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Defending Earth: Fact Vs. Fiction

By Michael Paine
Special to *SPACE.com*
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First, the good news: Asteroid 433 Eros is not on a collision course with the Earth.

At roughly twice the size of Manhattan Island, Eros is huge compared with other known near-Earth asteroids. A collision by an object this size would be more devastating than the impact that is thought to have finished off the dinosaurs 65 million years ago.

Eros is in the news because, on Monday, after a torturous four-year journey, the NEAR spacecraft will attempt to become an artificial moon of Eros. A successful NEAR mission to Eros will show that we have the ability to rendezvous with an asteroid, and to orbit it.

This ability is crucial if -- some scientists would say "when" -- an asteroid is discovered to be on a collision course with Earth.

Space missions to asteroids and comets might not seem as exciting as a landing on Mars, but the social, scientific and commercial benefits from these missions could be great. An asteroid or comet impact with Earth is the only type of natural disaster that could instantly wipe out human civilization, and yet -- unlike earthquakes, floods and volcanoes -- it is within our grasp to prevent the collision.

The know-how needed to protect Earth from collision could also be used for commercial mining in space. Comets and asteroids are packed with useful raw materials. Eventually, space prospectors might want to rendezvous with them and, perhaps, change their orbit.

CHASING ASTEROIDS: Previous spacecraft missions to asteroids and comets have involved quick flybys with no attempt to match speed with the object. In the future, vehicles will try to land on their surfaces. Want to learn more?

TO NUKE OR TO NUDGE? Blowing up asteroids may work in the movies, but in reality it could lead to bigger problems. However, nuclear warheads could be used to alter the course of an errant asteroid or comet. Want to learn more?

SAILING WITH SUNLIGHT: From solar-powered cannons to steering an asteroid away from Earth with giant solar sails, the alternatives to blowing up space objects are cutting edge. Want to learn more?

SPACE MISSIONS: The physical properties of asteroids and comets are still poorly understood. Here is a list of missions to asteroids and comets currently underway or being planned to learn more about these celestial bodies.

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Catching Comets; Angling Asteroids

By Michael Paine
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To learn more about the physical properties of asteroids we first have to reach them with spacecraft.

The NEAR mission is the first attempt to rendezvous with an asteroid. A rendezvous involves carefully maneuvering the spacecraft so that it follows nearly the same orbital path as the asteroid. The spacecraft (pictured below) slowly approaches the object then adjusts its speed so that the spacecraft and asteroid follow the same path around the Sun. In the case of NEAR a further maneuver will put the spacecraft into orbit around the asteroid.

CREDIT: Johns Hopkins University

Previous spacecraft missions to asteroids and comets have involved quick flybys with no attempt to match speed with the object. These missions were important steps in our exploration of these objects but improved technology was needed to achieve a rendezvous.

One recent space mission was designed to test new technology. In July last year the Deep Space 1 spacecraft passed within 10 miles (16 kilometers) of asteroid Braille. This mission successfully tested two important technologies - auto-navigation and the ion drive. Auto-navigation means that the robot spacecraft worked out its own location in space and the course to the target object.

The ion drive (pictured below) is an advanced form of propulsion where the particles coming out of the exhaust are electrically charged (ions) and they are accelerated by electrical means to very high speeds. Solar cells or a nuclear generator could provide electrical power.

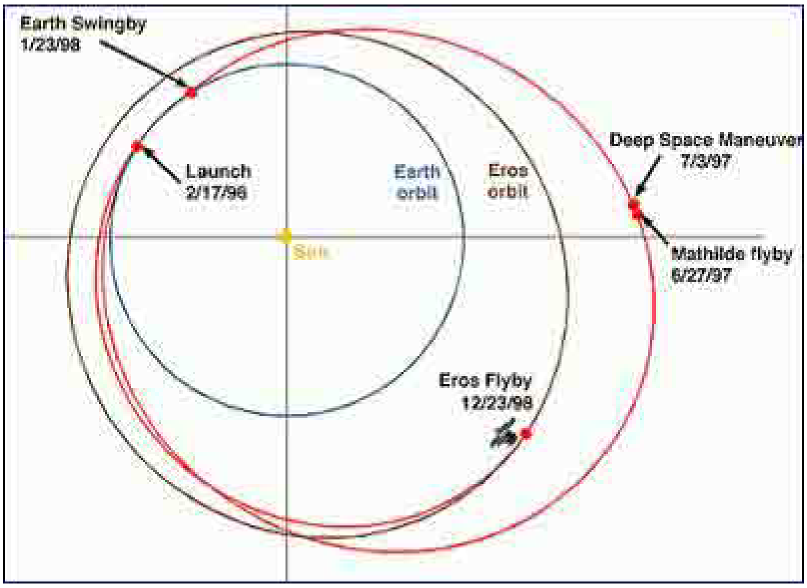
CREDIT: NASA/JPL

Deep Space 1 used an advanced solar collector to generate a stunning 2500 watts of power. By using a steady, reliable power source the ion drive can gradually accelerate the spacecraft to interplanetary speeds. Within twelve months Deep Space 1 will have consumed all of its 180 pounds (80 kg) of Xenon propellant and reached a speed of 9000 mph (4 kilometers per second).

Dr Marc Rayman from the Deep Space 1 mission team explained that the Braille flyby was a bonus for the primary mission that was mainly designed to test new technology. The experience gained at Braille will help them plan an encounter with Comet Borrelly - the main target of the extended mission. He added that the failure, last November, of the spacecraft's "star tracker" navigation aid meant that they had dropped plans to reach a second comet but otherwise the failure would not seriously hamper the extended mission.

Sling-shots from planets

Many recent interplanetary space missions have involved a gravity-assist flyby of the Earth. This sling-shot technique (illustrated below) can produce substantial reductions in the size of rocket needed to reach a planet or asteroid. For example, in January 1998 the NEAR spacecraft whizzed within 340 miles (550 km) of the surface of the Earth.



CREDIT: Johns Hopkins University

This planned encounter changed the course of the spacecraft so that it reached Eros one year later (unfortunately a technical bug prevented the spacecraft from going into orbit and the mission scientists had to wait a year for the next opportunity).

Of course, an Earth flyby would be very difficult to sell to the world's population if the spacecraft was carrying nuclear weapons intended to deflect an asteroid.

Adding further to the difficulties, the best time to nudge an asteroid is when it is closest to the Sun and this can make the mission much more challenging.

Alan Harris, Senior Research Scientist with JPL in California points out a mission to rendezvous with asteroid 1999 AN10 -- in an orbit which is typical of a "potentially hazardous asteroid" -- would involve a space mission which is formidable with current rocket technology. They run out of fuel well before the necessary speeds are achieved.

Maybe we should be dusting off the blueprints for the giant Saturn 5 rockets that were used for the Apollo Moon landings - just in case we need to quickly intercept an asteroid or comet on a collision course with the Earth. This may not be that easy - in his book "Mining the Sky", planetary scientist John Lewis reports that he went looking for the Saturn 5 blueprints a few years ago and concluded, incredibly, they had been "lost".

Harris cautions that even the mighty Saturn 5 could only deliver a few pounds/kilograms of payload to land on, or orbit, an asteroid such as 1999 AN10. He adds "Ion drive is probably the most feasible way out of this quandary."

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To Nuke or To Nudge

By Michael Paine
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An asteroid is heading for Earth. With just days to go before the collision a beefed-up space shuttle is sent to intercept it. A brave team of astronauts and oil-rig workers drills deep into the space rock, plants a nuclear bomb and blows it in two. The two halves fly apart and miss the Earth.

Dream on!

The idea of blowing up an asteroid makes for good movie scripts, but is not the way to do it in the real universe. Many of the fragments would remain on a collision course and like the blast from a shotgun; the fragments can do up to ten times as much damage as the original, intact object.

"Yippee-Ki-Yay …Hmmm, maybe not." Bruce Willis meant well in "Armageddon" but he could have doomed us all

In any case, Erik Asphaug from the University of Southern California has modeled "rubble-pile" asteroids and finds that blowing them up with bombs may be much more difficult than with asteroids made of solid rock. It is a bit like the difference between hitting a sandbag and a solid sandstone block with a sledgehammer -- the sandbag absorbs the impact with little disruption but the sandstone block shatters.

Applying a nuclear "nudge"

"Stand-off" nuclear explosions are favored by some scientists (see below) and might work with both solid and rubble-pile objects.

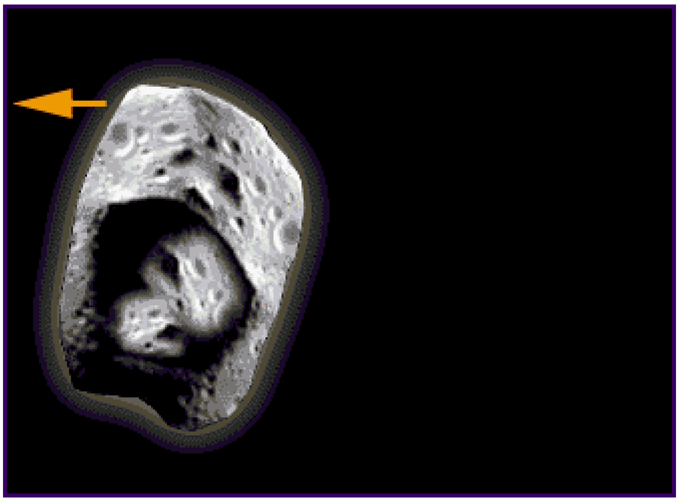
A nuclear bomb is detonated several hundred yards away from the object. Surprisingly, it is the intense radiation generated by the explosion that does the job. In one scenario, the radiation grills one half of the asteroid and causes a very thin surface layer to vaporize and fly off into space.

Tens of tons of material blasting off the asteroid at high speed would be sufficient to jolt the asteroid in the opposite direction. The effect is like the recoil of a rifle -- a small bullet moving at high speed causes the heavier rifle to recoil at low speed.

One thing most scientists agree on is there is no need to maintain an arsenal of nuclear weapons in space ready to intercept rogue asteroids. They also point out that there are ways to deflect asteroids that don't require nuclear explosions and we should be looking at these methods more closely.

In theory, an asteroid that is found to be on a collision course with our planet can be deflected to avoid an impact.

The deflection involves changing the asteroid's course with a sideways push or, preferably, changing its orbital speed so that it arrives before or after, rather than when Earth crosses its path. In either case the deflection is far more effective if it can be carried out years or decades ahead of the predicted collision.



Nuclear Deflection: A safer, more effective procedure

For example, after twenty years, a nudge of just 1 m.p.h. (1.6 kilometers per hour) would change an asteroid's location in space by about 170,000 miles (273,500 kilometers). That is more than halfway to the moon.

Recent discoveries suggest that deflection of some Earth-threatening asteroids may be easier than first thought. Most schemes for nudging asteroids into a safer orbit assumed a single catastrophic encounter with Earth. This meant changing the course of the object by at least 4,000 miles (6,300 kilometers) -- the radius of Earth.

Alan Harris, from NASA's Jet Propulsion Laboratory, explains that scientists now realize an asteroid will usually make several close passes by the Earth before a collision occurs.

The recently discovered 1000-yard (1-kilometer) wide asteroid designated 1999 AN 10 provides an instructive example. It will make a close pass of Earth every few decades. During each pass the asteroid is deflected slightly by the Earth's gravity.

Astronomers in Italy have calculated that a critical deflection could occur in 2027. This would involve the asteroid passing through an imaginary hoop in space they call a "keyhole". If the asteroid were to pass through this keyhole, which is only about 60 miles (100 kilometers) across, then it would collide with the Earth on its return in 2039.

When the initial calculations were made, astronomers didn't know the orbit well enough to determine if it might pass through the keyhole. After important follow-up observations were made they have now pinned down the orbit enough to be sure that it will not pass through any keyhole in 2027 and *there is no chance that it will collide with Earth in the next century or so*.

If, however, they had determined instead that there was a chance it would pass through a keyhole in 2027, then a mission to place a transponder, like a radio homing device, on the asteroid would have been wise so that its orbit could be determined precisely.

Harris explains that such a high level of precision would likely be required to determine for sure if the asteroid were on a course through a keyhole and, if it came to be, to measure the success of any deflection efforts. In this case a deflection of just a few hundred miles prior to the 2027 keyhole event would be all that was needed to avoid the 2039 collision.

Deflection of dangerous asteroids that are not in a "keyhole" orbit is more difficult because a larger change in course is required. The task is still feasible provided that sufficient warning time is given.

If a serious global effort is made to discover most large near-Earth asteroids within the next decade, then we should have decades, or even centuries of warning before a devastating impact. With such lead times only a relatively small nudge is required to change an asteroid's course so that, decades later, it will miss Earth.

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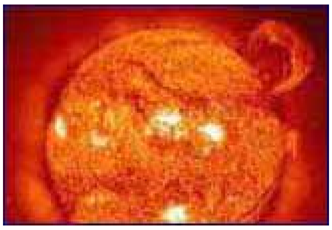

Sailing with Sunlight: Non-nuclear Asteroid Deflection

By Michael Paine
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Asteroid expert Jay Melosh from the University of Arizona has looked at a range of ideas for deflecting asteroids without resorting to nuclear weapons. They include:

- Deploying a giant parabolic mirror to concentrate the Sun's rays and vaporize rock on the surface of the asteroid. The vaporized material flies off at high speed and generates a recoil action that pushes the asteroid, slowly but surely, in the opposite direction.
- Landing cannon-like devices on the surface to fire asteroid material into space. This also depends on recoil action. An ion drive, as used on the Deep Space 1 spacecraft, might do the trick.
- Attaching a giant solar sail to the asteroid

The solar sail (pictured below) uses the small pressure of sunlight acting over a large area to steadily move the asteroid.

CREDIT: NASA/JPL

Melosh points out that the sail needs to be steerable, like the sails of a modern yacht, to tug the asteroid in the right direction:

"An along-orbit push (at right angles to the Sun) is by far the most effective in changing a collision into a miss," Melosh says.

There are two other ideas related to the solar sail concept: a giant silvery balloon (which in theory would be easier to deploy than a sail) and wrapping the asteroid in foil (or painting it) to increase its reflectivity. Melosh explains "with such a reflector it is hard to steer -- it can only apply a force directly away from the Sun, which is the least helpful direction".

Melosh is cautious about techniques that depend on being attached to the asteroid.

"The asteroid is rotating and perhaps tumbling -- a hard object to tie anything up to," he says. "It would probably have to be enclosed by a system of gimbals anchored to the asteroid surface: a mechanical nightmare begging for a catastrophe."

The solar mirror scheme, preferred by Melosh, has the advantage that it could avoid the need for physical attachment to the asteroid. During the 1960s NASA did some work on solar mirrors for use in space, but little has been done since then.

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Space Missions: Chasing Comets and Asteroids

By Michail Paine
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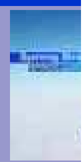
Several researchers are using super-computers to predict the effects of asteroid deflection techniques. One day these simulations may be needed to plan a mission to save the Earth from a collision.

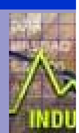
But the physical properties of asteroids and comets are poorly understood, and so the information gathered from space missions to these objects is crucial for these simulations.

Several challenging missions to asteroids and comets are underway or are planned.

Space Missions to Asteroids and Comets

Deep Space 1: NASA. Launched in 1998. DEEP SPACE 1 flew within 10 miles of asteroid 1992 KD(Braille) on July 28, 1999. The mission is mainly a test of new propulsion and navigation technology. The extended mission was to include flybys of two comets, Wilson-Harrington and Borrelly, but a problem with the tracking system meant that priority is now being given to Comet Borrelly.
NEAR: NASA. Launched in 1996. NEAR flew within 753 miles of Asteroid Mathilde in June1997. Earth swingby January 1998. Planned Eros rendezvous in January 1999 failed. Next attempt 14 February 2000 when NEAR will go into orbit around Eros.
MUSES-C: Japanese Space Agency. Launch planned for 2002. MUSES-C is a mission to asteroid Nereus. This mission will return fragments of the asteroid's surface to the Earth for detailed analysis.
CONTOUR: ASA/JPL Launch planned for 2002. The CONTOUR spacecraft will study three, Encke, Schwassmann-Wachmann 3 (SW3), and d'Arrest.
Rosetta: ESA (European Space Agency). Launch planned for 2003. ROSETTA is designed to land, and stay on, comet Wirtanen as it tours the inner solar system.
Stardust: NASA. Launched 1999. STARDUST will fly past comet Wild-2 and capture dust grains blown from the comet's surface. These will be returned to Earth for analysis.
NEAP: Spacedev Corp. SpaceDev is a publicly owned company. With the assistance of the science community, SpaceDev has selected 4660 Nereus, possibly a carbonaceous near earth asteroid, as its NEAP mission target. To reach Nereus, NEAP is currently scheduled to launch on April 3, 2001 (possibly put back 9 months to simplify the mission) NEAP will land a payload on the surface of the asteroid. It will be a demonstration of the potential for commercial mining of asteroids.





Deep Impact: NASA/University of Maryland. Launch planned for 2005. A University of Maryland proposed space mission to penetrate deep into the nucleus of a comet. The launch of the DEEP IMPACT mission is planned for January 2004. The schedule calls for the mission to reach its target, comet Tempel 1, at the beginning of July, 2005 with impact on July 4.

Although knowledge about asteroids is important for protecting the Earth from collisions it is more likely to be used, ultimately, for commercial purposes.

Over the next few decades an impact by a large asteroid is highly unlikely (but cannot be ruled out). During that time commercial mining of asteroids may be commonplace.

Many asteroids are rich in the raw materials needed for manufacturing in space, and some are easier to reach than the Moon. Of course, one way to deal with an earth-threatening object is to mine it away to nothing.

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