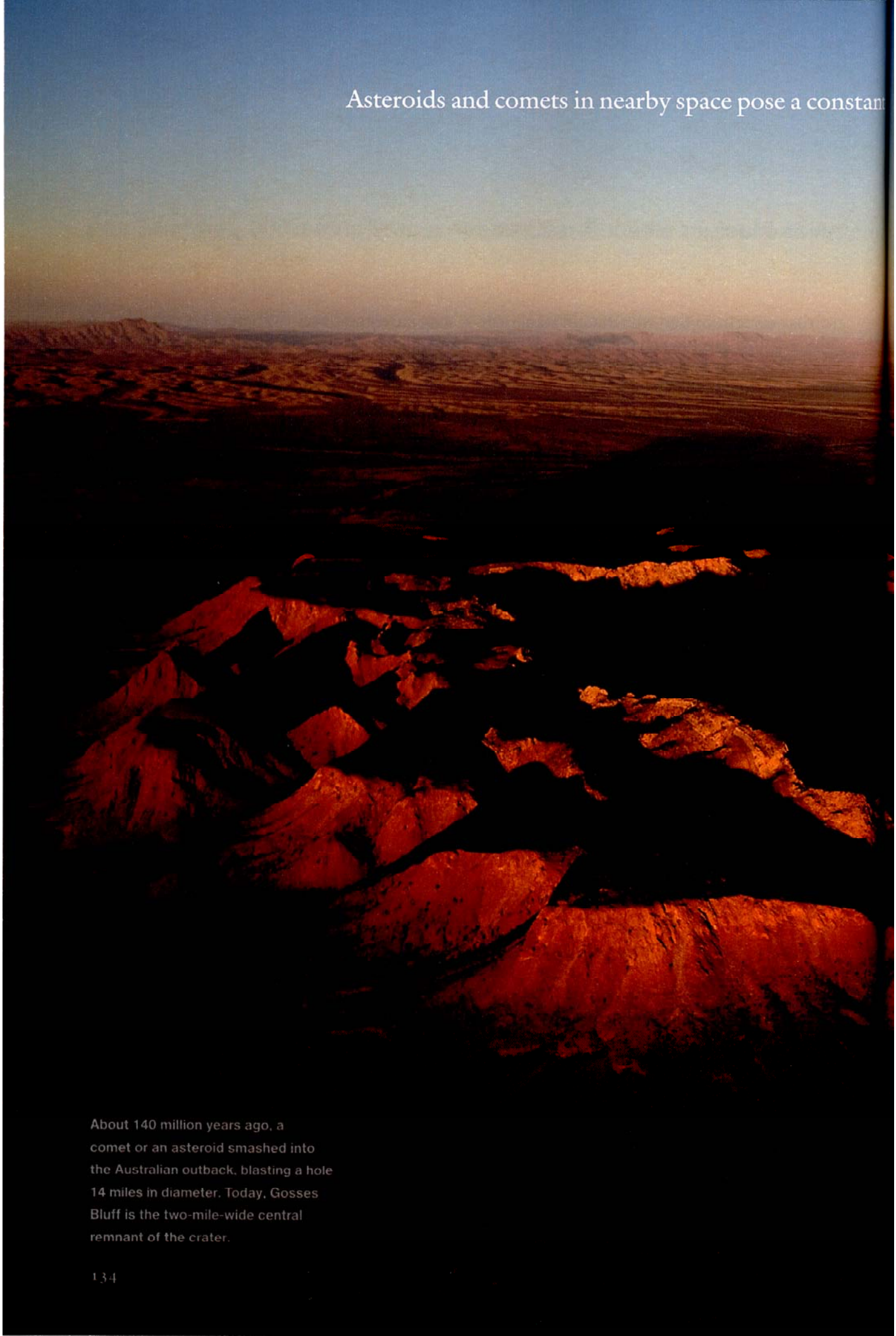
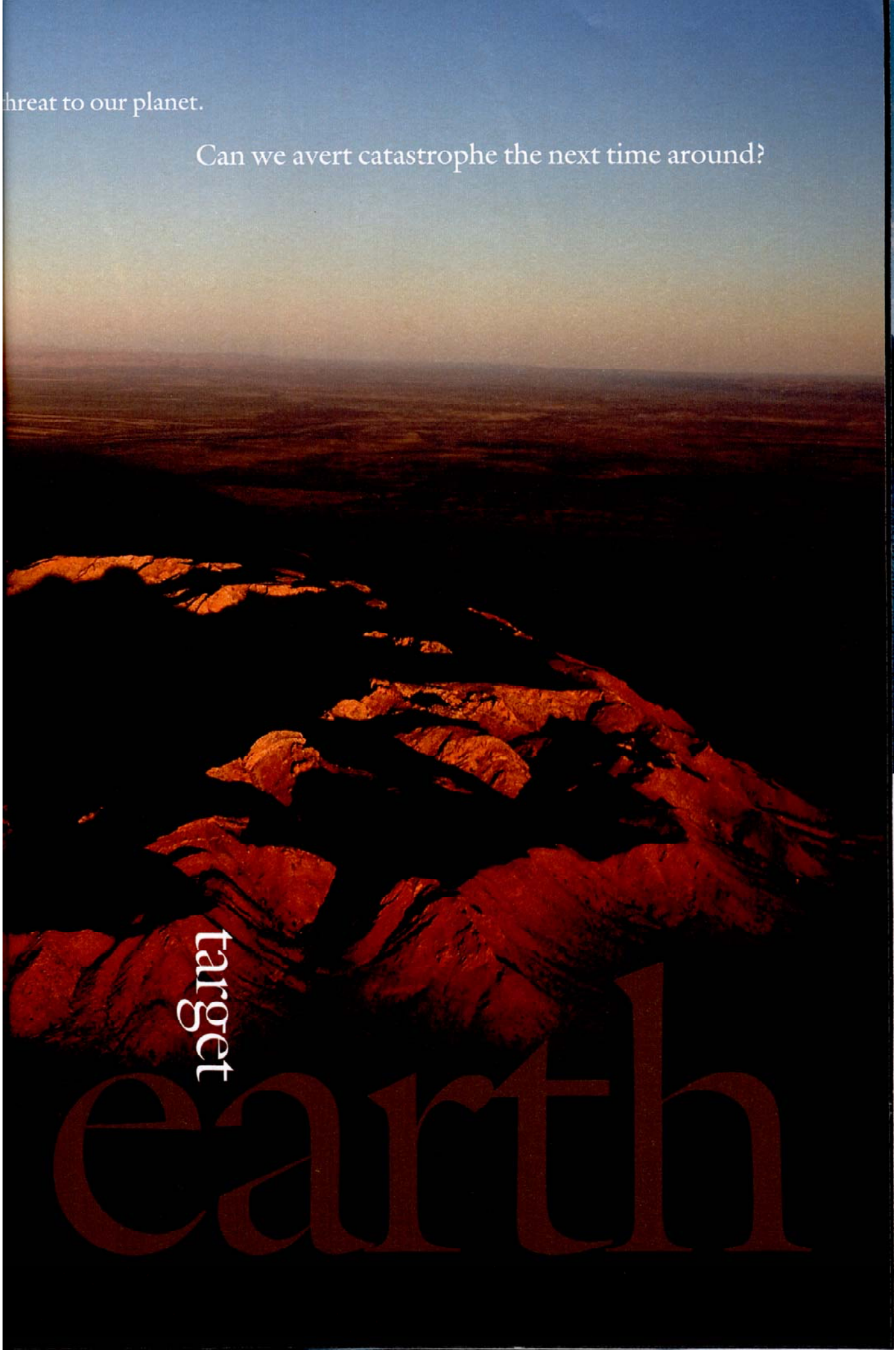


About 140 million years ago, a comet or an asteroid smashed into the Australian outback, blasting a hole 14 miles in diameter. Today, Gosses Bluff is the two-mile-wide central remnant of the crater.

hreat to our planet.

Can we avert catastrophe the next time around?



target

earth

BY RICHARD STONE • PHOTOGRAPHS BY STEPHEN ALVAREZ

The first sign of the threat was no more than a speck on a star-streaked telescope image.

Just after 9 p.m. on June 18, 2004, as twilight faded over Kitt Peak National Observatory in Arizona, David Tholen was scanning for asteroids in an astronomical blind spot: right inside Earth's orbit, where the sun's glare can overwhelm telescopes. Tholen, an astronomer from the University of Hawaii, knew that objects lurking there could sometimes veer toward Earth. He had enlisted Roy Tucker, an engineer and friend, and Fabrizio Bernardi, a young colleague at Hawaii, to help. As they stared at a computer, three shots of the same swath of sky, made a few minutes apart, cycled onto the screen. "Here's your guy," said Tucker, pointing at a clump of white pixels that moved from frame to frame.

Richard Stone is Science *magazine's Asia editor. Stephen Alvarez photographs expeditions and science for this magazine; his blog is at* picturestoryblog.com.

Tholen reported the sighting to the International Astronomical Union's Minor Planet Center, a clearinghouse for data on asteroids and comets. He and Tucker hoped to take another look later that week, but they were rained out, and then the asteroid disappeared from view.

When astronomers got a fix on it again that December, they realized they had a problem. The rock, bigger than a sports arena, tumbles menacingly close to our planet every few years. As observations streamed into the Minor Planet Center, the asteroid, named Apophis after the Egyptian god of evil, looked increasingly sinister. "The impact hazard kept getting higher and higher," says Tholen. By Christmas, models predicted 1-in-40 odds that Apophis would smash into Earth on April 13, 2029, and a ripple of alarm spread to the public. "One colleague called it the grinch that stole Christmas," Tholen says.

DAVID THOLEN, ROY TUCKER, AND FABRIZIO BERNARDI

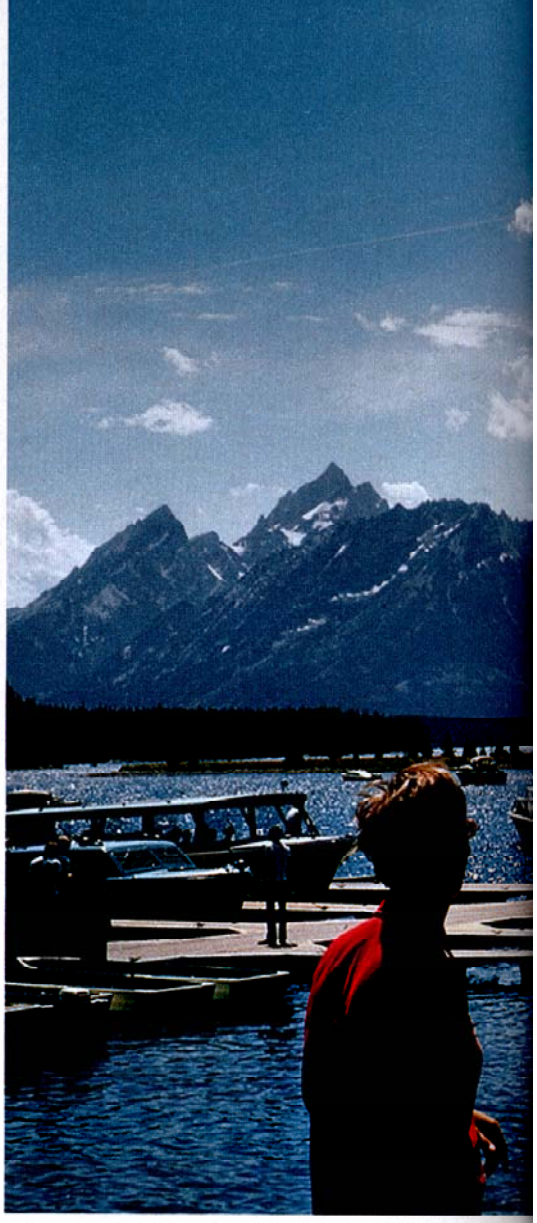
SPOTTING DANGER
Asteroid hunters study time exposures of the sky, looking for objects that don't move with the stars. In 2004, they found one that came to be dubbed Apophis—the Destroyer in ancient Egyptian lore. This 900-foot-wide asteroid will zoom past the Earth in 2029 and again in 2036. Odds that pass will end in collision? Scientists now say 1 in 45,000.

Then on December 26, 2004, a real catastrophe struck: the Indian Ocean tsunami, which claimed hundreds of thousands of lives. The public forgot about Apophis. In the meantime, astronomers had dug out earlier images of the asteroid. The extra data enabled the scientists to calculate its orbit, and they discovered that it would actually whiz safely by Earth in 2029. But they could not rule out a slender chance that Apophis would strike with catastrophic effect its next time around, on Easter Sunday, 2036.

An estimated ten million rocky asteroids and ice-and-dirt comets pirouette in outer space, and once in a while their paths fatefully intersect our planet's. One such encounter took place a hundred miles from present-day Washington, D.C., where a 53-mile-wide crater lies buried beneath Chesapeake Bay—the scar left when a two-mile-wide rock smashed into the seafloor 35 million years ago. More notorious is the titan, six miles in diameter, that barreled into the Gulf of Mexico around 65 million years ago, releasing thousands of times more energy than all the nuclear weapons on the planet combined. "The whole Earth burned that day," says Ed Lu, a physicist and former astronaut. Three-quarters of all life-forms, including the dinosaurs, went extinct.

Astronomers have identified several hundred asteroids big enough to cause a planetwide disaster. None is on course to do so in our lifetimes. But the heavens teem with smaller, far more numerous asteroids that could strike in the near future, with devastating effects. On June 30, 1908, an object the size of a 15-story building fell in a remote part of Siberia called Tunguska. The object—an asteroid or a small comet—exploded a few miles before impact, scorching and blowing down trees across 800 square miles. The night sky was so bright with dust from the explosion, or icy clouds from the water vapor it blasted into the upper atmosphere, that for days people in Europe could read newspapers outdoors at night. On Tunguska's hundredth anniversary, it's unsettling to note that objects this size crash into Earth every few centuries or so.

The next time the sky falls, we may be taken by surprise. The vast majority of these smallish bodies, capable of wiping a city off the map, are not yet on our radar screens. "Ignorance is bliss, in that if you don't know about these things, you just go about your merry way," says Lu. Over the next decade, however, sky surveys like Tholen's should begin filling that gap, cataloging asteroids by the thousands. "Every couple of weeks," says Lu, "we're going to be finding another asteroid with like a one-in-a-thousand chance of hitting the Earth."



JAMES M. BAKER

The goal is not just to foretell the date and time of a potential catastrophe. The goal is to forestall it. With years or decades of warning, a spacecraft, using its own minuscule gravity, might nudge a threatening asteroid off course. For objects requiring a bigger kick, a kamikaze spacecraft or a nuclear bomb might do the job. Vexing dilemmas would attend this showdown in space. How will governments decide to act? "This is a class of problem that the world isn't set up to deal with," says physicist David Dearborn, an advocate of a nuclear strike against an incoming asteroid.

Two facts are clear: Whether in 10 years or

NEAR MISS

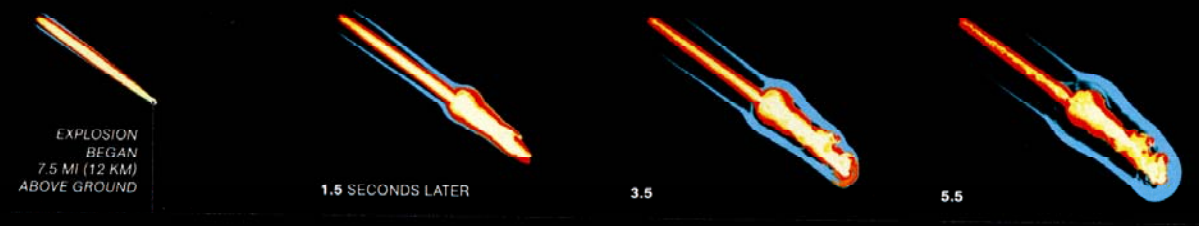
Streaking over Jackson Lake, Wyoming, in 1972, this 150-ton object skipped harmlessly off the atmosphere like a rock skipping off water. NASA classifies more than 950 much larger asteroids and comets as potentially hazardous because they stray uncomfortably close to Earth.

500, a day of reckoning is inevitable. More heartening, for the first time ever we have the means to prevent a natural disaster of epic proportions.

EVERY DAY, DOZENS OF TONS of detritus from outer space—dust from comets, tiny shards of asteroids—burn up in the Earth's upper atmosphere, leaving bright meteor trails at night. Most days a chunk or two of rock or metal, fist size or bigger, survives the fiery plunge.

Yet the odds of seeing a meteorite hit the ground, let alone being struck, are phenomenally low. Only one is known to have hit a person. Around 1 p.m. on November 30, 1954, a meteorite tore through the roof of a house near Sylacauga, Alabama, across the street from the Comet Drive-in Theatre. The rock, about the size of a softball, caromed off a console radio and clipped Ann Hodges as she snoozed on her couch, bruising her left hip and wrist. She was hospitalized to recover from the shock.

Since then, there have been some spectacular near misses. On August 10, 1972, an object around 15 feet across and weighing 150 tons skipped off the upper atmosphere. Hundreds of eyewitnesses



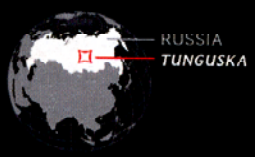
SPACE INVADER
A computer model of the 1908 event shows how an asteroid some 150 feet wide tore into the atmosphere at 32,000 miles an hour and began to explode.

INCANDESCENT TRAIL
As the asteroid ripped through the air and vaporized, it left a trail of ultrahot gases.

Siberian Blast

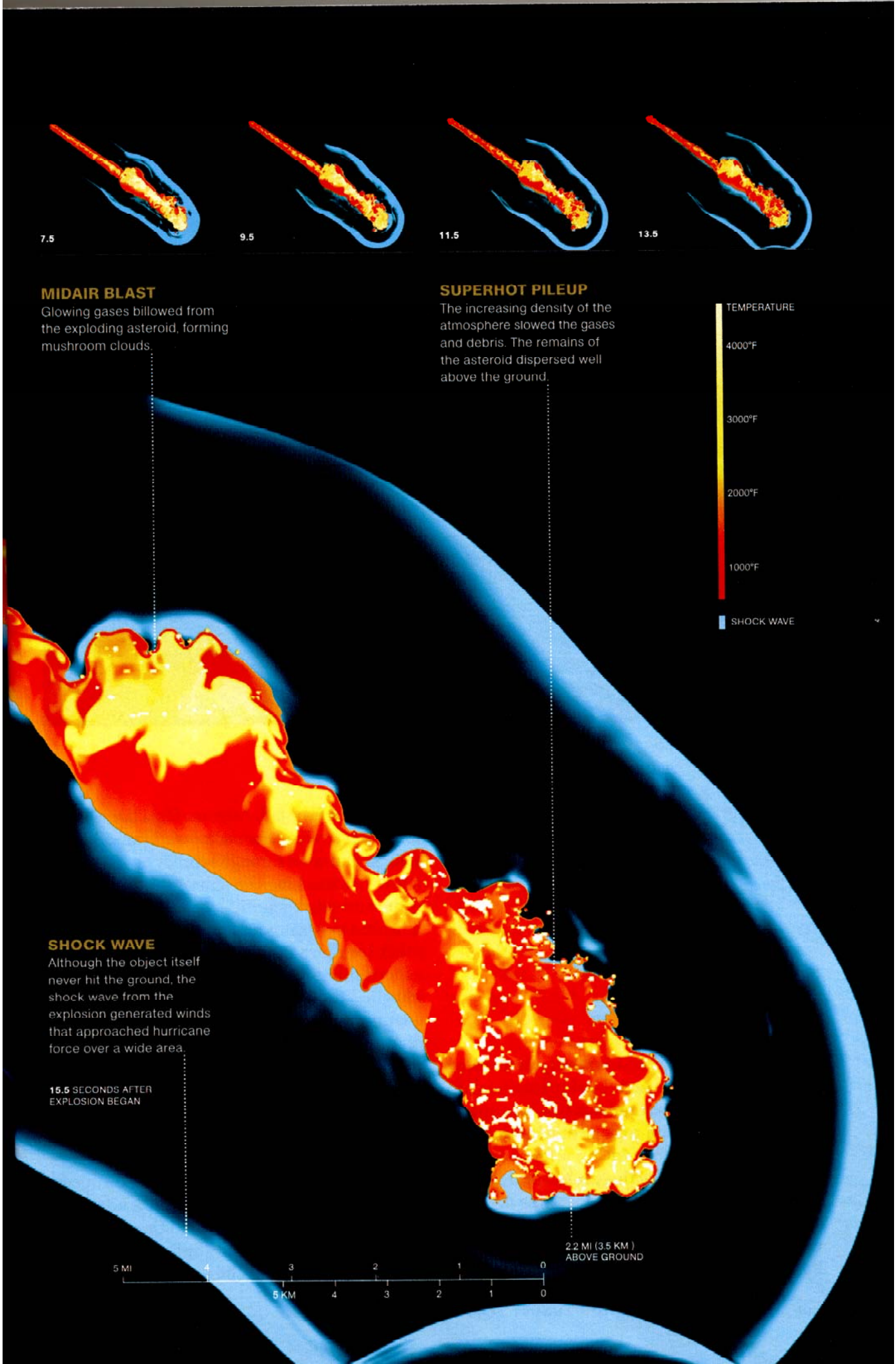
A new supercomputer simulation models the cataclysmic power of an asteroid strike.

Just after 7 a.m. on June 30, 1908, an asteroid or comet exploded above Tunguska, Siberia, leveling trees (above) across 800 square miles. Models by Sandia National Laboratories researcher Mark Boslough show that the destruction could have been caused by an object—and an explosion—about half the size previously believed. Smaller objects strike more often, but Tunguska-level events are nevertheless rare.



SEAN MCNAUGHTON, NG STAFF

SIMULATION FRAMES: MARK BOSLOUGH, SANDIA NATIONAL LABORATORIES. TASS FROM SOVFOTO (ABOVE)


7.5
9.5
11.5
13.5
MIDAIR BLAST
Glowing gases billowed from the exploding asteroid, forming mushroom clouds.
SUPERHOT PILEUP
The increasing density of the atmosphere slowed the gases and debris. The remains of the asteroid dispersed well above the ground.
TEMPERATURE
4000°F
3000°F
2000°F
1000°F
SHOCK WAVE
SHOCK WAVE
Although the object itself never hit the ground, the shock wave from the explosion generated winds that approached hurricane force over a wide area.
15.5 SECONDS AFTER EXPLOSION BEGAN
2.2 MI (3.5 KM) ABOVE GROUND
5 MI
4
3
2
1
0
5 KM
4
3
2
1
0

The number of experts working on deflecting objects would roughly staff a couple shifts at a McDonald's.

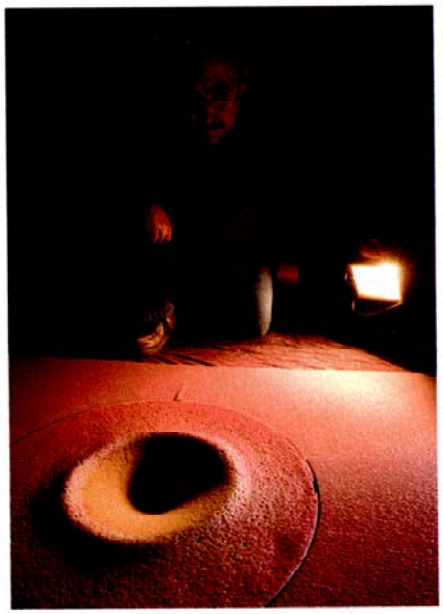
saw the glowing streak, dazzling on a sunny afternoon, as it traversed the sky from Utah to Alberta before whizzing back out into space. On March 22, 1989, a rock as much as a thousand feet across came within a few hundred thousand miles of Earth—an uncomfortably close shave.

Erosion and vegetation have erased most of the scars left by impacts in the geologic past. Perhaps the best preserved lies about half an hour east of Flagstaff, Arizona. On a late autumn morning Carolyn Shoemaker and I pull off Interstate 40 and wind through scrubby desert toward a low rise marking the rim of the crater. Fifty thousand years ago this was a forested plain inhabited by mammoths, giant ground sloths, and other Ice Age animals. Shoemaker, an asteroid expert with the Lowell Observatory in Flagstaff, imagines the day the sky fell. "Suddenly, there's a terrific, brilliant light," she says. In a flash, a searing-hot iron-nickel mass, 150 feet wide and weighing 300,000 tons, tears into the Coconino sandstone, flinging boulders and molten iron for miles. A blast of wind more powerful than any earthly tornado scours the landscape.

All that's left of the cataclysm now is a chasm three-fourths of a mile wide and 570 feet deep, fringed with Mormon tea bushes. At the turn of the 20th century, an engineer named Daniel Moreau Barringer was convinced that a massive iron meteorite lay beneath the crater and obtained

MODELING MAYHEM

Firing a tiny aluminum pellet into a sandpit at 12,000 miles an hour helps geologist Peter Schultz understand impact zones. "Standing downrange, you'd be broiled by the hot blast and pummeled by debris," he says. "Think of a hot landslide, without a mountain."



the mining rights to the land. But after a series of shafts revealed nothing, many prominent geologists concluded that a volcanic eruption, not a meteorite, had formed the crater.

Carolyn's husband, Gene, made Meteor Crater one of America's most recognizable landmarks. In the late 1950s he mapped the overturned rock around the crater and pointed out similarities to the Teapot Ess crater in Nevada, formed by a nuclear test. His data showed that Barringer was right: A meteorite had gouged the crater, although most of the iron had melted into tiny droplets. Several of Barringer's shafts can still be seen from the rim, along with a full-size cutout of a waving astronaut—a nod to NASA, which once used the crater as a training ground. Some visitors whisper and point at Carolyn, and one man plucks up the courage to come over and request her autograph. Carolyn is famous in her own right. She discovered a comet that, in 1994, vividly demonstrated the cosmic threat we face.

In 1980, their children grown and out the door, Gene suggested that Carolyn start a career as an asteroid hunter. "I'm a morning person," she says. "I had never stayed awake all night in my life. I didn't know if I could do that." But she decided to give asteroid hunting a shot. Gene had access to the Palomar Observatory near San Diego. "After a couple years, I learned how to discover things," she says, modestly. She has 32 comets and 367 asteroids to her credit. "Some are more interesting than others."

On March 25, 1993, Carolyn, Gene, and David Levy, an amateur astronomer, were at Palomar for their scheduled observation time. Snow was falling, and the night promised to be long and boring. Carolyn killed time by studying a batch of overexposed film from the previous night. Many frames were worthless. On one of the last images, however, she came across a smudge. "I said, 'It looks like a squashed comet.'" The team asked astronomers at Kitt Peak to take a look. It then occurred to Carolyn that her squashed comet might be a broken comet. Confirmation came that same night when Kitt Peak spotted a string of comet shards traveling together.

Other astronomers soon counted some two dozen pieces of comet Shoemaker-Levy 9 and worked out its strange history and fate. In July 1992, it seemed, the comet had swung so close to Jupiter that the giant's massive gravity had torn it apart. Now the remnants, some of them hundreds of feet wide, were destined to collide with Jupiter in July 1994. When the time came, most of the world's astronomers were watching.

The impacts took place on Jupiter's far side, out of sight of Earth, but the blows sent superheated gas billowing far above the atmosphere. The largest unleashed shock waves that roiled an area at least three times the width of Earth. "It was pretty awesome," Carolyn says. The Shoemakers basked in the glow of their discovery. Then tragedy struck. In 1997 they were in a head-on car crash in the Australian outback. Gene died at the scene. An ounce of his ashes traveled to the moon with NASA's Lunar Prospector spacecraft.

Carolyn scattered the rest at Meteor Crater.

IF THE SHOEMAKERS' NAMESAKE or the monster that annihilated the dinosaurs were bearing down on us, there would be little we could do. For every planet killer, however, there are thousands of smaller asteroids and comets—up to a mile

PHOTOGRAPHED AT VERTICAL GUN RANGE, NASA AMES RESEARCH CENTER (BOTH)

or so across—that could conceivably be deflected. First we'd have to see them coming.

In 1998 the U.S. Congress ordered NASA to identify at least 90 percent of the largest asteroids and comets in the inner solar system—objects six-tenths of a mile or more in diameter. To date, telescopes have pinpointed more than 700 out of an estimated population of 1,000. In 2005 Congress got more ambitious, directing the space agency to track down the far more numerous asteroids 460 feet or more in diameter—still big enough to take out a city or state.

A new telescope is about to begin scanning the sky for these dim, elusive objects. From a peak on Maui, the Panoramic Survey Telescope and Rapid Response System, or Pan-STARRS, will scrutinize the night sky with a 1.4-billion-pixel camera that produces images so detailed a single one, if printed, would cover half a basketball court. Computers will scan the data, flagging statistical curiosities that astronomers can check the old-fashioned way, by taking a look. The Maui telescope is just a prototype; ultimately, Pan-STARRS will include an array of four cameras. "We'll have catalogs of all the things that go bump in the night," says Ken Chambers of the University of Hawaii, including perhaps 10,000 potentially hazardous asteroids.

Within decades, the world's leaders may be forced to grapple with a momentous decision: whether and how to deflect an incoming object. Few experts are giving this much thought, says astronomer David Morrison of NASA's Ames Research Center: "The number would roughly staff a couple shifts at a McDonald's."

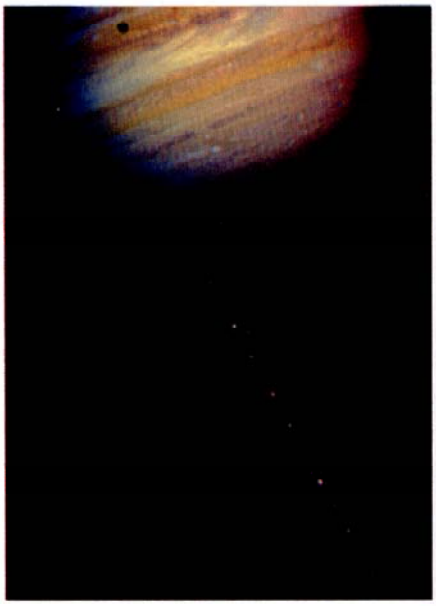
Lu, the former astronaut, is one. Now an executive at Google, he is helping design a massive database for a successor to Pan-STARRS, the Large Synoptic Survey Telescope, which will scrutinize the sky in even more detail starting in 2014. Lu is also the coauthor of a scheme for using a spacecraft to coax an earthbound asteroid off its dangerous path. "We were originally thinking about how you would land on an asteroid and push it," he says. "But that doesn't work well." If the surface is crumbly, the lander might skid off. Moreover, asteroids twirl through space. "If you're pushing and the thing is rotating, the pushing just cancels out," Lu says.

Then he and Stanley Love, a fellow astronaut, realized pulling would be much easier. A spacecraft could hover nearby and fire its thrusters, gently tugging the asteroid along. No harpooning or lassoing would be required. "Rather than having a physical line between you and the thing you're towing, you're just using the force of gravity between them," Lu says. The "gravity tractor" would tug the asteroid off course at a mere fraction of a mile an hour. But this subtle shift, magnified over the vastness of space, could mean missing Earth by tens of thousands of miles.

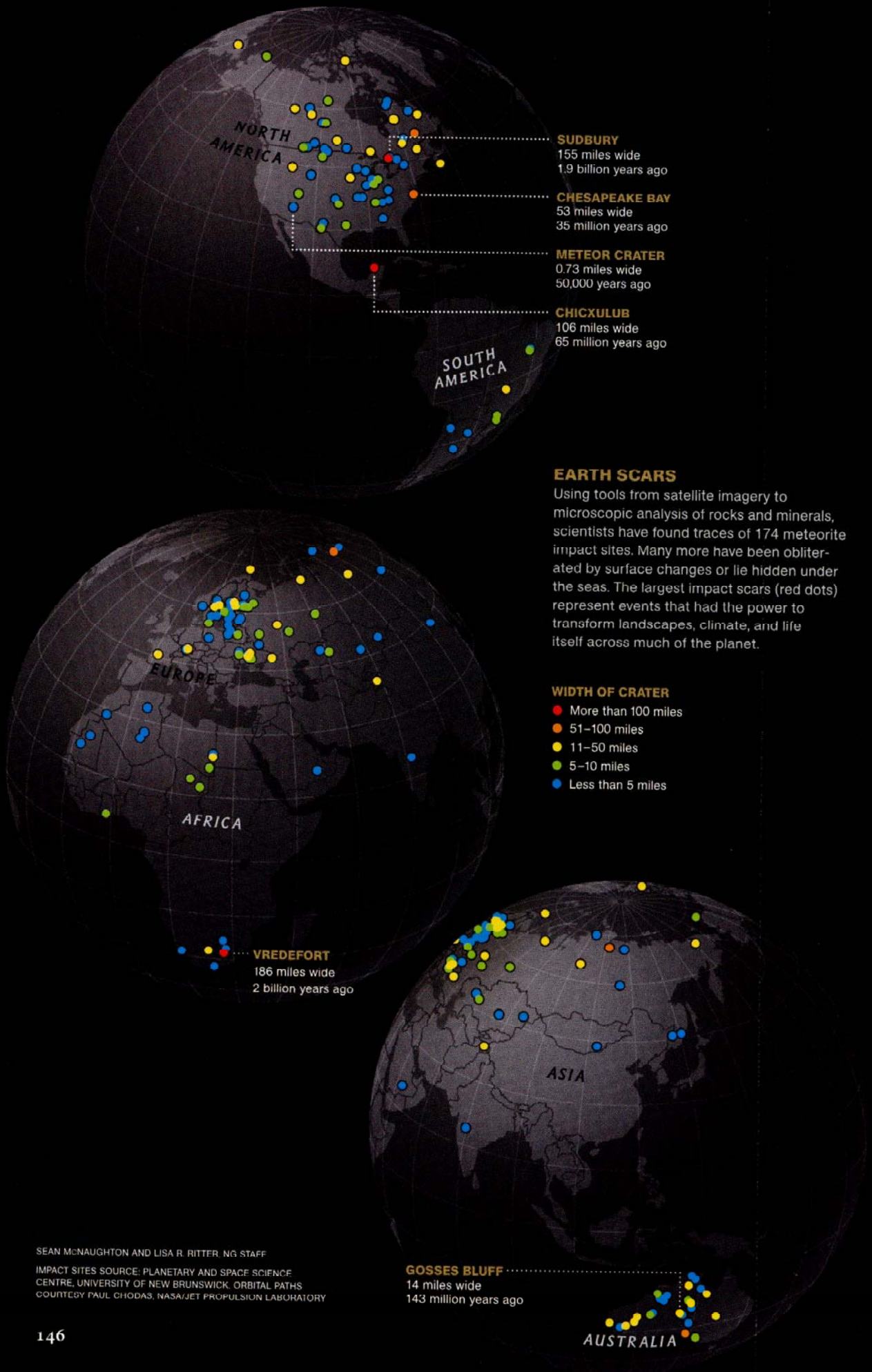
Lu's scheme would work only for asteroids up to a few hundred yards across that could be engaged far from Earth. If a small rock sneaks up on us, we could try ramming it with a spacecraft. But there's a drawback, says Morrison: "If you hit an asteroid with enough energy to break it apart, but not necessarily enough energy to disperse it widely, you now have a flying collection of stuff. You have to ask how practical that is." When all else fails, and for large asteroids and comets, only one strategy has a chance of working: We'll have to bomb them back to the Stone Age.

BATTERED GIANT

A string of roughly 20 fragments of comet Shoemaker-Levy 9 (composite view, below) hit Jupiter like machine-gun fire in July 1994. The impacts left bruises on Jupiter's atmosphere (right), some of them wider than Earth, and gave astronomers their first look at a planetary collision.



NASA/ESA/HAL WEAVER AND ED SMITH, SPACE TELESCOPE SCIENCE INSTITUTE, AND JOHN TRAUGER AND ROBIN EVANS, JPL (ABOVE); NASA/ESA/HEIDI HAMMEL, SPACE SCIENCE INSTITUTE (RIGHT)

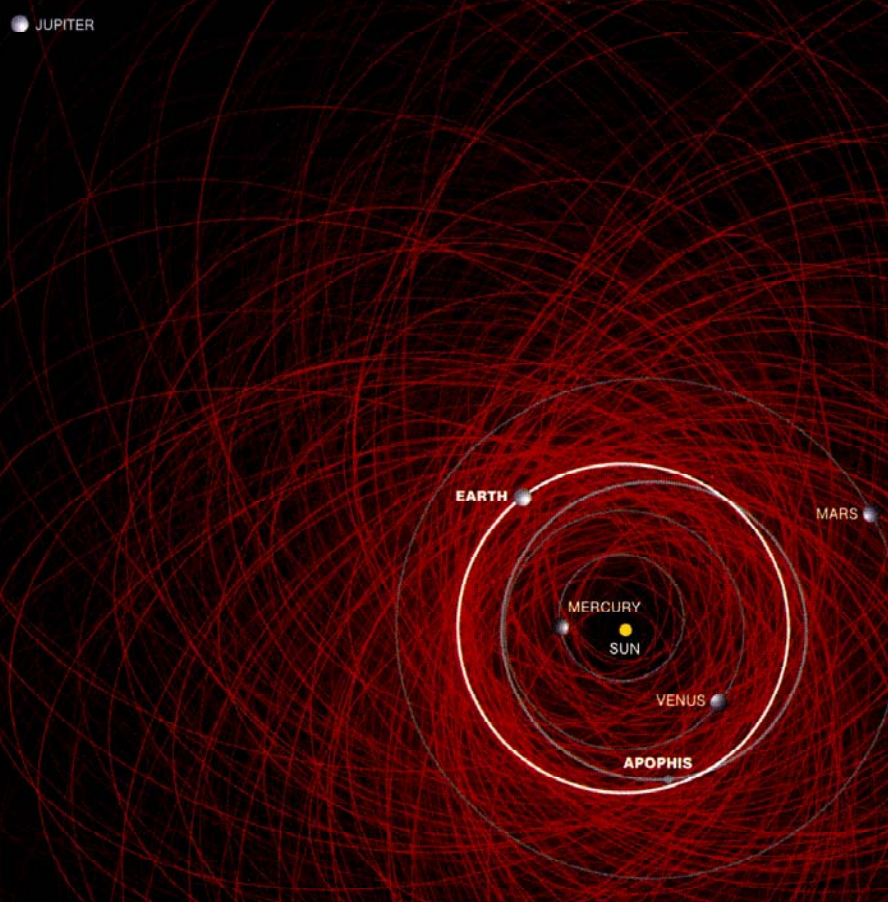


EARTH SCARS

Using tools from satellite imagery to microscopic analysis of rocks and minerals, scientists have found traces of 174 meteorite impact sites. Many more have been obliterated by surface changes or lie hidden under the seas. The largest impact scars (red dots) represent events that had the power to transform landscapes, climate, and life itself across much of the planet.

SEAN McNAUGHTON AND LISA R. RITTER, NG STAFF

IMPACT SITES SOURCE: PLANETARY AND SPACE SCIENCE CENTRE, UNIVERSITY OF NEW BRUNSWICK. ORBITAL PATHS COURTESY PAUL CHODAS, NASA/JET PROPULSION LABORATORY



Orbital diagram of potentially hazardous asteroids and comets. All orbits are to scale.

Heavy Traffic

Every year as the Earth loops through a solar system crowded with other bodies, there's a chance it could run into trouble.

So far more than 5,400 asteroids and comets have been spotted flying within 121 million miles of the sun—close enough to our planet for astronomers to classify them as near-Earth objects. Those that measure more than 460 feet across and pass within 4.6 million miles of Earth's orbit are considered potentially hazardous. As of April, astronomers had cataloged more than 950 such bodies (red tracks)—including Apophis, an asteroid that will come within 21,000 miles of Earth in 2029. None of the known potentially hazardous objects are believed likely to collide with Earth. But observers are constantly monitoring their positions, recalculating their orbital paths and the impact risks they represent—and searching nearby space for new threats.

STANDS OF FROSTED FIRS and white birch cluster along the highway leading southwest from Yekaterinburg, the city in the Ural Mountains where Russia's last tsar, Nicholas II, and his family were murdered 90 years ago. Under a dull sun, fishermen huddle over holes on a frozen lake, floppy-eared fur hats hiding their faces. A road with a misspelled signpost for a tiny village marks the turnoff for the formerly secret city of Snezhinsk, code-named Chelyabinsk-70 during the Cold War. Snezhinsk is home to one of Russia's two main nuclear weapons laboratories. After the collapse of the Soviet Union, it fell on hard times; ten years ago, with Russia's economy in shambles, staff salaries went unpaid, and the director committed suicide.

Nowadays, with Russia prospering, the laboratory is humming with top secret work. Obtaining permission to enter proved impossible. But Vadim Simonenko, the deputy scientific director, and experimentalist Nikolay Voloshin agreed to meet at a sanatorium in nearby Dalnyaya Dacha. In a cool, dim, and empty dining hall, Voloshin opens a bottle of cognac, and over salmon canapés, cold cuts, and sliced cucumbers, the two weapons scientists discuss how their bombs could save the world.

If Edward Teller is the father of the hydrogen bomb, Simonenko is the father of the asteroid bomb. In the mid-1960s the superpowers dreamed of using their nuclear arsenals for peaceful purposes, such as leveling mountains and digging canals. Simonenko, a new recruit to the lab, was asked to study the effects of a torpedo-shaped charge that would explode laterally, ideal for earthmoving. It occurred to him that such a device could also be used to deflect an object in space. He told his boss, who laughed and ordered the eager young physicist to get back to work.

Though nuclear excavation never became a reality, Simonenko went on studying nuclear asteroid deflection. He and Voloshin concluded that the best way to deflect an asteroid up to a mile or so wide would be to detonate a nuclear charge nearby. The intense radiation would fry the surface, driving off a "sacrificial layer" of rock. The expanding vapor would act as a rocket motor, nudging the asteroid onto a new trajectory. For a smaller, Tunguska-size rock, Simonenko says, "it would be simpler: We vaporize it."

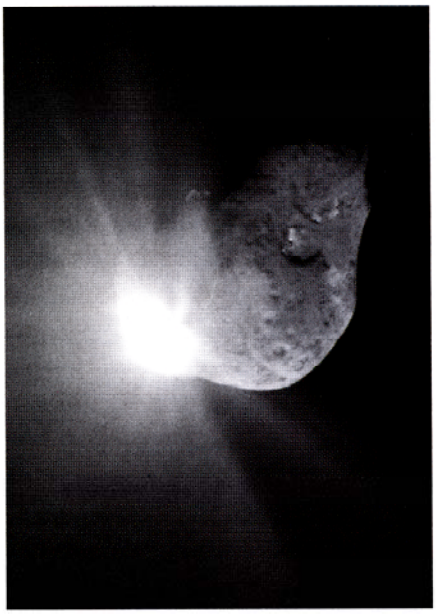
Simonenko has a brother-in-arms in nuclear physicist David Dearborn of Lawrence Livermore National Laboratory in northern California. Dearborn's day job is determining whether the aging weapons in the U.S. nuclear stockpile are reliable. In his spare time, he ponders asteroid defense. He, too, favors a standoff nuclear blast. "Not too close—then the blast is too intense, and things shatter too much. And not too far, or you don't get enough energy."

Although it may be technically straightforward to dust off a few warheads and sling them at an asteroid, deciding whether to press the red button—and which nation gets to press it—could be excruciating. First, the nation with its finger on the trigger would have to withdraw from the Outer Space Treaty, which bans the use of nuclear weapons in space. But if catastrophe looms, says Dearborn, "people would really have to say, 'Can we be brighter than the dinosaurs?'"

Apophis may pose the first real test of our collective intelligence. For now, scientists can give

DISASTER PLANNING

In 2005, a NASA spacecraft probed a comet by smashing into it (below) with the force of five tons of dynamite—yet barely shifted its path. Scientist James Szabo (right) develops plasma thrusters that could propel a "gravity tractor" to tug a threatening comet or asteroid to a safer orbit.



For large objects, only one strategy has a chance of succeeding: We'll have to bomb them back to the Stone Age.

only a range of probabilities for its future trajectory. As it swings past Earth in 2029, ducking under dozens of high-flying communications and spy satellites and appearing as a bright star lumbering across the night skies over Europe, there's a slim chance that Apophis will pass through a "keyhole." In this narrow corridor of space, maybe a few hundred yards wide, Earth's gravity would deflect the asteroid just enough to put it on a certain collision course with our planet on the next pass, in 2036. The odds that Apophis will pass through this fatal corridor are currently estimated at 1 in 45,000. Continued tracking will almost certainly deliver an all clear a few years from now. If not, we might have to wait until weeks after its close approach in 2029 to learn whether Apophis has squeezed through a keyhole, leaving us precious little time to avert calamity in 2036.

In the prophesies of the Hopi of the American Southwest, the arrival of a spirit called Yellow Star Kachina will herald the end of the world. When Hopi elders heard about Apophis in 2004, they worried that Yellow Star Kachina was on its way. Carolyn Shoemaker tried to reassure them that it was not.

Let's hope she was right. □

Interactive Map Learn where meteorites have crashed to Earth over geologic history and see the scars they left, at **ngm.com.**

NASA/JPL/CALTECH (LEFT). PHOTOGRAPHED AT BUSEK COMPANY (ABOVE)