

Killer Asteroids

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Introduction and Background written by [both authors]

When the solar system formed 4.6 billion years ago, solid flakes accreted together creating planetesimals which eventually turned into the planets we know today. Unfortunately not all planetesimals had the opportunity to become planets, which is how asteroids and comets were formed. Asteroids and comets are essentially leftovers of the planets (Bennett et al. 2003, Chapters 8 and 12). Every year astronomers collect more and more information about asteroids and comets. The question on everyone's minds these days is whether they are objects that we merely learn from, or are they objects that will kill us? They contain imperative information about the nature of the solar system as well as its history. Recent movies such as "Armageddon" and "Deep Impact" have created mass paranoia of asteroids and comets, with people fearing that they might mean the end of the world.

Asteroids have rocky and metallic compositions. The majority, about 90%, reside in the asteroid belt. The asteroid belt is the 20 million miles of space that orbits between Mars and Jupiter. Jupiter's gravity is said to have kept these floating rocks from ever forming a planet (Morrison et al. 2003). There is a group of asteroids that herds around the sun along Jupiter's orbit called the Trojan family. Two other groups are the Centaurs and the Transneptunians (Cellino et al. 1994). These orbit around where Neptune orbits. Most asteroids are small and rather harmless. In fact, nearly all the asteroids that impact the Earth are as small as tiny dust particles. These are called micro meteorites. However, some are larger and measure up to 1,000 km across.

On the other side of the solar system lie the comets, with icy compositions rather than rocky ones. These all live beyond the frost line and vaporize slowly with every pass of the sun. The nucleus is a small iron core covered in ices and dust. The coma is the cloud of gases which extends around the nucleus. The comet's tail forms when the solar wind pushes the gases away from the coma. This tail is always pointing away from the sun. Comets originate from two areas: the Oort cloud and the Kuiper belt. The volume of the Oort cloud is about 10^{12} times larger than that of the Jupiter family of comets (Davis and Farinella 1997). The Oort cloud lies along the edge of the solar system beyond the orbit of Pluto. It is home to over a trillion comets that have orbital periods longer than 200 years. The home of the short period comets is the Kuiper belt. It stretched from Neptune to Pluto. There are also three types of comets: active, dormant, and extinct.

Active comets have a detectable coma while dormant comets have no detectable coma and are only sometimes active. Comets that are extinct have lost all volatiles.

Impact Hazards: Asteroids versus Comets written by [author 1]

Although comets, meteors, and asteroids are all impact hazards, astronomers concerned with objects that could harm the Earth put the most focus on asteroids. This is due to the fact that asteroids are closer and pose the most immediate risk to the Earth. Anything that is a potential impact is considered a "near Earth object" or NEO. Near earth asteroids are classified as the asteroids that are within 1.3 AU from the Sun. Currently, over 250 NEOs have been detected (Website 8). Near Earth asteroids fall into 3 categories: Amor, Apollo, and Aten. The Amor asteroids cross the orbit of Mars, Apollo asteroids cross the path of Earth with a period of more than one year, and Aten asteroids cross the Earth's orbit with a period less than one year.

It is believed that the majority of near Earth asteroids were once main belt asteroids pushed out by collisions or by Jupiter's gravity. Other near Earth asteroids are thought to be remnants of extinct comets. Comets have the same potential as asteroids for causing a significant global disaster, but they impact 10 times less frequently. Comets have unusual paths that are highly elliptical and unpredictable. They come from the outer regions of the solar system and travel more than twice as fast as asteroids. Comets can reach speeds as fast as 150,000 miles per hour. The comets from the Oort cloud can be pushed into the inner solar system by the Alpha Centauri and other stars close by. The comets from the Kuiper belt have the possibility of being flung into the inner solar system if they come too close to the jovian planets. Neptune's gravity slowly pulls comets into the inner solar system from the Kuiper belt at 40 AU.

Calculation of the approximate kinetic energy of a comet and an asteroid on impact with the planet Earth. Written by [both authors]

1. Asteroid:

Density- 3500 kg/m^3 (approximate)

Mass- $m = DV = (3500 \text{ kg/m}^3) [(4/3)(\pi)(10,000 \text{ m})^3]$

$= 1.47 * 10^{16} \text{ kg}$ (For a 10 km asteroid)

Kinetic Energy- $ke = \frac{1}{2} mv^2$

$$= \frac{1}{2} (1.47 * 10^{16} \text{ kg}) (25,000 \text{ m/s})^2$$

$$= 4.59 * 10^{24} \text{ J (For an asteroid traveling 25 km/s on impact)}$$

2. Comet:

Density- 3500 kg/m^3 (approximate)

Mass- $1.47 * 10^{16} \text{ kg}$ (For a 10 km wide comet)

Velocity- 50 km/s

Kinetic Energy- $ke = \frac{1}{2} mv^2$

$$= \frac{1}{2} (1.47 * 10^{16} \text{ kg}) (50,000 \text{ m/s})^2$$

$$= 1.84 * 10^{25} \text{ J ("Asteroid/Comet- Earth Impacts")}$$

Based on this information, if one compares a comet and an asteroid of the same mass, the comet would cause greater damage. Collision with an asteroid of 10 km in diameter would liberate the same amount of energy as 918,000,000 1-megaton H-bombs. A comet of 10 km in diameter would cause the same amount of energy as 3,680,000,000 1-megaton H-bombs.

Results of an Impact written by [author 2]

The only impact that we have been able to observe to date has been Comet Shoemaker-Levy 9 crashing into Jupiter. To extrapolate to an asteroid impact, scientists are using computer simulations. The following data was generated at Intel. The calculation, consisting of 54 million zones, ran for 48 hours on 1500 processors on the Intel Teraflop computer (about 1/6 of its final configuration). The simulation begins with a 1 km diameter comet. Something this size is right about on the “planet-killing” threshold.

It would weigh about 1 billion tons and travel at 60 km per second relative to the Earth. The most probable angle of impact would be a 45 degree angle, cutting through

the atmosphere in a giant ball of fire. The impacting comet would immediately produce a bright and fiery bow shock in the atmosphere, heating it up and causing it to glow. This would be a large enough firework show to be seen half way around the world. After only a 0.7 second trip, the badly deformed comet explodes to the surface. If this giant were to land in a major ocean, (which is most likely since oceans take up a majority of the Earth's surface area) it would travel many miles into the sea before it was stopped, leaving a gaping hole in the sea. The surrounding water would vaporize instantly and the "tube" would act as a steam vent, exploding high pressure steam thousands of feet high into the stratosphere.

The amount of energy it would take to vaporize this much water is equivalent to 300 gigatons of explosives. At this point, depending on where it hit, everyone on the coast would have about 1-6 days to evacuate the shores before the tidal waves came. The waves would be hundreds of feet high and would submerge every coastal city in the world. That much water would be stopped by the Sierra Nevada mountains in the west, but would reach well into middle America from the south and the east. While everyone is running for their lives inland, they will have to be dodging fireballs falling from the sky. The computer calculated that if the asteroid were 2 kilometers across or less and fell into the sea, none of the debris would rebound with a speed greater than the escape velocity of the Earth. This means that for the next couple weeks, chunks of comet and rock would fall from the sky on ballistic paths that take them outside the atmosphere of the Earth. These chunks will heat up on their way back into the atmosphere and rain fire all over the planet.

Meanwhile, the water vapor, rock, and dirt that were tossed into the stratosphere would circulate fast, with all the disruption the atmosphere had, and cover the planet with a cloak of ash and soot. Temperature would fall, global photosynthesis would be disrupted, and any surviving plants would die. This could last for many years, and will be the main cause of global extinction. If the asteroid hit land, a similar scenario would happen. Of course there would be no tidal wave, but the cloak of dust generated by the impact would be larger, and much thicker. Global extinction would follow again due to the lack of sunlight.

This devastating scenario happens once every 300,000-1,000,000 years. How badly can the Earth's biosphere be affected by something like this? Data collected using simulations like this one (specifically, estimating of the amount of water and other

materials injected into the stratosphere) will be used to estimate the impact on the Earth's biosphere, but no one can really say if an asteroid would kill most life, or all life. Some day simulations such as this will be able to determine the risk that present day species face from these space killers.

Mass Extinctions on Earth in the Past written by [author 2]

Earth has experienced dozens of mass extinctions by asteroids and meteorites that have caused great destruction and possibly the extinction of dinosaurs. The biggest asteroid to hit this century was the stony asteroid, about 200 feet in diameter, which hit earth on June 30, 1908. This object flew across the sky near the Stony Tunguska River, and exploded midair at an altitude of five miles, flattening more than six hundred square miles of forest. This explosion released about fifteen megatons of energy. Had this asteroid struck near a city, it would have been catastrophic beyond belief. This impact would blast a heat wave at a temperature of 500° with a wind speed of 2500 km/hr. It would kill any type of life form over half the world, igniting widespread forest fires. Nitric oxides would be produced from the fire, causing destruction of the ozone layer, exposing any surviving life forms to life-threatening ultraviolet light.

Sixty five million years ago, a giant 10 km asteroid collided with the earth near the Yucatan Peninsula. There has been evidence showing that this 180 km impact started wildfires in forests all around the world, caused by a heat wave. Huge quantities of dust settled in the stratosphere, which blocked out sunlight, cooling the surface and affecting all organisms on earth. Without sunlight, plants died and the effects followed through the food chain. This was known as the Chicxulub impact. This was the catastrophe which was thought to have led to the extinction of dinosaurs along with 99% of all other living species.

Projects to Detect Near Earth Asteroids written by [author 1]

There are two projects that have been organized to study near-earth objects (NEOs). One of them is the Spaceguard Foundation that was founded in 1996 in Rome. The other is NASA's Near Earth Asteroid Tracking, or NEAT, which is the second NASA project to look for NEOs. Its predecessor was the Palomar Planet-Crossing Asteroid Survey.

Until 2000 scientists thought that there were 1000-2000 NEAs larger than one kilometer in diameter. Now thanks to new technology the estimate has been cut in half to 500-1000. This new estimate was made possible by the computerized technology of the

NEAT camera (Morrison et al. 2003 and Website 8). This will make it a lot easier for NASA to reach their goal of finding 90% of all large NEAs by 2010. By 2000 322 large asteroids had been identified which is a "large chunk" of what they think is out there. This is the most recent information on the website that talks about asteroid population.

In the past, photographic plates were taken of the nighttime sky and people would have to look over them to try and find the asteroids. One of the problems is that people looking over the plates couldn't be exactly sure how many asteroids they were missing, either because the people were getting tired or because the asteroids were too faint for them to see.

Machines don't get tired, and using computerized technology, asteroids can be found easier and counted more accurately. NEAT has two "autonomous observing systems" at Maui Space Surveillance Site, NEAT/MSSS, and at Palomar Observatory, NEAT/Palomar. At both sites the NEAT cameras use 1.2-m (48") telescopes to find Near-Earth objects (NEOs), both Near-Earth asteroids (NEAs) and comets.

Communicating with the Public written by [author 1]

Communication between scientists and the public is important. The public doesn't necessarily understand the threat that different size NEOs present. To communicate to the public the threat of a given asteroid the scientific community has come up with the Torino Scale, known as the Richter Scale of NEOs (Website 9). That comparison isn't the best though. The Torino Scale is used to classify the impact hazard associated with asteroids and comets. The scale uses numbers ranging from 0-10. A 0 means that there is no possibility of the object hitting the earth. And as the number rises

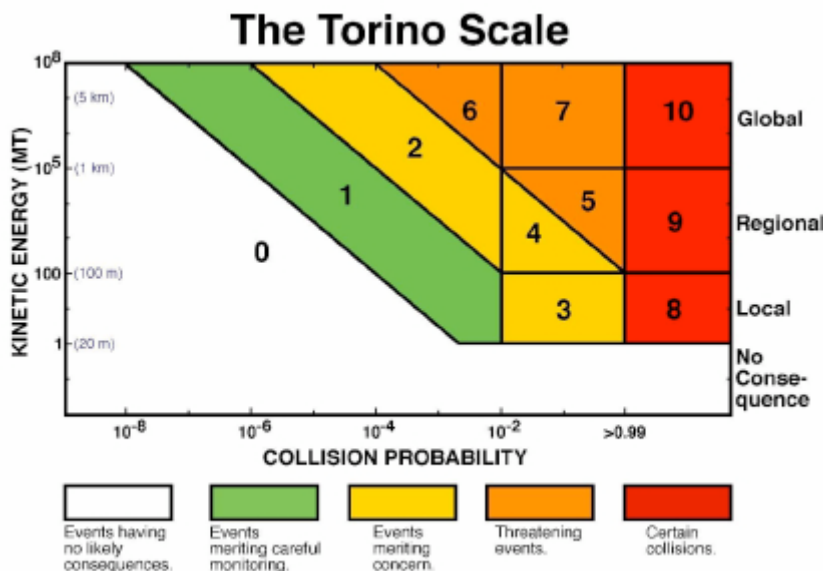


Figure 1. The Torino Scale of Asteroid Impact Severity. From Website 9.

so does the threat to the Earth. A 10 indicates that a collision is certain, and the impacting object is so large that it is capable of precipitating a global climatic disaster. There are five different shades on the scale. They are White, Green, Yellow, Orange, and Red. White events will probably have no impact on humans at all. Green means that the event needs to be monitored. Yellow events “merit concern.” Orange is a “threatening event” and Red means that there is going to be a “certain collision.”

How to Defend the Earth written by [author 2]

The defense of Earth is what these projects are all about in the end. There have been many possible scenarios thrown out there to deal with an oncoming asteroid. In most Hollywood movies the solution is to blow the thing out of the sky or use some kind of explosive device. One of the most studied ideas has been the use of nuclear weapons. But since there is a lack of knowledge about the composition and structure of asteroids many people doubt that it would actually work. And if it does cause damage to the asteroid then there is always the possibility that it will break up and cause even more damage in a greater area than the original threat. Another possibility is that if the object is identified early enough in advance then it might possibly be deflected. It is thought that anything less than a ten year notice would be too short to deflect the object. A possible scenario for deflection is sending a rocket that could be exploded close to the asteroid changing its orbit. A couple of ideas that have recently been proposed but need more time to be researched are the use of laser beams, microwave devices and solar panels.

Summary written by [both authors]

The chances of being hit by a NEO are very small, but the threat is out there. In the future there may be a time when all the world has to come together to face this threat. There are some plans in the works to fight against this threat. Within the next century there is a good chance that an asteroid could impact the earth and cause a great amount of damage. What NASA is doing now is a good start but it is not enough. Maybe there should be an international body like NEAT that has a greater amount of telescopes and man power. There is also the possibility that human kind will be able to exploit the asteroids in the future for their benefit. Further study needs to be done and only then will we know what we can get out of it and how much of a threat they actually are.

References: Books and Articles

- Allen, C. and Summers, C., Cosmic Pinball, McGraw-Hill, 2000
- Barnes-Svarney, P., Asteroid – Earth destroyer or new frontier?, Plenum Press, 1996
- Bennett, J., Donahue, M., Schneider, N., and Voit, M., The Cosmic Perspective, Pearson Addison Wesley, 2003
- Cellino, A., Di Martino, A., and Milani, A., Asteroids, Comets, Meteors 1993. Kluwer Academic Publishers, 1994.
- Davis D. R. and Farinella, P., “ Collisional Evolution of Edgeworth-Kuiper Belt Objects,” in Icarus, volume 125, page 50, 1997.
- Kowal, C. T., Asteroids: Their nature and utilization, John Wiley & Sons, 1996
- Morrison, D. et al., “Dealing with the Impact Hazard,” in Asteroids III (ed. William Bottke, Alberto Cellino, Paolo Paolicchi, and Richard P. Binzel), University of Arizona Press, 2003
- Peebles, C., Asteroids, A History, Smithsonian Institution, 2000

References: Websites

1. “Where are the asteroids?”
http://www.nasm.si.edu/ceps/etp/asteroids/AST_where.html
2. “Anatomy of a comet.” http://www.nasm.si.edu/ceps/etp/comets/comet_anatomy.html
3. “Asteroid/ Comet Earth Impacts.”
<http://aci.mta.ca/TheUmbrella/Physics/P3401/Investigations/AsteroidDAR.html>
4. <http://www.sandia.gov/media/comethit.htm>
5. <http://www.madsci.org/posts/archives/mar99/920494385.As.r.html>
6. www.parkes.atnf.csiro.au/people/jsarkiss/eternal_life/asteroid/asteroid.html
7. <http://www.jpl.nasa.gov.com>
8. <http://www.spaceguarduk.com/>
9. http://neo.jpl.nasa.gov/torino_scale.html