CHAPTER 5

NUCLEAR DEFENSE AGAINST STELLAR OBJECTS

11/24/2021

“Extraordinary claims require extraordinary evidence. Since the beginning of time there have been literally hundreds of thousands of predictions for the end of the world, and we are still here.”
Carl Sagan, Astronomer.

"The third angel sounded his trumpet, and a great star, blazing like a torch, fell from the sky on a third of the rivers and on the springs of water— the name of the star is Wormwood.
A third of the waters turned bitter, and many people died from the waters that had become bitter."
Holy Bible .Revelations 8:10–11

“That which is feared most, seldom comes to pass.”

5.1 INTRODUCTION

Collision between the Earth and other small planetary objects occurs frequently. They reach the Earth at speeds in the range of 28,800 miles/hour. Air friction leads to the disintegration and burning of the small objects in the Earth’s atmosphere. They are noticeable as meteorite trails and meteor showers at night, such as the Leonid meteorite shower when the Earth’s orbit intersects their path at certain times of the year. However, there exists a low, even though not negligible, probability of collision with large extraterrestrial objects of 1-2 kilometers in size. These events have in fact happened in the past with catastrophic global effects in some cases leading to mass species extinctions.

Scientists know that the Earth has routinely suffered from asteroid strikes over the course of its history. A number of large craters attest to these events, including the Barringer Crater in Arizona, the Nördlinger Ries in southern Germany and the Manicouagan Reservoir in Canada.

Every day tons of dust from comets and small shards of asteroids from outer space burn in the Earth’s upper atmosphere. Some fist-sized chunks of rock or metal reach the Earth’ surface. Called asteroids while in space, they are referred to as meteors once they interact through friction with the Earth’s atmosphere and begin to heat up and glow.

More than 5,400 asteroids and comets have been spotted within 121 million miles of the sun, close enough to be classified by astronomers as near-Earth objects. About 950 of those measuring more than 460 feet in diameter and pass within 4.6 million miles of the Earth’s orbit have been catalogued and are considered as potentially hazardous. These are a part of an estimated 10 million rocky asteroids and ice and dirt comets in space with paths that could intersect the Earth’s orbit around the sun.

Humans’ responsible stewardship of life on Earth and in the known universe obligates them to observe the ultimate duty of its protection against these improbable but nevertheless possible events. Good risk management dictates that some countermeasures be immediately available, for the deflection or shattering of any dangerous guests from the far reaches of space.

In addition, a backup system replicating life on Earth, or a modern day Space Noah's Ark needs to be constructed as an ultimate insurance against such calamity as a Lunar or Martian base. High specific impulse nuclear methods are humanity's and life's major hope for global defense against such potential catastrophic encounters.

5.2 NEAR EARTH OBJECTS, NEOs

A 900 feet wide, bigger than a sports arena, asteroid: Apophis or the Destroyer, the god of destruction in ancient Egyptian mythology, was discovered on June 19, 2004, and was thought to be on a collision trajectory with Earth, coming within a 21,000 miles distance by April 13, 2029. The size of 3 football fields, is expected to appear as a bright star in the night sky over Europe.

There was a slight probability that it could pass through a "keyhole" or a corridor in space a few hundred yards wide and be deflected by the Earth's gravity just enough to place it again on a possibly hazardous approach on Easter Sunday, 2036. According to a prediction that NASA scientists made in 2004, it was thought that there exists a likelihood that it will hit Earth of 1:45,000.

Based on recent tracking data it has only a 1 in 233,000 chance of passing through the keyhole, as it passes by the Earth in 2029 that would cause it to impact 7 years later in 2036. On the slim chance that it does still pose an impact risk, we have plenty of time to mount an internationally coordinated deflection campaign if, and only if, it is needed.

Alarm was sounded when the initial data suggested there was a fairly large, 2.7 percent chance of the asteroid impacting Earth in 2029. Apophis broke the record for the highest level on the Torino Scale when it was categorized as a level 4 threat for a short time before it was lowered to 1 and then determined to be of no threat in August 2006.

The April 13, 2029 fly-by will be a notable an event as it will come within 19,400 miles of the Earth's surface. An Earth impact from an asteroid the size of Apophis, around 325 meters, is expected about every 80,000 years. This has galvanized efforts among scientists to predict and prevent potentially apocalyptic impacts.

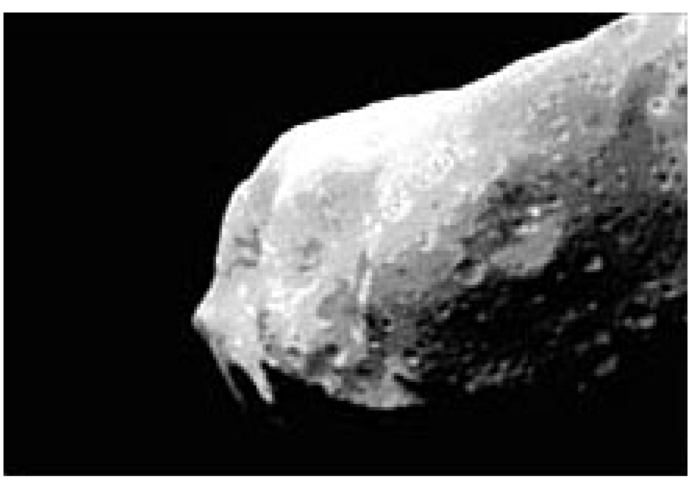
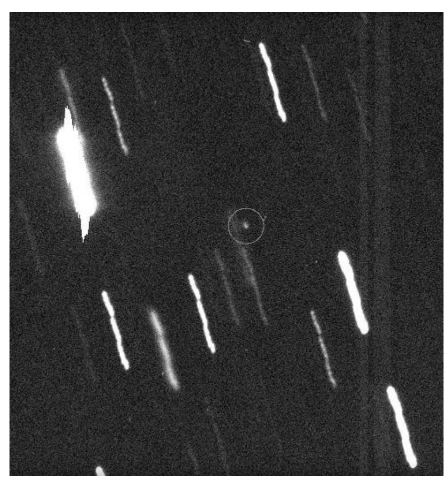

Figure 1. The Apophis, or Destroyer asteroid, named after the ancient Egyptian god of destruction. Source: NASA.

5.3 POTENTIALLY HAZARDOUS ASTEROIDS, PHAs

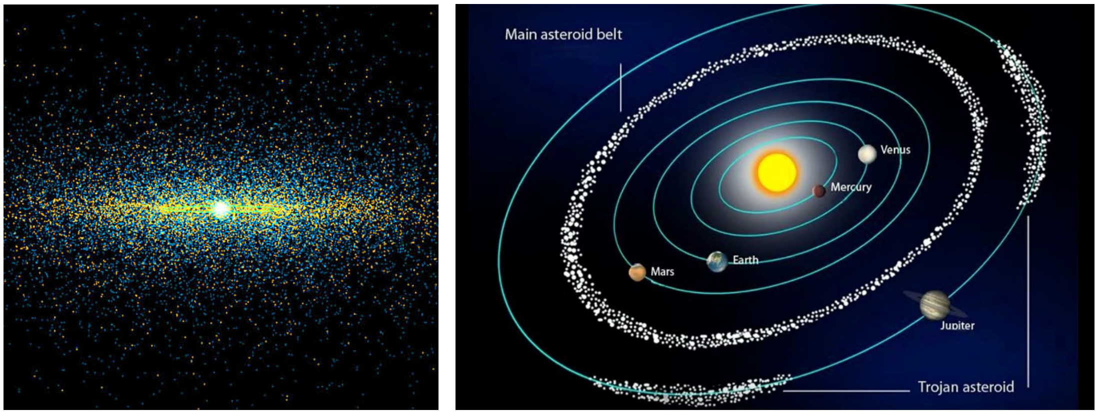

Figure 2. Asteroid belt population. The dots represent the known population of NEAs and PHAs that scientists think are likely to exist based on the NEOWISE survey. Positions of a simulated population of PHAs on a typical day are shown in bright orange, and the simulated NEAs are blue. The Earth's orbit is green. Source: NASA.

NASA's Near-Earth Object Wide-field Infrared Survey Explorer (NEOWISE) survey found that more Potentially Hazardous Asteroids (PHAs} are closely aligned with the plane of our solar system than previous models had suggested. PHAs are the subset of Near Earth Asteroids (NEAs) with the closest orbits to Earth's orbit, coming within 5 million miles. They are defined as being large enough to survive passage through Earth's atmosphere and cause damage on a regional or greater scale.

The survey results have found about 4,700 +/- 1,500 objects with diameters larger than 330 feet. Only about 20 - 30 percent of the PHAs thought to exist have actually been discovered so far.

5.4 NEAR EARTH OBJECTS IMPACTS

Studies of Near Earth Object (NEO) Interceptions suggest that impacts upon the Earth by civilization-killing sized asteroids or comets are a rare event. However the impact of smaller asteroids of 100 meters in diameters such as the one impacting near Tunguska, Siberia in 1908 is a more frequent event expected to occur with a frequency of 2 impacts each century. This meteorite is estimated to have been 70 meters in diameter. It leveled an area about 25 kilometers in radius.

The tools of satellite imagery and microscopic analysis of rocks and minerals, revealed 174 meteorite distinct impacts on Earth. Many more are believed to have been wiped out by erosion, tectonic movements or have been buried under sediment in the oceans. Some of these are:

Table 1. Location of some major asteroid and comet impacts.

Location	Name	Diameter [mile]	Impact Time

			[years]
North America	Sudbury, Canada	155	1.9×10^9
	Chesapeake Bay, Washington DC, USA	53 2 mile wide asteroid	35×10^6
	Meteor Crater, Arizona	0.73	50×10^3
	Chicxulub, Mexico	106	65×10^6
Africa	Vredefort, South Africa	186	2×10^9
Australia	Gosses Bluff	14	143×10^6

If hitting population centers, these events have enough energy to destroy whole metropolitan areas. They would cause earthquakes and fault disruptions, which would cause further damage such as landslides or even volcanic eruptions at the other side of their impact with Earth.

If falling in an ocean expanse they would cause a tidal wave or a Tsunami destroying large coastal areas. A doomsday tsunami washing over a city like New York and moving inland to the Appalachian Mountains could result from the impact of an asteroid three to four miles in diameter falling in the middle of the Atlantic Ocean. No asteroid or comet of such size has hit the Earth in recorded history.

However, 35 million years ago a 2 miles wide rock smashed into the ocean and caused a 53 miles wide crater under the southern end of what is known today as Chesapeake Bay in the eastern USA with resulting waves possibly thousands of feet high moving inland hundreds of miles.

Around 65 million years ago, a 6 miles wide meteorite hit the Gulf of Mexico releasing thousands of time more energy than all the existing nuclear weapons. About ¾ of all forms of life became instinct, including the dinosaurs.

Nudging the trajectory of an object of 100 meters in diameter is no trivial task, especially since if the asteroid is stony in composition; it would weigh 20,000 to 30,000 metric tonnes. It is necessary to impart a velocity increment of 10 cm/sec to the object to modify its trajectory and force it to miss the Earth-lunar system.

5.5 THE TUNGUSKA EVENT

The largest asteroid or comet meteorite impact that happened in the twentieth century happened in central Siberia on June 30, 1908 at 7:17 am. Residents of the Podkamennaya Tunguska River Valley witnessed a fireball through clear skies. A column of flames and clouds of thick black smoke rose after the fireball impacted the ground. A shock wave of hot air followed and knocked people and animals off their feet. Windows were shattered from the force of the blast. The Evenki native Siberian people reported the death of reindeer and dogs. About 80 million trees in a land area of 800 square kilometers were flattened by the blast.

It is believed that the object was 150 feet wide, the size of 15 story building, and tore into the atmosphere at 32,000 miles/hour with the following sequence of events.

Table 2. Sequence of events in the Tunguska asteroid impact.

Time [sec]	Event
0.0	Explosion started 7.5 miles or 12 km above ground
1.5-5.5	As it vaporized, it generated an incandescent trail of ultra hot gases
7.5-9.5	A midair blast of glowing gases billowed the explosion forming mushroom clouds
11-13	The increasing density of the atmosphere slowed the gases and debris in a superhot pileup. The remains dispersed high above ground
15.5	The object never hit the ground, but the shock wave from the explosion generated winds that approached hurricane force over a wide area

In Europe, the explosion was heard over a one million square kilometers area away, and seismographs recorded earthquake waves at 800 kilometers south of the event. The shock wave was recorded at meteorological stations, five hours later in Siberia, and 24 hours later back again after it had circled the globe. Dust particles from the explosion or icy clouds from the water vapor it blasted into the atmosphere reflected light illuminated the night sky over Europe and Asia to the point where people could read newspapers outdoors at night.

The meteorite that is thought to have exploded 10 kilometers above the Tunguska River has not been located, lacking a major crater or fragments. Investigation of the event was delayed as it occurred at a period of time when Russia was in the initial stages of the upheaval of its communist revolution. Thirteen years later four expeditions by the Soviet Academy of Science failed to find it. Samples collected at the site were later analyzed and revealed small spheres of formerly liquid meteorite dust. It is possible that it totally disintegrated in the atmosphere, scattering the object, likely a comet, into small debris that mostly burned out.

Figure 3. Fallen trees at five miles from the impact point of a 10-100 meters diameter meteorite at Tunguska.

Figure 4. Meteor Crater or Barringer Crater located 40 miles east of Flagstaff, Arizona, USA, resulted from a 150-feet diameter Ni-Fe asteroid that impacted 20,000 to 30,000 years ago resulting in a mile-wide and 550 feet deep crater. Source: NASA.

Figure 5. April 22, 2012 meteorite, Sierra Nevada, USA.

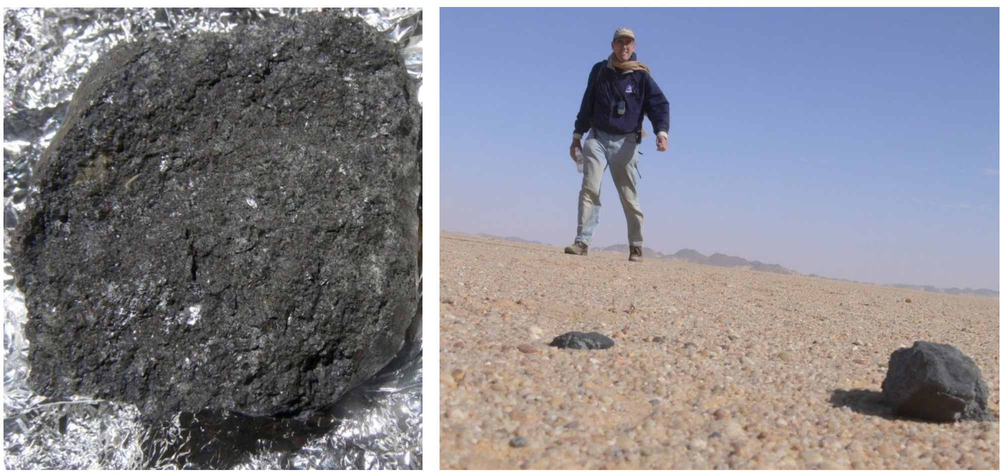

Figure 6. Meteorite 2008 TC3, Sudan desert.

For years, scientists thought the impact was by a comet that vaporized before striking the Earth. A Russian scientist, Vlasov, suggested it was an antimatter meteorite. There still exists some speculation that comets may contain some antimatter. If this were true, they could be mined for it as a rocket fuel for future space missions to distant planetary systems. The latest belief is that it was a stony meteorite, about 60 meters in diameter that disintegrated at a 5 to10 kilometers height in the atmosphere. The damage was generated by the shock wave, which had the equivalent, in terms of energy release, of a 15 to 20 Megatons (Mt) of Tri-Nitro-Toluene (TNT) high explosive equivalent thermonuclear weapon. This is close to the energy release by the Mount Saint Helen's volcanic eruption in 1980 in the state of Washington in the USA, at 10 megatons of TNT equivalent. Trees were downed at a five miles radius from the impact.

If the Tunguska event would have happened 4 hours later in time, it could have impacted St. Petersburg, totally annihilating it. The village of Vanavara, 70 kilometers from the blast, survived it. At the 100th anniversary of the event in 2008, the city repainted its buildings in vivid "meteoric" colors, and unveiled a monument as a colorful sphere as a symbol of a cosmic body. “Alternativist” mystic locals also built a marker by the blast spot resembling a sacred bird or an Unidentified Flying Object (UFO). Tourists are attracted to a Tunguska meteorite museum with photographs of what is claimed to be fragments of some extra terrestrial craft.

5.6 THE JUPITER EFFECT, MENACE OR SAVIOR?

The Comet Shoemaker-Levy 9 was spotted for the first time in March 1993. It turned out to be a string of more than 20 fragments that had separated under the influence of Jupiter’s gravitational force and ended up sequentially hitting Jupiter. These fragments ended up striking Jupiter on July 1994. The fragment A traveling at a speed of 200,000 kms/hr, struck Jupiter with an energy of 200,000 megatons of TNT, sending a plume 3,000 kms above Jupiter. Fragment G shot a pockmark of debris larger than the diameter of the Earth. The fragmentation before impact explains the linear chains of craters on the moon. But this also suggests that an impact of this kind can deliver a series of blows one after the other. There were suggestions that the collision could ignite Jupiter's atmosphere, turning the massive hydrogen gaseous planet into a small star, which did not come to pass. The fact that cannot be ignored is that cosmic collisions do occur in the time frame of human life.

As the 15th anniversary of the Shoemaker-Levy 9 comet collision and the 40th anniversary of the Apollo 11 moon landing just came to pass on July 21, 2009, a new impact on Jupiter occurred. Following up on a tip by an amateur astronomer, Anthony Wesley of Australia, that a new dark "scar" had suddenly appeared on Jupiter, scientists at NASA's Jet Propulsion Laboratory in Pasadena, California, using NASA's Infrared Telescope Facility at the summit of Mauna Kea, Hawaii, gathered evidence indicating an impact.

Infrared images show the likely impact point was near the south polar region, with a visibly dark "scar" and bright upwelling particles in the upper atmosphere detected in near-infrared wavelengths, and a warming of the upper troposphere with possible extra emission from ammonia gas detected at mid-infrared wavelengths.

One aspect of what makes the Earth a livable planet is that Jupiter’s large gravity acts as a gravitational shield deflecting incoming comets away from the inner solar system where it could repeat what an asteroid apparently did for the dinosaurs 65 million years ago. Astronomers, in their quest for other planetary systems, are looking for a similar configuration: a giant outer planet with room for smaller planets in closer to a home star in other planetary systems as an indication of their being hospitable to life.

However, Jupiter can be just as much a menace as a savior: it deflects a lot of comets out of the solar system, but it also throws them in. As an example, the Comet Lexell, named after the Swedish astronomer Anders Lexell, whizzed in 1770 only a million miles from the Earth. That comet had come streaking in from the outer solar system three years earlier and passed close to Jupiter, which diverted it into a new orbit and straight toward Earth. The comet made two passes around the sun and in 1779 again passed very close to Jupiter, which then threw it back out of the solar system.

Whether Jupiter is a menace or a protector depended on whether or not the comets came from the icy zone of debris known as the Kuiper Belt, which lies just outside the orbit of Neptune. Jupiter probably does increase our exposure to those comets.

On the other hand, Jupiter helps protect the Earth from a more dangerous band of comets coming from the Oort Cloud, a vast spherical deep-freeze surrounding the solar system as far as a light-year from the sun. Every once in a while, in response to gravitational nudges from a passing star or gas cloud, a comet is unleashed from storage and comes crashing inward. Jupiter's influence here comes in two forms. The Oort Cloud was initially populated in the early days of the solar system by the gravity of Uranus and Neptune sweeping up debris and flinging it outward, but Jupiter and Saturn gravity are so strong that they threw a lot of the junk out of the solar system altogether, lessening the size of this cosmic arsenal. Second, Jupiter deflects some of the comets that get dislodged and fall back in.

Asteroids pose the greatest danger of all to Earth. Asteroids lie peacefully in the asteroid belt between Mars and Jupiter, whose gravity keeps them too stirred to coalesce into a planet but can cause them to collide and rebound in the direction of Earth.

THE HYPATIA METEORITE

Figure 7. Tutankhamun's brooch has a scarab made of yellow silica glass which formed from a comet impact millions of years ago. Source: University of the Witswatersrand, Johannesburg, South Africa.

About 28 million years ago, a comet exploded over the Egyptian desert. A mysterious black pebble discovered years ago in the Egyptian desert was determined to be a piece of a comet nucleus. Jan Kramers of the University of Johannesburg in South Africa states: "It's a typical scientific euphoria when you eliminate all other options and come to the realization of what it must be" [12]. The pebblewas named "Hypatia" in honor of the ancient female mathematician, astronomer and philosopher Hypatia of Alexandria. It is studded with diamonds, which makes sense considering its cometary origin: "Diamonds are produced from carbon-bearing material. Normally they form deep in the Earth, where the pressure is high, but you can also generate very high pressure with shock. Part of the comet impacted, and the shock of the impact produced the diamonds" [12].

The comet exploded in the atmosphere, heating the sand below to a temperature of 3,630 degrees Fahrenheit or 2,000 degrees Celsius, and generating huge amounts of yellow silica glass across 2,317 square miles or 6,000 square kilometers of the Sahara Desert. One piece of this silica glass even found its way into a brooch that belonged to the Egyptian pharaoh Tut Ankh Amon.

5.7 OTHER IMPACTS AND ASTRAL ASSAILANTS

Were it not for erosion by water, wind and vegetation, craters from the impacts of celestial bodied would be much observable on Earth like on the moon and Mars. Nevertheless, some of the more recent impacts are clearly discernible.

Meteor Crater is also called the Barringer Crater and is located about 40 miles east of Flagstaff, Arizona in the USA. It is a tourist attraction with a museum. A nickel and iron meteorite about 50 yards in diameter weighting 175 million tons, and releasing energy in the megatons of TNT equivalent upon impact 10-100 million years ago, is thought to have caused it. The crater is 4,150 feet in diameter, 550 feet deep, a mile wide and 2.4 miles in circumference.

A comet or an asteroid smashed into Australia about 140 million years ago, creating a 14 miles wide crater with a 2 miles wide central remnant known as Gosses Bluff.

On August 10, 1972, a 150 ton object 15 feet in diameter was observed streaking over Jackson Lake and the Grand Tetons mountains in Wyoming. The near miss skipped off the atmosphere like a rock on the surface of water.

The Aorounga 17-km diameter crater in the Sahara desert in Chad appears to be a chain of two craters that could have resulted from fragmentation of a larger body as it entered the Earth’s atmosphere. The 70 km diameter Manicouagan crater in Canada is 206-214 million years old.

The 65 million years old Chicxulub 110-189 miles diameter crater is buried in the Yucatan Peninsula, Mexico. A synthetic aperture radar picture shows the 5 million years old Roter Camm crater in Namibia, Africa..

Figure 8. Aorounga 17 km diameter chain of multiple craters in the Sahara desert in North Chad. Formed 200-300 million years ago from an asteroid 1 mile or 1.6 km in diameter. Crater is 11 miles or 17 miles in diameter. Source: Space Shuttle SIR-C Radar, NASA.

Figure 9. The 70 km diameter Manicouagan crater in Canada is 206-214 million years old.

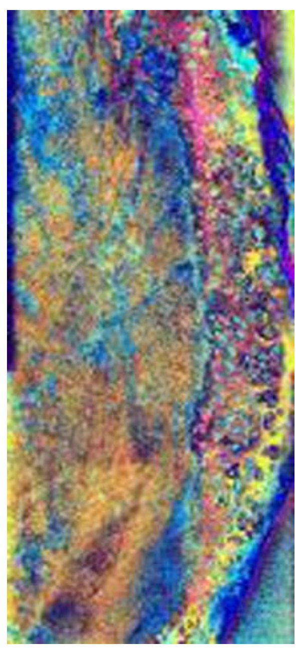

Figure 10. The 65 million years old buried Chicxulub 110-189 miles diameter crater in the Yucatan Peninsula, Mexico. It is thought to have trapped marine sediment eventually forming the giant Cantarell oil deposit.

Figure 11. Synthetic aperture radar picture of 5 million years old Roter Camm crater in Namibia, Africa.

Table 3. Characteristics of some Earth impact craters.

Crater	Projectile diameter [m]	Projectile material and density [kg/m^3]	Impact speed [km/sec]	Impact angle [degrees]	Target material
Meteor Crater, USA.	40	Fe 8,000	20	45	Sedimentary rock
Tunguska, Siberia, Russia, 1980.	60	Rock 2,700	20	45	Sedimentary rock
Ries Crater, Germany	1,500	Rock 2,700	20	30	Crystalline rock
Chesapeake Bay, USA	2,300	Rock 2,700	20	45	Water Depth: 300 m
Chicxulub, Mexico	17,500	Rock 2,700	20	45	Water Depth:100 m

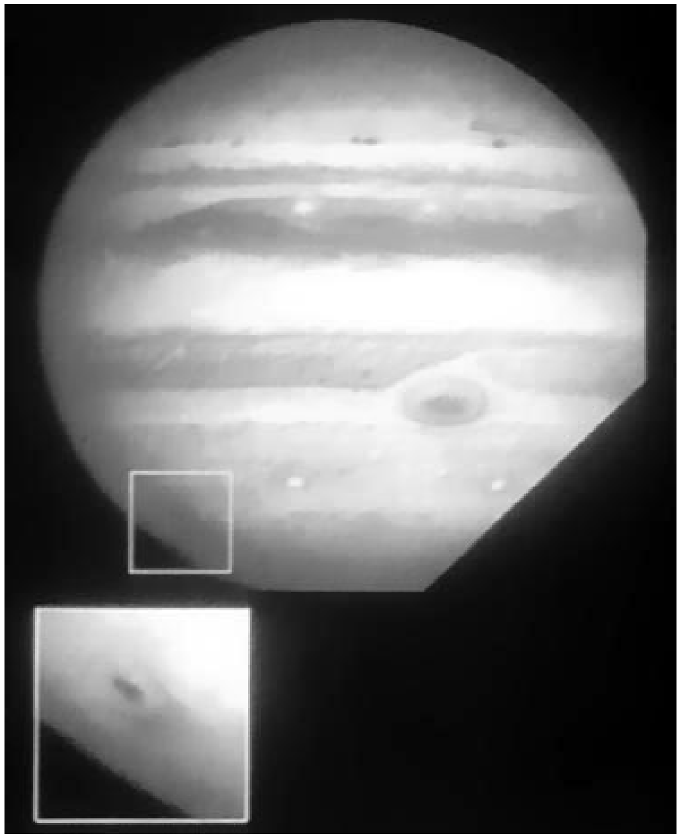

Figure 12. Impact on Jupiter of the Shoemaker-Levy 9 Comet. Source: NASA.

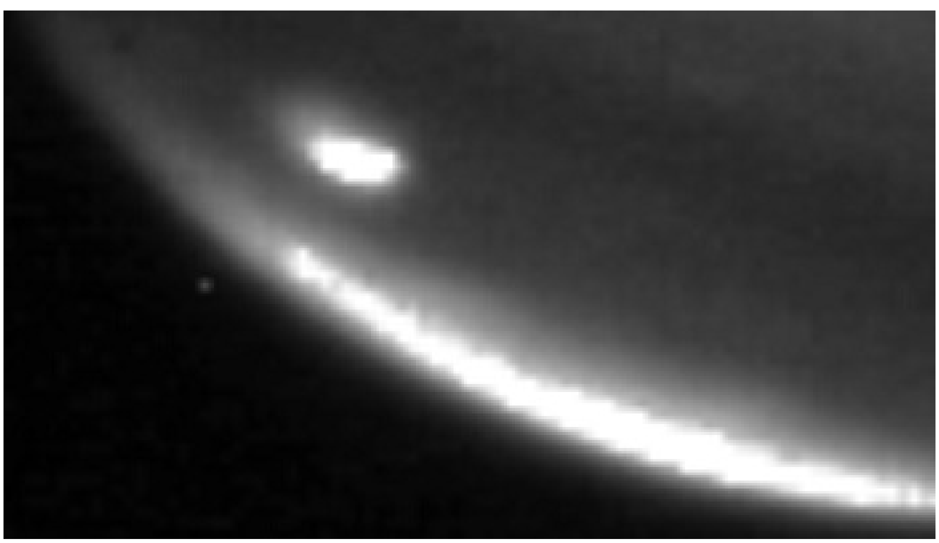

Figure 13. An image taken by the Infrared Telescope Facility in Hawaii shows the bright spot left by a body of unknown origin entering Jupiter's atmosphere. The image was taken at 1.65 microns, a wavelength sensitive to the reflected sunlight from the planet's atmosphere. Source: NASA/JPL/Infrared Telescope Facility.

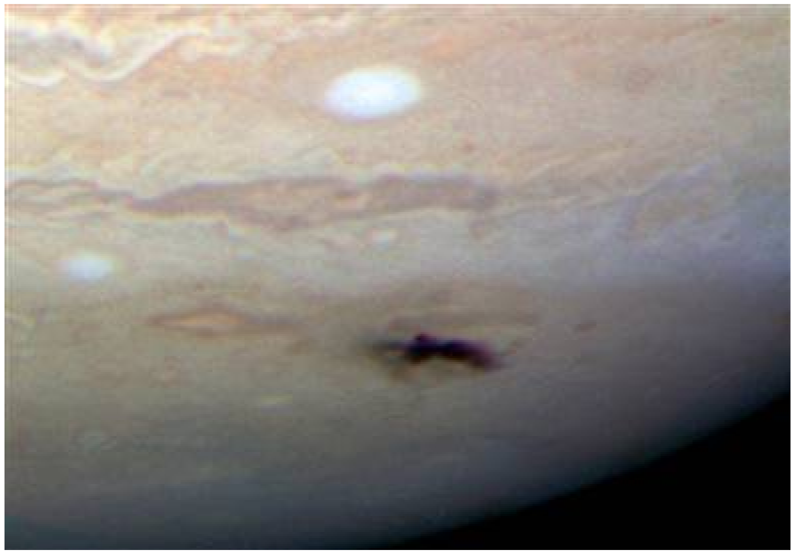

Figure 14. Hubble space telescope Wide Field Camera 3 photograph of 2009 comet or asteroid about 200 meters wide impact on Jupiter. Impact area is 6,000 miles wide or twice the width of the European continent. Source: H. Hammel (SSI), NASA, ESA, Jupiter Impact Team.

The Earth skies are crowded with 2,000 near Earth asteroids. Any one of them could become an "astral assailant" and strike Earth. The Earth resides within an asteroid swarm.

The closest object to Earth was spotted in May 1994 by Tom Gehrls. It is a 6 meters object moving away from Earth at a distance of 150,000 kilometers. A nine meters object at 105,000 kilometers was located in the same year by Jim Scotti. Asteroid 4179 or Toutatis is the most hazardous object known. It is a 2 to 3 kilometers wide object with a chaotic orbit that brings it close to Earth once every 4 years. On December 1992, it came to within 3.6 million kilometers of Earth. In September 2004 it came closer to 1.5 million kilometers.

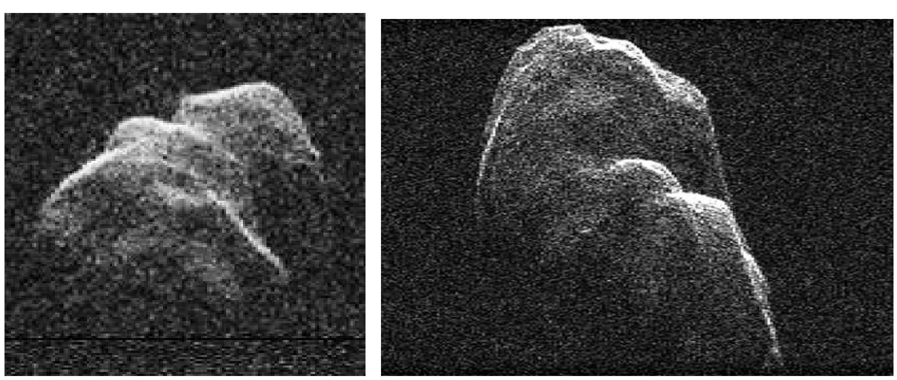

Figure 15. Asteroid Toutatis 4179. Radar image of asteroid Toutatis taken by NASA's Goldstone Solar System Radar on December 12 and 13, 2012. Source: NASA.

On December 12, 2012, the day of its closest approach to Earth, the 3-mile long Toutatis was 4.4 million miles away from Earth. The radar images, show an elongated, irregularly shaped object with ridges and craters and a very slow, tumbling rotational state, rotating on its long axis every 5.4 days.

Figure 16. Meteor sighting over the Grand Tetons in the Rocky Mountains chain, Wyoming, on August 10, 1972.

Only 5 percent of objects of a 1 km size have been identified. The smaller objects that can cause local damage will take decades to identify.

The asteroid 2000 BF19 is about a half mile wide and was spotted by James Scotti using the Spacewatch Telescope on Kitt Peak in Arizona. It is expected to come close to Earth in 2022. It has a probability of 10^{-6} or 1 in 1 million of hitting Earth.

Whereas asteroids would give Earth enough of a lead time to mount some defenses, this is not the case with comets which would not provide enough warning time. The only thing that can be done about long period comets, as suggested by Eugene Shoemaker is "…to maintain eternal vigilance." Figure 16 shows a sighting of a meteor over the Grand Teton Mountains in the American Rockies on August 10, 1972.

5.8 CHELYABINSK METEORITE, SIBERIA RUSSIA

Meteorite fragments reached the ground in central Russia on Friday, February 15, 2013 affecting 1,200 people who sought medical assistance in the Chelyabinsk Region of the Urals, Russia, with no deaths or serious injuries. Most people were hurt by shattering glass and flying debris. Some 3,000 buildings were reported to have sustained some damage in the 1.1 million people city of Chelyabinsk. An estimated 20,000 emergency response workers were mobilized and $30 million worth of damage occurred.

According to Russian authorities the meteorite weighted 10 tonnes. According to NASA, the meteorite was 55 feet in diameter with a mass of 10,000 tonnes. Its fireball lit up the sky above the Urals region causing shockwaves that injured 1500 people and damaged thousands of homes in an event unprecedented in modern times. The energy released as the meteor's exploded in the atmosphere was 500 kTs of TNT equivalent, around 30 times the size of the nuclear device dropped on Hiroshima in 1945. It entered the atmosphere at 44,000 miles per hour, taking 32.5 seconds to break up at an altitude of around 15 miles above the Earth's surface. The debris reached the Earth's surface at around 00 mph. The resulting explosion created a shockwave that blew out windows and set of car alarms in Chelyabinsk two and a half minutes later. An event of this magnitude occurs once every 100 years on average.

The object disintegrated into smaller fragments. The city's residents saw blinding flashes, followed by a bright flash of light. The Chelyabinsk governor said one fragment had fallen in a lake in his region, while others have been reported in the Tyumen, Kurgan and Sverdlovsk regions. An eight-meter wide crater occurred near the Chelyabinsk Lake. In west Kazakhstan two fragments fell in the country's Aktobe region.

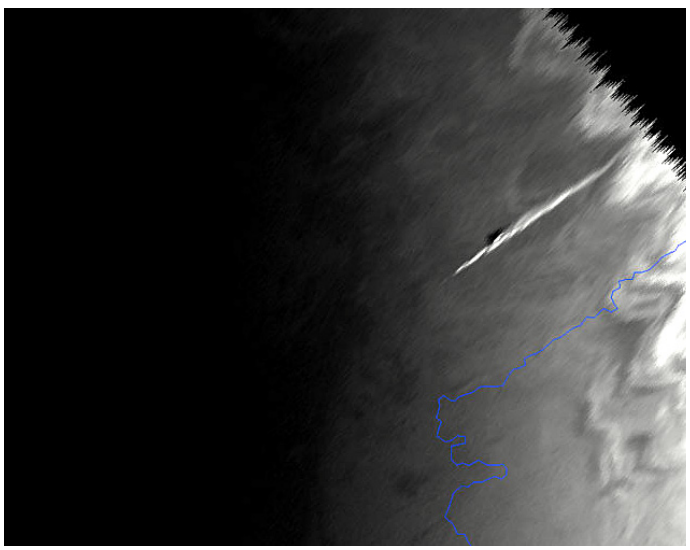

Figure 17. Weather meteostat satellite of Chebyalinsk meteorite, February 15, 2013..

Figure 18. Chebyalinsk meteorite, February 15, 2013. Double track suggests splitting of the meteorite. Source: RiaNovosti, Itar-Tass.

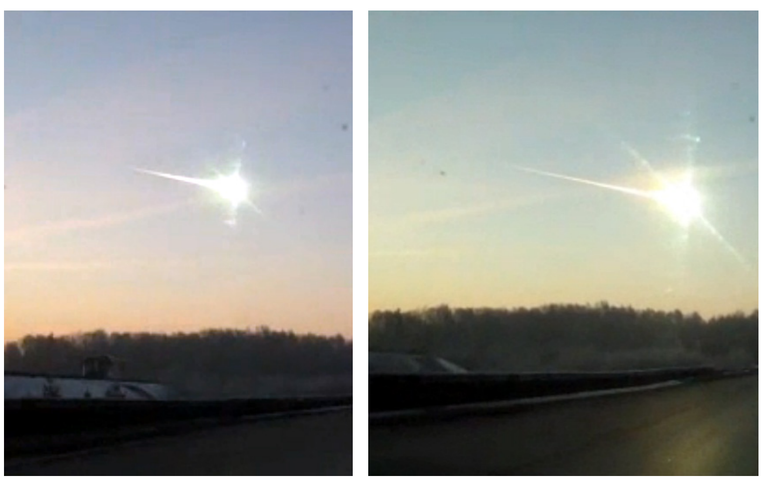

Figure 19. Fireball of Chelyabinsk meteorite, February 15, 2013. Source: RiaNovosti.

Figure 20. Blast wave and debris effects of Chelyabinsk meteorite on a zinc factory, power lines and window frames February 15, 2013. Source: RiaNovosti.

Figure 21. Meteorite fragment impact in Chebarkul Lake, February 15, 2013. Source: RiaNovosti, Andrey Orlov.

The European Space Agency (ESA) said there was no link between the meteorite and the 2012 DA14 asteroid which coincidentally passed close by the Earth later on that same Friday, February 15, 2013. NASA also said there was no connection because the asteriod 2012 DA14 and the Chelyabinsk meteorite were on very different paths.

The big boom over Chelyabinsk on February 15, 2013 produced an “infrasound” wave of low frequency thousands of times lower than a piano's middle C; far below the range of human hearing. The Comprehensive Test Ban Treaty Organization said that sound wave showed up on sensors from Greenland to Antarctica, making it the largest ever detected by its network of megaphones located on strategic locations on Earth. The nuclear test monitors pick up infrasound waves from about 20 meteoroids a year, if conditions are right, as small as a pea.

The duration of the sound wave was about 32 seconds. This leads to an estimate of the energy of the blast at between 450 and 500 kT of TNT equivalent, the size of about 30 early atomic devices. The size of the fireball can then be estimated; and using an estimate of the meteor's speed from the numerous dashboard and mobile-phone cameras that captured the scene, the approximate size and weight could be determined.

An estimate is that the Chelyabinsk meteor was about 56 feet or 17 meters in diameter, weighed more than 700,000 metric tonnes and was moving at about 18 km / sec or 40,000 mph.

NASA's Meteoroid Environment Office suggests the object originated in the asteroid belt between Mars and Jupiter. It was the Apollo group of asteroids, which circle the sun in oblong orbits that occasionally cross Earth's. The resulting fragments point to a stony asteroid with traces of nickel and iron.

A speculation was reported that the meteorite shower may have been caused by a yet undiscovered long-period comet according to Peter Jenniskens, of the Search for Extraterrestrial Intelligence (SETI) Institute. He suggested a possible return of the comet in 2016 or 2023, and after that not again until 2076. Jenniskens heads the Cameras for Allsky Meteor Surveillance (CAMS) project, which has been monitoring the San Francisco Bay Area's night skies with low-light video cameras in an effort to map meteor showers.

5.9 ASTEROID 2012 DA14

The asteroid 2012 DA14 came close to the Earth on February 15, at 2:24 pm EST, 2013 by 17,200 miles or 27,700 kilometers, ten times closer than the orbit of the moon, flying over the eastern Indian Ocean near Sumatra.

It is 150 feet or 45 meters across, half a football field in width. It passed within the orbits of many communications satellites, making it the closest asteroid flyby on record. An asteroid of this size passes this close to the Earth once every few decades.

It was first spotted by observers at the La Sagra Observatory in southern Spain in 2012, soon after it had just finished making a more distant pass of the Earth at 2.6 million miles or 4.3 million kilometers away. It is the closest known approach to Earth for an object its size. There is a 1-in-200,000 chance that it could hit the Earth in the year 2080.
Earth collision with an object of this size is expected to occur every 1,200 years on average. The asteroid 2012 DA14 has been getting closer and closer to Earth for a while, the 2013 event is the asteroid's closest approach in the past hundred years, and it probably would not get this close again for at least another century.

The asteroid 2012 DA14 passed 5,000 miles inside the ring of orbiting geosynchronous weather and communications satellites. An impact from an object this size would have the explosive power of a few megatons of TNT, causing localized destruction similar to what occurred in the Tunguska event in Siberia in 1908. It created an airburst explosion which flattened about 750 square miles or 1,200 square kilometers of a remote forested region of northern Russia.

An impact from an asteroid with a diameter of about half a mile or one kilometer could temporarily change global climate and kill millions of people if it hit a populated area. The small objects like 2012 DA14 could hit Earth once a millennia or so. A survey of nearly 9,500 near-Earth objects half a mile or one kilometer in diameter is ongoing.

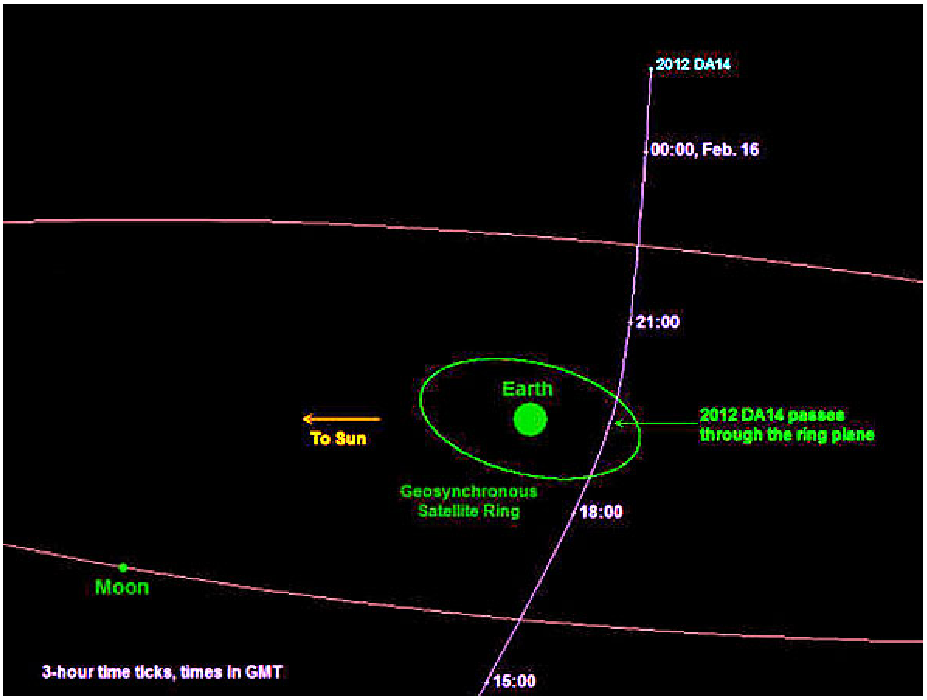

Figure 22. Asteroid 2012 AD14 17,200 miles approach to Earth on February 15, 2013.
Source: NASA.

5.10 RISK AND IMPACTING OBJECTS SIZES

The impact frequency appears f to be inversely proportional to the asteroid impact energy Y:

$$f \, \alpha_{\ell} \frac{1}{Y} \tag{1}$$

If we consider its mass as m, its speed v as a constant, the volume of the object as V, the density of the object as ρ, and that the yield is only equal to the kinetic energy of the object, then the yield can be expressed as:

$$Y = \frac{1}{2} m v^2 = \frac{1}{2} \rho V v^2 \tag{2}$$

EXAMPLE

A 200 meters diameter or 100 meters radius object would have a volume of:

$$V = \frac{4\pi R^3}{3} = \frac{4\pi (100)^3}{3} = 4.19 x 10^6 m^3$$

For a typical density of 1.0-3.5 gm/cm^3, taking the average density as 2.25 gm/cm^3, the mass would be:

$$m = \rho V = \frac{2.25 \times 100^3}{1,000} \times 4.19 x 10^6 = 9.43 x 10^9 \; kgs$$

Moving at a representative speed of 20 km/sec, the kinetic energy would be:

$$Y = \frac{1}{2} m v^2 = \frac{1}{2} 9.43 \times 10^9 \times (20 x 1000)^2 = 3.77 \times 10^{18} \; Joules$$

Using the equivalence:

$$1 \; kT \; TNT = 4.2 \times 10^{19} \; ergs = \frac{4.2 \times 10^{19}}{10^7} \; Joules = 4.2 \times 10^{12} \; Joules \, ,$$

The yield equivalent is:

$$Y = \frac{3.77 \times 10^{18}}{4.2 \times 10^{12}} = 0.89 \times 10^6 \; kT \; TNT = 890 \; MT \; TNT$$

The largest ever exploded thermonuclear weapon had a yield of 50 MT of TNT equivalent.

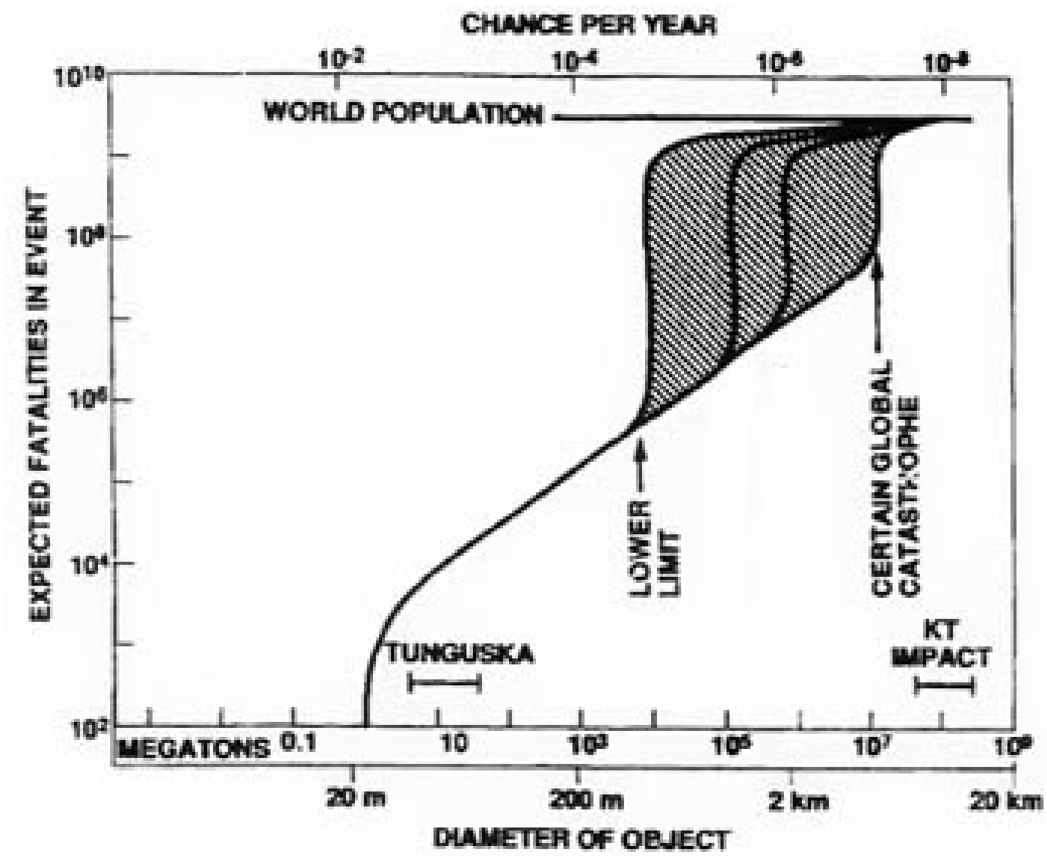

Figure 23. Risk in expected fatalities per event against the size of impacting space objects.

This suggests that the yield would depend on the density of the object, whether it is metallic, rocky or gaseous, as well as the square of its incoming velocity. The energy releases are measured in kilotons or megatons of Tri-Nitro-Toluene (TNT) chemical explosive. This unit is also used to measure the yields of atomic weapons as shown in Table 4.

Substituting from Eqn. 2 into Eqn. 1 we get for the impact frequency:

$$f \ \alpha_{\ell} \ \frac{1}{\frac{1}{2}\rho V v^2} \qquad (3)$$

Table 4. Energy Release equivalent of 1 kiloton (kT) of TNT.

Unit	Value [kT TNT]
Megaton TNT	10^{-3}
Calories	10^{12}
Ergs	4.2×10^{19}
Joules	4.2×10^{12}

Kilowatt.hours (kW.hr)	$1.2x10^{6}$
British Thermal Units (BTU)	$4.0x10^{9}$
Fissile nuclei fissions	$1.45x10^{23}$

If we further assume that the object is spherical in geometry, we can substitute for its volume V in terms of its radius R or diameter D = 2R as:

$$f \,\alpha_{\ell}\, \frac{1}{\frac{1}{2}\rho\frac{4\pi R^3}{3}v^2} \,\alpha_{\ell}\, \frac{12}{\rho\pi D^3 v^2} \tag{4}$$

This implies that the impact frequency will be inversely proportional to the cube of its diameter, up to a diameter of a few kilometers, under the assumption of a fairly constant impact velocity. Impact velocities of 10 to 60 km/sec have been suggested.

5.11 MASS EXTINCTIONS

The last period of dominance of the dinosaurs is in the geological time frame designated as the Cretaceous period and identified by the symbol K. Fossils in Cretaceous rocks strata contain dinosaurs fossils, conifer tree pollen, and small simple mammals. Rocks in the following period or the Tertiary, contain no dinosaurs' fossils, and are designated by the symbol T. They contain flowering plant species and mammals.

The transition between the Cretaceous and the Ternary period is designated as the K-T boundary and it occurred 70 million years ago. This K-T boundary also separates the middle life of the Earth; the Mesozoic Era, when reptiles dominated the planet and the current new life or Cenozoic Era, the age of mammals.

Humans live today in the Holocene Epoch, which is a part of the Quaternary Period of the Cenozoic Era.

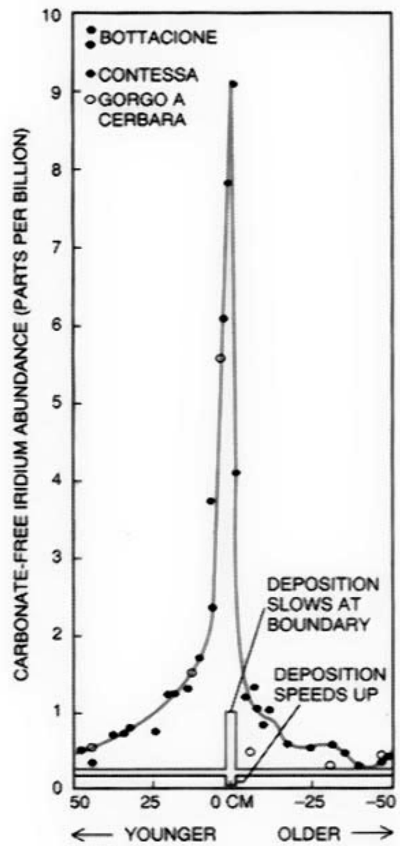

Figure 24. Rise of Iridium concentration in Gubbio, Italy at the K-T boundary.

Paleontologists, through the study of the fossil record over the last 540 million years, recognize 24 species extinction events, 5 of them major, and the others minor. The most recent major extinction event was the one that happened 65 million years ago at the K-T boundary, where 65-75 percent of all of earth's organisms vanished. No species of land animals weighing more than 25 kilograms survived the event. Insects, and small reptiles and amphibians near lakes and streams survived the devastation, as well as a few of our rodent mammalian ancestors. About 88 percent of land dwelling animals vanished, even though about 90 percent of those inhabiting fresh water survived. Figure 24 shows an increase of the concentration of iridium in the sediments in Gubbio, Italy at the K-T boundary. The normal iridium concentration is just 0.03 parts per billion (ppb) in the Earth's surface. In sediments, it originates from the constant rain of cosmic dust on Earth. The concentration at the K-T boundary is 3 ppb, or 100 times the normal concentration. The source of this iridium is extraterrestrial, since Chondrites, which are the most common type of meteors have an iridium concentration of 500 ppb. It is calculated that the iridium anomaly amounts to 0.5 million tons, implying a meteorite that was 10 kilometers in diameter. An abundance of soot is associated with the iridium anomaly, implying that wildfires around the world resulted from the impact. Tsunamis may have also resulted from the impact.

The Earth's greatest mass extinction occurred 250 million years ago, and was so severe that it took 10 million years for the planet to recover from it. Life was nearly wiped out, with only 10 per cent of plants and animals surviving. The sheer intensity of the crisis, and continuing grim conditions on Earth after the first wave of extinction, meant the bounce-back was quite slow.

This end-Permian crisis was triggered by a number of physical environmental shocks - global warming, acid rain, ocean acidification and ocean anoxia - and killed off 90 per cent of the living creatures on land and in the sea. There is no doubt from some of the fantastic rock sections in China and elsewhere around the world that this was the biggest crisis ever faced by life. The grim conditions continued in waves for five or six million years, with carbon and oxygen crises, warming and other ill effects. Life seemed to be getting back to normal when another crisis hit and set it back again. The carbon crises were repeated many times, and then finally conditions became normal again after five million years or so."

Once the environmental crises ceased to be so severe, more complex ecosystems emerged. In the sea, new groups, such as ancestral crabs and lobsters, as well as the first marine reptiles, came on the scene, and they formed the basis of future modern-style ecosystems. The causes of the killing - global warming, acid rain, and ocean acidification all sound eerily familiar to us today.

Table 5. Comparison of risk from astral impacts with other societal risks.

Risk source	Risk [fatalities / (person.year)]
Motor vehicle accidents	1.0×10^{-2}
Homicides	3.3×10^{-3}
Fires	1.3×10^{-3}
Firearms	4.0×10^{-4}
Lower limit, astral impacts	3.3×10^{-4}
Electrocution	2.0×10^{-4}
Average, astral impacts	5.0×10^{-5}
Aircraft crashes	5.0×10^{-5}
Flooding	3.3×10^{-5}
Tornadoes	1.7×10^{-5}
Venomous bites and stings	1.0×10^{-5}
Upper limit, astral impacts	4.0×10^{-6}
Fireworks	1.0×10^{-6}
Botulism food poisoning	3.3×10^{-7}
Water with Trichloroethylene (TCE) Environmental Protection Agency (EPA) limit	1.0×10^{-8}

Whereas events like what happened at the K-T boundary are presumed rare, events at the level of the Tunguska impact are more frequent and are expected to occur as often as twice each century. Table 5 gives estimates of the risks from astral impacts in units of fatalities per person per year compared with other societal risks. The average risk from astral impacts compares with the risk from passenger airlines crashes, and deserves the same attention from society as aircraft safety.

The Torino scale, similar to the Richter earthquake magnitude scale for the assessment of the severity of an astral impact was created by Professor Richard P. Binzel in the Department of Earth, Atmospheric, and Planetary Sciences at the Massachusetts Institute of Technology.

When a new asteroid or comet is discovered, initial predictions for where the object will be months or decades in the future are rough estimates, and subject to changes based on collecting additional data, however, for the majority of objects even the initial calculations are sufficient to show that they will not make any close passes by the Earth within the next century.

Hazard	Level	Description
No hazard	0	The likelihood of collision is zero, or is so low to be effectively zero. Also applies to small objects such as meteors and bolides that burn up in the atmosphere as well as infrequent meteorite falls that rarely cause damage.
Normal	1	A routine discovery in which a pass near the Earth is predicted that poses no unusual level of danger. Current calculations show the chance of collision is extremely unlikely with no cause for public attention or public concern. New telescopic observations very likely will lead to reassignment to level 0.
Meriting attention by astronomers	2	A discovery, which may become routine with expanded searches, of an object making a somewhat close but not highly unusual pass near the Earth. While meriting attention by astronomers, there is no cause for public attention or public concern as an actual collision is very unlikely. New telescopic observations very likely lead to reassignment to level 0.
	3	A *close* encounter, meriting attention by astronomers. Current calculations give a 1 percent or greater chance of collision capable of *localized destruction*. Most likely, new telescopic observations will lead to reassignment to level 0. Attention by the public and by public officials is merited if the encounter is less than a decade away.
	4	A *close* encounter, meriting attention by astronomers. Current calculations give a 1 percent or greater chance of collision capable of *regional devastation*. Most likely, new telescopic observations will lead to reassignment to level 0. Attention by the public and by public officials is merited if the encounter is less than a decade away.
Threatening	5	A *close* encounter posing a serious, but still uncertain threat of regional devastation. Critical attention by astronomers is needed to determine conclusively whether or not a collision will occur. If the encounter is less than a decade away, governmental contingency planning may be warranted.
	6	A *close* encounter by a large object posing a serious, but still uncertain threat of a global catastrophe.

		Critical attention by astronomers is needed to determine conclusively whether or not a collision will occur. If the encounter is less than 3 decades away, governmental contingency planning may be warranted.
	7	A *very close* encounter by a large object, which if occurring this century, poses an unprecedented but still uncertain threat of a global catastrophe. For such a threat in this century, international contingency planning is warranted, especially to determine urgently and conclusively whether or not a collision will occur,
Certain collisions	8	A collision is *certain*, capable of causing *localized destruction* for an impact over land or possibly a tsunami is close offshore. Such events occur on average between once per 50 years and once per several 1,000 years.
	9	A collision is *certain*, capable of causing *unprecedented regional devastation* for a land impact or the threat of a major tsunami for an ocean impact. Such events occur on average between once per 10,000 years and once every 100,000 years.
	10	A collision is *certain*, capable of causing *a global climatic catastrophe* that may threaten the future of civilization as we know it, whether impacting land or ocean. Such events occur on average once per 100,000 years, or less often.

Figure 25. The Torino Scale for the severity of Astral Impacts.

5.12 COMETS AND ASTEROIDS THREATS

The time elapsing between the discovery of a potential impactor and the date of its collision would determine the adopted defense strategy. Comets originate from the Oort Cloud, a reservoir of comets at 20,000 Astronomical Units (AU), at 500 times the distance from the sun to Pluto. It is estimated that up to a trillion comets exist in the Oort cloud. These comets are not affected by the sun's gravity, but other stars, that could propel them into the Milky Way galaxy or deflect them towards the sun, can affect them.

They also originate from the Kuiper belt containing up to 10 trillion comets orbiting closer to the sun beyond Neptune. The Kuiper belt comets can be very large with diameters of 100-300 kilometers. They are formed of icy low-density materials. The large planets like Jupiter and Saturn capture these comets if they veer towards the inner solar system, and in a unique way offer a protection for the Earth against them, allowing life to appear and evolve on Earth. The few that go past the large planets acquire orbits within the inner solar system and could collide with the inner planets.

We could suggest that the dense asteroids were preferentially captured allowing the lesser dense comets to impact Earth converting it into a water planet.

Figure 26. Haley's Comet nucleus.

Two categories of these comets exit.

1. Long Period comets:

Some have highly elliptic orbits or long period comets take millions of years to complete an orbit, and they spend most of their time outside the solar system. These can travel very rapidly within the inner solar system at 50-60 kms/sec. If it hits the atmosphere at high velocity, it would be vaporized before reaching the surface. If it penetrates the atmosphere, it can explode causing a blast and cause large damage. About 10 to 25 percent of the massive objects threatening the Earth are long period comets.

2. Short Period comets:

The second category is short period comets. These have velocities in range of 30 to 40 kms/sec. They could originate from long period planets affected by one of the large planets, changing its orbit from an elliptic to a more circular orbit. These comets spend most of their time within the inner solar system and can have orbits of less than 200 years. A renowned comet with a period of about 76 years is the Halley's Comet. The greatest threat to Earth comes from the short period comets since the time between detection and impact could be extremely short in the months range.

3. Asteroids:

In addition to short period comets, the greatest threat to Earth comes from asteroids designated as Near Earth Objects (NEOs). They travel at a typical speed of about 20 kms/sec. They originate from the asteroid belt, which is a broad zone between 1.8-4.3 AU from the sun, between Mars and Jupiter. It is suggested that they are the remains of a missing planet that was 2.8 times the mass of the Earth. It could have been shattered as an effect of Jupiter gravity.

We suggest that it could have shattered as a result of a collision also collided with Mars.

These are rocky fragments of main belt asteroids that end up within the inner solar system. A number of 18,000 of these small bodies are thought to exist. They range in length from 10 meters to 40 kilometers. About 200 of them have been identified. Between 5,000-10,000 of a diameter of 500 meters or more remain to be discovered, and there may be 2,000 of them of larger than 1 kilometer in diameters.

Three types of NEOs exist:

1. Atens orbit NEOs: These orbit very close to the sun with a mean distance to the sun of less than 1 AU, and an aphelian distance of larger than 0.983 AU.
2. Apollos orbit NEOs: These orbit just beyond the Earth, with a mean distance to the sun equal or larger than 1 AU. Their perihelion distance is less than 1.017 AU.
3. Amors orbit NEOs: These travel between Earth and Mars with a perihelion distance between 1.017 and 1.3 AU.

These near Earth asteroids have orbits that are highly chaotic and some do cross the Earth's path. The largest Earth path crossing asteroids are 1627 Ivar and 1580 Betulia with diameters of about 8 kms. Luckily NEOs have short lifetimes with 20 percent of them falling into the sun. However, a new supply of NEOs is generated from the main belt asteroids by impacts and by encounters with the planet Jupiter.

Extinct comets that have depleted their supply of volatiles are candidates for capture into near Earth orbits. It is estimated that about 0.3-0.5 of all near Earth asteroids are in fact extinct comets.

The orbits of asteroid objects, once detected, can be accurately calculated and can provide years of warning before an impact. This in contrast to long term comets orbits which can give only 250-500 days of warning, in addition to being dark objects that are hard to detect unless they get close to the sun which vaporizes their water and methane ice and displaying their characteristic tails.

COMET TAILS, METEOR SHOWERS AND COMAS

Comets have a lot of ice of carbon dioxide, carbon monoxide, and water. In deep space, these are frozen making up much of the solid nucleus of a comet. As the comet nears the sun in its orbit around it, it warms up, and these substances sublimate turning directly from solids into gases displaying the typical comet tail.

The gases and liquids can exist on and below the comet's surface. When they sublimate they can erupt from vents like geysers. These vents act like rockets, gently pushing on the comet nucleus. Over time, this can change the comet's orbit, which makes the accurate prediction of a comet's trajectory over very long periods of time difficult.

As the ices sublimates, the comet dissolves a little, and that rubble can escape. This material, usually objects the size of grains of sand up to small rocks, orbit along very nearly the same path as the comet nucleus itself causing meteor showers. The gas expands into a large fuzzy cloud around the nucleus, called the "coma, which is Latin for "hair." Although the nucleus may be a few kilometers in diameter, the coma can be several hundred thousand kilometers across.

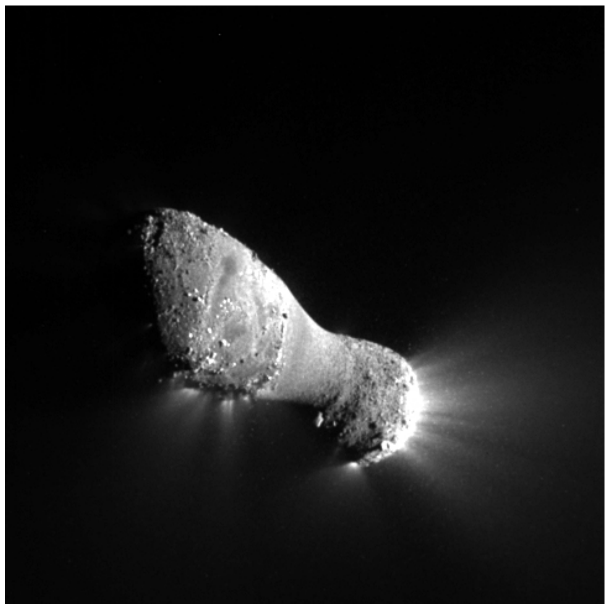

Figure 27. Comet Hartley 2 from NASA's EPOXI mission. It was taken from a distance of about 700 kilometers or 435 miles. The comet's nucleus, or main body, is approximately 2 kilometers or 1.2 miles long and .4 kilometers or 0.25 miles at the "neck," or most narrow portion. Jets can be seen streaming out of the nucleus. Source: NASA.

5.13 DEFENSE APPROACHES

GENERAL CONSIDERATIONS

The goal is to foretell the date and time of a potential catastrophe as well as forestall it. The defense approach would depend on both size of the object and the time at which it is detected.

Landing on an asteroid and pushing it as considered in Hollywood movies is not possible because it has a low gravity and with a crumbly surface, the lander might skid into space. Asteroids are also undergoing a twirling motion in space, and one cannot push a rotating object.

SPACE GRAVITY TRACTOR

For small objects, and with years of warning, a small spacecraft using its miniscule gravity could nudge an asteroid off course.

Only small impulses would be required to deflect a small to medium size object from its trajectory many decades before its encounter with Earth. Ordinary explosives can be used for that purpose. A spacecraft could hover near the object and fire its thrusters, gently tugging the asteroids along and towing it out of its initial trajectory. This "gravity tractor" would pull the asteroid off course at a fraction of a mile per hour. One can envision future space patrol whose task would be the elimination of such threats.

DEFLECTION APPROACHES

If an asteroid is hit with enough energy by ramming it for instance with a spacecraft to break it apart, the broken parts may continue on the initial trajectory. What is needed is to disperse the parts widely.

For large bodied, or for those that are close to impact time, nuclear explosives, whether fission or hybrid fusion fission devices would have to be used. Explosive devices that have been suggested for Pulsed Plasma Propulsion using directed energy can be used for the double purpose of propulsion and for deviation the objects from their paths. The characteristics of such a miniature nuclear explosive are given in Table 6.

It would take about 10 years to develop a defense system against astral assailants. This may be adequate for most asteroids and short period comets. But it may not be short enough to counter long period comets. It is suggested that a rail gun system positioned on Earth, on the moon, or in Earth orbit in space could double as an antimissile defense system and as an astral assailant interceptor. Such system might even be developed on an international cooperative basis.

Table 6. Characteristics of nuclear explosives used for astral object deflection and for Pulsed Plasma Propulsion.

Characteristic	Value
Yield	0.5 kT TNT
Mass	5 kgs, 11 lbs
Tamping Mass	1 kg, 2.2 lbs
Total Axial Impulse	1,113,070 N.sec
Equivalent Thrust	250,700 lbf.sec
Equivalent Specific Impulse, I_s	18,990 sec (lbf.sec/lbm)

A ground based deflection system has been proposed using gigantic lasers. The laser beams would heat up one side of the object causing it to crack and ultimately split off. The decrease in the object's mass would send it into a different orbit.

A mass driver system placed on a threatening asteroid has also been suggested. It would mine the material from the asteroid and launch it into space over a period of years. This would be a monumental engineering task considering that the asteroid would not have sufficient gravity for the driver system to stick to its surface.

Standoff explosions from a nuclear device detonated a few hundred meters from the target, would increase the temperature of one side ablating it, causing a rocket effect and altering the trajectory of the body. It is estimated that up to 10 kilotons of TNT equivalent explosive energy would be required to deflect a 10 kms wide body.

Surface explosions can result in cratering. This would be suitable for small objects since the fragments expelled could cause a threat to Earth themselves.

FRAGMENTATION APPROACHES

The best way to deflect an asteroid up to a mile in width is to detonate a nuclear charge nearby in a standoff nuclear blast. The intense x ray radiation would be absorbed on the surface, vaporizing and ablating it. The expanding vapor from the sacrificial layer would generate a rocket action propelling the asteroid away from its trajectory. Notice that because of the absence of air in space no blast wave would be formed.

A nuclear explosive would totally vaporize an object the size of the Tunguska comet around 150 feet.

The standoff distance and the yield must be optimized. At too far a distance, no effect would be noticeable and at at too close a distance too much shattering could occur.

Fragmentation is much less energy efficient than deflection. The generation of unpredictable fragments is the major disadvantage of such an approach. To avoid this problem, an explosion should be large enough to result in fragments of smaller than 10 meters in size. The only way to achieve this goal is to bury the nuclear explosive deep into the object. This would require the design of some sort of device to drill into the surface of the impactor while surviving in an extremely harsh environment, particularly on the surface of a comet.

Large amounts of energy would also be required. A 1 Mt TNT equivalent device would destroy a 750 meters sphere. A 1,000 Mt TNT device would be needed to shatter a seven kilometer body.

A proposal has been advanced to nudge other small asteroids into an exact Earth orbit to attack a larger asteroid.

These approaches are more suitable for asteroids than for long period comets. The only way to eliminate the threat of a long term comet is to totally disintegrate it requiring a prohibitive amount of energy.

5.14 FUTURE ALTERNATIVE DEFENSES

Some studies were conducted and suggested some defenses entailing ground and space based infrastructures much more extensive than those envisioned for ballistic missile defense. Because of the limitations of current space propulsion technologies these systems would require deployment of interceptors in deep space in order to allow engagement at a sufficient distance from Earth.

The low specific impulse methods suggested for altering these objects trajectories such as solar sails and electric thrusters would not provide enough time for reaching the orbit of the space object in time for altering the trajectories between the time of detection and the time of impact. Such schemes entail a high risk since their effectiveness will depend on the body’s shape, composition, trajectory and size, which are all unknowns beforehand. There is no room for error once the object is engaged and the propulsion system must operate for a long time for the maneuver to work. This is even more important in the case of comets since they offer a much shorter time detection span than asteroids.

Nuclear propulsion approaches with high specific impulses can offer more economical ground based defenses based on present day technology. If a catastrophic event were identified, high impulse nuclear systems can be promptly launched into space using conventional chemical lifting methods. The nuclear approach would provide high power density and specific impulse to rapidly travel to the space object to deflect it in time from its collision trajectory with Earth.

In addition, the high energy density of nuclear devices provides compactness, low weight and low cost per unit of energy output, as shown in Table 7.

Table 7. Comparative costs of energy release.

Source of Energy	Cost (Dollars/ 10^6 BTU)
Thermonuclear Explosive (2Mt TNT)	0.075
Electricity at $0.006 per kwh	1.78
Ammonium nitrate chemical explosive	4.50
Thermonuclear Explosive (10 kT TNT)	8.75
Trinitrotoluene (TNT) chemical explosive	250.0

Nuclear deflection approaches then can be also used to nudge the object at a large distance from the Earth from its trajectory, ablate its surface, or even fragment it into smaller objects with altered non impact trajectories.

Fusion based devices primarily generate x-rays which are absorbed in a few millimeters of an asteroid, ablating its surface and possibly nudging it from its trajectory.

Devices with primarily a neutron component can cause fragmentation since neutrons could penetrate the surface to about 10 cms.

A single or multiple pulse detonations of nuclear fission, fission/fusion or fusion devices can be used to easily alter the trajectory of the planetesimal from its collision course with Earth. Two stages occur in the process. First, the illumination of its surface by the prompt x-rays and gamma rays traveling at the speed of light from the pulse would cause ablation of the surface and generate thrust that is parallel to the object's projected area. This would be followed by a second wave consisting of the plasma of fission products producing a second impulse in the same direction. The process can be carried out remotely without astronauts being dispatched to carry out the process. It is also suggested that the thrust would be parallel to the object's projected area, independent of its mass distribution or angular momentum if it was rotating in space. The amount of impulse could be adjusted by the frequency of pulses, detonation standoff distance, and yield and type of the pulse unit.

If an External Pulse Plasma Propulsion (EPPP) system is used, it would double as the propulsion means as well the nudging means. This approach does not require any unrealistic asteroid capture or attachment of a propulsion unit to an unreachable surface that could be rotating, with insignificant gravity.

5.15 RAILGUN DEFENSE AGAINST STELLAR OBJECTS

It is suggested that hypervelocity electromagnetic rail guns, also called electric cannons, can be used to intercept stellar objects of different sizes. The payload from the rail gun can be launched from Earth or from space. It would be a reusable device since it would be far from the effects of any blast or debris from the diverted of shattered stellar object. The high speed allows the engagement of a target sooner and at a longer range. One can consider the delivery of kinetic energy projectiles such as Depleted Uranium (DU), fission of fusion devices payloads, or even an antimatter payload in the long term.

Hendrik Lorentz introduced the principle of operation of the railgun. The first rail gun was built in Germany during the World War II.

In a rail gun, the electric current path is I = ev and the magnetic flux is B. The current passes through the rails and the armature, which is a plasma. According to Lorentz law of magneto hydro magnetics, a resultant force F is generated that is perpendicular to both the current path and the magnetic flux. According to Lorentz equation:

$$\begin{aligned} \overline{F} &= e\overline{E} + \frac{1}{c} e\overline{v} \times \overline{B} \\ &= e\overline{E} + \frac{1}{c} \overline{I} \times \overline{B} \end{aligned} \qquad (5)$$

where c is the speed of light.

In the absence of an electric field E:

$$\begin{aligned} \overline{F} &= \frac{1}{c} e\overline{v} \times \overline{B} \\ &= \frac{1}{c} \overline{I} \times \overline{B} \end{aligned} \qquad (6)$$

The force uses the generated plasma to accelerate a projectile. The rails are constrained by the barrel, and the armature is allowed to move and accelerate the projectile. An arc discharge across the base of a projectile can act as an armature if it is confined behind the base of the projectile. Confinement of the plasma can be achieved if two rails are used above and below the projectile, and with insulating rail spacers to the right and left hand sides. In a solid armature were used, the projectile must maintain contact while sliding along the rails. With such type of device velocities of 2 km/sec can be attained. Higher velocities reaching 11 km/sec can be achieved with plasma arc armatures, eliminating the contact. This velocity is about 10 times the speed of a rifle bullet or 30 times the speed of sound. Problems of erosion of the gun barrel would have to be surmounted.

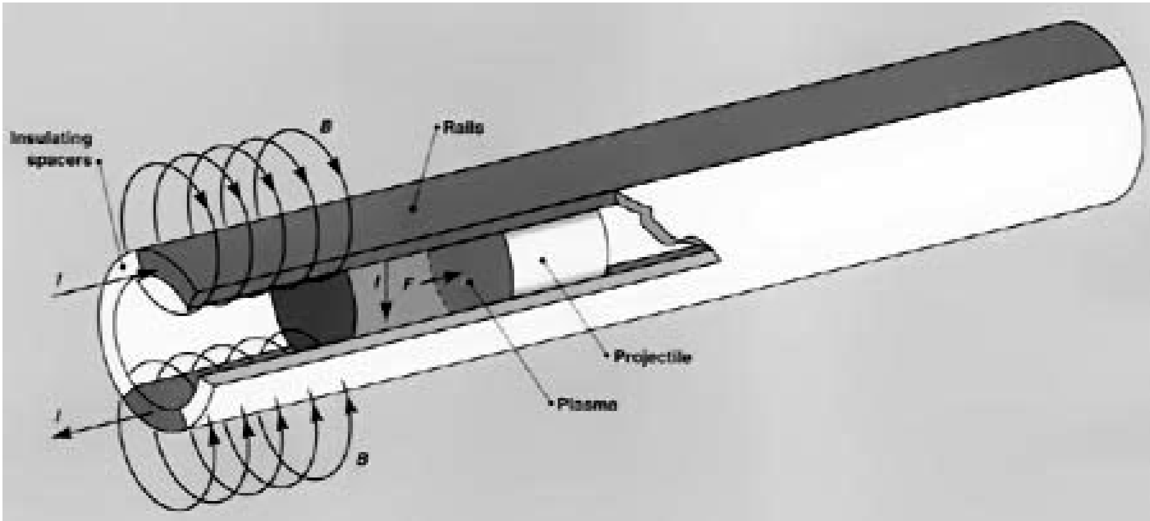

Figure 28. Principle of operation of a rail gun.

In the simplest type of armature shown in Fig. 28, a bore is fully packed with a plasma. The plasma is formed from a metal foil mounted on the back-side of the projectile. The current in the plasma initially vaporizes it. Long pulse mega-ampere currents have used large capacitor banks to generate a magnetic flux. Explosives were then used to compress the magnetic flux to generate the high current needed to power the gun. Explosive generators can be replaced with capacitor banks.

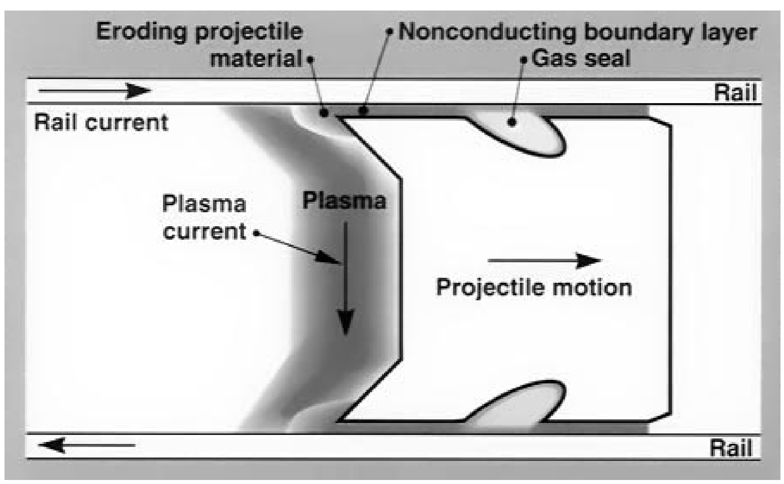

Figure 29. Full bore Plasma armature for railgun.

A two stage gun can be used with the first stage as a gas gun accelerating the particle to 1 km/sec. In the first stage, the hot gases from a powder propellant drive a piston which compresses hydrogen gas in a pump tube. In the second stage, the high pressure gas ruptures the valve, accelerating a projectile down the launch tube toward a target.

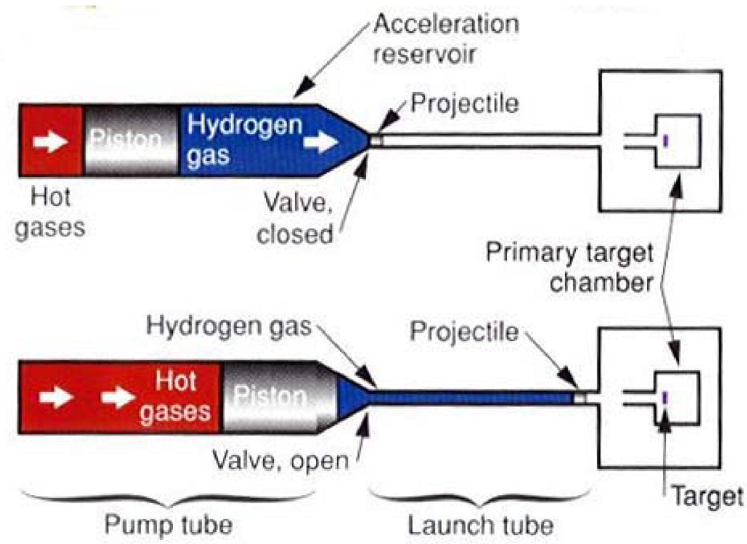

Figure 30. Operation of a two stage gas gun.

In a solid armature, the metal link conducts the current throughout contact through the rail. A hybrid armature uses a metal link that nearly touches the rails and plasma brushes at the interface of the link and rails. Magnetic pressure in the brush chamber keeps the plasma brush compressed to a short length. A tandem armature approach combines a hybrid armature to a full-bore plasma armature. The metal mass vaporizes gradually as the result of current flow. The vaporized metal supplies the plasma armature and keeps close to the projectile maintaining continuous acceleration. Some conductive materials seed the plasma could be from the brushes that erode from the projectile itself, instead of from the gun rails. Figure 31 shows an experimental rail gun at GA (General Atomics) Technologies, San Diego, California.

Figure 31. Rail gun at GA technologies, San Diego, California.

5.16 ANTIMATTER DEFENSE

There has been speculation that comets may contain antimatter material brought in from the far reaches of space. It is suggested that the gas and dust jets around the core of the Borelli comet contained antimatter. If proved true, they could become sources of antimatter for propulsion for distant interplanetary travel. It is suggested that the trapping of an antimatter meteorite for use to deflect a larger astral assailant may be a worthwhile scientific project for the protection of life on Earth.

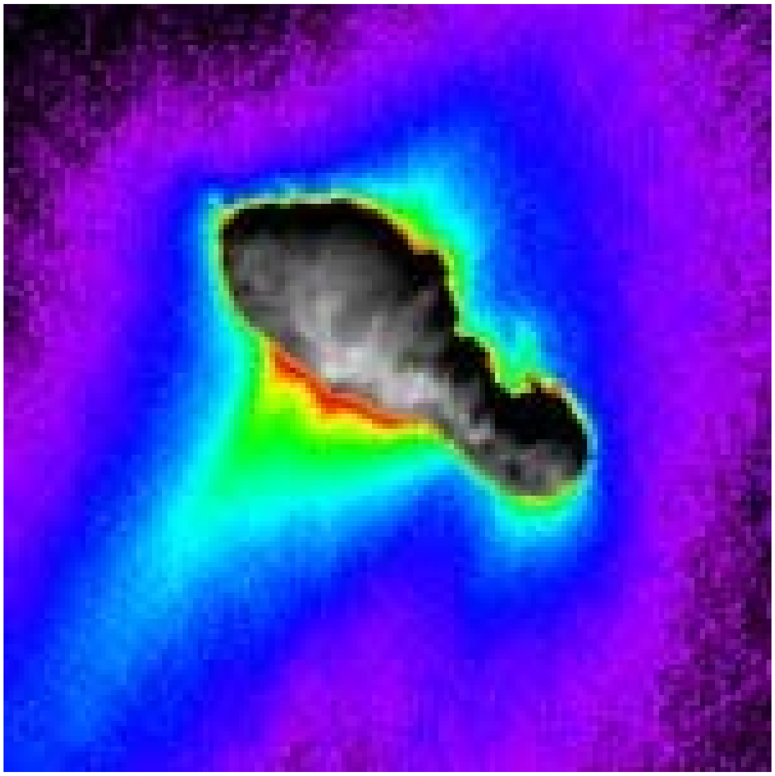

Figure 32. Comet Borelli dust and gas jets form a coma around its nucleus.

5.17 DEEP IMPACT PROBE

The Deep Impact mission was implemented by NASA to provide a glimpse beneath the surface of a comet, where material from the solar system's formation remains relatively unchanged. The project hoped to answer basic questions about how the solar system formed, by providing an in-depth picture of the nature and composition of the frozen celestial travelers known as comets.

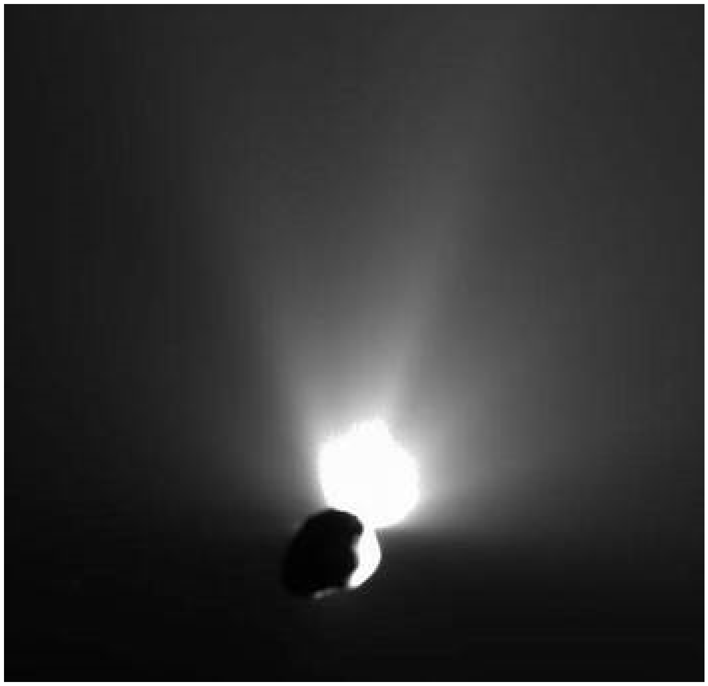

Figure 33. Collision of Deep Impact Probe with comet Tempel 1 on July 4th, 2005.

The hyper-speed collision of Deep Impact probe generated an immense flash of light, which provided an excellent light source for the two cameras on the Deep Impact mother ship. Deep Impact scientists theorize the 820 lb impactor was vaporized deep below the comet's surface when the two collided at 1:52 am July 4, 2005 at a speed of about 10 kilometers per second which corresponds to 6.3 miles per second or 23,000 miles per hour.

5.18 QUADRUPLE EXTINCTION THEORY

Offshore of Mexico's Yucatán Peninsula is a 110 mile or 180 km wide crater named Chicxulub. It is believed to be the site of an asteroid impact 65 million years ago that wiped out the dinosaurs. The associated mass extinction, thought to have obliterated 2/3 of the world's species in has been called the K-T extinction since it bridges the Cretaceous and Tertiary geologic periods.

The theory that the dinosaurs' extinction about 66 million years ago was linked to an asteroid impact was first proposed in 1980. The biggest piece of evidence was the so-called Chicxulub crater off the Yucatan coast in Mexico. It is believed to have been formed by a six-mile or 9.6-km wide object that melted rock as it slammed into the ground, filling the atmosphere with debris that eventually rained down on the planet. Glassy spheres known as tektites, shocked quartz and a layer of iridium-rich dust are still found around the world today.

However another theory exists that the dinosaurs were killed not by a lone asteroid strike but by the quadruple whammy of global climate change, massive volcanism, and two gigantic collisions. The theory involves tiny glass beads, the rare element iridium, and sediments that might be deposits from gigantic tsunamis caused by the Chicxulub impact.

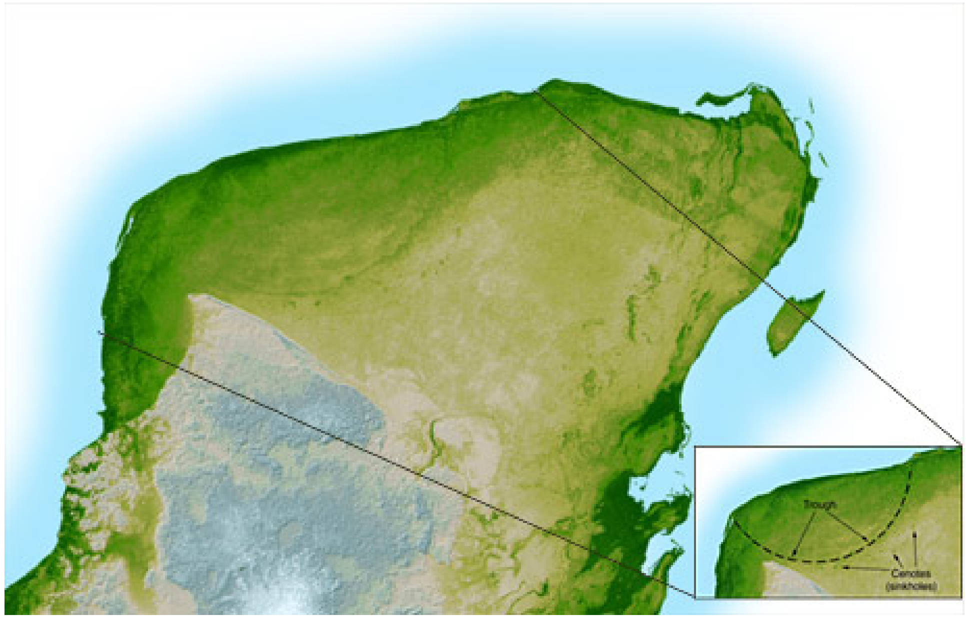

Figure 34. Chicxulub Crater mapping. Source: NASA, JPL, Caltech.

The theory is that the Chicxulub impact predated the K-T extinction by about 300,000 years. The Chicxulub event would have filled the atmosphere with vaporized rock that quickly condensed and rained to Earth as tiny spherules, about 1/10 of an inch or1-4 mm in diameter. The spherules and iridium occur in two separate layers of Earth, or strata, separated by as much as 25 ft or 8 m of intervening sediment. It is suggested that the intervening sediment was laid down quickly by a series of tsunami waves created by the Chicxulub impact. An analysis of the sediment layers suggests that the sediment was formed between two separate asteroid strikes, one that laid down the glass and the other the iridium.

According to this theory, Chicxulub, rather than causing widespread devastation, had no long term ecological effect. The geological evidence indicates that Earth was undergoing a large number of changes during the 500,000 years preceding the K-T boundary. These included a global climate change that had slowly cooled Earth during the previous several million years. Massive volcanism on the Indian subcontinent produced a rapid 7-13 degree Fahrenheit or 4-7 degree Celsius warming. The Chicxulub asteroid hit about a hundred thousand years after that, but the warming continued for another hundred thousand years until the Earth suddenly cooled again. The already stressed biota was hit by the second asteroid impact that produced the iridium layer. This was the straw that broke the Earth’s camel back, culling out all but the species that were already adept at adapting to rapid climate fluctuations.

5.19. GEOLOGICAL DATING RESULTS

The latest scientific geological dating results suggest that the dinosaurs died off about 33,000 years after the asteroid hit the Earth, much sooner than scientists had believed, and the asteroid may not have been the sole cause of extinction. The Earth's climate may have been already at a tipping point when the massive asteroid smashed into what is now Mexico's Yucatan Peninsula and triggered cooling temperatures that wiped out the dinosaurs.

The time between the asteroid's arrival, marked by a 110-mile or 180-km wide crater near Chicxulub, Mexico, and the dinosaurs' demise was believed to be as long as 300,000 years. A study based on high-precision radiometric dating techniques, suggest that the events occurred within 33,000 years of each other. The dinosaur extinction date and the crater formation event occurred within a much tighter window in time than previously known. The study looked at tektites from Haiti, tied to the asteroid impact site, and volcanic ash from the Hell Creek Formation in Montana, a source of many dinosaur fossils [10].

The previous data said that the tektites and the ash were different in age, that they differed by about 180,000 years and that the extinction happened before the impact, which would totally preclude there being a causal relationship.

The latest evidence suggests that the asteroid impact was not the sole reason for the dinosaurs' demise. Ecosystems already were in a state of deterioration due to a major volcanic eruption in India when the asteroid struck. The asteroid strike provided the coup-de-grace for the final extinctions. The theory was speculative, but backed by previous ties between mass extinction events and volcanic eruptions.

About 1 million years before the impact, Earth experienced six abrupt shifts in temperature of more than 2 degrees in continental mean annual temperatures. The temperature swings include one shift of 6 to 8 degrees that happened about 100,000 years before the extinction. The brief cold snaps in the latest Cretaceous, though not necessarily of extraordinary magnitude, were particularly stressful to a global ecosystem that was well adapted to the long-lived preceding Cretaceous hothouse climate. The Chicxulub impact then provided a decisive blow to already weakened ecosystems.

5.20 END-TRIASSIC EXTINCTION, 200 MILLION YEARS BEFORE PRESENT

The End-Triassic extinction, about 200 million years before present, is the 4th known major extinction in the history of the Earth. The extinction is thought to have opened provided opportunities for the dinosaurs to diversify and thrive in the following 135 million years.

The extinction was caused by the eruption of massive volcanoes in what is today Nova Scotia and New Brunswick in Canada, the northeastern USA and Morocco. One of the largest lava flows on Earth occurred in the Bay of Fundy, Canada, was capable of producing poisonous gases that affect the Earth's environment causing the End-Triassic extinction including early crocodile relatives, tree lizards, broad-leafed plants, eel-like fish or conodonts, and ammonites.

There was some scientific debate about whether the extinction was caused by a meteorite impact, like the one thought to have wiped out the dinosaurs 135 million year later, or a major volcanic eruption like the ones that caused most other major extinctions.

A study, led by Terrence Blackburn at the Massachusetts Institute of Technology [11], suggests that eruptions in Morocco likely started the mass extinction, while eruptions in Atlantic Canada and the northeastern USA ramped it up about 3,000 and 13,000 years later. The study suggests that both the Moroccan eruption and the start of the mass extinction started 201,564,000 years ago.

The ancient volcanoes were long, magma-spewing fissures in the Earth crust, similar to the Krafla eruptions in Iceland. At the time of the eruptions, the Atlantic Ocean did not exist, and Africa and North America were joined as part of a super continent known as Pangaea. Over 600,000 years, the eruptions in an area known as the Central Atlantic Magmatic Province, deposited roughly 10 million km^3 of lava.

Crystals of zircon that form as the lava cools, trapping small particles of uranium in the process, were analyzed. The uranium decays into lead at a consistent rate. By measuring the uranium to lead ratio, it is possible to date the age of the basalt layers.

The method cannot be used on the sedimentary rocks containing fossils. A way to measure the relative age of sedimentary rocks is by using the fingerprint left by changes in the Earth's orbit over time or “astrochronology” In cases where the sedimentary rocks were sandwiched between basalt, the astrochronological fingerprint can be calibrated to actual dates and use that to figure out the dates of events in sedimentary rock samples that were not close to any basalt layers.

The massive eruptions would have blasted CO_2 gas and a sulfurous smog into the atmosphere. The smog would have blocked out the sun, causing a multi-year winter. Once the sulfurous dust had settled, the CO_2 would have caused rapid warming.

5.21 COMET IMPACT, 12,900 YEARS BEFORE PRESENT

About 12,900 years before present, a massive global cooling event abruptly occurred, along with the end of the line for some 35 different mammal species, including the mammoth, as well as the native human prehistoric North American Clovis culture.

Nanodiamonds found in the sediments from this time period point to a massive explosion or explosions by a fragmentary comet, similar to but even larger than the Tunguska event of 1908 in Siberia.

Figure 35. Layer of dark sediment at Murray Springs, Arizona, 40 cm thick with nano-diamonds and a concentration of iridium points out to a comet impact about 12,900 years ago that wiped out 35 mammal species , including the mammoths. Photo: Doug Kennet, University of Oregon at Eugene, Oregon.

Sediments from six sites across North America at Murray Springs, Arizona.; Bull Creek, Oklahoma; Gainey, Michigan; Topper, South Carolina; Lake Hind, Manitoba; and Chobot, Alberta, yielded such nanodiamonds which only occur in sediment exposed to extreme temperatures and pressures, such as those from an explosion or impact.

A fragmented comet bursting in the atmosphere or raining down on the oceans could have set off the 12,900 years cooling period in the Northern Hemisphere known as the Younger Dryas for the abundance of an alpine flower's pollen found during the interval.

The cooling period interrupted an extended warming out of an ice age predicted by slight changes in Earth's orbit known as the Milankovitch cycles that continues today. It remains an unexplained anomaly in the climatic record.

A series of cometary fragments exploding over North America might explain a layer of soil immediately prior to the cooling containing unusually high levels of the element iridium which is more common in cosmic wanderers like meteoroids than in the Earth's crust. Paired with the fact that this layer occurs directly before the extinction of at least 35 genera of large mammals including the mammoths, it is strong circumstantial evidence for a cosmic event.

Strong impact indicators of a large scale comet or carbonaceous chondrite impact are found in the sediments directly above, and often shrouding in the case of Murray Springs, the remains of these animals and the people who were hunting them.

Preliminary searches further afield in Europe, Asia and South America, have turned up similar minerals and elements in sediments of the same are consistent with a fragmentary body breaking up with air shocks and possible surface impacts in various parts of North America. It could have occurred above the ice sheet or offshore in the ocean since no impact crater has been found to date.

5.22 ASTEROIDS DETECTION EFFORTS

The asteroid 2012 BX34, which is about the size of a city bus, passed within 36,750 miles (59,044 kilometers) of the Earth at about 10:30 a.m. EST (1530 GMT) on Friday, January 27, 2012. The space rock is about 36 feet (11 meters) wide, making it much too small to pose a threat to Earth. Asteroid 2012 BX34 zipped by at a distance about 0.17 times that separating Earth and the moon. The moon orbits Earth at an average distance of about 240,000 miles (386,000 km).

The next week in February 2012, an asteroid labeled "(433) Eros" measuring 30 by 13 by 13 kilometers (19 by 8 by 8 miles) approached Earth closer than any asteroid of this size has for a long time following a circular path far beyond the moon's orbit.

The USA Congress in 1998 mandated to NASA the task of identifying at least 90 percent of the largest asteroids and comets in the inner solar system. These include objects larger than 0.6 mile in diameter. Telescopes as of 2008 pinpointed more than 700 out of an estimated population of 1,000. In 2005, Congress directed NASA to track down the far more numerous asteroids larger than 460 feet in diameter, which can destroy a city or a state. It amended the Space Act to entrust NASA with the specific responsibility to “Detect, track, catalog and characterize” asteroids and other NEOs.

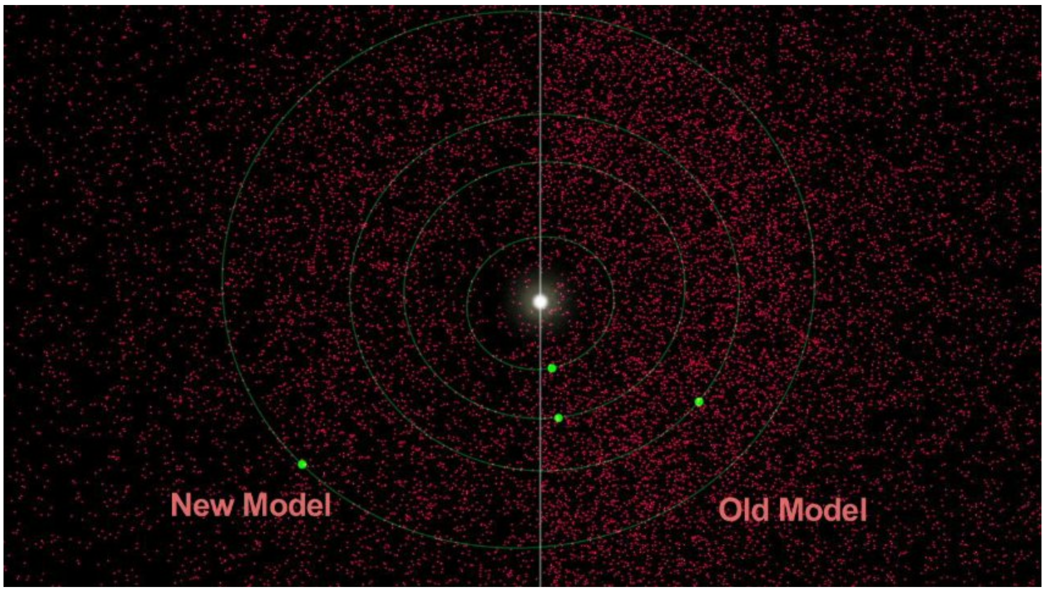

Figure 36. Asteroids with diameters greater than 330 feet (100 meters) are shown in red. The sun is shown in the middle, while the four green dots representing Mercury, Venus, Earth and Mars. The "Wise" infrared telescope data suggest there are over 980 asteroids with diameters of at least one kilometer in length. There are around 19,500 mid-sized examples, with diameters between 100-meters and one-kilometer long, most of which remain undiscovered. Source: NASA.

Figure 37. Bolide or meteorite explosion in the night sky. Photo: NASA.

There exist two large new survey telescope projects to detect would be killer asteroids.

On a peak on the Hawaiian island of Maui, the Panoramic Survey Telescope And Rapid Response System or Pan-STARRS, to begin operation in 2008 uses an array of four 6 ft or 1.8 m wide telescopes and camers in Hawaii to scan the skies for asteroids. It uses a 1.4 x 109 pixels camera that produces images that, if printed, would cover one half of a basketball court. The data is to be scanned by computers flagging statistical anomalies that astronomers can check with their eyes. Eventually 10,000 potentially hazardous asteroids will be catalogued.

The Large Synoptic Survey Telescope in Chile scheduled for 2014, will use a giant 27.5 ft or 8.4 m wide telescope to search for killer asteroids

The Outer Space Treaty which bans the use of nuclear weapons in space needs to be amended to allow for defense against extraterrestrial objects. The Association of Space Explorers, includes a team of scientists, risk specialists, and policymakers to draft a treaty, which will be submitted to the United Nations (UN) for consideration in 2009. The treaty would detail the standardized international measures that will be carried out in response to any asteroid threat. The uncertainty involved in predicting the path of an incoming asteroid makes a coordinated global response essential.

The occurrence of hurricanes or tornadoes cannot be prevented but humanity has evolved way beyond the dinosaurs with the intellectual and technological capability of preventing an asteroid impact, enhancing the survival of life on Earth.

5.23 TROJAN ASTEROIDS

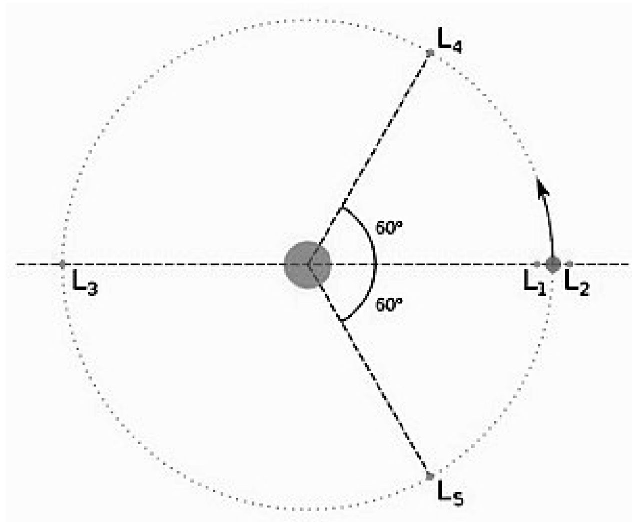

Figure 38. Lagrangian points around planets.

As the gravitational field of the Earth interacts with the gravitational field of the sun there are locations along the Earth's orbit with zero gravity where other bodies can hang out without getting shoved around too much by any celestial bodies. These spots are called the Lagrangian points: L1-L5. While there are five of them, only two are stable, and they are perpetually located 60 degrees in front of the Earth and 60 degrees behind the Earth in its orbit. A zero-gravity space manufacturing station can be built at these points.

Every planet in the solar system has these same stable points, and there are asteroids referred to as Trojans along the orbits of Mars, Jupiter, and Neptune. They are hard to see from Earth since one cannot look 60 degrees ahead or behind the Earth's orbit without getting a telescope glared with sunlight. The Wide-Field Infrared Survey Explorer was launched by NASA in December 2009 and it discovered that the Earth has company in the form of the 2010 TK7 1,000 foot (200-300 m) wide Trojan asteroid at the Lagrangian point L4 preceding the Earth in its orbit that the Earth is going to keep on chasing around the sun for eternity. It travels above and below the plane of the Earth's orbit and poses no immediate hazard as it is expected to remain stable for the next 10,000 years at 80 million km from Earth, coming no closer than 25 million km.

5.24 EUROPEAN MITIGATION STRATEGIES

A consortium is working on behalf of the European Union to develop "mitigation" strategies against potential cosmic killers. At the German Aerospace Center's Berlin-based Institute of Planetary Research, a three-year NEOShield project was launched.

The European Commission recently decided to invest €4 million ($5.3 million) in the NEOShield project. An additional €1.8 million will come from scientific institutions and industry partners. The goal is a blueprint for a test mission by European Space Agency (ESAto be launched as by 2020.

A host of ideas are proposed for how to deal with an approaching asteroid. The "kinetic impactor" idea envisions using a massive projectile to knock an asteroid off course. The "gravity tractor" idea entails having a small probe hover near the asteroid and use its gravitational traction to deflect it from an Earth-bound course. An approach to the problem involves launching an all-out attack with nuclear missiles.

Astrium, a subsidiary of the European aerospace giant EADS is involved in the project. Astrium has two teams working on potential designs for a "kinetic impactor." Company experts have already tinkered with ideas for this kind of spacecraft on behalf of the ESA. A so-called "Don Quijote" mission study program is on the drawing-board.

A team from the Carl Sagan Center of the SETI Institute, based in Mountain View, California, is exploring the concept of the "gravity tractor." In this case, a small probe would be brought into precise position to hover near the asteroid. Its mass would gradually provide "gravity traction to produce the required deflection" that would take the asteroid out of its collision course with Earth.

The "blast deflection" alternative is the "final, desperate approach." Russian experts at TsNIIMash, the engineering division of the Russian Federal Space Agency (Roskosmos) that develops things such as long-range ballistic missiles and air defense missiles, will also be involved in researching this idea as part of the larger NEOShield project. The United Nations has already put the issue of using nuclear explosives in space on its agenda, but nobody is counting on seeing an agreement made anytime soon.

Researchers at the German Aerospace Center (DLR) are considering the idea with the idea of launching an asteroid mission, even though it only entails observation designated as the "AsteroidFinder" mission.

5.25 USA AIR FORCE AND NASA BOLIDES MONITORING

During the Cold War period, the USA Air Force launched into Earth orbit satellites meant to spot nuclear tests and missile launches. The satellites were also quite good at detecting the explosions or of meteorites, or “bolides” like the one over Tunguska.

These events do occur several times a year. The USA Air Force has recorded a range of data on bolides, including: date, time, location and altitude of the explosion, meteorite velocity and total radiated energy of the blast. The Air Force shares information without giving away the capabilities of its most secret satellites.

The Air Force has run into a similar problem with its mysterious X-37B space plane. The X-37 is meant, in part, to boost military space awareness. A shared bolide-tracking system could be modeled on the current Space Situational Awareness Sharing Program, which uses USA military systems to track orbital debris, and shares that data with other government agencies, foreign countries and private companies.

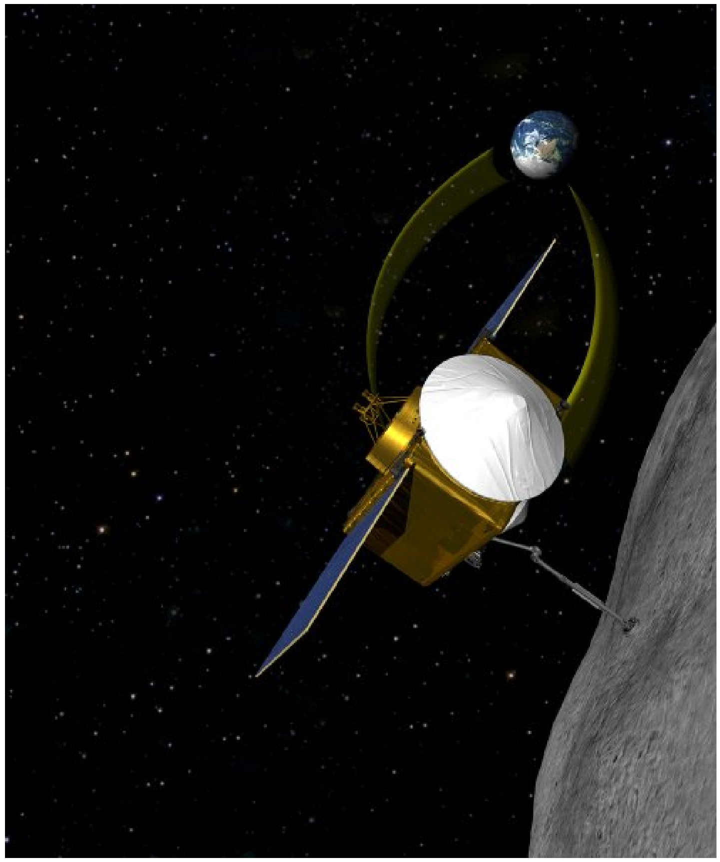

Figure 39. NASA plans to launch its "OSIRIS-REx" probe in 2016 to pay a visit to the asteroid "1999 RQ36." The probe will return to Earth seven years later with up to two kilograms (4.4 pounds) of sample material in its hold. Source: NASA.

In September 2011, NASA announced that it had catalogued about 90 percent of the largest asteroids whose orbits bring them near Earth. This is a major goal set by Congress in 1998. Using NASA's WISE asteroid-mapping mission as a guide, scientists estimate that there are about 981 near-Earth asteroids the size of a mountain or larger. About 911 of those space rocks have been spotted. NASA estimates from results of the Wise infrared telescope that there are over 980 asteroids with diameters of at least one kilometer in length. There are also around 19,500 mid-sized ones, with diameters between 100-meters and one-kilometer long, most of which are still undiscovered.

NASA plans to launch its "OSIRIS-REx" probe in 2016 to pay a visit to the asteroid "1999 RQ36." If everything goes according to plan, the probe will return to Earth seven years later with up to two kilograms (4.4 pounds) of sample material in its hold. Finding and mapping the orbits of these potentially hazardous space rocks is a task crucial to the long-term survival of our species.

5.26 KINETIC IMPACTOR TECHNIQUE DART ASTEROID BULGING MISSION [13]

A Falcon 9 rocket carrying the Dart spacecraft blasted off on November 34, 2021 from Vandenberg Space Force Base in California. It is the first attempt to deflect an asteroid for the purpose of learning how to protect Earth. Dart will only be changing the period of the orbit of Dimorphos by a tiny amount. The $325m (£240m) Dart mission will target a pair of asteroids that closely orbit each other - known as a binary. The larger of the two objects, called Didymos, measures around 780m across, while its smaller companion Dimorphos is around 160m wide.

Objects of Dimorphos' size could explode with many times the energy of a typical nuclear bomb, devastating populated areas and causing tens of thousands of casualties. Asteroids with a diameter 300m and larger could cause continent-wide destruction, while those bigger than 1km would produce worldwide effects.

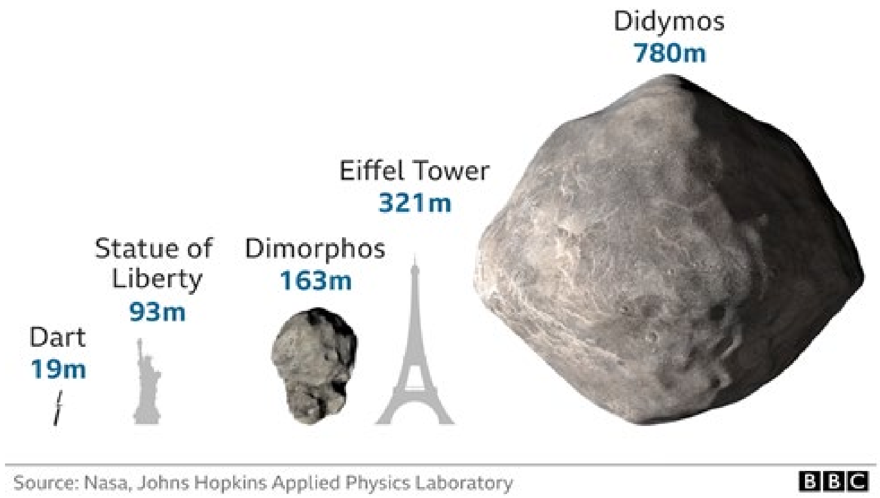

Figure 40. Size comparison of Didymos and Dimorphos asteroids.

Figure 41. Dart satellite. Source: NASA.

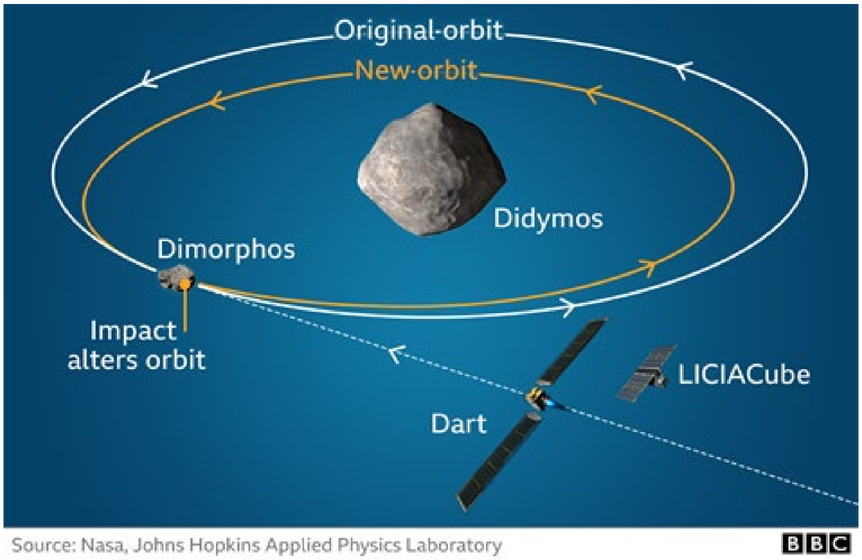

Figure 42. Dart mission in modifying the orbit of the binary asteroid system.

After escaping Earth's gravity, Dart will follow its own orbit around the Sun. It will then intercept the binary as it approaches within 6.7 million miles of Earth in September 2022. Dart will smash into the "moonlet" Dimorphos at a speed of around 15,000 mph (6.6 km/s). This should change the speed of the object by a fraction of a millimeter per second - in turn altering its orbit around Didymos. It is a very small shift, but it could be just enough to knock an object off a collision course with Earth.

In 2005, the USA Congress directed Nasa to discover and track 90% of near-Earth asteroids larger than 140m (460ft). No known asteroids in this category pose an immediate threat to Earth, but only an estimated 40% of those objects have actually been found. A binary is the perfect natural laboratory for such a test. The impact should change Dimorphos' orbit around Didymos by roughly 1%, a change that can be detected by ground telescopes in weeks or months.

Dart's method for dealing with a hazardous asteroid is known as the kinetic impactor technique. However, there are other ideas, including moving the asteroid more slowly over time and even detonating a nuclear device; an option familiar from science fiction movies such as Armageddon and Deep Impact.

EXERCISE

1. Calculate the kinetic energy and yield of an iron-nickel meteorite of 10 meters in diameter with a density of 8 gm/cm^3 travelling at a speed of 60 km/sec in Mt of TNT equivalent.

APPENDIX

METEORITE IMPACTS CRATERS

Figure A1. Discovered in 1902 by Daniel Barringer, Meteor Crater, Coon Butte, Canyon Diabolo, 55 km east of Flagstaff, Arizona, USA. 49,000 years old, 1.2 km, ¾ mile diameter, Ni-Fe meteorite 150 ft in diameter, speed 40,000 mph, 20 MT of TNT equivalent. 0.75 miles or 1.2 km diameter. Source: JPL, NASA.

Figure A2. New Québec, Québec, Canada. 1.5 million years old, 3.4 km, 2 miles in diameter. Source: JPL, NASA.

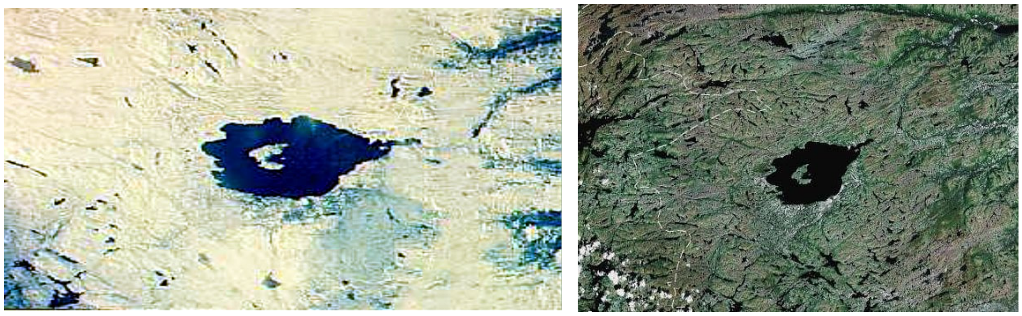

Figure A3. Mistastin Lake, New-Foundland, Labrador, Canada. 35-38 million years old, 28 kms 17.4 miles diameter. Source: JPL, NASA, Google Maps.

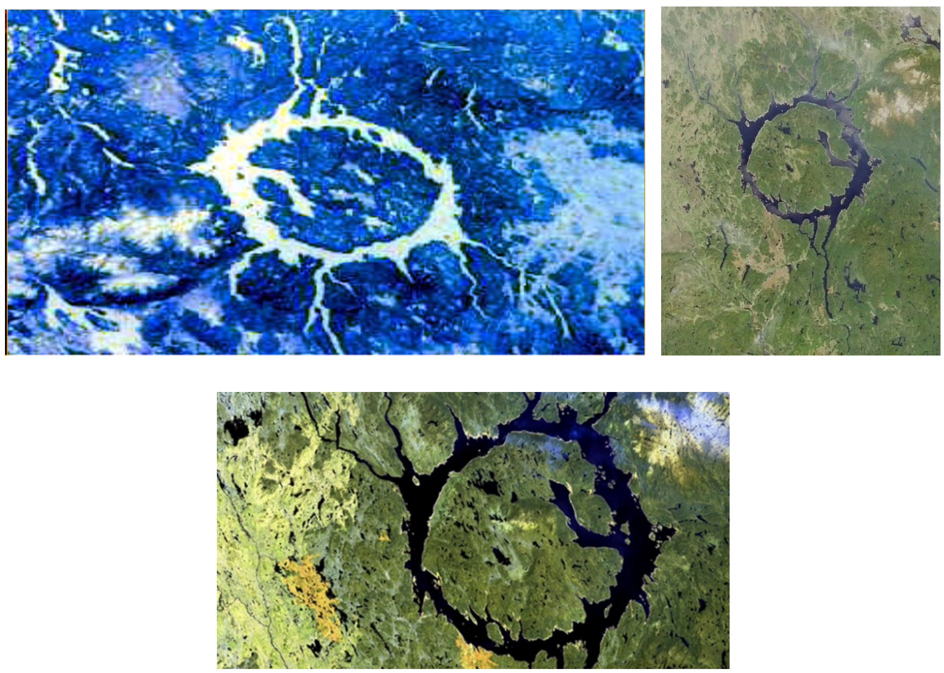

Figure A4. Lake Manicouagan Reservoir, Eye of Québec, Canada. 206-215 million years old. 100 km, 62 miles diameter. Caused by 3 mile, 5 km wide asteroid. Source: JPL, NASA.

Figure A5. Iturralde, Northern Bolivia. 11,000-30,000 years old. 8 km, 5 miles in diameter. Source: JPL, NASA.

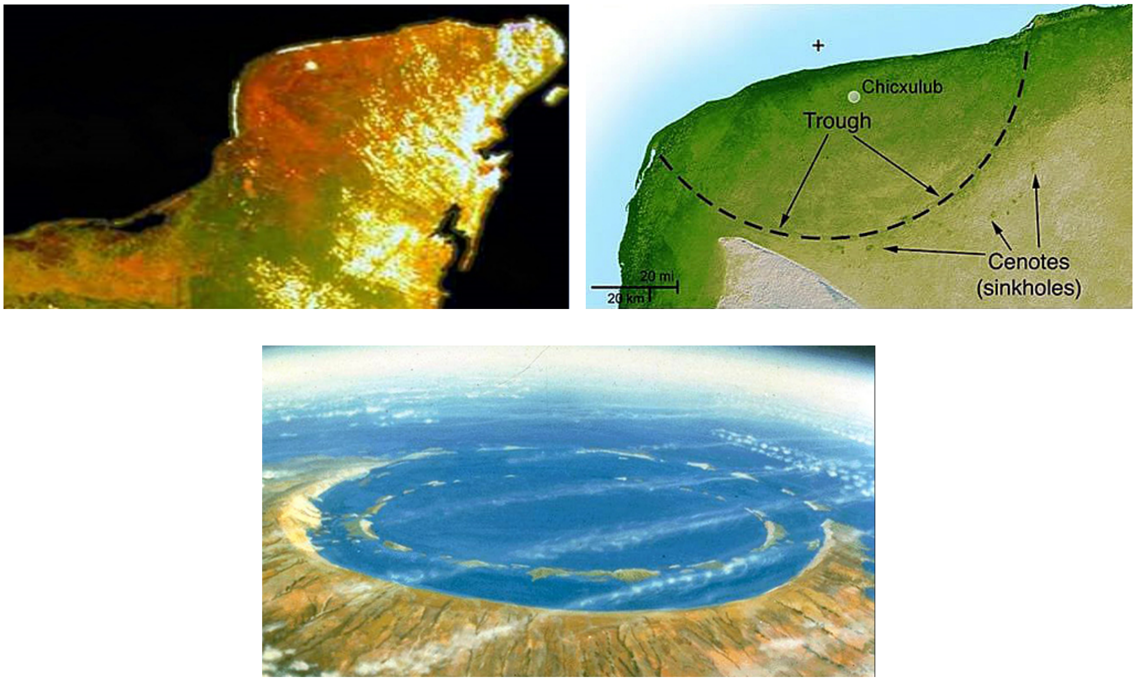

Figure A6. Chicxulub (The Tail of the Devil, in Mayan) crater, Yucatan Peninsula, Mexico. 65 million years old. Estimated 170-300 km, 106-186 miles diameter. Asteroid or comet the size of a small city with 100 teratons of TNT equivalent. Caused tsunamis, earthquakes, volcanic eruptions around the globe. Source: JPL, NASA.

Figure A7. Goat Paddock, Northwest Australia. 55 million years old, 5 km, 3 miles diameter. Source: JPL, NASA.

Figure A8. Wolf Creek Western Australia. 300,000 years old. 1.2 km, ¾ mile in diameter. Source: JPL, NASA.

Figure A9. Rotter Kamm, Namibia. 3.5 million years old. 3.5 million years old. 2.3 km, 1 mile diameter. Source: JPL, NASA.

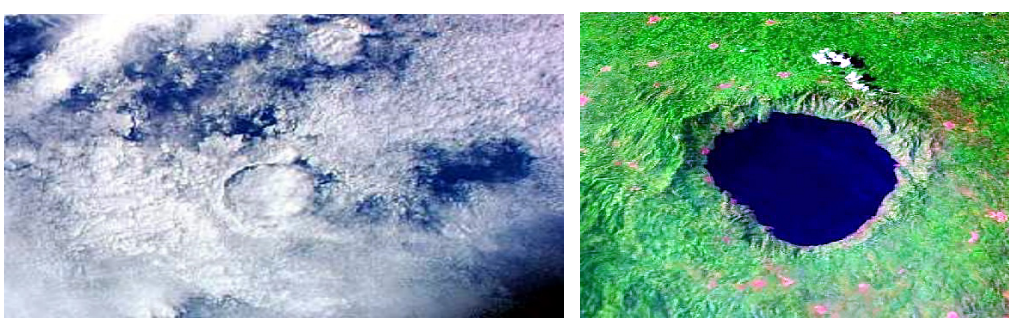

Figure A10. Lake Bosumtwi, 30 km SE of Kumasi, Ghana in West African Shield. 1.3 million years old. 10.5 km, 6 miles diameter. Source: JPL, NASA.

Figure A11. Aorunga, Chad. 350 million years old. 13 km, 8 miles diameter. Source: JPL, NASA.

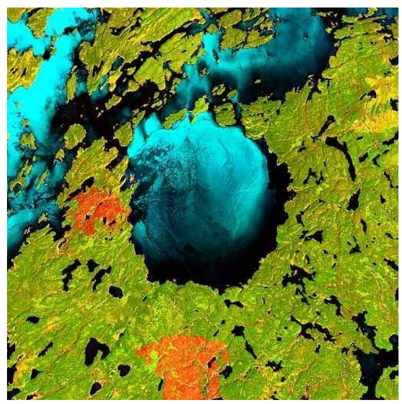

Figure A12. Deep Bay, near SW tip of Reindeer Lake, Saskatchewan Canada crater, 8-mile, 13-km wide, formed 100-140 million years ago.

Figure A13. Gosses Bluff, Australia. 142 million years ago, 15 miles or 22 km in diameter, 16,400 ft or 5 km depth crater from comet or asteroid 22-km in diameter impact at 40 km/sec speed. 22,000 MT of TNT equivalent.

Figure A14. Clearwater Lakes, eastern shore of Hudson Bay, Québec, Canada. 290 million years ago. West Clearwater Lake: 20 miles or 32 km diameter, East Clearwater Lake: 13.7, 22 km diameter.

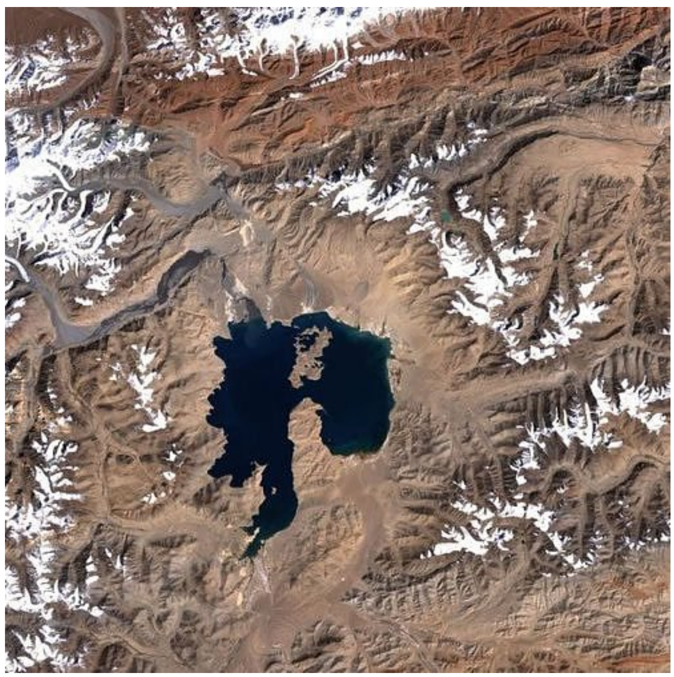

Figure A15. Kara-Kul, Qarokul Lake, and Ust-Kara craters, Pamir Mountains, Tajikistan. 70.3 million years ago, 16 mile, 25 km wide lake within a 28 miles or 45 km depression, 13,000 ft, 3,900 m above sea level.

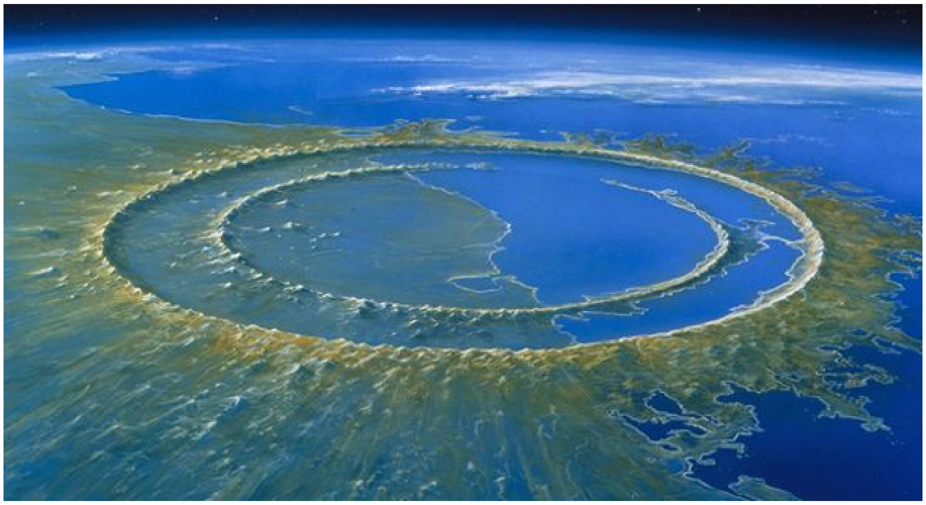

Figure A16. Vredefort crater, Free State, South Africa, 118 miles or 190 kms radius, 2 billion years before present. Known as the Vredefort Dome; world widest impact crater.

Figure A17. Acraman crater, Lake Acraman, South Australia, 580 years before present, 56 miles or 90 kms diameter.

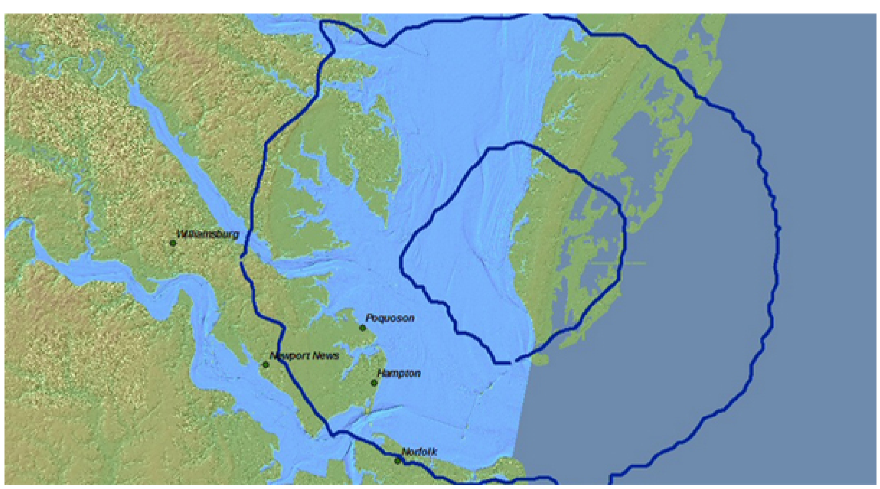

Figure A18. Cheasapeake Bay crater, discovered in the 1980s, 125 miles or 201 kms from Washington DC, USA. Impact was 35 million years before present, 53 miles or 85 kms diameter.

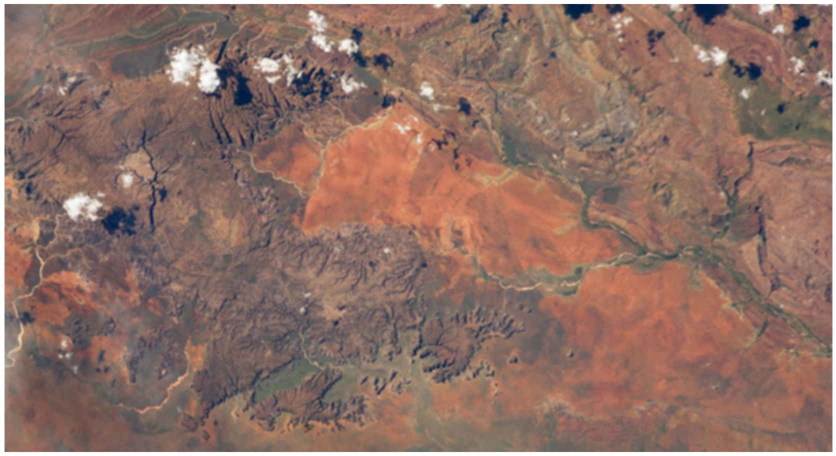

Figure A19. Popigai crater, Siberia, Russia, 35.7 million years before present. Considered a large deposit of “impact diamond.”

Figure A20. Morokweng crater, near Kalahari desert, North West South Africa, 145 million years before present.

Figure A21. Woodleigh crater, Western Australia, 365 million years before present, 25-75 miles or 40-120 kms in diameter.

Figure A22. Sudbury crater, Ontario, Canada, 1.8 billion years before present, 81 miles or 130 kms in diameter.

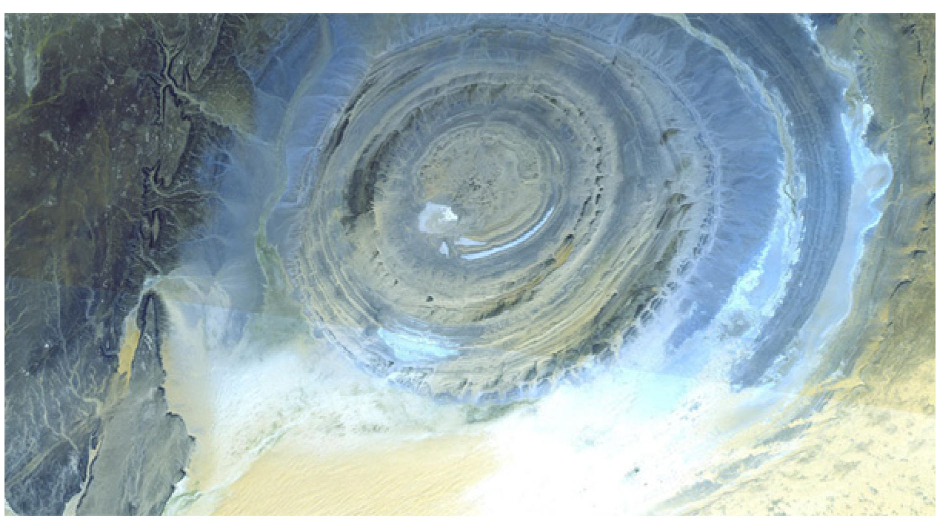

Figure A23. Richat Structure in Mauritania, Sahara desert is 50 kms in diameter. It lacks shock-altered rock and has a flat center, so it is not an impact crater. It lacks igneous rock, so it is not a volcano. Source: NASA.

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