The Ceres Connection

How Minor Planets Are Discovered and Named

This booklet describes the work of astronomers through the centuries to discover and classify minor planets. These asteroids, which orbit the Sun generally between Mars and Jupiter, were first noticed by astronomers observing the night sky through a telescope. The search for minor planets continues today, with astronomers using computer-assisted methods that pair highly sensitive image sensors with powerful telescopes. While these new methods are far more efficient and accurate than observing visually, they still rely on the strategy of comparing unidentified objects with what is known in the solar system.

Fewer than ten thousand people share the honor of having a minor planet designation. Minor planet designees include the four Beatles—(**4147**) Lennon, (**4148**) McCartney, (**4149**) Harrison, and (**4150**) Starr—along with other men and women of achievement, such as (**7042**) Carver, (**7000**) Curie, (**3895**) Earhart, (**2001**) Einstein, and (**4457**) van Gogh. Minor planet designations list first the number, then the name of the minor planet, as above. Throughout this booklet, however, the first mention of a minor planet designee is followed by the number of his or her associated minor planet. For example, the minor planet (**3665**) Fitzgerald would be cited as Ella Fitzgerald (**3665**).

The Massachusetts Institute of Technology's Lincoln Laboratory has partnered with Science Service to promote science education through a program called the Ceres Connection. This program awards minor planet designations to honor students in fifth through twelfth grades and their teachers. Students and teachers are selected through these Science Service competitions: the Discovery Channel Young Scientist Challenge, the Intel Science Talent Search, the Intel International Science and Engineering Fair, and the Intel Excellence in Teaching Award. All minor planets awarded in the Ceres Connection program have been discovered by the Lincoln Near Earth Asteroid Research (LINEAR) program, operated by Lincoln Laboratory.

Lost and Found Planets

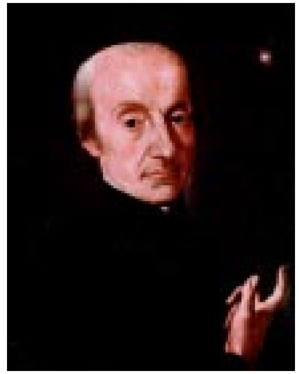
When Italian astronomer Giuseppe Piazzi (**1000**) discovered the first minor planet Ceres in 1801, European stargazers were actually looking for a "missing" major planet between Mars and Jupiter. Such an object had been predicted in 1766 by German physicist Johann Titius (**1998**), who developed a numerical formula for planetary distances from the Sun. His calculations not only matched the distances of the known planets but also predicted orbital distances for several uncharted planets. Titius's formula became known as the Titius-Bode law because German astronomer Johann Bode (**998**) popularized it.

In 1781 British astronomer William Herschel's (**2000**) discovery of Uranus at a distance predicted by the Titius-Bode law convinced astronomer Baron Franz von Zach (**999**) of Hungary that a planet between Mars and Jupiter was ripe for discovery. After searching alone for several years without success, von Zach organized several astronomers in 1800 to observe segments of the sky. When Piazzi, director of the Palermo Observatory in Italy, learned of this effort, he initiated a search for the missing planet.

On January 1, 1801, Piazzi began observing an object in the constellation of Taurus that moved slightly from night to night. Piazzi monitored the object until February 11, when bad weather and illness forced him to stop, and wrote about his find to other astronomers. By the time they received word of his discovery, the newly found planet had moved into the daytime sky and was no longer visible at night. Further complicating the situation was the fact that various orbits calculated from Piazzi's observations proved inaccurate, mainly because no general method for determining elliptical orbits existed at the time. German mathematician Carl Friedrich Gauss (**1001**), working with Piazzi's data, quickly invented a method, based on just three observations, for calculating elliptical orbits. After Gauss published the orbital elements for the missing planet, von Zach and German astronomer Heinrich Olbers (**1002**) relocated it the following winter, when it was once again visible at night.

Piazzi named the first minor planet Ceres after the Roman goddess of corn and harvests, establishing a convention (which was eventually dropped) of naming minor planets after female mythological figures. Olbers discovered a second object between the orbits of Mars and Jupiter in 1802 and named it Pallas. In 1804 German astronomer Karl Harding (**2003**) discovered Juno.

Olbers thought that the missing planet between Mars and Jupiter was being found one piece at a time. For much of the nineteenth century, Olbers and other scientists conjectured that asteroids were the fragments of an exploded planet. Modern scientists do not share this view. Current theories of solar-system formation suggest that Jupiter's gravity prevented the material between Mars and Jupiter from coalescing into a planet, leaving the remnants to form asteroids.



Giuseppe Piazzi pointing to the first minor planet Ceres, which he discovered in 1801 at the Palermo Observatory in Italy. (Portrait by G. Velasco, courtesy of the Osservatorio Astronomico di Palermo G. S. Vaiana.)

And Then There Were Hundreds

Fifty minor planets were known in 1857. That total doubled by 1868 and reached about 300 by 1890. Such growth forced astronomers to change the way they documented their discoveries. Although early discoveries were named after mythological figures, astronomers began numbering the minor planets in order of discovery in 1851. Originally, astronomers assigned symbols to the minor planets to mimic the symbols associated with the major planets. As these symbols grew in complexity, numbers enclosed in circles became the convention. As the numbers increased in value with more discoveries, the circles became ellipses. Eventually, the ellipses were abandoned in favor of parentheses surrounding the number, a format that continues today.

Despite the success of nineteenth-century astronomers, looking for minor planets was a time-consuming and meticulous process. Published star charts of the period were often incomplete and contained inaccuracies. Some observers therefore drew their own star charts from what they saw through the eyepiece. By watching the same field an hour or two later (or on the next clear night), an observer could compare the current view in the eyepiece with an earlier drawing. Any change might indicate the presence of a new object.

Minor Planet	Date of Discovery	Old Symbol	New Symbol
Ceres	January 1, 1801		①
Pallas	March 28, 1802		②
Juno	September 1, 1804		③
Vesta	March 29, 1807		④
Astraea	December 8, 1845		⑤
Hebe	July 1, 1847		⑥
Iris	August 13, 1847		⑦
Flora	October 18, 1847		⑧
Metis	April 25, 1848		⑨
Hygea	April 12, 1849		⑩
Parthenope	May 3, 1850		⑪
Clio	September 13, 1850		⑫
Egeria	November 2, 1850		⑬
Irene	May 20, 1851		⑭
Eunomia	July 29, 1851		⑮

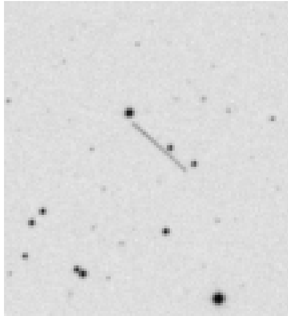
Symbols associated with early minor planet discoveries (adapted from B. A. Gould, "On the Symbolic Notation of the Asteroids," Astronomical Journal, *volume 2, 1852, p. 80). Note that the symbols for minor planets Egeria (**13**) and Irene (**14**) were never drawn. In his article, Gould defended the need to replace symbols with numbers: "Not only are many of the symbols proposed inefficient in suggesting the name of which they are intended to be an abbreviation; but some of them require for their delineation more artistic accomplishment than an astronomer is necessarily or generally endowed with."*

Pictures Speed Discovery

In the early 1890s, Max Wolf (**827** and **1217**) at the Heidelberg Observatory in Germany and Auguste Charlois (**1510**) at the Nice Observatory in France began photographing the sky to detect moving objects. By tracking the stars as they were photographed through the telescope, the astronomers could record the trail of any moving object (minor planet or comet) in the field of view. The length of the trail depends on the apparent motion of the object and the exposure time. This photographic method was quite successful in discovering new objects, many of which were difficult to observe visually, and the rate of discovery rose. By the 1930s, few serious astronomers were observing visually.

Today, almost all observations of minor planets and comets are obtained by using charge-coupled devices (CCDs), image sensors also used in digital cameras. A silicon CCD array consists of tiny light-sensitive sections called pixels. When photons of light strike a pixel, it fills with electrical charge. The more light that falls on the pixel, the greater the charge stored. The charge quantities in the array of pixels, representing a digital picture, are captured by circuitry on the CCD. These digital data can be fed into a computer and processed immediately, unlike photographic plates, which must be developed and then digitized with a scanner for computer analysis.

With CCDs, observers can record the same information as a photograph in less time. Collecting more images in a given time frame results in searching more of the sky, thereby increasing the chances for discovery. The widespread use of CCDs beginning in the mid-1990s increased the yearly discovery rate from 6,301 objects in 1994 to 72,000 objects in 2002. Most of these discoveries were made by professional search programs, such as the Spacewatch Project at the University of Arizona in Tucson and the Lincoln Near Earth Asteroid Research (LINEAR) program operated by the Massachusetts Institute of Technology's Lincoln Laboratory. Amateurs provide valuable follow-up observations of newly discovered objects, and they also account for a few percent of the total number of discoveries being made. Today, active groups of amateur minor planet observers exist in the United States, Japan, Italy, the United Kingdom, France, Germany, Brazil, Mexico, Slovenia, Slovakia, and Australia.



*Ninety-minute photographic exposure taken by the 1.2-meter Schmidt telescope on December 7, 1989, at Palomar Observatory in California. In this image, reproduced here as a negative, the sky is light and the stars are dark. Minor planet (**6354**) Vangelis, named after Greek composer Vangelis Papathanassiou, created the trail in the middle of the image as the asteroid moved with respect to the background stars. Such movement reflects the asteroid orbiting the Sun and the motion of the observing telescope, which sits on a rotating earth that also orbits the Sun. None of the stars visible in this picture are visible to the unaided eye. (Courtesy of Palomar Observatory/California Institute of Technology.)*

What's in a Name?

The clearinghouse for minor planet discoveries is the Minor Planet Center (MPC) in Cambridge, Massachusetts. The MPC operates at the Smithsonian Astrophysical Observatory under the auspices of a group of professional astronomers who form Commission 20 of the International Astronomical Union (IAU). Founded in 1947 at the Cincinnati Observatory in Ohio and moved to Cambridge in 1978, the MPC maintains a catalog of all known minor planets and comets.

The discovery process for a minor planet begins when observers from around the world forward their observations of a new object to the MPC staff, who identify any observations that correspond to known objects in the catalog. Generally, the first observer to report seeing a new object on two nights over a span of a few days receives credit for the discovery. Devoted astronomers who specialize in follow-up observation can download the predicted position of these minor planet candidates, observe them, and send their resulting observations to the MPC. Once confirmed, minor planets receive a provisional name based on the year of discovery plus two letters that range from AA to YZ, with the letter I omitted. When a particular object has been observed many times over a number of years, the MPC gives it a permanent number designation. The sequence of permanent numbers begins at one with Ceres, the first minor planet discovered.

Once an object has been numbered, its discoverer can submit a brief proposal in support of a particular name. About 30 percent of the currently numbered minor planets have received a name. The IAU's Committee for Small-Body Nomenclature, comprised of 13 professional astronomers from around the world, requires that names be under 17 characters long, pronounceable in some language, not offensive, and different enough from existing minor planet or satellite names to avoid confusion.

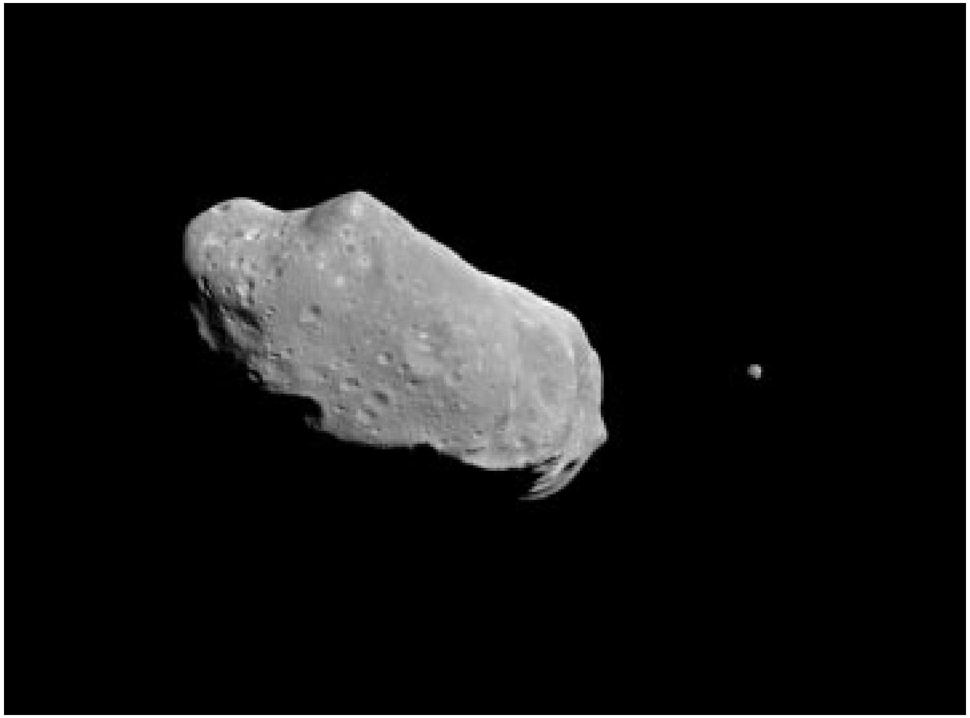
An accepted name becomes official when it is published, along with its accompanying citation, in the *Minor Planet Circulars*, issued monthly by the MPC. Only names assigned by the MPC are valid, permanent, and used by astronomers. Information and links about the names, locations, and orbits of minor planets can be found on the LINEAR program Web site at http://www.ll.mit.edu/mission/space/linear/.

Classes of Minor Planets

Minor planets represent material left over from the formation of the solar system, most likely material that never coalesced into a planet because of Jupiter's gravitational influence. The estimated total mass of all the minor planets is much less than that of Earth's Moon. Only two dozen minor planets in the main asteroid belt have diameters greater than 200 kilometers. With a diameter of about 1,000 kilometers, Ceres dwarfs all the other minor planets.

Astronomers categorize minor planets by their position in the solar system. For example, near-Earth asteroids (NEAs) have orbits that cross or approach Earth's orbit. Trojans revolve around the Sun in the same orbit as Jupiter, either ~60° ahead or ~60° behind the planet. Centaurs roam the outer solar system, generally between Jupiter and Neptune. There also exists in the outer solar system a belt of larger objects, many with diameters greater than 100 kilometers, called trans-Neptunian objects.

Most of the minor planets—the main-belt asteroids—move in nearly circular orbits between Mars and Jupiter. They are not distributed uniformly within this main asteroid belt. Certain zones known as Kirkwood gaps, where no minor planets are found, correspond to distances for which the orbital period of the minor planet would be a simple fraction of Jupiter's orbital period, such as 1/3 or 1/2. At these distances, Jupiter's gravitational pull can significantly elongate the orbits of the minor planets, and eject the minor planets from the main asteroid belt.



*Minor planet (**243**) Ida and, at right, its moon Dactyl, the first-known minor planet satellite. Ida is 58 kilometers long; Dactyl is 1.6 kilometers long. This image was taken on August 28, 1993, by a charge-coupled device (CCD) camera aboard the National Aeronautic and Space Administration (NASA)* Galileo *spacecraft, which discovered Dactyl on its way to explore Jupiter. (Courtesy of NASA and the National Space Science Data Center.)*

Barringer crater, near Flagstaff, Arizona. This 170-meter-deep crater is 3.8 kilometers in circumference. It was created some 50,000 years ago when an asteroid estimated to be about 50 meters in diameter struck the Earth. (Courtesy of D. Roddy.)

NEAs receive the most attention from the press, scientists, and government agencies because of their potential to collide with Earth. For example, scientists have traced the extinction of the dinosaurs to a large asteroid or comet that crashed into Mexico's Yucatan Peninsula some 65 million years ago. Such massive collisions still occur in our solar system—fragments of the comet Shoemaker-Levy 9 struck Jupiter in 1994. The good news is that no NEAs are known to be on a collision course with Earth.

While large-scale collisions with the Earth happen less than once every ten million years, smaller impacts that cause severe regional destruction like the Barringer crater near Flagstaff, Arizona, occur every few hundred years. For example, on June 30, 1908, a mysterious explosion in the skies over Tunguska, Siberia, knocked people unconscious and flattened about 2,100 square kilometers of forest. Scientists have concluded that the blast was an asteroid fragment exploding midair.

The premier search program for NEAs is the LINEAR program, which is funded by the United States Air Force and the National Aeronautics and Space Administration. Operating out of White Sands Missile Range near Socorro, New Mexico, it applies Lincoln Laboratory–developed technology used to track Earth-orbiting satellites in the hunt for minor planets. Two telescopes equipped with a new generation of highly sensitive CCD sensors collect data, which are processed on site to generate observations. LINEAR has discovered more minor planets than any other asteroid search program in the world.

Massachusetts Institute of Technology

is a coeducational, privately endowed research university dedicated to advancing knowledge and educating students in science, technology, and other areas of scholarship that best serve the nation and the world. An MIT education combines rigorous academic study and the excitement of discovery, supported by the intellectual stimulation of a diverse community. Located in Cambridge, Massachusetts, MIT has more than 900 faculty and nearly 10,000 undergraduate and graduate students.

Lincoln Laboratory

is the largest of MIT's interdisciplinary laboratories. The primary facility, located in Lexington, Massachusetts, has approximately 2,400 employees, including 1,300 technical professionals. The Laboratory is committed to the application of advanced technology in sensing, information processing, and communications for the nation's security by working with its sponsors and industry. Operated by MIT for over fifty years, Lincoln Laboratory carries out research and development for the United States Department of Defense, the Federal Aviation Administration, the National Aeronautics and Space Administration, and other government agencies.

LINEAR

—the Lincoln Near Earth Asteroid Research program— applies Lincoln Laboratory–developed technology used in tracking Earth-orbiting satellites to detect and catalog near-Earth asteroids, comets, and minor planets. Support for LINEAR comes from the United States Air Force and the National Aeronautics and Space Administration. LINEAR operates two 1-meter telescopes equipped with Laboratory-developed and fabricated CCD electro-optical detectors at the Laboratory's Experimental Test Site on White Sands Missile Range near Socorro, New Mexico. These highly sensitive CCD detectors coupled with efficient computer search algorithms have enabled LINEAR to become the most prolific discoverer of minor planets.

Society for Science & the Public

is a nonprofit organization founded in 1921 to promote public understanding and appreciation of science through publications, outreach, and science education programs. Its award-winning *Science News*, an international weekly news magazine covering all fields of science, reaches over 200,000 subscribers and 1.2 million readers. Society for Science & the Public organizes three science competitions for students. The Discovery Channel Young Scientist Challenge, established with Discovery Communications, Inc., offers students in fifth through eighth grades the opportunity to develop a science fair project. The Intel Science Talent Search targets high school seniors, and the Intel International Science and Engineering Fair attracts students in ninth through twelth grades.