

After Action Report

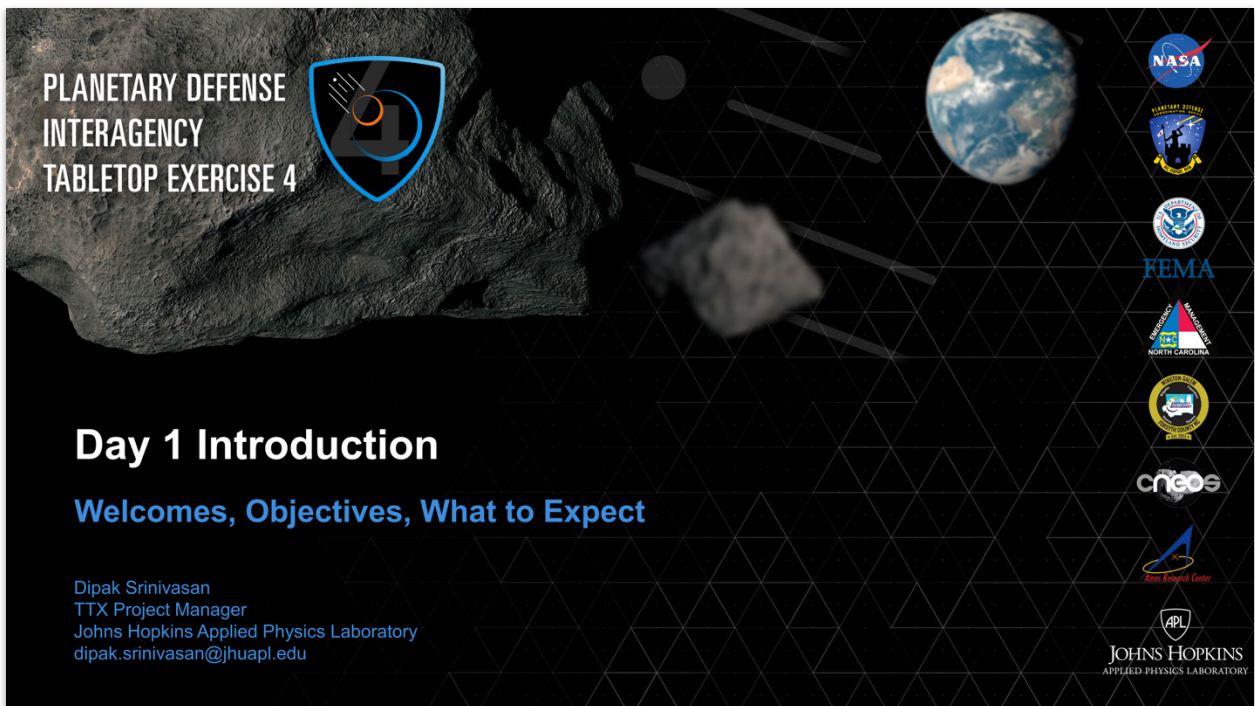
Appendix C: Presentation Slides

This appendix contains static versions of the as-presented slides from the 4th Planetary Defense (PD) Interagency Tabletop Exercise (TTX). The actual slides in some cases contained animations to better inform or describe the scenario.

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C.1 Introductory Material



Agenda

PLANETARY DEFENSE
INTERAGENCY
TABLETOP EXERCISE 4



- Welcome
- Few words from our sponsor
 - Lindley Johnson, NASA Planetary Defense Coordination Officer
- Few words from our TTX Director
 - L.A. Lewis, NASA PDCO FEMA Detailee
- Why we are here
- Objectives
- What to expect

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Why We Are Here

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- **What would we do** if we knew a sizable asteroid was headed our way?
- Do we **understand everyone's roles** in this scenario?
- After we're done, what can do well ahead of time to **be better prepared** for this?



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Objectives

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1. *Increase the understanding* by personnel and U.S. government institutions of near-Earth object (NEO) threats and their roles in mitigating that threat
 - Opportunity to understand what the role of USSPACECOM is
2. *Test methods of communicating* information both to and among decision-makers
3. *Exercise post-impact protocols*, including involvement of local government

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Structure of the TTX

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- Set of “Planetary Defense 101” short briefs
- TTX broken into five “modules,” numbered 0–4
 - Each module represents a different segment of time between discovery of the asteroid through post-impact protocols

Module	Description
0	Quick briefing of the read-ahead materials
1	6 months before impact
2	2 months before impact
3	6 days before impact
4	Post-impact response and recovery

- Module structure
 - Series of injects (either new information presented or questions posed) resulting in Q&A or discussion
 - Hot wash with Participant Feedback Forms (PFFs)

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Agenda for Day 1

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Day 1	Start (EST)	Stop (EST)	Duration	Activity
23-Feb	12:30	13:00	0:30	Arrival and Check-in <i>for any in-person people</i>
	13:00	13:20	0:20	Welcome, Objectives, What to Expect
	13:20	13:35	0:15	Technical logistics
	13:35	13:55	0:20	Introduction to Planetary Defense 101
	13:55	14:10	0:15	Why Planetary Defense 101
	14:10	14:30	0:20	Asteroid Detection and Tracking 101
	14:30	14:45	0:15	Break
	14:45	15:00	0:15	Asteroid Damage Modeling 101
	15:00	15:15	0:15	Space Mitigation Strategies 101
	15:15	15:30	0:15	Module 0: Background, Initial Detection
	15:30	15:40	0:10	Pre-exercise Participant Feedback
	15:40	16:30	0:50	Module 1a: Early Detection & Mitigation
	16:30	16:45	0:15	Debrief Day 1

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Agenda for Day 2

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TABLETOP EXERCISE 4




Day 2	Start (EST)	Stop (EST)	Duration	Activity
24-Feb	7:00	8:00	1:00	Arrival and Check-in (continental breakfast served)
	8:00	8:30	0:30	Welcome, Objectives, What to Expect
	8:30	9:30	1:00	Module 1b: Continue Early Detection Discussion
	9:30	9:45	0:15	Break
	9:45	11:35	1:50	Module 2: Early Preparedness
	11:35	12:35	1:00	Lunch
	12:35	14:25	1:50	Module 3: Final Preparedness and Readiness
	14:25	14:40	0:15	Break
	14:40	16:30	1:50	Module 4: Response and Transition to Recovery
	16:30	17:00	0:30	Debrief, capture comments

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Online Protocols

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- For Zoom participants
 - Keep mics muted when not in active conversation
 - Please rename your Zoom to include your Name and Organization, e.g., Dipak Srinivasan/APL
 - Smile! When speaking, or otherwise, we encourage you to keep your cameras on as much as possible
 - For chats:
 - Use Zoom Chat for only discussing administrative/logistic concerns
 - Use MeetingSphere Chat for any exercise-specific discussions
 - Feel free to use the TTX4 Zoom background provided to you
- For all participants – MeetingSphere Chat
 - MeetingSphere will be running a parallel set of static slides as the main Zoom PowerPoint
 - Each MeetingSphere slide will have its own chat thread, enabling focused topic-based conversation even if time constraints force the exercise to move on
 - Participants can either continue chats in the “main” chat room or scroll back to the prior slide(s)
 - There is also a “Parking Lot” discussion board to capture ideas or conversation threads that we had to abandon for time purposes, both for potential follow-up and to ensure inclusion in the final after-action report

**Your discussions are the data we seek to help make our TTX a success!
Please keep those good thoughts flowing!**

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PLANETARY DEFENSE INTERAGENCY TABLETOP EXERCISE 4



















C.2 Planetary Defense 101 and Module 0

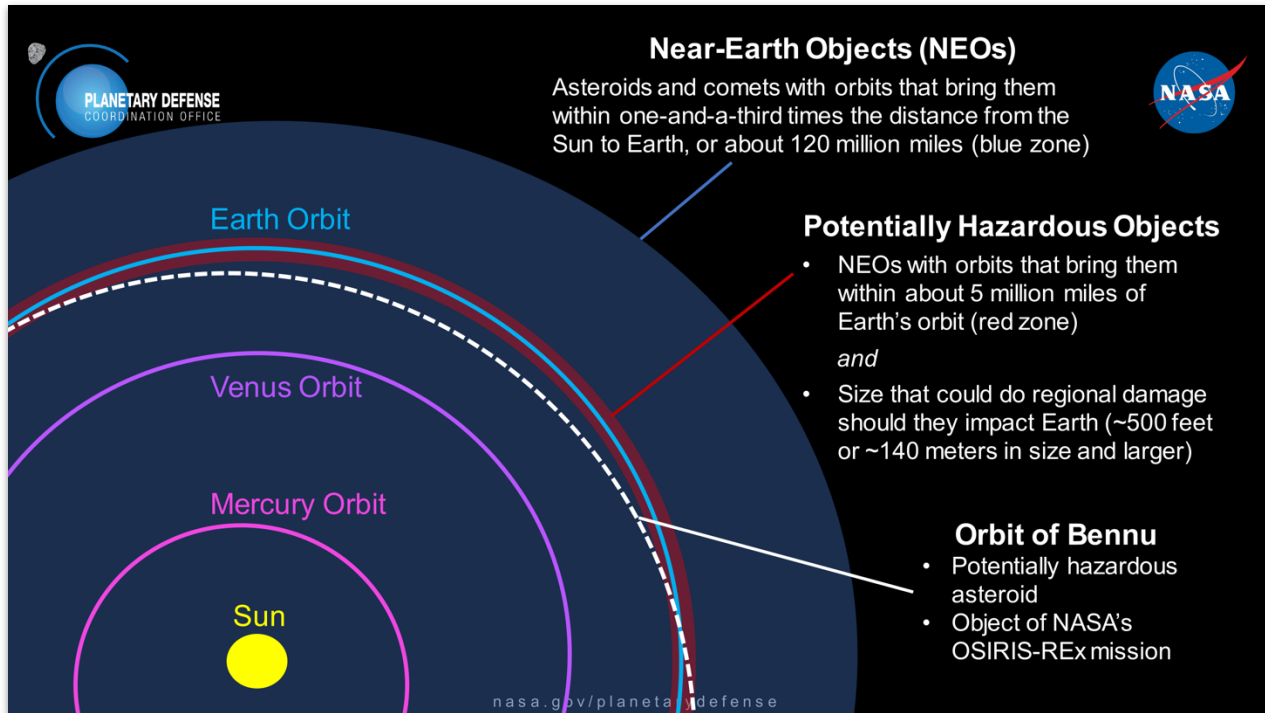
Slide 1



Slide 2



Slide 3



Slide 4

PLANETARY DEFENSE COORDINATION OFFICE

Planetary Defense Coordination Office

The Planetary Defense Coordination Office (PDCO) was established in January 2016 at NASA HQ to manage planetary defense-related activities across NASA as well as coordinate with both U.S. interagency and international efforts to study and plan a response to the asteroid impact hazard.

Mission Statement

Lead national and international efforts to:

- Detect any potential for significant impact of Earth by natural objects
- Appraise the range of potential effects by any possible impact
- Develop strategies to mitigate impact effects on human welfare

nasa.gov/planetarydefense

Slide 5

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White House
Guidance released
on 20 June 2018

<https://www.nasa.gov/sites/default/files/atoms/files/ostp-neo-strategy-action-plan-jun18.pdf>

NASA

EXECUTIVE OFFICE OF THE PRESIDENT OF THE UNITED STATES
OFFICE OF SPACE AND TECHNOLOGY POLICY

NATIONAL NEAR-EARTH OBJECT
PREPAREDNESS STRATEGY AND
ACTION PLAN

A Report by the
INTERAGENCY WORKING GROUP FOR DETECTING AND MITIGATING
THE IMPACT OF EARTH-BOUND NEAR-EARTH OBJECTS

of the
NATIONAL SCIENCE & TECHNOLOGY COUNCIL

JUNE 2018

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**National Near-Earth Object
Preparedness Strategy and Action Plan**

Goals in the 10-year Action Plan:

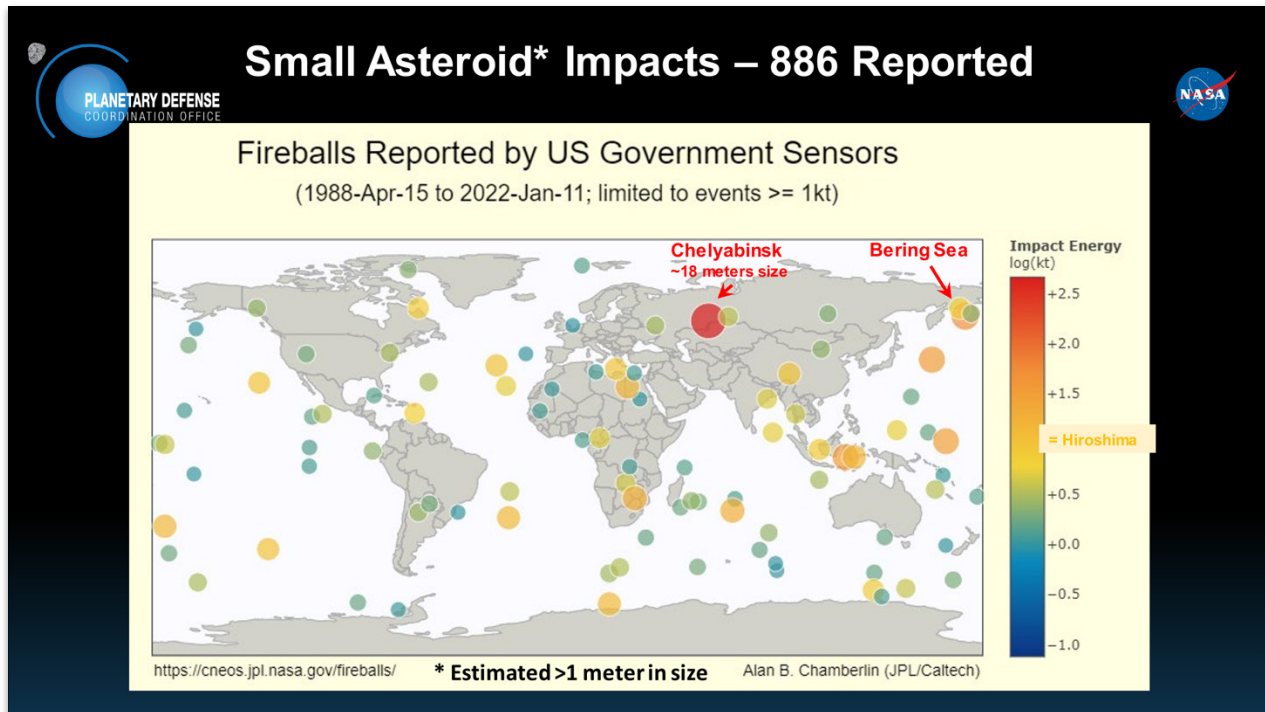
- Enhance NEO detection, characterization, and tracking capabilities
- Improve modeling, predictions, and information integration
- Develop technologies for NEO deflection and disruption
- Increase international cooperation on NEO preparation
- **Establish NEO impact emergency procedures and action protocols**

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Slide 7



Slide 8




Slide 9



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COORDINATION OFFICE

Asteroid Impact Relative Energy



Diameter of Impacting Asteroid	Type of Event	Approximate Impact Energy (MT)	Average Time Between Impacts (Years)
5 m (16 ft)	Bolide	0.01	1
10 m (33 ft)	Superbolide	0.1	10
25 m (80 ft)	Major Airburst	1	100
50 m (160 ft)	Local Scale Devastation	10	1000
140 m (460 ft)	Regional Scale Devastation	300	20,000
300 m (1000 ft)	Continent Scale Devastation	2,000	70,000
600 m (2000 ft)	Below Global Catastrophe Threshold	20,000	200,000
1 km (3300 ft)	Possible Global Catastrophe	100,000	700,000
5 km (3 mi)	Above Global Catastrophe Threshold	10,000,000	30 million
10 km (6 mi)	Mass Extinction	100,000,000	100 million

Protected by atmosphere

Still vulnerable

Working on it!

Found them all!

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NASA's NEO Search Program

(Current Survey Systems)





NEOWISE
JPL
0.4 m
Sun-synchronous low Earth orbit



ATLAS
U of HI
0.5 m Haleakala, Maui
0.5 m Mauna Loa, HI

ATLAS sites in Chile and South Africa were installed in 2021



Catalina Sky Survey
U of AZ
1.5 m
0.7 m
Arizona



Pan-STARRS
U of HI
1.8 m
1.8 m
Haleakala, Maui

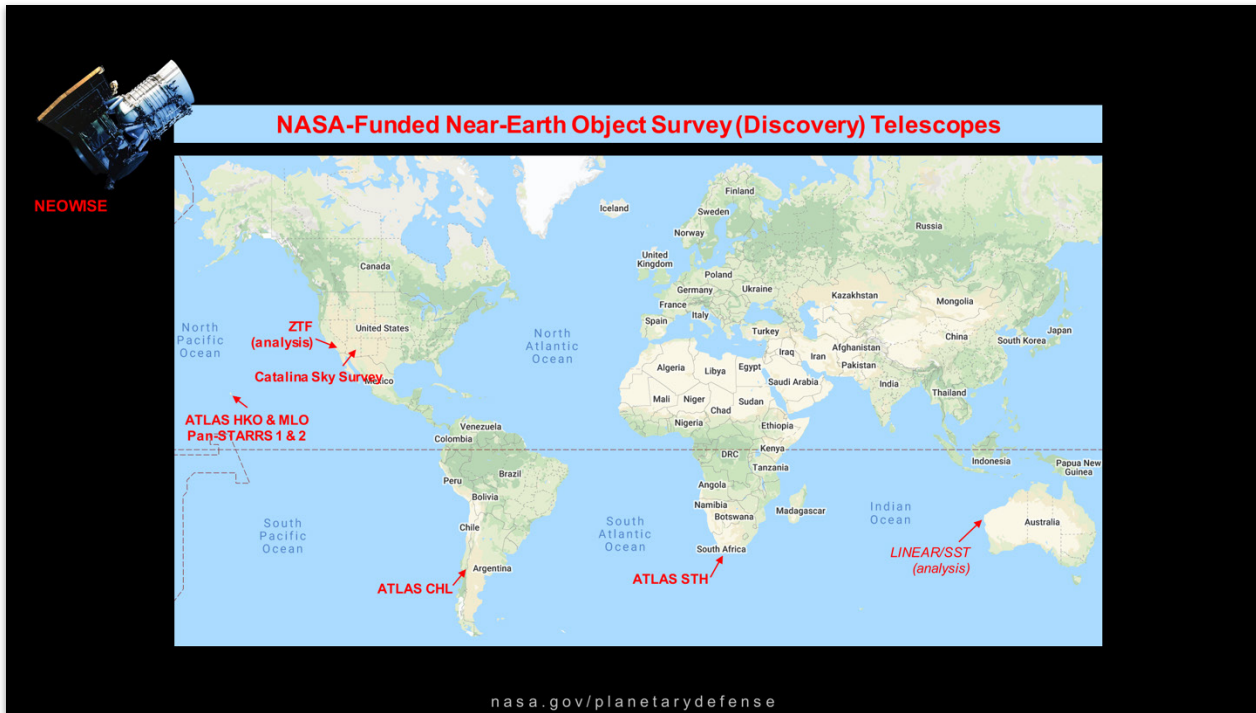


LINEAR/SST
MIT/LL
3.5 m
Testing in Australia

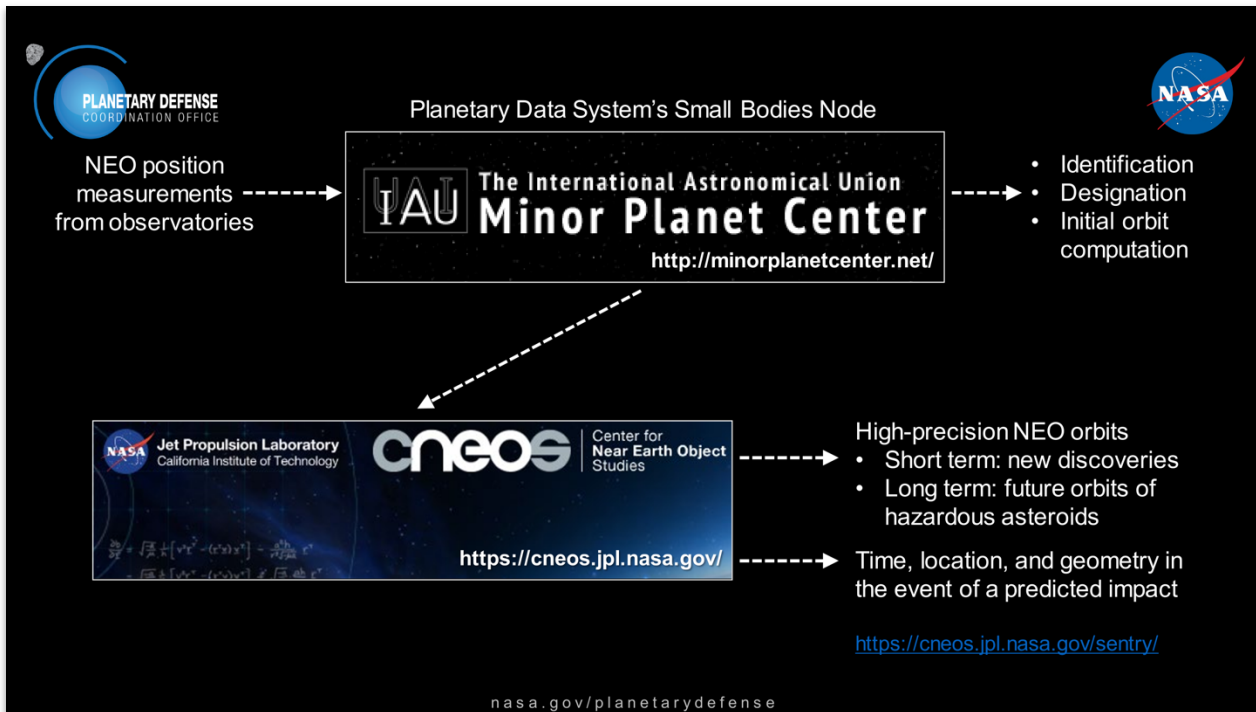
Also processing of data for NEO detections from Caltech's Zwicky Transient Facility

nasa.gov/planetarydefense

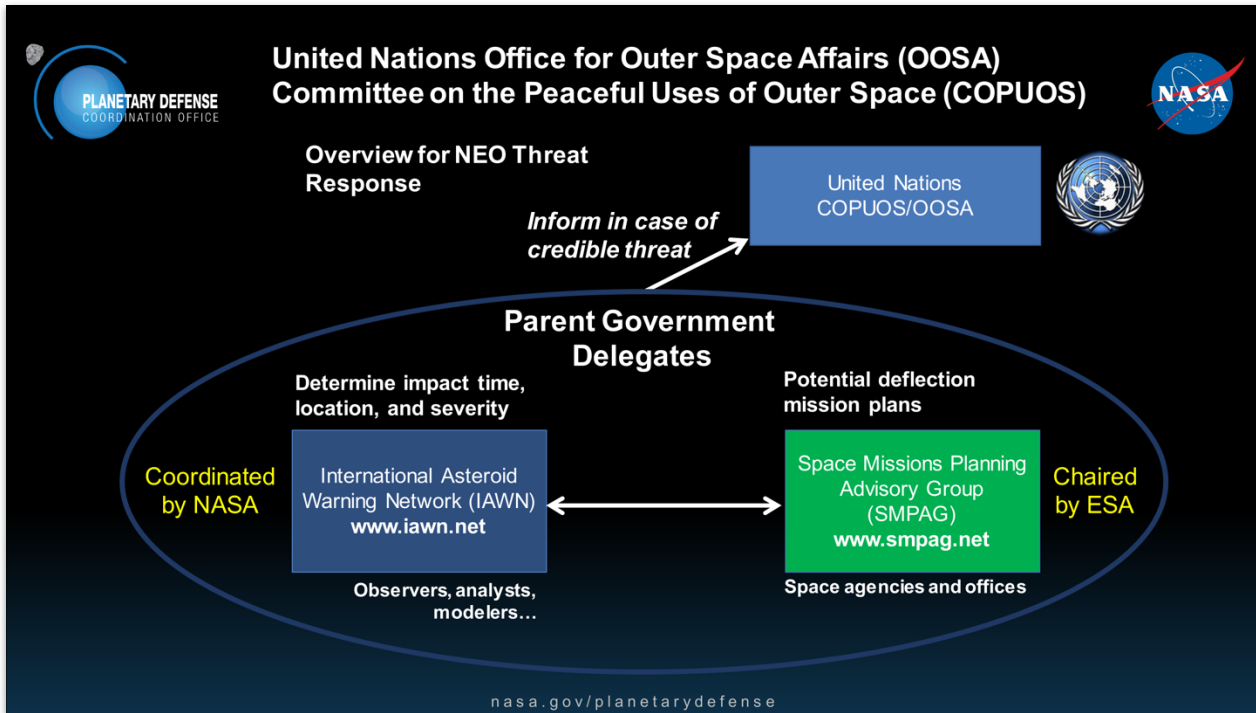
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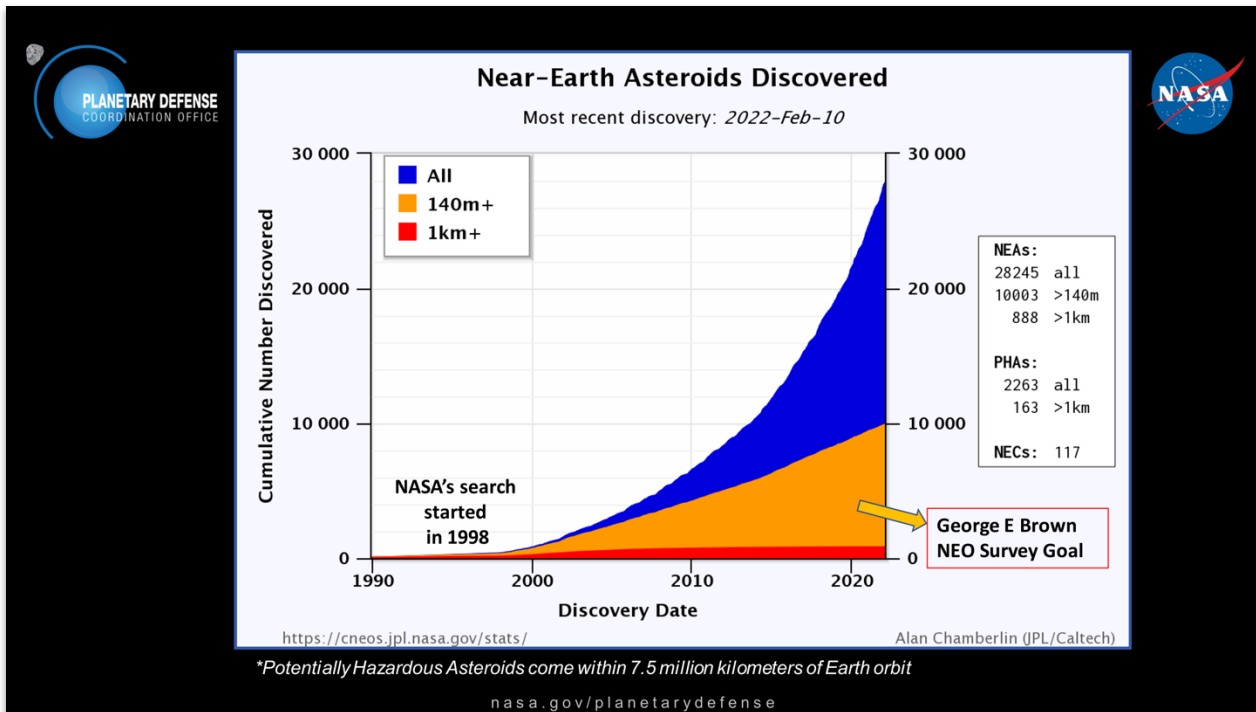
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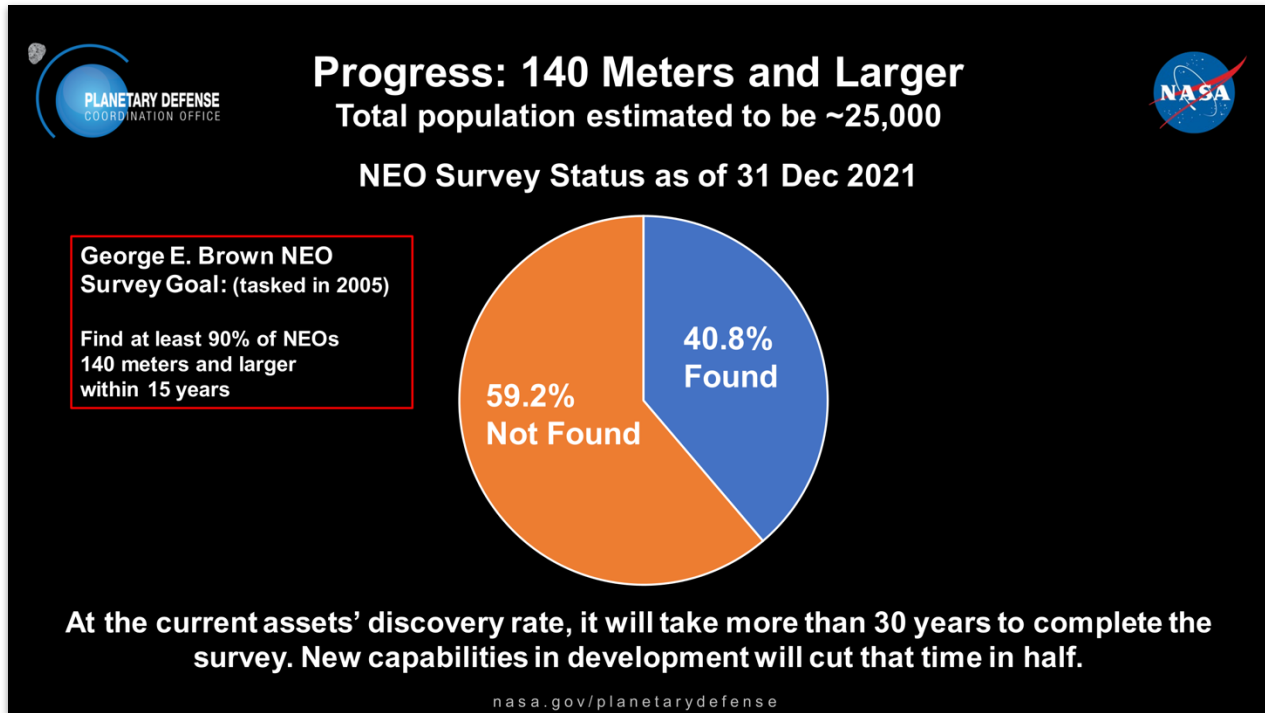
Slide 13



Slide 14



Slide 15



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NEO Surveillance Mission

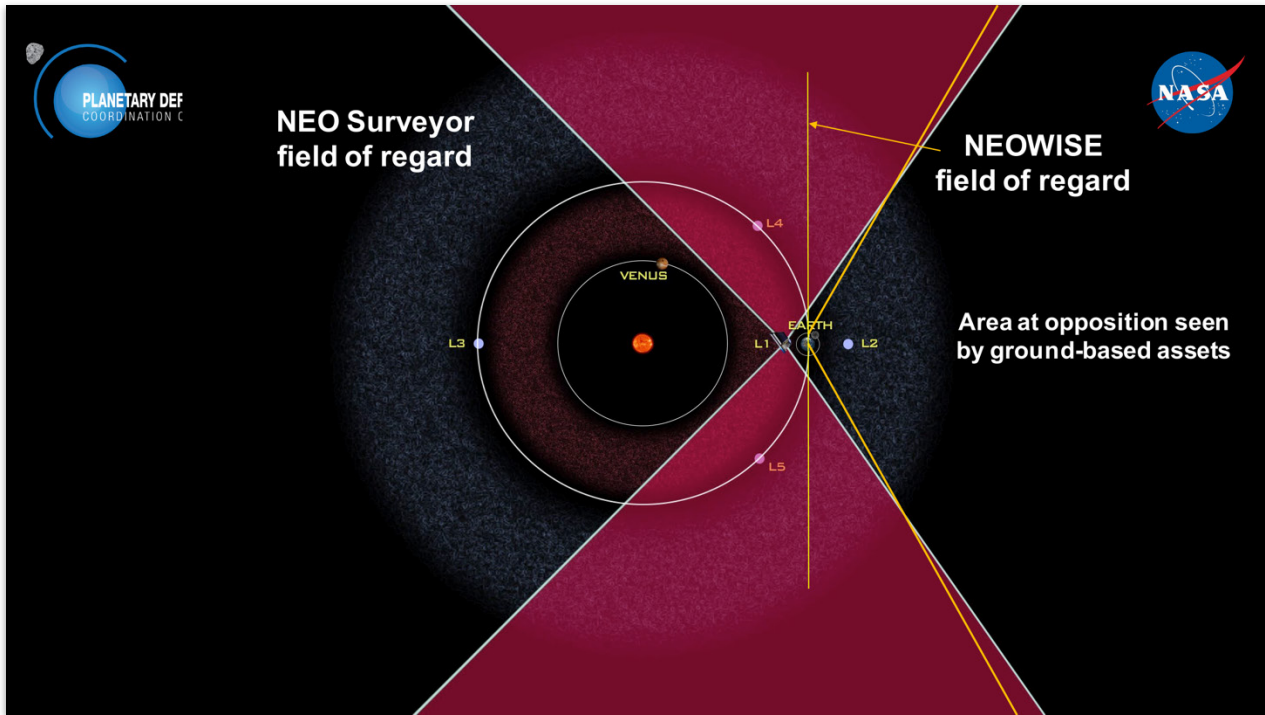
Objectives:

- Find 65% of undiscovered potentially hazardous asteroids (PHAs) >140 meters in 5 years (goal: >90% in 10 years)
- Estimate sizes directly from infrared signatures
- Compute cumulative chance of impact over next century for PHAs >50 meters and for comets
- Deliver new tracklet data daily to the Minor Planet Center
- On track for PDR and KDP-C “Confirmation” in fall 2022
- President’s Budget Request for FY22, if enacted, would fully fund the Phase B project development
- Planned launch readiness date in early 2026

NEO Surveyor Space-Based IR Observatory

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Slide 19

Launched on 24 Nov 2021 at 1:21 a.m. EST

SpaceX Falcon 9
Vandenberg Space Force Base, CA

- Target the binary asteroid Didymos system
- Impact Dimorphos and change its orbital period
- Measure the period change from Earth

Impact: 26 Sep 2022

LICIACube
(Light Italian Cubesat for Imaging of Asteroids)
Italian Space Agency contribution

DART Spacecraft
14,000 miles per hour

Dimorphos
160 meters
11.92-hour orbital period

Didymos
780 meters

Earth-Based Observations
6.8 million miles (0.07 AU) from Earth at DART impact

1,180-meter separation between centers

DART – Double Asteroid Redirection Test

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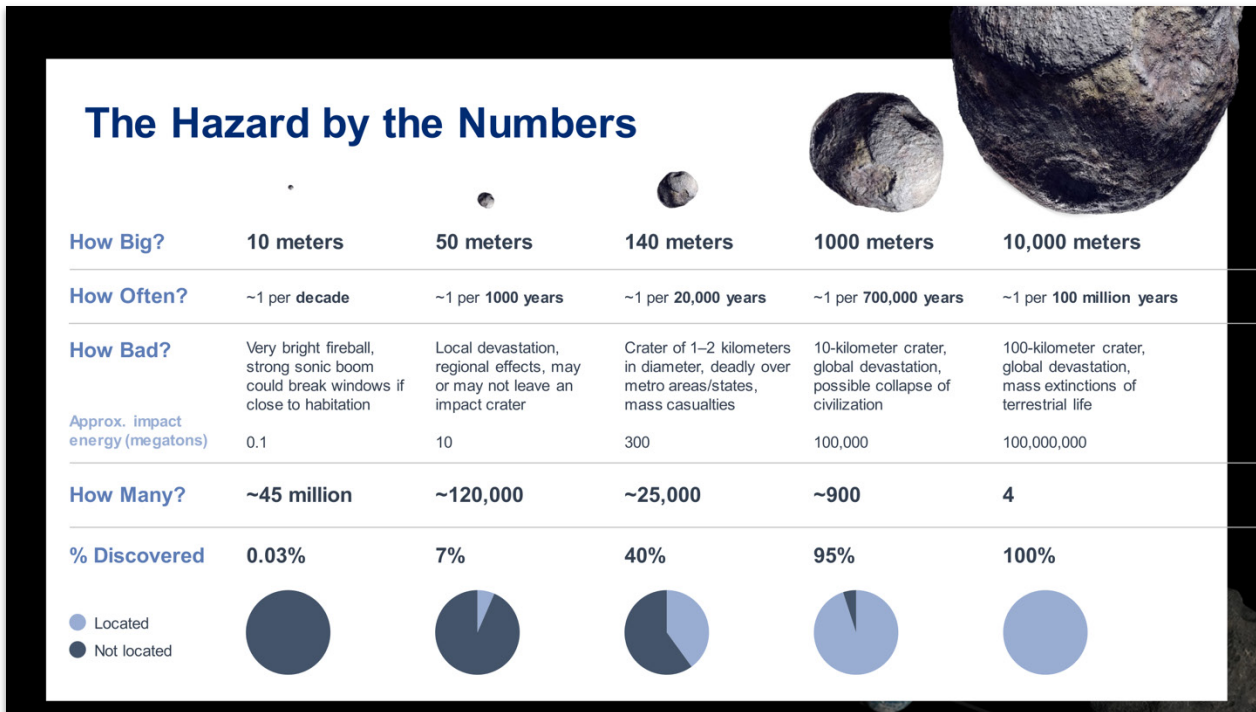
Asteroid Impacts

Consequences and Analogies

Andy Rivkin
Johns Hopkins Applied Physics Laboratory
andy.rivken@jhuapl.edu

Logos: NASA, PLANETARY DEFENSE, FEMA, NORTH CAROLINA, cneos, Johns Hopkins Applied Physics Laboratory

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Slide 23

Small Celestial Debris Hits Earth Frequently, Mostly Burns Up

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- 100 tons of material impacts the Earth every day (mostly dust)






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☐ Slide 24

Peekskill Impact, October 1992

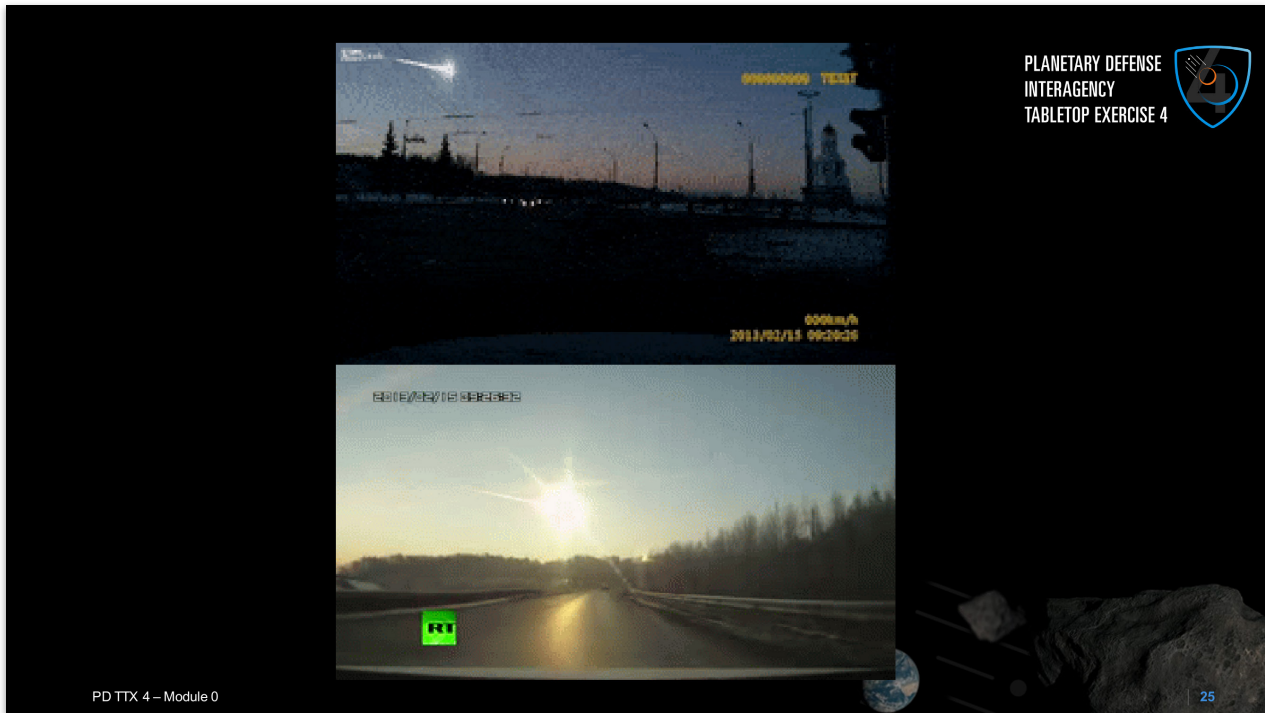
PLANETARY DEFENSE INTERAGENCY TABLETOP EXERCISE 4 

- Asteroid of roughly 1–2 m in diameter impacted Earth on 9 October 1992
- Airburst over eastern United States
- Largest recovered piece was 30 cm in diameter, struck car in New York City suburb of Peekskill



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Chelyabinsk Impactor's Orbit


- Originated in main asteroid belt
- Approached Earth from sunward direction
- Roughly 20–25 m in diameter


- Objects move counterclockwise around the Sun in this view

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A Sense of Scale

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Chelyabinsk impactor estimated to be about half the size of an Olympic-size pool (in two dimensions)

2016 U.S. Olympic trials in Omaha, Nebraska

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Main Chelyabinsk Meteorite Landed in a Frozen Russian Lake

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Meteor Crater (50,000 Years Ago)

EXERCISE EXERCISE EXERCISE

40- to 50-m metallic asteroid, 1-km crater, every 10 thousand years or so

Many of the early geological studies focused on finding the big iron body they thought would be there...

...but the nature of these supersonic impacts destroys and disperses the impactor.



EXERCISE EXERCISE EXERCISE

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Slide 31

Barringer (“Meteor”) Crater

USGS/D. Roddy

1.2 km

Meteor Crater

10 km 24 km 40 km

Fireball Large animals killed or wounded Hurricane-force winds

Kring, (2017). *Guidebook to the Geology of Barringer Meteorite Crater, Arizona (a.k.a. Meteor Crater)*, 2nd edition, Lunar and Planetary Institute, Houston, TX, LPI Contribution No. 2040.

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Barringer (“Meteor”) Crater

What if?

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DC

United States Capitol
Legendary home of the US legislature

VA Alexandria

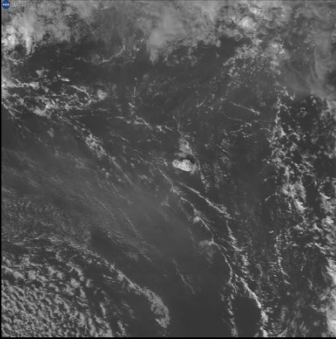
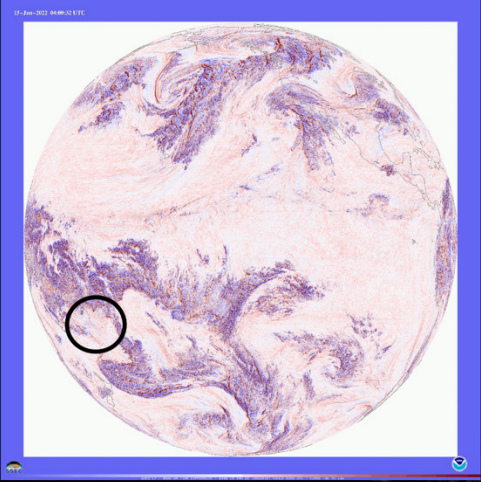
MD

Photograph by Mario Roberto Durán Ortiz, 2014 (Creative Commons CC-BY-SA 4.0)

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2/22/2022 32

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Tonga volcanic eruption on 15 January 2022:

- Estimated energy of 4–20 MT of TNT
- Equivalent to impact of typical 50- to 75-m asteroid at typical speeds

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What do we need to know, and how do we learn it?

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- Impact energy!
 - Speed
 - Mass
- Mass hard to remotely measure
 - Size
 - Density
- Size can be measured/estimated remotely
 - Measure reflected brightness, estimate reflectivity
 - Measure emitted heat, directly get size
- Can sometimes remotely measure composition
 - When available, allows density estimate, reflectivity estimate


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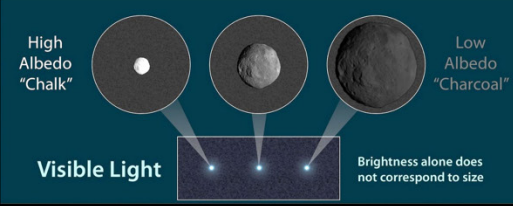
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Seizing Sizes

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- Usually, we observe brightness, not size.
- Big dark things can be as bright as small high-albedo (“shiny”) things.
- One of the snowballs on the right would be as bright as one of the bricks of charcoal if all we could measure was the amount of light from each.
- Until/unless a more diagnostic measurement can be made for a particular object, we must estimate its size from its brightness.




High Albedo
“Chalk”

Low Albedo
“Charcoal”

Visible Light

Brightness alone does not correspond to size




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Bottom-Line Takeaways

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- Impacts happen all the time.
- Larger impacts happen less frequently, but with increased consequences.
- Impacts of 50-m objects can devastate a region.
- Properties that we want to know must often be estimated rather than directly measured.



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TABLETOP EXERCISE 4

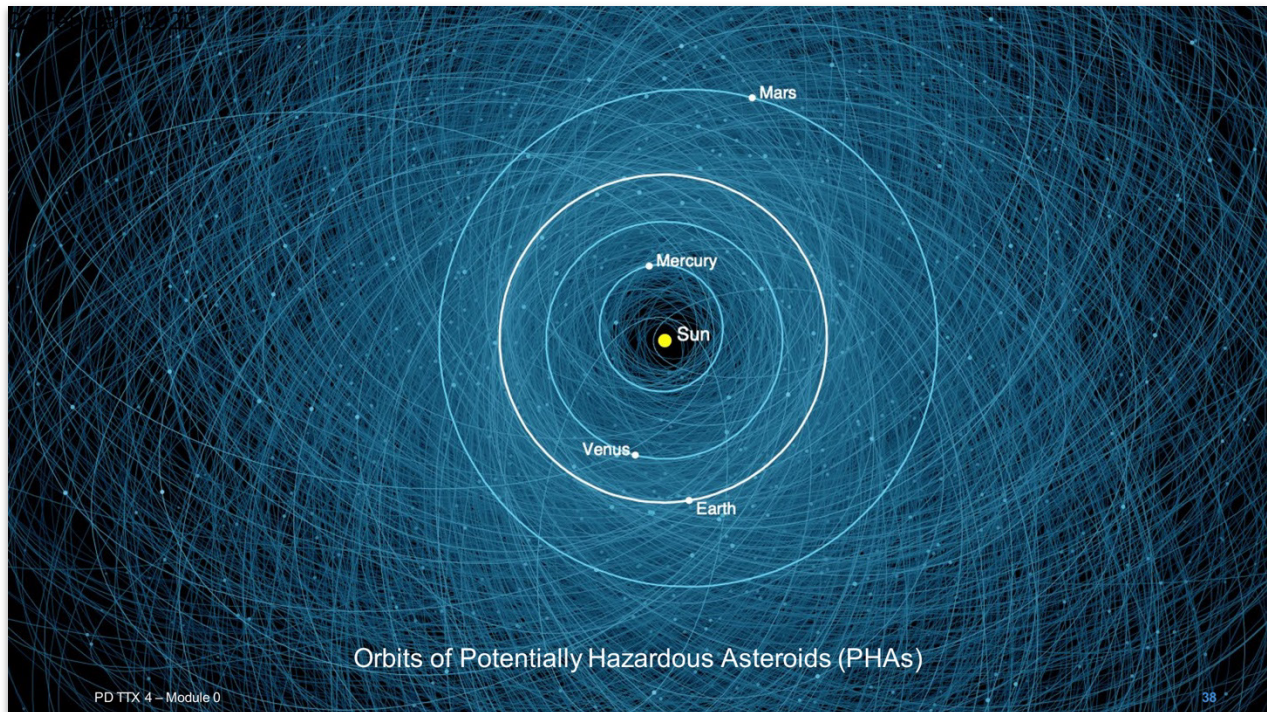
Introduction to CNEOS, Predicting Impacts, and 2022 TTX

How asteroids are discovered, orbits computed and the chances of impact assessed

Paul Chodas, Davide Farnocchia & Ryan Park
Center for NEO Studies (CNEOS)
Jet Propulsion Laboratory, California Institute of Technology


Logos: NASA, Department of Defense, FEMA, NORTH CAROLINA, CNEOS, Ames Research Center, JOHNS HOPKINS APPLIED PHYSICS LABORATORY

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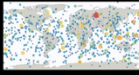






Center for Near Earth Object Studies

PLANETARY DEFENSE INTERAGENCY TABLETOP EXERCISE 4

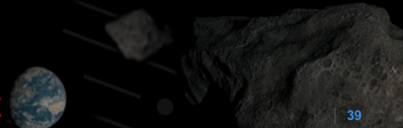


NASA's center for computing NEO orbits and assessing their chances of Earth impact

- 
 - Compute Orbits
- Fireball Reports 
- 
 - Predict Close Approaches
- Searchable Small-Body Database
- 
 - Predict Sky Positions (Future & Past)
- Predict Accurate Impact Times and Locations (e.g. Shoemaker-Levy 9 in 1993 and 2008 TC3 in 2008)
- 
 - Assess Chances of Impact (Sentry)
- Design Hypothetical Impact Scenarios
- 
 - Extensive Website (<https://cneos.jpl.nasa.gov>)

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EXERCISE EXERCISE EXERCISE



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EXERCISE EXERCISE EXERCISE



Center for Near Earth Object Studies

<https://cneos.jpl.nasa.gov/>


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CNEOS is NASA's center for computing asteroid and comet orbits and their odds of Earth impact.



Fireballs



Sentry

Quick Links

- [NEO Basics](#)
- [NEO DB Query](#)
- [Sentry \(impact risk\)](#)
- [Accessible NEAs](#)
- [Close Approach Tutorial](#)
- [NASA PDCO](#)
- [Asteroid Watch on Twitter](#)
- [Horizons](#)
- [Solar System Dynamics](#)

Next NEO Close Approach within 10 Lunar Distances (LD)

Object: [2022 BF](#)

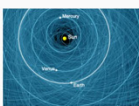
Date: 2022-Jan-26 01:50 ± 00:06 (hh:mm)

Dist: 1.27 LD (min: 1.27 LD)

H: 27.1

See our [Close Approach Tables](#) for more

Top News Stories



[NASA's Next-Generation Asteroid Impact Monitoring System Goes Online](#)

2021-12-06

To date, nearly 28,000 near-Earth asteroids (NEAs) have been found by survey telescopes that continually scan the night sky, adding new discoveries at a rate of about 3,000 per year. But as larger and more advanced survey telescopes turbocharge the search over the next few years, a rapid uptick in discoveries is expected. In anticipation of this increase, NASA astronomers have developed a next-generation impact monitoring algorithm called Sentry-II to better evaluate NEA impact probabilities.

[\[full story\]](#)



[International Observation Campaign Will Assess Asteroid Timing Accuracies](#)

2021-10-07

The International Asteroid Warning Network (IAWN) will conduct an observational campaign in November with the goal of assessing the accuracy of the observation times reported by asteroid observers.

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EXERCISE EXERCISE EXERCISE



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PD TTX4 – After Action Report, Appendix C

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EXERCISE EXERCISE EXERCISE

Asteroid Impacts Can Be Predicted Extremely Accurately


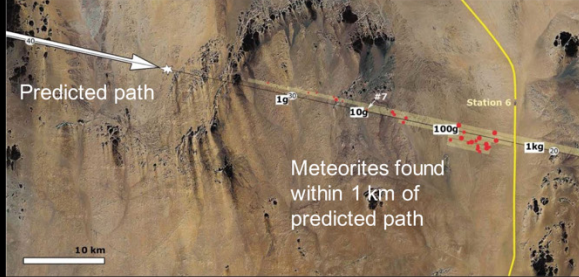
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Tiny asteroid **2008 TC3** discovered 19 hours before impact in Oct. 2008

As tracking data came in, impact probability went to 100% within 1 hour

11 hours before impact we predicted the asteroid would hit in N. Sudan

A month or so later a search party **found meteorites within 1 km of our predicted path**




Meteorite on the desert floor

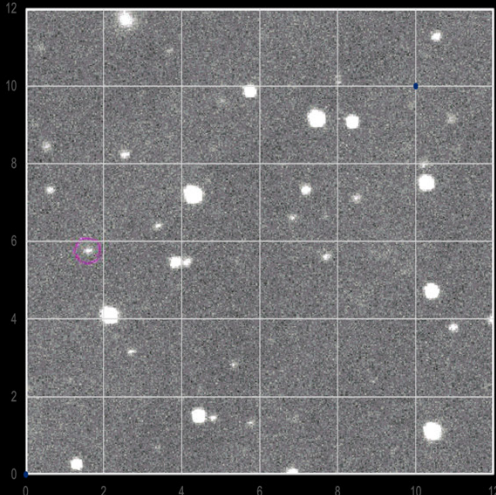
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How Asteroids Are Discovered

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Discovery images for 2008 TC3 from Catalina Sky Survey

Ground-based optical telescopes with wide-field cameras take hundreds of images of the sky every night

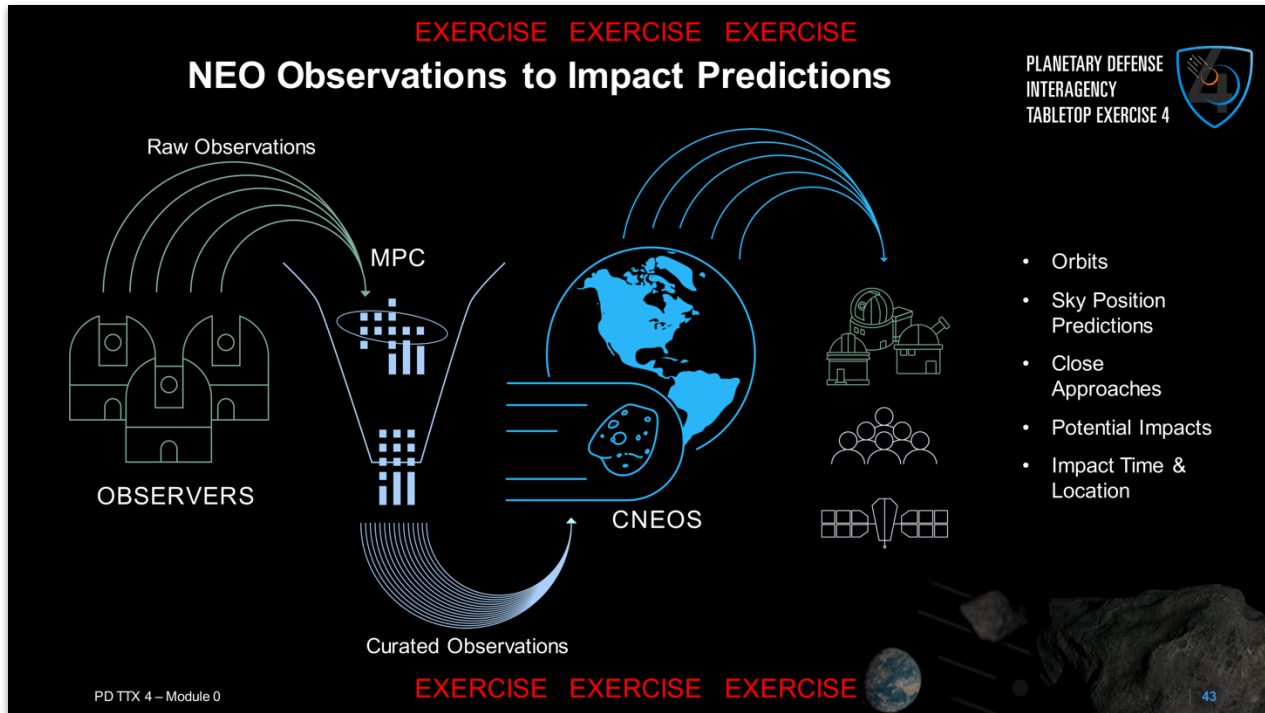
Typically, 4 images of each patch of sky are taken over the course of about 1 hour

An asteroid looks like a star, but it moves against the star background from one image to the next

The celestial latitude / longitude coordinates of the asteroid in each image are measured and reported along with the exact time of the image

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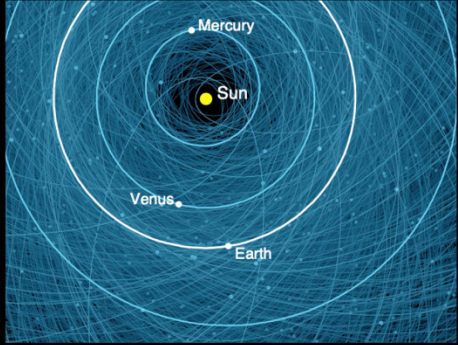
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EXERCISE EXERCISE EXERCISE

How an Asteroid's Orbit Is Computed

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- Tracking data are celestial sky coordinates: they don't tell us how far away an asteroid is, or how fast it's moving
- To determine an asteroid's orbit we try various possible orbits until we **find the one that most closely predicts all the observations**
- For a given orbit, we can compute the asteroid's future positions accurately
- No orbit fits all the observations exactly; the differences are due to small measurement errors in the observations
- We calculate the **orbit uncertainty** based on the uncertainties in the observations
- When we predict an asteroid's future position, we also compute the uncertainty in that position, which we call the **"uncertainty region"**
- **The longer we track an asteroid the better we know its orbit, and the more accurately we can predict its future position**



EXERCISE EXERCISE EXERCISE


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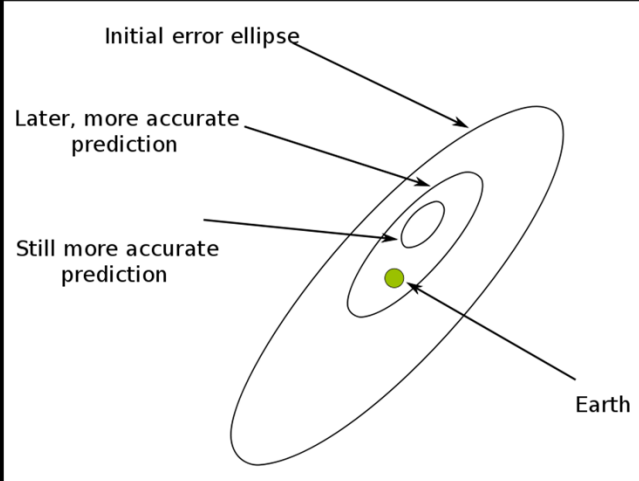
Slide 45

EXERCISE EXERCISE EXERCISE

Computing Impact Probability

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- An asteroid's uncertainty region is 3D, but we project it into a "target plane" to get an **uncertainty ellipse**
- If the ellipse intersects the Earth, an impact is possible; the fraction of overlap indicates the probability
- As the asteroid is tracked, its orbit gets more accurate and the ellipses will shrink
- If the ellipses shrink away from Earth the probability will go down; otherwise the probability will go up

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Slide 46

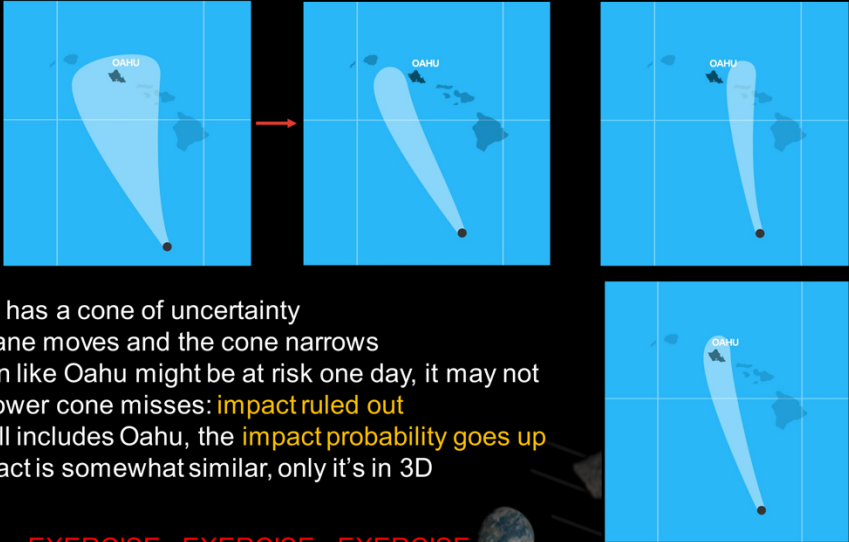
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Similarity with Predicting a Hurricane Trajectory

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- A hurricane prediction also has a cone of uncertainty
- As time passes, the hurricane moves and the cone narrows
- Whereas a specific location like Oahu might be at risk one day, it may not be the next day, if the narrower cone misses: **impact ruled out**
- Or, if the narrower cone still includes Oahu, the **impact probability goes up**
- Predicting an asteroid impact is somewhat similar, only it's in 3D

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EXERCISE EXERCISE EXERCISE

Introduction to the 2022 TTX Scenario

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- New asteroid is discovered on **11 February 2022**
- MPC assigns the designation: **2022 TTX**
- CNEOS computes the orbit and detects a small **chance of impact for 16 August 2022, six months away**
- Continued tracking over the next five nights leads to increasingly accurate orbits
- The Impact probability keeps rising each day, and **has now reached 5%**
- Asteroid size is highly uncertain: brightness measurement indicate the size range is **40–440 m (130–1440 ft)**
 - Orbital calculations do not depend on the size of the object, whereas impact effects predictions do
- Image archives are being searched for more predisccovery tracking data

M.P.E.C. 2022-Cxxx Issued 2022 February 12, 15:00 UT

The Minor Planet Electronic Circulars contain information on unusual minor planets and routine data on comets. They are published on behalf of Division F of the International Astronomical Union by the Minor Planet Center, Smithsonian Astrophysical Observatory, Cambridge, MA 02138, U.S.A.

CONTACT: CNEOS@JPL.NASA.GOV
URL: <https://cneos.jpl.nasa.gov/pd/ttx22>

2022 TTX

Observations:					
K22TXXT	C2022 02 11.00000	09 58 44.61	+12 26 16.3	21.5 V	500
K22TXXT	C2022 02 11.20000	09 58 16.34	+12 37 58.0	21.4 V	500
K22TXXT	C2022 02 11.20000	09 58 15.33	+12 38 23.1	21.4 V	500
K22TXXT	C2022 02 11.30000	09 58 14.32	+12 38 48.3	21.4 V	500
K22TXXT	C2022 02 11.30000	09 58 13.28	+12 39 13.4	21.4 V	500
K22TXXT	C2022 02 11.30000	09 58 08.23	+12 41 39.2	21.4 V	500
K22TXXT	C2022 02 11.37000	09 58 07.21	+12 41 46.4	21.4 V	500
K22TXXT	C2022 02 11.41000	09 58 03.14	+12 43 25.2	21.4 V	500
K22TXXT	C2022 02 12.00000	09 49 02.61	+13 08 28.0	21.3 V	500

Simulated discovery announcement from MPC

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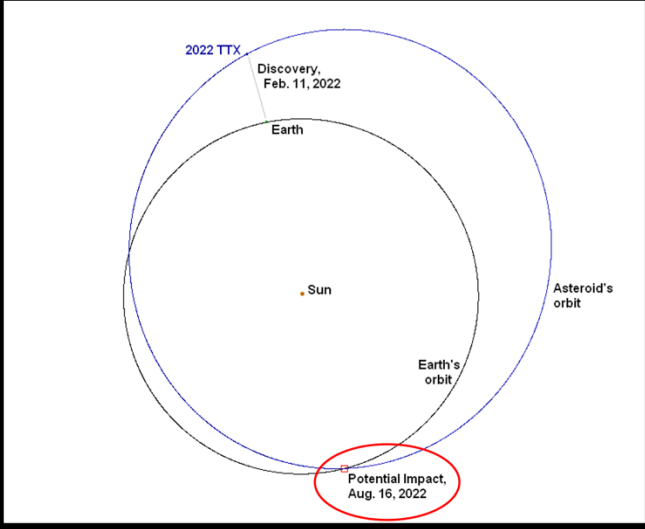
Slide 48

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The Orbit of 2022 TTX

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The asteroid orbit is mostly outside of Earth's orbit

The relative positions at discovery are noted

The point where the two orbits intersect is indicated by the tiny red box

The orbits don't intersect at the other crossing point because the asteroid orbit is tilted

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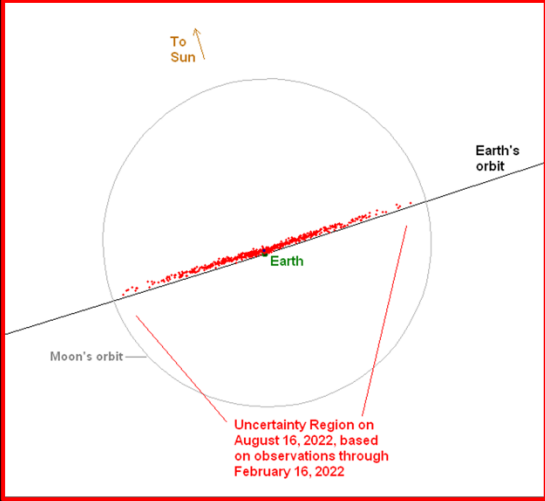
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Uncertainty in Predicted Position on Aug. 16

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- The **red dots** envelope a region of space where the asteroid will be when it encounters Earth on 16 August 2022
- The orbit is not yet accurate enough to indicate where the asteroid will be within this region
- 5% of the region intersects Earth
- As more observations are made, the uncertainty region will shrink

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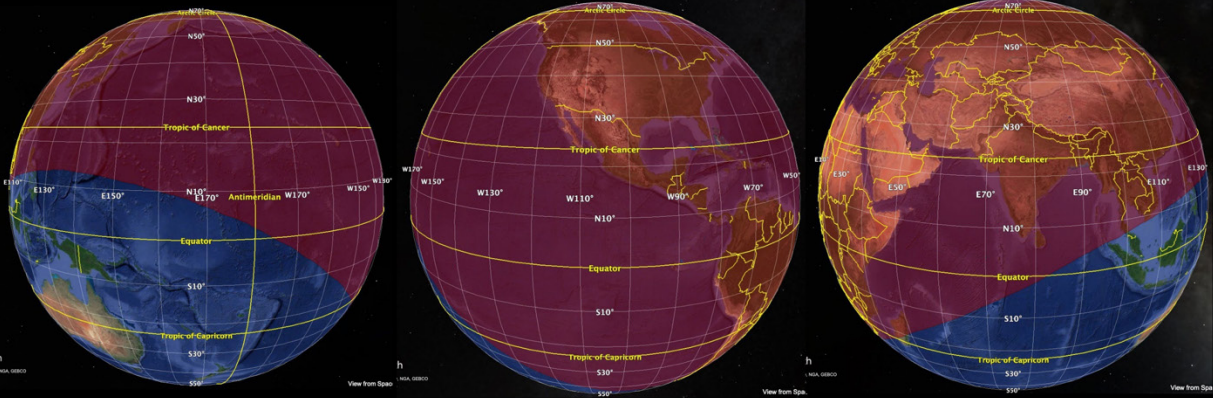
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Module 0: Predicted Impact Region

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The region covers 2/3 of the Earth surface, here shaded here in red/purple:



The region covers more than a hemisphere because Earth's gravity causes near-miss trajectories to bend inwards and impact


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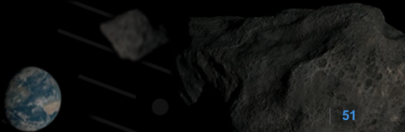
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Plans for More Observations of 2022 TTX

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- The asteroid is distant (37 million miles away), and it won't get much closer for several more months
- It is too distant to be detected by radar; it won't be within radar range until August
- The asteroid is faint but can be tracked optically, using large telescopes, for most of the six months up to impact; it will be observable on most nights through August
- Continued tracking of this asteroid is essential for obtaining the most accurate possible orbit and impact assessment
- Sky-image archives are being searched for possible predisccovery observations within the region of sky the asteroid may have traversed seven years ago, when it made a distant flyby of Earth


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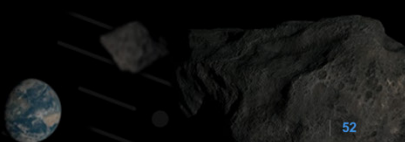
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Backups

- Sentry


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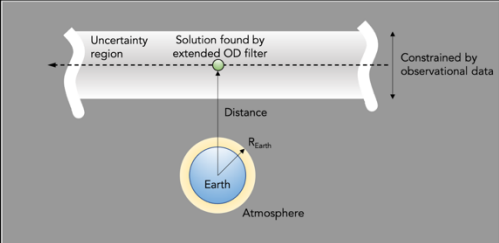
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Sentry: Long-Term Impact Predictions

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- Sentry is an impact monitoring system that checks all possible trajectories for an asteroid, looking for those **trajectories that might impact Earth over the next 100 years**
- For each potential impacting trajectory, Sentry reports the impact probability and assesses the risk
- The **Sentry Risk Table** is continually updated on the CNEOS website
- Currently there are **1378 asteroids** on the table
- Almost all of the potential impacts have either extremely low probabilities (less than 1 in a million), or are tiny asteroids that would likely disintegrate in the atmosphere if they should be headed for Earth



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- Comments on slide 53
- test (#1 | Aaron Chrietzberg)

Slide 54



C.3 Module 0b: Planetary Defense Briefing – Part 2

Slide 1

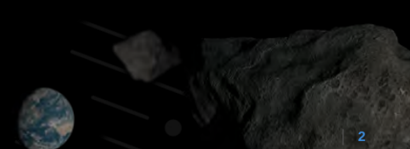


Slide 2

Outline

- What is asteroid impact risk assessment?
- Asteroid properties and uncertainties
- Impact hazards and damage effects
- Risk assessment modeling for specific impact scenarios
- Impact risk assessment result examples

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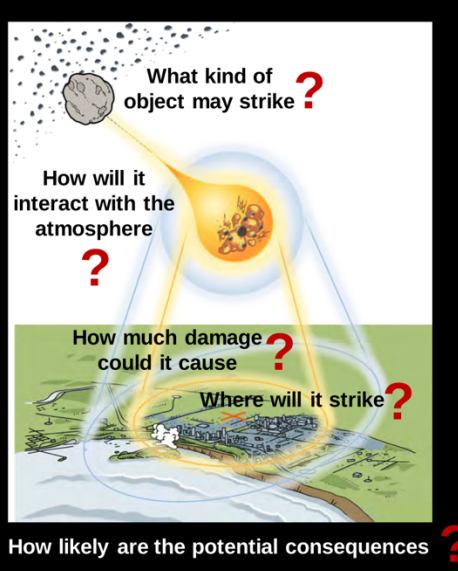


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Slide 3

What Is Asteroid Impact Risk Assessment?



- Risk assessment evaluates both the range and likelihood of potential outcomes, given the level of uncertainty or knowledge of the factors
- Evaluating asteroid impact risks involves large uncertainties across all aspects of the problem:
 - Impact probability, potential impact locations, entry trajectories (speed, entry angle)
 - Initial asteroid sizes and properties (density, strength, structure, composition, shape, etc.)
 - Atmospheric entry, breakup, airburst or impact behavior
 - Severity and range of resulting hazards
 - Population and infrastructure within damage regions
- Some uncertainties shrink as we gain knowledge over time (impact locations, asteroid size), while some remain unknown (specific asteroid properties, entry/breakup behavior, damage uncertainties)

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Slide 4

Asteroid Size and Property Uncertainty

What we would like to know about the object...






Image of asteroid Bennu from OSIRIS-REx mission (Image credit: NASA)

What we actually know...



Telescope observation of asteroid Apophis (Credit: Nic Erasmus, South African Astronomical Observatory's Lesedi Telescope, IAWN Apophis 2021 Observing Campaign, https://iawn.net/obs/apo/Apophis/apophis_gallery.shtml)

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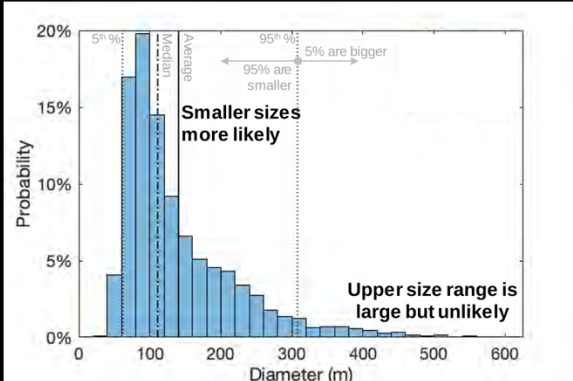
Slide 5

Asteroid Size and Properties


Asteroid sizes and physical properties are highly uncertain.

- Upper size range is large but relatively unlikely
- Smaller size ranges are more likely
- Asteroid properties (density, composition, structure, strength) are usually unknown, ranging from more common stony types and rubble piles to rarer high-density iron types
- Size and density uncertainties together result in very large ranges of potential mass and impact energy

Asteroid Diameter Distribution



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Asteroid Property and Damage Uncertainties

Cascade of uncertainty ranges from asteroid observation to damage potential

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- Size and density uncertainties together result in very large ranges of potential mass and impact energy
- Unknown composition/structural properties affect range of mass, strength, and atmospheric entry/breakup
- These properties determine how much energy the asteroid can deliver to the various hazards and how much damage they could do
- Asteroid impact energy:
 - Initial kinetic energy of the asteroid (asteroid mass, entry velocity)
 - Usually given in units of megatons (Mt) of TNT equivalent

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Asteroid Hazards

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- Asteroids can cause damage either by breaking up and bursting in the atmosphere or by impacting the surface
 - "Asteroid impact" generally refers to an asteroid hitting Earth, including airbursts (not just ground-cratering events)
- Blast damage:
 - Airbursts and surface impacts can produce explosive blast waves, which can cause damage ranging from shattered windows to flattened structures.
- Thermal damage:
 - Thermal heating from airburst/impact fireballs can cause damage ranging from mild skin burns to lethal infernos and structure fires
- Tsunami damage:
 - Ocean impacts could cause significant inundation if impact is very large and or near a populated coast
- For the asteroid sizes in this exercise scenario, blast damage from an airburst is the predominant hazard

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Airburst Blast Simulation (movie)


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Simulation of blast from a 120-m, 50-Mt asteroid airburst

- Entry: Shockwaves emanate from the entry path as the asteroid enters at high speeds
- Airburst: Asteroid disrupts catastrophically under high aerodynamic pressures, producing an explosion-like blast
- Ground damage: Shock front reflects off the ground and sends a powerful blast wave outward across the ground



Cart3D Computational Fluid Dynamics Simulation (Credit: Michael Aftosmis, Asteroid Threat Assessment Project, NASA Ames)

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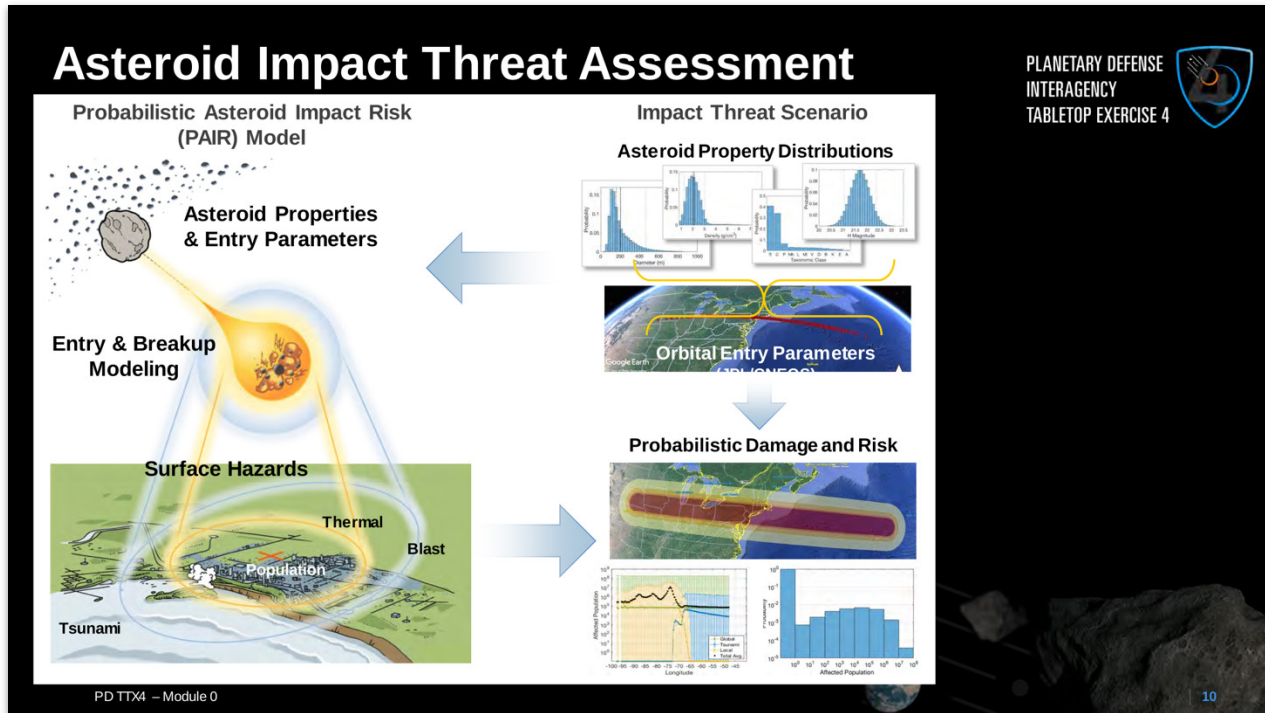
Risk Assessment for Impact Scenarios

Risk Modeling Process and Result Examples

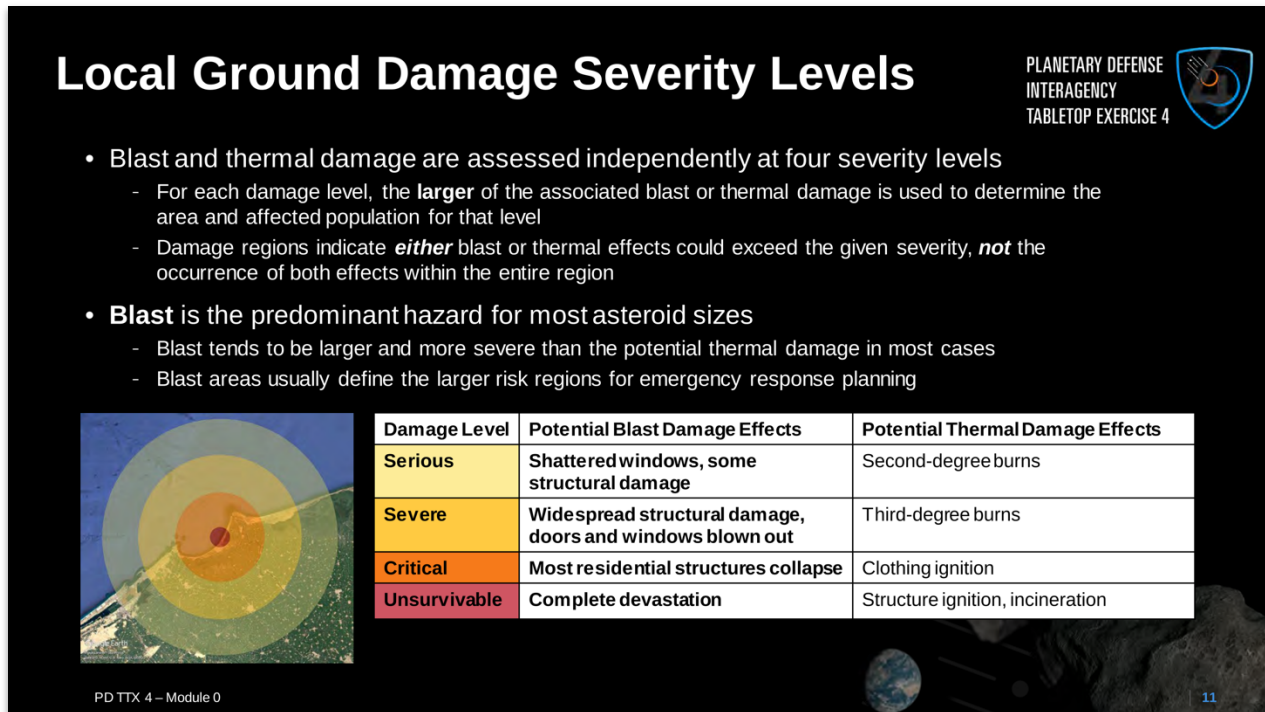
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Slide 11



Slide 12

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Risk Region Swath Maps

Regions potentially at risk, given range of damage sizes and locations

Airburst/impact region

Average-sized damage footprint rings

Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus

400 mi

Example from 2021 Planetary Defense Conference Exercise

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PLANETARY DEFENSE INTERAGENCY TABLETOP EXERCISE 4

Risk swaths show range of regions *potentially* at risk, including range of possible damage sizes and locations

- Black outline shows range of potential impact points (damage-center locations)
- Shaded areas show potential at-risk regions given range of damage sizes and locations
- Rings show an average-sized damage footprint at sample locations

Damage Level	Description
Serious	Window breakage, some minor structural damage
Severe	Widespread structure damage, doors/windows blown out
Critical	Most residential structures collapse
Unsurvivable	Complete devastation

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Risk Region Swath Maps

Airburst/impact region border bounds all potential damage center points

Likeliest locations near middle

Airburst/impact region

Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus

400 mi

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PLANETARY DEFENSE INTERAGENCY TABLETOP EXERCISE 4

Risk swaths show range of regions *potentially* at risk, including:

- Range of potential impact damage locations (from orbit and entry)
 - Orbital uncertainty gives spread of entry locations
 - Damage location depends on airburst/impact point along entry trajectory
 - Airburst/impact border bounds all potential damage center-points, with likelier regions toward the middle


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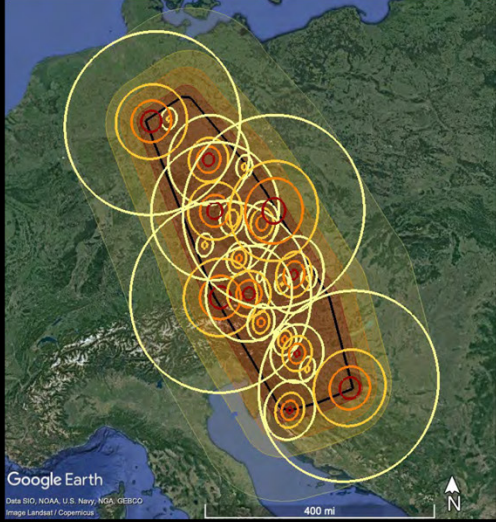
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Risk Region Swath Maps

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TABLETOP EXERCISE 4

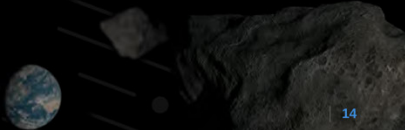




Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
400 mi

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Risk swaths show range of regions **potentially** at risk, including:


- Range of potential impact damage locations (from orbit and entry)
- Wide range of potential damage sizes and severities (from asteroid and entry)
 - Asteroid size and property ranges
 - + unknown entry, airburst, or impact factors

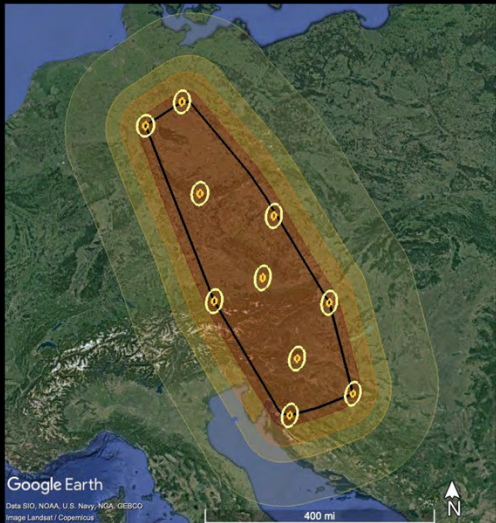
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Risk Region Swath Maps

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TABLETOP EXERCISE 4

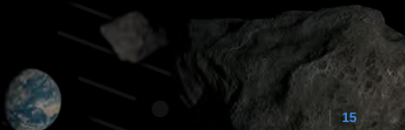




Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
400 mi

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15

Risk swaths show range of regions **potentially** at risk, including:


- Range of potential impact damage locations (from orbit and entry)
- Wide range of potential damage sizes and severities (from asteroid and entry)
 - Asteroid size and property ranges
 - + unknown entry, airburst, or impact factors
 - Smaller regions with only lower severity levels

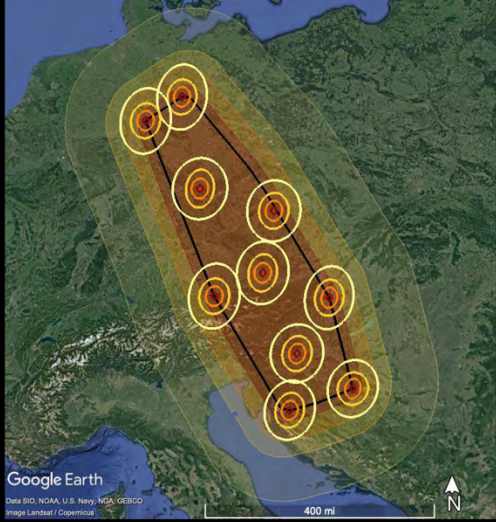
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Risk Region Swath Maps

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Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
400 mi


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Risk swaths show range of regions **potentially** at risk, including:

- Range of potential impact damage locations (from orbit and entry)
- Wide range of potential damage sizes and severities (from asteroid and entry)
 - Asteroid size and property ranges + unknown entry, airburst, or impact factors
 - Smaller regions with only lower severity levels
 - Mid-range, average areas (from the likelier asteroid sizes/properties)




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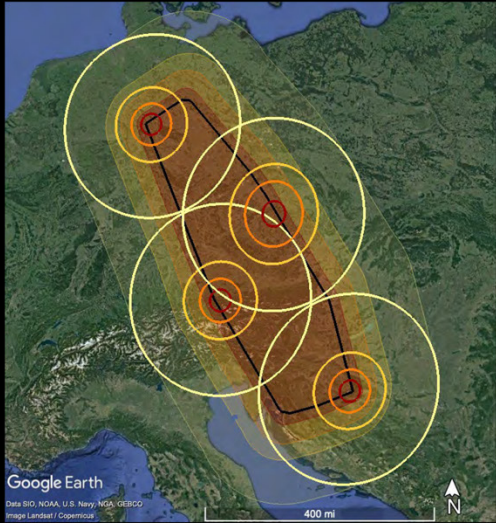
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Risk Region Swath Maps

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Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
400 mi


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Risk swaths show range of regions **potentially** at risk, including:

- Range of potential impact damage locations (from orbit and entry)
- Wide range of potential damage sizes and severities (from asteroid and entry)
 - Asteroid size and property ranges + unknown entry, airburst, or impact factors
 - Smaller regions with only lower severity levels
 - Mid-range, average areas (from the likelier asteroid sizes/properties)
 - Very large but unlikely areas (from the largest, least-likely possible impact sizes)



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Risk Region Swath Maps

Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus

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Risk swaths show range of regions **potentially** at risk, including:

- Range of potential impact damage locations (from orbit and entry)
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 - Asteroid size and property ranges + unknown entry, airburst, or impact factors
 - Smaller regions with only lower severity levels
 - Mid-range, average areas (from the likelier asteroid sizes/properties)
 - Very large but unlikely areas (from the largest, least-likely possible impact sizes)
 - And everything in between...

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Risk Region Refinement Over Time

Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus

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- Risk swath regions start out very large but will contract with additional observations during the asteroid's approach.


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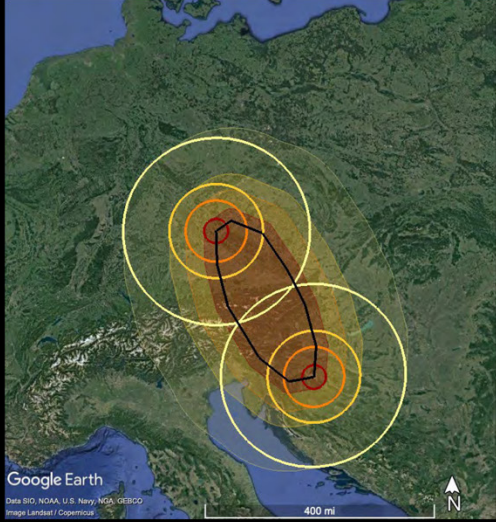
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Risk Region Refinement Over Time

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- Risk swath regions start out very large but will contract with additional observations during the asteroid's approach
 - Range of locations will shrink as the orbit is refined from additional observations
 - Potential damage range may remain large for longer because of asteroid size/property uncertainties through much of the approach

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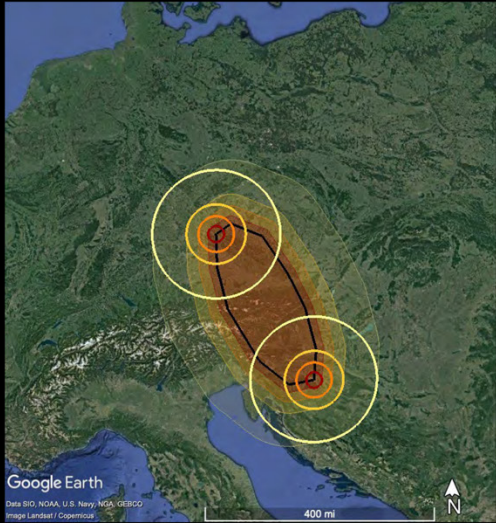
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Risk Region Refinement Over Time

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- Risk swath regions start out very large but will contract with additional observations during the asteroid's approach
 - Range of locations will shrink as the orbit is refined from additional observations
 - Potential damage range may remain large for longer because of asteroid size/property uncertainties through much of the approach
 - Largest damage estimates may also shrink if observations can refine asteroid size range

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Risk Region Refinement Over Time

Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus

400 mi

N

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- Risk swath regions start out very large but will contract with additional observations during the asteroid's approach
 - Range of locations will shrink as the orbit is refined from additional observations
 - Potential damage range may remain large for longer because of asteroid size/property uncertainties through much of the approach
 - Largest damage estimates may also shrink if observations can refine asteroid size range
 - Impact region will continue to shrink

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Risk Region Refinement Over Time

Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus

400 mi

N

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 - Range of locations will shrink as the orbit is refined from additional observations
 - Potential damage range may remain large for longer because of asteroid size/property uncertainties through much of the approach
 - Largest damage estimates may also shrink if observations can refine asteroid size range
 - Impact region will continue to shrink
 - In the final days before impact, the trajectory will be well known, location range will be small, and radar may be able to estimate asteroid size

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Risk Region Refinement Over Time



Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus

400 mi

N

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- Risk swath regions start out very large but will contract with additional observations during the asteroid's approach
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 - Potential damage range may remain large for longer because of asteroid size/property uncertainties through much of the approach
 - Largest damage estimates may also shrink if observations can refine asteroid size range
 - Impact region will continue to shrink
 - In the final days before impact, the trajectory will be well known, location range will be small, and radar may be able to estimate asteroid size
 - Only after impact will we know how much damage actually occurs from the wide range of initial possibilities

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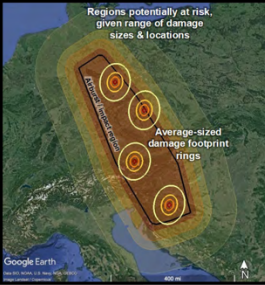
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Impact Risk Summary Dashboard

Asteroid Characterization Summary

- Earth-impact data to date (impact probability, potential impact date)
- Updates on any new observational data on the asteroid
- Estimated asteroid sizes, energies, or other properties



Regions potentially at risk, given range of damage sizes & locations

Average-sized damage footprint rings

Google Earth

400 mi

N

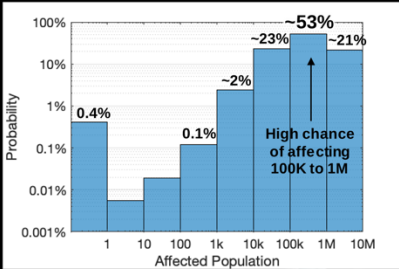
Risk Swath

Regions potentially at risk for ground damage, given ranges of potential impact locations damage sizes

Average-sized damage footprints are shown as rings over sample cities

Impact Hazard Summary

- Summary of potential impact hazards
- Ranges of damage sizes and severities
- How many people could be affected by the range of damage



Affected Population	Probability
1	0.4%
10	~0.1%
100	0.1%
1k	~2%
10k	~23%
100k	53%
1M	~21%
10M	~2%

High chance of affecting 100K to 1M

Population Risk

Probabilities of how many people could be affected by the potential damage

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Slide 1

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INTERAGENCY
TABLETOP EXERCISE 4

Deep Space NEO Mitigation 101

Brent W. Barbee
Principal Investigator for Planetary Defense Research at NASA/GSFC
brent.w.barbee@nasa.gov


NASA
PLANETARY DEFENSE
FEMA
NORTH CAROLINA
cneos
JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

- Comments on slide 1
- test (#2 | Aaron Chrietzberg)

Slide 2

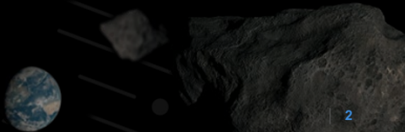
Planetary Defense Mission Types

PLANETARY DEFENSE
INTERAGENCY
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- **Reconnaissance**
 - Spacecraft collects data about the asteroid/comet (orbit, physical properties such as size, mass, etc.) and ascertains whether the object is indeed on an Earth impact trajectory.
 - A reconnaissance mission could include systems for asteroid/comet deflection or disruption, as an alternative to launching additional deflection/disruption spacecraft later. For example, a reconnaissance mission might carry a nuclear explosive device (NED) in case it is needed.
- **Deflection**
 - Spacecraft changes the asteroid/comet's speed around the Sun in a way that prevents Earth impact.
 - Deflection generally requires longer warning times than disruption.
- **Disruption**
 - Spacecraft carries an NED to the asteroid/comet that is sufficient to robustly disrupt the object.
 - Robust disruption means breaking the asteroid/comet into many small and widely scattered fragments, such that the fragments do not pose a threat to Earth's surface or orbital assets.
 - Robust disruption is possible with a short warning time, provided adequate infrastructure for rapidly launching a mission is in place.

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Reconnaissance Missions


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- Reconnaissance ideally precedes deflection/disruption, when circumstances permit.
- A flyby mission is usually easier to execute than a rendezvous mission, but it provides less benefit.

Capability	Flyby Reconnaissance	Rendezvous Reconnaissance
Improve Asteroid Orbit Estimate	Y	Y+
Reduce Uncertainties in Asteroid Earth Impact Location	Y	Y+
Reduce Uncertainties in Asteroid Earth Impact Probability	Y	Y+
Estimate Asteroid Mass	N	Y
Observe Asteroid Shape	P	Y+
Estimate Asteroid Size	P	Y+
Estimate Asteroid Rotation State	P	Y+
Observe Asteroid Composition and Other Details	P	Y+
Carry Along Asteroid Deflection Mechanism	Y	Y
Continue Monitoring Asteroid After Deflection Attempt	N	Y

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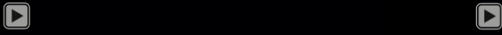
Slide 4

Deflection: Avoiding Earth Impact

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Much like two vehicles approaching an intersection at the same time, collision will occur unless one of the vehicles slows down or speeds up. Thus, to avoid Earth impact, we deflect an asteroid or comet by changing its speed (slowing it down or speeding it up).



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Slide 5

Deflection Technique Regimes of Applicability

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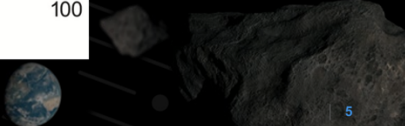
Ready to Launch Build and Launch

Diameter (m)

Warning Time (Years)

National Research Council (2010). *Defending Planet Earth: Near-Earth-Object Surveys and Hazard Mitigation Strategies*. Washington, DC: The National Academies Press, <https://doi.org/10.17226/12842>.

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5

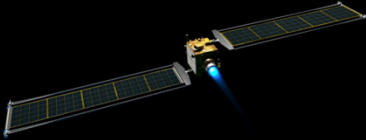
Slide 6

Deflection Technique: Kinetic Impactor


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- A spacecraft intercepts and rams into the asteroid/comet at high speed, creating ejecta that provides an additional push.
- DART is an example of a kinetic impactor.



- **Key enabling technologies:**
 - High-performance guidance and control systems
 - Heavy-lift launch
 - Multiple launches



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Deflection Technique: Standoff Nuclear Detonation

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- An NED is detonated near an asteroid/comet to vaporize surface material and cause the object to recoil, thus deflecting its path.
- **Key enabling technologies:**
 - High-performance guidance and control systems
 - NED/spacecraft interfaces
 - Heavy-lift launch





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Disruption Technique: Standoff Nuclear Detonation

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- The NED yield and detonation distance are chosen to create a strong shock that breaks the object up into small and widely scattered fragments.
- Key enabling technologies:
 - High-performance guidance and control systems
 - NED/spacecraft interfaces
 - Heavy-lift launch




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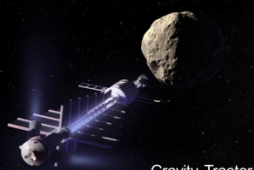
Slide 9

Other Deflection Techniques

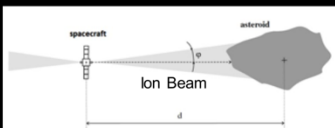
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- **Gravity Tractor**
 - A rendezvoused spacecraft station-keeps near the asteroid/comet so that the spacecraft's gravity gradually nudges the object over time.
 - *Key enabling technologies: high-efficiency solar electric propulsion systems, heavy-lift launch, multiple launches*
- **Enhanced Gravity Tractor**
 - A rendezvoused spacecraft collects a substantial mass from the asteroid/comet (e.g., a boulder) to increase the spacecraft's gravity before it begins station-keeping as a gravity tractor. This allows the spacecraft to deflect the asteroid more quickly than it would otherwise, but it requires more propellant and is still a gradual process.
 - *Key enabling technologies: high-efficiency solar electric propulsion systems, heavy-lift launch, multiple launches, advanced robotics*
- **Ion Beam Deflection**
 - A rendezvoused spacecraft station-keeps near the asteroid/comet and aims its ion thruster exhaust at the object to gradually nudge it over time.
 - *Key enabling technologies: high-efficiency solar electric propulsion systems, heavy-lift launch, multiple launches*



Gravity Tractor




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Rendezvous vs. Intercept/Flyby

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- **Rendezvous:** The spacecraft expends propellant to stop at the asteroid/comet and remain there.
- **Flyby/Intercept:** The spacecraft approaches the asteroid/comet at high relative speed and passes by it rapidly or hits it.
- Some kinds of missions require rendezvous, while some require intercept.
- Some kinds of missions can be either rendezvous or intercept.
- Intercept mission opportunities are often available earlier in the scenario timeline (and more frequently) than rendezvous mission opportunities (if any).
- Rendezvous is generally preferred when possible (except for kinetic impactors, of course).


Mission Type	Rendezvous	Flyby/Intercept	Rapid Response (less than 5 years of warning)
Reconnaissance	✓	✓	✓
Kinetic Impactor Deflection		✓	?
NED Deflection	✓	✓	✓
NED Disruption	✓	✓	✓
Gravity Tractor/Ion Beam	✓		


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Launch Considerations

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- Launch vehicle availability will likely be a challenge during rapid response scenarios (e.g., <1 year of warning).
- Multiple launches may be required to deliver sufficient mass for deflection or disruption.
- Additional launches may be desired for redundancy.
- Additional interfaces and protocols would be needed if launching an NED.

DART Launch
November 24, 2021
Image credit: NASA HQ

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Appendix

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Reconnaissance Data Priorities


- Notionally prioritized asteroid characteristics to measure for planetary defense purposes (in decreasing order of priority):
 - Orbit
 - Precise orbit of near-Earth object (NEO)
 - Impact location
 - Physical Properties
 - Mass: Most important to know for a deflection/disruption attempt
 - Binariness: Special considerations are required for deflecting/disrupting binary NEOs
 - Shape: With mass, we can then solve for bulk density
 - Strength: Influences NEO response to deflection/disruption attempt, cratering during kinetic impactor (KI) deflection, etc.
 - Internal structure including porosity: Influences NEO response to deflection/disruption attempt, cratering during KI deflection, etc.
 - Mineral composition: Particularly the iron fraction in the first few millimeters to centimeters of the NEO's surface (influences deflection/disruption method)
 - Detailed surface topology: Relevant for predicting how the ejecta from a deflection attempt might influence the achieved deflection; may inform understanding of internal structure through boulder distribution analyses, regolith presence, etc.

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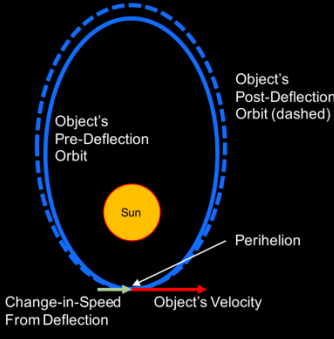
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Deflection: Orbital Physics

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- Deflection performance is usually maximized by applying the change-in-speed in the same direction as the asteroid/comet's velocity, and when the asteroid/comet is closest to the Sun (that location on the object's orbit is referred to as perihelion).
 - However, during the object's final orbit before Earth impact, the best-performing deflection direction becomes more radial (i.e., oriented at least partially along the line between the Sun and the object).
- Deflecting objects on more Earth-like orbits (i.e., more circular orbits) is harder, all else being equal.



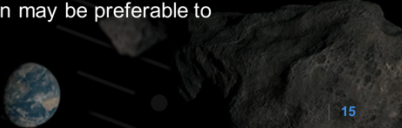
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Deflection Considerations

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- Deflection techniques are either impulsive or gradual.
 - Impulsive means a quick change in the speed of the asteroid or comet.
 - Gradual means a gentle push is applied to the asteroid or comet over a long period of time.
- Examples of impulsive deflection techniques:
 - Kinetic impactor
 - Standoff NED detonation
- Examples of gradual deflection techniques:
 - Gravity tractor or enhanced gravity tractor
 - Ion beam deflection
- For impulsive deflections, care must be taken to not push the asteroid/comet so hard that it begins to break apart.
 - If the asteroid/comet were to be partially/weakly broken apart, some significant pieces might still impact Earth.
 - If such a partial/weak fragmentation seems possible, then robust disruption may be preferable to deflection.




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Deflection/Disruption Considerations

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- Kinetic impactors have difficulty deflecting westward, while NEDs can deflect eastward or westward equally easily.
- The impulse imparted to an asteroid or comet by an NED can be tuned on the fly by selecting the distance from the object at which the NED is detonated.
- The amount of change-in-speed that an asteroid or comet can tolerate before beginning to break apart isn't well characterized and will vary from object to object. For now, we use the heuristic that if the required change-in-speed for deflection is 10% or more of the object's surface escape velocity, then there is a risk of accidentally breaking the object apart and we should consider designing a robust disruption mission rather than a deflection mission.
- Robust disruption definition: The NEO is purposely and forcefully blasted into many small and widely scattered fragments.
 - The largest remaining fragment is small enough that it would be harmlessly destroyed at high altitude in the Earth's atmosphere (e.g., <10 m).
 - However, the fragments are all so widely scattered that it is very unlikely any fragments would encounter the Earth in the future anyhow.
- Heuristic requirements for robust disruption:
 - A change-in-speed is imparted to the asteroid or comet via standoff NED detonation that is at least 10 times the object's surface escape velocity.
 - This is carried out at least 1 month before the object's original Earth encounter date, to provide ample time for the small pieces to spread so far apart that they would not pose a threat to the Earth-Moon system.

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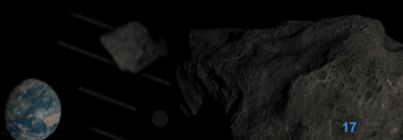
Other Challenges

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- High-speed intercept is challenging for kinetic impactors and the high-speed intercept version of standoff NED detonation:
 - Guidance, navigation, and control challenges for visible sensors versus infrared sensors at high solar phase angles
 - Proximity radar challenges for proper NED detonation distance sensing during high-speed approach
- We may be confronted with the need to deflect or disrupt a binary asteroid, which is an asteroid with its own moon, like the target of the DART mission, Didymos.
 - We believe ~1/6 of the near-Earth asteroids 200 m in size or larger are binary asteroids.
 - Contact binaries may comprise another ~1/6 of the population. These are asteroids formed of two smaller objects pressed against each other, like the asteroid Itokawa.

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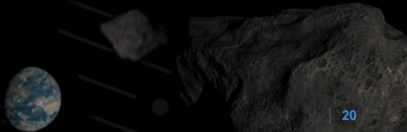
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Agenda

- Scenario briefing
- Hot wash and participant feedback

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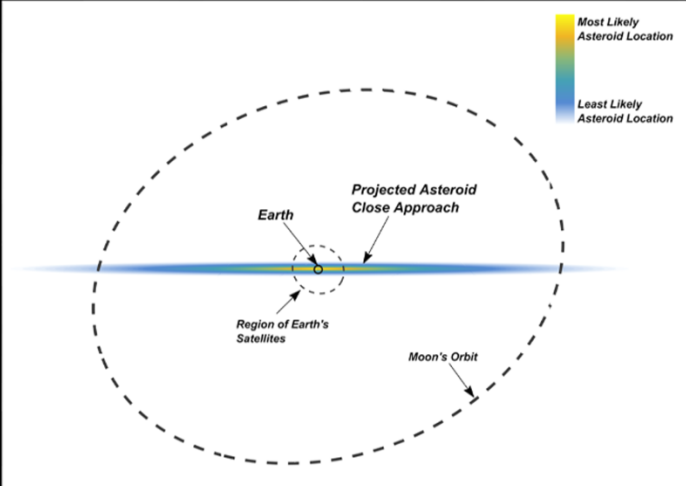
The Information We Have as of 16 Feb 2022

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Bottom line: We just discovered an asteroid, called **2022 TTX**, that has a **5% chance of hitting the Earth on 16 August 2022**.

Feb 11	• Initial discovery of 2022 TTX
Feb 12	• Tracking data from CNEOS gives us an impact probability of 0.04% on 16 Aug 2022
Feb 13	• Archival tracking data provide more information
Feb 16	<ul style="list-style-type: none"> • Additional data raise probability of impact to 5% • Asteroid size estimated to be between 40 and 440 m





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Going Forward Through the Modules

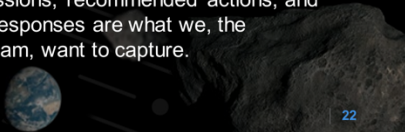
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 **The TTX team's job:**

- As time goes on, we will present new information as [simulated] additional tracking data provide refined estimates on the probability and potential location of impact.
- We will prompt discussions and decisions or recommendations that must be made.

Your job:

- As we move through the modules, you will be presented with more actionable information.
- Your discussions, recommended actions, and feedback responses are what we, the exercise team, want to capture.

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C.4 Module 1

Slide 2

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INTERAGENCY
TABLETOP EXERCISE 4

Module 1a
Early Mitigation Options
23 February 2022 (Six Months to Impact)

Emma Rainey
Module 1 Facilitator
Johns Hopkins Applied Physics Laboratory
Emma.Rainey@jhuapl.edu

NASA
DEPARTMENT OF DEFENSE
FEDERAL EMERGENCY MANAGEMENT AGENCY
FEMA
NORTH CAROLINA
cneos
Asteroid Research Center
APL
JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

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Module 1 Roadmap

- In Module 1, our scenario moves forward to **23 February 2022**
- Module 1 will be split across both days of the TTX
- In Module 1a (Day 1), we will:
 - Provide updated impact predictions and damage risk assessment
 - Discussion will focus on communication of the asteroid threat
- In Module 1b (Day 2), we will:
 - Provide information on space mission mitigation options
 - Discussion will focus on capability gaps, legal and policy implications, and communication as our knowledge evolves

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INJECT 1.1

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- Presentation from NASA Center for Near-Earth Object Studies on the latest observations of asteroid 2022 TTX as of 23 February 2022

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Impact Predictions: Module 1

Scenario Date: 23 February 2022
Impact Probability Increases to 71% and the CONUS Is at Risk

Paul Chodas, Davide Farnocchia & Ryan Park
Center for NEO Studies (CNEOS)
Jet Propulsion Laboratory, California Institute of Technology

NASA
PLANETARY DEFENSE
FEMA
NORTH CAROLINA
CNEOS
JOHNS HOPKINS
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Scenario Update: Module 1


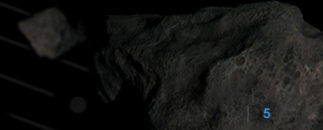
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- **23 February 2022:** A week has passed since Module 0, and 2022 TTX has been tracked nightly by astronomers around the world, using large optical telescopes
 - The asteroid is currently about 37 million mi (60 million km) away
- The new observations, along with prediscovery observations from several days before discovery, have enabled a more accurate orbit to be determined for 2022 TTX
- The impact probability has jumped to **71%**
- The predicted impact region has converged to a wide corridor spanning across the globe and **passing across much of the continental U.S.**
- The asteroid's size remains highly uncertain; based on its brightness, it's **most likely** in the range of **55–160 m** (180–520 ft), but it **could be as large as 440 m** (1440 ft)
 - The asteroid will not be within range of Goldstone radar until August

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2022 TTX Uncertainty Region

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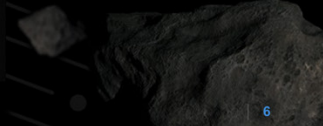
The **red dots** trace the uncertainty region, which encompasses all possible positions of the asteroid as it approaches Earth on Aug. 16

The **shaded region** shows the region swept by the uncertainty region

Half-hour time steps

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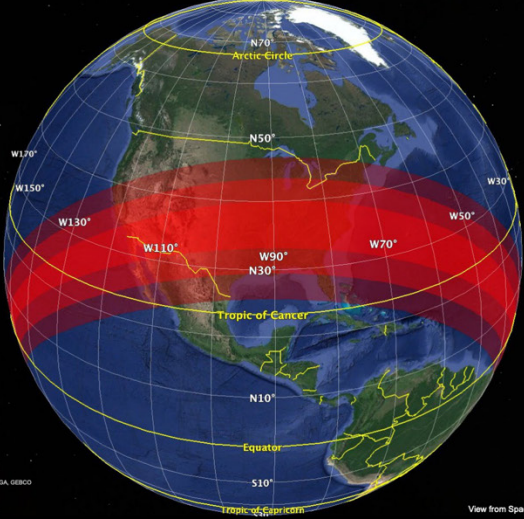
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Predicted Impact Region

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Shows the region where the 2022 TTX might impact on 16 August 2022, based on the latest orbit solution

Region extends from the mid-South Pacific, across North America, to mid-South Atlantic

The intensity of the red shading indicates the relative probability

Google Earth
Data: NOAA, U.S. Navy, NSA, GIBCO
Image: Landsat / Copernicus
Image: MODIS
Image: U.S. Geological Survey

View from Space (Altitude: 9650 km)

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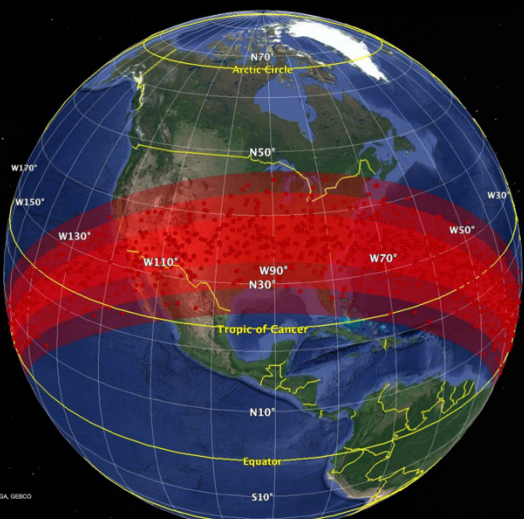
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Predicted Impact Region

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TABLETOP EXERCISE 4 



Shows the region where the 2022 TTX might impact on 16 August 2022, based on the latest orbit solution

Region extends from the mid-South Pacific, across North America, to mid-South Atlantic

The intensity of the red shading indicates the relative probability

With 980 sample impact cases

Google Earth
Data: NOAA, U.S. Navy, NSA, GIBCO
Image: Landsat / Copernicus
Image: MODIS
Image: U.S. Geological Survey

View from Space (Altitude: 9650 km)

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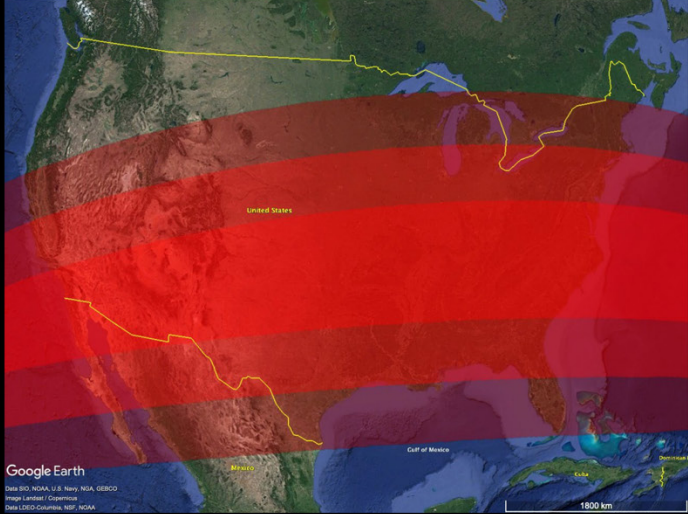
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Predicted U.S. Impact Region



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Shows the region where the 2022 TTX might impact on 16 August 2022, based on the latest orbit solution

Probability of impact within CONUS is about 19%

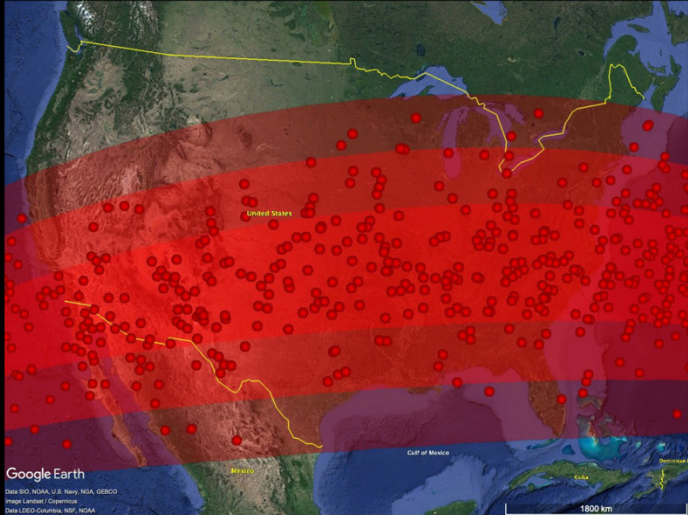
The intensity of the red shading indicates the relative probability

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Predicted U.S. Impact Region



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Shows the region where the 2022 TTX might impact on 16 August 2022, based on the latest orbit solution

Probability of impact within CONUS is about 19%

The intensity of the red shading indicates the relative probability

With sample impact cases

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OPERATIONS CENTER

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MANAGEMENT
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cneos

Ames Research Center

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NORTH CAROLINA

WESTERN STATE
UNIVERSITY OF KENTUCKY

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INJECT 1.2

- Presentation from NASA Asteroid Threat Assessment Project on the impact damage risk from 2022 TTX

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TABLETOP EXERCISE 4













Asteroid Impact Risk: Module 1

71% chance of Earth impact in under 6 months

Lorien Wheeler
Jessie Dotson, Michael Aftosmis, Eric Stern, Donovan Mathias
Asteroid Threat Assessment Project (ATAP)
NASA Ames Research Center

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Slide 15

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Asteroid Size & Properties

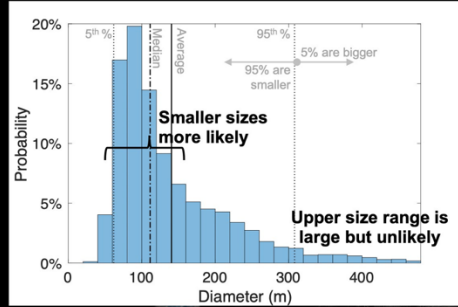
- Asteroid size is highly uncertain
 - Ranging from smaller objects that would pose little threat to objects hundreds of meters across with gigatons of impact energy
 - Upper size range is large but unlikely
 - Smaller size ranges are more likely
- Asteroid type and properties are unknown
 - Wide ranges of densities, strengths, structures, compositions
 - Ranging from more common stony types and rubble piles to rarer high-density iron types
- Size and property uncertainties result in **very large** ranges of potential mass, energy, and damage

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	Diameter	Energy
Range	40–440 m (130–1440 ft)	1–3000 Mt
Most likely range	55–160 m (180–520 ft)	2–100 Mt
Median	110 m (360 ft)	46 Mt

Asteroid Diameter Probabilities



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Potential Risk Swath

Legend:
■ Serious
■ Severe
■ Critical
■ Unsurvivable

Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
 Image Landsat/Copernicus
 Image BGAO

View from Space (Altitude: 4326 mi)

Damage risk swath: Shows extent of regions potentially at risk to local ground damage, given ranges of potential damage sizes and locations (not representative of likelihood).

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Damage risk swath:

- Shaded swath areas show regions **potentially** at-risk, given range of damage sizes and locations.
- Rings show a random sampling of individual potential damage footprints.

Extent of current risk region:

- Crosses U.S., Mexico, SE Canada, Antilles, E. Brazil. Water impacts also near Hawaii, S. Pacific, W. Africa.
- Swath width/length is due to range of unknown impact locations, **not** expected damage sizes
- Range of locations will shrink as observations refine the orbital data

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U.S. Potential Risk Swath

Legend:
■ Serious
■ Severe
■ Critical
■ Unsurvivable

Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
 Image Landsat/Copernicus

1200 mi

Damage risk swath: Shows extent of regions potentially at risk to local ground damage, given ranges of potential damage sizes and locations (not representative of likelihood). Rings show range of damage sizes at random locations.

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U.S. Impact Damage Risk:

- ~26% chance of U.S. damage among Earth-impacting cases (~19% total chance)

Wide range of damage sizes and severities

- Damage severities could range from shattered windows to unsurvivable blasts
- Outer damage radius ranges:
 - Potential range: 0–120 mi
 - Most likely range: 12–70 mi
 - Average: 50 mi

Damage Level	Description
Serious	Shattered windows, some minor structure damage
Severe	Widespread structure damage, doors blown out
Critical	Most residential structures collapse
Unsurvivable	Complete devastation

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U.S. Potential Risk Swath

Damage risk swath: Shows extent of regions potentially at risk to local ground damage, given ranges of potential damage sizes and impact locations (not representative of likelihood). Rings show average-sized damage footprints at example locations.

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U.S. Impact Damage Risk:

- ~26% chance of U.S. damage among Earth-impacting cases (~19% total chance)
- **Wide range of damage sizes and severities**
- Damage severities could range from shattered windows to unsurvivable blasts
- **Average U.S. Blast Footprint Radii:**
 - Serious: ~50 mi
 - Severe: ~30 mi
 - Critical: ~15 mi
 - Unsurvivable: ~6 mi

Damage Level	Description
Serious	Shattered windows, some minor structure damage
Severe	Widespread structure damage, doors blown out
Critical	Most residential structures collapse
Unsurvivable	Complete devastation

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Hazard Sources

Relative hazard probabilities among Earth-impacting cases (71% Earth-impact):

- No damage occurs in ~67% of Earth-impact cases
- Blast damage is the largest hazard source in ~30% of Earth-impact cases
- Thermal damage also occurs in ~12% of cases, but it is smaller and less severe than accompanying blast damage in nearly all cases
- Risk of tsunami damage is low, occurring in ~3% of impact cases (5% of ocean cases), but the largest water impacts could cause significant damage if near populated coasts
- No global-scale climatic effects are expected, but potential for regional environmental effects from larger impacts is unknown

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Hazard Occurrence Probabilities
(among 71% Earth-impacting cases)

Hazard Category	Probability
none	67%
blast	30%
thermal	12%
tsunami	~3%

* A single impact event can cause multiples hazards (such as blast + thermal, or tsunami + blast for near-shore cases). Sum of all hazard occurrence probabilities may exceed 100%.

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Impact Risk Summary: Module 1

Asteroid Characterization Summary

- Assessment date: 23 February 2022 (T - <6 months)
- Potential impact date: 16 August 2022
- Earth-impact probability: 71%
- Large uncertainties in asteroid size, energy, and other properties
- Diameter: 40–440 m (130–1440 ft), most likely ~55–160 m (180–520 ft), median size 110 m (360 ft)
- Energy: 1–3000 megatons (Mt), most likely ~2–100 Mt, median 46 Mt

Risk Region Swath

Regions potentially at risk, given range of potential damage locations and sizes. Average-sized damage footprints are shown over sample U.S. cities.

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Impact Hazard Summary

- Potential damage sizes and locations are very uncertain
- No damage is most likely (~77% chance) with moderate chance of large damage areas affecting 10k–1M people
- Primary hazard: Blast damage, ranging from blown out windows, to structure damage, to potentially unsurvivable levels
- Damage radii: 0–120 mi, most likely range 12–70 mi, median 40 mi
- Tsunami damage is unlikely and mostly minor
- Affected population: 0–millions, 50k total average risk, 20% chance of affecting >1k ppl, 16% >10k, 8% >100k, 1% >1M

Population Risk

Affected Population	Probability (%)
1	77%
10	~1%
100	2%
1k	~5%
10k	7%
100k	7%
1M	~1%
10M	~0.1%

Probabilities of how many people could be affected by the potential damage
(total probabilities including 71% Earth-impact probability)

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Module 1 Risk Backup

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Potential Risk Swath

Damage risk swath: Shows extent of regions potentially at risk to local ground damage, given ranges of potential damage sizes and impact locations (not representative of likelihood).

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Extent of risk region:

- >24,000 km (>15,000 mi) long, ~3000 km (~1900 mi) across at widest extents.
- Crosses U.S, Mexico, SE Canada, Antilles, E. Brazil. Water impacts also near Hawaii, S. Pacific, W. Africa.
- Swath width due to impact location uncertainty, not likely damage size

Impact hazard risks:
(among Earth-impact cases)

- ~67% chance of impact causing **no** population damage
- ~30% chance of blast damage to populated areas
- ~70% chance of ocean impact, but only ~3% chance of tsunami damage to populated areas (5% of ocean strikes cases)

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U.S. Damage Footprint Sizes

Local Ground Damage Radius (miles) Percentiles*

Damage Level	Mean	Min	5th %	25th %	50th %	75th %	95th %
Serious	52	0	16	25	50	75	106
Severe	27	0	4	16	27	37	50
Critical	14	0	0	6	16	22	30
Unsurvivable	6	0	0	0	6	11	15

* Percentiles give the chance that the damage region could be up to the given size or smaller (values shown are among U.S.-impacting cases modeled)

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Hazard Sources

Relative hazard probabilities among 71% Earth-impacting cases:

- No damage occurs in ~67% of cases
- Blast damage is the predominant hazard source in ~30% of Earth-impact cases
- Thermal damage also occurs in ~12% of cases, but it is smaller and less severe than accompanying blast damage in nearly all cases
- Risk of tsunami is low, occurring in ~3% of impact cases, but the largest water impacts could affect hundreds-of-thousands of people if near a high-population coast.
- No global effects expected, but potential for regional environmental effects from larger impacts is unknown

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Hazard Source	Occurrence Probability	Affected Population Ranges			
		Average	75 th %	95 th %	Full Range Modeled
No Damage	67%	0	0	0	0
Blast	30%	71K	2.7K	389K	0–16.5M
Thermal	12%	5.5K	0	3K	0–20M
Tsunami	3.4%	820	0	0	0–766K

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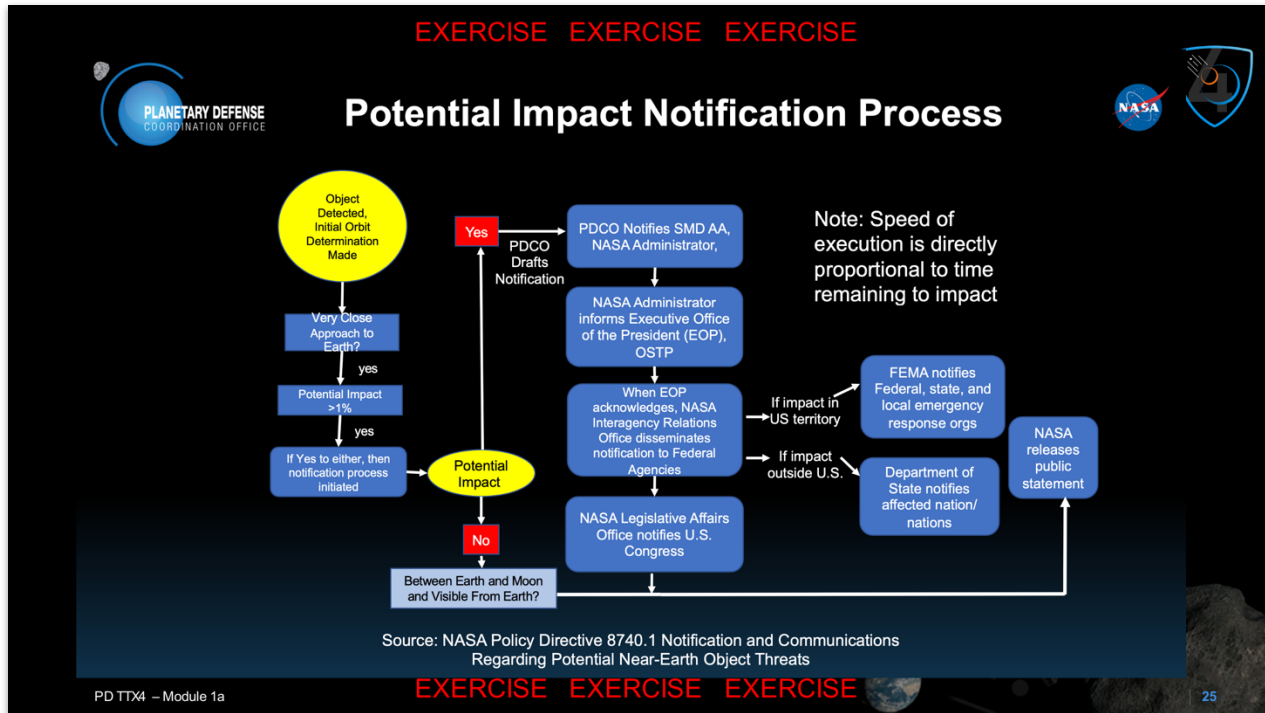
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INJECT 1.3

- The PDCO issues notifications per NASA Policy Directive 8740.1
- Notification content is as described in from the *Report on Near-Earth Object Impact Threat Emergency Protocols*

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EXERCISE EXERCISE EXERCISE
This is a simulated event.

February 23, 2022

From: NASA Planetary Defense Coordination Office
Title: Notification of Potential Asteroid Impact – Update #1

Impact Probability: 71%
Impact Date: 16 August 2022
Impact Risk Corridor: Impact in CONUS possible
Approximate Size: 130-1440 ft (40-440 m)
Expected Level of Damage if Impact Occurs: Local to Regional
Impact Prevention Feasible: Unknown at this time.

- Additional observations of the motion of asteroid 2022 TTX show there is a 71% probability the asteroid will impact Earth on 16 August 2022. While there is still uncertainty in whether the asteroid will impact Earth, if an impact occurs it will be on this date.
- The impact risk corridor, which is the region of Earth where it is possible that 2022 TTX could impact, extends from the mid-Pacific across the North American continent to the south Atlantic. Most of the CONUS is within the impact risk corridor.
- The potential impact effects are highly dependent on the size of the asteroid. Based on current data, the asteroid is estimated to be between 130-1440 ft (40-440 m) in size. At the small end of this size range, an asteroid impact over land could result in minor local damage (e.g., air blasts resulting in broken windows and damage to low-integrity structures). At the large end, an asteroid impact could result in a significant surface crater and widespread injuries/casualties and structural damage over a region extending tens to 100+ km. An impact in coastal waters could result in a tsunami wave that would inundate coastline areas.
- The asteroid 2022 TTX has been tracked since initial discovery on 11 February 2022. Further observations will reduce the uncertainty in the asteroid's trajectory and impact probability. The asteroid will be continually observable by telescopes leading up to the potential impact date, except during the full moon.
- The asteroid size cannot be estimated with further precision without radar observations or imagery from a spacecraft that can closely approach the asteroid. Radar observations will be possible no sooner than 13 days prior to the potential impact date, if the asteroid is at the large end of the size range, and possibly not until 5 days prior to the potential impact if the asteroid is at the small end.
- The feasibility of space missions to prevent the impact is under study.

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This is a simulated event.

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Potential Impact Notification

Summary details →

Impact probability and impact date/time →

Description of impact risk corridor →

Estimated impact effects →

Opportunities for further observations →

Feasibility of impact prevention space missions →

From: NASA Planetary Defense Coordination Office
 Title: Notification of Potential Asteroid Impact – Update #1

Impact Probability: 71%
 Impact Date: 16 August 2022
 Impact Risk Corridor: Impact in CONUS possible
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 Expected Level of Damage if Impact Occurs: Local to Regional
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- The feasibility of space missions to prevent the impact is under study.

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INJECT 1.3: Notification of Impact Probability Increase to 71% and CONUS at Risk

- How should your agency respond to this notification of an asteroid threat?
- Which stakeholders do you need to notify?
- What additional information would be helpful to have at this stage?

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INJECT 1.3: Notification of Impact Probability Increase to 71% and CONUS at Risk

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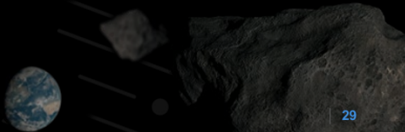


- How should your agency respond to this notification of an asteroid threat?
- Which stakeholders do you need to notify?
- What additional information would be helpful to have at this stage?

- Who should be responsible for informing the public?
- How should the nature of the asteroid threat be communicated to the public?

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INJECT 1.3: Notification of Impact Probability Increase to 71% and CONUS at Risk

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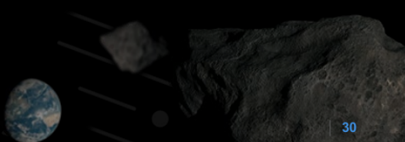
- How should your agency respond to this notification of an asteroid threat?
- Which stakeholders do you need to notify?
- What additional information would be helpful to have at this stage?

- Who should be responsible for informing the public?
- How should the nature of the asteroid threat be communicated to the public?

- What emergency preparations are necessary at this point?
- Who should be responsible for leading the preparations, and what steps should be taken?

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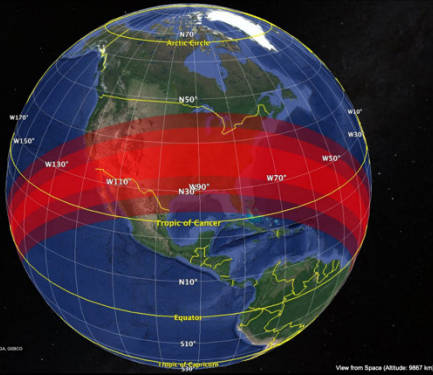
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INJECT 1.3: Notification of Impact Probability Increase to 71% and CONUS at Risk

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- Who should be responsible for international coordination?
- How should we approach coordination and communication with foreign countries who are also at risk?



Google Earth
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Map data ©2012
Map data ©2012
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View from Space (Altitude: 9867 km)

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INJECT 1.4

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- Information about the asteroid is being shared widely on social media. Much of the information is incorrect.

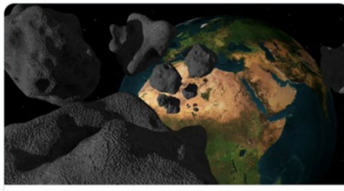
Feb 23

NASA finds asteroid that could wipe out a city!

[tinyurl.com/yy7a78bx](#)

#spacecraft #exploration #research #asteroid #armageddon

NASA: Asteroid that dwarfs Empire State Building heading for Earth; Huge NEO to reach soon



tech.hindustantimes.com

NASA: Asteroid that dwarfs Empire State Building heading for Earth; ...
NASA: Asteroid is monstrous at 4,265 feet wide and it is approaching Earth fast. 'Potentially hazardous' asteroid just a month away.

36 405 458

Following

The government already knows where the asteroid will hit. They won't tell us until it's time to evacuate.

RETWEETS 24,831 LIKES 14,654

2:15 PM - 6 Nov 2012

The existence of the asteroid is fake news – a lie spread to pump up NASA's funding and make the administration look good. Just wait and see – the asteroid threat will miraculously disappear once they have the money. What else are they lying about?

10:01 AM 23 Feb 2022

60 Retweets 73 Quote Tweets 356 Likes


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INJECT 1.4: Misinformation

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- What strategies should be used to counteract misinformation?
- Who is the most trusted person or entity to provide up-to-date, accurate information to the public?

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Comments on slide 10

Module (1a) Early Detection Wrap


<https://naad-jaf-co1.jhuapl.edu:8443/opinio/a?e=7309> | 60 (Aaron Chretzberg)

+ Your comment

Contributions identify the contributor

UNCLASSIFIED

Planetary Defense Interagency Tabletop Exercise IV - Module (1a) Early Detection Wrap


JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Instructions: We kindly request that you respond to all questions and provide as much detail as possible. Your responses are an essential part of the TTX and will help us capture lessons learned for the after action report and future exercises. Thank you for your time.

Module (1a) Early Detect on Wrap

1. Name and Title (Please include rank, if applicable)

2. Organization and link/Device

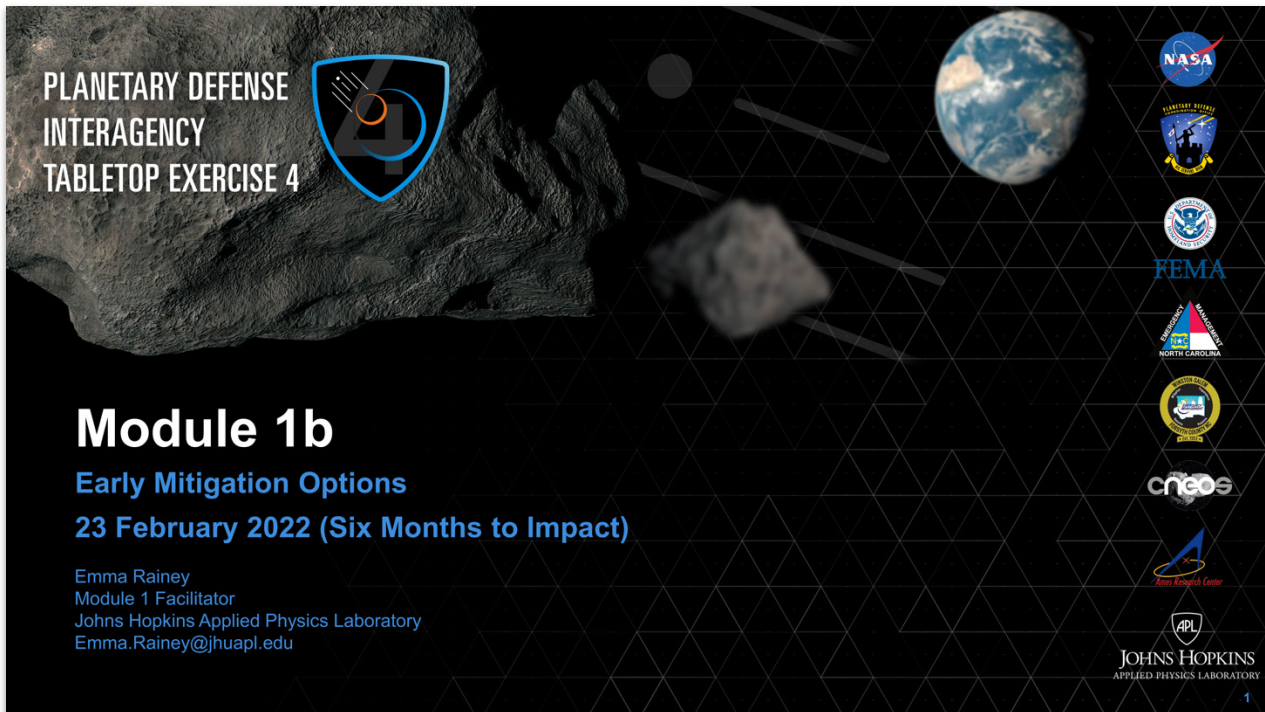
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Slide 1




Slide 2

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Module 1 Roadmap

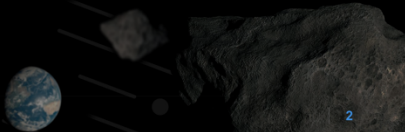
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- In Module 1, our scenario moves forward to **23 February 2022**
- Module 1 will be split across both days of the TTX
- In Module 1a (Day 1), we will:
 - Provide updated impact predictions and damage risk assessment
 - Discussion will focus on communication of the asteroid threat
- In Module 1b (Day 2), we will:
 - Provide information on space mission mitigation options
 - Discussion will focus on capability gaps, legal and policy implications, and communication as our knowledge evolves

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Module 1a Recap

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- INJECT 1.1
 - Impact predictions update from CNEOS: Additional observations have decreased the uncertainty in the orbit of 2022 TTX, and the impact probability has risen to 71%. The impact risk corridor is now a narrow band that crosses the globe and includes most of CONUS.



Google Earth
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View Earth Space (IMBULe 0887 km)

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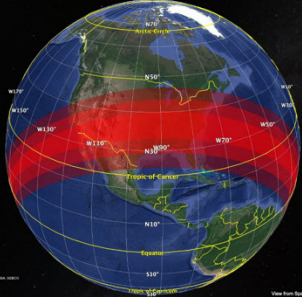
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Module 1a Recap

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- INJECT 1.2
 - Impact damage risk update from ATAP: Potential damage remains very uncertain due to the large uncertainty in the size and physical properties of the asteroid. There is a 19% chance of impact damage in the U.S.

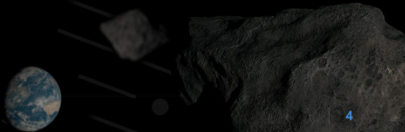


Google Earth
Satellite Imagery © 2019, Data Sourced from:
Mapbox, OpenStreetMap
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View Earth System (URL: 086714)

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Slide 5

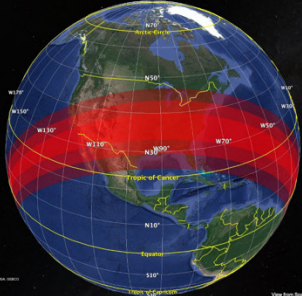
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Module 1a Recap

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- INJECT 1.3
 - Simulated notification from PDCO issued per protocols described in NASA Policy Directive 8740.1.




Google Earth
Satellite Imagery © 2019, Data Sourced from:
Mapbox, OpenStreetMap
Mapbox © OpenStreetMap contributors
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View Earth System (URL: 086714)

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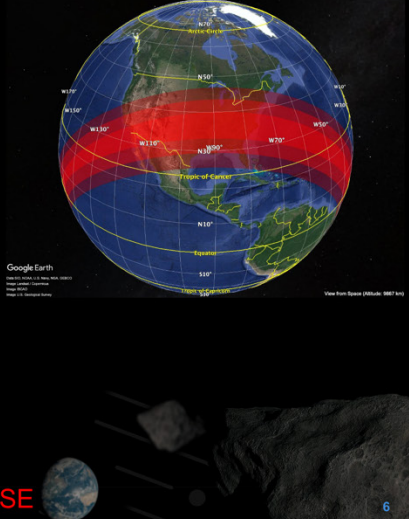
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Module 1a Recap

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- INJECT 1.2
 - Impact damage risk update from ATAP: Potential damage remains very uncertain due to the large uncertainty in the size and physical properties of the asteroid. There is a 19% chance of impact damage in the U.S.
- INJECT 1.3
 - Simulated notification from PDCO issued per protocols described in NASA Policy Directive 8740.1
- INJECT 1.4
 - Misinformation appears and spreads on social media.



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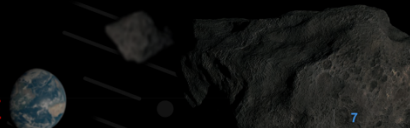
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INJECT 1.5

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- Presentation from NASA Goddard on space mission options for characterization or mitigation of asteroid 2022 TTX



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Space Mission Options for the 2022 TTX Hypothetical Asteroid Impact Scenario

Brent W. Barbee
Principal Investigator for Planetary Defense Research at NASA/GSFC
brent.w.barbee@nasa.gov

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NORTH CAROLINA
cneos
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Deflection Is Not Practical In This Scenario

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- Deflecting 2022 TTX one to several months before impact would require the following:
 - Launching rapidly and changing the asteroid's speed by a large amount
 - Assuming average asteroid properties, deflecting it with kinetic impactors (KIs) would require over a dozen heavy-lift rocket launches (notional NASA SLS 2Bs) and total spacecraft mass equal to about 20 James Webb Space Telescopes (JWSTs)
 - Deflecting it with a nuclear explosive device (NED) instead would require a single launch and total spacecraft mass equal to about 1/6 of JWST
- However, whether via KIs or NED, deflection would require a change in asteroid speed so large that the asteroid would likely begin to break apart, potentially leaving Earth still at risk.
- Therefore, instead of deflection we recommend designing missions for intentional robust disruption of the asteroid, eliminating or significantly reducing the risk to Earth.

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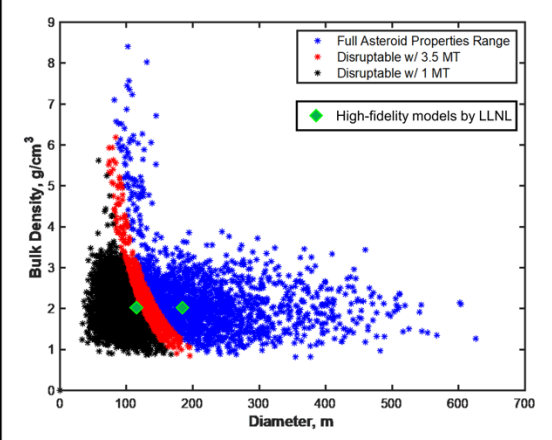
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NED Disruption Performance

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- Mission analysis indicates 3.5 MT is the largest yield NED that can be delivered to 2022 TTX.



Disruption thresholds based on empirical engineering model from Lawrence Livermore National Laboratory (LLNL) for NED effects on an asteroid.

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3.5 MT NED disrupts ~65% of the asteroid distribution
1.0 MT NED disrupts ~50% of the asteroid distribution

- Each point represents a potential size and mass (density) of the asteroid.
 - Points in the lower left are less massive.
- The red and black points are disruptable with a 3.5 MT NED.
- The black points are disruptable with a 1 MT NED.
- Disrupting the blue points would require a larger NED than 3.5 MT.
 - Even so, those realizations of the asteroid might be broken up at least somewhat by a 1 or 3.5 MT NED, which could spread out and reduce Earth-impact damage.


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Nuclear Disruption High-Fidelity Modeling

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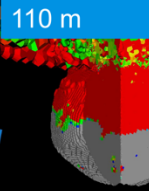


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Lawrence Livermore National Laboratory

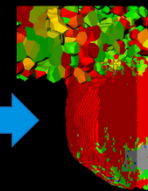
1 MT yield. Progression of damage imparted to the asteroid over time:



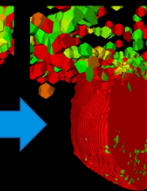
Time = 0s



Time = 0.1s

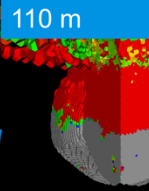


Time = 0.5s

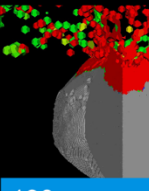


Time = 1.0s

110 m



190 m



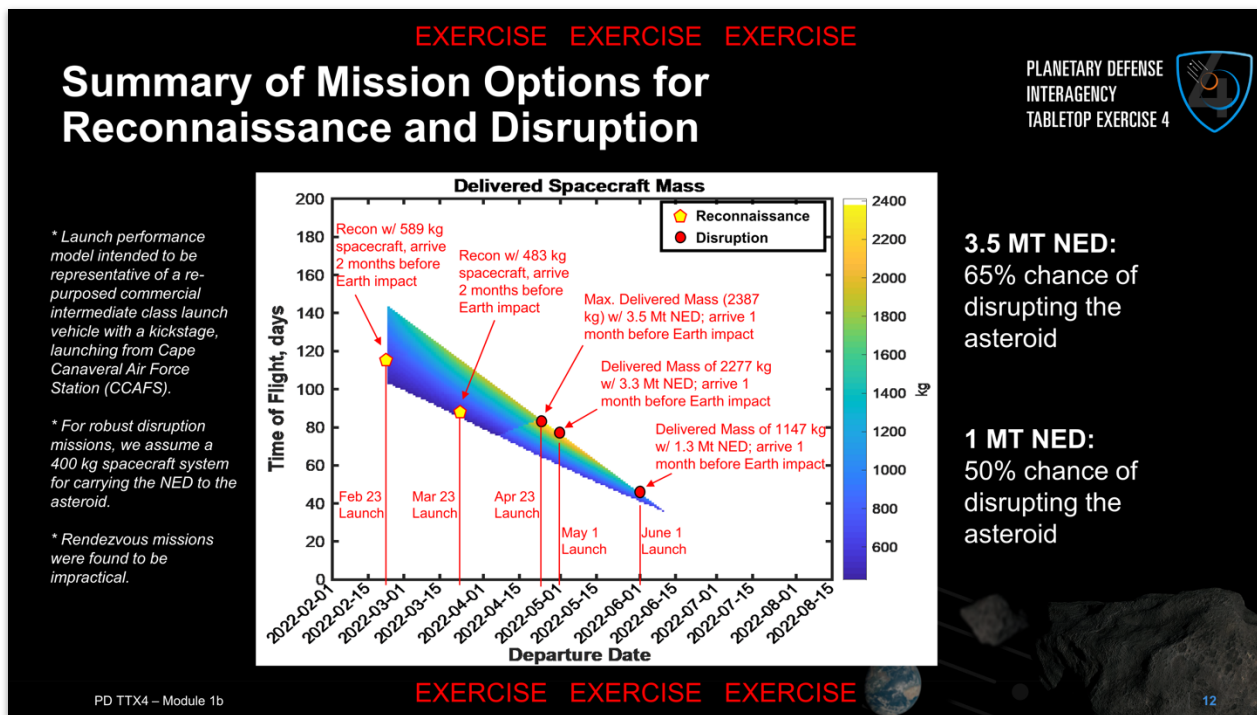
■ = fully damaged

Fully disrupted at 1s
1% of material reaches Earth if disrupted 1 month from impact

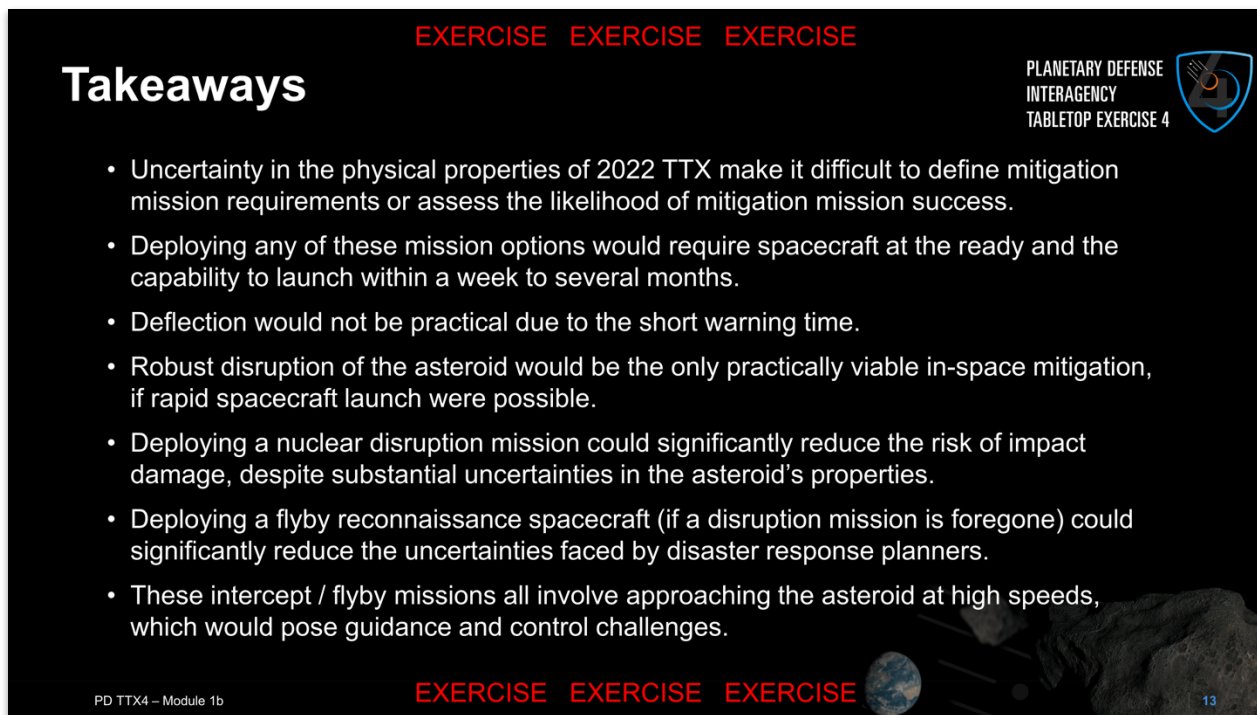
Remnant velocity is 1.5 m/s at 2s.
($V_{esc} = 0.1$ m/s)
90% of material reaches Earth if disrupted 1 month from impact

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Slide 12



Slide 13



Slide 14



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Nuclear Disruption — High-Fidelity Modeling

Asteroid Properties


- Two different asteroid sizes: 110 m (median diameter) and 190 m (78th percentile)
- Shape: Benu, Density: 2 g/cc, Material: Granite

Nuclear Device Setup

- Yield: 1 Mt, Standoff Distance: 9 m, Source Spectrum: 2 keV Black Body
- The X-ray energy deposition was modeled for silicon dioxide using the Kull Radiation-Hydrodynamics code

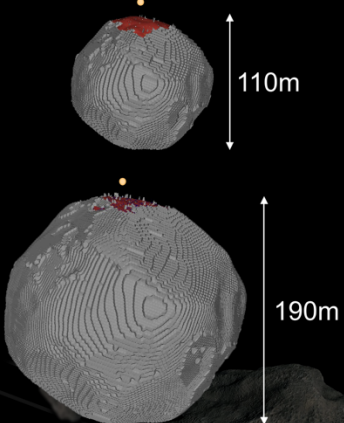
The full disruption process was simulated in Sphera equipped with strength and damage models

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Lawrence Livermore National Laboratory



Prepared by LLNL under Contract DE-AC52-07NA27344

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INJECT 1.6

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- Policy considerations for nuclear deflection or disruption mission

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Law and Policy

Treaty Overview as relevant to Nuclear Explosive Devices (NEDs)

Aparna Srinivasan, Esq.
TTX Evaluation Lead, Legal Analyst
Johns Hopkins Applied Physics Laboratory
aparna.srinivasan@jhuapl.edu

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Relevant International Law Treaty Overview

Outer Space Treaty (1967)

Art. IV: Parties cannot —

- Place in orbit around the Earth any objects carrying nuclear weapons, install such weapons on celestial bodies, or station such weapons in space.

Articles IX, XI, Duty to Inform, to Act w/ Regard

- Inform States of NEO predictions; conduct activities responsibly.

Limited Test Ban Treaty (1963)

Art. I: Parties undertake to —


- Prohibit any nuclear weapon test explosion or any other nuclear explosion, at any place under its j/s or control, in outer space or underwater.
- To refrain from causing, encouraging, or in any way participating in the carrying out of any nuclear explosion in the atmosphere, in outer space or underwater.

Nuclear Non-Prolif. Treaty (1970)

Art. I, II: Each —

- NWS Party undertakes not to transfer NEDs to NNWS and;
- NNWS Party undertakes not to receive the transfer or control of NW or NEDs directly or indirectly; and not to manuf. or otherwise acquire NW or NEDs.

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Considerations

- Asteroids as a Pretext
- Weasel Words: *Weapon, Install, Station, Control*
- Off-world vs. On-world
- Whether use undermines disarmament progress

NEDs are *prima facie* unlawful. However, unlawfulness within the context of a planetary defense mission remains complex and uncertain.

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Balancing Act

Duty to Act/Mitigate NEO Impact Threat

- UN Charter, International Human Rights Conventions:**
 - Negative obligation of States not to interfere; positive obligation to take appropriate steps to safeguard human lives from impending disasters.
 - Would the obligation to protect life within State's jurisdiction require a nuclear PD mission?
 - Weigh stringent nuclear prohibitions against the principal responsibility of a State to protect its population under its jurisdiction from harm.
- Law of State Responsibility:**
 - Internationally wrongful act defined as action or omission [that]: (a) is attributable to the State under international law; and (b) constitutes a breach of an international obligation of the State.
 - State responsibility law acknowledges circumstances in which compliance with international law is not feasible.

Nuclear Explosive Device Justification

- Circumstances precluding Wrongfulness:**
 - Consent — Distress — Necessity
- Work with the UN Decision Bodies:**
 - Security Council: Binding on Member States
 - Mandate to determine existence of a threat to int'l peace and security; reigns over treaty
 - Risk of P5 member veto, lack of majority
 - General Assembly (GA): Non-binding on Member States
 - Builds broader support to advise the UNSC
 - COPUOS: Strengthens int'l cooperation in space
 - IAWN, SMPAG
 - Advises the UNGA as subject matter experts

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Ames Research Center

EMERGENCY
MANAGEMENT
NORTH CAROLINA

WESTERN STATE
UNIVERSITY

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INJECTs 1.5–1.6: Considerations for Space
Mission Mitigation of 2022 TTX

- Should we develop the technical capabilities that would be required to launch one of the space mission options?

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INJECTs 1.5–1.6: Considerations for Space Mission Mitigation of 2022 TTX

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- Should we develop the technical capabilities that would be required to launch one of the space mission options?
- How should the U.S. balance legal considerations for launching a nuclear explosive device disruption mission with the need to protect the U.S. people?


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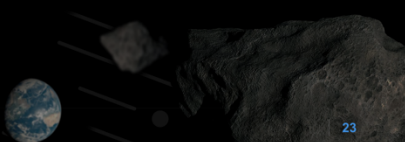
Slide 23

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INJECTs 1.5–1.6: Considerations for Space Mission Mitigation of 2022 TTX

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- Should we develop the technical capabilities that would be required to launch one of the space mission options?
- How should the U.S. balance legal considerations for launching a nuclear explosive device disruption mission with the need to protect the U.S. people?
- How should information about the risks, benefits, and uncertainties of space mission mitigation be communicated to decision-makers?
- How should the decision to launch (or not) be communicated to the public?

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INJECT 1.7

- Over the next weeks and months, astronomers will continue to observe asteroid 2022 TTX to improve our impact and damage predictions. Impact predictions will be updated regularly as new data is collected.
- Observational capabilities are summarized below.

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Capability	Tools
Refine 2022 TTX orbit and impact prediction	Ground-based telescopes
	Precovery observations (archival telescope data)
	Space-based telescopes
	Planetary radar
Refine 2022 TTX size estimate	Reconnaissance mission
	Space-based infrared (IR) telescopes
	Planetary radar
	Reconnaissance mission

NOTES

- New optical telescope data enable calculation of a more precise orbit but do not give additional information about size.
- Measurements from a space-based IR telescope (e.g., NEOWISE) could constrain the asteroid size.
- Planetary radar measurements enable calculation of a precise size and impact location.
 - 2022 TTX will come within range of radar observatories 5-13 days before impact.
- If launched, a reconnaissance mission would enable a detailed characterization of the orbit and properties of 2022 TTX.

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INJECT 1.7: Capabilities for Future Observations of 2022 TTX


- As more observations are collected over the next weeks and months, how should updated information about the asteroid be communicated?

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INJECT 1.7: Capabilities for Future Observations of 2022 TTX

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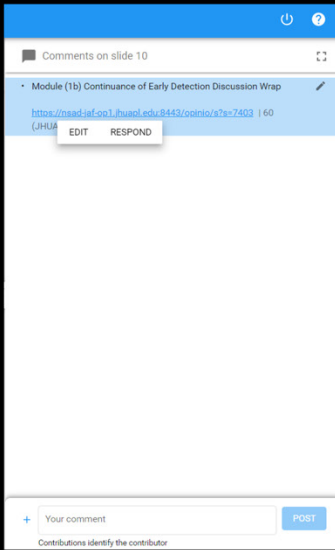
- As more observations are collected over the next weeks and months, how should updated information about the asteroid be communicated?
- What capabilities would be needed in order to more quickly characterize the asteroid threat? Should we develop those capabilities?

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Comments on slide 10

• Module (1b) Continuation of Early Detection Discussion Wrap

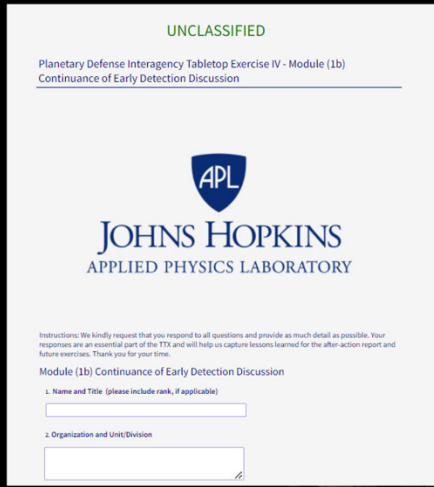
<https://msad.inf.on1.jhu.edu/8443/opinia/3e7493> | 60

(JHU)

EDIT RESPOND


+ Your comment POST

Contributions identify the contributor



UNCLASSIFIED

Planetary Defense Interagency Tabletop Exercise IV - Module (1b)
Continuation of Early Detection Discussion


JOHNS HOPKINS
APPLIED PHYSICS LABORATORY


Instructions: We kindly request that you respond to all questions and provide as much detail as possible. Your responses are an essential part of the TTX and will help us capture lessons learned for the after-action report and future exercises. Thank you for your time.

Module (1b) Continuation of Early Detection Discussion

1. Name and Title (please include rank, if applicable)

2. Organization and Unit/Division

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C.5 Module 2

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Module 2
Early Preparedness
15 June 2022 (Two Months to Go)

Angela Stickle, Ph.D.
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Module 2 Roadmap

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In this module, we will:

- Provide more information on the asteroid and its potential impact location and damage
 - Discussions will focus on the evolving response preparations and how to respond at a regional/local scale
- Provide information on a potential last-resort mitigation attempt
 - Discussions will focus on potential next steps

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INJECT 2.1: A Fireball Is Reported Over Japan

NEWS

Cell phone video of an unidentified fireball over Japan taken last night. No word yet on what caused the bright object.



3:19 PM · June 15, 2022

157 Retweets · 17 Quote Tweets · 327 Likes


Replying to [redacted] and 3 others

This literally the beginning of the War of the Worlds?

12:59 AM · June 15, 2022

♡ Reply ↗ Share

Did the asteroid come early?? Why didn't they tell us??




12:05 AM · June 15, 2022

3,946 Retweets · 1,356 Quote Tweets · 22.2K Likes


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INJECT 2.1: A Fireball Is Reported Over Japan

- How long does it take for our systems to detect and understand a natural fireball?
- How do we message what *we think* happened and calm people down, especially since all they've been hearing about is asteroids for the last four months?

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INJECT 2.1: A Fireball Is Reported Over Japan

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- How long does it take for our systems to detect and understand a natural fireball?
- How do we message what *we think* happened and calm people down, especially since all they've been hearing about is asteroids for the last four months?
- What are the gaps keeping us from being able to “beat the tweet” or be in a position to authoritatively respond within minutes rather than days?
 - Is it worth investing in closing these gaps?

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INJECT 2.2: Scenario Update

**15 June 2022: Two Months to Impact
Impact Is Now Certain; Location Is North Carolina**

Paul Chodas, Davide Farnocchia & Ryan Park
Center for NEO Studies (CNEOS)
Jet Propulsion Laboratory, California Institute of Technology




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Scenario Update: Module 2

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- New tracking data for 2022 TTX, now spanning 7 years, have produced a much more accurate orbit for the asteroid, enabling very precise predictions of the impact
- The asteroid is now **100% certain** to impact, and the **predicted impact location is N. Carolina**
- The most important new data were “**prediscovery**” **detections** of the asteroid from sky images taken in 2015, when 2022 TTX made a distant flyby of Earth
- Astronomers worldwide have continued tracking the asteroid at every opportunity over the last 4 months, contributing close to a hundred new observations
- 2022 TTX passed through the sky region where the NEOWISE spacecraft points its infrared telescope, but the asteroid was **not detected**
- If the asteroid is at the large end of its size range, larger than about 340 m (1100 ft), it should have been detected by NEOWISE; since it was not, the large end of the size range can be revised down somewhat to a **new size range of 40–340 m (130–1100 ft)**

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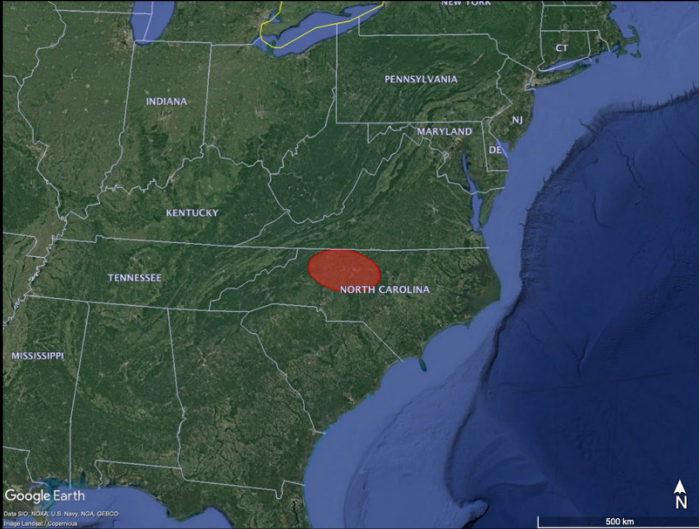
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Predicted Impact Region

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Shows the region where the 2022 TTX will impact

The impact will occur at:
16 August 2022 at 2:02:10 pm EDT

The asteroid will impact at a velocity of 15.5 km/s or 35,000 mph

This is not the same as the damage region

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How Precovery Detections Are Made

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Sky map showing sky regions imaged by asteroid survey 7 years ago, when 2022 TTX was last near Earth:

The image locations, and the images themselves, are **all archived in a database**


If we know an asteroid passed through these image locations, we can **go back into the archive and search for it**

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Precovery Detection of an Asteroid

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Credit: Catalina Sky Survey

- Many faint asteroid detections in sky images are spurious (false)
- The processing pipelines must avoid being swamped by too many false detections
- Marginal detections are mostly discarded
- However, if an asteroid is predicted to be in the image, and a marginal detection matches its predicted motion, it's a real detection!

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**PLANETARY DEFENSE
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INJECT 2.2: The Probability of Impact Has Risen to 100%

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This is a simulated event.

June 15, 2022

From: NASA Planetary Defense Coordination Office
Title: Notification of Asteroid Impact – Update #2

Impact Probability: 100%
Impact Date: 16 August 2022, 18:02 UTC (14:02 EDT)
Impact Risk Corridor: North Carolina
Approximate Size: 130-1100 ft (40-340 m)
Expected Level of Damage if Impact Occurs: Local to Regional
Impact Prevention Feasible: No

- Additional observation has now confirmed there is a 100% probability that asteroid 2022 TTX will impact Earth on 16 August 2022 at approximately 18:02 UTC (14:02 EDT).
- The impact risk corridor, which is the region of Earth where it is possible that 2022 TTX could impact, is in north-west North Carolina.
- The potential impact effects are highly dependent on the size of the asteroid. Based on current data, the size of the asteroid is estimated to be between 130-1100 ft (40-340 m) in size. At the small end of this size range, an asteroid impact over land could result in minor local damage (e.g. air blasts resulting in broken windows and damage to low-integrity structures). At the large end, an asteroid impact could result in a significant surface crater and widespread injuries/casualties and structural damage over a region extending tens to 100+ km.
- The asteroid 2022 TTX has been tracked since initial discovery on 11 February 2022. Detections were also extracted from archival sky images to reduce uncertainty in the asteroid's trajectory. Additional observations will further reduce the uncertainty in the asteroid's trajectory and impact location. The asteroid will be continually observable by telescopes leading up to the potential impact date, except during the full moon.

The PDCO issues an updated notification per NASA Policy Directive 8740.1.

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EXERCISE EXERCISE EXERCISE

Potential Impact Notification

Summary details →

Impact probability and impact date/time →

Description of impact risk corridor →

Estimated impact effects →

Opportunities for further observations →

Feasibility of impact prevention space missions →

Title: Notification of Asteroid Impact – Update #2

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- The asteroid size cannot be estimated with further precision without radar observations or imagery from a spacecraft that can closely approach the asteroid. Radar observations will be possible no sooner than 12 days prior to the potential impact date, if the asteroid is at the large end of the size range, and possibly not until 5 days prior to the potential impact if the asteroid is at the small end.
- Space missions to prevent the impact are not feasible. Deflection is not possible due to the large velocity change that would be required to deflect the asteroid away from Earth and the limited

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Potential Impact Notification Process

Module 1

Note: Speed of execution is directly proportional to time remaining to impact

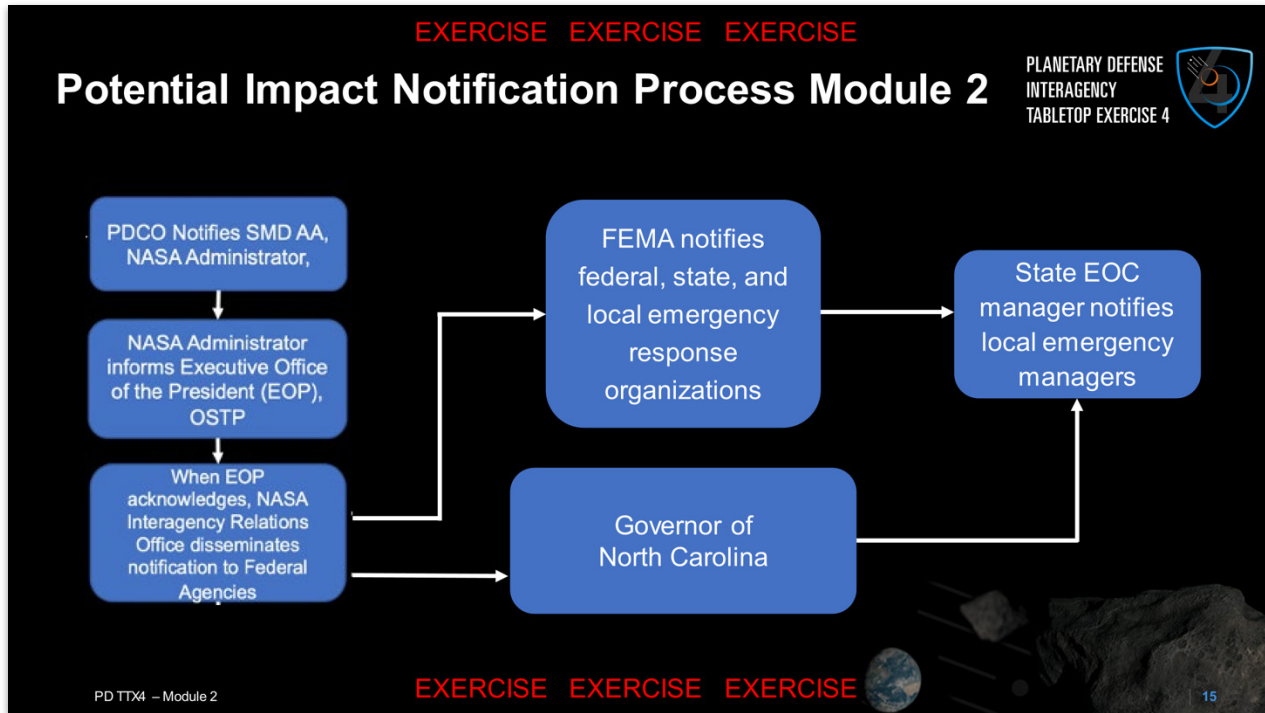
Module 2

Source: NASA Policy Directive 8740.1 Notification and Communications Regarding Potential Near-Earth Object Threats

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INJECT 2.2: The Probability of Impact Has Risen to 100%

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EXERCISE EXERCISE EXERCISE
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The PDCO issues an updated notification per NASA Policy Directive 8740.1.

How should your agency respond to this updated notification?

Is it different from module 1?

Are there additional stakeholders that need to be included in the conversation?

How should the public be notified with the new information?


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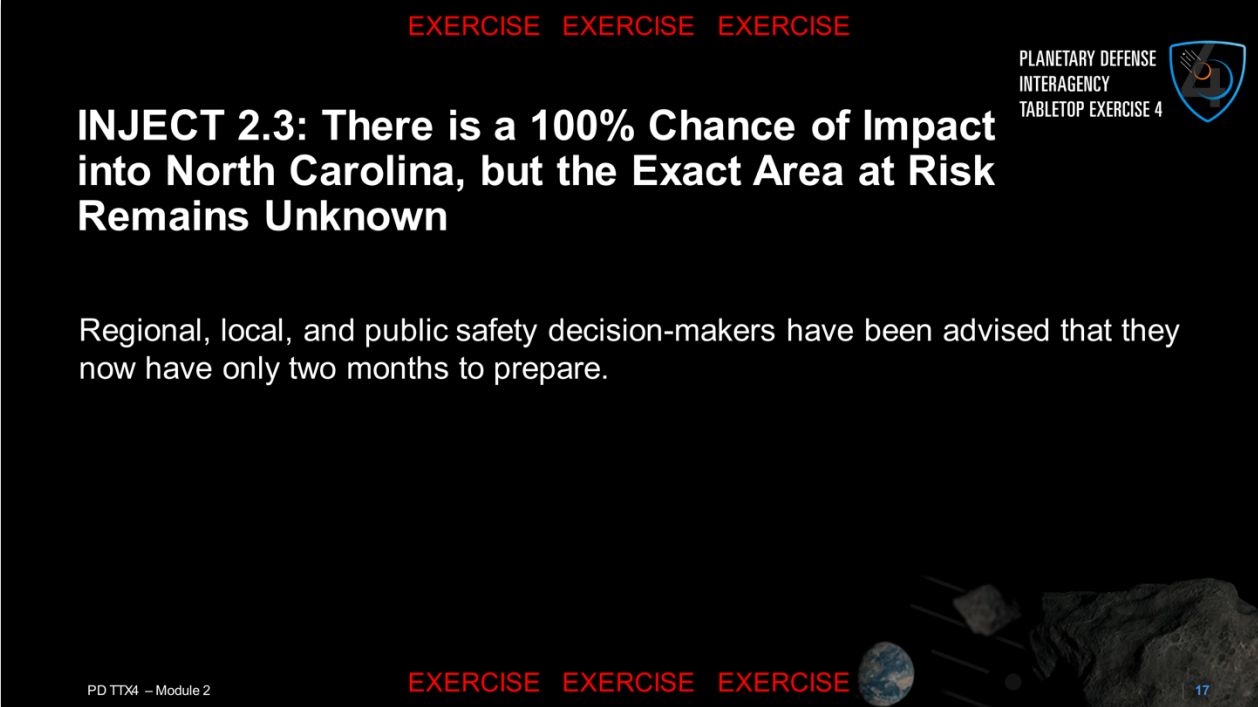


INJECT 2.3: There is a 100% Chance of Impact into North Carolina, but the Exact Area at Risk Remains Unknown

Regional, local, and public safety decision-makers have been advised that they now have only two months to prepare.

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Asteroid Impact Risk: Module 2

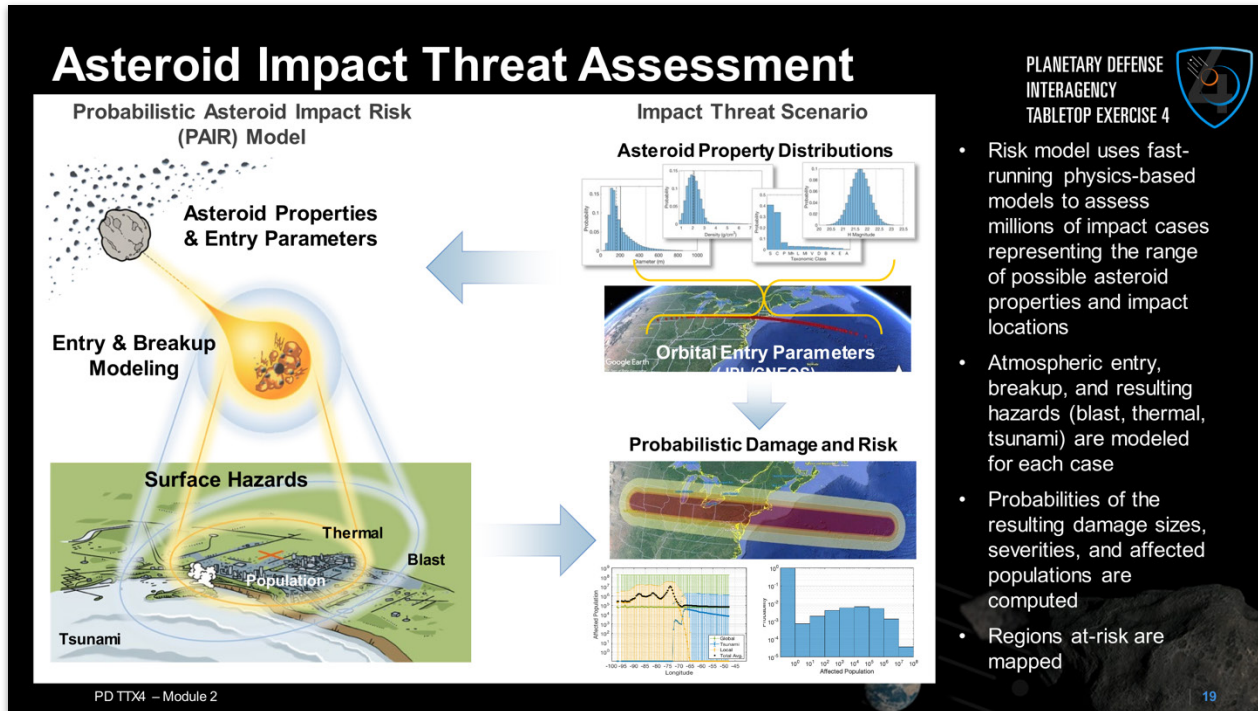
100% Chance of Earth Impact in Two Months

Lorien Wheeler
Jessie Dotson, Michael Aftosmis, Eric Stern, Donovan Mathias
Asteroid Threat Assessment Project (ATAP)
NASA Ames Research Center

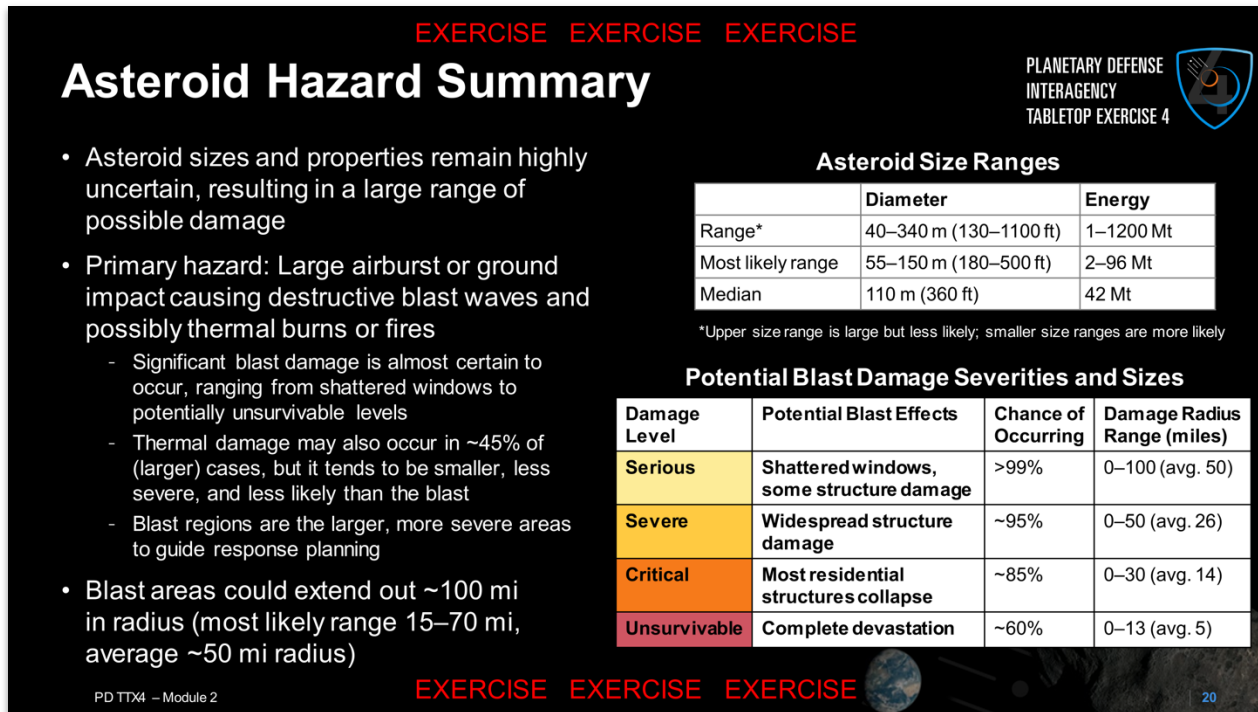


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Potential Risk Swath

Regions potentially at risk, given range of damage sizes & locations

Airburst/impact region

Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus

200 mi

Damage risk swath: Shaded swath areas bound potential at-risk regions given range of damage sizes and airburst/impact locations (black border).

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Risk swath shows range of regions **potentially** at risk, given **range** of possible damage sizes and locations

- Black outline shows current range of potential airburst / impact points (damage-center locations)
- Shaded areas show how far the larger damage estimates **could** extend out from around all those points
- Colors show the highest damage severity level that could occur from those larger damage sizes

Extent of risk region:

- Centered around NC, with damage potentially extending across many counties and into neighboring states
- 360 x 280 mi (580 x 460 km) across at widest extents

Damage Level	Description
Serious	Shattered windows, some minor structure damage
Severe	Widespread structure damage, doors blown out
Critical	Most residential structures collapse
Unsurvivable	Complete devastation

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Potential Risk Swath

Regions potentially at risk, given range of damage sizes & locations

Airburst/impact region

Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus

200 mi

Damage risk swath: Shaded swath areas bound potential at-risk regions given range of damage sizes and airburst/impact locations (black border). Dots show a sample of the potential airburst/impact points where the damage could be centered.

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Risk swath shows range of regions **potentially** at risk, given **range** of possible damage sizes and locations

- Black outline shows current range of potential airburst / impact points (damage-center locations)
- Shaded areas show how far the larger damage estimates **could** extend out from around all those points
- Colors show the highest damage severity level that could occur from those larger damage sizes

Damage Level	Description
Serious	Shattered windows, some minor structure damage
Severe	Widespread structure damage, doors blown out
Critical	Most residential structures collapse
Unsurvivable	Complete devastation

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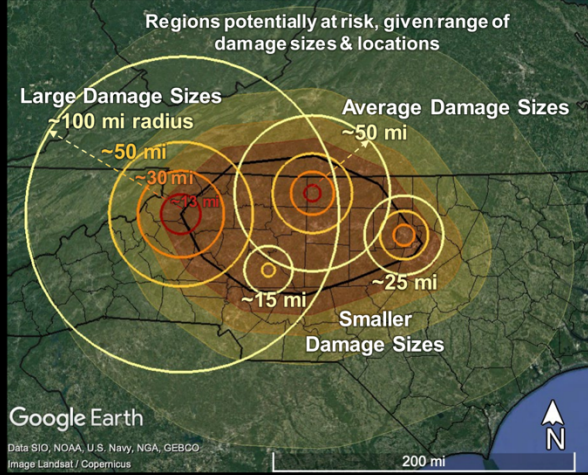
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Potential Risk Swath & Damage Sizes

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Regions potentially at risk, given range of damage sizes & locations

Large-Damage Sizes
~100 mi radius

Average Damage Sizes
~50 mi

Smaller Damage Sizes
~15 mi, ~25 mi, ~30 mi

Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus

200 mi

Damage risk swath: Shaded swath areas bound potential at-risk regions given range of damage sizes and airburst/impact locations (black border). Rings show range of damage footprint sizes at a sample locations.

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Wide range of damage sizes and severities could occur, depending on asteroid size and impact factors

- Rings show examples of potential damage footprint sizes and locations
- Each damage size range could occur around any of the potential airburst/impact points within black outline

Damage radius ranges:

- Serious: ~50 mi average (range 0–100 mi)
- Severe: ~26 mi average (range 0–50 mi)
- Critical: ~14 mi average (range 0–30 mi)
- Unsurvivable: ~5 mi average (range 0–13 mi)


Damage Level	Description
Serious	Shattered windows, some minor structure damage
Severe	Widespread structure damage, doors blown out
Critical	Most residential structures collapse
Unsurvivable	Complete devastation

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Impact Risk Summary: Module 2

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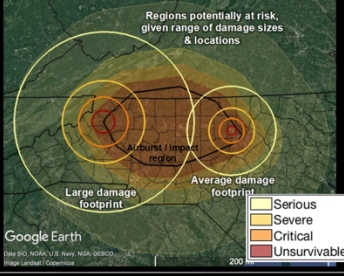


Asteroid Characterization Summary

- Assessment date: 15 June 2022 (T-2 months)
- Impact date: 16 August 2022, impact time ~14:02 EDT
- Earth impact probability: 100%
- Properties: Small reduction in upper size ranges from NEOWISE non-detection. Type and physical properties remain unknown.
- Diameter: 40–340 m (130–1100 ft), most likely range 55–150 m (180–500 ft), median size 110 m (360 ft)
- Energy: 1–1200 megatons (Mt), most likely range 2–96 Mt, median 42 Mt

Impact Hazard Summary

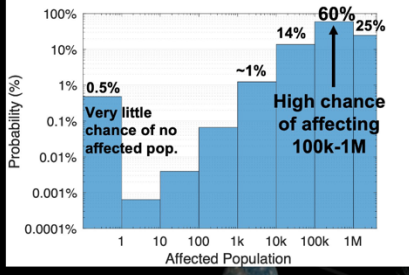
- Significant damage to populated areas around North Carolina is very likely
- Primary hazard: Airburst causing blast damage, ranging from shattered windows and structural damage to potentially unsurvivable levels
- Damage radii: 0–100 mi, most likely range 15–70 mi, average size ~50 mi
- Affected population: Thousands to millions, 650k average risk. 98% chance of affecting >10k, 85% >100k, 25% >1M, 1% >2M



Risk Region Swath

Range of regions potentially at risk to ground damage, given range of potential damage sizes and impact locations

Rings show an average and large damage footprint size at sample locations



Population Risk


Probabilities of how many people could be affected by the potential damage

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Module 2 Impact Risk Backup


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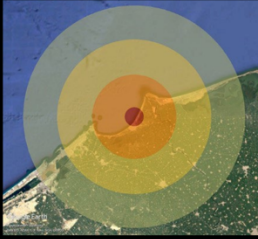
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Local Ground Damage Severity Levels

- Blast and thermal damage are assessed independently at four severity levels
 - For each damage level, the **larger** of the associated blast or thermal damage is used to determine the area and affected population for that level
 - Damage regions indicate **either** blast or thermal effects could exceed the given severity, **not** the occurrence of both effects within the entire region
- **Blast** is the predominant hazard for this scenario, and tends to be larger and more severe than the potential thermal damage in most cases

Damage Level	Potential Blast Damage Effects	Potential Thermal Damage Effects
Serious	Shattered windows, some structural damage	2nd degree burns
Severe	Widespread structural damage, doors and windows blown out	3rd degree burns
Critical	Most residential structures collapse	Clothing ignition
Unsurvivable	Complete devastation	Structure ignition, incineration



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Asteroid Size & Properties

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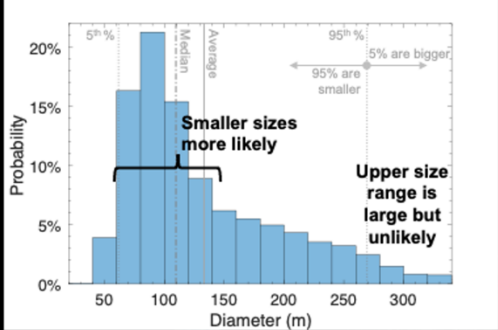
Asteroid sizes and properties remain highly uncertain

- Small reduction in upper size ranges from NEOWISE non-detection, but primary size probabilities remain similar
- Upper size range is large but relatively unlikely
- Smaller size ranges are more likely
- Type and properties are unknown, ranging from more common stony types and rubble piles to rarer high-density iron types
- Size and density uncertainties result in very large ranges of potential mass and impact energy

Large range of possible asteroid size and energy result in large range of possible damage

	Diameter	Energy
Range	40–340 m (130–1100 ft)	1–1200 Mt
Most likely range	55–150 m (180–500 ft)	2–96 Mt
Median	110 m (360 ft)	42 Mt

Asteroid Diameter Probabilities



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Hazard Summary

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- Asteroid sizes and properties remain highly uncertain, resulting in a large range of possible damage sizes and severities
- Primary hazard: Large airburst or ground impact causing destructive blast waves and possibly thermal heat damage
 - Significant blast damage is almost certain to occur, ranging from shattered windows to potentially unsurvivable levels
 - Thermal damage may also occur, but tends to be less likely, smaller, and less severe than the blast damage
- **Outer blast damage areas could extend out ~100 mi in radius** (most likely 15–70 mi, average ~50 mi radius)

Damage Level	Potential Blast Effects	Chance of Occurring	Damage Radius Range (miles)
Serious	Shattered windows, some structure damage	>99%	0–100 (avg. 50)
Severe	Widespread structure damage	96%	0–47 (avg. 26)
Critical	Most residential structures collapse	86%	0–28 (avg. 14)
Unsurvivable	Complete devastation	61%	0–13 (avg. 5)

Damage Level	Potential Thermal Effects	Chance of Occurring	Damage Radius Range (miles)
Serious	2 nd degree burns	44%	0–22 (avg. 5)
Severe	3 rd degree burns	37%	0–17 (avg. 4)
Critical	Clothing ignition	28%	0–12 (avg. 2)
Unsurvivable	Structure ignition	24%	0–10 (avg. ~1)

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Damage Sizes with Location Ranges

Median Damage Size (50th%)
Spread across range of locations

Large Damage Size (95th%)
Spread across range of locations

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- Rings show sample footprint sizes at a single location (Greensboro)
- Black border shows range of potential airburst/impact locations (damage center points)
- Shaded regions show spread of the damage sizes over range of locations

Damage Level	Mean	Min	5th %	25th %	50th %	75th %	95th %
Serious	50	0	16	26	49	70	103
Severe	26	0	4	16	26	35	47
Critical	14	0	0	7	15	21	28
Unsurvivable	5	0	0	0	5	10	13

Window breakage, some minor structure damage
Widespread structure damage, doors/windows blown out
Most residential structures collapse
Complete devastation

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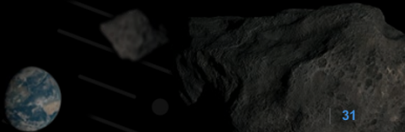
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INJECT 2.3: There Is a 100% Chance of Impact into North Carolina, but the Exact Area at Risk Remains Unknown

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Local and public safety decision-makers have been advised that they now have only two months to prepare.

- When and how does a unified command and/or multi-area coordination center begin to form?
- What are plans for ensuring continuity of government?
- What critical infrastructure in the area requires the most notice for shutdown/evacuation?

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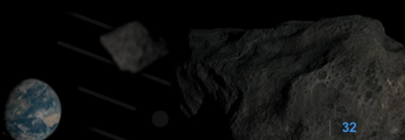
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INJECT 2.3: There Is a 100% Chance of Impact into North Carolina, but the Exact Area at Risk Remains Unknown

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- What operations can be limited to ensure minimal extra population is in North Carolina at the time of impact?
- What is the coordination with the Business Emergency Operations Center (BEOC) to ensure that business and industry maintain feasibility and reliability? How would reducing activities impact the business community as well as nearby businesses that receive resources via I-85 and I-95?


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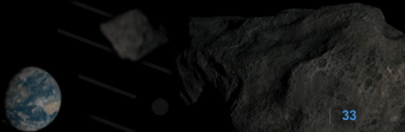
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INJECT 2.3: There Is a 100% Chance of Impact into North Carolina, but the Exact Area at Risk Remains Unknown

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- What are the roles of federal agencies/decision-makers in this scenario?
- What are the roles of state agencies?
- What information is required by each?
- How are actions and decisions by federal agencies coordinated with state-level EM teams?


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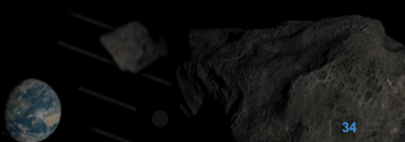
INJECT 2.4

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There might be a possibility to disrupt the asteroid with a suborbital explosion.

An intercontinental ballistic missile (ICBM) equipped with a nuclear explosive device might be able to intercept the asteroid a few minutes before impact.

We would have to prep for a go/no-go decision now.

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Law and Policy

Liability Overview as Relevant to Nuclear Explosive Devices (NEDs)

Aparna Srinivasan, Esq.
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Logos: NASA, PLANETARY DEFENSE, FEMA, NORTH CAROLINA, cneos, Johns Hopkins Applied Physics Laboratory

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Accountability for Mitigation Measures

Balancing Act Implemented via Political and Legal Instruments

Prime Rule for Liability of Launching States

- **Article VII OST:** *Each State Party...that launches or procures the launching of an object in outer space is internationally liable for damage to another State Party to the Treaty...*
- **Article II, III, The Liability Convention:** Two different liability regimes apply to payment of compensation:
 - Absolute liability: damage caused by a space object on the surface of Earth (or to aircraft in flight)
 - At-fault liability: damage caused by a space object elsewhere than on Earth's surface

Invocation of State Responsibility Exculpatory Clause: Necessity

- Note continued duty of restitution/compensation owed for damage
- May be further mitigated by authority of the UN Security Council

Elements of a Claim

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- Qualification as a "Launching State"
- ↓
- Damage
- ↓
- Causality or Causal Chain
- ↓
- Fault of the Actor

Liability depends on the unique factual circumstances and legal interpretation governing the planetary defense mission.

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Mitigating Liability Risk

Advance Following Potential Measures:

1. Support the establishment of an international decision-making framework
 - Carve out, from existing principles and customary law, standards to govern the specific context of near-Earth object (NEO) threat response actions
 - Develop customary and possibly treaty law to address voids, uncertainty, or absence of relevant international rules
 - Maintain level of global transparency and trust
2. Establish a multilateral agreement (before a NEO impact discovery)
 - Sanctioned by the UN Security Council or via resolution (Chapter VII, UN Charter) identifying thresholds/parameters to authorize a NED response
 - Obtain international acceptance of specific planetary defense measures
 - Incorporate ad hoc or cross waivers of liability
3. National Options to Explore
 - Set thresholds for a 6-month or 12-month mitigation plan
 - Close technology and knowledge gaps

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Questions to Consider:

- What if States decide to unilaterally and independently deploy an NED?
- Should we amend treaties to:
 - Deflect an asteroid?
 - Deploy nuclear option in an emergency or test mission?
- How should we ensure that countries will not exploit nuclear option exceptions for NEOs as a pretext for military purposes?
- Should we require that use of NEDs be sanctioned by the UN Security Council?
- What rules should govern storage/acquisition of nuclear material meant for disruption missions?

Determine confidence metrics for decision-makers

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Close Proximity Nuclear Disruption with Ballistic Missile Systems

Patrick King, Ph.D.
Staff Physicist
Johns Hopkins University Applied Physics Laboratory
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Ballistic Missile Nuclear Intercept Concept

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1. Radar/observations refine the orbit of the impactor to high precision.
2. Ballistic missile trajectory and guidance modified to an intercepting trajectory.
3. Ballistic missile is launched and the payload is detonated near impactor.
4. The nuclear explosive irradiates the surface of the impactor, which explodes and drives a strong shock.
5. The shock shatters the impactor and disperses the fragments, separating them spatially.
6. The dispersed fragments enter the atmosphere separately, distributing them into many separated bolides, possibly reducing damage.

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Effectiveness and Feasibility

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- Effectiveness will be closely related to how well-dispersed the fragments are
- Dispersal depends on both the strength of the disruption and how much time before atmospheric entry the fragments are allowed to disperse
- Disruption effectiveness is closely related to delivered yield (device yield, target size, and proximity of burst)
- Preliminary analysis (Hupp et al. 2015) suggests a notional system like a Minuteman III could provide intercept trajectories on the order of minutes before impact
- Further APL analysis suggestive that off-the-shelf guidance accuracy is an important limiting factor for this concept

Marginal Disruption

Robust Disruption

From Hupp et al. 2015

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Secondary Consequences and Hazards

- High-altitude nuclear events (HANEs) are known to produce several hazardous effects
- These effects would be concurrent with any impact consequences and could make a bad situation worse
- These effects may impact both U.S. and foreign assets
- Exact estimates would require detailed analysis but would use established tools (DOD and DOE)
- Persistent effects could potentially affect space operations for an extended period of time (from weeks to even years)
- Some of these effects might be able to be mitigated (e.g. circumvent & recovery procedures)
- These effects are all yield- and altitude-dependent

EMP

- EMP effects are generated at high altitude and could cause widespread effect on the ground
- EMP effects are also felt by space assets
- Intensity is highly device-dependent and altitude-dependent

Source: Nuclear Environment Survivability, U.S. Army, report AD-A279230 (1984)

Persistent Radiation Belts

- Radiation levels will be elevated for a significant length of time
- Higher/different radiation conditions can significantly degrade satellite lifetimes/space operations
- RF comms/radar may face degraded or altered conditions

Starfish Prime

Prompt Flash

- Direct line-of-sight flash can directly damage assets close enough to the detonation through:
- Exposed Surface and Internal Component Damage
- Suddenly occurring currents/charges – system-generated EMP (SGEMP)
- Damage of electronic components (bit flip to burnout) – Dose/Dose Rate

Fallout

- Fission fragments and neutron-activated rocky material
- Material will be injected into the atmosphere at high altitude
- Need to estimate potential contamination risks

Example Plume Mode from NARAC, LLNL

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Summary

- Disrupting the asteroid before atmospheric entry may significantly reduce the direct consequences of impact. However, this is only possible with a nuclear explosive, and the mitigation effectiveness needs to be studied in more detail.
- “Off-the-shelf” feasibility of using a representative class of suborbital ballistic missiles (similar to Minuteman III) has been explored, and not ruled out, but significant uncertainties do remain.
- The HANE would produce significant effects that could disrupt space operations and potentially cause adverse ground effects.
- All of these results are preliminary and need to be confirmed by more intensive analysis.

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PD TTX4 – After Action Report, Appendix C


C-111

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INJECT 2.4: There Might Be a Possibility to Disrupt the Asteroid with a Suborbital Explosion

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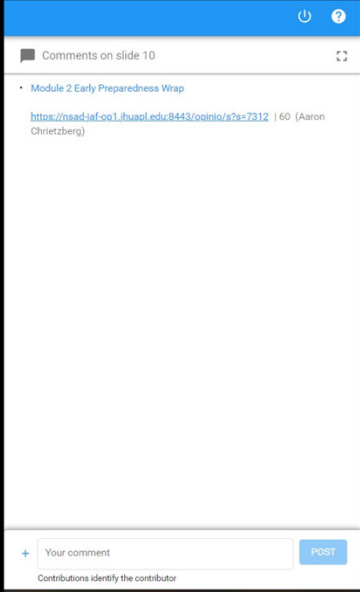
- What U.S. government agencies/departments would have a role in pursuing a course of action or in making a recommendation to the president regarding the decision to proceed?
- What factors, to include liability concerns, would need to be considered in the decision to pursue a close-proximity disruption mission?
- What would you consider to be the most critical gaps impacting the decision to launch a close-proximity disruption mission?

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Comments on slide 10


- Module 2 Early Preparedness Wrap
- <https://nsad-iaf-oo1.jhuapl.edu/oomio/s?e=7312> | 60 (Aaron Christzberg)

Your comment

Contributions identify the contributor

UNCLASSIFIED

Planetary Defense Interagency Tabletop Exercise IV - Module 2 Early Preparedness



JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Instructions: We kindly request that you respond to all questions and provide as much detail as possible. Your responses are an essential part of the TTX and will help us capture lessons learned for the after-action report and future exercises. Thank you for your time.

Module 2 Early Preparedness Wrap

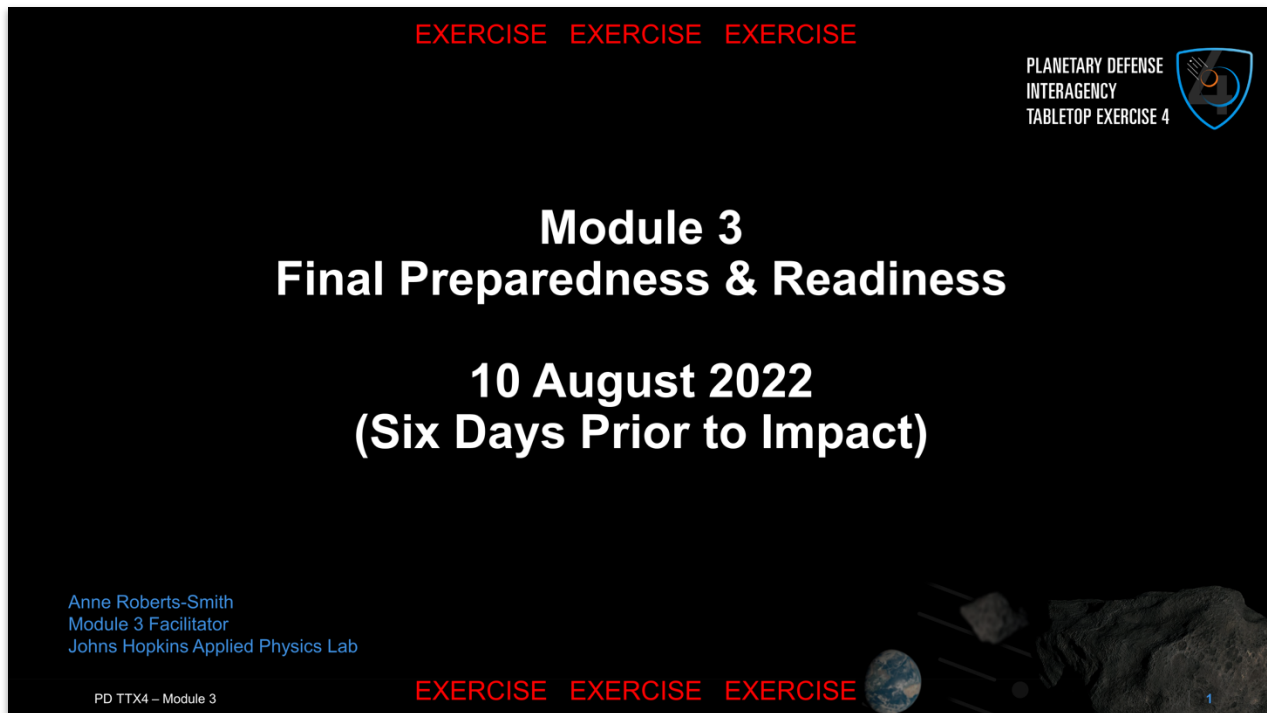
- Name and Title (please include rank, if applicable)
- Organization and Unit/Division

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C.6 Module 3


Slide 1



Slide 2


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Module 3 Roadmap

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In this module, we will:

- Provide more detailed information on the asteroid, its impact location, and potential damage
 - Discussions will focus on final preparations, how to respond at the local level, and what federal actions are required

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Module 3 Six Days to Impact

**10 August 2022:
2022 TTX Detected by Radar; Potential Severity Downgraded**

Paul Chodas, Davide Farnocchia & Ryan Park
Center for NEO Studies (CNEOS)
Jet Propulsion Laboratory, California Institute of Technology






Slide 4

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Scenario Update: Module 3


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- Goldstone has been attempting to detect 2022 TTX for the last week but was unsuccessful until today, Aug. 10; now there are **only 6 days until impact**
- If the asteroid was at the large end of its size range, it would have been detected before now
- The radar measurements indicate that 2022 TTX is about 70 m (230 ft), toward the small end of the previous size range
- There is still some uncertainty in size: the most likely range is 60-80 m (200-260 ft)
- The radar data also contribute to another dramatic improvement in orbit accuracy, adding to the growing set of tracking data accumulated over the last two months; the expected impact location is now known to an accuracy of about 20 km
- Although the asteroid size is now much better constrained, large uncertainties still remain in other physical parameters, such as density

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Module 3: Predicted Impact Region

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Shows the **region in which 2022 TTX will impact**, projected to the surface, not at the altitude of airburst

Impact date/time:
16 August 2022
2:02:10 pm EDT


Asteroid velocity:
15.54 km/s (34,700 mph)

Approach elevation:
64 deg (26 deg from vertical)

Approach direction:
37 deg (from NNE)

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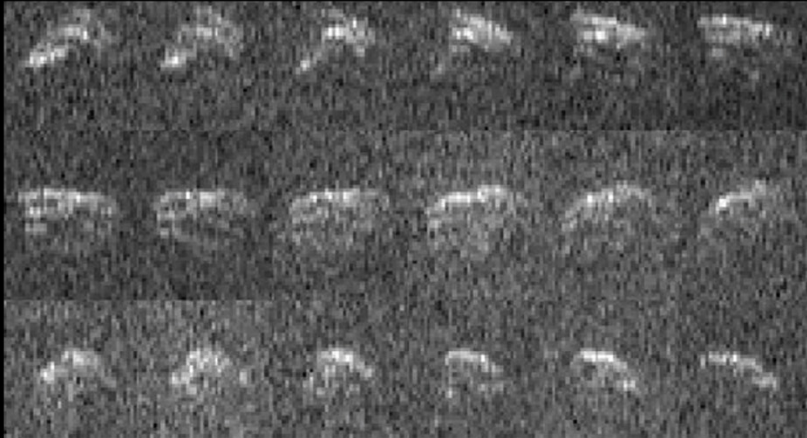


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Sample Radar Images of 2022 TTX


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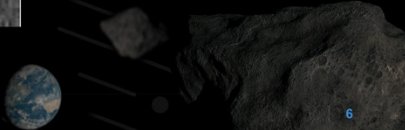


- Now that 2022 TTX is within range of Goldstone, range/Doppler images can be taken that reveal the asteroid's size, shape, and surface roughness
- Images are taken repeatedly, as the asteroid rotates, providing different views of the asteroid's profile

(Actual images of 2013 ET)

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Asteroid Impact Risk: Module 3

6 days before impending impact over Forsyth county

Lorien Wheeler
 Jessie Dotson, Michael Aftosmis, Eric Stern, Donovan Mathias
 Asteroid Threat Assessment Project (ATAP)
 NASA Ames Research Center

NASA
 PLANETARY DEFENSE
 FEMA
 NORTH CAROLINA
 cneos
 Johns Hopkins Applied Physics Laboratory

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Asteroid Size & Properties

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- Radar measurements from Goldstone estimate size to be ~70 m (230 ft) ± uncertainty
 - Potentially 50–90 m (170–290 ft),
 - Most likely 60–80 m (200–260 ft)
 - Type and physical properties remain unknown
- Effects on damage ranges:
 - More accurate size range reduces potential damage sizes significantly
 - However, substantial uncertainty in damage sizes remains due to unknown properties
 - Energy range still an order of magnitude due to unknown density
 - Structure and strength leave large uncertainties in potential breakup and resulting airburst altitude

Asteroid Size Ranges

	Diameter	Energy
Range	50–90 m (170–290 ft)	3–30 Mt
Most likely range	60–80 m (200–260 ft)	6–14 Mt
Median	70 m (230 ft)	11 Mt

Asteroid Diameter Probabilities

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Potential Risk Swath

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Regions potentially at risk, given full range of damage sizes & locations

Average damage footprint

Airburst region

~20 mi radius

10 mi

3 mi

0 mi

60 km

Google Earth

Damage risk swath: Shaded swath areas bound potential at-risk regions given range of damage sizes and airburst/impact locations (black border). Rings show an average-sized damage footprint at a sample location.

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Risk swath shows range of regions **potentially** at risk, including range of damage sizes and locations

- Black outline shows range of potential airburst / impact points (damage-center locations)
- Shaded areas show potential at-risk regions given range of damage sizes and locations
- Rings show an average-sized damage footprint at a sample location

Damage radius sizes:

- Serious: 20 mi average (range 10–40 mi)
- Severe: 10 mi average (range 0–20 mi)
- Critical: 3 mi average (range 0–10 mi)
- Unsurvivable: 0 mi average (range <2 mi)

Damage Level	Description
Serious	Window breakage, some minor structure damage
Severe	Widespread structure damage, doors/windows blown out
Critical	Most residential structures collapse
Unsurvivable	Complete devastation

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Likelihood of Damage Severities

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Regions potentially at risk, given full range of damage sizes & locations

Average damage footprint

Airburst region

75% chance radius will be under 5 mi

95% chance radius will be under 10 mi

5% chance of occurring - under 1-2 miles in radius

60 km

Google Earth

Damage risk swath: Shaded swath areas bound potential at-risk regions given range of damage sizes and airburst/impact locations (black border). Rings show an average-sized damage footprint at a sample location.

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- Serious and severe damage levels are very likely to occur over potentially large areas
- Higher damage levels are possible but less likely
- Critical levels: 45% chance of occurring
 - 75% chance radius will be under 5 mi
 - 95% chance radius will be under 10 mi
- Unsurvivable levels: 5% chance of occurring
 - under 1-2 miles in radius

Damage Level	Potential Blast Effects	Chance of Occurring	Damage Radius Range (miles)
Serious	Shattered windows, some structure damage	~100%	10–40 (avg. 20)
Severe	Widespread structure damage	~90%	0–20 (avg. 10)
Critical	Most residential structures collapse	~45%	0–10 (avg. 3)
Unsurvivable	Complete devastation	~5%	<2 (avg. 0)

EXERCISE EXERCISE EXERCISE

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Airburst Blast Simulation

Blast wave contours colored by Mach Number (fraction of speed of sound)

Cart3D Computational Fluid Dynamics Simulation. Credit: Michael Aftosmis, ATAP, NASA Ames

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INTERAGENCY
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Simulation of nominal radar size case:

- 70 m (230 ft) diameter
- 11.3 Mt energy
- Typical stony-type asteroid properties assumed
- Entry velocity 15.5 km/s (~35k mph)
- Entry angle 65°
- Effective airburst altitude ~12.5 km (~8 mi)

EXERCISE EXERCISE EXERCISE

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EXERCISE EXERCISE EXERCISE

Airburst Blast Simulation Movie

Blast Process:

- **Entry:** Shockwaves emanate from the entry path as the asteroid enters at high speeds
- **Airburst:** Asteroid disrupts catastrophically under high aerodynamic pressures, producing an explosion-like blast
- **Ground damage:** Shock front reflects off the ground and sends a powerful overpressure wave outward across the ground. *Damage is caused by the **pressure** wave (not windspeed)*

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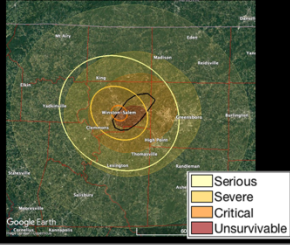
Impact Risk Summary: Module 3

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Asteroid Characterization Summary

- Assessment date: 10 August 2022 (T-6 days)
- Impact date: 16 August 2022, impact time ~14:02 EDT
- Refined asteroid size estimates from Goldstone Radar measurements. Other properties still unknown, leaving uncertainty in mass, energy, and entry/airburst factors
- Diameter: 70 m (230 ft) radar size estimate, potentially 50–90 m (170–290 ft), most likely range 60–80 m (200–260 ft)
- Energy: 3–30 Mt (megatons), most likely range 6–14 Mt, median 11 Mt



Risk Region Swath

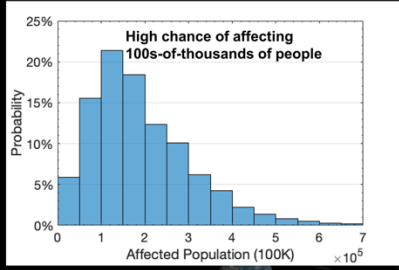
Range of regions potentially at risk to ground damage, given range of potential damage sizes and impact locations.

Rings show an average damage footprint size at a sample location

Black border shows range of potential airburst locations

Impact Hazard Summary

- High chance of damage affecting hundreds of thousands of people in Forsyth and potentially surrounding NC counties
- Primary hazard: Airburst causing blast damage, ranging from shattered windows and structural damage to potentially unsurvivable levels
- Damage region radii: 10–40 mi, most likely range 15–25 mi, median size ~20 mi
- Affected population: tens to hundreds of thousands, 190k avg risk, 80% chance of >100k people, 40% >200k, 15% >300k, 5% >400k



Population Risk

Probabilities of how many people could be affected by the potential damage


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Module 3 Impact Risk Backup

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Potential Risk Swath

Regions potentially at risk, given full range of damage sizes & locations

Average damage footprint

Airburst region

Google Earth

60 km

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PLANETARY DEFENSE INTERAGENCY TABLETOP EXERCISE 4

Likelihood of Damage Severities:

- Serious and severe damage levels are very likely to occur over large areas
- Higher damage levels are possible but less likely
- Critical levels are possible but less likely:
 - 45% chance of occurring
 - 75% chance radius will be under 5 mi
 - 95% chance radius will be under 10 mi
- Unsurvivable levels are very unlikely:
 - 5% chance of occurring
 - under 1-2 mi in radius

Damage Level	Description
Serious	Window breakage, some minor structure damage
Severe	Widespread structure damage, doors/windows blown out
Critical	Most residential structures collapse
Unsurvivable	Complete devastation

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Damage Sizes with Location Ranges

Median Damage Size (50th%)

Large Damage Size (95th%)

Google Earth

60 km

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- Serious and severe damage levels very likely, higher damage levels possible but less likely
- Critical levels are possible but much less likely (45% chance of occurring, 75% chance radius will be under 5 mi, 95% chance <10 mi)
- Unsurvivable levels very unlikely (5% chance of occurring in small areas under 1-2 mi in radius)

Local Ground Damage Radius Sizes (miles)								Damage Level Description
Damage Level	Mean	Min	5th %	25th %	50th %	75th %	95th %	
Serious	21	0	12	17	20	23	37	Window breakage, some minor structure damage
Severe	10	0	0	7	10	14	18	Widespread structure damage, doors/windows blown out
Critical	3	0	0	0	0	5	10	Most residential structures collapse
Unsurvivable	0	0	0	0	0	0	1	Complete devastation

*Percentiles give the chance that the damage region could be up to the given size or smaller

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Blast Simulation Ground Footprint

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Ground footprints from simulation of nominal radar size case:

- Peak Overpressure is 23.4% (3.44 psi) (Severe 2-4 psi level)
- Max wind speed is 29.4 m/s (65.7 mph)
- Serious (>1 psi) region: ~18-37 mi radius, ~2600 sq. mi. enclosed area
- Severe (>2 psi) region: ~10-15 mi radius, ~425 sq. mi. area
- Very severe (3-3.5 psi): ~2-6 mi, ~38 sq. mi.

Cart3D Computational Fluid Dynamics Simulation. Credit: Michael Aftosmis, ATAP, NASA Ames

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Inject 3.1: Six Days Out – Key Considerations

- Are you able to interpret the visuals and data you have seen?
 - With this information are you able to communicate complex information to both key decision makers and the public?
- Is the information you received sufficient to make decisions related to evacuation and public messaging?
- Given the unique nature of the threat, what gaps do you see in your current resources?
- Which agencies could provide ongoing consultation to the state and locals? How would that occur?
- At this point in the timeline, do you understand:
 - What types of casualties to expect?
 - What the environmental impacts might be?

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Inject 3.2: Social Media & Misinformation

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Local news in Central North Carolina is reporting a growing number of social media posts claiming that the asteroid is a government hoax.



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Slide 21

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Inject 3.2: Social Media & Misinformation

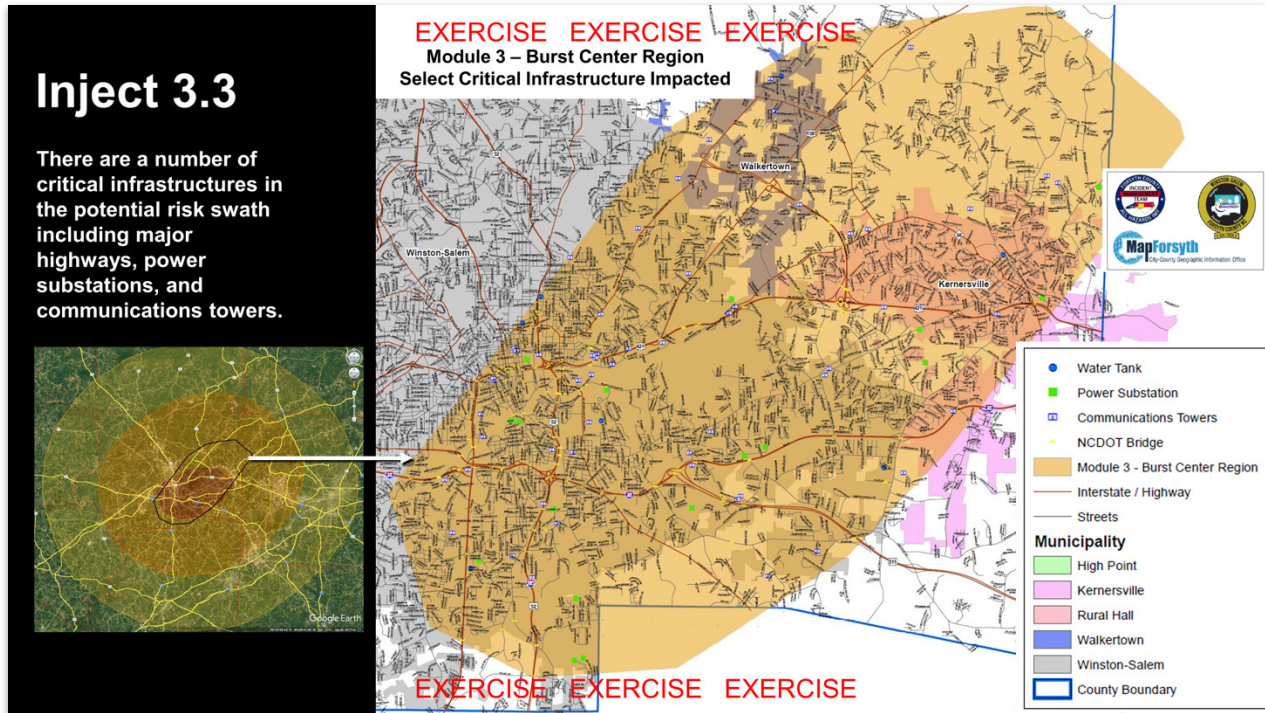
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- At this point in the scenario, who is the most trusted person/entity to provide information and update the public?
- Do state and local agencies have enough information to field questions?
 - What additional expertise is needed?
- How do you ensure continuity of messaging?
- What ongoing information is available to the general public and through what means?
- Are there concerns regarding foreign manipulation and the source of the misinformation?

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Slide 23

EXERCISE EXERCISE EXERCISE

Inject 3.3: Impacts to Infrastructure


- Based on the key infrastructure in the impacted area, what state and federal resources are being moved to the designated staging areas?
- What are your immediate concerns regarding continuity of government, emergency communications, security, and evacuation planning?
- What federal assistance do state and local organizations need?
- Are there executive actions that must be made to activate resources?



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Inject 3.4 FAST FORWARD: 24 hours to Impact

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PD TTX4 Team Meeting #4 EXERCISE EXERCISE EXERCISE  24

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Inject 3.4: 24 Hours to Impact

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With 24 hours remaining:


- What are the top three priorities for the next 24 hours?
- Approximately 20% of residents have refused to (or cannot) evacuate. How does this influence your next steps?
- What security needs are you anticipating given the level of interest from media and the general population? What supplemental security resources do you have access to? What federal resources are available in the field?

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EXERCISE EXERCISE EXERCISE

Participant Feedback for Module 3

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Comments on slide 10

- Module 3 Final Preparedness Wrap


<https://nsad-jaf-op1.jhuapl.edu:8443/opinio/s?s=7313> | 60 (Aaron Chrietberg)

+ Your comment

Contributions identify the contributor

UNCLASSIFIED

Planetary Defense Interagency Tabletop Exercise IV - Module 3 Final Preparedness and Readiness Wrap


JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Instructions: We kindly request that you respond to all questions and provide as much detail as possible. Your responses are an essential part of the TTX and will help us capture lessons learned for the after-action report and future exercises. Thank you for your time.

Module 3 Final Preparedness and Readiness Wrap

1. Name and Title (please include rank, if applicable)

2. Organization and Unit/Division

EXERCISE EXERCISE EXERCISE

PD TTX4 Team Meeting #426

C.7 Module 4

Slide 1

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FEMA




JOHNS HOPKINS
APPLIED PHYSICS LABORATORY


Module 4

Immediate Response and Transition to Recovery

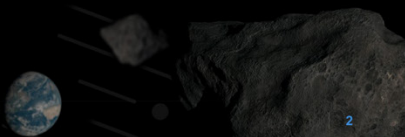
Facilitated by Ruth Vogel (APL) and Doug Logan (OTP)

Slide 2

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Asteroid 2022 TTX Impacts Earth

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Slide 3

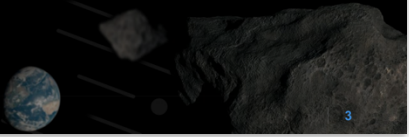
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Module 4 Overview

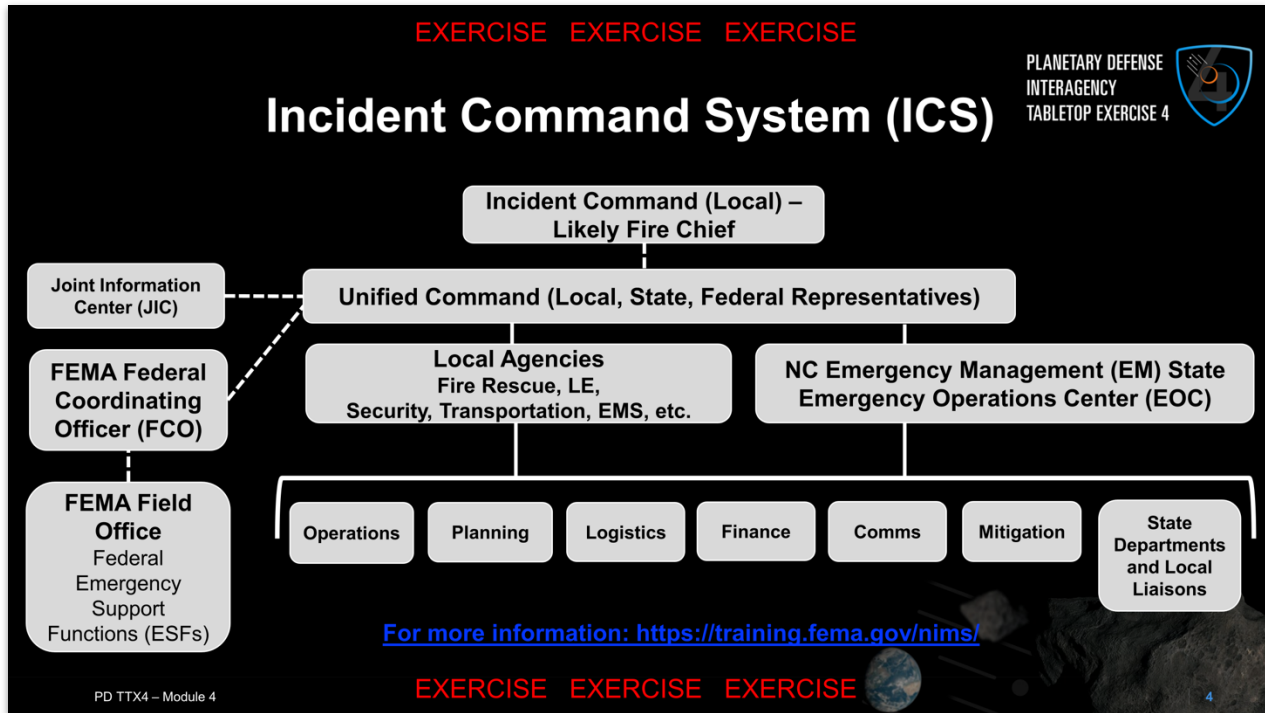
Immediate hours post impact, so our discussions will focus on:

- Acquiring situational awareness for informed decision-making
- Understanding risks and hazards
- Ensuring accurate public messaging
- Coordinating safety and security

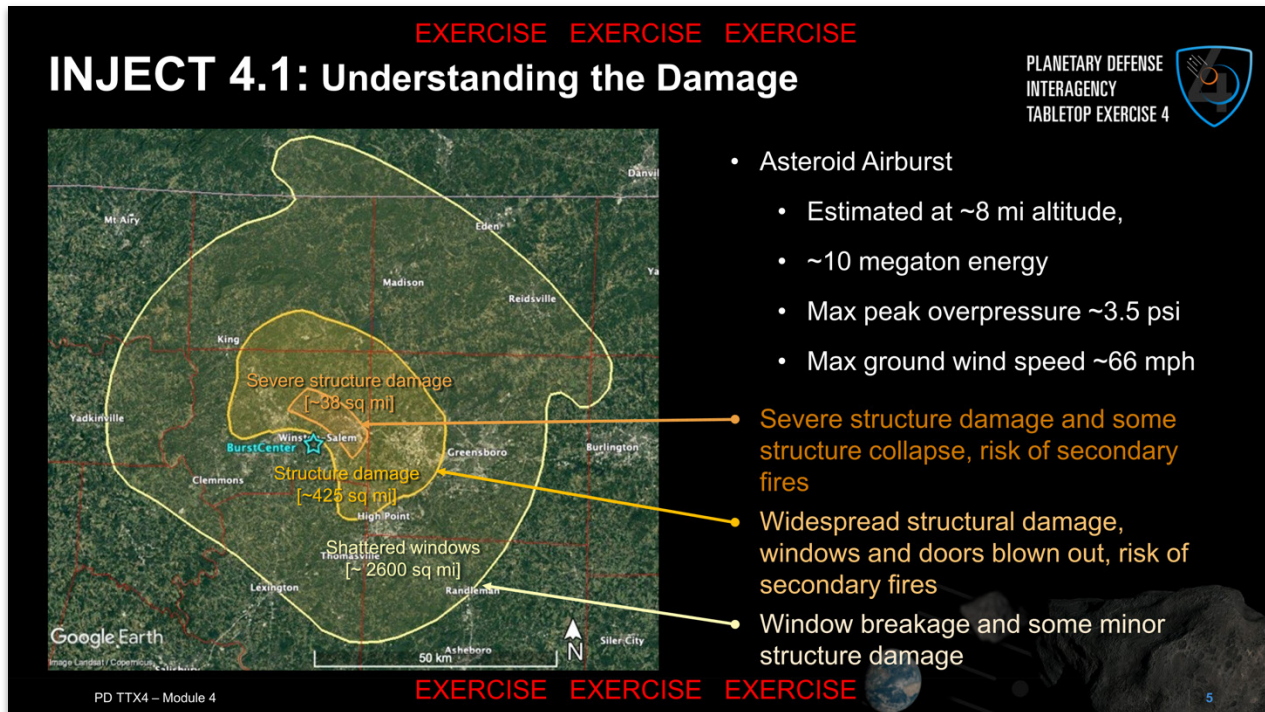
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3

Slide 4




Slide 5



Slide 6

EXERCISE EXERCISE EXERCISE

10 Megatons of Energy


PLANETARY DEFENSE INTERAGENCY TABLETOP EXERCISE 4 

1950s Nuclear Test

Doom Towns in Nevada constructed to understand nuclear blast-related damage

From: Nuclear Bomb Dropped on Village - 1950s Test
<https://www.youtube.com/watch?v=vMopb1eN2t4>


FA FootageArchive - Videos From The Past
137K subscribers

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EXERCISE EXERCISE EXERCISE

Drone Images

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Drones are capturing images of shattered windows, collapsed buildings and bridges, and secondary fires, and people are trapped and waving for help.

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Slide 8

EXERCISE EXERCISE EXERCISE

Reporting from the Public

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TABLETOP EXERCISE 4 

The Emergency Communications Centers (ECCs) are overwhelmed with calls from people reporting collapsed buildings and bridges, windows shattered, small fires, and people trapped under rubble.




EXERCISE EXERCISE EXERCISE

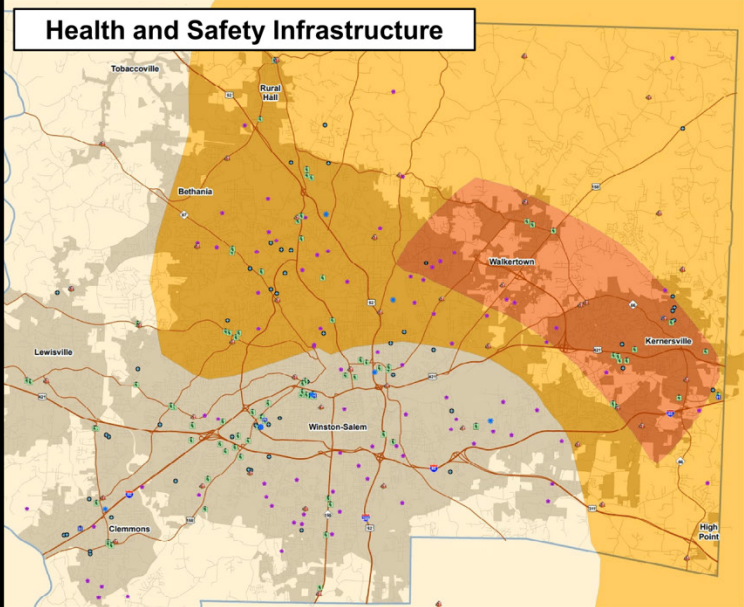
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EXERCISE EXERCISE EXERCISE

Health and Safety Infrastructure

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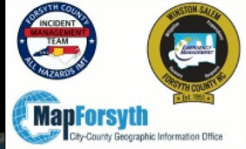


- Fire Station
- EMS Base
- Pharmacies
- Hospitals
- Longterm Care Facility
- Mental Health Facility
- Interstate / Highway
- Streets

Damage Level

- 1 psi
- 2 psi
- 3 psi

- Municipalities
- County Boundary




EXERCISE EXERCISE EXERCISE

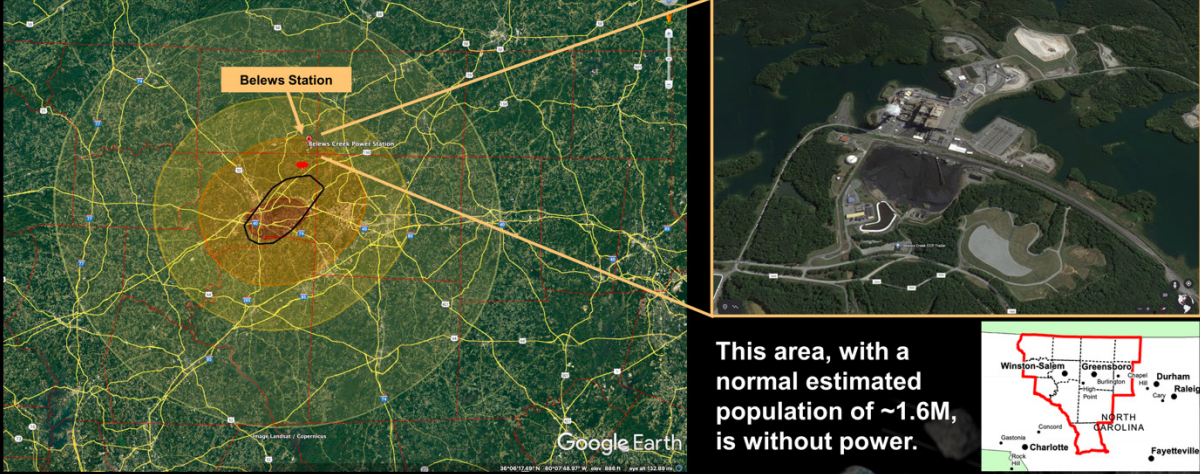
PD TTX4 – Module 4 9

Slide 10

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The Belews Power plant, which is ~15 miles NE of Winston-Salem, has been affected by the airburst and has been shut down. This has caused a power outage to the Piedmont Triad, which includes the cities of Greensboro, Winston-Salem, and High Point.

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EXERCISE EXERCISE EXERCISE

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Inject 4.1 Questions

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- What additional information is needed to help understand immediate needs in the first 24 hours after an event like this?
- Given this is an event type that the public safety community has never dealt with before, do you expect a different level of response and support to be available for immediate assistance?
 - *Would there be a fear of unknown risks, hazards, something from outer space has hit this earth . . . what does it contain?*
- What are your security-related concerns at this time?

EXERCISE EXERCISE EXERCISE


PD TTX4 – Module 4 11


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EXERCISE EXERCISE EXERCISE

Inject 4.2 – Misinformation

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PD TTX4 – Module 4

Experts are being interviewed by the media from around the world.

There is one local person, who is referring to himself as a “National Expert T.X. Asteroid,” who is posting misinformation on social media and being interviewed by national news organizations. T.X. Asteroid is warning people that **“the material from the asteroid contained toxic materials from outer space and that those materials were spread throughout the region by the air blast, and people should expect to experience radiation exposure-like symptoms.”**

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EXERCISE EXERCISE EXERCISE


Inject 4.2: Questions

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- How could we get ahead of this type of false reporting?
- Who is best voice of trust at this time?

EXERCISE EXERCISE EXERCISE





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EXERCISE EXERCISE EXERCISE

Ongoing Local Response Discussions

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PD TTX4 – Module 4


EXERCISE EXERCISE EXERCISE

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EXERCISE EXERCISE EXERCISE

Module 4 Wrap up Discussions – CAC

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**Participants at APL will return to discussions
that need to be continued from previous
modules as time allows**

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EXERCISE EXERCISE EXERCISE

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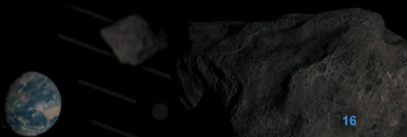
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Back-Up Slides

PD TTX4 – Module 4

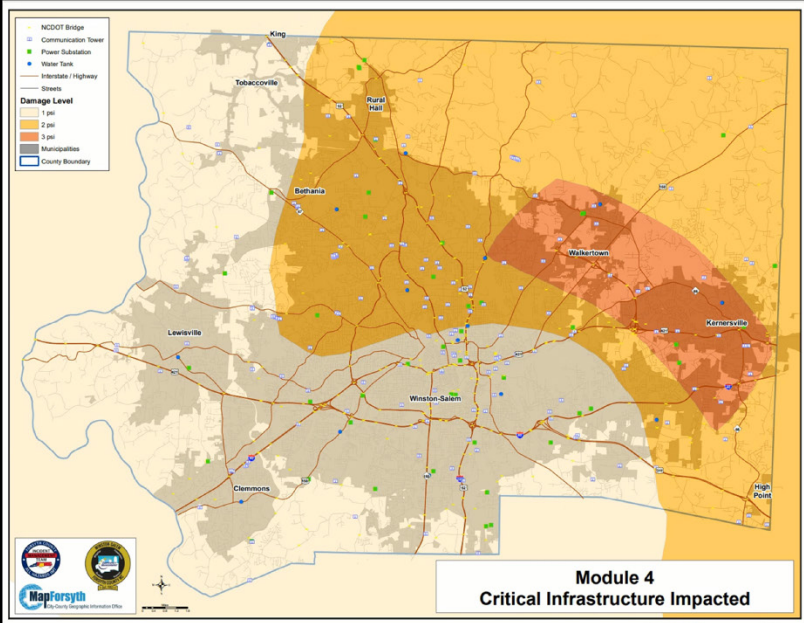

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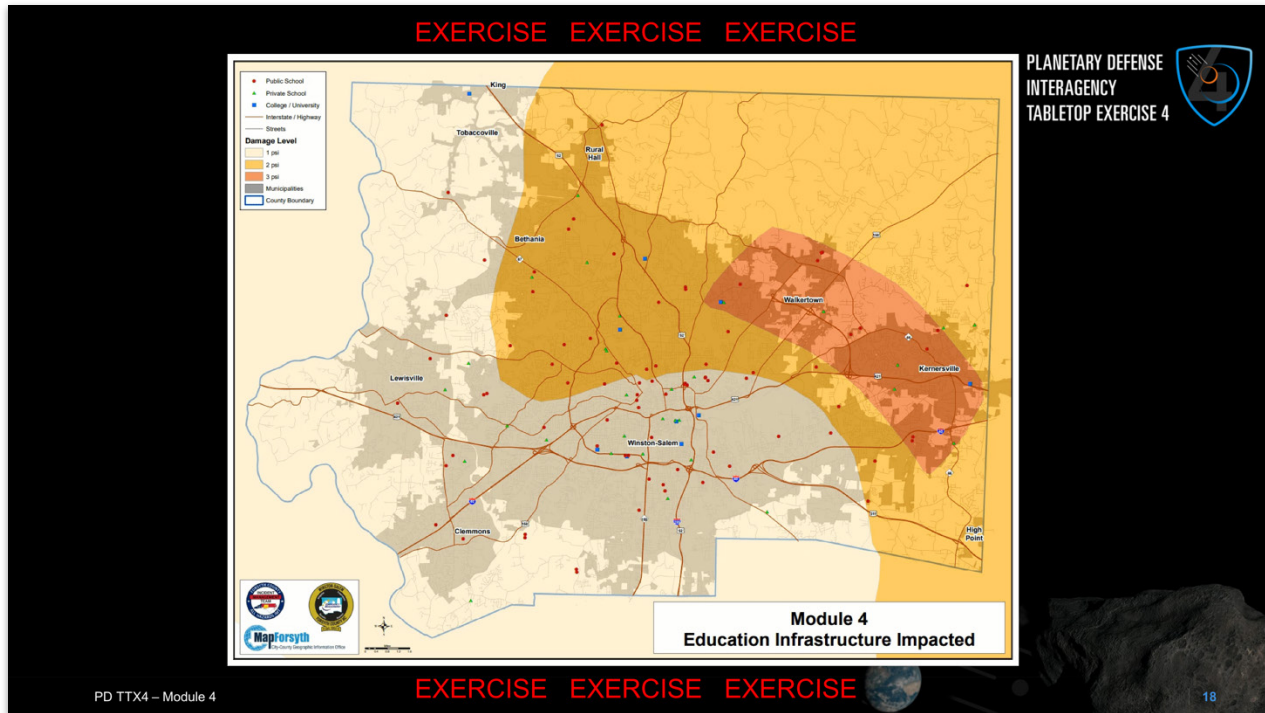
Module 4
Critical Infrastructure Impacted

PD TTX4 – Module 4

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Slide 18



Slide 19

EXERCISE EXERCISE EXERCISE

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INTERAGENCY
TABLETOP EXERCISE 4

Module 4 - Final Damage Footprint Infrastructure / Critical Facilities Damaged 3 psi				Module 4 - Final Damage Footprint Infrastructure / Critical Facilities Damaged 2 psi			
Facility Type	Count Impacted	Total Number in County	Percent of Total Impacted	Facility Type	Count Impacted	Total Number in County	Percent of Total Impacted
Airport	0	1	0.00%	Airport	1	1	100.00%
Animal Clinic	5	35	14.29%	Animal Clinic	16	35	45.71%
Bridge (NC DOT)	30	310	9.68%	Bridge (NC DOT)	117	310	37.74%
Bus Station	0	1	0.00%	Bus Station	0	1	0.00%
Child Day Care	23	169	13.61%	Child Day Care	90	169	53.25%
College/University Campus	2	10	20.00%	College/University Campus	4	10	40.00%
Communications Tower	16	172	9.30%	Communications Tower	94	172	54.65%
Electric Power Substation	5	44	11.36%	Electric Power Substation	19	44	43.18%
Emergency Management Office	0	1	0.00%	Emergency Management Office	0	1	0.00%
EMS Base/Station	2	11	18.18%	EMS Base/Station	5	11	45.45%
Entertainment Facility (ie Stadium, Theater, Shopping etc)	1	18	5.56%	Entertainment Facility (ie Stadium, Theater, Shopping etc)	10	18	55.56%
Fire Station	8	46	17.39%	Fire Station	26	46	56.52%
Government Admin Buildings	2	17	11.76%	Government Admin Buildings	5	17	29.41%
Grocery Store/Food Retailer	10	84	11.90%	Grocery Store/Food Retailer	39	84	46.43%
High Hazard Dam	4	50	8.00%	High Hazard Dam	21	50	42.00%
Hospital	0	5	0.00%	Hospital	1	5	20.00%
Long-term Care Facility	6	49	12.24%	Long-term Care Facility	22	49	44.90%
Mental Health Facility	9	85	10.59%	Mental Health Facility	40	85	47.06%
Pharmacies	13	88	14.77%	Pharmacies	62	88	70.45%
Private School	5	31	16.13%	Private School	13	31	41.94%
Public School	10	81	12.35%	Public School	36	81	44.44%
Retirement Community	1	8	12.50%	Retirement Community	4	8	50.00%
Water Tank	2	15	13.33%	Water Tank	8	15	53.33%
WSFCS Admin Facility	1	6	16.67%	WSFCS Admin Facility	5	6	83.33%

EXERCISE EXERCISE EXERCISE


PD TTX4 – Module 4 19

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EXERCISE EXERCISE EXERCISE

Module 4 - Final Damage Footprint Infrastructure / Critical Facilities Damaged			
1 psi			
Facility Type	Count Impacted	Total Number in County	Percent of Total Impacted
Airport	1	1	100.00%
Animal Clinic	35	35	100.00%
Bridge (NC DOT)	310	310	100.00%
Bus Station	1	1	100.00%
Child Day Care	169	169	100.00%
College/University Campus	10	10	100.00%
Communications Tower	172	172	100.00%
Electric Power Substation	44	44	100.00%
Emergency Management Office	1	1	100.00%
EMS Base/Station	11	11	100.00%
Entertainment Facility (ie Stadium, Theater, Shopping etc)	18	18	100.00%
Fire Station	46	46	100.00%
Government Admin Buildings	17	17	100.00%
Grocery Store/Food Retailer	84	84	100.00%
High Hazard Dam	50	50	100.00%
Hospital	5	5	100.00%
Long-term Care Facility	49	49	100.00%
Mental Health Facility	85	85	100.00%
Pharmacies	88	88	100.00%
Private School	31	31	100.00%
Public School	81	81	100.00%
Retirement Community	8	8	100.00%
Water Tank	15	15	100.00%
WSFCS Admin Facility	6	6	100.00%

PLANETARY DEFENSE
INTERAGENCY
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EXERCISE EXERCISE EXERCISE




PD TTX4 – Module 4 20

C.8 Closing





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INTERAGENCY
TABLETOP EXERCISE 4



FEMA

**JOHNS HOPKINS
APPLIED PHYSICS LABORATORY**

TTX Closing

Dipak Srinivasan
TTX Project Manager
Johns Hopkins Applied Physics Laboratory
dipak.srinivasan@jhuapl.edu

Slide 22

Agenda

- Back to the parking lot:
 - If there is time, we'll revisit some key discussions from earlier modules where we had to cut things off
- Hot wash
- Path forward

Module	Description
0	Quick briefing of the read-ahead materials
1	6 months before impact
2	2 months before impact
3	6 days before impact
4	Post-impact response and recovery

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INTERAGENCY
TABLETOP EXERCISE 4

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Slide 23

Hot wash

- Gather quick comments and impressions
- Two things to think about:
 1. Our national preparedness
 - Identify any policy, technology, or capability gaps
 - Identify ways we could improve our communications across relevant agencies
 2. Comments on this exercise
 - Strengths and opportunities for improvement
 - Ideas for the future
 - And of course anything else!
- Remember, you can post comments and responses to comments in the chat, too

Your comments and discussions are the data we seek to help make our TTX a success! Please keep those good thoughts flowing!


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INTERAGENCY
TABLETOP EXERCISE 4

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Path forward

PLANETARY DEFENSE INTERAGENCY TABLETOP EXERCISE 4 

- The team will work on consolidating all their observations and participant comments to produce a final After Action Report (AAR)
- AAR will contain:
 1. **Summary** of this exercise, including module presentation materials, attendees, etc.
 2. **Gap analysis**
 - Any identified policy, capability, or technology gaps
 - Recommendations on how to (and if we should) close them
 3. **Communications analysis**
 - Assessments on interagency communications and understanding of roles
 - Assessments on effectiveness of TTX briefings on relaying relevant, useful information to decision-makers
 - Ideas on public information dissemination
 - Summary of the parallel exercise the NASA, FEMA, and APL Public Affairs team ran regarding public messaging
 4. **Recommendations** for future exercises
 - Strengths, opportunities for improvement
 - Ideas for topics that we did not cover here, or did not have adequate time to really focus on

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THANK YOU for joining us!

PLANETARY DEFENSE INTERAGENCY TABLETOP EXERCISE 4 

