National Aeronautics and Space Administration

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Dawn at Vesta

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Media Services Information

NASA Television Transmission

The NASA TV Media Channel is broadcast as an MPEG-2 digital C-band signal accessed via satellite AMC-6, at 72 degrees west longitude, transponder 17C, 4040 MHz, vertical polarization. In Alaska and Hawaii, it's available on AMC-7 at 137 degrees west longitude, transponder 18C, at 4060 MHz, horizontal polarization. A Digital Video Broadcast–compliant Integrated Receiver Decoder is required for reception. For digital downlink information for NASA TV's Media Channel, access to NASA TV's Public Channel on the Web and a schedule of programming for Dawn launch activities, visit **www.nasa.gov/ntv.**

Briefings

A preview news conference to discuss Dawn's approach to Vesta and operations during the year Dawn will orbit Vesta will be held at NASA Headquarters, Washington, D.C., at 2 p.m. EDT on June 23, 2011.

On Aug. 1, the Dawn team is currently scheduled to hold a news conference at NASA's Jet Propulsion Laboratory, Pasadena, Calif., to discuss arrival into orbit around Vesta and first close-up imaging results.

All briefings will be carried live on NASA Television and on voice circuits provided to on-site news media.

Internet Information

News and information on the Dawn mission, including an electronic copy of this press kit, news releases, fact sheets, status reports and images, are available from the NASA Web site at **www.nasa.gov/dawn.**

Detailed background information on the mission is available from the Dawn project home page at **dawn.jpl.nasa.gov.**

Quick Facts

Spacecraft

Dimensions: The spacecraft bus is 5.4 feet (1.64 meters) long, 4.2 feet (1.27 meters) wide and 5.8 feet (1.77 meters) high. High-gain antenna is 5 feet (1.52 meters) in diameter. When the solar arrays are deployed, Dawn's wingspan is 64 feet, 9 inches (19.7 meters).

Weight: 2,684.6 pounds (1,217.7 kilograms) at launch, consisting of 1,647.1-pound (747.1-kilogram) spacecraft, 937 pounds (425 kilograms) xenon propellant and 100.5 pounds (45.6 kilograms) hydrazine propellant

Power: Two 27-foot-by-8-foot (8.3-meter-by-2.3-meter) solar panels, together providing more than 10 kilowatts, depending on distance from sun. Each wing weighs almost 139 pounds (63 kilograms). Power storage via 35-amp-hour rechargeable nickel hydrogen battery

Ion Propulsion System

Number of thrusters: 3

Thruster dimensions (each): 13 inches (33 centimeters) long, 16 inches (41 centimeters) in diameter

Weight: 20 pounds (8.9 kilograms) each

Fuel: 937 pounds (425 kilograms) of xenon propellant

Estimate of fuel remaining at the start of Vesta approach: 417 pounds (189 kilograms)

Spacecraft acceleration via ion propulsion: 0 to 60 mph in four days

Thrust: 0.07 to 0.33 ounce (19 to 91 millinewtons)

Estimated days of thrusting for entire mission: 2,000

Estimated days of thrusting up to the start of Vesta approach: 909 days

Mission

Launch: Sept. 27, 2007

Launch site: Cape Canaveral Air Force Station, Fla., Pad 17B

Launch vehicle: Delta II Heavy 2925H-9.5 including Star 48 upper stage

Earth–Vesta distance at time of launch: 202 million miles (324 million kilometers)

Mars gravity assist: Feb. 17, 2009

Vesta arrival: July 16, 2011

Vesta's distance to Earth at time of Dawn arrival: 117 million miles (188 million kilometers)

Distance traveled by spacecraft launch-to-Vesta: 1.7 billion miles (2.8 billion kilometers)

Vesta departure: July 2012

Ceres arrival: February 2015

Distance spacecraft will travel from Vesta to Ceres: 930 million miles (1.5 billion kilometers)

Total distance spacecraft will travel from Earth to Vesta to Ceres: 3 billion miles (4.9 billion kilometers)

End of mission: July 2015

Program

Cost: $466 million total, including $373 million to build and launch the spacecraft and $93 million for 10 years of operations and data analysis.

Why Dawn?

NASA's Dawn spacecraft will be going into orbit around the two most massive objects in the asteroid belt, Vesta and Ceres. Studying Vesta and Ceres allows scientists to do historical research in space, opening a window into the earliest chapter in the history of our solar system. At each target, Dawn will acquire color photographs, compile a topographic map, map the elemental composition, map the mineralogical composition, measure the gravity field and search for moons. The data gathered by Dawn will enable scientists to understand the conditions under which these objects formed, determine the nature of the building blocks from which the terrestrial planets formed and contrast the formation and evolution of Vesta and Ceres. Dawn's quest to understand the conditions that existed when our solar system formed provides context for the understanding of the observation of planetary systems around other stars.
Vesta and Ceres are two of the largest surviving protoplanets — bodies that almost became planets. They reside in the asteroid belt — an extensive zone between Mars and Jupiter that contains a large number of smaller bodies. But Vesta is more similar to the rocky bodies like the moon and Earth than other asteroids. Ceres is more similar to Jupiter's moon Europa or Saturn's moon Titan than other asteroids. Their special qualities are explained by the processes at work during the earliest chapters of our solar system's history, when the materials in the solar nebula varied with their distance from the sun. As this distance increased, the temperature dropped, with terrestrial bodies forming closer to the sun, and icy bodies forming farther away.

Vesta and Ceres straddle a boundary in the asteroid belt between primarily rocky bodies and ice-bearing bodies. They present contrasting stories of fire and ice. Vesta is a dry, differentiated object, shaped by volcanism, with a surface that shows signs of resurfacing. Ceres, by contrast, has a primitive surface containing water-bearing minerals, and may possess a weak atmosphere.

By studying both these two distinct bodies with the same complement of instruments on the same spacecraft, the Dawn mission hopes to compare the different evolutionary path each took as well as create a picture of the early solar system overall. Data returned from the Dawn spacecraft could provide opportunities for significant breakthroughs in our knowledge of how the solar system formed.

To carry out its scientific mission, the Dawn spacecraft will conduct four science experiments whose data will be used in combination to characterize these bodies. Dawn carries a pair of visible-light cameras known as the framing cameras, a visible and infrared mapping spectrometer, and a gamma ray and neutron spectrometer. Radio and optical navigation data will provide data relating to the gravity field and thus bulk properties and internal structure of the two bodies.

The Dawn mission to Vesta and Ceres is managed by the Jet Propulsion Laboratory, for NASA's Science Mission Directorate, Washington, D.C. It is a project of the Discovery Program managed by NASA's Marshall Space Flight Center, Huntsville, Ala. The principal investigator resides at UCLA, and is responsible for overall Dawn mission science. Orbital Sciences Corporation of Dulles, Va., designed and built the Dawn spacecraft.

The framing cameras have been developed and built under the leadership of the Max Planck Institute for Solar System Research, Katlenburg-Lindau, Germany, with significant contributions by the German Aerospace Center (DLR) Institute of Planetary Research, Berlin, and in coordination with the Institute of Computer and Communication Network Engineering, Braunschweig. The framing camera project is funded by the Max Planck Society, DLR, and NASA.

The visible and infrared mapping spectrometer was provided by the Italian Space Agency and is managed by the Italy's National Institute for Astrophysics, Rome, in collaboration with Selex Galileo, where it was built.

The gamma ray and neutron detector instrument was built by Los Alamos National Laboratory, N.M., and is operated by the Planetary Science Institute, Tucson, Ariz.

Dawn Firsts

Dawn's mission to Vesta is unique for the following reasons:

- Dawn is the first mission to Vesta and the first mission to Ceres.
- Dawn is the first spacecraft to orbit two bodies in the solar system.
- Dawn is the first mission to visit a protoplanet.
- Dawn's stay at Vesta is the first prolonged visit to a main belt asteroid.
- When Dawn arrives at Ceres in February 2015, it will be the first spacecraft to visit a dwarf planet. (New Horizons arrives at Pluto on July 2015.)
- Dawn has accomplished the largest propulsive acceleration of any spacecraft, thanks to its ion engines. It increased its velocity by 14,300 miles per hour (6.4 kilometers per second) by May 3, 2011, the start of its approach to Vesta.
- When its solar panels are extended, Dawn has the longest wingspan of any NASA interplanetary mission launched so far. (When Juno launches later this year and deploys its solar panels, Juno's wingspan will be wider by about 1 foot [0.3 meter].) Dawn's wingspan is 64 feet, 9 inches (19.7 meters).

Main Asteroid Belt

There is a region in the solar system — between Mars and Jupiter — where hundreds of thousands of small bodies orbit the sun. Known as the main asteroid belt, this zone consists of rocky bodies that formed about 4.5 billion years ago, at the same time and in similar environments as the bodies that grew to be the rocky inner planets — Mercury, Venus, Earth and Mars.

But why didn't these small rocky bodies band together and make themselves into a planet?

Blame it on Jupiter

Jupiter is more than the top god of the ancient Romans and the fifth planet from the sun. Jupiter is an enormously massive gravity well that tugs at literally everything in the solar system. And the closer you are, the more influence Jupiter's gravity has on you.

The space rocks between Mars and Jupiter were closest of all. Thus, even though they had all the celestial ingredients to form another planet, the gravitational tug of Jupiter denied them the chance of becoming more than the vast rubble field we call the asteroid belt.

Denied the opportunity to fulfill such a destiny, Ceres and Vesta became the two most massive remnants of this epoch of the planet-forming phase of the solar system. Ceres, the largest, alone accounts for about one-third of the estimated mass of all of the solar system's asteroids, while Vesta's mass is almost one-third that of Ceres. (In terms of size, Vesta competes for second with another asteroid called Pallas. But because Vesta is denser than Pallas, it has a greater mass.)

Though Vesta and Ceres are commonly called asteroids because they reside in the asteroid belt, the Dawn team prefers to think of them as protoplanets because of their history and size. The vast majority of objects in the main belt are lightweights, about 60 miles wide (100 kilometers wide) or smaller. In addition, Vesta and Ceres are evolved worlds, with layers inside them. The International Astronomical Union has also designated Ceres, the largest body in the asteroid belt, a dwarf planet because its size is sufficient to make its surface nearly spherical.

Even though there is a lot of empty space in the asteroid belt, all conditions there are not benign. Each asteroid is on its own orbital path around the sun and, every once in a while, two asteroids try to be in the same place at the same time. This celestial pinball, and the resulting collisions, can hurl small fragments far beyond the belt. In some cases, these small fragments make their way into the inner solar system where some become meteors hurtling across our sky — and even fewer survive as meteorites which make it to Earth's surface. In fact, about 5 percent of all meteorites we find on Earth are thought to have come from Vesta. Vesta and Ceres are survivors from an earlier time.

Dawn's First Target — Vesta

Discovered: March 29, 1807, by Heinrich Wilhelm Olbers of Germany (fourth asteroid discovered)

Dimensions: About 359 by 348 by 285 miles (578 by 560 by 458 kilometers)

Shape: Nearly spheroid, with a massive chunk out of the south pole

Rotation: Once every 5 hours, 20 minutes

Mass: About 30 billion billion tons (260 billion billion kilograms)

The official name for Vesta is "4 Vesta" because it was the fourth body discovered in the asteroid belt. Unlike most garden-variety asteroids, Vesta has a layered structure (core, mantle and crust). Like planets such as Earth, Venus and Mars, Vesta had sufficient radioactive material inside when it coalesced. The release of heat melted rock and enabled lighter layers to float to the outside. Scientists call this process differentiation.

About the length of Arizona, Vesta appears to have a surface of basaltic rock — frozen lava — which oozed out of the asteroid's presumably hot interior shortly after its formation 4.5 billion years ago, and has remained largely intact ever since. Scientists believe Vesta has the oldest known surface in the solar system. Its small size ensures that it cooled quickly, shutting down the resurfacing process present for longer times on larger bodies. Vesta may be the smallest relic from the solar system's formation to have experienced planetary differentiation, and the information scientists glean from studying the interior structure will contribute to understanding the process by which planets formed.

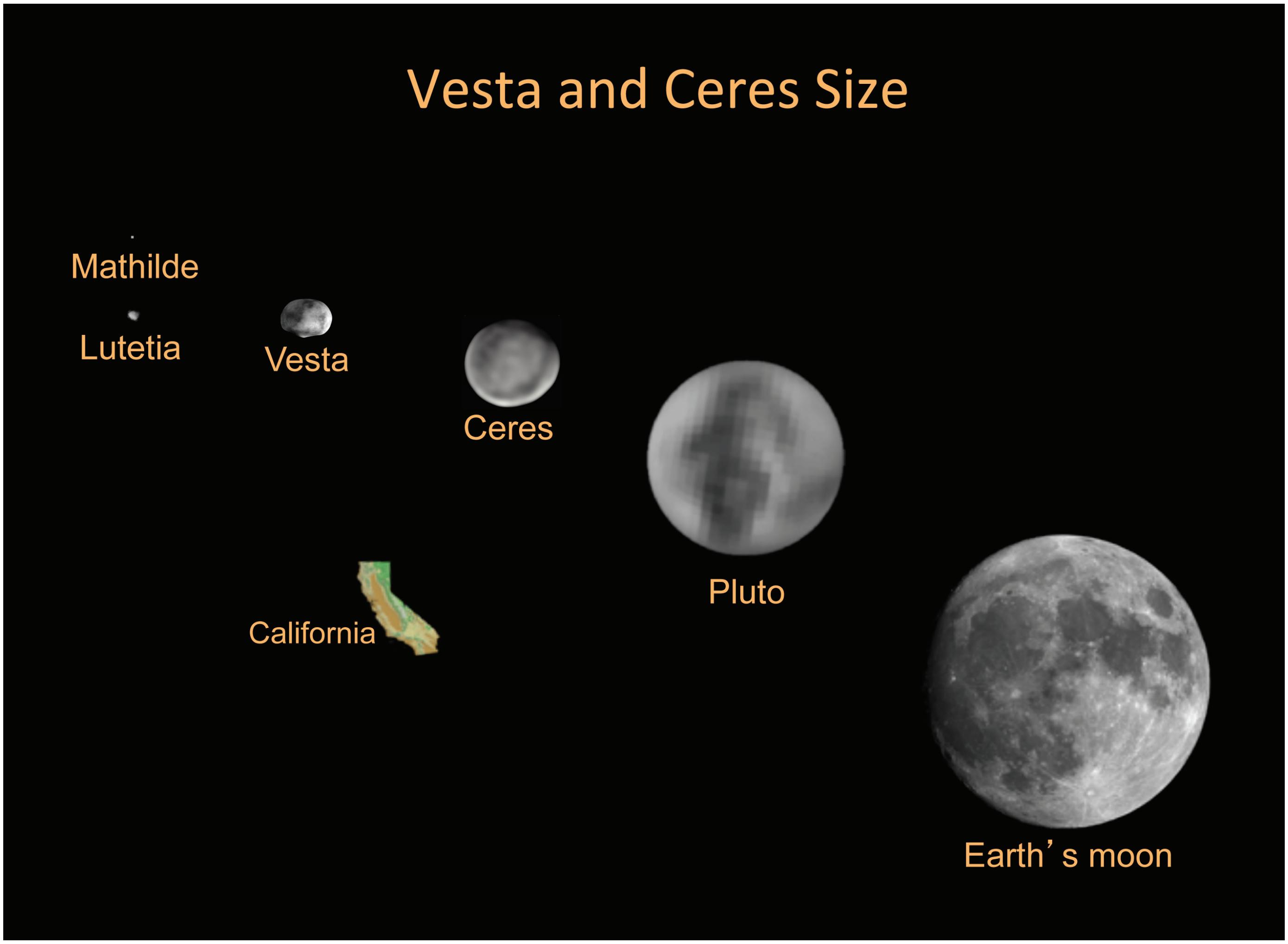
Vesta has a unique surface feature, which scientists look forward to peering into. At the asteroid's south pole is a giant crater — 285 miles (460 kilometers) across and 8 miles (13 kilometers) deep. The massive collision that created this crater gouged out one percent of the asteroid's volume, blasting almost 200,000 cubic miles (800,000 cubic kilometers) of rock into space.

To get an idea of the size of the crater on Vesta's south pole, the longest dimension of the asteroid Eros (which the Near Earth Asteroid Rendezvous Shoemaker spacecraft studied in 2000) is 20 miles (30 kilometers) long. That entire asteroid would quite easily be lost in the awesome maw of the crater near Vesta's south pole. Or, as another analogy, if Earth had a crater that was proportionately as large as the one on Vesta, it would fill the Pacific Ocean.

What happened to the material that was propelled from its Vesta home? The debris, ranging in size from sand and gravel to boulder and mountain, was ejected into space where it began its own journey through the solar system. Hundreds of the meteorites found on Earth are believed to have come from this single ancient crash in deep space. The meteorites thought to come from Vesta are rocks crystallized from melts formed deep in the interior of Vesta early in its history. Some, called eucrites, are lavas that erupted on the surface. Others, called diogenites, solidified slowly in the interior. And still others, called howardites, are crushed mixtures of eucrite and diogenite, formed by impacts onto the surface. The elements and isotopes that compose these meteorites help scientists figure out Vesta's age and the igneous processes that affected Vesta. These meteorites bear chemical signatures similar to the ones astronomers have seen on Vesta.

Most of what we know about Vesta comes from meteorites found on Earth that presumably come from Vesta and ground-based and Earth-orbiting telescopes like NASA's Hubble Space Telescopes. Telescopic observations reveal mineralogical variations across its surface. The telescopes have been able to give some hints of the surface composition, but they haven't been able to resolve distinct surface features.

When Dawn arrives at Vesta, the surface of this unknown world will finally come into focus. Scientists hope to figure out whether the chunks of rock that landed on Earth did indeed come from Vesta.



Relative size of some minor bodies.

NASA's Discovery Program

Dawn is the ninth of 10 missions in NASA's Discovery Program. The others are:

- **Near Earth Asteroid Rendezvous** was launched Feb. 17, 1996. It became the first spacecraft to orbit an asteroid when it reached Eros in February 2000. After a year in orbit, it achieved the first landing on an asteroid in February 2001, after returning more than 160,000 detailed images. "Shoemaker" was later added to the spacecraft's name in honor of the late planetary scientist Eugene Shoemaker.

- **Mars Pathfinder** was launched Dec. 4, 1996, and landed on Mars on July 4, 1997. It was the first free-ranging rover to explore the Martian surface, conducting science and technology experiments. Pathfinder's lander operated nearly three times longer than its design lifetime of 30 days, and the Sojourner rover operated 12 times its design lifetime of seven days. After sending back thousands of images and measurements, the mission ended Sept. 27, 1997.

- **Lunar Prospector** was launched Jan. 6, 1998. It orbited Earth's moon for 18 months, looking for water and other natural resources and returning extensive mapping data to provide insights into lunar origin and evolution. At the mission's end July 31, 1999, the spacecraft was intentionally crashed into a crater near the moon's south pole in an unsuccessful attempt to detect the presence of water.

- Launched Feb. 7, 1999, **Stardust** captured and returned to Earth interstellar dust particles and comet dust using an unusual substance called aerogel. On Jan. 2, 2004, it flew within 240 kilometers (149 miles) of the nucleus of Comet Wild 2, collecting samples of comet dust and snapping detailed pictures of the comet's surface. On Jan. 15, 2006, Stardust's sample return capsule returned to Earth, providing scientists worldwide with the opportunity to analyze the earliest materials that created the solar system. NASA extended Stardust's mission to fly by the comet Tempel 1, which occurred on Feb. 14, 2011. That mission was referred to as Stardust-NExT. The spacecraft obtained images of the scar on Tempel 1's surface produced by Deep Impact in 2005.

- Launched Aug. 8, 2001, **Genesis** collected atoms of solar wind beyond the orbit of Earth's moon to accurately measure the composition of our sun and improve our understanding of solar system formation. Its sample return capsule made a hard landing at the time of Earth return on Sept. 8, 2004. The mission's samples of solar wind were recovered and are currently being analyzed by scientists at laboratories around the world.

- The **Comet Nucleus Tour** launched from Cape Canaveral on July 3, 2002. Six weeks later contact with the spacecraft was lost after a planned maneuver that was intended to propel it out of Earth orbit and into a comet-chasing solar orbit. The probable proximate cause was structural failure of the spacecraft due to plume heating during the embedded solid-rocket motor burn.

- The **Mercury Surface, Space Environment, Geochemistry and Ranging** (Messenger) spacecraft was launched Aug. 3, 2004. It entered orbit around the planet closest to the sun in March 2011. The spacecraft is mapping nearly the entire planet in color and measuring the composition of the surface, atmosphere and magnetosphere.

- Launched Jan. 12, 2005, **Deep Impact** was the first experiment to send a large projectile into the path of a comet to reveal the hidden interior for extensive study. On July 4, 2005, traveling at 23,000 mph (39,000 kilometers per hour) a larger flyby spacecraft released a smaller impactor spacecraft into the path of comet Tempel 1 as both recorded observations. The Spitzer, Hubble and Chandra space telescopes also observed from space, while an unprecedented global network of professional and amateur astronomers captured views of the impact, which took place 83 million miles (138 million kilometers) from Earth. NASA extended the Deep Impact mission as EPOXI, a combination of the names for the mission's two components: the Extrasolar Planet

Observations and Characterization (EPOCh), and the flyby of comet Hartley 2, called the Deep Impact Extended Investigation (DIXI). The EPOXI mission successfully flew by Hartley 2 on Nov. 4, 2011, obtaining the first images clear enough for scientists to link jets of dust and gas with specific surface features.

- The **Kepler** mission is designed to find Earth-sized planets in orbit around stars outside our solar system. As the largest telescope launched beyond Earth orbit and with a vast field of view, Kepler is expected to detect transits of thousands of planets, including hundreds in or near a star's habitable zone — the region where water may exist in liquid form, increasing the probability of life. Launched on March 6, 2009, Kepler is monitoring 100,000 stars similar to our sun for four years.

- The **Gravity Recovery and Interior Laboratory** (GRAIL) mission, whose launch window opens Sept. 8, 2011, will produce a high-resolution map of the moon's gravitational field. It will place two spacecraft into the same orbit around the moon. As the spacecraft fly over areas of greater and lesser gravity, caused both by visible features such as mountains and craters and by masses hidden beneath the lunar surface, they will move slightly toward and away from each other.

Other Asteroid Encounters

Dawn will provide the most complete picture of the asteroid belt to date. But it is not the first mission to fly close to the solar system's dark and mysterious nomads. Some of these encounters were with asteroids that are not members of the main asteroid belt.

- NASA's Jupiter-bound **Galileo** was launched Oct. 18, 1989, and became the first spacecraft to encounter an asteroid when on Oct. 29, 1991, it flew within 1,600 kilometers (1,000 miles) of the object Gaspra. On Aug. 28, 1993, Galileo performed history's second flyby of an asteroid when it came within 1,500 miles (2,400 kilometers) of Ida, and discovered Ida's moon Dactyl.

- Launched Feb. 17, 1996, NASA's **Near Earth Asteroid Rendezvous** Shoemaker spacecraft flew within 753 miles (1,212 kilometers) of asteroid Mathilde on June 27, 1997. On Feb. 14, 2000, the spacecraft went into orbit around asteroid Eros. On Feb. 12, 2001, the craft touched down on asteroid Eros, after transmitting 69 close-up images of the surface during its final descent.

- **Deep Space 1**, launched Oct. 24, 1998, flew within 17 miles (28 kilometers) of asteroid Braille on July 28, 1999, during a NASA mission designed to flight-test a number of technologies including ion propulsion.

- En route to its encounter with comet Wild 2, NASA's **Stardust** (launched Feb. 7, 1999) flew within 1,900 miles (3,100 kilometers) of asteroid Annefrank on Nov. 2, 2002.

- Launched by the Japan Aerospace Exploration Agency on May 9, 2003, **Hayabusa** rendezvoused with asteroid Itokawa in mid-September 2005. The spacecraft landed on the asteroid Nov. 19, 2005, to collect samples. A sample capsule returned to Earth on June 13, 2010.

- The European Space Agency's **Rosetta** was launched March 2, 2004, and flew past asteroid Steins on Sept. 5, 2008, and asteroid Lutetia on July 10, 2010, on its way to rendezvous with Comet Churyumov-Gerasimenko in 2014.

- NASA's recently announced **Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer (OSIRIS-REx)** mission will send a spacecraft to an asteroid to pluck samples that can improve our understanding of the solar system's formation and how life began. Expected to launch in 2016, OSIRIS-REx will be the first U.S. mission to carry samples from an asteroid back to Earth.

Mission Overview

Since launching from Cape Canaveral Air Force Station, Fla., in 2007, the Dawn spacecraft has used hyper-efficient ion propulsion to glide toward its first destination, the protoplanet Vesta. After a planned year in orbit there, Dawn will depart for a nearly three-year cruise to the dwarf planet Ceres, where it will arrive in 2015. Dawn will spend five months in orbit at Ceres. The spacecraft will be the first ever to orbit one extraterrestrial body, depart, and then orbit a second body. Dawn's odyssey will cover 3 billion miles (4.8 billion kilometers) in all.

Dawn has already completed four phases of its mission: launch and initial acquisition, initial checkout, interplanetary cruise and Mars gravity assist. It is currently in the Vesta approach phase, with Vesta orbit, Ceres approach and Ceres orbit to come.

Launch, Initial Acquisition and Initial Checkout

Dawn launched from Space Launch Complex 17B at Cape Canaveral Air Force Station, Fla., at 7:34 a.m. EDT (4:34 a.m. PDT) on Sept. 27, 2007. The launch vehicle was a variant of the Delta II known as a Delta 2925H-9.5, with a Star 48 solid-fuel upper-stage booster. During the initial checkout, critical systems were tested and calibrated, ensuring that Dawn was ready for its journey ahead. The spacecraft moved from its post-launch configuration to normal flight configuration.

Interplanetary Cruise

Cruise began on Dec. 17, 2007, and covered 1.5 billion miles (2.4 billion kilometers), up to the beginning of the Vesta approach phase. During most of the cruise, the spacecraft alternated between thrusting with the ion propulsion system and coasting. Coasting periods allowed for communications and maintenance activities such as instrument and subsystem calibrations. Dawn typically pointed its high-gain antenna to Earth for communications once a week.

Mars Gravity Assist

Dawn flew by Mars on Feb. 17, 2009, swooping within 341 miles (549 kilometers) of the Red Planet's surface. Navigators placed the spacecraft on a close approach trajectory with Mars so the planet's gravitational influence would provide a kick to the spacecraft's velocity. Overall, the Mars gravitational deflection increased Dawn's velocity by more than 5,800 mph (9,330 kilometers per hour). The flyby helped propel the spacecraft farther out of the ecliptic, the plane containing the mean orbit of Earth around the sun. This was necessary because Dawn's next destination, the asteroid Vesta, has an orbit around the sun that is outside the ecliptic plane.

Dawn's science teams also used this massive target of opportunity to perform calibrations of some of the scientific instruments. Dawn's framing camera and gamma ray and neutron detector took data at Mars for calibration. These data have been compared to similar observations taken by spacecraft orbiting Mars.

After departing Mars, Dawn surpassed the previous record for accumulated propulsive acceleration (not including gravity assists) over a mission held by Deep Space 1. On June 5, 2010, Dawn had sped up over 9,600 mph (4.3 kilometers per second) with its own propulsion system.

Vesta Approach

Dawn cruised for another orbit around the sun after departing Mars, gradually spiraling outward into the asteroid belt, on its way to Vesta. Dawn's three-month approach phase began May 3, 2011, when the spacecraft was 752,000 miles (1.21 million kilometers) from Vesta, or about three times the distance between the Earth and the moon. At this point, Dawn had already flown more than 1.6 billion miles (2.6 billion kilometers).

During the approach phase, the spacecraft's main activity is to continue thrusting with the hyper-efficient ion engine that uses electricity to ionize and accelerate xenon. At the start of approach phase, Dawn still had 417 pounds (189 kilograms) of xenon left, plenty to carry out the rest of the mission.

The start of approach phase also signaled the start of optical navigation toward Vesta. Dawn previously navigated by measuring the radio signal between the spacecraft and Earth, and used other methods that did not involve Vesta. But as the spacecraft closes in on its target, navigation requires more precise measurements. The images supplement, but do not replace, Dawn's radio navigation. They will be released in sets during the approach period.

By analyzing where Vesta appears relative to stars in framing camera images, navigators can pin down its location and engineers can refine the spacecraft's trajectory. Using its ion engine to match Vesta's orbit around the sun, the spacecraft will spiral gently into orbit around the asteroid. When Dawn gets approximately 9,900 miles (16,000 kilometers) from Vesta, the asteroid's gravity will capture the spacecraft in orbit. That will happen on July 16, 2011. The exact time of orbit capture will be calculated after the fact by Dawn engineers.

The approach phase, which continues for about three weeks after the actual orbit capture day, will also feature a search for possible moons around Vesta, using framing camera images. None of the images from ground-based and Earth-orbiting telescopes have seen any moons, but Dawn will give scientists much more detailed images to determine whether small objects have gone undiscovered.

By early August, Dawn will have taken three observations of Vesta rotating during the spacecraft's slow approach to the protoplanet. In the last "rotation characterization," Vesta will take up almost the entire frame of Dawn's camera and will be almost fully illuminated by the sun.

During approach phase, the gamma ray and neutron detector instrument also will gather information on cosmic rays, providing a baseline for comparison when Dawn is much closer to Vesta. Dawn's visible and infrared mapping spectrometer will take early measurements to ensure it is calibrated. Navigators will also be measuring the strength of Vesta's gravitational tug on the spacecraft so they can compute the protoplanet's mass with much greater accuracy than available up to now. Up until this point, astronomers used Vesta's effect on Mars and other asteroids to calculate its mass. Refining Vesta's mass will help mission managers refine the altitudes of Dawn's orbits around Vesta and the encounter timeline.

At the start of Vesta approach, Dawn will have accumulated 909 days of ion engine operations. By the time the Vesta orbit phase begins in early August, Dawn will have accumulated 979 days of thrusting.

Vesta Orbit

This phase extends from the beginning of the first science-collecting orbit at Vesta — known as survey orbit — to the end of the last. It is expected to start in early August. The spacecraft will follow a series of near-circular polar orbits, allowing it to study nearly the entire surface of the asteroid. These different orbits will be varied in altitude and orientation relative to the sun to achieve the best positioning for the various observations planned. The specific altitudes of each orbit may vary slightly, based on data on Vesta's mass that were collected during approach. Because Vesta is an unknown environment, mission managers have scheduled more than enough observations during each orbit to fulfill the basic science objectives. This will enable Dawn to achieve its scientific goals even if delays occur or some data are not acquired. Dawn's path has been carefully mapped to avoid gravitational resonances that might prevent the spacecraft from unplanned changing of orbital altitudes.

Survey Orbit

At Vesta, the initial and highest orbit will be roughly 1,700 miles (2,750 kilometers) in altitude, providing a nice vantage point to obtain a global view of the rocky world. Science-gathering during the survey orbit begins when Dawn crosses over the darkened north pole of Vesta to the illuminated side of Vesta. The orbit will take Dawn over the equator, the south pole and back to Vesta's night side, in orbits that take almost three Earth-days to complete. Since Vesta is spinning at a period of 5.34 hours under Dawn's path, the spacecraft will have a view of virtually every part of the lit surface during this period.

The primary objective of the survey orbit is to get a broad overview of Vesta with color pictures and spectra – data in different wavelengths of reflected light. In this case, Dawn is collecting data in ultraviolet, visible and infrared wavelengths. The camera will obtain views with a resolution of 820 feet (250 meters) per pixel, about 150 times sharper than the best images from the Hubble Space Telescope. The mapping spectrometer will reveal much of the surface at better than 2,300 feet (700 meters) per pixel.

Although the closer orbits will be more revealing for the gamma ray and neutron detector and the gravity experiment, Dawn will be using the gamma ray and neutron detector instrument to gather data on the elemental composition of Vesta's surface and making ultrasensitive measurements of the spacecraft's motion using the radio signal to understand the protoplanet's gravity field.

The survey phase is planned to last for seven orbits, or about 20 days. During the half of an orbit that Dawn spends on the day side of Vesta, Dawn will make observations and fill its memory buffers with images and spectra. For most of the other half of each orbit, as it travels over the night side, the spacecraft will transmit the data through its main antenna back to Earth. Even when the Vesta surface is in darkness, Dawn's path keeps the spacecraft in sunlight, so its solar arrays will continue to provide electrical power. To free up memory space, the spacecraft will also break up some of its data acquisition on the sunny side of Vesta with radio transmissions back to Earth.

High Altitude Mapping Orbit

After it has completed its survey of Vesta, Dawn will resume thrusting, taking about a month to spiral down gently to its next science orbit for an even closer view. The orbit known as High Altitude Mapping Orbit (HAMO) begins in late September, at an altitude of around 420 miles (680 kilometers). (A second High Altitude Mapping Orbit — known as HAMO2 — will occur near the end of Dawn's time at Vesta.)

HAMO will also take a polar orbital path. In this orbit, Dawn will circle around Vesta in half a day, rather than three. Dawn will orbit a total of 60 times. HAMO is scheduled to last for about 30 days. Due to the tilt of Vesta's rotation axis, darkness will envelop Vesta's north pole during this part of science gathering.

HAMO, which will be the most complex and intensive science campaign at Vesta, has three primary goals: to map Vesta's illuminated surface in color, provide stereo data, and acquire visible and infrared mapping spectrometer data. For about 10 days, Dawn will peer straight down at the exotic landscape below it. For about 20 days, the spacecraft will view the surface at multiple angles. Scientists will combine the pictures to create topographic maps, revealing the heights of mountains, the depths of craters and the slopes of plains. This will help scientists understand the geological processes that shaped this protoplanet.

Though HAMO activities for the framing camera and visible and infrared mapping spectrometer will get priority, the gamma ray and neutron detector and the gravity experiment will also continue collecting data.

As with the survey orbit, the probe will devote most its time over the day side of Vesta to acquiring data and most of the time over the night side beaming those data back to Earth.

After the official end of HAMO, there will still be some science data in Dawn's memory. As the spacecraft transfers to a lower orbit, it will also be transmitting some of that treasure trove back to Earth.

Low Altitude Mapping Orbit

Dawn will take six weeks to spiral down to its lowest orbit, known as Low Altitude Mapping Orbit (LAMO), which will bring Dawn to an altitude of less than 110 miles (180 kilometers) above Vesta's surface. Dawn will spend at least 10 weeks in LAMO, the longest part of its Vesta orbit, revolving around the rocky body once every four hours. The framing camera and visible and infrared mapping spectrometer will image the surface at higher resolution than obtained at higher altitudes. But the primary goal of LAMO is to collect data for the gamma ray and neutron detector and the gravity experiment.

The gamma ray and neutron detector is designed to detect the by-products of cosmic rays hitting Vesta. Cosmic rays are energetic, subatomic particles — such as protons — that originate from outer space. Vesta's surface is exposed directly to space, so it doesn't have a protective shield against cosmic rays like Earth's atmosphere and magnetic field. Cosmic rays strike the nuclei of atoms in the uppermost meter (yard), producing gamma rays and neutrons that bear the fingerprints of their original atoms. LAMO will be the most effective time for the gamma ray and neutron detector, when it will sense enough of the emitted particles to reveal the identities of many kinds of atoms in the surface. It also will record some radioactive decays of atoms there.

The gamma ray and neutron detector can detect some of the cosmic rays directly — in fact, it did so during the Mars flyby in 2009. While the framing camera and visible and infrared mapping spectrometer detect relatively bright light reflected from Vesta's surface, the gamma ray and neutron detector can see the subatomic particles only as a very faint signal. Much of Dawn's time in LAMO will be devoted to pointing the gamma ray and neutron detector at Vesta since resolving a "dim" object requires a longer exposure than for a bright one.

LAMO also focuses on ultrasensitive measurements of Vesta's gravitational field and internal structure. As Dawn travels in its orbits, its motion is dictated by the combined gravitational attraction of all of the matter within the protoplanet. By measuring the probe's orbit, scientists can calculate the arrangement of Vesta's constituent masses. If, for example, there is a volume far below the surface filled with rock of greater density than the surrounding regions, Dawn will sense its stronger gravitational pull because the spacecraft will accelerate just a little as its orbit brings it closer to this feature. The spacecraft will decelerate just a little when it has passed by. These effects are miniscule and the measurements very challenging, but they will reveal a view of the interior of Vesta, from crust to core.

The principal type of data used in these calculations will be the Doppler shift of a radio signal transmitted from one of the giant antennas of NASA's Deep Space Network to Dawn, which then sends a signal back to the same antenna. This kind of measurement can detect changes in Dawn's speed of about 1 foot per hour (0.1 millimeters per second).

It is likely that the irregularities in the gravity field will also perturb Dawn's path enough that the probe will have to maneuver to maintain the orbit within the parameters needed for operations. The ion propulsion system will be used about once a week for a few hours to adjust the orbit. The specifics of these maneuvers will depend on the details of the gravity field, but engineers have planned several windows for orbital corrections.

In this phase, the pattern of science acquisition and data transmission will generally occur every two to three days, when the memory is full and the antenna is in its best position to point to Earth.

High Altitude Mapping Orbit 2

After LAMO, Dawn will spiral out during a six-week climb away from Vesta. It will pause its ascent for a second stop at the High Altitude Mapping Orbit (HAMO2) at the same height as HAMO — about 420 miles (680 kilometers) above Vesta's surface. HAMO2 is scheduled to last three weeks.

The principal distinction between HAMO and HAMO2 is that they are separated by about eight months, during which Vesta will have progressed in its orbit around the sun. Like Earth, Vesta has seasons, and the changing angle of the sunlight on the surface of that alien world during Dawn's visit affects Vesta's appearance and how much of it is visible to science instruments. Because more of the northern hemisphere will be illuminated, HAMO2 affords the opportunity to see previously hidden landscapes and to gain a new perspective on some terrain observed earlier.

Vesta Departure

Dawn is planning on beginning its departure from Vesta in June 2012, spending about five weeks getting out of Vesta's orbit. Based on calculations of how fast Dawn can travel and the positions of Vesta and Ceres, the spacecraft is expected to start cruising toward Ceres in July 2012. The cruise to Dawn's second destination will take a little more than two years and Dawn will travel about three-fourths of one orbit around the sun as it spirals outward toward the dwarf planet.

Ceres Approach

The Ceres approach phase is expected to start in November 2014, three months before the spacecraft reaches Ceres. The approach phase ends when Dawn achieves its first planned science observation orbit around the object. As at Vesta, Dawn will use its ion propulsion to make a slow approach to drop into orbit around Ceres.

Ceres Orbit

This phase, which is expected to last for five months starting in February 2015, extends from the beginning of the first observation orbit to the end of the last, and includes all Ceres science data-taking, data return and orbit transitions. As at Vesta, Dawn will enter a series of near-circular, near-polar orbits of different altitudes and orientations that will provide vantage points for studying nearly the entire surface of the dwarf planet.

End of Mission

Dawn's prime mission is scheduled to end in July 2015. At that time, the spacecraft will be in a "quarantine" orbit around Ceres at an altitude of about 435 miles (700 kilometers). This orbit ensures that the spacecraft will not impact Ceres for more than half a century.

Telecommunications

Throughout the mission, tracking and telecommunications will be provided by NASA's Deep Space Network complexes in California's Mojave desert, near Madrid, Spain, and near Canberra, Australia. Most data from the spacecraft will be received through the network's 112-foot-diameter (34-meter-diameter) antennas, but the larger 230-foot (70-meter) antennas will be used during some phases.

Planetary Protection

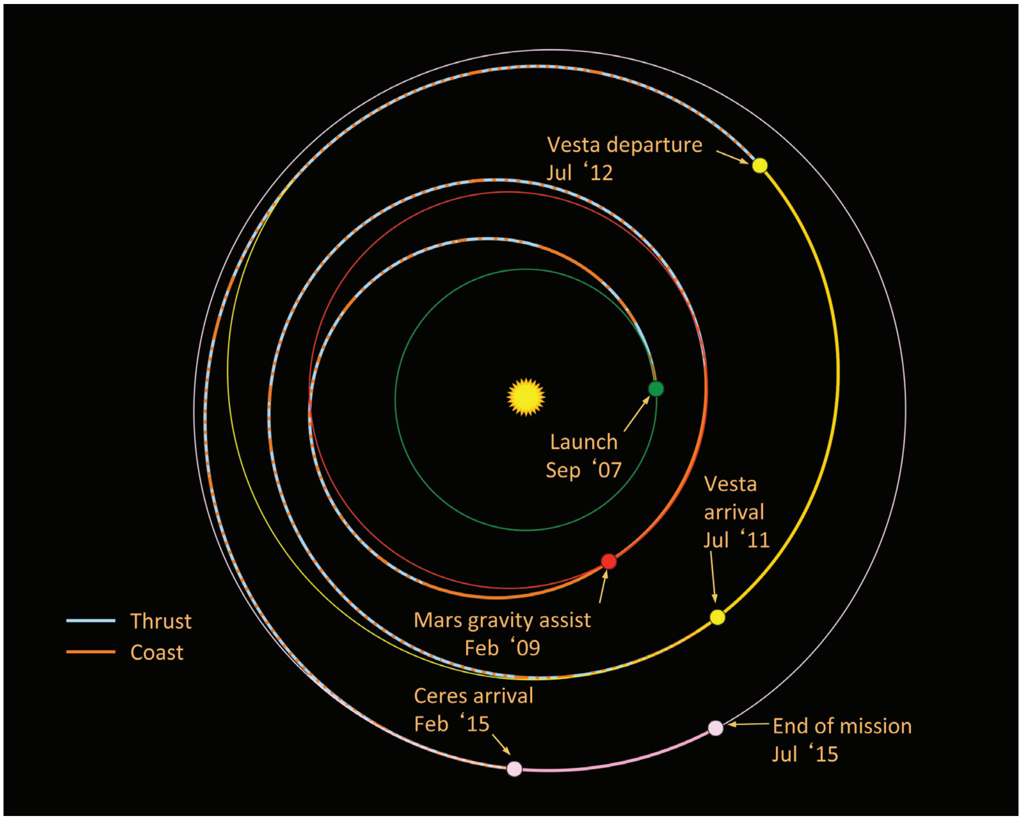
The United States is a signatory to the United Nations' 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies. Also known as the "Outer Space Treaty," this document states in part that exploration of the moon and other celestial bodies shall be conducted "so as to avoid their harmful contamination."

The policy used to determine restrictions that are applied in implementing the Outer Space Treaty is generated and maintained by the International Council for Science's Committee on Space Research, which is headquartered in Paris. NASA adheres to the committee's planetary protection policy, which provides for appropriate protections for solar system bodies such as asteroids in addition to planets, moons and comets.

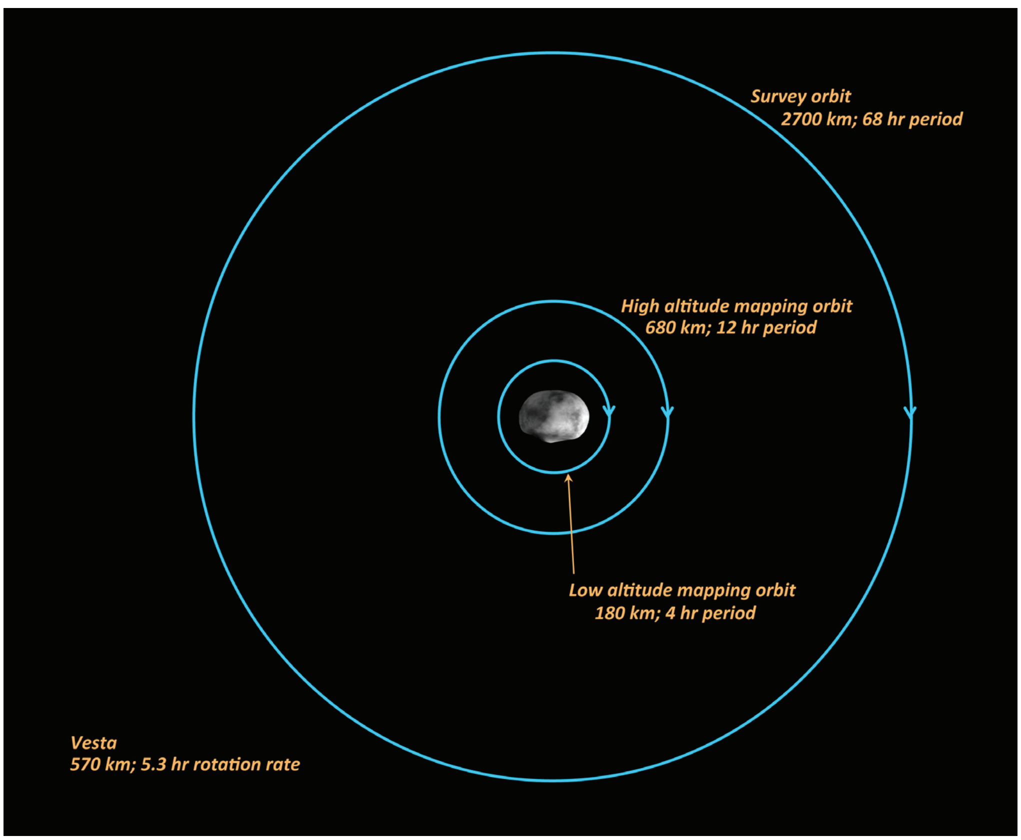
NASA's planetary protection officer has designated Dawn as a "Category III" mission under the policy. This requires the mission to demonstrate that it will avoid crashing into Mars during its flyby, and to document its encounters with Vesta and Ceres. Asteroids and dwarf planets are bodies that are of intense interest to the study of organic chemistry and the origin of life, but are not typically believed to be vulnerable to contamination by Earth-origin microorganisms. However, the potential for the presence of water ice on Ceres prompted the NASA planetary protection officer to impose an additional requirement that the spacecraft not impact Ceres for at least 20 years after completion of the nominal mission. An analysis by the Dawn project team predicts that, in fact, the spacecraft will remain in orbit around Ceres for more than 50 years after the mission ends.

Earthlings Rising with the Dawn

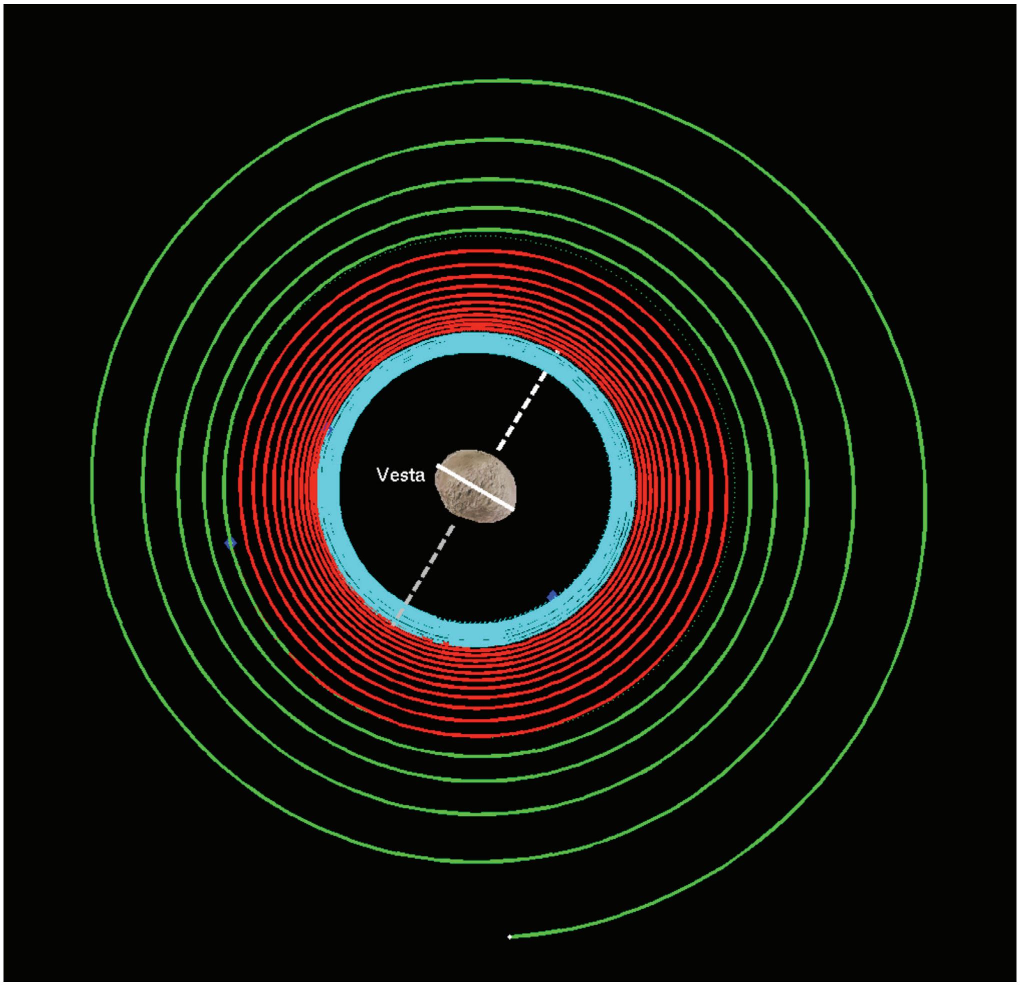
Some 365,000 intrepid explorers from around the world have hitched a ride aboard Dawn, thanks to the "Send Your Name to the Asteroid Belt" campaign. The names were etched onto a 0.31-by-0.31-inch (8-by-8-millimeter) silicon chip attached to the spacecraft.



Dawn trajectory



Dawn's science orbits around Vesta



Dawn spirals gently into each of its orbits around Vesta.

Spacecraft

The Dawn spacecraft combines innovative state-of-the-art technologies pioneered by other recent missions with off-the-shelf components and, in some cases, spare parts and instrumentation left over from previous missions.

Most systems on the spacecraft have a backup available if the main system encounters a problem. Automated onboard fault protection software will sense any unusual conditions and attempt to switch to backups.

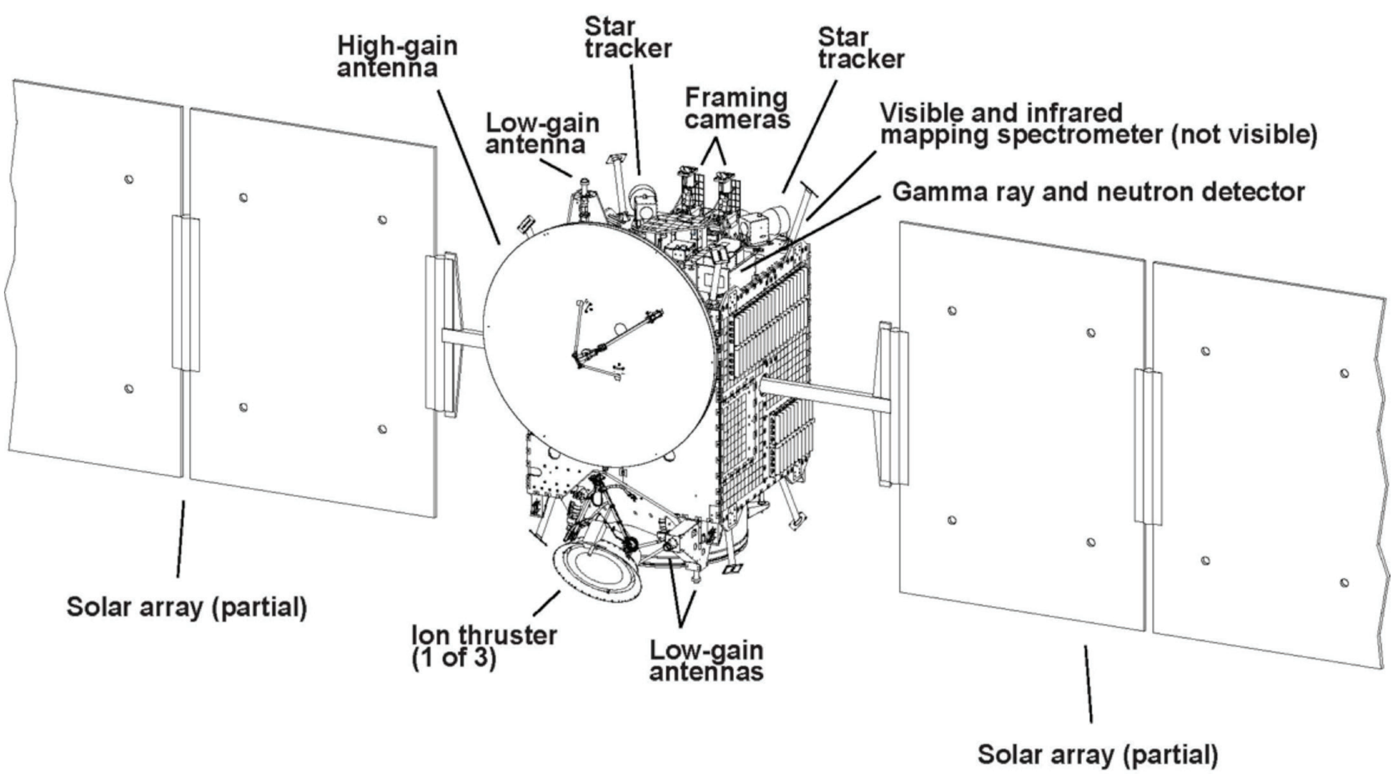
With its wide solar arrays extended, Dawn is about as long as a tractor-trailer at 65 feet (19.7 meters).

Structure

The core of the Dawn spacecraft's structure is a graphite composite cylinder. Tanks for the ion engines' xenon gas and the conventional thrusters' hydrazine are mounted inside the cylinder. The cylinder is surrounded by panels made of aluminum core with aluminum facesheets; most of the other hardware is mounted on these panels. Access panels and other spacecraft panels have composite or aluminum facesheets and aluminum cores. Blankets, surface radiators, finishes and heaters control the spacecraft's temperature.

Telecommunication

The telecommunication subsystem provides communication with Earth through any of three low-gain antennas and one 1.52-meter-diameter (5-foot) parabolic high-gain antenna. The high-gain antenna is the primary one used for most communication. The low-gain antennas are used when the spacecraft is not pointing the high-gain antenna toward Earth. Only one antenna can be used at a time.



Attitude Control

The attitude control system is responsible for determining the spacecraft's orientation in space, or "attitude," and providing control for maintaining and changing that attitude. Its hardware consists of two star trackers, three two-axis inertial reference units, 16 sun sensors and four reaction-wheel assemblies. The system controls gimbals to keep the solar arrays pointed towards the sun. In addition, it controls gimbaling of the ion thrusters, which can be moved in two axes. The system usually determines the spacecraft's attitude using its star trackers to sight known stars.

The spacecraft's attitude is usually controlled by the reaction wheels, devices somewhat similar to traditional gyroscopes that use the momentum of spinning mass to maintain or change the spacecraft's orientation. However, the attitude can also be maintained or modified by a set of twelve 0.9-newton hydrazine thrusters that are collectively called the reaction control system. Dawn's current plans require three reaction wheels for attitude control. One of the four reaction wheels developed excessive friction in June 2010 and the spacecraft automatically powered it off. Engineers have tested the reaction wheel since it was powered off, and it is not expected to return to service.

The current configuration of three reaction wheels allows Dawn to fulfill its science goals. But, to provide flexibility in the case of another reaction wheel anomaly, engineers have also uploaded software to the spacecraft so Dawn can use two wheels in combination with thrusters to help with attitude control.

Ion Propulsion System

Dawn's futuristic, hyper-efficient ion propulsion system allows Dawn to go into orbit around two different solar system bodies, a spacecraft first. The demanding mission profile would be impossible without the ion engines — and a trip even just to Vesta without ion propulsion would require 10 times more propellant, a much larger spacecraft and a dramatically larger launch vehicle. Ion propulsion was proved on NASA's Deep Space 1 mission, which tested it and 11 other technologies while journeying to an asteroid and a comet.

Each of Dawn's three 30-centimeter-diameter (12-inch) ion thrust units is movable in two axes to allow for migration of the spacecraft's center of mass during the mission. This also allows the attitude control system to use the ion thrusters to help control spacecraft attitude.

Three ion propulsion engines are required to provide enough thruster lifetime to complete the mission and still have adequate reserve. However, only one thruster will be operating at any given time. Dawn will use ion propulsion for years at a time, with interruptions of only a few hours each week to turn to point the spacecraft's antenna to Earth. Total thrust time up to the first science orbit will be 979 days, with more than 2,000 days of thrust accumulated through the totality of the mission. This surpasses Deep Space 1's 678 days of ion propulsion operation by a long shot.

The thrusters work by using an electrical charge to accelerate ions from xenon fuel to a speed 10 times that of chemical engines. The electrical level and xenon fuel feed can be adjusted to throttle each engine up or down. The engines are thrifty with fuel, using only about 3.25 milligrams of xenon per second (about 10 ounces over 24 hours) at maximum thrust. The Dawn spacecraft carried 425 kilograms (937 pounds) of xenon propellant at launch.

Xenon was chosen because it is chemically inert, easily stored in a compact form, and the atoms are relatively heavy so they provide a relatively large thrust compared to other candidate propellants.

At maximum thrust, each engine produces a total of 91 millinewtons — about the amount of force involved in holding a single piece of notebook paper in your hand. You would not want to use ion propulsion to get on a freeway — at maximum throttle, it would take Dawn's system four days to accelerate from 0 to 60 miles per hour.

As slight as that might seem, over the course of the mission the total change in velocity from ion propulsion will be comparable to the push provided by the Delta II rocket that carried it into space — all nine solid-fuel boosters, plus the Delta's first, second and third stages. This is because the ion propulsion system will operate for thousands of days, instead of the minutes during which the Delta performs.

Power

The electrical power system provides power for all onboard systems, including the ion propulsion system when thrusting. Each of the two solar arrays is 27 feet (8.3 meters) long by 7.4 feet (2.3 meters) wide. On the front side, 18 square meters (21.5 square yards) of each array is covered with 5,740 individual photovoltaic cells. The cells can convert about 28 percent of the solar energy that hits them into electricity. At Earth, the two wings combined could generate over 10,000 watts. The arrays are mounted on opposite sides of the spacecraft, with a gimbaled connection that allows them to be turned at any angle to face the sun.

A nickel-hydrogen battery and associated charging electronics provided power during launch and continues to provide power at any time the solar arrays are directed away from the sun.

Computer

The Dawn spacecraft's command and data handling system provides overall control of the spacecraft and manages the flow of engineering and science data. The system consists of redundant RAD6000 processors, each with 8 gigabits of memory.

Scientific Instruments

To acquire science data at Vesta and Ceres, Dawn carries three instrument systems. In addition, an experiment to measure gravity will be accomplished with existing spacecraft and ground systems.

- The **framing camera** is designed to acquire detailed optical images for scientific purposes as well as for navigation in the vicinities of Vesta and Ceres. Dawn carries two identical and physically separate cameras for redundancy, each with its own optics, electronics and structure. Each camera is equipped with an f/7.9 refractive optical system with a focal length of 150 millimeters and can use a clear filter or seven color filters, provided mainly to help study minerals on the surface of Vesta or Ceres. In addition to detecting the visible light humans see, the cameras register near-infrared energy. Each camera includes 8 gigabits of internal data storage. The Max Planck Institute for Solar System Research, Katlenburg-Lindau, Germany, was responsible for the cameras' design and fabrication, in cooperation with the Institute for Planetary Research of the German Aerospace Center, Berlin, and the Institute for Computer and Communication Network Engineering of the Technical University of Braunschweig. The team lead for the framing camera, Andreas Nathues, is based at Max Planck.

- The elemental composition of both Vesta and Ceres will be measured with the **gamma ray and neutron detector**. This instrument uses a total of 21 sensors with a very wide field of view to measure the energy from gamma rays and neutrons that either bounce off or are emitted by a celestial body. Gamma rays are a form of light, while neutrons are particles that normally reside in the nuclei of atoms. Together, gamma rays and neutrons reveal many of the important atomic constituents of the celestial body's surface down to a depth of 3 feet (1 meter). Gamma rays and neutrons emanating from the surface of Vesta and Ceres will tell us much about the elemental composition of each. Many scientists believe that Ceres may be rich in water; if that is the case, the signature of the water may be contained in this instrument's data. Unlike the other instruments aboard Dawn, the detector has no internal data storage. The instrument was built by Los Alamos National Laboratory, Los Alamos, N.M. The team lead for the gamma ray and neutron detector, Thomas Prettyman, is based at the Planetary Science Institute, Tucson, Ariz.

- The surface mineralogy of both Vesta and Ceres will be measured by the **visible and infrared mapping spectrometer**. The instrument is a modification of a similar spectrometer flying on both the European Space Agency's Rosetta and Venus Express missions. It also draws significant heritage from the visible and infrared mapping spectrometer on NASA's Cassini spacecraft. Each picture the instrument takes records the light intensity at more than 400 wavelength ranges in every pixel. When scientists compare its observations with laboratory measurements of minerals, they can determine what minerals are on the surfaces of Vesta and Ceres. The instrument has 6 gigabits of internal memory, which may be operated as 2 gigabits of redundant data storage. The visible and infrared mapping spectrometer was provided by the Italian Space Agency and is operated by Italy's National Institute for Astrophysics (INAF) in collaboration with Galileo Avionica, where it was built. The team lead for the visible and infrared mapping instrument is Angioletta Coradini, INAF, Rome.

- Dawn will make another set of scientific measurements at Vesta and Ceres using the spacecraft's radio transmitter and sensitive antennas on Earth. Monitoring signals from Dawn, scientists can detect subtle variations in the gravity fields of the two space objects. These variations will point to how mass is distributed in each body, in turn providing clues about the interior structure of Vesta and Ceres. The team lead for the **gravity science experiment** is Alex Konopliv, NASA's Jet Propulsion Laboratory, Pasadena, Calif.

Science Objectives

The primary goal of the Dawn mission is to explore protoplanet Vesta and dwarf planet Ceres with the same complement of instruments on a single spacecraft. In-depth analysis and comparison of these two celestial bodies will provide insight into their origin and evolution — and thus a better understanding of the conditions and processes that have acted upon them from their formation 4.56 billion years ago to the present.

During its orbital studies, Dawn will investigate the internal structure of Vesta and Ceres, in addition to their density and homogeneity by measuring their mass, shape, volume and spin state with radiometric tracking and imagery, and determine elemental and mineral composition. From this information, scientists can determine the relationship between meteorites and their parent bodies, and the thermal histories of the bodies. From images of the surface, knowledge of their bombardment, tectonic and possibly volcanic history will be revealed.

In particular, the mission's scientific objectives are to:

- Investigate the internal structure, density and homogeneity of two complementary protoplanets, Ceres and Vesta, one wet (Ceres) and one dry (Vesta).
- Determine surface shape and cratering via near-global surface imagery in three colors at Vesta and in three at Ceres.
- Perform radio tracking to determine mass, gravity field, principal axes, rotational axis and moments of inertia of both Vesta and Ceres.
- Determine shape, size, composition and mass of both Vesta and Ceres.
- Determine thermal history and size of each body's core.
- Determine the spin axis of both Vesta and Ceres.
- Understand the role of water in controlling asteroid evolution.
- Test the scientific theory that Vesta is the parent body for a class of stony meteorites known as howardite, eucrite and diogenite meteorites; determine which, if any, meteorites come from Ceres.
- Provide a geologic context for howardite, eucrite and diogenite meteorites.
- Obtain surface coverage with the mapping spectrometer from 0.25- to 5.0-micron wavelengths.
- Obtain neutron and gamma ray spectra to produce maps of the surface elemental composition of each object, including the abundance of major rock-forming elements (oxygen, magnesium, aluminum, silicon, calcium, titanium and iron), trace elements (gadolinium and samarium), and long-lived radioactive elements (potassium, thorium and uranium).

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Program/Project Management

The Dawn project is managed by the Jet Propulsion Laboratory, Pasadena, Calif., for NASA's Science Mission Directorate, Washington. Principal investigator Christopher T. Russell of UCLA leads the overall mission. Carol Raymond of JPL is the deputy principal investigator.

At NASA Headquarters, Ed Weiler is associate administrator for the Science Mission Directorate. Dr. James Green is director of the Planetary Division. Anthony Carro is Dawn program executive, and Michael Kelley is Dawn program scientist. Dennon Clardy of NASA's Marshall Space Flight Center is the Discovery program manager.

At JPL, Robert Mase is Dawn project manager. Marc Rayman is mission manager and chief engineer. JPL is a division of the California Institute of Technology, Pasadena, Calif.

Orbital Sciences Corp., Dulles, Va., built the Dawn spacecraft. Orbital provides technical support and consulting services to the flight operations team at JPL. Joseph Makowski is the Dawn manager.