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Neutron Energy Effects on Asteroid Deflection

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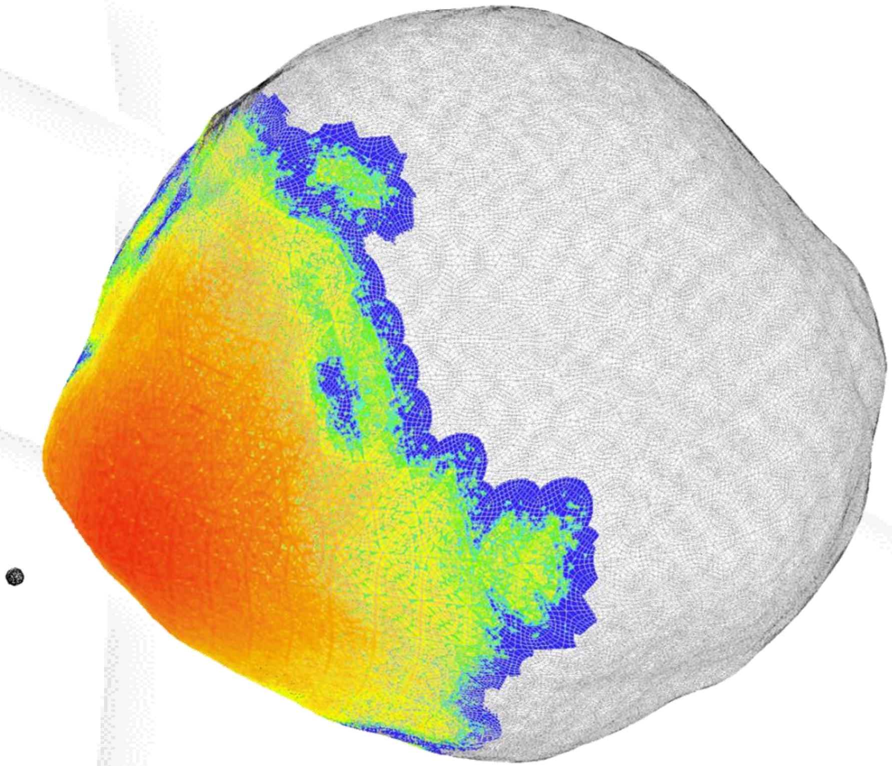
Overview

1. Background & Motivation
2. Problem & Hypothesis
3. Neutron Energy Deposition
4. Asteroid Deflective Response



https://www.llnl.gov/news/nuclear-impulse-could-deflect-massive-asteroid

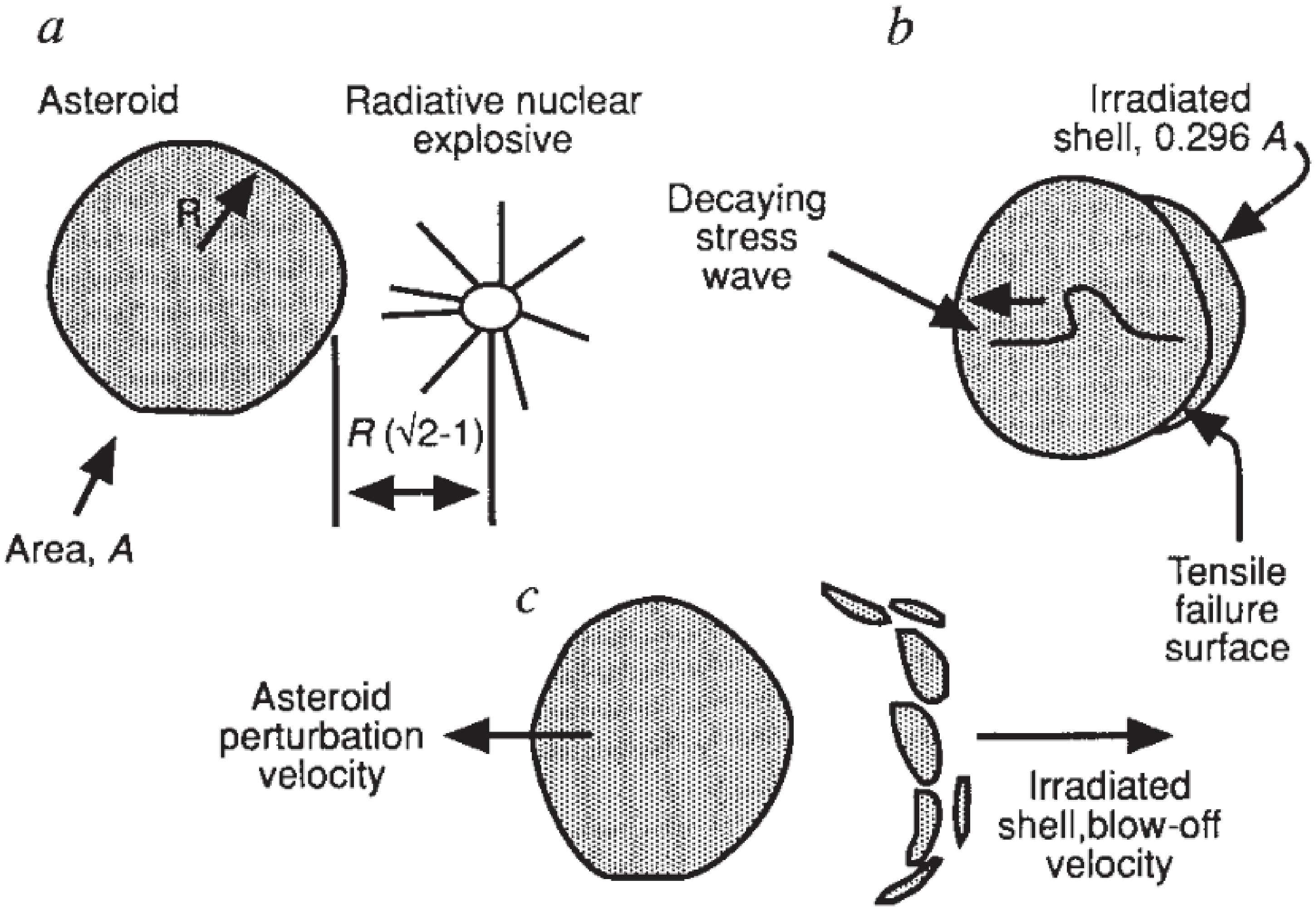
Acta Astronautica journal publication.

- This research was recently published in *Acta Astronautica*.
- Lansing Horan IV, Darren Holland, Megan Bruck Syal, James Bevins, Joseph Wasem, “Impact of neutron energy on asteroid deflection performance,” *Acta Astronautica*, Vol 183, 2021, DOI: https://doi.org/10.1016/j.actaastro.2021.02.028
- The journal article goes into much greater detail than this presentation, and documents our methodologies for discretizations and using MCNP and ALE3D, as well as several other case studies (this presentation only discusses the 50 kt yield case, but there were 3 other comparative scenarios studied).

1. Background & Motivation

How does asteroid deflection via a stand-off nuclear detonation work?

Thomas Ahrens & Alan Harris. Deflection and fragmentation of near-Earth asteroids. *Nature*, 1992.



Newton's Law of Conservation of Momentum.

2. Problem & Hypothesis

Nuclear deflection is mature in concept. But, does the neutron energy matter?

- **Problem:** Does the neutron energy affect asteroid deflection?
- **Hypothesis:** Affirmative.
- **Why?** Neutrons of different energies can interact very differently when they traverse the same material, which can change:
  - energy deposition profiles
  - energy coupling efficiencies

Why does this matter? This type of research could help determine which type of device outputs are most effective for deflecting asteroids, and whether altering the neutron energy spectrum would ever be worthwhile.

Specifications of the sources and the target considered in this work.

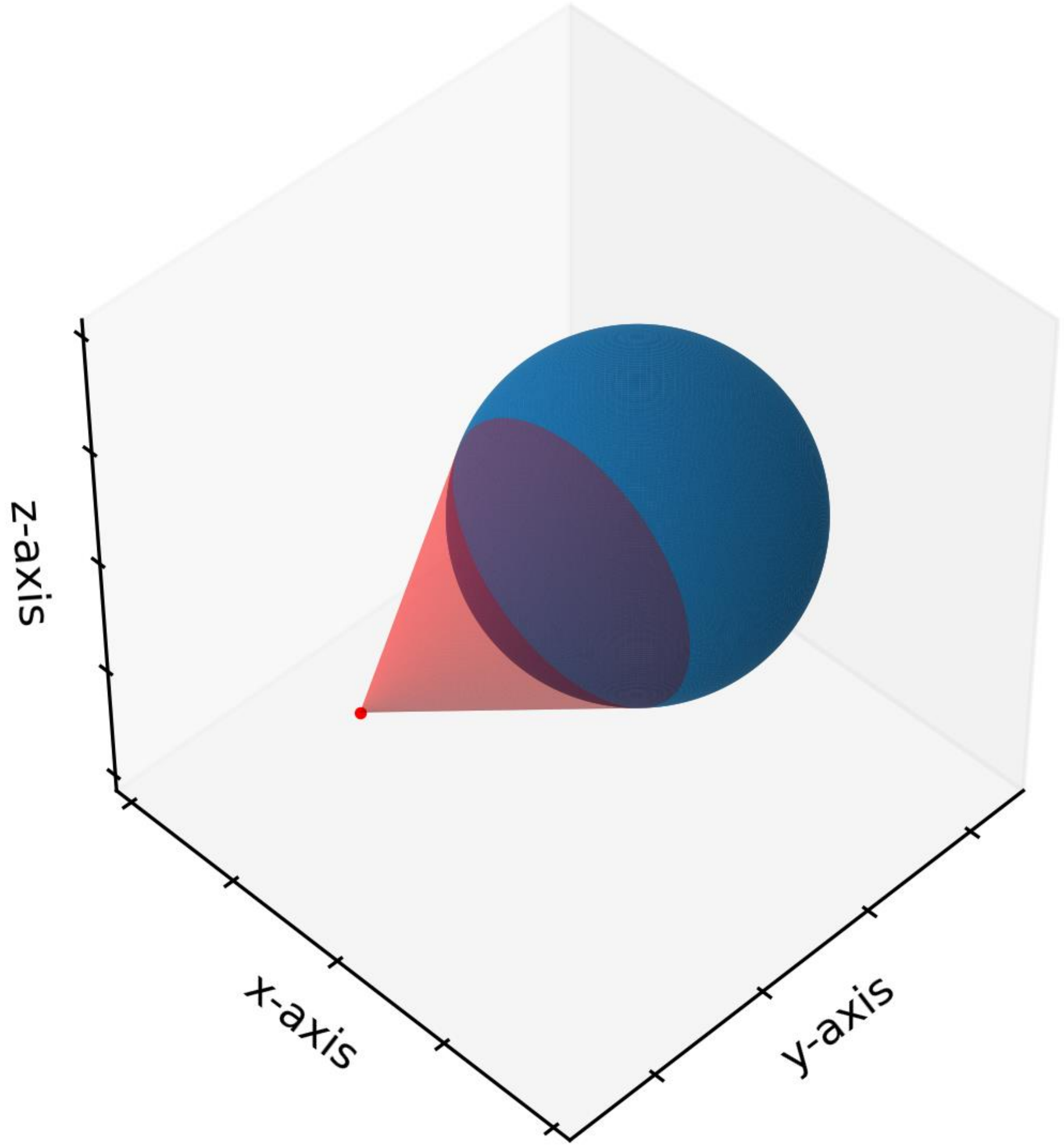
- **Sources:**
  - Neutron energies – 14.1 MeV (fusion) & 1 MeV (fission)
  - Neutron yield – 50 kt (detonation energy output)
  - Stand-off distance ~ 62 m from “Ground Zero” (GZ) of asteroid
- **Target:**
  - 300 m diameter asteroid, perfectly spherical
  - SiO_2 @ 2.65 g/cc, with 30% porosity (1.855 g/cc bulk density)

Phase I, Neutron Energy Deposition.
Sources were simulated in MCNP6.2,
a Monte Carlo radiation-transport code.

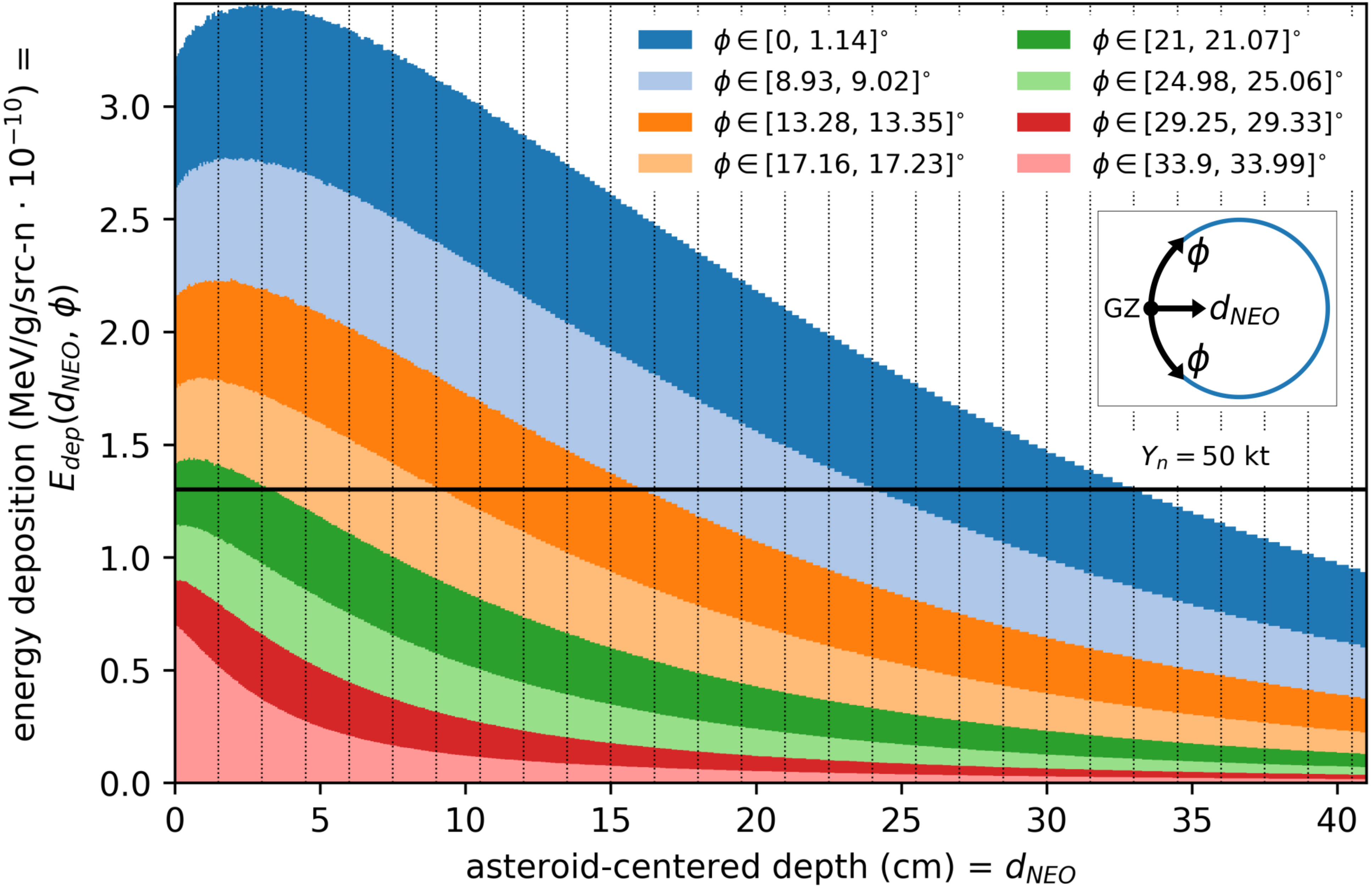
Phase II, Asteroid Deflective Response.
Target was simulated in ALE3D,
a hydrodynamic material response code.

3. Neutron Energy Deposition

MCNP6.2 radiation-transport simulations.

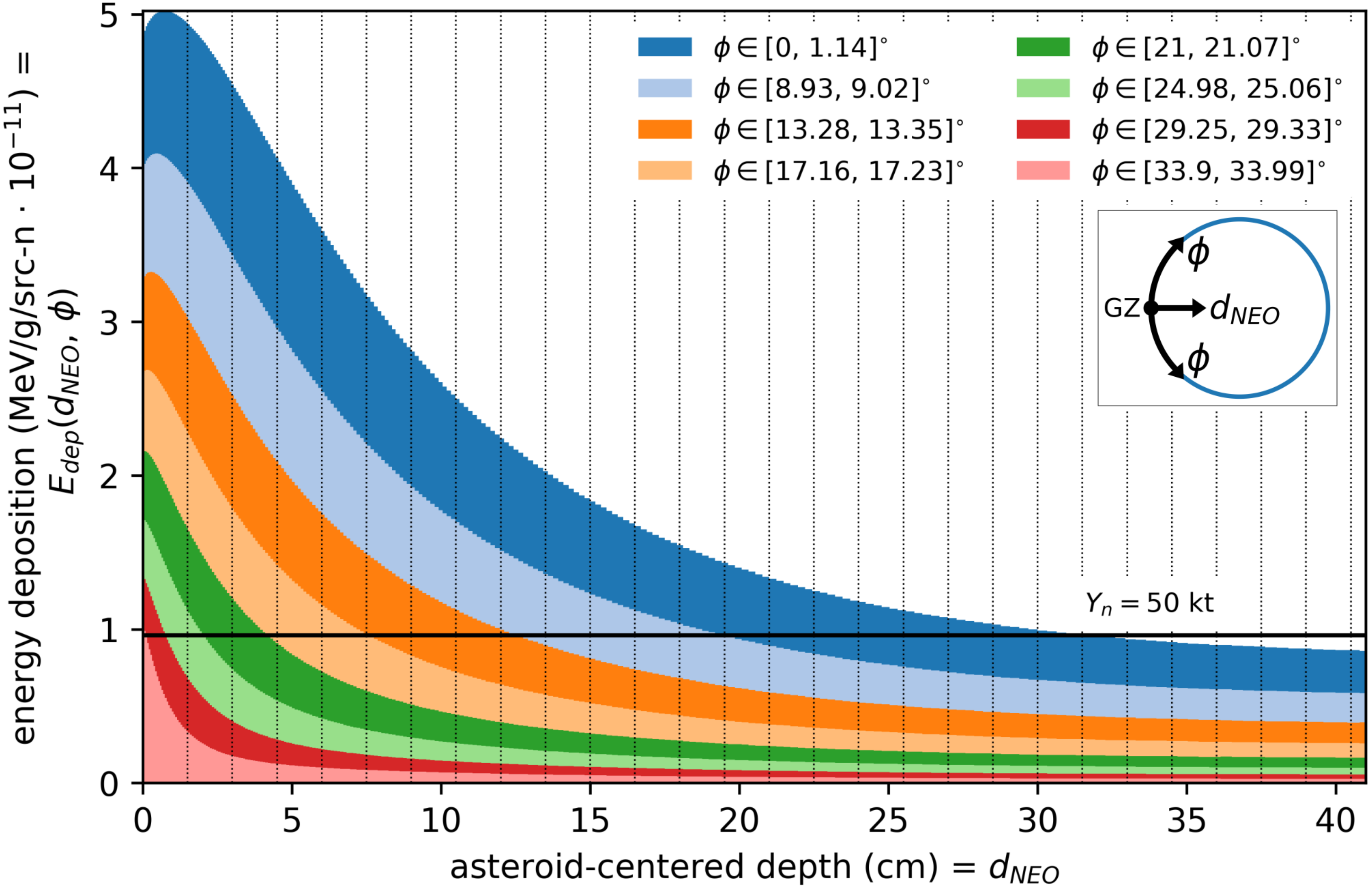


14.1 MeV neutron energy deposition profiles.



melt-depth ~33 cm
melt-angle ~22.5°

1 MeV neutron energy deposition profiles.



melt-depth ~31 cm
melt-angle ~35°

14.1 MeV & 1 MeV energy coupling efficiencies.

- Definition:

$$\eta_{rel} = \frac{E_{dep}}{Y_{int}}$$

Results:

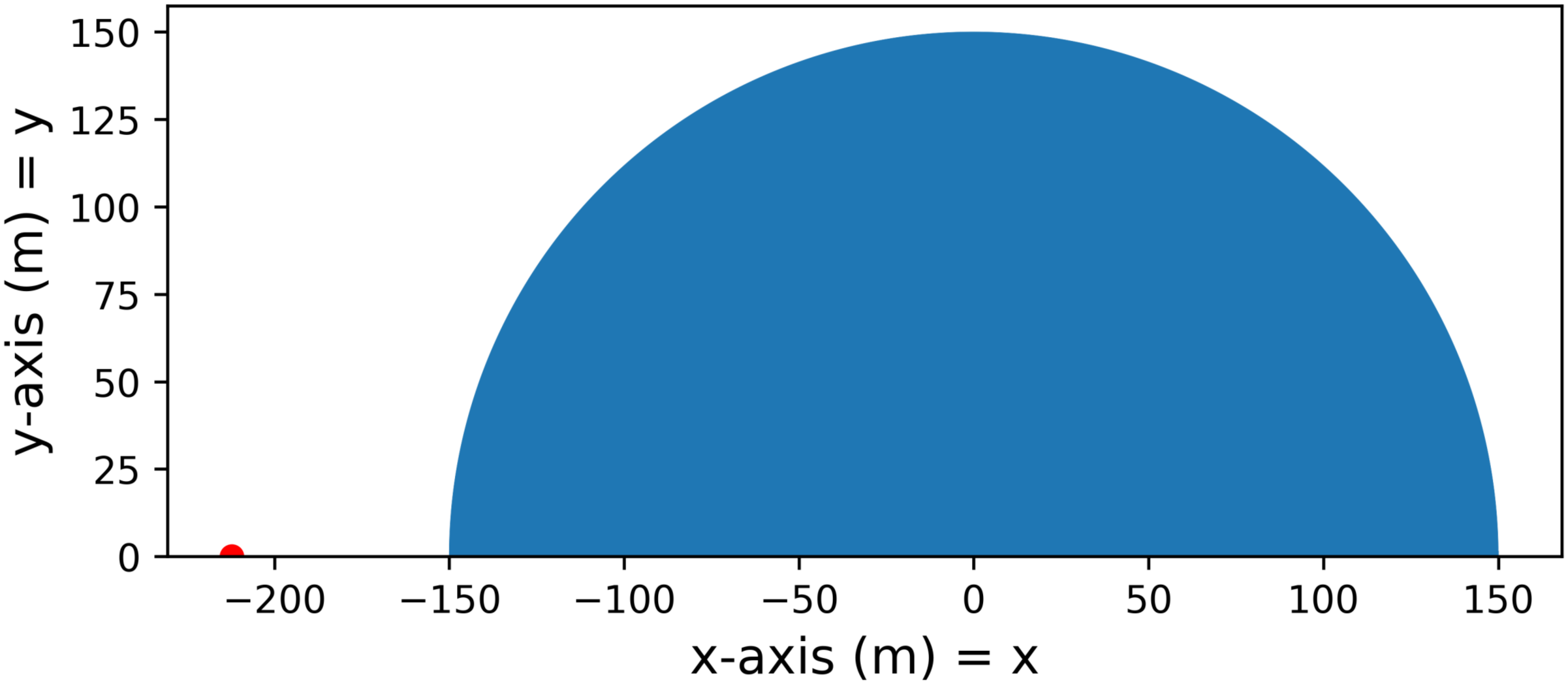
E_{src}	η_{rel}
14.1 MeV	0.6884
1 MeV	1.0896

- ^{28}Si(n,γ) = extra 8.474 MeV, ^{16}O(n,γ) = extra 4.143 MeV
- (n,γ) radiative capture is much more likely for 1 MeV neutrons interacting in SiO_2

For equal detonation yields, the 1 MeV source will always deposit more energy in the asteroid than the 14.1 MeV source.

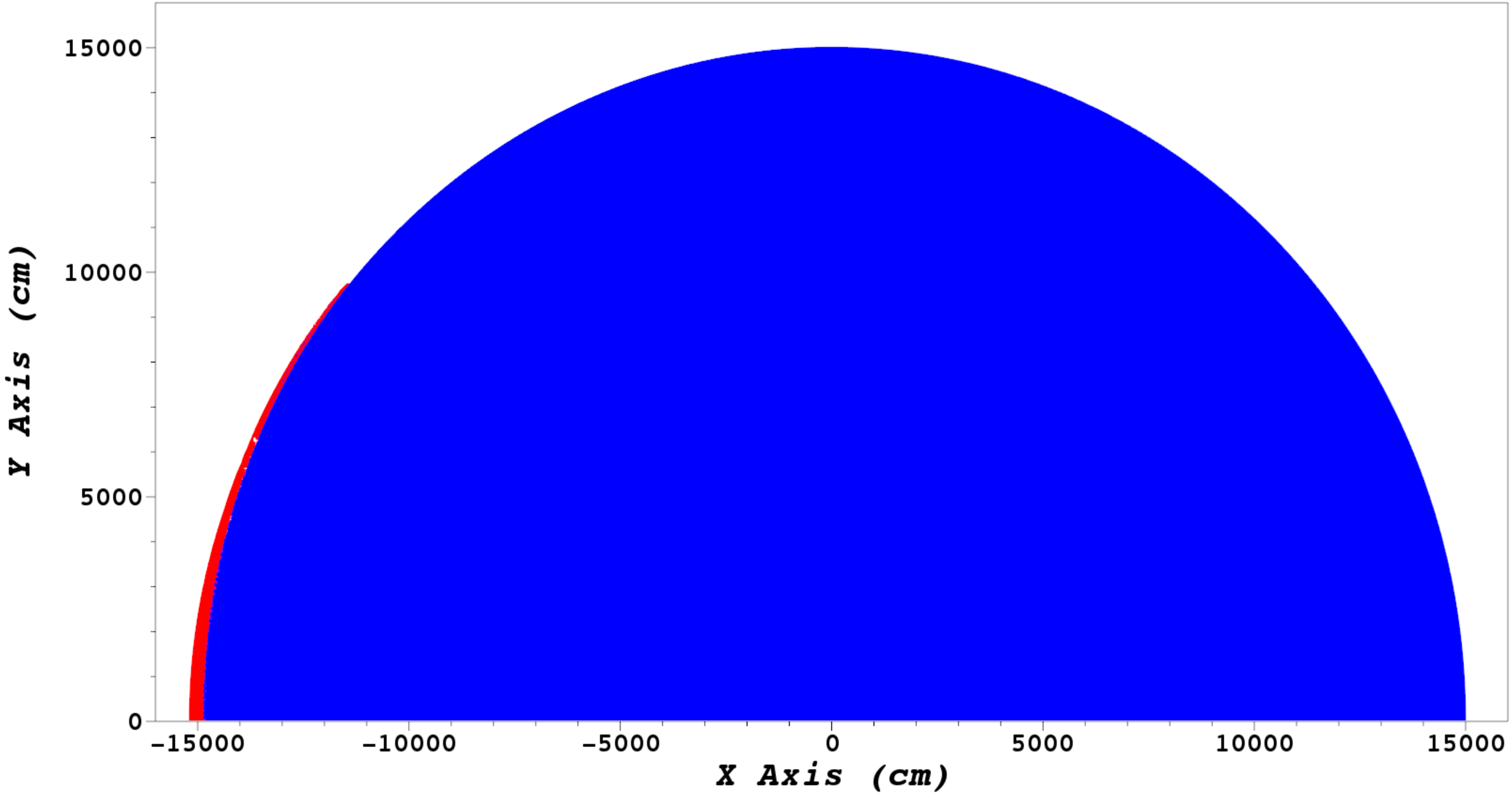
4. Asteroid Deflective Response

ALE3D hydrodynamic simulations.



2-D axisymmetric geometry allowed for a semi-circular asteroid model, saving computational resources and achieving sufficient mesh resolution.

Blow-off snapshot at 1 ms (14.1 MeV, *1 Mt example*).



Red = blow-off = fragments that are melted and traveling faster than escape velocity.

The momentum impulse from blow-off results in a δV velocity change in the asteroid body.

- **Results:**
  - **For a 50 kt neutron yield, the deflection δV is 61% higher for 1 MeV neutrons than 14.1 MeV neutrons.**

Y_n	E_n	src-n	$E_{dep,tot}^{ALE3D}$	δV
50 kt	14.1 MeV	$9.31469 \cdot 10^{25}$	5.0364 kt	6.19 ± 0.06 cm/s
50 kt	1 MeV	$1.26157 \cdot 10^{27}$	7.9785 kt	9.99 ± 0.12 cm/s

Summary & Conclusions.

- **Problem:** Does the neutron energy affect asteroid deflection?
- **Hypothesis:** Affirmative. <u>Confirmed.</u>
- **Why?** Because changing the neutron energy means changing the:
  - <u>energy deposition profiles</u>
  - <u>energy coupling efficiencies</u>

Why does this matter? This type of research could help determine which type of device outputs are most effective for deflecting asteroids, and whether altering the neutron energy spectrum would ever be worthwhile.

Acknowledgements.

- LLNL Planetary Defense Group Collaborators
  - Dr. Megan Bruck Syal
  - Dr. Joseph Wasem
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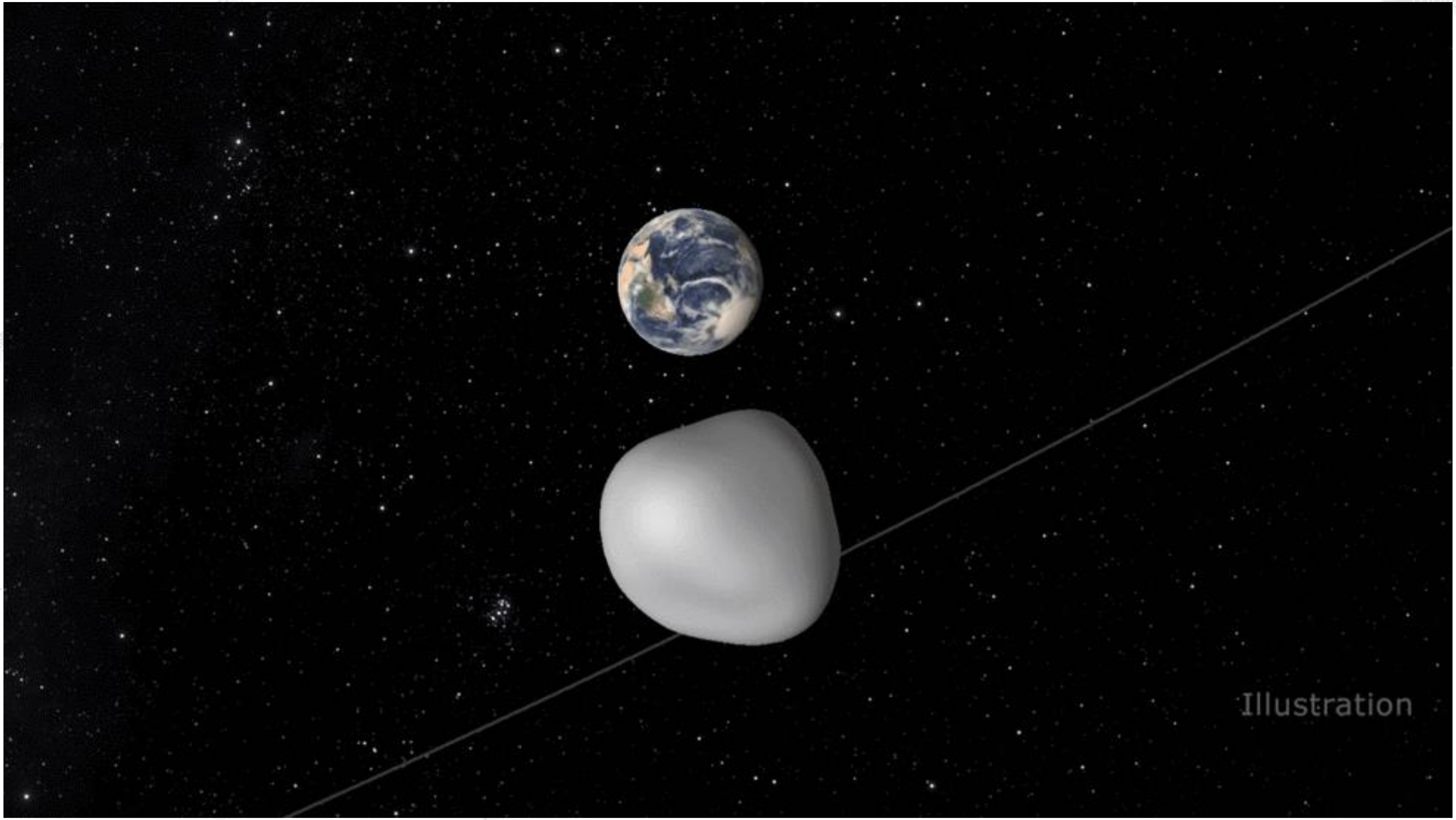
- SMART Scholarship, with AFTAC as sponsoring facility

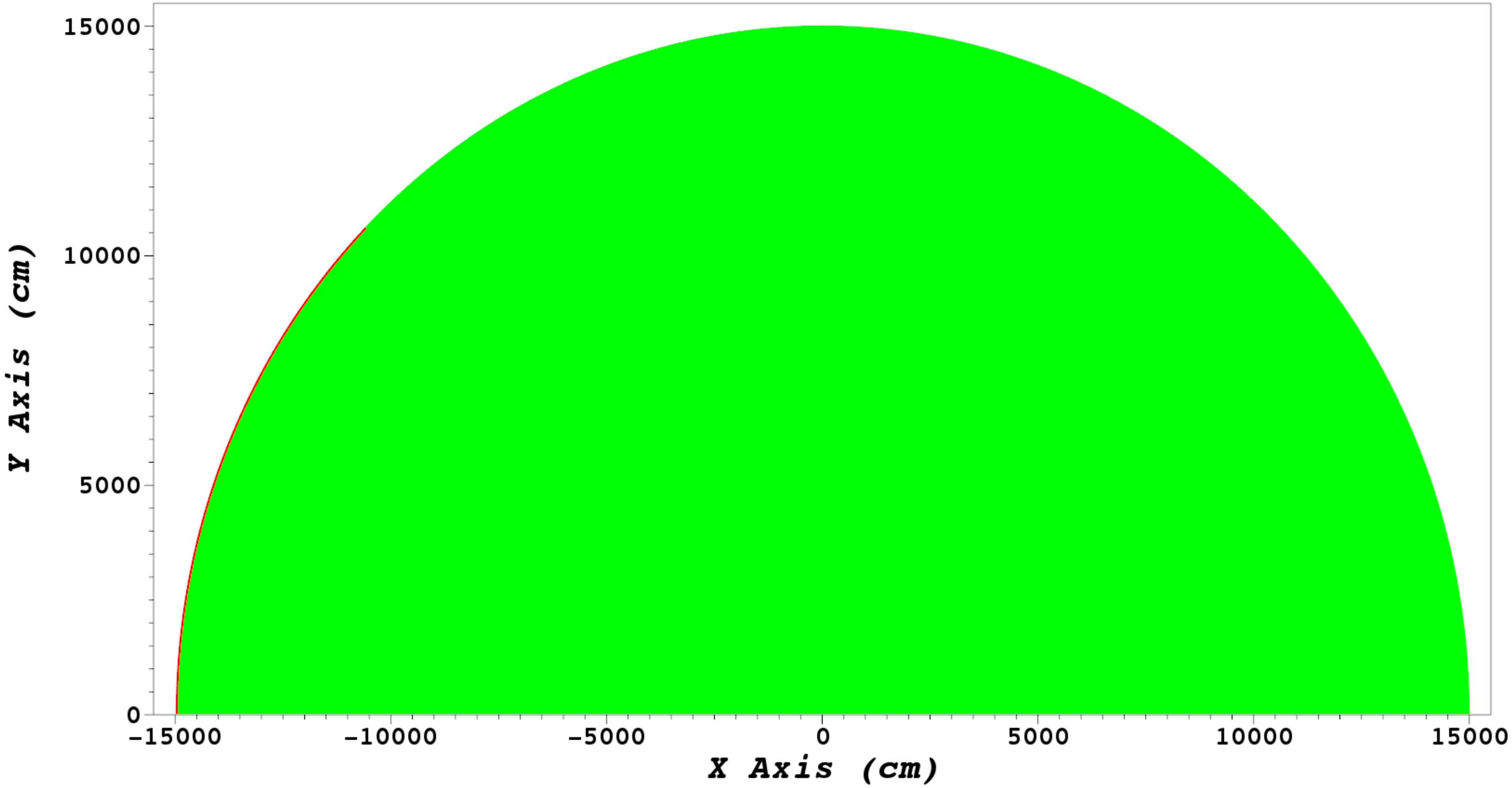
Questions?



NASA/JPL-Caltech: https://www.nasa.gov/feature/jpl/asteroid-flyby-will-benefit-nasa-detection-and-tracking-network

Extra Slides

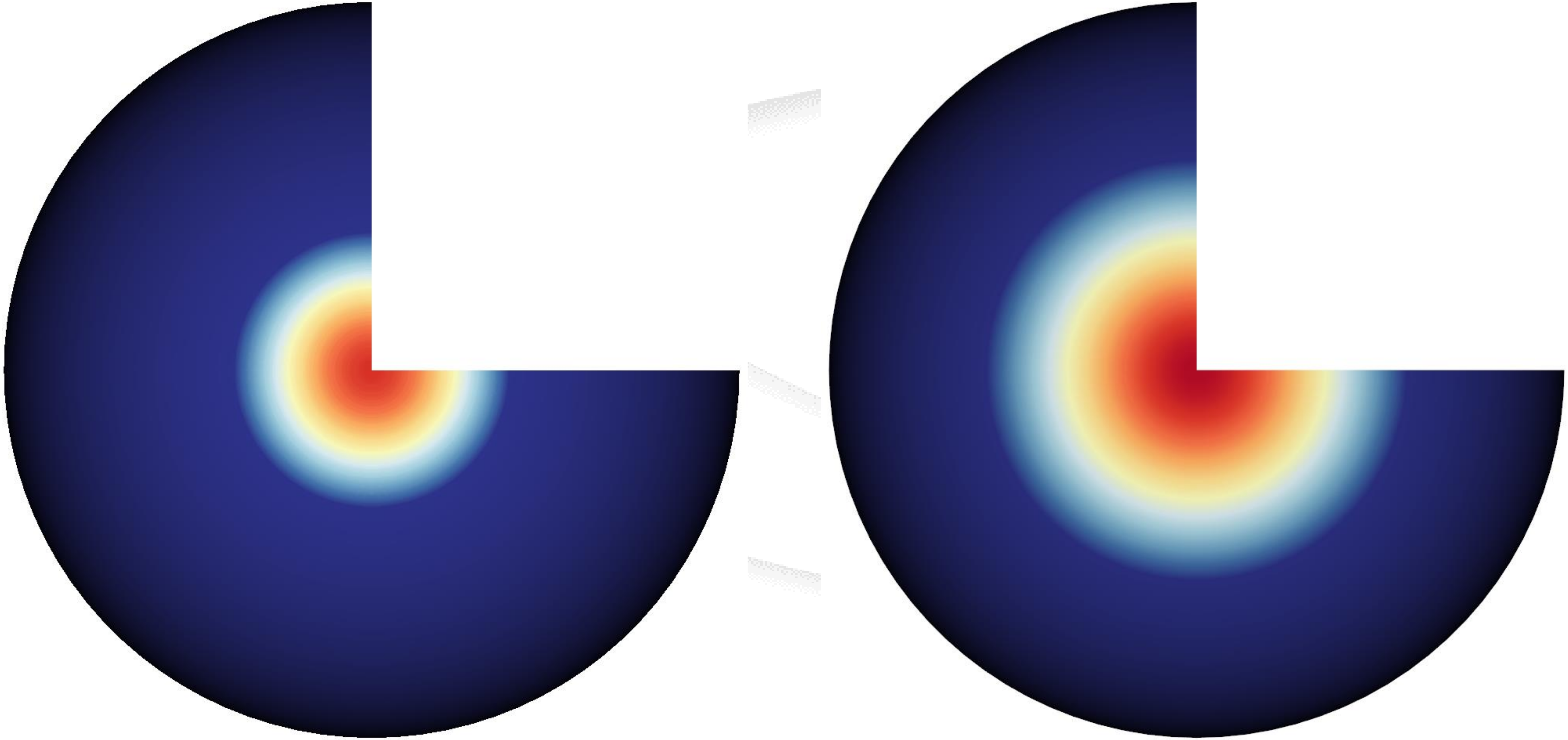
The region where some material is melted is very thin (in depth) and very long (in angle).



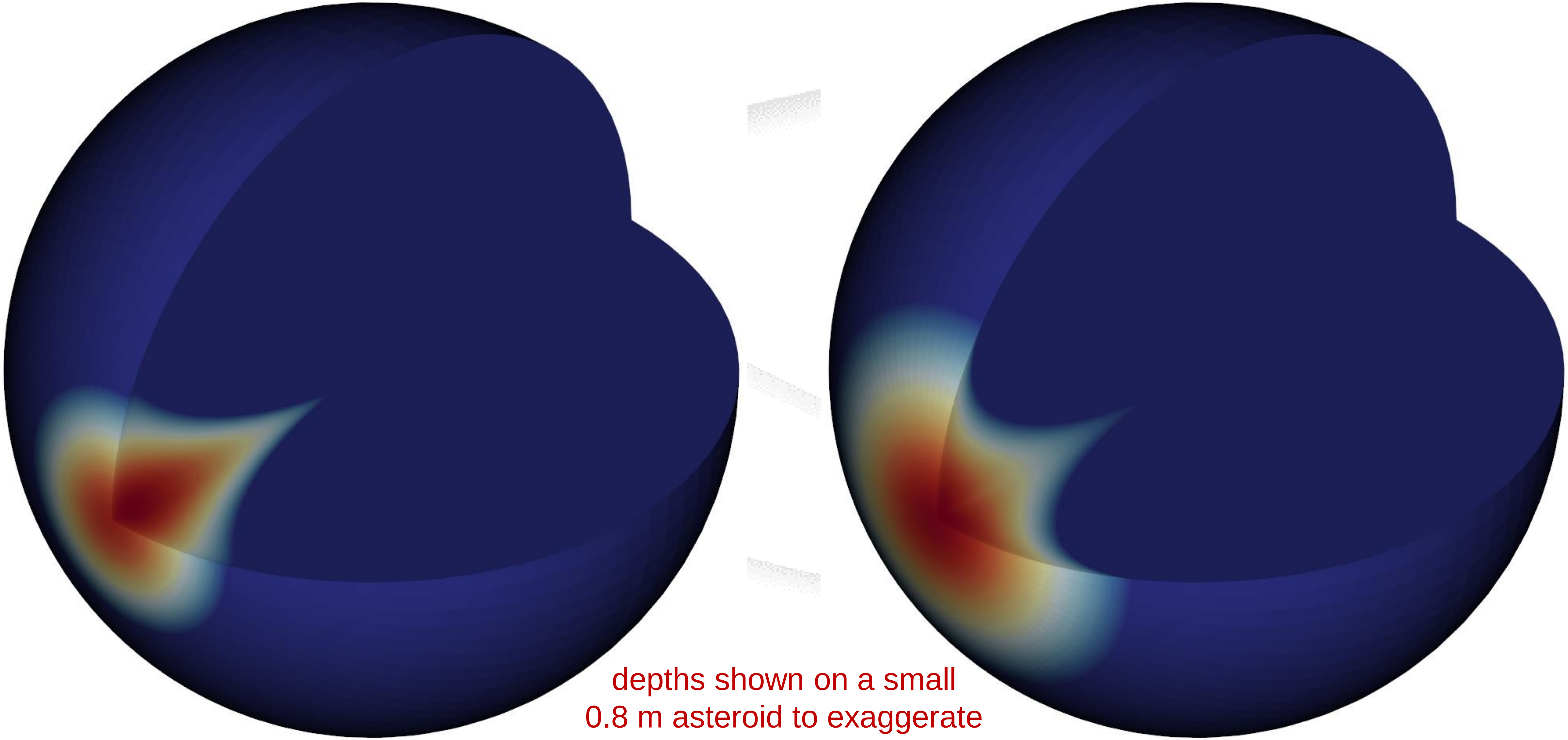
melt-depths ~ 19 cm up to 200 cm
arc-length ~ 11,781 cm

massive disparity

Energy deposition heatmap resulting from 50 kt's worth of 14.1 MeV neutrons (left) and 1 MeV neutrons (right).



Energy deposition heatmap resulting from 50 kt's worth of 14.1 MeV neutrons (left) and 1 MeV neutrons (right).



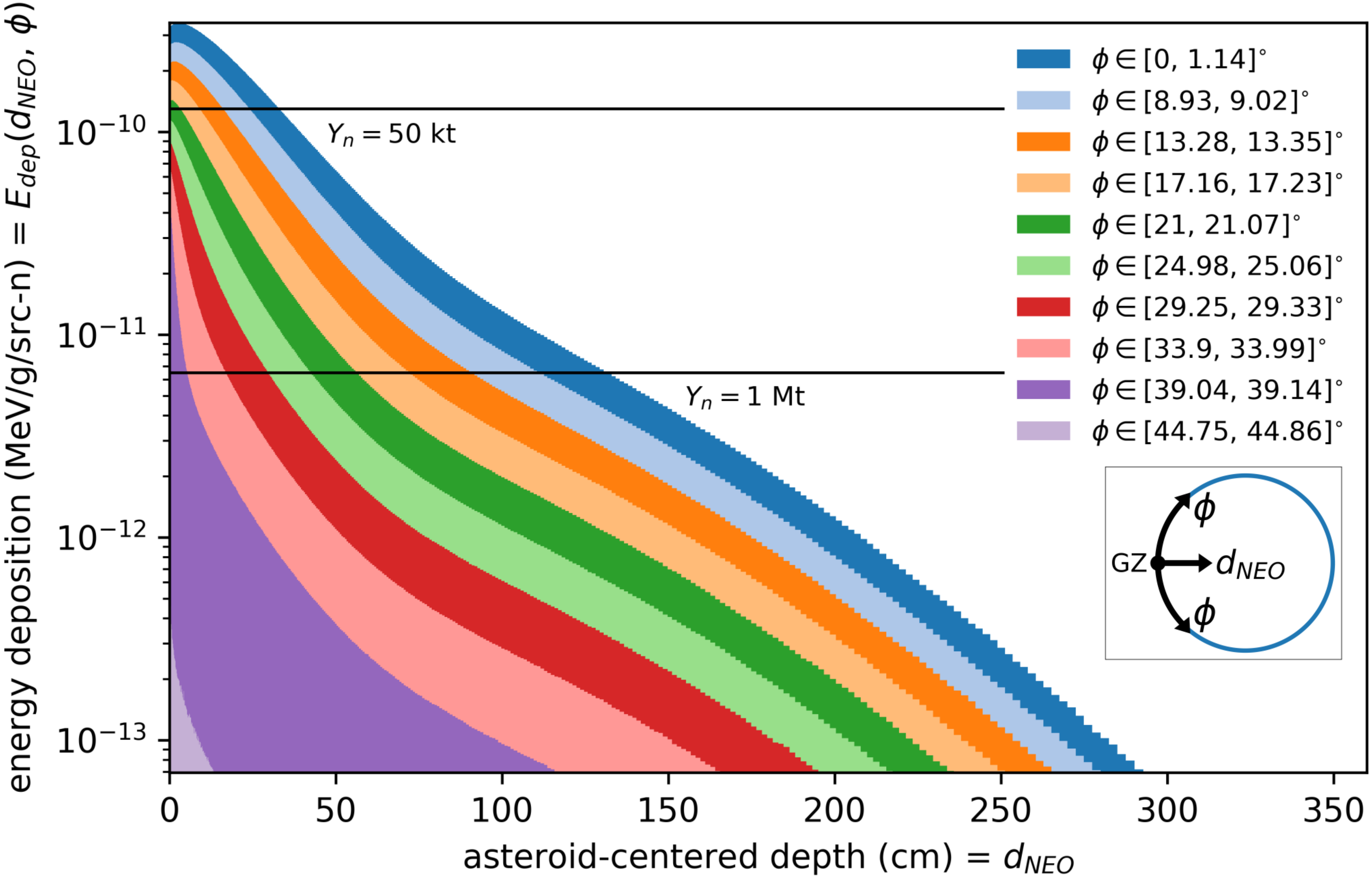
depths shown on a small
0.8 m asteroid to exaggerate
the area of energy deposition, for visualization

A nuclear device is the most efficient technology for asteroid deflection.

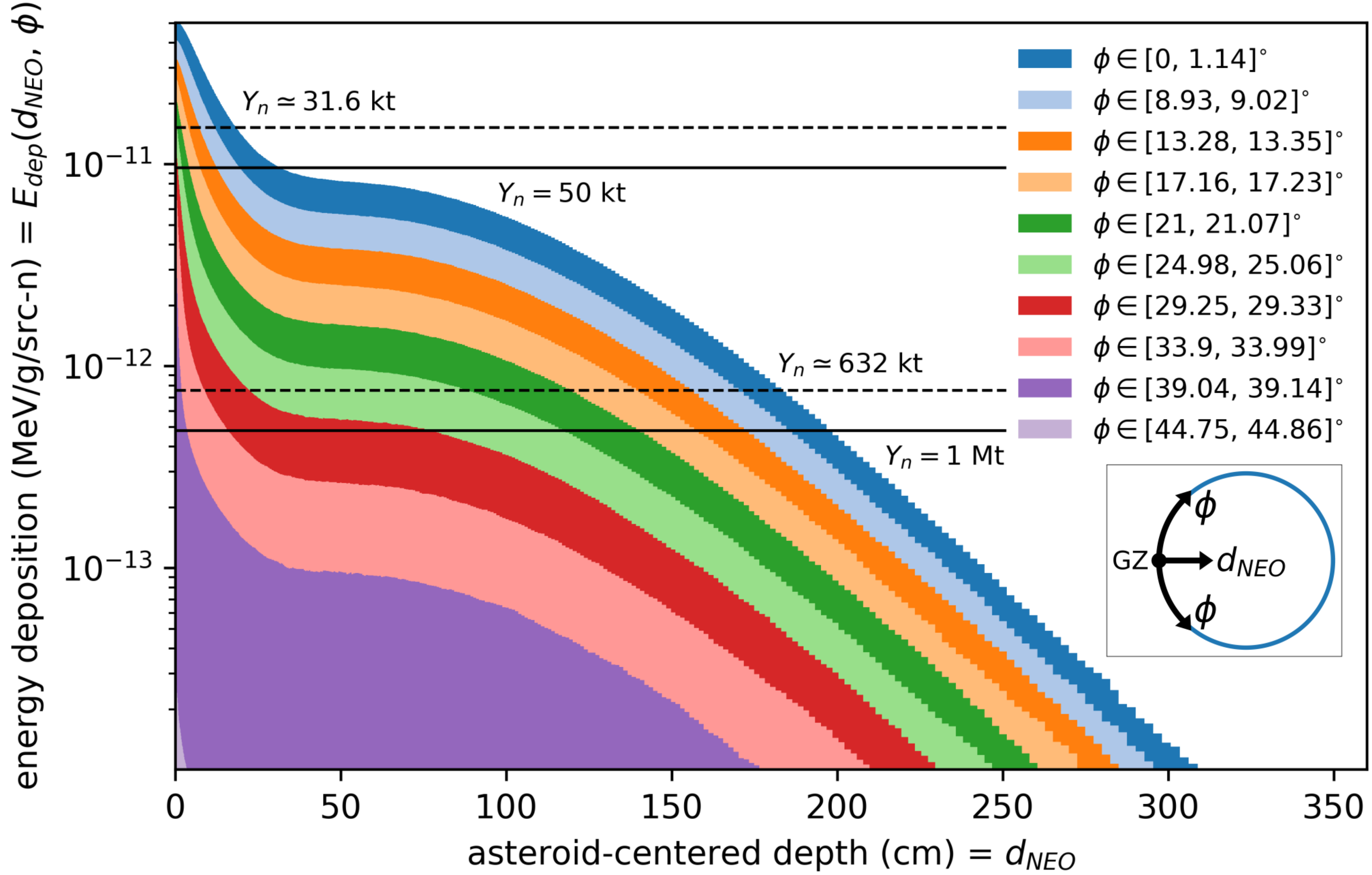
- Nuclear standoff explosions are "<u>10-100 times more effective than non-nuclear alternatives</u>"
  - NASA study
- Nuclear energy densities (energy/mass) are *millions of times greater* than chemical bonds
  - mass payload considerations are vital for space travel, delivery
- Nuclear deflection could mitigate an asteroid threat **within a few years** for objects a few hundred meters in size
  - other mitigation technologies **require decades or more** of warning time

If NASA announced tomorrow an asteroid was going to hit in 5 years, a nuclear device would likely be the most effective choice of combat.

14.1 MeV neutron energy deposition profiles.



1 MeV neutron energy deposition profiles.



The 1 MeV profiles have different spatial features than the 14.1 MeV profiles.

Summary table of all yield & neutron configurations.

Y_n	E_n	src-n	$E_{dep,tot}^{ALE3D}$	δV
50 kt	14.1 MeV	$9.31469 \cdot 10^{25}$	5.0364 kt	6.19 ± 0.06 cm/s
50 kt	1 MeV	$1.26157 \cdot 10^{27}$	7.9785 kt	9.99 ± 0.12 cm/s
31.5913 kt	1 MeV	$7.97093 \cdot 10^{26}$	5.0410 kt	6.02 ± 0.08 cm/s
1 Mt	14.1 MeV	$1.86294 \cdot 10^{27}$	100.68 kt	98.09 ± 0.41 cm/s
1 Mt	1 MeV	$2.52314 \cdot 10^{28}$	158.75 kt	166.9 ± 0.50 cm/s
631.825 kt	1 MeV	$1.59419 \cdot 10^{28}$	100.30 kt	114.7 ± 0.34 cm/s

Equal 50 kt detonation yields.

Y_n	E_n	src-n	$E_{dep,tot}^{ALE3D}$	δV
50 kt	14.1 MeV	$9.31469 \cdot 10^{25}$	5.0364 kt	6.19 ± 0.06 cm/s
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1 MeV δV is 61% greater than 14.1 MeV δV.
1 MeV E_{dep} is 58% higher.

Equal 1 Mt detonation yields.

Y_n	E_n	src-n	$E_{dep,tot}^{ALE3D}$	δV
50 kt	14.1 MeV	$9.31469 \cdot 10^{25}$	5.0364 kt	6.19 ± 0.06 cm/s
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631.825 kt	1 MeV	$1.59419 \cdot 10^{28}$	100.30 kt	114.7 ± 0.34 cm/s

1 MeV δV is 70% greater than 14.1 MeV δV.
1 MeV E_{dep} is 58% higher.

Equal ~5 kt energy depositions.

Y_n	E_n	src-n	$E_{dep,tot}^{ALE3D}$	δV
50 kt	14.1 MeV	$9.31469 \cdot 10^{25}$	5.0364 kt	6.19 ± 0.06 cm/s
50 kt	1 MeV	$1.26157 \cdot 10^{27}$	7.9785 kt	9.99 ± 0.12 cm/s
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631.825 kt	1 MeV	$1.59419 \cdot 10^{28}$	100.30 kt	114.7 ± 0.34 cm/s

14.1 MeV δV is 3±2% greater than 1 MeV δV.

Equal ~100 kt energy depositions.

Y_n	E_n	src-n	$E^{ALE3D}_{dep,tot}$	δV
50 kt	14.1 MeV	$9.31469 \cdot 10^{25}$	5.0364 kt	6.19 ± 0.06 cm/s
50 kt	1 MeV	$1.26157 \cdot 10^{27}$	7.9785 kt	9.99 ± 0.12 cm/s
31.5913 kt	1 MeV	$7.97093 \cdot 10^{26}$	5.0410 kt	6.02 ± 0.08 cm/s
1 Mt	14.1 MeV	$1.86294 \cdot 10^{27}$	100.68 kt	98.09 ± 0.41 cm/s
1 Mt	1 MeV	$2.52314 \cdot 10^{28}$	158.75 kt	166.9 ± 0.50 cm/s
631.825 kt	1 MeV	$1.59419 \cdot 10^{28}$	100.30 kt	114.7 ± 0.34 cm/s

1 MeV δV is 17% greater than 14.1 MeV δV.

How does changing the neutron interactions change the energy deposition? (cont.)

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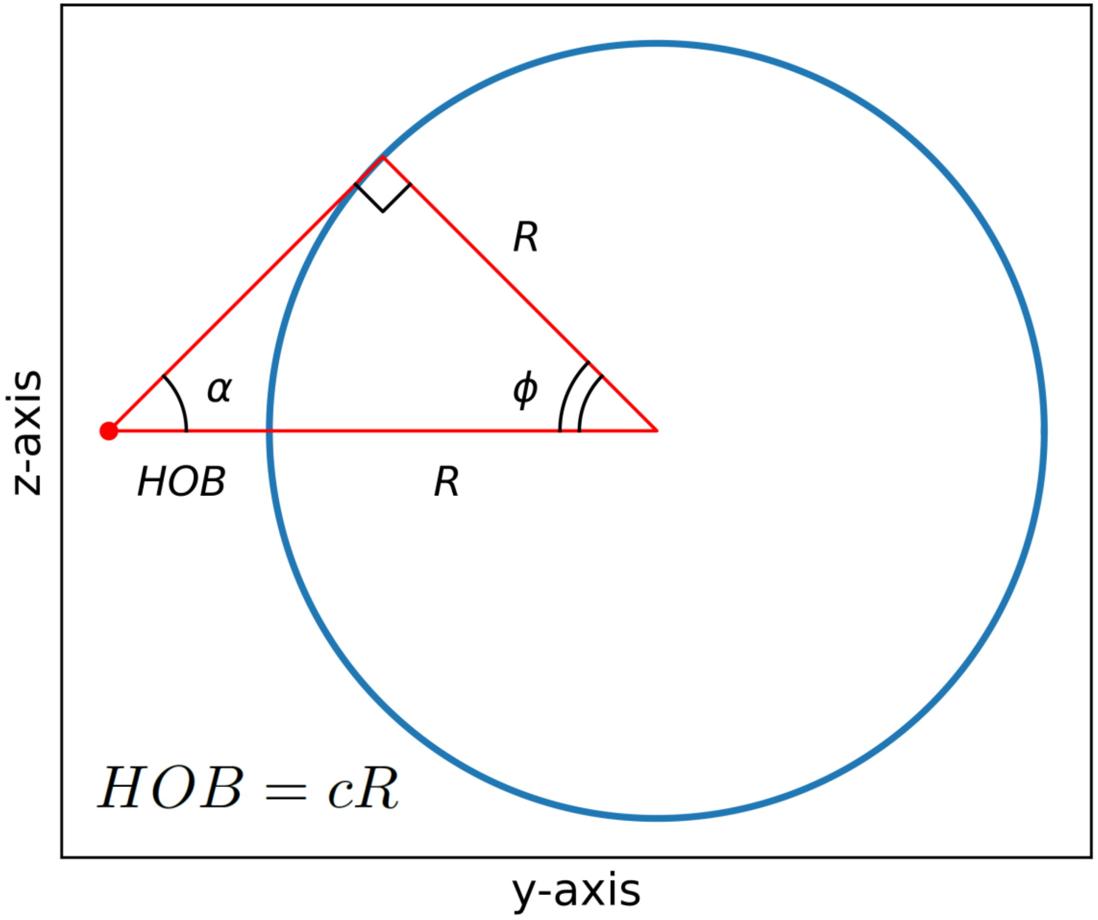
Isotope	Capture Reaction						E_1^*
	(n,γ)	(n,p)	(n,d)	(n,t)	(n,α)	(n,2n)	
^{28}Si	$\boxed{8.474}$	-3.466	-9.698	-16.743	$\boxed{-2.749}$	-17.799	-1.7790
^{16}O	4.143	-9.669	-10.527	-15.391	-2.355	-16.651	-6.0494

- Energy deposition = transferring the energy from radiation (neutrons) to the asteroid particle population (nuclei)
- Consider 14.1 MeV n's being absorbed by ^{28}Si:
  - (n,γ) = ^{29}Si nuclei keeps all 14.1 MeV, *and* an extra 8.474 MeV is shared between ^{29}Si and a γ. E_{dep} = 14.1 + 8.474*
  - (n,α) = ^{29}Si nuclei initially has all 14.1 MeV, *but* it quickly loses 2.749 MeV because it chose to emit an α. E_{dep} = 14.1 – 2.749

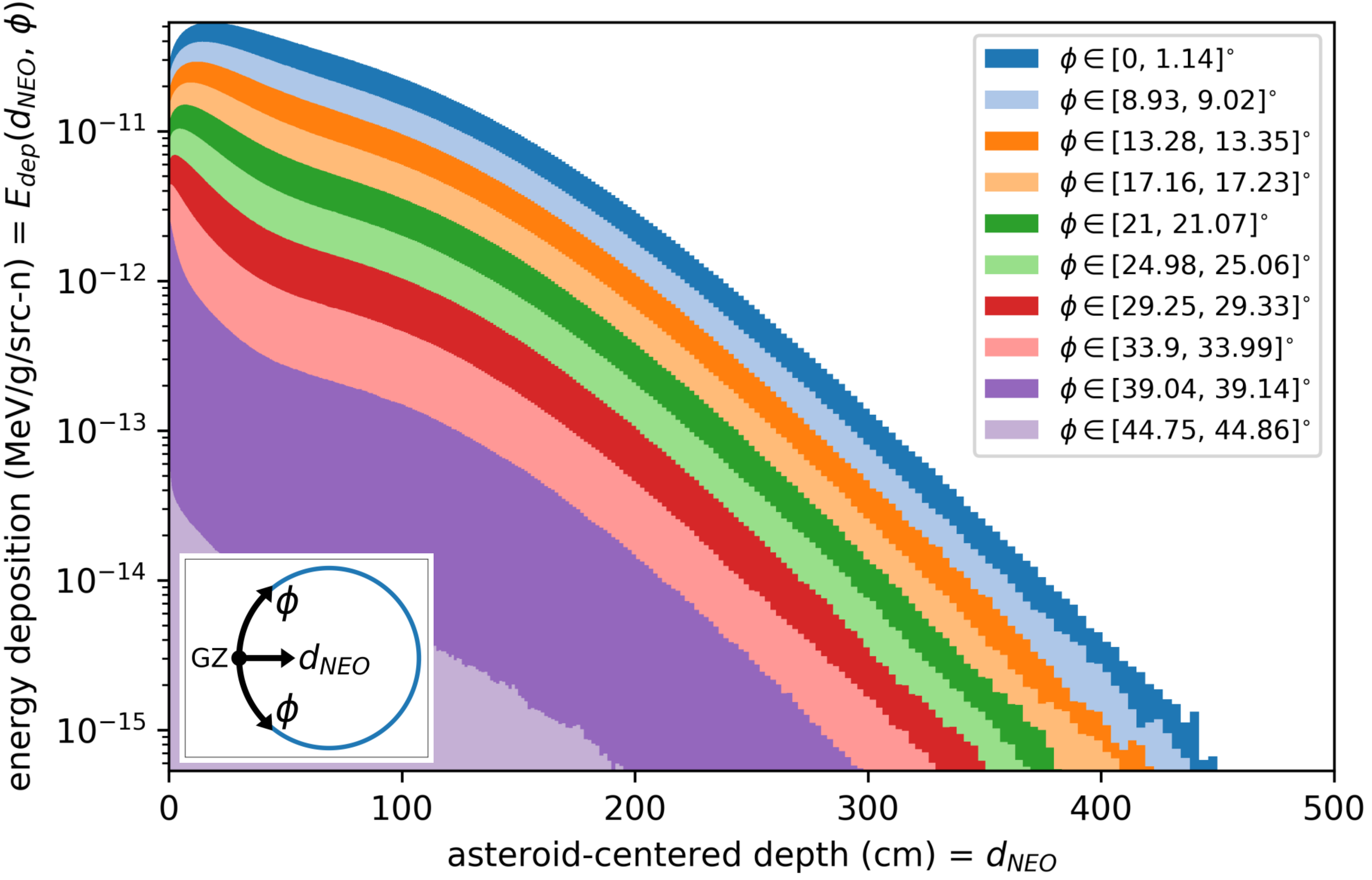
Exothermic (+Q) reaction channels are a bonus for energy coupling, while endothermic (-Q) reactions draw a coupling penalty.

Stand-off distance (HOB) selection.

- Hammerling & Remo: HOB ~ 0.414 × R
  - geometrical optimal HOB; $\alpha = \phi = 45°$
  - maximizes the sum of (fraction of asteroid surface area irradiated) + (fraction of nuclear energy incident on the asteroid)



~2.45 MeV neutron energy deposition profiles.



Actually, these profiles are from an average/midpoint energy of 2.346 MeV.