Planetary Defense Presentation Notes

Slide 1

This is a presentation about Planetary Defense, which means protecting Earth from impacts by comets and asteroids.

Asteroids and comets are abundant in Earth’s neighborhood, and impacts, though rare, are inevitable. The force of an impact can be greater than that of an atomic bomb. An impact could wipe out entire cities or even cause global devastation. Researchers are searching the skies for potentially dangerous near-Earth objects and are developing technologies for deflection. But the world today is still unprepared to prevent an asteroid impact unless the object is detected years in advance, and this much warning is far from guaranteed. Steps can and must be taken right now to defend the planet from the hazards of the solar system. We should be concerned about the impact threat, but the good news is that we can actually prevent a disaster. The Planetary Society has a plan.

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Near-Earth objects, or NEOs, include both asteroids and comets. Asteroids are small, rocky and/or metallic objects with or without carbon-rich materials. Comets are made of the same materials, but they originated much farther from the Sun, so they also contain ices. Comets and asteroids often have elliptical orbits that take them closer to and farther from the Sun. When a comet or asteroid has an orbit that approaches Earth’s, it is classified as a near-Earth object, even though most of the time it is far away from Earth. Specifically, “near Earth” means its orbit takes it within 1.3 astronomical units of the Sun, where an astronomical unit is the average distance between the Sun and Earth. That average distance is 93 million miles, or 150 million kilometers, or approximately 8 light-minutes.

Throughout Earth’s early history it was regularly bombarded by comets and asteroids. This process helped form Earth, provided some of the water for its oceans and carbon-rich material for life, and cleared Earth’s path along its orbit. Because of Earth’s perpetual geological activity, you don’t see most of the craters caused by these impacts today. On Earth’s Moon, where there is little geological movement and little erosion to reshape the surface, you clearly still see the history of impacts that both Earth and the Moon experienced.

This slide: asteroids and comets that have been visited by spacecraft to scale. Not all are NEOs. (created by TPS’ Emily Lakdawalla)
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In our solar system there are estimated to be billions of comets and billions of asteroids. The vast majority never approach Earth. Almost all comets are found in the cold outer reaches of the solar system in what is called the Oort Cloud. Almost all the solar system’s asteroids are found in the warmer inner solar system in a large asteroid belt between Mars and Jupiter. Comets and asteroids all orbit the Sun, and their orbital paths are sometimes changed by the gravitational attraction of nearby planets (usually Mars or Jupiter for asteroids, and passing stars for comets). These encounters do not “knock asteroids out of orbit.” They remain on orbits that are controlled by the Sun. They just acquire different orbits, sometimes ones that bring them into Earth’s neighborhood.

This slide: Left: Diagram showing the location of the asteroid belt, as well as Jupiter Trojan asteroids. NEOs are not shown in this diagram. Distances are to scale, but sizes are not. Right: Diagram not to scale representing distant objects in the solar system including the Oort Cloud.

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Impacts happen all the time -- thousands of tons of meteoric material per year. Almost all of this is dust. Small numbers of larger objects also hit every year. Thanks to our atmosphere, most of these never reach the ground. Impacts large enough to cause surface damage are rare, but there are still many comets and asteroids orbiting the Sun in the same area that we do, and from time to time there is a collision. Although dangerous impacts are infrequent, they do occur and can cause extensive damage to things on the surface of our planet.

This slide: The Manicouagan impact crater in Canada, created more than 200 million years ago by the impact of an object of five kilometers (three miles) diameter.

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Throughout Earth’s history, there have been many instances of NEOs impacting our planet, either reaching the surface or exploding above ground from the intense energy released as the object passed through the atmosphere. It is a natural process that shapes the surface of our planet, like volcanoes. The vast majority of these impacts were from very small objects, but there have been some remarkable exceptions.

This slide: the 1 kilometer (0.6 mile) diameter Meteor Crater in Arizona created 50,000 years ago.
In 2013, an asteroid about 20 meters in diameter entered Earth’s atmosphere above Chelyabinsk, Russia. This is a very small asteroid, so it is not surprising it had not been discovered before it hit. While it is possible for us to discover asteroids of this size before they impact, the Chelyabinsk asteroid came from the direction of the Sun, so astronomers weren’t able to detect it before it impacted. It exploded while it was still in the air, releasing the same amount of energy as 500 kilotons of TNT. Luckily it exploded about 30 kilometers above ground, avoiding direct impact damage. Still, it created a shockwave that injured 1,500 people and damaged 7,200 buildings across six cities. Most of the injuries were caused by curiosity: people saw the bright flash and walked to windows to look outside. The shock wave, traveling at the slower speed of sound, arrived later and shattered the windows, injuring people with flying glass. If you see a bright flash, duck and cover.

The last major impact event to occur in recorded history was the Tunguska Event of 1908. The object, in this case, was unknown, since the event itself was not observed. But it is clear that an approximately 30-meter diameter asteroid or comet entered the atmosphere and exploded above ground, an explosion that knocked down some 80 million trees over an area of 2,150 square kilometers (830 square miles). The explosion of this object has been estimated at 1,000 times more powerful than the explosion of the atomic bomb at Hiroshima. Had this taken place over a metropolitan area, that city would have been completely destroyed. Luckily, it happened in a remote area of Siberia, and nobody is thought to have been killed. In fact, not a single human being has ever been known to have been killed by a NEO impact.

But we have indications of even more devastating impacts than this in pre-history. The asteroid that killed the dinosaurs around 65 million years ago also wiped out 70% of all species on Earth. That asteroid is thought to have been 10 to 15 kilometers (6 to 9 miles) in diameter and hit Earth in what is now Mexico.

An impact of that size would have had devastating effects, and the geological record gives us some indication of what happened. The asteroid hit in water, creating mega-tsunamis reaching from southeastern Mexico all the way to Texas and Florida and up a shallow interior ocean that covered what is now the Great Plains. The blast would have thrown chunks of the asteroid and...
the planet so far that they would have left Earth’s atmosphere before falling back to earth. Like millions of shooting stars, all this material would have been heated to incandescence upon re-entry, heating Earth’s surface and igniting wildfires. It is possible that all of Earth’s forests burned. Meanwhile, colossal shock waves would have triggered global earthquakes and possibly volcanic eruptions. A cloud of super-heated dust, ash and steam would have spread from the crater as the impactor slammed underground in less than a second. This dust could have covered the entire surface of Earth for up to a decade, creating a harsh environment for living things. Perhaps more significantly, the dust could also have lingered in the atmosphere, blocking out the Sun and interrupting the photosynthesis of plants that the entire food chain depends on, as well as cooling the temperatures of the Earth for many years.

This slide: Artist’s impression of the dinosaur-killing Chicxulub Impact (left) and the location of the impact (right).

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That asteroid impact was clearly a disaster unlike anything humans have ever known. But it is entirely possible that something like this will happen again. There are currently more than 900 known near-Earth objects large enough to cause global effects (that is, with a diameter over a kilometer or half a mile), and although objects this large are statistically estimated to only impact the Earth every 500,000 years and no known large NEO is on an impact trajectory, this does not mean that a major impact is impossible.

Although immense impactors like the one that devastated the entire planet 65 million years ago are rare, NEOs of many different sizes can pose serious threats. An impact on or over a densely populated city could cause millions of deaths, and an impact on water could cause massive flooding on coastlines. Any major impact would lead to widespread damage, injury, and death, and would create unparalleled humanitarian and refugee crises around the world. So what do we do about the threat of NEO impacts? How do we protect humanity from the inevitable?

This slide: An impact over a populated area like this could be disastrous.

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The Planetary Society believes that asteroid and comet impacts are preventable; in fact, they are the only preventable large-scale natural disaster. But the people of Earth have to take action if we are going to protect our planet.
Around the world there are many efforts being made to defend Earth from NEO impacts. The Planetary Society describes three main types of effort being made: Locating NEOs, redirecting oncoming NEOs, and coordinating internationally to make these efforts possible. Let’s go into a bit more detail on each of these.

If we don’t know an asteroid or comet is there, we can’t prevent its impact. The further ahead of an impact we find a threatening NEO, the more options exist to change its orbit so it won’t hit Earth.

The probability of comet impact is about 1% of the probability of asteroid impact, which is part of the reason most focus now is on asteroids; the other is just because they are easier to find. Researchers around the world are finding asteroids at an ever-increasing rate. In 1900 there was 1 known near-Earth asteroid. In 1950 there were 13. In the year 2000, there were 879. And since then we’ve made huge progress in finding NEOs, tracking over 1,000 in 2013 alone and 1,500 in 2014. As of 2019 we have found more than 20,000 in total.

Even if we find a near-Earth object, how do we know if it will hit Earth? We need to track it and map out its orbit to very high precision to predict whether its path will cross our own at the wrong time. To do this, astronomers make thousands of telescopic observations over days, months, and years, each of which helps to refine the predicted future path of the comet or asteroid. NEOs can even be lost if their first detection isn’t followed up quickly: the orbits are so uncertain we don’t know where and when to find them again. Lost NEOs are more likely to be small ones, because they quickly become too faint to see from Earth.

Asteroid tracking has been very successful at reducing risk. By tracking asteroids year after year, we have learned that no discovered asteroid is likely to impact Earth in the next 150 years. The scientific community is confident that the majority of the giant asteroids have been found and are not a threat. But much remains to be done. The majority of the many smaller asteroids capable of causing regional disasters have not been discovered yet.

To both understand specific asteroids and comets in case we need to deflect them, and to more broadly understand the NEO population, we need to characterize the objects: collect many telescopic, and occasionally spacecraft observations, that can tell us things like spin rate, composition, physical properties, and even whether what at first appears to be one object is actually two. Asteroids and comets are highly varied, and every factor can affect how best to plan a mission to deflect one that is threatening Earth.
The Planetary Society Shoemaker NEO Grant Program provides grants, mostly to amateurs, to assist with observations critical to finding and understanding Near Earth Objects. Over the 22-year history of the program, it has made 56 awards to 41 observers in 18 countries on 6 continents, totaling more than $382,000. Past Shoemaker grant winners have made tremendous contributions to discovery, tracking, and characterization of potentially dangerous near-Earth asteroids using the upgrades facilitated by the grants.

This slide: The Pan-STARRS telescope in Hawaii is one of the primary NEO discovery telescopes currently active.

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If, or really when, an asteroid is found to be on a collision course with Earth, can we push it out of the way? No matter what, a great deal of planning will be needed. Right now there is a variety of possible techniques in various states of readiness, but all need more development and testing. Even when developed, it will take years to put a deflection mission into action. We should do that development and testing now, before an oncoming object is detected, not after.

If we detect a NEO many years before a predicted impact, we do not have to deflect it much. Just a few minutes’ change in its arrival time at Earth’s position could be the difference between an impact and a near miss. A tiny impulse to a NEO, many orbits before a predicted impact, could prevent the impact from happening. The more time we have, and the smaller the object, the easier deflection will be, at least theoretically. What ways might we deflect a potentially hazardous object?

Techniques include the slow gravity tractor, where a massive spacecraft is launched from Earth to meet the NEO and follow next to it, using the spacecraft’s own gravity to pull the object’s path away from a future collision. There is also the kinetic impactor technique, where a spacecraft or swarm of spacecraft slam into the comet or asteroid to impart a little force to shift its orbit. Another technique is laser ablation, where spacecraft reach the NEO and use lasers to vaporize rock to create jets that slow or speed the object’s path around the Sun. The Planetary Society worked with a team at the University of Strathclyde in Scotland to develop early lab research into this technique, through their Laser Bees project.

There are nuclear options for deflecting an asteroid that is on a collision course with the Earth. These options are not ideal, though, for several reasons. Blowing up a NEO, though popular in the movies, may create a bigger problem if large pieces of the destroyed object remain on course for the Earth. A powerful detonation would be necessary to spread the pieces out enough to avoid impacting debris. Another nuclear technique involves setting off nuclear fusion weapons above the surface to slightly change the object’s velocity without fracturing it. Although nuclear options could work, they pose geopolitical challenges that would need to be
dealt with here on Earth. For many reasons, nuclear options are best kept as a last resort. Other deflection techniques should be researched and developed now so that when a NEO on a collision course with Earth is detected, we are prepared to deal with it.

Even when we do have these technologies, it will take time -- likely years -- to build and launch the rendezvous spacecraft, and for it to navigate to the NEO and begin its work. That is why advance discovery is so important.

This slide: Artist’s impression of some possible deflection techniques.

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No matter how you look at it, a comet or asteroid impact is an international issue that requires international coordination. Any impact will require an international disaster response. Threats will require international coordination on how spacefaring countries will work together to prevent an impact. The politics of who takes responsibility and who pays will certainly arise. And sticky situations will come up. For example, if the United States deploys a mission to deflect an asteroid that is heading for New York, in the process of deflection it may temporarily move the asteroid’s target over Moscow or Beijing. Geopolitics will have to be taken into consideration.

For all these reasons, international coordination ahead of time is critical. As a first step, global education about the NEO threat is required at all levels from policymakers, to disaster management agencies, to the general public. It is important for all to be aware of the level of threat and how it can be prevented.

The Planetary Society has taken on a major role to lead this international education and coordination. We were part of the NEO working group of the United Nations that recommended international coordination groups that are now being implemented. We are a primary sponsor and participant of the Planetary Defense Conference, a global meeting of experts in all aspects of asteroid threat and impact. And every year we conduct educational public outreach around the world in collaboration with the international Asteroid Day movement.

All year round we educate the public about the threat of NEO impacts through video, radio, print and online communications. And by giving presentations like these, our volunteers are working to inform the world’s public about this issue and the steps we must take to protect ourselves and future generations.

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I don’t mean to terrify you with this presentation. The NEO impact threat is real, but we really can prevent a disaster if we work together. Along the way, we are discovering new worlds in our solar system, and visiting them with spacecraft. Right now there are two spacecraft, one from Japan and one from the United States, visiting near-Earth asteroids. Their scientific missions are teaching us about how the solar system formed, but the work they are doing to learn how to navigate spacecraft around small NEOs is enormously important to future deflection missions.

This slide: Left: asteroid Bennu as imaged by the OSIRIS-REx spacecraft. Right: Asteroid Ryugu as imaged by the Hayabusa2 spacecraft.

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Planetary Defense is an essential, complex, and solvable problem. With the help of our supporters, The Planetary Society is working to advance our ability to prevent disaster and defend Earth.

To learn more, go to planetary.org/defense.