The Near Earth Asteroid Rendezvous

A Guide to the Mission, the Spacecraft, and the People
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The NEAR mission is managed by The Johns Hopkins University Applied Physics Laboratory for the National Aeronautics and Space Administration.

NEAR mission Web site: http://near.jhuapl.edu
“The only conceivable way in which a continuing pace of pioneering planetary missions can be maintained is by making the spacecraft small, light, and elegant — while at the same time sacrificing little in the way of scientific productivity. . . But especially for the inner solar system, extraordinary opportunities seem to be before us. NEAR is the first.”

Carl Sagan
Cornell University
and The Planetary Society

(Comments read at the Low-Cost Planetary Mission Conference, held at The Johns Hopkins University Applied Physics Laboratory, April 1996)
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Introduction

The encounter of the Near Earth Asteroid Rendezvous (NEAR) spacecraft with asteroid 433 Eros on Jan. 10, 1999, begins a journey to a better understanding of asteroids, the Earth’s formation, and the history of our solar system. Asteroids, comets, and meteorites have stirred human imaginations for hundreds of years, inspiring great speculation as well as scientific observations. NEAR’s yearlong study of Eros comes at a time of unprecedented public interest in asteroids and their possible collision with the Earth and at a time of sufficient technical capabilities to unravel many mysteries that surround these near-Earth objects.

As the first mission in NASA’s Discovery Program, NEAR is setting the stage for future asteroid exploration and will undoubtedly form a base of knowledge that will be the framework for future missions. This document describes the NEAR mission, which is being managed by The Johns Hopkins University Applied Physics Laboratory (APL) from its Laurel, Md., campus.
The Mission

Journey to Eros

Launch

On Feb. 17, 1996, the NEAR spacecraft — the first asteroid orbiter of the Space Age — was successfully launched from Cape Canaveral Air Station in Florida aboard a Delta-2 rocket. Solar panels deployed minutes after launch provide power for the mission. In fact, NEAR is the first spacecraft to operate beyond the orbit of Mars solely on solar power.

Mathilde Flyby

On June 27, 1997, the NEAR spacecraft flew within 753 miles (1,212 kilometers) of asteroid 253 Mathilde. The Mathilde flyby was the closest spacecraft encounter with an asteroid and is the first close encounter with a C-type asteroid. The flyby was an add-on to NEAR’s primary mission at virtually no additional cost. The Multispectral Imager, a visible-light and infrared camera, provided a wealth of data on the asteroid’s surface. These data, together with Mathilde’s mass as determined from radio tracking data, also gave important information about Mathilde’s composition and density. (See page 11 for a discussion of the science results.)

Deep Space Maneuver

On July 3, 1997, the first firing of the spacecraft’s large bipropellant engine occurred to brake the spacecraft by 602 mph (269 meters per second). It was the first of three burns of the 100-pound bipropellant thruster. This maneuver was necessary to reduce the periapsis distance of NEAR’s trajectory — the closest point to the sun — from 0.99 to 0.95 astronomical unit (AU). (One AU is equal to the mean distance of the Earth from the sun.) NEAR’s maneuver changed the periapsis distance from 92 million miles (148 million kilometers) to 88 million miles (142 million kilometers), directing the spacecraft back to Earth for the mission-critical gravity assist.

Earth Swingby

On Jan. 23, 1998, the NEAR spacecraft flew by Earth for the gravity assist that put it onto the correct trajectory for its rendezvous with the asteroid Eros. Flying as close as 335 miles (540 kilometers) above southwestern Iran, the spacecraft produced a series of images of Asia, Africa, and Antarctica. A NEAR launch on the Earth swingby date would have required much greater launch energy (demanding a much more expensive Atlas-class launch vehicle) than the 1996 launch.

Asteroid Approach and Rendezvous

In preparation for the yearlong encounter with the asteroid, scientists and engineers have been developing and testing flight and ground software for the spacecraft and finalizing procedures for the spacecraft’s rendezvous and orbital maneuvers. To successfully rendezvous with the asteroid, a body also moving in space, the spacecraft has to be carefully maneuvered into position. If the spacecraft is moving too fast, it will fly right by Eros. Slowing the spacecraft too soon will add time to the mission.

The rendezvous burn sequence will slow the spacecraft relative to the speed of Eros and lower the altitude for closer investigation. On Dec. 20, 1998, a main engine burn should reduce the spacecraft’s speed from 2,180 to 700 mph (975 to 313 meters per second). A second burn is planned to decrease the speed to 68 mph (30 meters per second), and a third burn in early January should bring the approach speed to 18 mph (8 meters per second).

The orbit insertion maneuver is scheduled for Jan. 10, 1999. At that time, the spacecraft will be 240 million miles (386 million kilometers) from Earth, 161 million miles (259 million kilometers) from the sun, and 622 miles (1,000 kilometers) from Eros.

Throughout January, the spacecraft will continue to descend, becoming more and more subject to Eros’ gravitational force. By the end of the month, the spacecraft should be 126 miles (203 kilometers) from the surface of the asteroid.
As the spacecraft is maneuvered closer to the asteroid, estimates of mass, moments of inertia, gravity harmonics, spin state, and landmark locations will be determined with increasing precision. A search for satellites and debris around Eros should detect any body bigger than about 17 feet (5 meters).

**Orbital Phase**

With the orbit insertion burn on Jan. 10, 1999, the NEAR spacecraft will enter an initial orbit around Eros at an altitude of 622 miles (1,000 kilometers). By Feb. 21, 1999, mission planners will have gradually circularized the orbit to a radius of 62 miles (100 kilometers) and will begin tightening the radius to as small as 9.3 miles (15 kilometers).

Since the mass and density of Eros are unknown, and shape and rotation pole estimates are uncertain, it is not possible to plan a detailed “tour” of Eros in advance. Adjustments to the spacecraft orbit orientation will keep the asteroid within the fields of view for the science instruments, enable communications antenna coverage of the Earth, and provide illumination of the solar panels by the sun to power the spacecraft.

NEAR will remain in orbit around Eros for more than 12 months. This long time allows the NEAR instruments to determine the physical and geological properties of Eros and to measure its elemental and mineralogical composition. Many of these measurements require lengthy observations at close range; they could not be made during a flyby of the asteroid.

Altogether, the spacecraft will spend about 120 days in a 22-mile (35-kilometer) circular orbit around Eros. Although every instrument will be operating during the low-altitude phase, the highest-priority science will be the measurement of elemental composition. Much of the remaining time in orbit around Eros will be spent at distances of 31 miles (50 kilometers) or less.

When NEAR first enters its orbit around Eros, the south pole of the asteroid points almost directly toward the sun, keeping much of its northern hemisphere on the night side over the entire rotation period. The Multispectral Imager, Near-Infrared Spectrometer, and X-Ray Spectrometer can observe only the sunlit portions of Eros; the Gamma-Ray Spectrometer, Magnetometer, and Laser Rangefinder are independent of sunlight. To make the full set of measurements over the entire surface — and particularly to image all of Eros at highest resolution — NEAR must wait until the season changes as Eros moves in its orbit around the sun. About eight months after the rendezvous begins, all of Eros will become sunlit over the course of one rotation.

The irregular shape of Eros requires that NEAR remain in retrograde orbit relative to the asteroid spin. This means that the spacecraft and Eros are rotating in opposite directions. As compared with a direct orbit, a retrograde orbit tends to be more stable because the spacecraft is not affected as much by the unevenness of Eros’ gravity field. If both NEAR and Eros were rotating in the same direction, the spacecraft could be ejected from its orbit around Eros, or it could be pulled in and hit the asteroid’s surface.

Because of orbit dynamics, an orbital plane flip maneuver is required in early September 1999 to maintain the retrograde orbit. The orientation of NEAR’s orbit relative to the rotation pole of Eros will change slowly during the orbital phase due to the changing relative positions of Eros, Earth, and the sun.

When data are to be downlinked, the spacecraft will turn, if necessary, to point the high-gain antenna at Earth. The instruments face 90 degrees from the direction of the antenna, so they can point at Eros as the spacecraft rolls in its orbit. All or any combination of the instruments can operate simultaneously, taking data and storing data on the solid-state recorders.

**Mission Operations**

NEAR’s mission operations are conducted from the Mission Operations Center at The Johns Hopkins University Applied Physics Laboratory (JHU/APL) campus in Laurel, Md. The Mission Operations Center at JHU/APL is the first non-NASA space center to direct a NASA planetary mission. A team of flight controllers is responsible for the day-to-day operations of the spacecraft. Flight controllers work closely with the science teams, JHU/APL Mission Design, and the Navigation Team at NASA’s Jet Propulsion Laboratory (JPL).
Together, Mission Operations personnel and the science teams plan spacecraft and instrument activities. The science teams prepare requests for operations of the five science instruments and transmit them to Mission Operations two weeks before their intended execution. During NEAR’s rendezvous with Eros, activities will include commands to point instruments and image selected areas of the asteroid’s surface or activate the NEAR Laser Rangefinder to measure the distance between Eros’ surface and the spacecraft.

Working with Mission Design and the JPL Navigation Team, Mission Operations executes the orbit maneuvers by designing command sequences for the spacecraft’s propulsion system. Mission Design determines what the maneuvers should be and when they should be made.

The schedule calls for four rendezvous burns using the propulsion system’s thrusters to slow the spacecraft during its approach to Eros. Orbit insertion involves another firing of the thrusters. During the yearlong orbital phase, orbit correction maneuvers — adjusting NEAR’s orbit around Eros — are expected as the spacecraft’s instruments reveal more information about the gravity of Eros and its rotation.

All activities are integrated by Mission Operations into weekly command loads and are thoroughly tested through software simulation and verification. Once approved, NEAR flight controllers uplink as much as a week’s activities to the spacecraft through NASA’s Deep Space Network (DSN). Transmission time to NEAR’s onboard computers typically takes 30 to 60 minutes.

Once uploaded to NEAR’s flight computers, commands automatically execute at predetermined times. The science and engineering data are recorded to onboard solid-state recorders. Once a day, NEAR will re-point from its normal asteroid-pointing orientation to an Earth-pointing orientation to play back the recorded data. The NEAR data will travel back to Earth along the same path as the commands uplinked through the DSN.

All data will then pass back through the Mission Operations Center, where computers extract the science data from the incoming data stream and forward it to the Science Data Center. Flight controllers monitor NEAR engineering telemetry in real time to verify spacecraft operations.

Science Data Center

The NEAR spacecraft transmits all of its data to a global network of antenna tracking stations. The data are then forwarded to JHU/APL’s Science Data Center (SDC) for processing, distribution to the science teams, and archiving. The SDC was established for the NEAR mission as the central site for data processing activities. It performs the common data processing tasks — cleaning and merging the data coming down from the spacecraft by sorting, removing duplicates, and deleting errors.

The SDC also creates separate instrument files from the incoming data, which it then distributes to the respective science teams over the Internet. This way, critical mission data are delivered to the scientists’ desktops without delay.

Serving as the mission’s library, the SDC maintains an archive of telemetry, instrument, and command histories, along with the spacecraft’s navigation and pointing information. The data are used to produce the images that are posted on the NEAR Web site, including the “image-of-the-day.”

The SDC’s entire archive is available on-line over the Internet on the NEAR Web site: http://near.jhuapl.edu. Thanks to the World Wide Web, NEAR mission information is accessible to the scientific community and the general public soon after the data arrive at the SDC.

The SDC also sends NEAR data to NASA’s Planetary Data System (PDS), where the data are archived under the “small bodies” section of the PDS Web site. The PDS makes digital data on NASA missions available to the worldwide science community. The PDS Web site is http://pds.jpl.nasa.gov.

Mission Costs

The total mission cost is projected to be $211.5 million. The cost for spacecraft development came to $124.9 million, and launch support and tracking amounted to $44.6 million. The cost for mission operations and data analysis is $42 million.

*These are official NASA figures. However, due to an underrun during the development phase, approximately $8 million was carried forward to the mission operations phase.
NEAR Operations Flow

Science Teams → Science Data Center → NASA Deep Space Network

- Canberra, Australia
- Madrid, Spain
- Goldstone, USA

Instrument activity requests

Orbit updates/ maneuver plans

Mission Design & Navigation
JHU/APL & JPL

Real-Time Mission Operations Center (MOC): JHU/APL

- Plan/command to maximize science returns
- Performance assessment
- Health & safety monitoring
- Contingencies
Mission Timeline

Note: The NEAR mission is the first to orbit a small body, and much is unknown. Because the mission is exploring new frontiers, NEAR operations must remain fluid to respond to evolving scientific findings. Therefore, dates, altitudes, and event sequences listed may be adjusted as the mission unfolds. Check the NEAR Web site, http://near.jhuapl.edu, for the most up-to-date information.

Feb. 17, 1996
NEAR successfully launches from Cape Canaveral on a Delta-2 rocket.

Feb. 18, 1997
NEAR establishes record for the greatest distance from the sun for a solar-powered spacecraft (203 million miles/327 million kilometers).

June 27, 1997
In a flyby of asteroid 253 Mathilde, NEAR comes within 753 miles (1,212 kilometers) of the asteroid.

Jan. 23, 1998
An Earth swingby puts NEAR on its final approach path for an encounter with asteroid 433 Eros. At its closest point to Earth, the spacecraft passes about 335 miles (540 kilometers) above Ahvaz in southwestern Iran.

April 1, 1998
NEAR sets the record as the most distant manmade object detected by optical means when an amateur astronomer in New South Wales, Australia, spots the spacecraft at a distance of 20.91 million miles (33.65 million kilometers) from Earth. The previous record was the 1992 sighting of the Galileo spacecraft at a distance of 5 million miles (8.06 million kilometers) from Earth.

Dec. 16, 1998
Live press conference at NASA Headquarters, 1 p.m., highlighting background and upcoming events of the NEAR mission.

Dec. 20, 1998
Rendezvous Operations Begin. A 15-minute bipropellant engine burn is executed to align the spacecraft with the position and velocity of Eros.

Dec. 27, 1998
Satellite Search. In the first of four searches, the Multispectral Imager surveys the area within Eros’ full sphere of influence to look for small moons orbiting the asteroid.

Dec. 28, 1998
Rendezvous Burn 2. The second, and final, bipropellant burn is executed.

Dec. 29, 1998
Rendezvous Burn 3. If the spacecraft is on its scheduled course, this burn is eliminated.

End of December to Early January
The radio science experiment is expected to determine Eros’ mass.
The Multispectral Imager provides a small (about 23-pixel) image of Eros that shows its shape, but because of the distance from the asteroid — about 11,800 miles (19,000 kilometers) — features are not expected to be clear.

Jan. 1, 1999
Satellite Search. The second satellite search is conducted.

Jan. 2, 1999
Satellite Search. The third satellite search is conducted.

Jan. 3, 1999
Rendezvous Burn 4, using hydrazine fuel, is executed. The Science Team starts posting an Eros “image-of-the-day” on the NEAR Web site (http://near.jhuapl.edu).

Jan. 4, 1999
Satellite Search. The fourth and final satellite search is conducted.

Jan. 6, 1999
Images of Eros, taken at a distance of 1,860 miles (3,000 kilometers), are expected to reveal distinguishable features. The asteroid is about 100 pixels and fills half the frame.

Jan. 9, 1999
The Multispectral Imager takes a color movie of one full rotation of Eros from an altitude of 992 miles (1,600 kilometers). The image is expected to nearly fill the field-of-view and show distinct surface details.
Jan. 10, 1999  
**Eros Encounter.** NEAR enters into an elliptical orbit around Eros at about 10 a.m., beginning at an altitude of 622 miles (1,000 kilometers) and a velocity reduced to 1 meter per second.

Press briefing at JHU/APL Kossiakoff Center, noon. Briefing is transmitted live by NASA TV.

Jan. 10 to March 26, 1999  
**High-Orbit Phase.** NEAR travels in orbits with radii progressively decreased from 622 to 31 miles (1,000 to 50 kilometers) above Eros.

Jan. 14, 1999  
Press conference at JHU/APL Kossiakoff Center, 1 p.m., to report early science results. Conference is transmitted live by NASA TV.

Jan. 27, 1999  
NEAR spacecraft descends to 125-mile (200-kilometer) orbit.

Feb. 1, 1999  
Near-Infrared Spectrometer begins taking images for global mosaic of Eros. Final mosaic is complete mid-April 1999.

Data from the Multispectral Imager and Laser Rangefinder are combined to produce a shape model of Eros. Information from the shape model will help determine the volume and density of Eros.

Feb. 21, 1999  
NEAR reaches orbit of 62 miles (100 kilometers) from Eros.

March 5, 1999  
Low phase measurements begin on southern hemisphere of Eros from a distance of 93 miles (150 kilometers). The Near-Infrared Spectrometer begins taking measurements to determine the mineral composition of Eros.

March 26 to July 29, 1999  
**Low-Orbit Phase.** NEAR travels in an orbit radius of 22 to 31 miles (35 to 50 kilometers) from Eros.

The X-Ray/Gamma-Ray Spectrometer measures element abundances, which will help to determine the relationship between meteorites and asteroids.

July 29 to Oct. 7, 1999  
**High-Orbit Phase.** NEAR travels in an orbit radius of 25 to 339 miles (40 to 545 kilometers) from Eros. Most of these orbits are nearly polar to allow mapping of most of Eros’ surface.

Sept. 6, 1999  
NEAR’s orbital direction is reversed to begin low phase measurements of Eros’ northern hemisphere. The spacecraft pulls back to 339 miles (545 kilometers) from Eros to safely execute engine burns that send NEAR into retrograde orbit. This is the first time a spacecraft’s orbit has been reversed by its own propulsive maneuvers.

Oct. 7 to Dec. 31, 1999  
**Low-Orbit Phase.** NEAR travels in an orbit radius of 22 to 31 miles (35 to 50 kilometers) from Eros.

Jan. 1 to Jan. 31, 2000  
NEAR executes close passes over Eros at an altitude of 3 miles or less (1 to 5 kilometers).

Feb. 6, 2000  
Mission ends.
NEAR Science Objectives

Except for the moon, near-Earth asteroids (NEAs) are Earth’s nearest and most accessible planetary neighbors. These bodies have played a significant role in shaping the Earth; impacts of large NEAs have affected the evolution of the Earth’s atmosphere and biosphere. Along with comets and meteorites, asteroids preserve records of processes and conditions that existed in the early solar system.

By Feb. 6, 2000, the NEAR mission will provide the first comprehensive picture of the physical geology, composition, and geophysics of an asteroid. The overall science goals of the NEAR mission can be summarized as follows:

- To characterize the physical and geological properties of a near-Earth asteroid and to infer its elemental and mineralogical composition
- To clarify relationships among asteroids, comets, and meteorites
- To further the understanding of processes and conditions during the formation and early evolution of the planets.

High-resolution imagery will offer insight into the regolith — the rocky debris layer that forms on airless solar system bodies — and the history of impacts as recorded in the crater population. Spectroscopic analysis will provide maps of mineralogy at 1,000-foot (300-meter) resolution. The Radio Science and Magnetometer experiments will yield information on the strength and character of the magnetic field and on global density and density distribution.

The primary measurement objectives at Eros are:

- To determine the gross physical properties of the asteroid, including size, shape, configuration, volume, mass, density, and spin state
- To measure surface composition, elemental abundances, and mineralogy
- To investigate surface morphology (structure) through comprehensive imaging under a variety of lighting conditions.

Other measurement objectives are:

- To determine regolith properties and texture by imaging to sub-meter scales. These observations will be made during special close passes to within 1 mile (1.6 kilometers) or less of the surface near the end of the mission.
- To measure interactions with the solar wind and search for possible intrinsic magnetism.
• To search for evidence of current activity as indicated by dust or gas in the vicinity of the asteroid
• To investigate the internal mass distribution through measurements of the asteroid's gravity field and the time-variation of its spin state.

To accomplish these objectives, NEAR carries the following science payload:
• Multispectral Imager — to map the morphology and color at 10-foot (3-meter) resolution
• Near-Infrared Spectrometer — to map the mineralogy at 800-foot (250-meter) resolution
• X-Ray/Gamma-Ray Spectrometer — to measure the abundance of key elements
• NEAR Laser Rangefinder — to measure the topography to 15-foot (5-meter) vertical resolution
• Magnetometer — to search for a magnetic field
• Radio Science — to determine the mass and internal structure of Eros using the spacecraft's telecommunications system.

The Asteroids

Asteroids and Meteors

Asteroids are small bodies without atmospheres that orbit the sun but are too small to be classified as planets. Dubbed “minor planets,” tens of thousands of asteroids are known to congregate in the main asteroid belt: a vast, doughnut-shaped ring located between the orbits of Mars and Jupiter from approximately 2 to 4 AU (186 to 370 million miles/299 to 598 million kilometers).

Asteroids are thought to be primordial material that was prevented by Jupiter's strong gravity from accreting into a planet-sized body when the solar system was born 4.6 billion years ago. The estimated total mass of all asteroids would make a body about 930 miles (1,500 kilometers) in diameter — less than half the size of the moon.

Known asteroids range in size from the largest — Ceres, the first-discovered asteroid (discovered in 1801) at about 580 miles (930 kilometers) in diameter — down to tens of meters. Sixteen asteroids have diameters of 150 miles (240 kilometers) or more. Most main belt asteroids follow slightly elliptical, stable orbits, revolving in the same direction as the Earth and taking from three to six years to complete a full circuit of the sun.

Our understanding of asteroids comes from three main sources: Earth-based remote sensing, laboratory analysis of meteorites, and data from the Galileo and NEAR flybys. The yearlong encounter with Eros is an exciting prospect for scientists whose appetites were whetted in October 1991, when the Galileo spacecraft flew by the asteroid 951 Gaspra at a distance of 1,000 miles (1,600 kilometers). In August 1993, Galileo passed within 1,500 miles (2,400 kilometers) of another asteroid, 243 Ida. Later analysis of the Ida images revealed a small moon, Dactyl, about 1 mile (1.6 kilometers) in diameter. The most recent encounter with an asteroid took place on June 27, 1997, when the NEAR spacecraft flew within 753 miles (1,212 kilometers) of the C-type asteroid Mathilde. (Science results are discussed on page 11.) Gaspra, Ida, and Mathilde are all main belt asteroids.

Asteroids are classified into different types according to their albedo and spectra seen in reflected sunlight. Albedo refers to an object's measure of reflectivity. A white, perfectly reflecting surface has an albedo of 1.0; a black, perfectly absorbing surface has an albedo of 0.0.

The spectra of asteroids provide information on their compositions and bear similarities to those of known meteorite types. It is inferred that asteroids display a wide variety of compositions: some are rocky (for example, basaltic); some are metallic; some have hydrated minerals; and some are probably rich in organics.

The principal types of asteroids include:
• C-type (carbonaceous), including asteroid 253 Mathilde: This category includes more than 75 percent of the known asteroids. They are very dark, with an albedo of 0.03 to 0.09. Their composition is thought to be similar to that of the sun, but depleted in hydrogen, helium, and other volatiles — substances that
vaporize easily. Carbon compounds similar to coal are thought to predominate. C-type asteroids inhabit the main belt’s outer regions.

- **S-type (silicaceous)**, including asteroid Eros, Gaspra, and Ida: These asteroids account for about 17 percent of the known population and dominate the inner asteroid belt. They are relatively bright, with an albedo of 0.10 to 0.22. Their composition is metallic iron mixed with iron and magnesium silicates.

- **M-type (metallic)**: This group includes many of the remaining known asteroids and inhabits the main belt’s middle region. With an albedo of 0.10 to 0.18, these asteroids are relatively bright. Their composition is apparently dominated by metallic iron.

Numerous other types of asteroids have been identified. The proportions of asteroids in the known population do not simply reflect the actual populations because, for example, some types are easier to see than others.

The relationship between asteroids and meteorites remains a puzzle. Smaller than asteroids, meteoroids are interplanetary bodies. Meteoroids that enter the Earth’s atmosphere are called meteors, and the fragments that hit the ground are meteorites.

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The most common meteorites, known as ordinary chondrites, are composed of small grains of rock and appear relatively unchanged since the solar system formed. Stony-iron meteorites, on the other hand, appear to be remnants of larger bodies that were once melted so that the heavier metals and lighter rocks separated into different layers.

A long-standing scientific debate exists over whether the most common asteroids in the inner asteroid belt — the S-types — are the source of ordinary chondrites. Spectral evidence so far suggests that the S-type asteroids may be geochemically processed bodies akin to the stony-irons. If S-types are unrelated to ordinary chondrites, then another parent source must be found. If the two are related, however, then scientists need an explanation for why their color properties are not similar.

**Near-Earth Asteroids**

Asteroids with orbits that bring them within 1.3 AU (121 million miles/195 million kilometers) of the sun are known as near-Earth asteroids (NEAs). It is believed that most NEAs are fragments jarred from the main belt by a combination of asteroid collisions and the gravitational influence of Jupiter. Some NEAs may be the nuclei of dead, short-period comets. The NEA population appears to be representative of most or all asteroid types found in the main belt.

Traditionally, NEAs have been classified into three categories according to their orbits. Amors are asteroids that cross Mars’ orbit but do not quite reach the orbit of Earth. Eros — the target of the NEAR mission — is a typical Amor. Apollos are asteroids that cross Earth’s orbit with a period greater than one year. Atens are asteroids that cross Earth’s orbit with a period less than one year.

NEAs are a dynamically young population, meaning that their orbits evolve on 100-million-year timescales because of collisions and gravitational interactions with the sun and the terrestrial planets. An asteroid’s orbit can also change suddenly if a collision occurs.
Approximately 600 NEAs have been found to date, probably only a small percentage of their total population. The largest presently known is 1036 Ganymed, with an approximate diameter of 25.5 miles (41 kilometers). Estimates suggest that at least 1,500 NEAs may be large enough — 0.6 mile (1 kilometer) or more in diameter — to threaten civilization if they were to strike the Earth.

Many bodies have struck Earth and its moon in the past. One widely accepted theory blames the impact 65 million years ago of an asteroid or comet at least 6 miles (10 kilometers) in diameter for mass extinctions among many life forms, including the dinosaurs. Other theories suggest that the chemical building blocks of life and much of Earth’s water arrived on asteroids or comets that bombarded the planet in its youth.

On June 30, 1908, a small asteroid 330 feet (100 meters) in diameter exploded over the remote region of Tunguska in Siberia, devastating more than half a million acres of forest. One of the most recent close calls occurred on March 23, 1989, when an asteroid 0.25 mile (0.4 kilometer) wide came within 400,000 miles (640,000 kilometers) of Earth. Surprised scientists estimated that Earth and the asteroid — weighing 50 million tons and traveling at 46,000 mph (74,000 kilometers per hour) — had passed the same point in space just six hours apart.

433 Eros

The target of the NEAR mission is 433 Eros, the first near-Earth asteroid to be discovered and the second largest. Eros also is one of the most elongated asteroids, a potato-shaped body with estimated dimensions of 25.3 by 9.1 by 8.8 miles (40.5 by 14.5 by 14.1 kilometers). It is one of only three known NEAs with diameters above 6 miles (10 kilometers).

Eros was discovered on Aug. 13, 1898, by Gustav Witt, director of the Urania Observatory in Berlin, and independently observed on the same date by Auguste H. P. Charlois in Nice, France. As a member of the NEA group known as the Amors, Eros has an orbit that crosses Mars’ path but does not intersect the path of Earth. The asteroid follows a slightly elliptical trajectory, circling the sun in 1.76 years at an inclination of 10.8 degrees to the ecliptic. Perihelion distance — the closest point of the orbit to the sun — is 1.13 AU (105 million miles/169 million kilometers); aphelion — the farthest distance from the sun — is 1.78 AU (165 million miles/266 million kilometers). Eros’ average distance from the sun is 1.46 AU (135 million miles/218 million kilometers).

The closest approach of Eros to Earth in the 20th century was on Jan. 23, 1975, at approximately 0.15 AU (14 million miles/22 million kilometers). Previous close approaches occurred in 1938 at 0.215 AU (20 million miles/32 million kilometers) and in 1931 at 0.17 AU (16 million miles/26 million kilometers). Because of its
repeated close encounters with Earth, Eros has been an important object historically for refining the mass of the Earth-moon system and the value of the astronomical unit.

More than a century of ground-based study — including a worldwide observation campaign during the 1975 close approach — has made Eros the best observed of the NEAs. Astronomers assign the asteroid a rotation period of 5.27 hours. Albedo is 0.16. Thermal studies indicate the presence of a regolith, and radar suggests a rough surface. Eros is known to be compositionally varied: one side appears to have a higher pyroxene content and a facet-like surface, while the opposite side displays higher olivine content and a convex-shaped surface.

Eros has no atmosphere and no evidence of water. During the day, the temperature averages 100 degrees C (212 degrees F). At night, the temperature plunges to minus 150 degrees C (minus 238 degrees F). Gravity on Eros is very weak but sufficient to hold a spacecraft in orbit. A 100-pound (45-kilogram) object on Earth would weigh about an ounce on Eros, and a rock thrown from the asteroid’s surface at 22 mph (10 meters per second) would escape into space.

Eros is one of the S-type asteroids, the most common type in the inner asteroid belt and the subject of debate over the relationship between these asteroids and meteorites. Galileo’s flyby observations of Gaspra and Ida (both of which are S-type asteroids) did not resolve the debate, largely because remotely sensed spectral data cannot accurately determine the relative abundances of key elements. Solving the puzzle of the relationship between S-type asteroids and meteorites is a major goal of the NEAR mission to Eros.

253 Mathilde

Asteroid 253 Mathilde was discovered on Nov. 12, 1885, by Johann Palisa in Vienna, Austria. The name was suggested by V. A. Lebeuf, 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, then the vice-director of the Paris Observatory.

Although Mathilde’s existence has been known for more than a century, not until 1995 did observations with ground-based telescopes first identify the asteroid as a C-type. The 1995 observations also revealed an orbital period of 4.30 years. Perihelion is 1.94 AU (180 million miles/290 million kilometers). Mathilde’s inclination is 6.7 degrees and its albedo is 0.036.

On June 27, 1997, the NEAR spacecraft flew within 753 miles (1,212 kilometers) of asteroid 253 Mathilde. Mathilde was revealed as a very dark, heavily cratered object measuring 41 by 30 by 28 miles (66 by 48 by 46 kilometers). The Multispectral Imager, one of the six instruments on the spacecraft, found at least five craters larger than 12 miles (20 kilometers) in diameter, just on the sunlit side of the asteroid.

Mathilde showed no color or albedo variations over the 60 percent of its surface that was visible to the NEAR spacecraft. The asteroid reflects 3 to 5 percent of the sun’s light, making it twice as dark as a chunk of charcoal. Such a dark surface is believed to consist of carbon-rich material unaltered by planet-building processes, which melt and mix up the solar system’s original materials.

The dark surface and color are suggestive of a particular type of meteorite found on the Earth’s surface—the so-called CM carbonaceous chondrites. However, the volume derived from the images and the mass of the asteroid determined from the spacecraft tracking data yielded a bulk density for Mathilde of 1.3 grams per cubic centimeter, only about half that of CM chondrites. This suggests that asteroid Mathilde may have a very porous interior structure.

Mathilde rotates extraordinarily slowly. Its rotation period is 17.4 days, the third-longest known for an asteroid. In contrast, the Earth rotates on its axis in one day. The asteroid’s collision history could be a factor, but more research needs to be done. No moons have been discovered yet.
The Spacecraft

Spacecraft Description

NEAR is the first solar-powered spacecraft to fly beyond the orbit of Mars — a technical innovation in spacecraft design. It has a design lifetime of four years and the capability to operate at distances of 2.2 AU (203 million miles/327 million kilometers) from the sun.

Simplicity and low cost were the main drivers in developing the spacecraft. Simplicity was achieved by requiring that three major components — instruments, solar panels, and high-gain antenna — be fixed and body-mounted. Although this requirement somewhat increases the complexity of spacecraft operations, it was an important factor in overall cost.

The NEAR system is designed to be highly fault-tolerant. Fully redundant subsystems include the complete telecommunication system (except the high-gain and medium-gain antennas), as well as the solid-state recorders, command and telemetry processors, data buses, attitude interface unit and flight computers for guidance and control, and power subsystem electronics. Additional fault-tolerance is provided by use of redundant components: NEAR has two inertial measurement units, five sun sensors, and 11 small thrusters.

Onboard Subsystems

The spacecraft has six onboard subsystems: mechanical, propulsion, power, guidance and control, telecommunications, and command and data handling.

Mechanical Subsystem

The spacecraft structure is an eight-sided box made of 18.3 feet square (1.7 meter square) aluminum honeycomb panels connected to forward and aft aluminum honeycomb decks. The NEAR spacecraft launch mass, including propellant, is 1,775 pounds (805 kilograms).

NEAR is designed with two independent structures: the spacecraft structure and the propulsion system structure, which are coupled at the aft deck. Although this design exacted a small penalty in weight, it expedited spacecraft development by allowing the propulsion subsystem to be independently designed and tested.

Mounted on the outside of the forward deck are the X-band high-gain antenna, the four solar panels, and the X-ray solar monitor system. Most electronics are mounted on the inside of the forward and aft decks, and all but one of the science instruments are fixed in position on the outside.

• Three-axis stabilized
• Total weight: 805 kg
  - Propellants: 325 kg
  - Experiments: 56 kg
• Dual-mode propulsion system
  - Bipropellant (N₂H₄/N₂O₄)
  - Monopropellant (N₂H₄)
  - ΔV capability: 1450 m/sec
• Solar array power @ 1 AU: 1800 watts
• Data rate @ Eros rendezvous
  - 34-meter DSN antenna: 4.4 kbps
  - 70-meter DSN antenna: 17.7 kbps
• Two solid-state recorders: 1.7 x 108 bits
of the aft deck. The magnetometer is mounted on the high-gain antenna feed. A star camera points out to the side of the spacecraft away from the instruments so that a star-filled view is available during asteroid operations. The interior of the spacecraft contains the propulsion module.

**Propulsion Subsystem**

The NEAR propulsion subsystem, which was supplied by Gencorp Aerojet of Sacramento, Calif., contains the fuel and oxidizer tanks, 11 small monopropellant thrusters, a large bipropellant thruster, and a helium pressurization system. The location of the tanks was selected to maintain the spacecraft’s center of mass along the thrust vector of the large thruster throughout the mission as the bipropellant is depleted. The total change-in-velocity capability is approximately 3,240 mph (1,450 meters per second).

The monopropellant system is composed of four 5-pound (21-newton) large fine velocity control thrusters and seven 1-pound (3.5-newton) small fine velocity control thrusters, all fueled by pure hydrazine. The specific impulses of the monopropellant thrusters range from 206 to 234 seconds. They are arranged in six thruster modules mounted to the forward and aft decks and are located so that the loss of any one thruster does not affect performance. The 5-pound thrusters, which point in the same direction as the main thruster, are used for thrust vector control during the bipropellant burns. The 1-pound thrusters are used for momentum dumping and orbit maintenance around the asteroid. A minimum change-in-velocity increment of 0.02 mph (10 millimeters per second) is achievable in all directions.

The bipropellant thruster, or large velocity adjustment thruster, burns a mixture of hydrazine and nitrogen tetroxide (NTO) to produce a maximum 100 pounds (450 newtons) of thrust, with a specific impulse of 313 seconds. The large thruster is used for the major velocity changes of the NEAR mission: the deep-space maneuver in July 1997 and the series of rendezvous approach maneuvers at Eros arrival in December 1998.

The propulsion system carries 461 pounds (209 kilograms) of hydrazine and 240 pounds (109 kilograms) of NTO oxidizer in three fuel and two oxidizer tanks. The 14.5-gallon (55.1-liter) oxidizer tanks are located along the launch vehicle spin axis equidistant from the spacecraft center of mass. The 24.0-gallon (91.0-liter) fuel tanks are arranged 120 degrees apart in the main thruster plane.

**Power Subsystem**

The power system comprises four 6- by 4-foot (1.8- by 1.2-meter) gallium arsenide solar panels, a super nickel cadmium (NiCad) battery, and power system electronics. The solar array, which was produced by Spectrolab Inc., Sylmar, Calif., provides 400 watts of power at NEAR’s maximum solar distance of 2.2 AU (203 million miles/327 million kilometers) and 1800 watts at 1 AU (93 million miles/150 million kilometers).

The power provided by the solar array is a function of the spacecraft-to-sun distance and the incident solar angle, which must remain 30 degrees or less during the rendezvous at Eros. The solar power system is divided into 20 strings, so failure of any one string would lead to only a 5 percent reduction in available power.

The battery, which was produced by Hughes Aircraft Co., Torrance, Calif., is a 9 ampere-hour, 22-cell super NiCad battery with cells fabricated by Eagle-Picher Industries, Joplin, Mo. Battery capacity provided power to the spacecraft before the solar arrays were deployed to make solar power available. Thereafter, the battery was recharged, and it remains on-line to provide bus voltage regulation. The battery serves as a backup source of power in the event of momentary load increases or brief solar power deficits.

**Guidance and Control Subsystem**

The guidance and control subsystem is composed of a suite of sensors for attitude determination, actuators for attitude corrections, and processors to provide continuous, closed-loop attitude control.

The sensor suite comprises five digital solar attitude detectors, a star tracker, and an inertial measurement unit. The inertial measurement unit contains hemispherical resonator gyroscopes for rate determination and accelerometers for measuring change in velocity.

The actuator complement contains four reaction wheels plus the 11 small monopropellant thrusters and the large bipropellant thruster. All normal attitude control is achieved using the
reaction wheels alone. Any three of the reaction wheels provide complete 3-axis control, so a single reaction wheel failure results in no loss in functionality. The thrusters are used to dump excess angular momentum from the reaction wheels, accomplish rapid slew maneuvers when needed, and perform propulsive maneuvers.

Attitude control is to 0.1 degree; line-of-sight pointing stability is within 50 microradians over 1 second; and post-processing attitude knowledge is to 50 microradians.

**Telecommunication Subsystem**

The telecommunication subsystem is an X-band system capable of simultaneously transmitting telemetry data, receiving spacecraft commands, and providing Doppler and ranging tracking. In addition to the 5-foot (1.5-meter) high-gain antenna, there are two low-gain antennas and a medium-gain antenna with a fan-shaped radiation pattern. The worldwide stations of NASA’s Deep Space Network (DSN) provide contact with the spacecraft after launch.

Eight discrete downlink data rates are supported. In operation with the DSN 111-foot (34-meter) high-efficiency and beamguide antennas, the rates are 9.9 bits per second (bps) (emergency mode), 39.4 bps, 1.1 kilobits per second (kbps), 2.9 kbps, 4.4 kbps, and 8.8 kbps. During critical operations, the DSN 230-foot (70-meter) antennas can provide downlink rates of 17.6 and 26.5 kbps. The downlink hardware, which was developed by JHU/APL, uses a solid-state power amplifier with an output level of 5 watts. The normal uplink data rate is 125 bps. Emergency mode uplink is 7.8 bps.

**Command and Data Handling Subsystem**

The command and data handling subsystem consists of four major segments: two redundant command and telemetry processors, two redundant solid-state recorders, a power switching unit to control spacecraft relays, and an interface to two redundant 1553 standard data buses for communicating with other processor-controlled subsystems. The functions provided are command management, telemetry management, and autonomous operations.

The solid-state recorders, which were provided by SEAKR Engineering, Englewood, Colo., are constructed from 16-megabit IBM LunaC dynamic random access memories. One recorder has 0.67 gigabit of storage; the other has 1.1 gigabit capacity because it contains an additional memory board. This extra board is designated as the flight spare to replace either of the other memory boards in a ground test failure.

**Instruments**

The NEAR instrument payload consists of a Multispectral Imager fitted with a charge coupled device (CCD) imaging detector capable of photographing details on Eros’ surface as small as 10 feet (3 meters) in diameter, a Near-Infrared Spectrometer, an X-Ray/Gamma-Ray Spectrometer, a Laser Rangefinder, a Magnetometer, and a radio science experiment. Several of the instruments are derived from designs developed by JHU/APL for Department of Defense spacecraft, an example of dual-use technology transferred to the civilian sector.

Despite the lower cost and rapid development schedule of the NEAR spacecraft, the instrument designs incorporate many technical innovations:

- First space flight of a silicon solid-state detector viewing the sun and measuring the solar input X-ray spectrum at high resolution (X-Ray Spectrometer)
- First space flight of a bismuth germanate anticoincidence shielded gamma-ray detector (Gamma-Ray Spectrometer)
- First space flight of a laser incorporating an inflight calibration system (Laser Rangefinder)
• First space flight using a near-infrared system with a radiometric calibration target and an indium-gallium-arsenide focal plane array that does not require cooling with liquid nitrogen (Near-Infrared Spectrometer).

Multispectral Imager (MSI)

MSI is a high-resolution, visible-light and infrared camera that will determine the overall size, shape, and spin characteristics of Eros and will map the morphology and mineralogy of surface features. The imager also will be used for optical navigation at Eros and to search for satellites. Images taken during approach, flyby, and orbit of Eros can detect surface features as small as 10 feet (3 meters).

Adapted by JHU/APL from a military remote sensing system, MSI is a 537- by 244-pixel CCD camera with five-element, radiation-hard refractive optics. The instrument covers the spectral range from 0.4 to 1.1 micron. It has an eight-position filter wheel with filters chosen to optimize sensitivity to minerals expected to occur on Eros. MSI has a field-of-view of 2.26 degrees by 2.95 degrees and a pixel resolution that corresponds to 31 by 53 feet (9.6 by 16.2 meters) from 62 miles (100 kilometers). The instrument has a maximum framing rate of one per second with images digitized to 12 bits. It has a dedicated digital processing unit with an image buffer, autoexposure capability, and onboard image compression.

Near-Infrared Spectrometer (NIS)

NIS data will provide the main evidence for the distribution and abundance of surface minerals like olivine and pyroxine. Together with the measurements of elemental composition from the X-Ray/Gamma-Ray Spectrometer (XGRS) and color imagery from MSI, NIS will provide a link between asteroids and meteorites and clarify the processes by which asteroids formed and evolved. NIS will measure the spectrum of sunlight reflected from Eros in the near-infrared range from 0.8 to 2.7 microns in 64 channels.

NIS — also adapted from a military remote sensing instrument — is a grating spectrometer that disperses light from the slit field-of-view across a pair of passively cooled, one-dimensional array detectors. One detector is a germanium array covering the lower wavelengths from 0.8 to 1.5 microns; the other is an indium-gallium-arsenide array covering 1.3 to 2.7 microns. The NIS slit field-of-view is 0.38 degree by 0.76 degree in the narrow position and 0.76 degree by 0.76 degree in the wide position. At 62 miles (100 kilometers) from the asteroid, these positions correspond to 0.4 to 0.8 mile (0.65 to 1.3 kilometer) and 0.8 by 0.8 mile (1.3 by 1.3 kilometer). A scan mirror slews the field-of-view over a 140-degree range. Mirror scanning combined with spacecraft motion will be used to build up hyperspectral
images. NIS also carries a diffuse gold calibration target that can reflect sunlight into the spectrometer and provide in-flight spectral calibration.

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X-Ray/Gamma-Ray Spectrometer (XGRS)

XGRS will measure and map abundances of several dozen key elements at and near the surface of Eros. X-rays from the sun striking the asteroid can produce significant count rates of fluorescence X-rays from surface elements such as magnesium, aluminum, and silicon. The elements sulfur, calcium, titanium, and iron are also present in asteroids, but count rates are lower and data take longer to accumulate. Similarly, cosmic ray protons (and energetic particles associated with solar flares) can interact with the asteroid surface to produce gamma rays characteristic of the nuclear energy levels of a given element. Gamma rays also can be spontaneously emitted by naturally occurring radioactive elements such as potassium, uranium, and thorium.

The XGRS consists of two state-of-the-art sensors: an X-ray spectrometer and a gamma-ray spectrometer.

X-Ray Spectrometer (XRS). XRS is an X-ray resonance fluorescence spectrometer that detects the characteristic line emissions excited by solar X-rays from major elements in the asteroid surface. XRS covers the energy range from 1 to 10 kiloelectron volts using three gas proportional counters. The balanced, differential filter technique is used to separate the closely spaced magnesium, aluminum, and silicon lines below 2 kiloelectron volts. The gas proportional counters directly resolve higher energy line emissions from calcium and iron. A mechanical collimator gives XRS a 5-degree field-of-view to map the chemical composition at spatial resolutions as low as 1.2 miles (2 kilometers). XRS includes a separate solar monitor system to continuously measure the incident spectrum of solar X-rays. In-flight calibration capability also is provided.

Gamma-Ray Spectrometer (GRS). Abundances of several important elements, such as potassium, silicon, and iron, will be measured in four quadrants of the asteroid. GRS detects characteristic gamma rays in the 0.3- to 10-megaelectron volt range emitted from specific elements in the asteroid surface. GRS uses a body-mounted, passively cooled sodium iodide detector enveloped by an active bismuth germanate anti-coincidence shield to provide a 45-degree field of view.

NEAR Laser Rangefinder (NLR)

NLR will determine the distance from the spacecraft to the asteroid by precisely measuring the delay time between the firing of a laser pulse and its return reflection from the surface. It sends a small portion of each emitted laser pulse through an optical fiber of known length and into the receiver, providing 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 1,000 feet (300 meters). NLR also will measure detailed topographic profiles of surface features on Eros with a best spatial resolution of about 12 feet (4 meters). The profiles will be used as constraints on models of the origin and evolution of surface features.

NLR uses a neodymium-doped, yttrium-aluminum-garnet, solid-state laser and a compact reflecting telescope.

Magnetometer (MAG)

MAG will measure the strength of Eros’ magnetic field. Data from the Galileo spacecraft flybys of the asteroids Gaspra and Ida suggest that both of these bodies are magnetic, but the results are inconclusive. Discovery of an intrinsic magnetic field at Eros would be the first definitive detection of magnetism at an asteroid and would have important implications about its thermal and geologic history.

MAG is a 3-axis fluxgate sensor mounted on a tripod bracket above the high-gain antenna, a location chosen for minimum exposure to spacecraft-generated magnetic fields. Magnetometer electronics are located on the top deck. The instrument can determine the strength of the field to within 2 nanoteslas.

Radio Science Experiment

The radio science experiment will use the NEAR radio tracking system to determine the mass and mass distribution of the asteroid. Measurements will be made of the two-way Doppler shift in radio frequency between the spacecraft and Earth to an accuracy better than 0.025 inch per second (0.1 millimeter per second). These measurements will determine line-of-sight velocity variations induced in the spacecraft’s motion by the changing gravitational effects produced by the neighboring asteroid. Combined with data from other NEAR instruments, this information will allow accurate modeling of Eros’ density and mass distribution.

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The Discovery Program

Discovery Goals

The Discovery Program — NASA’s innovative approach to “faster, better, cheaper” planetary missions — marked its inaugural launch with the NEAR mission. Formally initiated in NASA’s fiscal 1994 budget within the Solar System Exploration Division, the Discovery Program grew out of NASA discussions with the science community to design a planetary exploration program that balances science return and mission cost in an era of declining space budgets. The Discovery Program represents a significant departure from previous NASA planetary programs in terms of total mission cost, development time, management approach, and scope of science objectives.

The Discovery Program goals and criteria include:

• **Lower Cost:** The cost of design and development through launch is limited to $190 million (fiscal 1999 dollars). Total mission cost is limited to $299 million and includes preliminary analysis, definition, launch services, and mission operations. NASA-provided launch vehicles for Discovery missions must be medium (Delta-2) class or smaller.

• **Rapid Development Time:** To meet the Discovery Program goal of launches every 12 to 18 months, constraints on mission development and definition times are tight. Design and development is limited to 36 months or less from start through launch plus 30 days.

• **Streamlined Management Approach:** Teaming is encouraged among industry, educational/nonprofit institutions, and government partners. NASA field centers are welcome as team members, as are non-U.S. individuals and organizations. Competitively selected teams have mission responsibility and authority, with a large degree of freedom in accomplishing objectives. NASA oversight and reporting requirements focus on the essentials for mission success and agreed-upon science return.

• **New Technology/Technology Transfer:** The Discovery selection process recognizes the inclusion of new technology to achieve performance enhancements and total mission cost reductions. The teaming of industry, universities, and government is meant to foster technology transfer occurring in parallel with technology development.

• **Public Awareness and Education:** Activities are encouraged to enhance the level of public understanding and awareness of solar system exploration. Such activities may include information programs to inform the public through the media or other means and educational activities coordinated with schools and science centers.

Discovery Missions

Since NEAR’s launch, two Discovery missions have been successfully launched. Mars Pathfinder sent back thousands of images and measurements after landing on the red planet on July 4, 1997. Dr. Matthew Golombek of NASA/JPL was project scientist. Lunar Prospector, launched in January 1998, sent back data that enabled scientists to create the first maps of the gravity, magnetic properties, and elemental composition of the moon’s entire surface. Led by Dr. Alan Binder of the Lunar Research Institute, the mission also detected a strong possibility of water ice at both lunar poles.

The Stardust mission, scheduled for launch on Feb. 6, 1999, will return the first samples of a comet. The spacecraft will collect comet particles, volatiles and dust, along with samples of interstellar dust, which will be dropped back to Earth in a reentry capsule. Dr. Donald E. Brownlee of the University of Washington is serving as principal investigator.

The Genesis mission, due to launch in January 2001, will gather samples of the charged particles in the solar wind and return them to Earth through an airborne capture. Dr. Donald Burnett of the California Institute of Technology is the lead scientist.

The Comet Nucleus Tour (CONTOUR), led by Dr. Joseph Veverka of Cornell University, will fly by three near-Earth comets. Set to launch in July 2002, CONTOUR will provide images and spectral maps of comet nuclei and analysis of comet dust.

One or two additional Discovery missions will be announced in June 1999.