# Deep Space 1 Mission

The text below is summarized from the *New Millennium Project Technology Validation Reports for Deep Space 1* with permission of the web site NASA Responsible official, C.W. Minning.

## Overview

The primary goal of the DS1 mission was to validate advanced, high risk technologies that are important for future space and Earth science programs. Secondary goals were scientific in nature, and included obtaining images, spectra and particles and fields measurements of a near-Earth asteroid and a comet.

Deep Space 1 was launched from Pad 17-A at the Cape Canaveral Air Station at 12:08 UT (8:08 a.m. EDT), 24 October 1998, the first launch under NASA's Med-Lite booster program, on a Delta 7326-9.5 (a Delta II Lite launch vehicle with three strap-on solid-rocket boosters and a Star 37FM third stage). At 13:01 UT the third stage burn put DS1 into its solar orbit trajectory. DS1 separated from the Delta II about 550 km above the Indian Ocean. Telemetry was received by the NASA Deep Space Network 1 hour, 37 minutes after launch, a 13 minute delay from the expected time. The reason for the delay is not known.

DS1 flew by the near-Earth asteroid 9969 Braille (1999 K2) at 04:46 UT (12:46 a.m. EDT) on 29 July 1999 at a distance of about 26 km at approximately 15.5 km/sec relative velocity. A software problem caused the spacecraft to go into a safing mode at approximately 12:00 UT on 28 July, but the problem was solved and the spacecraft returned to normal operations at 18:00 UT. Up to six minor trajectory correction maneuvers were scheduled in the 48 hours prior to the flyby. The spacecraft made its final pre- encounter transmission about 7 hours before closest approach, after which it turned its high-gain antenna away from Earth to point the MICAS camera/spectrometer camera towards the asteroid. The spacecraft had a target-tracking problem and the MICAS instrument was not pointed towards the asteroid as it approached, so no images or spectra were obtained. MICAS turned off about 25 seconds before closest approach at a distance of about 350 km and measurements were taken with the PEPE plasma instrument. The spacecraft then turned after the encounter to obtain images and spectra of the opposite side of the asteroid as it receded from view, but due to the target-tracking problem only two black and white images and a dozen spectra were obtained. The images were taken at 915 and 932 seconds after closest approach from 14,000 km and the spectra were taken about 3 minutes later. The data were transmitted back to Earth over the next few days. The diameter of Braille is estimated at 2.2 km at its longest and 1 km at its shortest. The spectra showed it to be similar to the asteroid Vesta.

The primary mission lasted until 18 September 1999, after which the spacecraft entered an extended mission phase. Early in this phase, the commercial star tracker failed, leaving the craft unable to point its main antenna toward Earth or operate its ion propulsion system. A two-phase approach allowed recovery of the mission. First, ground crews devised a new method of pointing the high-gain antenna at the Earth, so the radio signal received at the Deep Space Network could be used as an indicator of the spacecraft attitude. Second, new software was developed to allow the science camera to perform the duties of the star tracker, allowing the spacecraft to return to three-axis operation and continue its mission.

DS1 flew by Comet 19P/Borrelly at 22:30 UT on 22 September 2001 (8 days after the comet's perihelion). The flyby occurred at a distance of 2171 km with approximately 16.58 km/sec relative velocity. At the time, 19P/Borrelly was 1.36 AU from the sun and 1.48 AU from the Earth. Three different types of science data were obtained during the encounter: The miniature integrated camera and spectrometer (MICAS) obtained both optical (0.5 to 1.0 microns) images, and spectra from 1.3 to 2.6 microns, and the Plasma Experiment for Planetary Exploration (PEPE) obtained measurements of the ion and electron energy and ion mass to charge ratios. The images obtained near closest approach represent the highest resolution images of a comet's nucleus to date.

## Mission Phases

**DS1 Mission Timeline**

Launch (Cape Canaveral, Florida) : 24 Oct 1998

Instrument verification completed : 13 Jul 1999

Asteroid Braille (1992 K2) encounter : 28 Jul 1999

End of primary mission : 18 Sep 1999

Coast period (MICAS observes Mars) : 20 Oct 1999

Star tracker failure : 11 Nov 1999

Comet Borrelly encounter : 22 Sep 2001

Deep Space 1 retired : 18 Dec 2001

### Launch:

Following launch, several days were spent conducting an evaluation of the spacecraft, verifying its health and preparing it for mission operations. Dedicated technology experiments began within a week of launch. Of course, some technologies were used as part of regular spacecraft operations, in particular the solar array, transponder, and AuotNav, but those and all other technologies also were subjected to in depth characterization tests. Radiometric determination of the trajectory was combined with results of the IPS tests to generate and optimize an updated low-thrust trajectory that was transmitted to the spacecraft. After verification of its functional capability, AutoNav was tuned in flight, particularly to account for discrepancies between the predicted and the actual MICAS images. As the mission progressed, more reliance was placed on AutoNav, with conventional navigation used to validate its performance. After ten days of thrusting, the spacecraft was turned to thrust along the vector (subject to a variety of constraints) for reaching the encounter targets for the primary and extended mission.

### Cruise 1:

In February 1999, a completely new software load of 4.1 MB was installed. This new software enabled the testing of four of the previously excluded technologies (the software package remote agent was not in this load), upgraded AutoNav (to accommodate scattered light in the MICAS images), fixed bugs identified after launch and improved spacecraft operability. To accommodate the remote agent experiments in May, the flight software was patched and remote agent software was uploaded. In June, following the remote agent experiment, the flight software was replaced again. This last load contained new operational enhancements and upgrades to a number of systems, including AutoNav upgrades for enhanced image processing and functions needed to execute encounters.

The thrusting for the primary mission was accomplished in two major periods. The brief hiatus in the thrust arc was inserted to allow days for activation and initial testing of PEPE in the absence of the IPS plasma, and experiments incompatible with the IPS thrust attitude. The second thrust segment ended on April 27, 1999.

### Braille Encounter:

All the technology testing was completed by July 1999. Following the end of the testing, on July 29, 1999, the DS1 spacecraft encountered (9969) 1992 KD at 15.5 km/s. As a result, the closest approach to Braille was 28.3 +/- km rather than the planned 15 km. The asteroid is believed to be elongated with a mean radius of roughly 2 km and is the smallest solar system body targeted by DS1. During the final days of the spacecraft's approach to the body, AutoNav did lock onto the asteroid but the accuracy was not high.

### Cruise 2:

Following the encounter with Braille, DS1 had months of thrusting until the primary mission ended on Sept 18, 1999. When DS1 was launched, the plan for the primary mission incorporated a plan for an extended mission taking the spacecraft to comet Borrelly. The extension was approved by NASA in August 1999. Most of the extended mission would be devoted to IPS thrusting. On Oct 20 1999, a coast period began which lasted through mid-December 1999 during which calibrations of all MICAS channels were conducted. On November 11, 1999, after all the Mars infrared spectra were taken, the spacecraft's stellar reference unit (SRU) stopped reporting attitude data to the spacecraft computer. On June 21, 2000, the IPS thrusting was restarted under routine operations.

### Borrelly Encounter:

Following its primary mission, DS1 embarked on an extended mission devoted to comet science. In November 1999, the spacecraft had suffered the loss if its stellar reference unit (SRU), its source of 3-axis attitude knowledge. This was considered to be catastrophic, but the operations team completed an ambitious two- phase, 7-month recovery that included the development of new software and new methods for operating the spacecraft.

One feature of the recovery was to use the visible CCD camera in the miniature integrated camera/spectrometer (MICAS), one of the technologies tested during the primary mission, as an attitude sensor. The problem of navigating to the vicinity of the comet was different from that of reaching a typical planetary encounter, because the uncertainty in the comet's ephemeris dominated navigation errors. From 25 August to 10 hours before the closest approach to September 22, DS1 conducted 11 imaging sessions spanning ranges to the comet of 40.3 x 10^6 km to 6 x 10^5 km.

On approach to Borrelly, DS1 viewed the comet near the south ecliptic pole. The spacecraft's approach of 2171 km was at 22:29:33 UTC on 22 September 2001, with v(inf) = 16.58 km/s. The encounter took place 1.36 AU from the Sun, 8 days after perihelion.

Science data were acquired with 3 instrument suites. All were body- fixed, so pointing required spacecraft maneuvers. MICAS' 1024 x 1024 CCD with 13-micro-rad pixels collected images in the range of 0.5 to 1.0 micrometer. MICAS also obtained spectra from 1.3 to 2.6 micrometers with a sampling interval of 7 nm. Ion and electron energy and angle spectra and ion mass/charge measurements were made with an instrument included on the flight, the plasma experiment for planetary exploration (PEPE). Over its 2.8pi sr field of view, PEPE was sensitive between 8 eV and 32 keV, with a resolution of 5% (energy and mass/charge). Magnetic field and plasma wave measurements were made with sensors that had been carried as an assessment of the IPS. These IPS diagnostic sensors (IDS) measured the effects of the IPS on the spacecraft and space environment during the primary mission and were reprogrammed in flight to collect cometary science data.

### Cruise 3 (HYPEREXTENDED MISSION):

The return of the data from Borrelly concluded DS1's two-year extended mission. The spacecraft was undamaged by the encounter and continued operating after the extended mission.

DS1's hyperextended mission included testing eight of the technologies onboard, with a focus on the IPS. On 18 December 2001, following the last IPS test and the dumping of some final data, a command was sent to place the spacecraft in one of its safe states, now with the downlink off. This last command product was the 9905th of the mission.