CHELYABINSK AIR BURST

A DRAMATIC ILLUSTRATION OF A NEAR-EARTH ASTEROID IMPACT

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A Dramatic Illustration of a Near-Earth Asteroid Impact

— David A. Kring, Lunar and Planetary Institute

News headlines on Friday, February 15, 2013, alerted the world that a small near-Earth asteroid (NEA) penetrated Earth's atmosphere and catastrophically exploded over Russia, producing shock waves and an air blast that injured over a thousand people and damaged buildings in and around the city of Chelyabinsk. Like the impact of Comet Shoemaker-Levy 9 into Jupiter's atmosphere in 1994, the public saw, first hand, the effects of an impacting object.

The explosion startled the public and the scientific community, because the impacting object had gone undetected until it hit Earth. Scientists, however, mobilized immediately, both in Russia and elsewhere in the world. In North America, Bill Cooke of the Meteoroid Environment Office at NASA's Marshall Space Flight Center rapidly coordinated observations with a large number of investigators in the NEA community. Peter Brown and Margaret Campbell-Brown at the University of Western Ontario began to calculate the trajectory of the object and, importantly, the energy of the event from infrasound data captured by the International Monitoring System (IMS) operated by the Comprehensive Nuclear-Test-Ban Treaty Organization. Paul Chodas and his colleagues at NASA's Jet Propulsion Laboratory began to calculate the orbit and to obtain independent measurements of trajectory and energy of the event from U.S. government sensors. Mark Boslough began comparing and contrasting the event with the century-old Tunguska event, and I was tasked to use information gleaned from meteoritic and impact cratering studies to better interpret the blast. These and many other scientists throughout the international NEA and impact cratering communities answered questions from the public and provided input to their respective government officials.

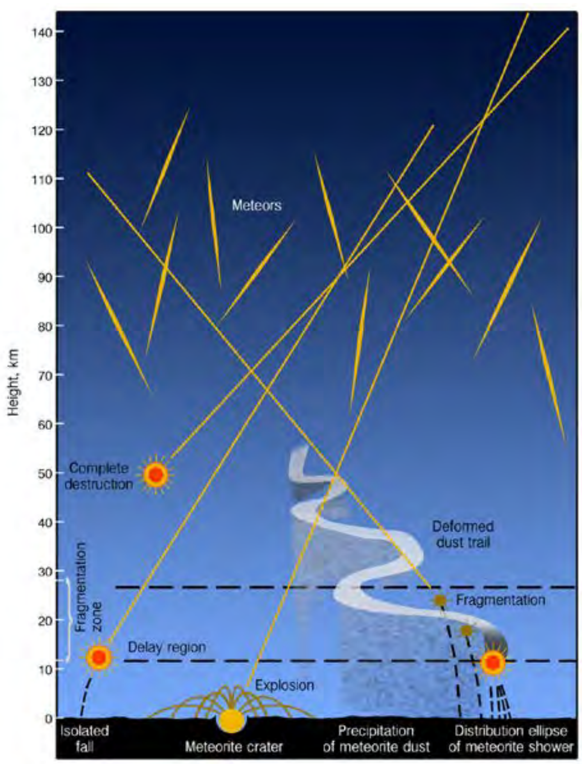

Fig. 1. The possible outcomes of impacting meteoroids, asteroids, and comets that hit the Earth's atmosphere. Modified after E. L. Krinov (1966).

Immediately after the explosion, the Chelyabinsk asteroid was estimated to have been about 17 meters in diameter, with a velocity of 17–18 kilometers per second, producing an ~500-kiloton explosion 15–20 kilometers above the Earth's surface. Final numbers are still being calculated, but the object is currently estimated to have been 20 meters in diameter, with a velocity of 18.6 kilometers per second, producing an ~440-kiloton explosion 23 kilometers above the Earth's surface. At the time the asteroid penetrated the Earth's atmosphere it was moving at supersonic speeds, approximately Mach 63 immediately prior to detonation, producing a ballistic shock wave and a split trailing plume. The dramatic terminal explosion created a second blast shock wave.

The event was roughly an order of magnitude more energetic than the Sikhote-Alin event of 1947 (~10 kilotons) and roughly an order of magnitude less energetic than the Tunguska event of 1908 (2–15 megatons). There is considerable uncertainty in the energy of Tunguska, Meteor Crater, and other relatively small impact events, which has undermined efforts to assess future hazards. For that reason, the Chelyabinsk impact event is incredibly important: It will produce the first high-precision values for the energy of a blast and the corresponding ground damage it caused.

Fortunately, the Earth's atmosphere screens most objects from reaching the surface with cosmic velocities (Fig. 1). Sometimes objects are large enough and strong enough, however, to penetrate deeply into the atmosphere before exploding to produce an air burst (e.g., Tunguska) or a hypervelocity impact crater (e.g., Meteor Crater), both of which can generate dramatic effects on the Earth's surface.

Fig. 2. The Chelyabinsk asteroid was a brecciated LL-chondrite that had been previously damaged by impact processes. Credit: Svend Buhl/Meteor Recon.

The Chelyabinsk air burst suggested the object was a structurally weak stony asteroid, an assessment soon confirmed when surviving fragments were recovered by the Russian public and scientists (Fig. 2). The material appeared to be a type of ordinary chondrite, and was later classified as an LL ordinary chondrite. The surviving stones indicate the asteroid had suffered the effects of collisional events in the past, producing a breccia that is cross-cut with submillimeter- to centimeter-wide impact melt veins and multi-centimeter-wide impact melt pockets.

With a diameter of 20 meters, it surpassed the 6–8-meter-diameter Gold Basin NEA impact event as the largest documented stony asteroid air burst with surviving meteoritic fragments.

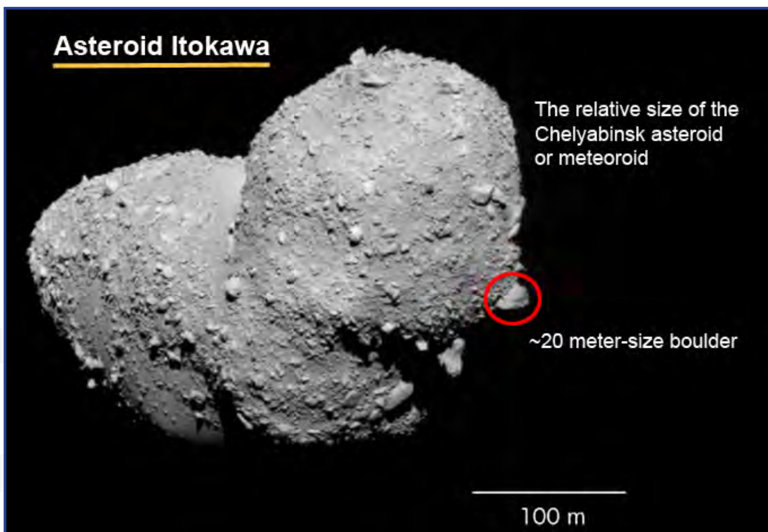

Fig. 3. The Chelyabinsk asteroid is compositionally related to the Itokawa NEA, which also has affinities with LL chondrites. Annotated illustration based on JAXA imagery.

We have about 40,000 ordinary chondrites in our collections, and nearly 6,000 of those have LL-chondrite affinities. In addition, the Japanese space agency, JAXA, returned to Earth samples from the Itokawa asteroid and showed that it, too, has LL-chondrite affinities. The Itokawa asteroid has a length of 540 meters and contains many boulders similar in size to the Chelyabinsk asteroid (Fig. 3). Both of those objects, however, are small compared to the original size of one or more LL-chondrite parent bodies, which are generally estimated to be ≥100 kilometers in diameter (Fig. 4). Numerous studies have shown that body to have had an extensive collisional history over the past 4.5 billion years. It is not yet clear if the impact event(s) that shattered and melted portions of the Chelyabinsk material occurred on that parent body or after being ejected. The parent body is so large (Fig. 4) that it can produce a huge number of Itokawa- and Chelyabinsk-sized NEAs.

The Chelyabinsk impact event occurred a little more than 16 hours before the 20 × 40-meter asteroid 2012 DA_{14} passed within 27,700 kilometers of Earth's surface, generating a lot of public speculation

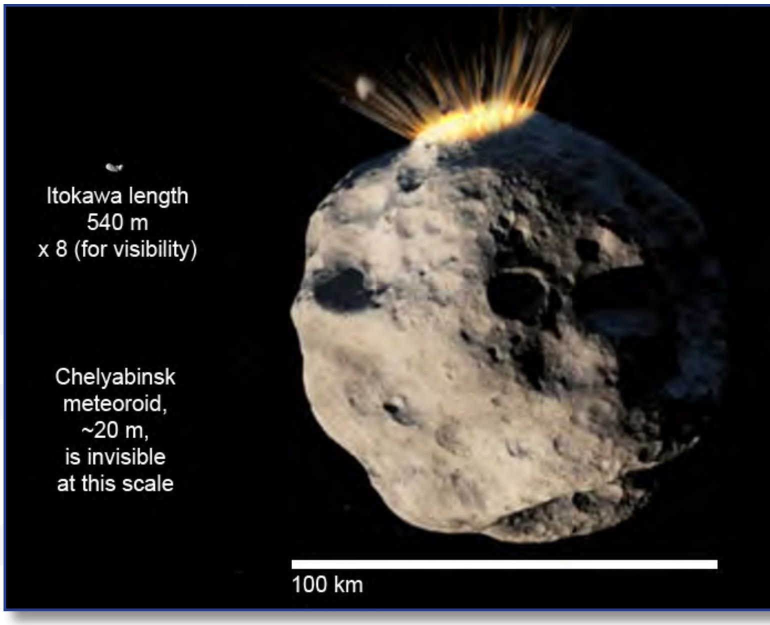

Fig. 4. The material in the Chelyabinsk and Itokawa asteroids are related to the LL-chondrite family, which came from one or more parent bodies that were originally ≥100 kilometers in diameter; i.e., there may be many other objects like Chelyabinsk and Itokawa in near-Earth space. Composite image using a detail from artwork by Daniel D. Durda for the LPI-JSC Center for Lunar Science and Exploration.

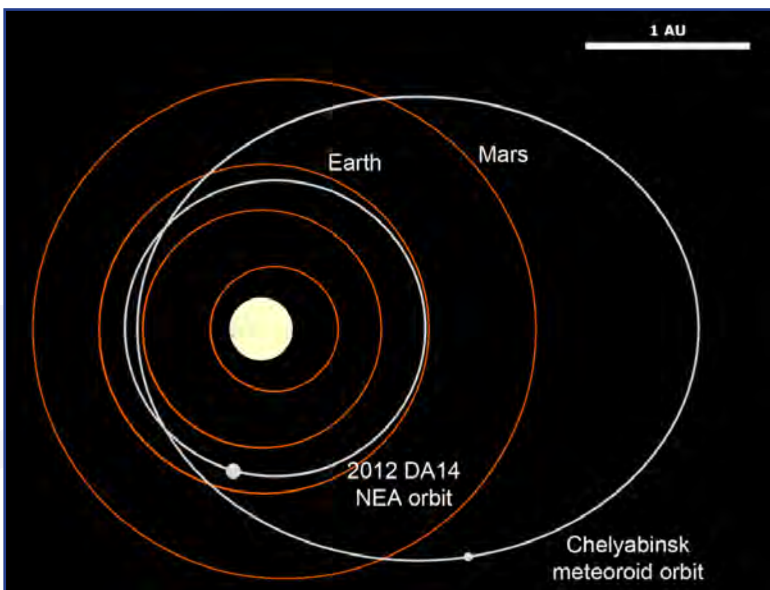

Fig. 5. The relative orbits of the Chelyabinsk and 2012 DA14 asteroids were very different.

that the two events were related. Scientists and space agency officials were able to immediately quench those rumors and any fears that other fragments of 2012 DA_{14} might hit Earth. The orbits of those two NEAs were much different (Fig. 5). The Chelyabinsk asteroid had an apogee in the asteroid belt, whereas 2012 DA_{14} has a near-circular orbit. The latter indicates 2012 DA14 was perturbed from the main DA_{14} belt millions of years before the Chelyabinsk asteroid. Furthermore, spectral analyses of 2012 DA_{14} by Nicholas Moskovitz and Richard Binzel at the Massachusetts Institute of Technology suggest that it is related to carbonaceous chondrites, rather than the ordinary chondritic material of Chelyabinsk.

The Chelyabinsk event was featured in a special session added to the IAA Planetary Defense Conference, which was hosted by David Trilling and others in Flagstaff, Arizona, on April 14–19. David Morrison, Mark Boslough, Clark Chapman, and Alan Harris organized the special session and asked Peter Brown to summarize observations, Paul Chodas to discuss the trajectory and orbit of the impactor, Mark Boslough to show his computer simulation of the air burst, Peter Jenniskens to describe circumstances on the ground in the blast zone, and me to provide a geologic and meteoritic perspective of the event. During the remainder of the meeting, the community explored the hazards of near-Earth objects, existing and proposed detection programs, and mitigation strategies. Moreover, the community was briefed on discussions occurring between NASA and the Federal Emergency Management Agency (FEMA) to prepare the U.S. for a future impact event. On the final day of the conference, the community was asked to participate in a simulation of an impact scenario.

With agency officials observing, an emergency response exercise was conducted for a hypothetical impact of an asteroid. The exercise utilized teams designed to characterize the asteroid; develop mitigation techniques and missions; calculate potential impact consequences; develop an emergency management and education response; and represent nations within the risk corridor, the United Nations and other international organizations, the media, and the space agencies. The teams were told that a 300-meter stony asteroid had been detected with a small but non-negligible probability of impact, and an orbit that generated a circular risk corridor that passed over portions of the Arctic, Europe, North Africa, and around the world until it passed over the eastern coast of China, and then back toward the Arctic. As the simulation proceeded, details of the impacting object were uncovered, all efforts to deflect or destroy the object failed, and preparations for impact became increasingly important. It was a riveting exercise for many scientists in the community, and one that identified several issues that need to be addressed to enhance the world's preparedness for impact events the size of Chelyabinsk and larger.

Cover images:

Top and bottom: YouTube screen capture of still shots taken from a video of the massive fireball streaking through the air in Chelyabinsk, Russia, on Friday, February 15.

Inset top: Map showing the location of Chelyabinsk in central Russia.

Inset bottom: The Chelyabinsk asteroid was a brecciated LL-chondrite that had been previously damaged by impact processes. Credit: Svend Buhl/Meteor Recon.

About the Author:

Dr. David Kring is a senior staff scientist at the Lunar and Planetary Institute in Houston, Texas. His research explores the origin of the solar nebula and its evolution into a geologically active planetary system; the geologic history of the Earth, Moon, Mars, and several smaller planetary bodies; impact cratering on the Earth, its effect on Earth's environment, and its possible role in the biological evolution of our planet; and the chemical and physical properties of meteorites. He has worked extensively with the Chicxulub impact crater and the Cretaceous-Tertiary mass extinction event. That led to an astrobiologically-relevant examination of the environmental and biological consequences of impact cratering throughout Earth history, including an inner solar system bombardment approximately 4 billion years ago. He is currently integrating his field experience in impact-cratered and volcanic terrains with his analytical experience of Apollo, Luna, and meteorite sample collections to assist training and mission simulations needed to advance the nation's human and robotic exploration programs.