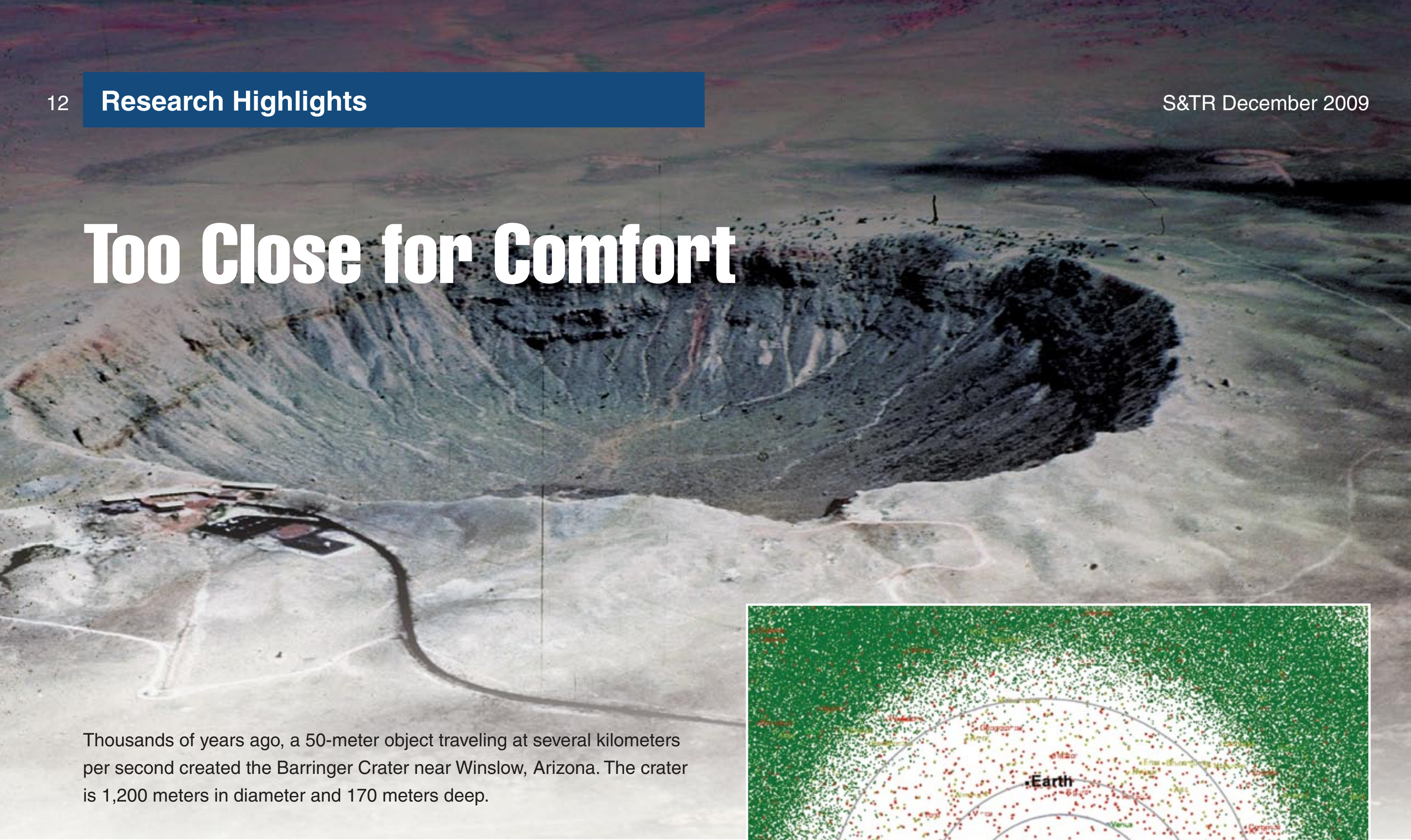


Too Close for Comfort

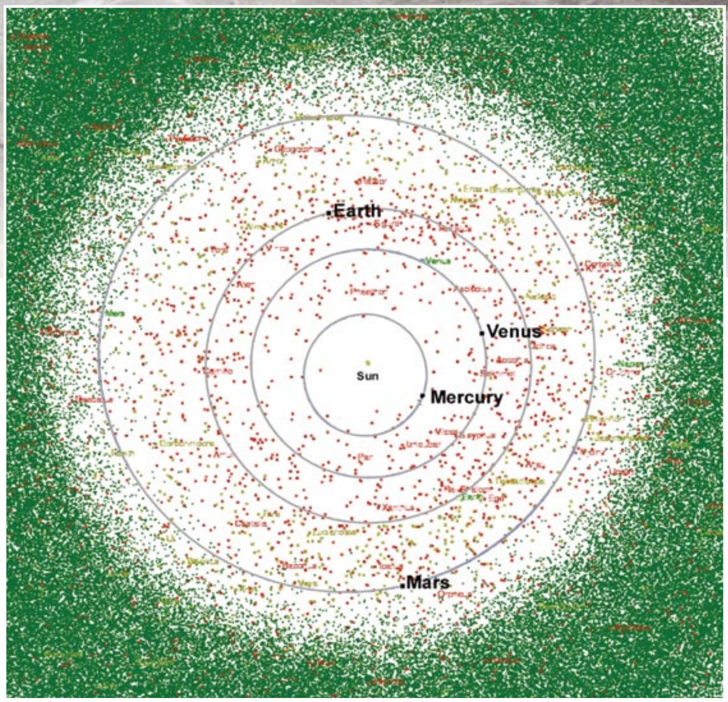
Thousands of years ago, a 50-meter object traveling at several kilometers per second created the Barringer Crater near Winslow, Arizona. The crater is 1,200 meters in diameter and 170 meters deep.

ASTEROIDS impacting Earth and causing mass devastation are a familiar topic in science fiction books and movies, but many people think such an event has little basis in reality. Scientists who study our solar system know better. For space-savvy professionals, this seemingly fantastical idea is not just fodder for entertainment purposes; it is a real concern. To prevent such a catastrophic event, scientists across the nation, including Livermore astrophysicist David Dearborn, are analyzing techniques to disrupt or divert asteroids on a collision course with Earth.

First discovered in the 1800s, asteroids—also known as minor planets—have become a hot topic in the last three decades, when space surveys began recording high concentrations of these celestial bodies in our solar system. As telescopes and other astronomical survey tools have become more precise, they have revealed that the number of asteroids within Earth's orbit is significantly greater than previously predicted. In addition, evidence of past impacts indicates that the collisions may have caused widespread devastation.

In 1998, the National Aeronautics and Space Administration (NASA) started the Spaceguard Near-Earth Object Survey to acquire data on objects that orbit close to the Sun. Survey data, such as those shown in the figure above right, allow researchers to estimate the potential danger of the many objects within Earth's orbit. The NASA program has primarily focused on identifying asteroids and comets that are larger than 1 kilometer in diameter.

"An object of this size would have approximately 1 billion tons of mass," says Dearborn, who works in the Laboratory's Science and Technology Principal Directorate. "If it traveled at 30 kilometers per second, it would have explosive power equivalent to 100 billion tons of TNT." In the event a 1-kilometer-size asteroid impacted Earth, the energy released would have global-scale effects.



Data from space surveys conducted in 2006 show the recorded near-Earth objects of various sizes that either cross (red) or are outside (green) Earth's orbit. (Courtesy of National Aeronautics and Space Administration/Jet Propulsion Laboratory.)

Dearborn serves on a research panel, spearheaded by the National Academy of Sciences, tasked with evaluating methods to divert potentially hazardous objects—those that could hit Earth in the next 100 years. The panel is considering several diversion

This view of the 52-kilometer-long asteroid 243 Ida is a mosaic of five image frames acquired by the Galileo spacecraft on August 28, 1993. (Courtesy of National Aeronautics and Space Administration/Jet Propulsion Laboratory.)

technologies, but for Dearborn, nuclear explosives provide the best solution for dealing with catastrophic asteroids.

Dearborn has extensive experience in designing and testing nuclear and conventional explosives and leads the effort to model the impact of a nuclear explosion on an object's trajectory in space. Ultimately, Congress, the National Science Foundation, and NASA will use the information to determine the most effective strategy for deflecting asteroids.

Deflection or Fragmentation

Scientists use an asteroid's size, speed, kinetic energy, and orbit to determine whether it is potentially hazardous. An impact occurs when the orbits of an asteroid and Earth intersect and the two bodies reach the same point simultaneously. As the asteroid enters Earth's atmosphere and plummets toward the ground, it picks up speed, increasing its kinetic energy. The potential hazard depends on the asteroid's composition and size. "Small asteroids typically break apart in the atmosphere, burn up, and pose no real threat," says Dearborn.

However, in 1908, an asteroid 30 to 50 meters in diameter broke apart in the atmosphere, and the resulting airburst sent a shock wave to the ground, destroying 2,000 square kilometers of forest near the Tunguska River in Russia. "Because of the increased population density in many parts of the world," says Dearborn, "a similar impact today could affect several hundred thousand people." He adds that even more damage would occur if the object were to reach the ground intact.

Such an event can be avoided by nudging the asteroid off course or by fragmenting it. The action needed depends on the object's size and the time available before impact. According to Dearborn, nuclear explosives are the optimal method for diverting large asteroids or those that are too close to Earth—less than a decade away in time—to be deflected through other means. One benefit is that nuclear explosives are an established technology. "They are well tested and characterized," says Dearborn, "and the outputs and effects of explosions are well understood." In addition, nuclear explosives have a high energy-to-weight ratio, so they offer the lowest mass method for transporting energy to the asteroid.

To evaluate the effectiveness of different approaches, Dearborn and his colleagues used the Laboratory's multidimensional hydrodynamic codes to simulate three scenarios in which a nuclear explosive diverts an inhomogeneous, 1-kilometer-diameter structure. For each scenario, the team altered nuclear outputs, explosives energies, distances from the object, and the height or depth at which the explosion occurs.

In the first scenario, called the standoff approach, the nuclear explosive is detonated at a distance from the asteroid. The x rays, gamma rays, or neutrons produced by the explosion heat a hemispheric area of the asteroid. The energy applied to the body's surface vaporizes or obliterates the heated area, reducing the object's mass and giving it a "push." This push changes the asteroid's speed by a fraction of a centimeter to a few centimeters per second—just enough to prevent a collision.

The second scenario, also designed to reduce an asteroid's mass and push it slightly, involves detonating a low-yield explosive on its surface. The third scenario—a last resort—is for asteroids that are too close to Earth. In this approach, a nuclear explosive is detonated a few meters below the object's surface, fragmenting it.

Each simulation produced data on the deformation and speed change induced by the explosion and the resulting dispersion of material within space. By viewing these simulations, Dearborn and his colleagues can determine whether a nuclear explosive would have the desired result and whether the fragmented material would pose additional threats.

The simulated results indicate that in all three scenarios, the fragments created would be small and fast enough to avoid collisions with Earth. Future studies will vary the simulated object's shape, density, and porosity to determine how an asteroid's composition affects the outcome.

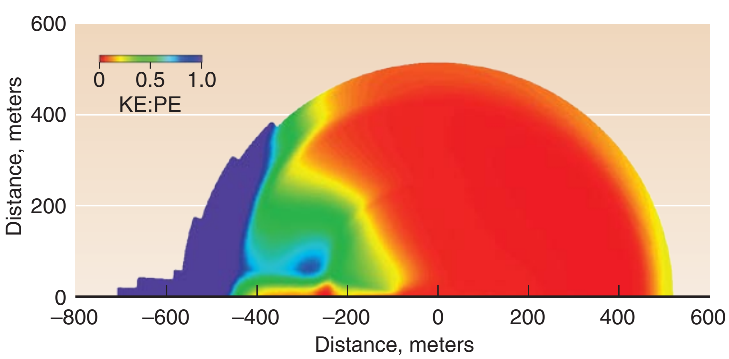
Exploring Options

Some potential deflection technologies are proving to be too expensive or too heavy to be feasible. Others would require too many technological advances to be implemented in the near future. One proposal is to attach rockets to an asteroid and push it out of its current orbit. This method would provide an adequate speed change and keep the bulk of the asteroid intact. However, asteroids have extremely low surface gravity, so attaching a rocket to one would be a logistical nightmare. "On a 1-kilometer asteroid, a 200-pound person would weigh less than one-fifth of an ounce," says Dearborn, "and a normal walking speed would be nearly two times escape velocity," that is, the speed needed to break free of the asteroid's gravitational field. Thus, the slightest pressure applied to the asteroid would push the rocket farther away, out of reach of the asteroid.

The rocket method could also be quite expensive. "Even if we ignore the challenges associated with anchoring a rocket engine to a rotating asteroid and with pushing an asymmetric object, a rocket would need thousands to millions of tons of fuel for successful diversion," says Dearborn. The closer the object is to Earth, the more fuel is required to produce the speed change needed. Deflecting an asteroid that is 20 to 30 years away would require about 10,000 tons of fuel. Significantly more fuel would be needed for objects less than a decade away.

NASA is evaluating impactor technology as a possible solution to diverting asteroids. These devices are designed to collide with the asteroid and change its momentum. "Tests during NASA's Deep Impact mission showed that impactors can divert smaller bodies, such as asteroids up to approximately 300 meters in size," says Dearborn.

Another diversion method is the gravity tractor. In this deflection scheme, the gravitational attraction between the asteroid and a spacecraft allows the spacecraft to move the asteroid off course over time, a process that could take years or even decades.



Simulation results show the effects of detonating a 1-kiloton nuclear explosive 150 meters above the surface of a 1-kilometer-diameter object. Colors indicate the ratio of kinetic energy (KE) to potential energy (PE) produced by the impact. The explosion obliterates the ejected debris (purple). In the bound areas (light blue to red), the object receives a "push," which changes its speed by a few centimeters per second.

According to Dearborn, this method may be advantageous for only about 5 percent of asteroids and would require major advances in technology before a spacecraft could carry out the mission successfully. Lasers have also been proposed, but even the most powerful lasers in existence would have to function over thousands of years to have any effect.

Methods that rely on elaborate launching stations or that add components to spacecraft could require putting an extra 20 tons of material into deep space. Conversely, nuclear explosives, with their high energy-to-weight ratio, would need comparatively less material to do the same job.

Dispelling Criticism

Not everyone shares Dearborn's enthusiasm and confidence in using nuclear explosives to deflect asteroids. Yet, in the face of skepticism, Dearborn remains resolute. "Part of my job is to respond to criticism and to dispel myths related to the use of nuclear explosives," he says. A common objection is that nuclear explosives will break the asteroid into large chunks and scatter debris all over Earth. Some critics are also concerned that radiation generated by the explosive will spread throughout the solar system and have undesirable effects. "This assumption is not true," says Dearborn. "Debris from the explosion would be spread over a solar system already full of cosmic rays. The solar wind would sweep the debris out of the solar system. If for some reason it did not, by the time the radiation was swept up by Earth, it would be a small amount compared to normal background levels."

Although there is some uncertainty in determining exactly when and where an asteroid could impact the planet, Dearborn notes that no asteroid currently being monitored poses an immediate threat. "But that doesn't mean we shouldn't have a deflection plan in place," he says. And nuclear explosives may prove to be the best technology for the job.

—Caryn Meissner

Key Words: asteroid, deflection, fragmentation, gravity tractor, impactor technology, Spaceguard Near-Earth Object Survey, nuclear explosive, space.

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