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PLANETARY DEFENSE
INTERAGENCY
TABLETOP EXERCISE 4

Module 1b

Early Mitigation Options

23 February 2022 (Six Months to Impact)

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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

Module 1a Recap

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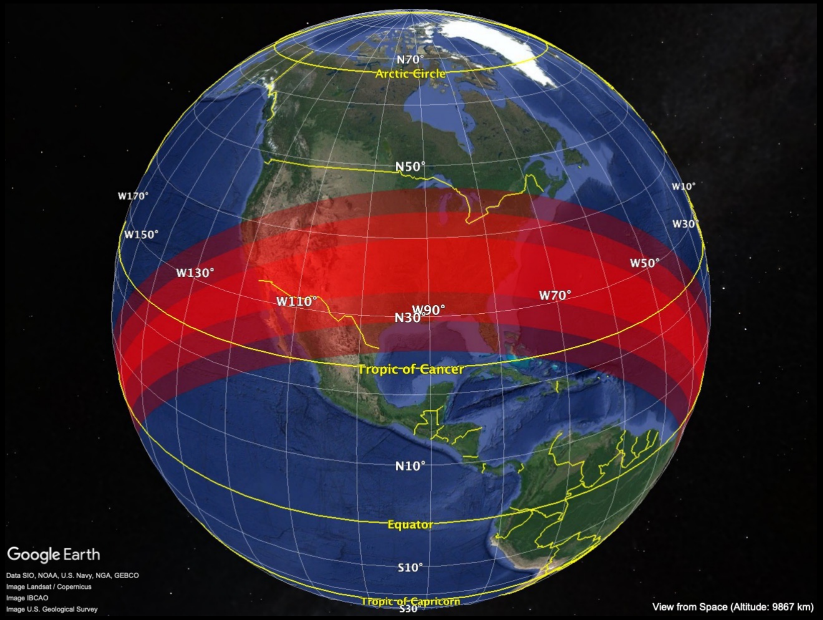
- INJECT 1.1
  - Impact predictions update from CNEOS: Additional observations have decreased the uncertainty in the orbit of 2022 TTX, and the impact probability has risen to 71%. The impact risk corridor is now a narrow band that crosses the globe and includes most of CONUS.



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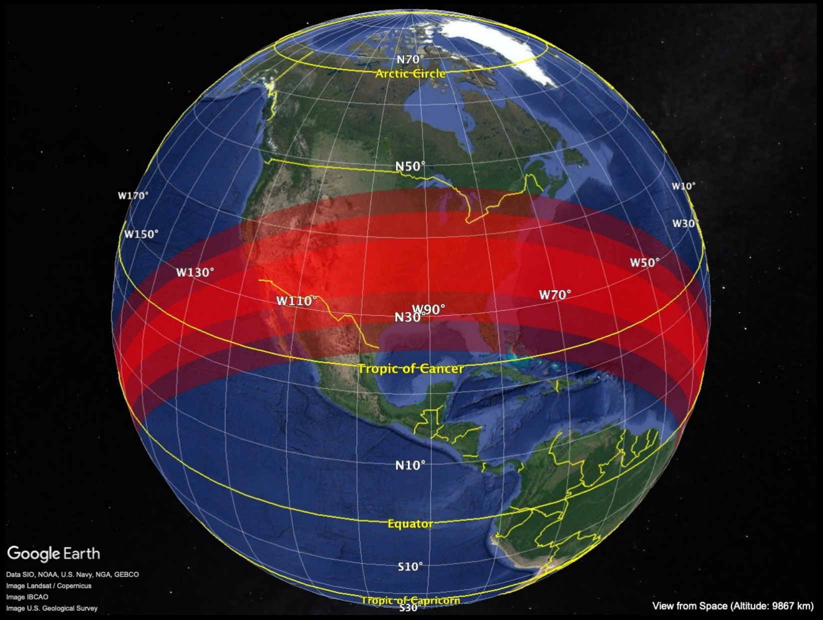

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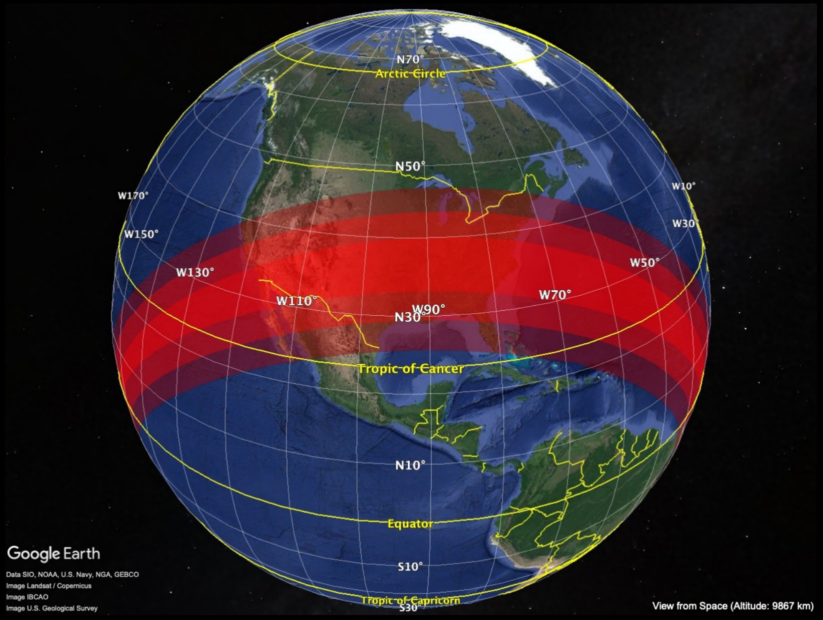
  - Simulated notification from PDCO issued per protocols described in NASA Policy Directive 8740.1.



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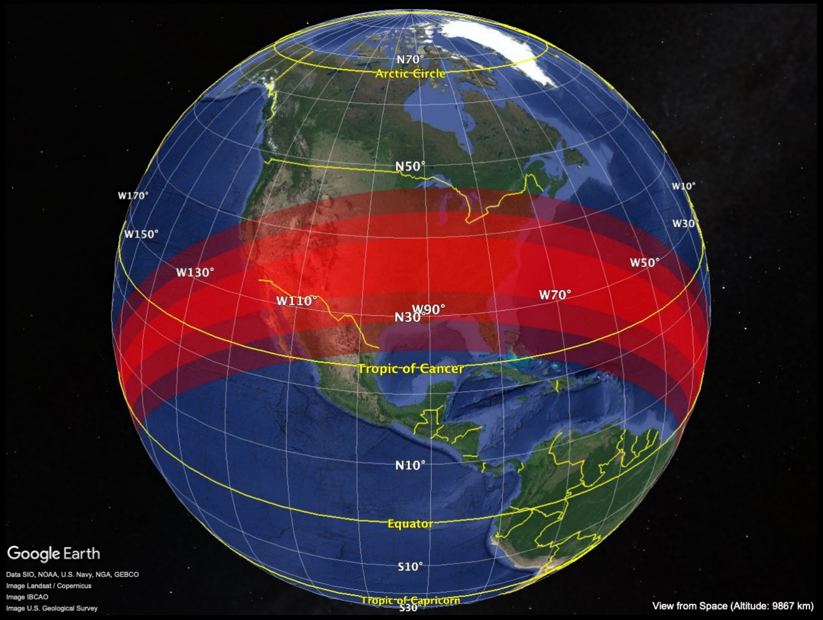
  - Simulated notification from PDCO issued per protocols described in NASA Policy Directive 8740.1
- INJECT 1.4
  - Misinformation appears and spreads on social media.



INJECT 1.5

- 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

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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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NED Disruption Performance

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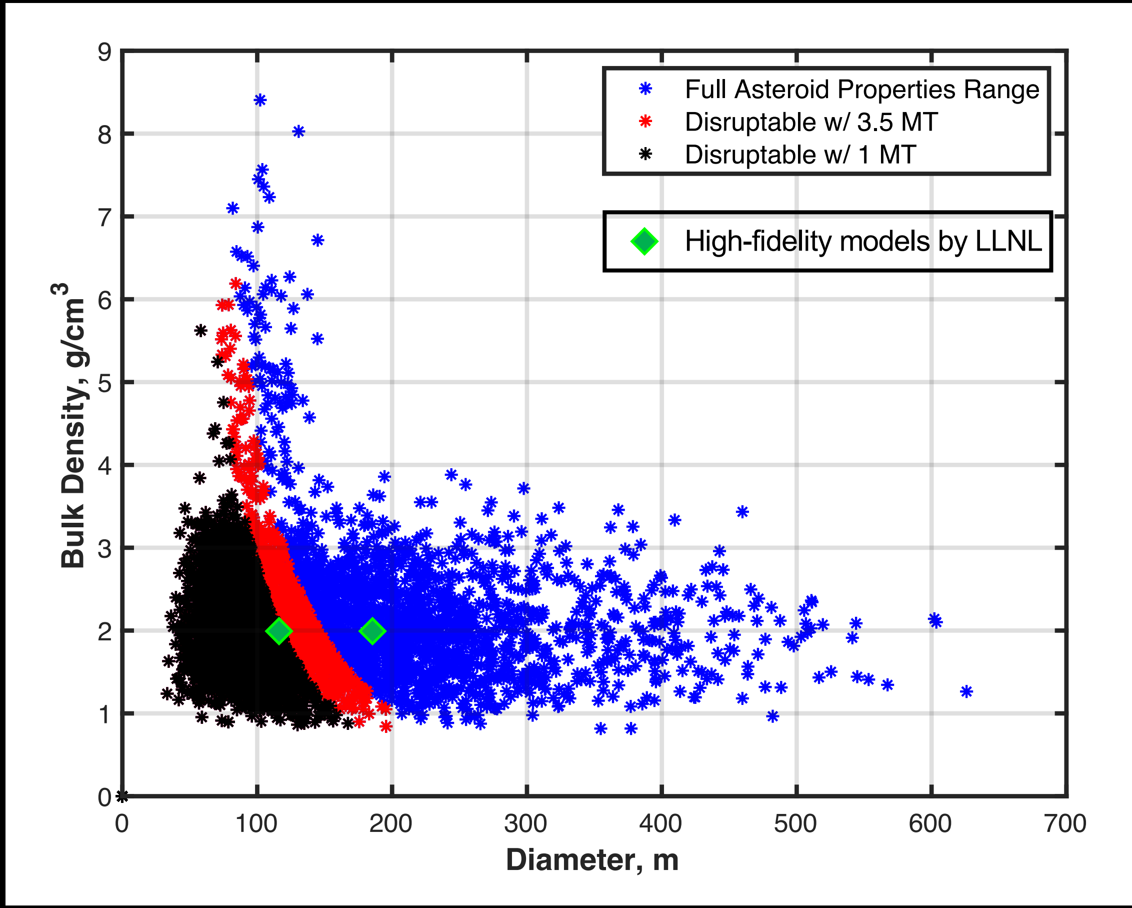
- Mission analysis indicates 3.5 MT is the largest yield NED that can be delivered to 2022 TTX.



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

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.

Nuclear Disruption High-Fidelity Modeling

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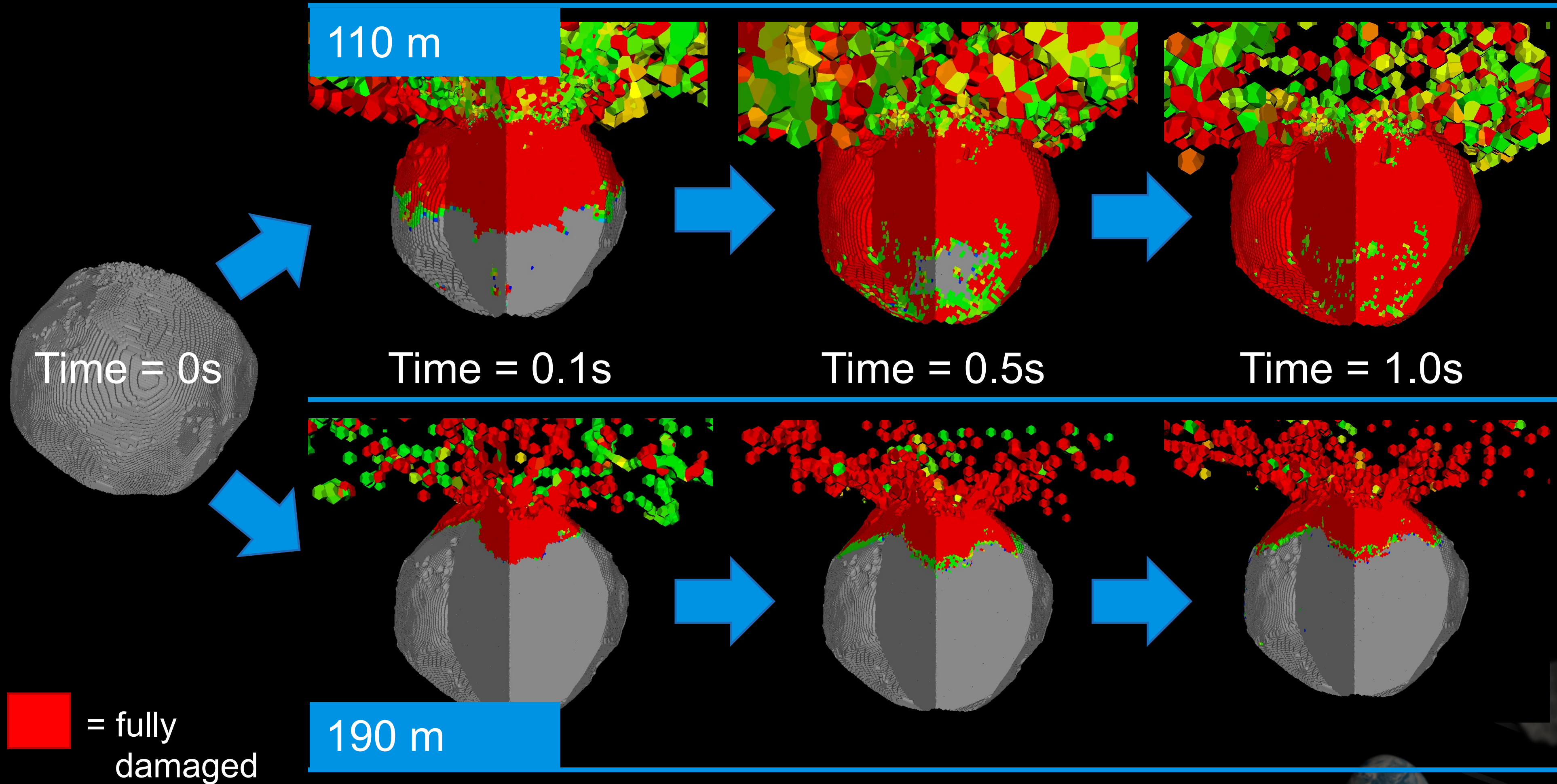
Lawrence Livermore National Laboratory

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



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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Summary of Mission Options for Reconnaissance and Disruption

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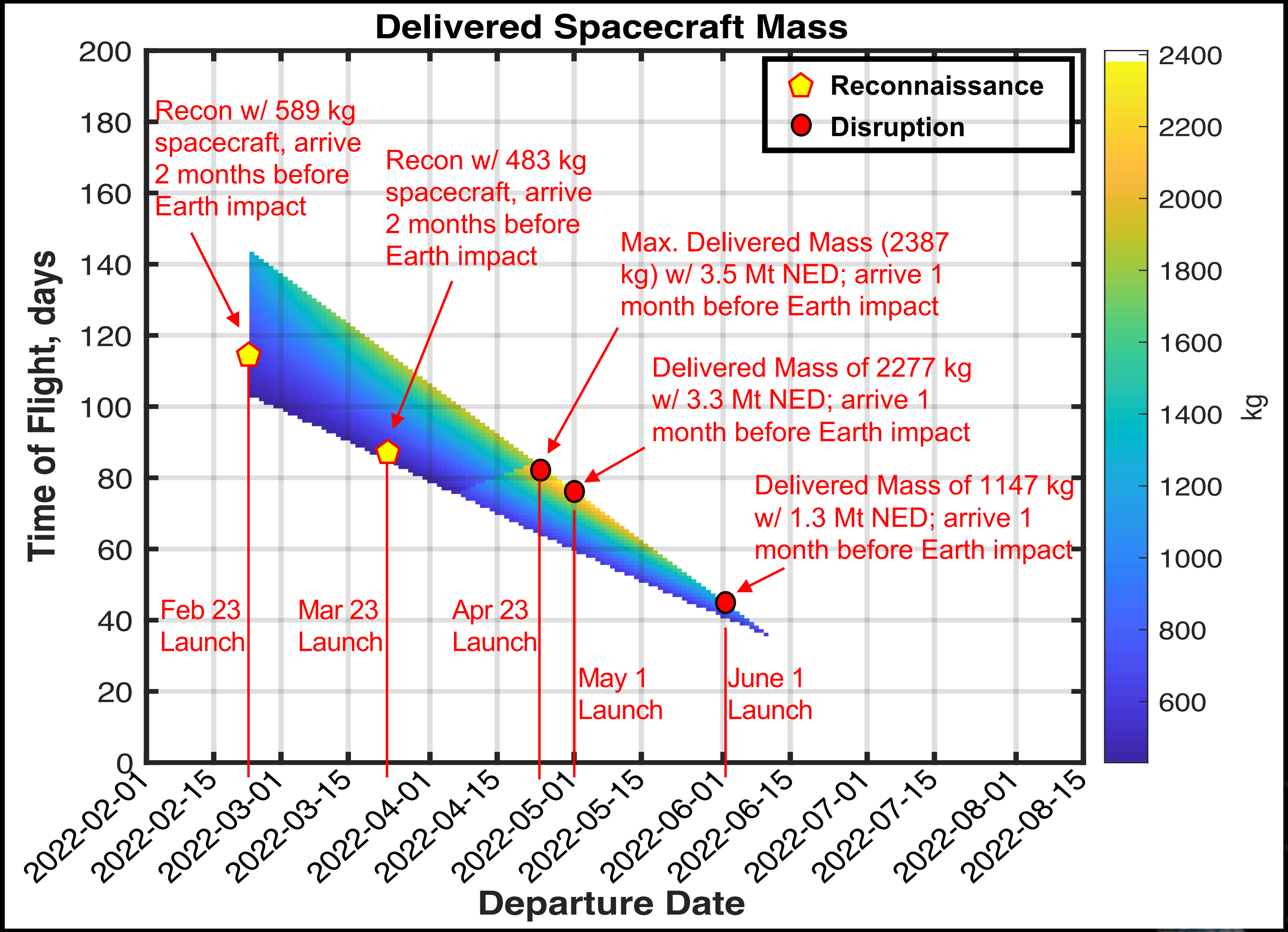
** Launch performance model intended to be representative of a re-purposed commercial intermediate class launch vehicle with a kickstage, launching from Cape Canaveral Air Force Station (CCAFS).*

** For robust disruption missions, we assume a 400 kg spacecraft system for carrying the NED to the asteroid.*

** Rendezvous missions were found to be impractical.*



3.5 MT NED:
65% chance of disrupting the asteroid

1 MT NED:
50% chance of disrupting the asteroid

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Takeaways

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- Uncertainty in the physical properties of 2022 TTX make it difficult to define mitigation mission requirements or assess the likelihood of mitigation mission success.
- Deploying any of these mission options would require spacecraft at the ready and the capability to launch within a week to several months.
- Deflection would not be practical due to the short warning time.
- Robust disruption of the asteroid would be the only practically viable in-space mitigation, if rapid spacecraft launch were possible.
- Deploying a nuclear disruption mission could significantly reduce the risk of impact damage, despite substantial uncertainties in the asteroid's properties.
- Deploying a flyby reconnaissance spacecraft (if a disruption mission is foregone) could significantly reduce the uncertainties faced by disaster response planners.
- These intercept / flyby missions all involve approaching the asteroid at high speeds, which would pose guidance and control challenges.

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Nuclear Disruption — High-Fidelity Modeling

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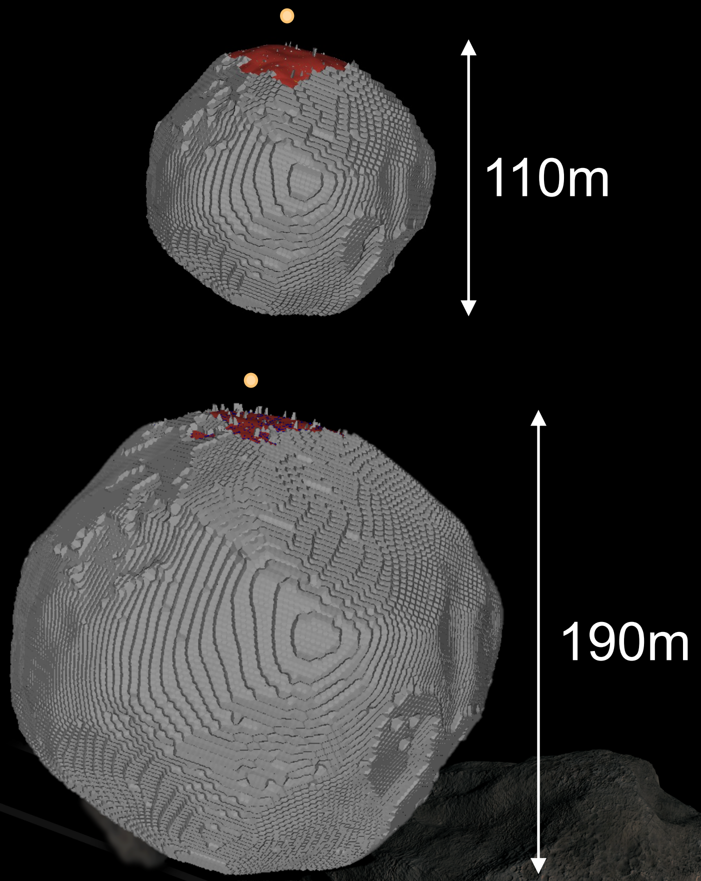
Asteroid Properties

- Two different asteroid sizes: 110 m (median diameter) and 190 m (78th percentile)
- Shape: Bennu, 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 Spheral equipped with strength and damage models



Prepared by LLNL under Contract DE-AC52-07NA27344

INJECT 1.6

- Policy considerations for nuclear deflection or disruption mission

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Law and Policy

Treaty Overview as relevant to Nuclear Explosive Devices (NEDs)

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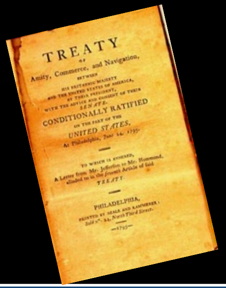
Relevant International Law
Treaty Overview



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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.

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.

Balancing Act

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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:

1. 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
2. General Assembly (GA): Non-binding on Member States
   - Builds broader support to advise the UNSC
3. COPUOS: Strengthens int'l cooperation in space
   - IAWN, SMPAG
   - Advises the UNGA as subject matter experts

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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?

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?

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?
- 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

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- 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.

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

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

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?
- What capabilities would be needed in order to more quickly characterize the asteroid threat? Should we develop those capabilities?

Comments on slide 10

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

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

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

2. Organization and Unit/Division