



Asteroid Threat Assessment Project (ATAP)

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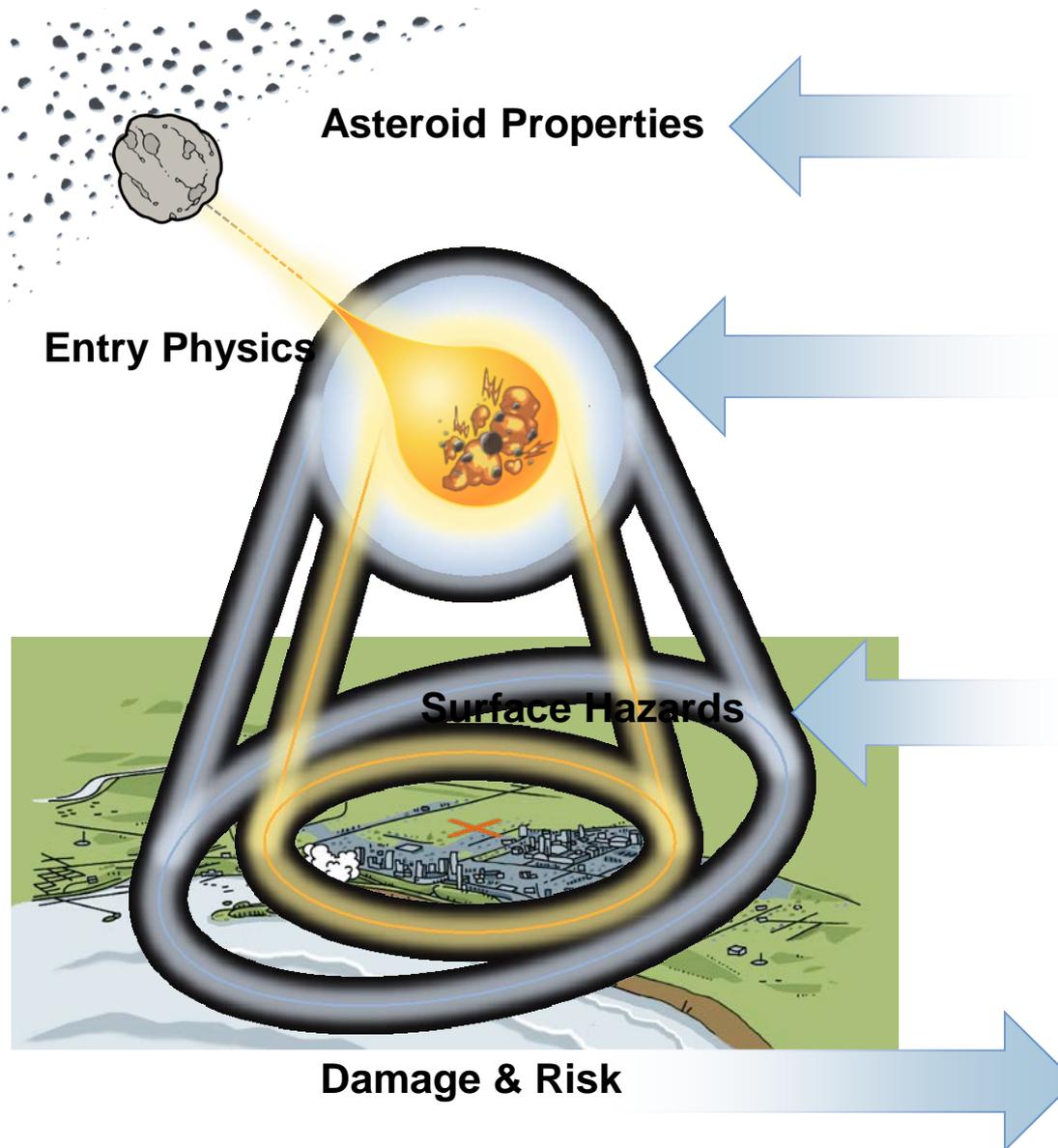
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Asteroid Threat Assessment Project
NASA Ames Research Center

Small Bolide Assessment Group (SBAG)

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Asteroid Threat Assessment



Characterization

- Measurements
- Inference
- Data aggregation
- Property database website

Entry Simulations & Testing

- Coupled aerothermodynamics
- Ablation & radiation modeling
- Arc jet testing

Hazard Simulations

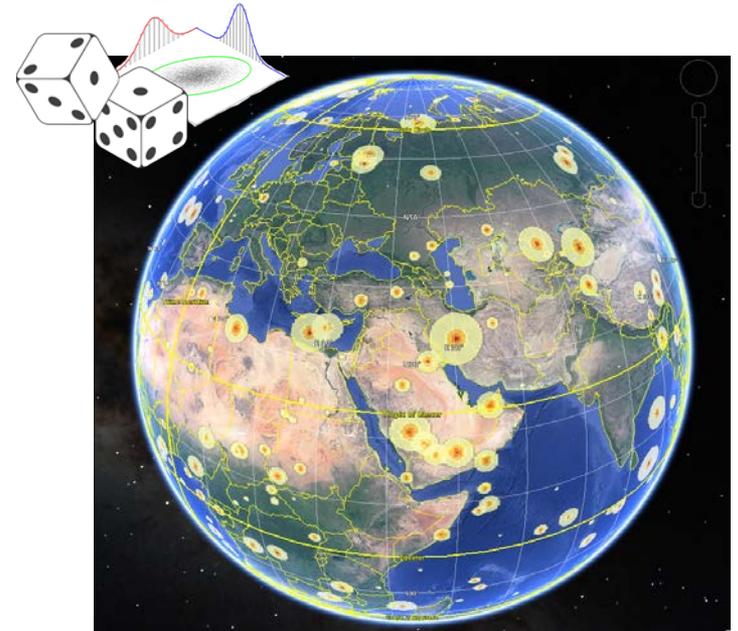
- 3D blast simulations
- Impact crater simulations
- Tsunami simulations
- Thermal radiation models
- Global effects

Probabilistic Risk Assessment

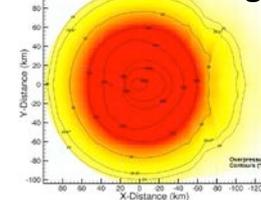
- Analytic physics-based entry and damage models
- Probabilistic Monte Carlo simulation using uncertainty distributions

Probabilistic Asteroid Impact Risk (PAIR) Model

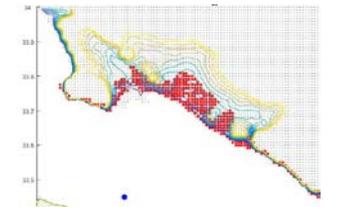
- PAIR model approach:
 - Uses analytic models of asteroid entry and hazards to assess damage from millions of impact cases
 - Samples uncertainty distributions of asteroid properties developed by characterization team
 - Location-specific affected populations capture range of consequences
 - Hazard models include blast overpressure, thermal radiation, tsunami, and global effects
 - Models anchored with high-fidelity simulations.
- Results & Applications
 - 2016 NEO Science Definition Team
 - Impact corridor risk assessment (TTX3 and PDC impact exercises)
 - Sensitivity to uncertainty in asteroid properties or modeling assumptions to guide model refinements and characterization efforts.



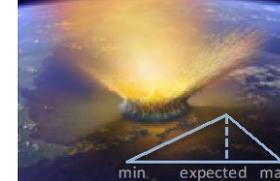
Local Blast and Thermal Damage



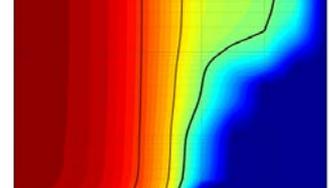
Tsunami Inundation



Global Effects

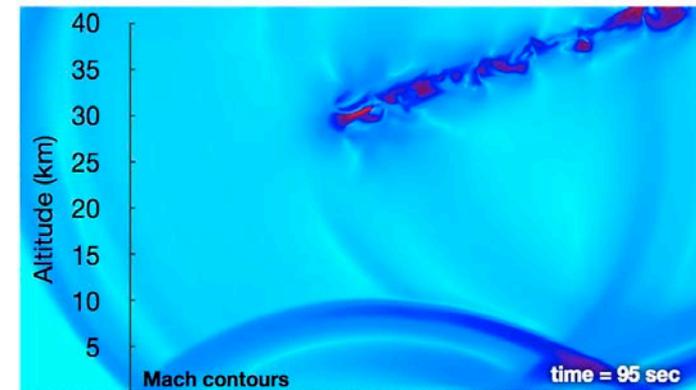
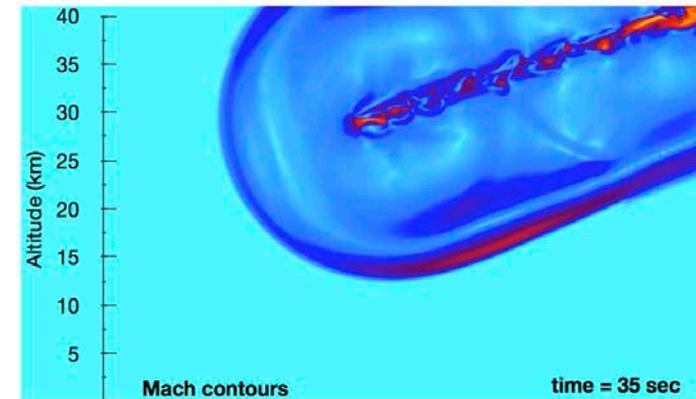


Ensemble Risk



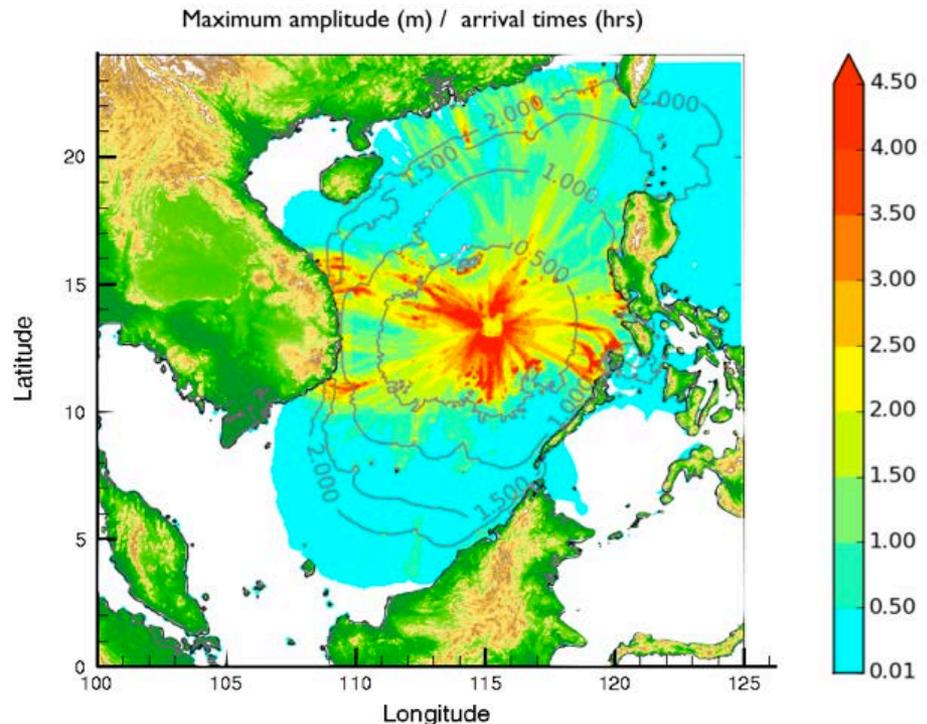
Hazard Simulation

- High-fidelity simulations of key impact hazards:
 - Tsunami Modeling
 - Surface Impact Modeling
 - Blast Overpressure Modeling
- Used to anchor and refine analytic models used in risk analysis
- Uses entry conditions and energy deposition from asteroid characterization and entry modeling efforts



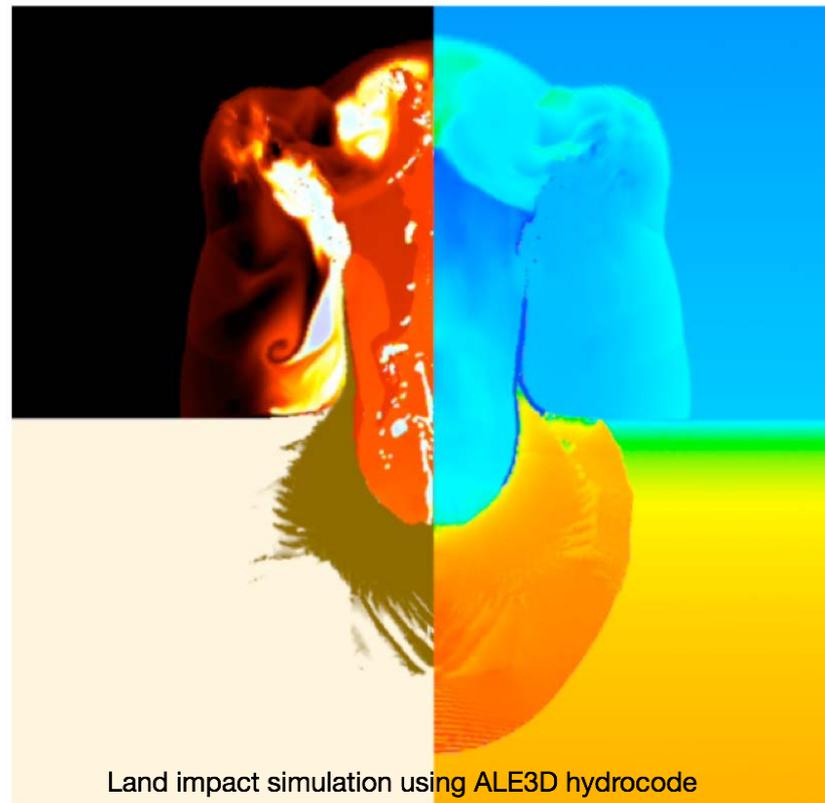
Tsunami Modeling

- Tsunami Workshop (Oct. 2016)
 - Sponsored the NASA/NOAA Workshop on Asteroid Threat Assessment: Asteroid-generated Tsunami (AGT) and Associated Risk, held in Seattle WA
 - Included head-to-head comparisons of tsunami simulations from NASA, DOE, NOAA and academia for a range of water impact and airburst cases (5, 100 & 250 MT)
- Outcome
 - 2003 SDT report may have overstated tsunami risk from asteroid airburst
 - Large airbursts may be reasonably modeled with Shallow Water Equations (SWE)
 - Higher frequencies associated with water impacts may merit study with Boussinesq or Linearized Euler solvers
- Follow-up
 - Parametric studies of SWE, Boussinesq, and Linearized Euler methods
 - Developing improved analytic models for tsunami run-up and run-in



Surface Impact Modeling

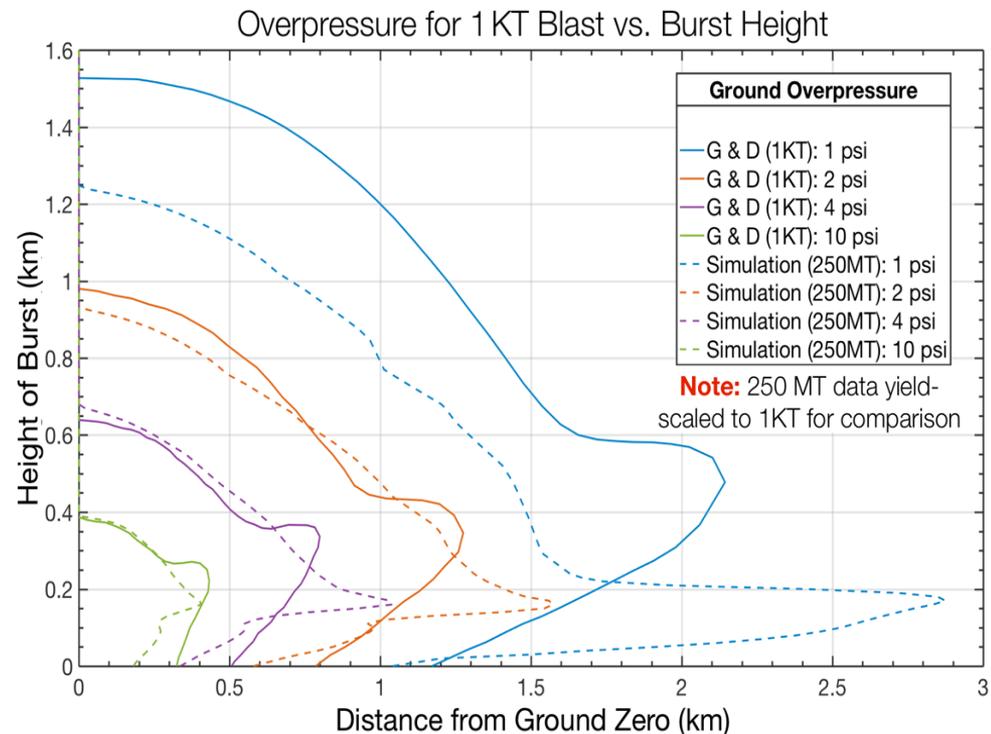
- Land Impacts
 - Nearfield: Hydrocode simulations of impactors up to 1 gigaton conducted for PDC17 impact scenario (Tokyo, Japan, May 2017)
 - Farfield Propagation: Coupling with NASA's Cart3D aerodynamic simulation code for far field blast propagation.
 - Includes both energy deposited in atmosphere and energy released at impact site.
- Water Impacts (Splashing)
 - High-fidelity hydrocode (ALE3D) simulations provide cavity size and salt water plume ejection, but expensive for long distance propagation
 - Provides initial waves for long distance propagation performed with developmental version of GeoClaw tsunami code
 - Formation of traveling wave trains from initial water cavities using different modeling approaches/wave equations
- Analytic model development/validation:
 - Impressive results for water impacts using engineering method based on use of Hankel functions (currently in development)



Land impact simulation using ALE3D hydrocode

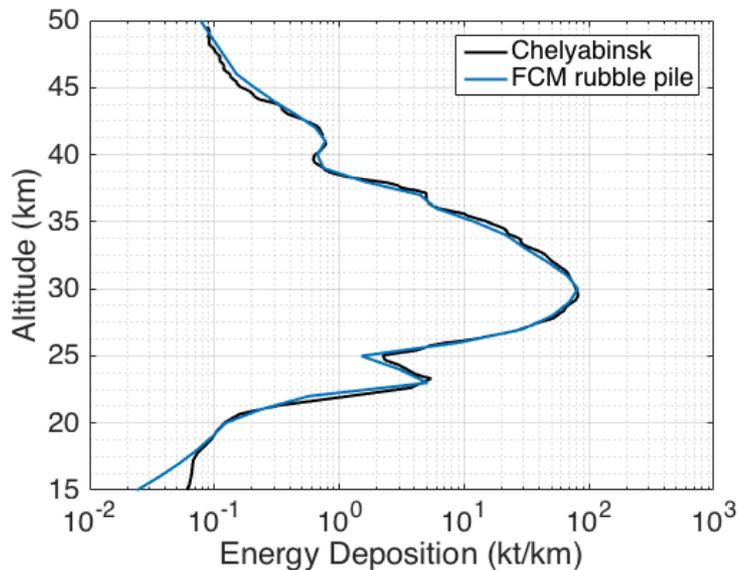
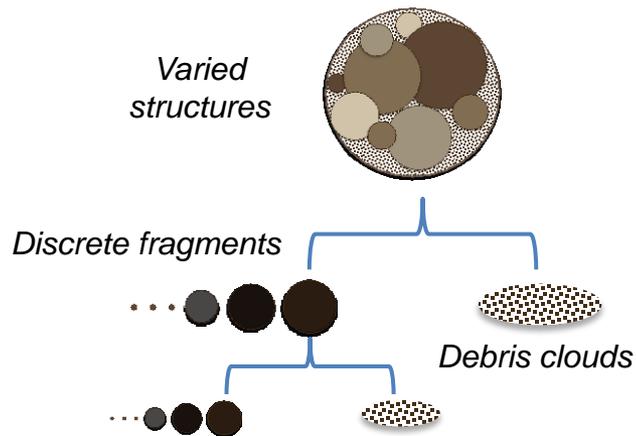
Blast Overpressure Modeling

- Computational fluid dynamics (CFD) simulations of blast propagation from asteroid airburst to overpressure levels on the ground.
- Height-of-Burst (HOB) map for risk assessment
 - HOB maps estimate blast damage areas for bursts of different energies and altitudes.
 - Yield-scaling based on smaller nuclear sources (Glasstone & Dolan)
 - Yield-scaling becomes inaccurate due to buoyancy effects for higher impact energies (KE >10-50 megatons, diameter > 50-80m)
- Used CFD simulations to generate improved HOB map for large impactors.
 - PAIR risk model interpolates between appropriate HOB maps to give improved prediction of ground footprint
 - Excellent example of high-fidelity analysis informing the fast-running methods for probabilistic risk assessment



Fragment-Cloud Model (FCM)

FCM Breakup Modeling

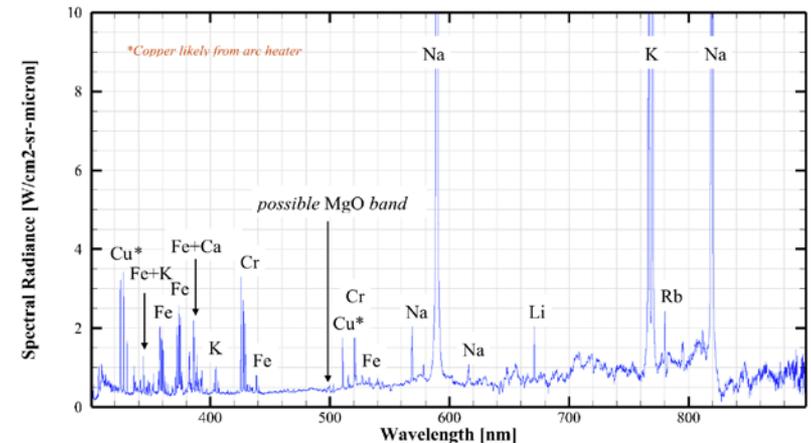
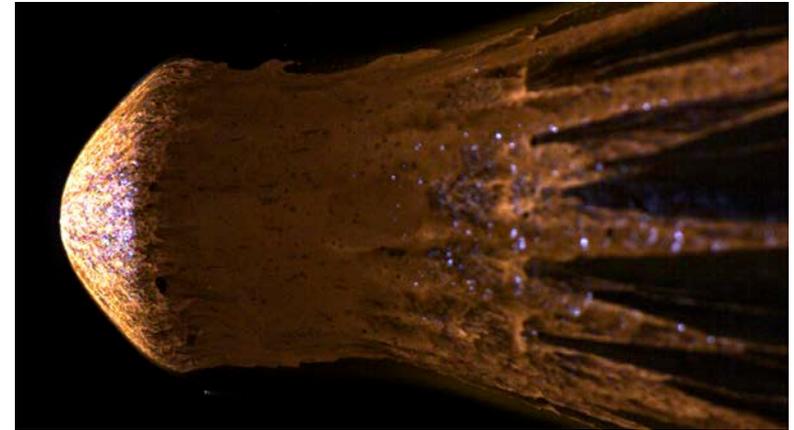


• FCM Approach

- Analytic model of energy deposited in the atmosphere during entry and breakup
- Represents breakup process using a combination of discrete fragments and aggregate debris clouds
- Can represent range of asteroid structures and breakup characteristics
- Energy deposition used to estimate airburst altitudes and ground energies for risk modeling
- FCM results can match observed meteor light curves to:
 - Infer pre-entry asteroid properties
 - Investigate breakup characteristics
 - Guide model refinements

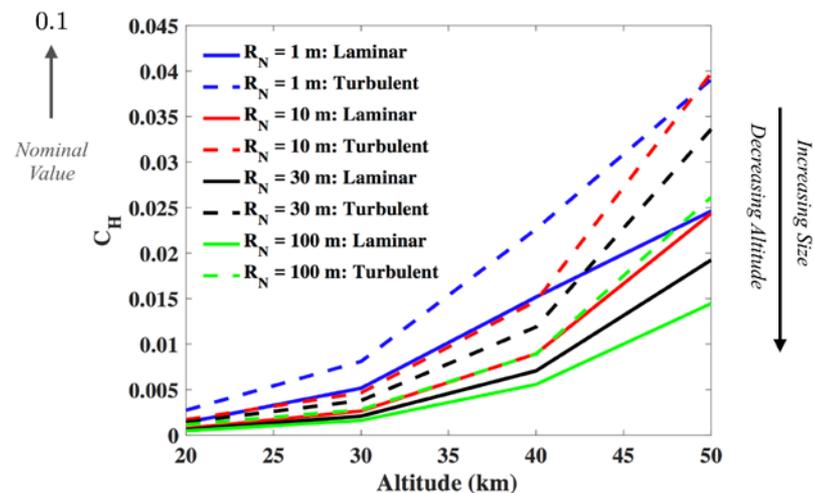
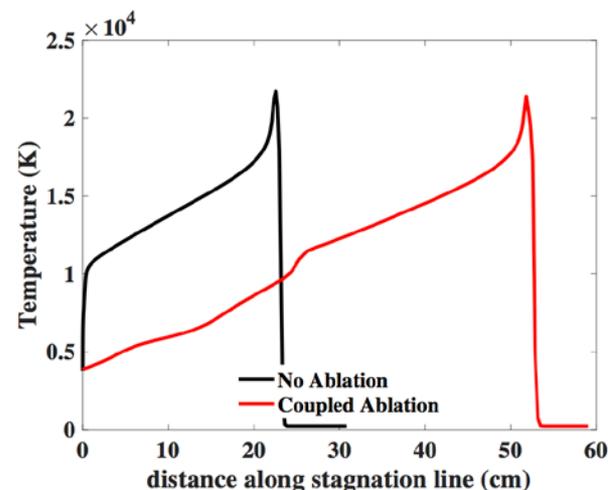
Meteoroid Ablation Experiments

- Asteroid ablation models:
 - State of the art asteroid energy deposition code uses single parameter to account for mass loss due to ablation
 - Ablation physics for large meteoroids and asteroids is poorly understood
- Development of detailed ablation model:
 - Laser scans of pre- and post-test model shapes have provided data for developing and validating melt flow ablation models
 - Results indicate much lower melt viscosity than previously assumed
 - Widespread melt flow results in significantly lower effective heat of ablation than state of the art
- Looking ahead: luminosity models
 - High-resolution spectra of ablation products from arc jet experiment provides unique data for development and valuation of meteoroid luminosity models



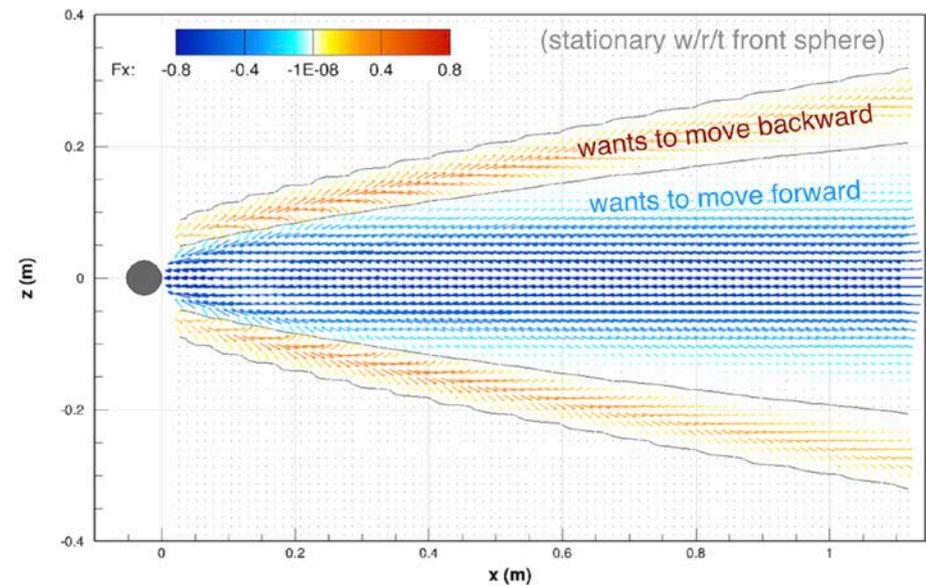
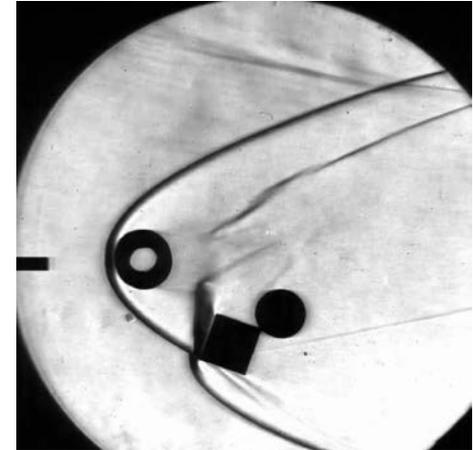
Heat Transfer Modeling

- Asteroid heating models:
 - State of the art asteroid energy deposition code uses single parameter to account for heating due to hyper-velocity interaction with the atmosphere
 - Heritage heat transfer coefficient value of ~ 0.1 does not account for effects of radiative cooling, nor blockage of radiative heat flux by ablation products
- Fully coupled flow simulations
 - Generated database of detailed fully coupled flow simulations across a range of asteroid sizes, velocities, and altitudes
 - Radiative cooling and radiation blockage reduces the effective heat transfer coefficient by as much as two orders of magnitude
 - Effect is more pronounced for larger asteroids and lower altitudes
- Methodology being extended to model:
 - Meteoroid luminosity
 - Thermal emission as a source of ground damage



Asteroid Fragment Spreading

- Asteroid fragment spread-rate:
 - Current atmospheric energy deposition code requires model for the rapid increases in aerodynamic drag area to produce realistic energy deposition profiles
 - Recent studies (Laurence et al.) have suggested that there may be significant uncertainty in the assumed historical model
- Collaboration with DLR to study multi-body aerodynamics:
 - DLR wind tunnel facility allows for free-flight experiments of multiple bodies in hypersonic flow
 - Utilize wind tunnel data to validate ATAP numerical simulations
 - Single-body simulations performed to-date show very good agreement with DLR experimental data
- Looking ahead:
 - Developing analytic model for asteroid fragment spreading based on database approach

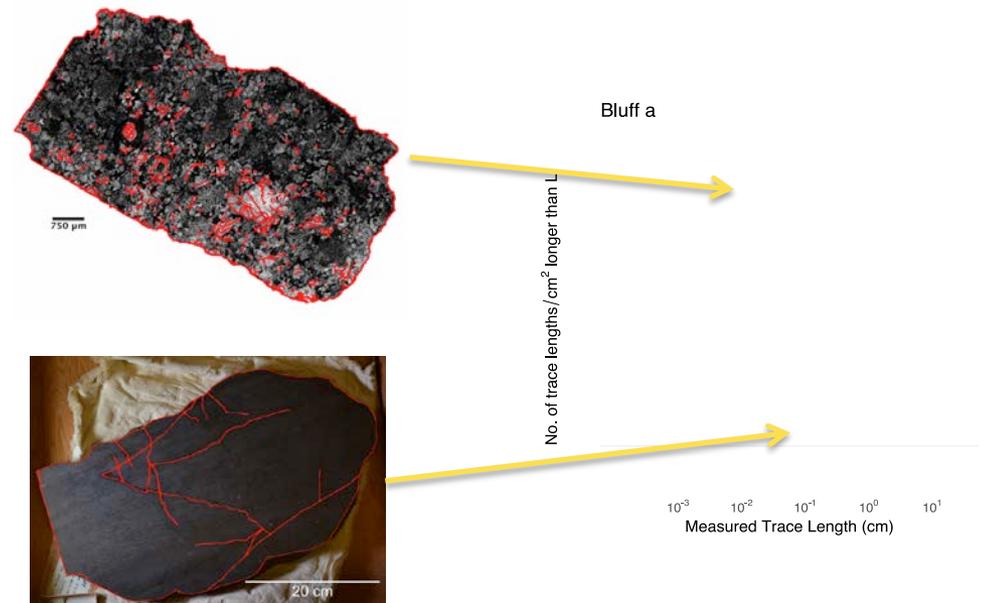


Meteorites as Asteroid Samples

- Measuring physical properties:
 - Bulk density
 - Grain density
 - Thermal emissivity
 - Acoustic velocity

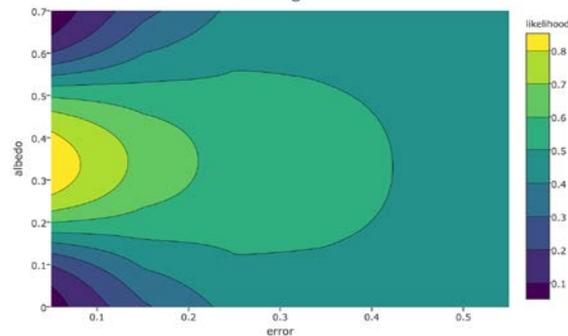
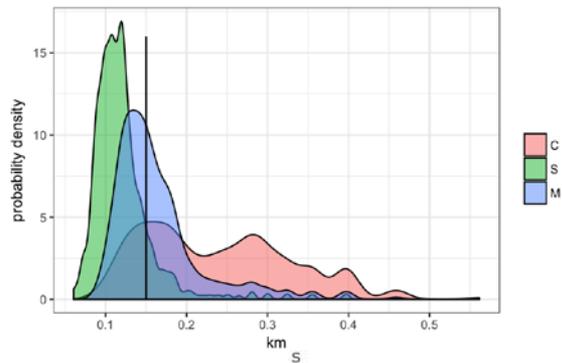
- Quantifying observed fractures:
 - Developed methodology to estimate Weibull scaling parameter (α) from visually observed fracture patterns.
 - α can be used in entry models to describe fracturing behavior.

Type	# measured to date	# planned for rest of FY17
H	5	3
L	2	0
LL	2	0
CM	0	1
Irons	0	1
EUC	0	1
HOW	0	1
<i>Total</i>	<i>9</i>	<i>7</i>

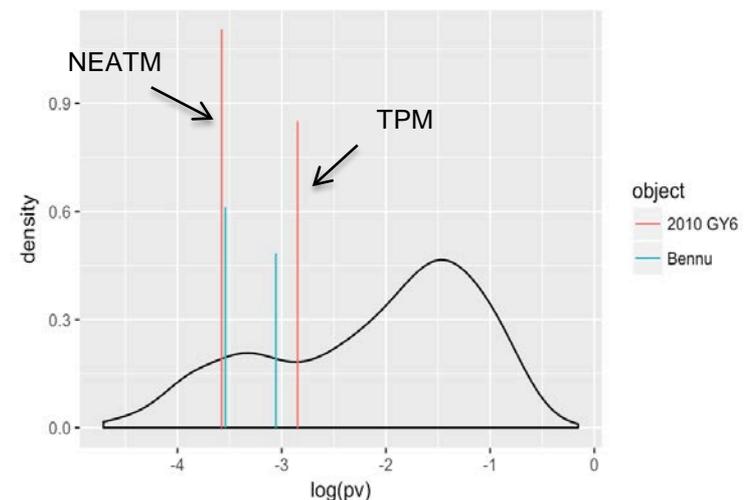


Asteroid Characteristics

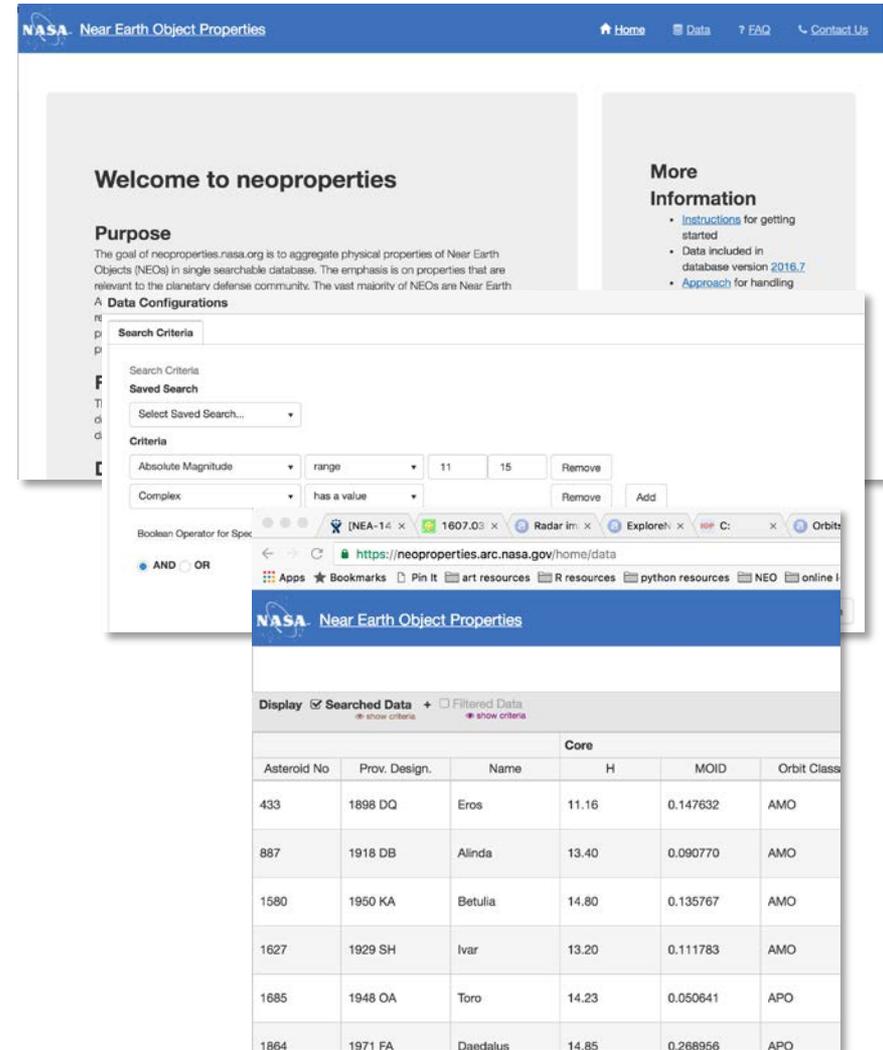
- Inferring characteristics and distributions
 - Developed distributions of key asteroid characteristics for use in risk models
 - Developing methodology to quantitatively infer characteristics given limited information.



- Modeling thermal emission of low albedo objects
 - ATAP is utilizing NEATM, NESTM and thermophysical models (TPM) to evaluate impact of model assumptions on conclusions for low albedo objects.
 - Since they are dim for their size, low albedo objects are significant drivers of risk.



- neoproperties website
 - Aggregates physical properties of NEOs and meteorites into a searchable database
 - Emphasis on properties of interest to the planetary defense community.
- Asteroid contents include:
 - Taxonomic class
 - Diameters & albedos
- Meteorite contents include:
 - Density & porosity
 - Compressive & tensile strength
 - Elastic & shear moduli
 - Heat capacity & thermal conductivity



The screenshot shows the NASA Near Earth Object Properties website. The page includes a navigation bar with 'Home', 'Data', 'FAQ', and 'Contact Us'. The main content area has a 'Welcome to neoproperties' section, a 'Purpose' section explaining the database's goal, and a 'Data Configurations' section with search criteria. The search criteria section shows 'Absolute Magnitude' set to a range of 11 to 15 and 'Complex' set to 'has a value'. Below this, a Boolean operator for 'AND' or 'OR' is visible. The bottom part of the screenshot shows a table of NEO data with columns for Asteroid No., Prov. Design., Name, H, MOID, and Orbit Class.

Core					
Asteroid No.	Prov. Design.	Name	H	MOID	Orbit Class
433	1898 DQ	Eros	11.16	0.147632	AMO
887	1918 DB	Alinda	13.40	0.090770	AMO
1580	1950 KA	Betulia	14.80	0.135767	AMO
1627	1929 SH	Ivar	13.20	0.111783	AMO
1685	1948 OA	Toro	14.23	0.050641	APO
1864	1971 FA	Daedalus	14.85	0.268956	APO

Feedback? Suggestions? Email jessie.dotson@nasa.gov