Maturation of the Asteroid Threat Assessment Project

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Roles of the PDCO and ATAP [1]

Planetary Defense Coordination Office (PDCO)

NASA Headquarters, Science Mission Directorate,
Planetary Science Division

Mission Statement

Lead national and international efforts to:

- **Detect any potential for significant impact of planet Earth by natural objects.**
- **Appraise the range of potential effects by any possible impact:** ***Function of the Asteroid Threat Assessment Project (ATAP) - Led by NASA Ames.***
- **Develop strategies to mitigate impact effects on human welfare.**

Asteroid Threat Assessment Project (ATAP)

Ames Research Center

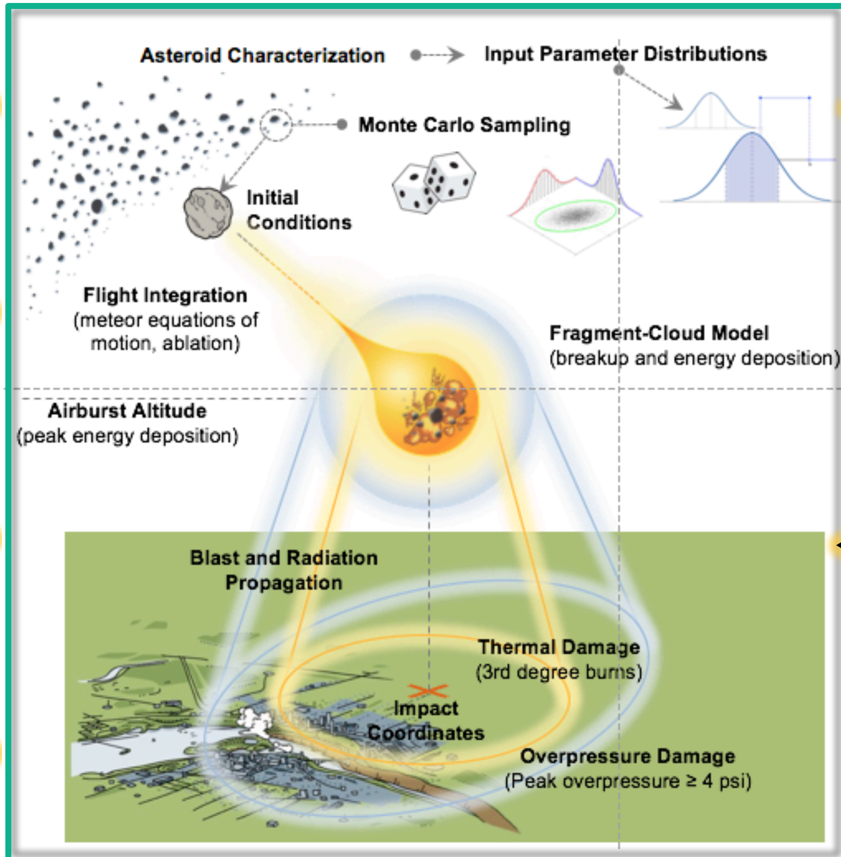
Manager: *Jaya Bajpayee* , Chf. Technologist: *E. Venkatapathy,* Chf. Scientist: *D. Morrison*

Initial Conditions
Jessie Dotson
- **Physical Properties**
- **Orbital Trajectories** (JPL)

Entry Modeling
Eric Stern
- **Entry Trajectories/Ablation**
- **Fracture/Energy Deposition**

Hazards
Michael Aftosmis
- **Ground Damage**
- **Tsunami**

Risk
Donovan Mathias
- **Quantitative Risk Metrics**
- **Sensitivity to Uncertainty**



Initial Conditions
- **Web: Meteorites/Asteroid properties and relationships**
- **Lab: Meteorite Properties**
- **Thermo Physical Modeling**

Hazards
- **Winds**
- **Radiation**
- **Cratering**
- **Regional**
- **Overpressure**
- **Tsunami**
- ***Earthquakes**
- **Global**

Probabilistic Asteroid Impact Risk (PAIR)

Decision Makers

Deflection Options

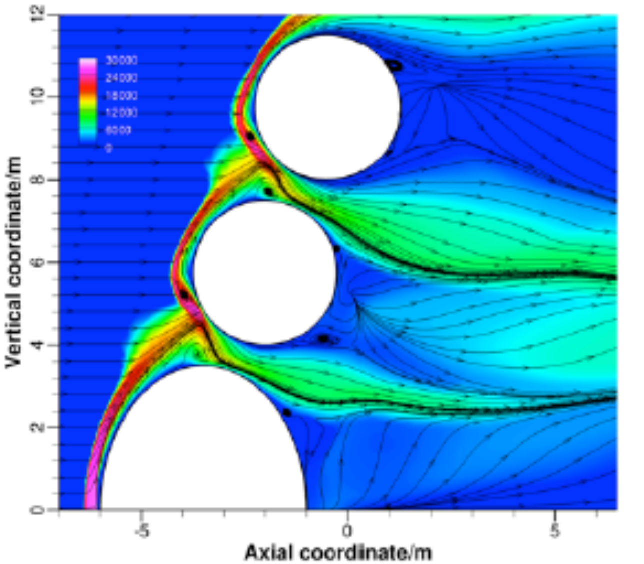
Civil Defense

*https://neoproperties.arc.nasa.gov

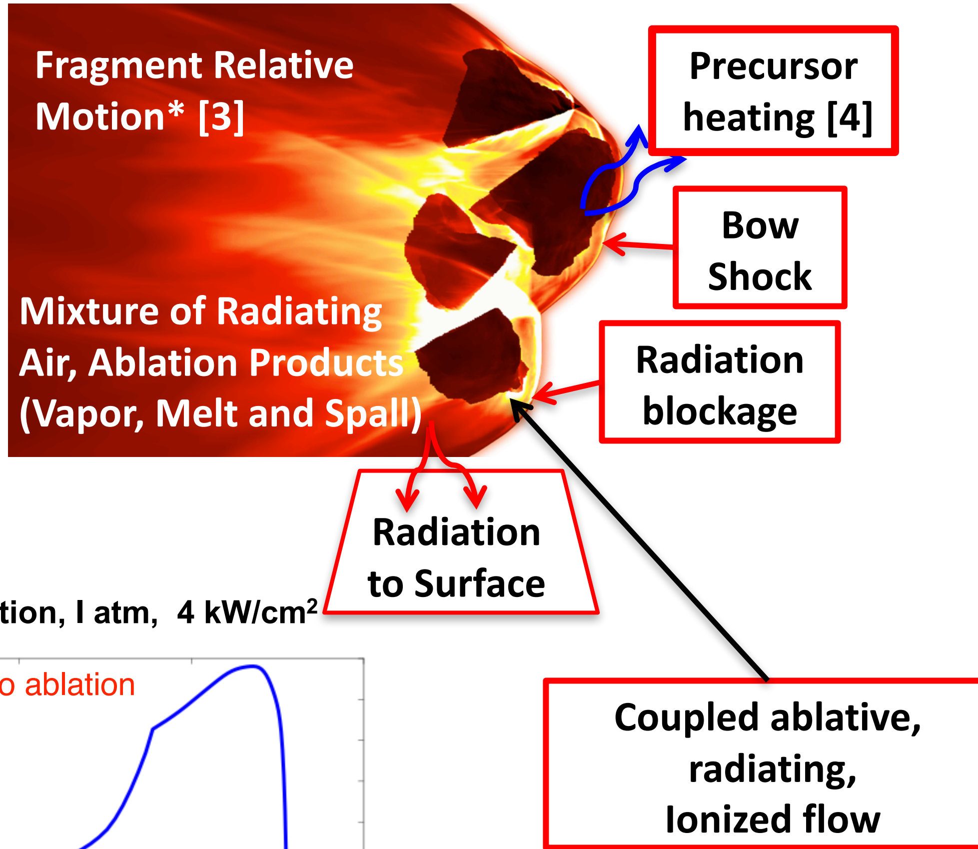
Entry Modeling (Eric Stern)

Simulate Atmospheric Entry & Breakup

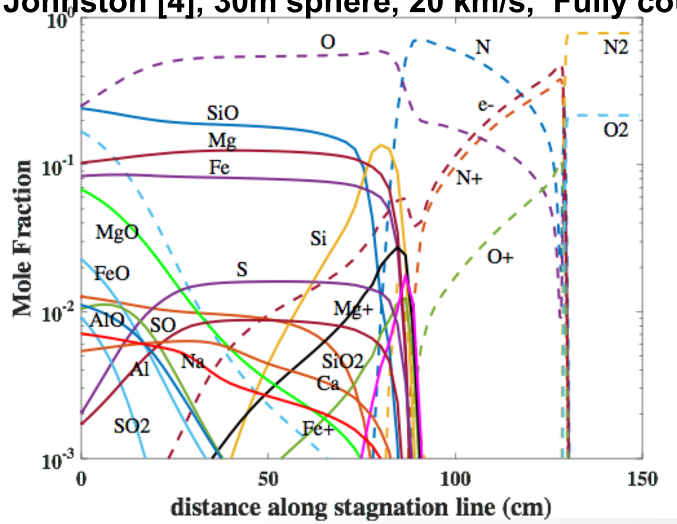
Prabhu & Saunders: [2] 20 km/s, 100 Atm. Blowing @ 10m/s

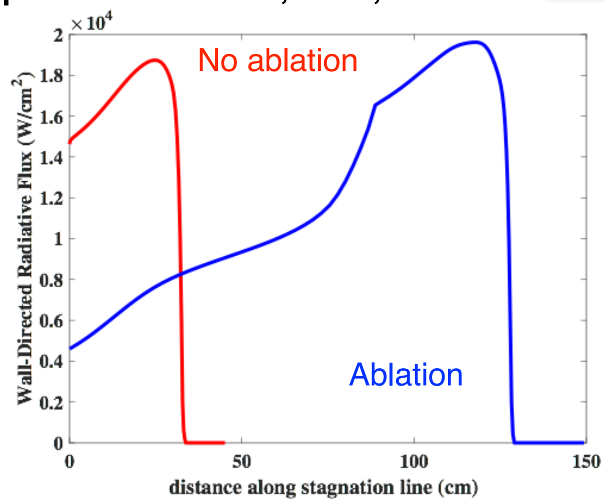


Nemac: Synthetic Schlieren (Ideal Gas)



Johnston [4], 30m sphere, 20 km/s, Fully coupled CFD/Ablation, I atm, 4 kW/cm^2





*NASA/DLR collaboration ongoing to validate CFD of Fragment Relative Motion [3]

Ground Testing: Motivation

POC: Eric Stern

- **Classical Meteor physics* treatment of meteoroid ablation reduces ablation and heat transfer phenomena to two parameters, which are typically assumed to be constant.**
- **Uncertainty in the heat transfer coefficient and the heat of ablation can strongly influence atmospheric energy deposition profiles, particularly for "smaller" asteroids (< 30m).**

$$\frac{dM}{dt} = -\underset{\text{Heating}}{\Lambda}\frac{S\rho v^3}{\underset{\text{Ablation}}{2Q}}.$$

$M =$ mass
$\Lambda =$ heat transfer coefficient
$S =$ wetted area
$\rho =$ gas density
$v =$ velocity
$Q =$ heat of ablation

*Note: Ablation is a complex process involving vaporization, melting and spallation

Objectives

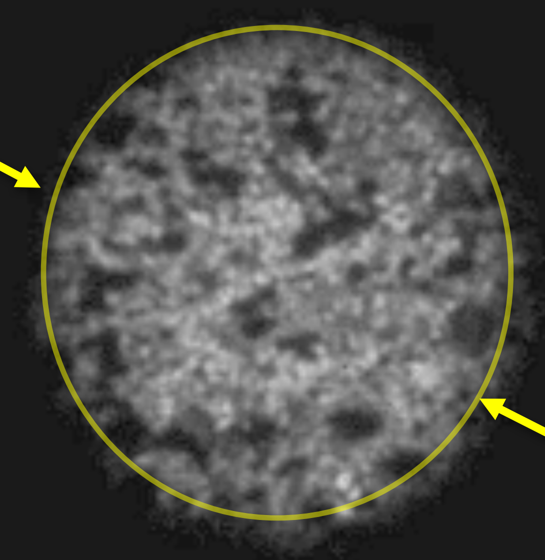
- **Utilize high energy/enthalpy testing facilities (LHMEL and IHF arcjet) to gain insight into meteoroid ablation phenomena at flight relevant conditions.**
- **Generate data that can be used to improve high-fidelity models for meteoroid ablation.**

** Öpik, 1958 [5] , Allen, Baldwin and Scheaffer, 1959-1971 [6,7]*

Pathfinder Laser Experiment (LHMEL)

Observations from High-speed Video

Tamdakht H5 Chondrite



5 kW/cm^2 Laser Spot 1 atm.

- **High-speed video (1000 fps) from the experiment provided insight into important phenomena in meteor ablation processes**
  - **Energetic vapor/soot plume produced by ablation process**
  - **Spallation and/or ejection of molten droplets appears to be a significant mechanism of** mass loss

Interactive Heating Facility Arcjet Testing [8]
POC Eric Stern, PI: Parul Agrawal

Test Objectives:

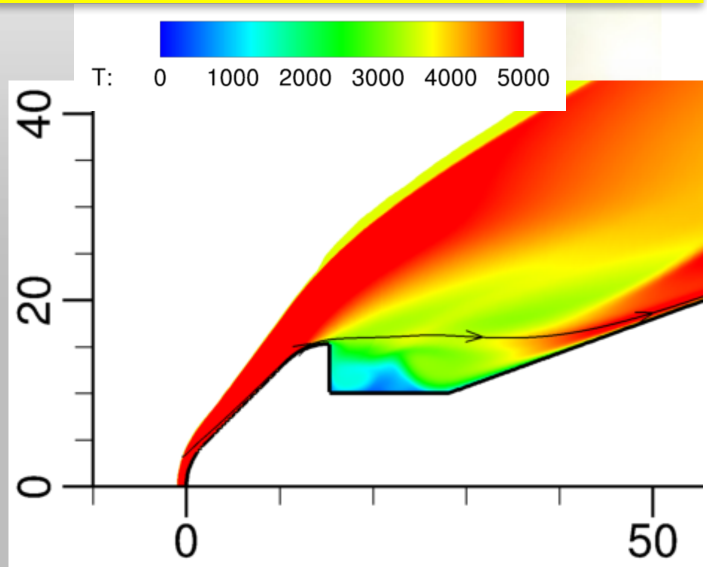
- Obtain *quantitative* recession data for development and validation of numerical models for meteoroid ablation: Looking for ablation processes: vaporization, melt and spallation.
- Obtain high-resolution spectra of the emission of ablation products to assess numerical models for meteor light production.

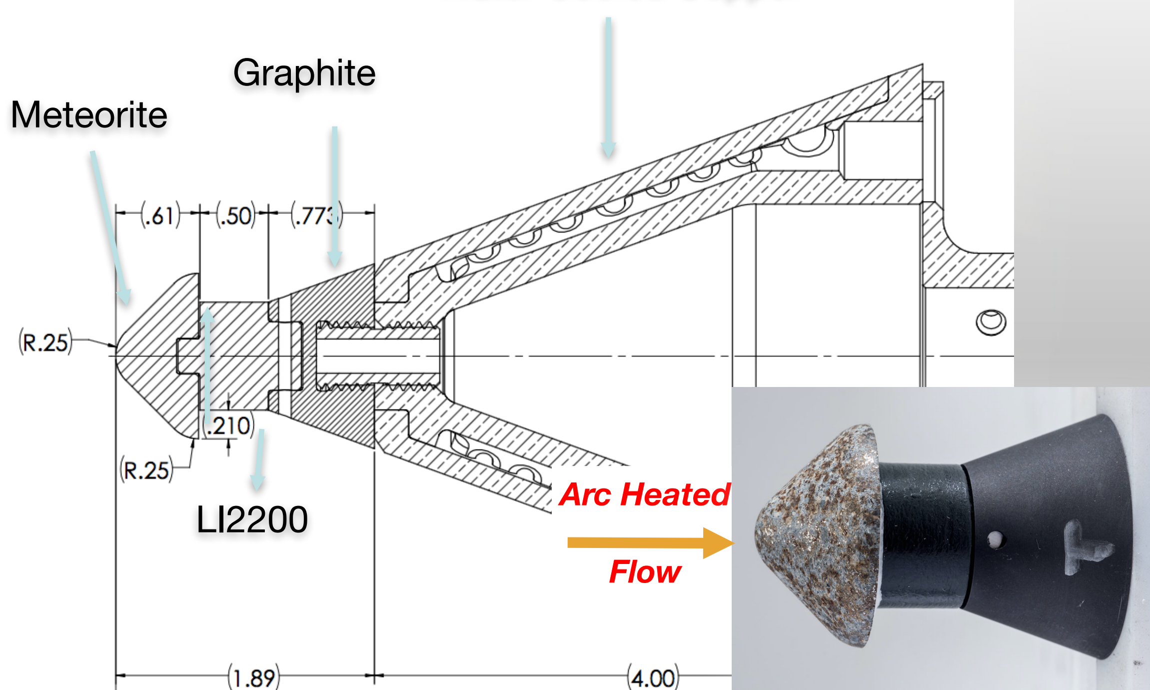
Test Concept: Dinesh Prabhu

Implementation: Agrawal, Stern, Arnold, Jenniskins & Burkhard

Test Conduct: Test Engineer: E. Rodriguez + Ames arcjet test crew

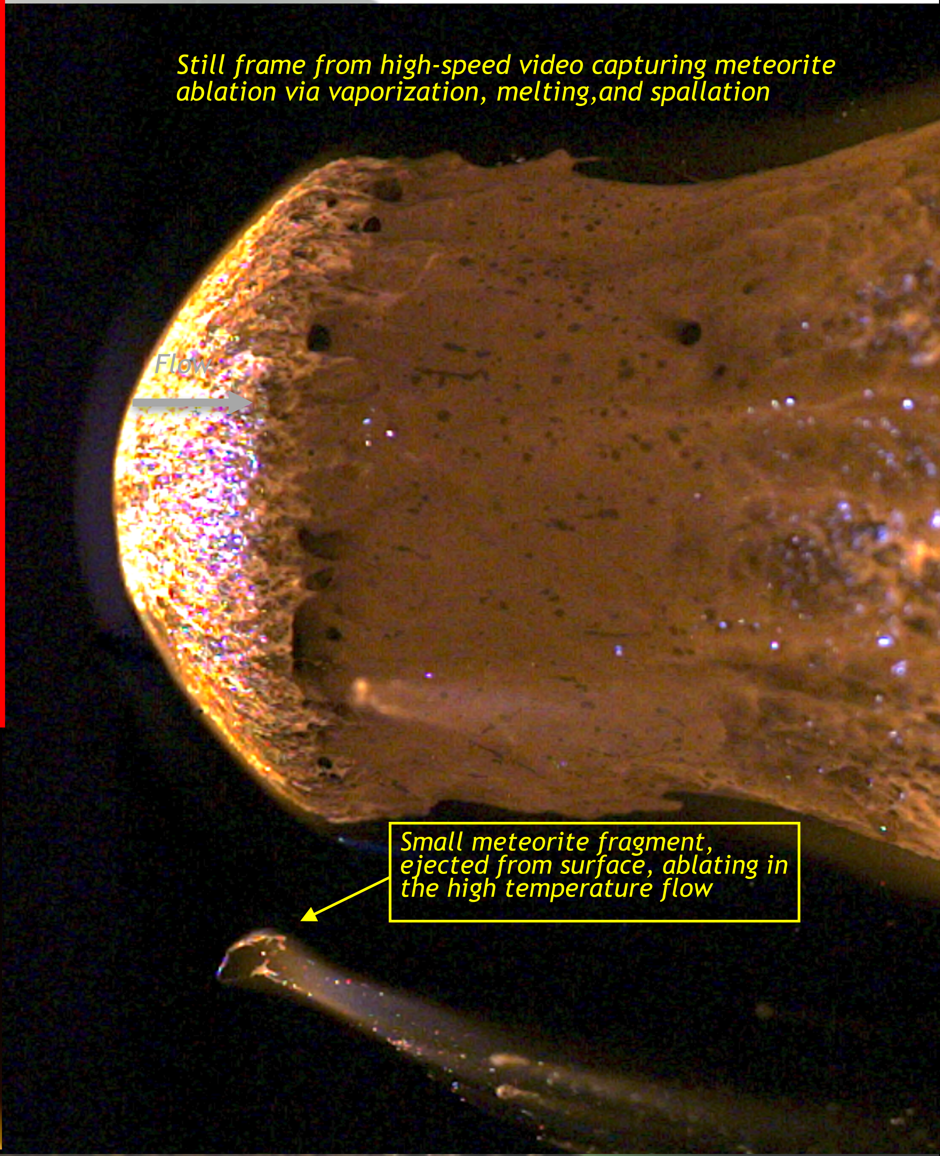
Pre-Test **Prediction**~ 4 kW/cm^2, 1 atm.
Simulates 65 km flight case.
Dimensions in mm for color figure.





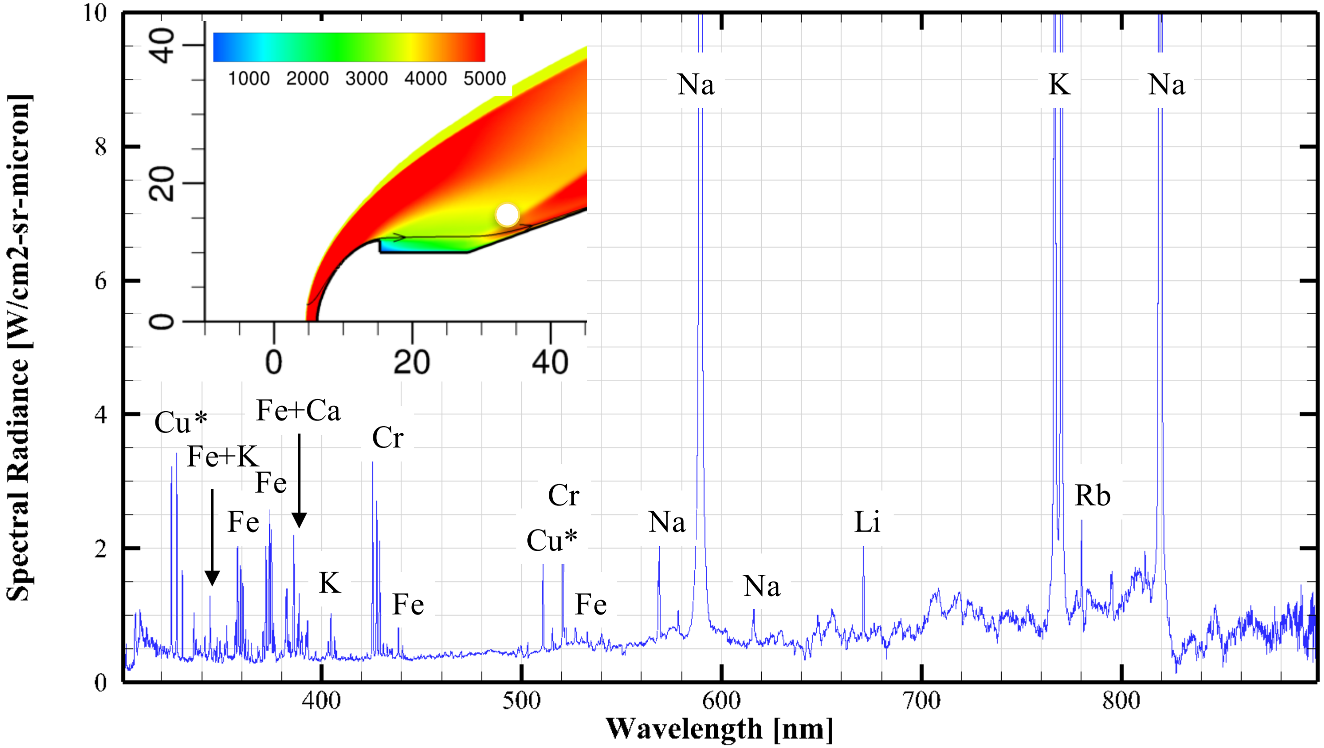
Meteor Entry Simulated in the Arcjet
POC: Eric Stern, PI: Parul Agrawal

High Speed Video goes here. COULD NOT INCLUDE IN 1676 AS IT MAKES THE FILE TOO LARGE TO ATTACH



Echelle Spectra from Tamdakht Arcjet Test

Jenniskins and Prabhu



- **Reduced spectrum clearly shows emission from ablation products has been observed.**
- **Spectrum for Tamdakht H5 chondrite is rich in more volatile elements (Li, Rb, Na, K); more refractory elements (Si, Mg, Al) in ordinary chondrite elemental composition are not strongly present in the spectrum.**
- **Quantitative spectrum is being used to assess and validate numerical models which can then be used to predict luminosity for meteoroids during entry.**

Ground Testing on Tamdakht H5 [8]

POC: Eric Stern

- **2015 Pathfinder LHMEL test shows significant spallation and probable that radiation blockage is occurring at ~ 5 kw/cm^2 and one atmosphere pressure, with no flow.**

- **2017 LHMEL test will help quantify radiation blockage at 1.07 microns at conditions up to 8 kW/cm^2 and 5 atmosphere pressure with shear flow.**

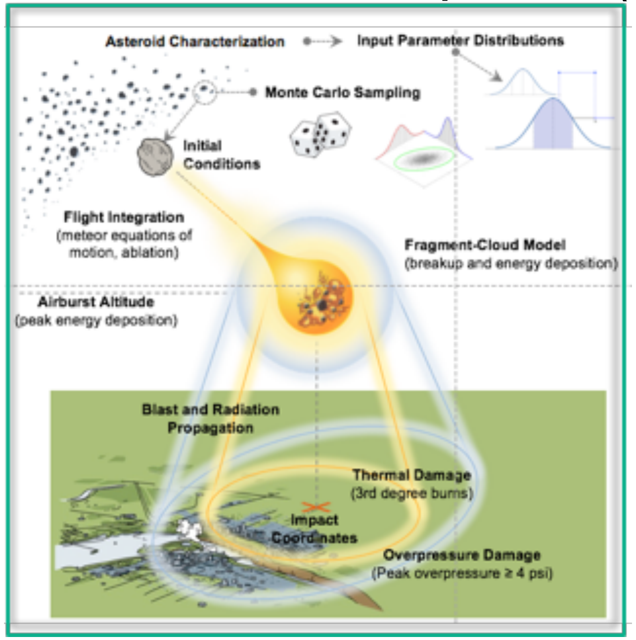
- **2016 Pathfinder arcjet test was highly successful showing ablation processes: vaporization, melt and spallation at flight relevant conditions.**

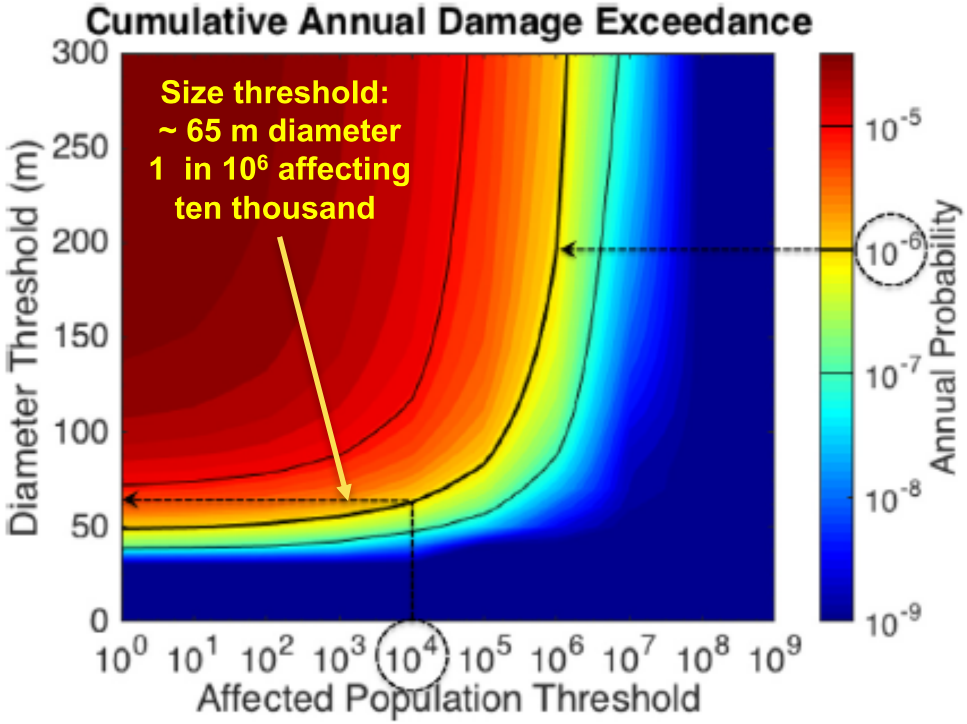
- **Testing results will go far in validation of CFD/Ablation simulations giving rise to improved models for Probabilistic Asteroid Impact Risk (PAIR) assessments. (Heating, Heat of Ablation and Luminosity)**

PAIR for the Asteroid Ensemble [9]

POC Donovan Mathias

Probabilistic Asteroid Impact Risk (PAIR)





Input Parameter Distributions
30 Million Impact Realizations

Size: H-magnitude from 20-30 corres-ponding to diameters up to 400m
Density: 1.1 to 7.5 g/cc
Macroporsity: 1 to 70%
Strength: 0.1 to 10 MPa
Strength Scaling Exponent: 0.1 to 0.3
Impact Velocity: 11 to 40 km/s
Entry Angle: 0 to 90 degrees, weighted to 45^0
Impact Location: Randomly selected over globe
Ablation Parameter: 3.5e-10 to 7 e-8 kg/J
Luminous Efficiency: 3e-4 to 3e-2

Definition of Affected Population

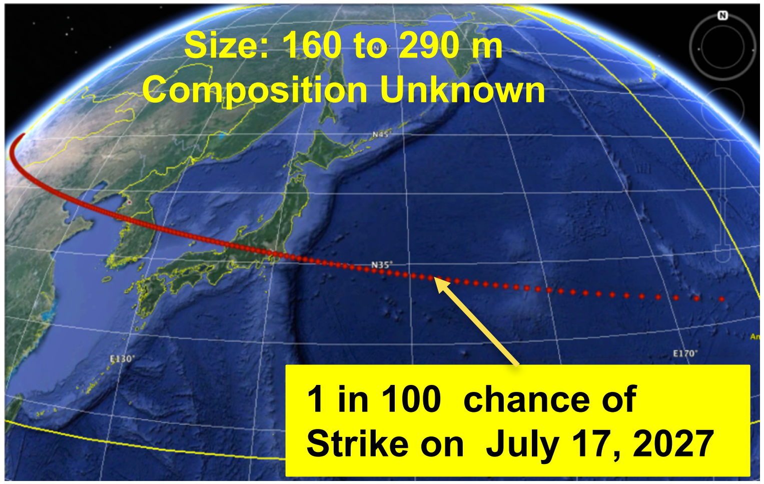
Number of persons within the area where overpressure > 4 psi' **or** 3^{rd} degree burns are suffered. Overpressure dominated.

Cumulative Annual Damage Exceedance

Probability that an asteroid within a given 10m size range will affect at least a given number of people or more assuming, an impact of that size occurs. Then weighted by the likelihood per year that such Impacts actually occur.

PAIR for a Specific Hypothetical Asteroid 2017 PDC [10]

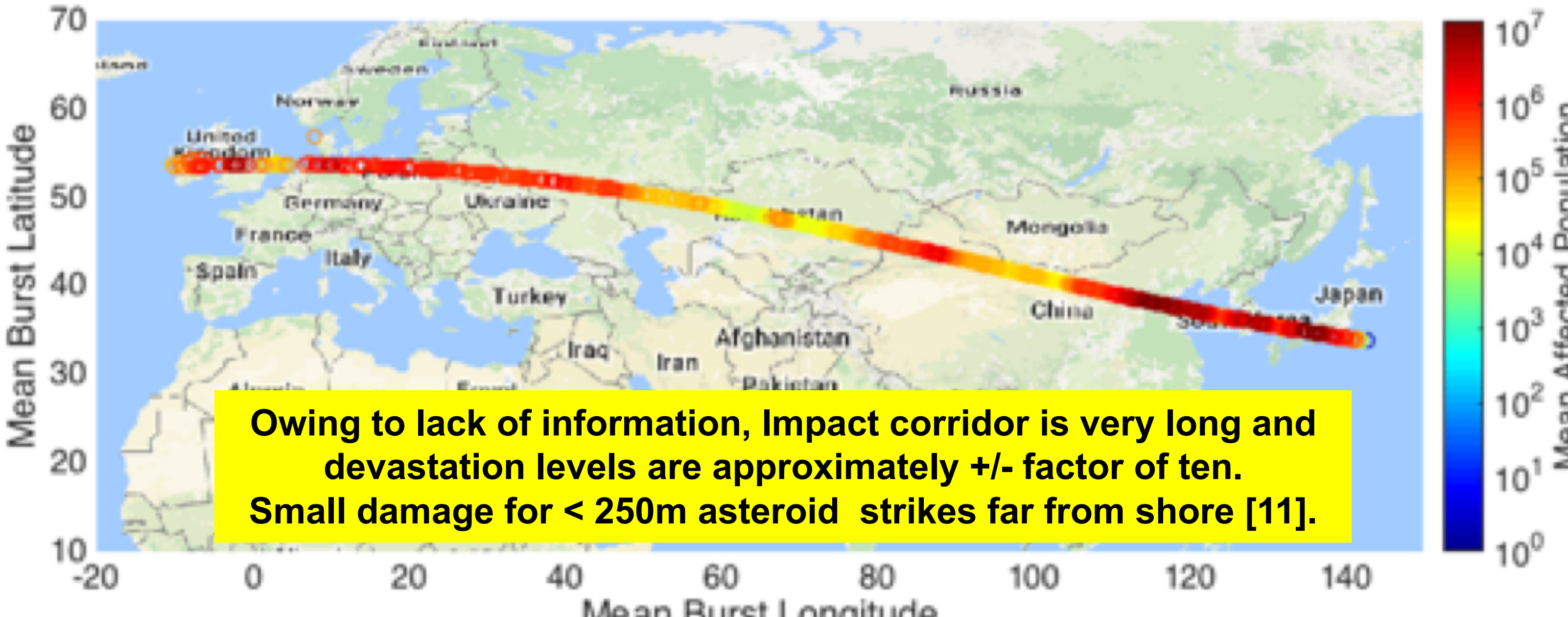
POC Donovan Mathias



Definition of Affected Population

Overpressure Range	Affected Population, %	Expected Damage
68 - 136 mbar 1 - 2 psi	10	Window breakage
136 - 272 mbar 2 - 4 psi	30	Partial collapse of roofs/walls
272 – 680 mbar 4 – 10 psi	60	Partial building destruction
680+ mbar 10+ psi	100	Total building destruction and fatalities

PAIR Analysis Based on Initial Orbital Information and Characteristics from Ensemble.



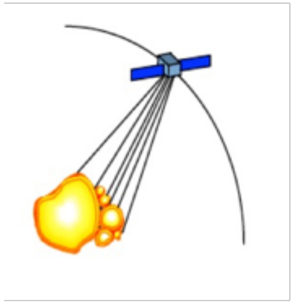
Data from a Rendezvous Mission Enables Best-Case PAIR Assessment [10]

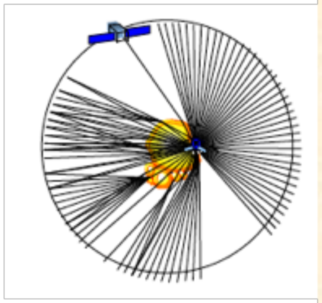
- Optical Navigation, combined with ground observations, dramatically improves definition of the asteroid's orbit and predictions of the strike location, probably to less than 100 km for Hypothetical Asteroid 2017 PDC. [10].

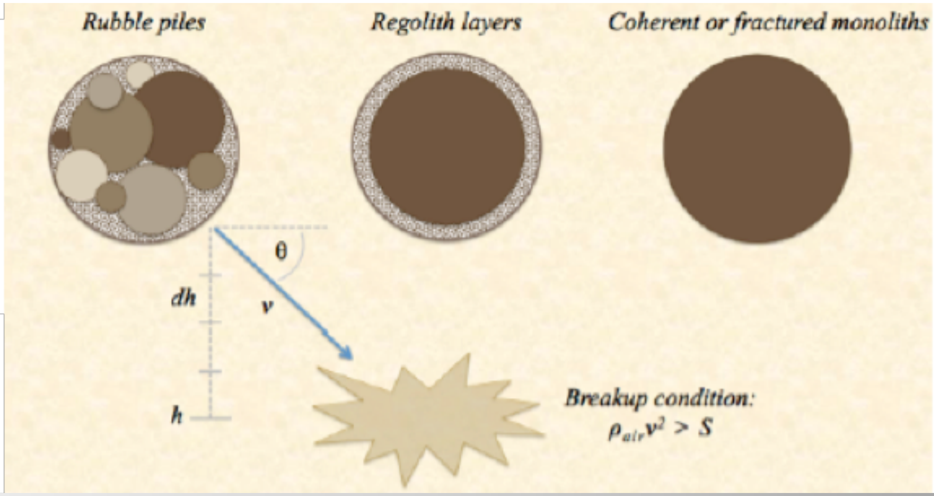
- In-situ measurements provide detailed information about the asteroids shape, size, mass, spin rate, spin orientation, regolith, surface structure (~ 1 meter resolution to ten meter depths) and interior structure resolved to 10-15m via radar[10].

- Knowledge from the rendezvous mission provides set-up information for a new ATAP model [12] that can treat entry and breakup of rubble pile and monolithic asteroids that could be representative of asteroids like 2017 PDC (part of future sensitivity study).

- Monostatic Bistatic Fragment Cloud Model – Rubble Pile







Summary

- **ATAP is fulfilling its role for NASA's PDCO with its Probabilistic Asteroid Impact Risk (PAIR) assessment capability to develop information [WHERE and HOW DEVASTATING STRIKES CAN BE].** ***In the event that a real threat materializes this information will be critical for planning mitigation (deflection or civil defense).***

- **Two of ATAP's functions have been described: (1) How ground testing is being used to validate simulations of entry and breakup of asteroids during atmospheric flight, and (2) Examples of the PAIR assessments dealing with the threat from the ensemble and from a specific, hypothetical asteroid 2017 PDC.**

- **Lessons learned from the simulations and validation testing of extreme atmospheric entry will benefit the advancement of the design of planetary probes for both very high speed flight, e.g. Jovian entry and multi-body hypersonic aerodynamics, e.g. re-contact of back shells.**

- **ATAP will continue its work under the PDCO and begin study of global effects created by asteroid strikes in FY 2018.**

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