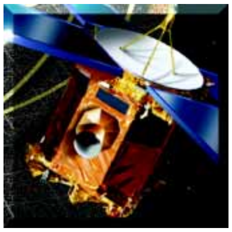

NEAR Overview

Andrew F. Cheng, Robert W. Farquhar, and Andrew G. Santo

The Near Earth Asteroid Rendezvous (NEAR) mission inaugurates NASA's Discovery Program. It will be the first to orbit an asteroid and will make the first comprehensive scientific measurements of an asteroid's surface composition, geology, physical properties, and internal structure. NEAR was launched successfully on 17 February 1996 aboard a Delta II-7925. It made the first reconnaissance of a C-type asteroid during its flyby of the main-belt asteroid 253 Mathilde in June 1997 and will orbit the unusually large near-Earth asteroid 433 Eros for about a year at a minimum orbit radius of about 35 km from the center of the asteroid. NEAR will obtain new information on the nature and evolution of asteroids, improve our understanding of planetary formation processes in the early solar system, and clarify the relationship between asteroids and meteorites. The NEAR Mission Operations Center and Science Data Center are both located at APL. The latter will maintain the entire NEAR data set on-line and will make data from all instruments accessible over the Internet to every member of the NEAR science team.
(Keywords: Asteroids, Discovery Program, NEAR mission.)

INTRODUCTION

Of the more than 7000 asteroids that have been named, most are found in the main asteroid belt between the orbits of Mars and Jupiter, but those that come within 1.3 AU of the Sun are known as near-Earth asteroids. The orbits of these dynamically young bodies have evolved on 100-million-year timescales because of collisions and gravitational interactions with planets. The present-day orbits of such asteroids do not necessarily indicate where they formed. Some are already in Earth-crossing orbits, and those that are not are highly likely to evolve into one. About 250 near-Earth asteroids are known, and they appear to typify a broad sample of the main-belt population.

Our current knowledge of the nature of asteroids comes from three sources: Earth-based remote sensing, data from the Galileo spacecraft flybys of the two main-belt asteroids 951 Gaspra and 243 Ida, and laboratory analyses of meteorites. Most meteorites are believed to be collisional fragments of asteroids, but they may represent a biased and incomplete sampling of the materials actually found in near-Earth asteroids. Firm links between meteorite types and asteroid types have been difficult to establish.[1] The uncommon eucrite (a basaltic achondrite) meteorite has been linked by visible and near-infrared reflectance measurements to the relatively rare V-type asteroid.[2,3]

However, controversy remains over whether and how the most common meteorite types (the ordinary chondrites) may be linked to the most common asteroid types (the S-type or stony asteroids) in the inner part of the asteroid belt.[4,5] (Gaspra, Ida, and the NEAR target 433 Eros are all S-type asteroids.)

The S-type asteroids are a diverse class of objects known to contain the silicate minerals olivine and pyroxene plus an admixture of iron/nickel metal. Some appear to be fragments of bodies that underwent substantial melting and differentiation. Others may consist of primitive materials like ordinary chondrites that never underwent melting and that may preserve characteristics of the solid material from which the inner planets accreted.

The Galileo flybys provided the very first high-resolution images of asteroids, revealing complex surfaces covered by craters, fractures, grooves, and subtle color variations.[6,7] Galileo also discovered a satellite at Ida, which is a member of the Koronis family (Eros is not an asteroid family member). The near-infrared spectrum of Gaspra indicates a high olivine abundance such that it is inferred to be a fragment of a differentiated body. Conversely, Ida and Eros display infrared spectra that may be consistent with a silicate mineralogy like that in ordinary chondrites.[8,9] The Galileo instrument complement did not include any capability to measure elemental composition, and debate continues about whether ordinary chondrites are related to S-type asteroids.

The NEAR mission will spend about a year in orbit around Eros. It will make the first comprehensive, spatially resolved measurements of the geology, mineralogy, and elemental composition of an S-type asteroid. NEAR will orbit Eros at low altitude, about 1 body radius above the surface. This long-duration, low-altitude orbit will allow NEAR instruments to measure the asteroid's abundant key elements with a maximum spatial resolution of about 2 km, more than an order of magnitude greater than Galileo. The NEAR data, especially when combined with those from the Galileo flybys, will greatly advance our understanding of S-type asteroids and their possible relationships to other small bodies of the solar system. NEAR will also map the entire surface of the asteroid in the near infrared and make a thorough search for satellites of Eros.

SCIENCE OBJECTIVES

The overall objectives of the NEAR mission are to rendezvous with a near-Earth asteroid, achieve orbit around such an asteroid, and conduct the first systematic scientific exploration of a near-Earth asteroid. NEAR will study the nature and evolution of S-type asteroids, improve our understanding of processes and conditions relevant to the formation of planets in the early solar system, and clarify the relationship between asteroids and meteorites.

Specific science questions to be addressed by NEAR are as follows.

- What are the morphological and textural characteristics of the asteroid surface, and how do they compare with those on larger bodies?
- What is the elemental and mineralogical composition of the asteroid? Is there evidence of compositional or structural heterogeneity?
- Is the asteroid a solid fragment of a larger parent body or a rubble pile?
- Is the asteroid's precursor body(ies) primitive or differentiated?
- Is there evidence of past or present cometary activity?
- Is the asteroid related to a meteorite type or types?
- Does an intrinsic magnetic field exist? What is it like?
- Does the asteroid have any satellites, and how might they compare with Eros?

SPACECRAFT DESIGN

NEAR is a solar-powered, three-axis–stabilized spacecraft[10] with a launch mass, including propellant, of 805 kg and a dry mass of 468 kg. The spacecraft is simple and highly redundant (Fig. 1). It uses X-band telemetry to the NASA deep space network; data rates at Eros will be selectable in the range of 2.9 to 8.8 kbps using a 34-m high-efficiency antenna. With a 70-m antenna, the data rates from Eros will range from 17.6 to 26.5 kbps. The command and telemetry systems are fully redundant. Two solid-state recorders are accommodated with a combined memory capacity of 1.8 Gbit.

Spacecraft attitude is determined using a star camera, a fully redundant inertial measurement unit, and

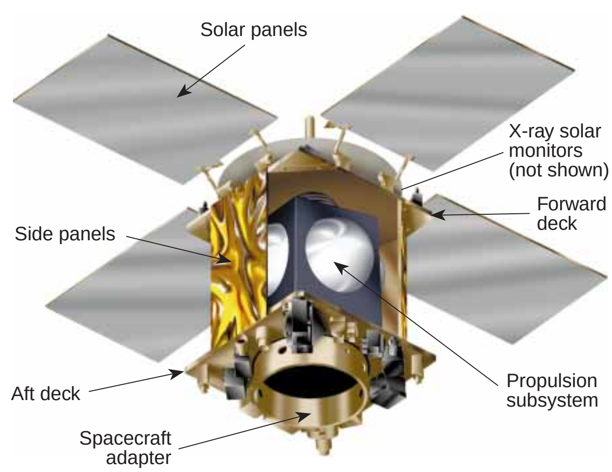

Figure 1. Structural view of the NEAR flight configuration after deployment.

redundant digital Sun sensors. The propulsion subsystem is dual mode (hydrazine is used as fuel for both the monopropellant and bipropellant systems) and includes one 450-N bipropellant thruster for large maneuvers, four 21-N thrusters, and seven 3.5-N thrusters for fine velocity control and momentum dumping. Attitude can be controlled by a redundant set of four reaction wheels or by the thruster complement to within 1.7 mrad. NEAR's line-of-sight pointing stability is within 50 μrad over 1 s, and postprocessing attitude knowledge is within 50 μrad.

Forward and aft aluminum honeycomb decks are connected with eight aluminum honeycomb side panels. Mounted on the outside of the forward deck are a fixed, 1.5-m-dia. X-band high-gain antenna (HGA), four fixed solar panels, and the X-ray solar monitor system. When the solar panels are fully illuminated, the Sun is in the center of the solar monitor field of view (FOV). No booms are accommodated on the spacecraft. The electronics are mounted on the inside of the forward and aft decks.

NEAR contains six scientific instruments, which are detailed in the next section.

1. Multispectral Imager (MSI)
2. Near-Infrared Spectrograph (NIS)
3. X-Ray Spectrometer (XRS)
4. Gamma-Ray Spectrometer (GRS)
5. NEAR Laser Rangefinder (NLR)
6. Magnetometer (MAG)

The MAG is mounted on top of the HGA feed, where it is exposed to the minimum level of spacecraft-generated magnetic fields. The remaining instruments (MSI, NIS, XRS, GRS, and NLR) are all mounted on the outside of the aft deck. They are on fixed mounts and are co-aligned to view a common boresight direction. The NIS has a scan mirror that allows it to look more than 90° away from the common boresight.

Key properties of the mission design permit the use of this fixed spacecraft geometry. Throughout the course of the rendezvous with Eros, the angle between the Sun and the Earth, as seen from the spacecraft, will remain less than about 30°. In addition, the mission aphelion will be reached during cruise. Hence, if the solar panels are sufficiently large to sustain NEAR at aphelion, there will be sufficient power margin at Eros for the spacecraft to pull its solar panels 30° off full illumination to point the HGA at Earth. Moreover, the rendezvous orbit plane will be maintained so that the orbit normal points approximately at the Sun. In this case, as NEAR orbits Eros, it will be able to roll around the HGA axis so as to keep the instruments pointed at the asteroid. (The instruments are usually pointed away from the asteroid when the HGA is used to downlink to Earth.) This mode of operation motivated the requirement for onboard data storage. With onboard image compression, NEAR can store more than 1000 images and downlink them within 10 h at its maximum data rate of 26.5 kbps.

The spacecraft is designed using a distributed architecture (Fig. 2), partitioned so that subsystems do not share common hardware or software. One major benefit of this approach is that careful design of interfaces allows development, test, and integration of subsystems in parallel. In addition, this architecture has a natural advantage of built-in contingencies and design margins. Truly parallel subsystem development requires independence at the subsystem interface, through careful partitioning of functional requirements and ample design margins at subsystem interfaces. On NEAR, subsystems are interfaced through a MIL-STD-1553 data bus, chosen because it is compatible with many off-the-shelf industry components. The data bus has additional attractive features: fewer interconnecting cables; built-in redundancy and cross-strapping; simplification of interface definition; a fault-tolerant, transformer-coupled interface; a common data architecture for sharing information among subsystems; and a flexible software-defined interface instead of a rigid hardware-defined interface.

Measured in constant dollars, NEAR is the lowest-cost U.S. planetary mission ever. The spacecraft's 27-month development schedule was unusually rapid. The distributed architecture and the selection of the 1553 data bus were key to developing NEAR on time and under budget. Previous planetary missions have not used a distributed architecture because they have been optimized for performance, i.e., to return maximum science within available technology. The distributed architecture approach comes with a mass penalty, and therefore a performance penalty: some hardware that can be combined at the system level is duplicated at the subsystem level. The distributed architecture approach for NEAR features interface margin and testability, optimizing the spacecraft for low cost and rapid schedule. Nevertheless, the performance penalty is minuscule, and the mass penalty for using the distributed architecture approach is only about 10 kg.

INSTRUMENT TASKS

Details on the many science objectives of the NEAR instruments can be found elsewhere.[11–16] A brief summary of instrument characteristics is given in this section. (Full descriptions of each science investigation and instrument will appear in a special upcoming issue of *Space Science Reviews*.) Detailed instrument descriptions and results of ground and in-flight calibrations appear in the companion articles of this issue of the *Technical Digest*.

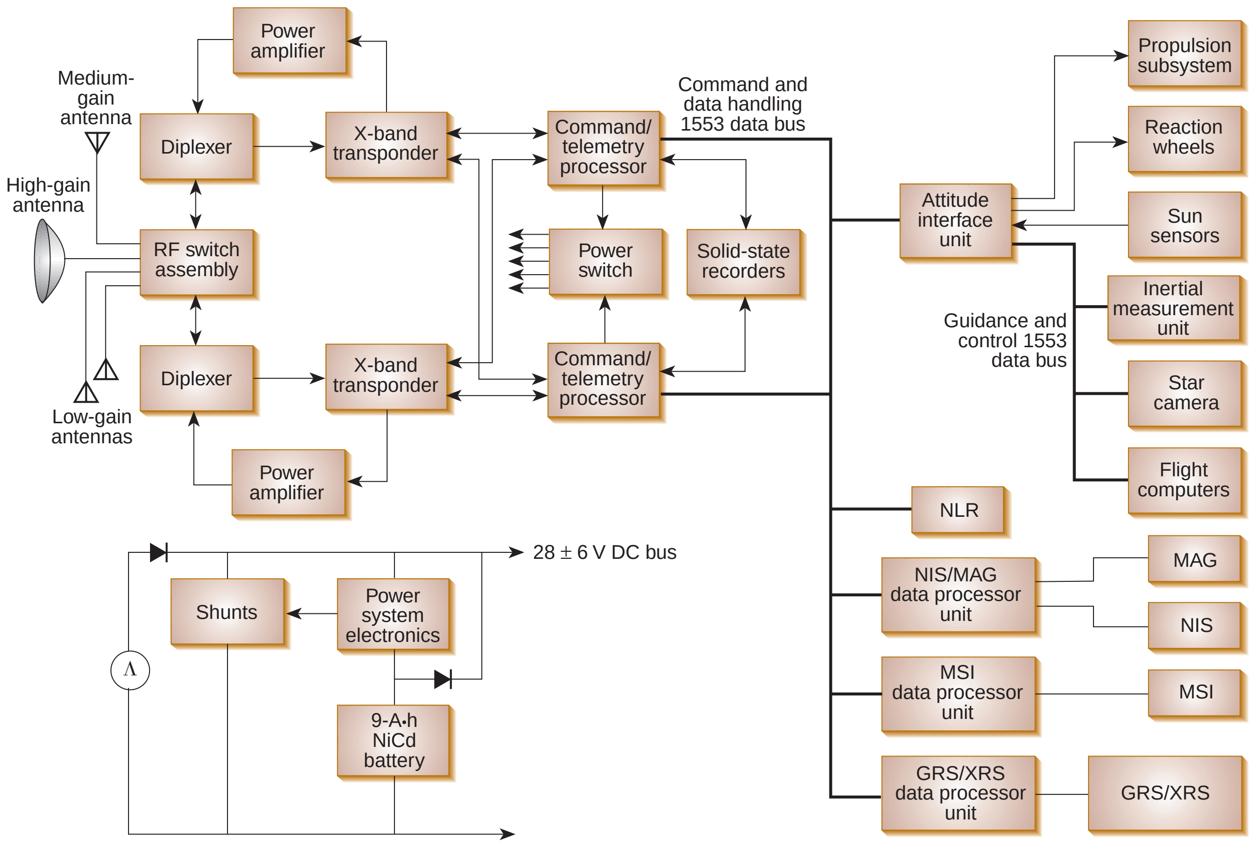

Figure 2. Block diagram illustrating the NEAR spacecraft's distributed architecture.

Multispectral Imager

The main goals of the MSI are to determine the shape of Eros and to map the mineralogy and morphology of features on its surface at high spatial resolution. MSI is a 537 × 244 pixel charge-coupled device camera with five-element radiation-hardened refractive optics. It covers the spectral range from 0.4 to 1.1 mm, and it has an eight-position filter wheel containing filters chosen to optimize the sensitivity of MSI to minerals expected or known to occur on Eros. The camera has an FOV of 2.90 × 2.25° and a pixel resolution of 95 × 161 mrad. It has a maximum framing rate of 1 per second with images digitized to 12 bits and a dedicated digital processing unit with an image buffer in addition to both lossless and lossy onboard image compression.

Near-Infrared Spectrograph

The NIS will measure the spectrum of sunlight reflected from Eros in the near-infrared range from 0.8 to 2.6 mm in 64 channels to determine the distribution and abundance of surface minerals like olivine and pyroxene. This grating spectrometer disperses the light from the slit FOV (0.38 × 0.76° in its narrow position and 0.76 × 0.76° in the wide position) across a pair of passively cooled one-dimensional array detectors, one a germanium array covering the lower wavelengths 0.8 to 1.5 mm and the other an indium/gallium-arsenide array covering 1.3 to 2.6 mm. The slit can be closed for dark current measurement. The NIS has a scan mirror that enables it to view the common boresight direction (within the MSI FOV) or directions more than 90° away. Spectral images can be built up by a combination of scan mirror and spacecraft motions. In addition, the NIS has a gold calibration target that can be positioned to scatter sunlight into the instrument and provide a quantitative, in-flight spectral calibration.

X-Ray Spectrometer

The XRS is an X-ray resonance fluorescence spectrometer that detects the characteristic X-ray line emissions excited by solar X-rays from major elements in the asteroid's surface. It covers X-rays in the energy range from 1 to 10 keV using three gas proportional counters. The balanced, differential filter technique is used to separate the closely spaced Mg, Al, and Si lines lying below 2 keV. The gas proportional counters directly resolve higher-energy line emissions from Ca and Fe. A mechanical collimator gives the XRS a 5° FOV, with which it will map the chemical composition of the asteroid at spatial resolutions as great as 2 km in the low orbits. It also includes a separate solar monitor system to measure continuously the incident spectrum of solar X-rays, using both a gas proportional counter and a high-spectral-resolution silicon X-ray detector. The XRS performs in-flight calibration using a calibration rod with Fe-55 sources that can be rotated into or out of the detector FOV.

Gamma-Ray Spectrometer

The GRS detects characteristic gamma rays in the 0.3- to 10-MeV range that are emitted from specific elements in the surface. Some of these emissions are excited by cosmic rays and some arise from natural radioactivity in the asteroid. The GRS uses a body-mounted passively cooled NaI scintillator detector with a bismuth germanate anticoincidence shield that defines a 45° FOV. Abundances of several important elements such as K, Si, and Fe will be measured in four quadrants of the asteroid.

NEAR Laser Rangefinder

The NLR is a laser altimeter that measures the distance from the spacecraft to the asteroid surface by sending out a short burst of laser light and then recording the time required for the signal to return from the asteroid. It uses a chromium/neodymium/yttrium-aluminum-garnet (Cr-Nd-YAG) solid-state laser and a compact reflecting telescope. It sends a small portion of each emitted laser pulse through an optical fiber of known length and into the receiver, providing a continuous in-flight calibration of the timing circuit. The ranging data will be used to construct a global shape model and a global topographic map of Eros with horizontal resolution of about 300 m. The NLR will also measure detailed topographic profiles of surface features on Eros with a best spatial resolution of about 5 m. The topographic profiles will enhance and complement the study of surface morphology from imaging.

Magnetometer

This fluxgate magnetometer uses ring core sensors made of highly magnetically permeable material. MAG will search for and map intrinsic magnetic fields of Eros. The recent Galileo flybys of the S-type asteroids Gaspra and Ida revealed that both of these bodies are magnetic, although the evidence is ambiguous.[17] Discovery of an intrinsic magnetic field at Eros would be the first definitive detection of magnetism at an asteroid and would yield important insights about its thermal and geological history.

Radio Science

In addition to the six major instruments, a coherent X-band transponder will be used to conduct a radio science investigation by measuring the Doppler shift from the spacecraft's radial velocity component relative to the Earth. Accurate measurements of the Doppler shift as the spacecraft orbits Eros will allow us to map the asteroid's gravity field. In conjunction with MSI/NIS and NLR data, gravity determinations will be combined with global shape and rotation state data to constrain the internal density structure of Eros, possibly revealing heterogeneity.

MISSION PROFILE

The NEAR spacecraft was successfully launched in February 1996, taking advantage of the unique alignment of Earth and Eros that occurs only once every 7 years.[18] A Delta-II 7925 rocket placed NEAR into a 2-year ΔV (trajectory correction maneuver)/Earth gravity-assist trajectory (ΔVEGA, Fig. 3). This trajectory represents a new application of the ΔVEGA technique: Instead of using an Earth swingby maneuver to increase the aphelion of the spacecraft

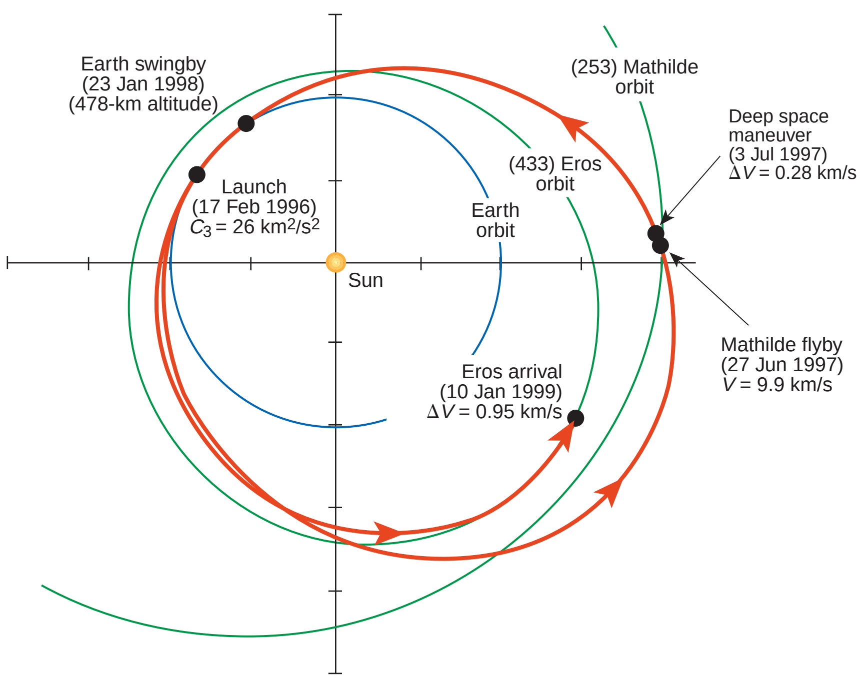

Figure 3. NEAR trajectory profile (C_3 = launch energy).

trajectory, the maneuver actually decreases the aphelion distance while increasing the inclination from 0 to about 10°. The circuitous 3-year flight path to Eros is the result of a Discovery Program requirement to use an inexpensive, but less capable, launch vehicle. With a larger launch vehicle such as an Atlas or Titan, a 1-year direct trajectory could have been used, but the total mission cost would have increased by at least $50 million. NEAR's total mission cost, including the launch vehicle, is about $210 million.

The Mathilde encounter occurred 1 week before the deep space maneuver on 3 July 1997. The Earth swingby occurred on 23 January 1998. Rendezvous operations at Eros are scheduled to begin on 20 December 1998. The initial close encounter with Eros (distance ≈500 km) will occur on 10 January 1999. Later, as NEAR is maneuvered closer to Eros, it will conduct science investigations from orbits that come as close as 15 km to the asteroid. In the last 2 months of the orbital phase, the minimum altitude will be lowered further, and on 6 February 2000 NEAR will attempt a soft landing on Eros.

Mathilde Flyby

Asteroid 253 Mathilde was discovered on 12 November 1885 by Johann Palisa in Vienna, Austria. The name was suggested by V. A. Lebeuf (1859–1929), a staff member of the Paris Observatory, who first computed an orbit for the new asteroid. The name is thought to honor the wife of astronomer Moritz Loewy (1833–1907), then the vice director of the Paris Observatory. Although Mathilde's existence has been known since 1885, it was only following the announcement of NEAR's possible flyby that extensive physical observations were carried out using telescopes on Earth. These showed that Mathilde was an unusual object, especially because of its rotation, which is at least an order of magnitude slower than typical main-belt asteroids.

Using a series of observations of this asteroid made in the first half of 1995, Stefano Mottola and his colleagues[19] determined that Mathilde's rotation period is an extremely long 17.4 days. Only two asteroids, 288 Glauke and 1220 Clocus, have longer periods (48 and 31 days, respectively), and there is no obvious mechanism that can account for these extremely long asteroid "days."

The only previous spacecraft encounters with asteroids, as noted earlier, had been the Galileo flybys of 951 Gaspra in October 1991 and 243 Ida in August 1993. Recall that both of these objects, as well as Eros, are S-type asteroids. However, the most common type of asteroid in the outer asteroid belt, the dark and primitive C-type objects, had not yet been investigated.

Spectral observations of Mathilde[20] showed that its spectrum was consistent with those of C-type asteroids and that it was similar to those of the large carbonaceous asteroids 1 Ceres and 2 Pallas (the two largest asteroids). (Mathilde is about twice the size of Ida and four times the size of Gaspra.) Before the NEAR spacecraft executed its flyby of Mathilde on 27 June 1997, these additional facts were known about the asteroid: estimated diameter, 61 km; H magnitude (a measure of absolute visual brightness), 10.30; perihelion, 1.94 AU; aphelion, 3.35 AU; and orbital inclination, 6.71°.

NEAR's encounter with Mathilde is summarized in Fig. 4. As noted earlier, the flyby occurred at about 2 AU from the Sun, where the available power from the spacecraft's solar panels was reduced to about 25% of its maximum mission level. Furthermore, a requirement to point the solar panels about 50° away from the optimal solar direction during the encounter reduced the available power by another 36%. Because of this power constraint, the only science instrument operated during the encounter period was the MSI.[21] However, spacecraft tracking data for the radio science experiment were obtained for an asteroid mass determination.[22]

The imaging experiment during the flyby had three major objectives:

1. Most importantly, to obtain at least one image of Mathilde near closest approach to provide the highest-spatial-resolution view of the surface
2. To obtain an image of the complete illuminated portion of the asteroid visible during the flyby
3. To acquire images of the sky around the asteroid to search for possible satellites

The entire imaging sequence was accomplished in about 25 min around closest approach (1200 km) at a speed of 9.93 km/s (Sun distance, 1.99 AU; Earth distance, 2.19 AU). A total of 534 images (24 high-phase, 144 high-resolution, 188 global imaging, 178 satellite search) were obtained during this interval. The whole illuminated portion of the asteroid was imaged in color at about a 500-m resolution before and after closest approach at phase angles of 125 and 140°, respectively. The best partial views were also in color, with a resolution of 200 to 350 m.

Mathilde's mass was determined by accurately tracking NEAR before and after the encounter. Apart from an interval of 1 to 2 h during the closest approach period, when imaging experiments were conducted, continuous tracking of the spacecraft was conducted for 3 days on either side of closest approach. During the flyby, Mathilde exerted a slight gravitational tug on NEAR. The corresponding gravitational tugs on the Galileo spacecraft at Gaspra and Ida were too small to allow mass determinations. However, because Mathilde's mass is so much larger than either Gaspra or Ida, its effects on NEAR's path were detectable in the spacecraft's radio tracking data.

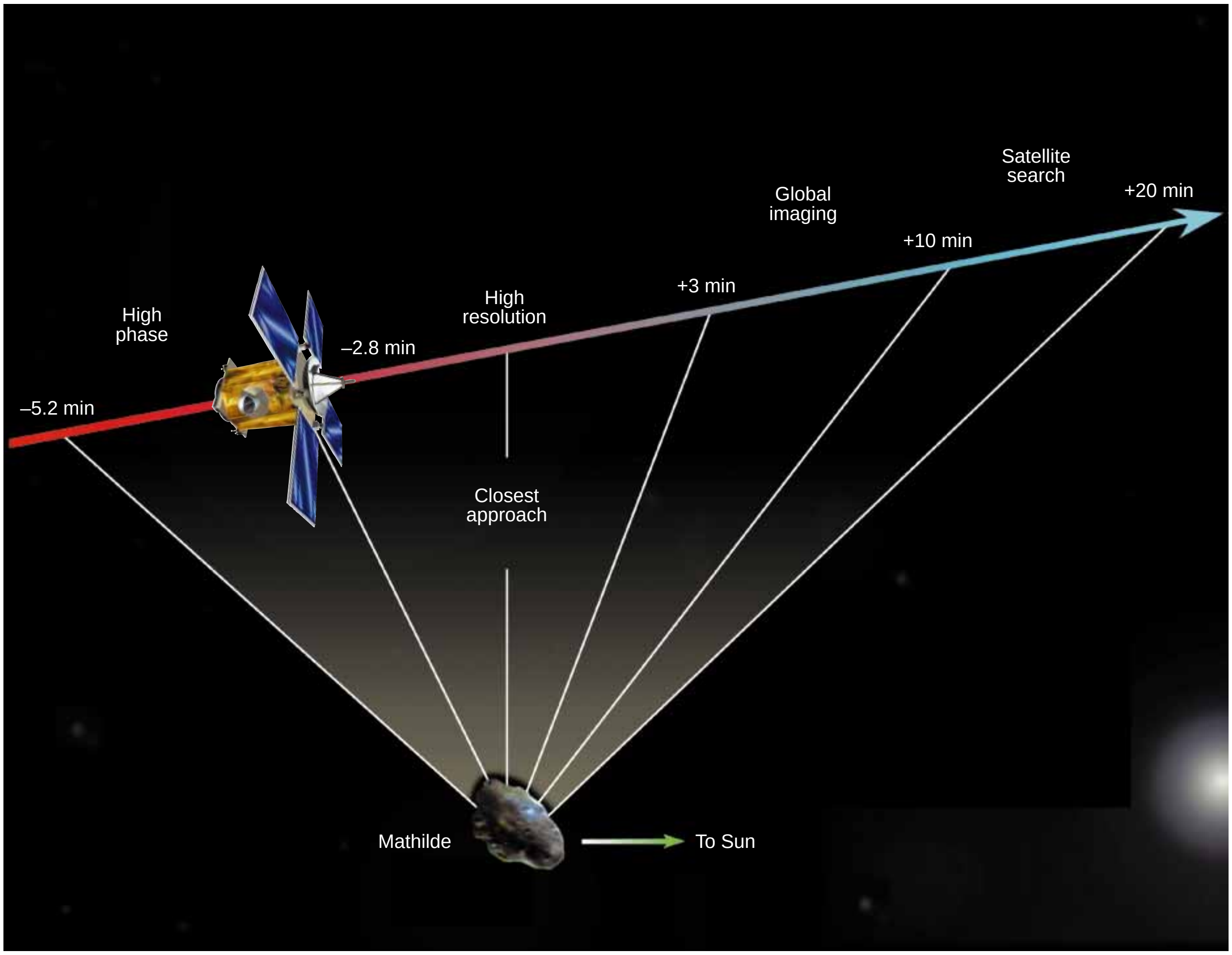

Figure 4. Timeline of the Mathilde flyby.

Earth Swingby

The next critical phase of NEAR's flight profile was scheduled for January 1998, when the spacecraft would pass by the Earth at an altitude of only 532 km (Fig. 5). This maneuver was expected to drastically alter NEAR's heliocentric trajectory, changing the inclination from 0.52 to 10.04°, and reducing the aphelion distance from 2.18 to 1.77 AU and perihelion distance from 0.95 to 0.98 AU. An interesting consequence of the Earth flyby was that the post-swingby trajectory remained over the Earth's south polar region for a considerable time.

Eros Encounter

The NEAR mission target, 433 Eros, is the second largest asteroid and is intermediate in size between Gaspra and Ida. Eros is one of only three near-Earth asteroids with maximum diameter above 10 km, and it is the only one whose heliocentric orbit is accessible enough to permit a rendezvous mission using the Delta II launch vehicle. The mean radius of Eros, at about 10 km, is an order of magnitude larger than that of typical known near-Earth asteroids.

Eros was discovered in 1898. It was the subject of a worldwide ground-based observing campaign in 1975 when it passed within 0.15 AU of Earth. Visible, infrared, and radar observations determined the approximate size, shape, rotation rate, and pole position of Eros (Table 1) and showed that a regolith (fragmentary material produced by impacts) was present on its surface.[23–25] Eros is presently in a Mars-crossing (but not Earth-crossing) orbit; however, numerical simulations suggest that it may evolve into an Earth crosser within 2 million years.[26]

More recent spectroscopic analyses have found a hemispherical heterogeneity in the near-infrared spectra of Eros.[9] One side of the asteroid has a spectrum consistent with higher pyroxene content and a radar signature consistent with a facet-like surface; the other side displays higher olivine content and a convex-shaped surface. The detection of variations in disk-averaged data with rotation phase suggests that substantial geologic and compositional complexity

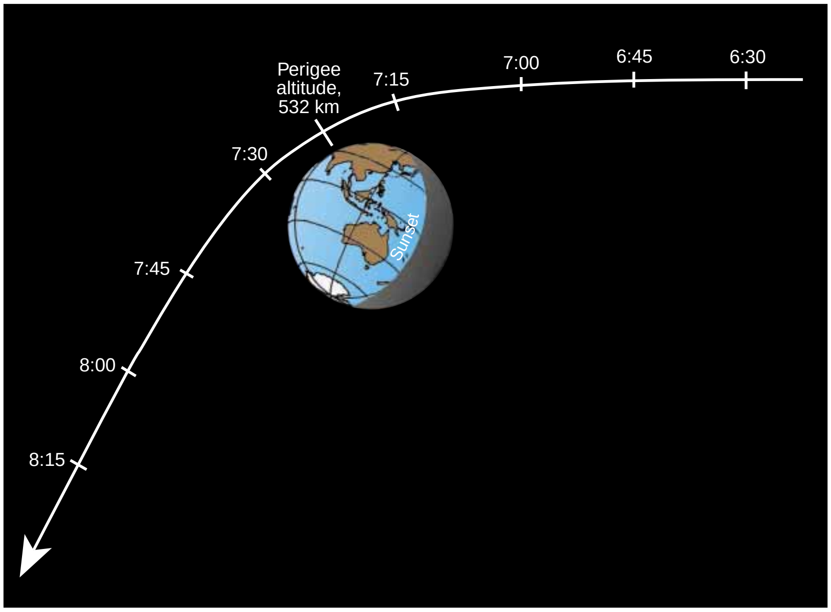

Figure 5. Earth swingby of 23 January 1998.

may be found at higher spatial resolution by NEAR. Such diversity may arise in a number of ways. One possibility is that Eros is a fragment of a large, differentiated parent body that did not survive intact to the present; this body may have had volcanic activity, for example, and Eros may preserve material from the surface or the interior of such a body. Alternatively, present-day Eros may have been assembled from fragments of many different parent bodies, and a detailed study of variations across the asteroid's surface may reveal evidence of such diverse origins.

Table 1. Features of 433 Eros.

Parameter	Measurement
Diameter of triaxial ellipsoid model	$40 \times 14 \times 14$ km
Heliocentric orbit period	1.76 years
Inclination of heliocentric orbit	10.8°
Perihelion, aphelion	1.133 AU, 1.784 AU
Rotation period	5.27011 h
Rotation pole	
Ecliptic longitude	16°
Latitude	11°
Spectral type	S (pyroxene, olivine, Fe–Ni metal)
Geometric albedo	0.16

Operations

Beginning on 20 December 1998, a sequence of rendezvous maneuvers will be used to decrease the relative velocity between NEAR and Eros to only 5 m/s. On 10 January 1999, NEAR will fly by Eros on its sunward side at a distance of about 500 km. In addition to gathering important scientific data, this first pass is expected to provide improved estimates of the asteroid's physical parameters (Table 2), which are needed for navigational purposes. Goals for the first pass include a mass determination to ±1% accuracy, identification of several hundred surface landmarks, and a vastly improved estimate of Eros's spin vector. As the spacecraft is maneuvered closer to Eros, estimates of its mass, moments of inertia, gravity harmonics, spin state, landmark locations, etc., will be determined with increasing precision.

The prime science phase at Eros will begin around 15 March 1999. During this phase, NEAR will be operating in orbits that come as close as 15 km to the asteroid's surface. The evolution of low-altitude orbits around Eros will be strongly influenced by its irregular gravity field. Orbits exist that are quite unstable, and the spacecraft could crash into Eros in a matter of days. Therefore, safe operation of NEAR during its 11-month prime science phase will require close coordination between the science, mission design, navigation, and mission operations teams.[21]

Figure 6 depicts the NEAR spacecraft in a 35-km circular orbit around Eros as viewed by an observer on the Sun. The orbit and Eros are drawn to scale, but obviously the spacecraft is not. This is a convenient reference frame to show NEAR's orbit because the orbital plane will be controlled so that it is always within 30° of a plane that is normal to the Sun–Eros line. In this configuration, NEAR's fixed solar panels are oriented toward the Sun. The science instruments are pointed at Eros's surface by slowly rolling the spacecraft as it orbits the asteroid.

Two fundamentally different orbital geometries are shown in Fig. 6. In Fig. 6a, Eros's rotation axis is aligned with the Sun–Eros line. Its South Pole points toward the Sun, which means that its Northern Hemisphere will be shadowed. Approximately 4 months later (Fig. 6b), as the asteroid's orbital position around the Sun changes, its rotation axis is perpendicular to the Sun–Eros line. Coverage of Eros's surface by NEAR's science instruments will vary considerably throughout the

Table 2. Sumary of science operations at Eros.

Phase	Goal
Approach/initial flyby	Mass determination (radio science)
	Shape/rotation state determinations (MSI)
	Color map production at low phase angle (NIS/MSI)
	Satellite search
Rendezvous	Imaging to 3 × 5 m resolution in seven colors (MSI)
	Light element map production at about 2-km resolution (XRS)
	Elemental composition analysis in four quadrants of Eros (GRS)
	Spectral map production at about 200 × 400 m resolution (NIS)
	Gravity field determination (radio science)
	Shape and topography determination (NLR/MSI)
	Determination of density homogeneity/ heterogeneity (various)
	Magnetic field mapping (MAG)

11-month prime science phase. However, careful planning of the mission and science operations should yield satisfactory global coverage by all NEAR instruments.

To simplify science operations, the rendezvous will be divided into distinct phases.[22] During each phase, particular aspects of the science will be emphasized (Table 2). The highest-priority science will vary by mission phase and during the course of the year in rendezvous orbit around Eros. The actual dates and orbit parameters during the rendezvous phase are still to be determined because of the uncertain mass of Eros.

The first detection of Eros by the imager is expected some 200 days before the unperturbed flyby closest approach date (i.e., the date that flyby would occur in the absence of rendezvous burns). Following this

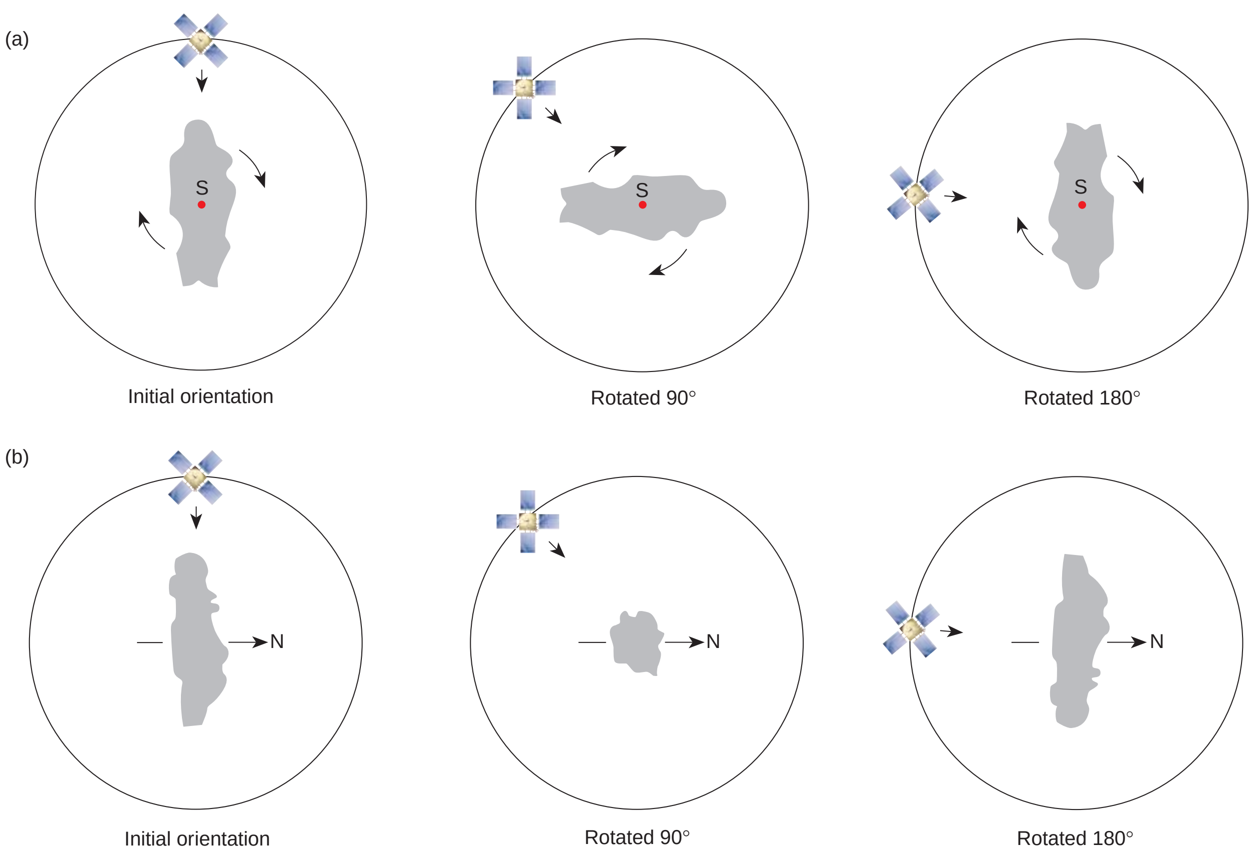

Figure 6. NEAR orbit around Eros as viewed from the Sun (35 × 35 km orbit; period of about 11.4 h). (a) Rotation axis aligned with Sun–Eros line (29 April 1999). (b) Rotation axis perpendicular to Sun–Eros line (2 September 1999). (Reprinted from Ref. 18 by permission.)

first detection, imaging of Eros will be undertaken for optical navigation and for initial shape and rotation studies.

The rendezvous burn sequence is targeted to put NEAR into an initial slow flyby trajectory past Eros, which, at a nominal speed of 5 m/s and a miss distance of 500 km, will take the spacecraft through a zero solar phase angle (Sun-asteroid-spacecraft angle). The purpose of this flyby will be to enable critical initial science observations. Since the nominal rendezvous orbit plane will be near the Eros terminator (plane dividing the dayside from the nightside), most of the observations during this period will be made at large phase angles that are favorable for imaging but unfavorable for infrared spectral mapping. The initial flyby will allow more than 30 h of observation at low phase angles that are not accessible within the nominal rendezvous geometry. Hence, it will provide an important opportunity to obtain global infrared spectral maps under optimal lighting conditions.

The approach to Eros and the initial flyby will also be used to perform an optical search for satellites of Eros. The satellite Dactyl of 243 Ida was discovered by Galileo.[24] If a satellite like Dactyl is present at Eros, it will not prevent NEAR from entering low-altitude orbit and achieving its primary science goals. Needless to say, if an Eros satellite is discovered, mission plans will be modified to include appropriate studies.

NEAR will remain in a bound orbit around Eros for more than 10 months. The spacecraft will spend at least 120 days in a 35×35 km orbit, during which time the highest-priority science will be measurement of elemental composition, although every instrument will be in operation. Much of the remaining time in orbit around Eros will be spent at semimajor axes of 50 km or less. Again, all instruments will be operating during these periods, but imaging and spectral mapping will have increased priority. The various mission phases at Eros are summarized in Fig. 7.

Data Flow

All data from the NEAR mission will be downlinked to the NASA Deep Space Network and then forwarded to the Mission Operations Center (MOC) at APL. Doppler and ranging data from the spacecraft will be analyzed primarily by the NEAR navigation team at the Jet Propulsion Laboratory (JPL) and processed to determine the spacecraft ephemeris as well as to perform radio science investigations. The entire spacecraft telemetry stream, including spacecraft and instrument housekeeping data and all science data, will be forwarded to the APL MOC together with the radiometric Doppler and range data along with results of navigation solutions. Navigation data will be forwarded to MOC in the form of SPICE kernels. (SPICE is an information system developed by the Navigation Ancillary Information Facility at JPL. It consists of data files and software for managing navigation-related data including spacecraft and planetary ephemerides, spacecraft pointing, timekeeping, gravity data, etc.)

From the APL MOC the spacecraft telemetry stream will be passed to the Science Data Center (SDC), the project facility responsible for low-level processing of spacecraft telemetry, data distribution, and data archiving. As such, the SDC supports the activities of the science team in data analysis and mission planning. The SDC will create and maintain an archive, which will be the central project repository for science data products such as images, asteroid models, and asteroid maps that will be stored in standard formats agreed upon with the science team. The SDC will enable easy access to mission data sets by members of the science team and by others, and it will collect observing requests and science priorities from the science team. It will maintain a telemetry archive, a record of instrument and spacecraft commands as executed, and records of science sequences as requested and as executed. It will provide ancillary data (spacecraft and planetary ephemerides, spacecraft and

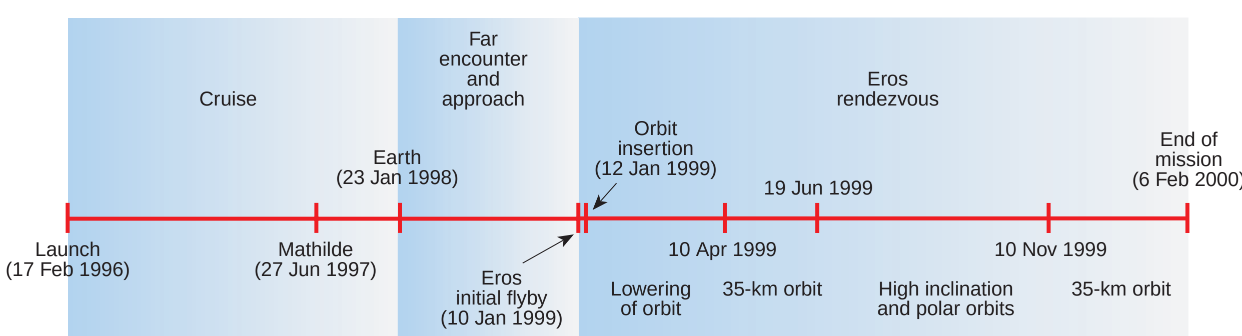

Figure 7. Mission phases at Eros.

planetary attitudes, shape and gravity files, and spacecraft clock files) in the form of SPICE kernels to the science team.

Moreover, SDC will create and maintain a database, called the Science Data Catalog, to facilitate access to science data. The catalog will provide pointers to data that satisfy specified criteria such as observing conditions, instrument status or mode, mission phase, target of observation, etc. The SDC will also be responsible for providing access to NEAR data for the scientific community at large and for the public. Uncalibrated data, including images, will be released publicly over the Internet as soon as they are validated. The Internet World Wide Web will be used for data released by the project at http://sd-www.jhuapl.edu/NEAR/.

CONCLUSION

NEAR will substantially increase our knowledge of primitive bodies in the solar system by providing a long, up-close look at the S-type asteroid 433 Eros and the first resolved images of the C-type asteroid 253 Mathilde. NEAR is the first mission to a near-Earth asteroid and a C-type asteroid, and it will be the first spacecraft to orbit a small body.

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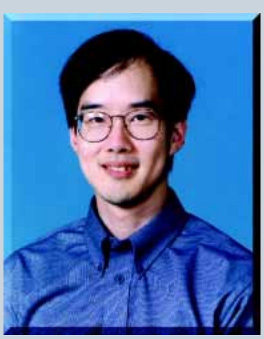
THE AUTHORS



ANDREW F. CHENG received an A.B. in physics from Princeton University in 1971 and a PhD. in physics from Columbia University in 1977. He joined APL in 1983. Dr. Cheng is a Principal Professional Staff member and is currently supervisor of the Planetary Science Section. His scientific interests include space plasma and astrophysical fluid dynamics, interactions of plasmas with atmospheres and solid surfaces, and magnetospheric physics. He is the project scientist for the NEAR mission, an interdisciplinary scientist on the Galileo mission to Jupiter, and a co-investigator on the Cassini mission to Saturn. Dr. Cheng is a fellow of the American Physical Society. He has served as an editor of *Eos Transactions* of the American Geophysical Union and as an associate editor for *The Journal of Geophysical Research* and *Geophysical Research Letters.* His e-mail address is andrew.cheng@jhuapl.edu.

ROBERT W. FARQUHAR is a member of APL's Principal Professional Staff. He received a B.S. in aeronautical engineering from the University of Illinois in 1959, an M.S. in engineering from UCLA in 1961, and a Ph.D. in astronautical sciences from Stanford University in 1969. Before coming to APL, Dr. Farquhar worked at several NASA facilities including Goddard Space Flight Center and NASA Headquarters from 1966 to 1990. Since joining APL in 1990, he has served as the mission director for the NEAR Program, playing a major role in the development of the flight profiles for the Mathilde flyby and the Eros rendezvous opportunity. Dr. Farquhar organized the technical programs for the first and second IAA Conferences in Low-Cost Planetary Missions. His e-mail address is robert.farquhar@jhuapl.edu.

ANDREW G. SANTO is a member of APL's Principal Professional Staff. He received a B.S. in engineering science (magna cum laude) from Pennsylvania State University in 1983 as well as an M.S. in electrical engineering and computer science (magna cum laude) in 1985 and an M.S. in technical management in 1994, both from The Johns Hopkins University. Before employment at APL, Mr. Santo worked at IBM (1983) and the Lawrence Livermore Laboratory (1984). Since joining the Laboratory in 1985, he has worked in the Space Department. Mr. Santo is the spacecraft system engineer and mission systems engineer for the NEAR spacecraft. He has also worked as the spacecraft system engineer for ALTAIR, spacecraft ground system lead for the UVISI instrument on the MSX spacecraft, launch vehicle interface lead for the Delta 183 spacecraft, and ground system lead for the Delta 180 and 181 spacecraft. His e-mail address is andrew.santo@jhuapl.edu.