NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

The Jupiter Millennium Mission

The Galileo and Cassini Encounter at the Fifth Planet

Press Kit
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RELEASE:

SPACECRAFT DOUBLE-TEAM THE KING OF PLANETS

Two NASA spacecraft are teaming up to scrutinize Jupiter during the next few months to gain a better understanding of the planet's stormy atmosphere, diverse moons, faint rings and vast bubble of electrically charged gas.

The joint studies of the solar system's largest planet by the Galileo and Cassini spacecraft will also resemble the passing of a baton from the durable veteran to the promising rookie, say mission controllers at NASA's Jet Propulsion Laboratory in Pasadena, CA.

Galileo has been running laps around Jupiter since December 1995, continuing to produce scientific discoveries after surviving more than double the orbital time and triple the radiation exposure originally intended for it. It will pass close to Jupiter's largest moon, Ganymede, on Dec. 28.

Cassini left Earth on Oct. 15, 1997, bound for Saturn with a dozen scientific instruments to carry into orbit there and a European-made probe, Huygens, to drop onto Saturn's biggest moon in 2004. Cassini will make its closest approach to Jupiter on Dec. 30. It will still be nearly 10 million kilometers (6 million miles) away, well outside the orbits of Jupiter's four large moons -- Io, Europa, Callisto and Ganymede -- but within the orbits of nine small ones.

Cassini began transmitting Jupiter pictures and data this month.

"We have a chance to make observations with a well-instrumented spacecraft that has more capabilities than any spacecraft that has previously visited Jupiter," said Robert Mitchell, JPL's Cassini program manager. "Fortunately, Galileo is still operating there, so we can get a synergistic effect in studies of Jupiter by having spacecraft at two different locations in the vicinity of Jupiter at the same time. That's not something we could have counted on in 1995."

One joint study will examine how the "solar wind" of charged particles speeding away from the Sun buffets Jupiter's magnetosphere, the bubble of charged gas rotating around Jupiter under the control of the planet's magnetic field. In November, Cassini will be in the solar wind upstream of where the wind hits the magnetosphere, while Galileo will be inside the magnetosphere. Cassini will monitor fluctuations in the solar wind while Galileo watches the response of Jupiter's magenetosphere to those fluctuations.

During the past five years, Galileo has measured frequent changes in the density of particles in the magnetosphere, but researchers have not had the opportunity to connect the effects to specific changes in the solar wind, said Dr. Torrence Johnson, Galileo project scientist at JPL.

JPL physicist Dr. Scott Bolton, on science teams for both Cassini and Galileo, said, "Having two spacecraft there at once is possibly the only chance in our lifetime to simultaneously connect changes in the solar wind to conditions inside Jupiter's giant magnetosphere."

Getting a better grasp on how Jupiter's magnetosphere acts and reacts will advance understanding of the smaller magnetosphere surrounding Earth and larger ones affecting areas of the galaxy where stars are being born, Bolton said. Disturbances in Earth's magnetosphere can disrupt electrical and communications systems.

Another study taking advantage of dual vantagepoints will focus on a stream of dust, finer than particles in cigarette smoke, originating from volcanoes on Jupiter's moon Io. Patterns in the stream as it passes first one satellite, then another, could give information about the dust's movement. Researchers also hope to identify its composition, which would be a sampling of material from Io.

Both spacecraft will study eclipses of Jupiter's large moons. While the moons are in the shadow of Jupiter, glows can be seen that are overwhelmed by reflected sunlight at other times. Excitation of the moons' thin atmospheres by energetic particles in Jupiter's magnetosphere causes the glows. Researchers hope to learn more about gases on the moons by studying these glows.

Cassini will study Jupiter's atmosphere from October through March as the craft approaches from the sunny side, then recedes from the dark side of the planet. "If we're lucky, we may even see a storm arise, and see how it starts and how it evolves," said Dr. Dennis Matson, Cassini project scientist at JPL. The Jupiter studies will also provide a dress rehearsal, checking out equipment and procedures for Cassini's main mission at Saturn, Matson said.

JPL manages the Cassini and Galileo missions for NASA's Office of Space Science, Washington DC. JPL is a division of the California Institute of Technology, Pasadena, CA. Cassini is a cooperative endeavor of NASA, the European Space Agency and the Italian Space Agency.

More information on the joint spacecraft study of Jupiter is available at http://www.jpl.nasa.gov/jupiterflyby . An expanded press kit on the study is available at http://www.jpl.gov/presskits/jupiterflyby .

[End of general release]

Media Services Information

NASA Television Transmission

NASA Television is broadcast on the satellite GE-2, transponder 9C, C Band, 85 degrees west longitude, frequency 3880.0 MHz, vertical polarization, audio monaural at 6.8 MHz. The schedule for television transmission of video animations, B-roll and live-interview opportunities will be available from the Jet Propulsion Laboratory, Pasadena, CA, and NASA Headquarters, Washington, DC.

News Releases

News releases, image advisories and status reports about the Cassini and Galileo studies of Jupiter will be issued by the Jet Propulsion Laboratory's Media Relations Office. They may be accessed online as noted below.

Briefings

A science briefing about the Galileo and Cassini joint studies of Jupiter will be held at the Jet Propulsion Laboratory, Pasadena, CA, on December 30, 2000, the date of Cassini's closest approach to Jupiter.

Additional details about the briefing will be available closer to those dates from NASA Headquarters and the Jet Propulsion Laboratory.

Internet Information

Extensive information about the Cassini and Galileo missions and their joint studies of Jupiter, including an electronic copy of this press kit, press releases, fact sheets, status reports and images, is available from the Jet Propulsion Laboratory's World Wide Web home page at **http://www.jpl.nasa.gov/** . Signup for e-mail subscriptions to news releases is available at the home page.

A special Internet site for the Jupiter Millenium Flyby offers graphics and educational material, and will provide updates of pictures and data gathered by the spacecraft and by related Jupiter research. The site is at **http://www.jpl.nasa.gov/jupiterflyby** .

The Cassini Program also maintains a home page at **http://www.jpl.nasa.gov/cassini** , and the Galileo Project maintains one at **http://galileo.jpl.nasa.gov** .

Cassini Quick Facts

Spacecraft
Spacecraft dimensions: 6.7 meters (22 feet) high; 4 meters (13.1 feet) wide
Weight: 5,712 kilograms (12,593 pounds) with fuel, Huygens probe and adapter. Unfueled orbiter alone weighs 2,125 kilograms (4,685 pounds)
Science instruments: camera; magnetic field studies; dust and ice grain analysis; infrared energy measurement; chemical composition of Saturn, its moons and rings; neutral and charged particle measurement; radar mapping; and gravitational wave searches
Power: 885 watts (at launch) from radioisotope thermoelectric generators

Huygens Probe
Probe dimensions: 2.7 meters (8.9 feet) in diameter
Weight: 320 kilograms (705 pounds)
Science instruments: spectrometer to identify atmospheric makeup; aerosol collector for chemical analysis; imager; sensors to measure atmospheric structure; wind speed measurements; sensors to measure conditions at impact site

Launch
Launch vehicle: Titan IVB/ Centaur Upper Stage

Mission
Launch: October 15, 1997, from Cape Canaveral Air Force Station, FL.
Venus flybys: April 26, 1998, at 337 kilometers (209 miles); June 24, 1999, at 623 kilometers (387 miles)
Earth flyby: August 18, 1999, at 1,175 kilometers (730 miles)
Jupiter flyby: December 30, 2000, at 9.7 million kilometers (6 million miles)
Saturn arrival date: July 1, 2004
Huygens probe Titan entry date: November 27, 2004
Distance traveled to reach Saturn: 3.5 billion kilometers (2.2 billion miles)

Program
Partners: NASA, the European Space Agency (ESA), Italian Space Agency (ASI, for Agenzia Spaziale Italiana); total of 17 countries involved
U.S. states in which Cassini work has been carried out: 33
Cost of mission: Total about $3.26 billion, including $1.422 billion pre-launch development, $704 million mission operations, $54 million tracking and $422 million launch vehicle, for U.S.cost of $2.6 billion, plus $500 million ESA, $160 million ASI.

Galileo Quick Facts

Spacecraft

Spacecraft dimensions: 5.3 meters (17 feet) high; magnetometer boom extends 11 meters (36 feet) to one side

Orbiter weight: 2,223 kilograms (4,902 pounds), including 118 kilograms (260 pounds) of science instruments and 925 kilograms (2040 pounds) of usable rocket propellant

Orbiter science instruments: camera; spectrometers to identify atmospheric makeup; atmos pheric particles and reflectance studies; magnetic fields measurements; investigations of charged particles and dust; plasma wave detection

Power: 570 watts (at launch) from radioisotope thermal generators

Descent Probe

Probe size: 127 centimeters (50 inches) diameter, 91 centimeters (36 inches) high

Probe weight: 339 kilograms (750 pounds)

Probe instruments: Devices to measure temperature, pressure, atmospheric composition, clouds, particles, and energy from lightning

Launch

Launch vehicle: Space Shuttle Atlantis, on mission STS-34, carried Galileo and its two-stage Inertial Upper Stage into Earth orbit

Mission

Launch: October 18, 1989, from Kennedy Space Center, FL

Venus flyby: February 10, 1990, at 16,000 kilometers (10,000 miles)

Earth flybys: December 8, 1990, at 960 kilometers (597 miles); December 8, 1992, at 303 kilometers (188 miles)

Probe descent into Jupiter's atmosphere: December 7, 1995

Galileo orbiter in Jupiter orbit since: December 7, 1995

Current orbit number during fall 2000: 29

Program

Cost of mission:$1.39 billion plus foreign contribution of $110 million

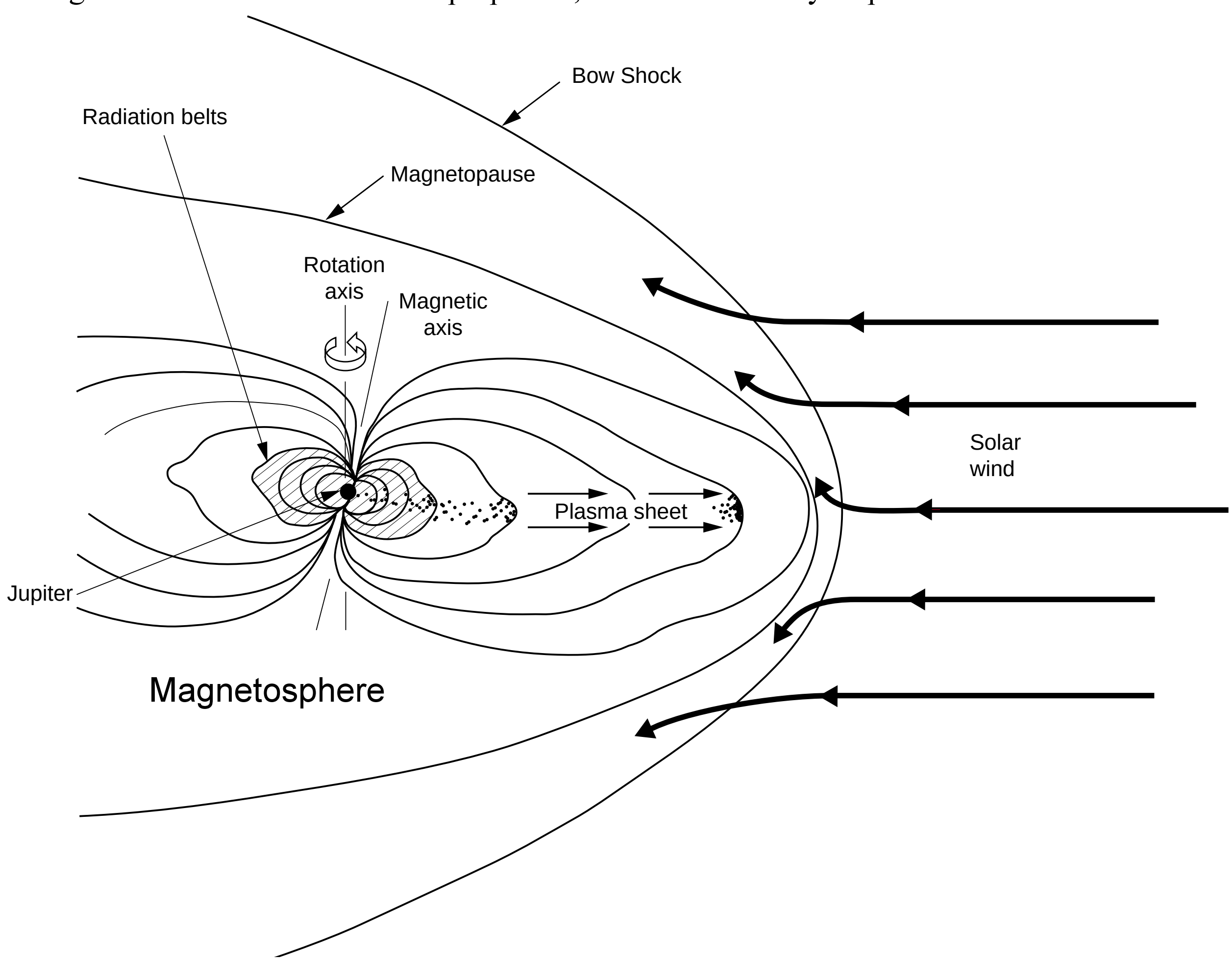
Millennium Flyby Science Objectives

The Cassini and Galileo spacecraft will study several aspects of Jupiter and its surrounding environment from October 2000 through March 2001, before, during and after Cassini's closest approach to Jupiter on December 30, 2000. Some of the scientific observations will take advantage of having two different vantage points in the vicinity of the planet at the same time. Some will make the most of using Cassini's measurement and transmission capabilities during its flyby to answer questions raised by longer-term Galileo observations. Here are some of the science objectives for Jupiter studies during the next few months:

❑ Examine interactions between the solar wind and Jupiter's magnetosphere by having one spacecraft inside the magnetosphere while the other is upstream in the solar wind.

❑ Detail Jupiter's atmospheric dynamics with Cassini imaging instruments in visible, infrared and ultraviolet wavelengths. Enough images are planned to produce a movie of jovian atmospheric dynamics.

❑ Observe Io and Ganymede during eclipses with both spacecraft to characterize surface gases and learn about surface properties, such as how fluffy or porous the surface is.



❑ Observe microscopic dust particles from Io with both spacecraft for information about their movement and composition.

❑ Study any changes in Io torus for connections with Io's volcanoes.

❑ Use Cassini spectrometers to study the surface composition of Jupiter's moons.

❑ Map changes in the highly directional "synchrotron" radio emissions from Jupiter's magnetosphere. Synchrotron radiation is the emission of very directional radio waves by electrons that are spiraling rapidly under the influence of the magnetic field.

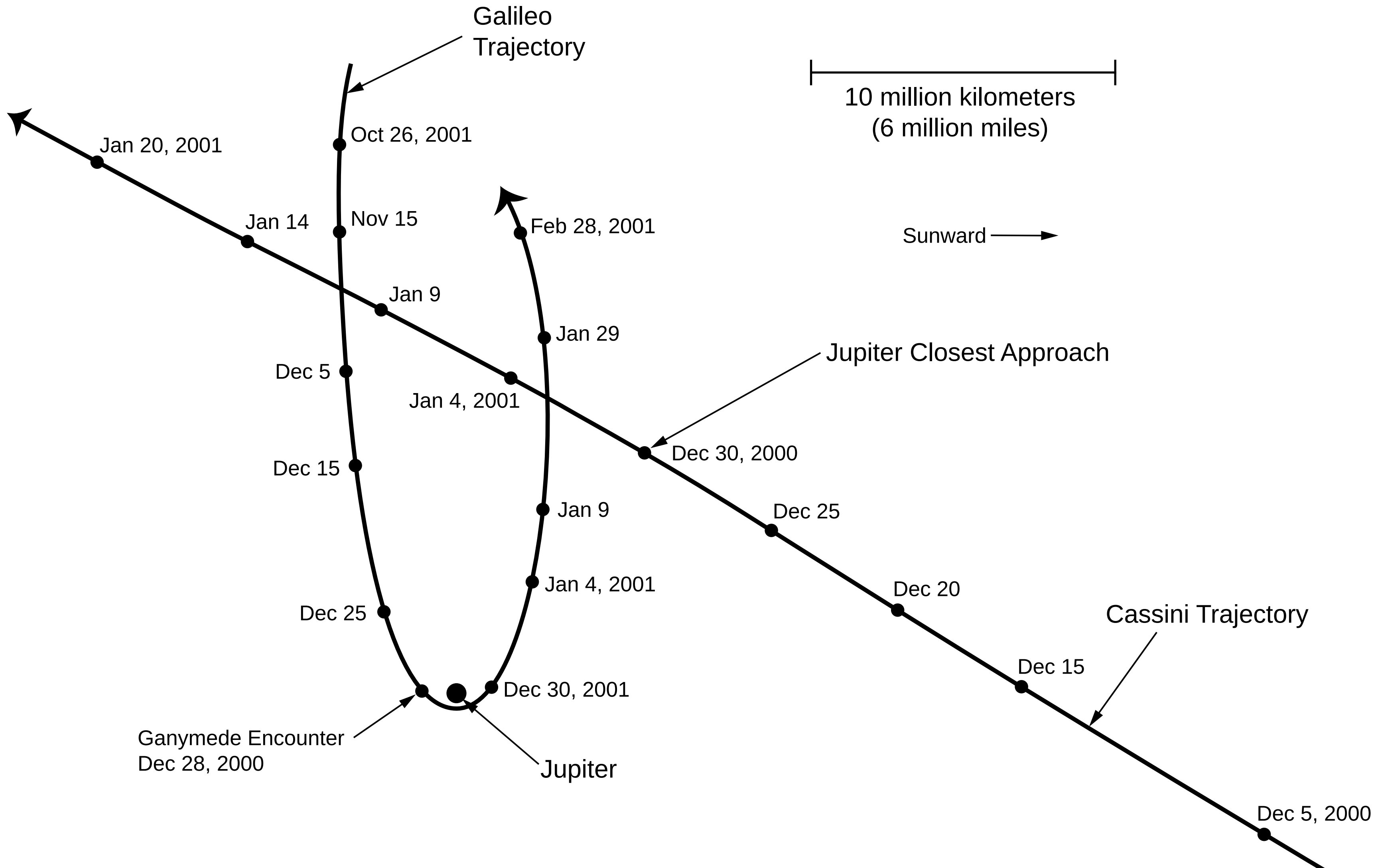
❑ Determine rotation period of the small moon Himalia.

❑ Study particle size in rings.

Telescopes on the ground will join Cassini and Galileo in studying Jupiter. Jupiter's synchrotron radiation will be studied in the radio wavelengths using the Very Large Array radio telescope in Socorro, New Mexico. A bit farther afield, in Earth orbit, the Hubble Space Telescope will be watching Jupiter as well. Observations coordinated between Cassini, Galileo and Hubble will study how Jupiter's aurora changes in response to changes in the solar wind near Jupiter and changes in Jupiter's magnetosphere.

Middle-school and high-school students participating in the Goldstone Apple Valley Radio Telescope project will also be watching Jupiter in radio wavelengths. Students will collect ground-based observations of Jupiter throughout the fall and winter using two radio telescopes located in Goldstone, CA. The students' observations will be combined with Cassini and Galileo observations to model the radiation environment of Jupiter's magnetosphere.

Galileo and Cassini at Jupiter
October 2000 – February 2001



Galileo and Cassini trajectories

Why Jupiter?

Jupiter predominates among our solar system's planets. It is more than twice as massive as all the other planets put together. It resembles the Sun in its hydrogen-rich composition and in having its own coterie of 17 diverse worlds in orbit around it.

The Planet

Jupiter is the fourth brightest natural object we see in the sky from Earth — after the Sun, Moon and Venus — so it has captured the attention of skywatchers since prehistoric times. It was named for the ruler and most powerful god of Roman mythology. Jupiter's size helps make it bright. Its volume is as great as 1,400 Earths. However, Jupiter's overall density is only a little more than the density of water. It is a gas planet, not a rocky one like Earth.

Through a telescope, Jupiter appears as a yellowish disc crossed with parallel orange-red bands. Since the mid-1600s, astromoners have noted spots moving across Jupiter's face as the planet rotates. Some of the spots and other cloud features last for years, much longer than clouds and storm systems do on Earth. Best known is the "Great Red Spot," an oval about three times as wide as Earth. It has likely persisted for more than three centuries.

Astronomers have used these moving spots to roughly gauge the planet's rotation period. A Jupiter "day" is less than 10 hours, making the biggest planet of the solar system also the quickest-spinning one. The fast twirling causes Jupiter to bulge out in the middle. Its diameter is about 10 percent greater at the equator than it is from pole to pole.

Four NASA spacecraft flew past Jupiter in the 1970s: Pioneer 10, Pioneer 11, Voyager 1 and Voyager 2. Their instruments returned data about Jupiter's atmosphere. The atmosphere is predominantly hydrogen and helium, with less than one percent from a combination of other ingredients, including methane, ammonia, phosphorus, water vapor, and various hydrocarbons.

How We Compare

Characteristic	***Earth***	***Jupiter***
Equatorial diameter	12,756 kilometers (7,926 miles)	142,984 kilometers (88,846 miles)
Mean density (grams per cubic centimeter)	5.52	1.33
Orbital revolution (Earth years)	1	11.86
Rotation period (hours)	23.93	9.92
Atmosphere	77% nitrogen 21% oxygen	86% hydrogen 14% helium

Jupiter's atmosphere displays alternating patterns of dark belts and light zones. The locations and sizes of the belts and zones change gradually with time. Within these belts and zones are clouds and storm systems that have raged for years. The Great Red Spot giant storm, rotates once counter-clockwise every six days. Since it is in the southern hemisphere of the planet, this rotational direction indicates it is a high-pressure zone, unlike Earth's cyclones, which are low-pressure zones.

Jupiter radiates more energy into space than it receives from the Sun. Its interior has a sustained temperature of approximately 20,000 degrees Kelvin (35,500 degrees Fahrenheit). The interior heat is generated by the slow gravitational compression of the planet. The heat flows outward from the planet's core, driving the circulation present in the Jovian atmosphere. This circulation process, called convection, involves the rise of hot gas from the Jovian interior to higher atmospheric layers where it cools and flows back down.

Jupiter's fast rotation combines with convection to drive the planet's global wind patterns. The light and dark bands visible through telescopes provide evidence of these processes. The white zones are colored by ammonia ice crystals while the dark belts are colored by unknown materials, collectively called chromophores. Theoretical studies indicate there are three cloud layers in the upper reaches of Jupiter's atmosphere. From the top down, the clouds are composed of ammonia ice, ammonium hydrosulfide, and water ice.

At some relatively unclouded and dry areas, heat from the planet's lower levels glows through brightly in infrared wavelengths. Galileo's atmospheric probe descended into one of these "hot spots" on Dec. 7, 1995.

The Jovian System

Just as the Sun has its solar system, Jupiter has its Jovian system. Studies of Jupiter's system have been advancing our understanding of the broader solar system for nearly four centuries.

In 1610, Galileo Galilee discovered Jupiter's four largest natural satellites, or moons: Io, Europa, Ganymede and Callisto. These four moons are now collectively called the Galilean satellites. This discovery was the first observational evidence of a center of motion not apparently centered on the Earth. It was a major argument in favor of Copernicus' heliocentric theory of the motions of the planets, which was an unpopular theory in early 17th century theology. Galileo's support of the Copernican theory got him arrested for heresy by the Inquisition and led to his life imprisonment under house arrest.

Researchers have now found 17 moons circling Jupiter. The latest discovery was announced in June 2000. They range from Ganymede, larger than the planets Mercury or Pluto, to rocks less than 50 kilometers (30 miles) across. NASA's Galileo spacecraft, orbiting Jupiter since 1995, has returned a steady stream of information about features of the Galilean satellites, such as the volcanoes on Io and ice on Europa. The spacecraft has provided several lines of evidence that Europa may cloak a deep ocean of liquid water under its surface ice. That has fueled speculation about possible life there, since life as we know it requires liquid water.

Besides moons, the Jovian system includes dark rings and a huge magnetosphere of energetic particles moving under the influence of the planet's strong magnetic field.

Jupiter's Moons

Jupiter's natural satellites take their names from women, nymphs and boys linked to the god Jupiter, or Zeus, in Roman and Greek mythology.

Jupiter's Moons

Satellite	Discovery	Orbit (from Jupiter)	Diameter	Orbital Period
Metis	1979	128,000 km (80,000 miles)	40 km (25 miles)	7 hours
Andrastea	1979	129,000 km (80,000 miles)	20 km (12 miles)	7 hours
Amalthea	1892	181,300 km (113,000 miles)	270 x166 km (167 x103 miles)	12 hours
Thebe	1979	222,000 km (138,000 miles)	100 x 90 km (62 x 56 miles)	16 hours
Io	1610	422,000 km (262,000 miles)	3,630 km (2,256 miles)	1.77 days
Europa	1610	671,000 km (416,000 miles)	3,138 km (2,256 miles)	3.55 days
Ganymede	1610	1,070,000 km (665,000 miles)	5,262 km (3,270 miles)	7.15 days
Callisto	1610	1,883,000 km (1,170,000 miles)	4,800 km (2,983 miles)	16.7 days
Leda	1974	11,094,000 km (6,895,000 miles)	16 km (10 miles)	239 days
Himalia	1904	11,480,000 km (7,135,000 miles)	186 km (116 miles)	251 days
Lysithea	1938	11,720,000 km (7,284,000 miles)	36 km (22 miles)	260 days
Elara	1905	11,737,000 km (7,295,000 miles)	76 km (47 miles)	260 days
Ananke	1951	21,200,000 km (13,176,000 miles)	30 km (19 miles)	631 days
Carme	1938	22,600,000 km (14,046,000 miles)	40 km (25 miles)	692 days
Pasiphae	1908	23,500,000 km (14,605,000 miles)	50 km (31 miles)	735 days
Sinope	1914	23,700,000 km (14,730,000 miles)	36 km (22 miles)	758 days
S/1999 J1	2000	24,200,000 km (15,040,000 miles)	12 km (7 miles)	774 days

Four small moons orbit closer to Jupiter than any of the Galilean moons do.

Metis, the innermost, and Adrastea, next closest in, were both discovered through data from the Voyager 1 flyby in 1979. Metis and Adrastea lie within Jupiter's main ring and may be the sources of material for the ring.

Amalthea, next out, was discovered in 1892 by Edward Emerson Barnard. It has an irregular shape, much longer in one dimension than others. Some of its many craters are extremely large relative to the size of the moon. The surface shows a dark red color, possibly from a dusting of sulfur from Io's volcanoes. Bright patches of unidentified green material appear on major slopes of Amalthea.

Thebe, the fourth innermost of Jupiter's satellites, also was discovered through Voyager 1 data. Thebe takes about 16 hours to complete each orbit around Jupiter.

Active lava flows are resurfacing portions of Io, the most volcanically active world in the solar system. Plumes from the volcanoes extend to more than 300 kilometers (190 miles) above the surface, with material being ejected at speeds up to a kilometer (0.6 miles) per second. Io's volcanoes apparently result from heating of the moon by tidal pumping. Io is perturbed in its orbit by Europa and Ganymede, two other large moons nearby. As a consequence of the forced eccentric orbit, the distance between Io and Jupiter changes as Io orbits, and the large gravitational pull from Jupiter results in tidal bulging as great as 100 meters (330 feet) on Io's surface.

Io is located within an intense radiation belt of electrons and ions trapped in Jupiter's magnetic field. As the magnetosphere rotates with Jupiter, it sweeps past Io and strips away about 1,000 kilograms (1 ton) of material per second. The material forms a torus, a doughnut-shaped cloud of ions that glow in the ultraviolet. The torus's heavy ions migrate outward, and their pressure inflates the Jovian magnetosphere to more than twice its expected size. Some of the more energetic sulphur and oxygen ions fall along the magnetic field into the planet's atmosphere, resulting in auroras.

Europa shows a bright surface of ice, with few craters but many intersecting linear features, apparently left from fissuring of the ice. Gravity measurements by Galileo show the uppermost layers of Europa to a depth of about 100 kilometers (60 miles) to consist of water, either frozen or liquid. Internal heating from tidal forces similar to Io's may keep some of the water ice melted.

Pictures from the Galileo spacecraft show large rafts of ice that have apparently broken away from each other and rearranged themselves. That is one line of evidence for a fluid layer underneath. Another comes from magnetic-field features that could be explained by a layer of electrically conductive saltwater, but not by solid ice.

Ganymede is the largest moon in our solar system. Like Callisto, the next farthest out, Ganymede likely has a rocky core with a water-ice mantle and a crust of rock and ice.

Ganymede has had a complex geological history. It has mountains, valleys, craters and lava flows. Ganymede is mottled by both light and dark regions. It is heavily cratered in the dark regions, implying ancient origin. The bright regions show a different kind of terrain, grooved with ridges and troughs. The grooved features were apparently formed more recently than the dark, cratered area, perhaps by tension from global tectonic processes.

Callisto, second-largest of Jupiter's moons, orbits just beyond the planet's main radiation belt. Callisto is the most heavily cratered satellite in the solar system. Its crust dates back 4 billion years, shortly after the solar system was formed.

Callisto has the lowest density of the Galilean satellites, though it is still denser than Jupiter itself. From recent observations made by the Galileo spacecraft, Callisto appears to have and icy crust about 200 kilometers (124 miles) thick. Beneath the crust is a possible salty ocean more than 10 kilometers (6 miles) deep. The Galileo data suggest the interior is composed of compressed rock and ice with the percentage of rock increasing as depth increases. Meteorites have punched holes in Callisto's crust, causing water to spread over the surface and form bright rays and rings around the craters.

Jupiter's nine outer moons fall into two distinct orbital groups. Leda, Himalia, Lysithea, and Elara all orbit at approximately 11 million kilometers (7 million miles) from Jupiter. Ananke, Carme, Pasiphae, Sinope, and the most recently discovered, still unnamed moon orbit at approximately 23 million kilometers (14 million miles). None of these 8 outer satellites has been explored in any detail or with enough resolution to gain a full understanding of the nature of the terrain.

Jupiter's Rings

The three known rings around Jupiter are thin and very dark. Only about five percent of the sunlight falling on the rings is reflected back. Because of this combination, the rings remained hidden from human discovery until the Voyager 1 spacecraft saw them backlit by the sun in 1979.

Jupiter's Rings

Ring	Distance from Jupiter*	Ring Width
Halo	92,000 km (57,178 miles)	30,500 km (18,956 miles)
Main	122,500 km (76,134 miles)	6,440 km (4,002 miles)
Gossamer	128,940 km (80,136 miles)	100,000 km (62,150 miles)

** Distance is measured from Jupiter's center to the ring's inner edge.*

The rings' dark appearance suggests they are composed of grains of rocky material and contain little or no ice. This differs from Saturn's vast ring system, which is primarily water ice in composition.

Atmospheric and magnetic drag doesn't allow particles in Jupiter's rings to remain in orbit for long. Data from the Galileo spacecraft shows that ring material is being constantly resupplied by dust formed through micrometeorite impacts on Jupiter's four innermost satellites.

Jupiter's Magnetosphere

The layer of metallic hydrogen within fast-spinning Jupiter generates an enormous magnetic field around the planet. Earth also has a magnetic field, generated by turning of Earth's iron core, but Jupiter's is much stronger, the strongest of any planet's.

Jupiter's magnetosphere is a tear-shaped bubble of charged particles — electrons and ions — constrained under the influence of the magnetic field. It is the largest thing in the solar system except the solar wind, which reaches across the entire solar system. Jupiter's magnetosphere tails outward past the orbit of Saturn and, if it shined in the visible wavelengths of the spectrum instead of at radio wavelengths, it would appear two to three times wider than the disc of the Sun or Moon to viewers on Earth.

The inner part of Jupiter's magnetosphere is doughnut-shaped, but farther out it flattens into a disc. The magnetic poles are tilted relative to Jupiter's axis of rotation, so the field appears to wobble around with Jupiter's fast rotation, sweeping up and down across the inner moons and making waves throughout the magnetosphere.

The solar wind, a variable flow of electrically charged particles blowing outward from the Sun, interacts with the magnetosphere. The field deflects most of the solar wind particles, and the wind shapes the magnetosphere. The boundary between the solar wind and the magnetosphere is called the "magnetopause." A "bow shock," named for the wave that builds up before a ship's bow as it plows through water, is formed in the solar wind upstream from the magnetopause. Downstream, on the side of the planet away from the Sun, the drag of the solar wind draws the magnetosphere out into an elongated "magnetotail."

Cassini Spacecraft/Mission

The Cassini mission to Saturn is the one of the most ambitious efforts in planetary space exploration ever mounted. A joint endeavor of NASA and the European Space Agency (ESA), with additional involvement of the Italian Space Agency, Agenzia Spaziale Italiana, Cassini will study the Saturnian system in detail over a four-year period beginning in 2004.

The sophisticated robotic spacecraft will go into orbit around the ringed planet, and will deliver a scientific probe called Huygens to be released from the main spacecraft to parachute through the atmosphere to the surface of Saturn's largest and most interesting moon, Titan.

Cassini's journey began on October 15, 1997, with liftoff of a Titan IVB/Centaur launch vehicle from Pad 40 at the Cape Canaveral Air Force Station in Florida.

In maneuvers called gravity-assist flybys, Cassini has flown twice past Venus then once past Earth. These flybys increased the spacecraft's speed as it approached and flew past each planet.

Jupiter Flyby

Those three gravity assists could not give Cassini quite as much cumulative boost as it needs to reach Saturn. The main reason Cassini will fly near Jupiter in December 2000 is for a final gravity assist. The opportunity to do some science at Jupiter is a side benefit. The Jupiter studies will also put Cassini's instruments, systems and personnel through a thorough checkout preparation for Saturn.

Cassini's distance from Jupiter at the time of its closest approach, at 5:12 a.m. Eastern Standard Time on December 30, 2000, will be about 9.7 million kilometers (6 million miles). That is well beyond the orbits of Jupiter's four largest moons, but within the orbits of nine small ones. It is the distance calculated to give the spacecraft just the right gravitational assist needed for the final leg of its trip to Saturn.

After a nearly seven-year journey, Cassini will arrive at Saturn July 1, 2004, where it will enter orbit and begin its detailed scientific observations of the Saturnian system.

Saturn is the second largest planet in the solar system. Like the other gaseous outer planets — Jupiter, Uranus and Neptune – its atmosphere is made up mostly of hydrogen and helium. Saturn's distinctive, bright rings are made up of ice and rock particles ranging in size from grains of sand to boxcars. More moons of greater variety orbit Saturn than any other planet. So far, observations from Earth and by spacecraft have found 18 Saturnian satellites ranging from small asteroid-size bodies to the aptly named Titan, which is larger than the planet Mercury. The 12 scientific instruments on the Cassini orbiter will conduct in-depth studies of the planet, its moons, rings and magnetic environment. The six instruments on the Huygens probe, which will be dispatched from Cassini during its first orbit of Saturn, will provide our first direct sampling of Titan's atmospheric chemistry and the first photographs of its hidden surface.

Saturn's face appears placid, but masks a windswept atmosphere where an equatorial jetstream blows at 1,800 kilometers per hour (1,100 miles per hour) and swirling storms roil beneath the cloudtops. Early explorations by NASA's Pioneer and Voyager spacecraft between 1979 and 1981 also found Saturn to possess a huge and complex magnetic environment where trapped protons and electrons interact with each other, the planet, the rings and the surfaces of many of the satellites. Saturn's famous rings were found to consist of not just a few monolithic bands but thousands of rings and ringlets with particles sometimes herded into complicated orbits by the gravitational interaction of small moons previously unseen from Earth.

Haze-covered Titan offers a tantalizing mix of a nitrogen-methane atmosphere and a surface that may feature chilled lakes of ethane or coatings of sticky brown organic condensate that has rained down from the atmosphere. Standing on Titan's surface beneath an orange sky, a visitor from Earth likely would find a cold, exotic world with a pungent odor reminiscent of a petroleum processing facility. Because Titan and Earth share so much in atmospheric composition, Titan is thought to hold clues to how the primitive Earth evolved into a life-bearing planet.

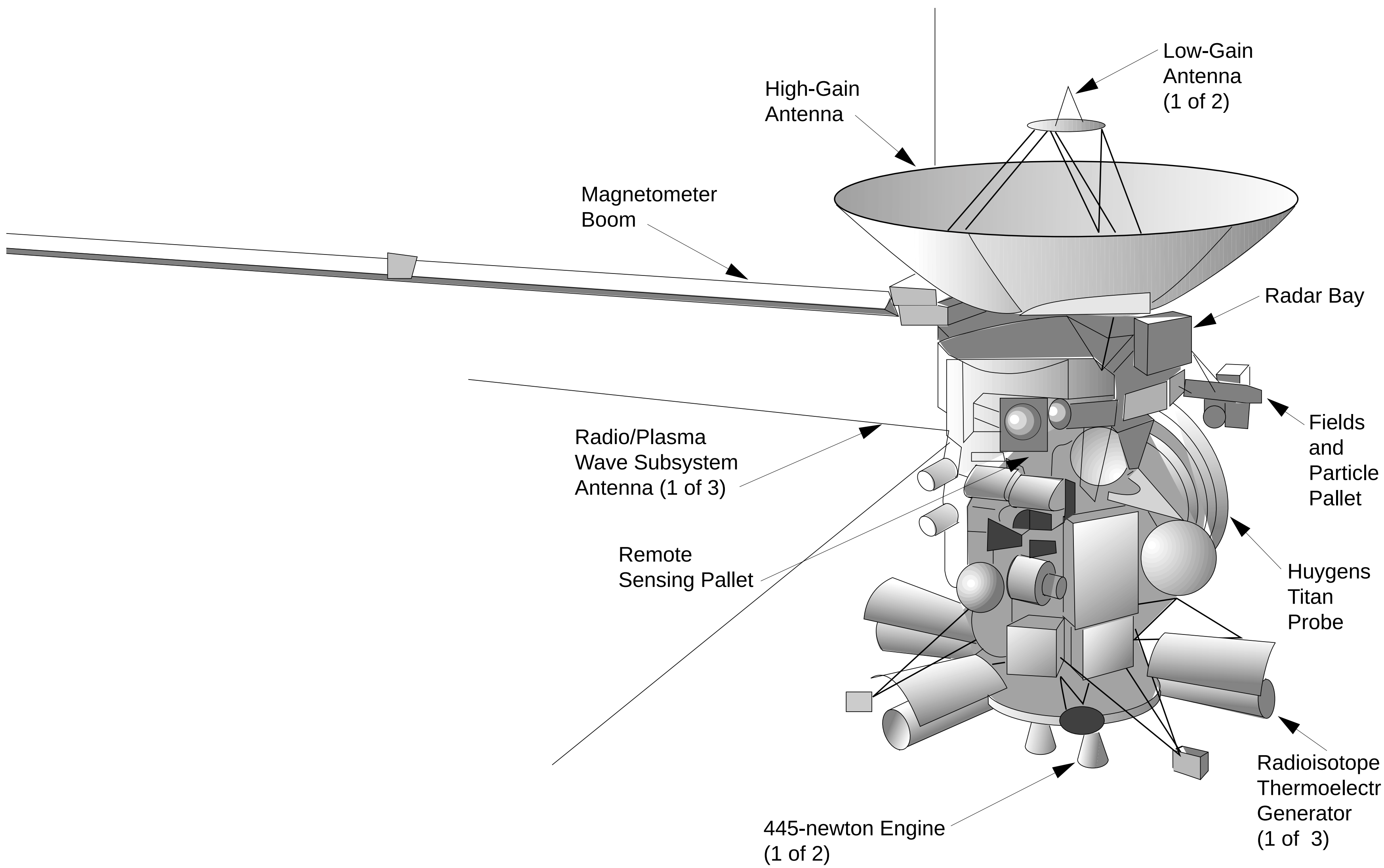
Mission at Saturn

Upon reaching Saturn on July 1, 2004, Cassini will fire its main engine for 96 minutes to brake the spacecraft's speed and allow it to be captured as a satellite of Saturn. Passing through the dusty, outer-most E-ring, Cassini will swing in close to the planet — to an altitude only one-sixth the diameter of Saturn itself — to begin the first of some six dozen orbits during the rest of its four-year mission.

On November 6, 2004, Cassini will release the European-built Huygens probe toward Titan. On November 27, Huygens will enter Titan's atmosphere, deploy its parachutes and begin its scientific observations during a descent of up to two and a half hours through that moon's dense atmosphere. Instruments onboard will measure the temperature, pressure, density and energy balance in the atmosphere. As the probe breaks through the cloud deck, a camera will capture pictures of the Titan panorama. Titan's surface properties will be observed, and about 1,000 images of the clouds and surface will be returned. In the final moments of descent, a spotlight will illuminate the surface for the camera.

If the probe survives landing at about 25 kilometers per hour (15 miles per hour), it can possibly return data from Titan's surface, where the atmospheric pressure is 1.6 times that of Earth's. The probe could touch down on solid ground, ice or even splash down in a lake of ethane or methane. One instrument on board will discern whether Huygens is bobbing in liquid, and other instruments on board would tell the chemical composition of that liquid. Throughout its mission, Huygens will radio data collected by its instruments to the Cassini orbiter to be stored and then relayed to Earth.

If the probe continues to send data to Cassini from Titan's surface, it will be able to do so for only about 30 minutes, when the probe's battery power is expected to run out.



Cassini spacecraft

After the Huygens probe mission is complete, Cassini's focus will be on taking measurements with the orbiter's 12 instruments and returning the information to Earth. During the course Cassini's mission, it will execute dozens of close flybys of Titan and several close flybys of selected icy moons. In addition, the orbiter will make other, more-distant flybys of Saturn's moons. Cassini's orbits will also allow it to study Saturn's polar regions in addition to the planet's equatorial zone.

The Cassini Spacecraft

The Cassini spacecraft, including the orbiter and the Huygens probe, is one of the largest, heaviest and most complex interplanetary spacecraft ever built. The orbiter alone weighs 2,125 kilograms (4,685 pounds). With the 320-kilogram (705-pound) Huygens probe and a launch vehicle adapter attached, and 3,132 kilograms (6,905 pounds) of propellants loaded, the spacecraft weighed 5,712 kilograms (12,593 pounds) at launch. Only the two Phobos spacecraft sent to Mars by the former Soviet Union were heavier.

The Cassini spacecraft stands more than 6.7 meters (22 feet) high and is more than 4 meters (13 feet) wide. The magnetometer instrument is mounted on an 11-meter (36-foot) long boom that extends outward from the spacecraft. Three other rod-like booms that each reach 10 meters (about 32 feet) outward from the spacecraft are antennas for the radio plasma wave subsystem.

The complexity of the spacecraft is necessitated both by its flight path to Saturn and by the ambitious program of scientific observations to be undertaken once the spacecraft reaches its destination. It has 22,000 wire connections and more than 14 kilometers (8.7 miles) of cabling. Because of the very dim sunlight at Saturn's orbit, solar arrays are not feasible, so electrical power is supplied by a set of radioisotope thermoelectric generators, which use heat from the natural decay of plutonium-238 to generate electricity to run Cassini's systems. These power generators are of the same design as those used on the Galileo and Ulysses missions.

Science Experiments

Equipment for 12 science experiments is carried onboard the Cassini orbiter. Another six fly on the Huygens probe. Descriptions of the instuments and the names of the principal investigators or team leaders are:

Orbiter

- ❑ **Imaging Science Subsystem**: Takes pictures in visible, near-ultraviolet and near-infrared light. Dr. Carolyn Porco, University of Arizona, Tucson, AZ.

- ❑ **Cassini Radar**: Maps surface of Titan using radar imager to pierce veil of haze. Also used to measure heights of surface features. Dr. Charles Elachi, NASA's Jet Propulsion

Laboratory, Pasadena, CA.

- **Radio Science Subsystem**: Searches for gravitational waves in the universe; studies the atmosphere, rings and gravity fields of Saturn and its moons by measuring telltale changes in radio waves sent from the spacecraft. Dr. Arvydas J. Kliore, NASA's Jet Propulsion Laboratory, Pasadena, CA.

- **Ion and Neutral Mass Spectrometer**: Examines neutral and charged particles near Titan, Saturn and the icy satellites to learn more about their extended atmospheres and ionospheres. Dr. J. Hunter Waite, Southwest Research Institute, San Antonio, TX.

- **Visible and Infrared Mapping Spectrometer**: Identifies the chemical composition of the surfaces, atmospheres and rings of Saturn and its moons by measuring colors of visible light and infrared energy given off by them. Dr. Robert H. Brown, University of Arizona, Tucson, AZ.

- **Composite Infrared Spectrometer**: Measures infrared energy from the surfaces, atmospheres and rings of Saturn and its moons to study their temperature and composition. Virgil Kunde, NASA's Goddard Space Flight Center, Greenbelt, MD.

- **Cosmic Dust Analyzer**: Studies ice and dust grains in and near the Saturn system. Dr. Eberhard Grun, Max Planck Institut fur Kernphysik, Heidelberg, Germany.

- **Radio and Plasma Wave Spectrometer**: Investigates plasma waves (generated by ionized gases flowing out from the Sun or orbiting Saturn), natural emissions of radio energy and dust. Dr. Donald A. Gurnett, University of Iowa, Iowa City, IA.

- **Cassini Plasma Spectrometer**: Explores plasma (highly ionized gas) within and near Saturn's magnetic field. Dr. David T. Young, University of Michigan, Ann Arbor, MI.

- **Ultraviolet Imaging Spectrograph**: Measures ultraviolet energy from atmospheres and rings to study their structure, chemistry and composition. Dr. Larry Esposito, University of Colorado, Boulder, CO.

- **Magnetospheric Imaging Instrument**: Images Saturn's magnetosphere and measures interactions between the magnetosphere and the solar wind, a flow of ionized gases streaming out from the Sun. Dr. Stamatios M. Krimigis, Johns Hopkins University Applied Physics Laboratory, Baltimore MD.

- **Dual Technique Magnetometer**: Studies Saturn's magnetic field and its interactions with the solar wind, the rings and the moons of Saturn. Dr. David J. Southwood, Imperial College of Science & Technology, London, England.

Huygens Probe

❑ **Descent Imager and Spectral Radiometer**: Makes images and measures temperatures of particles in Titan's atmosphere and on Titan's surface. Dr. Martin Tomasko, University of Arizona, Tucson, AZ.

❑ **Huygens Atmospheric Structure Instrument**: Explores the structure and physical properties of Titan's atmosphere. Dr. Marchello Fulchignoni, Paris Observatory, Meudon, France.

❑ **Gas Chromatograph and Mass Spectrometer**: Measures the chemical composition of gases and suspended particles in Titan's atmosphere. Dr. Hasso B. Neimann, NASA's Goddard Space Flight Center, Greenbelt, MD.

❑ **Aerosol Collector Pyrolyzer**: Examines clouds and suspended particles in Titan's atmosphere. Dr. Guy M. Israel, Service d'Aeronomie du Centre National de la Recherche Scientifique, Verrieres-le-Buisson, France.

❑ **Surface Science Package**: Investigates the physical properties of Titan's surface. Dr. John C. Zarnecki, University of Kent, England.

❑ **Doppler Wind Experiment**: Studies Titan's winds from their effect on the probe during its descent. Dr. Michael K. Bird, University of Bonn, Germany.

Cassini Signature Disk

In August 1997, a small digital versatile disk (DVD) was installed aboard the Cassini spacecraft during processing at NASA's Kennedy Space Center. The disk contains a record of 616,400 handwritten signatures from 81 countries around the globe. Signatures were received from people of all ages and backgrounds.

Mail came from individuals, families and, often, from entire schools of students. Signatures came from the very young, just learning to write, and from the very old, whose hands were no longer steady. Signatures were sent in behalf of loved ones who had died in the recent past. Even the signatures of Jean-Dominique Cassini and Christiaan Huygens were obtained from letters they wrote during the 17th century.

Sorting, counting and scanning the signatures was performed by volunteers from The Planetary Society, Pasadena, Calif.

Galileo Spacecraft/Mission

NASA's Galileo spacecraft was designed to study the large, gaseous planet Jupiter, its moons, and its surrounding magnetosphere, which is a magnetic bubble surrounding the planet. The craft was named for the Italian Renaissance scientist who discovered Jupiter's major moons in 1610 with the first astronomical telescope.

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. Its primary mission included a 23-month, 11-orbit tour of the Jovian system, including 10 close encounters of Jupiter's major moons.

Although the primary mission was completed in December 1997, the mission has been extended twice since then. The first extended mission, known as the Galileo Europa mission included 14 additional encounters of Jupiter's major moons — eight with Europa, four with Callisto and two with Io. The Galileo Millenium mission, in progress through the end of 2000, has included additional flybys of Io and Ganymede.

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 two-stage IUS solid rocket then accelerated the spacecraft out of Earth orbit toward the planet Venus for the first of three planetary "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 three and a half years to Jupiter, using a three-stage IUS. When this vehicle was canceled, plans were changed to a Centaur upper stage, and ultimately to the two-stage IUS, which precluded a direct trajectory. To save the project, Galileo engineers designed a 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. That flyby increased Galileo's speed enough to send it on a two-year elliptical orbit around the Sun. 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. Scientists obtained the first views of mid-level clouds on Venus and confirmed the presence of lightning on that planet.

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 sunshades and pointed the top of the spacecraft toward the Sun, with the umbrella-like high-gain antenna furled 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."

On August 28, 1993, Galileo carried out a second asteroid encounter, this time with a larger, more distant asteroid named Ida. Ida is about 55 kilometers (34 miles) long and 24 kilometers (15 miles) wide. Observations indicated that both Ida and Gaspra have magnetic fields, although Ida is older and its surface is covered with craters. Scientists discovered 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 (less than a mile). By determining Dactyl's orbit, scientists estimated Ida's density.

Comet Shoemaker-Levy

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 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 before deploying its parachute and dropping a heat shield.

The wok-shaped probe floated down about 200 kilometers (125 miles) through the clouds, transmitting data to the orbiter on sunlight and heat flux, pressure, temperature, winds, lightning and atmospheric composition. Fifty-eight minutes into its descent, high temperatures silenced the probe's transmitters. The probe sent data from a depth with a pressure 23 times that of the average on Earth's surface, more than twice the mission requirement.

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 orbit 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 helped mitigate possible damage to spacecraft sensors and computer chips from Jupiter's intense radiation environment.

During this first orbit, new software was installed which gave the orbiter extensive new onboard data processing capabilities. It permitted data compression, enabling 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 were. So many new 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. 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 until the next encounter in orbital "cruise," playing back the information in transmissions to Earth.

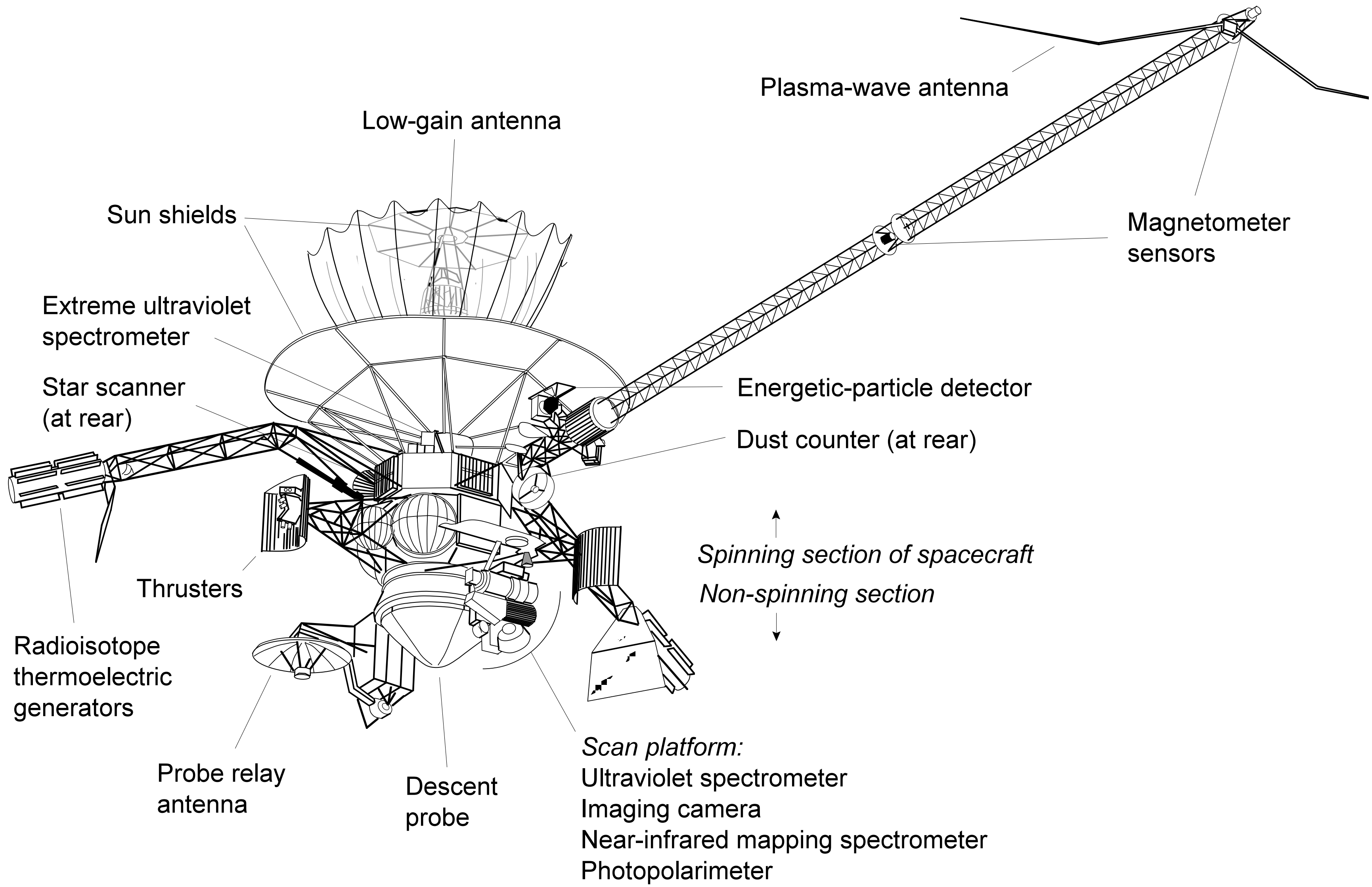
Extended Mission

A two-year extension, the Galileo Europa Mission, began in December 1997 and included intensive study of Europa through eight consecutive close encounters. The flybys added to knowledge about Europa's frozen surface and the intriguing prospect that liquid oceans may lie underneath. In addition, Galileo studied Callisto in four flybys, and approached Io twice, gathering new information on Io's volcanic activity. The Galileo Millenium Mission added another year of operations, including more flybys of Io and Ganymede, plus the joint studies with the Cassini spacecraft as it passes Jupiter in December 2000 for a gravity assist toward Saturn.

Spacecraft

The Galileo orbiter weighed 2,223 kilograms at launch (2-1/2 tons) and measured 5.3 meters (17 feet) from the top of the low-gain antenna to the bottom of the 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, and a "despun" section is counter-rotated to provide a fixed orientation for cameras and other remote sensors. A star scanner on the spinning side determines orientation and spin rate; gyroscopes on the despun 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. The spinning section also carries instruments to study magnetic fields and charged particles. These instruments include magnetometer sensors mounted on an 11-meter (36-foot) boom to minimize interference from the spacecraft's electronics; a



Galileo spacecraft

plasma instrument to detect low-energy charged particles; and a plasma-wave detector to study electromagnetic waves generated by the particles. There is also a high-energy particle detector and 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 de-spun section carries instruments 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 (CCD) sensor is much more sensitive than previous spacecraft cameras and is able to detect a broader color band. Galileo's de-spun 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 (22.5 pound force) thrusters and a single 400-newton (90 pound force) engine which use monomethyl-hydrazine fuel and nitrogen-tetroxide oxidizer. The propulsion system was developed and built by Messerschmitt-Bolkow-Blohm (MBB) 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.

These sequences operate through flight software installed in the spacecraft computers, with built-in automatic fault protection software designed to 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 natural radioactive decay of plutonium is converted to electricity (570 watts at launch, 485 at the end of the mission) to operate the orbiter spacecraft'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, Ulysses to study the Sun, and Cassini to Saturn.

Descent Probe

Galileo's descent probe had a mass of 339 kilograms (750 pounds), and included a deceleration module to slow and protect the descent module. The deceleration module consisted of an aeroshell and an aft cover designed to block heat generated by friction during atmospheric entry. Inside the aeroshells were the 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.

Orbiter Instruments

The Galileo orbiter spacecraft carries 11 scientific instruments. Another seven were on the descent probe. One engineering instrument on the orbiter, originally for measurements to aid design of future spacecraft, also collects scientific information. The orbiter instruments, what they study, and their principal investigators or team leaders are:

Remote sensing instruments on the non-spinning section

❑ **Solid-State Imaging Camera**: Galilean satellites, high resolution, atmospheric small-scale dynamics. Dr. Michael Belton, National Optical Astronomy Observatories, Tucson, AZ.

❑ **Near-Infrared Mapping Spectrometer**: Surface and atmospheric composition thermal mapping. Dr. Robert Carlson, NASA's Jet Propulsion Laboratory, Pasadena, CA.

❑ **Photopolarimeter-Radiometer**: Atmospheric particles, thermal/reflected radiation. Dr. James Hansen, Goddard Institute for Space Studies, New York, NY.

❑ **Ultraviolet Spectrometer/Extreme Ultraviolet Spectrometer Experiment**: Atmospheric gases, aerosols. Dr. Ian Stewart, University of Colorado, Boulder, CO.

Instruments on the spinning section, studying magnetic fields and charged particles

❑ **Magnetometer**: Strength and fluctuation of magnetic fields. Dr. Margaret Kivelson, University of California, Los Angeles, CA.

❑ **Energetic Particle Detector**: Electrons, protons, heavy ions. Dr. Donald Williams, Johns Hopkins University Applied Physics Laboratory, Laurel, MD.

❑ **Plasma Investigation**: Composition, energy, distribution of ions. Dr. Lou Frank, University of Iowa, Iowa City, IA.

❑ **Plasma Wave Subsystem**: Electromagnetic waves and wave-particle interactions. Dr. Donald Gurnett, University of Iowa, Iowa City, IA.

❑ **Dust-Detection Subsystem**: Mass, velocity, charge of submicrometer particles. Dr. Eberhard Grun, Max Planck Institut fur Kernphysik, Heidelberg, Germany.

Radio Science

❑ **Celestial Mechanics**: Masses and internal structures of bodies from spacecraft tracking. John Anderson, NASA's Jet Propulsion Laboratory, Pasadena, CA.

❑ **Propagation**: Satellite radii and atmospheric structure from radio propagation. H. Taylor Howard, Stanford University, Stanford, CA.

Engineering Experiment

❑ **Heavy Ion Counter**: Spacecraft charged-particle environment, ion flow from solar flares. Dr. Edward Stone, California Institute of Technology, Pasadena, CA.

Galileo Discoveries

The Galileo mission has returned a wealth of scientific findings since it arrived at Jupiter December 7, 1995. It began accomplishing a string of technical firsts even earlier.

❑ Jupiter has many large thunderstorms, with lightning strokes up to 1,000 times more powerful than those on Earth.

❑ Jupiter's atmosphere has a wide range of cloudiness and water vapor, just as Earth has humidity zones ranging from the Sahara to the tropics.

❑ Evidence of liquid water oceans beneath Europa's surface, which boosts the odds of life existing there. Iceberg-like "rafting," or floating ice chunks are apparent.

❑ Europa is criss-crossed by faults and ridges.

❑ Europa, Ganymede and Io have metallic cores with separated layers; Callisto has no core and less separation between layers.

❑ Europa is surrounded by an ionosphere, a cloud of electrically-charged gases.

❑ Ganymede has a very thin hydrogen atmosphere, a magnetic field, and magnetosphere. It is the first satellite known to possess a magnetic field.

❑ Ganymede's surface has faults, fractures, and some evidence of volcanic flows.

❑ Callisto's surface is blanketed by powder-like debris, perhaps created some unknown erosional process.

❑ Io is very active volcanically (perhaps 10 times more than Earth), and its surface is continually changing. During one four-month period observed by Galileo, volcanic debris spread over an area the size of Arizona.

Technical Firsts

❑ First flyby and imaging of an asteroid (Gaspra and later, Ida).

❑ Discovered first moon around an asteroid (the moon Dactyl orbits asteroid Ida).

❑ Only direct observation of Comet Shoemaker-Levy 9's impact into Jupiter's atmosphere.

❑ First spacecraft to deploy an entry probe into an outer planet's atmosphere. The Galileo probe measured the atmospheric composition and structure of Jupiter's atmosphere and provided clues to the origin of Jupiter and giant planets in other star systems.

❑ First and so far the only spacecraft to orbit an outer planet. (Cassini at Saturn in 2004 will become the second spacecraft to enter orbit around one of the outer planets.)

Deep Space Network

NASA's scientific investigations of the solar system are accomplished mainly through the use of robotic spacecraft, such as Galileo and Cassini. The Deep Space Network provides the two-way communications link that guides and controls spacecraft and brings back images and other scientific data they collect. The Deep Space Network encompasses complexes strategically placed on three continents. The largest and most sensitive scientific telecommunications system in the world, it also performs radio and radar astronomy observations for the exploration of the solar system and the universe. It is managed and operated for NASA by the Jet Propulsion Laboratory, a division of the California Institute of Technology.

The network features three deep-space communications complexes placed approximately 120 degrees apart around the world: at Goldstone in California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia. This configuration ensures that an antenna is always within sight of a given spacecraft, day and night, as the Earth rotates. Each complex contains up to 10 deep-space stations equipped with large parabolic reflector antennas.

Antennas and Facilities

Each of the network's complexes has one 70-meter-diameter (230-foot) antenna. These are the largest and most sensitive antennas, capable of tracking spacecraft traveling more than 16 billion kilometers (10 billion miles) from Earth. The surface of the 70-meter reflector must remain accurate within a fraction of the signal wavelength, meaning that the precision across the 3,850-square-meter (4,600-square-yard) surface is maintained within one centimeter (0.4 inch). The dish reflector and its mount weigh nearly 2.7 million kilograms (2,970 U.S. tons). Each complex also has a 34-meter-diameter (112-foot) high-efficiency antenna, incorporating more recent advances in antenna design and mechanics. The reflector surface is precision-shaped for maximum signal-gathering capability.

The most recent additions to the Deep Space Network are several 34-meter beam waveguide antennas. On earlier DSN antennas, sensitive electronics were centrally mounted on the hard-to-reach reflector structure, making upgrades and repairs difficult. On beam waveguide antennas, however, such electronics are located in a below-ground pedestal room, with the radio signal brought from the reflector to this room through a series of precision-machined radio frequency reflective mirrors. Not only does this architecture provide the advantage of easier access for enhancements and maintenance, but it also allows for better thermal control for critical electronic components and for more electronics to be placed in the antenna to support operation at multiple frequencies.

There is also one 26-meter-diameter (85-foot) antenna at each complex for tracking Earth-orbiting satellites, which are in orbits primarily 160 to 1,000 kilometers (100 to 620 miles) above Earth. The two-axis astronomical mount allows these antennas to point low on the horizon to pick up fast-moving Earth-orbiting satellites as soon as they come into view

All of the antennas communicate directly with the control center at JPL in Pasadena, CA, the operations hub for the network. The control center staff directs and monitors operations, transmits commands and oversees the quality of spacecraft telemetry and navigation data delivered to network users. In addition to the complexes and the control center, a ground communications facility provides communications linking the three complexes to the control center at JPL, to flight control centers in the United States and overseas, and to scientists around the world. Voice and data traffic between various locations is sent via land lines, submarine cable, microwave links and communications satellites.

The Radio Link

The Deep Space Network's radio link to spacecraft is basically the same as other point-to-point microwave communications systems, except for the very long distances involved and the very low spacecraft signal strength. "Very low" might be an understatement: The total signal power arriving at a network antenna from a spacecraft encounter among the outer planets can be 20 billion times weaker than the power level in a modern digital wristwatch battery. The extreme weakness of the signal results from restrictions placed on the size, weight and power supply of the spacecraft by the cargo area and weightlifting limitations of the launch vehicle. Consequently, the design of the radio link is the result of engineering tradeoffs between spacecraft transmitter power and antenna diameter, and the sensitivity that can be built into the ground receiving system.

Typically, a spacecraft signal is limited to 20 watts, or about the same power required to light a refrigerator bulb. When the signal arrives at Earth from outer space — say, from the neighborhood of Saturn — it is spread over an area with a diameter equal to about 1,000 Earth diameters. As a result, the ground antenna is able to receive only a very small part of the signal power, which is degraded by background radio noise, or static. Noise is radiated naturally from nearly all objects in the universe, including Earth and the sun. Noise is also inherently generated in all electronic systems, including the Deep Space Network's own detectors. Since there will always be noise amplified with the signal, the ability of the ground receiving system to separate the noise from the signal is critical. The network uses state-of-the-art, low-noise receivers and telemetry coding techniques to create unequaled sensitivity and efficiency.

International Team

The Cassini program is an international cooperative effort involving NASA, the European Space Agency (ESA), the Italian space agency, Agenzia Spaziale Italiana (ASI), and several separate European academic and industrial contributors. The Cassini partnership represents an undertaking whose scope and cost would not likely be borne by any single nation, but it made possible through shared investment and participation. Hundreds of scientists and engineers from 16 European countries and 33 U.S. states make up team that developed and will fly and receive data from Cassini and Huygens.

At NASA Headquarters, Mark Dahl is Cassini program executive and Dr. Jay Bergstralh is Cassini program scientist.

In the United States, the mission is managed for NASA's Office of Space Science by the Jet Propulsion Laboratory, Pasadena, CA. JPL is a division of the California Institute of Technology. At JPL, Robert Mitchell is the Cassini program manager, and Dr. Dennis L. Matson is the Cassini project scientist.

The major U.S. contractor is Lockheed Martin, whose contributions include the launch vehicle and upper stage, spacecraft propulsion module and the radioisotope thermoelectric generators. NASA's Lewis Research Center managed development of the Centaur upper stage.

Development of the Huygens Titan probe is managed by the European Space Technology and Research Center (ESTEC). ESTEC's prime contractor, Aerospatiale in Toulouse, France, assembled the probe with equipment supplied by many European countries. At ESA, Michel Verdant is Huygens project manager, and Dr. Jean-Pierre Lebreton is project scientist.

At ASI, Enrico Flameni is the project manager for Cassini's radio antenna and other contributions to the spacecraft.

Galileo

Galileo's scientific experiments are being carried out by more than 100 scientists from six nations.

The Galileo Project is managed for NASA's Office of Space Science by the Jet Propulsion Laboratory, Pasadena, CA. JPL is a division of the California Institute of Technology. This responsibility includes designing, building, testing, operating and tracking Galileo. Germany furnished the orbiter's retro-propulsion module and some of the instruments and is participating in the scientific investigations

NASA's Ames Research Center, Moffett Field, CA, was responsible for the atmosphere probe, which was built by Hughes Aircraft Company, El Segundo, California.

At NASA Headquaters, the Galileo program manager is Dr. Paul Hertz, and the program scientist is Dr. Denis Bogan.

At JPL, Galileo project manager is Jim Erickson, and project scientist is Dr. Torrence Johnson.

Deep Space Network

Gael Squibb is director of JPL's Telecommunications and Mission Operations Directorate.

Richard Coffin is deputy director. Joe Wackley is manager of operations.