PLANETARY DEFENSE INTERAGENCY TABLETOP EXERCISE 5

Read-Ahead Information

What would happen if astronomers suddenly discovered an asteroid or comet headed for an impact with Earth?

How would our nation react—both the government and its people?

Who would lead efforts for responding to such a rare threat?

What role might the agency or office where you have responsibilities play in mounting a viable response?

How would we interface and coordinate with other governments and space agencies around the world?

Unlike what has been shown in Hollywood movies, the 5th Planetary Defense Interagency Tabletop Exercise (TTX) will inform participants on the realities of current preparedness and response capabilities, including international coordination and involvement, for an asteroid impact threat.

After concise technical briefs, participants will engage in facilitated discussions about various challenges associated with preparing for and responding to a potential asteroid impact. These challenges will be approached from three perspectives: international space responses, disaster preparedness planning, and public information messaging. Part of the exercise is to examine how to proceed effectively—in the face of large uncertainties—to obtain better information and reduce the risks in the final outcomes of the scenario. On Day 1, facilitators will guide participants to attempt to reach consensus on a set of recommended courses of action to be shared with senior leaders on Day 2.

Sponsored by the NASA Planetary Defense Coordination Office (PDCO), in partnership with the Federal Emergency Management Agency (FEMA) and the U.S. Department of State Office of Space Affairs, this TTX will bring together a diverse set of officials from across the globe. Participants are encouraged to review this document and consider their agency's potential roles and responsibilities in an asteroid threat scenario. *This TTX will provide a low-stress, no-fault environment, and views expressed are not expected to be official government or organizational positions.*

This document provides a brief overview of the TTX scenario and gives additional background information that participants may find useful during the exercise.

What is the hypothetical asteroid threat scenario?

Six months before the start of the exercise, astronomers discovered an asteroid, designated 2023 TTX, that could possibly impact Earth on 12 July 2038. The Earth impact probability is calculated at approximately 72% at the time the exercise takes place. The asteroid's size and impact energy, and the potential damage it could cause, remain highly uncertain; therefore, the requirements for preventing its impact are unknown, but data indicate the asteroid could devastate a regional- to country-scale area if it should impact. If the asteroid should impact Earth, it will do so along the corridor shown in Figure 1.

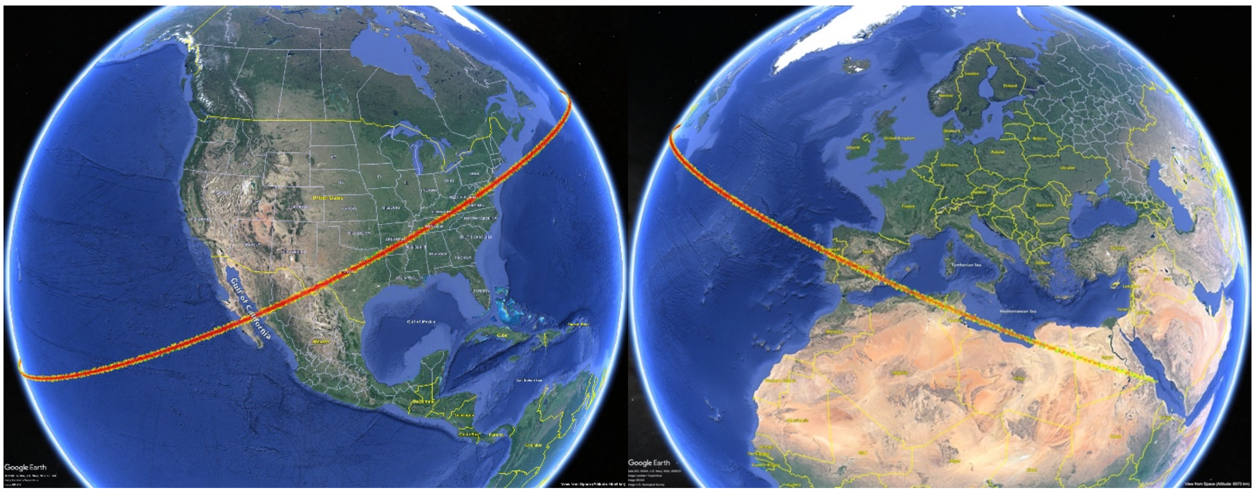


FIGURE 1. The impact risk corridor. The probability of Earth impact is 72% at the start of the TTX. If the asteroid is on track to impact Earth, the impact will occur at a point somewhere along the red swath. Potential impact locations span a corridor from the South Pacific across North America, the Atlantic, the Iberian Peninsula, the Mediterranean coast of Africa, and Egypt, to the coast of Saudi Arabia.

The following table summarizes events that have occurred before the first day of the TTX:

Date	Event
4 October 2023	Astronomers discover a previously unknown near-Earth asteroid. The discovery is confirmed the next day.
15 October 2023	After 10 days of observation to determine the asteroid's orbit, the Earth impact probability reaches 0.01%. Previously taken sky images are reanalyzed, resulting in a "precovery" detection of the asteroid in the archival data. These additional observations increase the precision of the orbit determination, and the impact probability rises to 2.7%. At this point, the threshold has been crossed for an official notification by the International Asteroid Warning Network (IAWN).
16 October 2023 to 30 March 2024	The asteroid continues to be observed daily, and the additional data narrow the orbit uncertainties, which results in the impact probability increasing.
18 November 2023	Impact probability rises above 10%, crossing the threshold that triggers the Space Mission Planning Advisory Group (SMPAG) to study development of space mission options.

31 March 2024 Further observations are prevented for the next seven months as the asteroid is too distant and appears too close to the Sun in the sky for telescopes to observe (Figure 2).

2 April 2024 Based on all observations to date, at the time of the TTX, the estimated probability of Earth impact has risen to 72%.

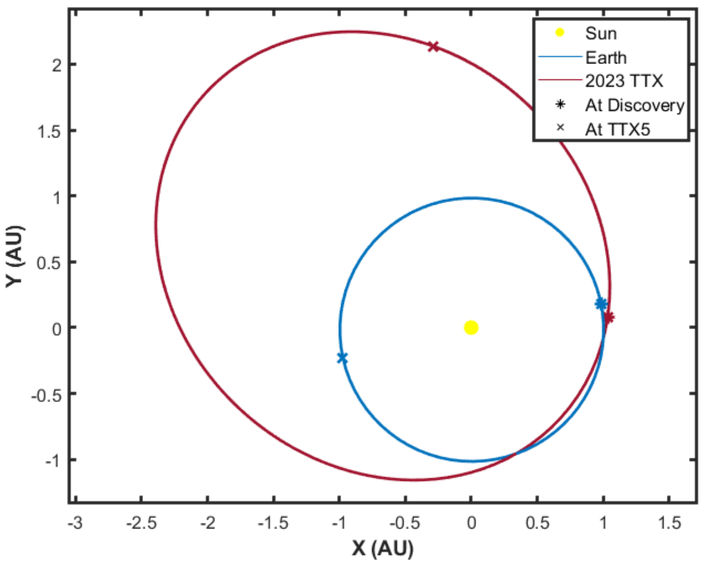


FIGURE 2. The orbit of asteroid 2023 TTX, shown in the XY plane of Earth's orbit. The blue ellipse shows Earth's orbit, and the red ellipse shows the asteroid's orbit. The yellow dot shows the location of the Sun. The red and blue asterisks indicate the locations of the asteroid and Earth, respectively, when 2023 TTX was discovered. The red and blue "x" symbols show the locations of the asteroid and Earth, respectively, in their orbits as of 2 April 2024.

What is planetary defense?

Planetary defense encompasses the capabilities needed to detect and warn of potential asteroid or comet impacts with Earth as well as the capabilities to either prevent such impacts or mitigate their possible effects. Planetary defense involves:

- Detecting and tracking near-Earth objects (NEOs) to find any that pose a hazard of impacting Earth. NEOs are a population of asteroids and comets that orbit the Sun like the planets, but whose orbits also bring them into Earth's neighborhood.
- Characterizing these hazardous NEOs to determine their trajectories, sizes, shapes, masses, compositions, rotational dynamics, and other parameters, to assess the likelihood and severity of a potential Earth impact and warn of its timing and potential effects.
- Studying the distribution of physical properties in the NEO population to facilitate meaningful estimates if they cannot be measured for a specific NEO of interest.
- Predicting the effects from a potential NEO impact, including ground and infrastructure damage, the probable damage ranges, and populations affected by the impact based on observations and modeling of the hazardous NEO and its impact.
- Planning, testing, and operationally implementing measures to prevent Earth impact by deflecting or disrupting a NEO on an impact course with Earth, or to mitigate the effects of an impact if it cannot be prevented. Mitigation measures that can be taken on Earth to protect lives and property include evacuation of the impact area and securing of critical infrastructure.

NASA established the PDCO to manage the elements of its ongoing mission of planetary defense.

How often do asteroids impact Earth?

Figure 3, below, shows how often, on average, asteroids of different sizes impact Earth, the associated consequences, and the percentage of such asteroid populations discovered. Astronomers estimate that there are ~25,000 NEOs roughly 140 meters (500 feet) or larger in size—large enough to cause regional devastation if they were to impact Earth. Only about 43% of near-Earth asteroids greater than 140 meters have been found to date. No currently known asteroid has a significant chance of impacting Earth for the next 100 years, but given the large numbers of NEOs yet to be discovered, an unknown asteroid could still impact with inadequate warning.

The Hazard by the Numbers

How Big?	10 meters	50 meters	140 meters	1000 meters	10,000 meters
How Often?	~1 per **decade**	~1 per **1000 years**	~1 per **20,000 years**	~1 per **700,000 years**	~1 per **100 million years**
How Bad?	Very bright fireball, strong sonic boom could break windows if close to habitation	Local devastation, regional effects, may or may not leave an impact crater	Airburst or km-scale crater; deadly over metro areas/states, mass casualties	10-kilometer crater; country-scale devastation, potential for global catastrophe	100-kilometer crater; global devastation, mass extinctions of terrestrial life
Approx. impact energy (megatons)	~0.1	~10	~100	~100,000	~100,000,000
How Many?	**~45 million**	**~120,000**	**~25,000**	**~900**	**4**
% Discovered	**0.1%**	**12%**	**43%**	**95%**	**100%**

FIGURE 3. Frequency, on average, of impacts by asteroids of various sizes.

In recent history, have asteroid impacts caused damage?

Yes. On 30 June 1908, a NEO estimated to be between 40 and 60 meters (130–200 feet) in size impacted in the Tunguska River valley, Siberia, Russia, and devastated over 2,000 square kilometers (800 square miles) of forested land. That area is more than 2.5 times the size of New York City. On 15 February 2013, a previously undetected, small asteroid exploded over Chelyabinsk, Russia (Figure 4), causing an airburst and shock wave that struck six cities within the region. The blast injured >1,600 people and caused an estimated $30 million in damage. The Chelyabinsk object was about 18 meters (60 feet) in size. The hypothetical asteroid in this exercise is much larger. Larger asteroid impacts lead to graver consequences.

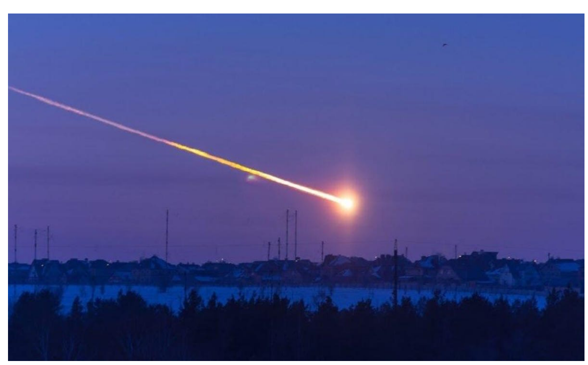
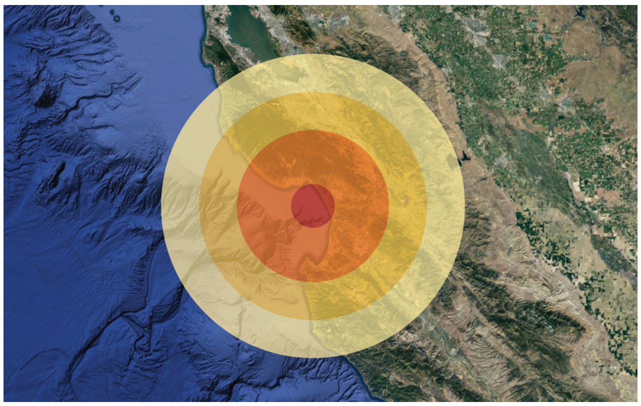


FIGURE 4. Asteroid airburst over Chelyabinsk, Russia, on 15 February 2013.

What kinds of damage could an asteroid impact cause?

The potential impact effects are highly dependent on the size of the asteroid and impact location. Although the most frequent damaging impacts are small asteroids that explosively disintegrate in the atmosphere, some asteroids are large enough to make it all the way to the ground and form an impact crater. Either way, the event would create a blast wave and, potentially, thermal effects. Impacts into the ocean could also cause tsunami(s) to damage coastlines if the asteroid is large enough and the impact occurs near enough to populated coasts. Damage is assessed at four relative severity levels, as shown in Figure 5. The table to the right of the figure provides a sense of the degrees of damage that may occur in the shaded areas.



Damage Level	Description
Serious	Windows shatter, some structure damage
Severe	Widespread structure damage, or 3rd degree burns
Critical	Residential structures collapse, or clothing ignites
Unsurvivable	Devastation, structures flattened or burned

FIGURE 5. Damage maps shown at the TTX will be formatted in this manner.

How are NEOs detected, catalogued, and tracked?

Using telescopes, astronomers observe the night sky, scanning for asteroids. Astronomers measure the positions of known or suspected asteroids and submit them to the Minor Planet Center (MPC). The MPC is the sole worldwide repository for these observations and is officially sanctioned by the International Astronomical Union. The MPC is responsible for the identification and orbit computation of the asteroids and disseminates information on objects of interest so they can be further investigated using telescopic or radar measurements. From the MPC, organizations such as NASA's Center for Near-Earth Object Studies (CNEOS) and the European Space Agency's (ESA) Near-Earth Object Coordination Centre (NEOCC) take the observations and do higher-precision orbit determination. These organizations quantify the risk of Earth impact for an asteroid and help coordinate follow-up observations to reduce uncertainty in the asteroid's orbit.

What uncertainties exist for a NEO threat, and how can they be minimized?

In the event of a potential NEO impact, often very little is known about the object. Ground-based observations can help refine the object's orbit and provide a range of potential sizes based on the object's brightness. However, uncertainties remain with regard to the asteroid's position in its orbit, size, and other properties. Those uncertainties translate into uncertainties about exactly where the impact would occur and what damage might result.

For example, brightness alone does not directly correspond to size. A large, dark asteroid can look the same in optical telescopes as a small, light-colored asteroid. This happens because some materials are more reflective than others, meaning smaller, more reflective asteroids can have a higher apparent brightness. In contrast, if the material has a low reflectivity, the asteroid can be quite large but show the same brightness. Figure 6 illustrates how three different asteroids of the same brightness in telescopes can vary in size.

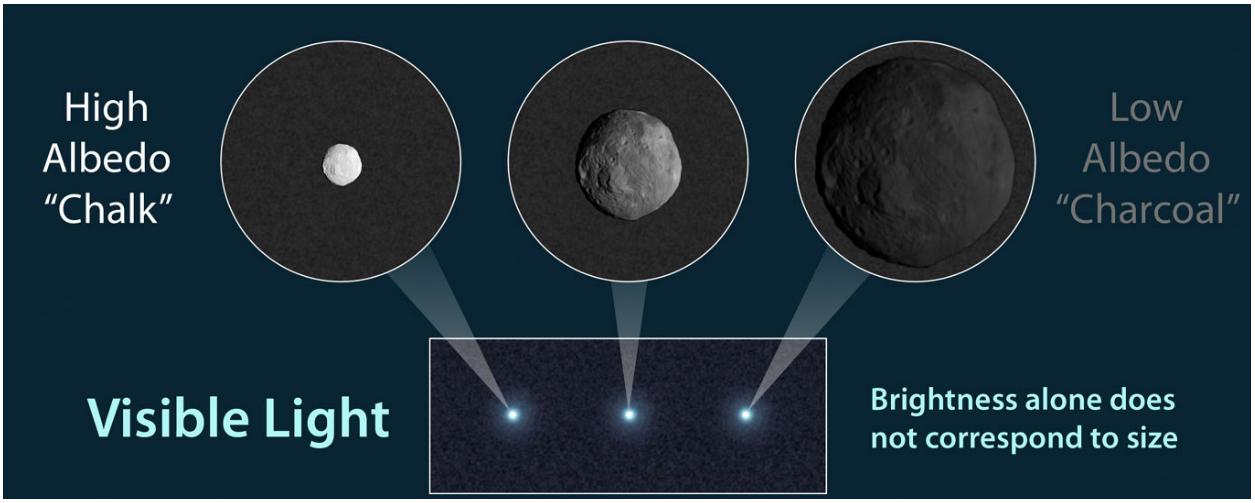


FIGURE 6. Asteroid brightness and size.
(Adapted from: http://wise.ssl.berkeley.edu/gallery_asteroid_sizes.html)

Space-based reconnaissance missions better constrain key asteroid properties to plan better missions designed to prevent an asteroid impact and reduce uncertainties for emergency preparedness and response planning. Two reconnaissance mission types exist: flyby and rendezvous.

Mission Type	Description
Flyby reconnaissance missions	"Flyby" missions use a spacecraft to fly past the asteroid at speeds of several kilometers per second (around 10,000 mph) or more and gather information on the asteroid's size and shape while passing by. Flyby missions are simpler than rendezvous missions, require less time to build, and have a wider range of potential launch dates. However, less data is obtained because the spacecraft only briefly observes one side of the asteroid and from farther away than a rendezvous mission. Figure 7 shows images obtained by the Lucy spacecraft during its recent flyby of asteroid Dinkinesh and by the Double Asteroid Redirection Test (DART) spacecraft during its flyby of asteroid Didymos.
Rendezvous reconnaissance missions	Rendezvous reconnaissance missions place a spacecraft very close to an asteroid at slow relative speeds, allowing the spacecraft to loiter near the asteroid for a long period of time, possibly even going into orbit around the asteroid if the asteroid is large enough. This proximity allows the spacecraft to monitor the asteroid and take multiple detailed measurements over several days, months, or even years. Rendezvous missions can provide many details about an asteroid, including detailed maps of the surface, as well as information about its shape, mass, and composition. However, rendezvous spacecraft are more complicated to design and take more time to construct than flyby spacecraft and, because of orbit synchronization requirements, typically have fewer launch dates available and take a longer time to reach the asteroid. Examples of recent near-Earth asteroid rendezvous missions include NASA's Origins, Spectral Interpretation, Resource Identification, and Security – Regolith Explorer (OSIRIS-REx) at asteroid Bennu (see Figure 8) and Japan Aerospace Exploration Agency's (JAXA) Hayabusa2 at asteroid Ryugu.

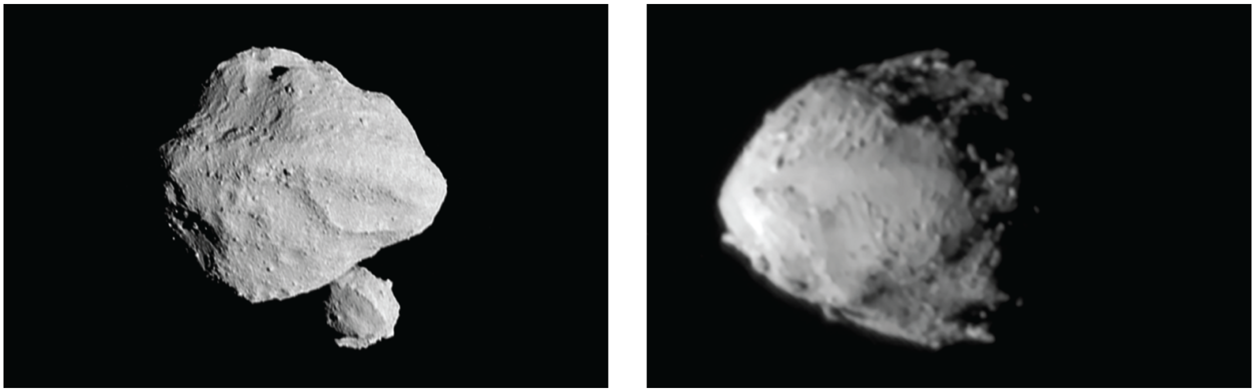


FIGURE 7. Images taken during spacecraft flybys of asteroids. Left: Image taken by NASA's Lucy mission as it flew past the Dinkinesh asteroid system. (Credit: NASA/Goddard/Southwest Research Institute/Johns Hopkins APL/NOIRLab) Right: Image taken by NASA's DART mission as the spacecraft flew past asteroid Didymos on its way to demonstrate kinetic impact technology at asteroid Dimorphos. (Credit: NASA/Johns Hopkins APL)

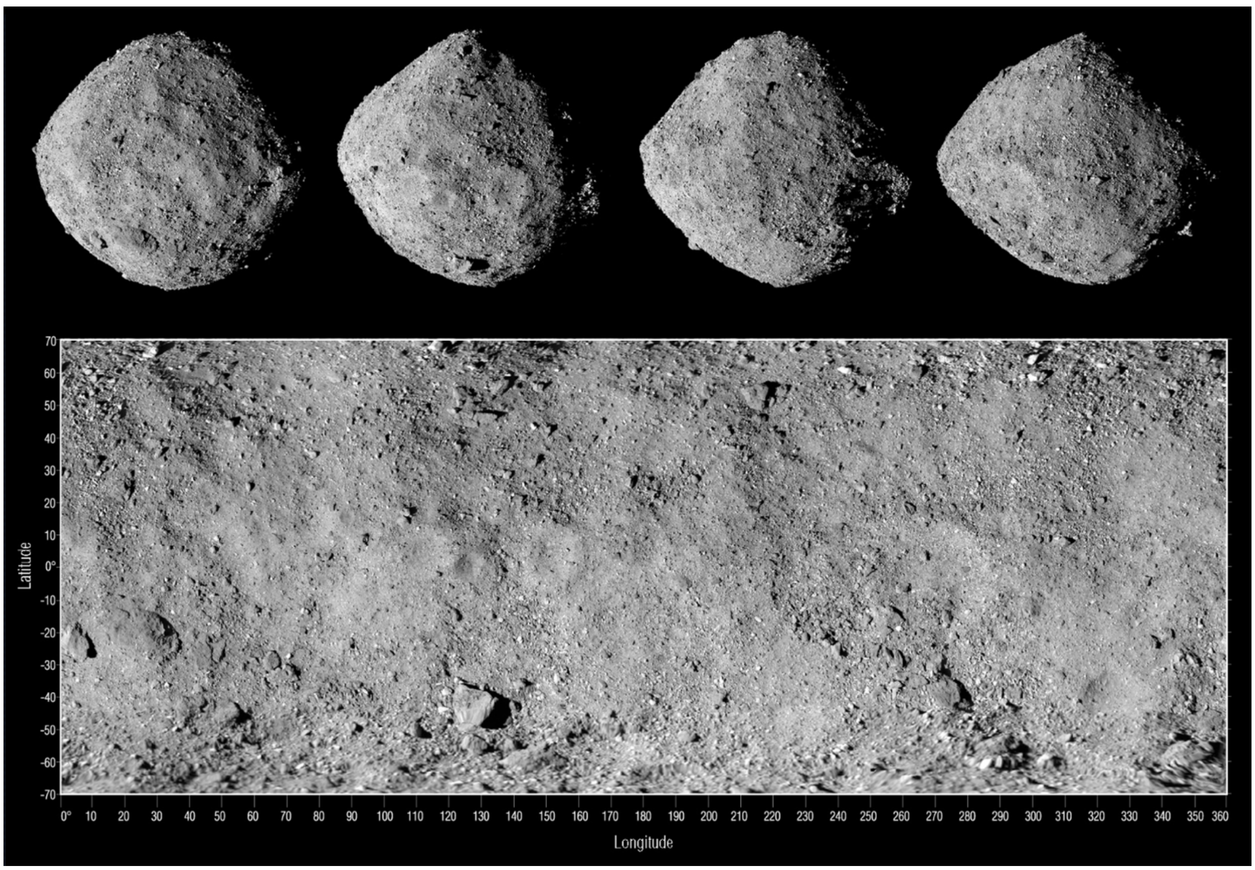
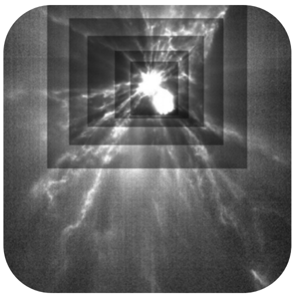


FIGURE 8. Examples of image data collected by a rendezvous mission. These images of asteroid Bennu were taken by NASA's OSIRIS-REx mission while the spacecraft orbited Bennu. (Credit: NASA/Goddard/University of Arizona, https://www.asteroidmission.org/bennu-sides-and-global-mosaic/)

Is it possible to prevent an asteroid impact?

Yes. There are several space-based mitigation concepts to avert an asteroid impact. They all work by either changing the asteroid's orbit, which is called deflection, or breaking the asteroid into many smaller pieces, which is called disruption. Three primary impact-prevention methods are relevant to the asteroid threat in this exercise:

Method	Description
Kinetic Impactor  Credit: ASI/NASA/APL	Kinetic impactors are the most technologically mature asteroid impact-prevention method. This method was successfully demonstrated by NASA's DART mission. Kinetic impactors are primarily used for deflection, although asteroid disruption may be possible if the asteroid is small enough and the spacecraft is massive enough. The kinetic impactor technique involves impacting the asteroid with a spacecraft that slightly changes the asteroid's orbital speed, which, in turn, alters the orbit of the asteroid through conservation of momentum. The specifics of launch timing and orbital mechanics affect the required mass and speed of the spacecraft at impact and the resulting "push" imparted to the asteroid. Because of the small amount of deflection that a kinetic impactor can achieve, this impact-prevention method must be employed several years in advance of a potential Earth impact.
Slow "Push–Pull" Techniques 	If there is long enough warning time of the Earth impact (generally a decade or more), a slow "push–pull" technique can be used, which could have the benefit of allowing more precise placement of the asteroid onto a new orbit that misses Earth. Slow push–pull techniques are for deflection only and cannot be used for asteroid disruption. There are two primary push–pull methods: ion beam deflection (IBD) and gravity tractor. IBD uses a high-energy ion source, such as a spacecraft ion thruster, to bombard the surface of the asteroid with ions that impart their momentum to the asteroid and over time slowly push the asteroid into a new orbit around the Sun that will miss Earth. Gravity tractors use the small gravitational attraction between a spacecraft and the asteroid to slightly alter the orbit of the asteroid over time. Both techniques must work over many months to years to change an asteroid's orbit enough that the asteroid will miss Earth. Neither IBD nor gravity tractor have been demonstrated, and both remain at the conceptual stage of development.
Nuclear Mitigation 	Nuclear explosive devices (NEDs) can be used to deflect or disrupt an asteroid, depending on the yield and "standoff distance" from the asteroid. In space, detonation of an NED does not create a blast or shock wave like it would in an atmospheric nuclear explosion. Instead, the device acts as a strong radiation source, emitting a large quantity of radiation, especially X-rays (but also other types such as gamma rays and neutrons). The radiation rapidly heats the asteroid's surface, which then "ablates," or vaporizes, and acts like a "rocket impulse" to push the asteroid, change its velocity, and therefore change its orbit. If the device is close to the surface or is higher yield, a shock from the force of the ablation could also cause the asteroid to break up. The orbital changes caused by an NED can greatly exceed those from either the kinetic impactor or the slow push–pull technique and therefore could be used in scenarios with shorter warning times. However, the use of nuclear explosives has international law and treaty restrictions, and as the time to impact becomes very short, even NEDs may be ineffective.

What is the current international structure for planetary defense notifications?

There are two primary international groups that have been established and will work together in the event of a predicted asteroid impact. The International Asteroid Warning Network (IAWN; see iawn.net), which is currently coordinated by NASA, consists of observers, modelers, and analysts who work together to detect, track, and predict any NEO impact hazard. This collaboration determines aspects of a potential impact threat, including time, location, and the range of potential damage severity. IAWN provides information to the Space Mission Planning Advisory Group (SMPAG; see smpag.net), currently chaired by ESA, which will coordinate potential space-based responses. This group consists of space agencies and their offices that collaborate to recommend viable concepts for a potential mitigation campaign. Figure 9 illustrates their relationships.

If IAWN determines there is a credible asteroid or comet Earth impact threat, they inform the United Nations Committee on the Peaceful Uses of Outer Space (UN COPUOS) through the United Nations Office for Outer Space Affairs (UNOOSA). Notification is issued by IAWN in accordance with report SMPAG-RP-003 on "Recommended Criteria & Thresholds for Action for Potential NEO Impact Threat," which defines the threshold for issuing warnings of possible impact as when a NEO has an Earth impact probability greater than 1% and a rough asteroid size estimate of at least 10 meters (33 feet).

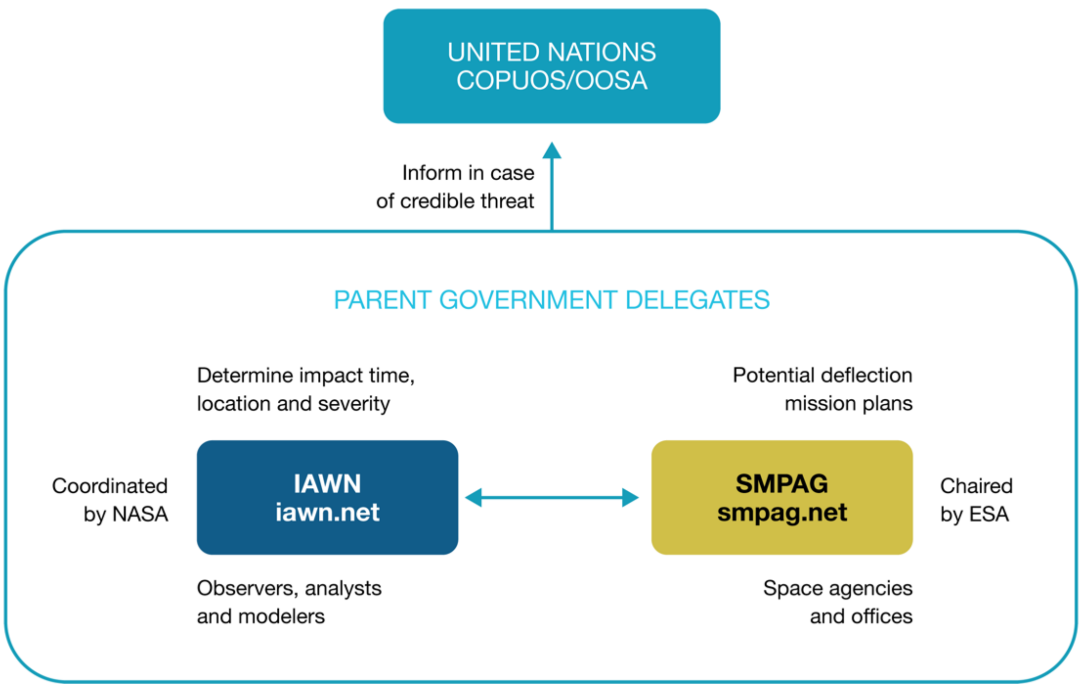


FIGURE 9. Overview of the international communication channels for planetary defense. (Credit: Adapted from the United Nations Office for Outer Space Affairs "Near-Earth Objects and Planetary Defence" report)

Where can I learn about emergency planning, preparedness, and response?

During this exercise, we will discuss how organizations might work together in the event of an asteroid impact threat. Part of that discussion will focus on emergency planning, preparedness, and response. One resource on the international aspects of emergency planning, preparedness, and response is available at:

https://www.undrr.org/implementing-sendai-framework/what-sendai-framework