Astro 110 Group Learning Activity 5: Killer Asteroids

Background Briefing

This activity brings into play a question of science and political decisionmaking. If scientists discover a public threat, how do policymakers evaluate the importance of that threat compared with other urgent matters and come to a decision on whether public money should be spent in countering it?

In this exercise we look at the threat of the Earth's being hit by asteroids and comets. How serious is such a threat, what sorts of dangers does it pose, and what, if anything, can we do about it? You are members of a select panel organized by the National Research Council to advise Congress and the President on these questions. Each of the subcommittees of the panel has been looking into different aspects of this complex issue, and you are now coming together to discuss your report. A specific question you need to address is whether this threat is serious enough to need government support. How does it compare with other dangers? If government support is needed, what sort of action should be taken?

You should divide yourselves, as usual, into groups of three or four: introduce yourself to your group partners if you don't already know them. One person from each group should then come down to the front and pick up a briefing paper for your group.

After you have read and extracted the key points from your own group's briefing paper, go around and discuss your findings with other groups. Remember, you are not allowed to show others your briefing paper —you have to describe the important findings in your own words. There are 6 different groups; it is possible that one or two of these may be duplicated.

Near-Earth Asteroids

You are astronomers specializing in the study of asteroids: the small chunks of rock and/or metal that seem mostly to be the leftovers from a failed case of planet formation in the big gap between Mars and Jupiter. Other astronomers working in more glamorous fields like cosmology, quasars, or star formation tend to look down their noses at you, but that may change soon. Now that it has been established beyond reasonable doubt that an asteroid impact killed off the dinosaurs and left room for the rise of mammals (including, of course, humans), asteroids are achieving new respect.

While almost all asteroids indeed seem to have formed in the region between Mars and Jupiter, the total mass of the ones there now is only about 1% of the mass of Earth. You are pretty sure that there used to be a lot more asteroids there when the Solar System was young, but that collisions between asteroids and, especially, gravitational interactions with Jupiter have thrown most of them out of their original orbits. Some have likely escaped the Solar System entirely, but many have been sent on elliptical orbits into the inner Solar System, where they end up falling into the Sun or crashing into one of the terrestrial planets.

In fact, one of your specialties is studying asteroids that are on orbits like this right now. You and your colleagues and competitors have found about 500 asteroids at least a kilometer in diameter that have orbits that cross Earth's orbit (these are called near-earth objects, or NEOs), and you have good reasons to believe that you have found only 25% to 50% of the ones of this size that are out there. You estimate that there are perhaps a million NEOs with diameters of 50 meters or more. While you have established that none of the large ones you have found is likely to hit the Earth anytime in the foreseeable future (meaning in the next thousand years or so), there are a lot more out there that you don't know about, and it only takes one….

Effects of Large Impacts

You use massive supercomputers to calculate the probable effects of impacts of very large objects on the Earth. You have found that objects up to 1 kilometer in diameter can cause a lot of local damage, such as wiping out a city or even a small country. But above that size, the risk becomes global. This is because such an impact would inject huge quantities of dust into the stratosphere, which would not settle out for several years. The blocking of sunlight would lead to massive crop failures and would depress temperatures. For objects between 1 and 2 kilometers in size, you estimate that at least 1/4 to 1/2 of the Earth's population would die as a direct result of the impact, ensuing fires, and famine due to the blocking of sunlight. And this doesn't even take into account the likely social disruption and breakdown of civilization.

Of course, there are some asteroids that cross the Earth's orbit that are even larger, up to 25 kilometers in diameter. Some of these larger ones have hit the Earth, such as the 10 to 15 kilometer one that wiped out the dinosaurs 65 million years ago. Your computer simulations have a lot of uncertainties for this size of impact, but it is pretty clear that if the dominant animal life form on Earth was completely wiped out, we wouldn't stand much of a chance either….

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Historical Impacts

You are sort of like impact archeologists: you analyze geological evidence of ancient impacts in sites around the Earth. Because of weathering and various forms of tectonic activity, this can be tedious and difficult work. But putting all of your research together with some astronomical knowledge of the size distribution of asteroids, you are able to come up with a rough idea of how frequently impacts of various sizes occur. About once or twice a year, on average, an asteroid about 10 meters in diameter (roughly the size of a small house) enters the Earth's atmosphere and explodes at a high altitude with the power of the bomb used at Hiroshima. Only asteroids with diameters of about 50 meters and above have a good chance of making it through the atmosphere intact and making a crater. But slightly smaller ones can still cause a lot of damage. The Tunguska event in Siberia in 1908 was probably a stony asteroid or a comet with a diameter of about 30 meters that exploded in the air with the force of 40 megatons of TNT, flattening the forest over an area of thousands of square kilometers, and vaporizing the region immediately below the explosion. Objects this size probably hit about every 100 years or so, although, of course, most likely over the ocean. If something like this happened to explode over a city, hundreds of thousands of people could be killed.

But all of this is minor, compared with the bigger ones. Asteroids 100 meters in diameter will likely reach the surface and make craters a couple of kilometers across as well as causing widespread devastation in the neighborhood; they hit every few thousand years. Kilometer-sized objects hit every 500,000 years or so, and 10-kilometer-sized ones, like the one that apparently wiped out the dinosaurs, come along about once every 50 or 100 million years.

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Deflecting the Killers

You let others find the potentially dangerous asteroids—your job is to think about what to do next if one is discovered. Any asteroid likely to hit the Earth is also likely to have many close approaches before it hits, so there is a good chance that it may be detected decades before it actually hits. That's a good thing, since the more time is available, the more likely it will be possible to do something about it.

There are two possibilities. One is simply to blow the thing up. That is not so easily done for a kilometer-sized object, and it has certain dangers: it is possible that some of the fragments might still be a threat. The preferred option is to give the asteroid a nudge, to change its orbit slightly so that it will miss the Earth. If you can do this several years before the projected impact, you only need to change its velocity by a few centimeters per second if you push in the right direction.

Of course, how to do this is the question you are wrestling with. A brute-force approach would be to place a large thermonuclear bomb on one side of the asteroid. Another possibility would be to attach a huge solar sail to the thing and let the gentle push of solar radiation, sustained over many years, gradually change the orbit. There are problems with both approaches, but you are convinced that, if you have at least several years warning, you will be able to save the Earth. With less than a year, however, you are equally sure that the situation would be hopeless.

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Risk Assessment

You are experts at calculating the risks that attend modern life. With considerable effort, you have assembled a huge database of causes of accidental death covering the U.S. and Canada. You have assembled the following table, which gives the average number of deaths per year, per million people.

300	Accidents (not motor vehicle)
200	Homicide & suicide
160	Motor vehicle accidents
10	Fire
5	Electrocution
1	Airplane accidents
0.3	Storms and floods
0.1	Earthquakes (poor statistics)
<0.01	Nuclear accidents (design goals)

You have been asked to compare the likelihood of death from asteroid impact with these more common causes. Your initial reaction was that the risk would be much less than any of these—after all, you have never heard of anyone who was killed or even badly injured by anything falling from the sky. But then you starting thinking: serious impacts may be really rare, but if one occurred, it could kill a large fraction of the Earth's population, so the average risk per year could still be significant. You are going to have to get some better estimates impact frequency and expected death toll to do your calculation. You hope some of the other people here can give you this information….

Comet Impacts

You feel a little left out. Almost everyone else here is concentrating on asteroids, and you are comet experts. It is true that comets don't strike the Earth as often as asteroids of similar sizes do. While there are a lot more comets, they spend most of their time far from the Sun in their highly elongated elliptical orbits (good old Kepler's 3rd Law again), so they are far rarer in the vicinity of the Earth. You estimate that there are only about 10% as many comet impacts in the size range 1 kilometer and up as there are asteroid impacts. Still, that is not negligible: it means that such a comet strikes the Earth about every 5 to 10 million years. And comets do have one really nasty feature. While most asteroids tend to be in orbits that are fairly close to circular, so they will likely be in the vicinity of the Earth for decades or centuries before they are likely to impact, comets are stealth impactors. They may have orbital periods of millions of years, so you almost certainly won't have a chance to discover them more than a few months before they hit. Worse, they could even come in from a direction so close to the Sun in the sky that you may see them at all.

You think that this meeting should be devoting a little more effort to this threat, but most people seem not to be paying it any attention. It is the usual attitude of scientists: they like to concentrate on problems they think they can solve. If you give them one where there is no obvious solution, no matter how important it is, they will just ignore you.

Hot Water Experts

You are physicists employed by a company that builds water heaters and showers. You have built up a worldwide reputation for your expertise in the properties of hot water at different temperatures.

At temperatures of around 20° C (68° F), water just sits there. Small amounts of water vapor evaporate from the surface, but nothing very significant. Unless you add perfume, that is: perfume evaporates even at 20° C, a feature that led to the success of your "Smell-Good Rose-Petal Washbasin™."

If the temperature rises, more and more water vapor evaporates. The increase is dramatic: even small increases in temperature can dramatically increase evaporation rates. You used this fact in your hot-air blowing auto-dry towel-free shower, a best-seller in Japan.

When the temperature rises above 100° C (212° F), of course (or slightly higher temperatures if the pressure is higher than that at sea-level on Earth), water will boil, and will all turn into vapor. Water vapor is normally stable: it lasts forever, as long as the temperature remains high. Unless it is exposed to strong ultra-violet (UV) light, that is. The one blemish on your otherwise brilliant research career was the combined Jacuzzi and sunbed you produced a few years back: as the water vapor steamed off the surface of the water, the UV light from the tanning lamps (designed to mimic the healthy rays from the Sun) broke it down into hydrogen and oxygen. The oxygen would make people euphoric and sleepy, while the hydrogen built up until any spark (say from the off switch) caused it to explode. Your company is still recovering from all the lawsuits….