Asteroid deflection: Planning for the inevitable

The autumn of this year is crowded with momentous events affecting our future in space. The shuttle Atlantis is poised on Pad 39A for a final servicing mission to the Hubble Space Telescope. On pad 39B sits its sister ship Endeavour, provisioned for a possible rescue mission. The Hubble flight occurs on the eve of the 2008 U.S. presidential election, whose outcome will determine the fate of American efforts to replace the shuttle, assure U.S. access to the ISS, and return astronauts to deep space. The reverberations of the late summer crisis in Georgia and uncertain relations with Russia continue to shape fast-evolving NASA plans for assuring that after 2010 we can still man the space station we built and largely paid for.

Sandia National Laboratories researcher Mark Boslough explains the downward energy transport in his team's supercomputer simulation of the 1908 Tunguska impact. The asteroid projectile might have been as small as 40 m.
Photo by Randy Montoya

This season is also significant for its advances in understanding threats not born of Earth: In late June, a Moscow conference marked the centennial of the Tunguska event, examining the scientific and historical research into that multi-megaton blast over Siberia, the result of a near-Earth object (NEO) collision with our planet.

Recent research by Mark Boslough of Sandia National Laboratories explains Tunguska as the impact of a small asteroid, perhaps 40 m in diameter. The object detonated in a 3-5-megaton airburst some 5 km up, scorching and flattening 2,000 km^2 of Siberian forest. Compared with previous estimates of the impact energy, this smaller explosion implies a smaller impactor as well (the old estimate was a diameter between 60 and 100 m).

Because smaller asteroids are more numerous, a Tunguska-like event should occur more often, perhaps every 300 years or so, rather than at the previously estimated rate of approximately once every millennium.

NEOs that have been there all along, but are now cataloged and tracked, will soon confront us with an asteroid-sized headache: What will we do about the thousands of NEOs that have a slight but stubbornly nonzero chance of causing a catastrophe?

The impact hazard

AS NASA's Spaceguard Survey searches for the last few dozen undiscovered large NEOs (1 km or larger in diameter, capable of a civilization-ending impact on Earth), more and more small, worrisome NEOs are turning up as by-products of the survey. For example, 2007 VK184, a 130-m-wide asteroid, will pass close to Earth four times between 2048 and 2057; it has a 1-in-29,000 chance of striking the planet. If it does, the impact will release the energy equivalent of 150 megatons of TNT. Such a titanic blast would destroy an area the size of a small state; even an ocean impact could cause hundreds of billions of dollars in tsunami damage.

Of course, Earth's long history has often been punctuated by much larger cosmic collisions. The Eltanin impact in the eastern Pacific 2.5 million years ago inundated the South American coastline with towering waves. Very large collisions, such as the KT event 65 million years ago, have caused mass extinctions and dramatically altered the course of life on Earth. The effects of a 1-km asteroid strike on today's fragile, interconnected

About 100 years ago, Tunguska, Siberia, suffered a multimegaton blast, the result of a near-Earth object collision with our planet.

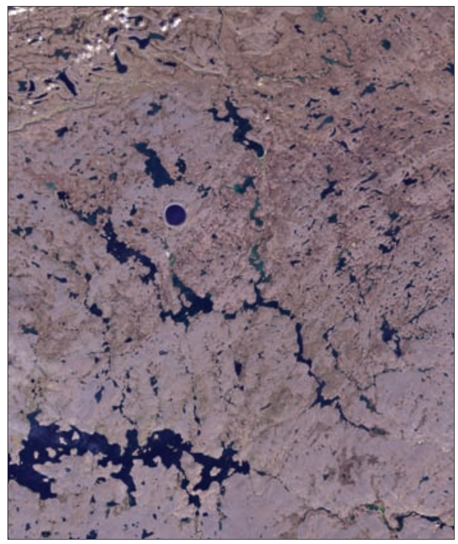
human society would probably cause global climatic disruptions, widespread crop failures, and worldwide famine.

Search and discovery

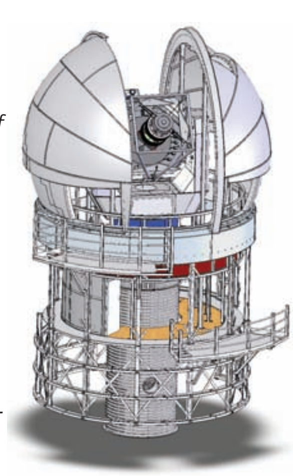
At least we are looking: New wide-field telescopes with advanced instrumentation, capable of searching large swaths of the sky for faint objects, promise large improvements in our near-Earth object detection capabilities.

One of these new systems is Pan-STARRS (Panoramic Survey Telescope and Rapid Response System), whose prototype element is now operating on Haleakala in Hawaii. When complete, Pan-STARRS will have 3-16 times the collecting power of current NEO survey telescopes. Using a massive array of state-of-the-art CCD detectors in the focal plane, it will detect objects 100 times fainter than those currently found by NEO surveys. Pan-STARRS should quickly complete a search, as directed by Congress in 1998, for 1-km (and larger) NEOs and will be able to find 99% of those objects bigger than 300 m across.

Another planned system is LSST, the Large Synoptic Survey Telescope, to be sited in northern Chile. Beginning in 2014, the 8.4-m telescope will scan the entire visible sky every three nights using a 3.2-billion-pixel CCD camera the size of a small car. The LSST will be able to find 90% of the near-Earth asteroid population 140 m and larger within about a dozen years—close to what Congress directed NASA to do in 2005 (a search program still unfunded). The Gates Foundation earlier this year put $30 million toward the telescope's construction, and the University of Arizona has just completed casting the main mirror.



Pingualuit Crater was formed 1.4 million years ago by an asteroid or comet impact. The crater, in northern Quebec, is 3.44 km across; the lake filling the cavity is 267 m deep. NASA Landsat 7 image.



Pan-STARRS, whose first unit is operational in Hawaii, will be composed of four individual optical systems, each with a 1.8 m diam mirror observing the same region of sky simultaneously. Each mirror will have a 3-deg field of view and be equipped with a CCD digital camera with 1.4 billion pixels. Credit: Institute for Astronomy.

Over the next 15 years, these NEO search systems will lead to the discovery of over 500,000 asteroids, large and small, in the inner solar system. Of these, several thousand will be categorized as potentially hazardous asteroids, or PHAs, defined as objects that come within 0.05 astronomical units of the Earth (about 7.48 million km) and measure at least 150 m in diameter. As of August, there were 211 known PHAs, and 140 of those were larger than 1 km—capable of causing global devastation. By 2020, we may be staring at a PHA catalog that numbers more than 5,000!

Deciding to deflect

Search programs will usually give us years, if not decades, of impact warning. But how should we use this vital, and worrisome, information? At the outset, we can prepare evacuation and disaster mitigation plans to cope with an unexpected or unavoidable impact. But our technology offers options: Spacecraft have rendezvoused with several NEOs, and we possess the means to deflect most asteroids on a collision course.

The first step would be to attach a transponder to the NEO, so we can predict its future orbit precisely; refined tracking will eliminate the uncertainty surrounding most impact calculations. If deflection is necessary, we can hover near an asteroid and change its velocity slightly with a "gravity tractor" spacecraft. We can ram an oncoming NEO with a high-speed projectile, transferring momentum and altering the object's velocity. In the very rarest of cases (a large NEO or little warning time), we can use a nuclear explosive to vaporize the top millimeter of its regolith, with the resulting jet of gas and debris nudging the asteroid off course.

Any efforts at NEO deflection must be international in scope. First, because of tracking uncertainties, a NEO's predicted impact point will lie along a thin line spanning most of a hemisphere (the projection of its orbital plane on Earth's surface). This risk corridor will span many nations until tracking accuracy improves, quite close to impact.

Second, the process of deflecting a NEO will necessarily shift that impact point along the corridor, toward the Earth's limb, lowering impact risk for one nation but temporarily raising it for another, until the threat is eliminated entirely. Only an international consensus on deflection decisions will succeed; without it, a serious impact threat will generate controversy, prolonged argument, and political inaction—in short, paralysis.

Of the several thousand PHAs we will face 10-15 years from now, several dozen will possess an uncomfortably high probability of striking Earth. With local or regional devastation a real possibility, the global community will face a decision, then, on whether to act to prevent an impact. What probability of a future impact will trigger a collective decision to deflect a NEO? We will seldom possess perfect knowledge about the threatening NEO. Indeed, because of the substantial lead time required to fund, plan, and execute an asteroid deflection campaign (the series of missions needed to assure a "miss"), our institutions may have to act before we are certain an impact will actually occur.

Erring on the side of caution, we may be forced to make crucial, timely decisions about NEO deflection much more frequently than the occurrence of actual impacts. For example, given the potential devastation an impact might cause, we may decide to deflect an object even if it has just a 10%, or as little as a 1%, probability of hitting Earth. If the actual NEO impact frequency for a future Tunguska is 1 per 500 years, but we decide to act at a threshold of impact probability of 2% (1 in 50), then we will face such a decision once every 10 years.

Astronauts Ed Lu and Stan Love at JSC devised the gravity tractor concept, a 20-ton nuclear-electric spacecraft that can tow a NEO by simply hovering near the asteroid. The steady thrust would gradually and predictably alter the course of the tug and asteroid, coupled by their mutual gravitational attraction. Credit: Dan Durda.

We clearly need an international process, in place and widely supported, enabling us to deal with a potential NEO threat consistently and promptly.

Preparing to act

Today, we can detect NEOs and predict their potential for collision with Earth. For the first time in our planet's 4.5-billion-year window of vulnerability to cosmic collisions, we have the technical capability to prevent such devastating events. The keys to succeeding in all cases are preparation, planning, and timely decision-making.

Three years ago, the Association of Space Explorers (ASE, the international nonprofit professional and educational organization of over 320 space fliers from 33 nations) approved an open letter calling on the world to take prudent action to prevent future asteroid and comet collisions. The association formed a committee from its cosmonaut and astronaut membership to promote discussion and possible solutions. Beginning in 2007, the committee raised private funds to mount a workshop series to understand the NEO challenge. The ASE gathered a respected panel of diplomats, scientists, engineers, and legal experts, called the Panel on Asteroid Threat Mitigation, to study the scope of the NEO hazard and recommend a cooperative way forward.

During the first three meetings, the panel met to draft a global framework for NEO decision-making. ASE's final workshop took place September 22-25 in San Francisco. At this session, the panel finalized and adopted a document called "Asteroid Threats: A Call for Global Response" (www.space-explorers.org).

Noting that a threat of global dimensions requires a global consensus for concrete action, the panel calls for harnessing information-sharing and communication capabilities to recognize and warn society of potentially hazardous NEOs. The panel also calls for consideration of and agreement on an international decision-making program, or framework, detailing how the world, led by the spacefaring nations, will respond to a potential impact.

A global response

The ASE "global response" document, endorsed by September's ASE Planetary Congress in Seattle, makes six major recommendations. First, it declares that international preparations, not unilateral action by a single spacefaring country, are the only way our society can effectively counter a specific impact threat. Unilateral action might put other nations at risk and miss the chance to harness the best of our technical capabilities in dealing with a NEO.

Second, the paper recommended that a global, coordinated NEO response include the execution of three logical, necessary functions: information gathering, analysis, and warning; mission planning and operations; and executive oversight. These functions could be carried out by existing scientific or intergovernmental institutions through multinational agreement.

The third recommendation calls for the international community to create and recognize a NEO information, analysis, and warning network. The network should include a web of ground- or space-based telescopes to detect and track potentially hazardous NEOs. Using existing or new research institutions, the network should analyze NEO orbits to identify potential impacts. Based upon that research, the network should establish criteria for issuing public NEO impact warnings.

The Mission Planning and Operations group would draw from the expertise of the world's spacefaring nations to outline the best means of mounting a successful deflection campaign. A kinetic impact deflection, for example, might be followed by a slow but precise trim maneuver by a gravity tractor spacecraft, assuring that the asteroid would miss not only the imminent Earth collision, but steer clear for centuries to come. In response to a specific NEO warning from the network, the planning and operations group should draw on a set of reference missions to propose an effective plan for deflection.

A fifth recommendation would establish oversight of both the NEO detection and warning network and the mission planning and operations function, through a NEO threat oversight group. This internationally sanctioned body would develop the policies and guidelines for global NEO response. An important function of this group would be establishing impact risk thresholds and threat criteria to help determine when to execute a deflection campaign. The oversight group would wrestle with such questions as: What impact probability is too high to ignore? What are the consequences of not acting?

Finally, the ASE and its panel sought the endorsement of the U.N. for this global response to the NEO hazard, stating that although imperfect, that organization offers the most immediately available path toward consideration and adoption of the first five recommendations. The U.N. has grappled with other global problems, including nuclear proliferation, disaster response planning and relief, climate change, and global disease prevention (with varying degrees of success); it offers existing institutions and forums for discussing the NEO hazard and its implications.

A consensus for action on NEOs

Scientists agree that cosmic impact has been a significant influence on Earth's biological evolution, and that impacts will continue to occur. We will soon know of thousands of potentially hazardous NEOs, some of which will put us squarely in the sights of a future collision. How will we respond to this complex situation?

The ASE has submitted its Call for Global Response to the current U.N. group tasked to consider the NEO hazard. That group is Action Team 14, chartered by the U.N.'s Committee on the Peaceful Uses of Outer Space. (Unraveling the U.N. bureaucratic structure is nearly as daunting as planning a NEO deflection mission.)

This February in Vienna, Austria, Action Team 14 (comprised of nations actively interested in NEO research and the impact hazard) and the NEO Working Group will formally accept the ASE document for U.N. consideration. Then the process of discussion and negotiation will move slowly forward, supported with technical advice from the ASE, the spacefaring nations on the action team, and scientific bodies that the U.N. may enlist. Adoption of the Call for Global Response will come years later, and the final recommendations may be quite different from those now proposed.

On its way to its 2014 rendezvous with comet 67/P Churyumov-Gerasimenko, the ESA probe Rosetta studied main belt asteroid (2867) Steins with a flyby that occurred on September 5, 2008. Credits: ESA/AOES Medialab.

As we talk, we should keep in mind that asteroids do not cruise their orbits in accord with the schedules of diplomatic and scientific institutions.

Acting together, we can prevent nearly all significant impacts (long-period comets are probably still beyond the reach of our space technology). We should also know that if we fail to adopt an effective, internationally recognized program for preventing them, our society will certainly suffer the effects of some future cosmic disaster.

That catastrophe will be all the more painful because we could have prevented those deaths, the economic devastation, and the long-lasting societal disruption. With the capability for stopping a NEO impact at hand, our species must now begin—and complete—the process of ensuring our long-term survival.

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