X-rays, neutrons, gammas, oh my! Why simulating asteroid deflection using a nuclear device is hard

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Abstract

For asteroid deflection using a nuclear device, simulating the energy deposition into an asteroid and the subsequent response poses notable modeling challenges. Energy is deposited into the asteroid in the form of thermal x-rays characterized by short mean-free paths, with lesser contributions from neutrons and gamma-rays characterized by longer mean-free paths. The partitioning of these energies and their detailed spectra depend on the specifics of the device used, but it is sufficient to say that the output is dominated by soft thermal x-rays. This poses a challenge in asteroid deflection simulations that must resolve orders of magnitude in length scales ranging from micrometers (soft x-rays) to kilometers (asteroid) to accurately model the physics. To complicate matters further, deposition of soft thermal x-ray energy is concentrated in the asteroid surface, and a significant amount of the deposited energy (up to 80-90%) is immediately lost to blackbody radiation before material can respond hydrodynamically.

In this ePoster we discuss the relative challenges, effectiveness and idiosyncrasies in modeling asteroid deflection using x-rays, neutrons and gamma rays. We find that soft thermal x-rays are the most abundant energy source in nuclear detonations and discuss challenges in numerical modeling of these deflection scenarios.

Asteroid deflection using a standoff nuclear detonation depends on the device output

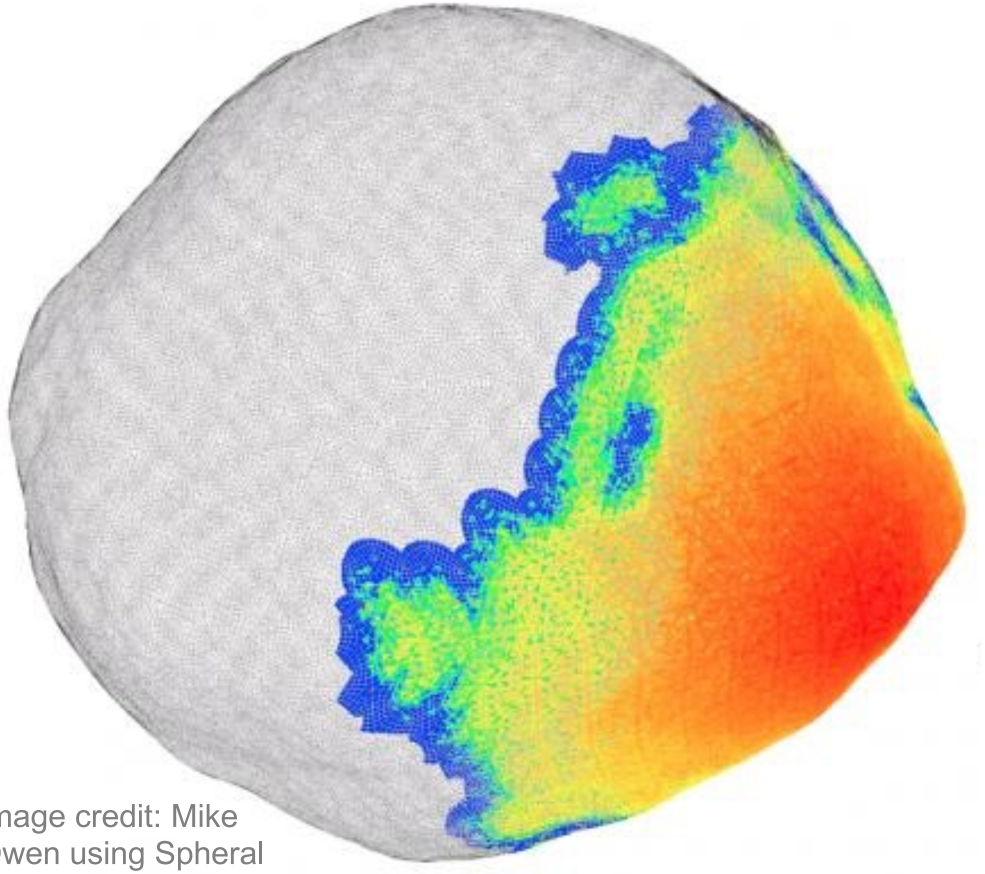
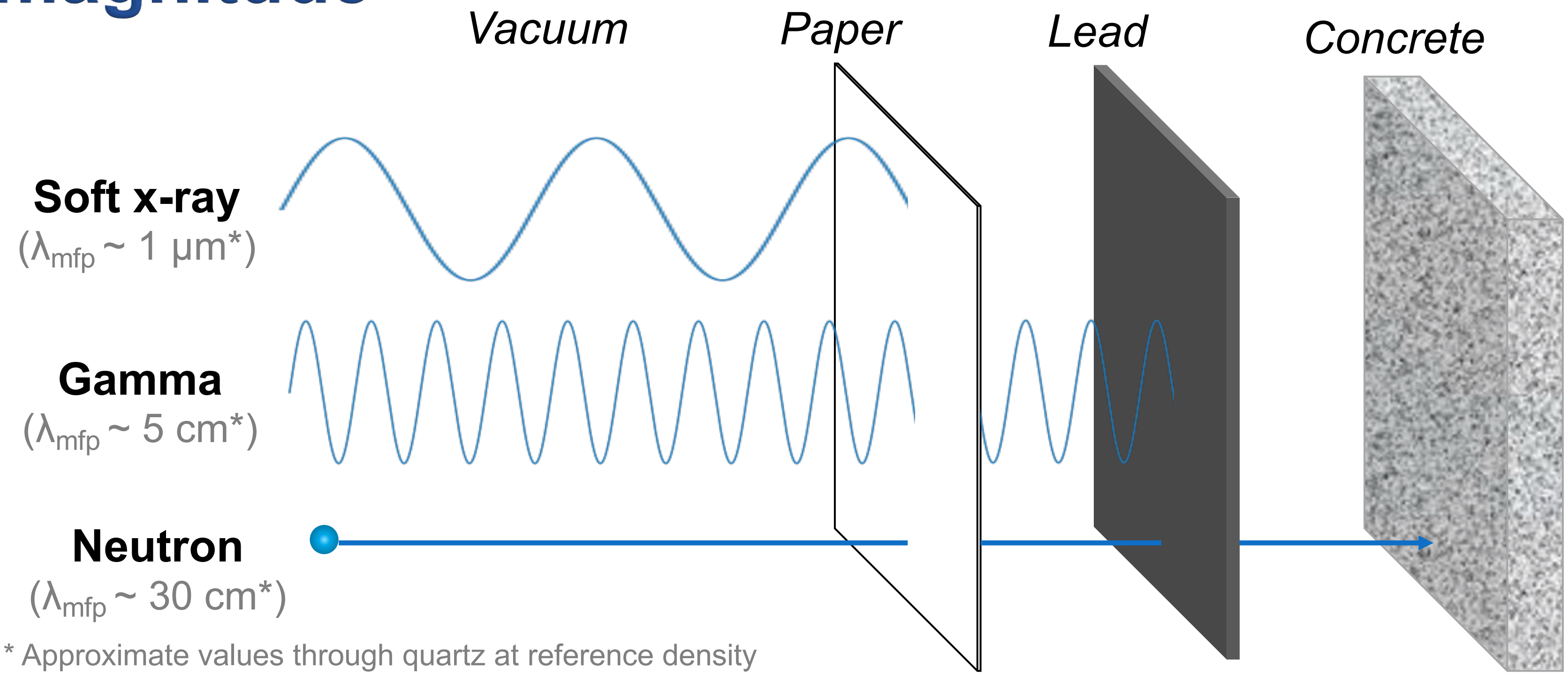


Image credit: Mike Owen using Spheral

A standoff nuclear detonation melts and vaporizes material by depositing photons and neutrons into the asteroid surface. Superheated surface material is ejected and acts as a propellant to the asteroid. The result is a ”push” with momenta equal and opposite to that of the melted and vaporized surface material. The direction and magnitude of this push is closely tied to how the incoming x-rays from the nuclear detonation (the dominant energy source) couple to the asteroid surface.

Nuclear detonation energy products have penetration depths that vary by orders of magnitude



Soft x-ray
(λ_{mfp} ~ 1 µm*)

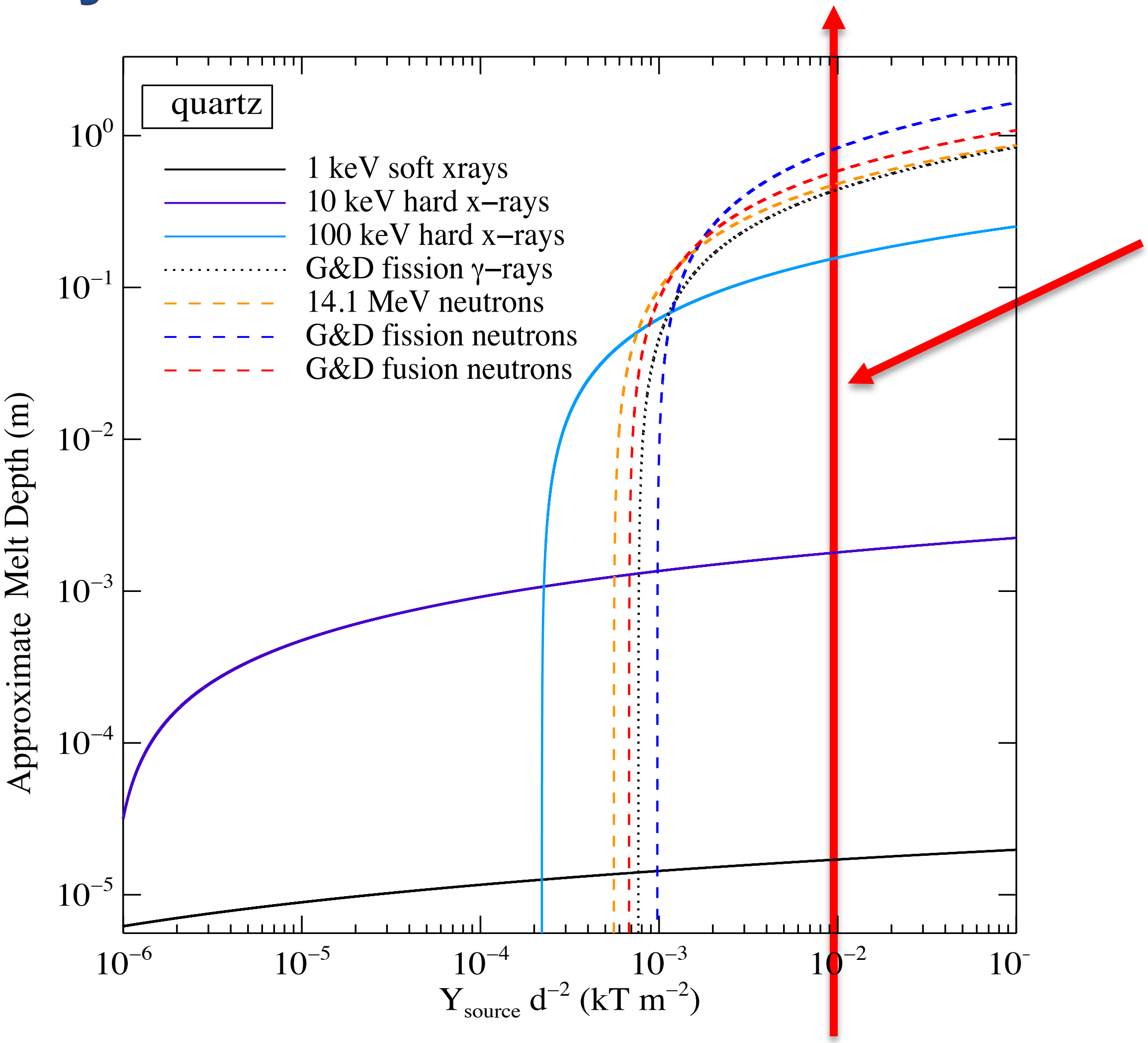
Gamma
(λ_{mfp} ~ 5 cm*)

Neutron
(λ_{mfp} ~ 30 cm*)

* Approximate values through quartz at reference density

Although neutrons penetrate deeply and are ideal for melting and vaporizing asteroid material, they are not an abundant energy source in nuclear detonations.

Neutrons can penetrate more deeply than x-rays into asteroid-like materials

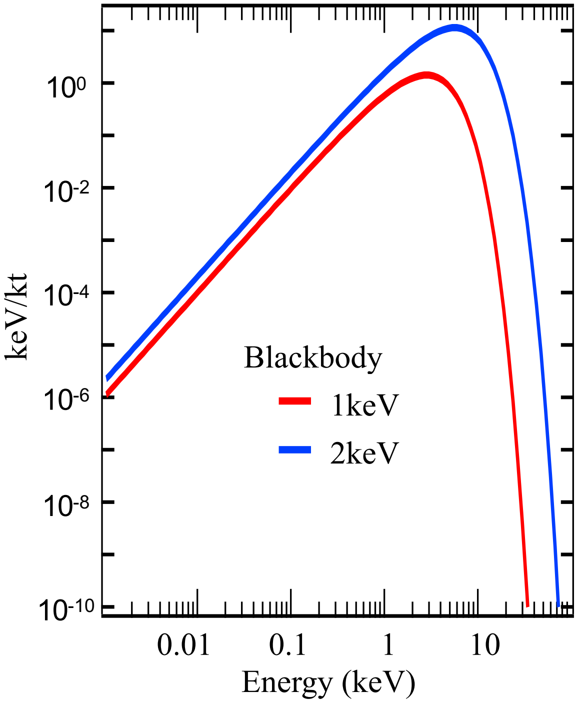


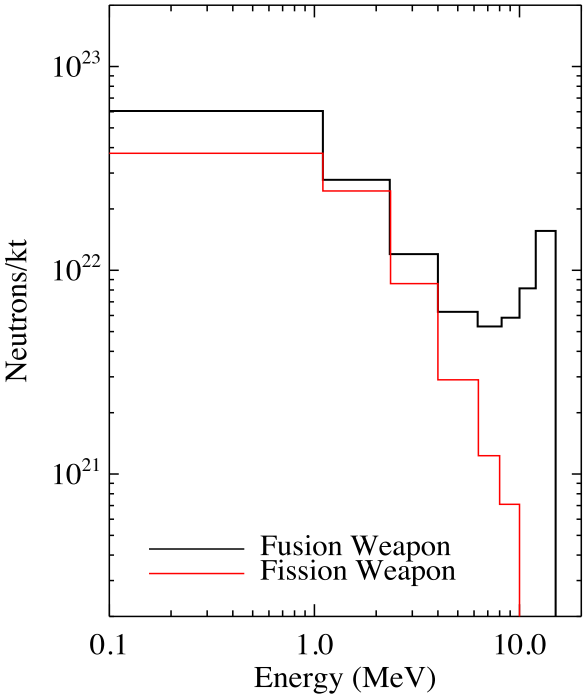
*G&D = Glasstone & Dolan 1977

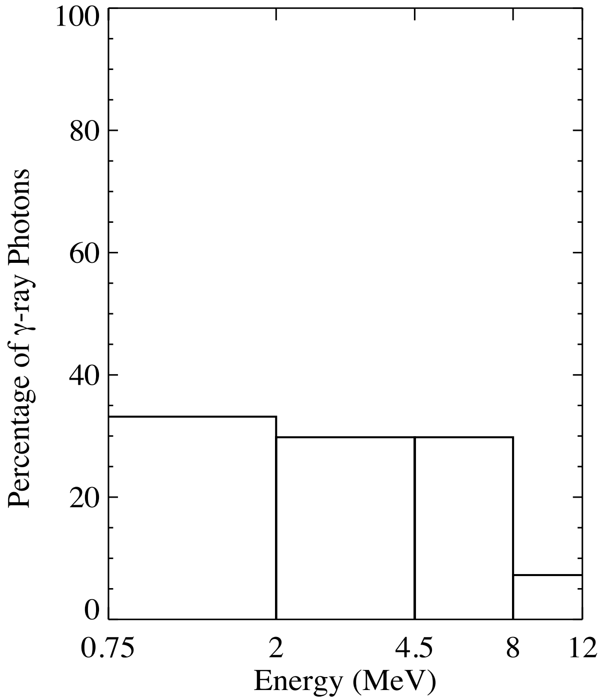
For example, 100 kt of fusion neutrons at a standoff distance of 100 m penetrates a meter of material, while an equivalent fluence of 1 keV x-rays penetrates only a micron of material.

Neutrons, however, are **not** a dominant energy source in a nuclear detonation (the example of 100 kt of neutrons is not realistic). The dominant energy source are thermal x-rays. They have the ability to melt & vaporize material at low fluences and/or large standoff distances.

Neutrons are not an abundant energy source, thermal x-rays dominate the nuclear device output


X-ray (70-80%)*

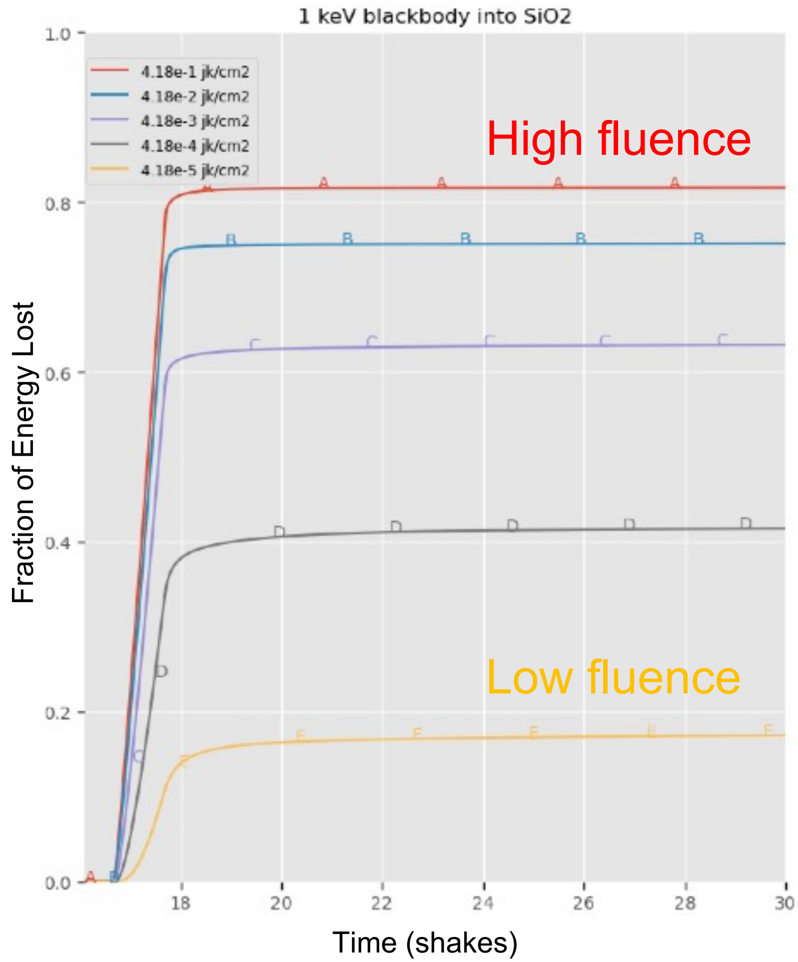

Neutron (< 3%)*


Gamma (< 1%)*

Asteroid deflection using a standoff nuclear detonation is dominated by the physics of x-ray interactions with material

*Initial radiation spectra. Remaining energy is in the form of kinetic debris. (Glasstone & Dolan 1977)

A significant fraction of deposited x-ray energy is lost to blackbody radiation



**Kull simulation, includes source travel time through vacuum*

The fraction of energy lost increases with fluence; hotter surfaces radiate away more energy. Over a range of realistic yields and stand off distances, energy loss due to reflections, scatters and blackbody radiation ranges from 20% ~ 80% (normal incidence).

We define a realistic range of x-ray fluences to be 4.18×10^{-5} to 4.18×10^{-1} jerks/cm^2. An example of a low fluence scenario is a 12.5kT device at a 100m standoff; an example of a high fluence scenario is the same 12.5kT device at a 1m standoff.

Modeling micrometer-length energy coupling in a kilometer-sized body presents unique computational challenges

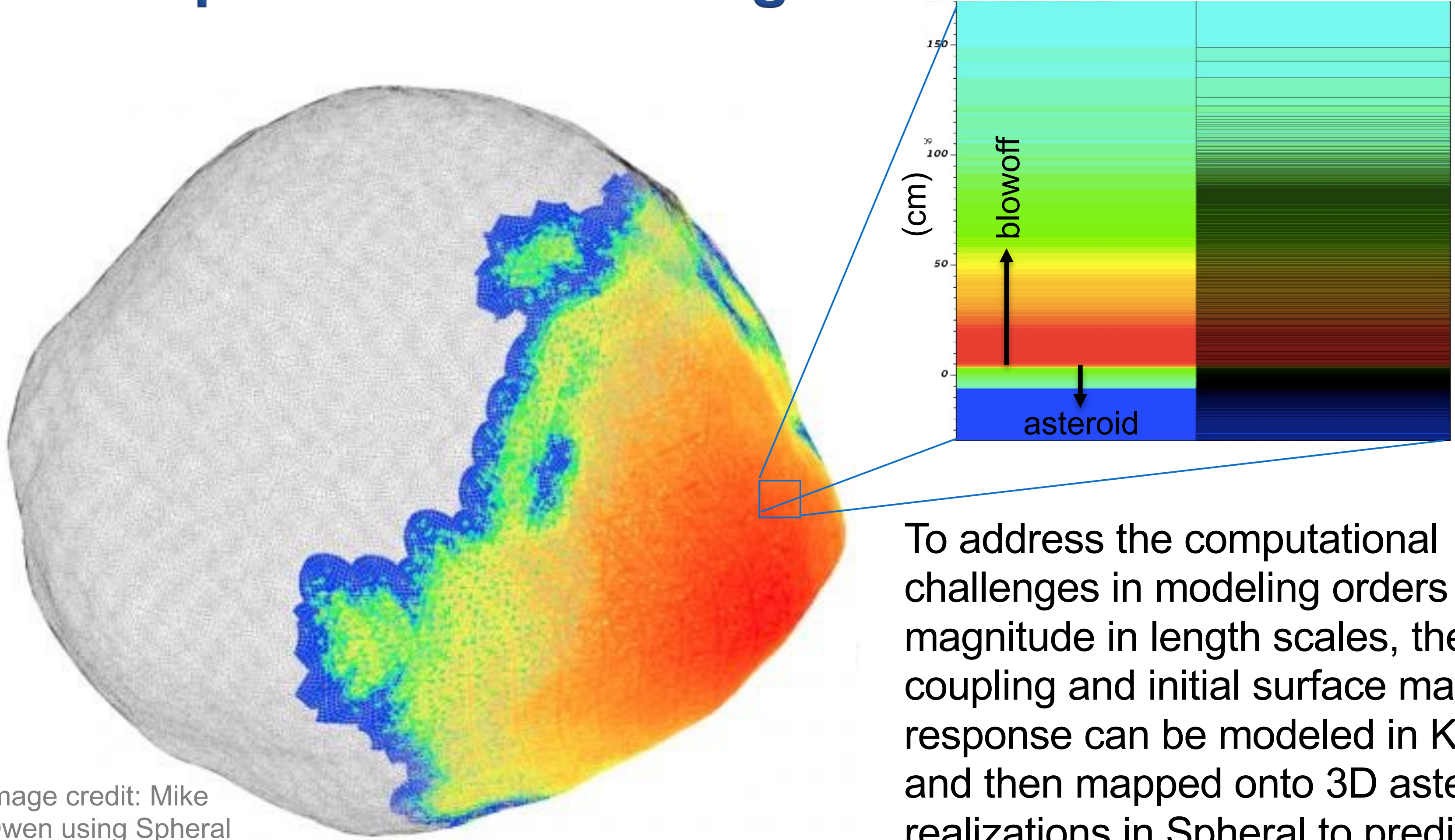


Image credit: Mike Owen using Spheral

To address the computational challenges in modeling orders of magnitude in length scales, the energy coupling and initial surface material response can be modeled in Kull in 1D and then mapped onto 3D asteroid realizations in Spheral to predict deflection responses.

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