

Analysis of Potentially Hazardous Asteroids



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(1) NASA Ames Research Center

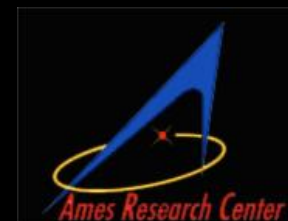
(2) ERC, Inc.

(3) Bay Area Environmental Research Institute

(4) NYU, Courant Institute of Mathematical Science

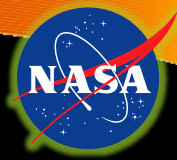
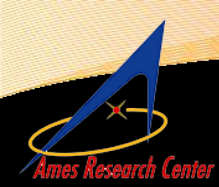
SBAG Meeting

06/29/2015 Washington D.C.



Outline

- **October 2014 Assignment to NASA Ames to address the asteroid threat: Project objective and approach.**
- **Four Tasks and sample results ~ 9 months into project.**
- **Multi-lateral workshop relevant to this project being held at NASA Ames July 7/8/9.**

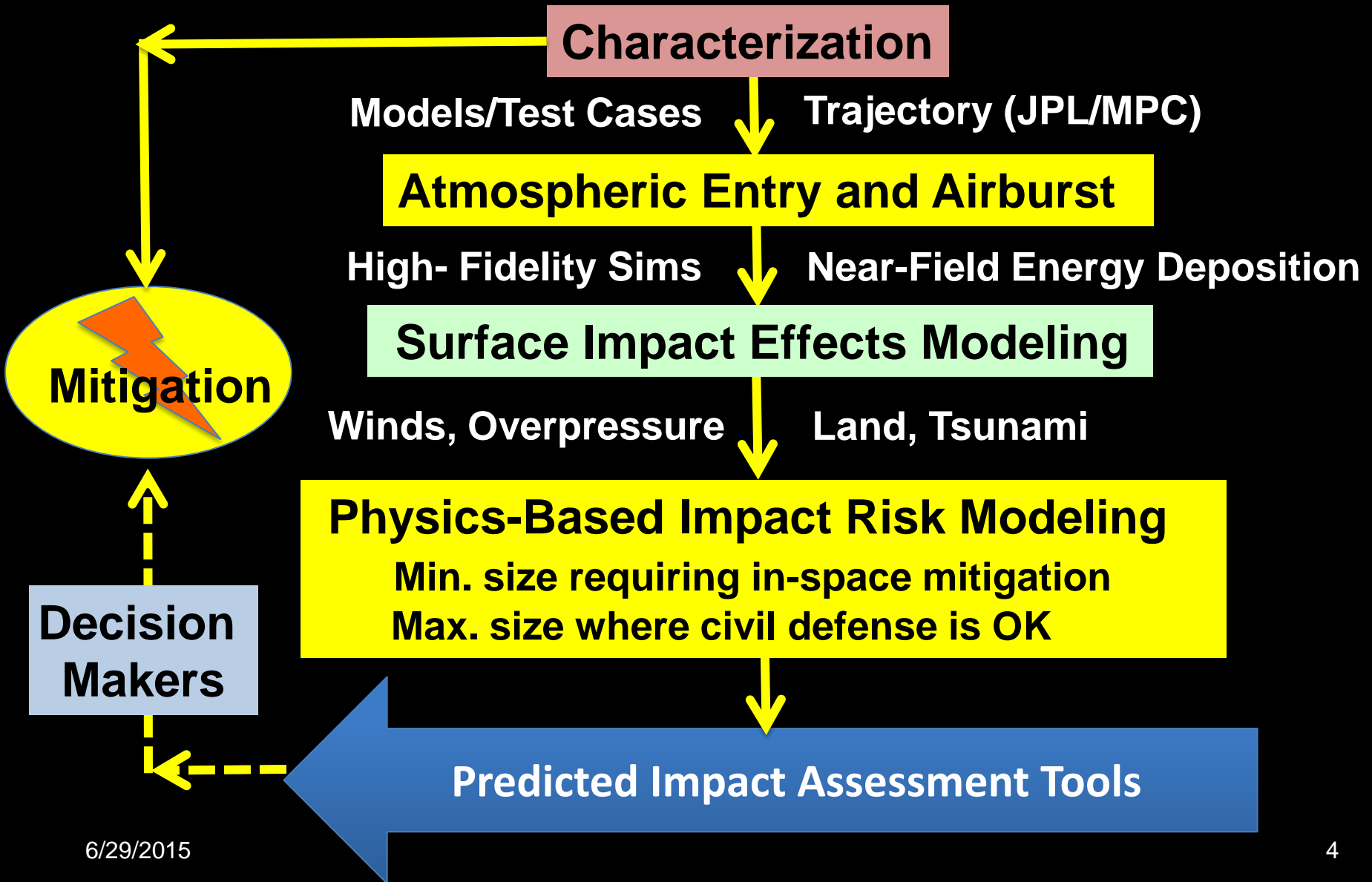


Planetary Defense Integrated Product Team

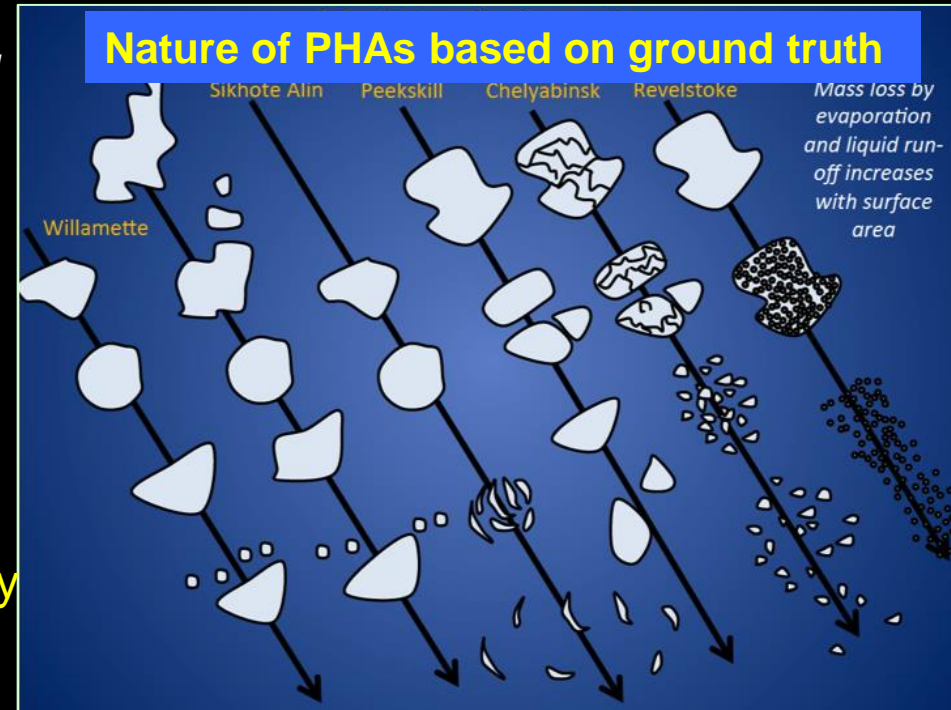
Objective: Develop Predictive Impact Assessment Tools to Support Decision Makers In the event of a pending impact by a PHA.

Approach: Characterize PHAs, Leverage NASA and DoE Codes to Conduct Physics-Based Simulations of Meteor Entry/Breakup, Surface Damage and Bound Associated Risks.

Focus is on objects under 100 m in diameter

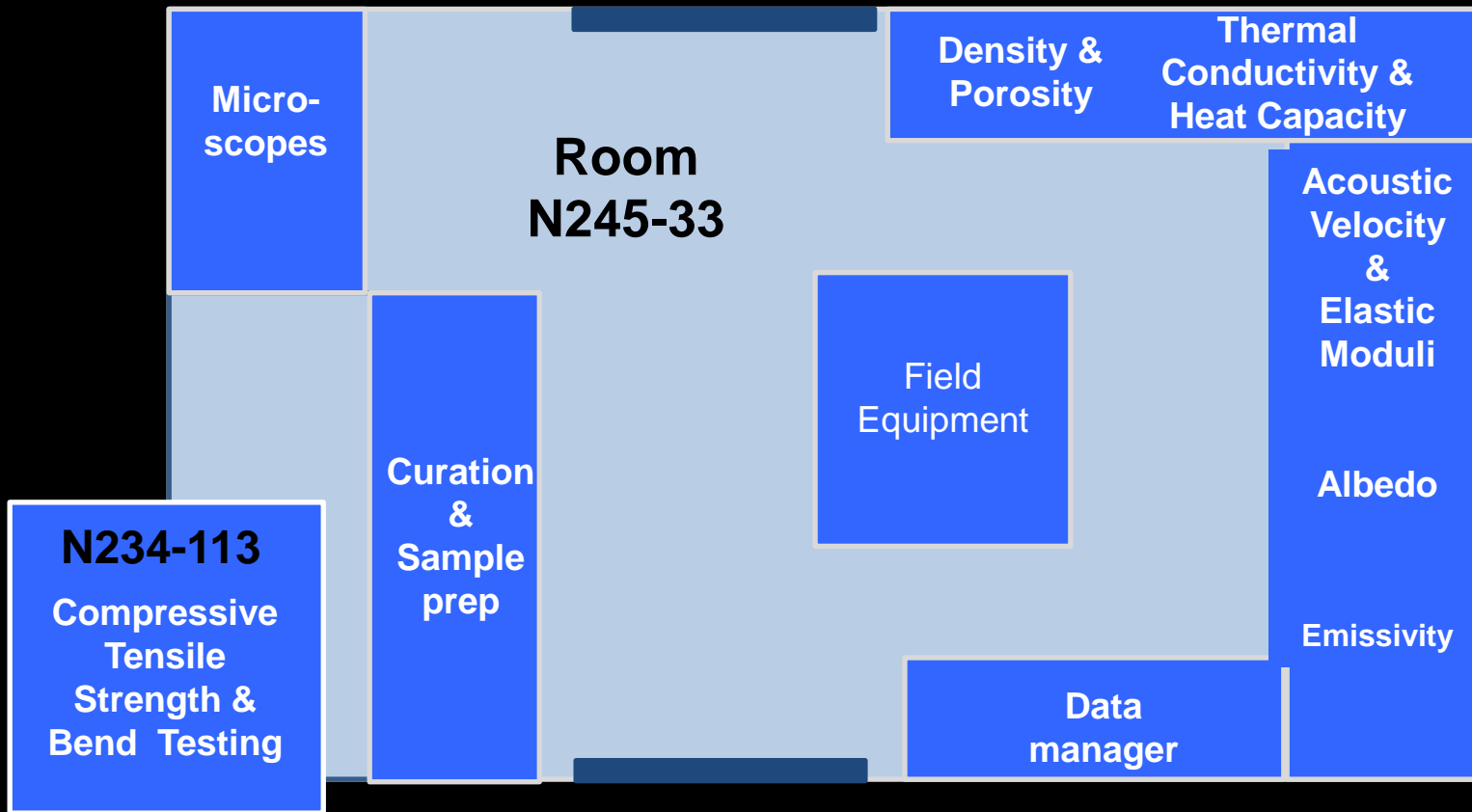


- **Task: Compile what is known about the characteristics of different spectral classes of NEA's by relating observations of the PHA population to what has been learned from the meteoritic collection. Validate these models and determine what they mean for atmospheric entry and impact effects.**
- **Characteristics compiled and modeled will be focused on those needed for entry and mitigation modeling. Will include mass, size, shape, internal structure, fracture state, spin, composition, density, etc.**
- **Initial version of compiled characteristics will be made available on Web starting 10/01/2015.**



- **Observational campaign to determine the effect of phase angle on derived asteroid parameters (diameters, albedos and IR beaming parameter completed in May and another approved for Fall 2015₅**

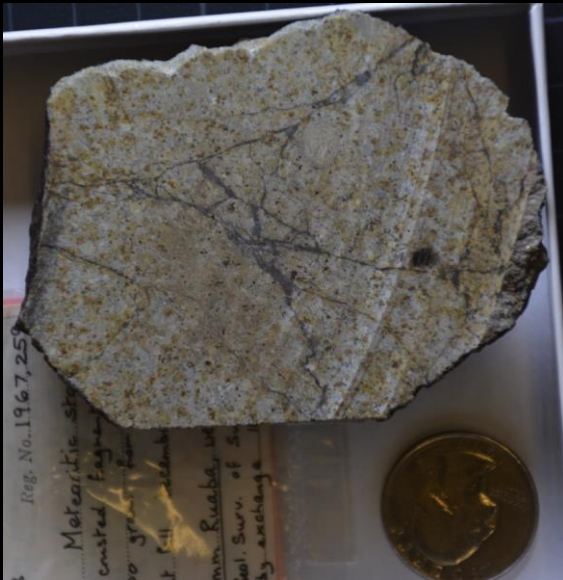
Meteorite Characterization Lab



Initial Operating Configuration

Primary equipment for each station in lab and undergoing initial tests.

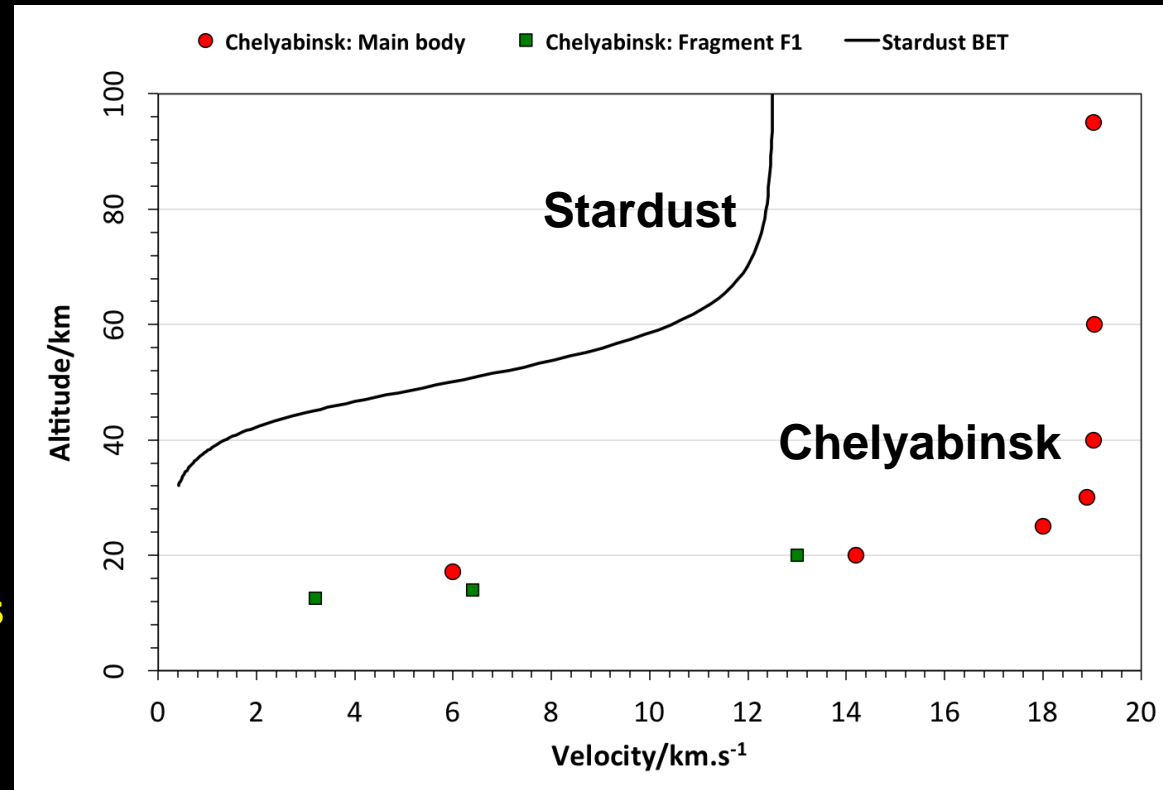
- Visited Natural History Museum of Vienna and Natural History Museum of London. Imaged 66 meteorites which exhibit internal fractures.
- In process of classifying observed structures.



- **Task:** Leverage NASA entry vehicle design expertise and what is known about the physical characteristics for different spectral classes of NEAs to model their atmospheric entry and breakup (airburst) effects.

Status:

- **NASA flow solver capability extended to 20 km/s – More work needed for 30 km/s.**
- **Material thermal response model has been developed for ordinary chondritic material.**
 - Material was tested in LHMEI at 20 kW/cm² radiative heating.
- **Structural response computations cracks and voids have begun.**



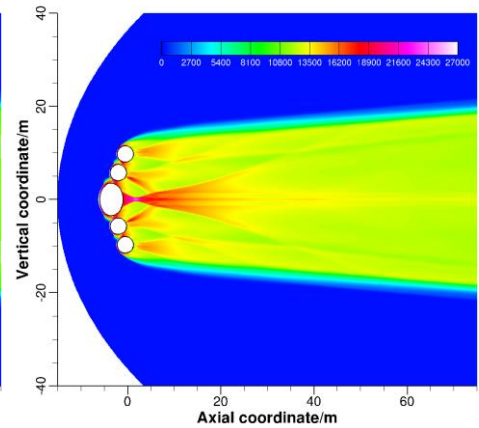
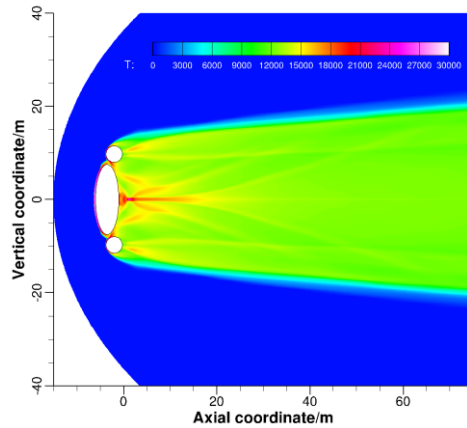
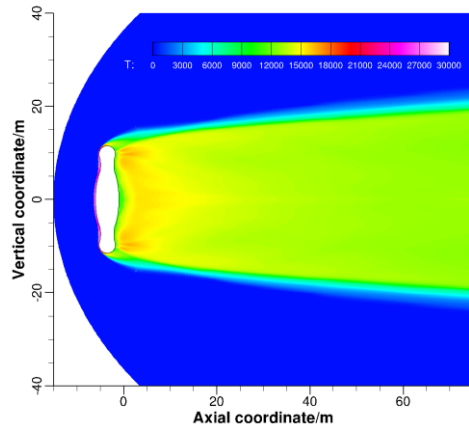
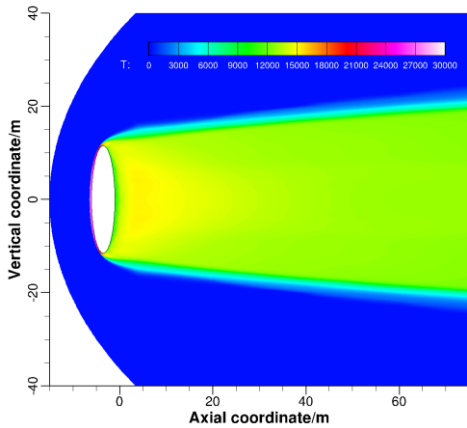
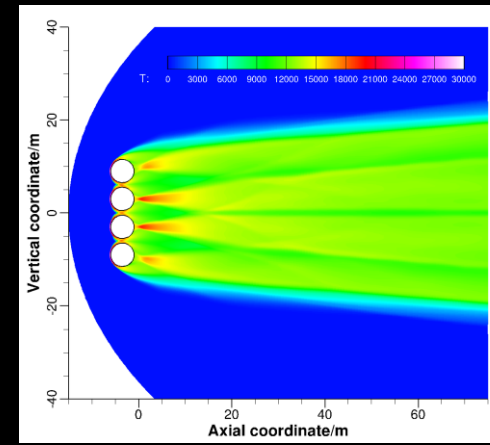
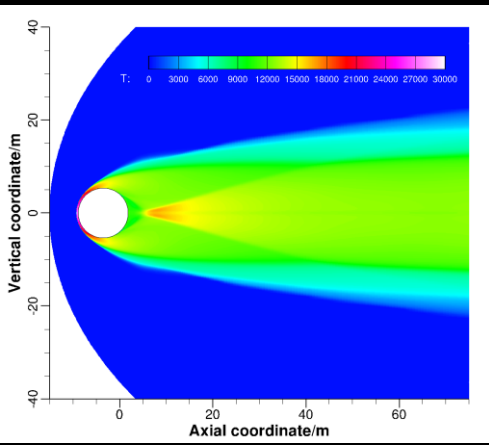
- **Luminous energy estimates computed for various “regular” sizes/shapes and velocities – Shown that “Shape Matters” in producing light curves.**

Multiple Body Analysis

- Currently no physics based model/mechanism for fragmentation.
- Supplemented current knowledge with computations for idealized shapes.

- **Status:**

- Computations performed for various shapes and arrangements
 - Extraction of luminous energy from the wake; Shape Matters.
 - Extraction of aerodynamic/aerothermodynamic interaction forces/energies from computations.



All results shown here are for a velocity of 20 km/s and 30 bar of stag. pressure

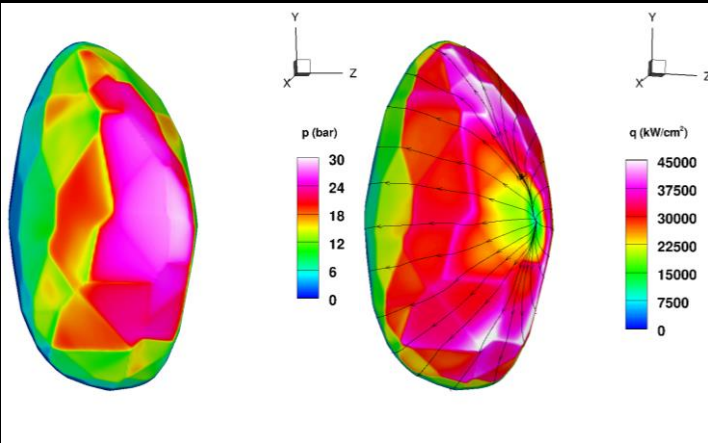
More Realistic Shapes

- Conventional meteor physics assumes a spherical shape at entry

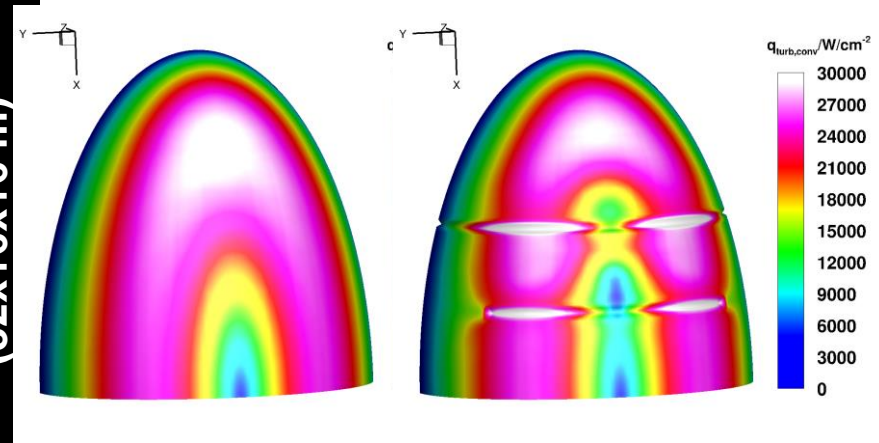
Status:

- Computations performed scaled versions of Asteroid Itokawa & NEO 2008 TC₃
 - 1/38 scale Itokawa is a dumbbell shape with “weakness” at the neck
 - 2008 TC₃ most likely oriented in flight
- Attempt to understand aerothermal impact of surface fissures

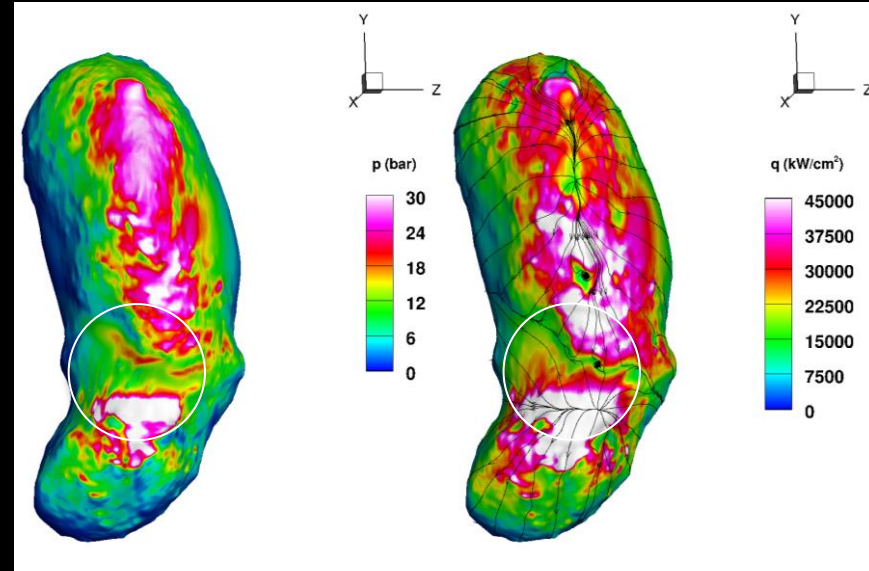
2x-scale NEO 2008 TC₃



Ellipsoid (32x16x16 m)



1/38-scale Itokawa

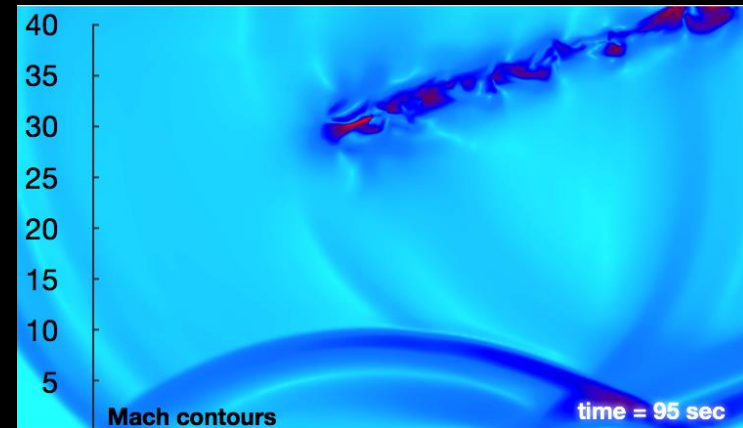
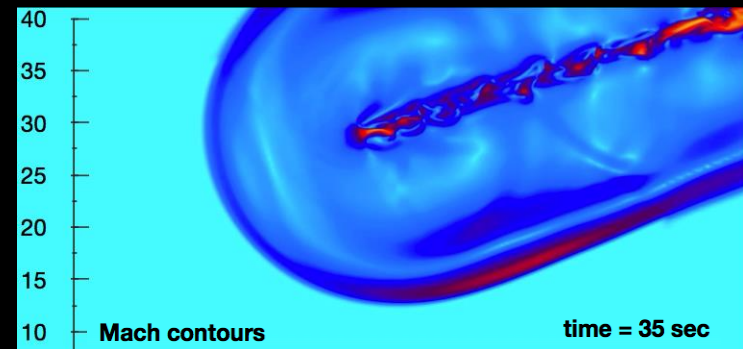
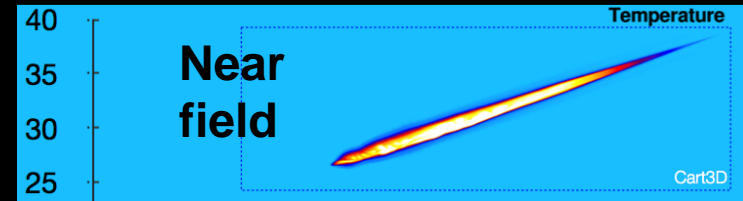


All results shown here are for a velocity of 20 km/s and 30 bar of stag. pressure 10

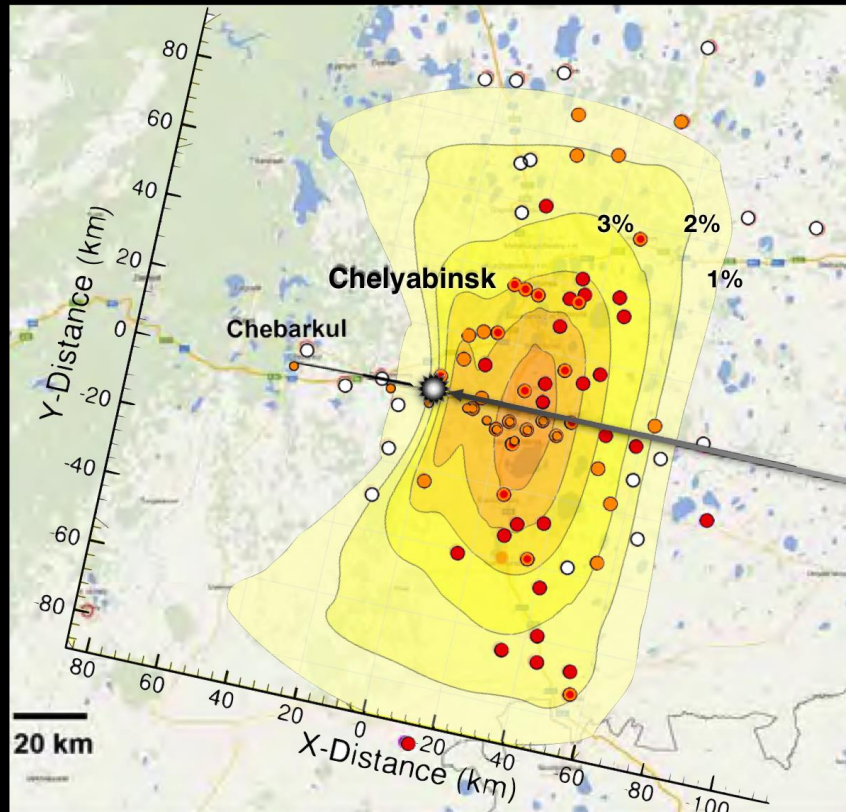
Work with impact effects expertise and physical characteristics of spectral classes to model surface impact effects on land and tsunami.

- Approach is to simulate blast propagation through the atmosphere using **Cart3D AND energy deposition from Task 2.**
 - Cart3D is a NASA developed code
 - Unstructured, Cartesian, Eulerian solver

Cart3D asteroid entry modeling



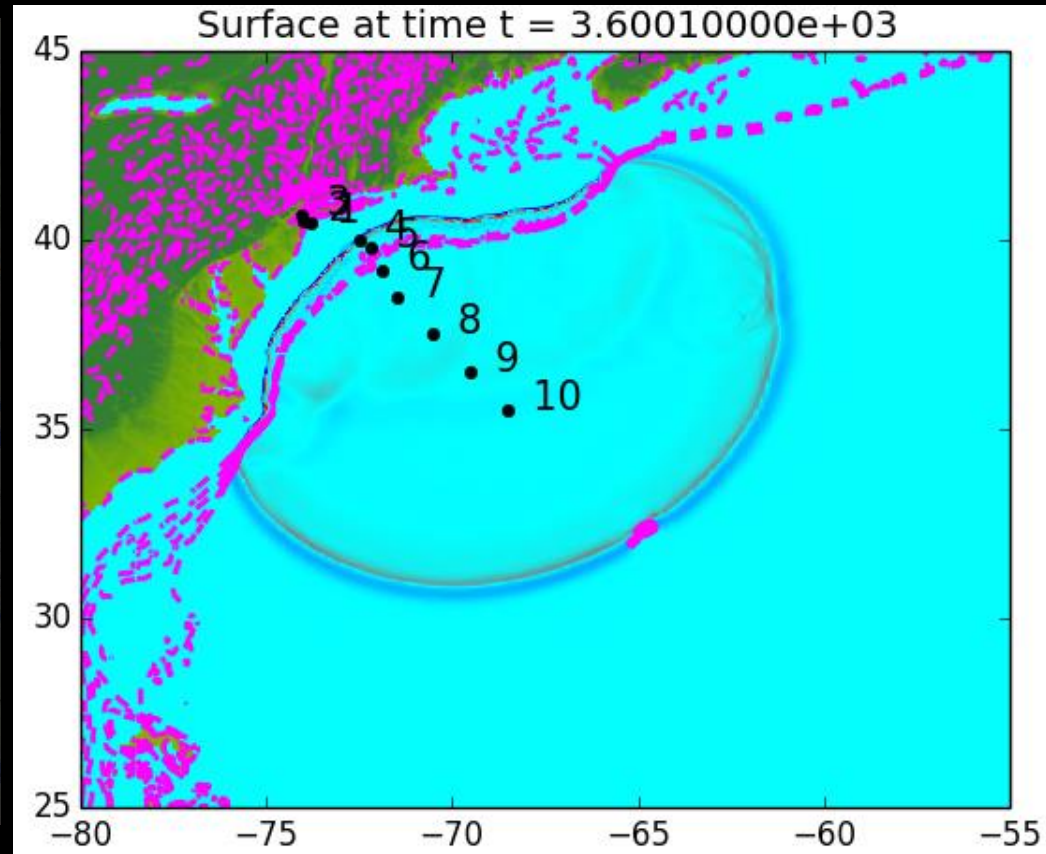
Land (Chelyabinsk)



Surface overpressure compared to observed glass breakage (Popova Science Express 2013). Based on Brown's energy deposition (Nature 2013)

6/29/2015

(Water)



Tsunami caused by a spherical airburst with same energy and altitude as Chelyabinsk located off the continental shelf on NY NY. Wave height in m.

Using inputs from Tasks 1-3, determine minimum size PHA impact requiring mitigation and advance warning.

Determine maximum size impactor for which civil defense measures emplaced weeks to days prior to impact are sufficient for mitigation.

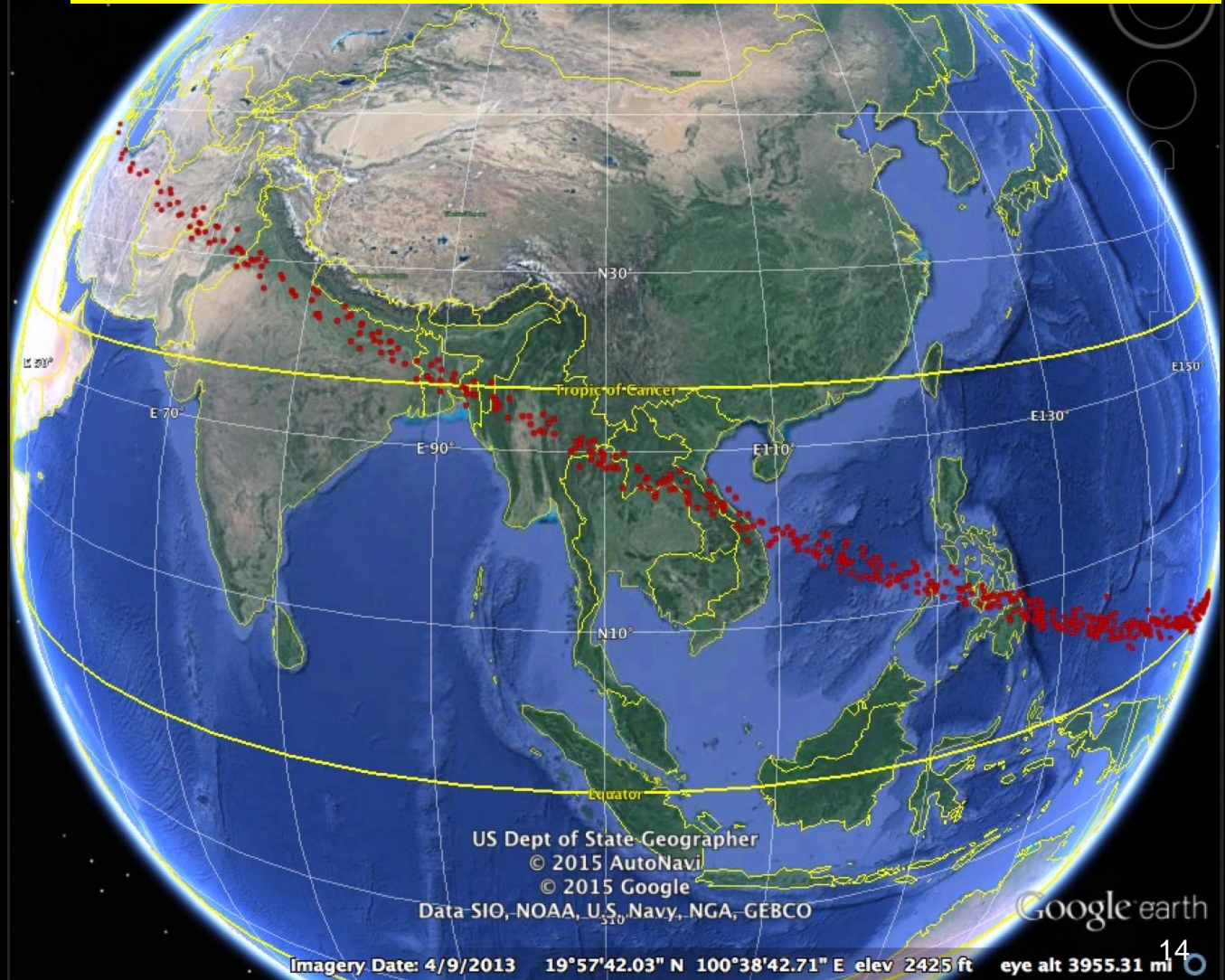
Develop Predicted Impact Assessment Tools to support and advise decision makers in the event of discovery of an impact threat.

PDC2015 Hypothetical Scenario

Strike by a 150 – 400 m PHA

- Generated by JPL (Paul Chodas) as an exercise at The IAA Planetary Defense Conf. – April 2015.
- Intentionally selected to be a really “bad day”.
- Red dots show swath of possible impacts, based on imprecise trajectory tracking from early ground observations.

<http://neo.jpl.nasa.gov/pdc15/2015pdc03b.jpg> (P. Chodas)



Physics Based Strike Scenario

(Used Hills & Goda “textbook equations”)

- Modeled 303 potential strike cases from the day 1 risk corridor/trajectory data (given lat/long, entry angle, speed for each case)
- Ran 1000 Monte Carlo realizations for each case, sampling from ranges of diameter, density, and strength:

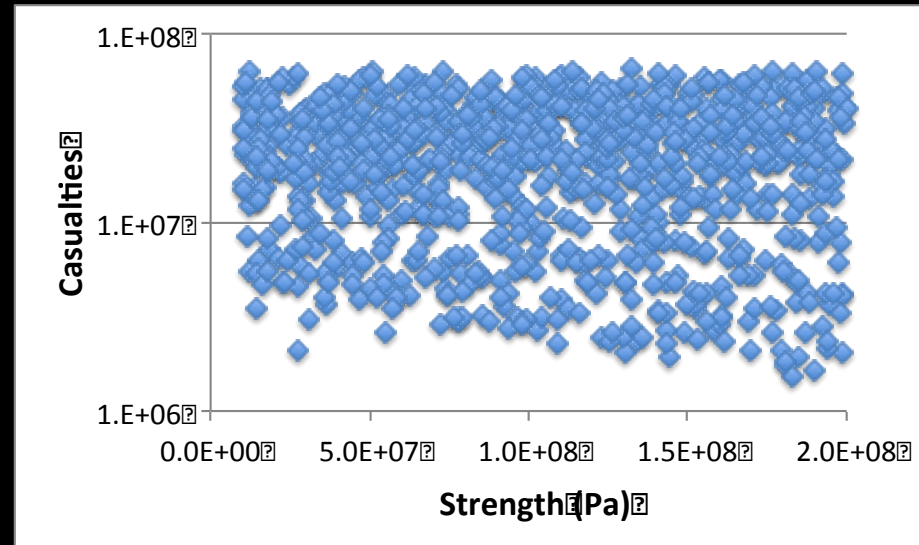
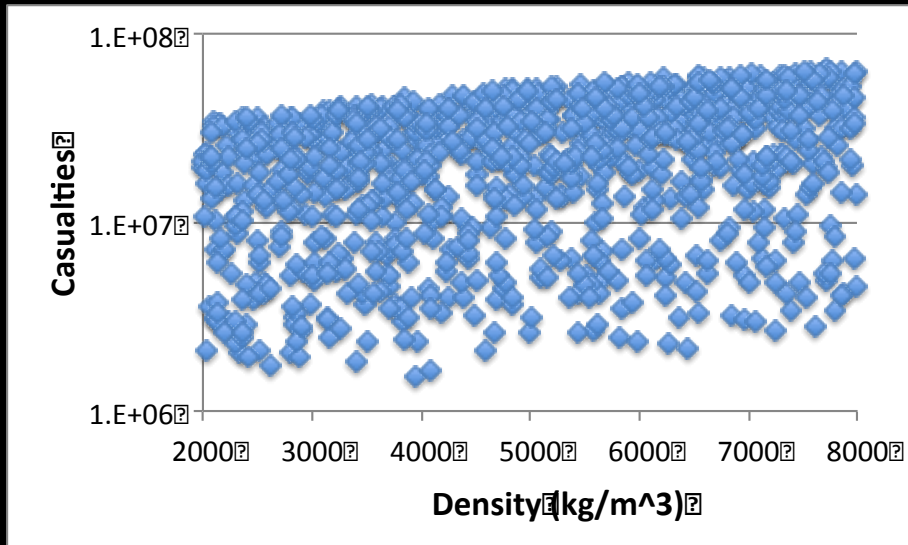
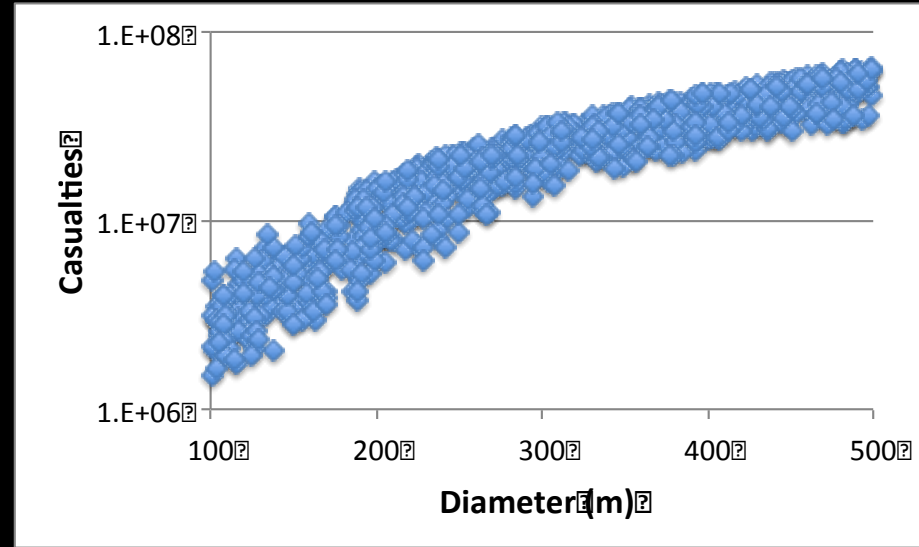
Diameter: 100-500 m

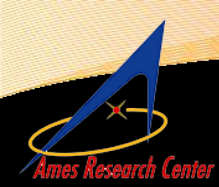
Density: 2000-8000 kg/m³

Strength 1E+7-2.0E+8 Pa

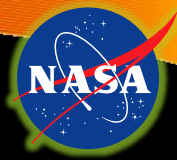
Sensitivity of Worst-Case Strike Scenario (270) to Uncertain Asteroid Parameters

Latitude 24.11, longitude 90.21, entry angle 35.7 deg, velocity 16.020 km/s





Workshop



<https://planetary-defense.arc.nasa.gov/workshop2015/>

First International Workshop on Potentially Hazardous Asteroids Characterization, Atmospheric Entry and Risk Assessment - July 7-9, 2015, NASA Ames Research Center

The NASA NEO Program (Program Executive, Lindley Johnson) is supporting research at NASA Ames Research Center on asteroid impacts through physical characterization, modeling of atmospheric entry/breakup, and risk assessments of impacts (land and water), with emphases on small impactors.

The workshop at Ames on July 7-9 brings together experts in these research areas to assess the state-of-the art and present recommendations for advancements

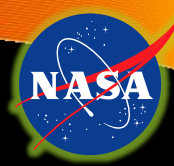
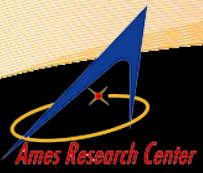
20 Oral presentations and 25-30 posters

Non Reimbursable Partnerships

- **Characterization, Entry/airburst [DoE LLNL (Miller), SNL (Summers, Boslough, Jennings)]**
- **Others to be determined following the July 7/8/9 workshop, e.g. Tsunami research with NOAA.**

Summary

- **Project started in FY 15 is progressing well (meeting milestones and producing deliverables).**
- **July 7/8/9 Workshop brings together world experts in the involved areas.**
 - **Leveraging opportunities afforded for the NEO Program Executive.**
 - **Outcome should provide basis for report on research for NEO generated tsunami to congress being conducted by NASA, NOAA and other government agencies.**
- **This activity fills a gap in the NEO Program's portfolio; namely quantifying risk of probable impact damage enabling sound advice to those making life or death decisions in the event of a pending PHA strike.**



Backup

Observational Investigation:

Quantify effects of phase angle on determination of asteroid parameters

- Embarked on an observational campaign to determine the effect of phase angle on derived asteroid parameters (diameters, albedos and IR beaming parameter.)
- Coordinated observing campaign in spring 2015 consisting of IRTF, UKIRT and Trappist observations of 3691 Bede, 1999 Cu3 and 2002FG7.

Object	Class	Phase Angle (°)	Photometry	Spectroscopy
3691 Bede	Xc	23 - 43	J, H, K, 10 μ m, 18.5 μ m	0.8 – 2.5 μ m
1999 CU3	Sl	8 - 69	J, H, K, 10 μ m, 18.5 μ m	0.8 – 2.5 μ m
2002 FG7	tbd	11 - 24	J, H, K, 10 μ m,	1.0 – 2.5 μ m, 7.5 – 13 μ m

Observational Investigation:

Quantify effects of phase angle on determination of asteroid parameters

NEA Characterization for Planetary Defense: Near-IR and Mid-IR Data vs Date UT
(PI D. Wooden, NASA Ames)

