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Giotto Mission Support

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This report summarizes Deep Space Network (DSN) support of the Giotto mission to Comet Halley. It describes the support beginning with the prelaunch testing and continues through the post comet encounter support.

I. Introduction

A primary objective of the European Space Agency's (ESA) Giotto mission was to detect the nucleus of Comet Halley using a multicolor camera to produce photographs of the surface from a distance of 1000 km with a 50 meter resolution. A second prime objective was to measure the elemental and isotopic composition of the cometary neutrals, ions, and dust particles, using three specifically designed mass spectrometers. A total of ten experiments were flown on the spacecraft to enable these *in situ* measurements.

The Giotto spacecraft is a spin-stabilized vehicle powered by a solar cell array. Communications with the DSN was via low gain antennas during the early mission phase. The de-spun high gain antenna was used during follow-on mission phases for all communications between the spacecraft and Earth. The spacecraft is able to transmit at both 2.3-GHz and 8.5-GHz frequencies and receive at 2.3 GHz. Only the 8.5-GHz downlink was used for the follow-on mission phases.

With a high flyby velocity at Halley's Comet of 68 km/s, the critical active experiment time was on the order of 4 hours. All data were transmitted in real time, without a backup recorder capability, at a data rate of 46 kbps. Spacecraft time at closest approach was 00:03:00.4 Universal Time Coordinated (UTC), on 14 March, 1986.

II. Deep Space Network Support

DSN support of the Giotto mission was divided into four major mission phases: Launch, Cruise, Rehearsals, and Encounter. The support began in June 1985 with prelaunch testing and continued through the comet encounter in March 1986.

A. Launch and Cruise

For the cruise phase of the mission the NASA Support Plan (NSP) called for 8 passes per week for the first three weeks following launch using the DSN's 34-meter subnetwork. In addition, two navigation campaigns were to be supported. The DSN was to provide for emergency command should the need arise.

Launch support requirements included prelaunch simulations and the launch phase. Horizon-to-horizon support was

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provided for the first seven days, following launch, by the 26-meter and 34-meter DSN subnetworks. Daily passes of four hours duration were requested from launch plus eight days through the end of July 1985.

1. Prelaunch Testing and Simulations. The DSN began support of Giotto on June 7, 1985 with Deep Space Station (DSS) 16's support of a premission test. Prelaunch testing continued through July 1, 1985. All three 26-meter stations (DSS-16, DSS-46, DSS-66), participated in the testing series. A total of 11 tests were conducted with the major portion of tests supported by DSS-46, the initial acquisition station.

2. Launch Support. The Giotto spacecraft was launched aboard an Ariane-1 launch vehicle from Kourou, French Guiana at 11:23 UTC, on July 2, 1985. The spacecraft was first placed into a standard geostationary transfer orbit. At third perigee, on July 3, 1985, at 19:24 UTC, it was injected into a heliocentric orbit with the firing of the onboard Transfer Propulsion System (TPS).

DSS-46 began the DSN support of the Giotto mission on July 3, 1985. DSS-46, the 26-meter tracking station located in Canberra, Australia, was selected for launch support due to its relatively wide antenna beamwidth and its high antenna slew rate. This station provided for telemetry reception, telecommand uplink, and radio metric data measurements. Data was routed to the European Space Operations Center (ESOC) at Darmstadt, West Germany via the Jet Propulsion Laboratory in Pasadena, California; the NASA Communications (NASCOM) switching center in Madrid, Spain; and the NASCOM switching center at Goddard Space Flight Center in Greenbelt, Maryland.

Subsequent spacecraft passes were supported by the remainder of the DSN's 26-meter subnetwork consisting of DSS-16 at Goldstone, California and DSS-66 at Madrid, Spain with coverage consisting of horizon-to-horizon passes for the first 7 days following launch. The 26-meter stations continued supporting the Giotto spacecraft throughout the month of July into the first week of August. Their support was supplemented by DSS-42, the 34-meter station located in Canberra, Australia and by DSS-12, the 34-meter station located at Goldstone, California. These passes were on a frequency of one per day with a duration of approximately four hours. Tracking support from the 34-meter antenna (DSS-61) in Madrid, Spain was not requested since the European Space Agency (ESA) stations covered that longitude.

3. Post Launch Cruise Support. The DSN support of the launch/early cruise phase concluded on August 6, 1985. No further tracking by the DSN was required until September 15, 1985 when the first Navigation Campaign began. The Navigation Campaign was supported by the DSN's standard 34-meter subnetwork of stations consisting of DSS-12, DSS-42, and DSS-61. The primary purpose of the Navigation Campaign was to provide ESA with radio metric data for comparison with and validation of the radio metric data collected by the ESA tracking network. The tracking coverage consisted of a series of daily double passes during a two-week interval. A double pass was defined as horizon-to-horizon passes at two stations on different longitudes with at least one of the stations located in the southern hemisphere. The DSN provided the combinations of DSS-12/42, and DSS -61/42 for this support. Data was provided to ESOC in the form of Orbit Data Files (ODF) within 12 hours of the end of each pass. The ODF files were generated from the raw radio metric data (2-way Doppler and ranging) collected during each pass. The data were transmitted via NASCOM high speed data lines to Madrid and then forwarded to ESOC via European communications lines.

B. Rehearsal Support

The DSN supported the preparation for encounter beginning in October 1985. This preparation consisted of a series of three Encounter Rehearsals. These rehearsals used the Giotto spacecraft as a data source and rehearsed the actual sequences that would be followed during the comet encounter. In addition to the rehearsals, training exercises were conducted by the DSN to insure that the network was fully tested and trained for the encounter. There were also a series of data flow tests conducted each time the wideband satellite circuit, to be used for encounter and rehearsal support, was activated. A final pre-encounter navigation campaign was supported just prior to the March 1986 encounter.

1. Pre-rehearsal testing. Pre-rehearsal testing was supported by DSS-42 and by DSS-45, the 34-meter high efficiency antenna in Canberra, Australia. The 34-meter stations were used in place of DSS-43, the 64-meter antenna in Canberra. DSS-43 was scheduled to be the prime supporting DSN station for the Halley encounter but was not available due to Voyager II's use of the station for the impending encounter with Uranus. The primary purpose of this testing was to verify the communications interface between JPL and ESOC using the newly activated satellite circuit. Data flowed to ESOC via NASCOM-provided circuits to the Goddard Space Flight Center (GSFC) and at GSFC the data were patched into a 56-kilobit (kbps) satellite circuit for the final transmission leg to ESOC. The tests utilized the station's Telemetry Simulation Assembly (TSA) to generate the encounter data rate of 46.080 kbps. During the first DSS-42 supported pass on October 2, 1985, data were successfully flowed to ESOC, demonstrating the data interface. Additional tests were scheduled through October 12 using DSS-42 and DSS-45 to further test the circuit interface.

2. **Encounter Rehearsal Number One.** DSS-42 successfully supported the first encounter rehearsal on October 13-14, 1985. Although numerous problems caused delays in acquiring receiver and telemetry lock, the station was able to process and forward telemetry data at rates of 5.7 kbps and 46 kbps. The second part of the first rehearsal was supported by DSS-42 on October 15-16, 1985. This test was less than successful in that anomalies experienced during the first test were still evident. The station had difficulties acquiring the main antenna beam and the main carrier. Predictions for Doppler were offset by several thousand hertz. A replay of the data recorded during the test was scheduled for October 17.

3. **Post Rehearsal Data Flow Tests.** Since the results of the first rehearsal test were not as expected, a series of data flow tests was scheduled between October 17 and 23 to troubleshoot the system. The first test was conducted on October 17 and used DSS-42 as a data source. Testing continued on nearly a daily basis with improving results on each test. The post rehearsal tests concluded with a spacecraft pass on October 23. Equipment problems at DSS-45 delayed the establishment of good data flow to ESOC. However during the final test period, data were 99.7 percent error free.

4. **Circuit Re-activation Data Flow Testing.** In November 1985, the DSN was notified by the Giotto project that the second navigation campaign, originally scheduled for December 1985, would not be required. The time previously scheduled for the campaign was used for data flow testing following the re-activation of the wideband satellite circuit between GSFC and ESOC.

The primary purpose of this series of tests was to:

(1) Validate and re-certify the communications interface between the station and ESOC.

(2) Test various configurations including ground communications error correction, and establish the encounter support configuration with the lowest throughput error rate.

The first tests were conducted on December 11, 12, and 13. The tests used a station digital recording with known good data quality, recorded during the October tests, as a data source. These tests determined that error correction was not a viable function for encounter support due to the expected high data rate of 46 kbps. It was also established that data from the two overseas complexes in Spain and Australia would be routed to GSFC and then directly to Europe via the satellite circuit. This configuration would reduce the transmission path by approximately 6000 miles and reduce the number of transmission errors. The overall data flow configuration is shown in Fig. 1.

Testing continued on December 16, 17, 18, 19, 22, and 29. These tests used a combination of recorded data playbacks and spacecraft passes to continue verification of the data delivery quality to ESOC in preparation for the second encounter rehearsal to take place in January 1986. These tests were all considered successful with system refinements being accomplished with each test.

5. **Encounter Rehearsal Number Two Support.** The second in a series of three encounter rehearsals was conducted on January 3, 6, 9, 12 and 15, 1986. DSS-42 provided DSN support for this rehearsal. DSS-43 was supporting the Voyager II Uranus encounter and was not available for Giotto support. The standard encounter support configuration was utilized with the spacecraft providing the data source. All DSN support was in parallel with the 64-meter antenna support provided by the radio astronomy facility at Parkes, Australia.

This series of passes resulted in the refinement of the procedures and techniques to be used for the encounter. Special attention was directed towards the switching and monitoring of data at the GSFC NASCOM switching center, the refinement of station predictions, monitoring of data quality as seen at JPL, a procedure for determination of downlink frequency while three-way with the Canarvon, Australia tracking station, and the localization of potential problem areas in the encounter configuration.

In January the DSN was notified of additional Giotto support requirements. As a result of the findings during the International Cometary Explorer (ICE) flyby of Comet Giocobini-Zinner it was determined that the data-taking period for a comet encounter should be greatly expanded. The Giotto project requested three days of continuous 64-meter antenna coverage beginning on March 12, 1986. The 64-meter stations in California, (DSS-14), Australia (DSS-43), and Spain (DSS-63) would provide this support. In addition to the expanded encounter support, the DSN was also requested to support a final navigation campaign during the first week in March 1986. The purpose was to refine the targeting for the comet flyby. The bulk of the campaign support was to be provided by DSS-12 at Goldstone, California.

6. **Giotto Spacecraft Emergency.** On January 24, 1986 the DSN was notified of a Giotto spacecraft emergency following the loss of downlink lock during a pass being supported by the German tracking station. Since the project had no visibility into the health of the spacecraft, they were greatly concerned about the possibility of the spacecraft overheating due to a possible misorientation. The project requested DSN support and was given DSS-12. This station was able to lock up to the spacecraft carrier, however the telemetry remained marginal due to the low downlink signal level. DSS-12 was able to pro-

vide telemetry with an error rate of about 50 percent. The 64-meter station at Goldstone was then requested. DSS-14 was supporting the Voyager II Uranus encounter at the time. However, following negotiations between the Giotto and Voyager project managers the station was turned over to Giotto. Even though this was the first support of Giotto by DSS-14, they were able to acquire the spacecraft and flow data to ESOC in about 37 minutes. Following the analysis of engineering telemetry it was determined that the spacecraft's high gain antenna was mis-pointed. A corrective command load was generated and was successfully transmitted to the spacecraft by Canarvon, Australia as soon as the spacecraft came into their view.

7. **Support of Encounter Rehearsal Three**. The third in the series of encounter rehearsals was supported on 5, 7, 9, 11 and 13 February, 1986. Unlike the previous rehearsals, this series was to be supported by DSS-43 as well as DSS-42. DSS-42 supported the passes on the 5th, 7th, and 13th while DSS-43 supported on the 9th and 11th. As in the other rehearsals, the goal of the test was to simulate as closely as possible the sequence of events to be followed for the actual encounter. The spacecraft was the data source.

The first four passes of this rehearsal were supported by the DSN nearly flawlessly. During the final rehearsal pass on February 13, DSS-42 data was of poor quality at ESOC following an apparent spacecraft modulation index change. ESOC verified that this change had not been observed at Canarvon. A troubleshooting effort at both the station and ESOC could not correct the problem and the last three hours of data were lost to the project. Extensive troubleshooting and investigation following the pass could not pinpoint the source of this outtage. It was learned, however, during a playback of the data recorded during the period in question, that the data recorded on the digital tape at DSS-42 was of good quality. A communications buffer was subsequently changed as the most likely trouble source. This problem did not recur.

8. **Uplink Handover Demonstration**. In order to demonstrate the DSN's ability to transfer uplink control of the spacecraft from an ESA to a DSN station, a test was conducted on January 22, 1986. The test showed that the uplink could be transferred between Canarvon and DSS-43 without difficulty. The DSS-43 uplink for command would be required during the encounter only in emergency support cases.

9. **SPC 10 and SPC 60 Encounter Training**. With the expanded DSN 64-meter subnetwork coverage requirement for the encounter, the DSN found it necessary to conduct additional training exercises with the Signal Processing Centers at Goldstone (SPC 10) and Canberra (SPC 40). The Giotto spacecraft was used as a data source and with the project's cooperation the data rate was commanded to 46 kbps so that the encounter rate could be processed. Six tests were conducted with each complex. Additional training was accomplished as a result of the complex's support of the final navigation campaign in March.

10. **Final Encounter Rehearsal**. The last two tests in the series of encounter rehearsals were conducted on February 28 and March 10, 1986. DSS-43 supported these tests. In addition to processing spacecraft telemetry at the encounter rate of 46 kbps, uplink handovers were also demonstrated between DSS-43 and Canarvon.

C. Encounter

1. **Final Navigation Campaign**. The last navigation campaign prior to the encounter was conducted from March 2 through March 12, 1986 and consisted of a total of 15 passes using DSS-12, DSS-42, and DSS-63 to obtain two-way coherent Doppler and ranging. The only problem encountered during this campaign was the failure of DSS-12 to obtain uplink lock during one pass. It was speculated that the high uplink power level being used by station 12 may have caused the failure to lock. A reduction in power level was requested during subsequent passes and the problem did not recur.

2. **Encounter Support**. Encounter Support by the Deep Space Network officially began on March 11, 1986 at 1610 (UTC). Coverage was for three continuous days by the 64-meter subnetwork. In addition to supporting the Giotto spacecraft, DSS-42 supported the Japanese MS-T5 (Sakigake) Halley Comet mission spacecraft on encounter day to collect radio metric data for calibration of the earth's atmosphere. After a nearly uneventful eight-month voyage through space, the Giotto spacecraft was about to begin the critical data-taking period. During the four hours leading up to the encounter, which took place at 00:03 UTC, spacecraft time, on March 14, 1986, the ten on-board experiments began to receive data. The closure speed between the spacecraft and the comet at that time was on the order of 68 km/sec. At 23:01 UTC the project reported the first dust impacts at a distance of about 287,000 km.

The DSN and spacecraft functioned perfectly up until two seconds before the time of closest approach when the spacecraft signal was lost due to dust particles impacting the spacecraft and causing nutation of the spin axis. The nutation caused the spacecraft's high gain antenna to offpoint and the downlink was lost. The spacecraft's nutation dampers slowly compensated for this effect. Receiver lock was restored after about 20 seconds; however, it took nearly 34 minutes for the real time telemetry to be fully restored. Analysis is still underway to fully understand this phase of the mission. Attempts are being made to recover data from this marginal period using the station's digital recordings and special recovery techniques. The project reported that the overall encounter results were spectacular. Pictures had been obtained to about 1500 kilometers from the nucleus before the signal was lost and had passed within 590 km of the nucleus and survived. Although post encounter assessments showed the spacecraft has received damage as a result of dust particle impacts, ESA made the decision to perform a maneuver which will allow Giotto to pass by the Earth in July 1990 for a possible retargeting to another comet. The spacecraft is now in a hybernation mode; DSN support of Giotto concluded on March 15, 1986.

References

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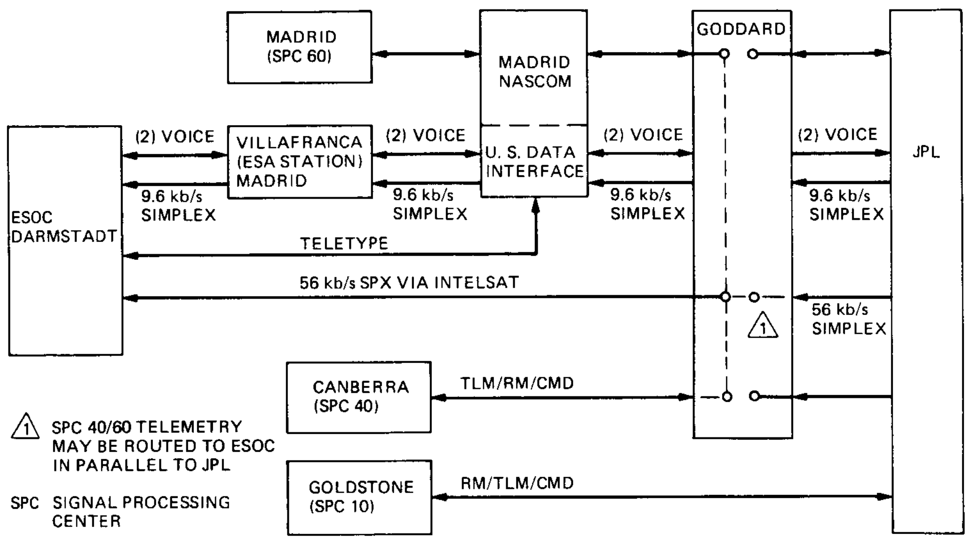

Fig. 1. Giotto DSN/ESOC data flow configuration