Asteroid Threat Assessment Project (ATAP)

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Small Bolide Advisory Group (SBAG)

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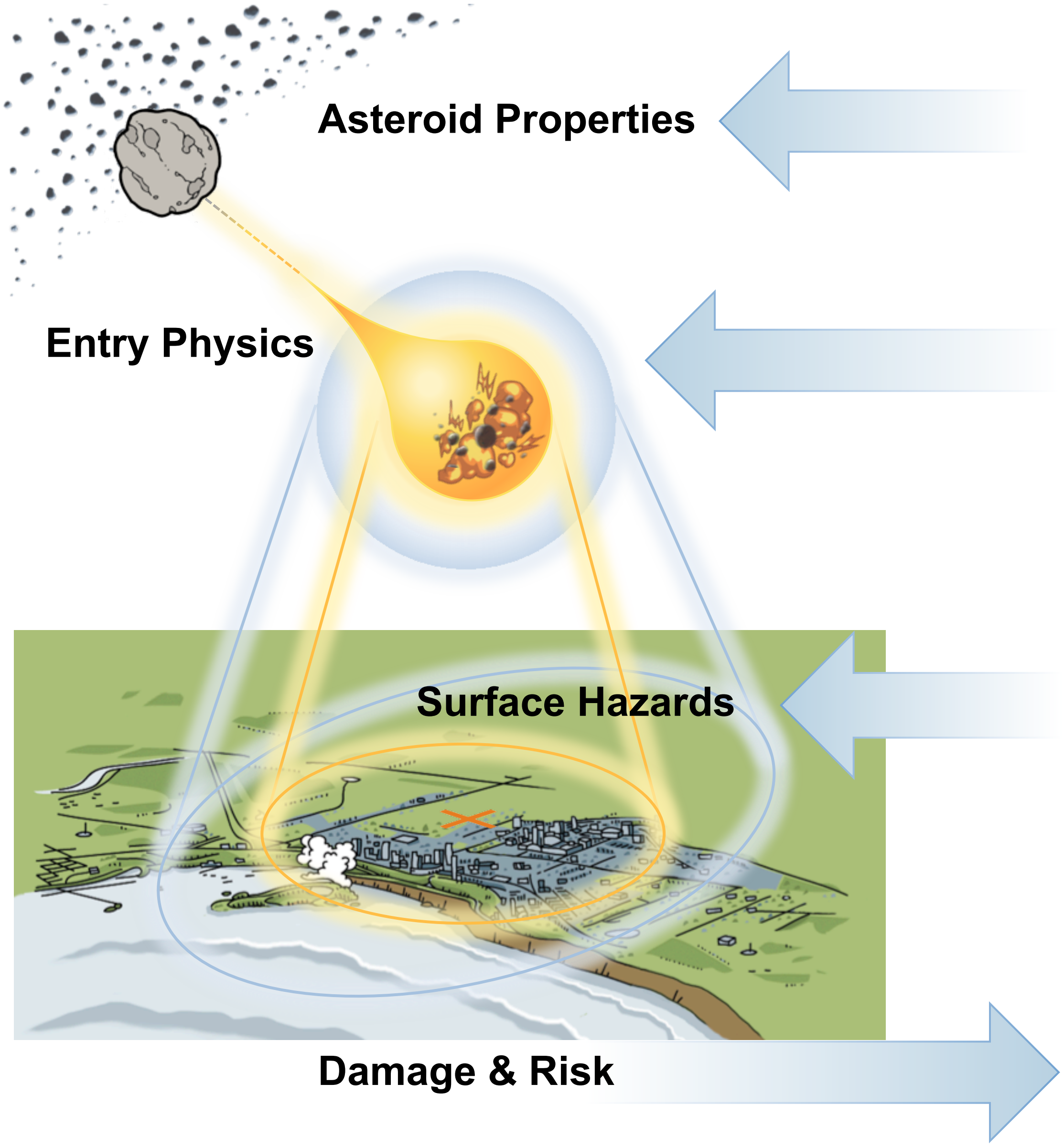
Asteroid Threat Assessment



Characterization
- Measurements
- Inference
- Data aggregation
- Property database website

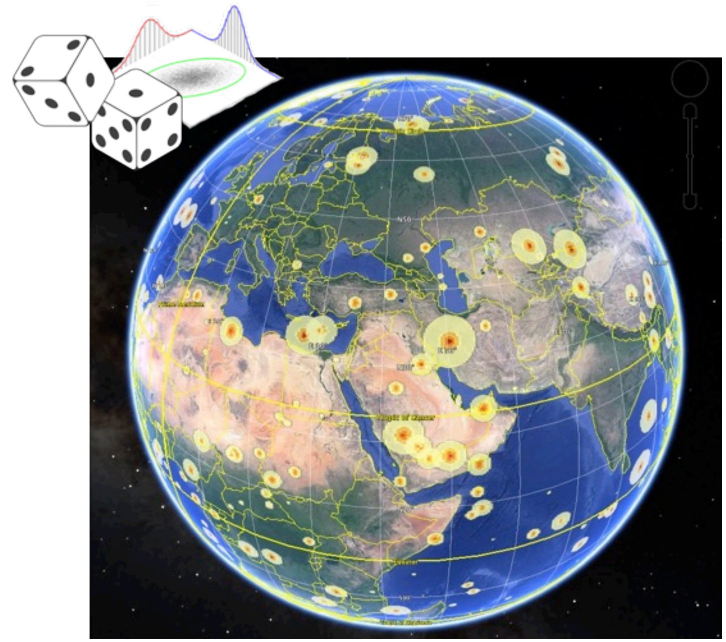
Entry Simulations & Testing
- Coupled aerothermodynamics
- Ablation & radiation modeling
- Arc jet testing

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

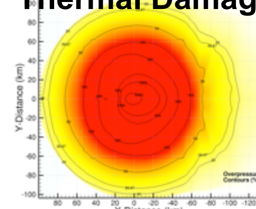
Probabilistic Risk Assessment
- Analytic physics-based entry and damage models
- Probabilistic Monte Carlo simulation using uncertainty distributions

Probabilistic Asteroid Impact Risk (PAIR) Model

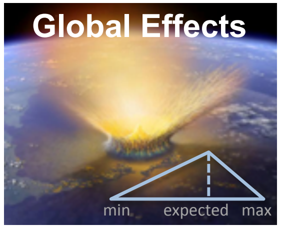
- PAIR model approach:
  - Uses analytic models of asteroid entry and hazards to assess damage from millions of impact cases
  - Samples uncertainty distributions of asteroid properties developed by characterization team
  - Location-specific affected populations capture range of consequences
  - Hazard 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.

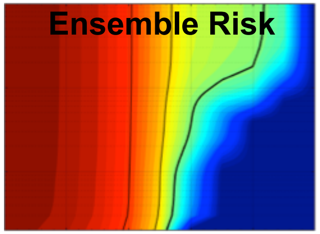


Local Blast and Thermal Damage



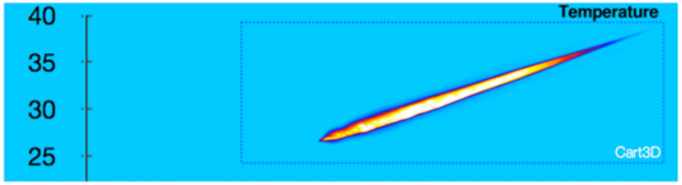
Tsunami Inundation

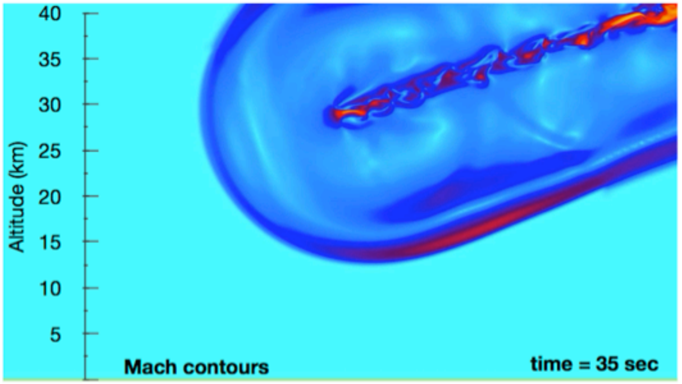


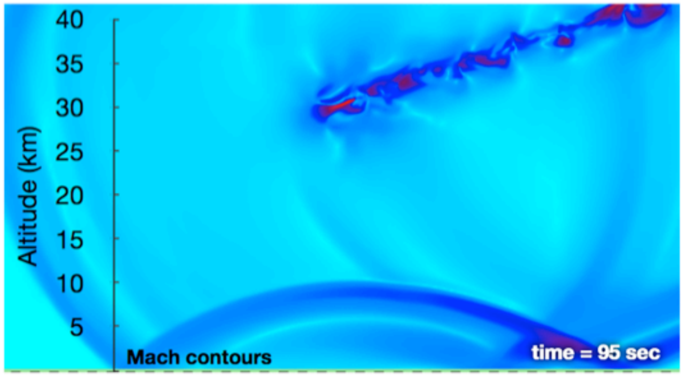


Hazard Simulation

- 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

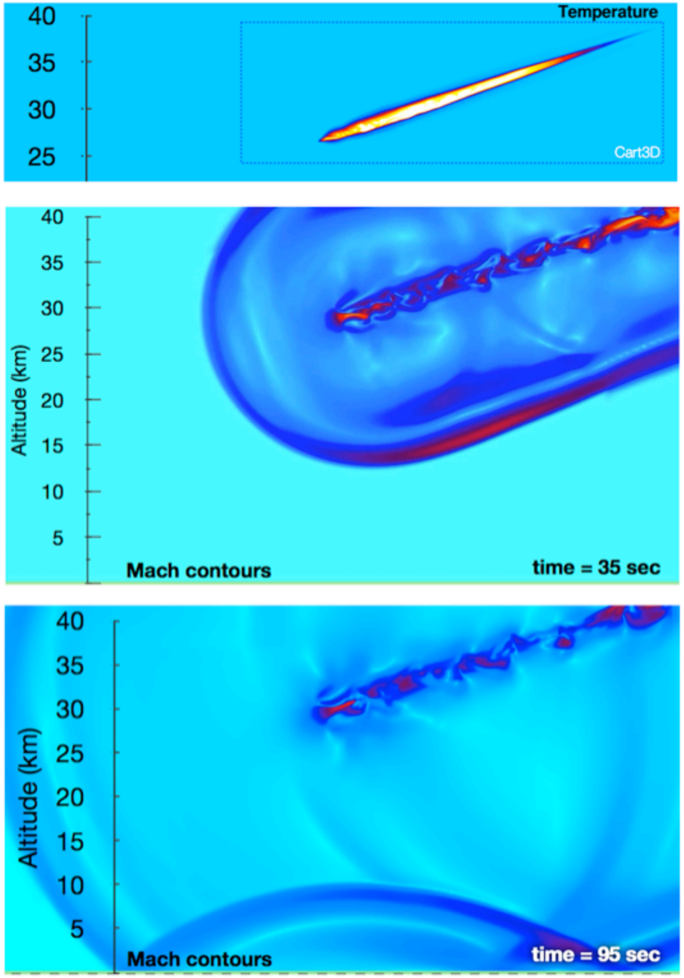






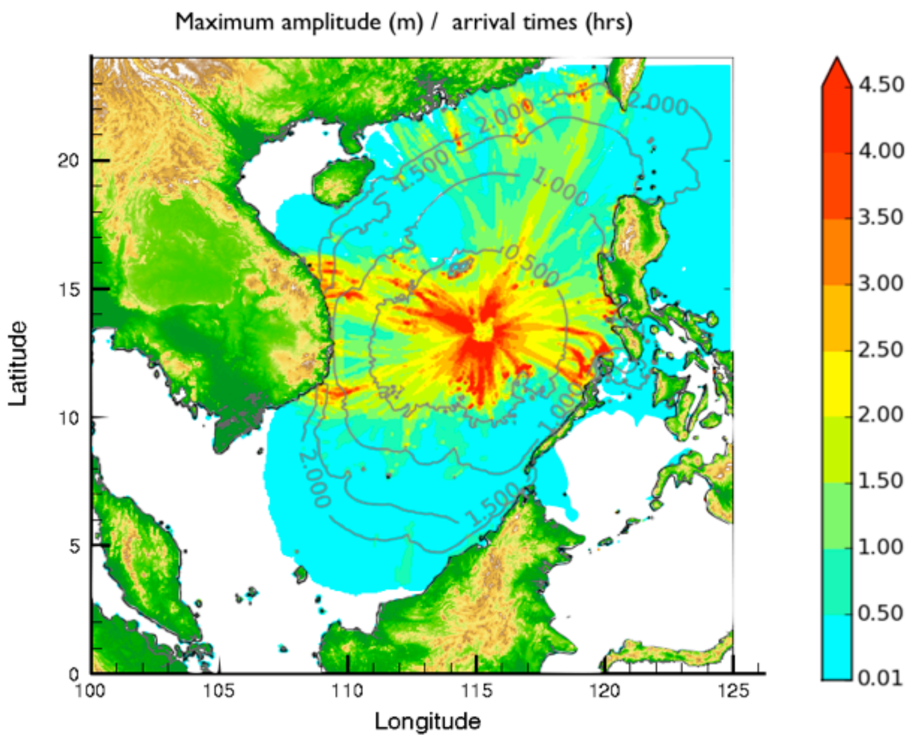
Hazard Simulation

- High-fidelity simulations of key impact hazards:
  - 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
  - Hydrocode simulations of water impacts and wave generation
  - GeoClaw simulations of wave propagation
- Surface Impact Modeling
  - Hydrocode simulations of surface impacts and cratering into land and water
- Blast Overpressure Modeling
  - CFD simulations of blast propagation through the atmosphere to the ground



Tsunami Modeling

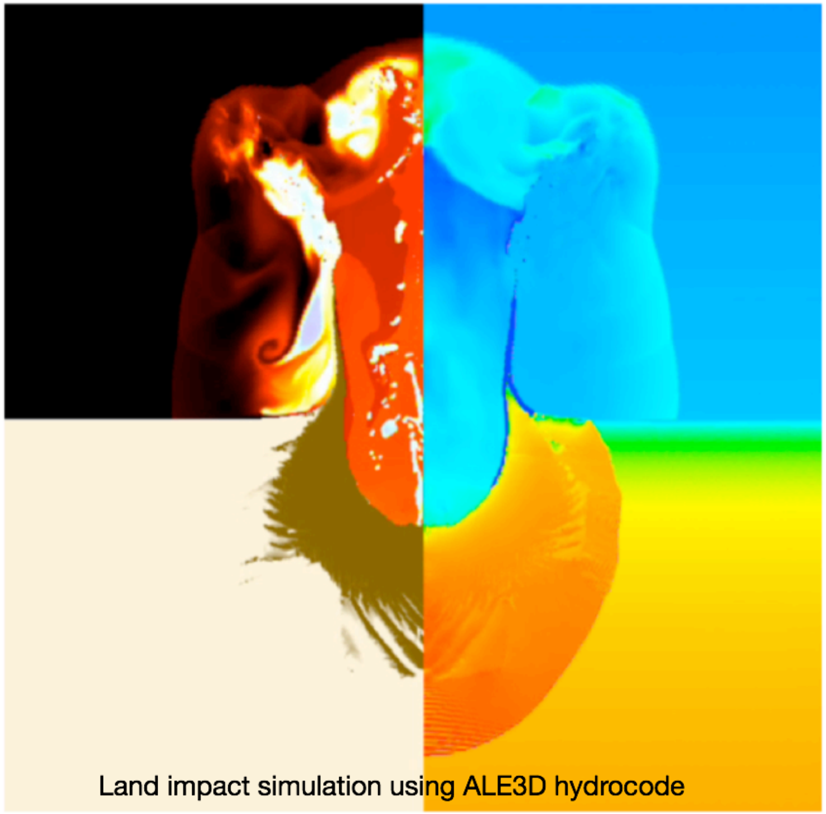
- Tsunami Workshop (Oct. 2016)
  - Sponsored the NASA/NOAA Workshop on Asteroid Threat Assessment: Asteroid-generated Tsunami (AGT) and Associated Risk, held in Seattle WA
  - Included head-to-head comparisons of tsunami simulations from NASA, DOE, NOAA and academia for a range of water impact and airburst 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)

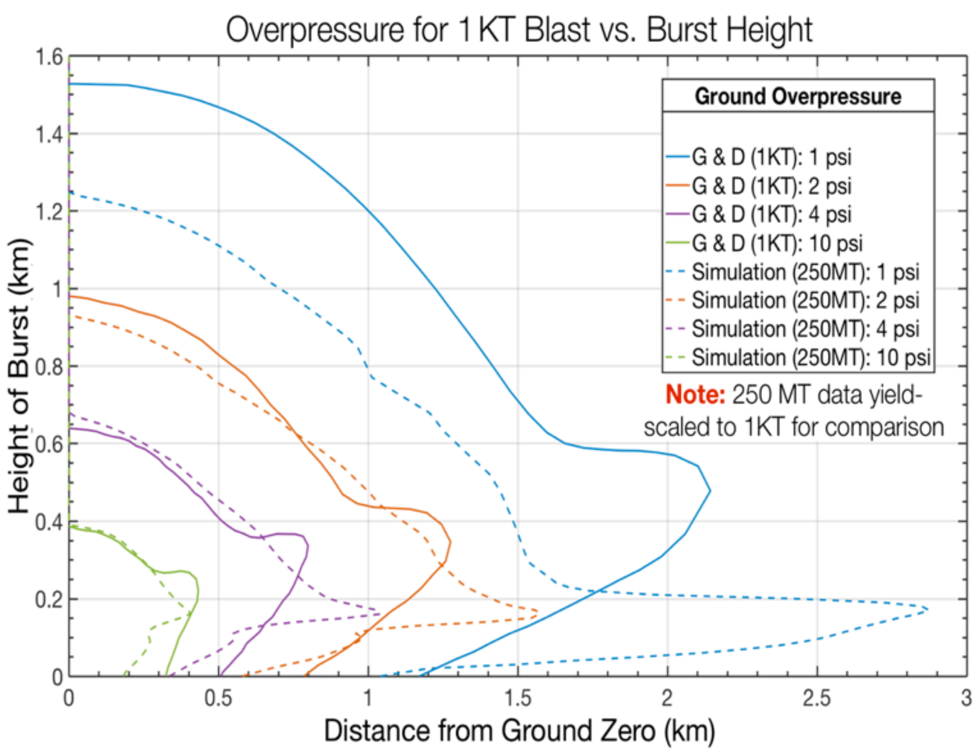


Land impact simulation using ALE3D hydrocode

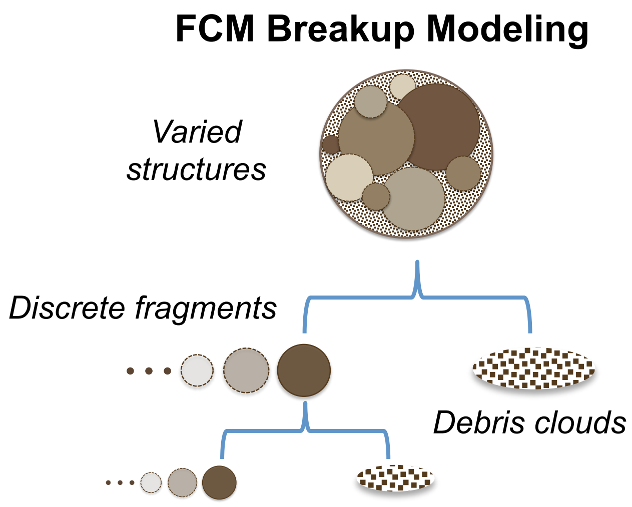
Blast Overpressure Modeling

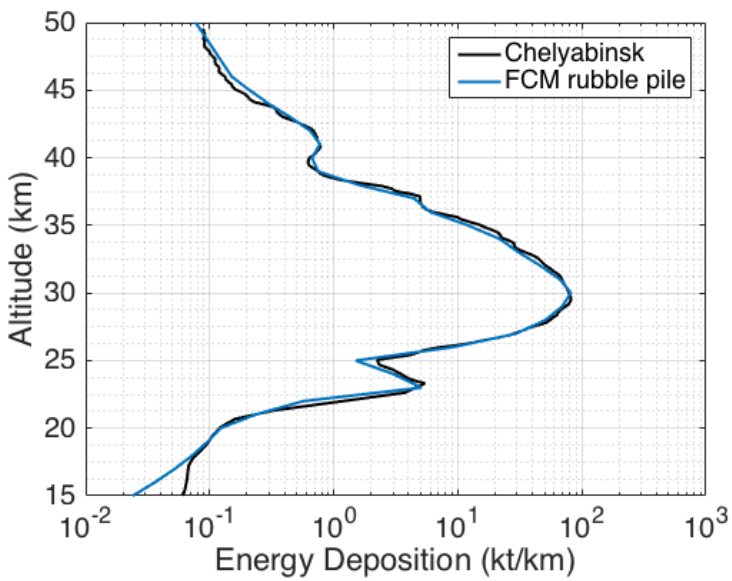
- Computational fluid dynamics (CFD) simulations of blast propagation from asteroid airburst to overpressure levels on the ground.

- 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)

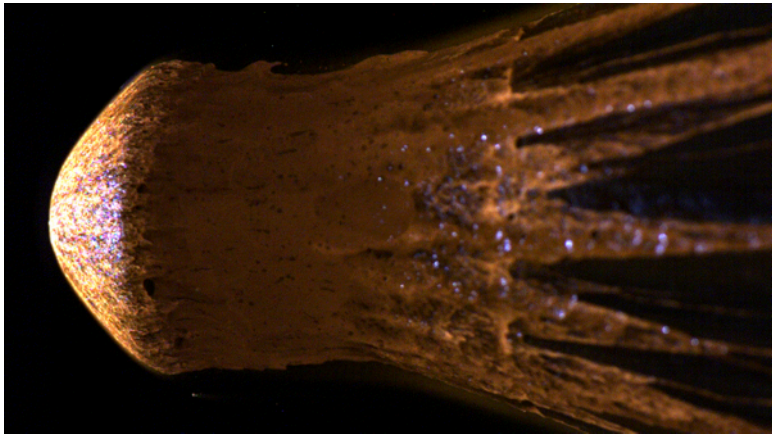


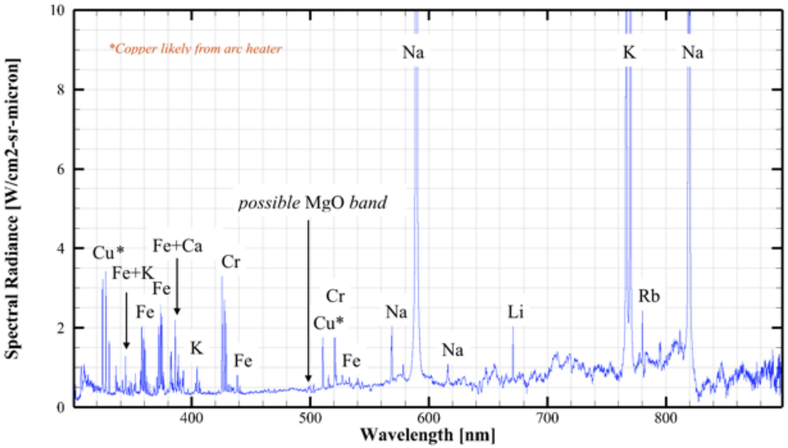


- FCM Approach
  - Analytic model of energy deposited in the atmosphere during entry and breakup
  - Represents breakup process using a combination of discrete fragments and aggregate debris clouds
  - Can represent range of asteroid structures and breakup characteristics
- Energy deposition used to 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

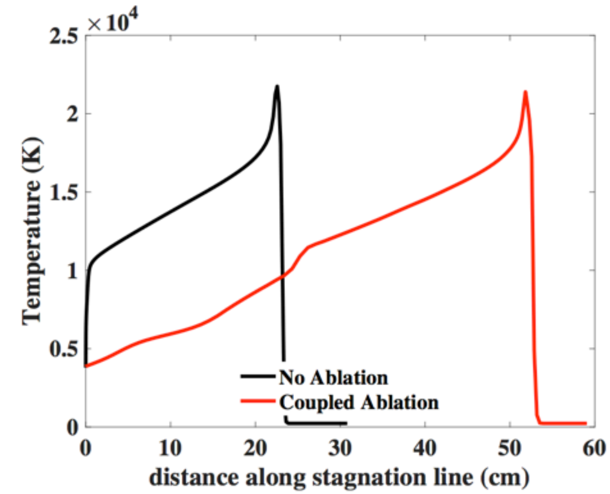
- Asteroid ablation models:
  - State of the art asteroid energy deposition code uses single parameter to account for mass loss due to ablation
  - Ablation physics for large meteoroids and asteroids is poorly understood
- Development of detailed ablation model:
  - Laser scans of pre- and post-test 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 SoA
- 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

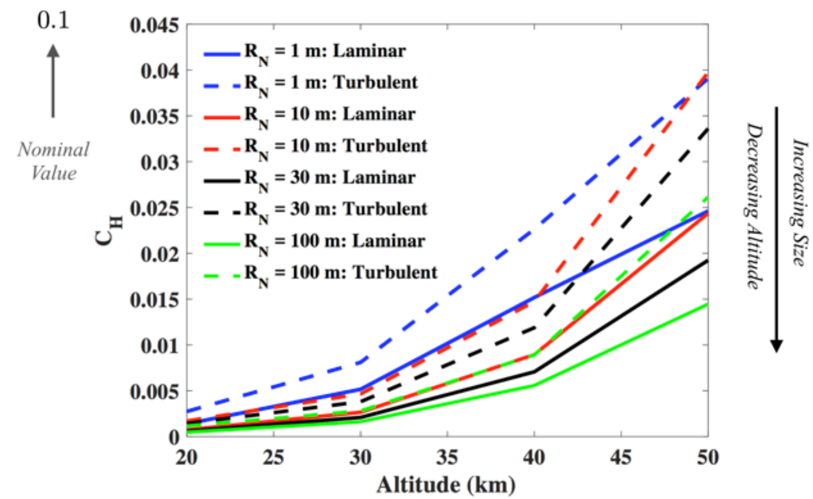




Heat Transfer Modeling

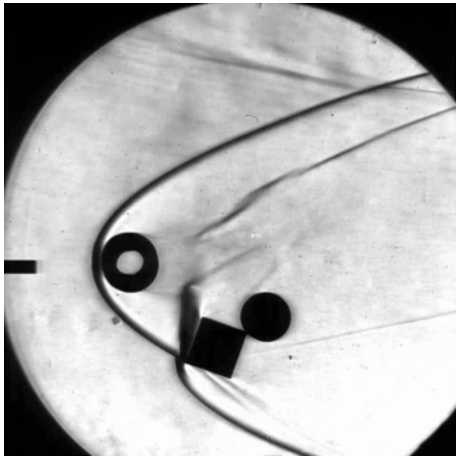
- Asteroid heating models:
  - SoA asteroid energy deposition code uses single parameter to account for heating due to hyper-velocity interaction with the atmosphere
  - Heritage heat transfer coefficient value of ~0.1 does not account for effects of radiative cooling, nor blockage of radiative heat 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

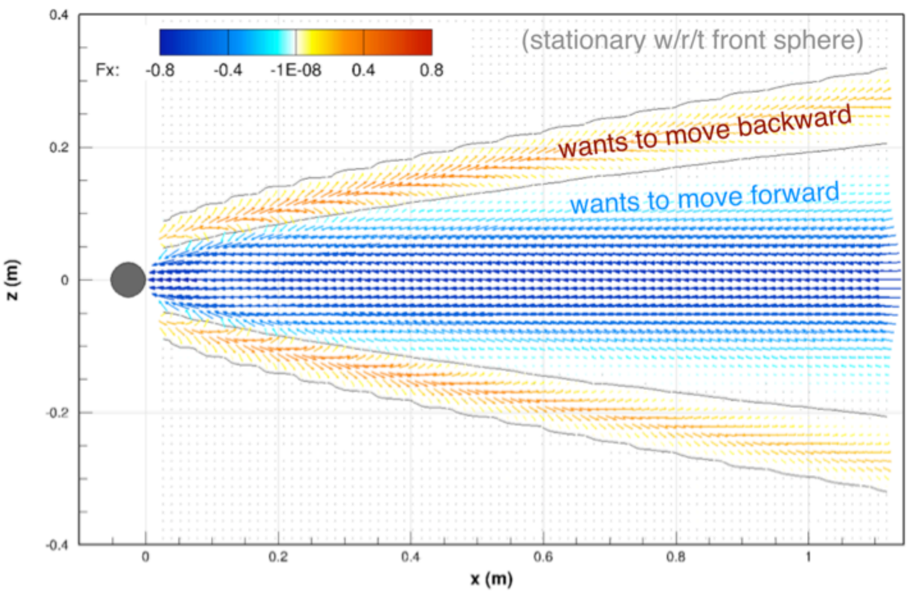




Asteroid Fragment Spreading

- Asteroid fragment spread-rate:
  - SoA 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

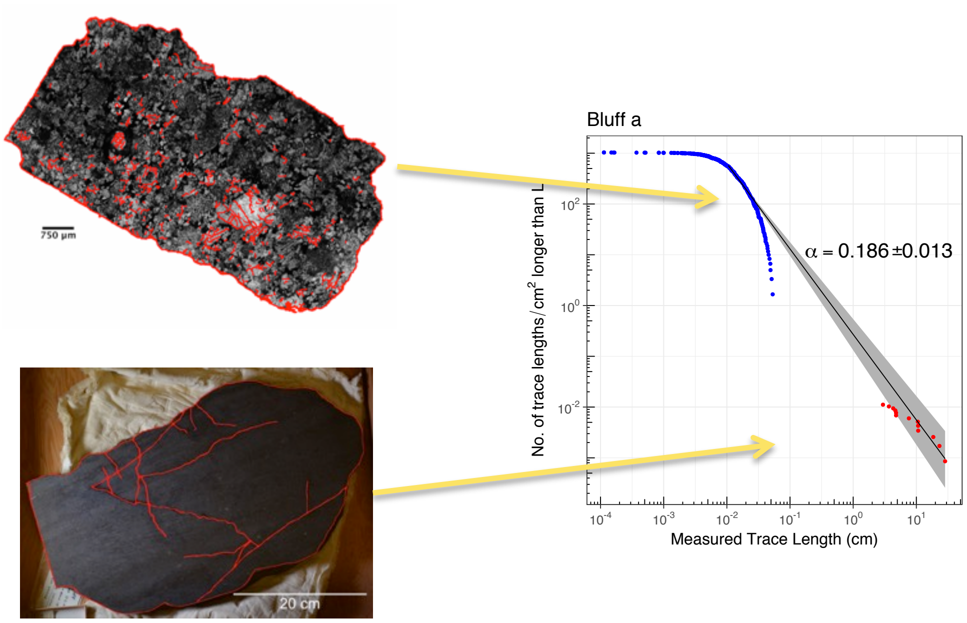




Meteorites as Asteroid Samples

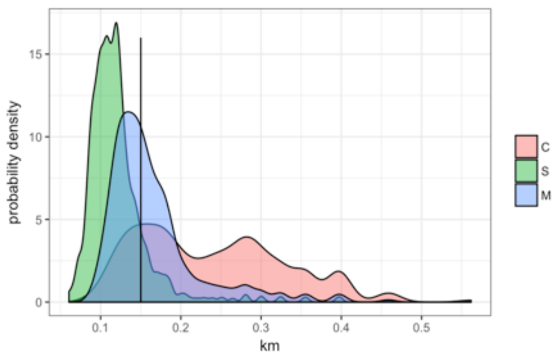
- Measuring physical properties:
  - Bulk density
  - Grain density
  - Thermal emissivity
  - Acoustic velocity
- Quantifying observed fractures:
  - Developed methodology to estimate Weibull scaling parameter (α) from visually observed fracture patterns.
  - α can be used in entry models to describe fracturing behavior.

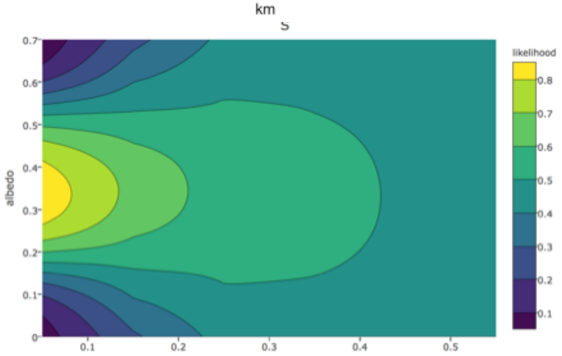
Type	# measured to date	# planned for rest of FY17
H	5	3
L	2	0
LL	2	0
CM	0	1
Irons	0	1
EUC	0	1
HOW	0	1
Total	*9*	*7*



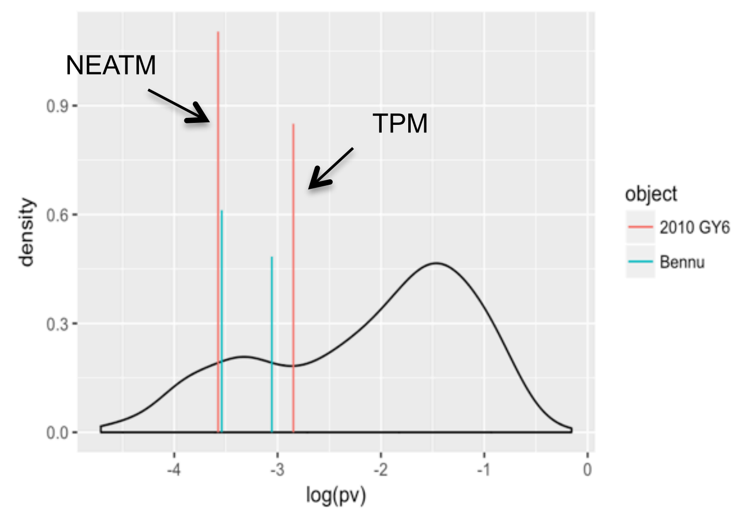
Asteroid Characteristics

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



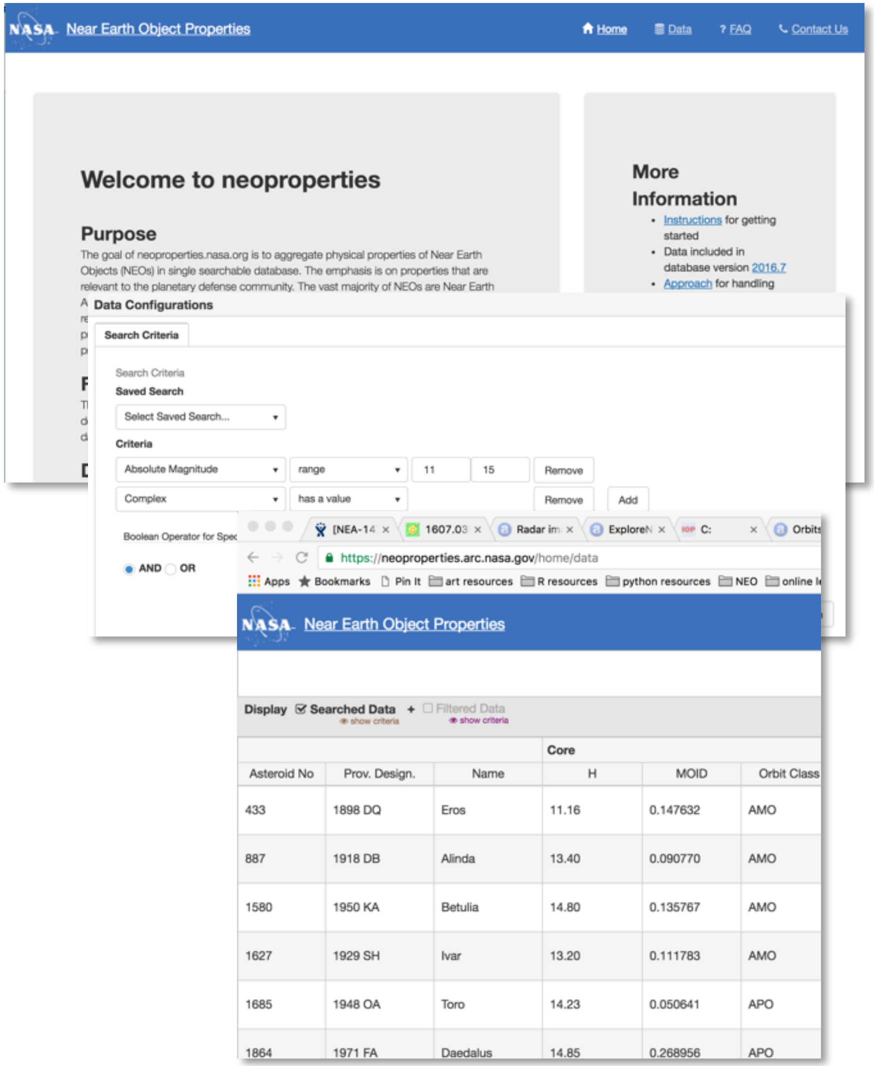


- Modeling thermal emission of low albedo objects
  - ATAP is utilizing NEATM, NESTM and thermophysical models (TPM) to evaluate impact of model assumptions on conclusions for low albedo objects.
  - Since they are dim for their size, low albedo objects are significant drivers of risk.



neoproperties.arc.nasa.gov

- 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



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