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Cosmic Collisions

by Sally Stephens, Astronomical Society of the Pacific

One planetary astronomer has likened our solar system to a "cosmic shooting gallery,'' with asteroids and comets whizzing through space, occasionally zooming perilously close to Earth. The cratered surfaces of the Moon, Mercury and Mars show the effects of cosmic collisions. What would happen to us if a large asteroid smashed into the Earth?

What killed the dinosaurs?

In 1980, Nobel-Prize winning physicist Luis Alvarez and his geologist son Walter rocked the scientific world with their proposal that dinosaurs became extinct as the result of an impact of a huge rock from space. They found *iridium* in a thin layer of clay that marked the boundary between the Cretaceous and Tertiary geological periods, at the same time as the end of the dinosaurs and the rise of mammals. Because iridium is rare in Earth rocks but abundant in rocks in space (for example, in meteorites), they theorized that the iridium had come from a cosmic impact.

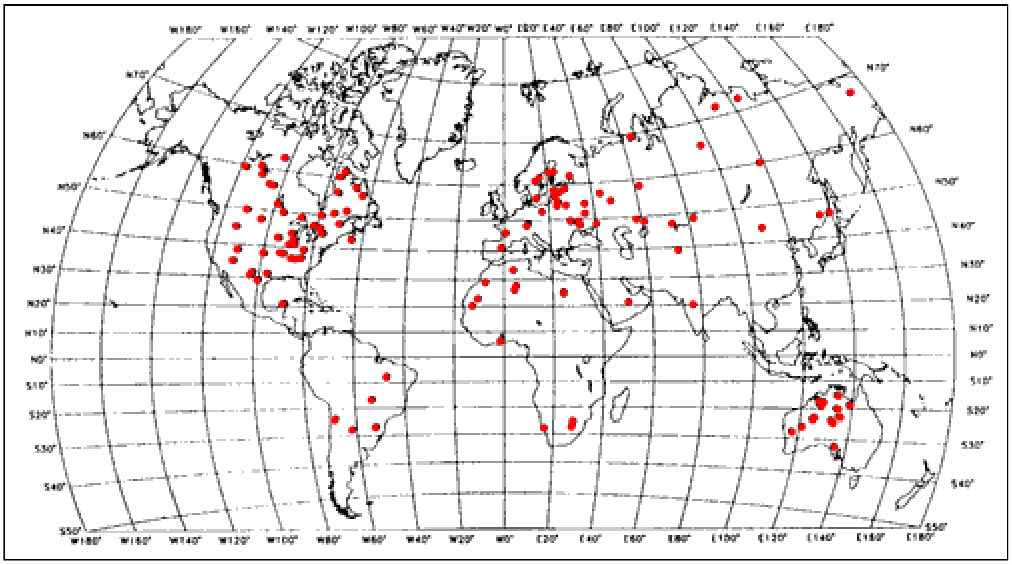
Most scientists now agree that, 65 million years ago, a six-mile-wide asteroid hurtling through space at 15 kilometers/second (9 miles/second), a hundred times faster than a speeding bullet, slammed into the Earth. The resulting explosion, with the force of a hundred million million tons of TNT, threw iridium-enriched dust high into the atmosphere, shutting off sunlight for weeks or months and cooling the planet. Acid rain and wildfires also followed the collision. Plants died, as did many of the animals that ate them.

Where did the impact occur?

Scientists have identified 139 impact craters scattered over the surface of the Earth. The collision that killed the dinosaurs should have left a crater about 150 to 200 kilometers (90 to 120 miles) across, but none of the known craters were both the right age and the right size. Analysis of the thickness of the iridium-enhanced deposits at different places around the world indicated that the asteroid hit somewhere in North America. In 1988, attention shifted to the Caribbean. Coarse rocky debris, thought to be have been deposited by giant waves spreading out from an impact, were found at several sites on the U.S. Gulf Coast, including outcroppings along the Braxos River in Texas. Then an 18-inch layer of debris full of small blobs of glassy rock called *tektites,* which form from melted rock ejected during an impact, was discovered near Beloc, Haiti.

Meteor Crater, in Northern Arizona, is one of the Earth's youngest impact craters. Studies indicate the crater was formed some 50,000 years ago by an iron mass or masses traveling in excess of 11 kilometers/second (7 miles/second) and releasing 10 to 20 megatons of energy on impact. The resulting bowl-shaped crater is approximately one kilometer across and over 200 meters (660 feet) deep. Note the highway and Visitor's Center on the left rim of the crater. (Photo courtesy Meteor Crater)

In 1990, scientists narrowed the search to the Yucatan Peninsula in Mexico. Earlier reports of magnetic and gravitational anomalies detected by scientists working for Pemex, Mexico's national oil company, revealed an impact crater roughly 170 kilometers (106 miles) in diameter buried nearly a kilometer underground and located near the village of Chicxulub (pronounced CHEEK-shoe-lube), a local Mayan name meaning "tail of the devil.'' Recent research has shown that the crater could not have been formed by volcanic action and is truly an impact crater. Other studies have found that rock samples taken during drilling in the area in 1965 have a composition related to the thick bed of *ejecta* (material thrown upward and outward by the impact) "splashed'' onto nearby Haiti. Many scientists now agree that the Chicxulub crater is the site of the impact that eventually wiped out the dinosaurs.



Map of identified impact craters on Earth. Most craters range in size from 140 to 200 kilometers (90 to 120 miles) in diameter and in age from recent to about two billion years old. More craters have been identified in Australia, North America and eastern Europe partly because these areas have been relatively stable for considerable geologic periods, thus preserving the early geologic record, and partly because active search programs have been conducted in these areas. (Art courtesy R.A.F. Grieve, Geological Society of Canada, from the NASA Spaceguard Survey report)

Could such a collision happen again?

The vast majority of asteroids are found somewhere between the orbits of Mars and Jupiter. But there is a sub-class of asteroids, called *Earth-Crossing Asteroids,* whose orbits bring them closer to the Sun than the Earth's orbit. Astronomers estimate that there are, in this sub-class, between 1000 and 4000 asteroids larger than one kilometer (0.6 miles) across (asteroids smaller than that can cause severe local damage where they hit but do not threaten the global ecosystem). Of these, only about 150 have been identified by astronomers.

In recent years, astronomers have undertaken studies aimed at discovering more asteroids. They look in photographs for faint specks of light that move with respect to the background stars. By the late 1980s, they were finding four or more new asteroids each month. They also discovered some cosmic close-calls. On March 23, 1989, an asteroid about a half- mile wide crossed the Earth's orbit about 640,000 kilometers (400,000 miles) from Earth. The Earth had been in that same spot a mere six hours earlier. The closest approach recorded was an asteroid, called 1991BA, about nine meters (30 feet) across, which passed within 170,000 kilometers (106,000 miles) of Earth, less than half the distance to the Moon, on January 17, 1991.

Based on the record of craters on other planets and moons, and an idea of the numbers and orbits of Earth-Crossing Asteroids, scientists estimate that the Earth is hit by an asteroid larger than one kilometer across about once or twice every million years. Such strikes carry the threat of global catastrophe, as the dinosaurs discovered. Smaller rocks, between about 90 meters (300 feet) and one kilometer in diameter, hit the Earth, on average, once every 300 years or so. Their effects are limited to the area where they strike. Because most of the Earth is covered with water, most will land there, with little effect on humans or other life. A 1978 explosion in the South Pacific, once though to be a nuclear test, is now thought to have been a small asteroid hit in the water.

A small asteroid roughly 90 meters (300 feet) across is thought to have exploded about 20 kilometers (12 miles) above the ground in a desolate valley of the Tunguska River in central Siberia on the morning of June 30, 1908. The blast, with a force of 12 million tons of TNT, 800 times more powerful than the atomic bomb dropped on Hiroshima, destroyed a forest the size of Rhode Island and booted a man off a chair at a trading post 112 kilometers (70 miles) away.

Comets, which sweep close to the Sun as part of their orbit, also pose a potential threat. Although they are thought to account for only about 5-10% of the impacts, they approach Earth with greater speeds and higher energies than Earth-crossing asteroids of the same size (the nucleus of a comet, the so-called "dirty snowball'' of ice and dust, is typically about ten kilometers across). But since they are not solid rock, comets will tend to break up into smaller pieces as they smash through the Earth's atmosphere, causing locally severe, but not necessarily globally catastrophic damage. Scientists estimate that one comet passes between the Earth and the Moon each century, and one strikes the Earth about every hundred thousand years. When talking about the these cosmic collisions, it is important to put the risk in perspective. During a human lifetime, the chance that the Earth will be hit by something large enough to destroy crops worldwide is about one in 10,000. Those are the same odds of dying from anesthesia during surgery, of dying in a car crash during any six month interval, or of dying of cancer from breathing car exhaust on Los Angeles freeways every day. While all of these are possible, most people don't alter their everyday life because of them.

Is there anything we can do to prevent another major collision?

Early last year, NASA hosted a conference to address the question of detecting objects that come near the Earth. They concluded that a network of six two- or three-meter telescopes would detect 90% of the asteroids that pose the threat of global catastrophe (those half-a-mile across and larger) and 35% of the comets (discovered at least three months before a potential impact) over the course of a 25-year search. Astronomers expect that such a program, called the *Spaceguard Survey,* would not find any object heading straight for Earth, but might find objects which, sometime within a hundred years or so, could pose a threat. The Spaceguard Survey would cost $50 million for the telescopes, and another $10 million a year to operate, a 4-cent investment for each American in the early warning system. Since asteroid collisions are an international problem, international cooperation in such a survey could reduce the cost to each country. Still, the proposed survey remains controversial, with some claiming it is not needed since there is not likely to be any collision in the next few hundred years and that it is too expensive.

What if we do detect an object headed straight for Earth? Another conference held by NASA dealt with interception of threatening objects. The farther away an object is intercepted, the easier it is to deflect or destroy (a closer one has to be given a bigger push to get it to miss the Earth). So far, the only source of energy powerful enough to deflect an asteroid like the one that struck the Earth 65 million years ago is nuclear. A nuclear blast on an asteroid's surface would blow off some of the its material. The motion of the material away from the surface acts almost like a "kick,'' pushing the asteroid in the direction opposite to the moving material. Comets, on the other hand, could fragment into many dangerous pieces if a bomb exploded on their surfaces. But a nuclear-tipped rocket exploded nearby would melt some of the comet's frozen gases turning them into "jets'' that act like rocket exhaust, nudging the comet away from its deadly path. No doubt, entirely new technologies will exist hundreds or thousands of years in the future when we will need to deflect an incoming cosmic cannonball.

What about the comet that's supposed to hit the Earth in 130 years?

Recent news reports have mentioned a possible collision between the Earth and Comet Swift-Tuttle on August 14, 2126. Comet Swift-Tuttle was first seen in July 1862 (when Abraham Lincoln was President) by two American astronomers (Lewis Swift and Horace Tuttle, hence the name Comet Swift-

Tuttle). Three months later it was too faint to be seen. Based on observations during those months, astronomers calculated that the comet had a highly elongated orbit with a period of about 120 years. Thus it was expected to return to the area near the Sun in the early 1980s.

This photograph of the asteroid Gaspra is the first close-up ever taken of an asteroid in space. It was taken by the Galileo spacecraft on October 29, 1991, when the spacecraft was 16,200 kilometers (10,000 miles) away from the asteroid. The potato-shaped Gaspra is a dozen miles long and seven or eight miles wide. Its shape suggests that it was once the core of a much larger body which was shattered by collisions with other asteroids. (Courtesy NASA/JPL)

Shortly after its discovery appearance, Italian astronomer Giovanni Schiaparelli noticed that the orbit of Comet Swift-Tuttle was remarkably similar to the orbit of the dust particles responsible for the Perseid meteor shower each August. During the peak of meteor showers, upwards of hundreds (and occasionally thousands) of meteors an hour can be seen (as compared to a few per hour visible on a normal night from a dark location). Schiaparelli's connection established comets as the originators of meteor showers — as comets move close to the Sun, solar heat turns their ice to gas, which explodes away from the surface of the comet in "jets'' of gas that pull some of the comet's dust out with them. The dust is left behind in the comet's orbit. When the Earth crosses the orbit, at the same time each year, it plows through the dust, unleashing a meteor shower.

During the 1970s, the number of meteors seen each year in the Perseid meteor shower increased. It seemed that Comet Swift-Tuttle was about to reappear. But it failed to show, and soon afterward, Perseid meteor activity dropped sharply. Astronomers wondered if the comet had somehow come and gone unnoticed. After all, its orbit was based on only three months of observations a century ago, and there was plenty of room for error.

In 1973, astronomer Brian Marsden, of the Harvard-Smithsonian Center for Astrophysics, suggested that the comet seen in 1862 might be the same comet reported in 1737 by a Jesuit missionary, Ignatius Kegler, in Beijing, China. The connection was possible if "jets'' on the comet, caused by ice turning into gas because of the Sun's heat, exploding away from the comet's surface and acting like rocket exhaust, slightly altered its orbit. Marsden predicted that Comet Swift-Tuttle, with a newly calculated period of 130 years, would return at the end of 1992. Increased numbers of Perseid meteors the past few years indicated the comet might be near.

On September 26, 1992, Japanese amateur astronomer Tsuruhiko Kiuchi, using six-inch binoculars, noticed a comet moving through the Big Dipper in an area where scientists had calculated Comet Swift-Tuttle should be, if it was indeed reappearing. Other astronomers confirmed that the lost comet had been found. Marsden's 1973 prediction was confirmed, although the date of the comet's closest approach to the Sun (its *perihelion*) was off by 17 days from his prediction. On November 7, 1992, the comet passed 177 million kilometers (110 million miles) from Earth (its closest approach) on its way to a December 12th perihelion.

Armed with new observations of the comet's motion, Marsden went to work revising his calculations of its orbit. He predicted the next perihelion would occur on August 14, 2126. But if the actual date of perihelion was off by 15 days from his prediction (as the 1992 perihelion had been off by 17 days), the comet and the Earth might be in the same place in space at the same time. Since Comet Swift-Tuttle is thought to be about six-miles across, about the same size of the asteroid that killed the dinosaurs, a possible collision looked ominous.

Marsden continued to refine his calculations, and discovered that he could trace Comet Swift- Tuttle's orbit back almost two thousand years, to match comets observed in 188 AD and possibly even 69 BC. The orbit turned out to be more stable than he had originally thought, with the effects of the comet's jets less pronounced. Marsden concluded that it is highly unlikely the comet will be 15 days off in 2126, and he called off his warning of a possible collision. His new calculations show Comet Swift-Tuttle will pass a comfortable 15 million miles from Earth on its next trip to the inner solar system. However, when Marsden ran his orbital calculations further into the future, he found that, in 3044, Comet Swift-Tuttle may pass within a million miles of Earth, a true cosmic "near miss.''

Marsden's prediction, and later retraction, of a possible collision between the Earth and the comet highlight that fact that we will most likely have century-long warnings of any potential collision, based on calculations of orbits of known and newly discovered asteroids and comets. Plenty of time to decide what to do.

Footnote

While out in space, a particle of dust or small rock that eventually strikes the Earth's atmosphere and burns up as a *meteor* is called a *meteoroid.* A portion of a meteoroid that survives its passage through the atmosphere and hits the ground is called a *meteorite.*

Cosmic Collisions

Activity: Impact Cratering

by Ronald Greeley, Arizona State University (Adapted from the NASA workbook, *Activities in Planetary Geology*)

Materials

- A tray or very strong box at least 2 feet on a side and about 4 inches deep
- A large supply of extremely fine sand
- Four identical marbles or small ball bearings
- Three solid spheres about 1 inch in diameter, all the same size but made of different materials, for example, glass, plastic, steel; or glass, wood, aluminum)
- Meter stick
- 10-centimeter ruler
- Toy Slingshot (Optional)
- Kitchen tea strainer
- Dark color of dry tempra paint (powder); for example, red or blue
- Safety glasses or goggles
- Large pack of assorted marbles
- One steel ball bearing about 1/2'' in diameter

Procedure

Pour sand into the tray to a depth of at least 3 inches. Smooth the surface of the sand with the edge of the meter stick. Divide the surface into two equal areas.

Importance of Mass of the Impacting Object on Craters

From a height of 2 meters (6 feet), drop each of the large spheres (three different types) into one area. Carefully measure the diameter of the craters formed by the impact without disturbing the sand. Students should then be asked to answer the following questions (answers in parentheses):

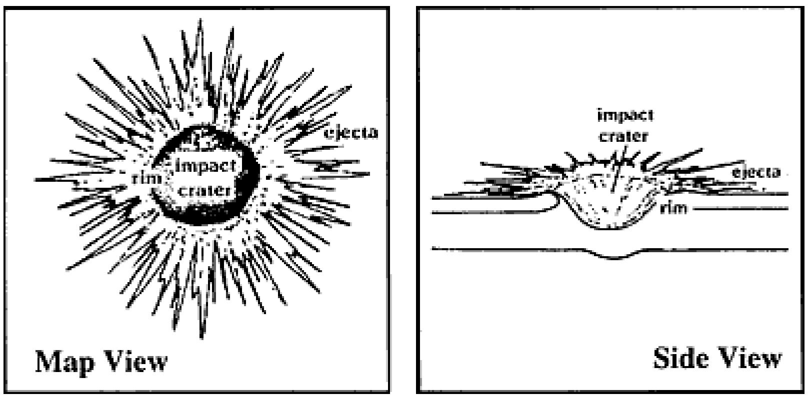
- Which sphere created the largest crater? (*The most massive.*)
- What is the only difference in the way each crater was made? (*The mass was varied.*)
- Each sphere represents a meteorite. What can you say about the importance of the mass of a meteorite in making a crater? (*Crater diameter increases with increasing mass.*)

Importance of Velocity of the Impacting Object on Craters

Drop the four identical marbles into the second area, each from a different height, from 10 cm up to 2 meters. If desired, the third and fourth marbles can be launched from an extended slingshot 23 cm (9 inches) and 36 cm (14 inches) above the sand, and aimed directly down into the sand. CAUTION: THE SLINGSHOT IS A POTENTIALLY HAZARDOUS DEVICE. USE EXTREME CAUTION WHEN IT IS EMPLOYED IN THIS ACTIVITY.

UNDER NO CIRCUMSTANCES SHOULD IT BE AIMED HORIZONTALLY. Without disturbing the sand, carefully measure the crater diameter. Students should then be asked the following questions:

- In this case, each marble (meteorite) had the same mass. What did dropping marbles from different heights (and propelling two marbles, if the slingshot was used) accomplish? (*This varies the velocity at impact.*)
- Did you measure any difference in the diameters of the craters? (*Yes, as velocity increases, so does crater diameter.*)
- Besides diameter, do you notice any other difference in appearance among the craters? (*No, all look qualitatively similar.*)
- Which do you think is more important in creating larger craters, more mass or more velocity? (*Velocity increases have more effect on crater diameter than mass increases. Velocity has a greater contribution to the energy of impact.*)



An ideal example of a fresh crater.

The Structure of a Crater

Remove all marbles and spheres from the sand and smooth the surface well. Again divide the tray into two areas. Sprinkle a very fine layer of dry tempra color over the sand using the tea strainer. The layer of colored powder should cover the surface just enough to conceal the sand. CAUTION: WEAR SAFETY GOGGLES AND BE SURE THAT NO GLASS OR BREAKABLE MATERIALS ARE IN THE VICINITY OF THE ACTIVITY.

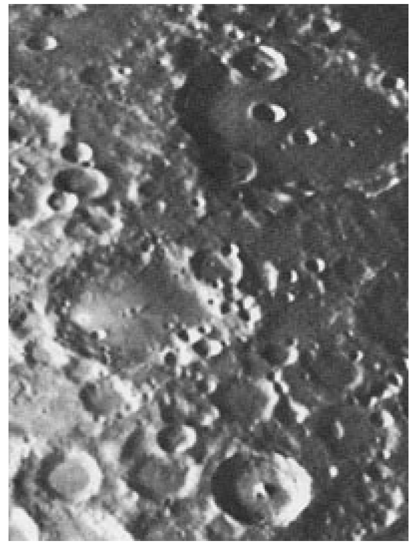
Use the slingshot to shoot the 1/2'' ball bearing vertically into the sand. DO NOT DISTURB THE RESULTING CRATER IN THE FOLLOWING STEPS. Draw two pictures of the crater, one looking down from above (map view), and one as seen from *ground level* (side view). Label the drawings with the words rim, ejecta and impact crater (see sample diagrams). Notice the sharp details of the crater. Ask the students the following questions:

- Where do you find the thickest ejecta? (*On the rim.*) What do you think caused the crater rim to form? (*Sand scooped out by the impact was deposited on the rim.*)
- The colored powder represents the most recent sediment deposited on a planet's surface. Any material beneath the top layer must have been deposited at an earlier time (making it physically older). If you were examining a crater on the Moon, where would you probably find the oldest material? Why do you think so? (*Near the rim. Because the deepest material ejected lands closest to the crater, i.e., on the rim.*)

Cratering on the Moon

In the second area create another crater using the 1/2" ball bearing. Drop each marble from the pack of assorted marbles from an arbitrary height into the second area so that each one impacts at a different speed. Be careful to drop the marbles near but not directly on top of the crater formed by the slingshot method. Watch the process very carefully as you do it. Ask the students the following questions:

- How does the appearance of the original crater change as you continue to bombard the area? (*It loses its crispness.*)
- Look at a photograph of craters on the Moon (see photo or use one taken from a book). Do all the craters have the same fresh, sharp, new appearance? Describe the various appearances? (*No — smooth rims to sharp rims, bowl-shaped to elliptical, etc.*)
- What do you think has happened in this area? (*Long-term bombardment.*)
- What do you think is an important source of erosion on the Moon? (*Impact cratering.*)
- What does the appearance of a crater tell you about its age? (*The younger the crater, the crisper the features; the older, the more subdued.*)



Craters in the Tycho-Clavius region of the Moon.

A note on procedure

This activity was developed for a high school science students. Impact craters can be demonstrated with younger or less advanced students using mud instead of sand and ball bearings. Add water to dirt until the mud has the consistency of thick cake batter, or until it slowly drips off a spoon. Then drop spoonfuls of mud onto a pie pan full of the thick mud to create craters. For more details on this variation, see *Ranger Rick's Naturescope - Astronomy Adventures* by the National Wildlife Federation (1989), or *Astronomy for Every Kid,* by Janice Van Cleave (John Wiley and Sons Publishers, 1991).

For further reading about cosmic collisions

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