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- ☐ **Planetary Defense – Recent Progress & Plans**
- ☐ **NEO Discovery**
- ☐ **NEO Characterization**
- ☒ **Mitigation Techniques & Missions**
- ☐ **Impact Effects that Inform Warning, Mitigation & Costs**
- ☐ **Consequence Management & Education**

OVERVIEW OF COLLISIONAL-THREAT MITIGATION ACTIVITIES AT LAWRENCE LIVERMORE NATIONAL LABORATORY

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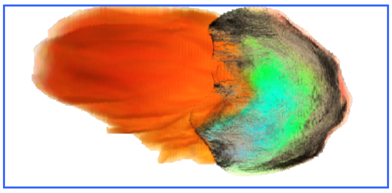
Nuclear explosions provide a means to divert objects on a collision course with Earth. For scenarios in which there is little warning time before impact, or if the object is very large, nuclear explosives are often the *only* option for mitigation, so understanding their effect is critical. Our project at Lawrence Livermore National Laboratory (LLNL) is investigating issues important to the nuclear approach, including the development of scenarios of impact objects, modeling energy coupling to asteroids, response to the energy deposition, and orbital dispersion. We are evaluating a variety of strategies for a range of scenarios and assessing current U.S. capabilities. In pursuit of this, we are also conducting verification and validation work, error analysis, optimization studies, and algorithmic and simulation advances. We employ a range of simulation codes, taking advantage of the strengths of each method. A selection of results from throughout the project will be presented.

Simulation tools

We are utilizing a range of simulation capabilities, taking advantage of the strengths of different approaches. Codes include Adaptive Smoothed Particle Hydrodynamics (ASPH), ALE rad/hydro, Godunov-based Eulerian with AMR, and Lagrangian Finite Element–Discrete Element capabilities.

Deflection



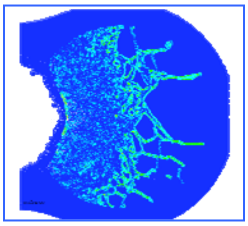
We are simulating the deflection of objects, including tools to visualize the PHO distribution and the minimum required deflection velocities as a function of orbital parameters. Here, an example uses a scaled Geographos model with a realistic shape but with a 500-m-equivalent diameter, 750 kt nuclear explosion with 150 kt deposited energy. The graphic combines volume rendering of three quantities: energy density in the ejecta (orange color scale), velocity (RGB color scale), and damage (grey scale).

Porosity

Object porosity has a strong influence on the propagation of shock waves and subsequent damage and fracture behavior resulting from a strong impulsive energy deposition. We will report on a study of the impact of porosity.

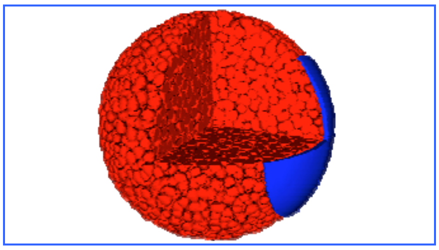
Strength, damage, and fracture modeling

We model objects with strength, and simulate damage and fracture from impulsive deflection events. On the right is an example of damage to an object with a strengthless layer of "regolith" on the outside.



Rubble piles

Evidence suggests that some asteroids may be conglomerations of loosely bound fragments, boulders, rocks, and finer particles or regolith. We are modeling "rubble pile" objects as collections of individual boulders, and are examining the response of the object to the impulse imparted by a nearby nuclear explosion. To the right is an example of an initial setup, with the energy deposition region shown as a blue cap.

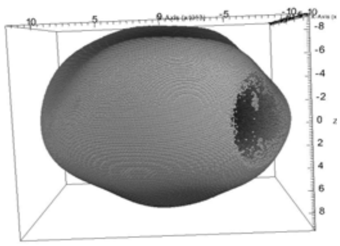


Dispersal

In the event of "rubble pile" types of objects necessitating a large deflection, as well as for other disruption scenarios, the potential for breakup and dispersal is significant. We have developed methods to assess the spread of fragments from an object through subsequent orbits. From this, mass deposition amounts and rates on the Earth may be estimated and plotted. Examples will be presented.

Validation

As part of our validation work, we have simulated impacts upon Mars' moon Phobos, and the resultant formation of the large Stickney crater. The energy released in the impact event is estimated at approximately 100 Megatons. The crater has a diameter of about 9 km.



Related work

Two additional papers describing related work by our group were submitted separately to the 2013 PDC. One investigates the details of energy deposition on an asteroid or comet, and examines the subsequent momentum imparted to the object. This process underpins all deflection and disruption by nuclear explosives. The second paper describes a new analytic description of the orbital change imparted to an asteroid by an impulsive deflection. We use that framework to explore the nonlinear propagation of error in deflection velocity to the final Earth-miss distance in order to quantify necessary accuracy in modeling deflection scenarios. Neither of those topics will be discussed in detail in this presentation.

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