PLANETARY REPORT

Volume XXX Number 1 January/February 2010

Defending Our World

From The Editor

They have the potential to destroy civilization, and they whiz past our planet with alarming regularity. Sometimes we see them coming, and sometimes we don't. They are generically known as near-Earth objects (NEOs), commonly called asteroids and comets, and they pose a natural threat greater than any faced by our species in history. Fortunately for us, it's a threat we can do something about.

It's only in the last few decades that science has understood that there was a threat. In 1980, the same year the Society was founded, Luis and Walter Alvarez, with Frank Asaro and Helen Michel, published the paper that triggered a revolution in the Earth and planetary sciences by positing that the dinosaurs were killed off by the impact of a comet or asteroid.

Barely a year and a half later, the Society funded its first NEO project—the pioneering search of Eleanor "Glo" Helin and Gene Shoemaker. Among their first discoveries was 1982 DB, whose near-Earth orbit makes it one of the easiest targets for spacecraft to reach (and which was renamed Nereus by Society Member Robert Cutler).

The Society regards NEOs as both dangers and opportunities for exploration, and our programs reflect that dichotomy. In this issue, we explore the threat and what can and should be done to protect our Earth. To convince governments to act, Planetary Society Members will have to act—something you've done many times before. The NEO threat must be addressed. We can make that happen.

—Charlene M. Anderson

Thank You:

Our thanks to the Secure World Foundation for its generous partnership in creating this special issue of *The Planetary Report*.

The Secure World Foundation promotes a unified policy approach to protection of our planet and, within that theme, focuses on global policies to govern how we detect, track, and deflect near-Earth objects. Find out more about our partner on its website at *secureworldfoundation.org.*

On the Cover:

Objects blazing through Earth's atmosphere can be absolutely enchanting—when they are small enough. On September 30, 2008, a stunning fireball meteor lit up the night sky for a group of amateur astronomers camped in Oklahoma's Black Mesa State Park. Howard Edin's camera was set up on a hillside to record the look and activity of the Okie-Tex Star Party throughout the night when the spectacular bolide appeared, momentarily illuminating the entire observing field. Photo: Howard Edin

Background:

On October 7, 2008, a small asteroid collided with Earth, fragmenting in the upper atmosphere and landing in many pieces over the Nubian Desert in northern Sudan. This asteroid—first called 2008 TC3—was the first near-Earth object to be discovered and tracked before it hit our planet. In December 2008, members on an expedition to the area where 2008 TC3 landed collected some 280 pieces of this meteorite, now called Almahata Sitta. This piece, about 4 centimeters (1.5 inches) in diameter, is seen where it came to rest on the desert floor.

Photo: Peter Jenniskens, SETI Institute and NASA/Ames Research Center

The Planetary Report (ISSN 0736-3680) is published bimonthly at the editorial offices of The Planetary Society, 65 North Catalina Avenue, Pasadena CA 91106-2301, 626-793-5100. It is available to members of The Planetary Society. Annual dues in the United States are $30 (U.S. dollars); in Canada, $40 (Canadian dollars). Dues in other countries are $45 (U.S. dollars). Printed in USA. Third-class postage at Pasadena, California, and at an additional mailing office. Canada Post Agreement Number 87424.

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A PUBLICATION OF THE PLANETARY SOCIETY

PROTECTING EARTH: WHOSE JOB IS IT?

BY LOUIS D. FRIEDMAN

This special issue of *The Planetary Report* examines the threat of an impact by a near-Earth object (NEO) on our planet and identifies the widespread damage that could result. Although much of the knowledge about this threat is relatively new, the danger has always existed, as evidenced by the cratered history of the Earth and the Moon. Ignorance of this danger was blissful—at least until a catastrophe occurred. As we learn more about Earth's celestial neighborhood, we must cope not only with that knowledge but also with the uncertainties associated with it.

The rate of asteroid discovery is accelerating due to increased observation, and the accuracy of orbit prediction increases with more observations. When a NEO is discovered, the prediction uncertainty is large, but with more observations, that uncertainty decreases. That is why the probability of impact almost always decreases after scientists discover an object that is potentially hazardous. At the same time that these known threats fall in likelihood, however, we are discovering more and more asteroids, and thus the known number of potentially hazardous objects rises.

As we learn more about the possibilities of damage from a NEO, we are led to ask, "What can we do about it?" Could we defend ourselves from a NEO that was headed for our planet, or our nation, or our city by blowing it up or deflecting it? The first seems unlikely to be a very good defense—it would still result in much of the asteroid, now in many parts, hitting Earth and causing major damage. The second might just be feasible—and indeed, a number of methods to deflect an asteroid are now being suggested. A problem with asteroid deflection is that it could reduce the probability of harm to one area of Earth and increase it for another area. The asteroid, and attempts to deflect it, could then reasonably be called a weapon of mass destruction.

Deflecting an asteroid is a big job. A number of ambitious (some would say "wild") engineering ideas have been proposed, but the most practical attention has been paid to three methods: towing, nuclear, and kinetic deflection. A recent NASA study concluded that the only way to deflect an asteroid quickly or upon short notice about a potential impact is by using nuclear weapons—an obvious danger in their own right. The Planetary Society seeks to avoid this danger by emphasizing other, more practical methods, and it is now funding the study of a fourth method—creating vaporization jets to maneuver the asteroid (see "We Make It Happen!" on page 18).

Uncertainty about NEO approaches and the means to prevent an impact raise concerns not unlike the Cold War danger of false interpretation of a nuclear attack. A potentially hazardous asteroid may, after many months or even years of observation, turn out not to be dangerous at all. The possible hazards cannot be ignored, however, and will lead to calls for action and needs to plan for planetary defense. Plans will be made as threats are identified, which is many times more often than impacts

When the asteroid that wiped out the dinosaurs struck Earth 65 million years ago, no humans were around to care about defending our planet against these killer rocks from space. Now this threat affects 6.8 billion humans and countless other species on our vulnerable blue world.
Illustration: Joe Tucciarone

actually occur. We have a choice in the planning process: leave the dissemination of information to the popular media and let public outcry drive planning and prevention, or bring together responsible minds in the government and scientific communities to create a scientific approach to the problem.

Planetary defense is thus not just a space issue—it is a military issue, a homeland defense issue, and a disaster issue. Whose job is planetary defense? When thinking of NEOs, most people tend to assume NASA is in charge, but NASA does not share this connection. NASA does have a scientific interest in exploring and observing NEOs, but such discovery and observation are largely conducted via conventional Earth-based astronomy. Issues of security and mitigation, as well as means of deflection, are largely military. Dealing with threats and disasters also is not NASA's responsibility.

The issue of planetary defense also lies beyond the purview of the United States. The very nature of the threat makes it a global issue, with both global consequences and global responsibilities. Thanks to the leadership of former astronauts Rusty Schweickart, Ed Liu, and Tom Jones and the Association of Space Explorers (ASE), the subject is now being considered by the United Nations Committee on Peaceful Uses of Outer Space. The ASE proposal envisions a command structure under the United Nations with mission groups responsible to the U.N. Security Council. This approach has the advantage of including broad international interests, in recognition of the fact that the threat posed by NEOs affects all countries. It has the disadvantage of putting implementation into the hands of countries that cannot be participants in the required action—that is, the nonspacefaring countries, which by definition lack the means to implement planetary defense without outside assistance. It is necessary to create an action team that can quickly and appropriately implement a deflection mission.

The Planetary Society has been active in the debates concerning appropriate strategies and has recently been invited to join the action team of the committee for purposes of developing a proposal for the United Nations and for the spacefaring countries. An International Astronautical Congress paper by Society Board member Bee Thakore and myself endorses the recommendations of the ASE and suggests that a NATO-type organization of spacefaring countries be considered for planetary defense. The spacefaring countries would work in concert with the broader international community on being prepared to take international action in the case of an identified threat.

Action is needed. The United States has done little to designate where the responsibility for planetary defense should be placed, but even its few efforts exceed those of other countries. The subject has been largely ignored by governments and space agencies in Russia, Europe, Japan, and China. Even the laudable U.N. consideration is moving ahead at a snail's pace.

Knowledge is needed. More NEO observations from the ground and from space are required to discover and characterize potentially hazardous objects. More research on mitigation and deflection methods is required. We do not want to face a panic situation when a threatening object is discovered. The Planetary Society is now supporting a new idea for asteroid deflection and will continue its long-standing and prescient (since 1982) effort to support NEO observers and discoverers around the world.

Knowledge must be disseminated. This special issue of *The Planetary Report* is one contribution toward that end.

Louis D. Friedman is executive director of The Planetary Society.

TO MOVE AN ASTEROID

BY WILLIAM AILOR

Could we deflect a dangerous asteroid? What techniques could we use in the event of a real threat? Might specific circumstances force us to use a specific technique?

A fleet of MADMEN (Modular Asteroid Deflection Mission Ejector Node) spacecraft swarms a menacing near-Earth asteroid. The small spacecraft will land on and eject mass from the body and thereby alter its trajectory. This illustration was part of a 2003 study on asteroid deflection by SpaceWorks Engineering for NASA's Institute for Advanced Concepts (NAIC). Illustration: Nathan Phail-Liff, Alien in the Box. Copyright © 2003 SpaceWorks Engineering, Inc. (SEI)

Eventually—inevitably—a near-Earth object (NEO) will approach Earth on a collision course. Earth will be hit unless Earth's inhabitants, for the first time in our planet's history, find a way to deflect a threatening space object.

Asteroids and comets have struck Earth and other planets in the past, and it is a certainty that they will strike again. In roughly the last 100 years, we've witnessed a number of dangerous space rocks.

June 1908—A relatively small asteroid, 30 to 50 meters in diameter, entered the atmosphere above a desolate region of Siberia and exploded an estimated 12 kilometers (7 miles) above the ground. The blast leveled trees over about 2,000 square kilometers (770 square miles), an area larger than Washington, D.C.

July 1994—Multiple fragments of comet Shoemaker-Levy 9 impacted Jupiter in a spectacular display. The impact of these objects may have unleashed energy equivalent to 10 million megatons of TNT.

June 2006—A large meteor entered the atmosphere over Norway and exploded with a force estimated to be comparable to that of an atomic bomb. The object reportedly struck a mountainside in a remote area, and no injuries were reported.

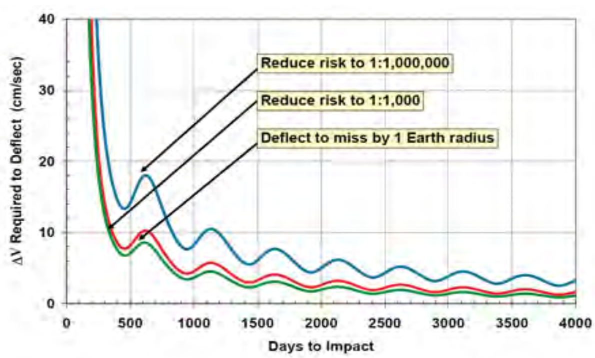
October 2008—Astronomers detected a small object entering Earth's atmosphere over northern Sudan. This was the first detection of a near-Earth object on a collision course with Earth. Fortunately, the object was small and was expected to fragment high in the atmosphere, posing no threat to people or property. Data after the event supported those predictions, and fragments were subsequently recovered.

2036—We now face the potential for another detected collision. In 2029, asteroid Apophis (270 meters in diameter) will pass within 40,000 kilometers (24,800 miles) of Earth, similar to satellites orbiting at geosynchronous altitude. In 2036, Apophis will make another close approach, and this time it could hit our planet (the current probability of impact is 1 in 250,000). Should it hit in 2036, the energy released would be the equivalent of more than 500 megatons of TNT—it would be a bad day for Earth and its inhabitants.

The likelihood that Apophis will make an impact is small, but one day, a NEO will be on a direct path with Earth. What could we do to protect our planet?

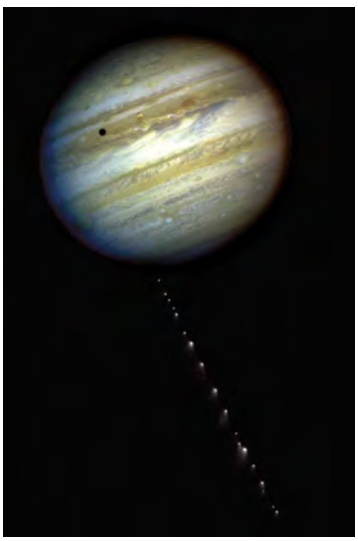
THE NEED FOR (REDUCED) SPEED

One way to prevent a NEO from hitting Earth is to change (increase or decrease) its velocity so that it is not at the intercept point when Earth arrives. The graph below shows

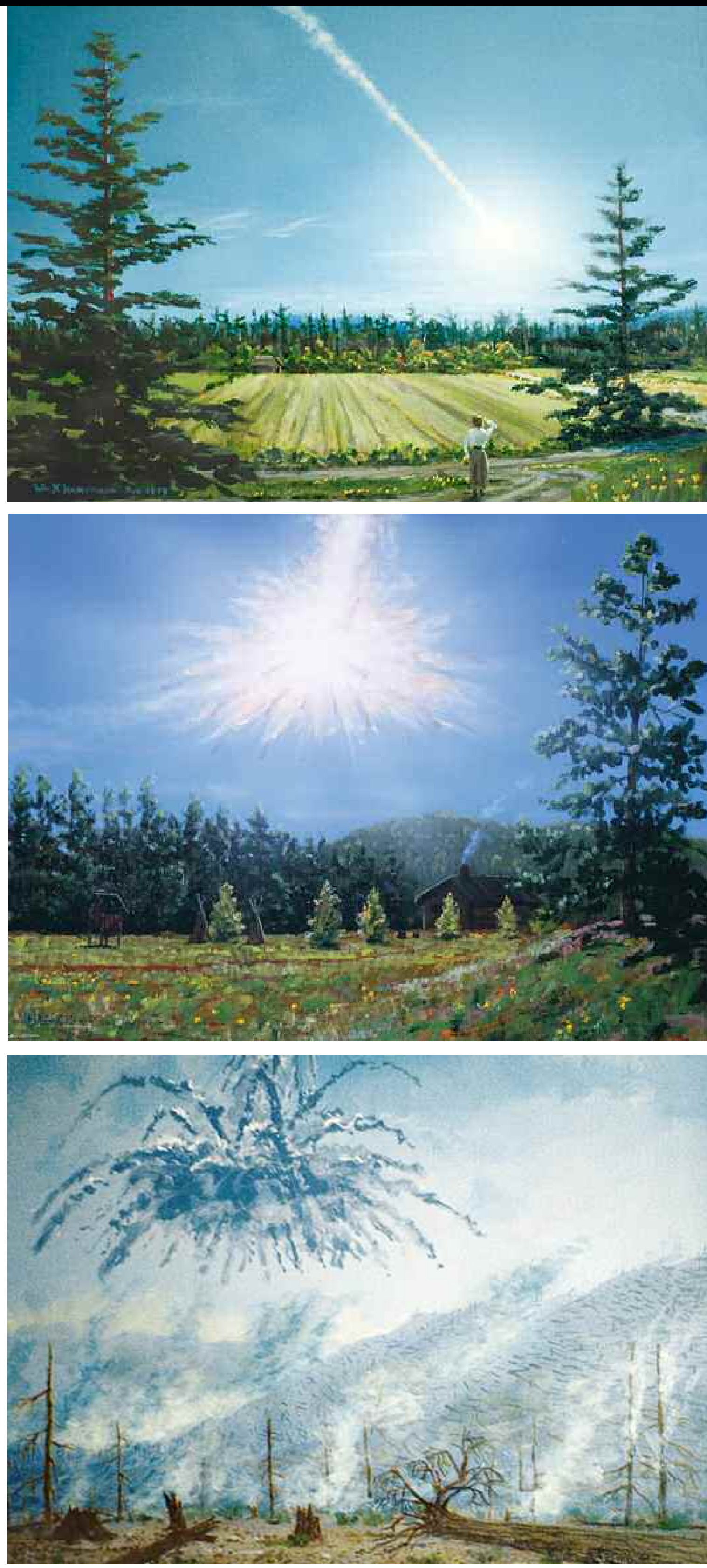


how much the velocity of an oncoming NEO must be changed to ensure that it misses Earth. If the NEO is detected far from Earth and long before the potential impact, the required change in the NEO's velocity is quite small because that velocity change will apply over a longer span of time. The later we try to deflect an asteroid, the larger the necessary change in velocity will be required to achieve the same result.

This mathematical relationship shows us the importance of discovering and tracking the orbit of threatening objects as many years—or decades—before impact as possible. Moreover, once we've identified and tracked the dangerous asteroid



In July 1994, the world watched as comet Shoemaker-Levy 9 broke up and sent a string of separate pieces crashing through Jupiter's atmosphere. We had the luxury of watching this cosmic spectacle from a safe distance—a luxury we cannot take for granted. *Image: H.A. Weaver and T.E. Smith (STScI) and J.T. Trauger and R.W. Evans (NASA/JPL)*



Above: These panels, painted from nature in possible Siberian analogs, depict the fireball explosion on June 30, 1908 in the sky over Tunguska. Not shown is the column of dark smoke—looking like a spear or rod—that people described rising from the forest 5 to 15 minutes after the event.
Paintings: William K. Hartmann

Slamming the Deep Impact *spacecraft into comet Tempel 1 had a side benefit. The 2005 mission's prime objective was to help determine the body's composition and physical attributes. It also served, however, as a kinetic impactor, slightly changing Tempel 1's velocity.*
Image: NASA/JPL/University of Maryland

The safest option for changing a NEO's velocity using a nuclear explosion would be to detonate the device tens of meters above the surface, decreasing the likelihood of fracturing the object and thereby creating more potentially deadly impactors.
Illustration: Rhys Taylor. Copyright © 2006 SpaceWorks Engineering, Inc. (SEI)

or comet, we then need to make a decision to act. The longer it takes to make such a decision, the closer the object gets, the greater the velocity change is required, and the greater the momentum (or energy) we will need to deliver to the oncoming object to effect the necessary velocity change.

HOW CAN WE DO IT?

The techniques that have been proposed to move an asteroid or comet typically are categorized into two groups: impulsive and slow-push. Impulsive techniques change a NEO's velocity instantaneously by striking it with another object, or possibly by using one or more explosive devices. Slow-push techniques transfer momentum slowly by applying a force over a long period. Descriptions of some proposed techniques follow.

IMPULSIVE TECHNIQUES

Hit it with something—Perhaps the most readily available technique is a *kinetic impactor*; like a bullet striking a rock, an object intercepts and strikes a NEO at a high velocity. The momentum transferred to the NEO by the impact is simply the mass of the impactor times the relative velocity. And since the impactor creates a crater on the target object, the ejected material adds to the momentum transfer and net velocity change of the NEO.

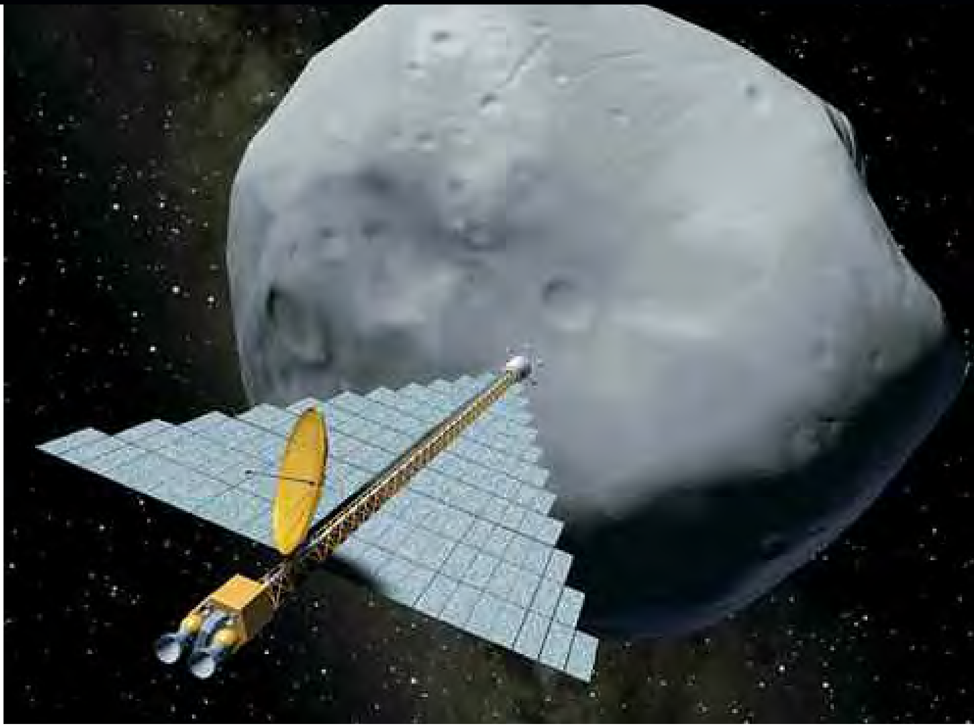
Since the physical properties of a NEO may not be well known at the time of the impact, a single kinetic impact might be insufficient or its effects uncertain, so a deflection campaign might include multiple impactors.

In a sense, we have already tested a kinetic impactor: the *Deep Impact* mission used a high-speed impact into comet Tempel 1 in 2005 to help determine the composition of the material and physical characteristics of that body. The 370-kilogram (820-pound) impactor struck the comet at a relative speed of 10.2 kilometers (6.3 miles) per second, resulting in a small, in this case minuscule (about 0.0001 millimeters per second), change in the velocity.

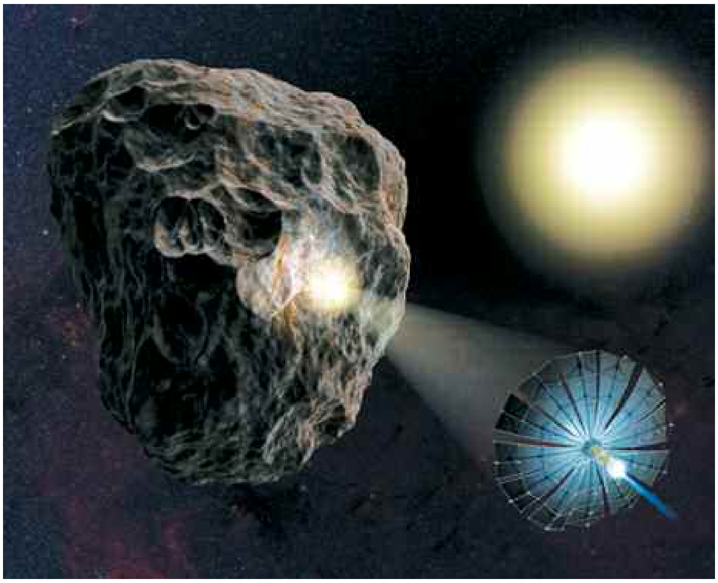
Use a big bang—Another impulsive technique involves the use of an explosion. As might be expected, the greatest amount of energy would be delivered to a NEO by a nuclear explosive. Such an explosive could act on a NEO in any of three ways: detonate the explosive below the surface of the NEO, detonate on the surface, or detonate above the surface.

The first two are potentially more efficient, since the explosion would create a crater and send material from the object away at high speeds, adding to the net momentum transfer. However, either a subsurface or surface explosion might fragment the NEO, potentially creating two or more NEOs possibly on collision courses with Earth. In some scenarios, fracturing the NEO might be desirable, but we would always want the fracture to be planned such that as many large fragments as possible miss Earth.

The third option is predicted to be much gentler. In this



One direct form of slow-push technology would be to attach a motorized "space tug" to an asteroid, gently moving it onto a safer path. Illustration: Rick Sternbach



Concentrated sunlight beamed onto a menacing asteroid would ablate material from its surface. In this slow-push technique, the resulting ejecta would impart an opposite momentum to the body, slightly altering its trajectory. Illustration: Rhys Taylor. Copyright © 2007 SpaceWorks Engineering, Inc. (SEI)

case, the nuclear device would be detonated tens of meters above the surface of the body. The radiation from the explosion would "boil off" some of the surface material, and the departure of this material would nudge the body slightly. The explosion would effectively act over a relatively large area of the NEO, and some believe that it would not be as likely to fracture the NEO or create significant debris. Although the momentum transferred by this third option is less than that of the other two, it has the advantage that a subsequent attempt at deflection, if required, would be acting on an essentially known object instead of the fractured remains of the NEO.

SLOW-PUSH TECHNIQUES

Slow-push options typically involve a small force acting on the NEO for a relatively long period, possibly months or years, to create a velocity change. Several slow-push options have been proposed.

Change its reflectivity—This option would change how sunlight interacts with the NEO. For example, the heating of a rotating asteroid's surface causes a small force when the heated area rotates away from the Sun, and this small force slightly changes the object's orbit. Changing the reflectivity of a NEO by "painting" the surface white would affect how sunlight interacts with the surface and would alter the object's orbit over the long term. A similar effect would result if the surface was coated or wrapped with a reflective material.

Vaporize part of it—Heating a spot on a NEO's surface, possibly using solar energy or a laser, would "boil off" material from the heated area, imparting a small velocity increment to the NEO. Proposals to implement this idea include parking a spacecraft with a solar-driven laser or a large solar reflector in the vicinity of the NEO.

Eject material from it—Another option is to use one or multiple devices that have been attached to the NEO to dig material from it and eject that material at high speeds in a controlled direction. This "mass driver" approach would impart a thrust on the NEO, just as a rocket engine does.

Pull it with spacecraft gravity—This slow-push technique would use a "gravity tractor" spacecraft designed to hover or orbit very close to a NEO. The gravity tractor would gently tug the NEO using the small gravitational attraction between the NEO and the spacecraft. This gravitational force would modify the NEO's orbit in a controlled fashion over a long period.

Put a motor on it—This option would involve attaching a rocket motor to the NEO. With this "space tug" approach, a propulsive device would be attached to the NEO, and the thrust of the device would move it.

DEALING WITH UNCERTAINTIES

The process of deflecting an asteroid or comet is complicated by uncertainties about the object to be deflected. These uncertainties influence the effectiveness of potential deflection techniques.

One uncertainty concerns the object's mass. Standard optical means for determining an object's size have an uncertainty of a factor of two. For example, observation of an object might indicate that it is anywhere from 100 to 200 meters in diameter. Assuming that the object is spherical, this means that the mass—a critical parameter in selecting the deflection option to be used—is uncertain by at least a factor of eight. We must also consider uncertainties concerning the shape, mass distribution, and actual density of the object we want to deflect.

The object's dynamics can also affect a deflection attempt. For example, if the object is rotating, use of a mass driver would be complicated by the fact that the mass must be directed in a particular direction to move the object away from a collision course with Earth. A single mass driver attached to a tumbling object would be able to operate only when pointed in the proper direction. One way of circumventing that problem would be to use multiple mass drivers planted around the object, with each being activated only when it is pointed correctly. A similar consideration would apply with a space tug attached to a rotating body.

Because gravitational attraction varies as the square of the distance between the centers of masses of objects, a gravity tractor should be as close as possible to the NEO during its operation. If the object has an irregular shape and is tumbling, the tractor might be required to operate farther away, extending the time it must operate to effect the necessary change in velocity.

Impulsive techniques must also consider these uncertainties. For example, a single kinetic impactor may provide the required velocity change for a 100-meter object, but multiple impacts might be required for an object 200 meters in diameter (with a correspondingly larger mass).

A third uncertainty is the object's composition. Is it a single, solid body, or several solid bodies, or a rubble pile of smaller objects held together by small gravitational forces? The composition could influence the effectiveness of a particular approach; for example, it might be difficult to attach a mass driver to a rubble pile. In addition, objects of different composition might be more likely to be fractured by a subsurface or surface-level explosion or kinetic impact, making subsequent deflection efforts more difficult.

Finally, the existence of a companion object might complicate deflection. If the NEO has a moon—and we know that some do—the moon could also represent a threat that must be considered.

Many of these uncertainties could be reduced given sufficient time for a reconnaissance mission. Such a mission would also enable precise tracking and characterization of the object, which would help determine whether the object actually is a threat to Earth and which deflection methods might be feasible.

MISSION AND CAMPAIGN REQUIREMENTS

A specific threat might evolve in a manner similar to that experienced during the Mars encounter in early 2007 with a 50-meter-diameter asteroid. When the asteroid was discovered, the probability that it would impact Mars two months later was 1 in 350. Measurements taken as the object approached Mars increased the prob-

On the surface, the MADMEN mass drivers use their excavating drills and electromagnetic catapults to launch small amounts of matter away from the asteroid. The multiple MADMEN provide redundancy and ensure that the asteroid will be moved slowly out of its beeline for Earth. Illustration: Nathan Phail-Liff, Alien in the Box. Copyright © 2003 SpaceWorks Engineering, Inc. (SEI)

ability to 1 in 75, then to 1 in 25. Later, the predicted probability of impact fell to 1 in 10,000. The object missed the planet.

If Earth had been the target, would we have initiated an all-out effort when the object was first detected? Or would we have waited until the probability reached 1 in 75, or 1 in 25? This example shows the value of a good discovery program. If we first detect an object only a few months before impact, we may have very few options for mitigation.

As the Mars scenario illustrates, time will be required simply to make the decision to act, then to fund the effort, to design a deflection campaign, to build the required hardware, and to send an appropriate number of spacecraft on their way. Then the spacecraft must reach their target, which could take months or years.

If we don't have confidence in the object's mass, we might be forced to be conservative and design the campaign to deflect a mass somewhat larger than expected. If we don't know its composition, we would want to select a technique that does not rely upon such detailed knowledge (for example, a nuclear explosion above the surface if time is short, or a slow-push technique like a gravity tractor if the threat is decades away).

Finally, deflection efforts must be properly coordinated worldwide. Mitigation efforts must be complementary, rather than acting at odds with each other. In addition, the deflection campaign must ensure success: if one launch vehicle or spacecraft fails or provides less impulse than expected, others must be available or already on their way to ensure that the desired velocity change is delivered.

Mission planners will have to consider an incoming NEO's composition before deciding on the best and safest method to deflect it. Some asteroids are actually loose rubble piles or, in the case of Ida and its moon Gaspra, multiple objects. Image: NASA/JPL

WHERE DO WE GO FROM HERE?

Time will be a critical resource for any deflection effort, so we must have a well-funded effort to find and catalog potential threats well in advance of their potential impact. The more time that is available, the greater will be the range of deflection options.

We could use existing technology to mount a deflection effort, but we are in the early stages of developing technology to the point at which we have confidence in its successful use. Right now, we have no deflection campaign designs that can be pulled "off the shelf" if required. To date, the only technique that has been tested to any degree is the kinetic impactor, which has been used only for scientific purposes, and none of the slow-push or more energetic impulsive techniques has been tested.

Fortunately, we have some time before we need to employ a deflection campaign—but now is the time to start preparing, as any of the options will require substantial time to implement. With an aggressive NEO discovery program, more technology development, and international collaboration, we will be able to determine just how much time we have, we will have confidence in our ability to deflect a threatening object, and we will have a coordinated plan to protect our planet from a NEO disaster.

William Ailor is director of the Center for Orbital and Reentry Debris Studies at The Aerospace Corporation. He was chair of the 2004 and 2007 Planetary Defense Conferences and cochair of the 1st International Academy of Astronautics–sponsored Planetary Defense Conference held in Granada, Spain in 2009. He is cochair of the second IAA Planetary Defense Conference, to be held in May 2011 in Bucharest, Romania.

TURNING COSMIC DISASTER INTO OPPORTUNITY

BY TOM JONES

A large asteroid heats up as it speeds through Earth's atmosphere over Los Angeles, seconds before a devastating impact.

Illustration: Copyright © 1991 Pat Rawlings

On July 19, 2009, a small comet or asteroid plunged into Jupiter's bottomless atmosphere near the planet's south pole. The cosmic projectile struck the giant planet at tens of kilometers per second, flashing solid rock into a fireball of superheated gas. The cooling plume marred Jupiter's banded cloud tops with a dark smudge of dust particles.

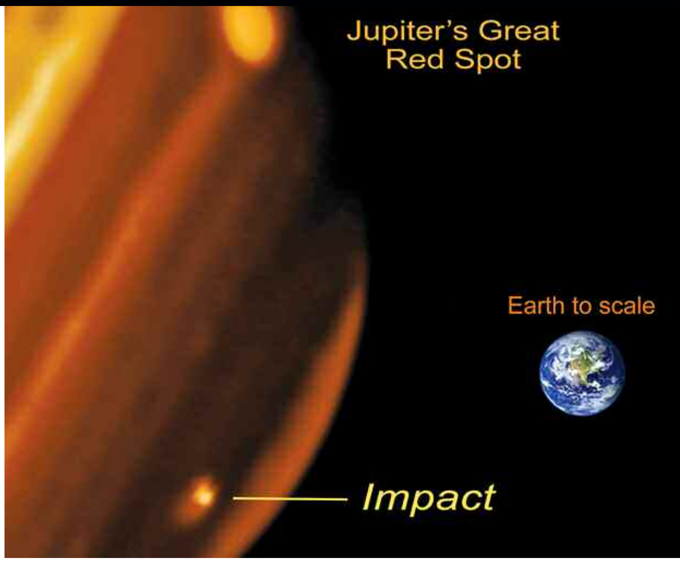
From our home planet, Australian amateur astronomer Anthony Wesley noticed the Earth-sized impact scar and notified astronomers across the globe. Within days, observatories, including the newly repaired Hubble Space Telescope, imaged the prominent scar, adding the latest chapter to the ongoing story of cosmic bombardment across our solar system.

COSMIC BOMBARDMENT

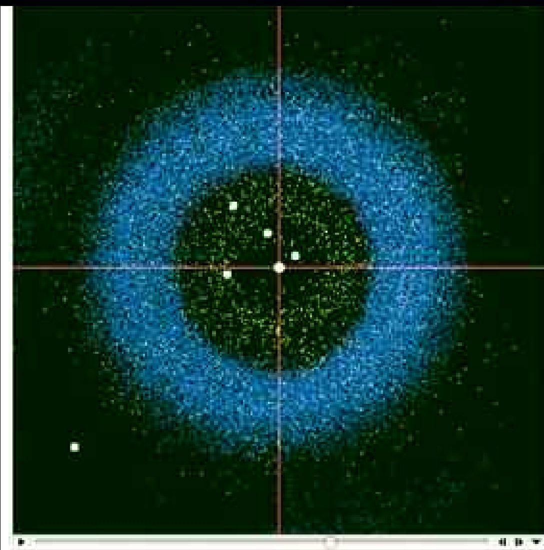
Earth orbits the Sun amid a swarm of hundreds of thousands of asteroids and comets that circulate through the inner solar system. Most were formed 4.6 billion years ago in the main asteroid belt between Mars and Jupiter. Collisions and Jupiter's far-reaching gravitational influence kick these leftover shards of planetary formation Sunward, where they orbit for an average of 100 million years before a planet either sweeps them up or ejects them from the Sun's family. Those that cross or approach Earth's orbit are called near-Earth objects (NEOs).

The first near-Earth asteroid (NEA) to be discovered, in 1898, was Manhattan-sized 433 Eros, some 32 kilometers across. Most NEAs are much smaller, like the 535-meter-long, potato-shaped 25143 Itokawa, visited in 2005 by Japan's *Hayabusa* spacecraft. Only a tiny fraction of this population of NEAs has been detected by our telescopes.

NEOs have collided with Earth throughout its dynamic history, but only a year ago did we see one coming. Observers at Arizona's Catalina Sky Survey picked up the truck-sized 2008 TC3 less than a day before it burned up



Last summer, Jupiter's southern hemisphere was struck by a comet or asteroid traveling at tens of kilometers per second, causing a flash of superheated gas and then leaving a dark smudge in the giant planet's upper atmosphere. This infrared image, taken on July 20, 2009 with Hawaii's Keck II telescope, shows the impact scar, which had grown to a size larger than Earth's Pacific Ocean. *Image: Paul Kalas, UCB; Michael Fitzgerald, LLN/UCLA; Franck Marchis, SETI Institute/UCB; James Graham, UCB*



This still frame of an animation showing the Sun, inner planets, asteroid belt, and Jupiter illustrates the often-used statement that Earth resides in a cosmic shooting gallery. The blue dots here represent asteroids that do not cross Earth's orbit; the yellow dots indicate those that do. To see the yellow dots in action, follow the link at **http://pan-starrs.ifa.hawaii.edu/public/asteroid-threat/near-earth.html.** *Animation: Nick Kaiser, Institute for Astronomy, University of Hawaii*

over Sudan on October 7, 2008. An impact from a kilometer-sized object would throw debris, or ejecta, outward from the crater and blast fine dust throughout the upper atmosphere. Wildfires, acid rain, and lack of sunlight would damage plant life worldwide. The ensuing agricultural collapse would wreak havoc on Earth's 6.8 billion people. Impacts on this catastrophic scale are expected every few hundred thousand years, on average.

Even NEOs a few hundred meters in diameter would cause blast damage, fires, and large tsunamis that would cost society hundreds of billions of dollars. Recognizing the hazard, the U.S. Congress provides NASA with about $4.1 million each year to search for civilization killers—NEOs exceeding 1 kilometer in diameter. As part of its 1998 goal to find 90 percent of that population, NASA's Spaceguard survey has (as of October 2009) cataloged 6,483 NEOs. (See the latest statistics at *neo.jpl.nasa.gov/stats/*.) Of the thousand or so NEOs larger than 1 kilometer thought to exist, 791 have been found.

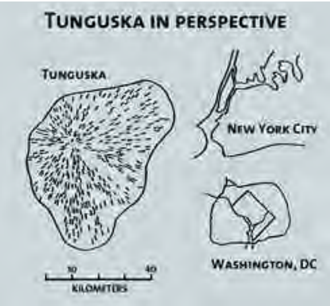
WHAT ARE THE ODDS?

NASA's follow-through in coming years should rule out most of the worst-case impact scenarios that are so popular with Hollywood screenwriters. The threat from smaller objects will remain, and small NEOs vastly outnumber the big ones. Most objects smaller than 40 meters will break up in our atmosphere instead of striking Earth's surface and forming a crater. Even an atmospheric breakup, however, can cause a huge release of energy in the form of a blast wave and fireball of superheated gases. The 1908 Tunguska impact, which occurred in central Siberia on June 30, 1908, produced an airburst equivalent to some 3–5 megatons of TNT, leveling 2,000 square kilometers of forest. Recent impact modeling at the Los Alamos National Laboratory has shown that the impactor may have been only 30–40 meters in diameter.

Astronomers estimate that a 40-meter-sized object collides with Earth about once every 300–500 years. Smaller impacts, like that of 2008 TC3, occur much more frequently. Fireballs on the order of 10 kilotons (the energy equivalent of the Hiroshima bomb) occur about once a year. Missile early warning satellites regularly detect airbursts with the energy equivalent of 10 tons of TNT.

Potentially hazardous asteroids (PHAs) are those NEOs that approach within 0.05 AU of Earth (roughly 7.5 million kilometers, or 4.5 million miles) and have a diameter larger than 110 meters (easily capable of surviving atmospheric entry). As of October 2009, NASA's NEO program office listed 1,066 PHAs, 145 of which are larger than 1 kilometer. Approximately 250 PHAs have some small probability of impact in the next century. At least one, 2004 BX159, is more than 1 kilometer in diameter.

The collision probabilities are extremely small. For example, 2007 VK184, some 130 meters across, has a 1 in 2,941 chance of hitting Earth during four close approaches between 2048 and 2057. Until last October, the 250-meter asteroid 99942 Apophis was thought to have



Recent impact modeling indicates that the bolide that blew up over Tunguska, Siberia on June 30, 1908 was between only 30 and 40 meters in diameter. Even though it didn't hit the ground, the immense force of the blast leveled 2,000 square kilometers (about 770 square miles) of forest. The map at left shows the size of the area affected in relation to New York City and Washington, D.C. *Photo: Leonid Kulik; Map: Courtesy of John Pike*

Fine points of the fireball that might be expected from an asteroid exploding in Earth's atmosphere are indicated in a supercomputer simulation devised by a team led by Sandia National Laboratory's Mark Boslough. *Photo: Randy Montoya*

a 1 in 43,478 probability of striking Earth on April 13, 2036. Last fall, astronomer Dave Tholen used archived images of the night sky to refine Apophis's orbit, enabling JPL to calculate much-reduced impact odds of 1 in 250,000. Bruce Willis can rest easy.

In fact, you are more likely to be swept up by a twister on the midwestern plains than blown away by a rogue asteroid. Most of the risk stems from large NEO impacts that would kill millions. It is that danger that NASA is addressing with its Spaceguard survey.

We do, however, recognize the risk from tornadoes. Through improved detection technology and better alerting systems, we strive to minimize the number of lives claimed by such natural disasters. We should be equally prudent when dealing with the threat posed by NEOs.

CONGRESS TACKLES THE NEO HAZARD

A small but persistent impact risk is posed by smaller NEOs that are capable of devastating a region or a city. The present NEO population (mostly undiscovered) harbors perhaps 50,000 objects greater than 140 meters in diameter. Today's likeliest impact scenario is from a relatively small object (about 100 meters across) hitting with little or no warning. The impact of a 140-meter NEO would cause an explosion equivalent to about 100 megatons of TNT.

Congress recognized this hazard in 2005, prompted by a 2003 NASA report on the feasibility of detecting smaller NEOs. Lawmakers directed NASA to find, by 2020, 90 percent of all objects larger than 140 meters. The 140-meter threshold was chosen to reduce Earth's impact risk to roughly 10 percent of that remaining after completion of the Spaceguard survey, which is looking for NEOs 1 kilometer or larger.

In addition, in 2005, Congress directed NASA to report back with its best recommendations and budget for executing the extended search program, along with an analysis of methods for deflecting a potential impactor. NASA responded in March 2007 with its "Near-Earth Object Survey and Deflection Analysis of Alternatives" (*neo.jpl.nasa.gov/neo/report2007.html*). The agency proposed easing the search task by looking only for 90 percent of PHAs (not all NEOs) larger than 140 meters. By sharing funding and observing time on several ground-based telescopes, NASA said, it could reach the revised 90 percent goal by 2026. The search could be completed more quickly by launching a small infrared telescope to

Hawaii's Panoramic Survey Telescope and Rapid Response System (Pan-STARRS) scans the sky nightly searching for killer asteroids. Photo: R. David Beals, University of Hawaii

The summit of Chile's Cerro Pachon is the future site of the National Science Foundation's Large Synoptic Survey Telescope (LSST). The 8.4-meter wide-field observatory will share the Cerro Pachon ridge with the Gemini South 8-meter and the SOAR 4.1-meter telescopes. Photo montage: C. Claver, NOAO/LSST

a Venus-like orbit, where it could look outward past the Earth for sunlit NEOs. Of course, such a space-based detector would cost more.

Two ground-based systems can address the 140-meter search goal. The Panoramic Survey Telescope and Rapid Response System, or Pan-STARRS, is a 1.8-meter telescope atop Haleakala volcano on Maui. Initial testing on the $60-million, Air Force–funded prototype has gone slowly, but a second telescope is being built. Astronomers hope eventually to operate four telescopes, each with a 1.4-billion-pixel camera, atop Mauna Kea, Hawaii. The complete system should be capable of detecting 99 percent of NEOs larger than 300 meters in diameter.

The National Science Foundation's (NSF) Large Synoptic Survey Telescope (LSST), an 8.4-meter wide-field observatory, is planned for the summit of Cerro Pachon in Chile. The LSST's main mirror has already been cast and is now being shaped, and if funding comes through from the NSF, NASA, and other science partners, it could see first light in 2014. Its sensitivity and fast survey capability could complete the Spaceguard 1 survey and meet the new 140-meter goal a decade after operations begin.

NASA DEMURS

NASA also reviewed several of the techniques that might deflect a marauding NEO, but it did not propose a specific program to detect a NEO, characterize it, and possibly demonstrate a deflection. Nor did the agency propose a budget for the search. Then-Administrator Michael Griffin told Congress in 2007 that "due to current budget constraints, NASA cannot initiate a new program at this time." In effect, NASA told Congress, "Show me the money."

Despite clear language that NASA should get on with the 140-meter search, the agency has been content since 2007 to continue the existing Spaceguard survey, waiting for dedicated funding. Dissatisfied, Congress directed the National Research Council (NRC) to advise NASA on NEO detection and hazard mitigation. The NRC's final report was not due until the end of 2009, but the council noted last summer that a successful survey should include

A close-up illustration of the LSST telescope now being built. Illustration: Tod Mason, Mason Productions Inc., LSST Corporation

Pan-STARRS, LSST, the Arecibo radar telescope, and possibly a space-based detector (see *nap.edu/catalog.php?record_id=12738*). To end the impasse, Congress should direct NASA to implement the NRC technical recommendations in 2010 and provide the funds to do so. Time is not on humanity's side.

DEFLECTING A CATASTROPHE

Our half-century of spaceflight gives us most of the tools we need to prevent small impacts. With sufficient warning, NEOs a few hundred meters across can be sped up or slowed down enough to miss the Earth, using the minute gravitational tug from a transponder-Gravity Tractor (t-GT) spacecraft. Designed first to track and then to deflect a NEO, the t-GT is especially effective at modifying an asteroid's trajectory before a close Earth encounter that puts an asteroid on a collision course. JPL determined for the B612 Foundation that a 1-ton gravity tractor would need just a few months to produce the necessary velocity change (see *b612foundation.org/press/press.html*).

To deflect a larger NEO, we could slam a series of

Near right: The large (32 kilometers across) 433 Eros found in 1898 was the first near-Earth asteroid ever detected. It would be 102 years before we were able to take a close look at it. This mosaic is composed of six images taken by Near Earth Asteroid Rendezvous *(*NEAR*) spacecraft on February 29, 2000.* *Image: NASA/JPL/JHUAPL*

Far right: Most NEAs are much smaller than Eros. For example, 25143 Itokawa, visited in 2005 by Japan's Hayabusa *spacecraft, is only 535 meters long.* Hayabusa *took this picture on October 1, 2005.* *Image: ISAS/JAXA*

kinetic energy impactors into the target asteroid at very high speed. The cumulative momentum transfer would cause the NEO to miss its fatal appointment with Earth. A t-GT nearby would observe the *Deep Impact*–style campaign and confirm a successful deflection.

Finally, in the rare cases (less than 5 percent) dealing with a large NEO or little warning time, we could employ a nuclear explosive. A detonation close to the asteroid would vaporize a very thin layer of its surface, boiling off gas and regolith in a broad jet. That impulse would nudge the asteroid in the opposite direction, changing its velocity. Because most NEOs are small, our warning systems are improving, and our spaceflight expertise is growing, deflecting a NEO using nuclear explosives probably will never be necessary.

A GLOBAL RESPONSIBILITY

As the new telescopes come online, they will add many fainter, smaller asteroids to the NEO catalog. With at least 50,000 objects larger than 140 meters out there, the number of PHAs will swell into the many thousands. A sizable fraction will be large enough to threaten regional destruction, representing a long-term global hazard: impacts can occur anywhere on Earth and could affect large areas of the planet.

Within 20 years, we'll be finding perhaps a dozen or more PHAs annually with worrisome impact probabilities. A few may rise to the 1-in-1,000 or 1-in-100 probability level, enough to worry dozens of nations along the line of possible impact points, the NEO's "risk corridor." Furthermore, it is unlikely that improved Earth-based tracking will be able to rule out an impact until after the window for deflecting that object slams shut. In other words, the international community will have to decide to act before we know positively that an impact will occur.

Consider the case of Apophis and its small probability of hitting us in 2036. If we roll "snake eyes" in 2029 and Apophis is deflected onto a collision course, it will already be too late. Seven years isn't enough time to mount an effective deflection campaign.

The coming wave of NEO discoveries will pose a host of questions. Among them:

- What criteria will trigger a decision to deflect a hazardous NEO?
- Who will decide whether to deflect such a NEO?
- How will the international community act in concert to counter a rogue NEO?
- Who will pay for protecting against this global hazard?

These and other knotty questions, each with international implications, demand a global response. The Association of Space Explorers (ASE), comprising more than 325 astronauts and cosmonauts from 35 countries, began in 2005 to work to establish a clear, international decision process for coping with the NEO hazard. The ASE convened a panel of experts and in 2008 completed a draft decision-making framework: *Asteroid Threats: A Call for Global Response* (*space-explorers.org/ATACGR.pdf*).

KEY FUNCTIONS

The ASE Panel on Asteroid Threat Mitigation formally submitted the draft program to the United Nations (U.N.) last year. The ASE recommended that any NEO decision-making process coordinate three vital functions:

- information and warning
- mission planning and operations
- mission authorization and oversight.

Information, analysis, and warning tasks concerning a possible NEO impact could be performed by linking existing institutions (such as NASA/JPL's NEO search and impact prediction effort, Europe's NEODyS impact prediction center, and the International Astronomical Union's Minor Planet Center) with next-generation telescopes and trajectory analyses. For mission planning, the U.N. might commission a group of spacefaring nations to produce a set of "reference missions" comparing possible deflection scenarios. For oversight, the U.N. General Assembly might empower the Security Council to authorize and

Near-Earth asteroids contain valuable supplies of water and other resources necessary for humans to live and work in space. Mining and exploration missions to asteroids not far from the safety of home would help ready astronauts for the more ambitious goal of working on Mars.
Illustration: Dan Durda

coordinate a future deflection campaign.

The U.N.'s Committee on the Peaceful Uses of Outer Space agreed in 2009 to use the ASE recommendations as the starting point for forging an international NEO agreement. Discussions continued at the committee's sessions in February and June, with the goal of elevating a decision-making agreement to the General Assembly three years hence.

ASE will continue to advise and support this effort, along with organizations such as The Planetary Society. Our space fliers can communicate effectively to their respective governments and will work to educate the public about the NEO hazard and the importance of an international solution.

TURNING RISK INTO BENEFIT

Whether or not we look for NEOs, our home planet continues to hurtle through a cosmic swarm of asteroids and dormant comets. A look at JPL's table of upcoming asteroid close approaches (*neo.jpl.nasa.gov/ca/*) illustrates how busy our space neighborhood is. Along with posing the potential for damage to Earth, these PHAs also represent an opportunity for scientific exploration and the discovery of valuable space resources.

NASA conducted a study in 2007 that showed how the new *Orion* spacecraft and its Constellation family of rockets will be capable of sending astronauts on multimonth voyages to nearby NEOs. Last August, the Augustine Committee noted the attractions of such expeditions in discussing its "flexible path" options for sending human explorers beyond low Earth orbit. Already, we know of a handful of NEOs that require less velocity change for a piloted expedition than would an *Apollo*-style round trip to the Moon's surface. The increasing asteroid discovery rate should expand the target set significantly.

Human NEO expeditions will return exciting scientific knowledge, discover water and other valuable resources, engage the public in dramatic exploration millions of miles from Earth, and stretch our space "legs" toward Mars. As accessible ore bodies with almost no gravity well, NEOs can help us create a thriving industrial economy in Earth-Moon space. Meteorites tell us that some NEOs are up to 20 percent water by mass; if we can tap it, that supply will help us establish humans off the planet and greatly reduce the cost of eventually reaching Mars.

Most important, NEO exploration will teach us how to operate capably around objects we might one day have to divert. As Carl Sagan noted in *Pale Blue Dot*, the human species cannot survive unless we develop the ability to protect Earth from future impacts. Our planet has been battered by cosmic impacts for billions of years. Isn't it time we crossed Earth off the target list?

Tom Jones is a planetary scientist, four-time shuttle astronaut, and Planetary Society adviser. His latest book, coauthored with Ellen Stofan, is Planetology: Unlocking the Secrets of the Solar System *(*www.AstronautTomJones.com*).*

WE MAKE IT HAPPEN!

DOING OUR PART TO PROTECT EARTH

BY BRUCE BETTS

As part of this special issue of *The Planetary Report* devoted to planetary defense, I want to update you on The Planetary Society's contributions to solving this problem. We are actively involved in elements of the solution, ranging from detection, to deflection, to political advocacy, and we are always striving to fill important niches not otherwise filled.

Among our efforts, we are issuing a new call for proposals for our Shoemaker NEO grant program; one of our researchers has discovered the largest crater in South America; and we are starting work with an exciting new NEO deflection program that would "zap" an asteroid and use the vaporized material to move it to a safer orbit.

Eugene Shoemaker at a stereoscopic microscope used for asteroid discovery. Photo: USGS

Shoemaker NEO Grants: A New Call for Proposals

The Planetary Society's Gene Shoemaker Near-Earth Objects (NEO) Grants fill an important niche in planetary defense, providing funding for amateur observers, observers in developing countries, and professional astronomers who, with seed funding, can greatly increase their programs' contributions to NEO research. So far, we've presented more than $200,000 to 31 awardees in 15 countries on 5 continents.

Once we know a NEO is out there, we need to learn whether or not it will hit Earth. Shoemaker Grant winners are especially critical for carefully locating and monitoring the positions of recently discovered NEOs. Our winners, past and present, operate many of the most successful asteroid follow-up observatories in the world. You can find information about the impressive accomplishments of our past awardees at *planetary.org/programs/projects/neo_grants/*.

We are excited to announce a new call for proposals for Shoemaker NEO Grants. Here is some general information on what we are looking for; we'll have more details on the call for proposals on our website in February. Anyone may submit a proposal.

This next round of Shoemaker Grants will focus on advancing amateur contributions in astrometric follow-up and physical studies of near-Earth objects. The need now is for larger telescopes (apertures larger than about 24 inches, or 60 centimeters), or effectively larger telescopes at superior observing sites, and for the automation of observing facilities and equipment.

Large telescopes at sites with dark, clear skies allow for the observation of NEOs fainter than magnitude V = 20 (where the professional surveys are discovering many new small objects), and the automation of observing facilities allows observers with "day jobs" to utilize their facilities nearly full time and much more efficiently. Priority will be given to applicants seeking to improve facilities with large telescopes and/or for automation. Priority will also be given to programs that can leverage Shoemaker Grant funds through matching contributions from other sources.

Stay up to date on this latest call for proposals and on our previous Shoemaker Grant winners at *planetary.org/programs/projects/neo_grants/*.

A New Way to Deflect a Dangerous Asteroid: Mirror Bees

What do we do if an asteroid is found to be on a collision course with Earth? The answer is not clear, but researchers are discovering more options. We need to understand the options and determine the most effective ones so we will be best prepared for the inevitable—a dangerous NEO—whether that occurs a year or a century or a millennium from now.

The Planetary Society is excited about a new undertaking: funding researchers at the University of Glasgow in Scotland to do laboratory experiments to learn more about a relatively new option for deflection. This technique involves one or more spacecraft, flying in tandem with the dangerous asteroid, that would deploy mirrors and focus sunlight on a spot on the asteroid. (Alternatively, the satellites may contain powerful lasers pumped by sunlight.) The focused light vaporizes the rock, thus creating a jet plume of superheated gases and debris that gently

This modified image from NASA's* Deep Impact *spacecraft is a rough approximation of what a swarm of spacecraft vaporizing an asteroid surface might look like.
Image: SpaceART/Christie Maddock

pushes the asteroid. By applying this push over time, we can significantly alter the orbit of the asteroid to one that is safe.

The technique is so new that it has is no agreed-upon name. Options include *solar collector*, *solar ablation*, and *ablation jets*. We call our project "Mirror Bees"—I'll explain why a little later.

Each deflection technique has its pros and cons, and some are more appropriate than others, depending on the circumstances. The group at the University of Glasgow—part of that institution's Space Advanced Research Team (SpaceART)—under the leadership of Massimiliano Vasile, became interested in the ablation technique when they set out to compare nine approaches to planetary defense. These included using nuclear warheads to jolt asteroids into new trajectories, planting electric rockets or solar sails directly on an asteroid, and excavating material and catapulting it away in order to push the asteroid in a new direction.

To their surprise, one of their results was that the solar collector approach worked more quickly and effectively than all but nuclear warheads. Unlike use of nuclear explosions, there would be no risk of breaking a huge asteroid into any number of equally deadly smaller asteroids, nor would the procedure face as many political and bureaucratic hurdles.

Other methods—such as low-thrust electric or chemical engines placed on an asteroid's surface—would be precise and safe. They require many years to be implemented, however, and a decade or more to do their work. This wouldn't do much good if we spotted an asteroid a year or two from impact. Kinetic impactors could shove an asteroid out of the way, but they are effective only with some smaller asteroids.

The good news is that the solar ablation method gives us another potentially effective technique. The bad news is that very little work has been done on testing this technique.

The Vasile group made the technique more practical by coming up with ways to use spacecraft flying in formation to do the job. Spacecraft orbits are one of the group's specialties, which they were able to apply to show that positioning swarms of spacecraft is completely feasible with existing technology. With multiple spacecraft, each mirror can be smaller—for instance, tens of meters of something like Mylar instead of hundreds of meters—making the concept more practical. Also, the technique is scalable, meaning that it can use fewer spacecraft with more warning time, or more craft with less time. The Vasile group call their solution involving a swarm of mirrored spacecraft "Mirror Bees."

I have to admit that when I first heard about this technique, it seemed far-fetched; I pictured high-quality mirrors of impractically large sizes, along with impossible orbits. That was my mistake. Reading their papers and talking to Vasile at the Planetary Defense Conference last April and elsewhere, I've found out that the procedure can work perfectly well with something like deployed Mylar, similar to our solar sail, in terms of mirror quality. The Glasgow group includes experts in orbits and has come up with practical orbits that will work, even for multiple spacecraft.

Major questions still remain about this technique, though funding has run dry. For example, will the plume of superheated gasses ejected from an asteroid dissipate, or will it block sunlight to the mirrors? Would the debris settle on the satellite mirrors? Can the aster-

What's Up?

In the Sky—February and March

Mars, which reached opposition (opposite side of Earth from the Sun) at the end of January, is rising around sunset and setting around sunrise. As Mars oppositions go, this one is pretty mediocre, but Mars still will look like a very bright, reddish star throughout February and March in the east in the evening and west in the predawn. Through a telescope, you may see Mars' north polar cap, and in the beginning of March, it will be nearly lined up with the Gemini bright stars Castor and Pollox. Saturn will be at opposition on March 22 and will be visible (looking yellowish) in the east in the early evening and in the west in the predawn. Its rings are close to edge-on.

Random Space Fact

As seen from the Moon, "Full Earth" is about 50 times brighter than Full Moon as seen from Earth. This results from a combination of Earth's higher albedo (reflectivity) and larger size.

Trivia Contest

Our July/August contest winner is Frank Tinius of Santa Maria, California. Congratulations!

The Question was: On what body in the solar system will you find a volcano named Pele, after the Hawaiian volcano goddess?

The Answer is: Jupiter's moon Io, appropriately the most volcanically active body in the solar system.

Try to win a free year's Planetary Society membership and a Planetary Radio T-shirt by answering this question:

As seen from the Earth at visible wavelengths, what is the next-brightest star in the sky after the Sun and Sirius?

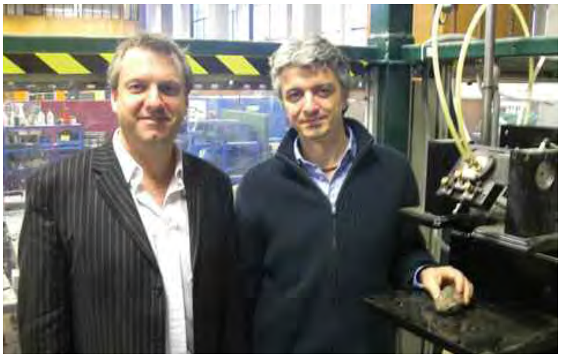
E-mail your answer to *planetaryreport@planetary.org* or mail your answer to *The Planetary Report*, 65 North Catalina Avenue, Pasadena, CA 91106. Make sure you include the answer and your name, mailing address, and e-mail address (if you have one).

Submissions must be received by April 1, 2010. The winner will be chosen by a random drawing from among all the correct entries received.

For a weekly dose of "What's Up?" complete with humor, a weekly trivia contest, and a range of significant space and science fiction guests, listen to Planetary Radio at *planetary.org/radio.*

oid's rotation be dealt with effectively? Will the gas plumes be enough to deflect the asteroid?

The Planetary Society is stepping in to fund a series of laboratory experiments to answer these and other questions. Vasile's group, working with Ian Watson and the laser lab of the University of Glasgow's Mechanical Engineering Department, has devised some ingenious small-scale experiments. We'll be funding equipment, supplies, and a graduate student dedicated to working on the experiments.



University of Glasgow "Mirror Bees" investigators Massimiliano Vasile (left) and Ian Watson in the lab. *Photo: Courtesy of Massimiliano Vasile*

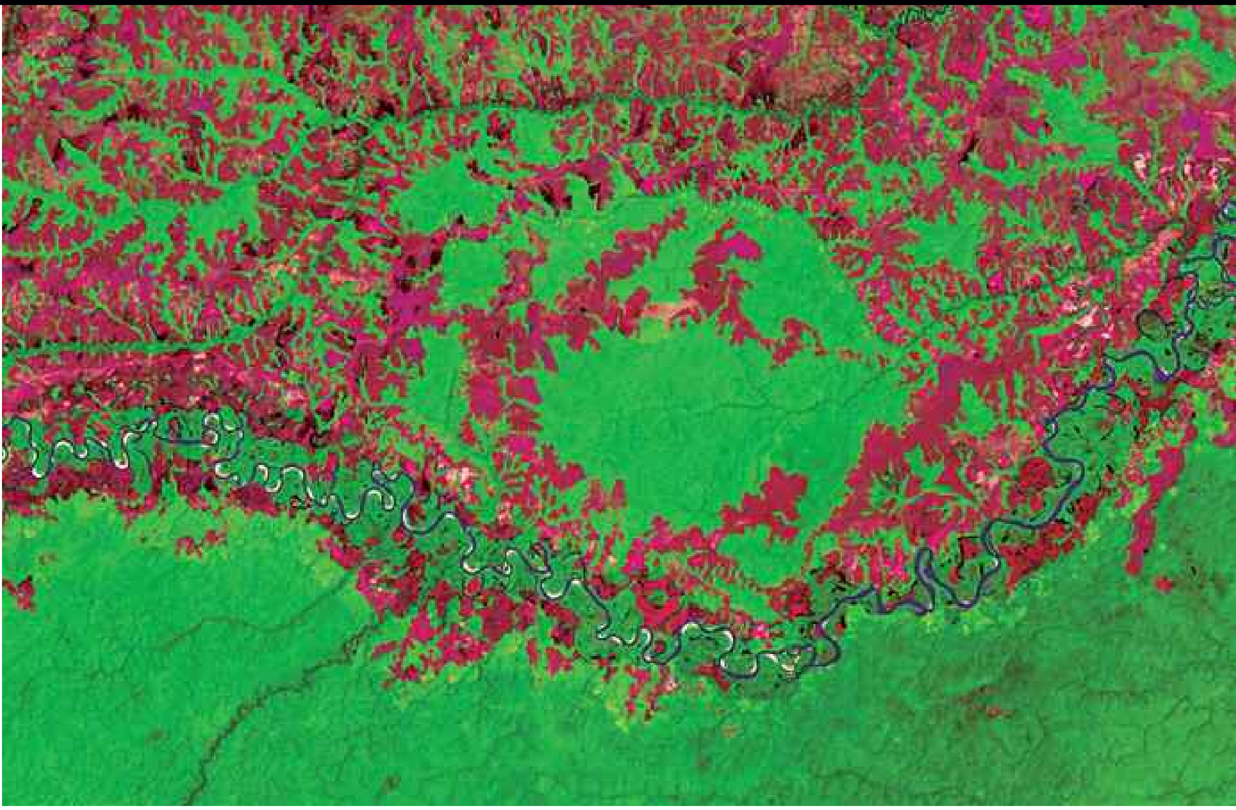
Only through these types of studies, as well as additional theoretical research, can the details of this technique be worked out and understood. If it pans out, it will be a rapid, effective, and safe option to use against the asteroid that inevitably will come Earth's way.

Discovering the Largest Crater in South America

Part of understanding the NEO threat is understanding impacts into the Earth that already have occurred. The Planetary Society has supported Argentinean Max Rocca in his scouring of satellite and aerial photographs for previously unidentified impact structures.

In the September/October 2009 issue of *The Planetary Report*, we described his work involving a field of more than 100 craters. Now, Colombian geologists have confirmed and published that the Rio Vichada structure discovered by Max is indeed an impact structure—the largest in South America. Max not only discovered the 50-kilometer (30-mile) circular structure in *Landsat* photos, but he also got Colombian researchers involved in studying the feature. They used gravity anomalies to "image" the gravitational variations in the area, and they've just published the results, crediting Max for the discovery. The article in *Earth Sciences Research Journal* is by researchers from Universidad Nacional de Colombia in Bogotá and from Ohio State University: Orlando Hernandez, Ralph R. B. von Frese, and S. Khurama. The latter did a Ph.D. thesis on the subject.

The impact crater is one third the size of the Chicxulub crater, of dinosaur-killing infamy. A dense jungle



This Landsat-5 *image features the circular Rio Vichada impact structure—the largest in South America—which was discovered by Planetary Society–funded Max Rocca.*
Image: NASA/SSC

covers the central 20-kilometer (12-mile) basin, and the basin is surrounded by two concentric rings of heavily eroded low hills a few meters high. The outermost ring is 50 kilometers (30 miles) in diameter, and the Rio Vichada wraps around the edge of it, providing the half-circle feature that got Max's attention.

Max writes, "Now we can say that we have discovered the largest impact crater in South America . . . thanks to The Planetary Society!!!"

Working to Save the World

Planetary defense is a rapidly changing field and an international one. The Planetary Society is advocating action in the United States and in other spacefaring nations, as well as in the United Nations Committee on Peaceful Uses of Outer Space. We are also excited to have been added recently to the United Nations Action Team 14 on near-Earth objects. During 2009, I also attended the Planetary Defense Conference (see the May/June 2009 issue of *The Planetary Report*) in Granada, Spain and the Asteroid Deflection Technologies Workshop in Chantilly, Virginia.

We all know that the odds of an impact from a dangerous asteroid are tiny. We also know that without human intervention, an impact is inevitable. Thanks to you, our Members, for helping us work to prevent the only preventable natural disaster!

Bruce Betts is director of projects for The Planetary Society.

Members' **Dialogue**

Don't Wait!

In the September/October 2009 issue of *The Planetary Report*, Terrence Churchman counters the pro-human argument of ensuring the survival of the species by implying such arguments are about running away from our problems on Earth rather than solving them. It is naive to believe that humanity is capable of even predicting all possible threats to our existence on Earth, never mind taking action to defend against all of them. One must consider all threats—those that are external to our influence as a global civilization as well as those that are external to the planet. Of course we should do everything we can to maintain a healthy humanity on a healthy Earth, but as a species, our only possible insurance against unspecified perils is self-sufficient off-world colonization.

Mr. Churchman concludes his letter with the sentiment that we should "wait until . . ." I cringe every time I hear words such as these because they are tantamount to saying "never." One can always come up with a reason to wait. If one continuously follows the lines of these arguments, one ends up with the conclusion that humanity on Earth must achieve some kind of highly advanced, affluent, perfect utopia before venturing off the planet. Such a state is, of course, completely unattainable. You can always imagine improving the state of something, which means that it can never be perfect. Subscribing to this philosophy, therefore, ensures that humanity will eventually become extinct.

There is immediate value to investing in human space exploration. It is well known that investment in space programs is a catalyst for the advancement of knowledge and leads to rich developments in science and technology. For example, if we could learn how to do the very difficult thing of creating a self-sufficient colony on Mars, imagine how useful the resulting technologies would be for solving many of the problems here on Earth: from water issues to climate issues and even social and housing problems. Let's have the courage and the wisdom to think big and think far. We need determination and collaborative vision, not detraction from the goal.

—PHILIP HACHEY,
Ottawa, Ontario, Canada

I just read Rand Wrobel's letter in the November/December 2009 Members' Dialogue and I felt compelled to respond. First, get over the Bush bashing. You may not agree with his politics, but he advanced the grandest vision for space exploration since Kennedy. Now it is unfortunate that neither the previous nor the current administration has backed that vision with a sufficient budget. Describing this vision as ill-timed is naive at best. Just when is the ideal time for such a proposal? Should we conquer war, poverty, world hunger, et cetera, before we ever consider journeying farther into space? That may be a noble sentiment, but it is not grounded in reality.

It has been nearly 50 years since President Kennedy first advanced his vision, and nearly 40 years since the logical next steps to that vision were essentially abandoned. Does anyone truly believe that if we gut manned exploration now, we would simply be able to start again at a "more opportune" time? And if we're going to abandon manned exploration, why not abandon robotic as well? Other than orbital monitoring satellites, those missions wouldn't help with climate change, and we could use those billions of dollars elsewhere.

Climate research does indeed require further study, since it is far from a settled science. Unfortunately, there are zealots on both sides: one side says (human-caused) global warming is impossible and/or not happening, and if it were, there's nothing we could do anyway; the other says that it's established fact, there is no need for further debate, and we need to take draconian measures because we're in a crisis. I submit that both extreme positions are wrong.

There will always be problems in the world to solve, many of which can be viewed as crises and many that can affect all humanity. That doesn't mean we shouldn't continue to invest in manned space missions. The reality is that a lot of what captures the public's attention—and, therefore, gets the bucks—are grand missions involving manned spaceflight.

I joined The Planetary Society for its advocacy of both manned and unmanned missions, and it is my fondest hope that you will continue to support both.

—JOHN A. FERKO,
Colorado Springs, Colorado

Please send your letters to
Members' Dialogue
The Planetary Society
65 North Catalina Avenue
Pasadena, CA 91106-2301
or e-mail: *tps.des@planetary.org*

Society News

Liftoff! You Get Us There

We have liftoff! What sweet words.

Thanks to you—Planetary Society Members and donors, volunteers, and partners—we hear those words often.

Whether it's setting us on our way to fly *LightSail-1*, launching the Carl Sagan Fund for the Future, influencing the world's space agencies through advocacy and action to chart a clear course, preparing to send our LIFE module to the Martian moon Phobos, rallying to support Planetary Radio, searching for extraterrestrial intelligence, or providing grants for astronomers intent on keeping Earth safe from asteroids and comets, your generous support—of donations, planned gifts, time, and participation—gets us to liftoff for every Planetary Society project and campaign. Thank you!

Here's to the year ahead and to the many times that, together, we will have liftoff.

Please let me know if you have any questions—call me at (626) 793-5100, extension 214, or send me an e-mail at *andrea.carroll@planetary.org*.

Cheers to you!

—Andrea Carroll,
Director of Development

Wanted: Your E-mail Address

You may be wondering why we'd like your e-mail address. The answer is simple: when we have your e-mail address, we can let you know more quickly about upcoming events and provide time-sensitive advocacy alerts. Plus, you'll receive our monthly electronic update about Planetary Society happenings.

Be assured, we will not sell or exchange your e-mail address.

You can provide us with your e-mail address in one of the following ways:

1. Go to our website at *planetary.org/emailupdate*
2. Fax us with your e-mail at (626) 793-5528
3. Call one of my colleagues in our membership department at (626) 793-5100.

Just give us your name, your member number (it's the six-digit number on the back of this magazine, just above your name), and your e-mail address.

Questions? Please call (626) 793-5100 or e-mail *tps@planetary.org*.

Thank you! We look forward to seeing you on e-mail.

—Lu Coffing,
Financial Director

Sail Away—on *LightSail* and *IKAROS*

Two pioneering missions are preparing to set sail, and you can be aboard! The Planetary Society is now collecting messages to fly on two exciting missions: our own *LightSail* mission and JAXA's *IKAROS* mission.

LightSail, a project of The Planetary Society, will merge the ultralight technology of nanosats with the ultra-large technology of solar sails, setting a course to the stars. *LightSail* will be ready for launch by the end of 2010.

IKAROS (Interplanetary Kite-craft Accelerated by Radiation Of the Sun) is a solar sail that gathers sunlight by means of a large sail and uses it as a means of propulsion. *IKAROS* will be launched together with the Venus Climate Orbiter, *Akatsuki*, in fiscal 2010 by JAXA.

All Planetary Society Members' names automatically will be aboard these missions, but if you would like to add a message to your name, please use our online submission forms at *planetary.org/special/fromearth/sail*. (Note that in order to give you time to submit a message with your name, Planetary Society Member names have not yet been added to the certificate database that will fly on the spacecraft.)

This campaign is open to anyone in the world, so feel free to tell a friend—or go ahead and add a friend's name and send him or her on a ride into space!

Simply go to *planetary.org/special/fromearth/sail*, fill out the form, and print your official participation certificate when you are done!

The deadline to sign up for the *IKAROS* mission is March 14, 2010.

—Monica Bosserman Lopez,
Marketing and Interactive Manager

World Watch

by Louis D. Friedman

As 2009 drew to a close, the space community continued to wait for the Obama administration to declare its position on the options suggested by its Review of U.S. Human Space Flight Plans Committee, chaired by Norm Augustine. As we go to press, we are awaiting the administration's budget proposal for fiscal year 2011.

In mid-December, the U.S. Congress finally passed the appropriations bill for fiscal year 2010 (which began in October 2009). NASA received a budget increase of $942 million, for a total of $18.7 billion. The five percent increase is significant, given the many economic and other program constraints in the budget.

The money permits the continued development of the Constellation program, including the Ares I rocket, which is designed to return human explorers to the Moon before sending them on to Mars. The Augustine Committee has questioned whether Constellation is achievable within NASA's projected budget and suggested alternatives, which the administration is considering.

The budget bill also included start-up money to rebuild the *Orbiting Carbon Observatory* (*OCO*), which was lost to a launch vehicle failure last February. *OCO* will gather data about where carbon in the atmosphere comes from and where it goes, information crucial for monitoring the process of global climate change.

Congress also fully funded NASA's robotic Mars program, ensuring that *Mars Science Laboratory* remains on track for a 2011 launch. It also gave the *Europa Jupiter System* mission a boost of $15 million to advance its readiness for an official new start next year.

THE PLANETARY SOCIETY
65 North Catalina Avenue
Pasadena, CA 91106-2301

Printed in USA

The asteroid that slammed into Earth 65 million years ago at the Cretaceous-Tertiary (K-T) boundary was about 10 kilometers (6 miles) in diameter. The debris thrown by the huge impact severely altered our planet's climate, leading to the extinction of about three quarters of the species living at the time—including the dinosaurs.

Most of the Earth-crossing asteroids of this type are now known to scientists, and most (but not all) of them are smaller than the K-T impactor. It is only a matter of time before a comet or asteroid large enough to do significant damage heads toward a collision with Earth. We need to be ready.

Mark Garlick began his career as an astrophysicist and then decided that illustrating and writing about Earth and space sciences, technology, and science fiction were more to his liking. He has written and illustrated five books, and his art has appeared in a wide array of publications and advertisements.