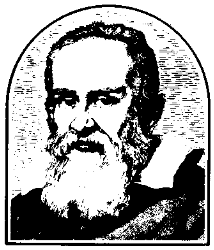
SECTION 8



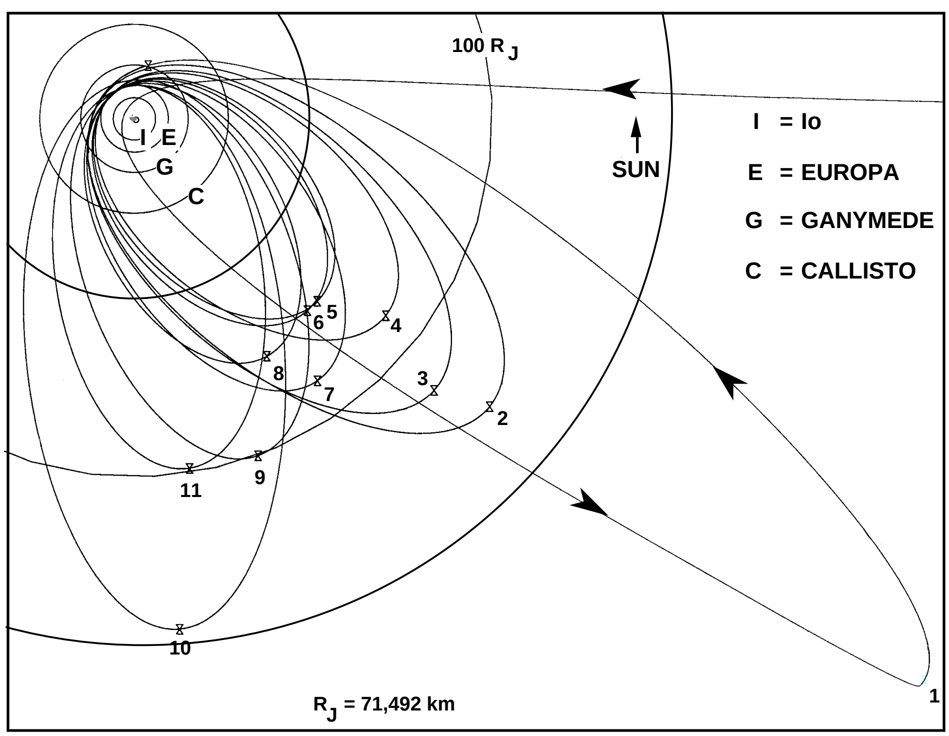
THE TOUR

The Jovian tour is much more that just a series of targeted encounters with the Galilean satellites. The tour is the culmination of a strategy developed over 20 years ago to thoroughly explore Jupiter's system. The first part of that strategy was accomplished by the probe. The second part was assigned to the orbiter: the comprehesive examination of Jupiter's magnetosphere, satellites, and atmosphere over an almost 2-year period.

The tour was set up by the gravity assist from the Io flyby and the Jupiter orbit insertion (JOI), which maneuvered the orbiter into the first, and by far the longest (nearly 7 months), highly elliptical path about the planet. Galileo is now on its way to a close encounter (844 kilometers or 524 miles) with Ganymede on June 27, 1996.

A glance at the figure below will show you the series of 11 flower-petal-shaped orbits for the tour. The view is from north of the plane of the satellites' orbits. A total of four encounters at Ganymede, three at Europa, and three at Callisto are planned. After the first encounter, the orbits will be much shorter, and the time for each will range from one to two and a half months. After the mission has been completed (December 1997), Galileo will continue to orbit Jupiter for probably thousands of years.

Satellite Tour Petal Plot



Orbit Names

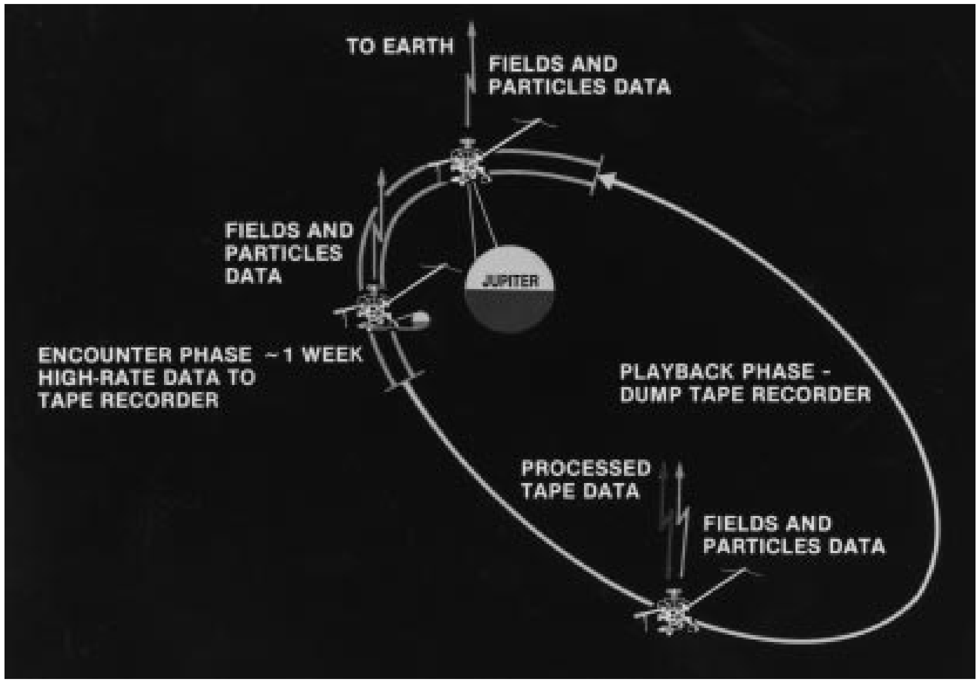
First, how do we name an orbit? "Orbit MN"—where "M" is the first letter of the moon (C, E, or G for Callisto, Europa, or Ganymede) and "N" numbers the orbits from 1 to 11—actually names the set of observations and spacecraft activities performed between successive encounters of the tour. The insertion orbit was the zeroth orbit. Since the orbit insertion maneuver, Galileo has been in the initial orbit around Jupiter, J0, on its way to Ganymede. G1 is the first encounter with Ganymede and begins the second complete revolution around Jupiter. On each subsequent orbit (except number 5) there will be one close satellite encounter.

Tour Highlights

Orbit	Satellite Encounter	Date (UTC)	Altitude (km)	Altitude (miles)
G1	Ganymede	June 27, 1996	844	524
G2	Ganymede	September 6	250	155
C3	Callisto	November 4	1104	686
E4	Europa	December 19	692	430
J5	(Solar conjunction)		(no close flyby)	
E6	Europa	February 20, 1997	587	365
G7	Ganymede	April 5	3059	1901
G8	Ganymede	May 7	1585	985
C9	Callisto	June 25	416	258
	Magnetotail Apojove	August 8		
C10	Callisto	September 17	524	326
E11	Europa	November 6	1125	699

The Orbiter At Work

What will the orbiter be doing during the satellite tour? Each orbit is divided into an encounter period of approximately one week and a cruise period of several weeks duration, the remainder of the orbit prior to the next encounter (see figure, Typical Orbit, ~1 To 2 Months). During parts of each encounter period, Galileo will be recording data at high rates onto its tape recorder in addition to returning real-time fields and particles data. This recorded data will include images, ultraviolet and infrared spectra, and high-rate fields and particles measurements (especially around closest approach to the targeted satellite for that orbit). During the cruise period of the orbit, the recorded data will be played back to Earth, interspersed with more real-time fields and particles data.



Typical Orbit ~1 to 2 months

The Science Opportunity

The science elements for a typical orbit are remote sensing of the Galilean satellites and Jupiter atmosphere (performed primarily within a few days of each satellite encounter) and in situ measurements of the magnetosphere, acquired nearly continuously but with higher resolution near the satellite encounter and during Galileo's trip down Jupiter's magnetotail (between C9 and C10). Most of the remote-sensing data will be recorded for playback between encounters, although some NIMS and UVS measurements are sent in realtime. Fields and particles measurements, the core of the magnetosphere data, will also be recorded during encounter, as well as being edited for real-time inclusion in the downlink.

Three working groups—Atmospheres, Satellites, and Magnetospheres—were established early in the Project to address the science objectives of the tour (see The Galileo Orbiter section). Each group has its own focus and needs for acquiring and retrieving data. But as you can imagine, there are restrictions on just how much data is available for each discipline. So the working groups bargain and make trades to deal with the operational limitations imposed by the amount of tape recorder space available, the number of bits of data that can be returned to Earth prior to the following encounter, and the amount of spacecraft memory available to retain the observing/engineering sequences.

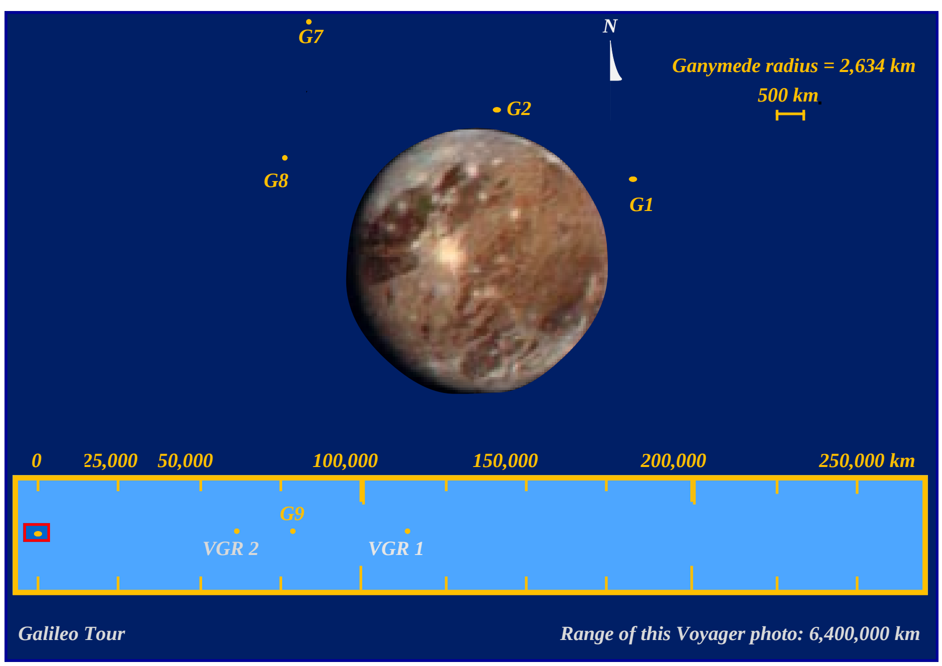
Aiming the Spacecraft

How will the Project Galileo team "steer" the spacecraft so that it will encounter the other Galilean moons? Rocket propulsion could have done the job, but the amount of propellant required to perform the maneuvers in Jupiter's strong gravitational field would have added too much mass to the spacecraft. Remember VEEGA? (See The Journey to Jupiter section.) Yes, gravity-assist will be the answer. At each encounter, the gravitational force of the satellite will be used to alter the course of the orbiter. This technique requires only a small amount of propellant to fine–tune the spacecraft path. The entire tour can be flown so that thrusters need to supply a change in speed of only about 100 meters per second, 60 times less than would otherwise be needed. We think of this trajectory design as a 10-cushion shot in a celestial billiard ball game! (If you could make very small corrections along the way.)

Both radio tracking and optical data (satellite and star images) are required to navigate the orbiter. Special navigation tracking passes are provided three times a week and more often around orbit trim maneuvers (OTMs) and satellite encounters. Post encounter (+3 days) maneuvers will typically be used to correct the previous satellite encounter flyby energy. The maneuvers for apojove and before encounters (–3 days) are typically used to target to the next satellite encounter.

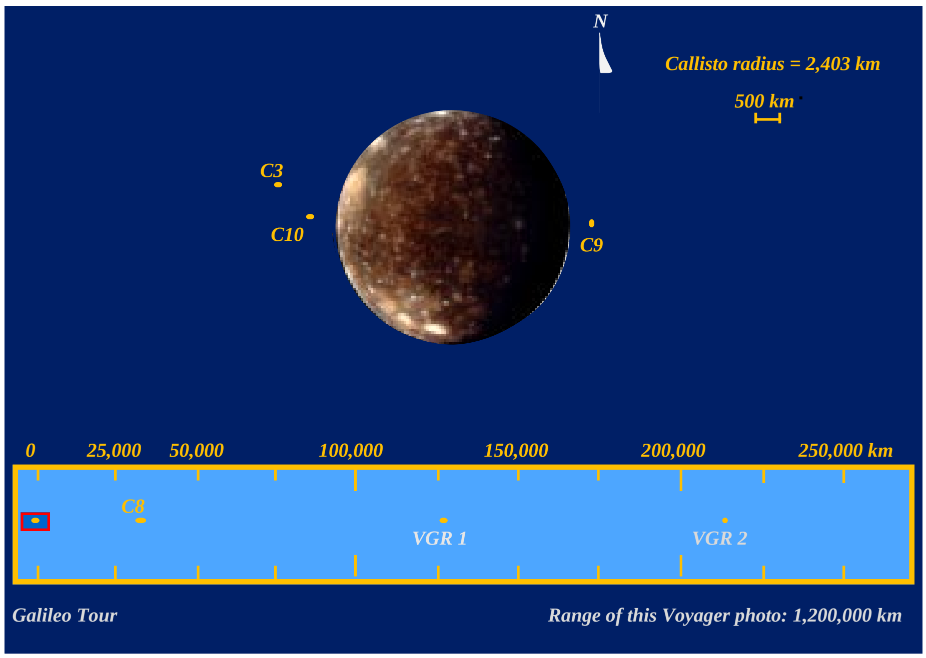
Aimpoints for the close flybys for Ganymede, Callisto, and Europa are shown in the following three figures. Positions of the spacecraft for these close encounters are superimposed on Voyager images of the satellite to

Ganymede Encounters (four times)

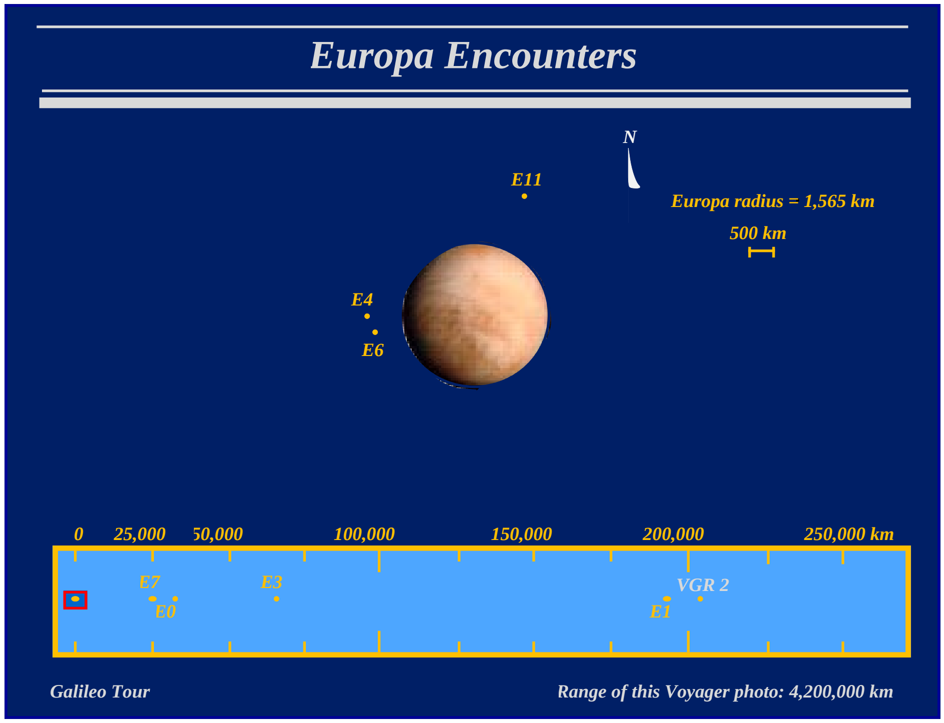


emphasize how much closer (up to 350 times closer) Galileo will fly by each moon. Even the nontargeted flybys of moons that occur when the spacecraft is en route to or from a different moon are by far closer than the Voyager flybys. Note these nontargeted flybys by Galileo compared to the closest Voyager flybys shown on the inset scale at the bottom of the figure. The small box at the left (with the targeted satellite in the center) represents a shrunken version of the entire figure. (These views are accurate in altitude, latitude, and whether darkside or lightside, but they cannot accurately represent the longitude or face presented during each of the close encounters.)

Callisto Encounters (three times)



Europa Encounters (three times)



Getting a Lift!

Steering the spacecraft to G1 was critical to achieving the tour. The 400-newton engine was called upon (for its third and last time) to change the course of Galileo, on March 14, 1996, when it performed the perijove raise maneuver (PJR). The same as with the ODM and JOI, the 400-newton engine did its job well, this time doubling the orbital speed of the spacecraft while it was at apojove, its greatest distance from the planet. And PJR raised the spacecraft perijove (closest approach) from 4 R_J to 11 R_J (Jupiter radii) while setting up conditions for G1.

Why was this maneuver essential? As you know, Jupiter has intense radiation belts that could damage the science instruments and the orbiter itself. Galileo's electronic parts were designed and shielded to withstand 150 krad during its lifetime, a lethal dose for humans. On arrival, the orbiter was subjected to about one-third of its lifetime allowance, flying through perijove at an altitude of 215,000 kilometers or about 3 R_J (4 R_J from the center of the planet). There was no damage at that time (although the star scanner was temporarily saturated, as expected), but repeated doses of radiation could and probably would be a different story. That is why PJR was performed. To limit further radiation exposure which is much less at higher altitudes, PJR raised the perijove to an altitude just above that of Europa's orbit.

Pointing the Spacecraft

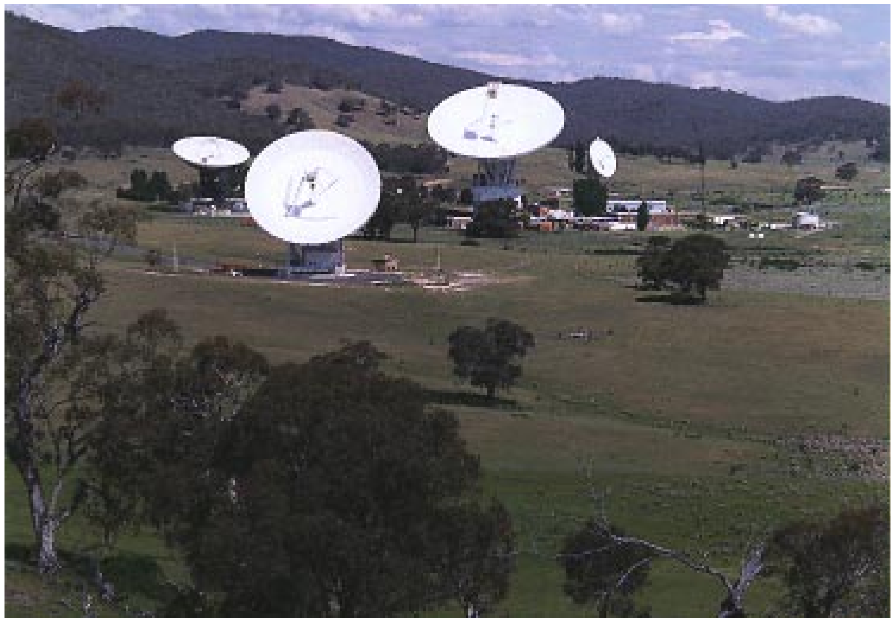
Spacecraft housekeeping chores include attitude maintenance to keep the spacecraft pointing within 4 degrees of Earth for telecom link performance and engineering monitoring. Real-time engineering (RTE) data is supplied at either 2 or 10 bits per second (the lower rate is nominal). On most orbits, special turns of the spacecraft are planned to allow the scan platform instruments to view parts of the sky which are otherwise blocked by the booms or the main body of the spacecraft. These turns are called "spacecraft inertial turns" or SITURNS, but they are more commonly known as "science turns." Targets that are enabled by SITURNS are Jupiter darkside observations, such as aurora, lightning, and ring observations. During the mission, 20 kilograms of propellant are budgeted for SITURNS; a typical 90-degree turn and return costs about 3 kilograms.

Tele-communications

Receiving and Sending Radio Signals From Earth

Galileo's radio puts out about 20 watts of power, about the power of a refrigerator lightbulb. The spacecraft's low-gain antenna broad beam disperses this power so widely that by the time the signal has traveled the 750 million kilometers (average) to reach the DSN antennas on Earth, a 70-meter antenna is able to scoop up only about one part in 10 to the 20th watt, in other words 0.000 000 000 000 000 000 01 watt. New receivers, enhanced S-band reception (ultracone), and the ability to array multiple antennas all contribute to the capability of receiving these tiny signals from the spacecraft. These changes will increase the 8- to 16-bits per second data transmission rate by up to 10 times.

The Deep Space Network (DSN) stations are at Goldstone, California; Madrid, Spain; and Canberra, Australia. Canberra is in the best position for reception most of the time. Galileo appears in Canberra's sky for about 12 hours per day, as opposed to 9 hours and 7 hours for Goldstone and Madrid, respectively. Starting in November 1996, nearby Parkes Radio Telescope (not part of the DSN) will help boost coverage. Not only will there be arraying of antennas in Australia at the Canberra site and with Parkes, but also between continents when the Goldstone 70-meter antenna is arrayed with Canberra. (The figure shows Stations 34, 42, and 43 from left to right; Station 46 on the far right is not a part of the array for Project Galileo.)



Arrayed Antennas At Canberra

Spacecraft To Earth, "Now Hear This"

Galileo's radio signal to Earth is our only communication line and must carry all the navigation, engineering, and science data—real-time and recorded—to the DSN receivers for analysis by Project Galileo. New spacecraft software that will make more effective use of the improved telecommunications was uploaded in the spring of 1996. This new software modified most science instruments, the Command and Data Subsystem (CDS), the Attitude and Articulation Control Subsystem (AACS), and most of the Project Galileo ground data systems. The upgrade allows editing and compression of the science and engineering data streams and provides a buffering mechanism to manage the flow from real-time data sources and the Data Memory Subsystem (DMS) tape recorder playback into the downlink channel.

Prior to being sent to Earth, the data are stored in the multi-use buffer (MUB). The MUB is a 71-kilobyte region in the CDS used to temporarily store raw real-time science data, raw playback data, and processed data prior to downlinking. Data compression contributes to the effective use of the downlink. Once data is in the MUB, Galileo's computer (the CDS), begins processing it, using instructions from the stored sequence. These instructions apply special rules that delete data not wanted and apply special formulas to the remaining data to reduce data volume while retaining the information content. Data are further encoded, using telecommunication techniques that allow error correcting of the data received at Earth; this process permits transmission of data at Galileo's lower signal strength.

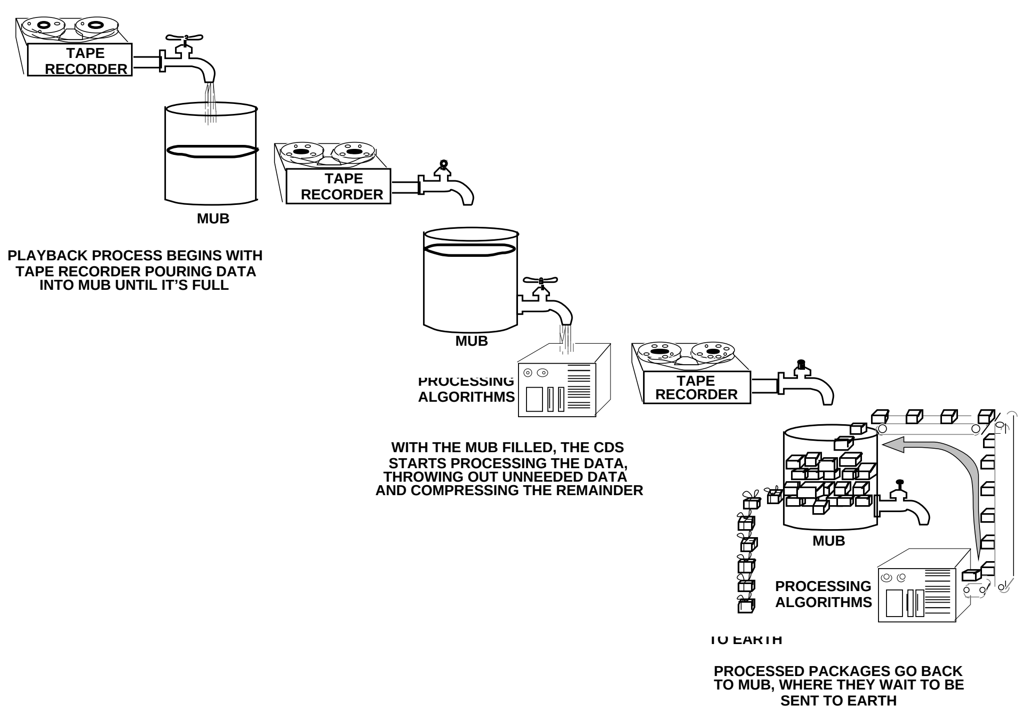
Playing Back the Tape Recorder

Playback of data from the tape recorder is scheduled during the cruise phase of each orbit. The playback data shares the available telemetry capability with real-time science (RTS) after the higher priority engineering data has been placed into the downlink. The playback process is initiated, paused, resumed, or terminated through commands in the stored sequence.

In what order is the playback data returned? Generally, in a first-in, first-out order, but spread over the several weeks of the orbital cruise. So data recorded in the first day or so of the encounter will be played back in the first week or so of cruise, and data recorded on the last day of the encounter will be played back in the last week or so of cruise. An interesting but also complicating characteristic of Galileo’s playback process is that the achieved compression is not deterministic—probably not predictable to within better than days exactly when a given data set will be returned.

The following figures give a very simplified overview of the data flow through Galileo’s data processing system. Imaging data is not included; it is processed by the AACS before storage in the MUB and subsequent downlink.

Filling the Downlink Efficiently



The Trip Detailed

Where and when will events take place? Project Galileo has prepared Quick-Look Orbit Facts sheets to help you track our itinerary.
The time of arrival, the altitude and position at the time of closest approach, and the science highlights are just a few of the facts you'll have handy for each orbit. Maps of the encounter trajectory and the flyby geometry for each encounter offer some visual relief and point the way.
A timeline summarizing the major tour events and the set of Quick-Look Orbit Facts can be found in the Appendix; they complete our description of the Galileo tour.

A Unique Experience

Though our tour will be ending in December 1997, the work of the scientists will be in full swing. They will be piecing together the observations and analyzing this valuable data for years to come. No doubt new understandings of our solar system will emerge from this first spacecraft orbiting of an outer planet. We look forward to unlocking the mysteries Jupiter holds.