Physics Based Simulation of Potentially Hazardous Asteroids Entry, Break-up and Impact

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Tasks, Products & Interactions

1. Characterization

Properties, Test cases ↓ Trajectory (JPL/MPC)

2. Physics-based entry & breakup

Hi-fidelity simulations ↓ Near-field energy deposition

3. Surface damage effects

Winds/overpressure ↓ Land, tsunami

4. PHA Risk Assessment: Min. size and time req'd for mitigation. Max. size where civil defense is OK

↓

Predicted impact assessment tools → **Decision Makers**

Mitigation

(3) Meteorite Properties

The Chemical Classes – Extreme Diversity

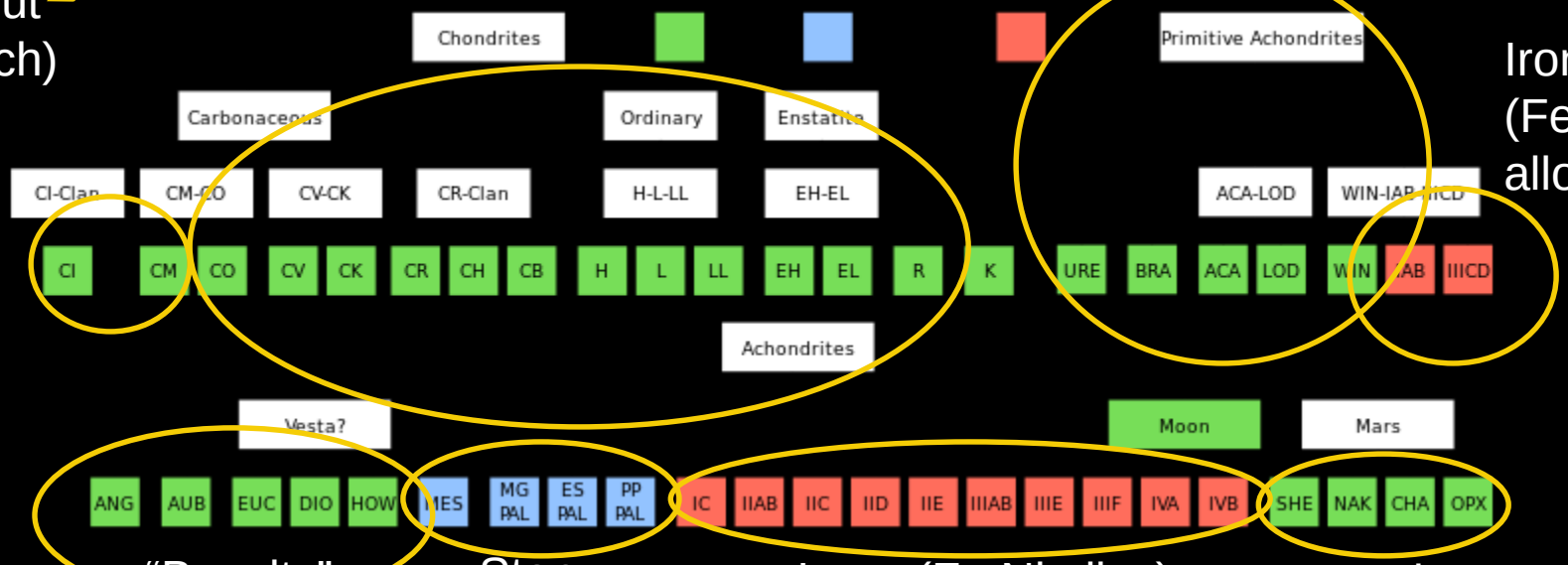
Based on asteroids, these are probably most common, but …..

Chondritic (Solar but water-rich)

Chondritic (Solar)

Chondritic (Solar) but igneous

Irons (Fe,Ni alloy)



"Basalts"

Stony-irons

Irons (Fe,Ni alloy)

"Basalts"

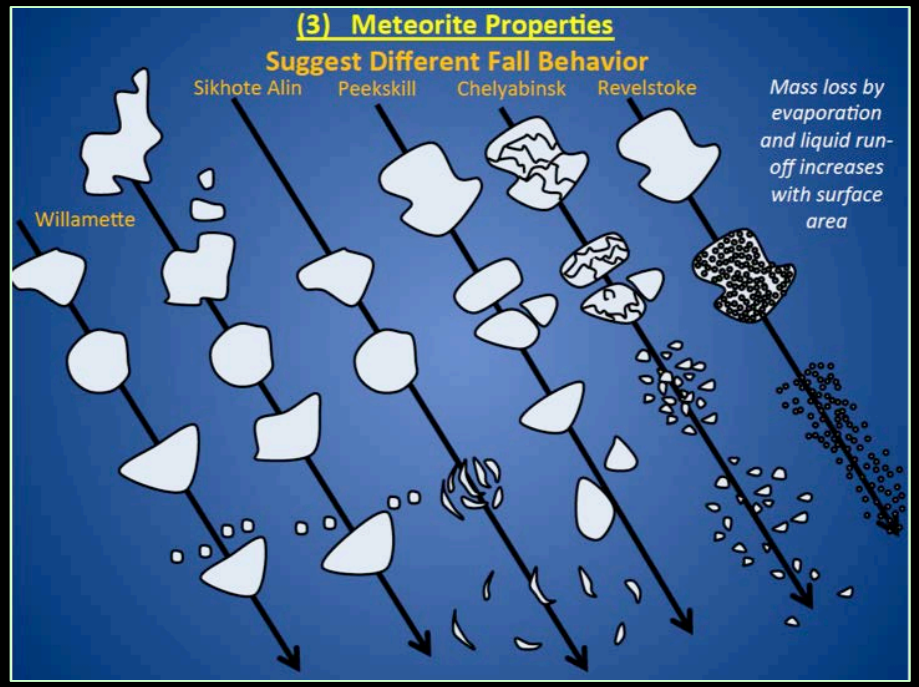
Meteorite compositions (elemental, isotopic, molecular,=mineralogical) are extremely well-known. Physical properties are not.

Asteroid Characterization

- The atmospheric interaction and break-up depend on characteristics
  - (Mass, size, composition, shapes, spin, fissures and fractures, etc.)

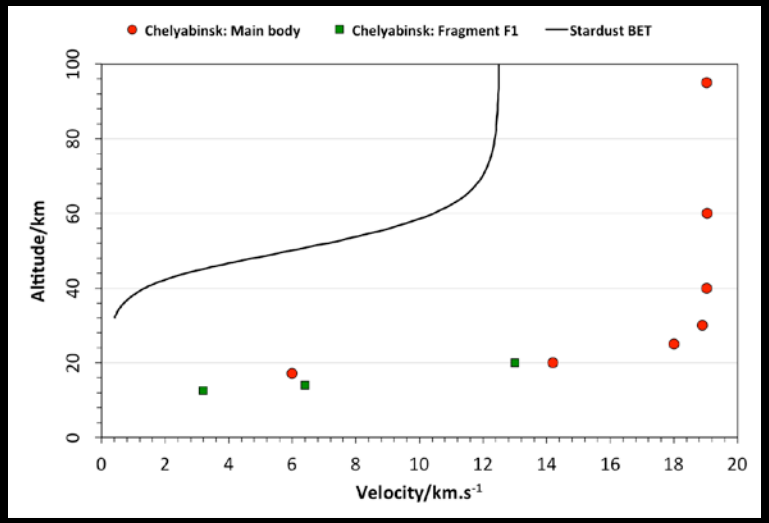
- Characterization Task: Models of the different classes of asteroids in space environment coupled with physical properties of PHAs from literature and from in-house study of meteorites, ground-based observations, and eventually, in-situ measurements

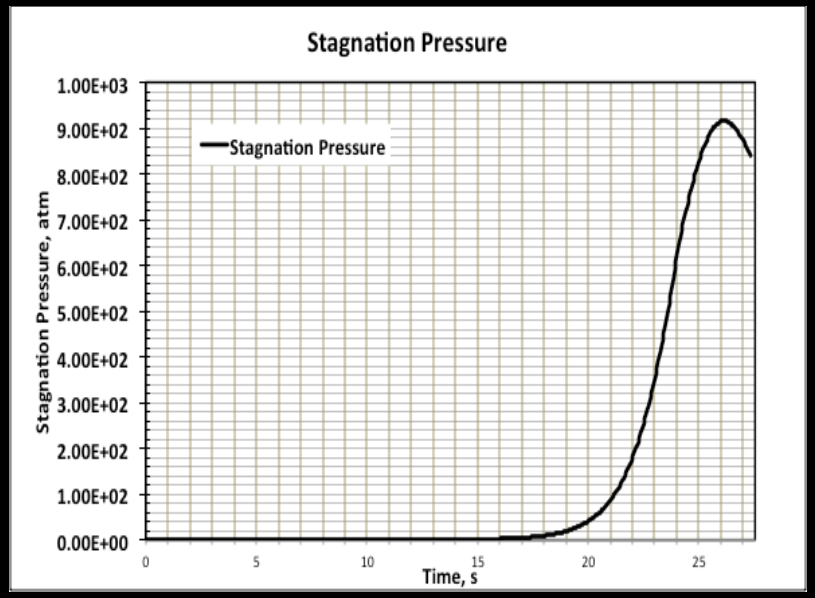
- Limited observations of meteor breakup and the characteristics of the recovered meteorites are part of the clue to reconstruction

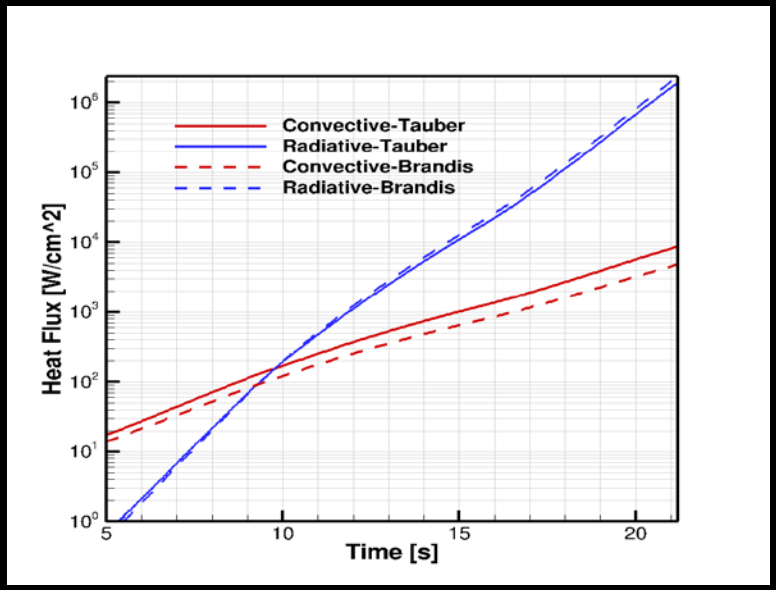


Entry Break-up:
SOA Physics based Simulation Tools

- Stardust V=12.7 km/s Chelyabinsk = 20 km/s
  - Break-up of Chelyabinsk 20 m object (70 km – 20 km)
- NASA entry body design and analysis tools are valid up to 16 km/s
  - Above 16 km/s our flow solvers need to be modified due to higher levels of ionization
- 5m asteroid entering at 16 km/s:
  - Shock layer generates 1 MW/cm2, and
  - Stagnation pressure of 40 atm (at 20 sec)

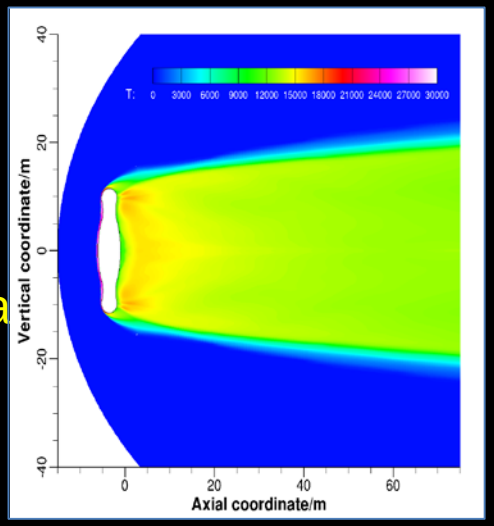


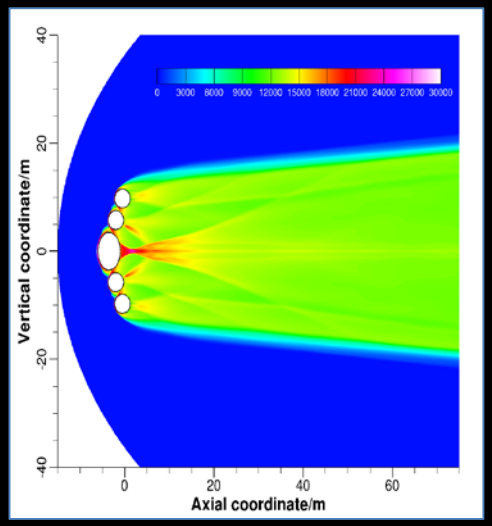


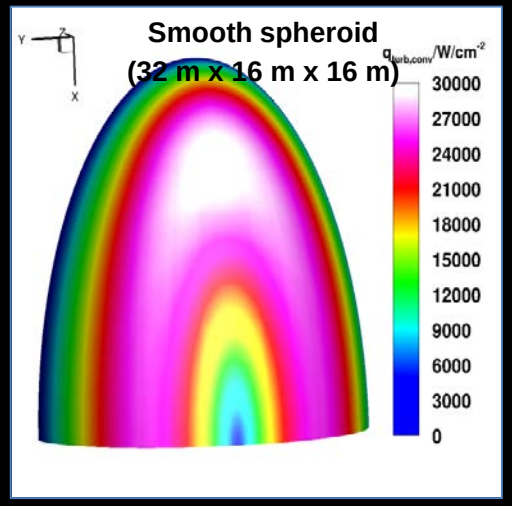


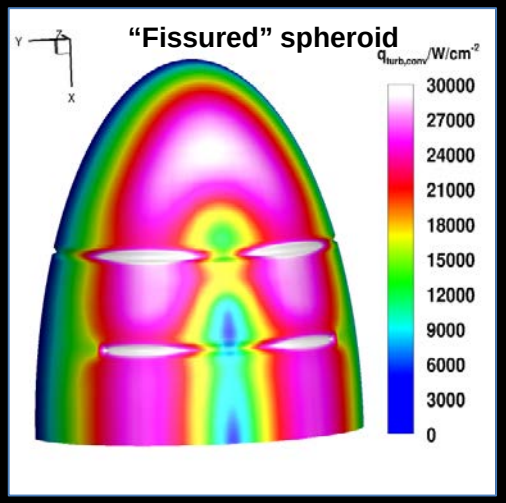
Examples from High-fidelity Simulations

- Single body (smooth)
- Shape changes
- Post-break-up – Multi-bodies
- Complex shapes with fissures a
- Complex physics

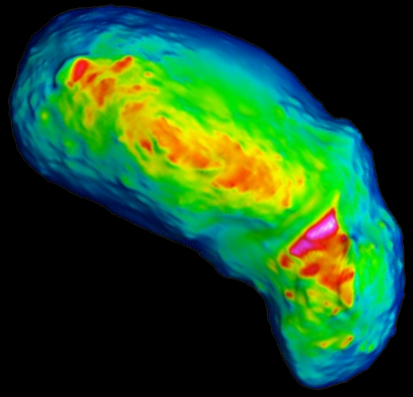








Pressure contours 1/38-scale Itokawa (20 km/s, 30 bar stag. Pressure)

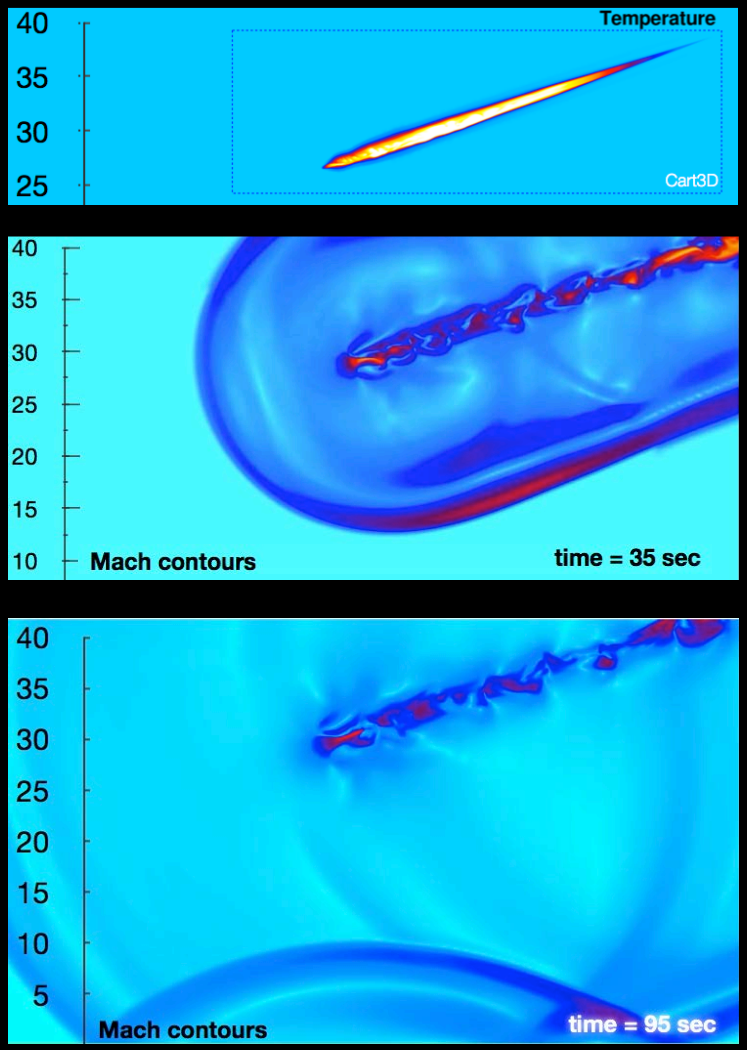


High-fidelity exploratory simulations define instantaneous conditions that can lead to understanding the cause of break-up. Fracture/Break-up models will be complex

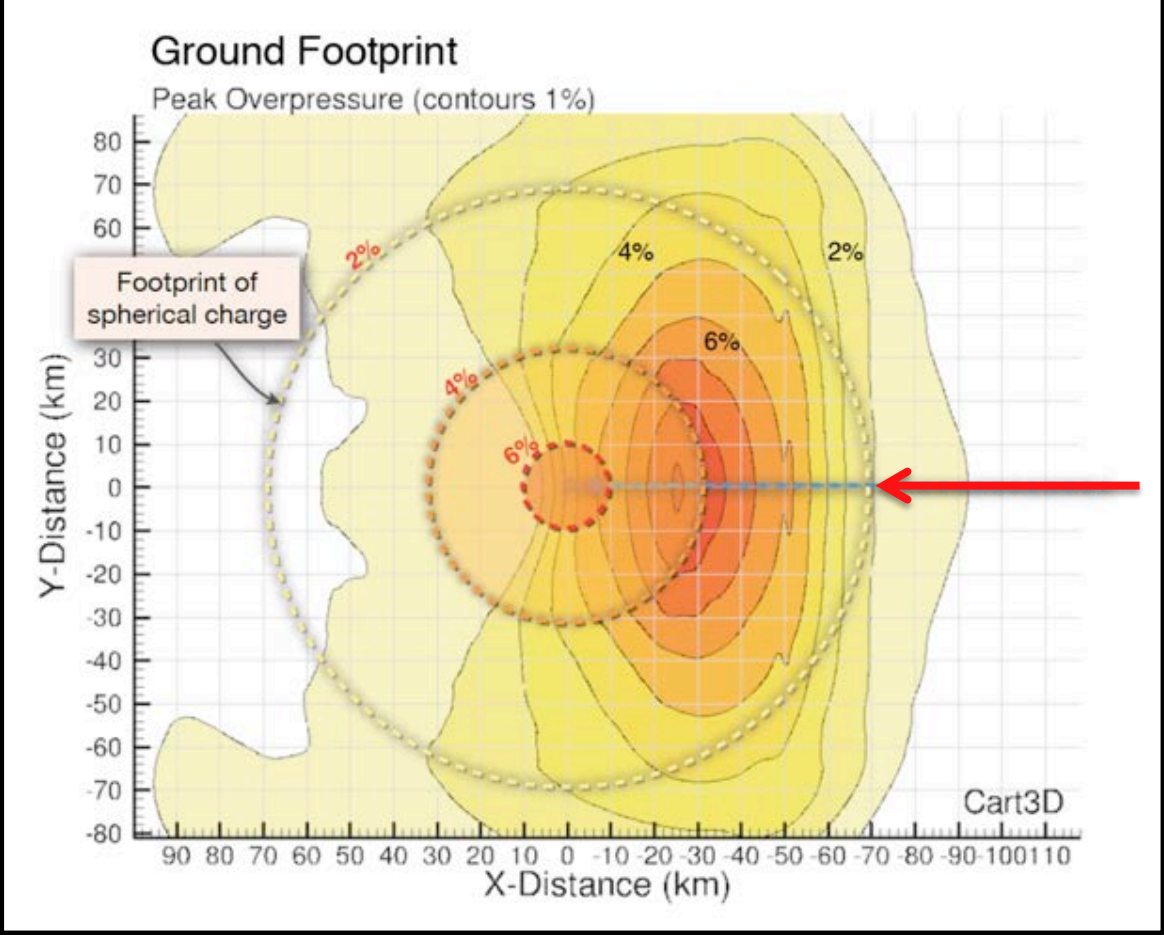
Blast Propagation

- Blast propagation through the atmosphere, simulated using Cart3D
  - Cart3D is a NASA developed code
  - Unstructured, Cartesian, Eulerian solver
  - Energy added to flow in multiple ways
    - Static spherical charge
    - Line source
- Time-dependent pressures tracked on the ground
  - Peak pressure magnitude
  - Arrival times
- Computed results compared with Popova et. al (2013)
  - ~20m diameter
  - ~20 km/s entry velocity

Cart3D asteroid entry modeling



Surface Interaction and Consequence



The predicted surface over-pressure pattern appear to be similar to observations and other predictions

Concluding Remarks

Current efforts focused on multiple fronts to address this "Grand Challenge"

- Characterization, high-fidelity physics based tools development, atmospheric and surface interaction, and damage estimation.
- The meteor characteristics and the physics of entry/break-up are more demanding than the spacecraft entry problem
- Developing tools for the break-up may lead us to design space-craft better

Synergy exists between planetary probe, airless body and the planetary defense communities

- The problems lend themselves naturally for collaboration and communication and is international in nature

<u>If interested:</u>

- First International Workshop on "Potentially Hazardous Asteroids Characterization, Atmospheric Entry and Risk Assessment"
- July 7-9, 2015 @ NASA Ames Research Center
  - https://planetary-defense.arc.nasa.gov/workshop2015/