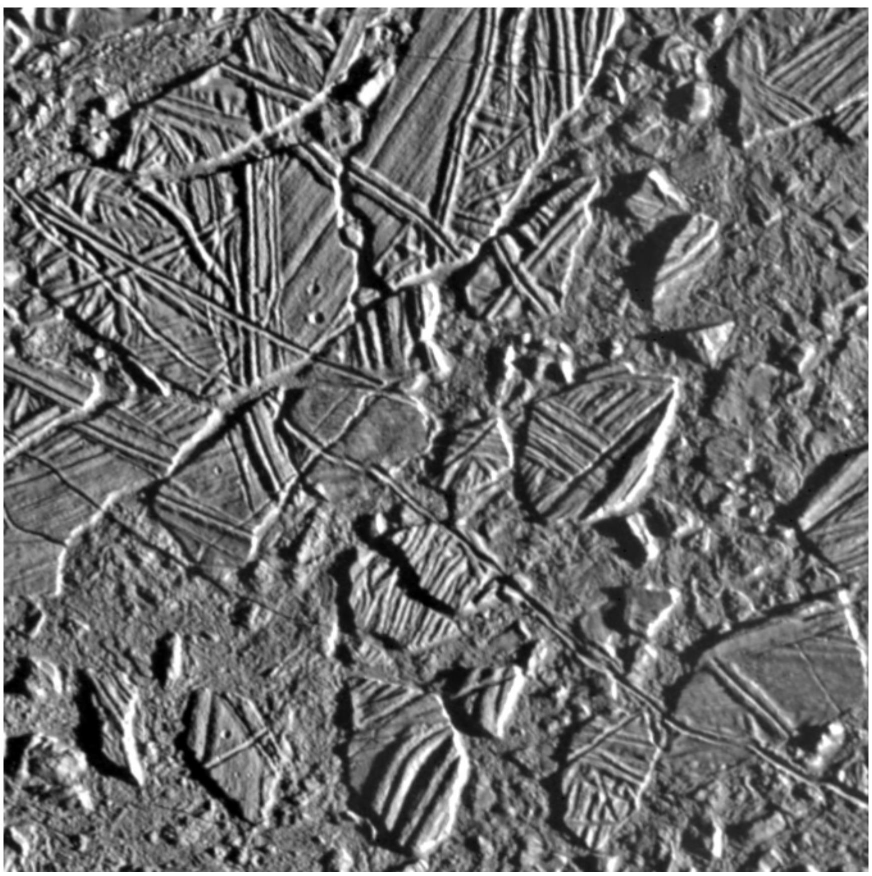
NASA Facts

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109

Galileo Mission to Jupiter

NASA's Galileo spacecraft continues to make discoveries about the giant planet Jupiter, its moons and its surrounding magnetic environment after more than five years in orbit around Jupiter. The mission was named for the Italian Renaissance scientist Galileo Galilei, who discovered Jupiter's major moons in 1610 with the first astronomical telescope.



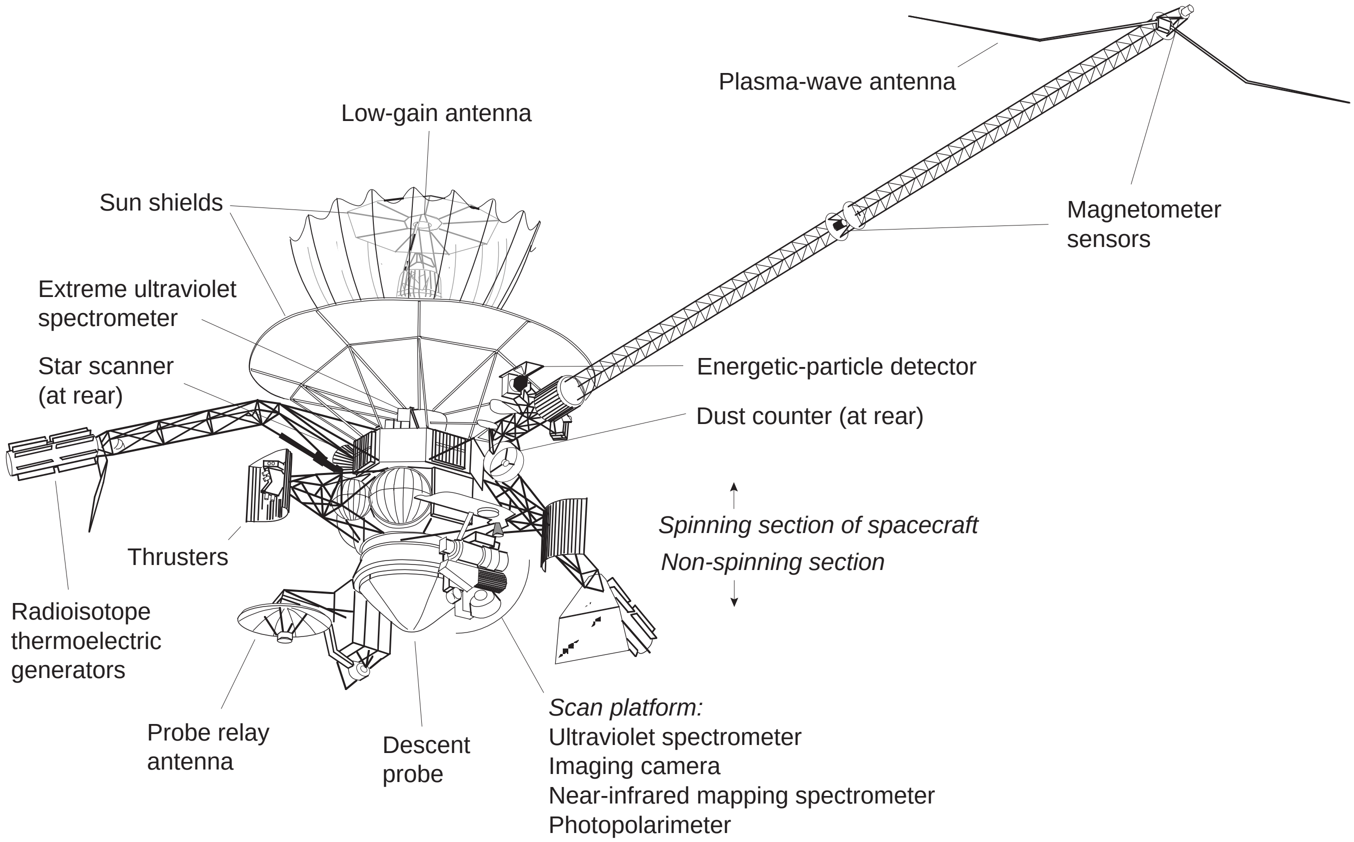
Ice rafts on Jupiter's moon Europa, photographed by the Galileo spacecraft during a flyby February 20, 1997.

Mission Overview

Galileo's primary mission at Jupiter began when the spacecraft entered into orbit around Jupiter in December 1995, and its descent probe, which had been released five months earlier, dove into the giant planet's atmosphere. The primary mission included a 23-month, 11-orbit tour of the Jovian system, including 10 close encounters of Jupiter's major natural satellites, or moons.

Although the primary mission was completed in December 1997, the mission has been extended three times to take advantage of the spacecraft's durability with 24 more orbits. The extensions have enabled additional encounters with all four of Jupiter's major moons: Io, Europa, Ganymede and Callisto. Galileo will fly near a small inner moon, Amalthea, before making a mission-ending plunge into Jupiter's atmosphere in September 2003.

Galileo was the first spacecraft ever to measure Jupiter's atmosphere directly with a descent probe, and the first to conduct long-term observations of the Jovian system from orbit around Jupiter. It found evidence for subsurface liquid layers of saltwater on Europa, Ganymede and Callisto, and it documented extraordinary levels of volcanic activity on Io. During the interplanetary cruise, Galileo became the first spacecraft to fly by an asteroid and the first to discover the moon of an asteroid. It was also the only direct observer as fragments from



the Shoemaker-Levy 9 comet slammed into Jupiter in July 1994.

Launch. The Galileo spacecraft and its two-stage Inertial Upper Stage (IUS) were carried into Earth orbit on October 18, 1989 by space shuttle Atlantis on mission STS-34. The solid-fuel upper stage then accelerated the spacecraft out of Earth orbit toward the planet Venus for the first of three planetary flybys, or "gravity assists," designed to boost Galileo toward Jupiter. In a gravity assist, the spacecraft flies close enough to a planet to be propelled by its gravity, creating a "slingshot" effect for the spacecraft. The Galileo mission had originally been designed for a direct flight of about 3-1/2 years to Jupiter, using a planetary three-stage IUS. When this vehicle was canceled, plans were changed to use a liquid-fuel Centaur upper stage. Due to safety concerns after the Challenger accident, NASA cancelled use of the Centaur on the space shuttle, and Galileo was moved to the two-stage IUS; this, however, made it impossible for the spacecraft to fly directly to Jupiter. To save the project, Galileo engineers designed a new and remarkable six-year interplanetary flight path using planetary gravity assists.

Venus and Earth flybys. After flying past Venus at an altitude of 16,000 kilometers (nearly 10,000 miles) on February 10, 1990, the spacecraft swung past Earth at an altitude of 960 kilometers (597 miles) on December 8, 1990. The spacecraft returned for a second Earth swingby on December 8, 1992, at an altitude of 303 kilometers (188 miles). With this, Galileo left Earth for the third and final time and headed toward Jupiter.

The flight path provided opportunities for scientific observations. At Venus, scientists obtained the first views of mid-level clouds and gained new information about the atmosphere's dynamics. They also made many Earth observations, mapped the surface of Earth's Moon, and observed its north polar regions.

Because of the modification in Galileo's trajectory, the spacecraft was exposed to a hotter environment than originally planned. To protect it from the Sun, project engineers devised a set of sun shades and pointed the top of the spacecraft toward the Sun, with the umbrella-like high-gain antenna stowed until well after the first Earth flyby in December 1990. Flight controllers stayed in touch with the spacecraft through a pair of low-gain antennas, which send and receive data at a much slower rate.

High-gain antenna problem. The spacecraft was scheduled to deploy its 4.8-meter-diameter (16-foot) high-gain antenna in April 1991 as Galileo moved away from the Sun and the risk of overheating ended. The antenna, however, failed to deploy fully.

A special team performed extensive tests and determined that a few (probably three) of the antenna's 18 ribs were held by friction in the closed position. Despite exhaustive efforts to free the ribs, the antenna would not deploy. From 1993 to 1996, extensive new flight and ground software was developed, and ground stations of NASA's Deep Space Network were enhanced in order to perform the mission using the spacecraft's low-gain antennas.

Asteroid flybys. Galileo became the first spacecraft ever to encounter an asteroid when it passed Gaspra on October 29, 1991. It flew within just 1,601 kilometers (1,000 miles) of the stony asteroid's center at a relative speed of about 8 kilometers per second (18,000 miles per hour). Pictures and other data revealed a cratered, complex, irregular body about 20 by 12 by 11 kilometers (12.4 by 7.4 by 6.8 miles), with a thin covering of dirt-like "regolith" and a possible magnetic field.

On August 28, 1993, Galileo flew by a second asteroid, this time a larger, more distant asteroid named Ida. Ida is about 55 kilometers (34 miles) long, by 20 and 24 kilometers (12 by 15 miles). Like Gaspra, Ida may have a magnetic field. Scientists made a dramatic discovery when they found that Ida boasts its own moon, making it the first asteroid known to have a natural satellite. The tiny moon, named Dactyl, has a diameter of only about 1.5 kilometers in diameter (less than a mile). Scientists studied Dactyl's orbit in order to estimate Ida's density.

Comet event. The discovery of Comet Shoemaker-Levy 9 in March 1993 provided an exciting opportunity for Galileo's science teams and other astronomers. The comet was breaking up as it orbited Jupiter and was headed to dive into the giant planet's atmosphere in July 1994. The Galileo spacecraft, approaching Jupiter, was the only observation platform with a direct view of the impact area on Jupiter's far side. Despite the uncertainty of the predicted impact times, Galileo team members pre-programmed the spacecraft's science instruments to collect data and were able to obtain spectacular images of the comet impacts.

Jupiter arrival. On July 13, 1995, Galileo's descent probe, which had been carried aboard the parent spacecraft, was released and began a five-month freefall toward Jupiter. The probe had no engine or thrusters, so its flight path was established by pointing of the Galileo orbiter before the probe was released. Two weeks later, Galileo used its 400-newton main rocket engine for the first time as it readjusted its flight path to arrive at the proper point at Jupiter.

Arrival day on December 7, 1995, turned out to be an extremely busy 24-hour period. When Galileo first reached Jupiter and while the probe was still approaching the planet, the orbiter flew by two of Jupiter's major moons - Europa and Io. Galileo passed Europa at an altitude of about 33,000 kilometers (20,000 miles), while the Io approach was at an altitude of about 900 kilometers (600 miles). About four hours after leaving Io, the orbiter made its closest approach to Jupiter, encountering 25 times more radiation than the level considered deadly for humans.

Descent probe. Eight minutes later, the orbiter started receiving data from the descent probe, which slammed into the top of the Jovian atmosphere at a comet-like speed of 170,000 kilometers per hour (106,000 miles per hour). In the process the probe withstood temperatures twice as hot as the Sun's surface. The probe slowed by aerodynamic braking for about two minutes, then deployed its parachute and dropped its heat shield.

Like the other gas giant outer planets, Jupiter has no solid surface. The wok-shaped probe kept transmitting data for nearly an hour as it parachuted down through Jupiter's atmosphere. Temperatures exceeding 150 degrees Celsius (302 degrees Fahrenheit) eventually caused electronics to fail at a depth corresponding to about 22 times sea-level air pressure on Earth, a pressure more than double what had been the mission objective. That descent took the probe about 130 kilometers (81 miles) below the level corresponding to Earth sea-level air pressure. As it descended, the probe relayed information to the orbiter about sunlight and heat flux, pressure, temperature, winds, lightning and the composition of the atmosphere.

An hour after receiving the last transmission from the probe, at a point about 200,000 kilometers (130,000 miles) above the planet, the Galileo spacecraft fired its main engine to brake into orbit around Jupiter.

This first loop around Jupiter lasted about seven months. Galileo fired its thrusters at its farthest point in the orbit to keep it from coming so close to the giant planet on later orbits. This adjustment prevented possible damage to spacecraft sensors and computer chips from Jupiter's intense radiation environment.

During this first orbit, new software was installed to give the spacecraft extensive new onboard data-processing capabilities. It enabled data compression, permitting the spacecraft to transmit up to 10 times the number of pictures and other measurements that would have been possible otherwise.

In addition, hardware changes on the ground and adjustments to the spacecraft-to-Earth communication system increased the average telemetry rate tenfold. Although the problem with the high-gain antenna prevented some of the mission's original objectives from being met, the great majority of them were. So many objectives were achieved that scientists feel Galileo has produced considerably more science than ever envisioned at the project's start 20 years ago.

Orbital tour. During its primary mission orbital tour, Galileo's itinerary included four flybys of Jupiter's moon Ganymede, three of Callisto and three of Europa. These encounters were about 100 to 1,000 times closer than those performed by NASA's Voyager 1 and 2 spacecraft during their Jupiter flybys in 1979. During each flyby, Galileo's instruments scanned and scrutinized the surface and features of each moon. After about a week of intensive observation, with its tape recorder full of data, the spacecraft spent the next one to two months in orbital "cruise," sending to Earth data stored on the onboard tape recorder.

Mission extensions. Galileo's prime mission ended in December 1997. Since then, three mission extensions have taken advantage of the spacecraft's ability to continue returning valuable scientific discoveries.

The two-year Galileo Europa Mission used eight close encounters with Europa to examine that moon intensively, then made four passes near Callisto and two near Io. This first extended mission added to the evidence that a liquid ocean has existed and probably still exists beneath Europa's icy surface. The spacecraft came so close to Europa that it could see features the size of a schoolbus. Galileo also returned information about thunderstorms in Jupiter's atmosphere during this extended mission. The spacecraft is exposed to harsh radiation from Jupiter's radiation belts whenever it comes near the planet, so examination of Io, closest in of Jupiter's four major moons, was saved until after the Europa flybys. As Galileo approached Io, engineers worked through the night to

Close encounters by the Galileo orbiter

Orbit	Target	Date (Universal Time)	Altitude (kilometers and miles)
0	Io	Dec. 7, 1995	897 km (558 mi)
1	Ganymede	June 27, 1996	835 km (519 mi)
2	Ganymede	Sept. 6, 1996	261 km (162 mi)
3	Callisto	Nov. 4, 1996	1136 km (706 mi)
4	Europa	Dec. 19, 1996	692 km (430 mi)
5	none		
6	Europa	Feb. 20, 1997	586 km (364 mi)
7	Ganymede	April 5, 1997	3102 km (1928 mi)
8	Ganymede	May 7, 1997	1603 km (996 mi)
9	Callisto	June 25, 1997	418 km (260 mi)
10	Callisto	Sept. 17, 1997	535 km (333 mi)
11	Europa	Nov. 6, 1997	2043 km (1270 mi)
12	Europa	Dec. 16, 1997	201 km (125 mi)
13	none		
14	Europa	March 29, 1998	1644 km (1022 mi)
15	Europa	May 31, 1998	2515 km (1562 mi)
16	Europa	July 21, 1998	1834 km (1140 mi)
17	Europa	Sept. 26, 1998	3582 km (2226 mi)
18	Europa	Nov. 22, 1998	2271 km (1411 mi)
19	Europa	Feb. 1, 1999	1439 km (894 mi)
20	Callisto	May 5, 1999	1321 km (821 mi)
21	Callisto	June 30, 1999	1048 km (651 mi)
22	Callisto	Aug. 14, 1999	2299 km (1429 mi)
23	Callisto	Sept. 16, 1999	1052 km (654 mi)
24	Io	Oct. 11, 1999	611 km (380 km)
25	Io	Nov. 26, 1999	301 km (187 mi)
26	Europa	Jan. 3, 2000	351 km (218 mi)
27	Io	Feb. 22, 2000	198 km (123 mi)
28	Ganymede	May 20, 2000	809 km (502 mi)
29	Ganymede	Dec. 28, 2000	2338 km (1452 mi)
30	Callisto	May 25, 2001	138 km (86 mi)
31	Io	Aug. 6, 2001	194 km (120 mi)
32	Io	Oct. 16, 2001	184 km (114 mi)
33	Io	Jan. 17, 2002	102 km (63 mi)
34	Amalthea	Nov. 5, 2002	160 km (99 mi)

Planned Encounter

35	Jupiter	Sept. 21, 2003	impact

counteract radiation effects to the onboard computer. Galileo provided new insight into Io's intense volcanic activity and captured images of an actively erupting fire fountain. A second extended mission, the Galileo Millennium Mission, was initially approved through 2000, then extended further to gain more discoveries and send the spacecraft to a controlled impact into Jupiter's atmosphere in 2003. During the Galileo Millennium Mission, Galileo has made additional close flybys of all four of Jupiter's major moons. A major benefit to science was obtained by having Galileo still functioning well when NASA's Saturn-bound Cassini spacecraft passed Jupiter in December 2000. Observations and measurements by Galileo and Cassini were coordinated to examine Jupiter's huge magnetosphere and other parts of the Jupiter system in ways that neither spacecraft could have done alone. Later, Galileo flybys over Io's north and south poles in 2001 provided measurements useful for determining whether that moon generates its own magnetic field.

In November 2002, Galileo swung closer to Jupiter than ever before, flying by the moon Amalthea, which is less than one-tenth the size of Io and less than half as far from Jupiter. Scientists used measurements of Galileo's radio signal to estimate the mass and density of Amalthea. They are also studying data collected as Galileo flew through Jupiter's gossamer ring to gain new understanding of the magnetic forces and the energetic charged particles close to the planet.

Galileo's final orbit is an elongated loop away from Jupiter. In September 2003, the spacecraft will head back for a direct impact and burn up as it plows into Jupiter's dense atmosphere.

Spacecraft

Orbiter. The Galileo orbiter weighed 2,223 kilograms (2-1/2 tons) at launch and measured 5.3 meters (17 feet) from the top of the low-gain antenna to the bottom of the descent probe. The orbiter features an innovative "dual-spin" design. Most spacecraft are stabilized in flight either by spinning around a major axis, or by maintaining a fixed orientation in space, referenced to the Sun and another star. As the first dual-spin planetary spacecraft, Galileo combines these techniques. A spinning section rotates at about 3 rpm, while a non-spinning section provides a fixed orientation for cameras and other remote sensors. A star scanner on the spinning side determines orientation and spin rate; gyroscopes on the non-spinning side provide the basis for measuring turns and pointing instruments.

The power supply, propulsion module and most of the computers and control electronics are mounted on the spinning section. Two low-gain antennas mounted on the spinning section supported communications during the Earth-Venus-Earth leg of the flight. One was pointed upward toward the Sun, with the other was mounted on a deployable arm to point down. The upward-pointing antenna is currently carrying the communications load, while the lower antenna has been re-stowed and there are no plans to use it again.

The Galileo orbiter spacecraft carries 11 scientific instruments. Another seven were on the descent probe.

The orbiter's spinning section carries instruments to study magnetic fields and charged particles. The instruments include magnetometer sensors mounted on an 11-meter-long (36-foot) boom to minimize interference from the spacecraft's electronics, a plasma instrument to detect low-energy charged particles, and a plasma-wave detector to study electromagnetic waves generated by the particles. There are also a high-energy particle detector, a detector of cosmic and Jovian dust, an extreme ultraviolet detector associated with the ultraviolet spectrometer, and a heavy ion counter to assess potentially hazardous charged-particle environments the spacecraft flies through.

Galileo's non-spinning section carries instruments such as cameras that need to be held steady. These instruments include the camera system; the near-infrared mapping spectrometer to make multispectral images for atmosphere and surface chemical analysis; the ultraviolet spectrometer to study gases; and the photopolarimeter-radiometer to measure radiant and reflected energy. The camera system obtains images of Jupiter's satellites at resolutions from 20 to 1,000 times better than the best possible from NASA's Voyager spacecraft; its charge-coupled-device sensor is much more sensitive than previous spacecraft cameras and is able to detect a broader color band. Galileo's non-spinning section also carries a dish antenna that picked up the descent probe's signals during its fall into Jupiter's atmosphere.

The spacecraft's propulsion module consists of twelve 10-newton thrusters and a single 400-newton engine, which use monomethyl-hydrazine as fuel and nitrogen tetroxide as the oxidizer. The propulsion system was developed and built by Messerschmitt-Bolkow-Blohm and provided by the Federal Republic of Germany as NASA's major international partner on Galileo.

Because radio signals take more than one hour to travel from Earth to Jupiter and back, the Galileo spacecraft was designed to operate from computer instructions sent to it in advance and stored in spacecraft memory. A single master sequence of commands can cover a period ranging from weeks to months of quiet operations between flybys of Jupiter's moons. During busy encounter operations, one sequence of commands covers only about a week.

The flight software includes fault-protection sequences designed to automatically put Galileo in a safe state in case of computer glitches or other unforeseen circumstance. Electrical power is provided by two radioisotope thermoelectric generators. Heat produced by the natural radioactive decay of plutonium is converted to electricity (570 watts at launch, 432 in Galileo's final days in 2003) to operate the orbiter's equipment. This is the same type of power source used on other NASA missions including Viking to Mars, Voyager and Pioneer to the outer planets, and Cassini to Saturn.

Descent probe. Galileo's descent probe had a mass of 339 kilograms (750 pounds). It was slowed and protected by a deceleration module consisting of an aeroshell and an aft cover designed to block heat generated by friction during atmospheric entry. Inside the aeroshells were a descent module and its 2.5-meter (8-foot) parachute. The descent module carried a radio transmitter and seven scientific instruments. These were devices to measure temperature, pressure and deceleration, atmospheric composition, clouds, particles, and light and radio emissions from lightning and energetic particles in Jupiter's radiation belts.

Science Results

Among the Galileo mission's key science findings since reaching Jupiter are the following:

❑ Jupiter has numerous, large thunderstorms concentrated in specific zones above and below the equator, where winds are highly turbulent. Although individual lightning strokes appear less frequently than on Earth, they are up to 1,000 times more powerful than terrestrial lightning.

❑ The descent probe that entered Jupiter's atmosphere encountered lower humidity, or atmospheric water levels, than anticipated. In fact, it entered a "dry spot" that was relatively free of clouds. Like Earth, Jupiter has a wide range of cloudiness, and the amount of water vapor in its atmosphere can vary greatly from place to place. The presence of water, composed of hydrogen and oxygen, indicates that oxygen is typically found in greater relative abundance on Jupiter than in the Sun.

❑ Evidence supports a theory that liquid oceans exist under Europa's icy surface. There are places where recognizable features that once were whole have been separated from each other by new, smooth ice. These areas indicate that when the older features were separated, they floated for a time in liquid water, much as icebergs float in Earth's polar regions. Scientists believe the water later froze solid, creating "rafts" of ice, similar to some seen on a smaller scale at Earth's polar regions. There are also indications of volcanic ice flows, with liquid water flowing from Europa's volcanoes. These discoveries are particularly intriguing, since liquid water is a key ingredient in the process that may lead to the formation of life. Europa is crisscrossed by faults and ridges, with regions where large pieces of crust have separated and shifted. Faults are breaks in the moon's outer crust where the crust on either side has shifted. Ridges indicate that sections of the crust have also moved.

❑ Galileo magnetic data provide evidence not only that Europa still has a liquid-saltwater layer under its ice, but that such layers also exist, farther below the surface, on Ganymede and Callisto. Magnetometer readings show that magnetic fields around those moons vary in ways indicating the presence of electrically conducting layers -- possibly oceans -- under the surface.

❑ Europa, Io and Ganymede all have metallic cores. Processes on these three inner moons have permitted denser elements to separate out and sink to the moons' respective centers. On the other hand, the composition of the more distant moon Callisto is fairly uniform throughout, indicating it did not follow the same evolutionary path as the other three moons.

❑ Europa has an ionosphere, a cloud of electrically charged gases surrounding the moon. Europa's ionosphere is generated by the effect of ultraviolet radiation from the Sun and collisions with charged particles in Jupiter's magnetosphere. Oxygen atoms in Europa's thin atmosphere lose electrons, leaving them positively charged particles in the ionosphere.

❑ Ganymede has a very thin hydrogen atmosphere. Since lightweight hydrogen escapes easily from Ganymede's low gravity, it must be replenished continuously.

❑ Ganymede generates a magnetic field, just as Earth does. In fact, Ganymede is the first moon of any planet known to possess an intrinsic magnetic field, though other of Jupiter's moons have secondary magnetic fields induced by the strong magnetic field of Jupiter itself. Ganymede's magnetosphere - the small magnetic "bubble" created by its field within the surrounding, more powerful, magnetic field of Jupiter - is actually somewhat larger than Mercury's, a planet of similar size. There even appears to be trapped radiation in a miniature radiation belt similar to Earth's Van Allen radiation belts on magnetic field lines close to Ganymede. The discovery of a magnetic field within Ganymede challenges theoretical models of how planetary magnetic fields arose on Earth and other celestial bodies.

❑ Ganymede's surface shows high tectonic activity, with faulting and fracturing observed on its surface. There is some evidence of volcanic ice flows, but much of the satellite's resurfacing has been accomplished by faulting and fracturing.

❑ Callisto's surface shows evidence for extensive, though still mysterious, erosion that smooths out features on the surface. Small features are blanketed by powder-like debris.

❑ Io's extensive volcanic activity may be 100 times greater than that found on Earth's. It is continually modifying its surface. Many changes have been recorded since Voyager's visit in 1979, and other major changes have been seen during the course of the Galileo mission. During one four-month interval, an area the size of the state of Arizona was blanketed by volcanic debris thrown out of the volcano Pillan. Imaging and spectral analyses have shown that most of the eruptions on Io must be composed of liquid silicate rock, which contain silicon-oxygen compounds. The temperatures of these lavas are too high for other materials, such as sulfur, and in fact are even significantly hotter than most eruptions on Earth today. The composition of these hot lavas may be more similar to a type of volcanism that occurred on the Earth more than 3 billion years ago.

❑ 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 within the other.

❑ Galileo has found a strike-slip fault on Europa as long as the California segment of the San Andreas Fault. Galileo images show evidence of movement along the fault.

Orbiter Scientific Experiments

The following is a list of the science instruments on each part of the spacecraft, with the name of the principal investigator responsible for the instrument and notes on the experiment's main object of study.

Remote sensing instruments on non-spinning section:

❑ **Camera** - Dr. Michael Belton, National Optical Astronomy Observatories. Galilean satellites, high resolution, atmospheric small-scale dynamics.

❑ **Near-infrared mapping spectrometer** - Dr. Robert Carlson, Jet Propulsion Laboratory. Surface, atmospheric composition thermal mapping.

❑ **Photopolarimeter-radiometer** - Dr. James Hansen, Goddard Institute for Space Studies. Atmospheric particles, thermal/reflected radiation.

❑ **Ultraviolet spectrometer/extreme ultraviolet explorer** - Dr. Ian Stewart, University of Colorado. Atmospheric gases, aerosols.

Instruments studying magnetic fields and charged particles, located on spinning section:

❑ **Magnetometer** - Dr. Margaret Kivelson, University of California, Los Angeles. Strength and fluctuations of magnetic fields.

❑ **Energetic particle detector** - Dr. Donald Williams, Johns Hopkins Applied Physics Laboratory. Electrons, protons, heavy ions.

❑ **Plasma investigation** - Dr. Lou Frank, University of Iowa. Composition, energy, distribution of ions.

❑ **Plasma wave subsystem** - Dr. Donald Gurnett, University of Iowa. Electromagnetic waves and wave-particle interactions.

❑ **Dust-detection subsystem** - Dr. Harald Krueger, Max Planck Institut für Kernphysik. Mass, velocity, charge of particles smaller than a micrometer in size.

Engineering Experiment:

❑ **Heavy ion counter** - Dr. Edward Stone, California Institute of Technology. Spacecraft's charged-particle environment.

Radio Science:

❑ **Celestial mechanics** - Dr. John Anderson, Jet Propulsion Laboratory. Masses and internal structures of bodies from spacecraft tracking.

❑ **Propagation** - Dr. H. Taylor Howard, Stanford University. Size and atmospheric structure of Jupiter's moons from radio propagation.

Scientific Experiments on Descent Probe

❑ **Atmospheric structure** - Dr. Alvin Seiff, San Jose State University Foundation. Temperature, pressure, density, molecular weight profiles.

❑ **Neutral mass spectrometer** - Dr. Hasso Niemann, NASA Goddard Space Flight Center. Chemical composition.

❑ **Helium abundance** - Dr. Ulf von Zahn, Institut für Atmospharenphysik, Universitat Rostock. Helium/hydrogen ratio.

❑ **Nephelometer** - Dr. Boris Ragent, San Jose State University Foundation. Clouds and particles.

❑ **Net flux radiometer** - Dr. Larry Sromovsky, University of Wisconsin. Thermal/solar energy profiles.

❑ **Lightning and radio emissions/energetic particles** - Dr. Louis Lanzerotti, Bell Laboratories, and Dr. Klaus Rinnert, Max Planck-Institut für Aeronomie; Harald Fischer, Institut für Reine und Angewandte Kernphysik, Universitat Kiel. Lightning detection, energetic particles.

❑ **Doppler wind experiment** - Dr. David Atkinson, University of Idaho. Measure winds, learn their energy source.

Ground System

Galileo communicates with Earth via NASA's Deep Space Network, a worldwide system of large antenna complexes with receivers and transmitters located in Australia, Spain and California's Mojave Desert, linked to a network control center at the Jet Propulsion Laboratory in Pasadena, Calif. Through this network, the spacecraft receives commands, sends science and engineering data, and is tracked by Doppler and ranging measurements.

Doppler measurements detect changes in the frequency of the spacecraft's radio signal that reveal how fast the spacecraft is moving toward or away from Earth. In ranging measurements, radio signals transmitted from Earth are marked with a code which is returned by the spacecraft, enabling ground controllers to keep track of the distance to the spacecraft.

Management

The Galileo project is managed for NASA's Office of Space Science, Washington, D.C., by the Jet Propulsion Laboratory, Pasadena, a division of the California Institute of Technology. JPL designed and built the Galileo orbiter, and operates the mission.

At NASA Headquarters, Dr. Barry Geldzahler is Galileo program manager and Dr. Denis Bogan is program scientist.

At JPL, the position of project manager has been held successively by John Casani, Richard Spehalski, Bill O'Neil, Bob Mitchell, Jim Erikson and, currently, Dr. Eilene Theilig. Dr. Torrence V. Johnson is project scientist.

NASA's Ames Research Center, Moffett Field, Calif., managed the descent probe, which was built by Hughes Aircraft Co, El Segundo, Calif. The position of probe manager was held successively by Joel Sperans, Benny Chinn and Marcie Smith. The probe scientist is Dr. Richard E. Young.

Galileo's experiments are being carried out by more than 100 scientists from the United States, Great Britain, Germany, France, Canada and Sweden.

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