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An object entered the atmosphere over the Urals early in the morning of February 15, 2013. The fireball exploded above the city of Chelyabinsk, resulting in damage to buildings and injuries to hundreds of people. Photo was taken by Alex Alishevskikh about a minute after he noticed the blast. Credit: Alex Alishevskikh, courtesy ESA.

NEO threats

Near-Earth objects whose orbits take them dangerously close to Earth are no longer dismissed as an exaggerated threat. The bolide that exploded over Russia in February caused widespread damage and injuries, sparking renewed concerns about the problem. Technology for improved detection and even deflection of NEOs already exists, say experts, but an effective planetary defense will require international cooperation as well.

There is mounting global interest in celestial bodies that may be on a collision course with our planet. These near-Earth objects, or NEOs, primarily are asteroids circling the Sun in orbits that come close to our own. So far, there are over 600,000 asteroids identified in our solar system. Nearly 10,000 of them are NEOs.

The historic record is clear—comets and asteroids have been punching our planet since its formation 4.5 billion years ago. While the near-term odds that an intruder will crash into us are slight, they are not zero…and the effects of a strike by a sizable body would be severe.

Homeland security for planet Earth

But there is good news on the planetary defense front, in areas ranging from detection of NEOs to understanding their properties to determining what action plan must be in place to deal with a potential collision.

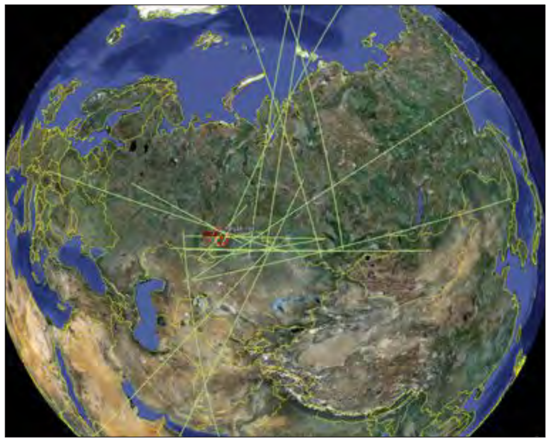
Wake-up call

In large measure, the 'giggle factor' associated with discussions of NEO strikes is on the wane. That was brought home, quite literally, on February 15 near Chelyabinsk in Russia, when a space rock plowed through the atmosphere above the area, exploded, and let loose window-shattering shock waves over an expansive region.

The results: some 1,500 individuals injured, dozens hospitalized with cuts from flying shattered glass and other materials, and over 4,000 buildings damaged. It was the largest extraterrestrial object encountered since June 30, 1908, when a NEO believed to be an asteroid flattened 1,000 square miles of forest in Tunguska, Siberia.

Many experts consider the Chelyabinsk event a cosmic wake-up call. The previously undetected object, weighing an estimated 7,000 tons and measuring roughly 55-65 ft in diameter, struck the atmosphere at about 40,000 mph, exploding nearly 15

by **Leonard David**
Contributing writer



Seventeen infrasound stations in the Comprehensive Nuclear-Test-Ban Treaty Organization's network detected the infrasonic waves from the meteor that brokeup over Russia's Ural Mountains. Credit: CTBTO.

mi. above Chelyabinsk with 20-30 times the energy of the Hiroshima atomic bomb.

As it moved through the Earth's atmosphere at a shallow angle, the fireball—or the 'superbolide,' as it is sometimes called—released a huge amount of energy. The high-altitude breakup produced a shower of fragments that fell to the ground as meteorites.

The far-flung system of detectors that comprise the Comprehensive Nuclear-Test-Ban Treaty (CTBT) network made its largest-ever detection as the body shattered over the Urals. The CTBT Organization, based in Vienna, runs the International Monitoring System, which consists of widely dispersed infrasound stations. When the space rock detonated, the resulting blast was detected by 17 stations in the CTBTO's network, which tracks atomic blasts across Earth. The farthest station to record the blast was some 9,320 mi. away in Antarctica.

According to former Apollo astronaut Russell Schweickart, there *is* need to sweat the small stuff. Schweickart is cofounder and recent chairman of the B612 Foundation, a group dedicated to protecting the Earth from asteroid strikes.

"The main thing we're seeing evolve is a gradual understanding—although it's not there yet—that the dominant challenge is going to be the smaller objects. While they don't do as much damage, the world will not want them to hit. And that's the issue. If you don't want them to hit, then the smaller ones are the ones you're going to be dealing with," Schweickart tells *Aerospace America*.

An image from the spinning enhanced visible and infrared imager aboard Eumetsat's Meteosat-10 geostationary satellite shows a vapor trail left by an asteroid that struck Earth near Chelyabinsk. This image uses data from the high-resolution visible channel of the imager that can provide both high spatial and temporal resolution. Credit: Eumetsat.

Congressional reverberations

The February blast over Russia had far-flung ripple effects, reverberating even in the halls of the U.S. Congress. The event highlights the need to pay greater attention to the NEO threat, according to Rep. Dana Rohrabacher (R-Calif.), vice chairman of the House Science, Space and Technology Committee. He noted that although the U.S. has been spending millions to find and track asteroids and comets, the space rock that exploded over Chelyabinsk was apparently so small that sky-watchers are not even looking for objects that size.

"This is the only preventable natural disaster, and we have mounting evidence that this is a real and tangible danger," said Rohrabacher. "Our heartfelt prayers go out to all those affected by this event, and it shows that we must protect ourselves, and the planet, from this clear danger."

What concerned the lawmaker even more, he said, was that "we have no plan that can protect the Earth from any comet or asteroid. So, even if we find one that will hit us, we might not be able to deflect it."

Rep. Jim Sensenbrenner (R-Wis.) also expressed concern, noting that the damage caused many to wonder how such an event could happen without warning.

"Locating and tracking these objects is clearly just the first step in preparedness," said Sensenbrenner. "The ability to eliminate the threat of an asteroid or meteor impacting Earth, colliding with the Moon, or disrupting our space-oriented communications and scientific equipment could be vital," he added.

Referring to Chelyabinsk, Sensenbrenner said, "We would be remiss if we did not use such headline-making events as an opportunity to survey our current capabilities and assess how we can better use limited resources to identify potential threats."

Characterizing the danger

The NASA Authorization Act of 2005—in a section called the George E. Brown Jr. Near-Earth Object Survey Act—directed the agency to detect, track, catalog, and characterize 90% of all NEOs with a diameter of 140 m or more by 2020. It extends a 1998 congressional directive that tasked NASA with locating at least 90% of all NEOs with a diameter greater than 1 km—those judged by many experts to have the potential to threaten civilization—within 10 years.

The 1-km goal was achieved in 2011, according to John Holdren, assistant to the president for science and technology and director of the White House Office of Science and Technology Policy (OSTP). Testifying before Congress after the Chelyabinsk event, Holdren said statistical calculations indicate that more than 90% of NEOs this size have been found.

The prospect of detecting 90% of NEOs 140 m and larger "is much more challenging," said Holdren. He noted that President Obama's 2010 National Space Policy reinforced NASA's charge to "pursue capabilities, in cooperation with other departments, agencies, and commercial partners, to detect, track, catalog, and characterize" NEOs.

Holdren also said the OSTP has been working closely with several departments and agencies to draft plans and procedures, including potential mitigation strategies, that could be used in the event of a NEO threat. Under these plans, it is NASA's responsibility, he said, to provide initial notice of such a threat. Following that notification, the Federal Emergency Management Agency would communicate the information domestically. The State Dept.'s diplomatic mechanisms would come into play for international communications as needed.

Holdren told Congress that the U.S. program for discovering larger NEOs is effective, but that our capabilities for identifying and characterizing smaller NEOs need improving. "With our current or near-future capabilities, both on the ground and in space, it is unlikely that objects smaller than 100 m in diameter on collision courses with the Earth will be detected with greater than weeks of advance warning—a matter of some concern, since the larger objects in this range could be city-destroyers," he concluded.

Eyes closed

"We citizens of Earth are essentially flying around the solar system with our eyes closed. Asteroids have struck Earth before, and they will again…unless we do something about it," said former NASA astronaut Ed Lu, chairman and CEO of the B612 Foundation. "Currently there is no comprehensive, dynamic map of our inner solar system showing the positions and trajectories of these asteroids that might threaten Earth," he told the Senate Committee on Commerce,

Dealing with NEOs: Key steps

The past several years have brought real and significant advances in understanding and dealing with the threat of NEOs. Reflecting this progress are recommendations cited in a specially prepared International Academy of Astronautics white paper, based on a meeting of nearly 250 experts gathered at the 2013 IAA Planetary Defense Conference in April. Key recommendations include:

•Discovery: Locating Earth-threatening objects continues to be the most critical aspect of planetary defense. Only a small percentage of those that could destroy a city or devastate a region have been discovered, 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 of their responses to kinetic impact and other such efforts. This work will increase confidence in the success of such missions and potentially limit the number of launches needed to achieve the desired result.

•Skills for moving an asteroid: Proposed ideas include missions that would use kinetic impactors to move an asteroid while an observer spacecraft verifies the impact and motion away from the original path. Designing these missions and developing the tools and payloads they require would verify model predictions and build confidence in our ability to deal with an actual threat.

•Disaster mitigation: Several 'tabletop' exercises conducted for limited audiences have proven effective in making people aware of the unique aspects of asteroid threats and of where work is needed. These drills, which involve disaster response agencies at the local, state, national, and international levels, would help agencies prepare for impact events.

•Being prepared: Although atmospheric entries of NEOs—those of sufficient size to cause serious damage—are rare, the need for an active deflection/disruption response could arise at any time. The challenge is to develop response plans and put in place cost-effective procedures to maintain the needed technologies and capabilities. Procedures should be developed for cataloguing the necessary equipment and tools and for ensuring that the required capabilities are tested and verified on other missions. Similarly, procedures for launching spacecraft should be examined to see if ways can be found to reprogram an existing launch vehicle and to mount and launch a new payload quickly.

•International efforts: Planetary defense is an international responsibility. Current efforts at the U.N., which is seeking to provide opportunities for space agencies to plan for shared responsibilities and coordinated actions, should be supported. Bilateral and multilateral agreements will also be necessary for coordination of resources and capability.

•Communications: There is a need to increase and solidify awareness of the requirement for developing and moving forward on an overall coordination and communication plan for planetary defense-related efforts. Information on the nature of the NEO threat, 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.

Special thanks to 2013 IAA Planetary Defense Conference organizing committee cochairs William Ailor of The Aerospace Corporation and Richard Tremayne-Smith.

Japan's Hayabusa-2: Building on success

JAXA is staging an ambitious sojourn to asteroid 1999 JU3 via Hayabusa-2, spurred by the success of its predecessor spacecraft. The flight of Hayabusa-1 to asteroid Itokawa and its return to Earth took place from May 9, 2003, to June 13, 2010.

Hayabusa-2, slated for launch next year, is to arrive at its target asteroid in 2018. It will loiter there and carry out a slew of challenging firsts before leaving in late 2019 and returning to Earth with asteroid specimens around the end of 2020.

Its roughly one-and-a-half-year stay at 1999 JU3 will permit scientists to carry out observation and sample collection duties.

The two probes are comparable in design, but the newer one will haul inventive hardware. While the first spacecraft's antenna was parabolic in shape, Hayabusa-2 will sport two flat high-gain antennae to support faster communication speeds. Also, Hayabusa-2 is to be nudged through space by increased propulsion power from its set of ion engines.

Another key add-on is a 4-lb (2-kg) 'collision device'—a way of producing an artificial crater on the asteroid's surface. That small depression, expected to be just a few meters across, should enable the probe to acquire samples that are newly exposed by the impact and less weathered by the brutal environment of space.

To create the crater, Hayabusa-2 will use a small carry-on impactor (SCI), a 30-cm-diam. disk made of copper. The SCI will be deformed by an explosion to form a semispherical shell and will then be accelerated to a velocity of roughly 2 km/sec for the collision onto the asteroid's surface.

1999 JU3 is a C-type (carbonaceous) asteroid whose 4.5-billion-year-old material is believed to have changed very little. It is a more primordial body than Itokawa, which is an S-type (stony) asteroid. Hayabusa-2 will deploy the Japanese-built MINERVA (micro/nano experimental robot vehicle for asteroid), a small robot lander. The German Aerospace Center's (DLR) Institute of Space Systems in Bremen is contributing the MASCOT (mobile asteroid surface scout), developed by DLR in collaboration with the French space agency, CNES, and JAXA.

MASCOT is a 'hopping' lander that will move about and take measurements at different sites. It will use a camera to image the fine structure of the surface and a radiometer to take its temperature. The lander is designed to work on the asteroid for a total of 16 hr.

Under the current plan, Hayabusa-2 has a 2014 launch window and would reach the asteroid in the middle of 2018. It would return to Earth at the end of 2020 with its asteroid samples safely tucked inside a return capsule.

Science and Transportation in March.

The B612 Foundation is leading the Sentinel project, an effort to build, launch, and operate a solar orbiting infrared space telescope. Commercial practices are being used to manage this deep-space telescope under a milestone-based, fixed-price contract with prime contractor Ball Aerospace and Technologies. Sentinel is philanthropically financed and privately managed, but with a crucial government partnership.

B612's goal is for Sentinel to be launched in July 2018. During its first 6.5 years of operation, the spacecraft will be able to discover and track the orbits of over 90% of the population of NEOs larger than 140 m, and the majority of those bigger than the asteroid that struck Tunguska (roughly 40 m). Sentinel's instrumentation, Lu said, is capable of discovering 100 times more asteroids than have been found by all other telescopes combined.

"Deflecting asteroids is technologically feasible, *if* we have adequate early warning," Lu emphasized. "If we know decades in advance of an impact, we can predict and actually prevent an impact using existing technology—kinetic impactors, gravity tractors, and, if required, even standoff nuclear explosions—to nudge the asteroid and subtly change its course to miss Earth. Conversely, we can do nothing about an asteroid we have not yet found and tracked."

Planetary defense, or public safety, will be Sentinel's primary mission, said Lu. Once it is in operation, it will generate a flood of new NEO discoveries, far in excess of those found by all other observatories combined. After 6.5 years of operation, it will likely discover and track approximately 1 million NEOs; the currently known total is about 10,000.

This catalog not only will "provide a list of potential targets for robotic and human exploration," said Lu, but also "can allow us to successfully mount a deflection campaign and prevent a catastrophe" should any of these NEOs threaten us. "Our future may depend on it," he concluded.

Global response

One group keen on evolving a global response to the NEO impact threat has been the U.N. Scientific and Technical Subcommittee's Action Team on Near-Earth Objects (AT-14), chaired by Sergio Camacho. A former director of the U.N. Office for Outer Space Affairs, he has been an assiduous advocate for international cooperation on this matter.

AT-14's recommendations for an international response to NEOs have been years in the making. They include establishing an International Asteroid Warning Network (IAWN) and a Space Mission Planning Advisory Group (SMPAG).

IAWN would be open to contributions from a wide spectrum of organizations. It would be formed by linking together institutions that are already performing a variety of relevant functions, including discovering, monitoring, and physically characterizing the potentially hazardous NEO population and maintaining an internationally recognized clearinghouse for receiving, acknowledging, and processing all NEO observations. The network would also recommend criteria and thresholds for notification of an emerging impact threat.

SMPAG would comprise U.N. member states that have space agencies and would include representatives of spacefaring nations and other relevant entities. It would be responsible for laying out the framework, timeline, and options for initiating and executing space mission response activities. It would also promote opportunities for international collaboration on research and techniques for NEO deflection.

In the wake of the Chelyabinsk impact, Camacho was quick to note that if the proposed coordination mechanism had been in place, then "at minimum it would have allowed for more observation and better understanding and education of the population on what to expect, rather than having a surprise effect with people not knowing what was happening."

Increased global attention to NEOs was evident as nearly 250 experts from around the world attended the International Academy of Astronautics (IAA) Planetary Defense Conference, held in April in Flagstaff, Arizona.

Participants included Alan Harris, a senior scientist and NEOShield coordinator at the German Aerospace Center's Institute of Planetary Research. The NEOShield consortium consists of several world-leading European research institutes and organizations and leading U.S. and Russian space research groups.

While there are great strides being made in NEO research, Harris emphasized, there is plenty of work ahead.

"We really don't know what the consequences will be of a very severe NEO impact. You can make rough predictions as to what would happen if it occurred over a populated area. But we really don't know," he said. As the world becomes increasingly interconnected, he added, loss of a city due to an asteroid strike would have consequences for the entire world.

"But we do need to have some sort of background level of competence," Harris told *Aerospace America*. Research must continue, he said, adding that we need to "make sure we spend money on space missions that are multipurpose, and one of those purposes should be impact hazard mitigation."

For the U.S., the next steps in dealing with the NEO threat should include better coordination of the relevant government agencies, suggested Lindley Johnson, program executive for NASA's NEO Program Office in Washington, D.C.

"I think more thought is needed at the

USAF Space Command-operated Defense Support Program satellites are a key part of North America's early warning systems. In their 22,300-mi. geosynchronous orbits, DSP satellites can detect missile and space launches, nuclear detonations, and large fireballs entering the Earth's atmosphere. Credit: USAF.

Security duty for OSIRIS-REx

OSIRIS-REx (origins, spectral interpretation, resource identification, security, regolith explorer) is a name reflecting the many missions of this NASA spacecraft. It is to be launched in 2016 on a journey to a worrisome asteroid named 101955 Bennu (formerly 1999 RQ36). OSIRIS-REx would rendezvous with Bennu in 2019-2021, gather specimens of the near-Earth carbonaceous asteroid, and return them to Earth in 2023. The mission is a partnership of the University of Arizona, NASA Goddard, and Lockheed Martin, with collaborators worldwide.

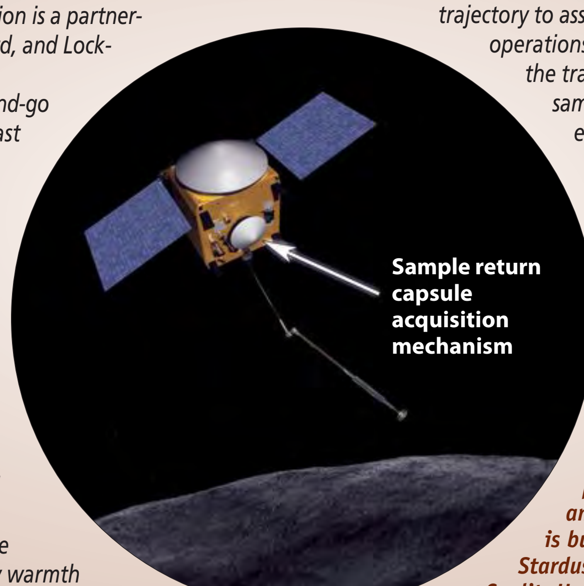
The spacecraft is to use a TAGSAM (touch-and-go sample acquisition mechanism) to collect at least 60 g of material. That would be the largest specimen of an extraterrestrial object brought home since the days of Apollo, the human exploration program that ended over 40 years ago.

The 'security' aspect of OSIRIS-REx involves Bennu's high potential for crashing into Earth in the late 22nd century. Indeed, every six years its orbit takes it to within 278,867 mi. of Earth. Calculations of Bennu's future orbits indicate that for the next few centuries its probability of impacting Earth will be among the highest of any known asteroid.

OSIRIS-REx will measure what is termed the Yarkovsky effect, the degree to which the daily warmth of the Sun affects the asteroid's path. This warm-up generates escaping radiation that acts like a tiny thruster on the space rock. That small nudge, day after day, year after year for hundreds of years, can alter an asteroid's orbit. The shift can result in an Earth impact, a close flyby, or a 'clean miss.'

After the OSIRIS-REx encounter, scientists will recalculate the asteroid's trajectory to assess the actual long-term effect of sampling operations. Depending on TAGSAM's location on Bennu, the trajectory may be altered. That touch-and-go sampling is a 5-sec, light touch, unlike the Yarkovsky effect, which, although minuscule each day, occurs daily over centuries.

Quantifying the Yarkovsky effect on this potentially hazardous asteroid will demonstrate yet another way of helping to protect Earth from future impacts. With time, policymakers may well be required to agree on what steps, if any, should be taken to mitigate asteroid Bennu's risk of colliding with Earth.



NASA's OSIRIS-REx has an amalgam of asteroid duties, including spectral interpretation, resource identification, security, and regolith exploration. Lockheed Martin is building the spacecraft using heritage from Stardust, NASA's comet sample return mission. Credit: University of Arizona/NASA Goddard.

A new resource

NEO research efforts have an important new resource. Data gleaned by sensors aboard U.S. military spacecraft that detect bright bolides entering Earth's atmosphere are now posted on a NASA NEO Program Office website.

A newly crafted memorandum of agreement was signed earlier this year by the Air, Space, and Cyberspace Operations Directorate of the Air Force Space Command and NASA's Science Mission Directorate. The MOA details the public release of bolide data collected by U.S. spaceborne sensors.

Capt. Chris Sukach of Air Force Space Command says that as a result of the agreement, the NEO Observation Program is receiving information on bolide/ fireball events based on analysis of data collected by U.S. government sensors. In fact, data on the Chelyabinsk event was released as the first new entry on the civilian website.

The MOA was signed on January 18 at Peterson AFB, Colorado, says Capt. Sukach. For security reasons, the actual MOA is classified. At a NASA/JPL website, the entry on the February 15 Russian event provides the following information about the fireball:

- *Date and time of maximum brightness: 15 Feb. 2013/03:20:33 GMT*
- *Geographic location of maximum brightness: Lat.: 54.8 deg. N Long.: 61.1 deg. E*
- *Altitude of maximum brightness: 14.5 mi., (23.3 km)*
- *Velocity at peak brightness: 11.6 mi./s (18.6 km/s)*
- *Approximate total radiated energy of fireball: 3.7 x1,014 Joules. This is the equivalent of about 90 kilotons of TNT explosives, but it does not represent the total impact energy, which is several times larger than the observed total radiated energy.*
- *Approximate total impact energy of the fireball in kilotons of TNT explosives (the energy parameter usually quoted for a fireball): 440 kilotons.*

Testifying before the House Science, Space and Technology Committee last March, Gen. William Shelton, head of Air Force Space Command, said the Joint Space Operations Center (JSpOC) of the Joint Functional Component Command for Space can in some cases task space surveillance sensors to help track close approaches by asteroids and help predict potential collisions with Earth-orbiting objects.

Shelton noted, for example, that when NASA's Stardust spacecraft returned to Earth from collecting cometary samples in 2006, JSpOC was able to modify some parameters of existing models and use space surveillance sensors to track the Stardust sample return capsule in its parabolic return to Earth.

government level to put together a more coherent approach," Johnson noted. "We are attempting to talk to each other across the agencies and stay in synch with each other. But there is not yet a coherent, government-wide effort." He said there is no need for spending huge sums of money, "but there does need to be an overall coordinated effort so that everybody is working toward the same objectives."

An artist's rendition of Japan's Hayabusa-2 spacecraft making an artificial crater on an asteroid, later touching down on the resulting feature for sampling. Specimens would be brought back to Earth for detailed study. Credit: JAXA/Akihiro Ikeshita

There were numerous take-aways from the IAA conference. We are better informed about asteroids and comets that could pose a threat. There has been progress in devising techniques and tools that might be used to deflect or disrupt an oncoming object. And there is a far greater understanding of the potential consequences of an impact, the design of deflection campaigns, and the political and policy issues that might affect a decision to take action.

"We've come so far," said the Planetary Defense 2013 cochair, William Ailor of The Aerospace Corporation. "Back in the old days we were speculating and guessing about so many things. Now there is so much good work under way. Even though we still have uncertainties, those uncertainties are being narrowed down."

Nevertheless, there are a number of thorny issues, he noted. One is the need for improved communications, to increase not only the public's understanding of the NEO issue, but also that of decision-makers.

Another challenge "centers on a cost-effective way to maintain capability," Ailor said. "That's a key piece."

Also, while the February blast over Russia was assuredly a wake-up call, its lingering message is likely to fade over time.

"One real trick here," Ailor concluded, "[is that] we may not see another Chelyabinsk for another 100 years. That's the issue with the probability business. It may not happen for another 100 years, but it might happen tomorrow."