# KILLING KILLER
ASTEROIDS

In 2004 an alarm went around the globe that a very large near-Earth asteroid, about three football fields in diameter, had a frighteningly high chance (1 in 37) of striking the planet in 2029. Named Apophis for the Egyptian god of darkness and destruction, this space rock would pack a gigantic wallop if it actually struck Earth, releasing the energy of 500 megatons (million tons) of TNT, or 10 of the largest hydrogen bombs ever tested.

Also, we know with certainty from many fields of study that 63 million years ago, a 6-mile-diameter asteroid collided with Earth, striking Mexico's Yucatan peninsula, releasing 10 million megatons of energy, creating a huge crater, and causing the extinction of the dinosaurs, a major change in climate, and the beginning of a new geological age. Any near-Earth object greater than a half-mile in diameter can become a deadly threat, potentially causing a mass extinction of us.
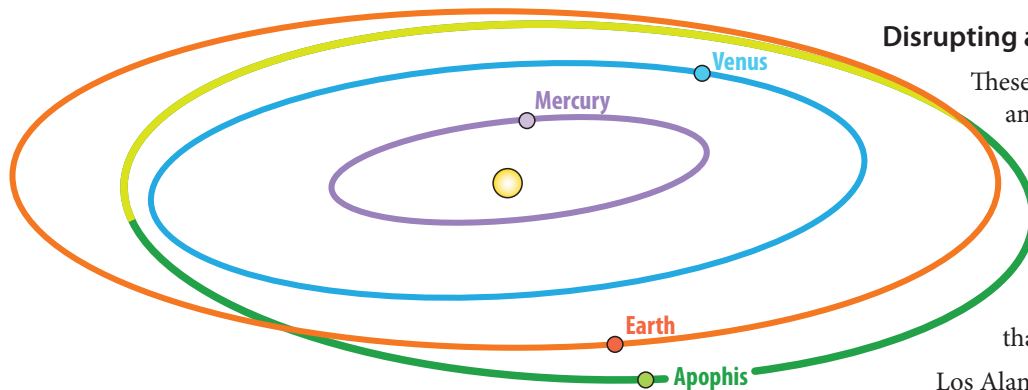
The orbit of the asteroid Apophis is so close to Earth's that we can expect many close encounters in the future.

As more observations accumulated, the Apophis threat was dramatically downgraded. Apophis was expected to pass relatively close to Earth in 2029, at a distance closer than the geosynchronous communication satellites that keep us all in touch with one another, but it would not be on an impact trajectory. However, should it pass through a small region of space called a "gravitational keyhole," the killer asteroid would return seven years later on a collision course and strike Earth on February 13, 2036!

Then during January of this year, scientists used NASA's giant Goldstone radar dish to track Apophis as it passed within 9 million miles of Earth and, from the results, recalculated its future orbits. Mercifully, its chance of passing through the keyhole in 2029 is now zero, and its return in 2036 will be at a very comfortable 14 million miles away.

Disrupting a Killer Asteroid

These facts keep many professional and lay astronomers busy monitoring the sky. Recognizing the risk, astrophysicists are working on ways to intercept a killer asteroid and disrupt it in some way that will avert disaster.

Los Alamos astrophysicist Robert Weaver is working on how to protect humanity from a killer asteroid by using a nuclear explosive. Weaver is not worried about the intercept problem. He would count on the rocket power and operational control already developed by NASA to intercept a threatening object and deliver the nuclear device. NASA's Dawn Mission has been able to place a spacecraft in orbit around Vesta, a huge almost-planet-size asteroid in the asteroid belt between Mars and Jupiter, and the NASA Deep Impact mission sent a probe into the nucleus of comet 9P/Tempel. In other words, we have the technology to rendezvous with a killer object and try to blow it up with a nuclear explosive. But will it work?

> *Simulations on Los Alamos' powerful Cielo supercomputer suggest that a 1-megaton nuclear blast could deter a killer asteroid.*

Weaver's initial set of simulations on Los Alamos' powerful Cielo supercomputer demonstrates the basic physics of how a nuclear burst would do the job. The simulations suggest that a 1-megaton nuclear blast could deter a killer asteroid the size of Apophis or somewhat larger.

By far the most detailed of Weaver's calculations is a 3D computer simulation of a megaton blast on the surface of the potato-shaped Itokawa asteroid. Visited by Japan's Hayabusa asteroid lander back in 2005, Itokawa is a conglomerate of granite rocks, a quarter of a mile long and about half as wide, held together by self-gravity (the gravitational attraction among its constituents). Weaver used the most modern, sophisticated Los Alamos codes to predict the progress of

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Whew! We can all temporarily breathe a sigh of relief. However, the likelihood that one day a killer asteroid will be on a collision course with Earth is very high. Under a 2005 congressional mandate, government-sponsored surveys using ground and space-based telescopes have discovered 9,500 near-Earth objects; 1,300 of these, are deemed potentially hazardous. New asteroids and comets can be expected to enter Earth's neighborhood as the gravitational pull of passing stars and collisions between asteroids do their work to alter the orbits of these (mostly) Solar-system residents.

a megaton nuclear blast wave from the point of detonation through the asteroid.

"A big plume coming out of the asteroid in the simulation [see image on opposite page, bottom left] is the effect of all that heated rock in the vicinity of the explosion being expelled from the asteroid at high velocities," Weaver says. "The shock wave from the explosion transfers kinetic energy to the individual rocks, and then as the rocks move, they hit other rocks, causing more rock-to-rock kinetic energy transfers. These rock-to-rock interactions propagate the energy from the surface all the way through to the opposite end of the asteroid, totally disrupting these rubble piles." A YouTube video of the 3D simulation can be seen at http://www.youtube.com/watch?v=hOcNbAV6SiI.

> *A calculation of this complexity requires the next generation of supercomputers, the so-called exascale computers.*

Computing Limitations

Los Alamos' Cielo supercomputer is a 1.43-petaflops machine—meaning it performs just over a quadrillion (million billion) arithmetic computations per second. It is one of the most powerful computers on the planet. Cielo is composed of 32,000 independent computers that work "in parallel"; that is, they work on separate parts of the calculation simultaneously.

Even with Cielo's massive computing power running for a full month, the 3D calculation simulated the detonation's progress for only 30 milliseconds, at which point the blast wave had traveled through only about 25 percent of the asteroid's volume. To reach completion the simulation needs to run 10–60 seconds past detonation, following the blast wave through the entire asteroid, computing the breakup into rocks that then collide with each other, and finally following the trajectories of the individual pieces resulting from the breakup. That would take Cielo about three years of running time. To be practical, a calculation of this complexity should take only a few days, and that requires the next generation of supercomputers, the so-called exascale computers that would calculate a billion billion computations per second, or 1,000 times more calculations than a 1-petaflop supercomputer.

The 2D Results

To complete the simulation on Cielo, Weaver made some drastic simplifications to the asteroid model so that it could be run in 2D instead of 3D. The lumpy asteroid became a simple, smooth cylinder made up of smooth cylindrical rocks. The asteroid model's symmetry meant that the outcome of the blast could be calculated in just a couple of days on Cielo, compared with three years for the full 3D calculation.

Weaver was very encouraged by the results. "In my 2D calculations, I'm seeing velocities of meters per second imparted to expelled rock on the side of the asteroid opposite the detonation point," Weaver says. "The escape velocity [the velocity needed to escape the self-gravity of the asteroid] for an asteroid like Itokawa is only fractions of a centimeter per second, so the expelled rocks have over 100 times the escape velocity and can therefore overcome the forces of gravity tending to reassemble them into a loose pile of rock. That was a surprise to me and gave me some confidence that a nuclear blast really would be an effective mitigation technique. The asteroid would not re-collect, and it would not pose a hazard of a bunch of smaller rocks hitting the Earth."

Some astrophysicists had predicted that fragments from a nuclear blast would move very slowly, so slowly that they

This photograph, taken in 2005 by a Japanese space probe, shows the elongated, lumpy shape of the asteroid Itokawa. The asteroid was the basis of Weaver's simulations, performed on the Cielo supercomputer.
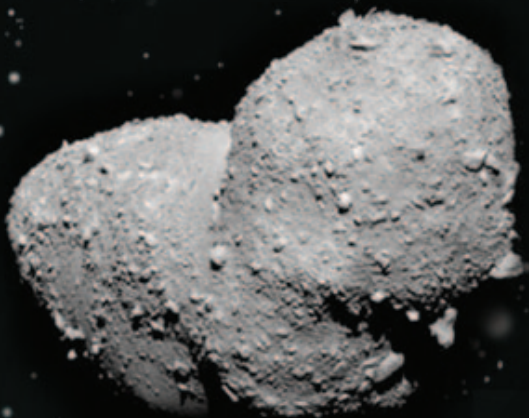
100 yd

This 3D simulation shows the asteroid Itokawa during the initial impact of a blast wave (red and white) from a nuclear detonation on its surface. Itokawa is depicted as a random distribution of rocks 5–50 yards in diameter.
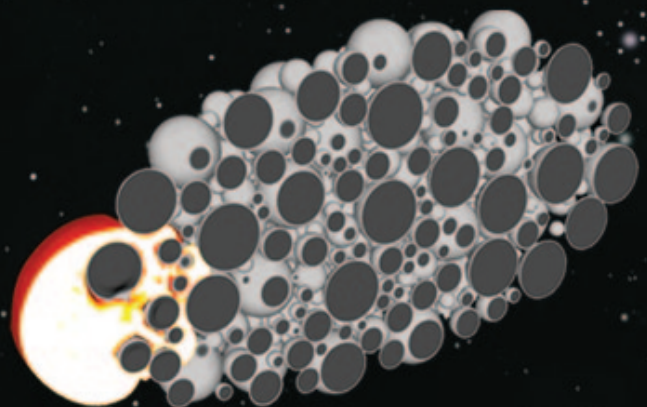
would recondense into a bunch of large rocks, large enough to hit Earth's surface with damaging impact. The fact that the simulated fragments had speeds well beyond the escape velocity refuted that prediction. Moreover, pointing the blast in a direction perpendicular to the asteroid's motion would make the rocket effect of the blast (which heats material at the asteroid's surface and creates a blowoff opposite the direction of impact) force the fragments to move in the same direction as the blast impact, out of the asteroid orbit and away from Earth. In other words, a nuclear blast could act like a propulsion system, directing the asteroid fragments in a desired direction.

> *Weaver will next turn to simulating larger and larger rocks of varying compositions up to the size of a "dinosaur killer."*

"All this depends obviously on exactly where the intercept is done, how far away from the Earth it is, how much time we have left—and all of these are unknowns until we discover a threatening asteroid," Weaver says. "What I think I'm bringing to the table for the first time are truly validated simulations of these nonuniform, nonspherical compositions that will hopefully give policy makers a better understanding of what their options are." Weaver will next turn to simulating larger and larger rocks of varying compositions up to the size of a "dinosaur killer" (about 6.2 miles across). To that end, Weaver and Los Alamos will soon begin a collaboration with Lawrence Livermore National Laboratory that will pool computational and funding resources to take this kind of asteroid mitigation exploration to the next level, assessing a range of potential threats.

Nuclear versus Alternative Options

In suggesting a nuclear energy source for asteroid mitigation, Weaver says he is being practical. Nonnuclear options could prevent impact by deflecting the incoming asteroid through the use of gravitational tractors (spacecraft that travel alongside the asteroid for a decade or two and have enough mass to pull the object off its collision course with Earth) and impactors (rockets that make direct hits on the asteroid and throw it off course). Weaver believes these nonnuclear options would need a decade of planning and development before they could be deployed. In addition, they would need to be deployed many years in advance of the impending collision.

But objects can appear with little warning, he explains. The most likely ones are extraplanetary comets, objects not bound in orbit around the Sun that travel toward us in a plane different from the Earth-Sun plane. If we have only a 6-month lead time, the most practical option is a nuclear device. "From my perspective," he says, "the nuclear option is for the surprise asteroid or comet that we haven't seen before, one that basically comes out of nowhere and gives us just a few months to respond," says Weaver.

As if to illustrate Weaver's point, Earth recently got a violent demonstration from one of his "out of nowhere" objects. On February 15 a meteor blazed through Russian skies and exploded, generating a brilliant flash and a shower of meteorites. Fifteen hundred people were injured by the broken glass and debris resulting from the shock wave.

With such a graphic example in people's minds, the pros and cons of alternatives are being hashed out at the next biannual Planetary Defense Conference. There, scientists of all persuasions discuss the best mitigation strategies and the international agreements that must be put in place before any of the strategies can be implemented.

~ Necia Grant Cooper

As the blast wave travels through the asteroid, it creates a backward-flowing plume of hot material (red, orange, and white in this simulation), propelling the asteroid in the opposite direction.
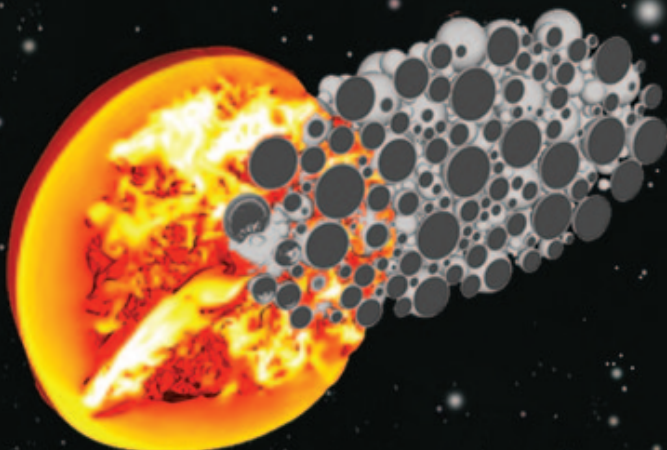
Alternative proposals for altering an asteroid's path include using the gravitational pull between the asteroid and an unmanned space "tractor" to shift the asteroid to a new orbit.