Physicists blast model asteroids with a laser

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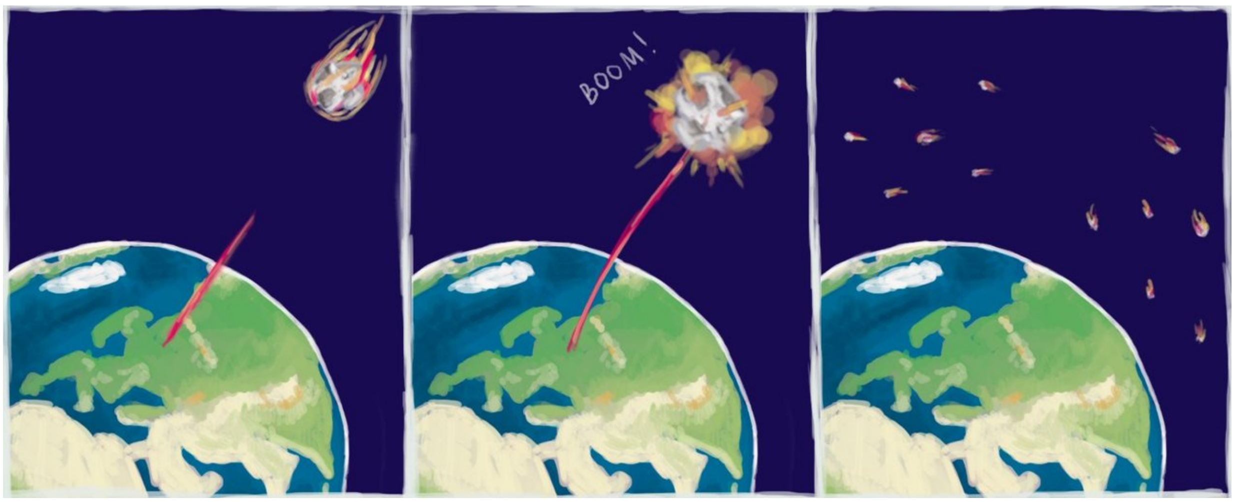

Asteroid destruction. Credit: Elena Khavina, MIPT

A large team of Russian researchers from Rosatom, joined by three MIPT physicists, has modeled the impact of a nuclear explosion on an Earth-threatening asteroid. They manufactured miniature asteroids and blasted them with a laser. The modeling technique developed in this study is a way of experimentally evaluating asteroid destruction criteria such as the explosion energy needed to eliminate a dangerous object on a collision course with Earth. The English translation of the paper reporting the results will appear in the upcoming issue of the *Journal of Experimental and Theoretical Physics*.

Asteroids are celestial bodies consisting of carbon, silicon, metal, and sometimes ice. Scientists usually classify objects larger than 1 meter as asteroids, although this lower limit is disputed. On the other end of the scale, asteroids get as big as 900 kilometers across. Traveling at 20 kilometers per second, such giants pose a threat of obliterating all life on Earth.

There are two basic options when it comes to protecting the planet from a collision with an asteroid: It either has to be deflected or blown into pieces, most of which will miss the Earth entirely or burn up in the atmosphere. The authors of the paper explored the second option by modeling the effects of a powerful shock wave released by a nuclear explosion on the asteroid surface. The research team showed that a brief laser pulse aimed at a miniature replica of an asteroid produces destructive effects similar to those of a nuclear explosion on an actual space rock. The distributions of heat and pressure predicted for the real event generally matched those measured in the scaled-down experiment.

For accuracy, the researchers made sure the small-scale asteroids features, including density, rigidity and shape, mimicked the real thing, and controlled the shockwave pressures. Thus, the researchers had a way of directly calculating the required energy of a nuclear explosion on the actual asteroid from the energy of a laser pulse destroying the miniature replica. To eliminate a 200-meter asteroid, for example, the bomb needs to deliver the energy equivalent of 3 megatons of TNT. The team drew this conclusion by using a 500-joule laser pulse to destroy a model eight to 10 millimeters in diameter. For the sake of comparison, the most powerful explosive ever detonated—Tsar Bomba, or "the king of bombs," built by the Soviet Union in 1961—had an energy output of about 58.6 megatons, though accounts vary.

The research team came up with a technology for manufacturing artificial asteroid material. Its composition corresponds to that of the chondrite (stony) meteorites, which account for about 90 percent of asteroid remains reaching the surface of the Earth. The properties of the model asteroid, including its chemical composition, density, porosity and rigidity, were adjusted during manufacturing. The replicas were made using the data on the chondrite meteorite recovered from the bottom of Lake Chebarkul. It is the largest fragment of the asteroid that entered the Earth's atmosphere in February 2013, exploding over Chelyabinsk Oblast, Russia. The asteroid material was manufactured using a combination of sedimentation, compression, and heating, imitating the natural formation process. Out of cylinder-shaped samples, imitation asteroids of various shapes were made, among them spherical, ellipsoidal, and cubical ones.

To confirm that their laser modeling fits with reality, the researchers also did compressible flow calculations. They showed that a lab asteroid 14 to 15 orders of magnitude less massive than its space prototype requires almost twice as much energy per unit mass to be completely disrupted.

The experiments made use of three laser devices: Iskra-5, Luch, and Saturn. The laser beam was first amplified to a predetermined power and then directed at the asteroid replica fixed in a vacuum chamber. Model destruction was monitored from behind as well as from the side, and fragmentation dynamics were registered. The laser affected model asteroids for 0.5-30 nanoseconds.

To estimate asteroid destruction criteria, the researchers analyzed the data available from the Chelyabinsk meteorite. It entered the Earth's atmosphere as a 20-meter asteroid and fractured into small fragments that caused no catastrophic damage. It therefore makes sense to say that a 200-meter asteroid would be eliminated if it were fractured into pieces of a diameter 10 times smaller and a mass 1,000 times smaller than the Earth-threatening rock itself. For obvious reasons, this conclusion only holds for a 200-meter asteroid entering the atmosphere at a similar angle and for fragments traveling along trajectories similar to that of the

Chelyabinsk meteor.

The researchers were also interested in whether the explosion effect is cumulative—that is, can one powerful explosion be replaced by a succession of smaller ones? They found that multiple weaker laser pulses provide no significant advantage over a single pulse combining their power in terms of the general destruction criterion. This holds for simultaneous as well as consecutive pulses.

In some of the experiments, the laser was targeted at a cavity made in the miniature asteroids ahead of time. By exploiting the cavity, the researchers spent less energy—namely, 500 instead of 650 joules per gram. Similarly, the effect of a buried nuclear bomb is expected to be more pronounced.

Calculations accounting for the scaling effects indicate that it takes a three-megaton bomb to eliminate an Earth-threatening nonmetallic asteroid measuring 200 meters across. The research team now plans to expand the study by experimenting with asteroid replicas of different composition, including those containing iron, nickel, and ice. They also intend to identify more precisely how the shape of the asteroid and the presence of cavities on its surface affect the general destruction criterion.

"By accumulating coefficients and dependencies for asteroids of different types, we enable rapid modeling of the explosion so that the destruction criteria can be calculated promptly. At the moment, there are no asteroid threats, so our team has the time to perfect this technique for use later in preventing a planetary disaster," says study co-author Vladimir Yufa, an associate professor at the departments of Applied Physics and Laser Systems and Structured Materials, MIPT. "We're also looking into the possibility of deflecting an asteroid without destroying it and hope for international engagement."

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