it was never launched. In 1976 NASA transferred the craft (without RTG) to the Smithsonian. The actual physical transfer occurred in January 1977.

As far as its successors, the planned US spacecraft for an *International Solar Polar Mission* (1979) was canceled in 1981. In 1990, the Ulysses spacecraft was built by the European Space Agency with the instruments split between *European Space Agency* and NASA for this Out-Of-The-Ecliptic (OOE) mission—first proposed by the Pioneer 10/11 principal investigators 20 years earlier.

Current location



Pioneer H as it hangs in the National Air and Space Museum

Pioneer H hangs in the Milestones of Flight Gallery at the National Air and Space Museum in Washington, D.C., serving as a stand-in for the Pioneer 10 probe.

While described in official Smithsonian records as a "replica", the spacecraft was considered fully-functional by Pioneer mission planners. Mark Wolverton quotes James Van Allen in *The Depths of Space*:

> "We mounted an intensive campaign to launch the flight-worthy spare spacecraft and its instrument complement on a low-cost, out-of-ecliptic mission via a high-inclination flyby of Jupiter. However, our case fell on deaf ears at NASA

headquarters, and the spare spacecraft now hangs in the main gallery of the National Air and Space Museum, at 1 AU and zero ecliptic latitude."