Stanford University

Federal Aviation Administration

COE CST Second Annual Technical Meeting:

Space Environment MOD Modeling and Prediction

Sigrid Close

October 31, 2012

Overview

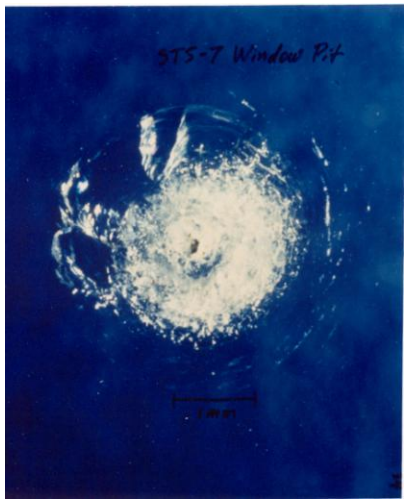
- Team Members
- Purpose of Task
- Research Methodology
- Results
- Next Steps
- Contact Information

Team Members

- **Sigrid Close, Stanford University (PI)**
- **Alan Li, Stanford University (graduate student)**
- **Steven Pifko and Ryan Volz, 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**

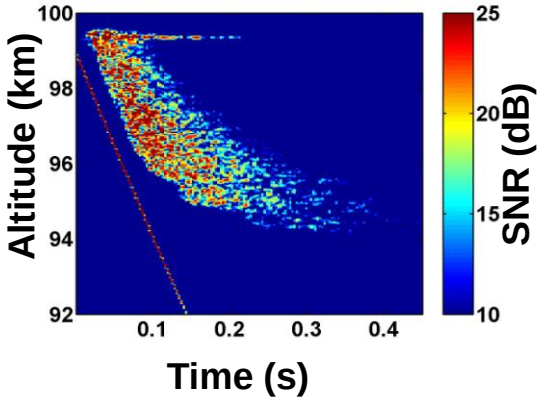
Impactors

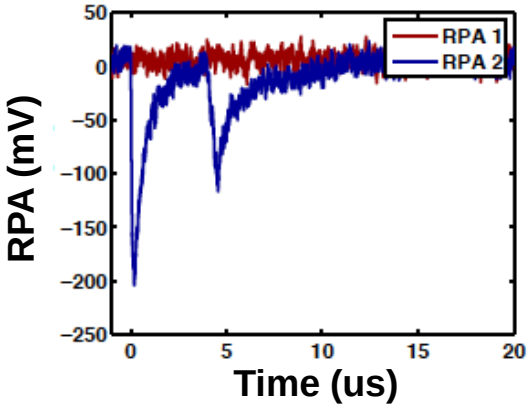
- **Meteoroids**
  - **Speeds**
    - 11 to 72.8 km/s (interplanetary)
    - 30-60 km/s (average)
  - **Densities**
    - ≤1 g/cm^3 (icy) or > 1 g/cm^3 (rocky/stony)
  - **Sizes**
    - < 0.3 m (meteoroid)
    - < 62 μm (dust)

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

Methodology: Meteoroids

- **Atmospheric Plasmas**
  - Data: ground-based radar
  - Models: Particle-In-Cell (PIC) for plasma formation, 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: PIC for plasma formation and RF emission
  - Deliverables: plasma composition, temperature, RF spectra

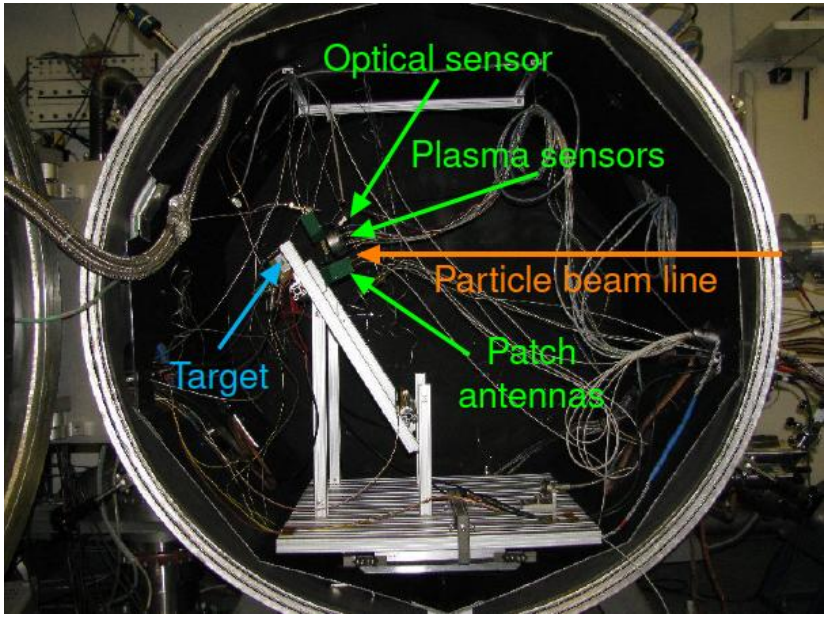




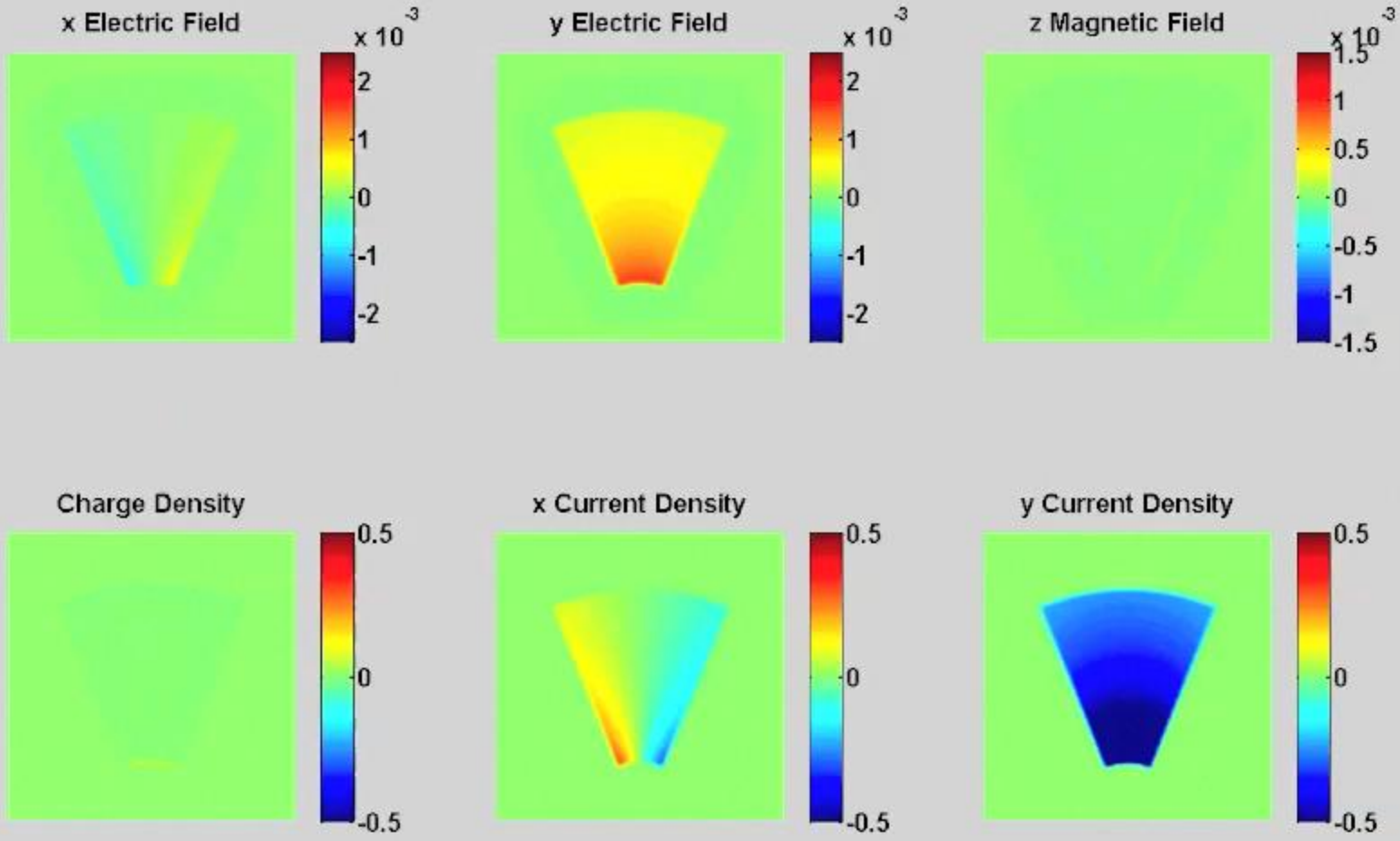
Meteoroid Data

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

- **Accelerator**
  - Van de Graaff at Max Planck Institute

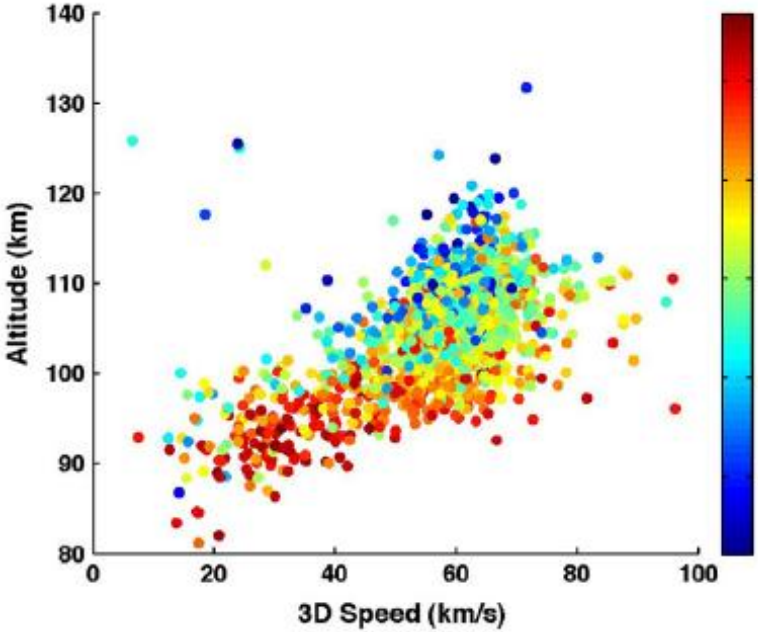


Plasma Modeling Results: PIC

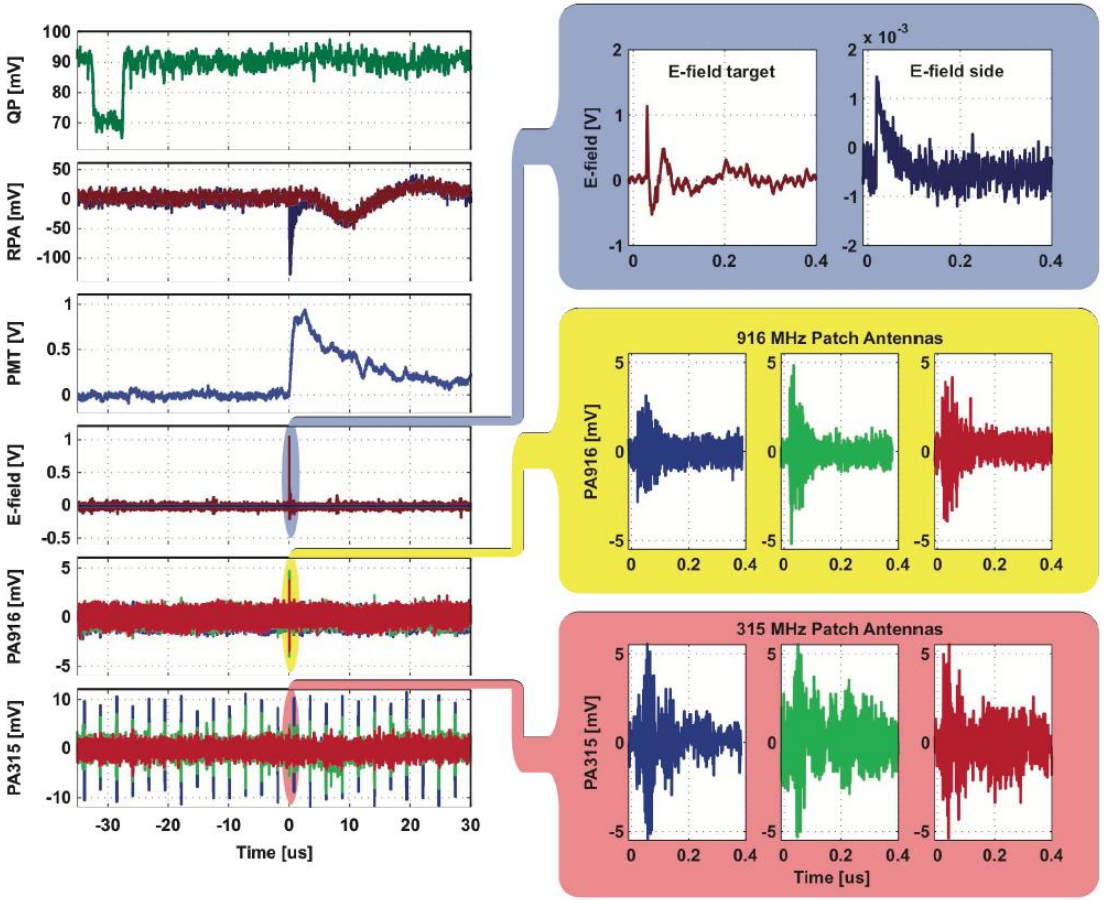


Meteoroid Results

Atmospheric Plasmas

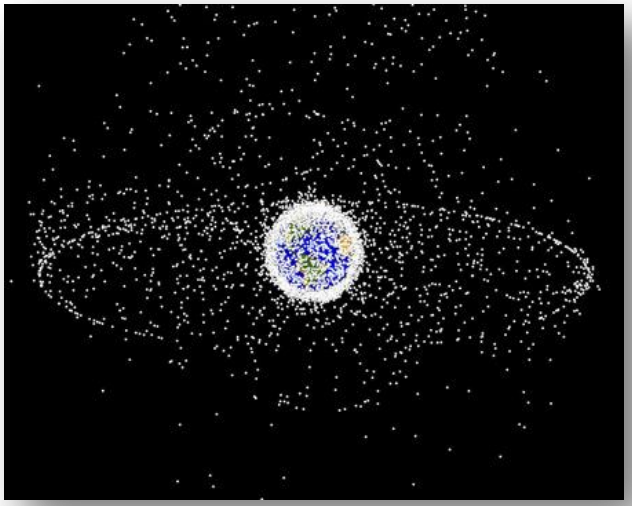


Impact Plasmas



Methodology: Debris

- **Orbital Debris**
  - Models: force models for source (collisions), propagation in space/time, atmospheric models
  - Data: ground-based radar, in situ
  - Deliverables: flux, mass, orbit, source, prediction



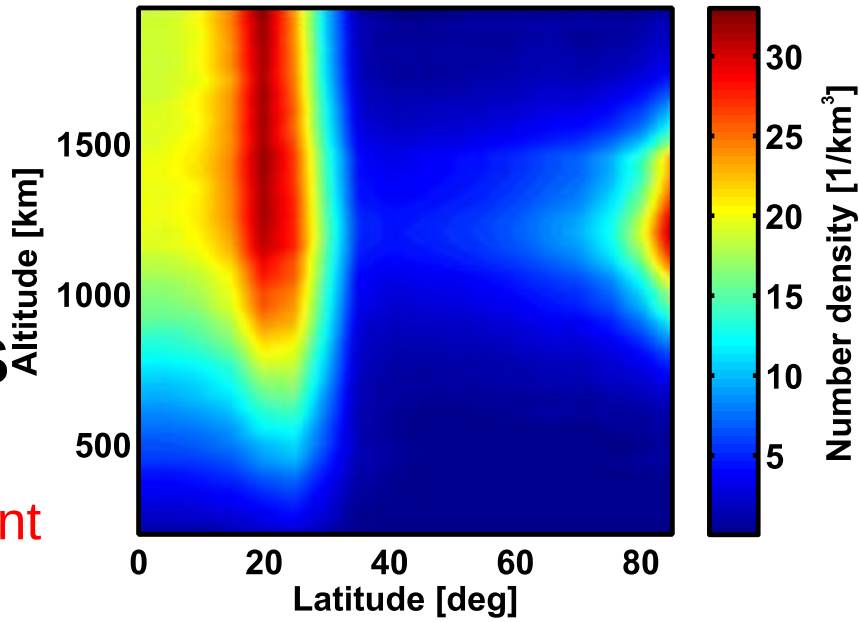
Debris Data

- **EISCAT Svalbard radar**
  - 78.1°N, 16.0°E
  - 500 MHz, 32 m dish, 0.8 MW peak power
  - Az 182.1°, El 81.6°
- **Data collection**
  - Primarily during IPY (International Polar Year) from January 2007 to February 2008

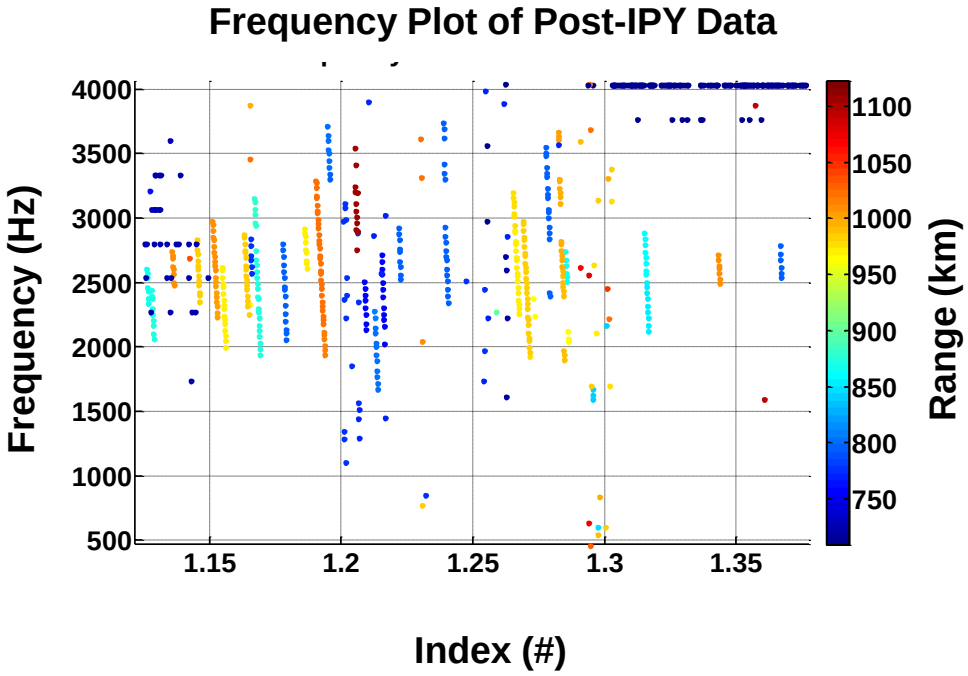
Debris Modeling Results

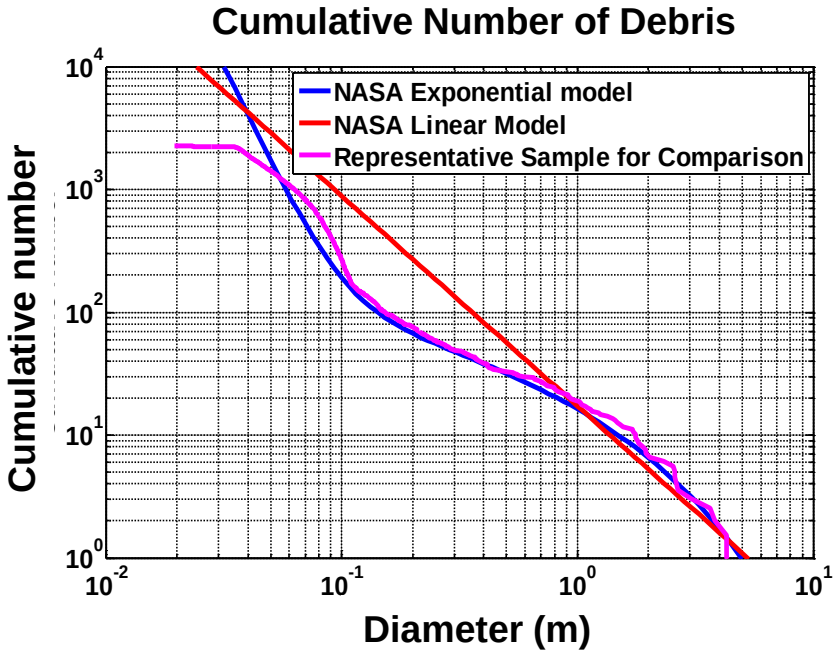
- **ORDEM (NASA)**
  - Environment
  - Data: SSN, HAX, Goldstone, LDEF, returned arrays from HST
  - Model: EVOLVE (used to extrapolate where data is scarce
- **LEGEND (NASA) and MASTERS (ESA)**
  - Collision and propagation (environment evolution)
  - Includes drag modeling
  - MASTERS predicts lower amount of small debris

ORDEM 2000 for debris > 0.01 mm



Debris Results





Next Steps

- **Meteoroids**
  - Energy flux model
  - Spectra of RF emission
  - Effect of charging on electrical failure mechanism
- **Debris**
  - Continue EISCAT analysis
  - Comparison of EISCAT data with MASTERS/ORDEM
  - Light-gas gun experiments

Initial Threat Assessment Model

Publications

- Volz, R. and S. Close (2012), Inverse filtering of radar signals using compressed sensing with application to meteors, *Radio Sci.*, *47*, RS0N05, doi:10.1029/2011RS004889.
- Close, S., R. Volz, R. Loveland, A. Macdonell, P. Colestock, I. Linscott, M. Oppenheim (2012), Determining meteoroid bulk densities using a plasma scattering model with high-power large-aperture radar data, *Icarus*, doi:10.1016/j.icarus.2012.07.033.
- Kelley, M., S. Pancoast, S. Close, Z. Wang (2012), Analysis of electromagnetic and electrostatic effects of particle impacts on spacecraft, *Adv. Space. Res.*, *49*, doi: 10.1016/j.asr.2011.12.023.
- Pifko, S., D. Janches, S. Close, J. J. Sparks, T. Nakamura, and D. Nesvorny (2012), Modeling the meteoroid input function at mid-lattitude using meteor observations by the MU radar, *Icarus*, in review.
- Li, A., S. Close and J. Markannen (2012), EISCAT space debris after the international polar year (IPY), IAC, 12.A6.1.8.

Quad Chart Task 186

PROJECT AT-A-GLANCE

- AST RDAB POC: Karen Shelton-Mur
- AST RESEARCH AREA: 1.1 STM & Ops – Orbital STM
- UNIVERSITY: Stanford University
- PRINCIPAL INVESTIGATOR: Sigrid Close
- STUDENT RESEARCHER: Alan Li (MS)
- PERIOD OF PERF: Jan 1, 2011 – Dec 31, 2012
- STATUS: Ongoing

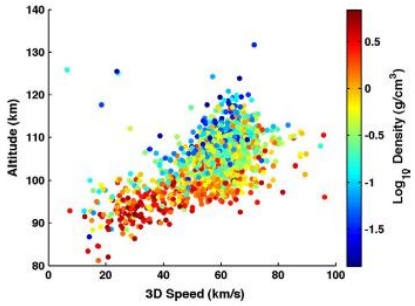
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

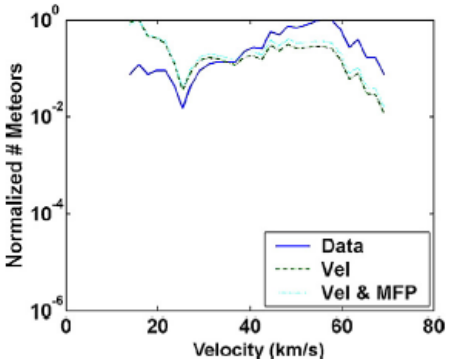
- An integrated air and space traffic management system requires knowledge of the threat to objects in and entering Low Earth Orbit (LEO). LEO spacecraft are routinely struck by impactors, both human-made (space debris, posing a mechanical threat) and natural (meteoroids, posing a mechanical and electrical threat). Characterizing the impactor population through data analysis and modeling will help predict meteoroid and orbital debris (MOD) threat to the launch and operation of commercial LEO spacecraft.

STATEMENT OF WORK

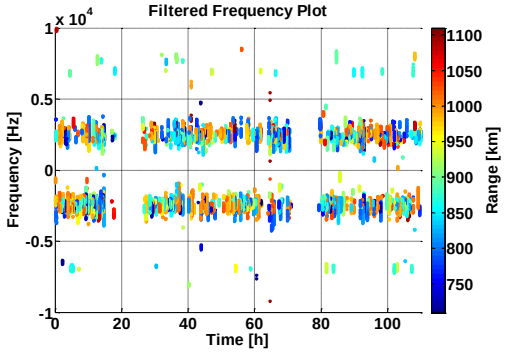
- Provide the first characterization of debris and meteoroid parameters, including e.g. energy flux, orbit, and bulk density, in order to assess MOD threat to LEO spacecraft.

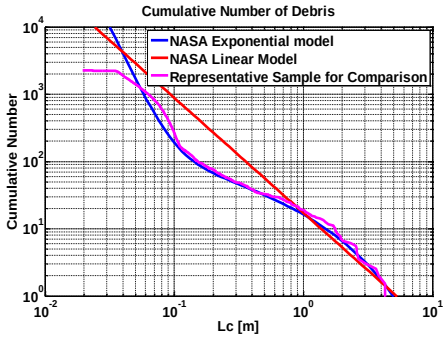
METEOROID RESULTS





DEBRIS RESULTS



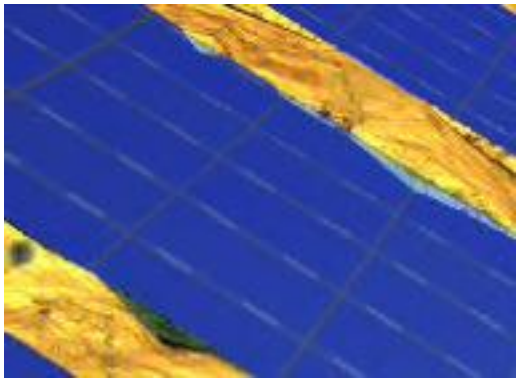


FUTURE WORK

- Meteoroids
  - Energy flux model incorporating sporadic sources
  - Effect of spacecraft charging on electrical impact failure
- Debris
  - Analysis of radar (i.e. EISCAT) debris data
  - Comparison of radar data with MASTERS/ORDEM
  - Initial threat assessment model

Thank You!

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

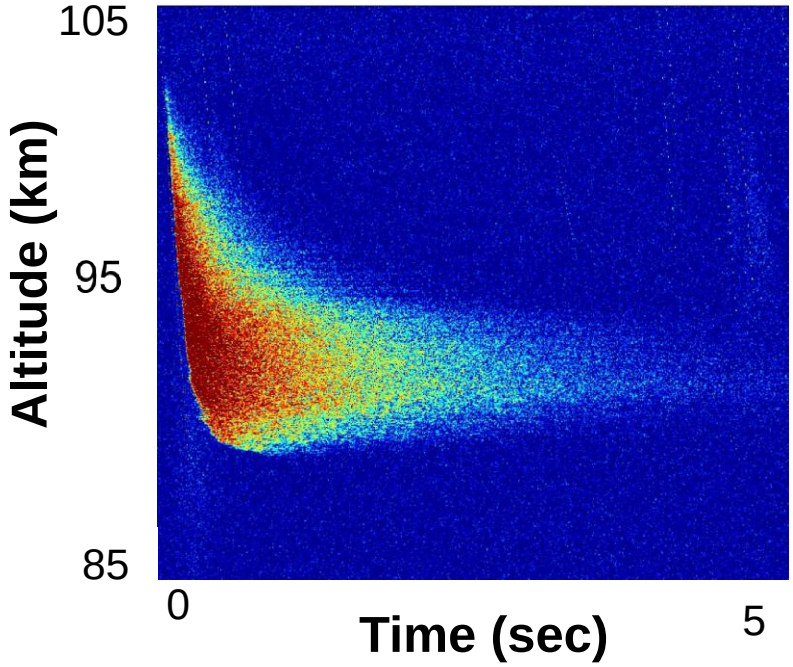


Backup

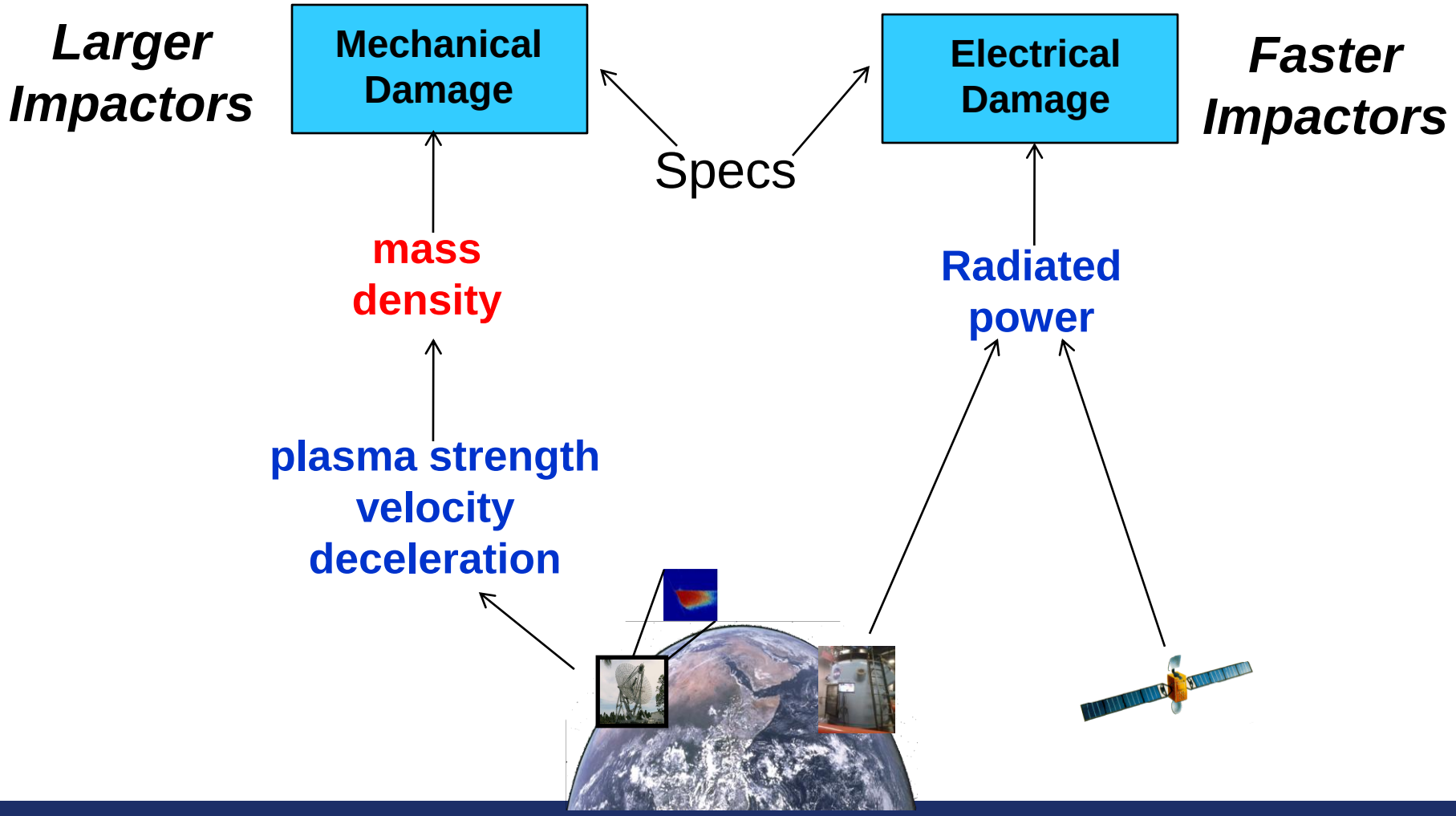
ALTAIR Radar Data

VHF

UHF



Mechanical and Electrical Damage



NASA Approach