Near-Earth Objects: Responding to the International Challenge

April 2014

Secure World Foundation

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ACRONYMS

ASE	Association of Space Explorers
AT-14	Action Team 14 (UN)
CNES	Centre National d'Études Spatiales (French Space Agency)
COPUOS	Committee on the Peaceful Uses of Outer Space (UN)
CRECTEALC	Regional Center for Space Science and Technology Education for Latin America and the Caribbean
DLR	Deutsches Zentrum für Luft und Raumfahrt (German Space Agency)
DSP	Defense Support Program (U.S.)
ESA	European Space Agency
IAA	International Academy of Astronautics
IADC	Inter-Agency Space Debris Coordinating Committee
IAWN	(*formerly*) Information, Analysis and Warning Network (*currently*) International Asteroid Warning Network
IGO	International Governmental Organization
ISON	International Scientific Optical Network
JAXA	Japanese Aerospace Exploration Agency
km	kilometer
LASP	Laboratory for Atmospheric and Space Physics (University of Colorado at Boulder)
MPC	Minor Planet Center
MPOG	Mission Planning and Operations Group
NASA	National Aeronautics and Space Administration (U.S.)
NEO	Near-Earth Object
NEOWISE	Near-Earth Object Wide-field Infrared Survey Explorer
NGO	Non-governmental Organization
OOSA	Office for Outer Space Affairs (UN)
OSIRIS-Rex	Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer
ROSCOSMOS	Russian Federal Space Agency
SMPAG	Space Mission Planning Advisory Group
SSA	Space Situational Awareness
STSC	Scientific and Technical Subcommittee (UN COPUOS)
SWF	Secure World Foundation
TOR	Terms of Reference
UN	United Nations
UNISPACE III	Third United Nations Conference on Exploration and Peaceful Uses of Outer Space
U.S.	United States

INTRODUCTION: WHY THIS BOOKLET?

Asteroids and comets have long attracted the scientific community because study of these curious astronomical bodies contributes immeasurably to our understanding of the origin and development of the solar system. They also interest the public and scientists alike because of the impact craters they have left on the surfaces of the Moon, the Earth and other planets.

This booklet is designed to bring into focus the key issues faced by the international community in dealing with the threat of near-Earth objects (NEOs) and the prospect of a celestial body hitting Earth. In particular, it reviews the state of research on asteroids and summarizes the various efforts to mitigate potential future threats. It also identifies areas of future research and development.

The 1.2 kilometer Barringer (or Meteor) Crater Arizona, was created about 49,000 years ago by a small nickel-iron asteroid. Photo by D.J. Roddy and K. Zeller, United States Geological Survey.

Asteroid and comet impacts on Earth have resulted in the creation of several large craters, one of the largest of which likely precipitated the ultimate destruction of non-avian dinosaurs and many other prehistoric species. The weight of scientific evidence points to the conclusion that some 65 million years ago a large comet struck the Earth in what is now the Northern Yucatan Peninsula, causing a mega-tsunami and sending millions of tons of water vapor and soil high into the atmosphere to form the Chicxulub crater. The resulting dust particles high in the atmosphere are thought to have led to a dramatic long-term cooling of Earth, drastically reducing food production over the entire planet. The disrupted food chain likely led to extinction of the dinosaurs.

Strikes on Earth from asteroids or comets, particularly large ones, are extremely rare. Yet in recent years, asteroids, especially, have become of interest to policy makers because of the growing realization that a special class of asteroids, termed near-Earth objects or NEOs because they travel in orbits near Earth's orbit, may pose a threat to humans. The February 15, 2013 atmospheric impact of a 17- to 20-meter-sized asteroid near Chelyabinsk, Russia serves as a very public reminder that Earth is not free of potential future asteroid strikes.

Among other outcomes, that event over Russia has enriched an important debate about how to respond to a potential future asteroid threat. Asteroid impacts can occur anywhere on Earth, but almost uniquely among potential natural disasters, most large asteroid strikes can be averted with sufficient warning and preparation by the world's space agencies.

Well before the Chelyabinsk event, Secure World Foundation (SWF) began working with partners such as the Association of Space Explorers (ASE), the Planetary Society, and the United

TERMINOLOGY

ASTEROID: Any of many small celestial bodies that orbit the sun, most of which lie between Mars and Jupiter.

BOLIDE: Fireballs that explode in the atmosphere. The terms bolide and fireball are often used interchangeably, even in the scientific literature.

FIREBALL: Exceptionally bright meteors that enter the atmosphere and flare from the heat of friction with the atmosphere but do not explode.

COMET: Icy, small celestial bodies. When near the sun, they begin to heat up and lose gases and dust, often causing a long tail. Comets without the characteristic tail may appear to be asteroids.

METEOROID: A very small body orbiting the sun, smaller than an asteroid. The boundary between a meteoroid and an asteroid is not well defined, but is about 1 to 10 meters in diameter.

METEOR: A bright streak across the night sky caused by a small meteoroid burning up in the atmosphere.

METEORITE: The remainder of a meteoroid or asteroid that survives the heat of encounter with Earth's atmosphere and falls to Earth.

Nations Committee on the Peaceful Uses of Outer Space (UN COPUOS) and its Scientific and Technical Subcommittee (STSC), to help develop international cooperative mechanisms for responding to an asteroid threat.

That work, in part, has recently led to an important report by the Working Group on NEOs of the STSC, endorsed by UN COPUOS in its annual report to the UN General Assembly. That report contains specific recommendations for creating international institutional mechanisms for identifying and responding to a threatening asteroid. In December 2013, the General Assembly "welcomed with satisfaction the recommendations for an international response to the near-Earth object impact threat" (UN General Assembly Resolution A/Res/68/75, 11 December 2013, para. 8).

Background: What are NEOs?

NEOs are part of the leftover debris from our solar system's formation about 4.6 billion years ago. NEOs act as time capsules, offering important scientific insight into the primitive solar system and its development. Asteroids can range from piles of rubble—loose-fitting collections of fragments held together weakly by the force of gravity—to composite mixtures of metals, such as iron, and carbon and silicon compounds.

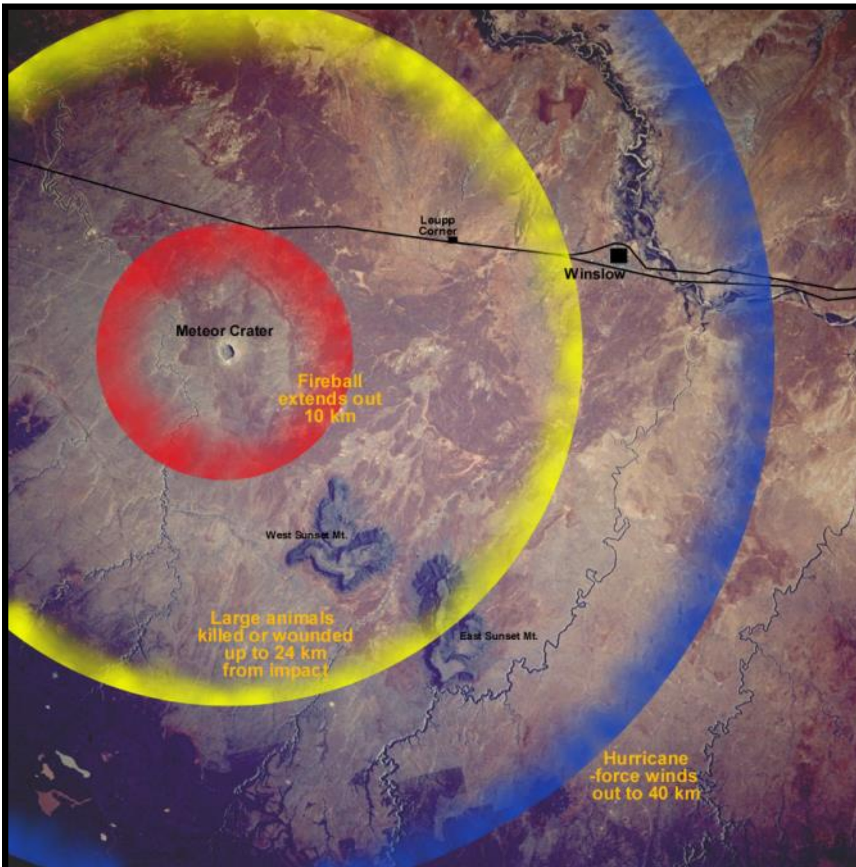
Icy active comets also occasionally pass close to Earth and can also be considered NEOs. Nevertheless, asteroids of various sizes and shapes are of far greater concern because they are more numerous.

By the end of 2013, over 600,000 asteroids have been identified in our solar system. Nearly 10,000 of them are NEOs. Thanks to leading efforts by the U.S. National Aeronautics and Space Administration (NASA), an estimated 95 percent of all NEOs over 1 kilometer (km) in size have been catalogued. None of these identified larger NEOs pose any threat of impact to the Earth anytime in the next century.

NEOs from 140 meters down to roughly 20 meters, perhaps even smaller, while not threatening to human civilization on a planetary scale, are capable of causing severe localized damage if they enter Earth's atmosphere above populated land areas.

There is growing global interest in those dangerous natural objects that may have their celestial cross-hairs on planet Earth. Yet, at present, no comprehensive dynamic map of our inner solar system exists showing the positions and trajectories of asteroids that might menace our planet.

The Earth has the scars to highlight the fact that asteroids can be trouble-makers from the heavens. The extinction of the dinosaurs has even caused some to joke that they became extinct because they did not have a space program. And if humankind becomes extinct because we have not been able to counter an imminent NEO danger, then, we are indeed no better off than the dinosaurs, though unlike them, we will likely know of our demise ahead of time. There is thus a need to mitigate the NEO risk first by finding them before they find us.



Artwork of Barringer Meteor Crater shows the range of environmental effects created by the impact. Credit: Dr. David A. Kring

THE MISSING RECORD

Over geologic time, these cosmic interlopers have left their mark on our world. But assembling a true inventory of Earth's impact craters is made difficult by erosion and other geological processes. Indeed, it is a geological forensics problem. Yet, one look at Earth's crater-pocked Moon tells a disquieting story of violent impact rates that must have also played a similar role in Earth's early years because Earth and Moon reside in the same cosmic neighborhood.

While there is a missing record of impacts here on Earth, we do have obvious tell-tale signs that Earth has been on the receiving end of large and small impactors. For instance, some 50,000 years ago an asteroid traveling about 72,000 km/hour (45,000 miles/hour) plowed into what is now the Arizona desert near Winslow, Arizona. Today known as the Barringer Meteor Crater, this impact feature is about 170 meters (570 feet) deep and 1.2 km (0.75 mile) wide. A 60-story building could rest at the crater's bottom and not reach as high as the crater rim. Twenty football fields could be put on its floor and more than 2 million fans could watch games from the crater walls. It is considered the world's best preserved meteorite impact site.

This impacting rock from space was composed of nickel-iron and thought to be about 45 meters (150 feet) across, tipping the scales at about 270,000 metric tons (300,000 tons), with an explosive strength equal to 2.5 megatons of TNT.

The ground-shaking collision tossed over 160 metric tons (175 million tons) of limestone and sandstone into the air to form a continuous blanket of debris surrounding the crater for a distance of over a mile. Research at the crater site has shown that the impact produced a 19-km (12-mile) diameter scorch zone where everything was burned. All large animals were killed or wounded within a 24-km (15-mile) wide zone. Last, there was a 40-km (25-mile) wide zone of hurricane-force winds emanating from the blast.

One could easily envision the destruction that would ensue from a similar object striking a populated area today. An impact equal to the one that caused Meteor Crater, would prove catastrophic in the New York metropolitan area.

While digging back into geologic time is one way to gather evidence that Earth has been struck by asteroids, confirmation of the fact is as fresh as news coverage in 2013.

21ST CENTURY WAKE-UP CALL

Labeled by many experts as a 21st century warning shot, on February 15, 2013, near the city of Chelyabinsk in Russia, a previously undetected orbiting asteroid plowed through the atmosphere over that area, exploded and let loose window-shattering shock waves over an extensive region. That airburst event caused injuries to some 1,600 individuals and hospitalized dozens from cuts caused by flying glass and other materials. Over 4,000 buildings were damaged. Scientists have estimated the pre-entry diameter of the object to be roughly 20 meters (65 feet) with a mass of approximately 12,000 metric tons. It exploded with a force of 500 kilotons (five to six times the yield of the Hiroshima nuclear bomb).

Chelyabinsk sky rendering is a reconstruction of the asteroid that exploded over Chelyabinsk, Russia on Feb. 15, 2013. Scientific study of the airburst has provided information about the origin, trajectory and power of the explosion. This simulation of the Chelyabinsk meteor explosion by Mark Boslough was rendered by Brad Carvey using the CTH code on Sandia National Laboratories' Red Sky supercomputer. Andrea Carvey composited the wireframe tail. Photo by Olga Kruglova. Credit: Sandia National Laboratories.

The asteroid at Chelyabinsk was the largest known extraterrestrial object encounter with Earth since June 30, 1908, when an incoming object apparently exploded in the atmosphere and flattened approximately 2,600 sq. km. (1,000 square miles) of forest in Tunguska, Siberia. That overhead detonation was equal to the explosive force of a 4 megaton bomb. If the Tunguska airburst had taken place above a more populated region of the planet, be it London, New Delhi or New York, millions of people would have been killed with no advance warning.

In fact, when you add the Chelyabinsk incident to the 1908 Tunguska explosion, along with a large 1963 airburst near the Prince Edward Islands off the coast of South Africa, there is growing realization that the incoming rate of small space rocks may be much higher than asteroid experts have previously estimated, leading some NEO researchers to suggest that the airburst hazard may be greater than previously thought.

Supercomputer simulation shows details of a fireball that might be expected from an asteroid exploding in Earth's atmosphere. Credit: Randy Montoya/Sandia National Laboratories.

The most likely kind of NEO threat will be from a body tens of meters in size that is discovered and predicted to strike in a matter of days, weeks or months. Civil defense/disaster management authorities should be ready to warn people to prepare for the NEO impact.

Detailed modeling of the effects of small impactors—from Chelyabinsk-size to 140 meters in diameter—is a gap that should be filled, although most of the computer codes to address this problem accurately are under restricted access because of the close tie to nuclear weapon blast effects.

Nevertheless, great progress is being made to discover, track and characterize the population of near-Earth objects that may pose threats to Earth. As NEO work continues, it will also become increasingly important to ascertain the whereabouts of the small objects for which the warning time may be very short, as well as of the larger objects.

WHAT IS BEING DONE?

The NASA Authorization Act of 2005—in a section labeled the George E. Brown, Jr. Near-Earth Object Survey Act—directed the U.S. space agency to detect, track, catalogue, and characterize 90 percent of all NEOs with a diameter of 140 meters or greater by 2020. This legislation extends congressional direction from 1998 that tasked NASA, within 10 years, to locate at least 90 percent of all NEOs with a diameter of 1 km or greater. These larger asteroids are judged by many experts to have the potential to threaten civilization. NASA and its university and amateur partners achieved the 1-km goal in 2011. The task of detecting 90 percent of NEOs larger than 140 meters, however, is far more challenging.

Thanks to the march of technology and appropriate funding of research tools, the discovery rate of NEOs has been on the increase over the last several years. This is exemplified by the large NEO catalogue maintained by the Minor Planet Center (MPC) in Cambridge, Massachusetts. This facility is regarded as the nerve center of asteroid detection in the solar system, collecting and distributing data to the international community. The center also helps to coordinate asteroid searches.

The European Space Agency (ESA) is successfully contributing to the global effort of coping with the NEO impact threat. It has developed a multi-segment Space Situational Awareness (SSA) Program. The three segments involve hazards that stem from possible collisions between objects in orbit, harmful space weather and potential NEO strikes. ESA's SSA-NEO segment is focused on providing information about the impact threat of NEOs, being aware of the positions and physical properties of NEOs and assessing their impact probabilities, effects, and gauging possible mitigation activities.

Yet another vital effort in preparing techniques for preventing an NEO impact on a long-term basis is called NEOShield. The European Commission is providing funding to support this initiative, an undertaking consisting of research institutes, universities and industrial partners in Germany, France, the United Kingdom and Spain, and in the U.S. and Russia. One primary aim of NEOShield is to investigate promising asteroid threat-reduction techniques.

Also on the international front, work by the Russian Federation is underway toward establishing an SSA program aimed at revealing and counteracting space threats, including the asteroid/comet impact hazard. A significant contribution toward this goal is being made by the International Scientific

Optical Network (ISON). ISON is a growing international network of small telescopes linked together to discover and track space debris and asteroids from around the world. Also in Russia, Moscow State University operates the MASTER network of robotic telescopes located throughout Russia for asteroid discovery. In addition, Russia also operates several radar telescopes for characterization of identified asteroids and is planning to build several new telescopes to use at least in part for asteroid observations. Finally, it is also looking to build and launch a space-based NEO telescope by 2021.

Japan, which has successfully carried out a NEO sample return mission with the Hayabusa 1 spacecraft, is planning a second mission. The Japan Space Guard Agency is also planning to build a dedicated ground-based telescope for NEO observations.

Amateur observers, some with moderately large telescopes and sophisticated digital equipment, have had an important role in asteroid discovery and tracking. Although their ability to discover new asteroids will diminish as most of the larger, brighter ones are catalogued, amateurs will continue to have a role in follow-up observations focused on defining asteroid orbits.

The U.S. private sector has also become interested in asteroids—as a source of minerals rather than their threat potential. For example, the start-up firms Planetary Resources and Deep Space Industries have recently announced that they have plans to orbit their own asteroid finders to assess the potential of small asteroids as sources of minerals useful on Earth and for utilization in space.

From the Ground Up

NEO discoveries are being made by a range of ground-based instruments, such as the noteworthy work at these sites: the Catalina Sky Survey that operates near Tucson, Arizona; the Pan-STARRS survey operation atop Haleakala, Maui, Hawaii; and the LINEAR survey near Socorro, New Mexico.

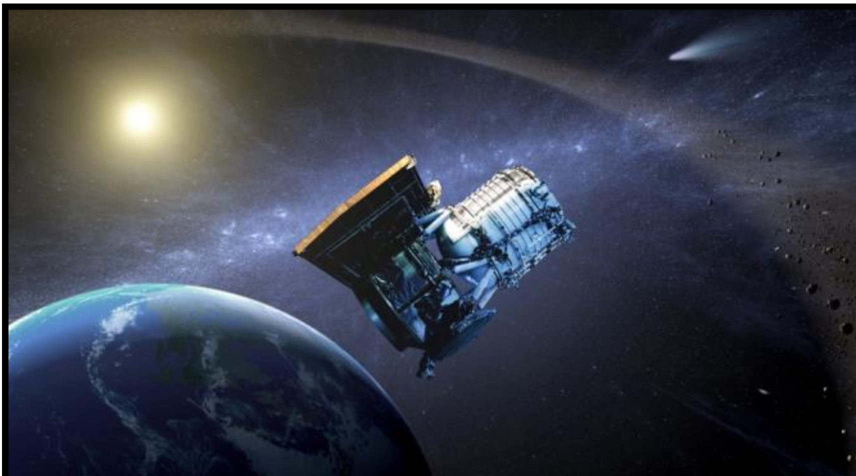
Additional observational tools include the Infrared Telescope Facility on Mauna Kea in Hawaii, while an increasing number of radar detections of NEOs are carried out both at the Goldstone facility in California and the Arecibo Observatory in Puerto Rico. Radar observations are important because they help characterize asteroid composition and determine size, rotation rate and precise orbit.

An important planned future contributor to NEO reconnaissance in coming years is the Space Surveillance Telescope being developed by the Massachusetts

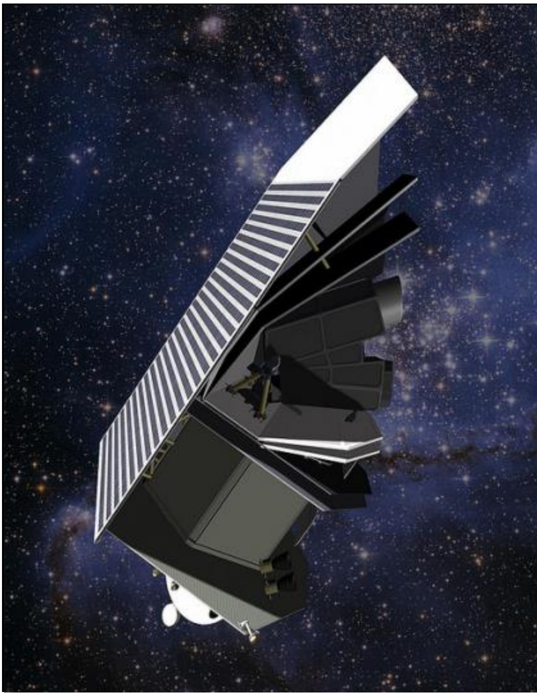
Institute of Technology's Lincoln Laboratory for the Defense Advanced Research Projects Agency and the U.S. Air Force. Similarly, the Large Synoptic Survey Telescope is slated to begin operations in Chile within the early 2020s, funded by the U.S. National Science Foundation, along with a consortium of private and international agencies and universities.

Under a NASA five-year grant, the University of Hawaii is developing the Asteroid Terrestrial-impact Last Alert System Project, or ATLAS Project. It will couple modest-sized, commercially available telescopes with custom-equipped cameras and special software to cover the entire available sky each night for 100-meter-sized asteroids and smaller objects as they come closer to the Earth. It could provide days to weeks of warning of objects tens of meters in size that are on impact trajectories with Earth.

The U.S. Defense Support Program (DSP) satellites, designed to support the monitoring of nuclear explosions around the world, also generally collect data about other bright flashes, including those caused by small asteroids entering the atmosphere that result in fireballs and bolides. Information about these phenomena, which were formerly classified, is an important input to our understanding of the frequency of small asteroid impacts with Earth. In 2013, fireball and bolide data was declassified and are now available on a NASA website.



This artist's concept shows the NASA Near-Earth Object Wide-field Infrared Survey Explorer (NEOWISE) spacecraft, on the hunt for more asteroids and comets. Credit: NASA/JPL-Caltech.



The B612 Foundation, in partnership with Ball Aerospace, has initiated the Sentinel Mission to build, launch, and operate an infrared space telescope to find and track the hundreds of thousands of threatening asteroids that cannot be tracked with current telescopes. Credit: Ball Aerospace.

View from Space

NEO spotting from outer space can significantly augment Earth-based detection skills. That, too, is in the arsenal of planetary defense tools.

For example, NASA's Near-Earth Object Wide-field Infrared Survey Explorer (NEOWISE) is now on duty. NEOWISE began as WISE, a mission launched in December 2009 to scan the entire celestial sky in infrared light. NASA turned off most of WISE's electronics when it completed its primary mission in February 2011. Upon reactivation, after more than two years of hibernation, the still-capable spacecraft was renamed NEOWISE, with the goal of discovering and characterizing asteroids and comets whose orbits approach within 45 million km (28 million miles) from Earth's path around the sun.

Canada is well engaged in the international effort to catalog the near-Earth population of asteroids. Its NEOSSAT, a suitcase-sized microsatellite, was launched in February 2013 to discover asteroids orbiting near the sun that are difficult for ground-based surveys to find.

The private B612 Foundation is leading the Sentinel endeavor, to build, launch and operate a solar orbiting infrared space telescope. Sentinel is philanthropically financed and privately managed, but also includes U.S. government partnership.

B612 plans to launch Sentinel in July 2018. According to its developers, during the first 6.5 years of operation the spacecraft will be able to discover and track the orbits of over 90 percent of the population of NEOs larger than 140 meters (153 yards), and the majority of those bigger than the asteroid that struck the Tunguska area (roughly 40 meters—or 44 yards). Sentinel's sharp-eyed instrumentation will be capable of discovering 100 times more asteroids than have been found by all other telescopes combined.

In late 2012, after China's Chang'e 2 lunar spacecraft had completed its lunar mission, space officials diverted the spacecraft from lunar orbit to pass close by and photograph asteroid Toutatis. The encounter yielded several excellent photographs of the asteroid. Such serendipitous observational opportunities can add important information about the shape and possible composition of asteroids.

Other space endeavors include future robotic missions to asteroids and comets. These spacecraft investigations provide invaluable data for understanding NEOs, and help us appreciate the formidable task of thwarting an object that is found to intimidate Earth.

For instance, the Japanese Aerospace Exploration Agency (JAXA) is staging an ambitious sojourn to asteroid 1999 JU3 via the Hayabusa-2 spacecraft. It is being readied for launch in 2014 and will arrive at the targeted asteroid in 2018. It will loiter at that space rock and carry out a number of challenging experiments before leaving the scene at the end of 2019 and returning to Earth with asteroid specimens around the end of 2020.

ESA's Rosetta spacecraft was launched in 2004 to rendezvous with Comet 67P/ Churyumov–Gerasimenko in August 2014. It will attempt to complete a detailed study of the comet, including sending a lander to the NEO to analyze the comet's composition close up.

Headed for a 2016 planned departure from Earth is NASA's Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx) mission. It will rendezvous with the near-Earth carbonaceous object, asteroid Bennu, and then gather specimens of the space rock for delivery to Earth in 2023. The "security" facet of OSIRIS-REx results from the high potential for Bennu to crash into Earth in the late 22nd century.

Dealing with a Dilemma: NEO Impact Threat Mitigation

NEOs have in the past and will in the future pound our planet and disturb our life-sustaining ecosystem. The historic track record is clear. On one hand, the odds of a civilization-crippling asteroid crashing into our world are slight. On the other hand, they are not zero.

When could Earth be subjected to the next major impact? The answer is that it's all about probabilities. It is not a question of *if* a NEO will hit the Earth, but rather *when* and *how big*. Additionally, there is the need to "know the enemy," to appreciate the diversity of potentially hazardous objects in terms of their different compositions, densities, porosities and structures.

Exemplary work is underway by the European Union-supported NEOShield project that is centered on a global approach to NEO impact threat mitigation. NEOShield is carrying out a detailed analysis of the many options for preventing the collision of a NEO with Earth.

How best to avert a NEO from striking Earth? In most cases, with enough warning, only a relatively small force is needed to shift an asteroid's trajectory sufficiently to miss Earth. Over the years, promising asteroid threat-reduction techniques have been proposed, for instance, kinetic impactors, gravity tractors, and the explosive blast-deflection method.

Examples of NEO mitigation techniques include:

- ***Kinetic Impactor***: A NEO is deflected following an impact from a space-craft designed to impact the asteroid, causing its orbit to shift slightly. The principle of momentum transfer is used, as the impactor crashes into the much larger NEO at a very high velocity. The mass and velocity of the impactor (the momentum) are transferred to the NEO, causing a small change in velocity that alters its course slightly.
- ***Gravity Tractor***: A spacecraft hovers near an asteroid and relies on the small gravitational attraction between the two to ever-so-slightly change the pair's center of gravity, thus altering the asteroid's course. Alternatively, multiple, smaller spacecraft flying in formation could be deployed near an asteroid to perform the gravity tractor maneuver.
- ***Blast Deflection***: This technique requires the use of a nuclear explosive close to an asteroid. The blast causes the outer layers of the asteroid to evaporate, acting just like rocket fuel, altering the asteroid's trajectory to avoid it striking Earth. Alternatively, non-nuclear standard explosives

could be used to impart small or medium pushes to the asteroid. Burying an explosive on the asteroid before setting it off is another proposed deflection method.

- **Additional potential mitigation methods:** Other suggested techniques include using lasers to boil off material from the asteroid's surface, thereby creating a force that moves an asteroid. Similarly, the use of large mirrors or lenses to concentrate the sun's energy onto an asteroid using single or multiple spacecraft has been advocated. So too has changing an asteroid's thermal properties; both concepts could result in a change of the NEO's orbit.

These ideas, and many others, have been voiced over the years. Using several methods together to prevent an impact could prove useful. As the United Nations implements the first-ever international contingency plan for defending Earth against an asteroid strike, a key component of that plan is setting up an advisory group to further study options for deflecting an asteroid.

GOVERNING THE DARK

International observations, tracking, and cataloging the thousands of NEOs in space are essential elements in learning which objects from the dark depths of space carry Earth's address as their final destination. International cooperation is also critical in helping to shape a coherent action plan in the event that a wayward outsider threatens Earth.

No government in the world today has explicitly assigned the responsibility for planetary protection to any of its agencies. The challenge ahead is that planetary defense cannot be met by any single nation or government alone. Instead, the effort will require international cooperation.

For this reason, the most effective way forward is for governments to work closely with their respective domestic partners in industry, academia, and other sectors and to tap the talents of international organizations. Doing so will be key in realizing a shared goal of NEO risk mitigation, fed by a strong effort of scientific discovery and tracking using ground- and space-based technologies.

Providing a leadership role in developing an international decision-making program for global response to NEO threats is the ASE—the international professional organization for those who have been to space.

Its seminal report – *Asteroid Threats: A Call for Global Response* – was released on September 25, 2008, and was prepared by the ASE's International

Panel on Asteroid Threat Mitigation. It was submitted to UN COPUOS for consideration and subsequent action by the United Nations. The report's goal was to assist the international community in preventing loss of life and property resulting from an asteroid impact on Earth. "Because NEO impacts represent a global, long-term threat to the collective welfare of humanity, an international program and set of preparatory measures for action should be established," the report states.

Among other things, the action-oriented report called for a global, coordinated response by the United Nations to the NEO impact hazard, one that should ensure that three logical, necessary functions are performed:

- Information Gathering, Analysis, and Warning
- Mission Planning and Operations
- Mission Authorization and Oversight

Major progress has been made toward a viable plan as a result of the steadfast work by the Action Team on NEOs, also referred to as Action Team 14 (AT-14), established in 2001 by the UN COPUOS in response to recommendation 14 of the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III), held in Vienna, Austria in 1999.

That team, composed of representatives of governments, non-governmental organizations (NGOs) and international governmental organizations (IGOs), was mandated by UN COPUOS to review ongoing efforts in the field of NEOs, identify gaps that could be filled by coordination and propose steps for such coordination in collaboration with specialized bodies. As part of the mechanism to carry out its mandate, AT-14 produced annual interim reports, which were provided to the UN COPUOS STSC for its consideration.

Beginning in 2009, following the reception by AT-14 of the ASE report, the STSC established a Working Group on NEOs to assist the Subcommittee in considering the item on NEOs, particularly the interim report of AT-14.

Indeed, since its creation, AT-14 has encouraged the establishment of more international efforts for NEO detections and cataloging, for addressing deflection issues and for establishing protocols to be used by the international community in response to a potential NEO threat. The Action Team has successfully pushed forward the acceptance of an international response to the impact threat of asteroids and other near-Earth objects.

The work of AT-14 has flagged the critical efforts to identify and track asteroids in order to counter NEOs before they do serious damage to population centers, spur loss of life, economic devastation, and cause long-lasting societal disorder.

Gluing together a planetary defense strategy is not easy and includes a number of components: from finding potentially hazardous objects, to predicting their future locations, and providing warning about future impacts with Earth.

In its discussions, AT-14 has focused on three primary components of NEO threat mitigation, derived in part from the ASE report:

- Discovering hazardous asteroids and comets and identifying those objects requiring action,
- Planning a mitigation campaign that includes deflection and/or disruption actions and civil protection activities,
- Implementing a mitigation campaign, if the threat warrants such action.

Furthermore, AT-14 has emphasized the value of finding hazardous NEOs as soon as possible in order to better characterize their orbits. This would help to avoid unnecessary NEO threat mitigation missions or facilitate the effective planning of missions, should they be deemed necessary.

Following a generally favorable response to the ASE report within UN COPUOS, AT-14 worked through its recommendations, beginning with an Information, Analysis and Warning Network (IAWN), designed to gather and analyze NEO data and provide timely warnings to national authorities should a potentially hazardous NEO threaten Earth.

IAWN – many of the components of which already exist and are working together – would pool together the expertise of the world’s many existing relevant scientific organizations to discover and track objects and generate early warnings of potential impacts.

Putting in place an adequate and effective decision-making mechanism will decrease the risk that the international community would fail to react productively in the face of such a threat. Moreover, to counteract a prospective NEO danger of regional or global dimension, information-sharing and communications capabilities must be harnessed to identify and warn society of hazardous NEOs. To avert an actual impact, an international decision-making program, including necessary institutional requirements, must be agreed upon. How such an international action can be implemented would most likely be discussed within the framework of the United Nations.

UN Action on NEOs

In October 2013, the Fourth Committee of the General Assembly adopted a draft resolution that endorsed a set of measures to protect our planet from the dangers of incoming asteroids. The recommendations were made by the Working Group on NEOs of the UN COPUOS Scientific and Technical Subcommittee, endorsed by the Subcommittee and then subsequently endorsed by UN COPUOS. These adopted guidelines are designed to deal with issues such as global coordination and establishing a response plan in the event that a troublesome NEO might impact Earth.

The UN plan to establish an "International Asteroid Warning Network" (IAWN) is a critical step in collecting and sharing information about potentially hazardous NEOs. If an Earth-threatening asteroid is detected, UN COPUOS could help to facilitate a spacecraft mission intended to deflect that object from its collision course with Earth.

The NEO Working Group of the STSC has recommended an action agenda, including the following steps:

- An IAWN open to contributions by a wide spectrum of organizations, should be established by linking together the institutions that were already performing, to the extent possible, the proposed functions, including discovering, monitoring and physically characterizing the potentially hazardous NEO population and maintaining an internationally recognized clearing house for the receipt, acknowledgment and processing of all NEO observations. Such a network would also recommend criteria and thresholds for notification of an emerging impact threat.
- IAWN should interface with the relevant international organizations and programs to establish linkages with existing national and international disaster response agencies in order to study and plan response activities for potential NEO impact events and to recommend strategies using well-defined communication plans and procedures to assist governments in their response to predicted impact consequences. This does not limit the possibility of organizing additional international specialized advisory groups, if necessary.
- A space mission planning advisory group (SMPAG) should be established by Member States of the United Nations that have space agencies. The group should include representatives of spacefaring nations and other relevant entities. Its responsibilities should include laying out the

framework, timeline and options for initiating and executing space mission response activities. The group should also promote opportunities for international collaboration on research and techniques for NEO deflection.

SWF's Support Role

Over several years, SWF has supported the establishment of international mechanisms for responding to an asteroid threat. From the beginning, SWF was at least as concerned about how countries might react to the independent action of others in the face of a perceived NEO threat as it was about the asteroids themselves. If misinterpreted, independent action could be dangerously destabilizing. SWF also recognized that without a multilateral network of information sources, the declaration by any one country of an imminent asteroid threat could be viewed with suspicion by others who questioned that country's motives. To imagine how destabilizing such suspicion could be, reflect on what might have happened if the asteroid that exploded over Chelyabinsk, Russia, once the center of Soviet nuclear weapons production, had made its appearance at the height of the Cold War.

Secure World Foundation and the Association of Space Explorers convened a two-day workshop in November 2011, bringing together NEO researchers, experienced reporters, communications experts and risk management authorities to review effective communications regarding the threat of NEOs. Meeting was held at the Univ. of Colorado, Boulder's Laboratory for Atmospheric and Space Physics (LASP). Credit: SWF

To enhance the credibility and transparency of asteroid warning and in support of AT-14, SWF, together with ASE and the Regional Center for Space Science and Technology Education for Latin America and the Caribbean (CRECTEALC), organized a January 2010 workshop hosted by the Mexican Ministry of Foreign Affairs. That gathering in Mexico City explored the components that would be needed to establish the first of the functional groups—the IAWN.

The workshop made several key recommendations, among them:

- An effective IAWN will need additional capability to fulfill its mission. Among other things, its expertise should include analysis of the physical effects caused by a NEO impact, including the study and modeling of tsunami effects. Such analysis and modeling will enable IAWN to be more effective in providing appropriate warning to potentially affected communities.
- The current network institutions should study the existing communications methods used for distribution of NEO detection, orbit analysis, impact prediction, and notification protocols, and recommend improvements.
- The IAWN should investigate the communication channels and contacts used today by other disaster warning networks to communicate with the disaster management community.

Given the importance of clear, accurate communications regarding NEOs as recommended in the January 2010 workshop, SWF and ASE convened a November 2011 meeting of experienced reporters, communications experts and risk management authorities to consider the factors that need to be included in developing an effective communications strategy. The two-day meeting was held at the University of Colorado, Laboratory for Atmospheric and Space Physics (LASP) in Boulder, Colorado.

This workshop's report urged the development of "a communications strategy…and an outreach and education plan" as key elements of an effective response to the NEO threat.

The report underscored the fact that establishing an effective international communications strategy for potentially hazardous NEOs and/or an impending NEO strike is, indeed, a daunting task – one that will require effective use of mass communication tools, from television to the Internet, and other information channels and technologies. Furthermore, IAWN must employ "trust agents" that have the skill set to communicate adequately with non-expert audiences. An IAWN risk communication program needs to have structural and content clarity. It cannot be ad hoc.

As noted in the report, general education should include information about NEOs and their place in our solar system, the nature of the potential threat, and specific information related to warnings of a potentially hazardous NEO.

The critical role of the world's space agencies was the topic of discussion at an October 2010 AT-14 workshop held at ESA's European Space Operations Center in Darmstadt, Germany. Sponsored by ESA, NASA, ASE and SWF, that workshop included representatives from several space agencies and began the serious work on defining terms of reference (TOR) for the ASE-recommended Mission Planning Operations Group (MPOG), which has now been superseded by the Space Mission Planning Advisory Group (SMPAG). Two fictional asteroid threat scenarios were used in discussion to gain insights as to how such a group might actually function in the real world when operational.

In August 2011, SWF again teamed up with ASE in support of AT-14, this time to assist agencies that would take part in the MPOG to further define and develop its TOR. Representatives of NASA, ESA, DLR (the German space agency), CNES (the French space agency) and several members of AT-14 attended. The draft TOR were based in large part on the TOR for the Interagency Debris Coordinating Committee (IADC), since there are many potential similarities in the organizational structure of the two groups.

IN CONCLUSION…

The work of AT-14 and the Working Group on NEOs underscores the valuable contributions that civil society can make to the deliberations of international political institutions. Now the task ahead is to achieve full implementation of the report of the NEO Working Group of the STSC. Many years of discussion, deliberation and decision-making have underscored the understanding that planetary defense — to survey, identify, classify and catalog, and potentially thwart a near-Earth object harmful to Earth — is an international and shared responsibility.

The prospect that Earth can be on the receiving-end of a NEO was punctuated, quite literally, by the February 2013 event near Chelyabinsk, Russia. Moreover, that incident, combined with other information, has sparked a realization that the incoming rate of small space rocks may be much higher than previously thought, and their impact greater than previously thought. Therefore the airburst hazard is far more worthy of worry than previously estimated.

It is clear that additional observations are needed to reduce the potential for a surprise asteroid strike by one that we do not see. Along with continued support and augmentation of ground-based observations, there is urgent need for instrumentation situated in outer space capable of surveying for large NEOs that could be highly disastrous to Earth, be it on a city, country, or global scale. Locating such an object years before it hits would allow for its diversion beforehand. This will require greater national and international understanding of the governance and policy implications for responding sensibly, orderly, and in a timely fashion to future discoveries of potentially menacing NEOs to our home planet, Earth.

Reconstructions of the path and damage caused by the asteroid that exploded over Chelyabinsk, Russia on Feb. 15, 2013, provided information about the origin, trajectory and power of the airburst. These details, published in a pair of papers in Nature*, a leading scientific journal, may help to refine theoretical models about the likely frequency of such events and potential damage that could be caused. Credit: Sandia National Laboratories.*

Appendix—Planetary Defense: A Roster of Recommendations

The International Academy of Astronautics (IAA) has held three planetary defense conferences, focusing on NEO discovery, characterization, composition, impact effects and mitigation methods. The latest Planetary Defense Conference, attended by 250 experts, was held April 15-19, 2013 in Flagstaff, Arizona. The meeting was co-sponsored by SWF, NASA, ESA, JAXA, the Romanian Space Agency, the United Kingdom Space Agency, the Russian Federal Space Agency (ROSCOSMOS) and the United Nations Office for Outer Space Affairs (UN OOSA).

Stemming from that meeting were key recommendations, among them:

- ***International Efforts***: Planetary defense is an international responsibility. Current efforts at the United Nations to provide opportunities for space agencies to begin to plan for shared responsibilities and coordinated actions should be supported. Bi-lateral and multi-lateral agreements will also be necessary as part of the overall coordination of resources and capability.
- ***Discovery***: Locating Earth-threatening objects continues to be the most critical aspect of planetary defense. Only a small percentage of the objects have been discovered that could destroy a city or cause severe regional destruction, and such an object could enter our atmosphere today with little or no warning.
- ***Characterization***: Research is increasing our understanding of the types of structures and materials that might be encountered by deflection/disruption missions and the responses to kinetic impact and other deflection/disruption efforts. This work will increase confidence in the success of deflection/disruption missions and potentially limit the number of launches required to achieve the desired result.
- ***Being Prepared***: Atmospheric entries of NEOs of sufficient size to cause serious damage are rare on human time scales. Still, the need for an active deflection/disruption response could arise at any time. The challenge is to develop response plans and to put cost-effective procedures in place to preserve technologies and capabilities necessary for a response. Procedures should be developed that will maintain a catalog of necessary equipment and tools and ensure that these capabilities are tested and verified as part of other missions. Similarly, current procedures for launching spacecraft should be examined to see what can be done to make it possible to reprogram an existing launch vehicle and mount and launch a new payload quickly.
- ***Disaster Mitigation***: Several “tabletop” exercises for limited audiences have been carried out, demonstrating the effectiveness of these exercises in making people aware of the unique aspects of asteroid threats and where work needs to be done. These drills involve disaster response

agencies at the local, state, national and international level and underscore the fact that such training workouts would help agencies be prepared for disasters that might be caused by asteroid impacts.

- ***Skills to Move an Asteroid***: Missions are being proposed that would use kinetic impactors to move an asteroid, and the impact and motion away from the original path would be verified by observer spacecraft. Designing these missions and developing the necessary tools and payloads for these types of actions would verify model predictions and build confidence in our abilities to deal with an actual threat.
- ***Communications***: There is need to solidify the importance of developing and moving forward on an overall coordination and communication plan for planetary defense related topics. Information on the nature of a NEO threat, possible deflection/disruption options, the evolution of a threat scenario, risk and uncertainty, and credible tools for simple deflection mission design should be added to currently available, authoritative web pages.

References and Additional Resources

References

1. "Asteroid Threats: A Call for Global Response," Association of Space Explorers, (2008).

2. Executive Summary of the Workshop on a Near-Earth Object Information, Analysis, and Warning Network (IAWN), 2010; Association of Space Explorers and Secure World Foundation.

3. "Crafting an Effective Communications Plan for an International Response to a Threatening Near Earth Object," presented at 63rd International Astronautical Congress, Naples, Italy, October 1-5, 2012. Ray Williamson, Leonard David and Russell Schweickart.

4. "NEOs: Media/Risk Communications Working Group Report," presents the findings from the working session held in November 2011. Leonard David and Ray Williamson.

5. "NEOs, the Media, and Risk Communications - Workshop report," presented at the 49th Session of the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space, Vienna, Austria, February 13, 2012. Ray Williamson.

6. Near Earth Object Mission Planning and Operations Group (MPOG) Workshop Report. October 2010.

7. "Responding to the Threat of Potentially-Hazardous Near Earth Objects,"

IAC-E.3.1.B4, 23rd Symposium on Space policy, Regulations and Economics, International Astronautical Congress, Prague, October 2010. Ray Williamson, Brian Weeden, Sergio Camacho, Tom Jones, and Rusty Schweickart.

8. Near Earth Object International Analysis and Warning Network (IAWN) Workshop Report, February 15, 2010.
9. "Initial Assessment of Recent NEO Response Strategies for the United Nations," IAC 2009 in Daejeong, South Korea, October 12-16, 2009. Agnieszka Lukaszczyk and AC Charania.
10. "Different Institutional Models For NEO Response," presented at "Near Earth Objects: Risks and Opportunities," University of Nebraska — Lincoln, April 23, 2009. Ben Baseley-Walker.
11. "Legal Aspects of NEO Threat Response and Related Institutional Issues," Executive Summary, and Final Report (2010).
12. "Dealing With the Threat to Earth From Asteroids and Comets," International Academy of Astronautics, (2009).
13. Defending Planet Earth: Near-Earth-Object Surveys and Hazard Mitigation Strategies. Space Studies Board, National Research Council. The National Academies Press, Washington, DC. (2010).
14. Report of the NASA Advisory Council Ad Hoc Task Force on Planetary Defense, (2010).
15. Near-Earth Object Surveys and Hazard Mitigation Strategies: Interim Report, Committee to Review Near-Earth Object Surveys and Hazard Mitigation Strategies, National Research Council (2009).
16. Committee on the Peaceful Uses of Outer Space, Scientific and Technical Subcommittee, Fiftieth session, Vienna, February 11-22, 2013, Item 12 of the provisional agenda: Near-Earth objects, 2012-2013 — Final report of the Action Team on Near-Earth Objects
17. Committee on the Peaceful Uses of Outer Space, Scientific and Technical Subcommittee, Fiftieth session, Vienna, February 11-22, 2013, Item 12 of the provisional agenda: Near-Earth objects, 2011-2012— Recommendations of the Action Team on Near-Earth Objects for an international response to the near-Earth object impact threat
18. "A Communications Plan for an International Response to a Threatening NEO," Leonard David, Ray Williamson, Planetary Defense Conference 2013, Flagstaff, Arizona, USA, IAA-PDC2013-06-01 (2013).

Additional Resources

NASA: Asteroids and Comets

European Space Agency: NEO Coordination Centre
Precursor services

A Call for Global Response
The NEOShield Project

The B612 Foundation

Association of Space Explorers: Near-Earth Objects Committee

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