University of Kent

Stage 1

PH307

Near Earth Objects: Bodies in Space which might hit the Earth.

<u>What hazards for mankind arise from giant impacts on the Earth from space?</u>

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Content

Introduction

“This is the Earth at the time when the dinosaurs roomed a lush and fertile planet. A piece of rock just 6 miles wide changed all that. It hit with a force of ten thousand nuclear weapons. A trillion tons of dirt and rock hurtle into the atmosphere, creating a suffocating blanket of dust the sun was powerless to penetrate for a thousand years. It happened before, it will happen again. It’s just the question of when.” (1) These are the first few words in the Hollywood Blockbuster “Armageddon”, which is one of the films made by the so called “dream factory” depicting the topic of a giant space rock hitting earth, threatening to kill all life on this planet. In good old Hollywood tradition, the world was saved in the last few seconds by a handful of heroes, as the asteroid was deflected and avoided hitting earth by 400 miles. Referring to the title of this essay, I will try to find some answers to question like, “What hazards for mankind exist from giant impacts? What are the chances of a giant space rock striking Earth? Will mankind survive?” A lot of questions need to be answered to give a sensible and clear picture of the situation mankind will face in the near or not so near future.

Asteroids, Comets and Near-Earth Objects

To assess a hazard from a giant impact from space, we need to know what kind of objects are out there and where they come from. Asteroids and Comets are believed to be ancient remnants of the beginning of the formation of our solar system more than four billion years ago. (2) According to Zeilik, Asteroids can be classified into 3 categories, according to their composition. S-type asteroids are composed of stony material. C-type asteroids are composed of carbon, whereas the M-type asteroids are composed of metallic material, mainly iron and nickel. Comets are different. In 1950 the American Astronomer F.L.Whipple developed the dirty snowball comet model. It pictures cometary nuclei as compact, solid bodies made from frozen ices of water, ammonia and methane embedded within rocky material.(3) Near-Earth Objects (NEOs) are asteroids and comets with perihelion[1] distance q less than 1.3 AU[2]. Most of these asteroids, around 90%, are situated in the "asteroid belt", which lies between the orbits of Mars and Jupiter. Table 1 represents the groups of NEOs. (4)

[1] perihelion: The point at which a body orbiting the sun is nearest to it

[2] AU: astronomical Unit (average distance between earth and sun; 149.6 x 10^6 km) (3)

Group	Description	Definition
NECs	**N**ear-**E**arth **C**omets	q< 1.3 AU P[3]< 200 years
NEAs	**N**ear-**E**arth **A**steroids	q< 1.3 AU
Atens	Earth-crossing NEAs with semi-major axes < Earth´s (named after asteroid 2062 Aten)	a[4]<1.0 AU Q[5]> 0.983 AU
Apollos	Earth-crossing NEAs with semi-major axes > Earth`s (named after asteroid 1862 Apollo)	a> 1.0 AU q<1.017 AU
Amors	Earth-approaching NEAs with orbits exterior to Earth`s but interior to Mars` (named after asteroid 1221 Amor)	a< 1.0 AU 1.017<q<1.3 AU
PHAs	**P**otentially **H**azardous **A**steroids: NEAs whose Minimum Orbit Intersection Distance (MOID) with the Earth is 0.05AU or less and whose absolute magnitude (H) is 22.0 or brighter.	MOID<=0.05AU H<=22.0

Table 1: Groups representing NEO's.

The origin for comets are believed to be the Kuiper belt and the spherical "Oort cloud" which lies far beyond the outer planets (out to about 100000 AU).

Images 3 and 4 give a visual representation of these regions in space.

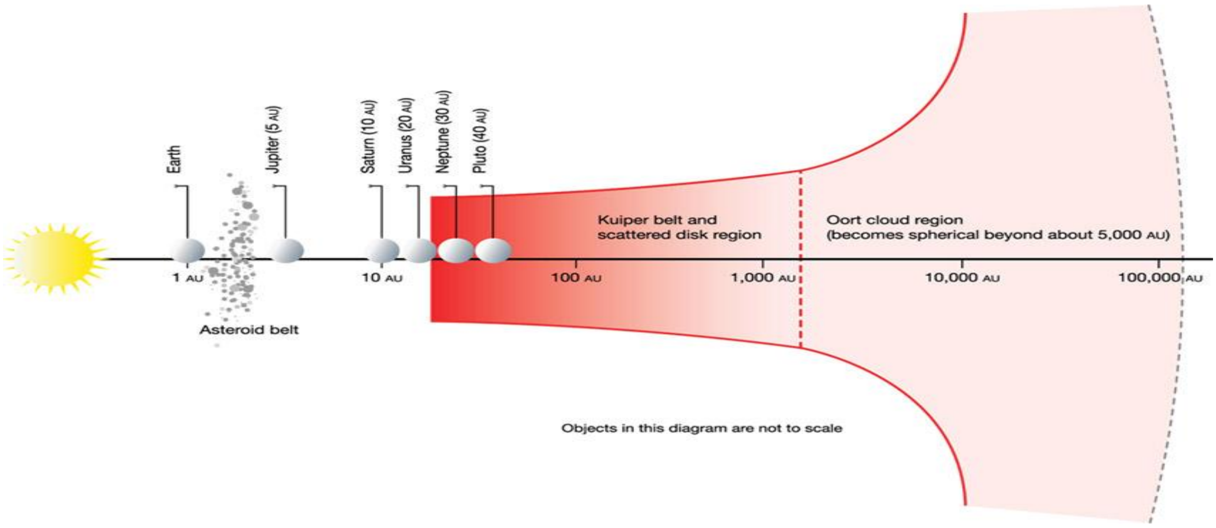


Image 3 (5)

[3] P: orbital Period
[4] a: semimajor axis (half of major axis of an ellipse; distance from the center of an ellipse to its farthest point)
[5] Q: aphelion (The point on the orbit of a body orbiting the sun that is farthest from the sun)

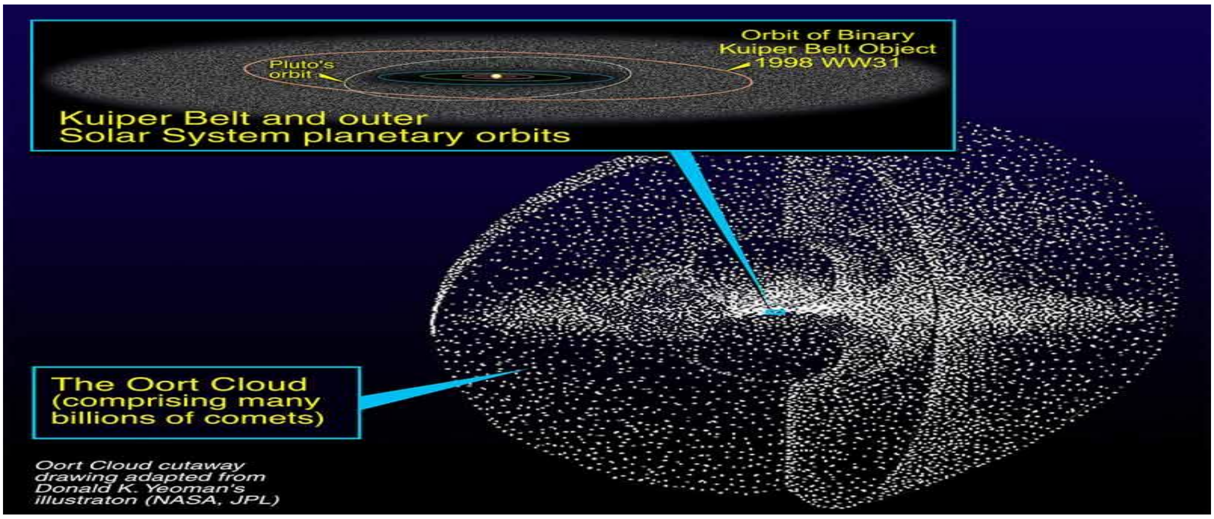


Image 4 (6)

According to Rudnyk, various factors can change the orbits of the main asteroid belt asteroids. One of them is the gravitational pull of the planet Jupiter. Those asteroids get pushed out of their original orbits into a trajectory towards the inner solar system and therefore also towards earth. (7) The same applies for the comets. Lang theorizes that their orbits get disturbed from nearby stars and molecular clouds, which will then, sent them on a trajectory towards the inner solar system as well.(8) In those cases, a giant impact on our planet might occur. But the emphasis in this sentence lies on the word might. Before we can make any prediction about a giant impact, we have to find out how many asteroids and comets we are dealing with. Because of the difficulty of observing the outer solar system, the numbers vary and all numbers are uncertain estimates. Lang proposed that the estimate for the Kuiper belt is around 100 million to 10 billion, or 10^8 to 10^{10}, objects. For the Oort cloud the number gets even higher. The estimate is one hundred billion to ten trillion, or 10^{11} to 10^{13} objects. Rudnyk suggests that the asteroid belt contains more than 200 asteroids larger than 100 kilometer in diameter. Scientists estimate that there are more than 750000 asteroids with a diameter larger than 1km and millions of smaller asteroids. (7) “As of November 7, 2008, 5801 Near-earth objects have been discovered. 760 of these NEOs are asteroids with a diameter of approximately 1 kilometer or larger. Also, 988 of these NEOs have been classified as PHAs.”(2) Image 5 gives an idea of what kind of situation humankind faces, regarding the orbits of NEOs. This image was made in the year 2000, when about 800 NEOs were known. The different colours symbolizing the different subgroups of the NEAs, where yellow orbits depict Amors and the red orbits depict the Apollos and Atens. (9)

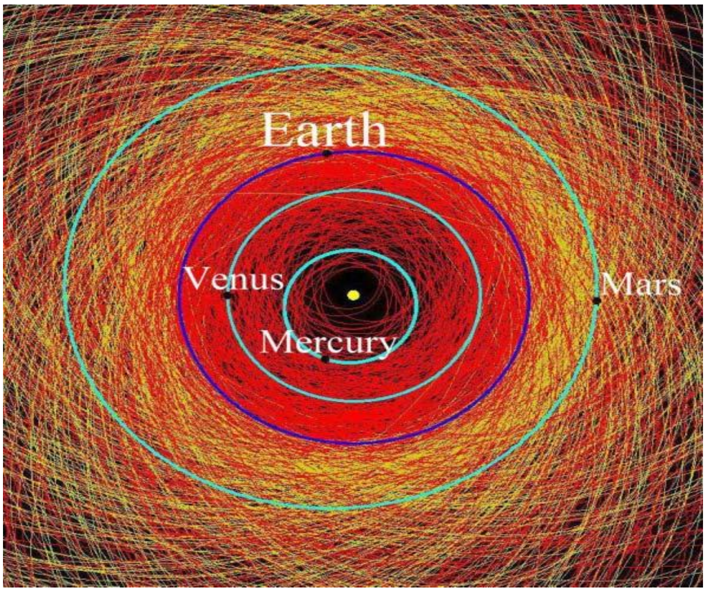


Image 5 (9)

Look at Image 5, one might wonder why we don't have an asteroid impact on Earth more frequently than we actually have in real life. The first and last giant impact which was actually recorded was the impact of the Comet P/ Shoemaker-Levy 9 on Jupiter in July 1994. On the approach towards the Planet Jupiter, the nucleus of the comet broke up into several fragments, which had estimated diameters up to 2 kilometres (10), which plunged into the gas giant's surface. The astronomical community watched with interest to see what kind of effects an impact of that size will have on Jupiter and collected as much data as they could. Image 6 and 7 show this spectacular event in the near infrared spectra.

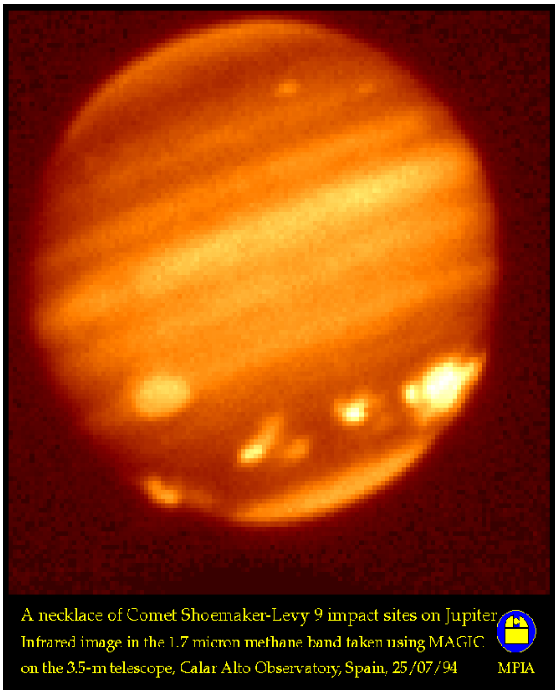


Image 6 (11)

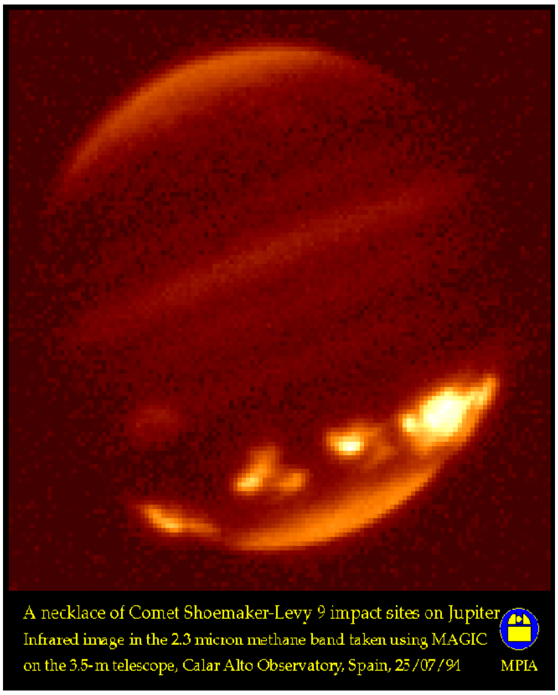


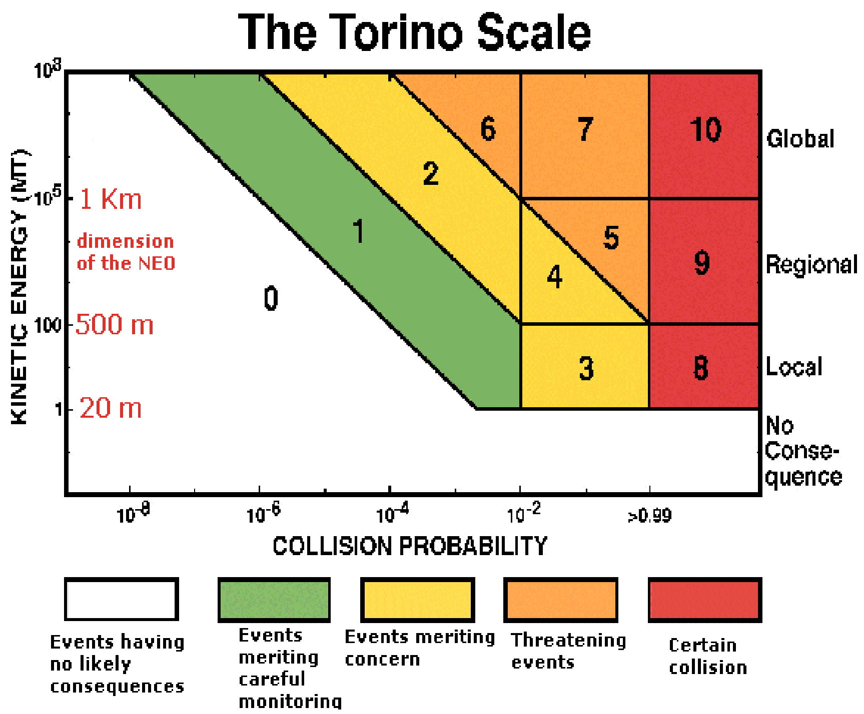
Image 7 (11)

A similar event occurred on our own planet just about 100 years ago. A comet with an estimated diameter of 60 metres exploded in the atmosphere over

Siberia, which destroyed a vast area of Siberian forest in 1908. This is known as the Tunguska event, named after the river running through this region. So, how often does Planet Earth get hit?

The Torino Scale

To assess the possibilities of how often an impact occurs, on Earth, Scientists developed a statistical scale. This is known as the Torino scale. The scale relates the objects size with its Kinetic Energy to the impact probability as well as to the impact consequences of that impacting object in a time frame that is important to the human civilisation.



A more detailed explanation of the Torino scale is given in the Appendix of this essay.

Image 8 (12)

Chapman suggests that with an estimated size of 10-20 kilometres, the asteroid that might have killed the dinosaurs 65 million years ago, has only a occurrence chance of once-in-100-million years. (13) Keeping in mind that it is only ≈ 100000 years ago, since the modern human species started to populate this planet, the chances are pretty slim to experience an event like that. According to Chapman, the chances are so slim that scientists just ignore such events. On the other side of the scale range are the really small asteroids / comets with a diameter between <3 metre and >0.3 metre. Earth gets bombarded by them very regular, like 1000 per year, but these are entirely harmless and therefore of no practical concern as well. To assess the risk to humankind posed by asteroids impacting earth, we need to look at the objects with a diameter range between >200 metres and <3.5 kilometres. Their chances of striking earth in this century are between 0.2% to about < 1-in-50000.(13)

Impact Scenarios

Using this data from the end of the previous paragraph, I will use 2 different impact scenarios. Scenario A will be an impact of a stony asteroid with diameter of 200 metres, impacting an Ocean with an estimated water depth of around 100 metres. I chose this Scenario as A, because the likelihood of an impact in water is preferred, as 70% of the earth's surface is covered by water. Scenario B will concentrate on a 200 m metallic asteroid impacting a rocky surface. The data shown in these 2 scenarios were obtained from the Earth Impact Effects Program of the Lunar and Planetary Laboratory at the University of Arizona. (14)

SCENARIO A[6]

Energy	Energy before atmospheric entry: 2.51 x 10^{18} Joules = 6.00 x 10^{2} MegaTons TNT Average interval between impacts of this size somewhere on earth during last 4 billion years is 1.5 x 10^{4} years
Atmospheric Entry	The projectile begins to break up at an altitude of 56600 meters, projectile strikes surface at velocity of 17.4 km/s, impact energy: 1.90 x 10^{18} Joules = 4.54 x 10^{2} MegaTons
Major Global Changes	Earth is not strongly disturbed and loses negligible mass, no noticeable change in Earth`s rotation period or tilt of its axis, no shift of Earth`s orbit
Crater Dimensions	Crater opened in the water has a diameter of 4.86 km, Final Crater Diameter: 2.95 km, Final Crater Depth: 0.41 km, Maximum thickness of broken rock debris in crater floor: 0.0 m, volume of the target melted or vaporized: 0.00643 km^{3}
Thermal Radiation	Time for maximum radiation: 0.142 seconds after impact, visible fireball radius: 1.97 km Thermal Exposure: 1.05 x 10^{5} Joules/m^{2} Duration of Irradiation: 32.2 seconds
Seismic Effects	Major seismic shaking will arrive at approximately 16 s after impact; Richter Scale Magnitude: 6.2
Ejecta	Will arrive approximately 129 seconds after impact At distance of 80 km fine dusting of ejecta with occasional larger fragments, Average Ejecta Thickness: 784 micrometers Mean Fragment Diameter: 3.24 cm
Air Blast	Will arrive after approximately 242 seconds Peak Overpressure:8200 Pa = 0.082 bars Max wind Velocity: 18.7 m/s Sound Intensity: 78 dB (Loud as heavy traffic)

Table 2 Scenario A

[6] Impact Parameter: Distance from Impact: 80km, Projectile Diameter: 200 m, Projectile Density: 3000 kg/m^{3}, Impact Velocity: 20 km/s, Impact Angle: 45 degrees, Target Density: 1000 kg/m^{3}, Target Type: Liquid Water of depth 100 metres, over typical rock.

SCENARIO B[7]

Energy	Energy before atmospheric entry: 6.7 x 10^{18} Joules = 1.60 x 10^{3} MegaTons TNT Average interval between impacts of this size somewhere on earth during last 4 billion years is 3.2 x 10^{4} years
Atmospheric Entry	The projectile begins to break up at an altitude of 16800 meters, projectile strikes surface at velocity of 19.7 km/s, impact energy: 6.49 x 10^{18} Joules = 1.55 x 10^{3} MegaTons
Major Global Changes	Earth is not strongly disturbed and loses negligible mass, no noticeable change in Earth`s rotation period or tilt of its axis, no shift of Earth`s orbit
Crater Dimensions	Final Crater Diameter: 5.45 km, Final Crater Depth: 0.493 km, average thickness of melt that remains in crater: 2.26 m, volume of the target melted or vaporized: 0.0409 km^{3}
Thermal Radiation	Time for maximum radiation: 0.19 seconds after impact, visible fireball radius: 3.23 km Thermal Exposure: 4.02 x 10^{5} Joules/m^{2} Duration of Irradiation: 48.5 seconds
Seismic Effects	The major seismic shaking will arrive at approximately 16 s, Richter Scale Magnitude: 6.7
Ejecta	Ejecta will arrive approximately 129 seconds after impact, Average Ejecta Thickness: 6.9 mm, Mean Fragment Diameter: 6.1 cm
Air Blast	Will arrive after approximately 242 seconds Peak Overpressure: 15500 Pa = 0.155 bars Max wind Velocity: 34.3 m/s Sound Intensity: 84 dB (Loud as heavy traffic)

Table 3 Scenario B

[7] Impact Parameter: Distance from Impact: 80 km, Projectile Diameter: 200 m, Projectile Density: 8000 kg/m^{3}, Impact Velocity: 20.00 km/s, Impact Angle: 45 degrees, Target Density: 2500kg/m^{3}, Target Type: Sedimentary Rock

In both Scenarios I chose a distance of 80 km from the impact. The reason for this choice was mainly down to the fact that it matches the distance of Canterbury to London. In this way the scenarios will offer effects we can relate to and picturing of the events will be better facilitated. In both Scenarios the observer is located in Canterbury. In Scenario A, according to Chapman, the 200 meter asteroid will crash on Earth at a speed a hundred times faster than that of a jet airliner. It would plunge into the North Sea and explode with an energy of about 600 MT (MT = million tons of TNT equivalent), about ten times the yield of the largest thermonuclear bomb ever tested. Disrupting some communication and destroying any ships nearby, the impact would also lift cubic kilometres of water into the atmosphere, which would have some short-term, local or regional meteorological consequences. (13) An earthquake of a Richter Scale Magnitude of 6.2 would be created, which arrives after 16 seconds. Some dishes and windows might break. Unstable objects will overturn and Pendulum clocks may stop. The ejecta will arrive approximately after 129 seconds in form of fine dusting with occasional larger fragments of a diameter of 3.24 cm. The Air blast which follows after 242 seconds will also shatter more glass structures. (14) Chapman suggests that the impact would also create a tsunami ("tidal wave") which would be more than 10 meters high as it breaks on the coast of western Europe, devastating vast areas. In Scenario B, the asteroid would explode with a force of around 1500 megatons of TNT. The crater that would form would be around 5 km wide. Anything within several of kilometres of the crater rim would be smashed and buried by flying material excavated from the crater. Thermal radiation arrives after 1.7 seconds. 16 seconds after the impact the major seismic shaking will arrive with a Richter Scale Magnitude of 6.7, which would destroy poorly build structures. While less than total, devastation and death due to the blast and associated phenomena would be serious out at least 50 km in all direction The ejecta will arrive approximately 129 seconds after the impact. The ejecta size of a diameter of 6.1 cm will fall to the ground. 110 seconds later, the air blast will shatter glass windows. (13,14)

Discussion

From the Tables 2 and 3 we know that the average interval between impacts of the scenario A and B size asteroids during the last 4 billion years is around 1.5 - 3.2 x 10^4 years. According to Chapman, an asteroid of that size has a one chance in several hundred of happening, worldwide, during this century. Bringing humankind not to an end but devastating large area, in this case most of the Western Europe coastline, might lose 10000, maybe 100000 or more lives. Consequences for nations without coastlines or on opposite side of the planet would be restricted to comparatively minor meteorological effects or highly indirect, but possibly major, economic and political repercussions. For

Scenario B the outcome of such a disaster could be even more devastating than in scenario A. Destroying an area the size of a small country or a modest-size American State, an impact of this size could cause serious problems worldwide, costing thousands to hundreds of thousands maybe million lives, depending on the population density of that region. Because cosmic impacts are not selective, Earth largest countries, like Russia, United States, Canada, Australia and Brazil, would be likely targets. Even with the total destruction of a small country, this kind of asteroid impact would not qualify as a Civilisation Destroyer. At this point, it is sufficient to point out the indirect danger an asteroid of ≈ 3 m of diameter could cause at the present global security situation in the world. An asteroid of that size impacting earth would result in a blinding explosion of about 2 kilotons of TNT, in the sky, which could be mistaken for a nuclear bomb. Impacts like this statistically happen twice per year. A phenomenon like this over a military unstable country might mistake this event as a hostile act of an enemy and retaliate dangerously.(13) As discussed earlier the sizes of asteroids needed to destroy human civilisation are much greater and range between 2-3 km in diameter or greater. NEOs of this size are well known and already mapped by projects like the space guard foundation and the Near Earth Asteroid Tracking (NEAT). None of them will hit earth in the 21st century. Looking at the scenarios A and B, it becomes clear that most of the impact results are fairly common and well understood. Earthquakes, Tsunamis, volcanic eruption and gigantic explosions are either natural or manmade disasters occurring often on this planet and humankind knows how to deal with those. Depending on the time scale, how early the asteroid striking earth is discovered, preparing for such an event is possible. According to Chapman, large scale evacuation procedures, improvements to the coastal infrastructure to soften tsunami impact, improved communications, transportation and emergency services, optimal advance production and food storage (13) are more effective ways to prepare for events on that scale, than rather spending money on a funded space mission sitting on a launch pad waiting for deployment. Options like this might be considered in the case, of an asteroid approaching Earth is actually sighted. Given enough warning time is at hand, current technology is available to deflect the asteroid. In the mean time varies space missions have been subjected to the study of asteroids in the last decade. Missions like Deep Space 1 in 1998, a comet flyby and testing of new space technologies, and Deep Impact in 2004, were a space probe crushed into Comet Tempel 1, just to name a few, were highly successful to broaden our understanding of asteroids. Space Missions which are currently under way are Rosetta, were the space probe attempts to land on the comet surface to study the composition and structure of the asteroid, and Dawn, which studies the asteroids Vesta and Ceres are only few examples of the attempt of humankind to learn more about the threat giant space rocks pose.

Conclusion

Having heroes to save the planet and blowing up asteroids to prevent them from destroying the earth works well for a Hollywood Blockbuster. In real life this notion is far more complicated. As the possibilities of such an event occurring in our lifetime and the next few generations, are virtually none existent, events like giant impacts over the size of 10 km can be ignored completely. Looking at asteroids of the size of few hundred metres, the picture changes. The likelihood of an event like this occurring in this century is about 0.2%. But there is no reason to panic. Projects surveying the sky, cataloguing and tracking objects of this size, predicting no impacts for this size of asteroids in this century from the near earth objects. In the case of a discovery of a new object outside the NEOs group, on an impact course towards earth, at this size, the impact would not be anything like a civilisation destroying event. An impact like this, would cause similar results as natural or manmade disasters, which humankind is dealing with on a regular basis. Improving civil defence systems to counteract impact effects will also work in natural disasters events. Looking ahead and gathering knowledge about asteroids and comets and developing new technologies will ensure that humankind will survive even an event on a larger scale.

Appendix

THE TORINO SCALE

Assessing Asteroid/Comet Impact Predictions

No Hazard	0	The likelihood of collision is zero, or is so low as 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 re-assignment 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 will lead to re-assignment to Level 0.
	3	A close encounter, meriting attention by astronomers. Current calculations give a 1% or greater chance of collision capable of localized destruction. Most likely, new telescopic observations will lead to re-assignment 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% or greater chance of collision capable of regional devastation. Most likely, new telescopic observations will lead to re-assignment 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 three 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 if close offshore. Such events occur on average between once per 50 years and once per several 1000 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 per 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.

Fig. 2. Public description for the Torino Scale, revised from Binzel (2000) to better describe the attention or response that is merited for each category.

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