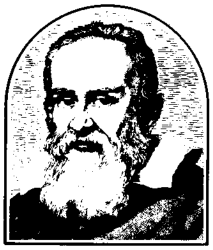
SECTION 2



THE JOURNEY TO JUPITER

Every cloud has a silver lining. Consider the journey of Galileo from Earth to Jupiter. When the Challenger exploded in January 1986, preparations were under way to launch Galileo in May. This launch would have used a shuttle to carry the spacecraft to low-Earth orbit. Galileo would then have been boosted to Jupiter using the powerful Centaur rocket as an upper stage.

The Galileo project was hit by a double whammy. First, the shuttle fleet was grounded while problems were identified and fixed. Second, the Centaur was forbidden to be carried on a space shuttle.

Mission designers worked to find another way to Jupiter. Several ideas were suggested. One idea was to split the flight system into two pieces and launch each separately. All the proposed schemes were either too costly or not able to accomplish all the mission's scientific objectives.

VEEGA—The Solution

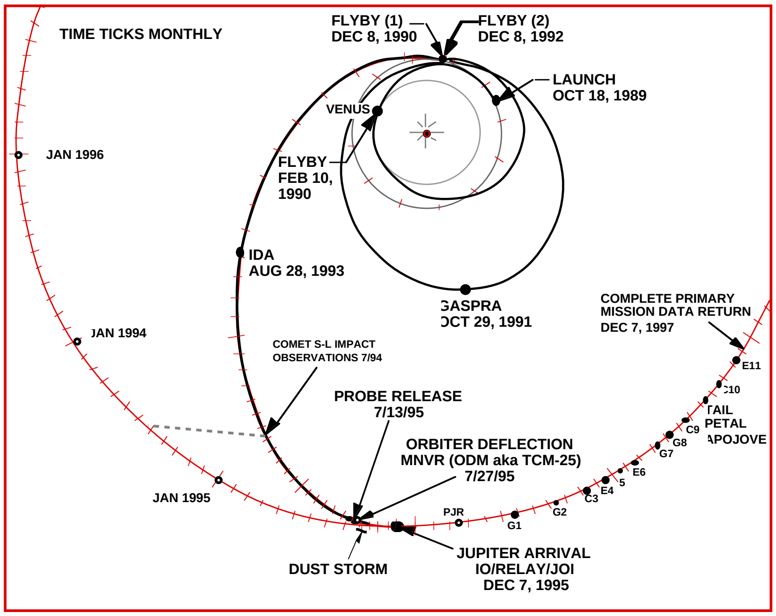
Finally, trajectory experts discovered that if they launched the spacecraft toward the planet Venus they would be able to get to Jupiter using a series of gravity assists. The spacecraft would fly by Venus and then twice by the Earth itself. These three gravity assists would make up for chemical energy that was lost with the banned Centaur rocket. The trajectory was named "VEEGA" for "Venus–Earth–Earth Gravity Assist."

A gravity assist occurs when a spacecraft flies past a massive body at just the right place. The spacecraft receives a boost in energy (and a change in direction) by the gravitational action of the body.

One of the big drawbacks of the VEEGA trajectory was that going near Venus would bring the Galileo spacecraft closer to the Sun than it had been designed to fly. (Venus is only two-thirds of Earth's distance from the Sun.) So, spacecraft engineers had to change the thermal protection of Galileo to prevent damage as it swung toward the Sun. Other drawbacks included having to add another low-gain antenna, performing a lot of new aging analysis to address the extended time here and in space, and extensive new navigational analysis.

With the VEEGA trajectory, scientists realized that there was also a silver lining. The complex path to Jupiter would carry the Galileo spacecraft by several interesting objects. The detour was not just an annoying delay. Fascinating opportunities lay ahead.

The VEEGA Trajectory

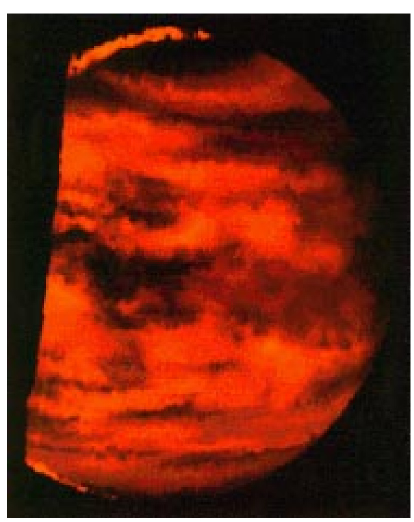


Liftoff!

Galileo was launched aboard the Space Shuttle Atlantis on October 18, 1989. In place of the Centaur, the Inertial Upper Stage (IUS) was used to boost the spacecraft on its journey. Along the way to Jupiter there were encounters with Venus (February 10, 1990), Earth-1 (December 8, 1990), asteroid 951 Gaspra (October 29, 1991), Earth-2 (December 8, 1992), and asteroid 243 Ida (August 28, 1993). In addition to their science value, these encounters were used to calibrate and characterize the spacecraft's instruments in support of its future activities at Jupiter.

On February 10, 1990, the Galileo spacecraft flew to within 16,000 kilometers of Venus. Scientific observations, including 81 images of the planet, were performed from closest approach –1 day to +7 days during the encounter period. The pictures of cloud-covered Venus revealed new information on the structure and dynamics of the thick atmosphere.

Venus Flyby,
An Infrared Image of the Clouds



Galileo looped back to Earth later that year. The spacecraft passed above the western Atlantic at an altitude of 960 kilometers. Galileo took more than 1000 pictures of Earth to create a stunning Earth-rotation movie. This movie displayed weather patterns from Galileo's unique perspective.

How Aliens Would See Us

At a press conference after the Earth-1 encounter, the Project Scientist, Dr. Torrence Johnson, provided a unique overview of the flyby. He imagined Galileo was an alien spacecraft from somewhere near the star Arcturus. What would the aliens have learned about planet Earth? They would know that Earth's oceans were not very deep since the planet's density was more than 5 times that of water. A magnetic field would have been detected. This field would allow them to deduce the presence of the planet's fluid, conducting core. The chemistry of the atmosphere, with its low amount of carbon dioxide and high amount of oxygen, might indicate life. Radio signals, most likely not of natural origin, would have been detected. This further supported the possibility of life. There were probably volcanoes, but no active volcanoes were spotted. Plate tectonics were not detected. Johnson concluded his talk by saying that the Arcturan Academy of Sciences would certainly ask their government to fund another mission to Earth, preferably an orbiter.

Earth Flyby

The High-Gain Antenna

In April 1991, the Galileo flight team prepared to open the spacecraft's 4.8-meter mesh high-gain antenna. The antenna had been stowed like a closed umbrella since launch. People are always nervous about doing a major mechanical operation in space. You can't go out there with your tool box if it doesn't work. This time their worst fears came true. The antenna failed to open.

For many months, the problem was studied and various fixes were attempted—heating the antenna using sunlight, cooling it by turning it toward the cold darkness of deep space, and trying to force it open with its motors. The device remained stuck.

Analysis of the available engineering measurements showed that the antenna had only partially opened. It was of little or no use as a communications device. Reluctantly, the project began to consider how to carry out its mission using only the low-gain antenna to transmit data to the ground.

The recovery strategy had two main thrusts. First, the sensitivity of the Deep Space Network (DSN) was increased substantially. (The DSN is a network of three deep space communications facilities located around the Earth at about 120 degrees apart, allowing constant observation of a spacecraft as the Earth rotates.) Second, methods of compressing data onboard the spacecraft before they were sent to the ground were to be developed. That way fewer "bits" could do the work of more. So effective were the plans of spacecraft engineers and mission planners that it has been estimated 70 percent of Galileo's original scientific objectives will be met.

Cruising the Asteroid Belt

Asteroid 951 Gaspra was the next target after Earth-1. The closest approach to Gaspra, on October 29, 1991, was at 1600 kilometers. Imaging of the asteroid started at one Gaspra "day" (7 hours and 3 minutes) before closest approach. Images were taken as close as 5000 kilometers. Approximately 60 percent of the surface was photographed. Objects as small as about 50 meters could be seen in some images. The images were stored on the spacecraft's tape recorder for later transmission over the low-gain antenna. This first space encounter with an asteroid showed it to be an irregular object (19 by 12 by 11 kilometers) covered with craters.

The December 1992 flyby of Earth went smoothly. Closest approach was at an altitude of only 305 kilometers. (The space shuttle, the space transportation system or STS, typically orbits the Earth at an altitude of

300 kilometers.) Scientists again imaged the Earth–Moon system and calibrated Galileo's instruments.

Galileo's final encounter, before arriving at Jupiter, was its most exciting in terms of providing scientific information. The second spacecraft encounter with an asteroid, Ida, revealed an irregular, cratered object more than twice the size of Gaspra. The spacecraft flew as near as 2400 kilometers on August 28, 1993.

The surprise was found in pictures played back several months after the encounter. A small moon was orbiting Ida! This object, only about 1.5 kilometers in diameter (Ida's long axis is about 56 kilometers), has been named "Dactyl." The moon was in orbit about 100 kilometers from the center of Ida.

We Fly By Gaspra
(two views)

And Ida Has a Moon!
(look to the right)

Immediately upon the heels of the Ida data return, the Galileo spacecraft would have a direct view of an extremely rare event. It would witness the impact of a comet with Jupiter. No Earth-based (or orbiting) telescope would be similarly favored.

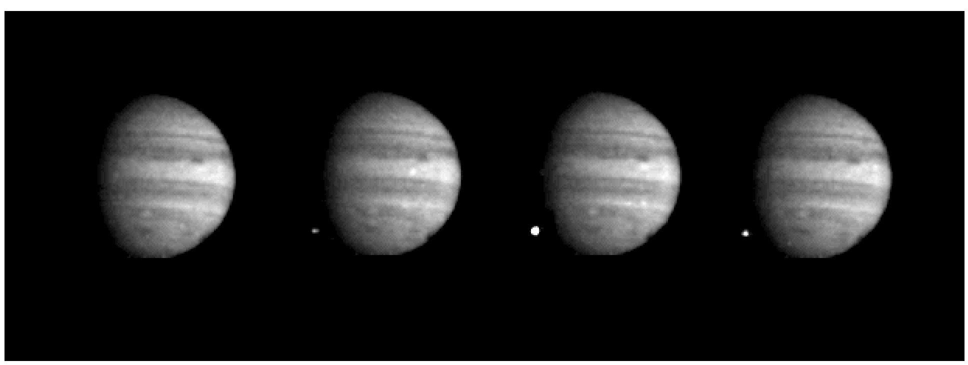
The Comet Spectacle—S/L-9

Gene and Carolyn Shoemaker and David Levy discovered a fragmented comet on March 24, 1993. Since the comet was the ninth discovered by this team, it was labeled “Shoemaker–Levy 9” (S/L-9). The discovery was made with the 0.5-meter Schmidt telescope at the Palomar Observatory in California.

Originally a periodic comet in orbit about the Sun, the comet was captured by Jupiter. It may have broken into pieces in July 1992 when it passed about 100,000 kilometers from the giant planet. By cosmic standards, this is a very close passage, but when astronomers examined the future path of the cometary fragments, they were astounded to find that in July 1994 the comet would actually slam into Jupiter.

Galileo was approximately 240 million kilometers from Jupiter at the time of the impacts. All told, 23 fragments splashed into the atmosphere between July 16 and July 22 while Galileo performed many scientific observations from its unique perspective.

S/L-9 Arrives at Jupiter



The following table summarizes the highlights during the cruise portion of the mission and identifies the instruments that contributed to them. (See The Galileo Orbiter section for a description of the instruments.)

the highlights during

Cruise Highlights

Venus	• Confirmation of lightning (PWS) • Images of mid-cloud level (NIMS, SSI) • Images of surface (NIMS) • Bow shock observed (EPD)
Earth, Moon	• Unique measurements of the distant regions of the magnetotail (MAG, PLS) • Discovery of intelligent life (PWS) • Earth-rotation movie (SSI) • Movie of Moon passing in front of Earth (SSI) • Images of Antartica (SSI) • Visual and infrared images of the Andes mountains (NIMS, SSI) • Visual and infrared images of the lunar farside and the polar regions (NIMS, SSI)
Asteroids (Gaspra, Ida)	• First and second close encounter with an asteroid (all instruments except HIC) • Discovery of first confirmed asteroid moon, Dactyl (NIMS, SSI) • Unexpected solar wind/asteroid interaction—magnetic signature? (MAG)
Comet Collision with Jupiter (Shoemaker–Levy 9)	• Only direct observations of impacts (SSI, PPR, NIMS, UVS) • Only direct characterization of the size and temperature of the impact fireball (NIMS, PPR, UVS) • Detection of the “splash-back” of the material ejected from the impacts (NIMS)
Interplanetary Cruise	• Discovery of the most intense dust storm ever recorded by a spacecraft (DDS) • Mapping of hydrogen and helium distribution in the solar system (EUV, UVS) • Characterization of large solar flare (HIC)
Engineering	• Demonstration of deep-space optical communication using lasers (SSI) • Complete rework and reloading of primary computer software (AACS, CDS)

Note: Acronym Definitions:

AACS = Attitude and Articulation Control Subsystem
CDS = Command and Data Subsystem
DDS = Dust Detector Subsystem
EPD = Energetic Particles Detector
EUV = Extreme Ultraviolet (Spectrometer)
HIC = Heavy Ion Counter
MAG = Magnetometer
NIMS = Near-Infrared Mapping Spectrometer
PLS = Plasma Subsystem
PPR = Photopolarimeter Radiometer
PWS = Plasma Wave Subsystem
SSI = Solid State Imaging
UVS = Ultraviolet Spectrometer

Probe Release and ODM

The final major mission event in getting ready for Jupiter arrival occurred in July 1995. On July 13, the atmospheric probe was cut loose from the orbiter. The probe was pushed gently away on a trajectory that guided it into Jupiter's atmosphere on December 7. By design, the probe did not communicate with the orbiter during the cruise to Jupiter.

The orbiter had to be deflected from its course so it wouldn't follow the probe into the atmosphere of Jupiter. The orbiter deflection maneuver (ODM) occurred on July 27. It was the first use of the 400-newton main engine of the spacecraft; after 6 years in space, the system functioned well. (Except for a 2-second "wake-up" burn 3 days earlier, this engine actually had not been fired since 1984.)

At ODM the engine burned for 308.1 seconds. Valuable data on engine characteristics were gained. These data were used to plan the burn sequence to insert the orbiter into a trajectory about Jupiter. After a burn lasting 49 minutes, the orbiter would begin its 2-year tour of the gas giant and its complement of satellites, rings, and magnetosphere.

The Tape Recorder Challenge

The Jupiter approach phase officially began on October 9, 1995. On October 11, the orbiter recorded a global image of Jupiter with the probe entry site in view. When the tape recorder was commanded to rewind so that the picture could be transmitted to Earth, Project personnel received an unexpected jolt. Data from the spacecraft showed that the tape recorder had failed to stop rewinding.

After commands were sent in real time to stop the recorder, engineers quickly began an extensive analysis of the problem. Was the tape broken? Was it slipping? Had the tape recorder actually stopped but sent a faulty reading?

On October 20, the tape recorder was tested and a few seconds of data were played back. The tape recorder was still operational! However, a preliminary study indicated that the tape recorder could be unreliable under some of the planned Jupiter approach operating conditions.

On October 24, the spacecraft executed commands for the tape recorder to wind on the reel an extra 25 times around the section of the tape involved in the anomaly. This section had been possibly weakened when the recorder was stuck in rewind mode for about 15 hours. Indications were that the tape had not moved during this entire time. The drive mechanisms had been slipping and possibly rubbing against the tape. Spacecraft engineers are uncertain about the condition of this area of tape so it is now "off-limits" for future 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 on October 11 is stored on the off-limits portion of the tape and will not be played back.

Engineers continued to analyze the tape recorder's condition so that they could fully understand its capabilities and potential weaknesses. They hoped to find ways to operate the recorder with little loss to the orbital mission objectives. Consequently, the decision was made to use the tape recorder on arrival only to record the probe data, since this was by far the most important arrival data and required only the most benign operation of the recorder. All imaging and other high-rate data (including the pictures of Europa and Io) were eliminated from the arrival sequence. Ultimately, the equally benign recording of unique fields and particles data in the Io torus was also accommodated.

Looking back, the cruise phase of Galileo was very valuable. The spacecraft was characterized, indicating the performance we could expect from it. The instruments were calibrated. We added to our knowledge of Venus, the Earth, and the Moon. We rewrote the book on asteroids. We had the best perspective on the cosmic show provided by Shoemaker–Levy 9. And the primary mission was yet before us. . . .