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From Vermin to Destination: A Mission to an Asteroid

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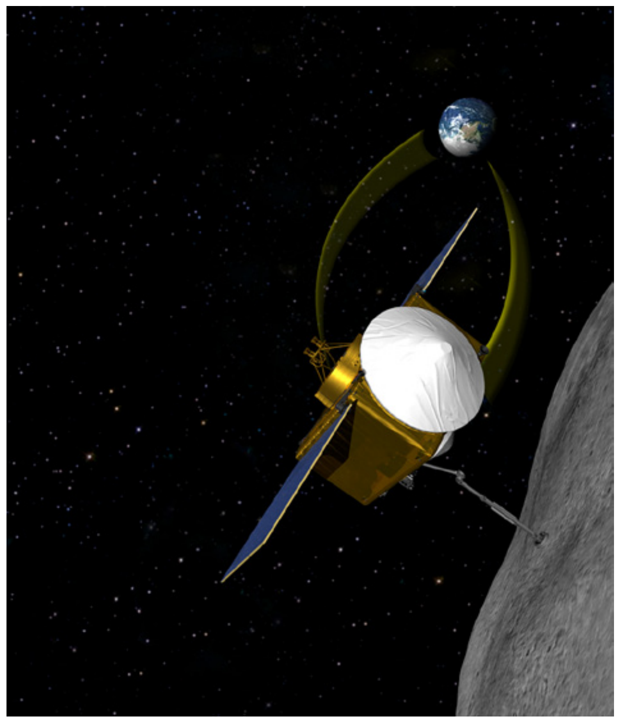
Why go to an Asteroid?

Long ago astronomers used to call asteroids "vermin of the skies." These small rocky bodies "got in the way" of "important" objects of study. But now asteroids are one of the hottest topics of interest for researchers, students, and policy makers. They are destinations, remnants of earliest materials, sources for precious minerals, possible threats, and even targets for human colonization. No longer simply thought of as fragments or pieces of a failed planet, they are fascinating objects in their own right and can hold the clues to our past as well as our future. The next big step in understanding asteroids is NASA's, OSIRIS-REx mission, which will explore one of these primitive objects and return a sample to Earth.

Scientists study asteroids through telescopic observations and by analyzing meteorites, rocks from space. Observations through telescopes and laboratory analyses reveal much information, but traveling to an asteroid and returning a sample to Earth will furnish scientists with opportunities to analyze an unaltered sample and directly link the source with the sample. Researchers will hold in their (gloved) hands some of the oldest material in the Solar System. In fact, when the OSIRIS-REx



The OSIRIS-REx spacecraft will launch in 2016, spend 505 days at 1999 RQ36 and return a sample of the asteroid to Earth In 2023.

What's in an Acronym?

It Reveals the Scientific Goals of the Mission!

O –	Origins	study earliest materials to learn about origins of the Solar System and of life
S I –	Spectral Interpretation	compare to telescope observations and meteorite analyses
R I –	Resource Identification	identify useful metals and materials
S –	Security	more fully characterize the orbit to understand behavior and trajectory
R – Ex –	Regolith Explorer	examine surface rock composition and distribution on the asteroid

asteroid sample return mission is complete (launch in 2016 and sample return in 2023) future scientists will use instruments and techniques not yet developed to unlock secrets about the truly fundamental building blocks of our Solar System and provide clues to origins of life on our planet.

Visiting an asteroid that crosses the Earth's orbit will also give researchers a chance to learn more about the orbits of potentially hazardous objects. The OSIRIS-REx mission's rendezvous with an asteroid having a relatively high potential for an Earth impact late in the 22nd century will help scientists better understand the factors affecting asteroid orbits and help predict their future trajectories.

Robotic missions such as the OSIRIS-REx asteroid sample return mission are the precursor to human missions to asteroids. The journey, the information obtained during rendezvous, and the materials returned to Earth will all provide data to evaluate asteroids as stepping stones to even more distant destinations or as "filling stations" with precious materials such as water and metals.

What Do We Know About Asteroids?

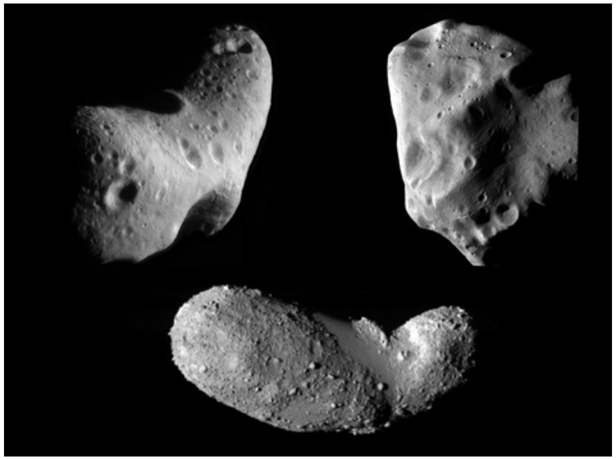
Asteroids are the most direct remnants of the original building blocks that formed the planets of our Solar System and are relatively pristine samples of the initial conditions in the solar nebula 4.6 billion years ago. They are fundamental to our understanding of planet formation and may provide important clues about the origin of life here on the Earth.

The early Solar System was a chaotic place. Planets and planetesimals — small rocky fragments — may have collided and shifted positions creating reservoirs of small bodies, asteroids and comets. The collisions and gravitational interactions over 4.6 billion years moved these small bodies around. Now they reside not only in distinct areas such as the main asteroid belt (between Mars and Jupiter), the Kuiper Belt (beyond the orbit of Neptune) and the Oort Cloud (at about ¼ of the distance to the nearest star), but travel in other orbits, some of which cross Earth's path. The Solar System is a much messier place that we imagined even just a few years ago.

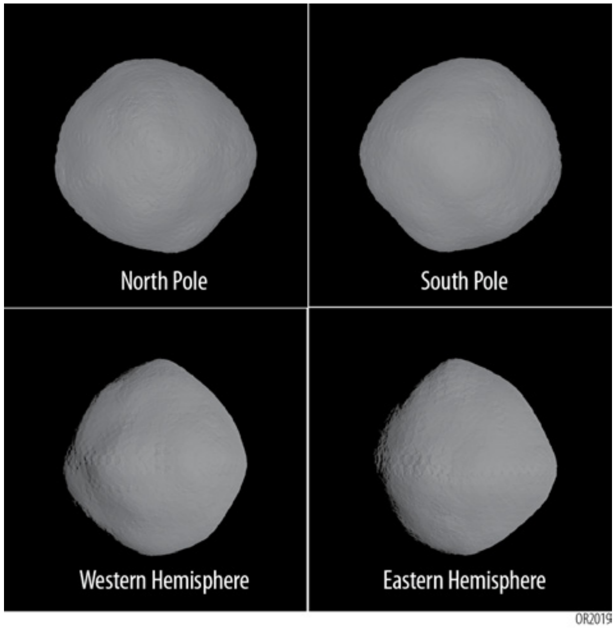
Asteroids come in many varieties: some have remained relatively untouched since they coalesced, some have melted or been disrupted. Scientists have defined their characteristics using telescopic observations and analyzing meteorites. Most asteroids are small and irregularly shaped — think "potato."

News from Telescopic Observations

Using telescopes, ground-based observers concentrate on finding asteroids, examining light curves, and taking spectra. Several large surveys of small bodies, most notably the Catalina Sky Survey and LINEAR, have discovered over 500,000 asteroids in the main belt and over 8,000 near-Earth objects (NEOs). [To see a remarkable video by Scott Manley that shows the accelerating pace of discovery between 1980–2010, go to http://www.youtube.com/watch?v=S_d-gs0WoUw.]



Three asteroids (433 Eros, 21 Lutetia and 25143 Itokawa) visited by spacecraft demonstrate the variety of appearance in asteroids. Credit: NASA, ESA, and ISAS/JAXA.



Ground-based radar observations in 1999 and 2005 revealed the shape and rotation state of 1999 RQ36. Credit: Arecibo Observatory and Goldstone Planetary Radar System.

Scientists use a variety of observations to study asteroids:

- Optical observations can estimate the shape, rotation period, orientation of the rotation axis, and whether the object is solid or a rubble pile (a collection of smaller rocks loosely held together by gravity).
- Observers use radio observations to infer composition. Radio waves react differently to different materials: rock does not look like metal. Astronomers on Earth can also bounce

a radio signal off of an asteroid to get shape information and to refine the orbit.
- Astronomers using both orbiting and ground-based telescopes employ infrared spectroscopy to tease out the compositions of asteroids.

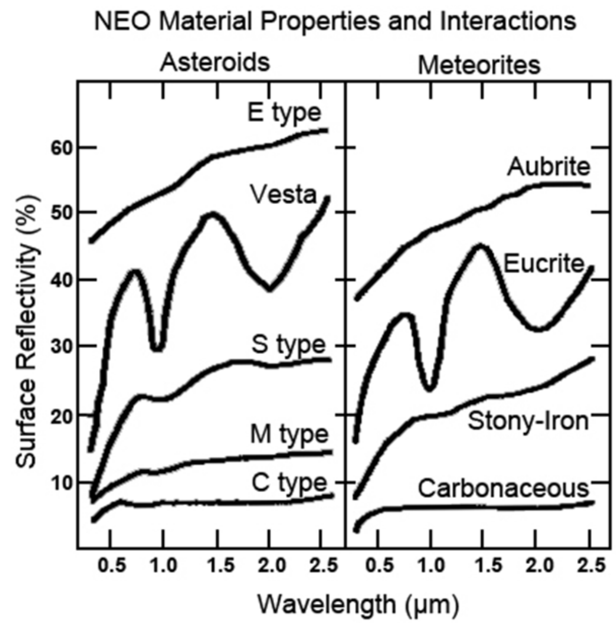
News from Meteorites

The rocks that fall to Earth from space, meteorites, provide abundant examples of the variety of materials in our Solar System. Scientists classify meteorites based on composition, mineralogy, and age. They conclude that these rocks represent parts of asteroids originally from the area between Mars and Jupiter but through orbital perturbations and collisions were fragmented and thrown into orbits which intersect with Earth.

Scientists can make connections when they match meteorite spectra to asteroid spectra: they infer compositional similarity based on similar features exhibited in the spectra. But unless they observe an object prior to its fall or go to an object and return a sample, making an unambiguous connection is hard.

The only time that people observed an NEO in orbit, watched it fall to Earth, and collected its fragments was in October 2008. Richard Kowalski of the Catalina Sky Survey discovered 2008 TC3. Calculations quickly revealed that it would enter the Earth's atmosphere just 19 hours later. The bolide exploded above Sudan's desert and a few months later, searchers recovered over 10 kilograms (23 pounds) of the object, now a meteorite called Almahata Sitta.

With 8,000 known NEOs, and tens of thousands still undiscovered, it isn't difficult to see why astronomers observe close fly-bys fairly frequently. Earth fly-bys can offer terrific opportunities to learn



A comparison of reflectance spectra of asteroid and meteorite types. After: "Classifying and Modeling NEO Material Properties and Interactions", John L. Remo, in Hazards due to Comets & Asteroids (1994, T. Gehrels, ed., The University of Arizona Press, 1300 p.), p. 561.

more about NEOs. In 2011, asteroid 2055 YU55 passed within the Moon's orbit, just 324,900 kilometers (201,900 miles) from Earth. Radar and optical observations, revealed puzzling surface features. Scientists measured the albedo (reflectivity) of this C-type (carbonaceous or carbon-rich) asteroid and assessed the composition. The OSIRIS-REx mission scientists were quite excited to use these data to inform their modeling and planning for what they might find when they reach their target asteroid.

What Can a Mission to an Asteroid Tell Us?

Traveling to an asteroid and bringing back a sample gives us material to inspect and understand so scientists can examine fundamental questions about the Solar System and life:

- How did the Solar System form?
- What kinds of materials exist in the Solar System?
- What was the source of organic materials that led to the origin of life?
- Where did Earth's water come from?
- Are asteroids bringers of life or death — or both?

In the last decade several robotic spacecraft have visited asteroids, including NASA's Near Earth Asteroid Rendezvous (NEAR)-Shoemaker mission to Eros, NASA's Dawn mission to Vesta and Ceres, and Japan's Hayabusa mission to 25143 Itokawa, an S-type (stony) asteroid Hayabusa collected about

Completed Missions to Small Bodies

Cassini-Huygens: mission to Saturnian system with fly-by of asteroid 2685 Masursky

Dawn: mission to asteroids 4 Vesta and 1 Ceres

Deep Space 1: mission to asteroid 9969 Braille

Galileo: mission to Jovian system with fly-by of asteroids 951 Gaspra and 243 Ida

Hayabusa: asteroid sample return from 25143 Itokawa

NEAR-Shoemaker: near-Earth asteroid rendezvous mission to 433 Eros

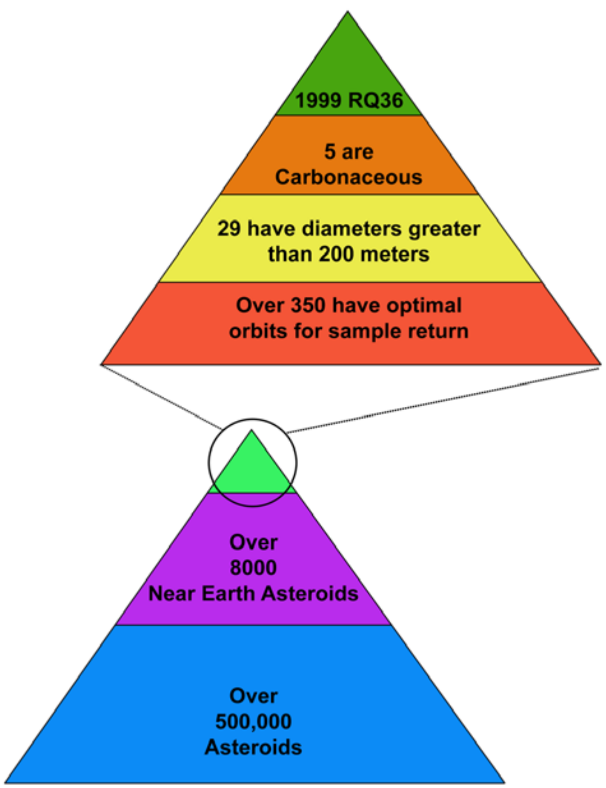
Rosetta: mission to comet 67P/Churyumov–Gerasimenko with fly-by of asteroid 21 Lutetia

Stardust: mission to 5535 Anne Frank and collect samples from comet Wild 2

1,500 microscopic grains (mostly 10–100 micrometers) and returned them to Earth. Dawn is orbiting Vesta now and will depart for Ceres in July 2012.

Different asteroids can provide different information. Eight years ago meteoriticists Michael Drake and Dante Lauretta wondered what type of asteroid could best provide answers the fundamental questions about the Solar System and the origins of life. They formed a team to devise a mission that would return a sample from such an asteroid, and they decided that a *carbonaceous* asteroid would best be able to answer these questions.

Carbonaceous asteroids are the direct remnants of the original components of the terrestrial planets. Scientists link them with carbonaceous chondrites, fragile, volatile- and organic-rich meteorites. The presence of complex organics in primitive meteorites has led to speculation that they could have seeded the early Earth with the compounds that formed the building blocks of life.



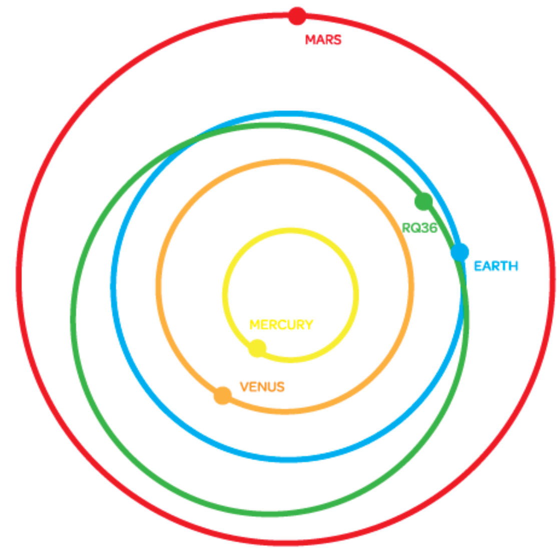
Out of over 500,000 asteroids now known, selection criteria narrow down the choice of mission target to 1999 RQ36.

Although we currently know the locations of over 500,000 asteroids, most reside in orbits that do not intersect with the Earth's. NEOs would be the best mission targets because they come close (sometimes very close) to the Earth.

Asteroid size was an additional constraint on target selection. A large fraction of asteroids with diameters less than 200 meters (656 feet) rotate quickly (less than one rotation every two hours). Not only does such rapid rotation greatly increase the risk to spacecraft operations, but the acceleration due to gravity is not enough to retain easily sampled regolith on the surface. Less than one hundred objects have relatively easily accessible orbits and are still large enough to be good sample return targets for a mission. Of these, only five are known to be carbonaceous.

The target the team selected was near-Earth object (101955) 1999 RQ36, the most accessible volatile- and organic-rich remnant from the early Solar System. Scientists classify 1999 RQ36 as a B-type asteroid, a sub-group of carbonaceous asteroids, which are primitive and volatile-rich.

1999 RQ36 intrigues scientists — and policy makers — for another reason: it has one of the highest probabilities of impacting the Earth, but not until the late 22nd century. Although 1999 RQ36 is only 1/20th of the size of the asteroid which doomed the dinosaurs, its impact could still cause regional damage. Scientists want to understand more about its orbit and how it will evolve. One force affecting its orbit is called the Yarkovsky effect, which is produced by unbalanced radia-



1999 RQ36 is a near-Earth asteroid with an orbit that brings it close to Earth every 6 years. This shows the orbital positions in March 2021 when the OSIRIS-REx spacecraft begins its journey back to Earth.

Fast Facts about 1999 RQ36

- Near-Earth asteroid
- About 500 m (1/3 mile) diameter
- 4.5-hour rotation period
- 436.6-day orbit of Sun at 27.8 meters/second (62,120 mph)
- Ancient carbon, volatiles
- Rocky fragments with fractures and pores
- Potential hazard to Earth

tion from the daily heating and cooling of the 1999 RQ36. Its effect is small but over hundreds of years could change an asteroid's orbit significantly.

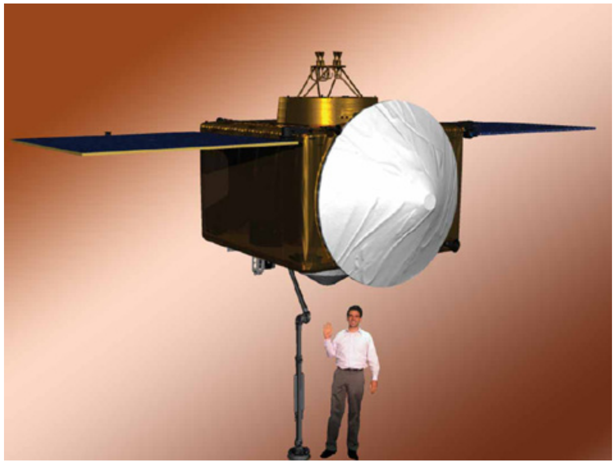
Who are the People Behind the Robotics?

The OSIRIS-REx mission is a multi-generational effort with over 150 scientists, engineers, and managers working together to bring back a sample from an asteroid. As part of this effort, the team sponsors an Education and Public Outreach (E/PO) program for public and school activities, works to hire and train students, provides experiences for teachers, and reaches out to communities. The E/PO group is working with scientists and technical experts to create materials and opportunities for involvement in education and outreach. They are particularly interested in encouraging interest in science, technology, engineering, and mathematics (STEM) education and careers.

Fast Facts about the OSIRIS-REx Spacecraft

- 2 meters (6.6 feet) per side
- 8.5 m2 (91 square feet) of solar panels
- Lithium ion batteries
- 5 Instruments:
- Measurements in x-ray, visible and infrared
- Laser altimetry
- Touch-and-Go Sampler

The OSIRIS-REx student collaboration project also provides a unique chance to undergraduates to design, build, and fly an instrument. Three teams of undergraduates competed to build an instrument for the mission. A team from MIT and Harvard won the competition, and NASA funded the Regolith X-ray Imaging Spectrometer (REXIS). REXIS will provide information about asteroid composition by observing X-rays excited by solar radiation emitted from minerals in the surface of 1999 RQ36.



Comparison of OSIRIS-REx and human

This 14-year mission will provide experiences for many age groups and the chance for students to participate throughout their lives. Our goal is to engage students early and continue engaging them throughout their school years: a child attending a team member's presentation at an elementary school in 2012 may be the scientist analyzing the return sample in 2023 or an astronaut traveling to an asteroid!

Resources and Classroom Activities

The OSIRIS-REx mission team is working with various partners to develop resources and classroom activities about asteroids and this mission. Roll-out of OSIRIS-REx formal education resources will occur around the mission launch date in 2016. In 2012, the mission will introduce two informal education programs: *Target Asteroids!*, a citizen science program to collect data on asteroids, and a naming contest to find a more accessible name for (101955) 1999 RQ36. Visit the OSIRIS-REx mission website for more information.

For more information about asteroids, meteorites and the OSIRIS-REx mission, visit the OSIRIS-REx website and its links at http://osiris-rex.lpl.arizona.edu.

To learn more about asteroids and meteorites, there are many other relevant resources available for classroom use.

Here are links to several of these sources:

NASA Solar System Exploration – Education:
http://solarsystem.nasa.gov/educ/index.cfm

Lunar and Planetary Institute – resource lists:
http://www.lpi.usra.edu/education/resources/s_system/acm.shtml

NASA's Near Earth Object Program:
http://neo.jpl.nasa.gov/

The NASA Asteroid Watch page:
http://www.jpl.nasa.gov/asteroidwatch/

The NASA Asteroid and Comet Impact Hazards program page: http://impact.arc.nasa.gov/

NASA's Lunar and Planetary Science page on asteroids: http://nssdc.gsfc.nasa.gov/planetary/planets/asteroidpage.html

Asteroid resources and activities from the NASA Night Sky Network:
http://nightsky.jpl.nasa.gov/download-list.cfm

NASA's WISE Mission (Wide-field Infrared Survey Explorer) mapped the sky in infrared light, allowing astronomers to search for a variety of objects including asteroids: http://wise.ssl.berkeley.edu/

Dawn mission website — Education:
http://dawn.jpl.nasa.gov/education/

Information on the NEAR-Shoemaker Mission (Near Earth Asteroid Rendezvous):
http://near.jhuapl.edu/ and
http://nssdc.gsfc.nasa.gov/planetary/near.html

The Rosetta Mission of the European Space Agency includes robotic spacecraft explorations of both a comet and main belt asteroids. The Rosetta Mission website has good information on asteroids, comets, and the mission itself.
http://www.esa.int/esaMI/Rosetta/index.html

Classroom Activities:

Featured Activity: *Vegetable Light Curves*

Most asteroids are small chunks of rock, orbiting in a belt between Mars and Jupiter. We see them through large telescopes because they reflect the light of the Sun. Occasionally, it is possible to see variations in the reflected sunlight and use these to determine the shape and surface features of the asteroid.

Students will observe the surface of rotating potatoes to help them understand how astronomers can sometimes determine the shape of asteroids from variations in reflective brightness. (Astronomers have joked over the years that irregularly shaped asteroids resemble nothing as much as potatoes.)

Download the entire activity *Vegetable Light Curves* as a PDF here.

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Vegetable Light Curves is an activity developed for NASA's Dawn Mission, and is included in The Universe at Your Fingertips 2.0, an extensive collection of astronomy teaching resources published by the Astronomical Society of the Pacific. This collection includes a section on Comets, Asteroids and Meteors, with 7 activities and 3 background articles
http://astrosociety.org/uayf/index.html

Other Activities

The NEAR Education Activity Book has activities to explore asteroid characteristic such as density, mass and volume; the dynamics of traveling to and orbiting an asteroid; creating digital images; and more! Download the NEAR Activity Book at:
http://near.jhuapl.edu/ed/Activity.pdf

Asteroid activities from the NASA Night Sky Network:
Asteroid Hunter Activity: Find asteroids in a star field and discover why astronomers are locating even more asteroids using infrared detectors.
http://nightsky.jpl.nasa.gov/download-view.cfm?Doc_ID=468

Scaling the Asteroid Belt: Explore the Asteroid Belt and learn some surprising truths about just how difficult it would be to navigate. http://nightsky.jpl.nasa.gov/download-view.cfm?Doc_ID=466

The Asteroids: Education page of NASA's Solar System Exploration website has a number of asteroid related activities including: Analyzing Elemental Abundances, Edible Asteroid Mining, and Modeling Asteroid Vesta in 3-D.
http://solarsystem.nasa.gov/planets/profile.cfm?Object=Asteroids&Display=Educ

Discover an asteroid in the activity Hunting for Asteroids. This activity from the UK's National Schools' Observatory engages students in image analysis to find asteroids. http://www.scienceinschool.org/2011/issue20/asteroids