

WINTER 2008

The background of the cover is a composite image. The upper portion shows a view of Earth from space, with the blue oceans and white clouds of the planet curving over the horizon. The lower portion shows the dark, cratered surface of the Moon, with a large, dark shadow cast across it. The sun's rays are visible in the top left corner, creating a bright, starburst effect.

THE THREAT OF IMPACT

**A Special
Report
on NEOs**

BEYOND THE SHUTTLE
What it means for the ISS

SHACKLETON DOME
Envisioning A Lunar City

BOOKS:
ANDREW CHAIKIN'S
A PASSION FOR MARS,
THE RETURN TO LUNA
SHORT STORY CONTEST,
and 50 YEARS OF NASA ART



DEALING WITH THE THREAT OF IMPACT

Detection, deflection, or deep impact? BY RUSSELL L. SCHWEICKART

The near Earth object environment has remained virtually constant for the past three billion years.

Our society has been vulnerable to the destructive power of impact events ranging from the 1908 Tunguska event (in which the impact of an estimated 45-meter-diameter object destroyed 2,000 square kilometers of Siberian forest) to the 12-kilometer-diameter object responsible for the Chicxulub impact 65 million years ago, which is thought to have caused the extinction of the dinosaurs and 70 percent of all species alive at the time. Such cosmic collisions occur infrequently compared with a human lifetime, yet when they do happen, they dwarf the natural disasters that are more common in human experience.

Surprisingly, in the instance of this most devastating of natural disasters, humankind is far from helpless. With modern-day telescopic and spaceflight capabilities, we can detect and predict potential impacts, and with adequate early warning we can deploy space systems capable of altering the orbit of threatening NEOs and force them to pass harmlessly by Earth, avoiding impact. Even if our discovery of the NEO were insufficient to successfully divert it, a prepared society

would nevertheless be able to mitigate the effects of an impact by evacuation and other disaster preparedness measures.

IMPACTS AND IMPACT PRECURSORS

A NEO impact will occur when the orbits of a NEO and Earth intersect in space and both bodies reach that intersection at the same time. Most frequently, a NEO threatening impact with Earth has experienced prior close passes by Earth which have, in fact, set up the subsequent impact. Close gravitational encounters with the Earth can substantially change the orbit of a NEO, and on occasion, cause a precise change which brings the NEO back several years later for a direct impact.

The small region near the Earth through which a NEO must pass for such a resonant impact to occur is referred to as a gravitational keyhole. Whenever a NEO passes nearby, whether passing in front of or behind the Earth, it passes through a field of dozens of such keyholes. Consequently, NEO deflection is most easily accomplished when it can be diverted from a precursor keyhole rather than from a direct impact. A deflection operation to avoid a keyhole target of a kilometer or so







in size is far less daunting than a deflection to avoid an Earth-sized target of several thousands of kilometers.

DEFLECTION TECHNIQUES

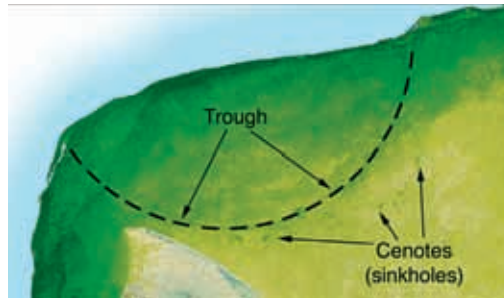
The diversion of a NEO on a path toward an Earth impact requires, depending on the specific circumstances, either a precise, but modest orbit change, or the combination of a robust orbit change followed by a precise orbit trim. A successful deflection campaign is one in which both an immediate impact and all near-term return impacts are prevented. These conditions correlate with the robust and precise deflection requirements respectively.

Robust orbit change, i.e., orbit changes requiring substantial total impulse applied to the NEO, can be provided by either a kinetic impact (KI) or a nuclear stand-off explosion. Both technologies are available; KI was demonstrated conceptually during the 2005 Deep Impact mission, albeit that impact was designed for a different purpose. A nuclear stand-off explosion has not been demonstrated, but the technology is arguably available for use. Both these techniques, while capable of transferring substantial momentum change to a NEO, cannot do so with adequate precision to assure a fully successful deflection.

A precise NEO orbit adjustment is conceptually available via a number of techniques. The most simple and readily available concept is the gravitational tractor (GT), which provides precise adjustment to the NEO orbit by “hovering” in close proximity to the NEO, using mutual gravity to change the NEO’s velocity. While the non-nuclear combination of a kinetic impact and gravity tractor will suffice for approximately 98 percent of the statistical impact threat, the use of nuclear means cannot be ruled out without further technology development. The frequency of NEO impacts which would require the use of nuclear means is approximately 1 in 100,000 years based on the current best estimate of NEO size-frequency distribution.

DEFLECTION IMPLICATIONS

The deflection process, regardless of the technology used, can be understood as an operation which, by slightly adjusting the velocity of a NEO, will cause it to arrive at the impact point slightly earlier or later than it



otherwise would have. With a sufficient change in the NEO velocity, the change in the arrival time is enough that the impact point has been avoided.

A deflection can thus be seen as a process whereby an impact point is shifted from its original location to a point ultimately off the Earth’s limb, so that the NEO will fly past the Earth, and not into it. Should, for any reason, the deflection be only partially completed, the NEO’s pathway will change, but it could still hit the Earth at a different impact point. Whether the deflection is a continuous gravity tractor process or an impulsive kinetic impact or nuclear explosion, a partial completion would therefore result in a new impact point along the risk corridor. People not near the original impact point may then be at risk as a result of the action taken to deflect the NEO. Risk-shifting is an inseparable element of risk elimination in NEO deflection. Agreeing to deflect a NEO and deciding which direction the impact point should be shifted are clearly decisions that must be coordinated among the international community.

DEALING WITH THE THREAT OF IMPACT

What is needed to match the technical capability for responding to the NEO impact challenge is an international system of preparation, planning, and timely decision making. Because NEO impacts can occur anywhere on our planet and affect the entire international community, a collaborative, global response is necessary. International coordination is necessary in making any decision regarding a NEO, because of the low, but inevitable risk in the process of deflection. Deflecting a NEO from impacting one population center could directly elevate the concern of another.

Furthermore, it is highly desirable that a decision process, with agreed criteria, policies, and proce-

FIRST STEPS

New telescopic resources coming into service within the next decade will dramatically increase the number of NEOs discovered and tracked. The U.S. Congress has charged NASA with discovering and tracking 90 percent of all NEOs larger than 140 meters in diameter by 2020. While meeting this goal poses a considerable challenge, it is clear that with new telescopes coming online, this goal will be approached in the 2020–2025 timeframe. In the process of achieving the 140-meter goal, many smaller but still dangerous NEOs will be discovered with the number of such objects likely to exceed 300,000. Based on current empirical experience, the number of potentially damaging NEOs with a non-zero probability of impact within the next 100 years is likely to exceed 10,000 by this time. Of these NEOs with at least a small probability of impact over the next 100 years, many are likely to appear threatening enough to necessitate a decision of whether action should be taken to prevent an impact.

Above, a computer-enhanced, shaded relief image of the Yucatan Peninsula in Mexico highlights a subtle, semicircular trough at the Chicxulub impact site, related to the extinction of dinosaurs 65 million years ago. Opposite page, a series of impact sites that include—clockwise from top photo—Meteor Crater in Arizona; Wolf Creek crater in western Australia; the new Quebec crater in Quebec Canada; and Manicouagan Reservoir in Quebec, which is located in an eroded ancient impact crater. Preceding pages: An artist’s illustration of a massive asteroid belt in orbit around a star that is the same age and size as our Sun.



dures be established prior to the development of a specific threat in order to assure that minimization of risk to life and property prevail over competing national self-interests. A global, coordinated response should ensure that three logical, necessary functions are performed.

First, a warning network should be established. This network would operate a global system of ground- and space-based telescopes to detect and track potentially hazardous NEOs. The network should also establish criteria for issuing NEO impact warnings.

Next, an operations group, drawing on the expertise of the spacefaring nations, should outline the most likely options for NEO deflection missions. This group should assess the current, global capacity to deflect a hazardous NEO by gathering necessary NEO information, identifying required technologies, and surveying the NEO-related capabilities of interested space agencies. In response to a specific warning, the group should use these mission plans to prepare for a deflection campaign to prevent the threatened impact.

Finally, an oversight group should develop the policies and guidelines that represent the international will to respond to the global impact hazard. This group should establish impact-risk thresholds and criteria to determine when to execute a NEO deflection campaign.

PREVENTING AN IMPACT

Whenever a sufficiently threatening NEO is discovered early enough to mount a deflection campaign, an impact can be averted. For such a scenario to be realized, three essential elements have to be in place: a capable early warning system, a deflection capability, and an institutional process capable of making timely decisions.

In order to provide the time required for preparation and deployment of a deflection campaign, the early warning system will have to provide the information required to

make a deflection decision at least 10–15 years ahead of impact. On top of that, deflection systems should be designed and flight-tested well in advance of their use to ensure a successful deflection capability is available and well understood.

Most critical, however, is the requirement that the international community be prepared to authorize a deflection campaign in a timely manner. Failing to provide a decision-making framework before a threatening NEO situation is discovered will risk lengthy argument, political delays, and collective paralysis. Such avoidable inaction will preclude a deflection and force the world to absorb a damaging—and preventable—impact. With the lead time for an authorization decision typically needed 10–15 years ahead of a potential impact, a program to develop that vital decision process must begin now.

TAKE ACTION

Now that humankind has the scientific, technical, and operational capabilities both to predict whether an asteroid will come too close for comfort, and to launch operational missions to divert a potential impact, it is time for the international community to identify the decision-making institutions and begin the development of a coordinated decision-making process. Scientific knowledge and existing international institutions, if harnessed today, offer society the means to avoid such a catastrophe. We cannot afford to shirk that responsibility.

An adequate global action program must include deflection criteria and campaign plans which, when conditions warrant, can be implemented rapidly and with little debate by the international community. In the absence of an agreed-upon decision-making process, we may lose the opportunity to take action to prevent impact, leaving evacuation and disaster management as our only response to a pending impact. The international community must begin work now on forging its warning, technology, and decision-making capacities into an effective shield against a future collision.

A COMING WAVE OF DISCOVERY

The current NEO search program (Spaceguard Survey), initiated in 1998, has resulted in the discovery and tracking of over 5,700 NEOs in the past 10 years. These NEOs, of all sizes, have been discovered in the process of achieving the goal of discovering 90 percent of all NEOs greater than one kilometer in diameter by the end of 2008. So far, approximately 80 percent of the statistical population of these large NEOs has been discovered, and the search continues.

In 2005, the U.S. Congress established a new goal for the Spaceguard Survey: to discover 90 percent of all NEOs greater than 140 meters in diameter over the next 15 years. It is estimated that within the next 15 years, over 500,000 NEOs will be discovered and enter the tracking database, and 200,000–400,000 of these will be of a size capable of doing substantial damage to the Earth's surface on impact. About 3 percent of these new NEO discoveries will likely have some, generally small, probability of impact in that timeframe. Within these thousands of potential Earth impactors, there will likely be dozens which will appear threatening enough that they will require proactive decisions regarding mitigation or deflection.

Opposite page: An image from space shows the Vredefort Dome in South Africa, site of an extreme impact event that took place more than 2 million years ago—the oldest and largest known site of its kind.

REMOVING THE BLINDERS

ONE OF THE
GREATEST
THREATS TO
CIVILIZATION
REMAINS
UNACCOUNTED FOR

BY PETER GARRETSON

Fragments of a short-period comet, discovered by Eugene and Carolyn Shoemaker and David Levy, enroute to their collisions with Jupiter at 60 km/sec.

From July 16 to July 22, 21 distinct impacts were observed, the largest of which released an energy equivalent to 6,000,000 Megatons of TNT (600 times the world's nuclear arsenal), a fireball plume rising to a height of 3,000 km, and left a scar 12,000 km across (Earth's diameter).

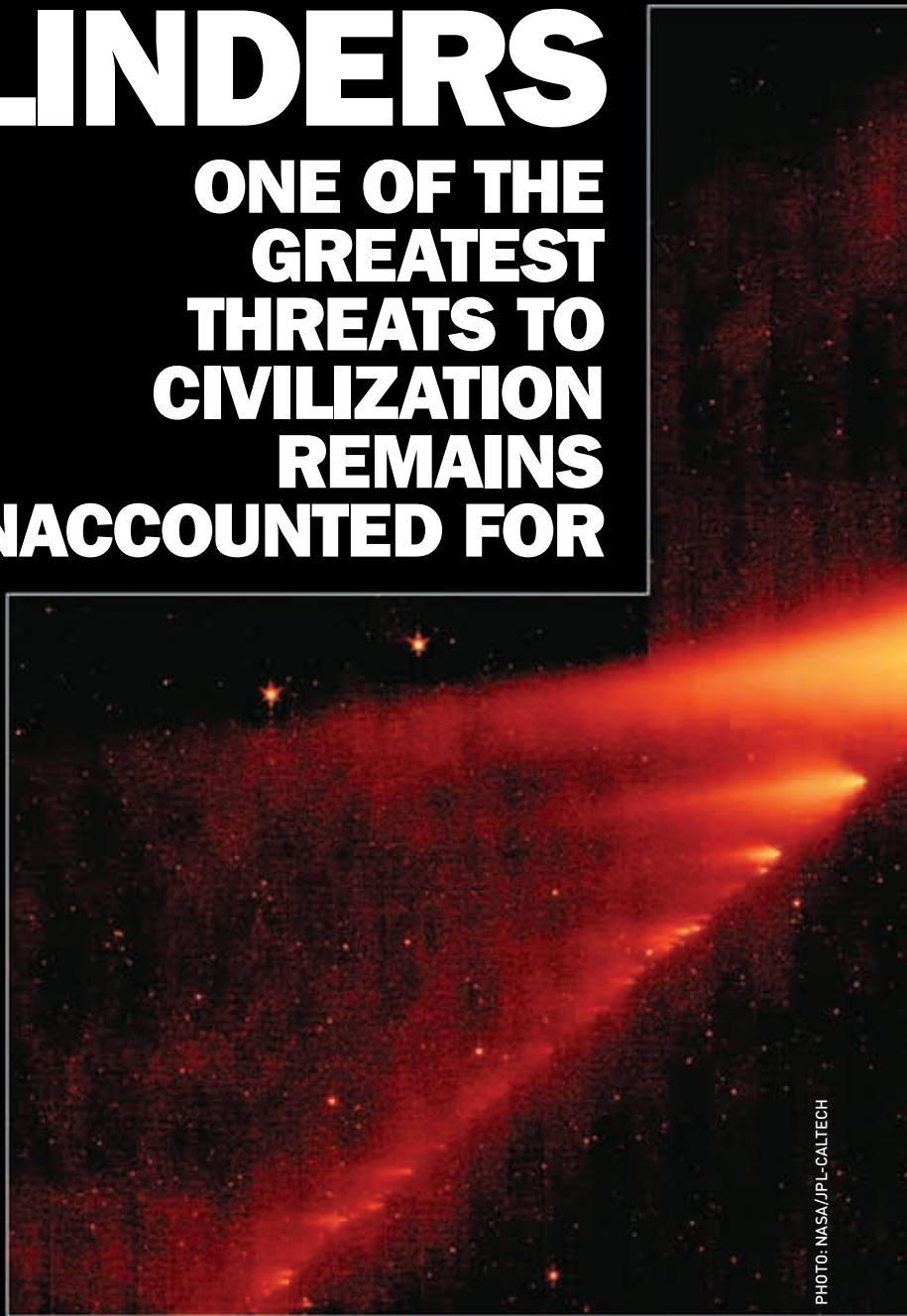


PHOTO: NASA/JPL-CALTECH



Here are the facts: Our solar system is a cluttered shooting gallery of objects that threaten our lives and the existence of life on Earth. We know that objects have struck the Earth in the past, causing huge devastation and mass extinction. Today, we don't have the capability to know with certainty where and when the next impactor will strike. Yet virtually zero space or defense dollars are going toward creating such a capability. It is time to move the topic of Earth-colliding asteroids and comets from discussions in the academic halls of astronomy and astrophysics and onto the agenda of national security policymaking.

WHAT IS THE THREAT?

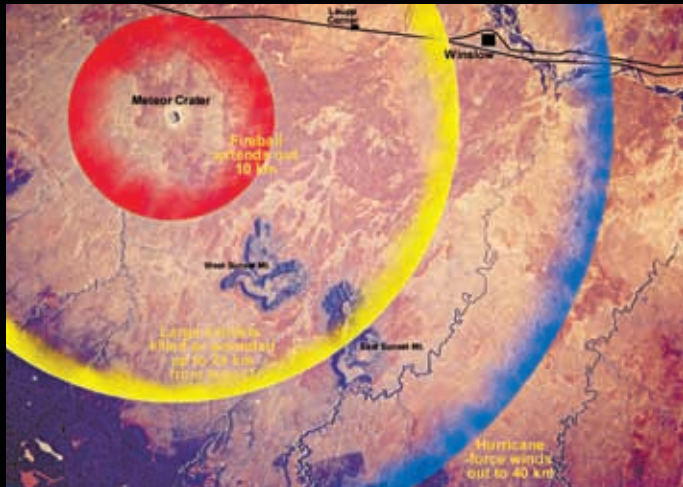
Fortunately, we now have a very developed scientific and operational knowledge about the very real threat that asteroid and comet impactors could pose to our national and international security. To provide some perspective on the difficulty, the asteroid Apophis (previously 2004 MN4), scheduled to pass Earth closely in 2029 and 2036, has an estimated mass of 20 billion

kilograms. Think what it would take to deflect a mass of 50,000 Boeing 747s traveling at 36,000 kilometers per hour! If it were to impact Earth, its kinetic energy would exceed five million times that of 9/11. It is estimated that developing a capability to deflect an asteroid would require decades of advance warning to successfully respond.

On March 18, 2004, an asteroid came within 3.4 Earth radii—inside the orbits of our geostationary satellites—but it wasn't discovered decades in advance. In fact, it was detected only two days in advance. More recently, in July of 2008, a binary near Earth object consisting of one 600-meter object and one 200-meter object cruised past us at a distance only six times farther than the orbit of the Moon. It was discovered only seven months in advance. Apophis, the most threatening asteroid, was discovered only four years ago. As I was editing this, 2008 TC3, a mere 5-meter asteroid, created an atmospheric airburst over Sudan, releasing 1–2 kilotons of energy. It was discovered 20 hours in advance. There must be significant improvement in our advance-warning capabilities because time is the most important factor in preventing such a catastrophe.

WHAT ARE THE ODDS?

Our space situational awareness capabilities as yet are very modest. After 13 years of searching, we are only now approaching the goal of finding 90 percent of the near Earth asteroids greater than one kilometer in size and capable of global destruction (742 have been discovered out of an expected population of approximately 1,000). At the time of this writing, we know of 5,443 NEAs (we discover between 3–5 new large NEAs per month), of which 957 are classified as potentially hazardous. All are larger than 150 meters and capable of causing at least regional destruction. Recent modeling at Sandia National Lab suggests that asteroids as small as 30 meters can penetrate and airburst, completely devastating an area the size of the Washington, D.C., metropolitan area. Estimates of the number of near Earth asteroids in this size category suggest a population of 400,000 to 750,000.



This illustration shows the devastation that would accompany a 50-meter nickel-iron impact, such as the asteroid that excavated the 1.2 kilometer-wide, 170 meter-deep Barringer Crater near Winslow Arizona 50,000 years ago. Impacting in excess of 12.8 km/sec with a mass of 300,000 tons, it released 2.5 megatons of TNT (150 times the bombs used on Hiroshima and Nagasaki), excavating 175 million tons of rock, a fireball flash-incinerating anything within 10 km, a 2,000 km/sec shockwave leveling everything within a 24 km radius, and producing hurricane-force winds as far out as 40 km. Below: In 1908, an object, perhaps only 30 m in diameter air-bursted 5–10 km above a remote region in Tuguska, Siberia releasing the equivalent of 5 to 30 megatons TNT.

planetary size objects, some larger than Earth. Periodically, passing stars knock an Oort comet loose and send it hurtling toward the Sun. A comet hitting the Earth would be unpredictable and deadly. Comet threats are not likely to give us the courtesy of a multi-decade warning.

PROTECTING THE PLANET

It is now past the time for this to move out of the realm of science and into the realm of policy and national security. So why hasn't action been taken?

Planetary defense is greeted with a certain amount of "not my job" syndrome. It is a sort of tragedy of the commons—it is everybody's job and nobody's job. Defense agencies, science groups, emergency institutions, and Congress each know a threat exists, but nobody seems to want the responsibility. Who will have the nerve to take it on?

TIME TO TAKE ACTION

As space advocates armed with knowledge of the threat of near Earth objects, we share in the responsibility of these agencies. We should not be tolerant of polite giggles when the topic is raised. We need to project the deadly serious gravity of this issue. We must act to ensure that the decision-makers follow through with policy to uphold what we have now confirmed about this threat and what must be done about it.

As space advocates, we also recognize that the technologies that address planetary defense also empower space exploration, open the space frontier, and enable space settlement. We should be asking our legislators what their stance on the issue is—and if their answer is uneducated, unacceptable, or negligent, we should not be silent. We should put pressure on our elected officials and the organs of national security. As space advocates, we must take action to inspire the decision-makers in our nation to use our capabilities in space to provide for the common defense of our planet and the prosperity of the human race.

In fact, the Association of Space Explorers (ASE) has stated that while we are tracking perhaps 79 percent of potentially civilization-ending NEAs, we are tracking less than 1 percent of the Tunguska-sized NEAs that could cause enormous destruction on the planet. Today, 206 of the discovered NEAs have some probability of impact. ASE estimates that within a little over a decade we are likely to be tracking perhaps as many as 1,000,000 NEOs, of which 10,000 may have some probability of impacting Earth in the next 100 years. In that time, perhaps 50–100 will appear threatening enough to warrant active monitoring and/or deflection. Statistically, that leaves 75–150 asteroids that will be threatening enough to warrant action, but will remain undetected by our detection and tracking programs.

THE COMET DANGER

Unfortunately, the asteroids are the easy problem when compared to a comet collision. A comet would actually hit the Earth eight times faster than a near Earth asteroid—at speeds of up to 288,000 kilometers per hour. A comet is now thought to have impacted North America only 13,000 years ago and killed off most of its human inhabitants, the Clovis culture, and large mammals such as the woolly mammoth.

The potential population of comets is staggering. More than 1,000 Kuiper Belt objects have been detected, and astronomers say there might be 50–100,000 more, mostly small but some rivaling Pluto in size. The Oort Cloud is thought to contain as many as a trillion comets with perhaps 1,000

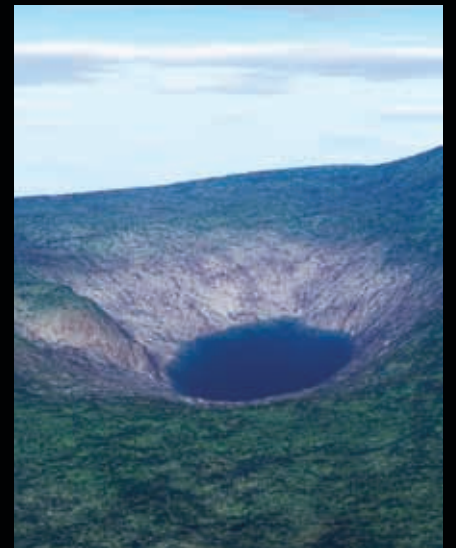


ILLUSTRATION COURTESY OF WWW-TH.BO.INFN.IT/TUNGUSKA; PHOTO: NASA/LEONID KULIK

SPACE LEGISLATION: HR 6063

This year, a major legislative step forward was taken in planetary defense. On October 15, 2008, the president signed HR 6063, the 2008 NASA Authorization Act into law. Excerpted below are the sections that specifically deal with near Earth objects. Recognizing the severity of the threat and the possibility of avoidance, it requests basic information for sound policy making, including a mission to rendezvous and characterize the near Earth asteroid Apophis as well as a larger space mission to find asteroids as small as 140 m in diameter. Most significantly, it tasks the President's Office of Science and Technology Policy (OSTP) to establish a policy for notification of federal agencies and emergency response institutions of an impending NEO threat and recommend a lead agency for deflection.

TITLE VIII—NEAR EARTH OBJECTS IN GENERAL

The Congress reaffirms the policy direction established in the National Aeronautics and Space Administration Authorization Act of 2005 (Public Law 109-155) for NASA to detect, track, catalog, and characterize the physical characteristics of near Earth objects equal to or greater than 140 meters in diameter. NASA's Near Earth Object Program activities will also provide benefits to NASA's scientific and exploration activities.

FINDINGS

Congress makes the following findings:

- 1) Near Earth objects pose a serious and credible threat to humankind, as many scientists believe that a major asteroid or comet was responsible for the mass extinction of the majority of the Earth's species, including the dinosaurs, nearly 65,000,000 years ago.
- 2) Several such near Earth objects have only been discovered within days of the objects' closest approach to Earth and recent discoveries of such large objects indicate that many large near Earth objects remain undiscovered.
- 3) Asteroid and comet collisions rank as one of the most costly natural disasters that can occur.
- 4) The time needed to eliminate or mitigate the threat of a collision of a potentially hazardous near Earth object with Earth is measured in decades.



Ida, a 15.7 kilometer stony-iron asteroid and its tiny satellite Dactyl (1.5 km diameter) as photographed by the Galileo spacecraft in 1993. It was the first binary asteroid of any kind ever discovered. At present, there are 29 known binary near Earth objects.

5) Unlike earthquakes and hurricanes, asteroids and comets can provide adequate collision information, enabling the United States to include both asteroid-collision and comet-collision disaster recovery and disaster avoidance in its public-safety structure.

6) Basic information is needed for technical and policy decision making for the United States to create a comprehensive program in order to be ready to eliminate and mitigate the serious and credible threats to humankind posed by potentially hazardous near Earth asteroids and comets.

7) As a first step to eliminate and to mitigate the risk of such collisions, situation and decision analysis processes, as well as procedures and system resources, must be in place well before a collision threat becomes known.

REQUESTS FOR INFORMATION

The Administrator shall issue requests for information on—

- 1) a low-cost space mission with the purpose of rendezvousing with and characterizing the Apophis asteroid, which scientists estimate will in 2029 pass at a distance from Earth that is closer than geostationary satellites; and
- 2) a medium-sized space mission with the purpose of detecting near Earth objects equal to or greater than 140 meters in diameter.

ESTABLISHMENT OF POLICY

The Director of OSTP shall—

- 1) develop a policy for notifying federal agencies and relevant emergency response institutions of an impending near Earth object threat, if near-term public safety is at stake; and
- 2) recommend a federal agency or agencies to be responsible for protecting the nation from a near Earth object that is anticipated to collide with Earth and implementing a deflection campaign, in consultation with international bodies, should one be required.

PLANETARY RADAR CAPABILITY

The Administrator shall maintain a planetary radar that is, at minimum, comparable to the capability provided through the NASA Deep Space Network Goldstone facility.

ARECIBO OBSERVATORY

Congress reiterates its support for the use of the Arecibo Observatory for NASA-funded near Earth object-related activities. The Administrator shall ensure the availability of the Arecibo Observatory's planetary radar to support these activities until the National Academies' review of NASA's approach for the survey and deflection of near Earth objects, including a determination of the role of Arecibo, that was directed to be undertaken by the fiscal year 2008 Omnibus Appropriations Act, is completed.





FOOTPRINTS ON NEOs

Possibly more accessible than the Moon,
could a near Earth asteroid be the next
stop for manned space exploration?

BY MARK WILLIAMSON



As recently as October 6, 2008, an asteroid measuring a few meters across was discovered by the Catalina Sky Survey from the group's observatory near Tucson, Arizona. The Jet Propulsion Laboratory quickly confirmed that an atmospheric impact would occur early the next morning over northern Sudan, northeastern Africa. And at around 2:45 a.m. local time, a "brilliant fireball"—in the words of the NASA/JPL Near Earth Object Program Office—impacted the Earth's atmosphere with an estimated energy equivalent to a kiloton of TNT.

According to JPL's Don Yeomans, "The follow-up astrometric observations from professional and sophisticated amateur astronomers alike were rather extraordinary, with 570 observations from 26 observatories being reported between the time of discovery ... to just before the object entered Earth's shadow ... less than 19 hours!"

Luckily, asteroid 2008 TC3 was too small for the rest of us to lose sleep over. In fact, according to Yeomans, objects of this size enter Earth's atmosphere "every few months on average." However, as JPL's Sentry System for impact risks has shown, there are much bigger near Earth asteroids (NEAs) that have our planet potentially in their sights. Additionally, more than 900 asteroids and comets are designated potentially hazardous objects.

Currently, the Sentry System flags only one NEA, designated 2007 VK184, that registers on the Torino impact hazard scale (and only at the lowest level), but that could change without warning as others come into view.

SERIOUS ISSUE

That the issue is taken seriously by the professional

space community is shown by the fact that the world-renowned International Academy of Astronautics and the European Space Agency are sponsoring the 1st IAA Planetary Defense Conference (subtitled "Protecting the Earth from Asteroids"), in Granada, Spain, in April 2009. "More and more evidence confirms that impacts by asteroids and comets are not uncommon and that even relatively small objects can cause local and regional disasters," says William Ailor of The Aerospace Corporation and co-chair of the meeting.

Conference delegates will discuss everything from detection, tracking, and characterization of objects to deflection techniques and the political, legal, and policy issues that the organizers say "should be considered as part of an overall mitigation strategy." Of course, this begs the question of what a "mitigation strategy" might entail.

Most authorities believe it is necessary to understand the composition of near Earth objects—a term that includes comets as well as asteroids—before contemplating their deflection. The first phase has already begun, most notably with NASA's Near Earth Asteroid Rendezvous probe, NEAR-Shoemaker (which became the first spacecraft to orbit the asteroid Eros in 2000 and the first to make a landing the following year), and Japan's Hayabusa sample-return spacecraft, which landed on asteroid Itokawa in 2005 and is due to return a sample in 2010.

Nor should we forget NASA's Deep Space 1, which crashed into Comet Tempel 1, and Dawn, a cooperative effort between the U.S. and Europe that was launched to asteroids Vesta and Ceres in 2007. But note the difference between these real-life products of spacecraft engineering and the spaceships we



see in the movies: Bruce Willis is nowhere to be seen! Surely it would be better to round up a gang of oil drillers, strap a couple of extra solid rocket boosters on a space shuttle, and send them off to an asteroid with a surplus Cold War nuclear device? Well, actually, no ... on several levels.

Let's be absolutely clear that there is a universe of difference between real "rocket science" and the story lines that make Hollywood blockbusters. Even the producer/director of the 1998 asteroid deflection epic *Armageddon*, Michael Bay, was quoted as saying "the solution for the asteroid situation was great for the movie but not possible in real life." Indeed, NASA apparently shows the film as part of

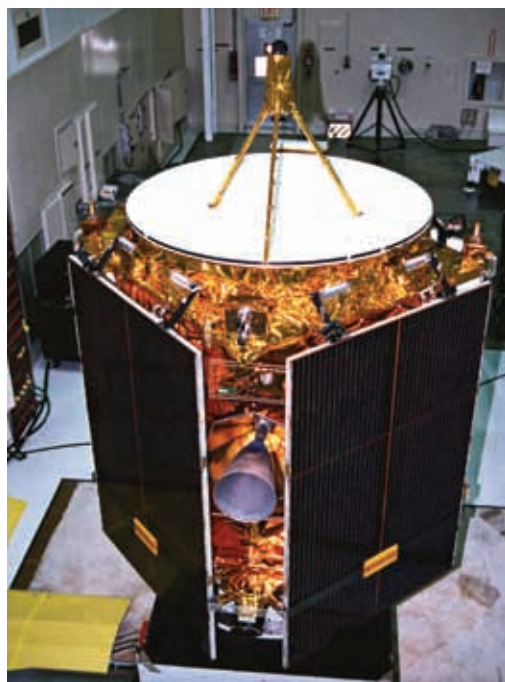
its management training program, to see how many inaccuracies prospective managers can spot (168 "impossible things" have been found so far).

MAN VERSUS MACHINE

The debate over whether manned or unmanned spacecraft are more effective in the realm of space exploration has been running almost as long as the Space Age itself, and shows no signs of abating anytime soon. The most reasoned conclusion is that there is a role for both, but the decision between one or the other for a particular mission depends on factors such as available technology, cost, and risk (both real and perceived).

Do we have the technology for a manned asteroid mission today? No, but that doesn't mean it couldn't be developed, albeit at high cost. How long would it take to develop a spacecraft to transport a crew to an asteroid? That depends not only on how much money we are willing to spend, but on how much time we have before the asteroid hits—there's nothing quite like impending doom to galvanize the bean counters! What about the risk? In our currently risk-averse environment, it seems impossible to contemplate missions so far beyond the relative comfort zone of low Earth orbit.

In 2006–7, a NASA feasibility study considered the cost, risk, and technological needs associated with a human mission to an asteroid. Sponsored by the Advanced Programs Office of the Agency's Constellation Program, "A Piloted Orion Flight to a Near Earth Object" examined the capabilities of the Crew Exploration Vehicle and its Ares launch vehicles to determine the feasibility of a baseline 90-day mission to Asteroid SG344, which has an orbit similar to that of Earth.



Above, A true-color, 3-D model of the asteroid Eros generated from laser rangefinder data; Right, NASA's Near Earth Asteroid Rendezvous probe, NEAR-Shoemaker, in the clean-room prior to its mission to asteroid Eros; Preceding pages: An artists conception of a hypothetical star with an asteroid belt similar to our own as it might have appeared when the Sun was only 30 million years old.

PHOTO: NASA MARSHALL SPACE FLIGHT CENTER (NASA-MSFC)

It concluded, perhaps surprisingly, that “NEOs are the most easily accessible bodies in the solar system,” and justified a mission as a validation of the “foundational infrastructure for the Vision for Space Exploration ... in the run-up to the lunar sorties and lunar outpost build up at the end of the next decade.” So, far from seeing a manned asteroid mission as a risky venture, the study group characterized it as “a feasible, attractive stepping-stone to the Moon and beyond.”

In engineering terms, the crux of the issue is the delta-V, or change in velocity, required to transfer a spacecraft from one orbital path to another. If the NEO’s orbit is similar to Earth’s, the delta-V is relatively small and, because of their small size and gravity, the thrust required to decelerate a spacecraft for rendezvous is also small. According to the study, the delta-V required to brake into or depart from lunar orbit is about 0.8 km/s, which combined with the 3.2 km/s delta-V for a typical lunar transfer gives a total of about 4.8 km/s (compared with an estimated 4.5 km/s for the SG344 baseline). “Thus, many NEOs,” it states, “are more easily accessible than lunar orbit (let alone the lunar surface).”

Looked at pragmatically, the study’s conclusion is not at all surprising, considering that its authors work in an environment that thrives on pushing the boundaries. They also know that NASA will take as much support for “the Vision” as it can get.

But, as the authors themselves admit, the notion of a manned mission to a NEO was discussed as long ago as 1966 to make use of Apollo/Saturn V hardware, revisited in 1989 as part of the doomed Space Exploration Initiative, and examined in four subse-

quent studies between then and 2005. What would be surprising is that any of them might conclude that such a mission was impossible or inadvisable, especially given the premise that Earth’s populations might one day be eliminated. But they are still only paper studies and metal has yet to be cut.

Besides, before an asteroid deflection mission can be designed, it will be necessary to characterize the surface and interior of a few example bodies, which are believed to range from rocky to metallic and from solid to loose aggregate in nature. Amazingly, the writers of *Armageddon* got this bit right by having the first crew land in an iron-rich, difficult-to-drill region, while the second crew found an easier site.

Certainly, the safest, most cost-efficient way to do this would be with an unmanned spacecraft, thus mirroring the process for all previous space exploration programs and providing the necessary “comfort factor.” The goal of Rusty Schweickart’s B612 Foundation, for example, is “to significantly alter the orbit of an asteroid, in a controlled manner, by 2015.” If Schweickart and his colleagues are to see this dream come true in this time frame, it certainly won’t be by virtue of a manned spacecraft.

Richard Tremayne-Smith, co-chair of the forthcoming Planetary Defense Conference and former chairman of the U.N. Working Group on NEOs, confirms this: “Robotic missions are all that is planned,” he says. “Manned missions would not be cost-effective without the addition of a mining element.”

While it seems unlikely that a mining mission would be combined with an asteroid deflection mission, this mention of a commercial application opens



Left: Artist’s conception of the Deep Space 1 encounter with comet Borrelly in September 2001 and, above, Deep Impact on collision course with comet Tempel 1 in July 2005.

ILLUSTRATION: NASA



ILLUSTRATION: PAT RAWLINGS

another huge can of worms, not least with regard to mining rights, the balance between exploration and exploitation, and other space environment protection issues—but that’s another story.

WE’RE IN IT TOGETHER

If we’re talking “beat the asteroid, save the planet,” it’s hard to think of a space mission better suited to international cooperation. For one thing, it would help spread the cost, which was part of the rationale behind the International Space Station, arguably the most successful international space project to date.

This leads some to assume that a manned asteroid deflection mission would use the ISS as a stepping stone, simply because it is there. But the likelihood is that such a mission would do exactly what Apollo did and the Constellation lunar missions are expected to do: fly right past. It all comes down to delta-V and the waste of time and energy that a sta-

tion stop would involve ... and, as we know, time could be the most important factor.

Whether the ISS has a role to play, and whether the U.S. would relax its ITAR export regime sufficiently to allow international contributions—not least from that budding space power China—remains to be seen. Certainly, few of the decisions will be easy, but if we fail to prepare before the call comes, we could lose more than the chance to apply an impressive array of space technology in an international, collaborative program. Our reluctance to band together against an unflinching adversary from space could mark the beginning of the end of civilization as we know it.

Mark Williamson is a space technology consultant and writer. His book on the space environment—Space: The Fragile Frontier—was published by AIAA in 2006.



NEAR EARTH OPPORTUNITIES

A NEW WAY TO CONSIDER THE ASTEROID THREAT

BY BRAD BLAIR

Imagine the relationship between asteroid defense and commercial asteroid mining as damming a river that regularly floods a fertile valley. By using the water locally for hydroelectric power, the potential for regular damage to infrastructure and loss of life is converted to an economic positive for the community. It provides steady water, power, and recreation for the population while reducing the natural hazard.

The asteroid threat is a vast resource in disguise. The shared features of systems-level hardware between asteroid mining and planetary defense are many, particularly for the exploration stage, but also for the mitigation and mining stage. By precisely timing the departure of a payload and properly selecting the launch mechanism, an asteroid mining mission could actually reduce the overall threat of an asteroid.

Private finance could be dedicated to characterization and asteroid mitigation by simply planning ahead and inviting the right parties to the table. In addition, mixing private money into the search for potentially threatening asteroids and asteroid mining targets brings the prospect of near-term space settlement closer. This is inspiring, and could help lift some of the cost burden of asteroid response off the

shoulders of taxpayers. Saving planet Earth, opening the space frontier for settlement by providing a source of local commodities, and becoming wealthy in the space resource business are mutually compatible goals.

While the idea of finding benefits in asteroid exploration is straightforward, seeing its benefits come to fruition requires something considered impossible by many in today's aerospace industry: in-space customers. The greatest struggle for would-be planetoid miners is to convince decision-makers and investors that a marketplace for asteroid-derived commodities will emerge.

Today, no rocket fuel is sold on-orbit (although some claim that the capability of refueling for existing transportation elements such as the Centaur upper stage, lies within reach). Nor are there currently any orbital customers waiting for delivery of precious or base metals, ceramics, silicon, or hydrocarbon-based products.

Lucrative markets could emerge, particularly as commercial and private space industries continue to challenge some of the more archaic space-age paradigms (e.g., space can only be accessed by large government programs). One great economic success of the emerging space entrepreneurs could trigger

a cascade of private investment, accelerating the opening of the space frontier. Asteroids offer a promise of low-cost raw materials in space, and, when combined with orbital manufacturing, could underwrite exponential growth in orbital infrastructure and expedite human expansion into space.

Microgravity materials research, an ongoing NASA program since the days of Skylab, has yielded many breakthroughs. Innovations discovered in space have worked their way into modern industry through tech transfer and commercialization. The bulk of our industrial technology base is thousands of years old, at least in terms of the basics of mining, separation, refining, manufacturing, and assembly of 99.5 percent of the "stuff" we use every day. Orbital mechanics is well understood. Space transportation is routine. Once the marketplace emerges, asteroids will go into production.

The technological advancements that we would garner from experiences on asteroids justifies the expenses and risks of such an operation. However, as humans and intelligent beings, we also have the moral responsibility to research natural phenomena that could cause catastrophe on Earth. In this case, the more noble cause of potentially saving civilization through NEO deflection will open opportunities.

ILLUSTRATION: NASA/JPL