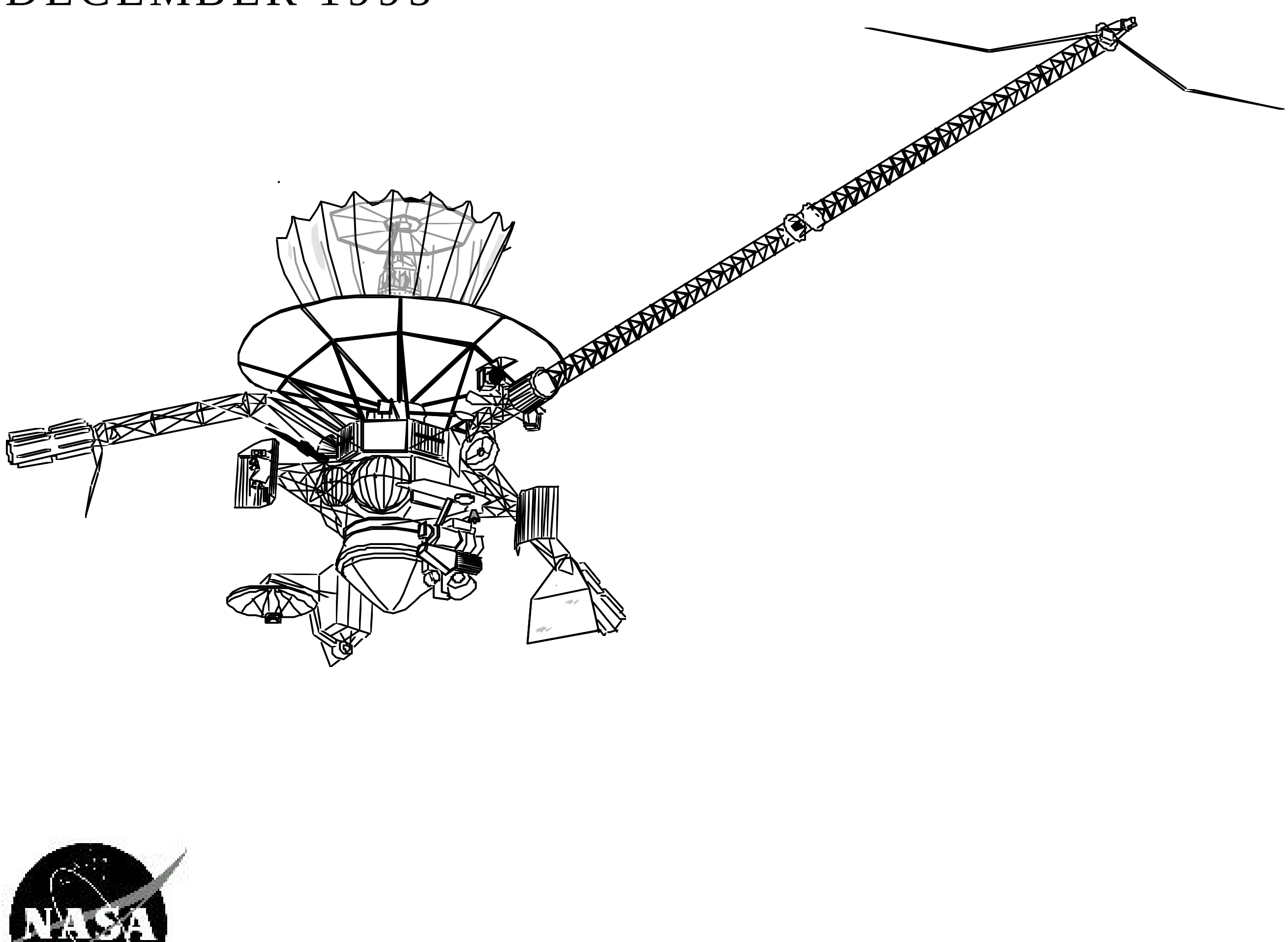
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GALILEO JUPITER ARRIVAL

PRESS KIT
DECEMBER 1995



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GALILEO'S MISSION AT JUPITER POISED TO BEGIN

Reaching its ultimate destination after an already eventful space journey of more than six years and 2.3 billion miles, NASA's Galileo mission will arrive at the giant planet Jupiter on Dec. 7, 1995.

The jam-packed arrival day calls for the Galileo spacecraft and its recently separated atmospheric probe to carry out a detailed choreography of data gathering and critical engineering events almost 20 years in the making. By day's end, Galileo should be the first spacecraft to enter orbit around one of the solar system's giant outer planets, and the first to send an instrumented probe directly into one of their atmospheres. The Galileo orbiter spacecraft then will begin at least two years of close-up observations of Jupiter, its moons, its faint rings and its powerful radiation, magnetic field and dust environment.

Galileo's scientific instruments represent the most capable payload of experiments ever sent to another planet. The data they will return promises to revolutionize our understanding of the Jovian system and reveal important clues about the formation and evolution of the solar system.

Jupiter is 318 times more massive and 1,400 times more voluminous than Earth, but only 1/4th as dense, since it is composed primarily of hydrogen (89 percent) and helium (10 percent). The fifth planet from the Sun is known primarily for the banded appearance of its upper atmosphere and its centuries-old Great Red Spot, a massive, hurricane-like storm as big as three Earths. Jupiter generates the biggest and most powerful planetary magnetic field, and it radiates more heat from internal sources than it receives from the Sun.

"In many ways, Jupiter is like a miniature solar system in itself," says Dr. Wesley T. Huntress, Associate Administrator for Space Science at NASA Headquarters, Washington, DC. "Within Jupiter's constellation of diverse moons, its intense magnetic field, and its swarms of dust and charged particles, the Galileo mission should uncover new clues about how the Sun and the planets formed, and about how they continue to interact and evolve."

The 2,223-kilogram (2-1/2-ton) Galileo orbiter spacecraft carries 10 scientific instruments; the 339-kilogram (746-pound) probe carries six more instruments. The spacecraft radio link to Earth and the probe-to-orbiter radio link serve as instruments for additional scientific investigations.

The chain of key mission events for Galileo on Jupiter arrival day begins with a close flyby of the moon Io by the Galileo orbiter at a distance of just 600 miles (1,000 kilometers). The probe has been traveling a separate path toward atmospheric entry since it was released by the Galileo spacecraft on July 13.

Io's gravity will change Galileo's direction to help it go into orbit around Jupiter. Due to the high radiation in this interior region of the Jovian system, this is the closest that Galileo is planned to come to this moon, although the spacecraft will observe Io during many subsequent orbits.

Four hours later, the orbiter wll link up by radio with the previously released Galileo probe as it floats via parachute downward through the top level of Jupiter's atmosphere. By that time, the conical probe will have slammed into the upper fringe of Jupiter's atmosphere at a top speed of 106,000 mph and endured deceleration forces as high as 230 times Earth's gravity. Dropping downward on its eight-foot diameter parachute, the probe will make the first direct measurements of Jupiter's atmosphere and clouds, and it may encounter lightning or even water rain as it descends more than 125 miles (200 kilometers) from the top of Jupiter's clouds.

The Galileo orbiter will record the measurements radioed from the probe for up to 75 minutes, before finally turning away to prepare for a crucial 49-minute-long burn of its main rocket engine that will insert the spacecraft into Jovian orbit. The probe below is expected to succumb a few hours later to the increasingly intense heat it will find deep below the clouds.

The orbiter will then beginits tour of at least 11 orbits of the Jovian system, including 10 close encounters with three of the four Galilean satellites (four with Ganymede and three each with Callisto and Europa), and observing Io's erupting volcanoes. In mid-March, Galileo will fire its main rocket engine for one last major burn to put itself into an orbit away from the most intense Jovian radiation environment.

The Galileo mission had originally been designed for a direct flight to Jupiter of about two-and-a-half years. Changes in the launch system after the Space Shuttle Challenger accident, including replacement of the Centaur upper-stage rocket with the Inertial Upper Stage (IUS), precluded this direct trajectory. Galileo engineers designed a new interplanetary flight path using several gravity-assist swingbys (once past Venus and twice around Earth) called the Venus-Earth-Earth-Gravity-Assist or VEEGA trajectory.

Galileo was launched aboard Space Shuttle Atlantis and an IUS on Oct. 18, 1989. In addition to its Earth and Venus flybys, Galileo became the first spacecraft ever to fly closely by two asteroids, Gaspra and Ida. During the second asteroid encounter, two of Galileo's 10 science instruments discovered a small moon -- later named Dactyl -- orbiting around Ida, the first time such an object has been confirmed. Galileo's instruments also performed the only direct observations of the impact of the fragments of Comet Shoemaker-Levy 9 with Jupiter in July 1994, providing key insights into the early stages of the impact evolution.

Communications to and from Galileo are conducted through NASA's Deep Space Network, using tracking stations in California, Spain and Australia. A combination of new, specially developed software for Galileo's on-board computer and improvements to ground-based signal receiving hardware in the Deep Space Network will enable the mission to accomplish at least 70 percent of its original science goals using only its small, low-gain antenna, despite the failure of its high-gain antenna to unfurl properly in April 1991. The data return will include an average of two to three images per day once the spacecraft begins transmitting imaging data to Earth in July 1996.

The total cost of the Galileo mission, from the start of planning through the end of mission in December 1997, is $1.354 billion, including $892 million in spacecraft development costs.

Galileo's arrival in the Jovian system represents the culmination of a project that began formally in 1977, and the realization of a dream of planetary scientists since the earliest days of the field.

"The Pioneer and Voyager spacecraft that flew by Jupiter so quickly in the 1970s stunned us with their pictures of rings, active volcanoes on the moon Io and other unexpected findings," Huntress said. "Right now, we can still only imagine the discoveries that will flow from Galileo as it travels for months in this most unusual and unearthly environment."

NASA's Jet Propulsion Laboratory, Pasadena, CA, built the Galileo orbiter spacecraft and manages the overall mission. Galileo's atmospheric probe is managed by NASA's Ames Research Center, Mountain View, CA.

-- end of general release --

Media Services Information

NASA Television Transmission

NASA Television is available through the Spacenet 2 satellite on transponder 5, channel 9, 69 degrees west longitude, frequency 3880 MHz, audio subcarrier 6.8 MHz, horizontal polarization. The schedule for television transmissions on Jupiter arrival day, December 7, 1995, will be available from the Jet Propulsion Laboratory, Pasadena, CA; Ames Research Center, Mountain View, CA; Kennedy Space Center, FL; and NASA Headquarters, Washington, DC.

Status Reports

Status reports on mission activities before, during and after Jupiter arrival will be issued by the Jet Propulsion Laboratory's Public Information Office. They may be accessed online as noted below.

Briefings

A pre-arrival press conference to outline plans for Jupiter orbit insertion will be held at the Jet Propulsion Laboratory on November 9, 1995. Press conferences are scheduled at 10 a.m. and at 6:45 p.m. PST December 7, 1995, during Jupiter arrival. A press conference on quick-look science findings from the atmospheric descent probe is planned from the Ames Research Center on December 19, 1995.

Internet Information

Extensive information on the Galileo mission, 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 . In addition to offering such public affairs materials, the JPL home page links to the Galileo Project's Web home page, http://www.jpl.nasa.gov/galileo , which offers additional information on the mission.

The general JPL site may also be accessed via Internet using anonymous file transfer protocol (FTP) at the address ftp.jpl.nasa.gov . Users should log on with the username "anonymous" and enter their E-mail address as the password. For users without Internet access, the site may additionally be accessed by modem at 818/354-1333.

Galileo Quick Look Facts

Times below are all Earth-received times, allowing for the time it takes the transmissions from the spacecraft to reach Earth (approximately 52 mins.)

Launch and deployment: STS-34 Atlantis and IUS	October 18, 1989
Venus flyby (about 16,000 km/9,500 mi)	February 10, 1990
Earth 1 flyby (about 1,000 km/620 mi)	December 8, 1990
Asteroid Gaspra flyby (about 1,600 km/950 mi)	October 29, 1991
Earth 2 flyby (about 300 km/190 mi)	December 8, 1992
Asteroid Ida flyby (about 2,400 km/1,400 mi)	August 28, 1993
Probe release	July 12, 1995 11:07 p.m. PDT
Jupiter arrival (probe and orbiter)	December 7, 1995
Io flyby (about 1,000 km/6,200 mi)	December 7, 1995 10:38 a.m. PST
Probe atmospheric entry and relay	December 7, 1995 2:56 p.m. PST
Probe mission duration:	40-75 minutes
Jupiter Orbit Insertion (JOI):	December 7, 1995 5:19 p.m. PST
Orbital tour of Galilean satellites	December 1995- November 1997

Orbiter satellite encounters:

- Io: Dec. 7, 1995 (no imaging or spectral data will be taken at this opportunity)
- Ganymede: July 4 and Sept. 6, 1996; April 5 and May 7, 1997
- Callisto: November 4, 1996; June 25 and Sept.17, 1997
- Europa: Dec.19, 1996; Feb. 20 and Nov.26, 1997

Orbiter End of Mission	December 7, 1997

Quick Look Facts (continued)

Mission Cost	$1.35 billion plus international contribution estimated at $110 million.

Galileo Orbiter and Jupiter Atmospheric Probe

	Orbiter	Probe
Mass, kilograms (pounds)	2,223 (4,890)	339 (746)
Usable propellant mass	925 (2,035)	--
Height	6.15 m (20.5 ft)	86 cm (34 in.)
Instrument payload	12 experiments	7 experiments
Payload mass, kg (lb)	118 (260)	30 (66)
Electric power	Radioisotope thermoelectric generators (570-470 watts)	Lithium-sulfur battery, 730 watt-hours

Shuttle Atlantis (STS-34) Crew (Johnson Space Center)
Donald E. Williams, Commander
Michael J. McCulley, Pilot
Shannon W. Lucid, Mission Specialist
Franklin R. Chang-Diaz, Mission Specialist
Ellen S. Baker, Mission Specialist

Galileo Management

Galileo Project (Jet Propulsion Laboratory)
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Atmospheric Probe (Ames Research Center)
Marcie Smith, Probe Manager
Dr. Richard E. Young, Probe Scientist

Galileo Program (NASA Headquarters)
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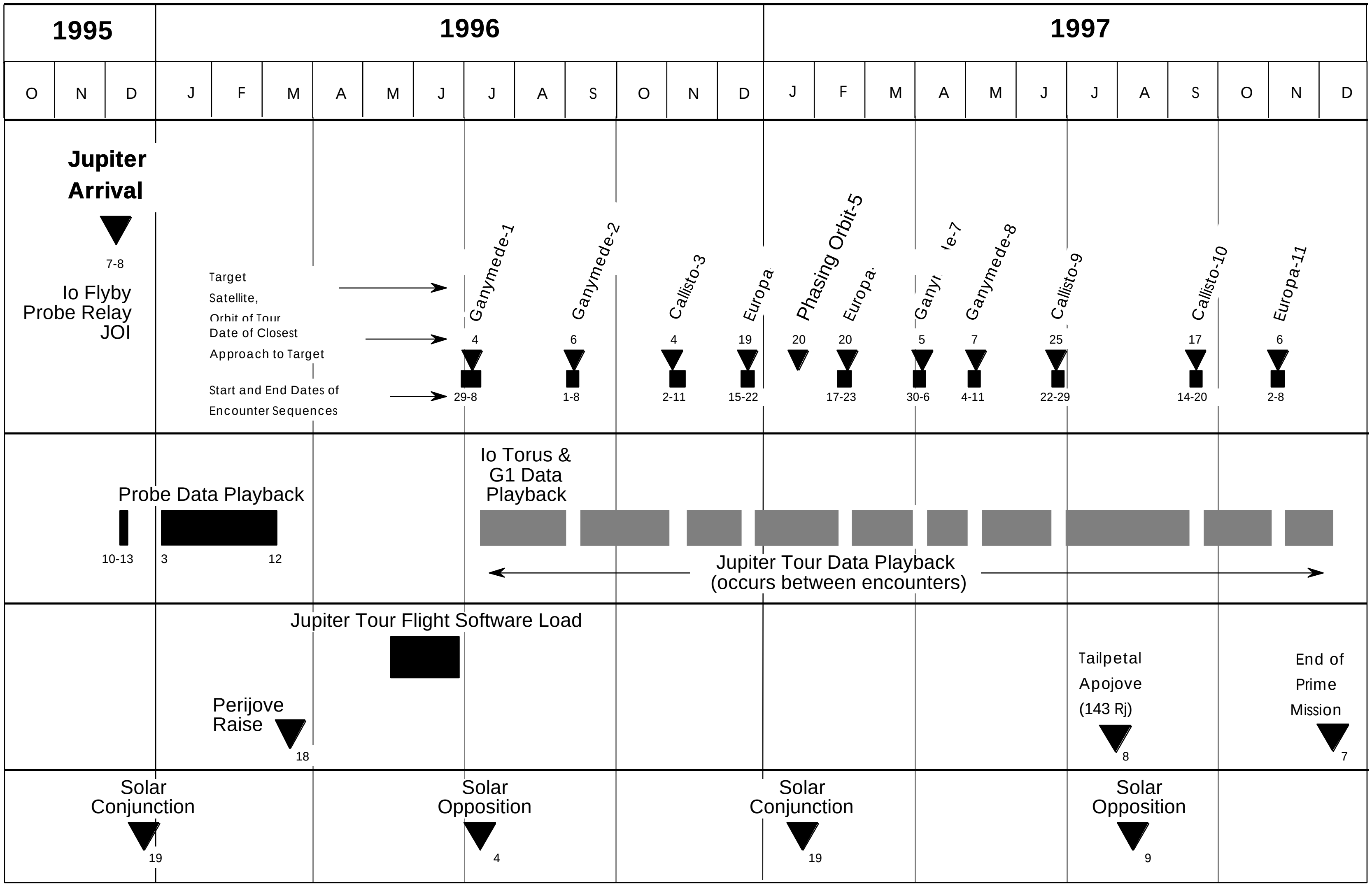
Dr. Jay Bergstralh, Program Scientist
Dr. Wesley Huntress Jr., Associate Administrator for Space Science

Galileo Mission Overview
(1995 to End of Mission)



Atmospheric Probe Mission

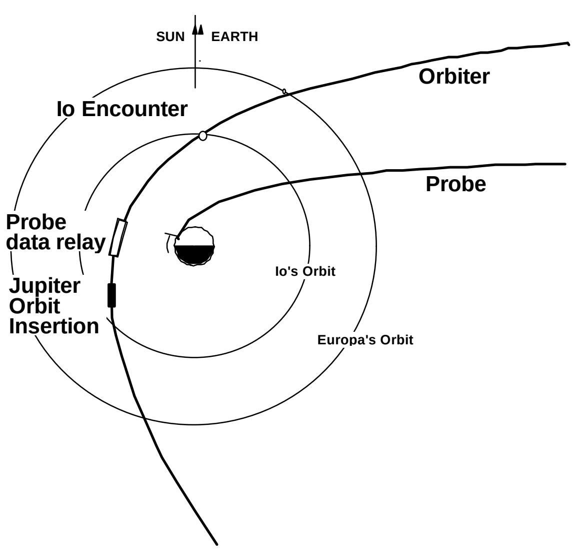
On July 13, 1995, the Galileo spacecraft spun up to 10 rpm and aimed its cone-shaped Jupiter atmospheric entry probe toward its Jupiter entry point 51 million miles (82 million kilometers) away. Guillotine-like cable cutters sliced though umbillicals connecting the two, and the probe was released from the main spacecraft for its solo flight to Jupiter.

On Dec. 7, 1995, the probe's descent into Jupiter will provide the first-ever on-the-spot measurements of Jupiter or any other outer planet. Instruments on board will identify the chemical components of Jupiter's atmosphere and their proportions, and search for clues to Jupiter's history and the origin of the solar system.

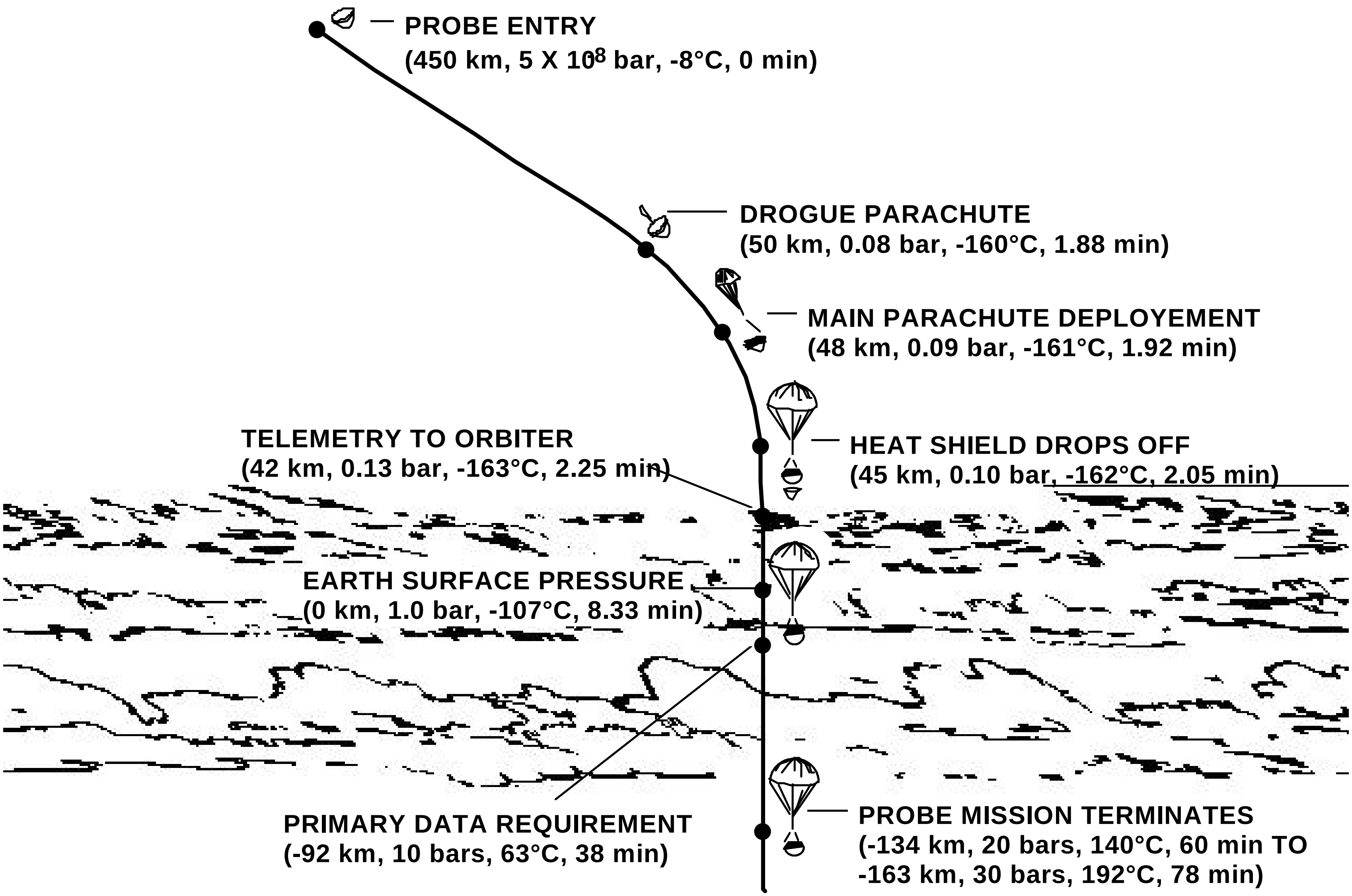
Six hours before entry the command unit signals the probe to "wake up," and three hours later instruments begin collecting data on lightning, radio emissions, and charged particles.

The probe will strike the atmosphere at an angle of only 8 degrees to the horizon -- steep enough so it won't skip out again into space, yet shallow enough to survive the heat and jolting deceleration of entry. The probe will enter the equatorial zone traveling the same direction as the planet's rotation.

During its entry, the incandescent gas cap ahead of the probe would be as bright as the Sun to an observer and twice as hot (15,555 degrees Celsius or 28,000 degrees Fahrenheit) as the solar surface. With the exception of nuclear radiation, entry will be like flying through a nuclear fireball. The probe will be subjected to wrenching forces as it decelerates from 106,000 mph to 100 mph (about 170,000 to about 160 km per hour) in just two minutes -- a force estimated at up to 230 times Earth's gravity.



Once it survives the hazards of its blazing entry, the probe will be operating in Jupiter's primarily hydrogen and helium atmosphere. For part of the descent through Jupiter's three main cloud layers, the probe will be immersed


PROBE ENTRY
(450 km, 5 X 10-8 bar, -8°C, 0 min)
DROGUE PARACHUTE
(50 km, 0.08 bar, -160°C, 1.88 min)
MAIN PARACHUTE DEPLOYEMENT
(48 km, 0.09 bar, -161°C, 1.92 min)
TELEMETRY TO ORBITER
(42 km, 0.13 bar, -163°C, 2.25 min)
HEAT SHIELD DROPS OFF
(45 km, 0.10 bar, -162°C, 2.05 min)
EARTH SURFACE PRESSURE
(0 km, 1.0 bar, -107°C, 8.33 min)
PRIMARY DATA REQUIREMENT
(-92 km, 10 bars, 63°C, 38 min)
PROBE MISSION TERMINATES
(-134 km, 20 bars, 140°C, 60 min TO
-163 km, 30 bars, 192°C, 78 min)

in gases at or below room temperature. It may encounter hurricane winds of up to 200 mph (about 320 km per hour) and lightning and heavy rain at the base of the water clouds believed to exist within the planet's atmosphere.

The Galileo orbiter, about 214,000 kilometers (133,000 miles) above, will acquire the probe signal within 50 seconds. It will receive the probe's science-data transmissions and store them both in the spacecraft tape recorder and in computer memory for later transmission to Earth.

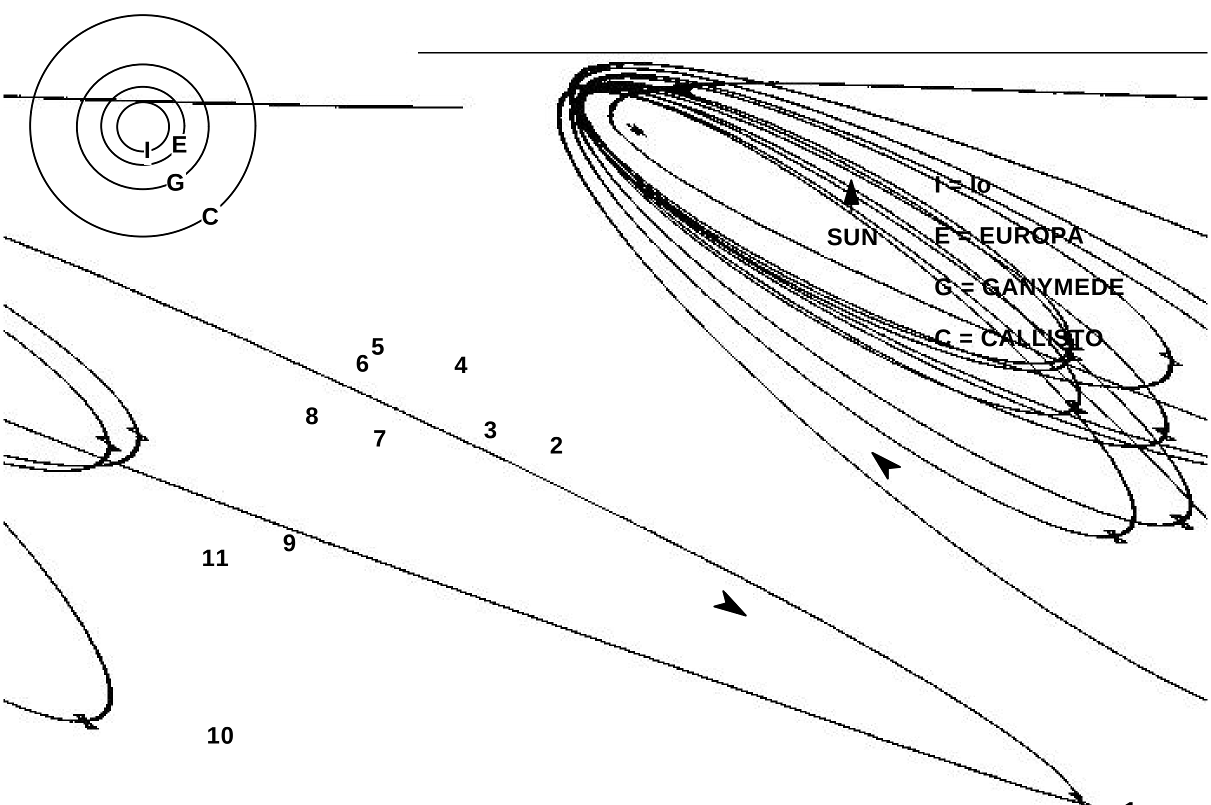
The probe will pass through the white cirrus clouds of ammonia crystals on the highest cloud deck. Beneath this ammonia layer probably lie reddish-brown clouds of ammonium hydrosulfides. Once past this layer, the probe is expected to reach heavier water clouds. This lowest cloud layer may act as a buffer between what some scientists believe will be uniformly mixed regions below the clouds and the turbulent whirl of gases above. Eventually, the probe will pass below these clouds, where rising pressure and temperature will melt and vaporize the craft.

The probe's observations from within the clouds of Jupiter are uniquely valuable to the scientists, and every effort is being made to secure them. The entire probe data collection will be tape-recorded for later playback. It also will be stored in a compressed and shortened version in onboard computer memory. The spacecraft computer will be able to store almost 70 minutes of the planned 75-minute probe observing time and capture the critical part of the atmospheric data. Playback of the first 40 minutes of probe data, stored in the spacecraft's computer memory, will occur in December. Because the Sun will be between Earth and Jupiter and causing radio interference with Galileo in late December, full playback of the probe data will be delayed until early 1996. The December playback is planned on a "best effort" basis due to the very small Sun-Earth-spacecraft angles and will be repeated twice more in January as the communication angles improve.

Orbiter Mission

Galileo's flyby of the Jovian satellite Io at 10:38 a.m.PST (Earth-received time) on December 7 provides the spacecraft a gravity-assist toaid getting into its own orbit around Jupiter. After the atmospheric probe mission is completed, the Galileo orbiter will turn from receiving probe data to performing its own mission. It will carry out a 49 -minute rocket firing that will slow the spacecraft to allow it to be captured into orbit around Jupiter. Three months later, another rocket firing will lift the spacecraft's orbit out of the high-radiation environment of Jupiter's charged particle belts, which could damage Galileo's electronics.

Galileo's two-year orbital tour of the Jovian system is an elaborate square dance requiring the spacecraft to swing around one moon to reach the next. The first Ganymede encounter in July 1996 is the first of these satellite swingbys, and will shorten and change the shape of Galileo's ensuing orbit. Each time the orbiter flies closely past one of the major inner moons, Galileo's course will be changed due to the satellite's gravitational effects. Careful targeting allows each flyby to direct the spacecraft on to its next satellite encounter and the spacecraft's next orbit around Jupiter. Galileo will fly by Ganymede four times, Callisto three, and Europa three. Io gets only the one



Galileo's Eleven Orbit Trek Around Jupiter

close pass, on arrival day, because Galileo cannot linger long in the hazardous radiation environment in which Io resides without damaging the spacecraft's electronics.

These satellite encounters will be at altitudes as close as 200 kilometers (125 miles) above the surfaces of the moons, and typically 100 to 300 times closer than the Voyager satellite flybys, to determine surface chemical composition, geological features and geophysical history. Galileo's scanning instruments will scrutinize the surface and features of each. After a week or so of satellite observation, with its tape recorder full of data, the spacecraft will spend the next months in orbit playing out the information to Earth. Throughout the 23-month orbital tour, Galileo will continuously gather data on the Jovian magnetospheric and dust environment.

Early in Galileo's first seven-month orbit of Jupiter, the complete set of data radioed by the atmospheric probe will be played back to Earth. Time will also be taken to radio new data processing software to the spacecraft to give Galileo new data compression and storage capabilities, and allow the spacecraft to return data at a low rate using the low-gain antenna.

Galileo's Orbital Tour, 1995-1997

The spacecraft's orbital tour consists of 11 different elliptical orbits around Jupiter. Each orbit (except one) includes a close flyby and gravity assist at Ganymede, Callisto or Europa, near the inner (Jupiter) end of the orbit. The outer end of the orbit will vary from 5 to almost 20 million kilometers (3.2 to more than 12 million miles). No close flyby is planned for Orbit 5, when Galileo is out of communication due to solar conjunction when the Sun will be between Jupiter and Earth. Distant scientific encounters with additional satellites are scheduled for a number of orbits, and the spacecraft will observe Io at medium range on every orbit.

The Jovian System

Jupiter is the largest planet in the solar system. Its radius is 44,400 miles (71,500 kilometers), more than 11 times Earth's, and its mass is 318 times that of our planet. It is made mostly of light elements, principally hydrogen and helium. Its atmosphere and clouds are deep and dense, and a significant amount of energy is emitted from its interior. It has no solid surface. Its gases become hotter and denser with increasing depth.

Early Earth-based telescopic observations showed bands and spots in Jupiter's atmosphere; one storm system, the Red Spot, has been seen to persist over three centuries. The light and dark bands and some of the spots have disappeared and reappeared over periods of many years, and as the quality of Jupiter observation has improved so has the amount of variability seen in the clouds.

Atmospheric features were seen in greatly improved detail with the Pioneer and Voyager missions of the 1970's. The Voyager encounters in the spring and summer of 1979 allowed the observation of short-term variations in real time as Jupiter turned beneath the spacecraft's cameras. Astronomers using Earth-based infrared telescopes have recently studied the nature and vertical dynamics of deeper clouds, and the new Earth- and orbit-based telescopes observe Jupiter's atmospheric developments and climate changes, most notably during the Comet Shoemaker-Levy 9 impacts.

Sixteen Jovian satellites are known. The four largest, discovered by Galileo in 1610, are about the size of small planets, and were seen by Voyager's experimenters to have the varied terrain of small worlds. The innermost of these, Io, has active sulfurous volcanoes, discovered by Voyager 1 and further observed by Voyager 2, Earth-based infrared astronomy and the Hubble Space Telescope. Io and Europa are about the size and density of Earth's moon (3-4 times the density of water) and probably mostly rocky inside. Europa may also exhibit surface activity. Ganymede and Callisto, further out from Jupiter, are the size of Mercury but less than twice as dense as water; their interiors are probably about half ice and half rock, with mostly ice or frost surfaces which show distinct and interesting features.

Of the others, eight are in inclined, highly eccentric orbits far from the planet, and four (three discovered by the Voyager missions in 1979) are close to the planet. Voyager also discovered a thin ring system at Jupiter in 1979.

Jupiter has the strongest planetary magnetic field known; the resulting region of its influence, called the magnetosphere, is a huge teardrop-shaped bubble in the solar wind pointing away from the Sun. The inner part of the magnetically-constrained charged-particle belt is doughnut-shaped, but farther out it flattens into a disk. The magnetic poles are offset and tilted relative to Jupiter's axis of rotation, so the field appears to wobble around with Jupiter's rotation (about every 10 hours), sweeping up and down across the inner satellites and making waves throughout the magnetosphere.

Orbit	Satellite Encounter	Date	Altitude, km (miles)	
1	Ganymede	July 4, 1996	500	(300)
2	Ganymede	September 6	259	(161)
3	Callisto	November 4	1,102	(685)
4	Europa	December 19	693	(431)
(5)	(Solar conjunction)		(no close flyby)	
6	Europa	February 20, 1997	587	(365)
7	Ganymede	April 5	3,056	(1,899)
8	Ganymede	May 7	1,580	(982)
9	Callisto	June 25	416	(258)
10	Callisto	September 17	524	(326)
11	Europa	November 6	1,124	(698)

Jupiter's Satellites

Name	Discovery	Mean dist. to Jupiter, km.	Period, days	Radius, km.	Notes
Metis	Voyager, 1979	127,960	0.3	(20)*	
Adrastea	Voyager, 1979	128,980	0.3	12 x 8	
Amalthea	Barnard, 1892	181,300	0.5	135 x 75	
Thebe	Voyager, 1979	221,900	0.7	(50)	
Io	Galileo, 1610	421,660	1.8	1,815	density 3.57**; volcanic
Europa	Galileo, 1610	670,900	3.5	1,569	density 2.97**; icy crust
Ganymede	Galileo, 1610	1,070,000	7.2	2,631	density 1.94**; deep ice crust
Callisto	Galileo, 1610	1,883,000	16.7	2,400	density 1.86**; deep ice crust
Leda	Kowal, 1974	11,094,000	239	(8)	long, tilted elliptical orbit
Himalia	Perrine, 1904	11,480,000	250	(90)	in "family" with Leda
Lysithea	Nicholson, 1938	11,720,000	259	(20)	in Leda "family"
Elara	Perrine, 1905	11,737,000	260	(40)	in Leda "family"
Ananke	Nicholson, 1951	21,200,000	631	(15)	retrograde in long, highly tilted, elliptical orbit
Carme	Nicholson, 1938	22,600,000	692	(22)	in "family" with Ananke
Pasiphae	Melotte, 1908	23,500,000	735	(35)	in Ananke "family"
Sinope	Nicholson, 1914	23,700,000	758	(20)	in Ananke "family"

* Radius numbers in parentheses are uncertain by more than 10%
**Density is in grams per cubic centimeter (water's density is 1)

Jupiter's Rings

Inner "Halo" ring, about 100,000 to 122,800 kilometers from Jupiter's center.
"Main" ring, 122,800-129,200 kilometers from center.
Outer "Gossamer" ring, 129,200 to about 214,200 kilometers.
Note that satellites Metis, Adrastea and Amalthea orbit in the outer part of the ring region.
The Jovian satellites are named for Greek and Roman gods. Names of new moons are conferred by the International Astronomical Union.

Interplanetary Cruise Science

Galileo has already returned a wealth of surprising new information from the "targets of opportunity" it has observed on the way to Jupiter. Two first-ever asteroid encounters yielded close-up images of the asteroids Gaspra and Ida, and the extraordinary discovery of a moon (later named Dactyl) orbiting Ida.

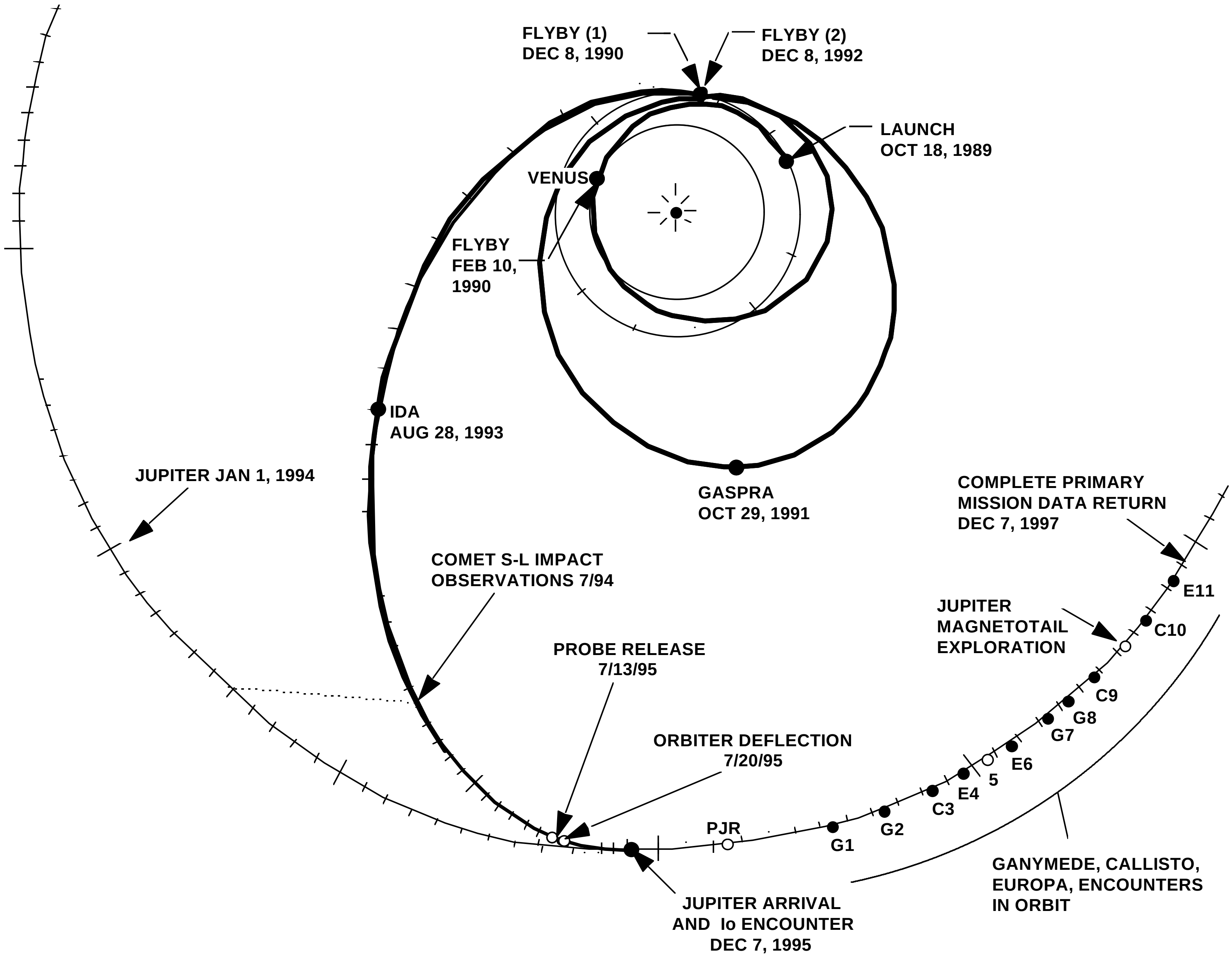
Lunar science

In 1992, Galileo revisited the north pole of the Moon explored by early spacecraft, imaging the region for the first time in infrared color and providing new information about the distribution of minerals on the lunar surface. The spacecraft flew within 68,000 miles (110,000 kilometers) of the Moon on Dec. 7, 1992, obtaining multispectral lunar images, calibrating Galileo's instruments by comparing their data to those of previous lunar missions, and getting additional baselines for comparing our Moon with the Jovian satellites Galileo will be exploring.

A major result of Galileo's first lunar flyby was the confirmation of the existence of a huge ancient impact basin in the southern part of the Moon's far side. The presence of this basin was inferred from Apollo data in the 1970s but its extent had never been mapped before. Galileo imaged the Moon's north pole at several different wavelengths (including infrared), a feat never before accomplished. Scientists found evidence that the Moon has been more volcanically active than researchers previously thought.

The Near-Infrared Mapping Spectrometer (NIMS) imaged the polar region in 204 wavelengths, another first in lunar mapping. The spacecraft also collected spectral data for dark mantle deposits, areas of local explosive volcanic eruptions. These maria deposits are more compositionally diverse toward the near side of the Moon. Specifically, scientists discovered that titanium is present in low to intermediate amounts toward the far side, suggesting that the far side has a thicker crust. This type of spectral data also allows scientists to determine the sequence of meteoric impacts and the thickness of ancient lava flows.

In observing the features of the Imbrium impact basin on the near side of the Moon, the imaging team found the Moon to have been more volcanically active earlier than previously thought. They found hidden maria, or "cryptomaria," are overlain by other features visible only through special


FLYBY (1)
DEC 8, 1990
FLYBY (2)
DEC 8, 1992
LAUNCH
OCT 18, 1989
VENUS
FLYBY
FEB 10,
1990
IDA
AUG 28, 1993
JUPITER JAN 1, 1994
GASPRA
OCT 29, 1991
COMPLETE PRIMARY
MISSION DATA RETURN
DEC 7, 1997
COMET S-L IMPACT
OBSERVATIONS 7/94
E11
JUPITER
MAGNETOTAIL
EXPLORATION
C10
PROBE RELEASE
7/13/95
C9
G8
G7
ORBITER DEFLECTION
7/20/95
E6
5
E4
C3
PJR
G2
G1
GANYMEDE, CALLISTO,
EUROPA, ENCOUNTERS
IN ORBIT
JUPITER ARRIVAL
AND Io ENCOUNTER
DEC 7, 1995

spectral bands. Nearly 4 billion years ago, the impact in the Imbrium basin threw out a tremendous amount of rock and debris that blanketed the Moon and caused erosion of the highland terrain. This blanketing and sculpture can be seen in Galileo's images of the north pole.

Gaspra

Nine months into its two-year Earth-to Earth orbit, Galileo entered the asteroid belt, and on Oct. 29, 1991, it accomplished the first-ever asteroid encounter. It passed about 1,600 kilometers (1,000 miles) from the stony asteroid Gaspra at a relative speed of about 8 kilometers per second (18,000 miles per hour); scientists collected pictures of Gaspra and other data on its composition and physical properties. These revealed a cratered, complex, and irregular body about 19 by 12 by 11 kilometers (12 by 7.5 by 7 miles), with a thin covering of dirt-like regolith and a possible magnetic field.

Ida

On Aug. 28, 1993, Galileo had a second asteroid encounter, this time with Ida, a larger, more distant body than Gaspra. There, Galileo made the discovery of the first moon of an asteroid. Ida is about 55 kilometers or 34 miles long; like Gaspra, it is very irregular in shape; it rotates every 4.6 hours around an offset axis. Apparently, like Gaspra, it may have a magnetic field.

The closest-approach distance was about 2,400 kilometers (1,500 miles), with a relative speed of nearly 12.6 kilometers per second or 28,000 miles per hour.

Ida's satellite, later named Dactyl, was found in a camera frame and an infrared scan. The 1.5-kilometer satellite was estimated to be about 100 kilometers (60 miles) from the center of the asteroid.

Comet Shoemaker-Levy

The discovery of Comet Shoemaker-Levy 9 in May 1993 provided an exciting new opportunity for Galileo's science team.

The Galileo spacecraft, approaching Jupiter, was the only observation platform capable of making measurements in line of sight to the comet's impact area on Jupiter's far side. Although there was no additional funding available for this new target of opportunity an observation program was planned for Galileo's remote sensing instruments. All of Galileo's observations had to be programmed in advance into the spacecraft computer, notwithstanding uncertainties in the predicted impact times. The data were stored on the spacecraft (one tape load plus some computer memory space) for playback at the 10 bits-per-second rate. Playback continued, with necessary interruptions for other activities, until late January 1995.

Galileo's imaging system used different methods to cover the time uncertainties (amounting to hours) of the impacts for different events. Repeated imaging, rather like a very slow motion picture, captured the very last impact (fragment W) which appeared to last 26 minutes. A smeared image, producing a streak representing the night-side impact fireball among smears showing Jupiter and some satellites, provided brightness histories of two events, the impact of fragments K and N. The photopolarimeter-radiometer detected three events. The infrared spectrometer detected two events, providing critical information on the size, temperature and altitude of the impact fireball and the heating of the atmospehre by the impact "fallback." Galileo scientists have combined their data to produce interpretive histories of the 90-second impact events.

Interplanetary Dust

In the summer of 1995, Galileo found itself flying through the most intense interplanetary dust storm ever measured. It was the largest of several dust storms encountered by Galileo since December 1994, when the spacecraft was still almost 110 million miles (about 175 million kilometers) from Jupiter. The dust particles are apparently emanating from somewhere in the Jovian system and may be the product of volcanoes on Jupiter's moon, Io, or could be coming from Jupiter's faint ring system. Probably no larger than those found in cigarette smoke, the particles may also be leftover material from Comet Shoemaker-Levy's collision with Jupiter.

Scientists believe the particles are electrically charged and then accelerated by Jupiter's powerful magnetic field. Calculations indicate the dust is speeding through interplanetary space at between nearly 90,000 and 450,000 miles per hour (40 and 200 kilometers per second), depending on particle size. Even at such high speeds, these tiny particles pose no danger to the Galileo spacecraft because they are so tiny.

Chances of understanding the nature of these dust storms are improving since, after the onset of the current storm, Galileo flight engineers commanded the spacecraft to collect and transmit dust data as often as three times a day. The normal collection rate had been twice per week. When Galileo enters Jupiter orbit, its first measurements should provide key information about the origins of this strange phenomena.

Galileo's New Telecommunications Strategy

Engineers and scientists involved with the Galileo mission to Jupiter have successfully devised several creative techniques to enable the spacecraft to achieve the majority of its scientific objectives despite the failure of its main communications antenna to open as commanded.

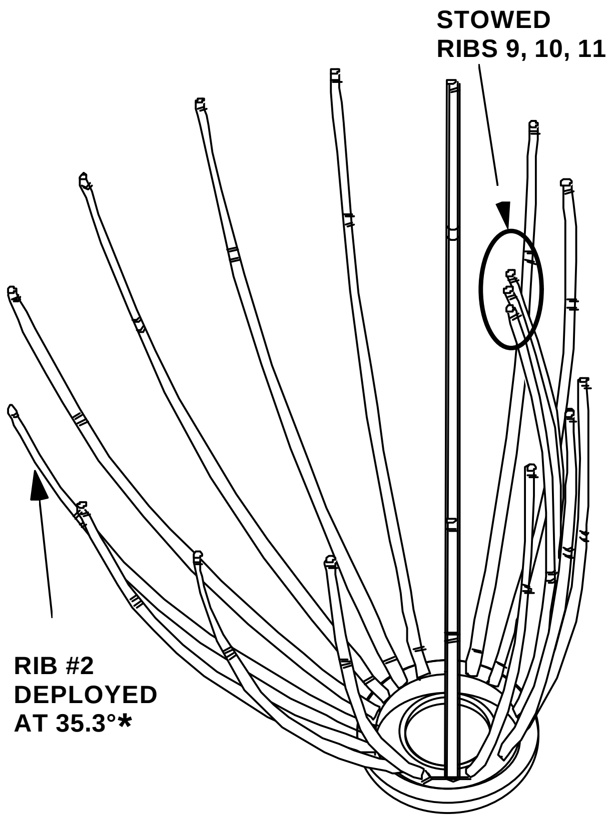
Upgrades to Galileo's on-board computer software and its ground-based communications hardware have been developed and tested by JPL in response to what would have been a profound loss for the orbiter portion of the mission. (The spacecraft's Jupiter atmospheric probe mission can be executed without the new techniques, but the upgrades will enhance the orbiter's ability to reliably record and re-transmit the unique data to be collected by the probe as it descends on a parachute.) The new telecommunications strategy hinges on more effective use of the spacecraft's low-gain antenna, which is limited to a very low data rate compared to the main, high-gain antenna.

The switch to the low-gain antenna and its lower data rate means that far fewer data bits will be returned from Jupiter. However, new software on the spacecraft will increase Galileo's ability to edit and compress the large quantity of data collected by the spacecraft and then transmit it to Earth in a shorthand form. On Earth, new technology is being used to greatly sharpen the hearing of the telecommunications equipment that will be receiving Galileo's whisper of a signal from Jupiter. Together, these efforts should enable Galileo to fulfill at least 70 percent of its original scientific objectives.

The High-Gain Antenna

The 4.8-meter (16-foot) wide, umbrella-like high-gain antenna is mounted at the top of the spacecraft. When unfurled, the antenna's hosiery-like wire mesh stretches over 18 umbrella ribs to form a large parabolic dish. Galileo was to have used this dish to radio its scientific data from Jupiter. This high-performance, X-band antenna was designed to transmit data back to Earth at rates of up to 134,400 bits of digital information per second (the equivalent of about one imaging frame each minute).

Galileo's original mission plan called for the high-gain antenna to open shortly after launch. For the Venus-Earth-Earth Gravity-Assist (VEEGA) trajectory mission, however, the heat-sensitive high-gain antenna had to be left closed and stowed behind a large sun shade to protect it during the spacecraft's passage through the inner solar system. During this portion of Galileo's journey, two small, heat-tolerant low-gain antennas provided the spacecraft's link to Earth. One of these S-band antennas, mounted on a boom,



* AFTER HAMMERING RIB #2 NOW AT 43°

was added to the spacecraft expressly to bolster Galileo's telecommunications during the flight to Venus. The other primary low-gain antenna mounted to the top of the high-gain was destined to become the only means through which Galileo will be able to accomplish its mission.

The Antenna Problem

On April 11, 1991, after Galileo had traveled far enough from the heat of the Sun, the spacecraft executed stored computer commands designed to unfurl the large high-gain antenna. But telemetry received minutes later showed that something went wrong. The motors had stalled and the antenna had only partially opened.

In a crash effort over the next several weeks, a team of more than 100 technical experts from JPL and industry analyzed Galileo's telemetry and conducted ground testing with an identical spare antenna. They deduced that the problem was most likely due to the sticking of a few antenna ribs, caused by friction between their standoff pins and sockets.

The excessive friction between the pins and sockets has been attributed to etching of the surfaces that occurred after the loss of a dry lubricant that had been bonded to the standoff pins during the antenna's manufacture in Florida. The antenna was originally shipped to JPL by truck in its own special shipping container. In December 1985, the antenna, again in its own shipping container, was sent by truck to NASA's Kennedy Space Center (KSC) in Florida to await launch. After the Challenger accident, Galileo and its antenna had to be shipped back to JPL in late 1986. Finally, they were reshipped to KSC for integration and launch in 1989. The loss of lubricant is believed to have occurred due to vibration the antenna experienced during those cross-country truck trips.

Extensive analysis has shown that, in any case, the problem existed at launch and went undetected; it is not related to sending the spacecraft on the VEEGA trajectory or the resulting delay in antenna deployment.

Attempts to Free the Antenna

While diagnosis of the problem continued, the Galileo team sent a variety of commands intended to free the antenna. Most involved turning the spacecraft toward and away from the Sun, in the hope that warming and cooling the apparatus would free the stuck hardware through thermal expansion and contraction. None of these attempts succeeded in releasing the ribs.

Further engineering analysis and testing suggested that "hammering" the antenna deployment motors -- turning them on and off repeatedly -- might deliver the force needed to free the stuck pins and open the antenna. After more than 13,000 hammerings between December 1992 and January 1993, engineering telemetry from the spacecraft showed that additional deployment force had been generated, but it had not freed the ribs. Other approaches were tried, such as spinning the spacecraft up to its fastest rotation rate of 10 rpm and hammering the motors again, but these efforts also failed to free the antenna.

Project engineers believe the state of the antenna has been as well-defined as long-distance telemetry and laboratory tests will allow. After the years-long campaign to try to free the stuck hardware, the project has determined there is no longer any significant prospect of the antenna being deployed.

Nevertheless, one last attempt will be made in March 1996, after the orbiter's main engine is fired to raise Galileo's orbit around Jupiter. This "perijove raise maneuver" will deliver the largest acceleration the spacecraft will have experienced since launch, and it follows three other mildly jarring events: the release of the atmospheric probe, the orbiter deflection maneuver that follows probe release, and the Jupiter orbit insertion engine firing. It is possible, but extremely unlikely, that these shocks could jar the stuck ribs enough to free the antenna. This will be the last attempt to open the antenna before radioing the new software to the spacecraft to inaugurate the advanced data compression techniques designed specifically for use with the low-gain antenna.

The Low-Gain Antenna

The difference between Galileo sending its data to Earth using the high-gain antenna and the low-gain is like the difference between the concentrated light from a spotlight versus the light emitted diffusely from a bare bulb. If unfurled, the high-gain would transmit data back to ground-based Deep Space Network (DSN) collecting antennas in a narrowly focused beam. The low-gain antenna transmits in a comparatively unfocused broadcast, and only a tiny fraction of the signal actually reaches DSN receivers. Because the received signal is 10,000 times fainter, data must be sent at a lower rate to ensure that the contents are clearly understood.

New Software on the Spacecraft

Key to the success of the mission are two sets of new flight software. The first set, called Phase 1, began operating in March 1995 and was designed expressly to partially back-up and ensure receipt of the most important data collected from the atmospheric probe. Once the critical scientific data from the probe is safely returned to Earth, a second set of new software will be radioed and loaded onto the spacecraft in March 1996.

This Phase 2 software will provide programs to shrink the voluminous science data the Galileo orbiter will collect and store on its tape recorder during its two-year mission, while retaining the scientifically important information, and return that data at the lower data rate.

Without any new enhancements, the low-gain antenna's data transmission rate at Jupiter would be limited to only 8-16 bits per second (bps), compared to the high-gain's 134,400 bps. However, the innovative Phase 2 software changes, when coupled with hardware and software adaptations at Earth-based receiving stations, will increase the data rate from Jupiter by as much as 10 times, to 160 bps. The data compression methods will allow retention of the most interesting and scientifically valuable information, while minimizing or eliminating less valuable data (such as the dark background of space) before transmission. Two different methods of data compression will be used. In both methods, the data are compressed onboard the spacecraft before being transmitted to Earth.

The first method, called "lossless" compression, allows the data to be reformatted back to their original state once on the ground. This technique is routinely used in personal computer modems to increase their effective transmission rates. The second compression method is called "lossy," a term used to describe the dissipation of electrical energy, but which in this case refers to the loss of some original data through mathematical approximations used to abbreviate the total amount of data to be sent to the ground. Lossy compression will be used to shrink imaging and plasma wave data down to as little as 1/80th of its original volume.

Customizing Receivers on Earth

S-Band telecommunication was once the standard for space missions, and several S-band performance-enhancing capabilities were implemented at DSN tracking stations in the 1980s. For Galileo and its S-band low-gain antenna, these capabilities are being restored at the Canberra, Australia, 70-meter antenna. Because Australia is in the southern hemisphere and Jupiter is in the southern sky during Galileo's tour, the Canberra complex will receive most of Galileo's data.

Another critical, ongoing DSN upgrade will be the addition of so-called Block V receivers at the tracking stations. These receivers, which are being installed for multi-mission use, will allow all of Galileo's signal power to be dedicated to the data stream by suppressing the traditional carrier signal, thus allowing use of higher data rates.

Finally, starting early in the orbital tour, the 70-meter and two 34-meter DSN antennas at Canberra will be arrayed to receive Galileo's signal concurrently, with the received signals electronically combined. The arraying technique allows more of the spacecraft's weak signal to be captured, thereby enabling a higher data rate, which translates into the receipt of more data. In addition, other arraying is planned: the 64-meter Parkes Radio Telescope in Australia will be arrayed with the Canberra antennas, as will the 70-meter DSN antenna in Goldstone, CA, when its view of Galileo overlaps with Canberra's.

The Tape Recorder Problem

Galileo’s tape recorder is a key link in techniques developed to compensate for the loss of use of Galileo’s high-gain antenna. The tape recorder is to be used to store information, particularly imaging data, until it can be compressed and edited by spacecraft computers and radioed via Galileo’s low-gain antenna back to Earth.

On Oct. 11, 1995, with just weeks to go before Jupiter arrival, the tape recorder malfunctioned. Data from the spacecraft showed the recorder failed to cease rewinding after recording an image of Jupiter.

A week later, following extensive analysis, the spacecraft tape recorder was tested and proved still operational, but detailed study of engineering data indicates that the tape recorder can be unreliable under some operating conditions. The problem appears to be manageable, however, and should not jeopardize return of the full complement of images of Jupiter and its moons that are to be stored on the recorder for playback over the course of the mission.

On Oct. 24, the spacecraft executed commands for the tape recorder to wind an extra 25 times around a section of tape possibly weakened when the recorder had been stuck in rewind mode with the tape immobilized for about 15 hours. Due to uncertainty about its condition, spacecraft engineers have declared that portion near the end of the tape reel is “off-limits” for future data recording. The extra tape wound over it secures that area of tape, eliminating any stresses that could tear the tape at this potential weak spot. Unfortunately, the approach image of Jupiter that Galileo took October 11 was stored on the portion of tape that is now off-limits, and will not be played back. More significantly, project officials also decided not to take pictures of Io and Europa on Dec. 7, including what would have been the closest encounter of Io (from a distance of 600 miles or 1,000 kilometers). Instead, the tape recorder will be completely devoted that day to gathering data from Galileo’s Jupiter atmospheric probe.

Analysis of the tape recorder's condition continues so spacecraft engineers can fully understand its capabilities and potential weaknesses. Currently, the prospects look very good for finding ways to reliably operate the recorder with little loss to the orbital mission objectives.

Science Saved and Science Lost

Very few of Galileo's original measurement objectives have had to be completely abandoned as a result of the high-gain antenna problem. For the most part, science investigations on the spacecraft have adapted to the lower data rates using a variety of techniques, depending on the nature of the experiment. The new software and DSN receiver hardware will increase the information content of the data that will be returned by at least 100 times more than what would have been possible otherwise.

The onboard data processing made possible by the Phase 2 software will allow the spacecraft to store and transmit nearly continuous observations of the Jovian magnetosphere and extensive spectral measurements of the planet and its satellites in the infrared, visible, and ultraviolet, including more than 1,500 high-resolution images.

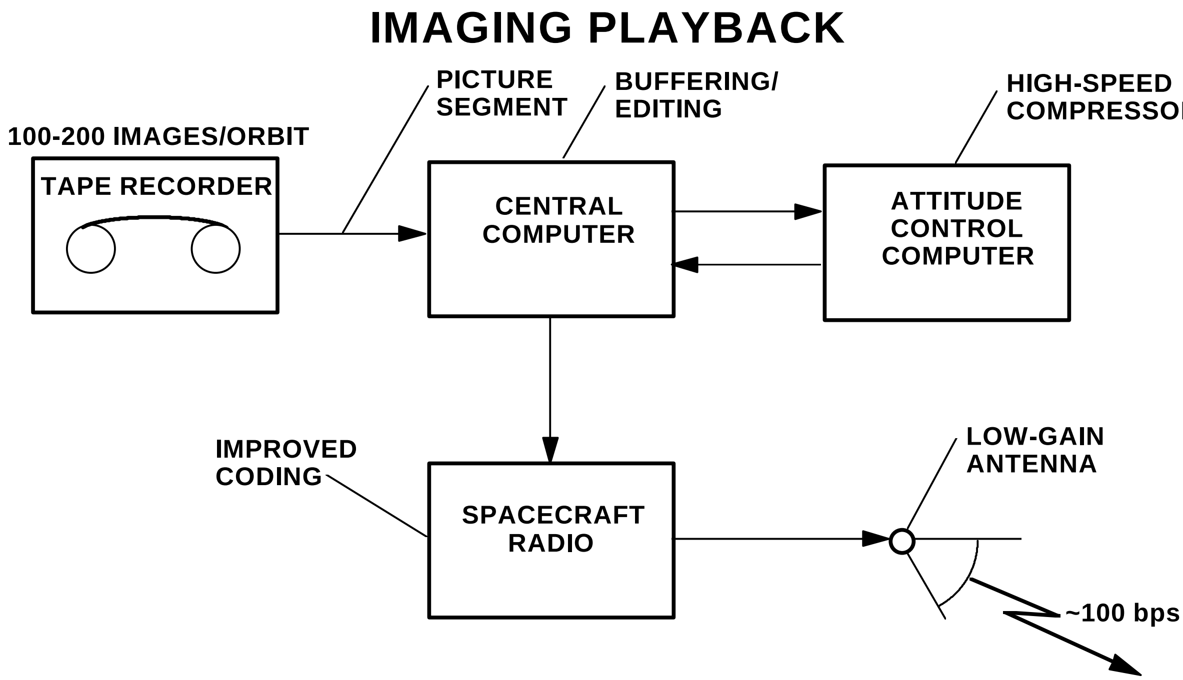
While tens of thousands of images would be required for large-scale movies of Jupiter's atmospheric dynamics, the hundreds of images allocated to atmospheric imaging will allow in-depth study of several individual features in the clouds of Jupiter. Cooperative observations with Hubble Space Telescope investigators and ground-based observers has long been planned as part of the Galileo mission to provide information on the global state of Jupiter's atmosphere.

Like a tourist allotted one roll of film per city, the Galileo team will select its observations carefully at each encounter to ensure the maximum amount of new and interesting scientific information is returned. The imaging campaign will focus on the planet and the four large Galilean moons, but it will also cover the four inner minor satellites and Jupiter's rings. Ten close satellite encounters will be conducted: one Io flyby (on approach), three of Europa, three of Callisto, and four of Ganymede. Five additional mid-range encounters (from closer than 80,000 kilometers, or about 50,000 miles) will be conducted with these moons.

For the orbiter portion of the mission, it is useful to realize that Galileo, with its sophisticated instruments, closer satellite flybys, and long duration in Jovian orbit, was specifically designed to answer many of the questions that the Pioneer and Voyager spacecraft were unable to answer. None of those characteristics have been affected by the loss of the high-gain antenna: only the total volume of data has been reduced.

As a result, when Galileo examines a class of phenomena, fewer samples of that class can be studied, and often, the spectral or temporal resolution will be reduced to lessen the total volume of data. The resulting information, however, will nevertheless provide unique insight into the Jovian system.

Some specific impacts from the loss of the high-gain antenna include: elimination of color global imaging of Jupiter once per orbit; elimination of global studies of Jupiter's atmospheric dynamics such as storms, clouds, and latitudinal bands (efforts to image atmospheric features, including the Great Red Spot, are still planned, however); a reduction in the spectral and spatial coverage of the moons, which provided context for study of high-resolution observations of their key features; and reduction of much of the so-called fields and particles microphysics (requiring high temporal- and spectral-frequency sampling of the environment by all instruments) during the cruise portion of each orbit. Most of the fields and particles microphysics, however, will be retained during the satellite encounters.



Highlights of Jupiter Science to be Returned Via Galileo's Low-Gain Antenna:

- 100 percent of probe data
- Nearly continuous, real-time survey of Jovian magnetosphere for two years
- Approximately 1,500 images of the four Galilean satellites, four inner minor satellites, Jupiter and its rings
- Ten very close encounters: Europa (3), Callisto (3) and Ganymede (4)
- Five Voyager-class (less than 80,000 km) encounters with Galilean satellites

Ground Systems and Spacecraft Operations

Galileo communicates with Earth via NASA's Deep Space Network (DSN), which has a complex of large antennas with receivers and transmitters located in the California desert, in Australia and in Spain, linked to a network control center at JPL in Pasadena, CA. The spacecraft receives commands, sends science and engineering data, and is tracked by doppler and ranging measurements through this network. Mission control responsibilities include commanding the spacecraft, interpreting the engineering and scientific data it sends in order to understand how it is performing and responding, and analyzing navigation data obtained by the Deep Space Network. The controllers use a set of complex computer programs to help them control the spacecraft and interpret the data.

The Galileo spacecraft carries out its complex operations, including maneuvers, scientific observations and communications, in response to stored sequences which are sent up to the orbiter periodically through the Deep Space Network in the form of command loads.

The spacecraft status and health are monitored through data from 1,418 onboard measurements. The Galileo flight team interprets these data into trends to avert or work around equipment failure. Their conclusions become an important input, along with scientific plans, to the sequence design process. The telemetry monitoring is supported by computer programs written and used in the mission support area.

Navigation is the process of estimating, from radio range and doppler measurements, the position and velocity of the spacecraft to predict its flight path and to design course-correcting maneuvers. These calculations must be done with computer support. The Galileo mission, with its complex gravity-assist flight to Jupiter and 10 gravity-assist satellite encounters in the Jovian system, is extremely dependent on consistently accurate navigation.

In addition to the programs which directly operate the spacecraft and are periodically transmitted to it, the mission operations team uses software amounting to 650,000 lines of programming code in the sequence design process; 1,615,000 lines in the telemetry interpretation; and 550,000 lines of code in navigation. These all had to be written, checked, tested, used in mission simulations and, in many instrument cases, revised before the mission could begin.

Science investigators are located variously at JPL or at their home laboratories, linked by computer communications. From either location, they are involved in developing the sequences affecting their experiments and, in some cases, helping to change preplanned sequences to follow up on unexpected discoveries with second looks.

The Spacecraft

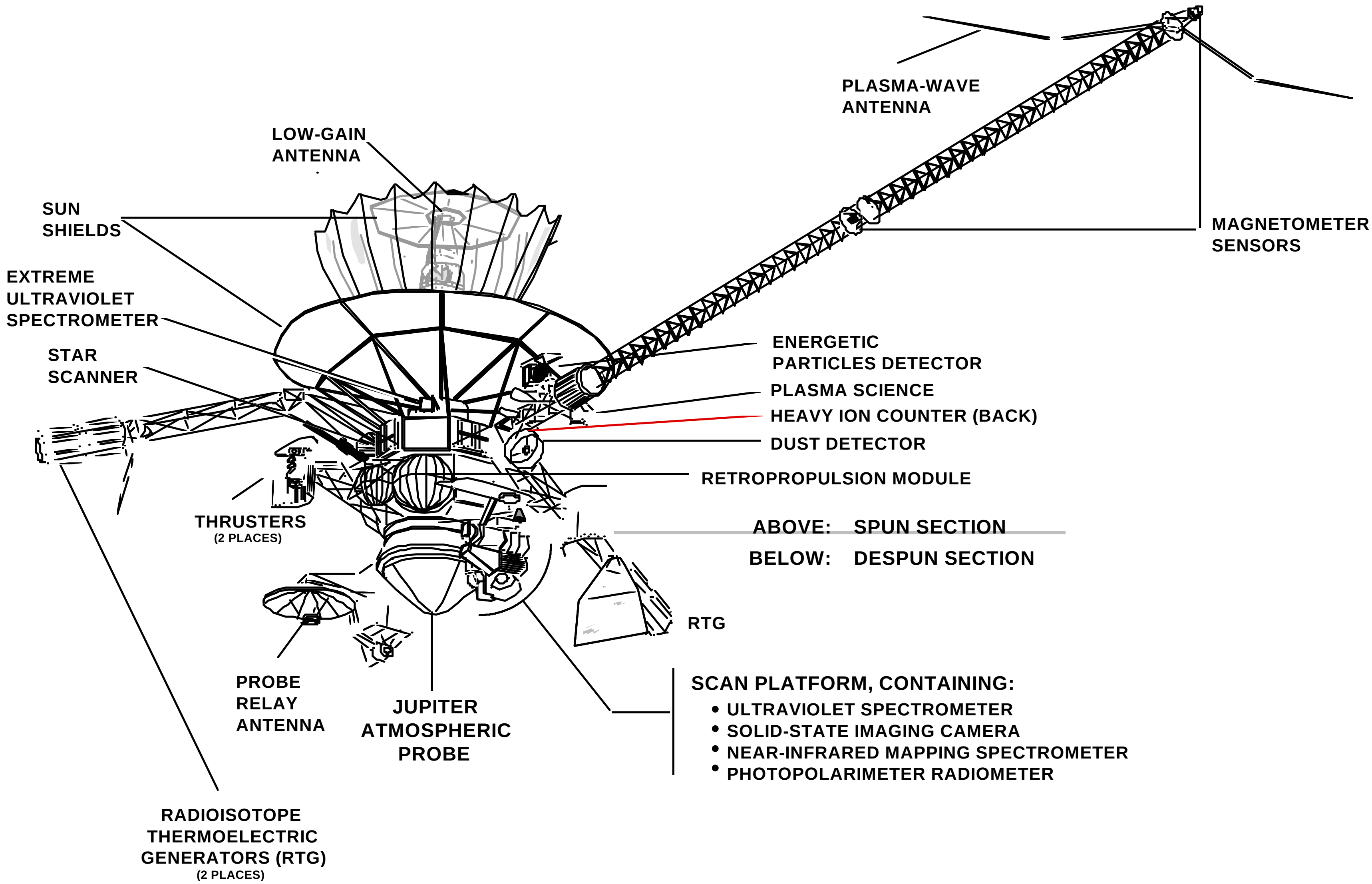
The Galileo mission and systems were designed to investigate three broad aspects of the Jovian system: the planet's atmosphere, the satellites and the magnetosphere. The spacecraft was constructed in three segments, which help focus on these areas: 1) the atmospheric probe; 2) a non-spinning section of the orbiter carrying cameras and other remote sensors; 3) the spinning main section of the orbiter spacecraft which includes the fields and particles instruments, designed to sense and measure the environment directly as the spacecraft flies through it. The spinning section also carries the communications antennas, the propulsion module, flight computers and most support systems.

This innovative "dual spin" design allows part of the orbiter to rotate constantly at three rpm, and part of the spacecraft to remain fixed. This means that the orbiter can easily accommodate magnetospheric experiments (which need to take measurements while rapidly sweeping about) while also providing stability and a fixed orientation for cameras and other sensors. The spin rate can be increased to 10 revolutions per minute for additional stability during major propulsive maneuvers.

Galileo's atmospheric probe weighs 339 kilograms (746 pounds), and includes a deceleration module to slow and protect the descent module, which carries out the scientific mission.

The deceleration module consists of an aeroshell and an aft cover, designed to block the heat generated by friction during the sharp deceleration of atmospheric entry. Inside the shells are the descent module and its 2.5-meter (8-foot) parachute. The descent module carries a radio-relay transmitter and six scientific instruments. Operating at 128 bits per second, each of the dual L-band transmitters send nearly identical streams of scientific data to the orbiter. Probe electronics are powered by batteries with an estimated capacity of about 18 amp-hours on arrival at Jupiter.

Probe instruments include an atmospheric structure group of sensors measuring temperature, pressure and deceleration; a neutral mass spectrometer and a helium-abundance detector supporting atmospheric composition studies; a nephelometer for cloud location and cloud-particle observations; a net-flux radiometer measuring the difference, upward versus downward, in radiant energy flux at each altitude; and a lightning/radio-emission instrument with an energetic-particle detector, measuring light and radio emissions associated with lightning and energetic particles in Jupiter's radiation belts.


PLASMA-WAVE ANTENNA
LOW-GAIN ANTENNA
SUN SHIELDS
MAGNETOMETER SENSORS
EXTREME ULTRAVIOLET SPECTROMETER
STAR SCANNER
ENERGETIC PARTICLES DETECTOR
PLASMA SCIENCE
HEAVY ION COUNTER (BACK)
DUST DETECTOR
RETROPROPULSION MODULE
THRUSTERS
(2 PLACES)
ABOVE: SPUN SECTION
BELOW: DESPUN SECTION
RTG
PROBE RELAY ANTENNA
JUPITER ATMOSPHERIC PROBE
SCAN PLATFORM, CONTAINING:
• ULTRAVIOLET SPECTROMETER
• SOLID-STATE IMAGING CAMERA
• NEAR-INFRARED MAPPING SPECTROMETER
• PHOTOPOLARIMETER RADIOMETER
RADIOISOTOPE THERMOELECTRIC GENERATORS (RTG)
(2 PLACES)

The Galileo orbiter spacecraft, in addition to supporting the probe activities, will support all the scientific investigations of Jupiter's satellites and magnetosphere, and remote observation of the giant planet itself.

At launch, the orbiter weighed about 2,223 kilograms (4,900 pounds), not counting the upper-stage-rocket adapter but including about 925 kilograms of usable rocket propellant. This propellant is used in almost 30 relatively small maneuvers during the long gravity-assisted flight to Jupiter, three large thrust maneuvers including the one that puts the craft into its Jupiter orbit, and the 30 or so trim maneuvers planned for the satellite tour phase. It is also consumed in the small pulses that turn and orient the spacecraft.

The propulsion module consists of twelve 10-newton thrusters, a single 400-newton engine, the monomethyl-hydrazine fuel, nitrogen-tetroxide oxidizer, and pressurizing-gas tanks, tubing, valves and control equipment. (A thrust of 10 newtons would support a weight of about one kilogram or 2.2 pounds at Earth's surface.) The propulsion system was developed and built by Messerschmitt-Bolkow-Blohm (MBB) and provided by Germany as a partner in Project Galileo.

In addition to the scientific data acquired by its 10 instruments, the Galileo orbiter acquires and can transmit a total of 1,418 engineering measurements of internal operating conditions including temperatures, voltages, computer states and counts. The spacecraft transmitters will operate at S-band frequency (2,295 megahertz).

Two low-gain antennas (one pointed upward or toward the Sun, and one on a deployable arm to point down, both mounted on the spinning section) supported communications during the Earth-Venus-Earth leg of the flight. The top-mounted antenna is currently carrying the communications load, including science data and playbacks, in place of the high-gain antenna, and is the basis of the redesigned Jupiter sequences. The other low-gain antenna has been re-stowed after supporting operations during the early VEEGA phase, and is not expected to be used again.

Because radio signals take more than one hour to travel from Earth to Jupiter and back, the Galileo spacecraft was designed to operate from programs sent to it in advance and stored in spacecraft memory. A single master sequence program can cover from weeks to months of quiet operations between planetary and satellite encounters. During busy encounter operations, one program covers only about a week.

These sequences operate through flight software installed in the principal spacecraft computers. In the command and data subsystem software, there are about 35,000 lines of code, including 7,000 lines of automatic fault protection software, which operates to put the spacecraft in a safe state if an untoward event such as an onboard computer glitch were to occur. The articulation and attitude control software has about 37,000 lines of code, including 5,500 lines devoted to fault protection.

Electrical power is provided to Galileo's equipment by two radioisotope thermoelectric generators. Heat produced by natural radioactive decay of plutonium 238 dioxide is converted to electricity (570 watts at launch, 485 at the end of the mission) to operate the orbiter equipment for its eight-year baseline mission. This is the same type of power source used by the two Voyager spacecraft missions to the outer planets, the Pioneer Jupiter spacecraft, and the twin Viking Mars landers.

Scientific instruments to measure fields and particles, together with the main antenna, the power supply, the propulsion module, most of the computers and control electronics, are mounted on the spinning section. The instruments include magnetometer sensors, mounted on an 11-meter (36-foot) boom to minimize interference from the spacecraft; a plasma instrument detecting low-energy charged particles and a plasma-wave detector to study waves generated by the particles; a high-energy particle detector; and a detector of cosmic and Jovian dust. It also carries the Heavy Ion Counter, an engineering experiment added to assess the potentially hazardous charged-particle environments the spacecraft flies through, and an added Extreme Ultraviolet detector associated with the UV spectrometer on the scan platform.

The despun section carries instruments and other equipment whose operation depends on a steady pointing capability. The instruments include the camera system; the near-infrared mapping spectrometer to make multispectral images for atmospheric and moon surface chemical analysis; the ultraviolet spectrometer to study gases; and the photopolarimeter-radiometer to measure radiant and reflected energy. The camera system will obtain images of Jupiter's satellites at resolutions from 20 to 1,000 times better than Voyager's best, largely because it will be closer. The CCD sensor in Galileo's camera is more sensitive and has a broader color detection band than the vidicons of Voyager. This section also carries an articulated dish antenna to track the atmospheric probe and pick up its signals for recording and relay to Earth.

Technology Benefits Derived from Galileo

The research and development necessary to build and fly Galileo has produced several technological innovations.

Charge-coupled devices like those in Galileo's television systems are used in some home video cameras, yielding sharper images than ever conceived of in the days before the project began. In addition, radiation-resistant components developed for Galileo are now used in research, businesses, and military applications where radiation environment is a concern. Another advance, integrated circuits resistant to cosmic rays, has helped to handle disturbances to computer memory that are caused by high-energy particles; these disturbances plague extremely high-speed computers on Earth and all spacecraft.

Program/Project Management

Galileo's scientific experiments are being carried out by more than 100 scientists from six nations. These experimenters use dedicated instruments and the radio subsystems on the Galileo orbiter and probe. In addition, NASA has appointed 17 interdisciplinary scientists whose studies reach across more than one Galileo instrument data set.

The Galileo Project is managed for NASA's Office of Space Science by the Jet Propulsion Laboratory, a division of the California Institute of Technology. This responsibility includes designing, building, testing, operating and tracking Galileo. Germany has furnished the orbiter's retro-propulsion module and some of the instruments and is participating in the scientific investigations. The radioisotope thermoelectric generators were designed and built by the General Electric Company for the U.S. Department of Energy.

NASA's Ames Research Center, Mountain View, CA, is responsible for the atmosphere probe, which was built by Hughes Aircraft Company, El Segundo, CA. At Ames, the probe manager is Marcie Smith and the probe scientist is Dr. Richard E. Young.

At JPL, William J. O'Neil is project manager, Dr. Torrence V. Johnson is project scientist, Neal E. Ausman Jr. is mission director, and Matthew R. Landano is deputy mission director.

At NASA Headquarters, the program manager is Donald Ketterer.The program scientist is Dr. Jay Bergstralh. Dr. Wesley T. Huntress Jr. is Associate Administrator for the Office of Space Science.

Galileo Scientific Experiments

Experiment/Instrument	*Principal Investigator*	*Objectives*
PROBE		
Atmospheric Structure	Alvin Seiff, NASA Ames Research Center	Temperature, pressure, density, molecular weight profiles
Neutral Mass Spectrometer	Hasso Niemann, NASA Goddard SFC	Chemical composition
Helium Abundance	Ulf von Zahn, Bonn University, FRG	Helium/hydrogen ratio
Nephelometer	Boris Ragent, NASA Ames	Clouds, solid/liquid particles
Net Flux Radiometer	Larry Sromovsky, Univ. of Wisconsin	Thermal/solar energy profiles
Lightning/Energetic Particles	Louis Lanzerotti, Bell Laboratories	Detect lightning, measure energetic particles

ORBITER (DESPUN)		
Solid-State Imaging Camera	Michael Belton, NOAO (Team Leader)	Galilean satellites at 1-km resolution or better, other bodies correspondingly
Near-Infrared Mapping Spectrometer	Robert Carlson, JPL	Surface/atmospheric composition, thermal mapping
Ultraviolet Spectrometer (includes extreme UV sensor on spun section	Charles Hord, Univ. of Colorado	Atmospheric gases, aerosols, etc.
Photopolarimeter Radiometer	James Hansen, Goddard Institute for Space Studies	Atmospheric particles, thermal/reflected radiation
ORBITER (SPINNING)		
Magnetometer	Margaret Kivelson, UCLA	Strength and fluctuations of magnetic fields
Energetic Particles	Donald Williams, Johns Hopkins APL	Electrons, protons, heavy ions in atmosphere
Plasma	Lou Frank, Univ. of Iowa	Composition, energy, distribution of ions
Plasma Wave	Donald Gurnett, Univ. of Iowa	Electromagnetic waves and wave-particle interactions
Dust	Eberhard Grun, Max Planck Inst. fur Kernphysik	Mass, velocity, charge of submicron particles
Radio Science: Celestial Mechanics	John Anderson, JPL (Team Leader)	Masses and motions of bodies from spacecraft tracking
Radio Science: Propagation	H. Taylor Howard, Stanford Univ. (Team Leader)	Satellite radii, atmospheric structure, from radio propagation
Engineering Experiment:		
Heavy Ion Counter	Edward Stone, Caltech	Spacecraft charged-particle environment

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James Van Allen, University of Iowa