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Title: Further RAGE Modeling of Asteroid Mitigation: Surface and Subsurface Explosions in Porous Objects

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Based on
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Further RAGE Modeling of Asteroid Mitigation: Surface and Subsurface Explosions in Porous Objects (U)

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Abstract

Disruption or mitigation of a potentially hazardous object (PHO) by a high-energy subsurface burst is considered. This is just one possible method of impact-hazard mitigation. We present RAGE hydrocode models of the shock-generated disruption of PHOs by subsurface nuclear bursts using scenario-specific models from realistic RADAR shape models. We will show 2D and 3D models for the disruption by a large energy source at the center of such PHO models (~100 kt -10 Mt) specifically for the shape of the asteroid 25143 Itokawa. We study the effects of non-uniform composition (rubble pile), shallow buried bursts for the optimal depth of burial and porosity.

Physical Intervention for PHOs (Potentially Hazardous Objects) -- Introduction

- Significant public interest in this topic
  - Several Hollywood movies; interest from government; popular articles on this topic
- many methods of mitigation have been proposed:
  - Explosive disruption
  - Stand-off momentum/velocity transfer (see Plesko talk)
  - Non-nuclear methods; gravity attractors; solar energy absorption (paint) etc
- Explore surface and subsurface explosion energies from 100 kt - 10 Mt
- Here we use realistic (non-spherical) shapes and explore composition from uniform to "rubble piles".
- Question to be addressed: can the current version of RAGE provide physically reasonable hydrodynamic disruption or mitigation of such an asteroid?

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Simulations of the Destruction of an Asteroid by a Massive Internal Energy Explosion

- obtain NASA generated geometry of interesting asteroids (Itokawa and Goleva)
- Apply the Rage hydrocode to 2D (cylindrical) and 3D models
- Explore explosion energies from 100 kt - 10 Mt
- CAMR allows mesh refinement down to 1-2 meters

- Question to be addressed: can the current version of RAGE provide physically reasonable hydrodynamic disruption or mitigation (deflection) of such an asteroid?

The RAGE Code at Los Alamos

- **This code is a well documented with extensive Verification and Validation (V&V)**
- **The fundamental multi-material hydrodynamics is Eulerian based Godunov scheme that features Continuous Adaptive Mesh Refinement (CAMR)**
- **The code has been used extensively to simulate complex 1D, 2D and 3D hydrodynamic interactions, mainly involving shock physics**
- **Detailed tabular equations-of-state (EOS) as well as a detailed material strength model (Steinburg-Guinuan or SG) with failure set by P_{min}. A more realistic failure package (Johnson/Cook) has recently been implemented (needs V&V)**

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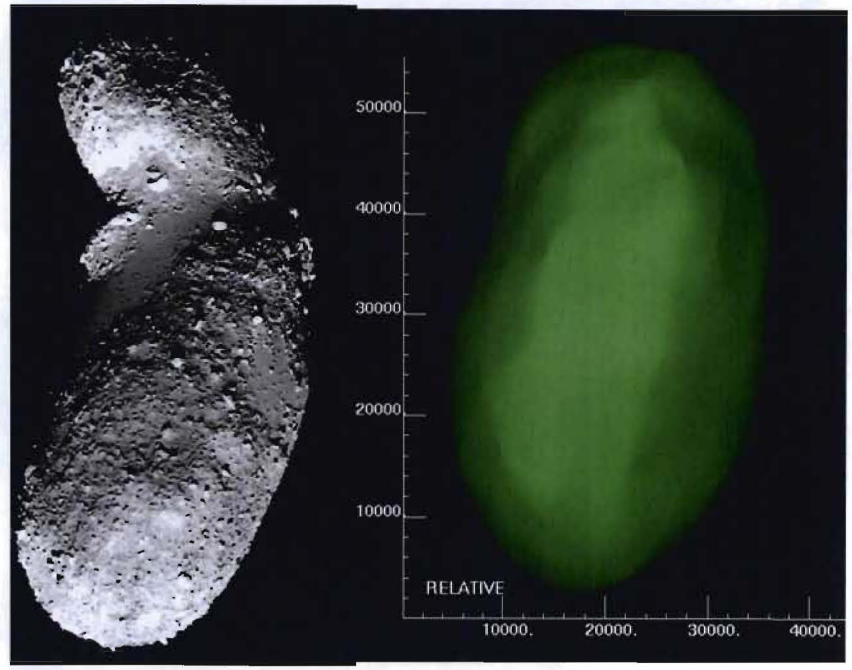
Our Preliminary Asteroid Disruption Simulations

- We obtained 3D shapes from NASA[1] radar imaging to use a the geometry for this work. (Itokawa)
- We are running both 2D and 3D simulations
- In 2D we rotated the center plane geometry around the cylindrical axis
- Our first models used a uniform composition of a well exercised (in RAGE) material: iron
- Initial study is to examine hydrodynamic effects of disruption from the non-spherical shape.

Courtesy of JAXA 3D OSO Geometry



[1]S.J. Osto et. Al. (2002) in the Asteroids 3 book

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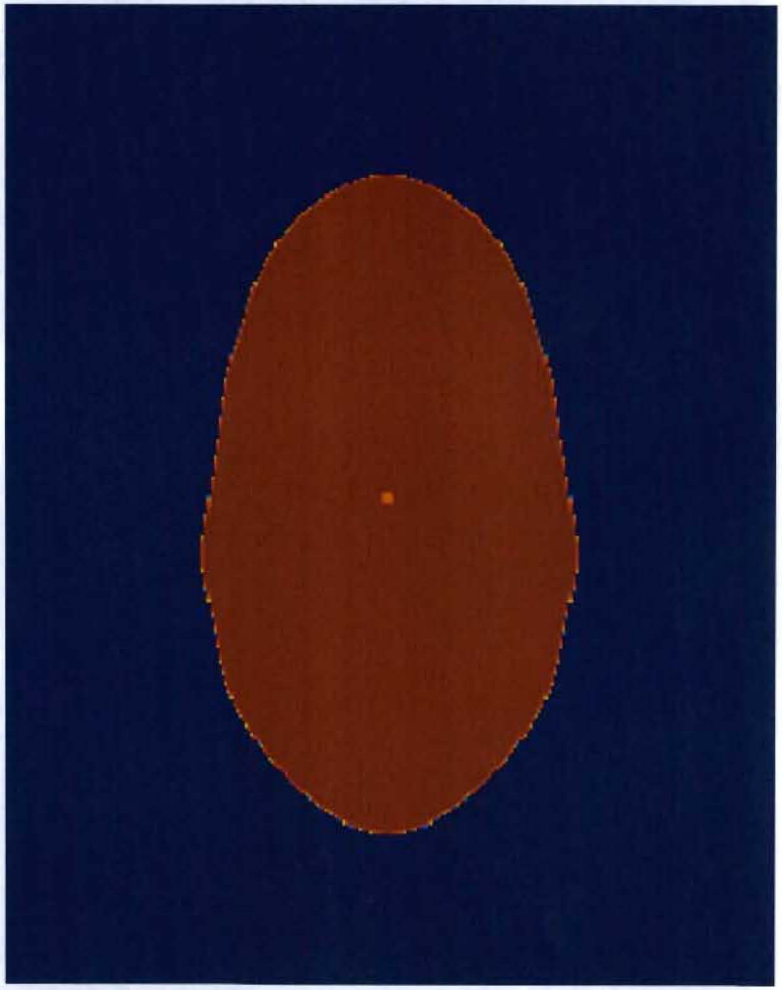
Initial Results from a 1 Mt Energy Source at the Center of the model – uniform composition

2D initial conditions for RAGE simulation. The mid-plane, long-axis shape of the Itokawa a asteroid has been used to represent the 2D cylindrical geometry. A spherical energy source put at the center (0,0) with a radius of 5 m and Energies from 100 kt - 10 Mt. Here 1Mt was used.



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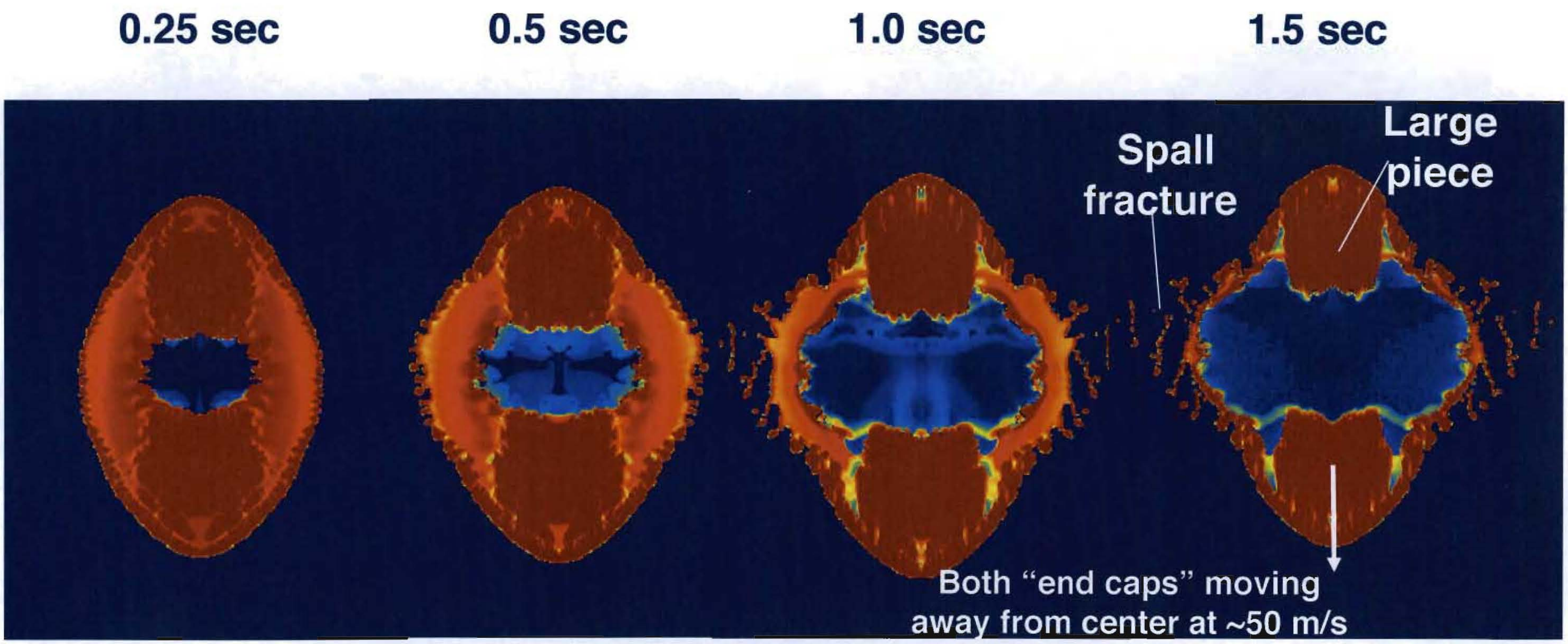
Initial Results from a 1 Mt Energy Source at the Center of the model -- log Density Images

Snapshots of the density structure (log-scale) during the explosion



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Analysis of the 1 Mt Energy Source Disruption of the Asteroid

- **Using a realistic shape (Itokawa) but a uniform iron composition is an attempt to isolate the hydrodynamic effects on a realistic geometry (non-spherical)**
- **The result is the shock propagates to the minimum chord to the surface (short length) and creates spall planes (path of least resistance)**
- **This effect releases the internal pressure and prevents further fracture in the remaining large end caps**
- **However, as a result of the extremely high internal pressure, the end caps have been accelerated to a speed of ~50 m/s away from the central point**
- **This early time velocity is probably enough to alter the resulting orbit to miss Earth contact**

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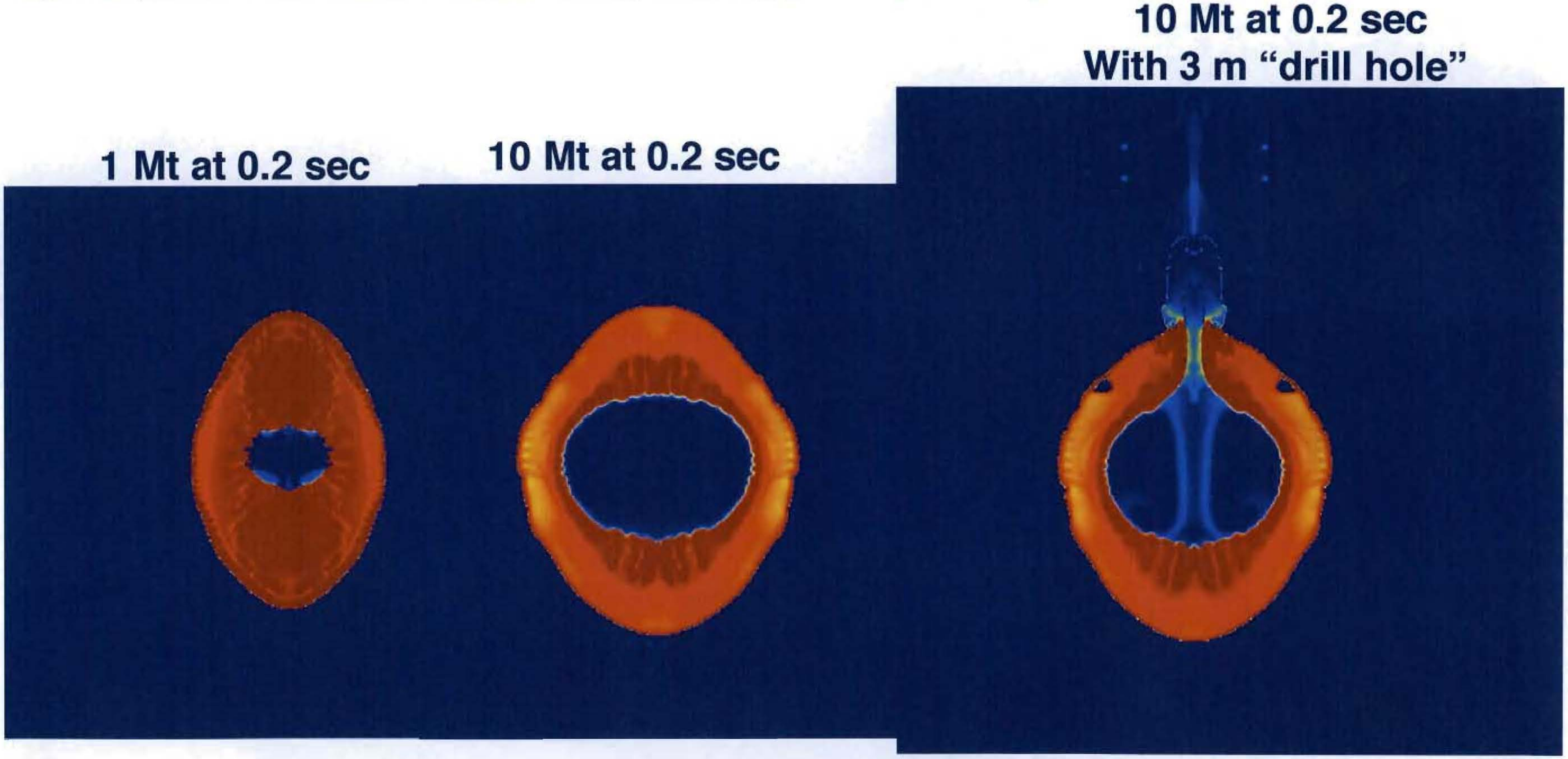
Early Time comparisons of the 1Mt source to a 10 Mt and a 10 Mt source with a "drill hole"

Using a realistic shape (Itokawa) but a uniform iron composition is an attempt to isolate the hydrodynamic effects on a realistic geometry (non-spherical)



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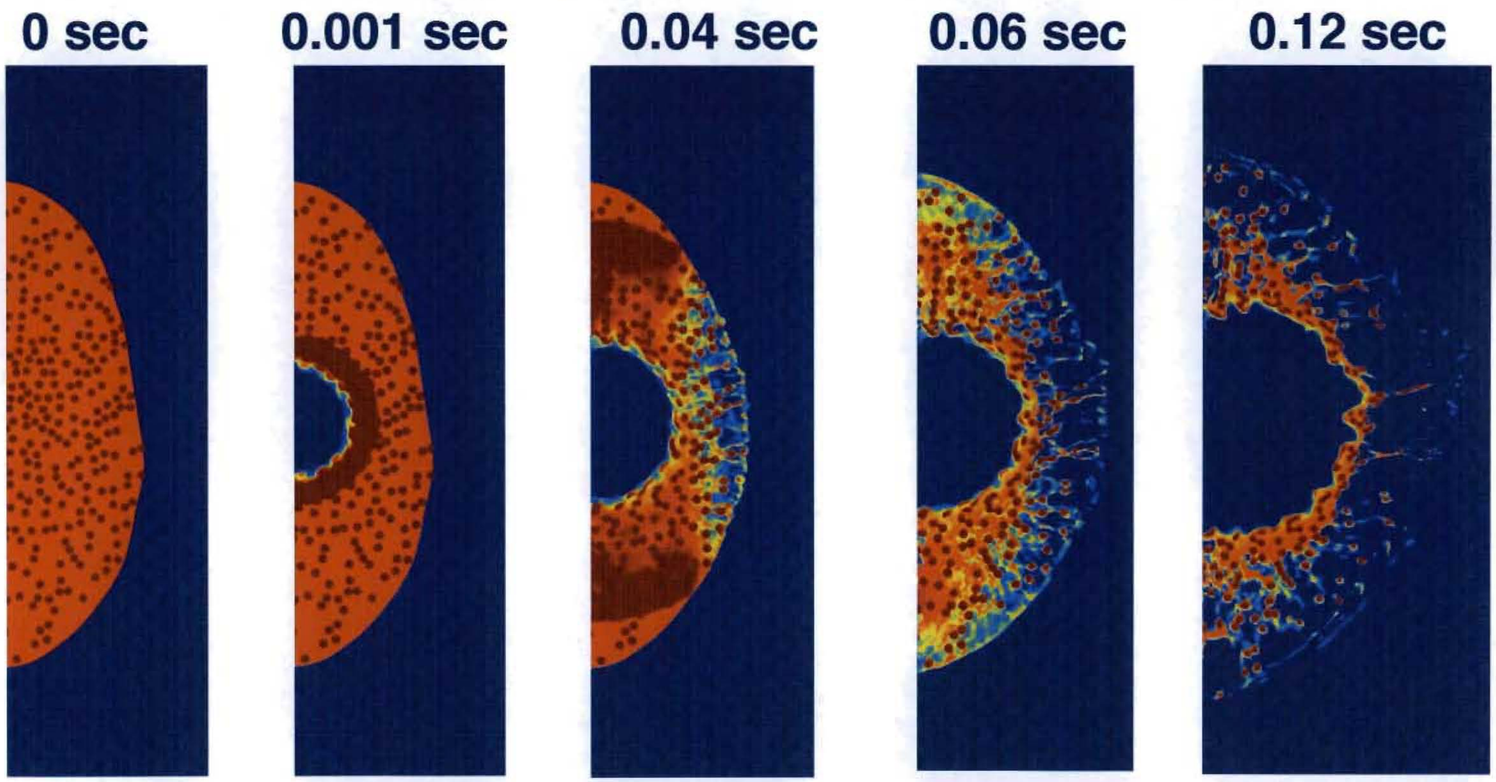
Initial Results from a 10 Mt Energy Source at the Center of the "rubble pile" model -- Density Images

Using realistic shapes (Itokawa) but a "rubble pile" composition (many spherical "rocks" of 5 m radius – 10 Mt
Ito255 – Non-filling composition (linear scale (1 -4 g/cc)



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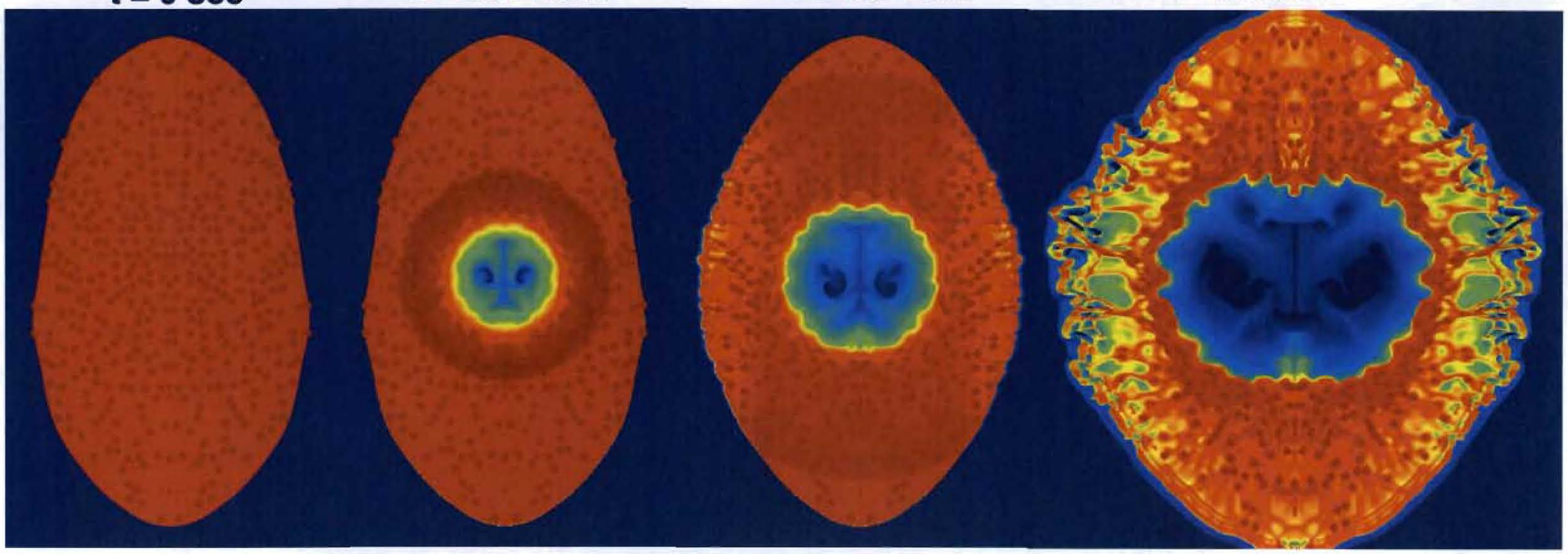
Non-Uniform internal structure (rubble pile) with a central explosion

Using a realistic shape (Itokawa) but a non-uniform rubble pile (many spherical "rocks")
5 m radius 10 Mt
More complete filling

t = 0 sec **t = 0.011 sec** **t = 0.04 sec** **t = 0.1 sec**



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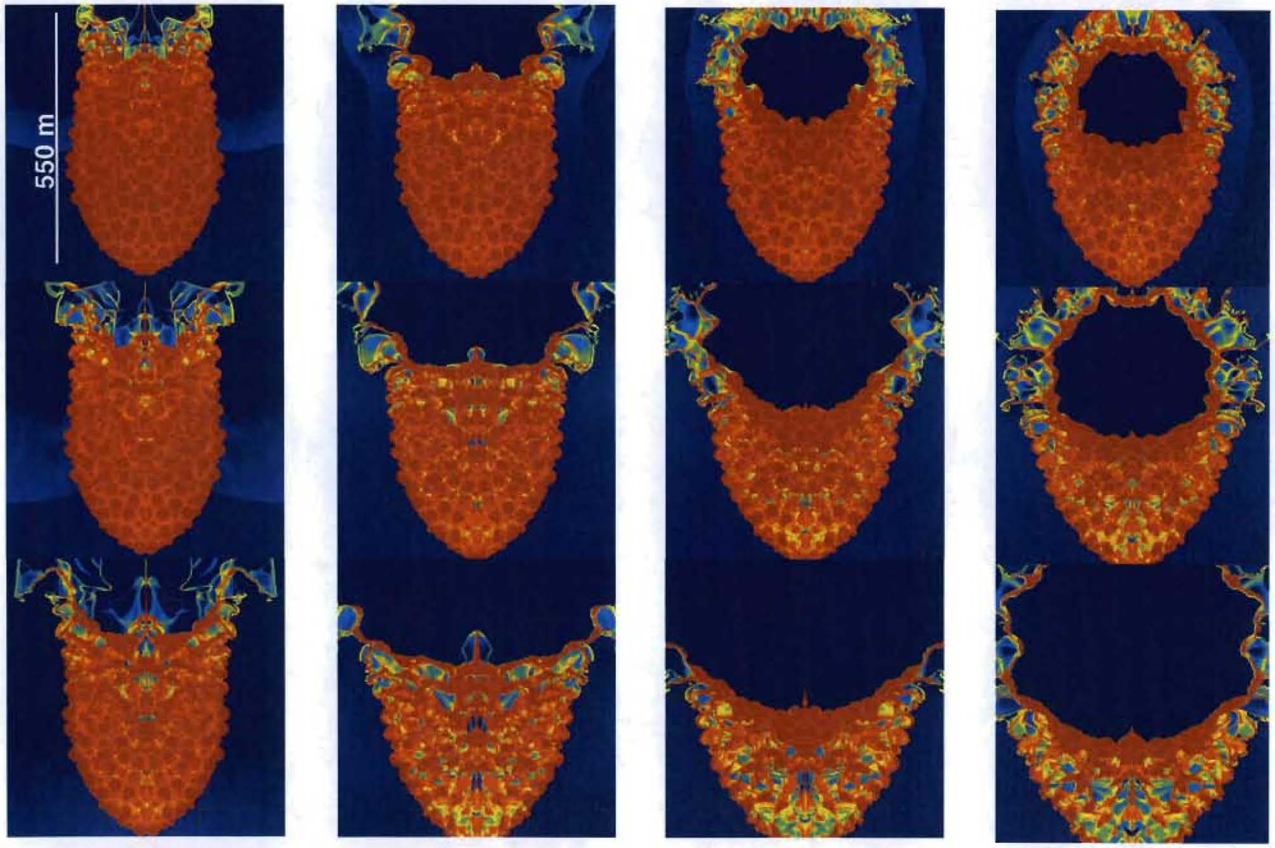
Initial Results from a 1 Mt Energy Source as a function of Depth-of-burial -- log Density Images

DOB 0 m | **DOB 45 m** | **DOB 120 m** | **DOB 170 m**

0.25 sec

0.5 sec

1.0 sec



14 m/s | **34 m/s** | **44 m/s** | **54 m/s**

Snapshots of the density structure (log-scale) during the explosion

End velocity at 1 sec

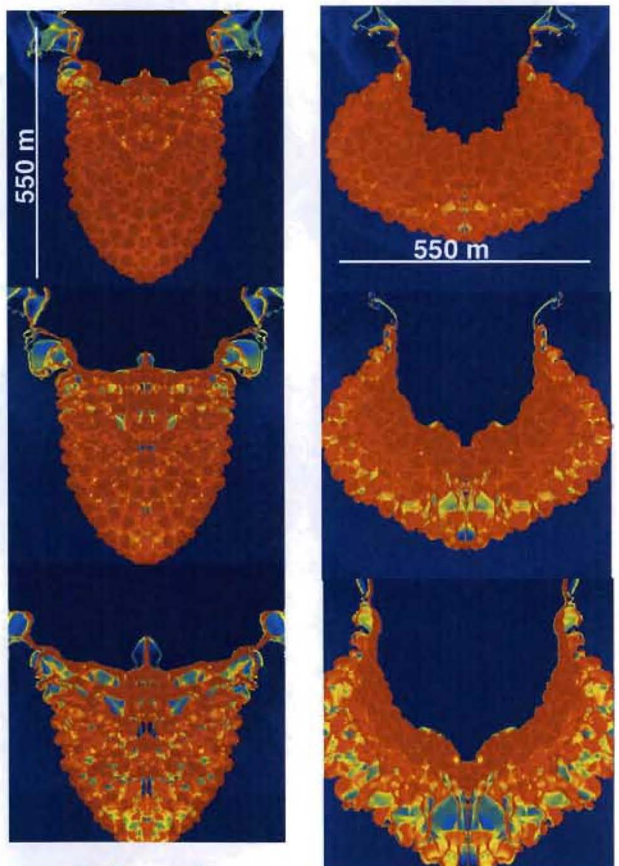
Compare short side explosion to long side – 1 Mt

DOB 45 m | **DOB 33 m**

0.25 sec

0.5 sec

1.0 sec



34 m/s | **167 m/s**

End velocity at 1 sec

Snapshots of the density structure (log-scale) during the explosion

> **Explosions from the shorter side are ~5 times more effective at imparting momentum to object**

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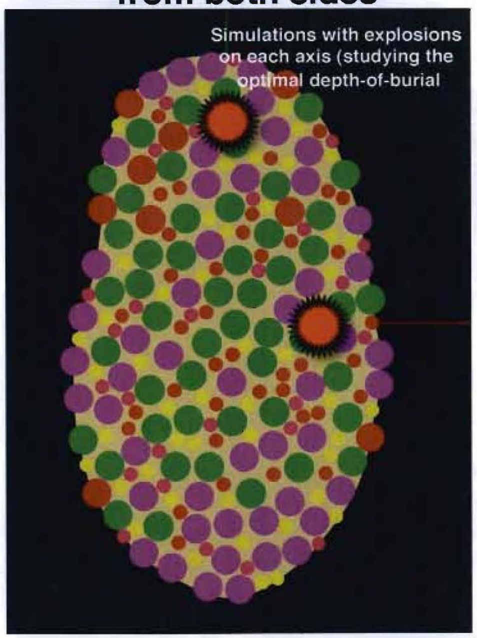
Current Work – Examine shallow buried bursts for optimum depth of burial

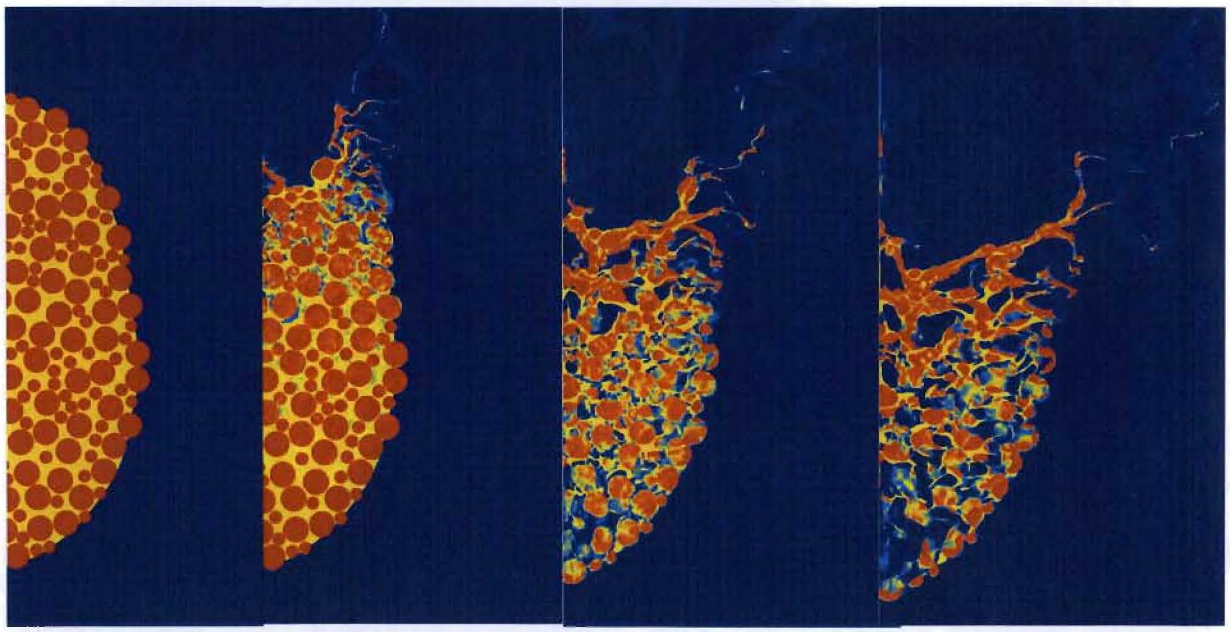
- **Shallow buried bursts (one-sided momentum transfer)**
- **distribution of rocks sizes**
- **vary strength of materials (minimal strength in background material)**

Shallow buried bursts from both sides



1 Mt explosion at depth of burial: 50 m from long axis

t = 0.0 sec t = 0.1 sec t = 0.5 sec t = 1. sec



velocity of asteroid fragments at 1 sec ~40 m/s

Effects of porosity in the asteroid geometry

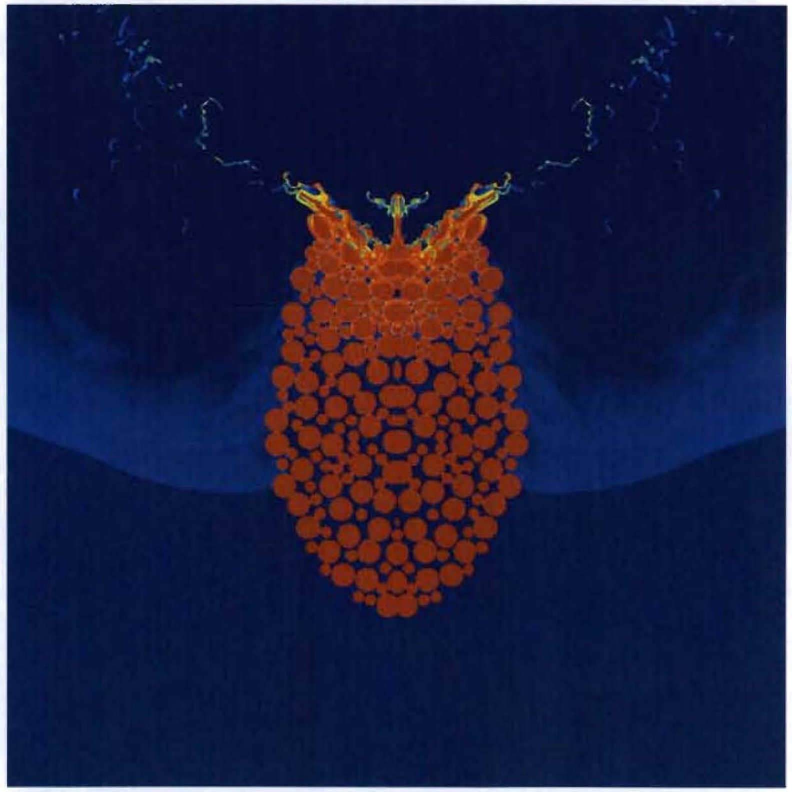
- Asteroids have a wide spectrum of compositions from metallic objects to "rubble piles" of loosely bound "rocks"
- The internal composition and distribution of mass is not well understood nor actually known for any object
  - However, from volume and mass data on many asteroids, the "rubble pile" class typically have significant porosity (~30-50%)
  - This porosity has significant physical effects on momentum transfer to the object: energy used to crush voids depletes energy available for disruption or mitigation (momentum)
- In order to assess the magnitude of the porosity in mitigating PHO asteroids from explosive effects we repeat the DOB study at 500 kt with a "porous" object
- The RAGE code needs additional physics refinement to properly calculate the shock transmission through porous "solid" material such as sand
- However, the present RAGE code can capture well the hydrodynamics of solid "rocks" with interstitial voids – this is what we examine next

Effects of porosity in the asteroid geometry

Porosity is achieved by taking out the background alluvium, leaving only the "rock pile"

The porosity in this particular case is ~25%

Goal is to see quantitatively how much energy is absorbed by crushing the voids between rocks



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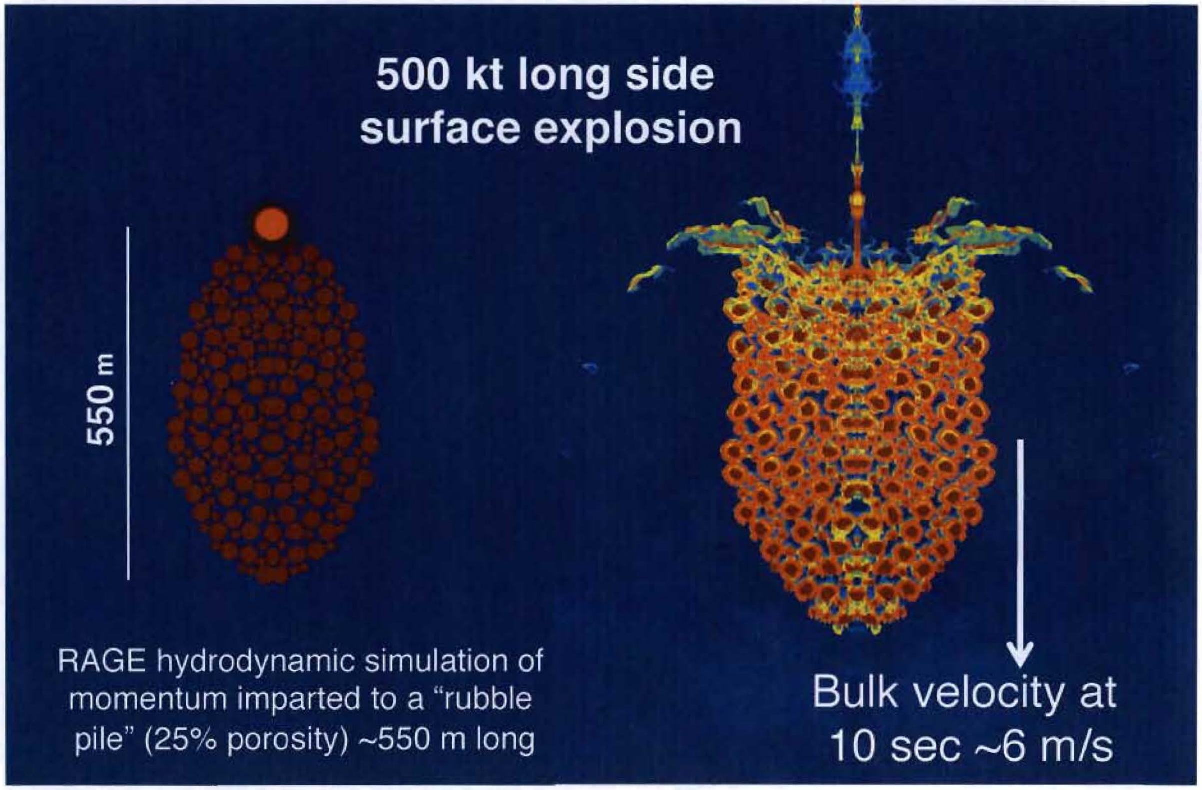

Weaver et. al. 2010

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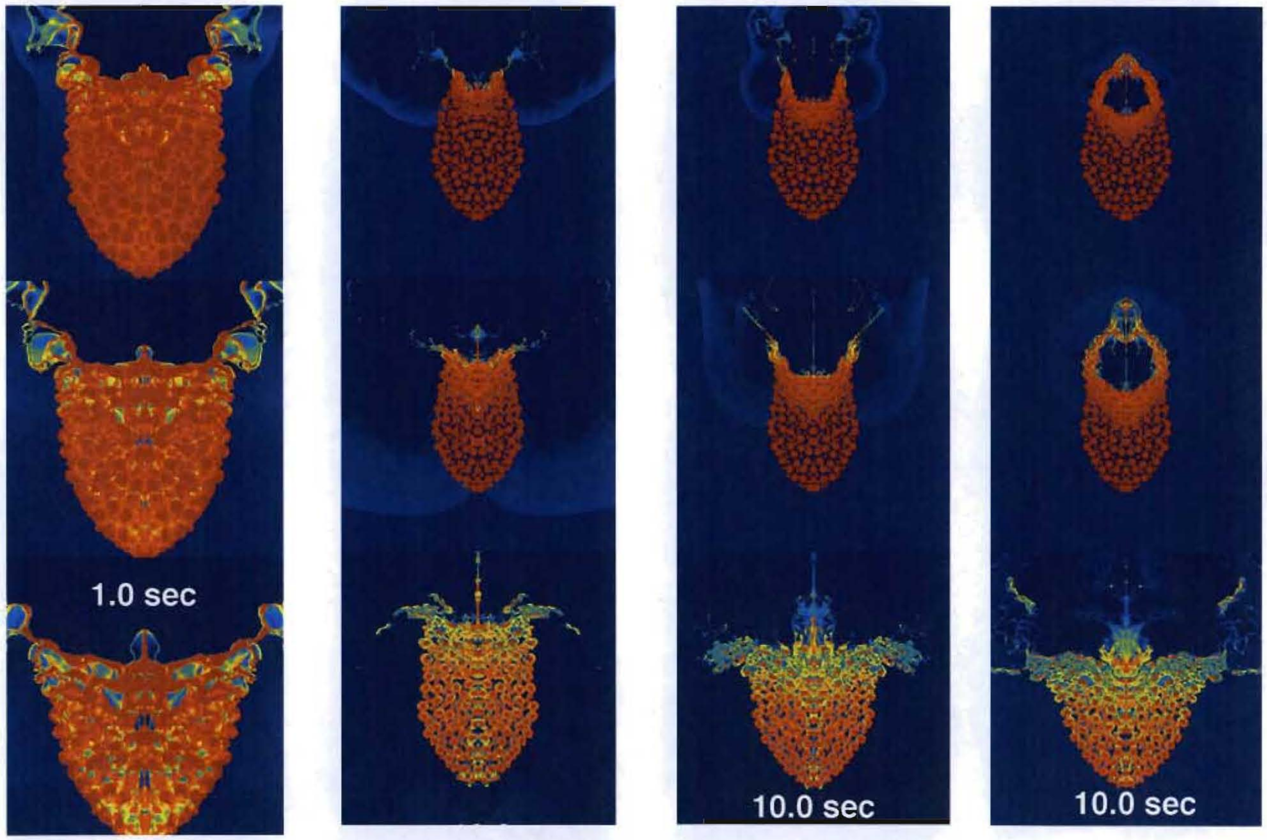
Initial Results from a 500 kt Energy Source as a function of Depth-of-Burial – effects of porosity

DOB 0 m Background alluvium	DOB 0 m Porous object	DOB 45 m Porous object	DOB 95 m Porous object

0.2 sec

0.5 sec



34 m/s (1 s)	6 m/s (10 s)	8 m/s	7 m/s

Snapshots of the density structure (log-scale) during the explosion

0.001 – 5 g/cc

As expected porosity depletes available shock energy and results in bulk velocity transfers ~5 times smaller

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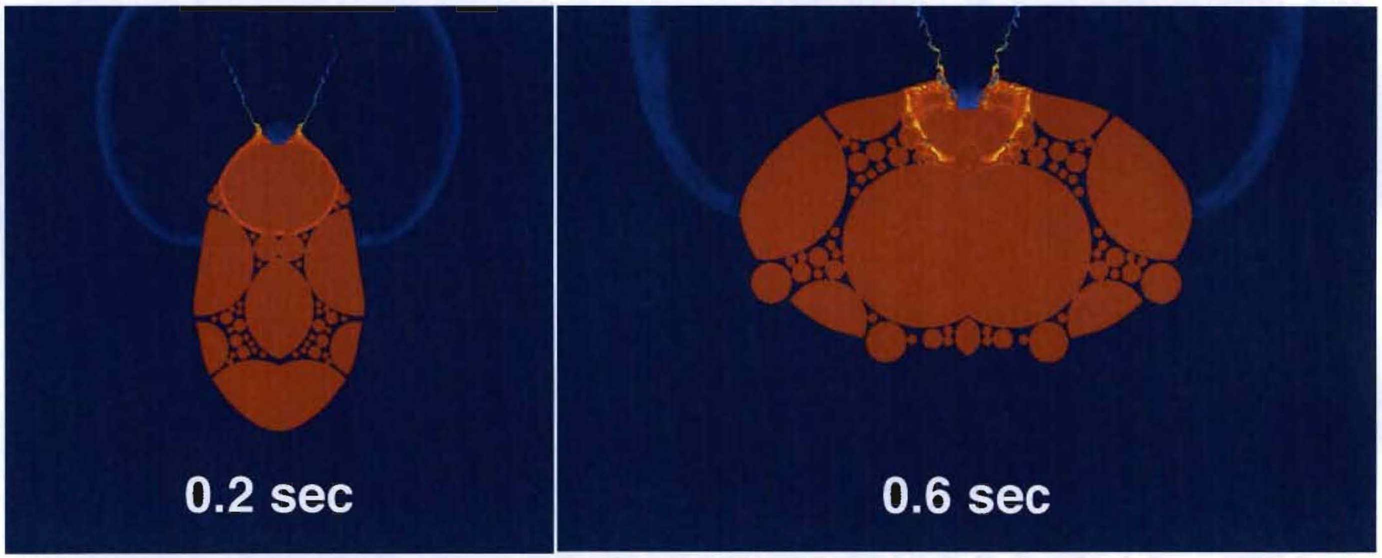
Vary internal composition with porosity

Surface burst (long side); large internal structures

Surface burst (short side); large internal structures



One suggestion is that Asteroid 25143 Itokawa has large internal "rocks"; here we explore 500 kt explosions with non-spherical large rock internal composition

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Summary of Current Asteroid Mitigation by Surface or Subsurface Nuclear Explosions

Surface and subsurface nuclear explosions of "modest" energy (~500 kt) seem to be extremely effective at a total disruption of the models examined so far (~500 m length)

- **Our calculations have progressed from simple solid shape conforming models with a central explosion to "rubble pile" composition with and without porosity**
- **A nuclear explosive is not a bad thing for this use; We are examining the "peaceful" use of nuclear explosives: international consensus on which country's explosive to be used; viable alternative to mitigate PHO hazard; only possibility for short notice**
- **The escape velocity from the Asteroid 25143 Itokawa is ~0.2 m/s (Wikipedia), so any imparted velocities to fragments greater than this will not re-aggregate**
- **Average results from RAGE modeling:**
  - **Solid iron asteroids of the 500 m class with a central explosion result in velocities of ~ 50 m/s**
  - **Non-porous and non-uniform (rubble pile) objects have imparted velocities >10 m/s of all DOBs**
  - **Porous objects with basic shock mechanics have imparted velocities ~ 5 m/s and take about 10 times longer to achieve peak velocities (10 sec vs 1 sec)**

Future work proposed to continue this investigation

- For future work with the RAGE calculations, we will include the more realistic Johnson/Cook material failure model (as available in code)
- We will examine various "rubble pile" compositions
  - Variation of size of "rocks"
- Perform additional 3D models with these changes
- Effects of radiation deposition (additional momentum) will be examined for contact/surface bursts
- We will also examine other asteroid shapes from the NASA database