SPOTLIGHTS

Diverting Doomsday

IN JULY OF 1994, COMET SHOEMAKER-LEVY 9 CRASHED into Jupiter. Astronomers watched in awe as dozens of comet fragments bombarded the giant planet's southern hemisphere and debris clouds billowed to 12,000 kilometers (km) across, roughly the same diameter as the earth. It was the first time anyone had witnessed two major celestial bodies collide within our solar system, leading stargazers around the world to the same apprehension: what if it had been Earth?

The drama on Jupiter was a wake-up call, underscoring the reality that demise-by-comet isn't just for dinosaurs. Humanity has had 22 years since then to put into place a planetary defense system capable of deterring a doomsday comet. And yet, today, no such system exists.

Roughly every million years, an object measuring at least 1 km across hits the earth. And roughly every 100 million years, an object measuring at least 10 km across hits it; one of these is thought to have caused the extermination of the dinosaurs 66 million years ago. Comets on orbits of more than 200 years are called long-period comets and are believed to come from the Oort cloud, a spherical region full of icy objects surrounding our solar system. These objects occasionally get dislodged from their orbit within the Oort cloud and begin to fall toward the inner solar system. We earthlings call them comets when they get close enough to the sun to begin to vaporize; the boiled-off surface material is pushed outward by the solar wind, creating their characteristic tails.

Comets, especially long-period comets, are more worrisome than asteroids in terms of planetary defense for several reasons. First, they are the fastest objects in our solar system, which doesn't leave much time for defensive measures—18 months at most from the time of a comet's discovery. Second, their orbits are so long they usually come around only once on the timescale of our civilization, making them impossible to anticipate based on a prior appearance. Third, they tend to be quite large, ranging 1–40 km in diameter. If a long-period comet just 10 km across were to hit Earth, it would deliver over a billion times the combined energy of the nuclear bombs that devastated Hiroshima and Nagasaki.

"It's a great cosmic billiards game out there," says Los Alamos plasma physicist Glen Wurden, "and there *is* a comet somewhere that *is* going to hit us. We just don't know when—it could be in millions of years or it could be tomorrow." In his plasma research lab, Wurden, who is also an avid backyard astronomer, chucks tiny pieces of ice into plasmas, making what amount to very, very small comets. This got him thinking about very, very big comets, and he came up with a wild idea.

There isn't much to be done, defense-wise, about a comet's size or orbit, but Wurden's idea is to change its trajectory. It would require a rocket with enough speed to close the distance between Earth and the comet quickly, typically in about half the time until impact. No such rocket exists, but Wurden believes it could, if scientists put their minds and skills to the task.

It would have to be nuclear. Only a rocket propelled by thermonuclear fusion would have the necessary combination of power and speed to get there in time, and only a thermonuclear warhead would deliver the bump needed to change the colossal comet's trajectory. This is both convenient and inconvenient at once. It's convenient because some of the technology already exists, and scientists, especially Los Alamos scientists, have the nuclear skills and technical know-how to pursue such a rocket. It's inconvenient, however, because there are two international treaties that would require amending: one to allow nuclear devices in temporary orbit around Earth and another to allow detonation of nuclear explosives in space. Both of these are presently prohibited.

Comet Lovejoy (C/2013 R1) over Los Alamos, New Mexico, December 2, 2013.
CREDIT: Glen Wurden

Should the legalities get resolved, the comet interceptor would accelerate continuously as the distance to the comet narrows then detonate the explosive when the rocket is about 1 km away. The explosion wouldn't destroy the comet, but the radiation from the explosion would burn and boil material off the side of the comet, changing its mass and momentum. In a scenario where the comet is intercepted six months before its predicted calamity, Wurden calculated that the explosion would need to exact a change of 10 meters per second to amount to a 150,000-km difference by the time the comet whizzes past Earth. That's still a close shave, but humanity would behold a spectacle in the night sky rather than the end of days.

Wurden points out that although fusion rocket engines don't technically exist yet, preliminary designs do exist, and Los Alamos National Laboratory, with its nuclear, space travel, engineering, and computational expertise, is ideally equipped for the tremendous task of answering this cometary call to arms.

But then there's the price tag to consider. What is the insurance premium for a planet and all of its inhabitants? Wurden estimates an annual budget of $10 billion in perpetuity. That may seem high, but a single aircraft carrier runs in the neighborhood of $13 billion. Besides, we would split the check with other space-faring nations, so our cost would be just a fraction of the total.

"It's not chicken little," Wurden emphasizes. "A hit in the Pacific Ocean would create a tsunami that would cream every city on the Pacific Rim. Dust and debris would make short work of the rest of humanity. There are some catastrophes, like volcano eruptions, that we really can't do anything about. This isn't one of them."

It's a wild idea indeed, but perhaps it shouldn't be.

— *Eleanor Hutterer*

Renegade Particles

NEUTRINOS LOVE CONTROVERSY. AND EARLIER THIS YEAR, evidence for a new type of neutrino, whose existence was first implied by a Los Alamos experiment in the 1990s, was both amplified *and* refuted.

Neutrinos, lightweight and thoroughly invisible subatomic particles, weren't even supposed to exist until it was discovered that the radioactive beta-decay process needs them to conserve energy and momentum. Then they weren't supposed to have any mass, until it was discovered that they spontaneously transform, or "oscillate," from one variety, or "flavor," to another, which requires mass. They certainly weren't supposed to come in more than three flavors (no other fundamental matter particle seems to) or behave asymmetrically with respect to their antimatter counterparts, but now both acts of defiance may be necessary to explain a resilient collection of measurement anomalies.

All along, Los Alamos has been at the forefront of the neutrino oscillation mystery. It began with the Lab's Liquid Scintillator Neutrino Detector (LSND) experiment—for a long time, the only outlier in a suite of otherwise consistent neutrino-oscillation experiments. LSND's results agreed with those of other experiments, indicating that neutrinos oscillate from one flavor to another. But the oscillation parameters depend on the relative neutrino masses, and LSND's measurements implied much larger masses than those obtained elsewhere. Like so many things from the 90s (sagging pants and transparent cola spring to mind), the LSND results didn't make much sense.

So vexing were the results that a follow-up experiment was commissioned expressly to confirm or disprove them. That experiment, MiniBooNE (Mini Booster Neutrino Experiment)—designed in part by Los Alamos scientists and operating at the Fermi National Accelerator Laboratory (Fermilab) in Illinois since 2002—proved everybody right. In neutrino mode, MiniBooNE initially agreed with the consensus of neutrino experiments, producing results consistent with small neutrino masses. But when it used antineutrinos instead, it agreed with LSND, also an antineutrino experiment, requiring much larger neutrino masses. Because particle and antiparticle masses are identical, MiniBooNE and LSND together require additional neutrino flavors with masses greatly exceeding those of the three original flavors. Yet other high-precision cosmological data sets strongly restrict the number of active neutrino flavors to just the original three.

To fit the bill, then, physicists suggested there might be one or more additional flavors of *sterile* neutrino, in addition to the three active flavors. Sterile neutrinos are so named because they would never interact with anything (except via gravity, to which nothing is immune). That means they wouldn't show up in the cosmological data but could still appear when neutrinos oscillate from one flavor to another. Then, when a known number of neutrinos is fired at a detector, and the detector registers fewer than it's supposed to, researchers might infer that the missing neutrinos oscillated from an active flavor to a sterile one, as though the particles had oscillated right out of existence.

Such disappearances have been reported periodically at experiments around the world, especially those using antineutrinos produced by nuclear power reactors. Earlier this year, the Daya Bay reactor-based experiment in China reported the highest-precision measurement to date of the possible sterile-neutrino signal. Yet by late summer, a large neutrino observatory called IceCube (so named because it is set within a cubic kilometer of ice at the South Pole), announced that it had firmly