COE CST Fourth Annual Technical Meeting:

Space Environment MMOD Modeling and Prediction

Alan Li and Sigrid Close

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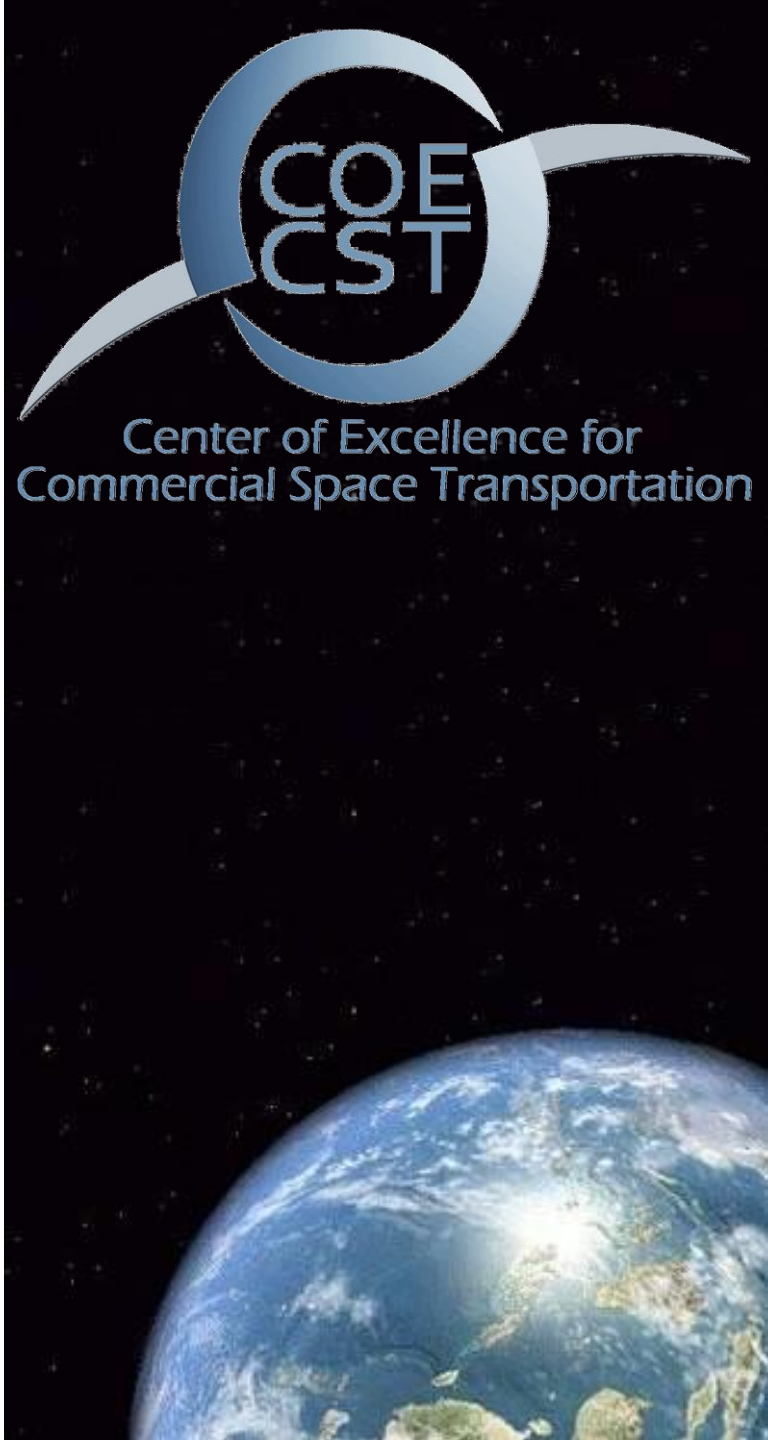
Washington, DC

Center of Excellence for Commercial Space Transportation



Overview

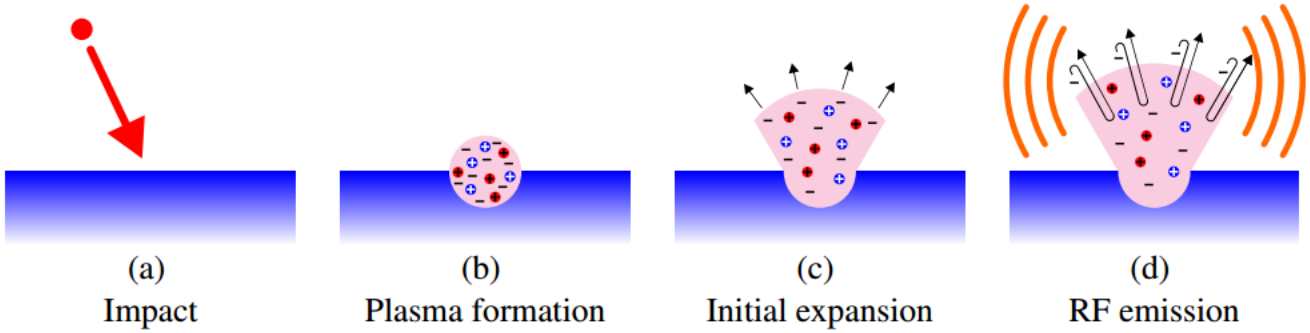
- Team Members
- Task Description
- Goals
- Results
- Conclusions and Future Work

Team Members

- **Sigrid Close, Stanford University (PI)**
- **Alan Li, Stanford University (graduate student)**
- **Steven Pifko, Ryan Volz and Jonathan Yee, Stanford University (graduate students supported by NSF)**

Purpose of Task

- **Spacecraft are routinely impacted by space debris and natural impactors**
  - Mechanical damage: "well-known", larger (> 120 microns), rare
  - Electrical damage: "unknown", smaller/fast, more numerous



- **Goal: Characterize impactor population and provide predictive threat assessment**

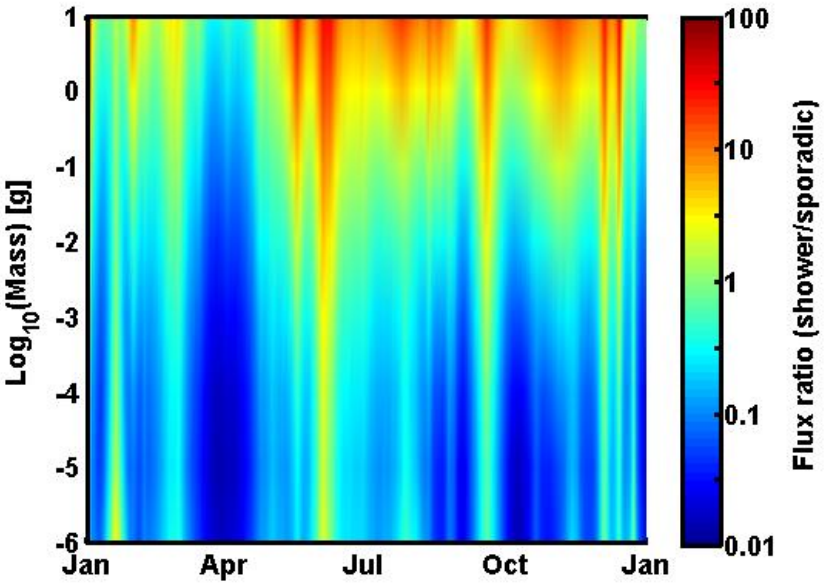
Impactors

- **Meteoroids**
  - **Speeds**
    - 11 to 72.8 km/s (interplanetary)
    - 30-60 km/s (average)
  - **Densities**
    - ≤1 g/cm^3 (icy) or > 1 g/cm^3 (rocky/stony)
  - **Sizes**
    - < 0.3 m (meteoroid)
    - < 62 μm (dust)

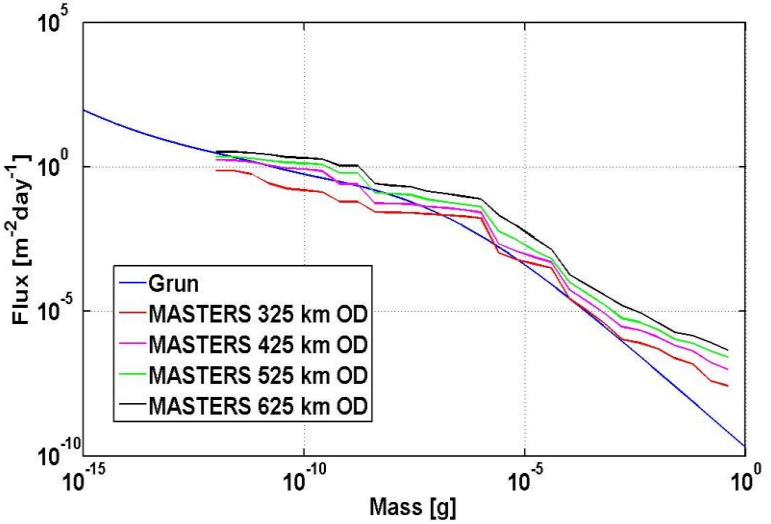
- **Space Debris**
  - **Speeds in LEO**
    - < 12 km/s
    - 7-10 km/s (average)
  - **Densities**
    - > 2 g/cm^3
  - **Sizes**
    - < 10 cm (small)

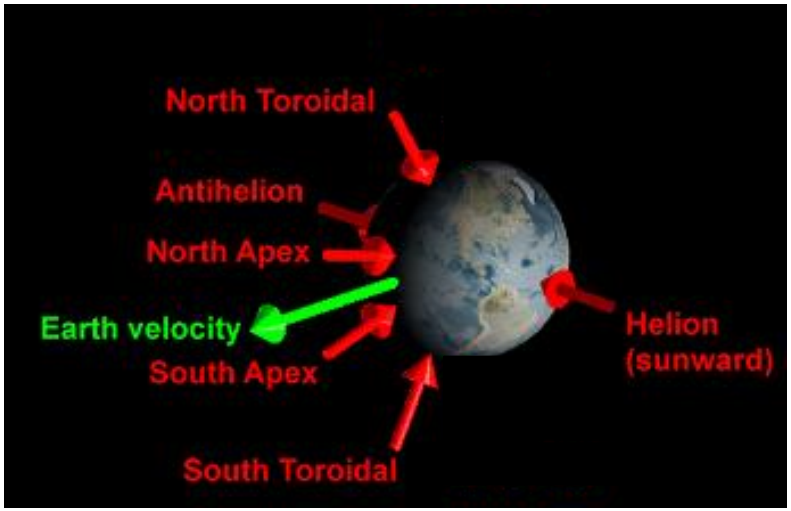
Flux

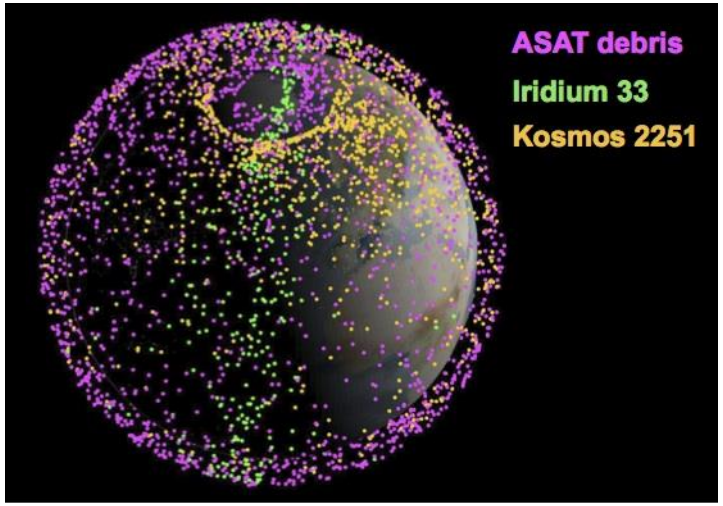
Meteoroids



Meteoroids and Debris

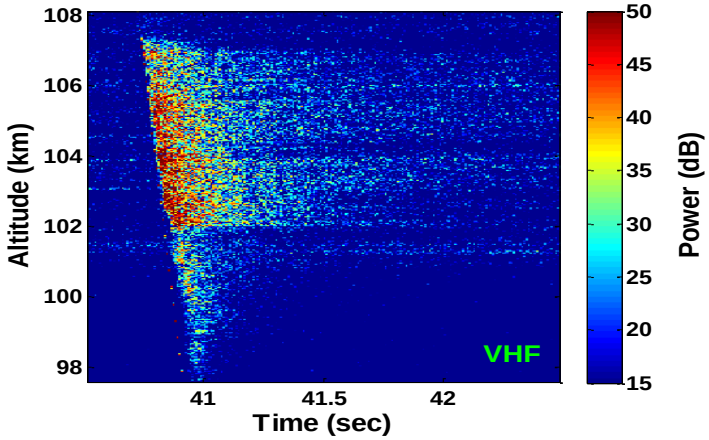






Methodology: Meteoroids

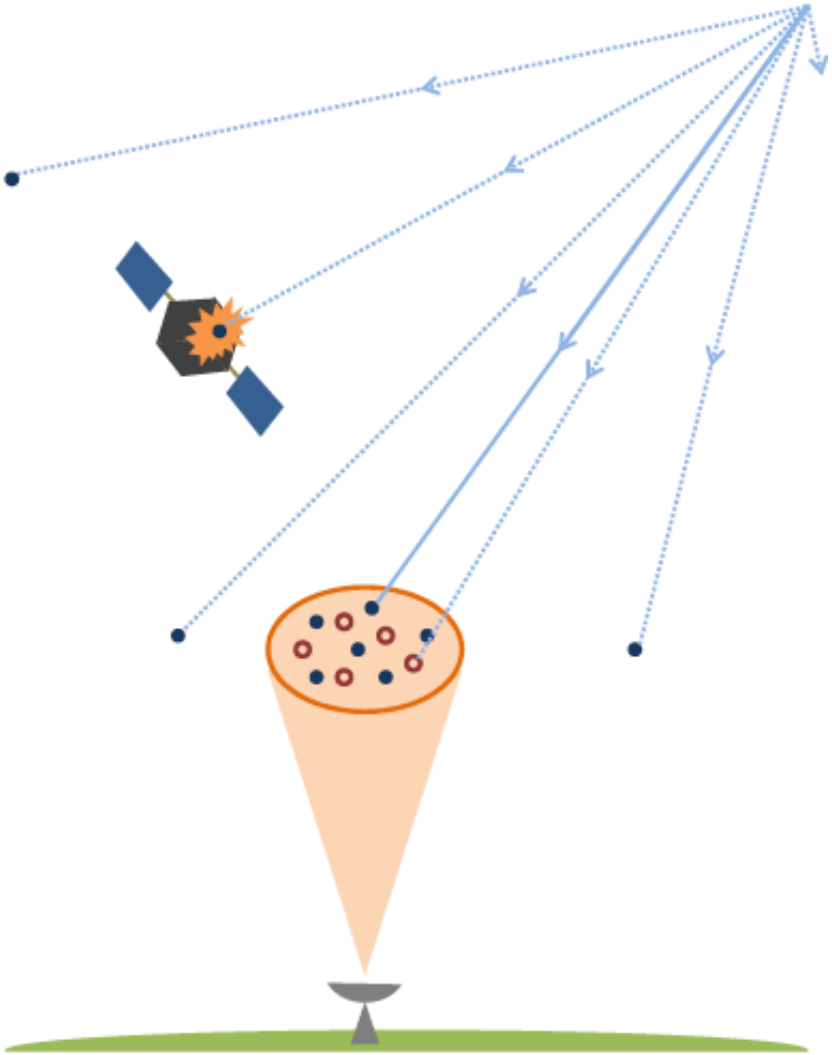
- **Atmospheric Plasma**
  - *Data*: ground-based radar
  - *Models*: Particle-In-Cell (PIC) for plasma development, Finite Difference Time Domain (FDTD) for EM interaction with plasma
  - *Deliverables*: energy flux, mass, bulk density, orbit prediction



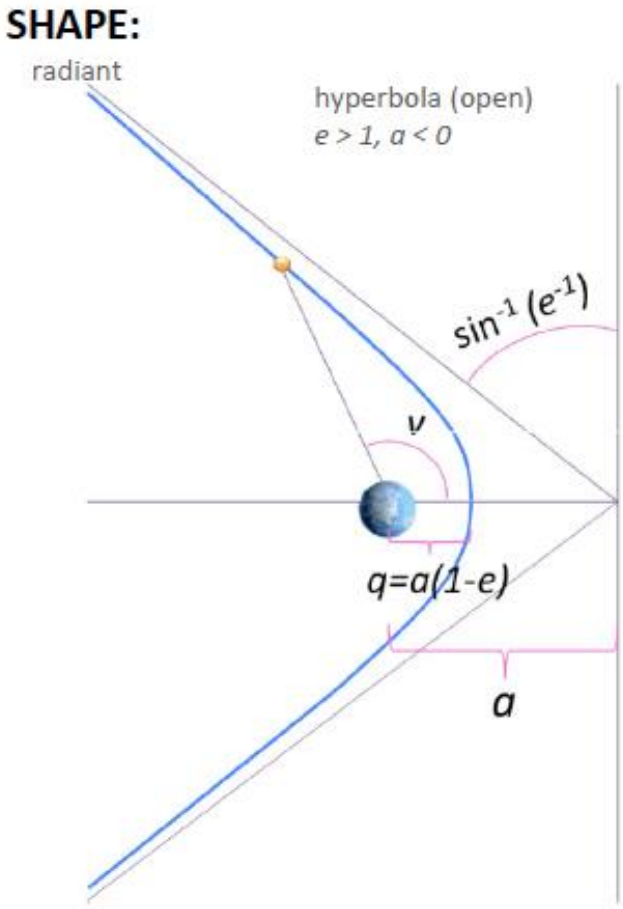
- **Impact Plasma**
  - *Data*: ground-based accelerators
  - *Models*: Computational Fluid Dynamics (CFD) for initial conditions, PIC for plasma development and RF emission
  - *Deliverables*: plasma composition, temperature, RF spectra

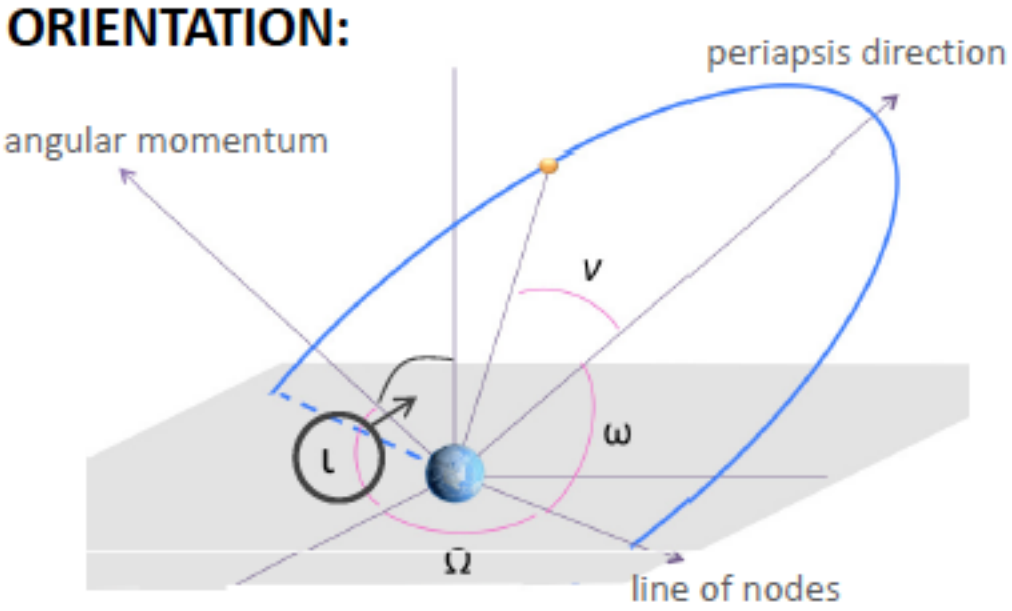
Atmospheric Data: Meteors

- **Radars**
  - ALTAIR
  - Arecibo Observatory
  - MIT Millstone
  - MU

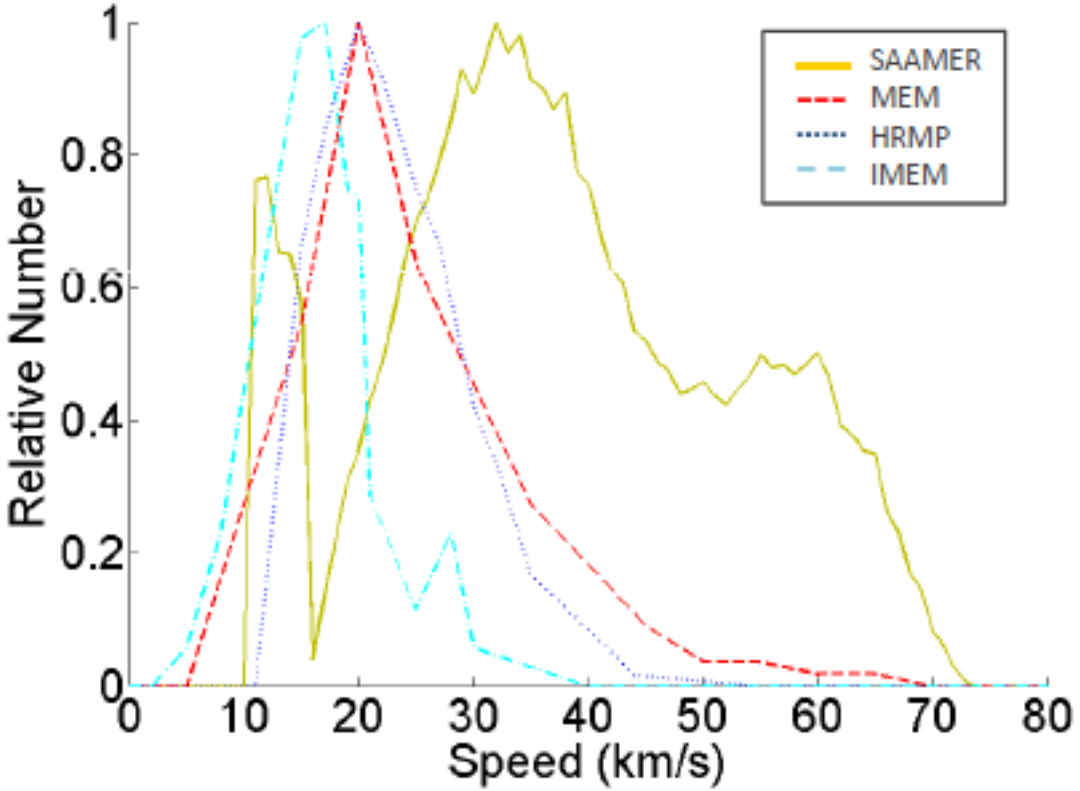


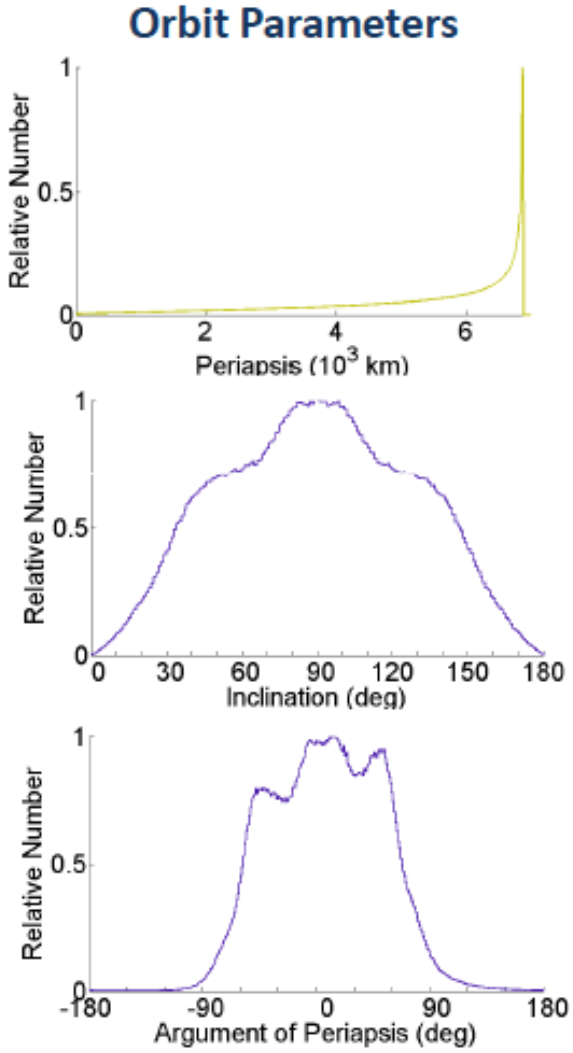
Orbit Determination





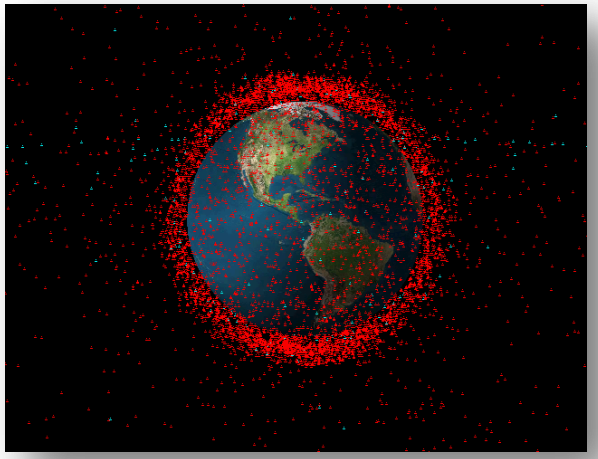
Meteoroids at LEO





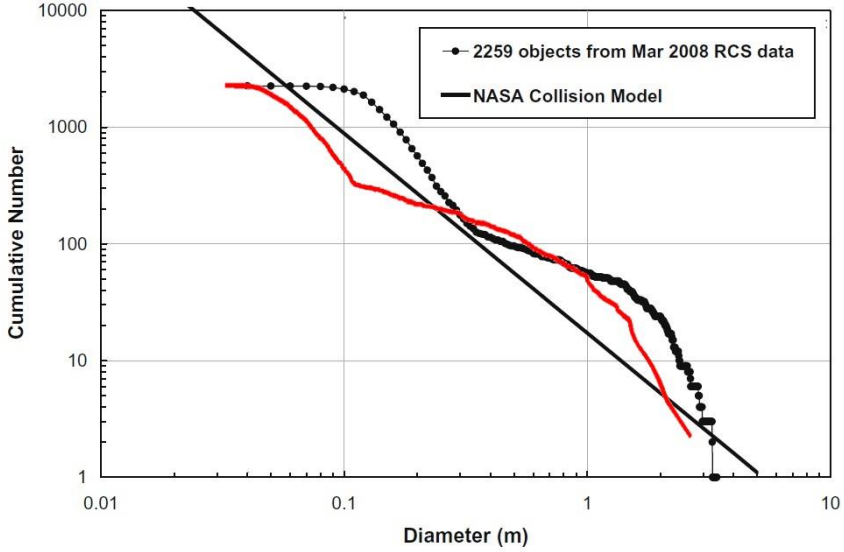
Methodology: Debris

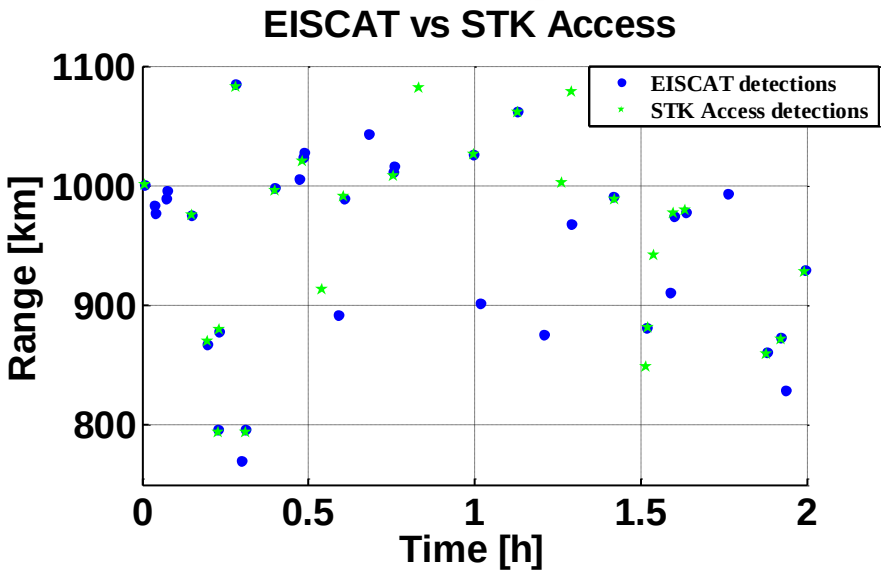
- **Remote Sensing**
  - *Data*: ground-based radar
  - Models: ORDEM for environment, LEGEND and MASTERS for collision and propagation
- **In Situ**
  - *Data*: CubeSats
- **Impact Experiments**
  - *Data*: future light-gas gun tests
  - *Models*: Computational Fluid Dynamics (CFD) for initial conditions, PIC for plasma development and RF emission



Debris

- **Characterization of debris field during impact**
- **EISCAT Radar**
- **Minimum eccentricity solution gives inclination bands**
- **Cumulative number of debris detected of smaller size than reported by NASA**
- **Correlation with Spacetrack to see untracked debris**
  - 42.4% confirmed detections from ASAT test

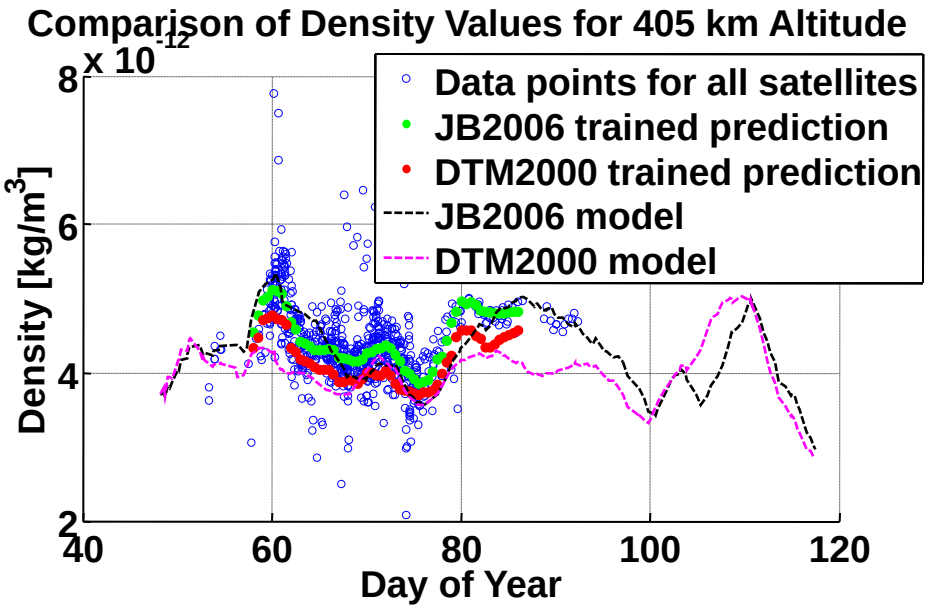


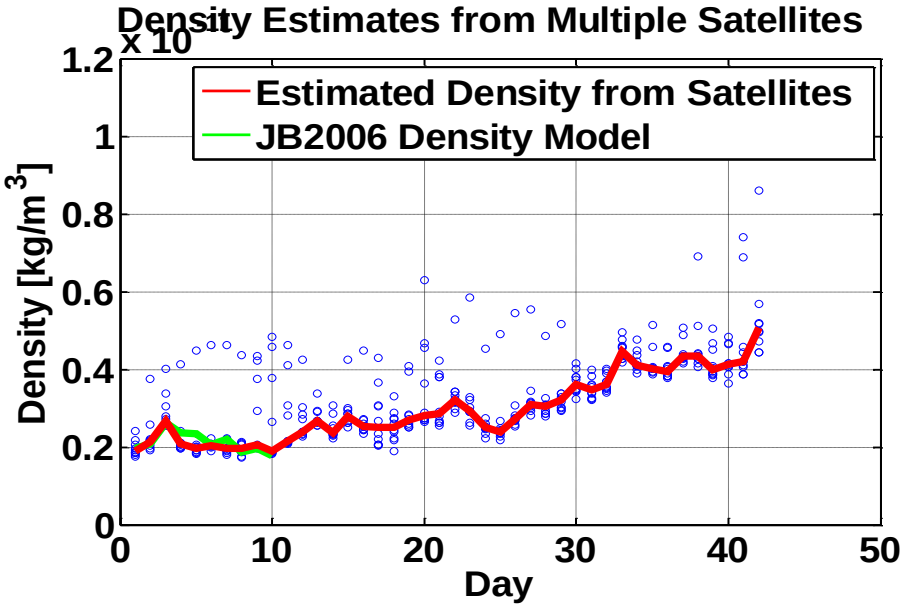


In Situ Data and Models

- **Advent of Cubesats**
  - **Many Cubesats in orbit, now starting in constellations**
  - **Known mass & area**
  - **Low Earth Orbit**
  - **Commercial Space Flight likely to remain in this region**
- **Drag in LEO is the predominant force other than gravity**
- **Models:**
  - **Jacchia-Bowman (JB)**
  - **Drag Temperature Model (DTM)**
  - **High Accuracy Satellite Drag Model (HASDM)**
- **Issues:**
  - **Most models have error of 10%-20% depending on solar conditions**
  - **Specialized drag satellites required**

Neutral Density Estimation





- **Known minimum ballistic coefficient**
- **Likelihood of satellite frontal area given ADACS and decay measurements**
- **Calculate most likely neutral density observed with confidence intervals**

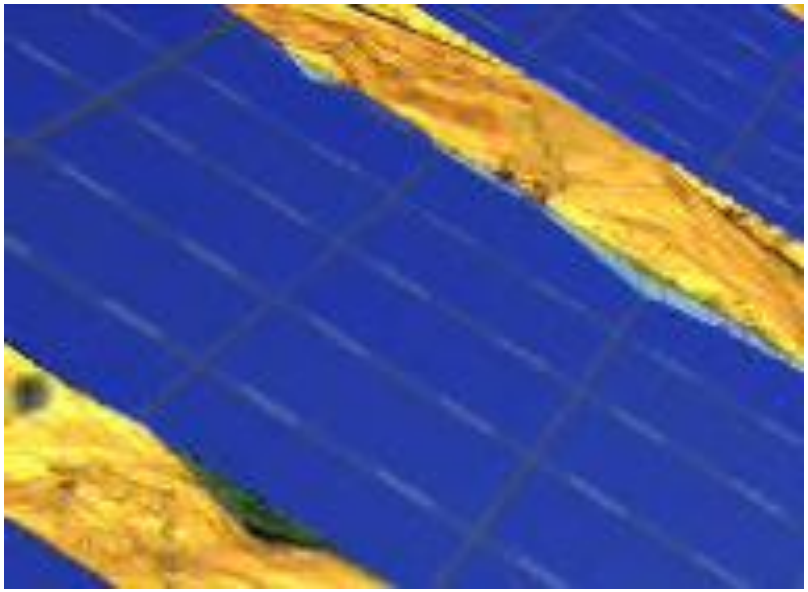
Conclusions and Future Work

- **Meteoroids**
  - Bulk density determination
  - FDTD scattering
  - Effect of charging on electrical failure mechanism
- **Debris**
  - Filtering methods for larger constellation of satellites
  - Propagation of debris using near real time density data

Initial Threat Assessment Model

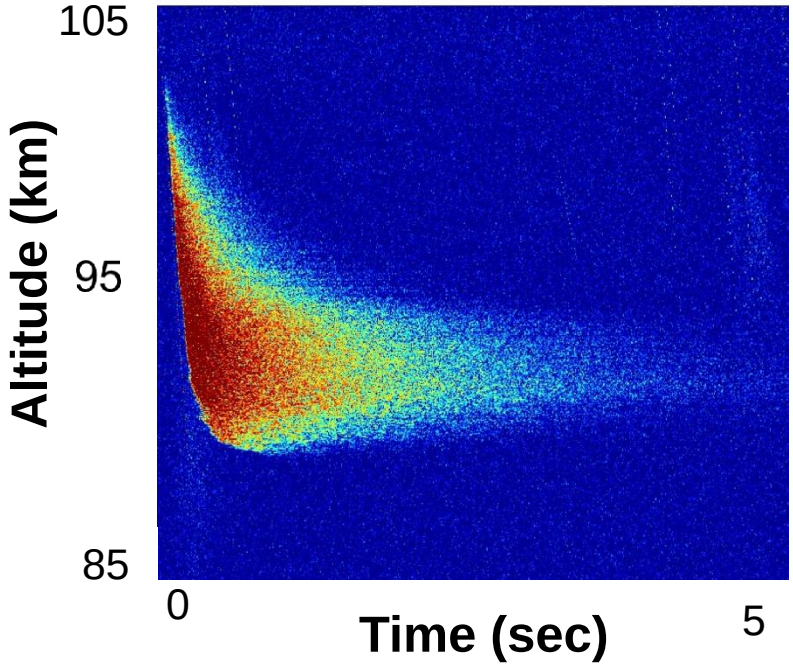
Thank You!

- **Alan Li (alanli@stanford.edu)**
- **Sigrid Close (sigridc@stanford.edu)**

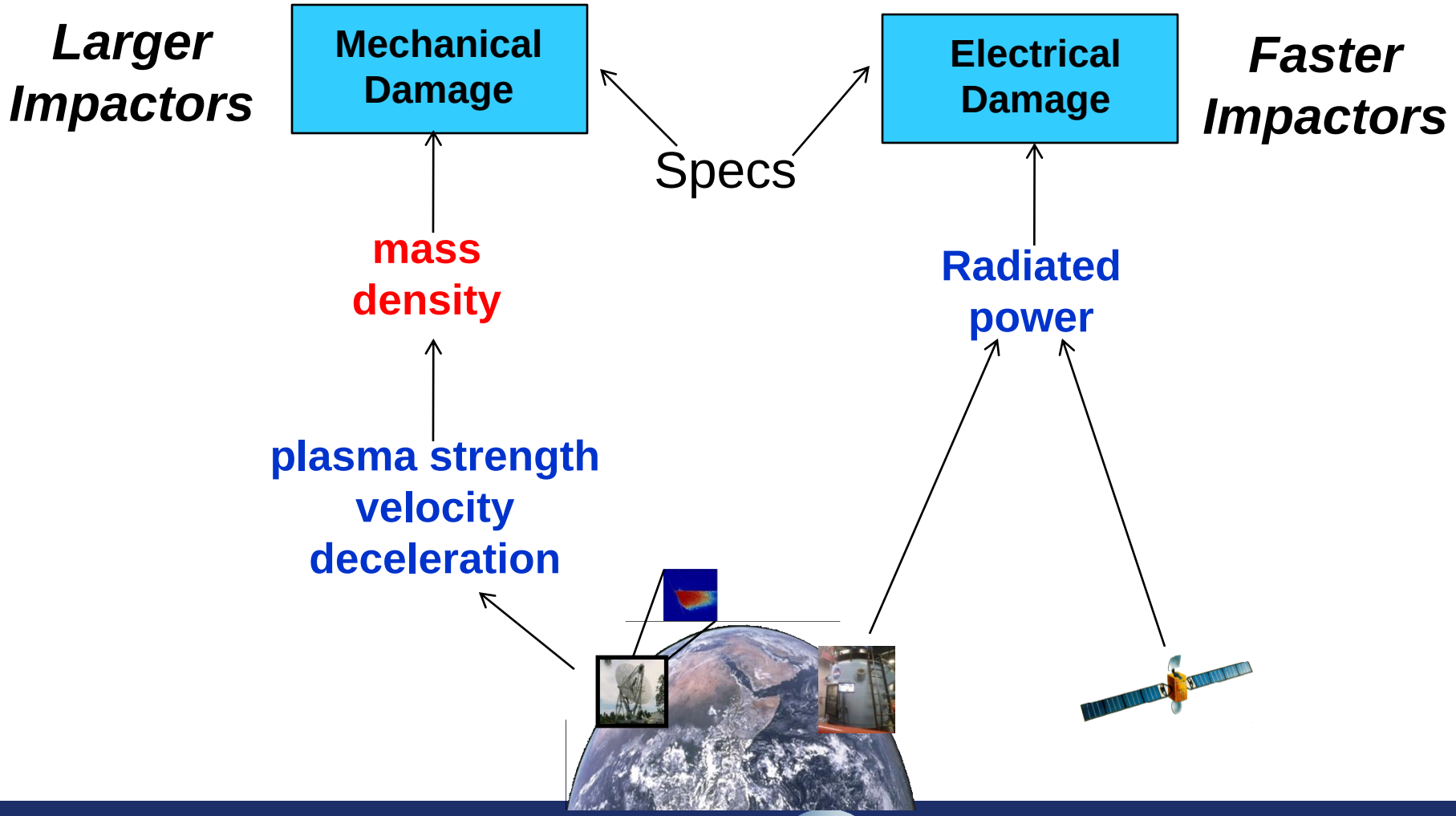


Backup

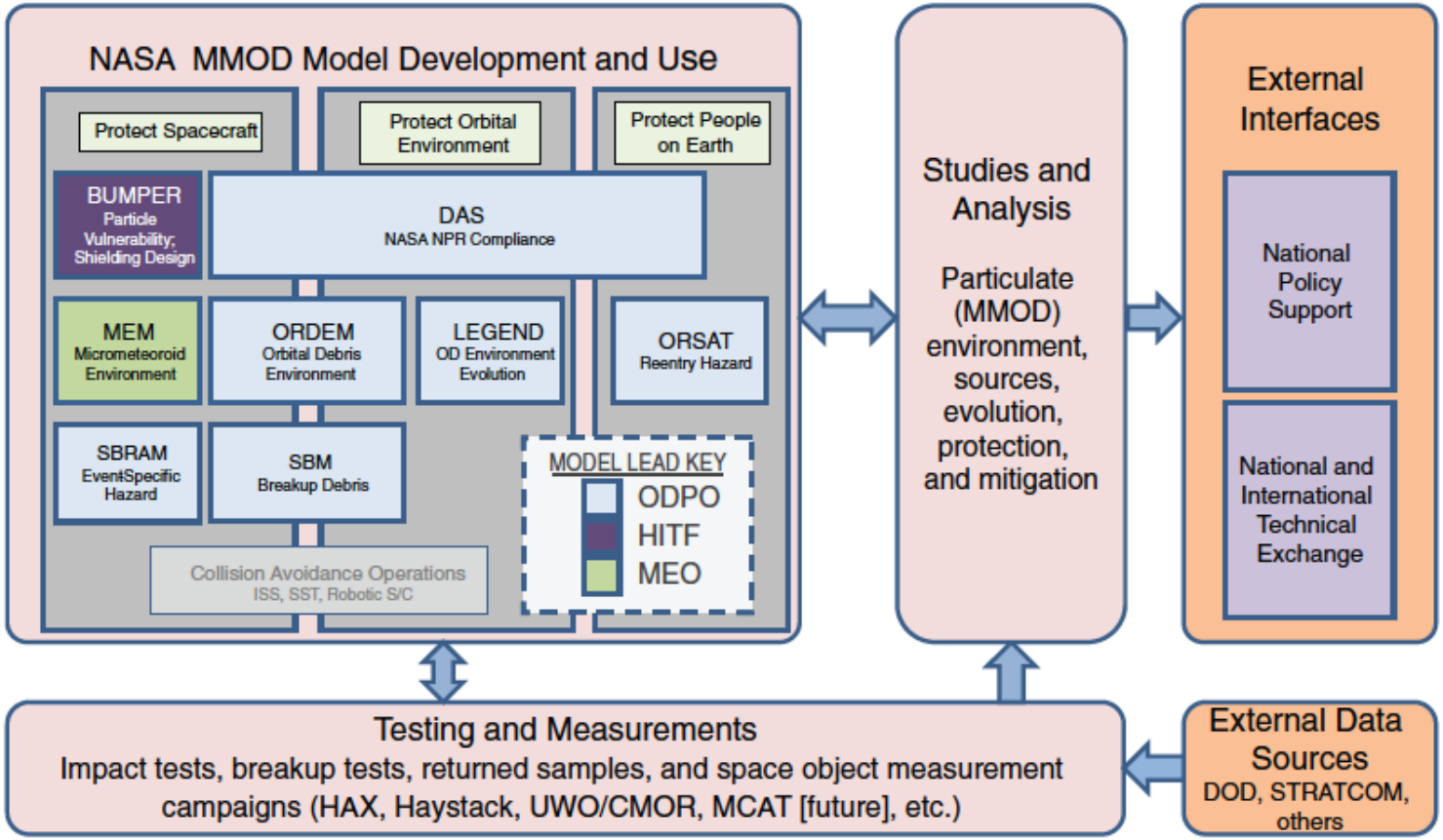
ALTAIR Radar Data



Mechanical and Electrical Damage



NASA Approach



Results or Schedule/Milestones

- 1-2 slides

Next Steps

Contact Information