HOW TO SAVE THE WORLD

An asteroid impact is the one natural disaster we can actually prevent.

THE NASA ADMINISTRATOR GETS THE CALL. A new asteroid has been detected. It's big—not drove-the-dinosaurs-to-extinction big, but still nearly a kilometer across. Its trajectory suggests that, in a few years, it could crash into the earth. If it does, it will completely devastate some part of the world: obliterate a major city, flatten a forest, bury a huge swath of land in fiery rock, or, if it hits at sea, potentially wipe out hundreds of miles of coastline with a tsunami.

There are thousands of asteroids with Earth-crossing orbits, and close calls are not so rare. Just this past July, an asteroid large enough to destroy a city passed within about 75,000 kilometers (km) of the earth; that's only about five earth-widths away and less than one fifth of the average distance to the moon. Had it crossed directly ahead of the earth's path, it would have missed by only 42 minutes.

There are a handful of people in the world making preparations to defend the world against killer asteroids. Among them, Cathy Plesko and her collaborators at Los Alamos—colleagues, postdocs, and students—are working out the plans necessary to intercept an incoming asteroid and nudge it off course with as little advance notice as possible. As things stand today, Plesko thinks we could develop and implement a plan to deflect a large asteroid if we had five or ten years of lead time—time to develop and launch a mission, time for the spacecraft to reach the asteroid, and time for the redirected asteroid to edge far enough off course to skirt around our planet.

"That far out, we couldn't gauge its orbital path with enough accuracy to know for certain that it will hit," says Plesko.

“There might only be a one-in-four chance. But if we wait long enough to become fairly certain, there won’t be enough time to act. It’s a difficult problem.”

Chelyabinsk and Chicxulub

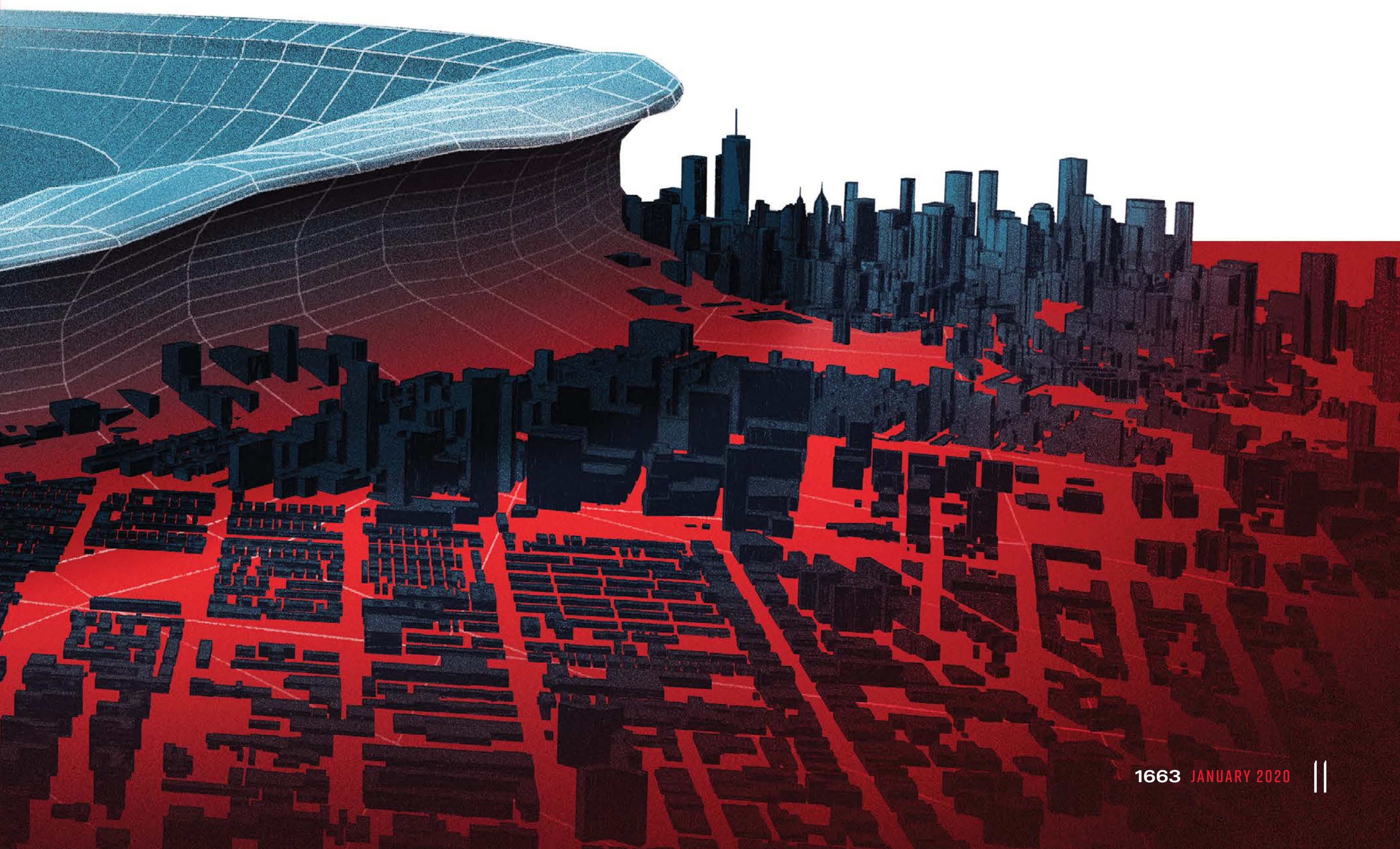
Different asteroids threaten different amounts of damage, depending largely on their size. In 2013, a 20-meter (20-m) diameter asteroid exploded about 30 km above Chelyabinsk, Russia, well above most of the atmosphere. The explosion was reportedly brighter than the sun and produced a shock wave that arrived on the ground several minutes later, breaking glass and causing other damage to thousands of buildings in the dead of winter. In the shock wave and the subsequent panic, about 1500 people were injured. Although no one was killed, the explosion produced about 30 times more energy than the Hiroshima atomic bomb.

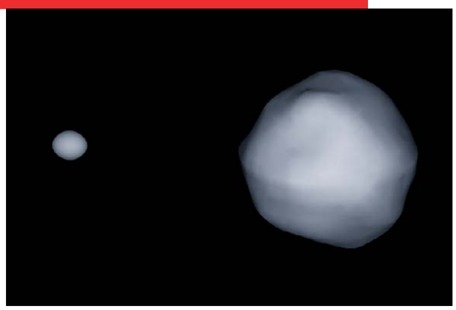
The most powerful meteoric airburst ever recorded was a little over a century earlier—also, coincidentally, over Russia. That object was probably several times larger than the Chelyabinsk asteroid and its explosion perhaps 50 times more energetic (estimates vary). It is believed to have penetrated to less than 10 km above the ground, where its fireball flattened 2000 square kilometers of forest and killed several people.

Such airburst events, from asteroids in the tens or low hundreds of meters in diameter, would be difficult to prevent. By virtue of their small size, these objects reflect little sunlight and can therefore be virtually undetectable; the Chelyabinsk object, for example, was unknown prior to its arrival. Furthermore, the level of damage caused by such events is limited enough that it may not justify the expense of a space mission to prevent it.

At the other end of the spectrum, an incoming object several tens of kilometers in diameter, such as the one that produced the Chicxulub crater in the Mexican Yucatán and is believed to have caused the mass extinction that wiped out the dinosaurs, would be very difficult to deflect from a collision course because of its sheer inertia. Perhaps it could be done, but it would probably require a large number of space missions to do it.

Plesko has so far focused on the fertile ground in between: objects ranging from several hundred meters to several kilometers in diameter. Such objects are more numerous than the extinction-causing ones and generally survive the trip through the atmosphere and reach the ground. A best-case scenario would be an impact in the middle of the ocean, far from land. A series of large circular waves would expand outward in all directions, attenuating as they travel, perhaps generating a small tsunami on the closest shorelines. If the same event occurred within a few hundred kilometers of land, however, the effects would be devastating. Plesko’s colleague Galen Gisler developed a computer simulation that showed such an impact would produce waves hundreds or thousands of meters high. (The tallest building in the Western hemisphere, One World Trade Center in New York, stands at 541 m.)





(Above) The asteroid Bennu is currently being orbited by NASA's OSIRIS-REx spacecraft, which will eventually touch down, collect a sample, and return the sample to Earth for study. Bennu could threaten a collision with the earth in the 22nd century; understanding its composition will help scientists determine how best to deflect it, and others like it, off of a collision course. (Right) NASA's DART mission will experiment with intercepting and deflecting an asteroid in the binary-asteroid system Didymos. A kinetic impactor (weighted spacecraft) will slam into "Didymoon," the smaller of the pair, and thereby alter its orbit around the larger body without changing the likelihood of either one approaching Earth in the future.

CREDIT: (Above) NASA/Goddard, University of Arizona, Lockheed Martin; (right) NASA

A similar object striking land would result in a crater ranging from a few kilometers in diameter to several tens of kilometers. For example, an asteroid a few kilometers across could produce a crater roughly 20–30 km wide—several times the size of Washington, D.C.—and eject a massive amount of rock, soil, and other debris, burying everything over hundreds of kilometers in every direction.

This is what one rocket, or maybe a few, might prevent.

Plan A: ram it

Plesko uses computer models to evaluate the effectiveness of potential space interventions to deflect asteroids off of a collision course. There are two options: a nonnuclear option and a nuclear option. The nonnuclear option is called a kinetic impactor; the spacecraft itself, heavily weighted, rams the asteroid. (The nuclear option, in this context, isn't metaphorical; it's an actual nuclear detonation.)

"On the face of it, the kinetic impactor is severely limited by how much weight we could get off the ground and then get up to speed," says Plesko. "But here the devil is in the details. Depending on the composition of the asteroid in question, we might get a serious enhancement effect on impact."

It may seem counterintuitive, but simulations show that the momentum ultimately imparted onto the asteroid can be significantly larger than the momentum of the impactor itself. When the impactor strikes, it causes a great deal of ejecta to blast off of the impact surface, producing an equal and opposite recoil. As a result, there is a gain relative to the kinetic impactor strike. How much of a gain depends on the "competence" of the asteroid. For a single, solid (competent) chunk of rock, there will be little ejecta; the gain might be 20 percent. For a loose assembly of smaller rocks held together only by the relatively weak gravity of the asteroid, there could be a great deal of ejecta, and the gain might be as much as ten times the original momentum of the impactor.

> If you hit a rock **hard enough,** it **flows like water.**

However, even if the asteroid is loosely bound together, simply breaking it apart with an impactor may not be ideal; the details matter. If the asteroid produces a modest amount of high-speed ejecta and the remaining body is deflected off course, then great. But if the asteroid essentially disintegrates but remains on course for Earth, then the resulting spray of smaller objects could still do a great deal of damage by shredding satellites and by heating and dust-loading the atmosphere, resulting in various complex and destructive climate processes.

Plesko works with Los Alamos mathematical physicist Len Margolin. Together, they build and run simulations on kinetic impactor outcomes. First the impact compresses the asteroid and vaporizes part of it. This produces an explosion and a pressure wave rippling through the asteroid body and resulting in ejecta launching from across a wide stretch of the asteroid's surface centered on the point of impact. To understand the transmission of forces through the asteroid, the simulation captures not only the physical properties of rock—an area that Plesko, a geophysicist by training, holds near and dear to her heart—but also the detailed physics of fluid flows.

"If you hit a rock hard enough, it flows like water," says Plesko. The simulation she and Margolin built treats the asteroid accordingly, breaking it up into a large number of tiny fluid cells, like compressible 3D pixels. But instead of the pixels having values for red, green, and blue, they have values for pressure, temperature, and other fluid properties, and a supercomputer tracks how forces are transmitted from one cell to the next. By virtue of its experience with nuclear-weapons simulations, Los Alamos has tremendous expertise in this kind of computer modeling.

Bennu and Didymoon

Computer simulations are only as good as the physical data fed into them, and here, Plesko and Margolin are getting help from NASA on the biggest unknown factor, the composition of the asteroid. In most incoming threat cases, this will be unknown; but it may be possible to either compare telescope observations with data from other asteroid-visiting space missions in order to make an educated guess or, if there's enough lead time, launch an earlier spacecraft to study the asteroid before settling on the trajectory and other details of the intercept mission.

A NASA spacecraft called OSIRIS-REx is currently orbiting an 800-m asteroid called Bennu. Bennu passes near Earth every six years but is not expected to threaten a collision until sometime in the next century, possibly. However, Bennu is considered representative of a class of dangerous asteroids, and OSIRIS-REx is will collect some material from the asteroid in 2021 and fly it back to Earth for scientific study.

Meanwhile, another NASA mission will actually test a kinetic impactor on an asteroid. The Double Asteroid Redirection Test, or DART, for which Plesko is an active collaborator, will launch in 2021 and visit a binary asteroid system called Didymos. Within Didymos, a smaller, 160-m asteroid, affectionately but unofficially called "Didymoon," is bound in orbit with a larger, 780-m one. DART will converge with Didymoon in 2022 on a trajectory designed to alter Didymoon's orbit around the larger body without changing either body's orbit around the sun. Data collected by ground-based observations will be used to evaluate the effectiveness of kinetic impactors.

Both OSIRIS-REx and DART will return valuable information to help constrain the major unknowns in the Los Alamos simulations and calibrate expectations with hard data. Undoubtedly, that will sharpen the line between those incoming asteroids that can be effectively handled by kinetic impactors and those that cannot.

Plan B: fry it

The ideal course of action to deflect an incoming asteroid depends on many factors, such as its size, competence, and orbital trajectory—and how much time remains before it hits. For the right kind of asteroid, kinetic impactors are appealing because of their simplicity: a large mass attached to a rocket. But if the asteroid is too large or there isn't enough time, and the only way to save the world is by delivering a lot of energy to the asteroid as quickly as possible (rather than launching a series of kinetic impactors, say), then a nuclear explosion is the only way to do it.

To assess the nuclear option, Plesko collaborates with the Lab's Steve Becker. Their simulations have demonstrated two promising approaches. The first is the obvious one: fly right up to the asteroid and detonate the weapon on it. This "disrupt and disperse" approach is suitable when there isn't time for anything else and, as Plesko puts it, "you just have to get rid of the sucker."

But a more promising nuclear option, the simulations reveal, would be a nuclear detonation near, but not actually on, the asteroid. The explosion would produce a blast of energetic x-rays, which would immediately vaporize, or ablate, the surface of the asteroid. The resulting expanding gas would produce a powerful recoil, driving the asteroid away without creating a lot of dangerous debris. How far away to detonate depends on two competing factors; the closer the detonation, the more energy is directed at the asteroid rather than empty space, but the farther away, the more of the asteroid's surface will be exposed to x-rays. The ideal distance strikes a compromise between these two effects, and Plesko and her colleagues can calculate approximately how far from the surface that "sweet spot" lies.

An additional benefit of this ablation-from-a-distance method is that it spreads out the pressure on the asteroid, pushing evenly across a wide surface (like a shove), rather than concentrating all the force on one spot (like a stab), as a surface detonation or a kinetic impactor would do. In fact, even for incoming asteroids with size and lead time suitable for a kinetic impactor, nuclear ablation may still be the way to go if the competence of the asteroid is in question, as it often is.

Be prepared

Plesko has the simulation producing realistic results. Two NASA missions will provide important calibrating data. It then remains to examine the simulation under a variety of conditions: various incoming trajectories, shapes, sizes, masses, and compositions. So far, she has focused on roughly kilometer-scale asteroids; she will need to broaden that focus to include larger objects (like the one that caused Chicxulub) and comets (which are not made of rock). The goal is to have a set of ready responses for different classes of incoming objects. It would also help to build one or more rockets in advance. If the hardware is already in place and allows a reasonable degree of operational flexibility, then humanity can shave years off the necessary lead time: spot a threat, run the simulation, identify an intercept trajectory, load either a warhead or a kinetic impactor mass, and start the countdown.

> The **blast of ejecta** produces an **equal and opposite** recoil in the **asteroid body.**

Humanity lives now much as it ever has, at the mercy of numerous types of natural disasters. Tornadoes. Hurricanes. Volcanoes. Earthquakes. Yet unexpectedly, a catastrophic meteor strike is the one that's technologically preventable, given enough preparation. And rapidly spooling up new technology to address an urgent threat—well, that's a big part of what Los Alamos is known for. LDRD

—Craig Tyler

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