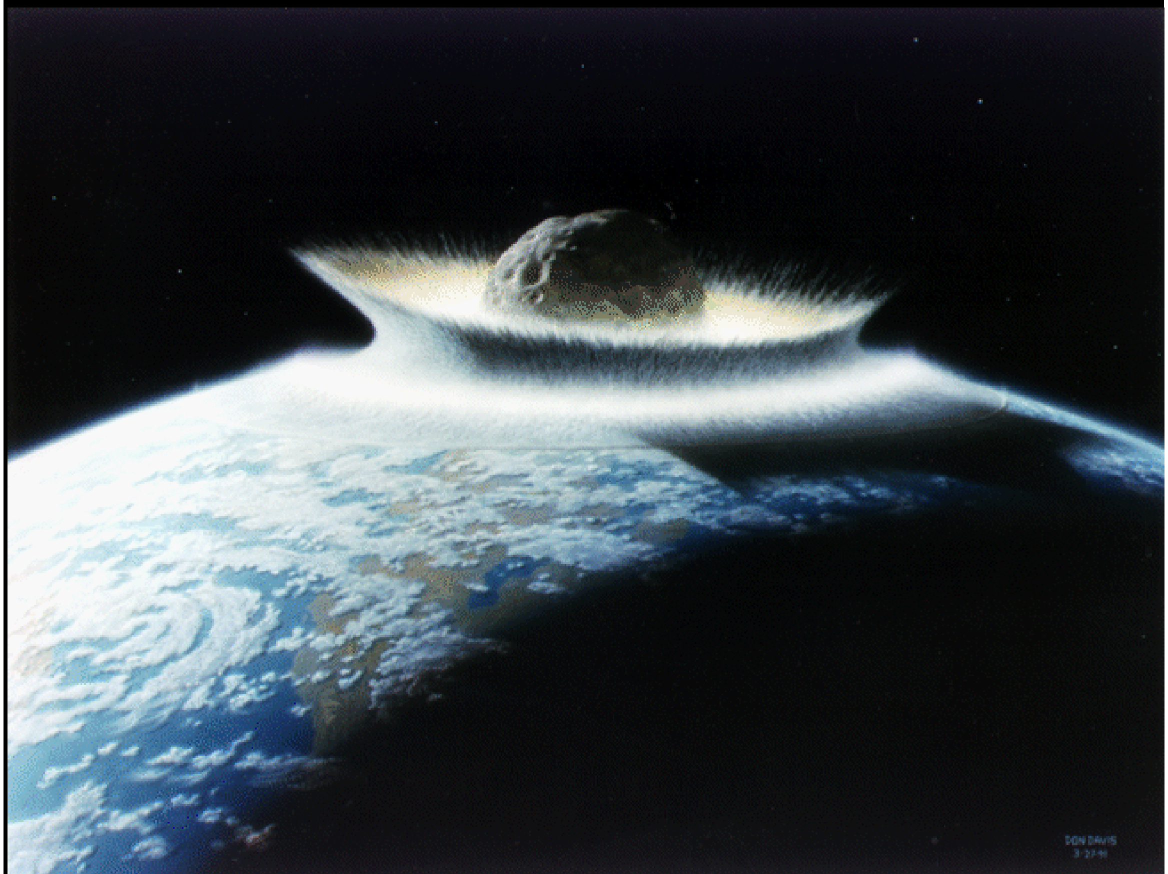
Asteroid Avoidance



How to Avert a Cataclysmic Impact

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GEOS105

"An asteroid has never met a planet it wasn't attracted to." - J. Z. Ponder[1]

Introduction

An old man was sitting on his porch in turn-of-the-century Siberia, when a bright flash illuminated the sky. Before he had time to wonder what that was he was knocked off his porch by a huge shockwave that rolled over his small village, leaving a rumbling boom ringing through the air. It was June 30, 1908 and the Tungusta Event, as it has come to be called, was the result of a comet fragment exploding over remote Siberia. If time had been advanced by less than five hours, St. Petersburg would have been destroyed by what was probably a twenty to thirty megaton blast. As it was, the blast scorched 2,000 square kilometers (700 sq. mi.) of Siberian forest, and the shockwave was detected circling the Earth twice (*Meteor Defense*). Sixty-five million years ago the dinosaurs were wiped out by a massive collision

Figure 1 Barringer Meteor Crater - *35°02'N, 111°01'W; diameter: 1.186 kilometers (.737 miles); age: 49,000 years* - Likely the result of an impact by an object smaller than the Tungusta Event object (*Bang Homepage*)

[1]On The Cover: An artist's rendition of a significant impact, from the *Asteroid and Comet Impact Hazard Homepage*. This scale of impact would undoubtedly destroy all life on Earth, and may alter the configuration of the planet.
Quote from *They're Out There... Asteroids & Comets: The Sky is Falling*

with a ten to twenty kilometer (6 - 12 mi.) diameter object. On October 9, 1992, a huge fireball was seen streaking across the sky from Montana all the way to New York. A twelve kilogram (27 lb.) chrondrite meteorite crashed through the trunk of an automobile and came to rest underneath it in Peekskill, New York (*Bang Homepage*). So how common are such collisions, and what can be done to avert them?

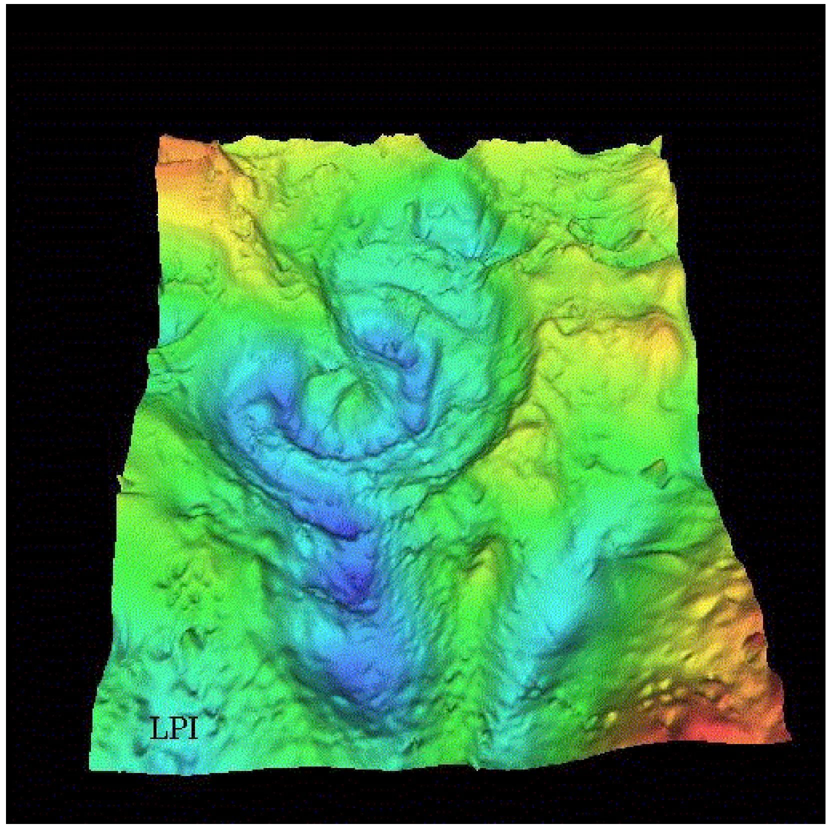

Figure 2 Chicxulub, Yucatan Peninsula, Mexico - *21°20'N, 89°30'W; diameter: 300 km; age: 64.98 million years* - This is a map of local gravity and magnetic field variations and shows a multiringed structure named after a village located near its center. The impact basin is buried by several hundred meters of sediment, hiding it from view. NASA scientists believe that an asteroid 10 to 20 kilometers (6 to 12 mi.) in diameter produced this impact basin. The asteroid hit a geologically unique, sulfur-rich region of the Yucatan Peninsula and kicked up billions of tons of sulfur and other materials into the atmosphere. Half of the species on Earth became extinct including the dinosaurs. (*Bang Homepage*) Evidence has been found of a huge tsunami washed over much of central Texas as a result of this impact and deposited sediments and shark teeth (Oceanography).

Probability of Impact

Objects must be larger than ten meters (33 ft) to survive entry into the atmosphere and impact on the surface. But there are many objects smaller than this that are swept up by the planet every day. Most "shooting stars," while spectacular, are no larger than a grain of sand. This process adds 1,000 tons to the mass of the planet every day *(The Sky is Falling).* These grains of sand, usually the diffuse remnants of comet tails, pose no threat to anyone. The Tungusta Event, however, was created by a comet fragment perhaps 100 meters (330 ft) across. The Barringer Meteor Crater was formed by a sixty meter (197 ft) nickel-iron meteorite that dissipated 6 - 7.4 x 10^{16} joules into the Arizona landscape. These types of impacts occurs once or twice every 1,000 years (*Bang Homepage*). A 350 meter object hits every 1,900 years, and could produce a 5,000 megaton explosion. It is thought that the planet is overdue for such an impact (*Meteor Defense*). A 1,500 meter (5,000 ft) object hits every million years or so, and an object greater than eight kilometers (5 mi.) in diameter impacts once every 50 - 100 million years, the last one being 65 million years ago. Theory postulates that an object greater than one kilometer (0.6 mi.) would produce a nuclear winter scenario, and anything larger than eight kilometers (5 mi.) would cause mass extinction.

Objects the size of the Tungusta or Barringer Crater events would likely destroy a city, but would not threaten civilization as a whole (*Bang Homepage*). It is thought that the comet fragment which exploded in the Tungusta Event was a fragment from comet Encke. On June 25, 1178, a monk, Gervase of Canterbury, witnessed another fragment of Encke impact the moon, producing a twenty kilometer (12 mi.) crater called Giodano Bruno. It is expected that more fragments of Encke will swing by Earth again in 2042 (*Meteor Defense)*. There has been no recent record of a human death caused by a meteorite, but ancient Chinese records indicate such events did occur (*Bang Homepage*).

The probability of impact does not decrease with time. There is evidence that the supply of inner-solar system asteroids and comets is resupplied. Several processes could be responsible for this, one of which is the massive gravity of Jupiter. It is felt that Jupiter is responsible for the Kirkwood Gaps in the asteroid belt. Theses are regions where orbital periods that are integer multiples of Jupiter’s period have become depleted of asteroid (*ABCs of NEOs*). Unfortunately, probabilities tell only about the frequency of impacts, not exactly when they occur, which is why sharp eyes need to be trained on the sky, and methods of defense need to be devised (*Meteor Defense*).

Detection

It is important to make a distinction between comets and asteroids, because an impact of a 100 meter (330 ft) comet will produce a very different result than the impact of an asteroid of the same size. This is because asteroids and comets differ greatly in composition. Comets are often compared with "dirty snowballs," being mostly water ice and other volatiles, with traces of rocky material. Asteroids, however are tend to be solid rock, or nickel-iron combinations. They are low in volatiles, relatively high in carbon when compared with comets. Nickel-iron objects tend to survive the best through the atmosphere, while objects high in volatiles tend to burn up quicker and explode as the heat of atmospheric entry begins to melt them. When searching the skies for comets and asteroids, a comet will appear as a fuzzy spot, due to outgassing, while an asteroid will be sharp.

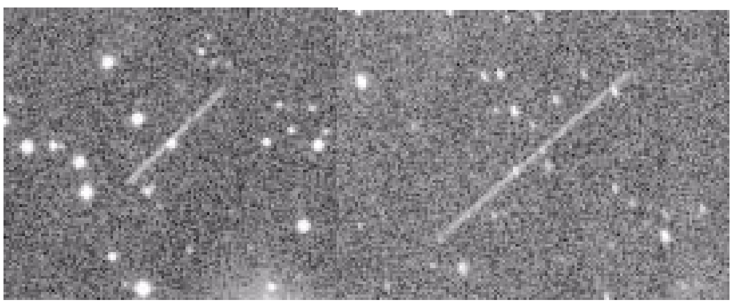

Figure 3 Two Steward Observatory images of *1994 XM1*, the asteroid that holds the record for the closest near miss ever. Note longer streak in the second image as the asteroid gets closer (*Spacewatch*).

There are two basic methods used to search for asteroids and comets. One is to use photographic plates, the other is to use Charged Coupled Devices (CCDs). There is little difference between the two methods, except that recent developments in CCD technology have resulted in higher resolution than with photographic plates. Each methods uses comparisons of successive exposures to identify asteroids and comets. A comet or asteroid will be seen to move by a larger amount than the background stars when the two exposures are compared[2].

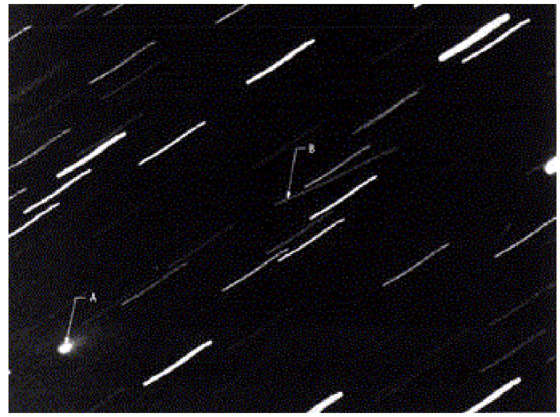

Figure 4 This image shows a fuzzy comet (labeled A) in the lower left, and an asteroid (labeled B) in the middle (*ABCs of NEOs*).

There have been many sky surveys throughout the decades identifying numerous Near Earth Objects (NEOs) that cross Earth orbit. The most current program is the Spacewatch telescope, operated out of Kitt Peak in Arizona. The Spacewatch program found *1994 XM1*, the object that holds the record for the closest near-miss in history, just 105,000 kilometers (63,000 mi.) at closest approach. That translates to an orbital difference of *only six hours (Spacewatch).* There are currently 200 known NEOs, with an estimated population of 10,000 (*ABCs of NEOs*).

Defense

Any attempt to protect the planet can be categorized in one of two ways: asteroid, or long period comet. An asteroid (or a short period comet) has a fairly high probability of being detected long before impact, usually on the order of decades, based on the nature of the orbit. A [long period] comet does not share that benefit. The highly elliptical orbit of such bodies gives a warning time on the order of mere months. Thus a

[2]This information is from lecture notes of GEOS105, *The Planets*, and can also be found in the text for the course, Exploring the Planets.

program to defend the planet from an impact has a higher probability of success if the offending object is an asteroid, because a long lead time allows more time for development and delivery of technology.

Strategies for attacking a threatening comet or asteroid vary with the target. An object can be either diverted from its collision course, or fragmented. If an object is to be pulverized, the largest surviving fragment must be no larger than thirty meters, the accepted size for vaporization upon entry into the atmosphere. A rendezvous mission with a slow astral object may be successful in diverting or fragmenting it, but fast moving objects will require pinpoint accuracy and a high velocity delivery system. It is estimated that an object larger than 100 meters across may require a nuclear device to either divert or fragment it. Chemical explosives may prove too expensive to make feasible anyway (Gurley, et al).

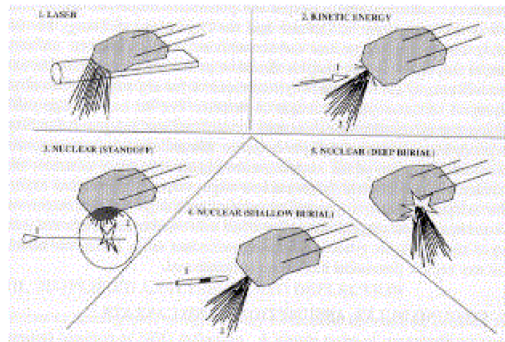

Figure 5 A summery of the various methods availible for deflecting an asteroid. CW for left, laser, ramming, buried nuclear charge, surface nuclear charge, & proximity nuclear charge (H.J. Melosh, et. al.).

Asteroids tend to be fairly dense in composition, which presents the large possibility of a fragment being large enough to survive the atmosphere and cause damage. Diverting an asteroid is the strategy with the best chance of success. Several plans are currently under consideration. One is to detonate a nuclear warhead near the asteroid. The resulting shockwave will shove the asteroid. In addition, the first twenty meters of the surface of the asteroid will be vaporized and will vent away from the asteroid. This will give the asteroid an extra push. If everything goes well, the asteroid will miss Earth by a comfortable margin (T. J. Ahrens & A. W. Harris). Another plan is to launch a high power laser to the region of the asteroid and illuminate a portion of its surface. This will produce a jet of material venting off the surface that may impart enough thrust to shove the asteroid out of the way of the Earth. A similar plan is to launch a solar collector and aim it at the surface of the asteroid. A jet would form on the surface in a similar manner. The laser has the advantage of having a smaller beam divergence, thus it can be further away from the asteroid, possibly giving more time to act upon it. Both of these plans will require more time to act than an explosive, but they have perhaps a smaller likelihood of a misfire (H. J. Melosh, et. al.). There are other plans that involve mass drivers and the like, but they require far too much time for setup and to act to be of serious contention.

Comets differ from asteroids in composition, being mostly dirty snowballs. It is thought that they tend to be structurally unsound, thus an attempt to divert a comet may result only in fragments. In addition, the coma and tail may obscure sensors, making proper positioning of a diversionary device nearly impossible. A several megaton nuclear warhead will need to penetrate beneath the surface of the comet to properly fragment it. The device may be able to achieve penetration by sheer impact velocity, but there is a chance that a dual charge round (used against tank armor) may need to be employed. Once again, the coma and tail will cause problems in placement of the device. In addition, the size, shape and mass of the comet may be unknown or uncertain. This will also cause problems in warhead placement and in warhead size. These problems, coupled with a short warning time make the probability of success in protecting the Earth from a comet impact low (Gurley, et al).

The current defensive status of the planet leaves much to be desired. Technology exists that, with a minimal amount of development, can either fragment or deflect an object. Equipment to target and navigate a device also exists and needs only minor development. The problem lies in the delivery to the object. Currently, only chemical propulsion methods are available to launch a device from the surface and deliver it to an astral object. There are plenty of choices of chemical launch vehicles available.

The dangerous exhaust from nuclear propulsion systems preclude their use as launch systems. The large fuel mass of chemical systems make them an unfavorable choice of delivery from Earth orbit to the offending body. A variety of nuclear propulsion systems are currently under development in both the United States and the Commonwealth of Independent States (Gurley, et. al.).

Figure 6 Ida and its moon Dactyl. Ida is 56 km by 24 km, roughly the size of Long Island, Dactyl is about 1km, the “nuclear winter” impact size. Imagine what Ida would do if it hit Earth (*Bang Homepage*).

Conclusion

Ultimately, for the protection of civilization, some sort of concerted effort to detect and then deflect or fragment incoming astral objects must be undertaken. This is an opportunity for the entire world to convert the nuclear stockpile into a useful tool to protect the planet from wayward planetismals. The benefits of such programs would go beyond the mere protection of the planet, as some of the slower moving objects could be captured and mined for minerals including nickel, iron, and various basalts, as well as water and other volatiles. If terraforming is tackled in the future, such objects could be a valuable supply of water and other essentials. The technological achievements would also be beneficial, especially if newer and faster propulsion technologies were developed that would allow astronauts to travel to far off places in a fraction of the time it takes now. But the subject boils down to a prudent policy of simply protecting the planet from the dangers found in outer space.

Appendix

Amor An asteroid that has a semi-major axis greater than 1 astronomical unit (AU) and a perihelion distance between 1.017 and 1.3 AU. Over time, orbits for many Amor asteroids change and cross Earth's orbit. Spacecraft can rendezvous with Amors because of their orbits and close approaches.

Apollo An asteroid that has a semi-major axis greater than or equal to 1 AU and a perihelion distance less than 1.017 AU. Apollo asteroids cross Earth's orbit.

Aten An asteroid that has an orbital semi-major axis less than 1 AU and an aphelion distance greater than 0.983 AU. Aten asteroids cross Earth's orbit.

NEO Near-Earth Object. This broad category includes both asteroids and comets and does not distinguish by their telescopic appearance or assumed origin.

Short-Period Comet An object displaying a non-stellar appearance owing to the observable presence of a coma and/or tail. Short-period comets take less than 200 years to orbit the Sun, and half of them take less than seven years. One third of the known short-period comets have orbits that either cross or approach that of Earth.

Event	Energy, *J*	Energy, *Relative*
Two 3,500 lb. cars colliding head-on at 55 mph	9.6×10^{5}	1
Explosion of 1 U.S. ton of TNT	4.2×10^{9}	4,271
Explosion of a 20 megaton fusion bomb	8.4×10^{16}	87,500,000,000
Total U.S. annual electric power production, 1990	1×10^{19}	10,400,000,000,000
Energy released in last second	$\sim 9 \times 10^{21}$	9,375,000,000,000,000

of10^{13} kg fragment of Shoemaker-Levy 9		
Total energy released by 10^{13} kg fragment of Shoemaker-Levy 9	1.8 *x* 10^{22}	18,750,000,000,000,000
Total sunlight on Jupiter for one day	6.6 *x* 10^{22}	68,750,000,000,000,000

Table 1 Energy comparisons (*Bang Homepage*).

	Titan II	H-1	Ariane 40	Long March 3	Delta II	Atlas II	Zenit-2	Shuttle	Energia
Country	USA	Japan	ESA	China	USA	USA	Russia	USA	Russia
LEO (kg)	2545	3318	4909	5000	6364	13773	24409	24409	88182
GTO (kg)	-	1091	1905	1500	1864	2682	-	5909	18182

Table 2 Large Launch Vehicles *LEO = Low Earth Orbit, GTO = Geostationary Transfer Orbit* (P.L. Rustan)

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[3]Note: Citations with names of authors reference papers found in Gehrels' book.

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