May 15, 1992

Galileo Early Cruise, Including Venus, First Earth, and Gaspra Encounters

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This article documents DSN support for the Galileo cruise to Jupiter. The unique trajectory affords multiple encounters during this cruise phase. Each encounter had or will have unique requirements for data acquisition and DSN support configurations. An overview of the cruise and encounters through the asteroid Gaspra encounter is provided.

I. Introduction

The Galileo mission is designed to make long-term investigations of the Jovian system by using a spacecraft comprised of a Probe and an Orbiter. After being released on the initial approach to Jupiter, the Probe will enter the Jovian atmosphere and make in situ measurements; its data will be relayed to Earth by the Orbiter. The Orbiter will then enter orbit around Jupiter for an approximate two-year, ten-orbit tour of the Jovian system. This article will only address DSN support and operations during the early cruise phase, through the asteroid Gaspra encounter in October 1991. Earth-2 encounter, asteroid Ida encounter, Probe support, and Jupiter operations will be the topics of future articles. Figure 1 is included as a mission overview.

The Galileo spacecraft (Fig. 2) was launched on October 18, 1989, on the Space Shuttle Atlantis (STS-34). A two-stage Inertial Upper Stage (IUS) rocket was used to place the combined Orbiter and Probe on a Venus–Earth–Earth gravity assist (VEEGA) trajectory to Jupiter. The Galileo VEEGA trajectory is shown in Fig. 3. Following is a description of the Galileo cruise and the included DSN support, as well as planetary and asteroid encounter support during the cruise period.

The Galileo interplanetary cruise has been divided into the following phases for planning purposes:

(1) Earth–Venus cruise: October 29, 1989–February 19, 1990.

(2) Venus–Earth cruise: February 19, 1990–April 29, 1991.

(3) Earth–Earth cruise: April 29, 1991–March 15, 1993.

(4) Earth–Jupiter cruise: March 15, 1993–October 9, 1995.

Thus, the Venus encounter on February 9, 1990, occurred in Earth–Venus cruise; Earth-1 encounter on December 8, 1990, occurred in Venus–Earth cruise; the Gaspra asteroid encounter on October 29, 1991, occurred in Earth–Earth cruise; Earth-2 encounter on December 8,

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1992, will also occur in Earth–Earth cruise; and the potential for an Ida asteroid encounter will occur in Earth–Jupiter cruise. The final decision to commit to an Ida encounter has not been made at the time of this writing.

II. DSN Configuration for Galileo Launch and Initial Acquisition

The first acquisition of the S-band (2295-MHz) downlink signal from the spacecraft by DSS 16, on October 18, 1989, marked the beginning of full DSN operational support for Galileo. This most significant event was the culmination of more than ten years of planning, and the start of the DSN support for the 1989 Galileo mission to Jupiter, which is planned to continue to November 7, 1997 (end of Prime Mission).

The DSN configuration required for Galileo launch and cruise support in accordance with the Support Instrumentation Requirements Document and the NASA Support Plan commitments is shown in Fig. 4. This configuration includes all the stations of the network that are required for support at various stages of the Galileo mission. The 26-m antennas performed a critical role in the initial acquisition sequences and the first Earth encounter in December 1990. They are not able to provide support again until the second Earth encounter in December 1992. Because the Galileo high-gain antenna (HGA) remained stowed for the first one and a half years of the mission, the early phases of the mission relied on one or the other of the two low-gain antennas (LGA's). Resulting minimal telecommunications link margins necessitated the use of the DSN 70-m antennas within a few weeks of launch to achieve the relatively high data rates desired for spacecraft and science instrument characterization.

The current DSN capabilities are adequate to support Galileo telemetry data rates from 10 bps to 134.4 kbps (convolutionally coded) and command at 32 bps (Manchester coded). Until the HGA is deployed, the spacecraft can support only S-band downlink and S-band uplink. When the HGA becomes available, an operational X-band (8415-MHz) downlink will be used for telemetry, and an X-band uplink capability will be demonstrated for command use.

Navigation and radio science data will be provided by the DSN radio metric systems by using Doppler, ranging, and very long baseline interferometery (VLBI) techniques. A new, high-precision navigation data type called delta differential one-way range (ΔDOR) will also be used by the DSN on this mission.

Wideband digital communications links among all three complexes and the Network Operations Control Center (NOCC) at JPL will allow the real-time transmission of telemetry data to the project at the maximum Galileo data rate of 134.4 kbps.

The NOCC has the capability to provide the project with permanent data records in tape or file form, from which errors and omissions have been removed in accordance with an agreed level of criticality. These are called Intermediate Data Records (IDR's) and are used by the project for further processing to extract engineering or science data and for archival purposes.

A period of intense test and training exercises carried out over the preceding nine months had prepared the DSN operations personnel for the critical initial acquisition phase of the mission. Because this was a Shuttle launch combined with an IUS injection vehicle, a high degree of coordination and technical interfacing with other centers was involved. To prepare for this, the DSN participated in the Galileo Joint Integrated Simulation Tests with Kennedy Space Center (KSC), Johnson Space Center, and the Air Force Consolidated Space and Test Center (CSTC). In these tests, state vectors were received from CSTC and processed by the DSN Navigation Team to produce predictions for eventual use by the initial acquisition station in making its first contact with the spacecraft. Data transfers were made in a timely manner and delivered to the correct destinations.

A Galileo/STS-34 Readiness Review was held on August 31, 1989, and the Review Board's assessment based on these results confirmed that the DSN was ready to support the launch.

A final Operational Readiness Test at Goldstone on September 15, using DSS 12 and DSS 16 in the cross-support mode, and a final proficiency test at DSS 46 to verify some last-minute modifications to the receiver/exciter on September 17, allowed the DSN to declare "ready for launch support" status. STS-34 was successfully launched from KSC on October 18, 1989, at 16:53:40 UTC, and the subsequent deployment of the IUS and Galileo spacecraft from the shuttle cargo bay on revolution 5 (rev. 5) was nominal.

Following deployment, all events of concern to the DSN were controlled by a very detailed Initial Acquisition Plan that provided DSN parameters for all possible combinations of launch time and actual deployment and injection conditions. The critical events in this period are shown in the IUS/Galileo nominal trajectory profile of Fig. 5. In accordance with this plan, initial acquisition of the IUS S-band signal prior to IUS separation from the spacecraft was accomplished by DSS 16, followed 20 minutes later by acquisition of the Galileo S-band downlink first at DSS 16, and immediately thereafter at DSS 12. This provided continuous telemetry coverage of the critical IUS/Galileo separation event, which occurred 10 minutes later. The timely delivery of all the required state vectors from CSTC to the NOCC, enabled the DSN Navigation Team to run the necessary pointing predictions and transmit them to the stations for use in these time-critical sequences.

III. Earth–Venus Cruise

With the critical DSN-to-spacecraft telecommunications link firmly established in the two-way mode, the DSN settled down to continuous tracking passes at high data rates, while the project set about verifying and conditioning the spacecraft in accordance with the Earth–Venus (E–V) timeline shown in Fig. 6.

A command memory load consisting of 128 elements was uplinked over DSS 61 on October 25, and a Probe checkout over DSS 63, DSS 43, and DSS 14 on October 26 at 28.8 kbps captured 26.7 hours of Probe data. The first of many calibrations of the spacecraft radio-frequency system, called the radio-frequency system automatic gain control (RFSAGC) was carried out on October 27 over DSS 63. These events and the prevailing data rates are also shown in Fig. 6, together with a profile of DSN tracking required to support them.

As the Earth-to-spacecraft range continued to increase, the telemetry signal-to-noise ratio (SNR) began to fall rapidly, which necessitated a continuous demand for 70-m support to sustain even a 1200-bps telemetry data rate. Galileo's dependency on 70-m support created severe conflicts for other DSN users, and conflict resolution became a continuing critical activity. By mid-November the spacecraft changed from LGA1 to LGA2 in order to sustain the 1200-bps telemetry rate needed for the Trajectory Correction Maneuver 2 (TCM-2) and science instrument calibrations and checkout, which were scheduled for the month of December. TCM-2 was supported by the DSN without any problems and excellent radio metric data were provided to the Galileo Navigation Team.

On December 13 in the midst of this intense 70-m activity, the right-side inboard elevation bearing on the DSS-63 antenna failed, and the antenna was immobilized. The DSN responded immediately, and a team of JPL engineers arrived on-site on December 15 to start repair work. Under heavy pressure because of the rapidly approaching Venus encounter and working under extremely difficult winter conditions, the Team was able to report that the bearing replacement was complete and that the antenna was operational on January 25, 1990. This outage required Galileo to replan the science instrument checkout events, but no science data were lost, since active science events had not started at that time.

By the beginning of January 1990, the Project reported that TCM-2, which had been executed in December, was very satisfactory, based on the radio metric data that had been analyzed since then. These data were being used to refine the Venus targeting parameter for the Venus flyby in February 1990. The replanned science instrument calibrations executed during the Christmas period had been replayed over DSS 43 by then, and were found to be quite satisfactory despite some minor anomalies. Because of DSS-63 downtime, Galileo tracking time had been negotiated to minimize data loss through January 31, 1990. DSN support with the remainder of the Network continued to meet minimum requirements, using DSS 61 as a fill-in for DSS 63.

On January 1, DSS 15 returned to operational status, and the first of the 34-m X-band transmitters on this antenna was expected to be operational by January 15. This capability on all three high-efficiency (HEF) antennas had been committed for support later in the Galileo mission. The 34-m X-band uplink was to be used for a command demonstration. It was also considered to be a vital capability for the Gravitational Wave Experiment in 1994 and 1995. The 34-m HEF antennas were also to be used to generate high-precision (50-nanoradian) ΔDOR navigation data.

However, analysis had shown that a ΔDOR demonstration on S-band (using the ΔDOR tones already implemented in the spacecraft radio system for the later demonstration on X-band) could yield significantly improved navigation data for the Earth 1 encounter, which would occur well before the planned X-band became available from the spacecraft in May 1991. Consequently, a set of seven demonstration passes of S-band ΔDOR was planned, the first of which was scheduled for January 9 and would use the baseline pairs between DSS 14 and DSS 65, and DSS 14 and DSS 43.

DSN support for Galileo continued to work around the DSS-63 outage by relying heavily on support from DSS 61. The DSN status for the Venus encounter was now conditional upon DSS 63 returning to service. This was expected to occur on January 21, coincident with the return of Signal Processing Center (SPC) 60 to operations after some extensive modifications of SPC 60 for purposes of relocation and integration of DSS 66.

While the bearing repair progressed at DSS 63, the DSN worked through seven of the S-band ΔDOR demonstration passes by using the baseline pairs of DSS 14 and DSS 65, and DSS 14 and DSS 43. One of the passes failed because of a software anomaly relating to tracking across a day-of-year change (which was subsequently corrected), and one was lost due to a spacecraft emergency. The other five yielded excellent data according to evaluation by the Galileo Navigation Team. The lessons learned by both the DSN and the Project from this demonstration were incorporated in the planning for the Earth encounter later in the year, when a much larger ΔDOR campaign was proposed.

The Galileo Project declared a spacecraft emergency on January 15 due to an unexpected switch to the fault protection mode, which resulted in a downlink change from 1200 to 10 bps. This occurred near the end of the Goldstone view period, and a Pioneer track was preempted to give Galileo additional time for assessment of the spacecraft's condition. The problem was rapidly diagnosed to be an incorrect command that had been sent earlier, and the spacecraft was commanded back to 1200 bps.

DSS-15 X-band uplink capability was declared to be operational on January 22, and the DSN began a series of operational verification tests to qualify it for future Galileo support. Operational Readiness Tests were being conducted simultaneously, with all elements of the DSN and Project to prepare for the rapidly approaching Venus encounter. Meanwhile, the DSS-63 elevation bearing replacement was on schedule for completion on January 25 at 14:00 UTC, with the full operational status on January 26 at 00:00 UTC following two satisfactory demonstration passes.

The two successful demonstration passes, plus two additional tracking passes finally resolved the remaining DSN concerns regarding DSS-63 support for the Galileo–Venus encounter, which was then scheduled for the period from February 8–17. Venus closest approach was to occur at 22:10 PST on February 9 at an altitude of approximately 17,000 km, during mutual view at DSS 43 and DSS 63. The gravity assist expected from the flyby was equivalent to a velocity increase ΔV of 2.2 km/sec. The downlink bit rate would be 40 bps at that time, but would increase to 1200 bps as soon as the link margins improved at the higher DSN antenna elevation angles.

The DSN made a special provision for critical Class 1 support throughout the Venus flyby phase. This included diesel generater power and communications backup, as well as spectrum protection during the important two-day memory readout period on February 13–14 when special selected infrared and video images would be returned at 1200 bps. On February 8 the DSN was declared ready to support the Venus encounter phase with no anomalies or exceptions being reported. Closest approach occurred at an altitude of 16,123 km at 05:58:48 UTC, February 10, 1990.

The Galileo encounter of Venus was supported by DSS 43 and DSS 63. Bad weather at DSS 43 degraded the already marginal telecommunications conditions for 1200-bps telemetry. However, excellent ranging and Doppler data were generated by both stations. Early in the DSS-63 pass, the spacecraft ranging channel was turned off to improve the telecommunications margin for the 1200-bps telemetry, which consisted only of engineering data.

Playback of selected images began with the DSS-14 pass on Tuesday, February 13. Because the limited data rate precluded a direct playback off the spacecraft tape recorder, the data were played into Command and Data Subsystem (CDS) memory and then transmitted to Earth in the engineering data format via memory readouts (MRO's). Although this introduced considerable complexity into the operational procedures for the DSN station operators, the procedure had received much attention during the pre-encounter test and training exercises, and was executed without problems.

About three hours into the DSS-14 pass, the 70-m antenna was put to "stow" because of high winds at Goldstone. DSS 43 was called up from a Pioneer pass and was able to resume the Galileo track at spacecraft rise, which occurred one and a half hours later. Approximately 1 hr and 23 min of imaging telemetry was lost, which amounted to about one third of the first Venus image. It was decided to try to recover these data in October, when the entire Venus sequence would be replayed under improved telecommunications conditions.

All the remaining MRO passes were carried out in the "ranging off," "listen only" diplexer bypass mode to maximize the SNR for the 1200-bps telemetry rate. MRO sequences continued through February 14, when critical coverage throughout the Network was lifted at the end of the DSS-43 pass. Reports from the Galileo science team commented very favorably on the quality of the data received, the excellent performance of the DSN in handling the complex operational procedures, and on the response to unexpected problems that occurred during the encounter period. Due to the low data rate, only three images and limited other science data were planned from this MRO process. However, of utmost importance to the Project was the DSN Doppler and ranging data to be used by the Navigation Team for orbit determination, and by the Radio Science Team for Venus ephemeris improvement.

IV. Venus–Earth Cruise

Within a few days of the Venus encounter, the sustainable telemetry data rate on the 70-m antennas had dropped to 40 bps, and by March 7 it had fallen still further to 10 bps. This was due to the orientation of the spacecraft with the spin axis pointed to the Sun. The activity profile for this phase of the mission is shown in Fig. 7.

On March 12 the spacecraft switched to its alternate LGA, and because of the more favorable Earth–spacecraft sight line, the signal margins slowly started to improve. DSN support for Galileo continued at 10 bps without problems, although the B-string telemetry equipment at the stations experienced difficulty in maintaining lock due to the non-optimum use of the higher frequency subcarrier (360 KHz) for this extremely low bit rate. However, the Project elected at that time not to change the subcarrier to the design value of 22.5 KHz for other reasons.

In addition, the DSN began to experience a problem known as "false lock" due to the prevailing minimal SNR of the Galileo downlink telemetry signal. To alleviate this problem, a special operational procedure was developed in which receiver lock was first established and verified, before lockup of the telemetry processors was attempted. Although this procedure resulted in some delay to the delivery of the telemetry data, it avoided the excessive delays that were being caused by false lock conditions.

In early April, the project decided to raise the data rate to 40 bps, which required the DSN to operate the 70-m antennas in the "listen only" diplexer bypass mode to maximize the link margin. Even under these conditions telemetry performance was at times marginal.

Following repair of the DSS-63 elevation bearing, it had been decided to inspect and carry out a bearing maintenance program on the other two 70-m antennas to assure their availability for the balance of the Venus–Earth (V–E) segment of the mission. The impact of this plan on the Galileo mission sequences already loaded in the spacecraft, particularly the trajectory correction maneuvers shown in Fig. 7, was evaluated in some detail by the Project. Eventually, a workable plan was developed, and the elevation-bearing maintainence program was successfully completed prior to Earth-1 encounter.

The VEEGA mission design called for many periodic TCM's that depended on precision ranging and Doppler navigation data to be provided by the DSN. These data were provided as required, and met or exceeded the prelaunch commitments for quality and accuracy.

Encouraged by the results from the first S-band ΔDOR demonstration in January and February, the Galileo Navigation Team asked for DSN support for an S-band ΔDOR campaign that would yield a minimum of eight good passes on each baseline. These data would be used as the prime navigation data type for the Earth-1 encounter, and would have the potential for realizing a significant spacecraft fuel savings if the accuracies could be met. The DSN agreed to schedule about twice as many passes as needed, to ensure that the minimum requirements could be met.

Between August 21 and November 22, 1990, 27 ΔDOR passes were completed, 16 of which were on the north–south baseline (DSS 14–DSS 43) and 11 on the east–west baseline (DSS 63–DSS 14). Of this total, 23 were successful and yielded good data, while four failed for various operational reasons. Overall, however, the yield of good data far exceeded the minimum data return requested by the Project, and contributed significantly to the outstanding targeting accuracy achieved for the actual Earth-1 encounter.

A considerable effort went into planning an optimum operational strategy for DSN tracking through the rapid station transfers that would occur during the short time interval around closest approach to Earth (960 km). The DSN conducted extensive classroom training sessions in Pasadena for key personnel from all three complexes, and carried out a comprehensive series of Earth encounter simulation exercises, to ensure the highest possible level of proficiency for the encounter. By integrating this effort with the Project's plan for preparing the Galileo Flight Team, it was possible to make the most effective use of the limited DSN and spacecraft time available for test and training purposes, without compromising the level of proficiency required by all personnel.

The 34-m and 26-m stations at Canberra, Madrid, and Goldstone supported the operationally intense, four-hour period of Galileo Earth-1 encounter, from 18:00 UTC through 22:00 UTC on December 8, 1990, with no significant incidents or anomalies reported.

During this period, very high signal levels (greater than −100 dBm) were able to sustain telemetry data rates at 115.2 kbps and 134.4 kbps. One hundred percent of the available telemetry data was delivered to the Project.

The operationally complicated strategy to accommodate the high-angle and Doppler rates while rapidly transferring uplink and downlink from DSS 42, to DSS 61, to DSS 12, and back to DSS 42 in this short period, was carried out perfectly by all supporting elements of DSN operations.

The time-critical two-way transfer from DSS 42 to DSS 61 at the mutual low elevation of 6 degrees occurred at 18:52 UTC on schedule. DSS 61 continued to track through the spacecraft switch from coherent to noncoherent mode at 19:38 UTC until the spacecraft executed its stored command to switch from LGA1 to LGA2 at 20:15 UTC. The critical ground backup command to switch the LGA's was correctly transmitted at 20:16 UTC, as planned, prior to turning off the station transmitter. Four minutes later, at 20:20 UTC, the spacecraft reverted to the two-way coherent mode.

The expected drop in downlink signal strength due to the spacecraft antenna switch did not occur, and as a consequence DSS 61 was able to maintain lock on the downlink until 20:25 UTC when track was terminated due to approaching limits on the antenna slew rate. However, DSS 66, which was tracking in backup mode, was able to track down to spacecraft set, thereby providing an additional 15 minutes of telemetry data beyond that which was called for in the planned sequence. Earth closest approach occurred at 20:34:34 UTC at an altitude of 960 km over the Caribbean Sea, out of view of the DSN between Madrid set and Goldstone rise. Immediately upon spacecraft rise at Goldstone, DSS 12 acquired the one-way downlink with telemetry in lock at 134.4 kbps at 20:40 UTC as scheduled. Two-way acquisition was completed at 20:46:53 UTC.

The second time-critical transfer from DSS 12 to DSS 42 was planned for 21:10 UTC when the spacecraft's best lock frequency would be seen simultaneously by both stations. DSS 42 was able to acquire the incoming signal about three minutes early, and complete the transfer on time at 21:10 UTC.

From this point on, DSS 42 continued to provide tracking support at 134.4 kbps and 115.2 kbps until the end of the scheduled pass at 06:20:00 UTC the following day. Throughout this critical period, the DSN executed all the complex, time sensitive sequences without error, due in no small part to the well-planned test, training and documentation effort that preceded the real-time events.

The effort expended by the DSN on the ΔDOR campaign prior to the encounter was well justified when the Galileo Navigation Team estimated that the improved targeting errors resulting from use of the ΔDOR data translated into a spacecraft fuel savings of approximately 6 kg, an important factor for consideration in the eventual design of the Jupiter satellite tour.

In the immediate post-encounter period, the Project took advantage of the prevailing telecommunication link performance to return all the Earth encounter science data at high bit rates. However, as the Earth-spacecraft range increased, the link margin rapidly decreased, and the sustainable bit rate declined again to 40 bps by the end of January 1991. By that time, the DSN had resumed regular tracking support on the spacecraft as the Project commenced the final days of the Venus-Earth segment of the mission.

One of the final events of the Venus-Earth (VE) cruise was the unfurling of the HGA. This event was in the final VE sequence. However, on March 26 the spacecraft experienced a bus reset signal and consequently safed itself. The safing incident automatically canceled the on-board sequence. So, the HGA unfurling attempt was carried out with real-time commands on April 11, 1991.

The unfurling was not successful. Real-time observations by the Spacecraft Team detected a quick ramp-up in motor current to well above the expected value. The redundant deployment motors ran for eight minutes, at which time the sequence turned them off. A normal full deployment would have been completed in about three minutes. Then a microswitch should have cut off the motors. No microswitches tripped. Two other observations also pointed to an HGA anomaly. Namely, the spacecraft's spin rate decreased by less than that expected for a full deployment. Finally, the sun gate indicated an obscuration.

It was immediately determined that except for the HGA, the spacecraft was completely normal. An anomaly investigation team was then convened. Intensive modeling, analysis, and testing have been carried out and refined since then. The primary scenario is that three (of the eighteen) ribs are restrained in the stow position. Two additional ribs may have been involved initially and sequentially released. But no hardware is thought to have suffered any damage or structural failure.

The HGA anomaly team, now called the HGA Recovery Team, has determined that to free the stuck ribs, the antenna tower must be expanded and contracted to walk the guide pins out. A warming turn was conducted in May, then cooling turns in July and August (see Fig. 8) were supported by the DSN. Each involved about 50 hours of near-continuous coverage, with many more tracks after the turn to analyze the results. To date, the turns have not been successful in freeing the ribs.

V. Earth–Earth Cruise Summary (Through Gaspra Encounter)

As a result of the HGA anomaly, the DSN lost two significant opportunities planned for early in the Earth–Earth cruise. First of these was a long constraint length Viterbi decoding demonstration planned for May and June. A constraint length = 15, rate = 1/4 convolutional code was implemented on the spacecraft to enable better performance for the Io encounter. This code was implemented only for X-band, which is dependent on the HGA. So the Big Viterbi Decoder implementation has continued without the use of flight data.

Also lost during this period was the X-band uplink demonstration. This was to be a one-station demonstration during opposition. This demonstration is in support of the Gravitational Wave Experiment. Two brief X-band uplink periods were undertaken in support of an HGA characterization, but were in no way beneficial to the Gravity Wave Experiment.

The spacecraft again entered safing on May 3, 1991. Extensive ground problem isolation activities were initiated during the DSS-43 pass to determine that the problem was not on the ground. After determining the state of the spacecraft, recovery plans were initiated, and the Project requested extra ground support. The DSN consequently provided continous coverage from May 3, 1991, when the problem was first noticed, through 9:00 P.M. PDT on May 4, 1991.

The rest of 1991 was devoted to two primary activities: trying to overcome the HGA anomaly, and preparing for the first asteroid encounter. The maneuvers to free the stuck HGA ribs have been discussed briefly above. Figure 8 is included as a time line for this period. More details on the Gaspra encounter support follow.

After the HGA anomaly, the DSN recommended to the Project that the DSN could better support the low data rates on the 22.5-kHz subcarrier. A demonstation was scheduled for July 23, but the spacecraft had gone into fault protection and reverted to a repeating memory dump at 10 bps sometime following the tracking support on July 19. This was discovered on July 22, 1991, and recovery was not accomplished until July 25. The 22.5-kHz subcarrier demonstration was rescheduled for August 23, 1991. It was successful, and improved performance led to the decision to operate on the 22.5-kHz subcarrier through the Gaspra optical navigation recovery period, the Gaspra encounter, and indefinitely during subsequent low data rate operations.

Planning for the asteroid Gaspra encounter necessitated an early decision to commit to an LGA encounter. This commitment involved much less optical navigation data than had been planned with the HGA, thereby making those data even more critical to the Navigation Team. Optical navigation data has become a key data type for the Galileo mission. DSN support to recover the data was crucial for Gaspra, as the data rate was reduced to 40 bps during this time frame. To recover the optical navigation data, it was necessary to play the imaging data from the tape recorder to the CDS, and then subsequently read the data out as a subset of the engineering data. This is analagous to the Venus MRO's, only at the reduced data rate. The DSN supported nearly 400 hours of these optical navigation playbacks, with no significant problems. As can be seen in Fig. 8, these playbacks occurred throughout September and October.

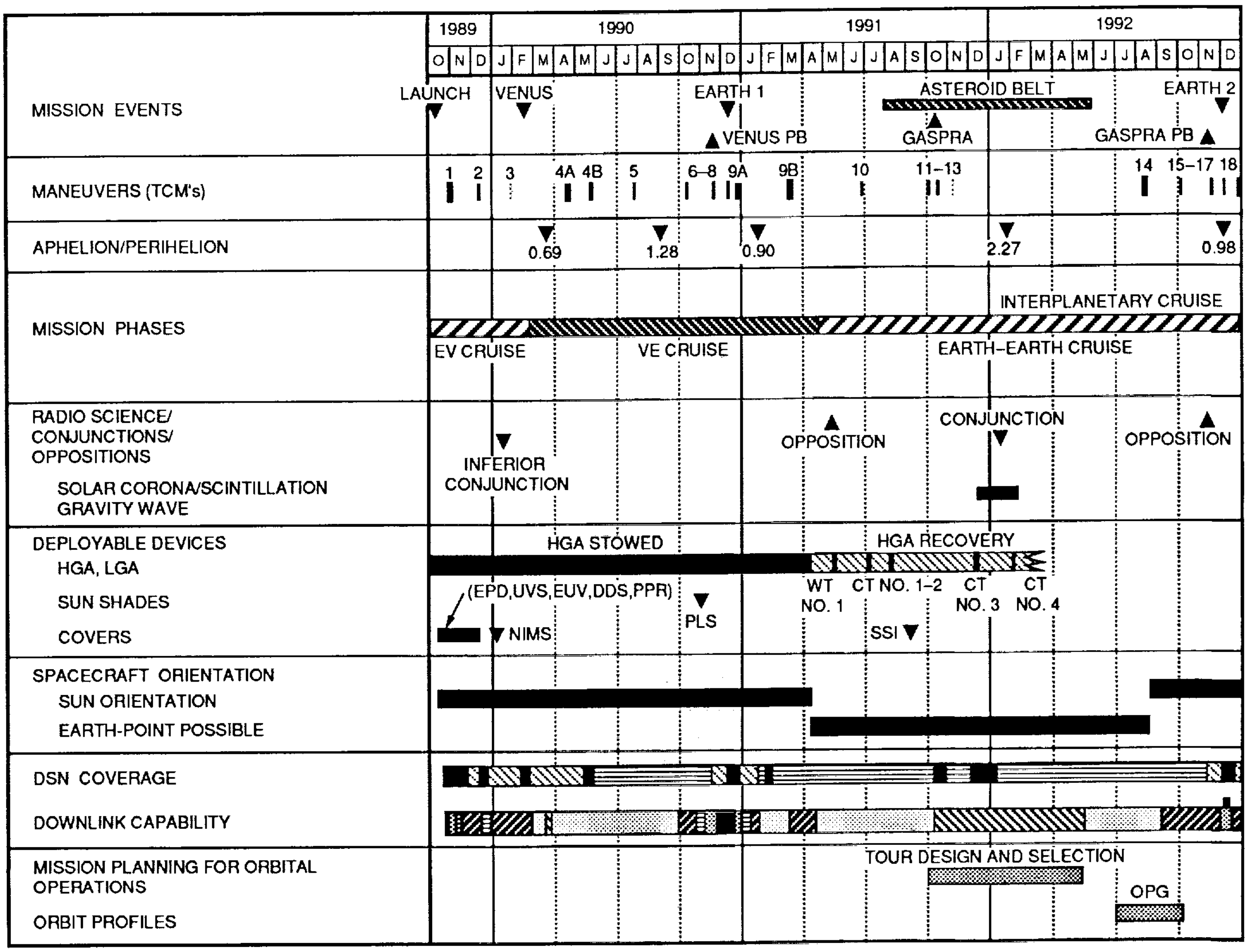
As for previous encounters, the DSN made special provision for critical Class I support throughout the Gaspra encounter, including the final time-critical optical navigation frame. MRT's were conducted at all three 70-m sites, and classroom training was provided in Pasadena for key Project and DSN personnel. A Gaspra Readiness Review was held by the Project on October 14, 1991, and the DSN was declared ready for support at that time.

Accomplishing the encounter on the LGA also meant that no real-time science could be realized; only 10-bps engineering from a 70-m antenna was possible at closest approach. Furthermore, only one tape load of science data could be realized. In fact, one track was reserved for engineering data in case analysis of anomalous spacecraft events might be required. Despite this constraint, the Project was able to realize excellent science, and recover on the tape recorder essentially all the basic science goals. These data will be relayed to the ground when higher data rates are achievable during the Earth-2 flyby period.

Closest approach to Gaspra occurred on October 29, 1991. Galileo passed within 1601 km of the main-belt, S-type asteroid. The time of closest approach was 22:36:59 UTC.

Subsequent to the encounter, it was decided to attempt to recover one image of Gaspra in the same fashion as was done for the early Venus playback data, and the aforementioned Gaspra optical navigation data. There were two contributing factors to this decision: (1) DSN performance was significantly better than had been predicted, which allowed 40-bps capability for a few weeks after Gaspra encounter; and (2) high probability was established for being able to recover the medium resolution image.

This image was about 77 lines long (out of 800 for a full image). When it was recovered within the first three days of scheduled DSN time, a decision was made to attempt to recover more images of Gaspra. Within the window of the time Galileo had reserved to recover the one image, it became possible to play back a total of four images of Gaspra, each through a different filter. DSS 43 was the only DSN antenna to be utilized for this effort because of significantly better elevations during the passes. The four images permitted a full-color Gaspra image. The 40-bps data rate was only supportable in the low-noise, diplexer bypass mode for this period.



1. TOUR SHOWN IS REPRESENTATIVE
2. GSOC OPERATIONS ARE ASSUMED TO BEGIN IN MARCH 1993
3. DOWNLINK CAPABILITY SHOWN IS FOR A 70-m DSN STATION, RANGING ON, 90-PERCENT CONFIDENCE. PRIOR TO FEBRUARY 1993, DOWNLINK IS ASSUMED TO BE VIA LGA-1 (S-BAND TRAVELING WAVE TUBE AMPLIFIER, HIGH POWER).

DSN COVERAGE
- CONTINUOUS
- 4–7 TRACKS/WEEK
- 2 TRACKS/WEEK

DATA RATE
- 134.4 kbps
- 28.8 kbps
- 7.68 kbps
- 1200 bps
- 40 bps
- 10 bps

CT	COOLING TURN	PB	PLAYBACK
DDS	DUST DETECTOR	PLS	PLASMA SUBSYSTEM
EPD	ENERGETIC PARTICLES DETECTOR	SSI	SOLID STATE IMAGING SUBSYSTEM
EUV	EXTREME ULTRAVIOLET SPECTROMETER	UVS	ULTRAVIOLET SPECTROMETER
OPG	ORBITAL PLANNING GUIDE	WT	WARMING TURN

Fig. 1. Galileo mission overview.

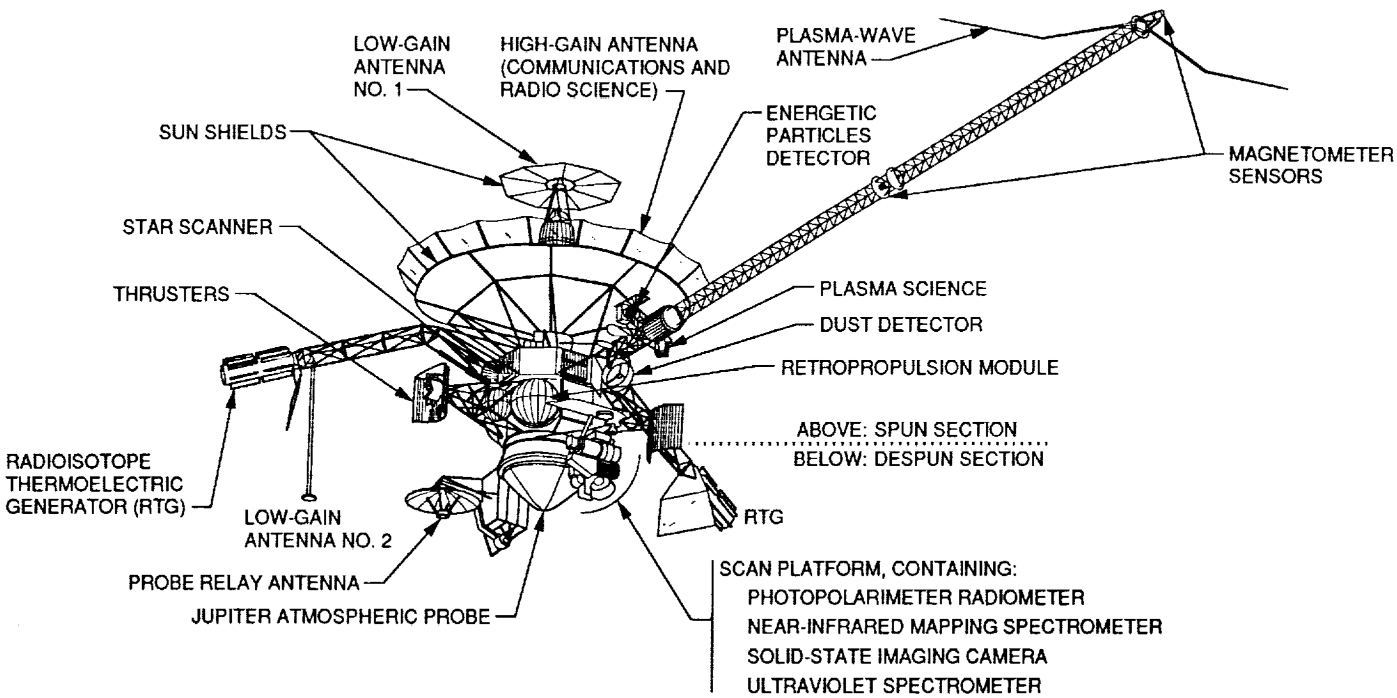


Fig. 2. Galileo spacecraft configuration.

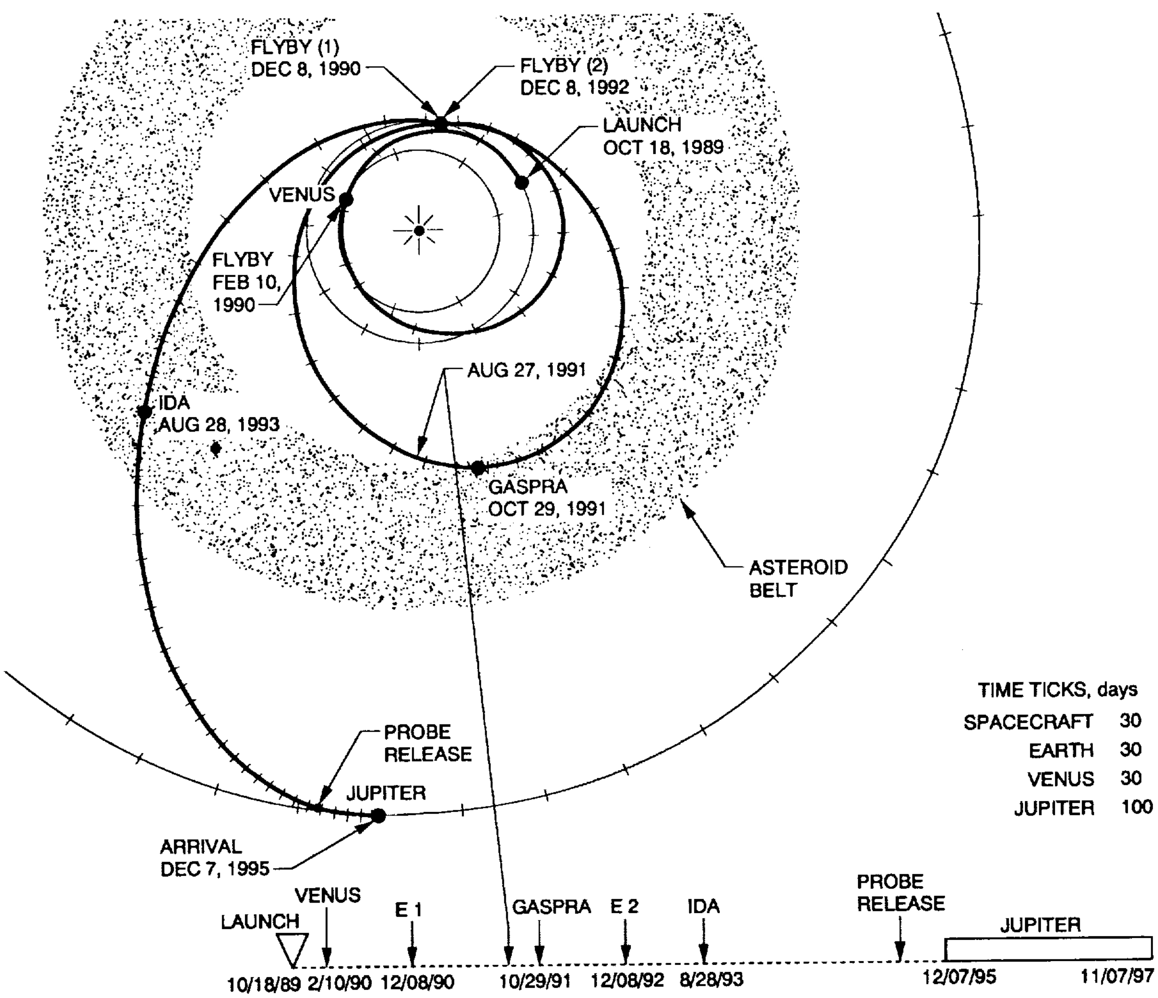
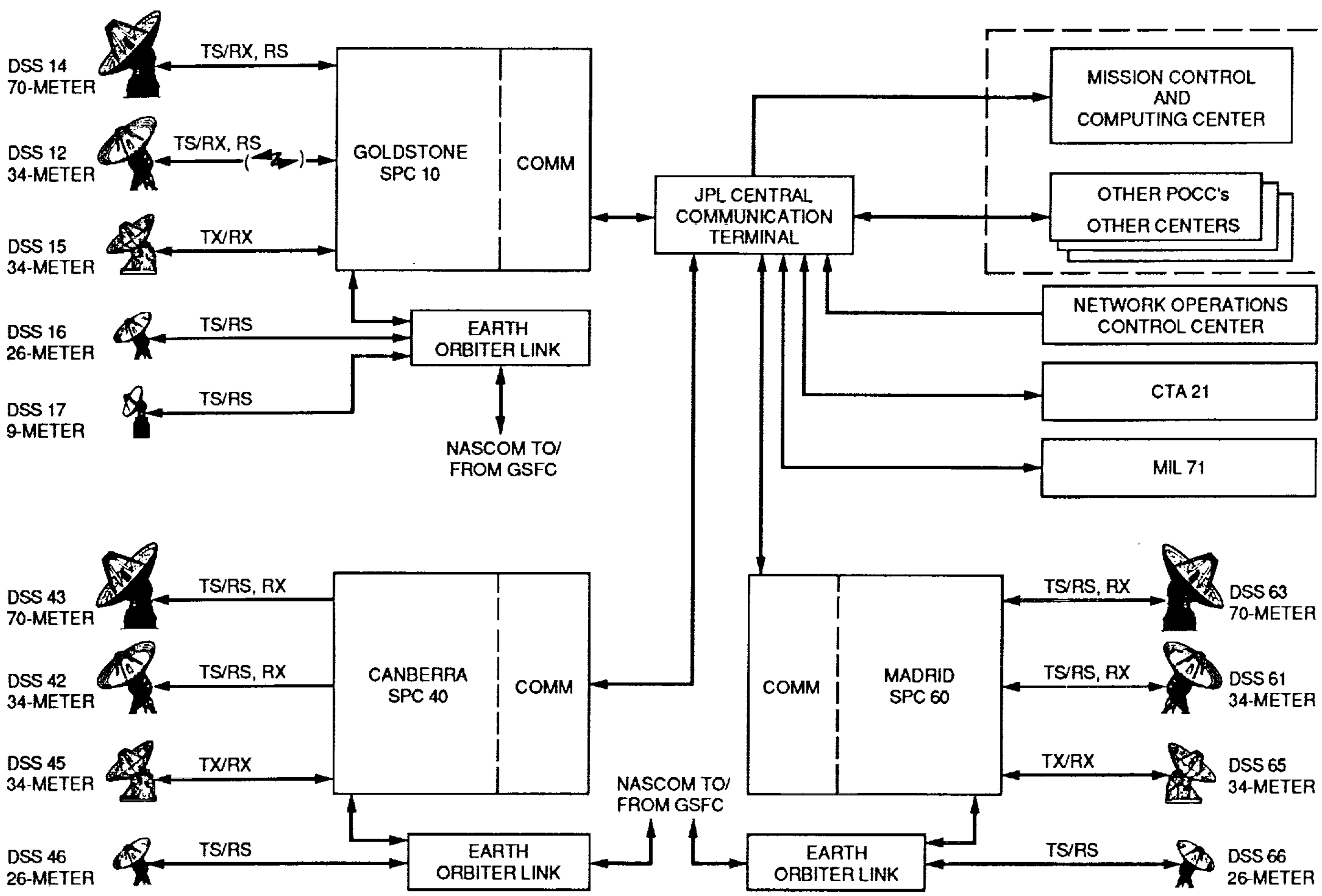


Fig. 3. Galileo trajectory.



COMM	GROUND COMMUNICATIONS	RS	RECEIVE S-BAND
CTA	COMPATIBILITY TEST AREA (PASADENA)	RX	RECEIVE X-BAND
DSS	DEEP SPACE STATION	SPC	SIGNAL PROCESSING CENTER
GSFC	GODDARD SPACE FLIGHT CENTER	TS	TRANSMIT S-BAND
MIL 71	MERRIT ISLAND LAUNCH AREA (FLORIDA)	TX	TRANSMIT X-BAND
POCC	PROJECT OPERATIONS CONTROL CENTER		

Fig. 4. 1989 DSN configuration for Galileo.

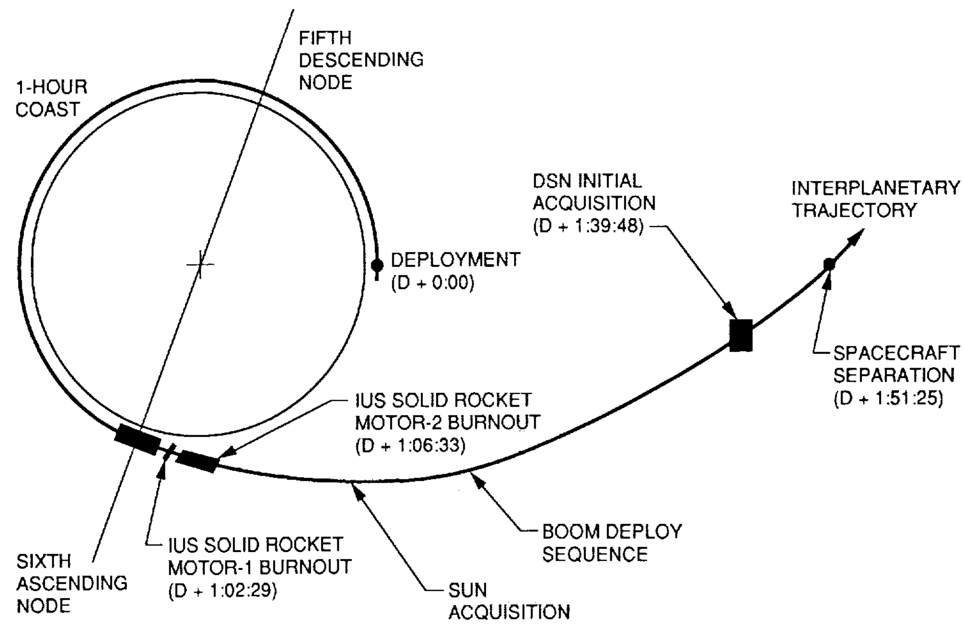


Fig. 5. IUS/Galileo nominal trajectory profile.

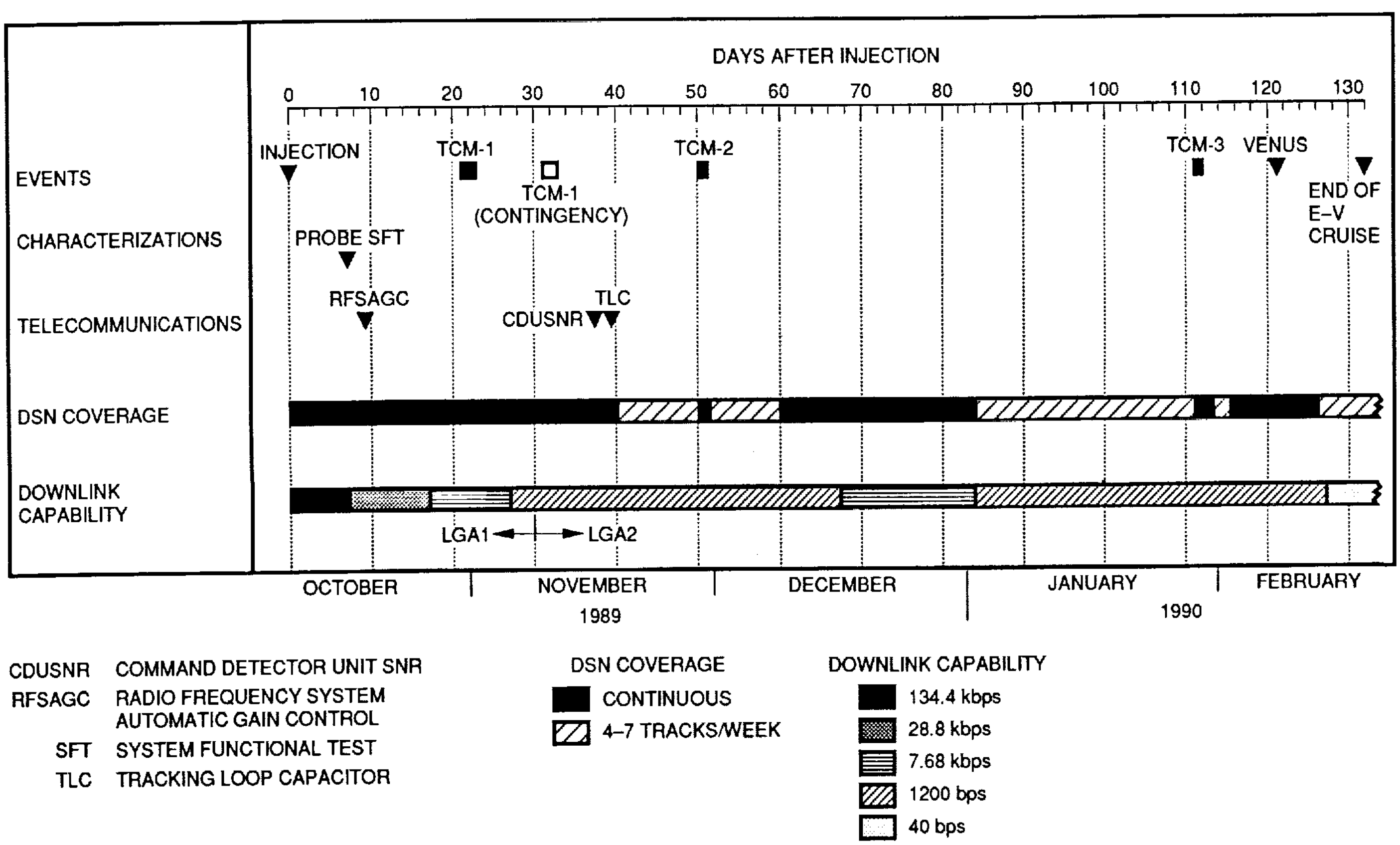


Fig. 6. Earth–Venus time line.

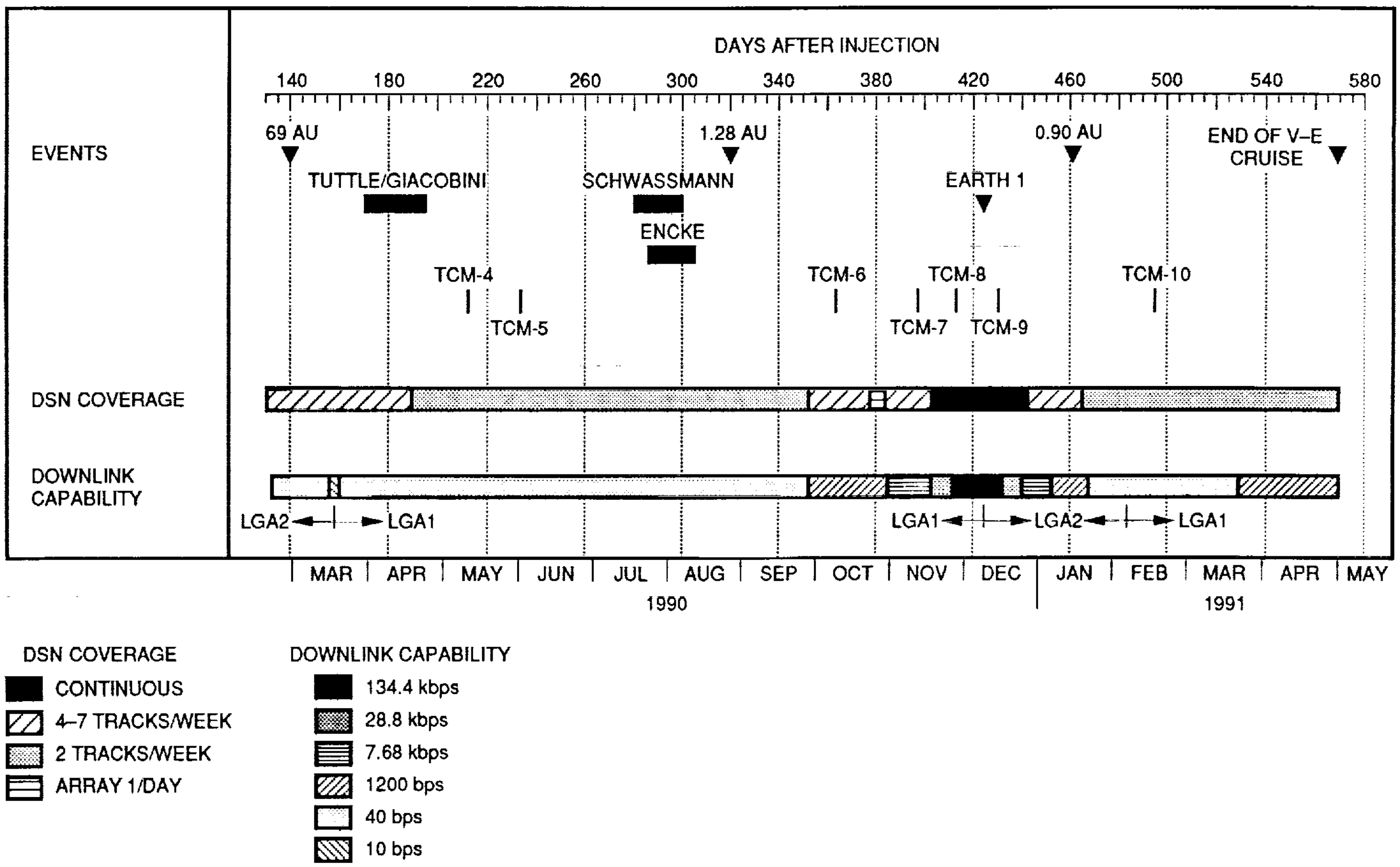


Fig. 7. Venus–Earth time line.

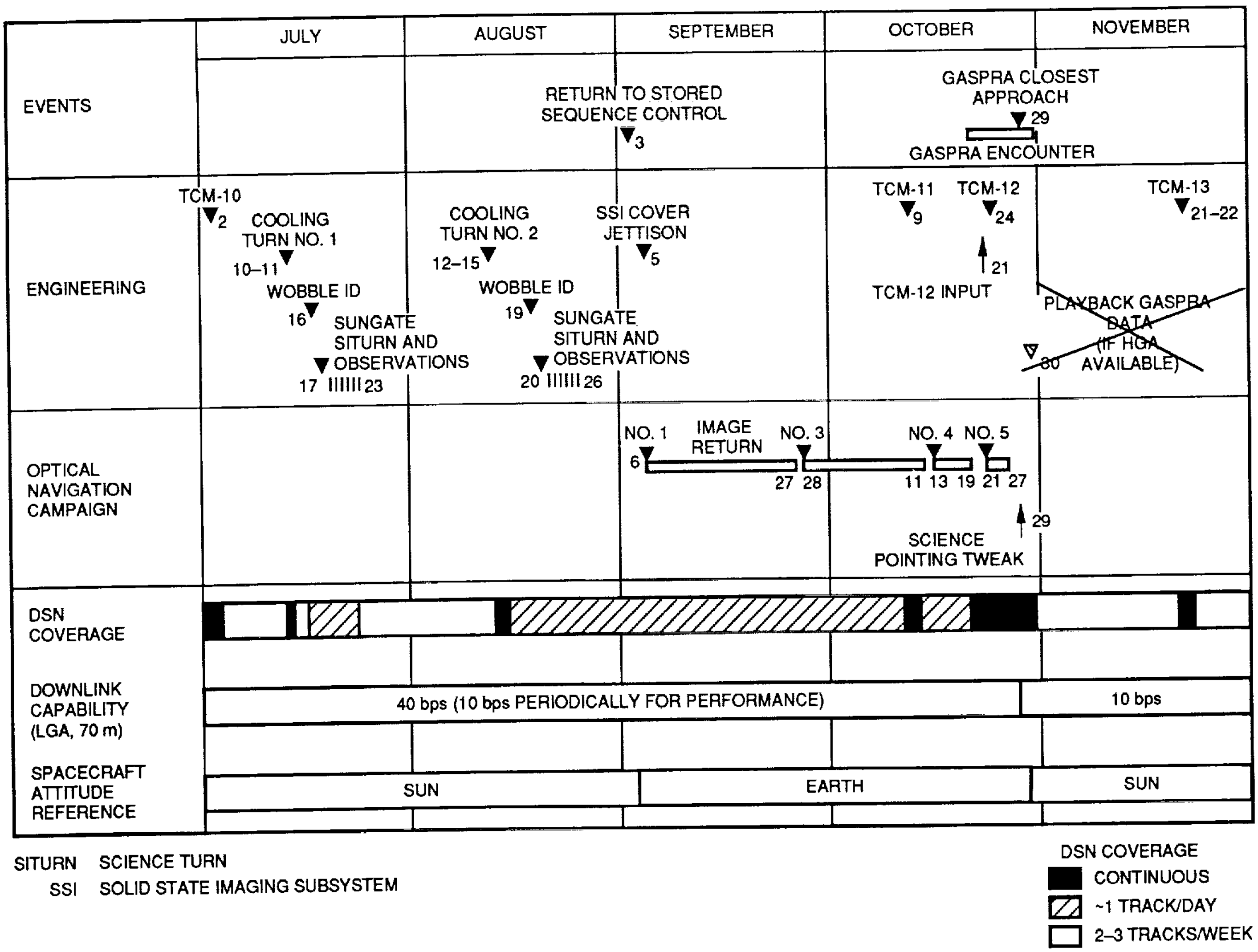


Fig. 8. Galileo events through Gaspra encounter, 1991.

Appendix

The total tracking support provided to the Galileo Project by the DSN in the period from launch (October 1989) through the Gaspra encounter (October 1991) is shown in Fig. A-1. The height of each bar represents the number of tracking hours scheduled for the month, with the lost time shown as a blank at the top, and the actual support time shown as shading within the bar.

During the review period, 8224.65 hours of support on all antennas was scheduled, of which 98.67 percent (8115.58 hours) was actually provided and 1.33 percent (109.07 hours) was lost for various operational and technical reasons. The large peaks in tracking time provided for launch in October–December 1989, Earth encounter in November–December 1990 and Gaspra encounter in October 1991 are clearly evident.

The telemetry data capture performance is also shown in Fig. A-1 as a profile at the the top of the figure. The vertical scale shows the monthly percentage of available data captured and delivered to the Project. A level better than 95 percent was maintained for the entire period.

The command performance is reflected in the total number of commands sent to the spacecraft and the number of aborts over the period October 1989–December 1991: The number of commands transmitted was 6202 and the number of commands aborted was 7.

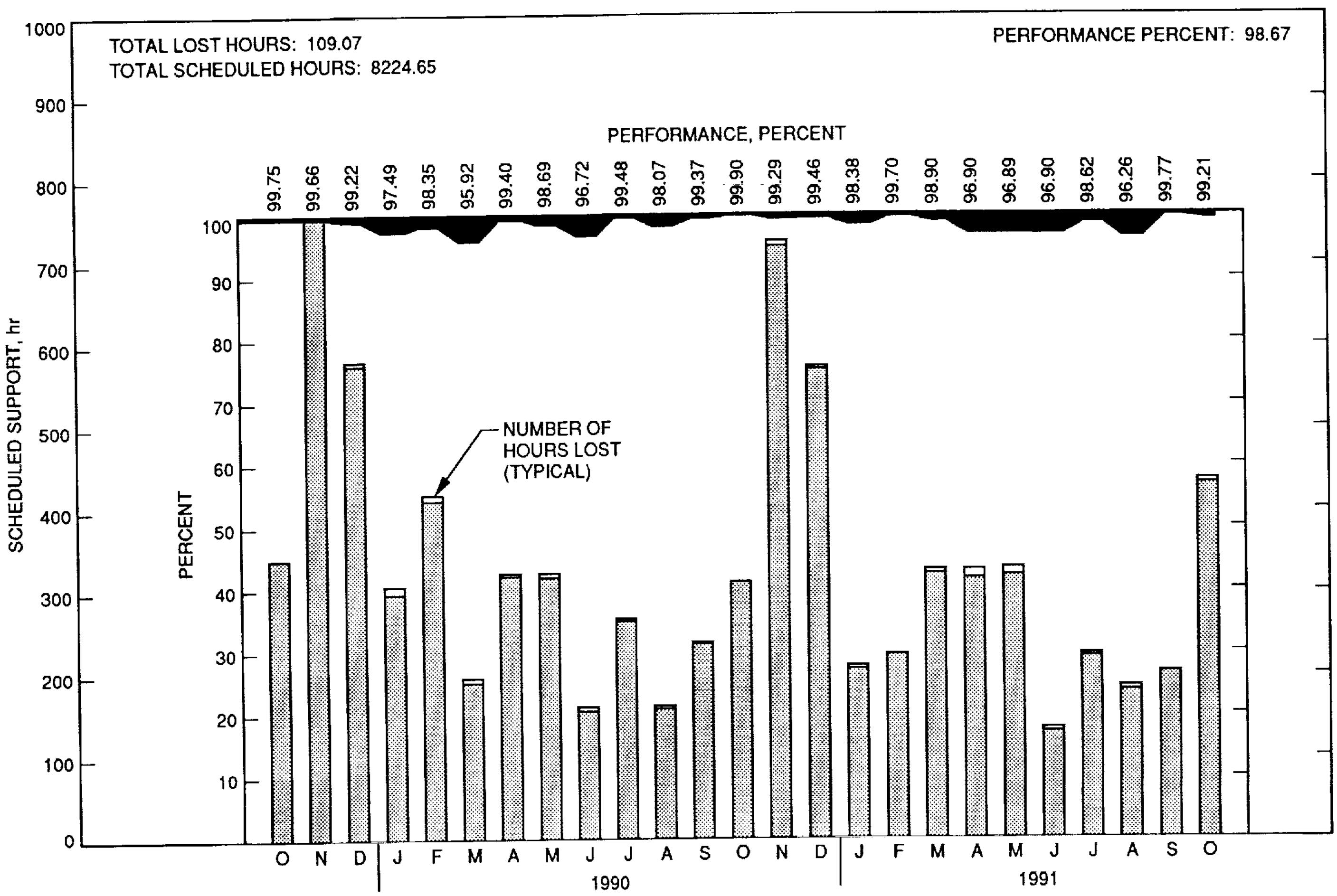


Fig. A-1. DSN telemetry performance.