GALILEO ON JUPITER APPROACH

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Abstract

After six years of interplanetary flight, in just two months, on December 7, 1995, Galileo will arrive at Jupiter. In July, Galileo released its Atmospheric Entry Probe on the five-month solo, ballistic flight to Jupiter entry. After Probe release, the Orbiter fired its 400-N main engine for the first time to deflect the Orbiter to its Io flyby aim point, establishing the trajectory for Probe radio relay link acquisition and orbit insertion. The 400-N engine was specifically used for the deflection in order to check it out prior to orbit insertion.

Last February, the Galileo Orbiter Command and Data Subsystem (CDS) and Attitude and Articulation Control Subsystem (AACS) computers were completely re-loaded to provide new software capabilities for main engine and relay link autonomous fault protection and for backup Probe data storage on the Orbiter. The execution and results of this complete inflight software change are discussed. The status of the Entry Probe prior to release is described—once released there is no communication link with the Probe until after entry. The operation and performance of the 400-N main engine at the deflection burn is explained in the context of its required use for orbit insertion.

Final predictions for the Probe entry conditions, Probe-to-Orbiter radio relay link, and Orbiter insertion performance are given. Overall mission status and spacecraft health are summarized.

1 Introduction

After six years of truly remarkable interplanetary flight, in just two more months, on December 7,1995, Galileo will arrive at Jupiter. On December 7th Galileo will perform the first-ever direct sampling of an outer planet atmosphere and become the first spacecraft to orbit an outer planet.

Figure 1 shows Galileo's interplanetary trajectory indicating the targets of opportunity observed in past years and the momentous events of this past summer—Probe Release and Orbiter Deflection. Galileo has just 0.9 percent of its interplanetary journey left to complete. Also indicated is Jupiter's location at each of the ten Galilean satellite encounters during Galileo's two-year, eleven-orbit tour of the Jovian system.

A more detailed view of the approach is presented in Figure 2. Notice that Galileo crossed the heliocentric distance at which it will encounter Jupiter on July 10th and reached aphelion on September 18th. Galileo has been flying beyond Jupiter's orbit since August 28! Note in Figure 1 that Jupiter aphelion was in June 1993. Jupiter's *near* circular orbit has an aphelion and perihelion of 5.45 and 4.95 AU. So, in addition to rapidly chasing Galileo, Jupiter has been gradually descending to the rendezvous point, which is at 5.28 AU. Although barely discernable in the figure, the separation between the Probe and the Orbiter reaches over 600,000 km before Jupiter gravity focusing brings them closer together.

Customarily, we look at final approach geometry in target-planet-centered coordinates; i.e., the motion is relative to the target. Jupiter's tremendous gravity makes the sun-centered view of the final approach quite astonishing. This view is shown in Figure 3, where both Jupiter and the spacecraft are shown in the heliocentric, inertial coordinate frame. As Jupiter closes in on the spacecraft its gravitational pull stops the forward motion of the spacecraft and causes them to fly backward—toward the rapidly approaching Jupiter! (When the heliocentric, in plane, motion "stops," the spacecraft approach speed to Jupiter is essentially Jupiter's heliocentric speed and thereafter the approach speed increases rapidly as the distance diminishes rapidly--of course, this is all smooth and continuous with no discontinuities.) The edge view of the motion, which is to the same scale as the ecliptic plane view, shows that there is continuous south-to-north motion during the reversal in downtrack motion. It will be quite a celestial mechanics ballet in December.

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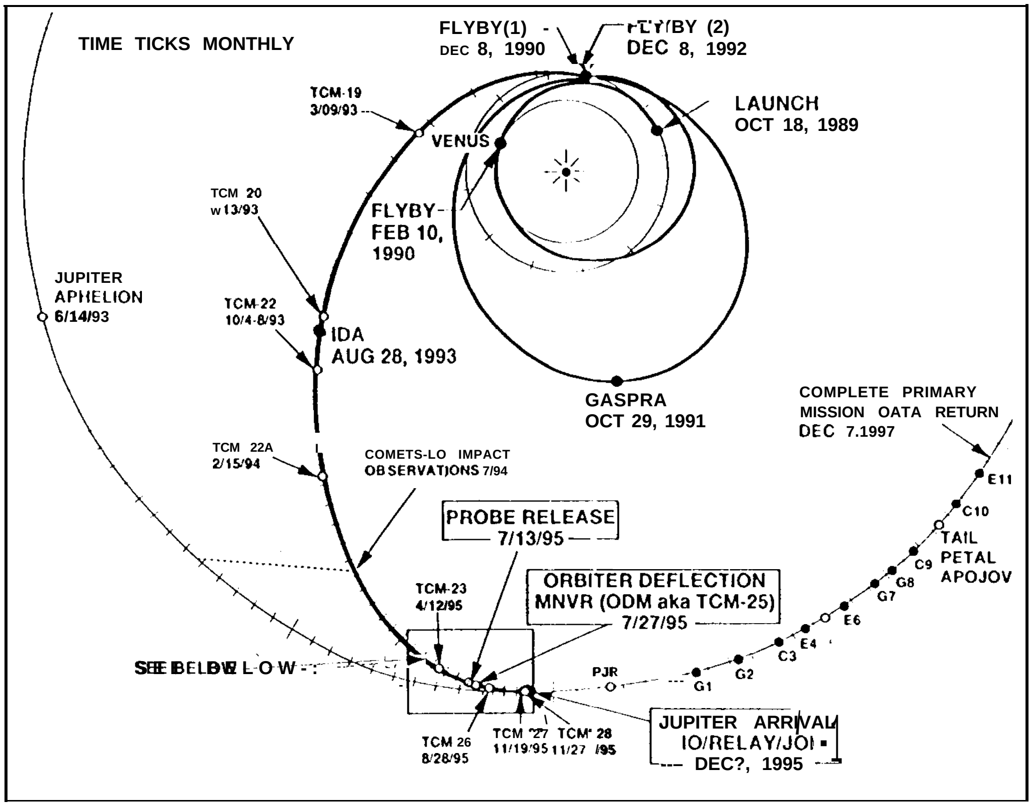

Figure 1. The Galileo VEEGA Trajectory

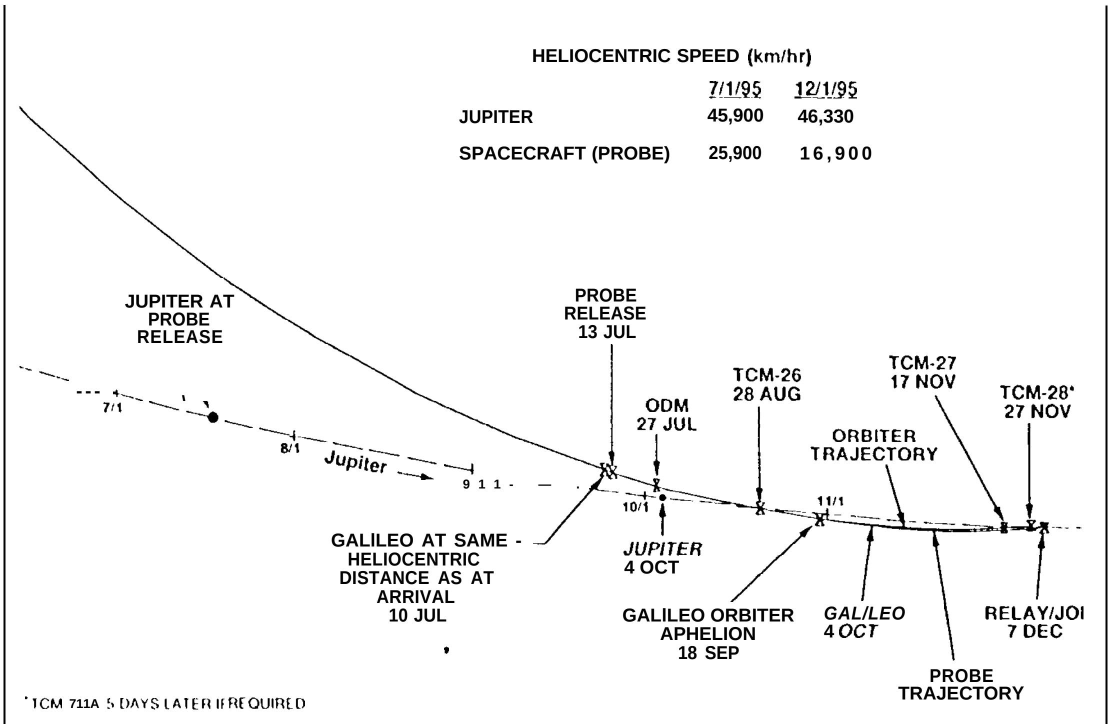

Figure 2. Probe and Orbiter Trajectories 1995

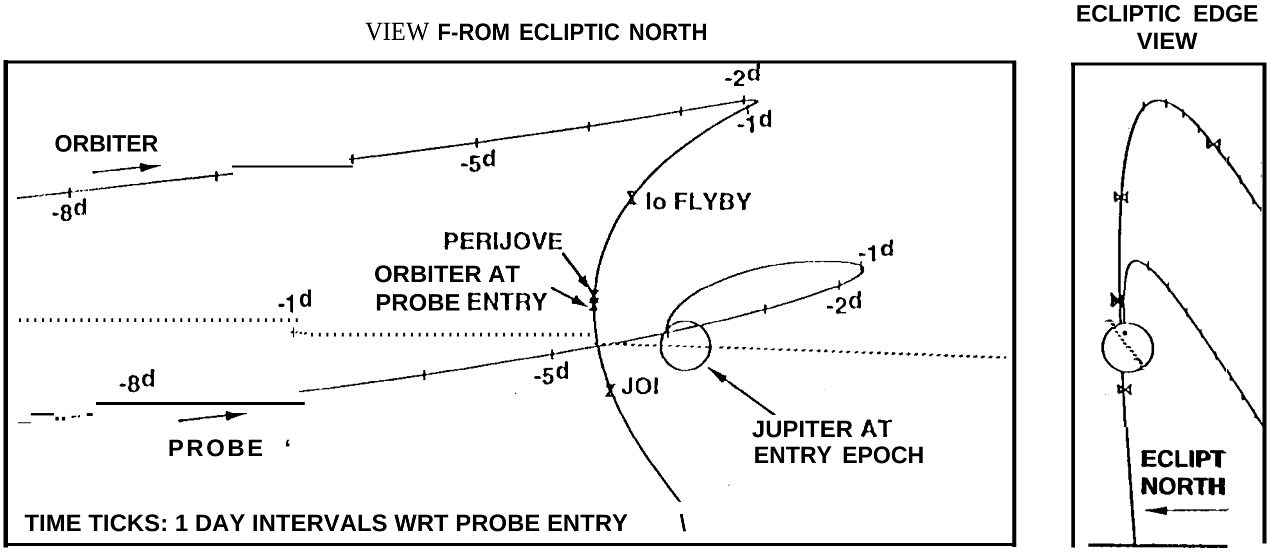

Figure 3. Heliocentric inertial View of Arrival

With the many successful observations of targets of opportunity well behind, this past year was totally focused on the extraordinary preparations required for Jupiter arrival and orbital operations. An Overview of the spacecraft activities is given in Figure 4. During the 1994 winter solar conjunction, the new Deep Space Network (DSN) Block V Receiver (BVR) was tested and demonstrated telemetry and Doppler tracking capability with a Galileo fully-suppressed carrier signal; this is required for Jupiter operations with the spacecraft low-gain antenna.

The return of all the high priority Shoemaker–Levy 9 data from the spacecraft tape recorder was completed on schedule in January in spite of some

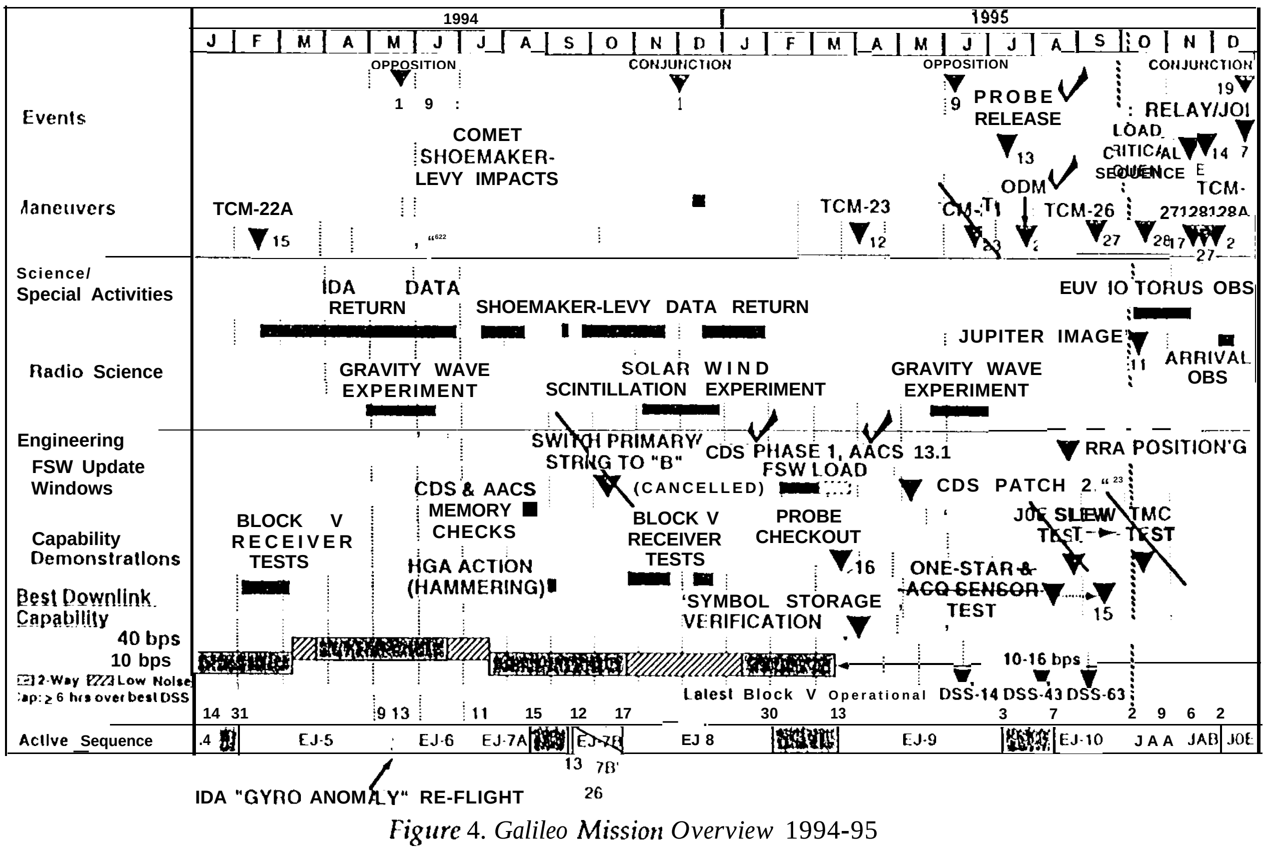

Figure 4. Galileo Mission Overview 1994-95

totally unexpected problems. In February, the Command and Data Subsystem (CDS) and the Attitude and Articulation Control Subsystem (AACS) computers were completely reloaded to incorporate the new Phase 1 Flight Software required for Probe Relay and Jupiter Orbit Insertion (JOI). This was unprecedented on a planetary spacecraft and was flawlessly performed in half the time allocated.

In March, the final Probe checkout was performed. The new Phase 1 Probe Symbols storage capability was used to return the checkout data and it performed perfectly. The checkout data showed the Probe to be in perfect condition. The ground battery test exactly paralleling the flight temperature profile and electrical loads using flight lot battery modules executed pre-entry and descent in February and showed the flight lot batteries to have excellent capacity. The excellent checkout and battery test results effectively eliminated what would have otherwise been a difficult release configuration decision. It was completely clear that the Probe should be released in nominal configuration to perform the full-up Probe mission.

Navigation continues to be excellent. The DSN tracking-data-based "orbit determination" used to design Trajectory Correction Maneuver (TCM)-23 and the execution of TCM-23 were so accurate that the scheduled final pre-Probe release TCM(-24) was cancelled; the Current Best Estimate (CBE) trajectory was essentially perfect— it could not be improved.

All aspects of Probe Release were revisited this year to ensure a successful Probe mission. The Probe was released flawlessly on schedule July 13th. The Probe is in excellent health and its trajectory and attitude are well within specification.

The Orbiter Deflection Maneuver (ODM) was particularly momentous because it was the first use of the 400-N main engine. The Project in conjunction with DARA/DASA exhaustively analyzed all aspects of the 400-N operation and performed extensive testing in Germany to establish the most reliable operating plan for ODM and JOI considering all

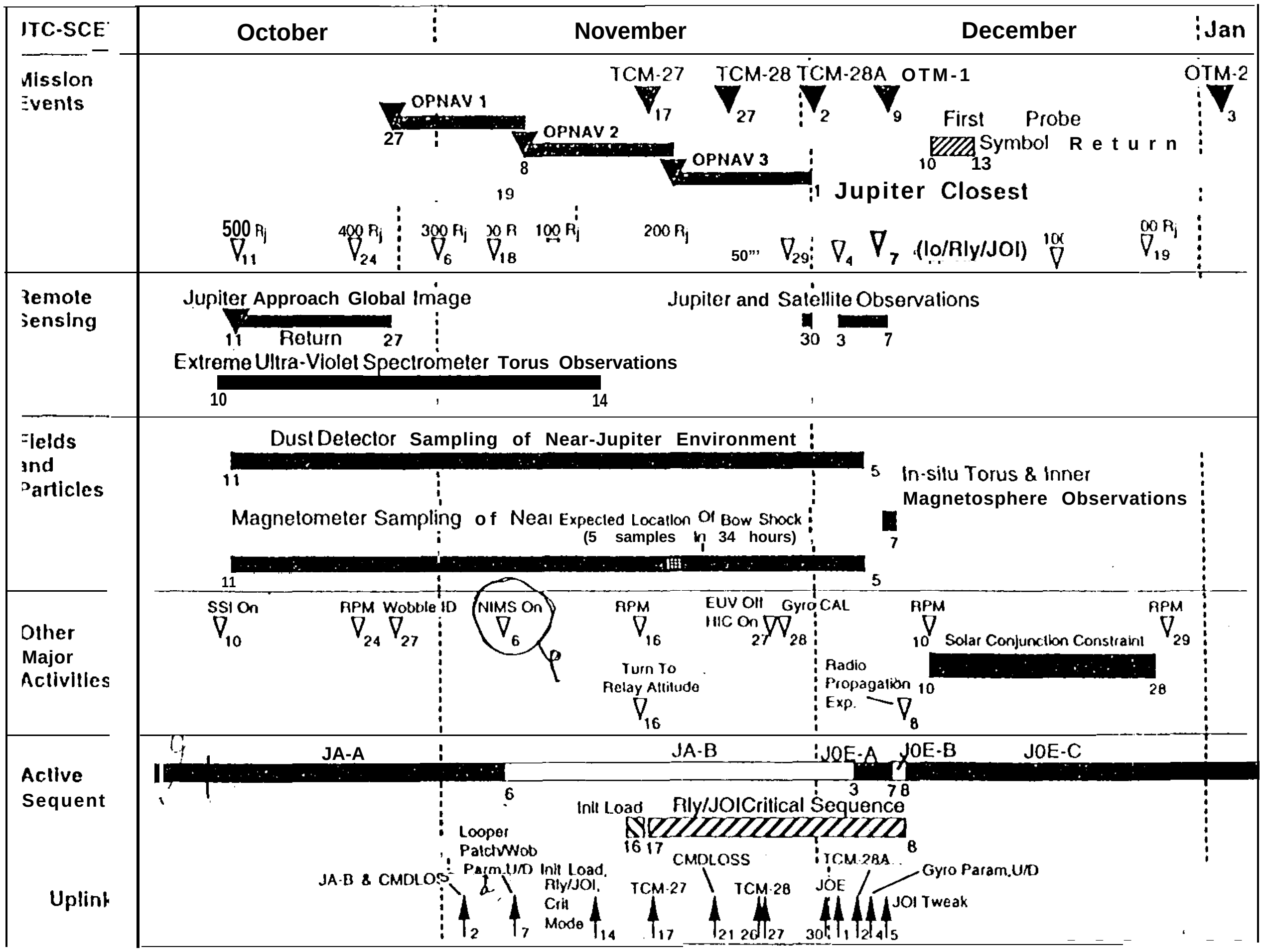

Figure 5. Galileo Timeline of Events (October 1995–January 1996)

contingencies. Germany supplied the Galileo propulsion system free of charge to NASA as their most major contribution to the joint U.S.-FRG Galileo Project. ODM was *the* opportunity for a now crucial demonstration of the 400-N engine prior to JOI. Several **inflight** tests of previously unused components including the engine itself were specified and performed prior to the 5-minute ODM main burn. The ODM was flawlessly executed on July 27th. The performance characterization has been used to update the JOI bum model and set the backup cutoff timing. Detailed telemetry analysis following ODM indicates that the helium pressurant checkvalve on the oxidizer side is not closed. The design of the Galileo propulsion system presents very little potential for deleterious mingling of propellant vapors-even with open checkvalves. Nonetheless, the propellants are now being held at constant temperature to minimize any propellant vapor transport.

In August the Galileo Dust Detector Instrument measured the largest interplanetary dust storm ever observed—apparently emanating from Jupiter.

Next week the Galileo approach observations begin. These are summarized in Figure 5. On October 11th Galileo will take a color image of Jupiter containing the Galilean satellites Io and Ganymede as illustrated in Figure 6. This image will be returned to earth during the rest of October. This will be the only image returned before arrival. It is scheduled

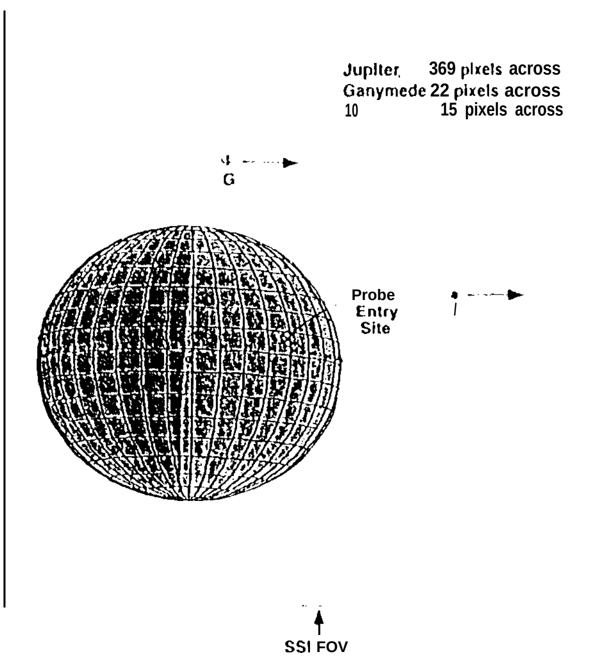

Figure 6. Jupiter Approach Global Image
(October 11, 1995)

for reconstruction **and** release in early November. Most all the imaging and other approach remote sensing as well as the most important magnetospheric sensing occurs on the day of arrival and remains on the tape recorder until mid-May 1996 when the newly installed Phase 2 flight software (FSW) enables its playback].

Figure 5 also shows the Critical Engineering Sequence (CES) executes from November 17th to December 8th. The CES is the only spacecraft sequence designed to continue regardless of any spacecraft faults. It contains only the commands required for Relay and JOI and spacecraft safety. A tremendous effort has been made this past year to make the CES as "bulletproof" as possible.

Arrival geometry is presented in Figure 7. The key event times at the spacecraft are given in UTC (GMT); add 52 minutes for Earth Received Time (ERT). At 3:04 P.M. Pacific Standard Time (PST) December 7th at JPL-Pasadena a status word is to be received indicating that Orbiter Relay Receivers have locked on the Probe signal!

Project Galileo has been extremely ambitious in working with the science investigators to incorporate the maximum possible capabilities in the Phase 2 Orbital Operations Flight Software in order to achieve the best possible science via the low gain antenna. While the quoted expectation remains 70 percent of the original objectives, the Phase 2 capabilities enable a substantially better return than was envisioned when the concept for doing the mission with the low-gain antenna was conceived. The Phase **2 Development** was the Project's greatest challenge this past year. It took many Herculean efforts to solve problems and get this software into system test in time to be ready for the March 1996 loading on the spacecraft.

Also particularly noteworthy, the Jupiter approach science observation sequences were completed this past year and so were five of the ten orbital tour satellite encounter sequences.

References 1 through 4 provide a comprehensive history of the flight of Galileo as presented at each IAF Congress since launch, except the 1990 Congress. Detailed descriptions of the Galileo science investigations and instruments are given in Reference 5. The navigation strategy for the rest of the mission is detailed in Reference 6.

A final introductory note. The Galileo spacecraft experienced its first and only memory cell failure to date a year ago in September. The failed cell is in a Harris 6504 chip in the CDS; the symptom observed is consistent with an oxide defect mechanism. This

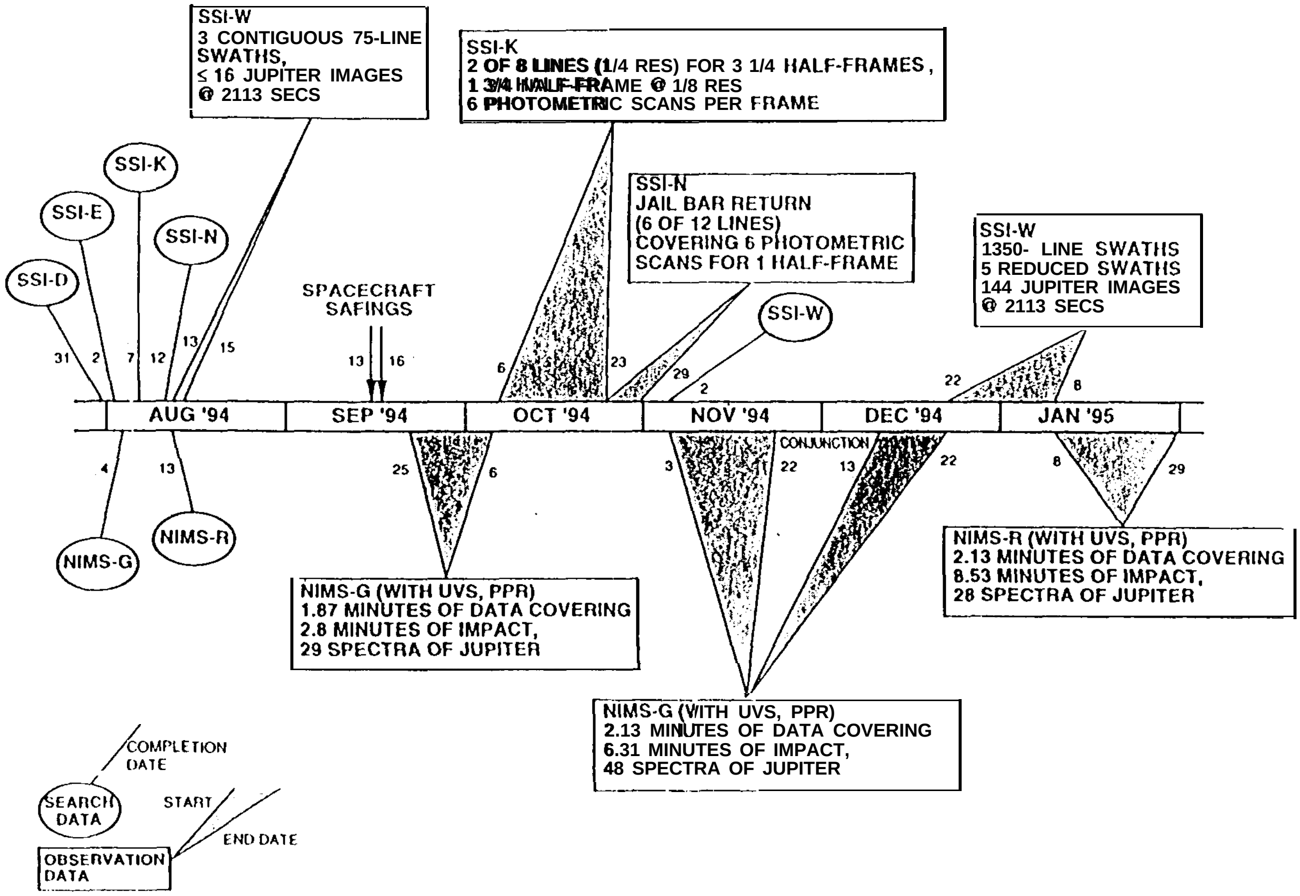

Figure 8. S-L9 Data Return Schedule

memory cell failure in the Galileo spacecraft to date, and no long-term consequences are expected from this failure. The 256-byte block containing this cell is no longer used by either the flight software or sequencing operations (less than 0.1 percent of the total memory is unusable).

Figure 8 shows the schedule for all of the data returned, including the search data used to locate where the actual impact data for the various events were on the tape. As the events described above unfolded, the playback sequence was adapted to insure that the remaining downlink capability was used to return the data which were of greatest scientific significance and most complementary with the Earth-based observations.

The overall campaign to return the S-1.9 data was remarkably successful, particularly considering the downlink data rate was only 10 bps, and that significant amounts of the originally planned playback time were lost. All data of scientific priority were returned. Some of the science results are presented in References 7 through 10.

3. Telecommunication Performance

Since Relay/JOI occurs near solar conduction, telecommunication tests were performed around the immediately preceding solar conjunction in late 1994 to verify and characterize operation of the telecommunication link, using the spacecraft fully suppressed carrier signal, Block V Receiver (BVR), and Full Spectrum Recorder (FSR) at the Deep Space Network (DSN) station at Goldstone, California to mimic the arrival day conditions. This also represented the most stressful case for the Orbital tour. Telemetry and Doppler were demonstrated with the spacecraft carrier fully suppressed, but the system performance signal-to-noise (SNR) ratio was about 1 db less than predicted. At first the lower performance was thought to be an artifact of the test configuration or an error in predicts but because the FSR at Goldstone and at Canberra also observed about 1 db less than the anticipated performance, immediate investigative efforts were initiated. Intensive investigation so far has been unsuccessful in isolating the cause(s) for the lower performance.