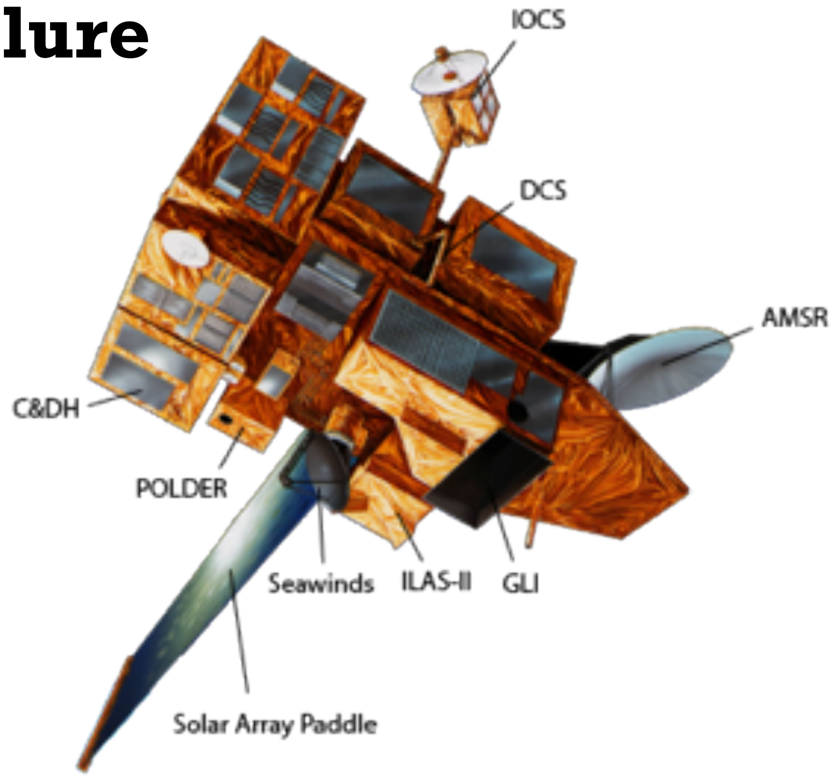
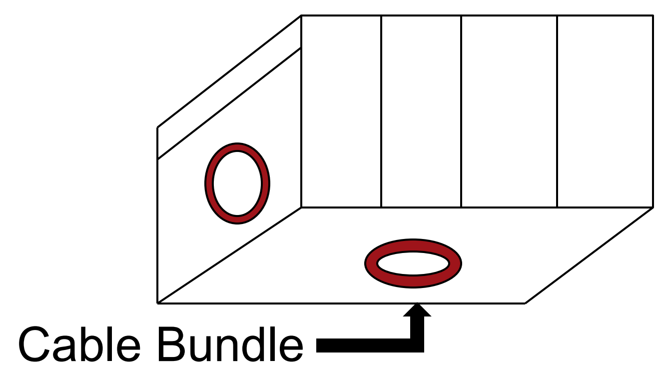
# Table of Contents

- **Why…? (10 min.)**
- **How…? (2 min.)**
- **Q&A (3 min.)**

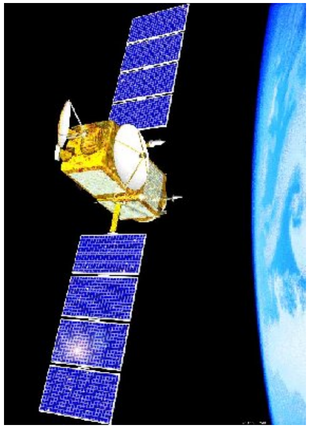
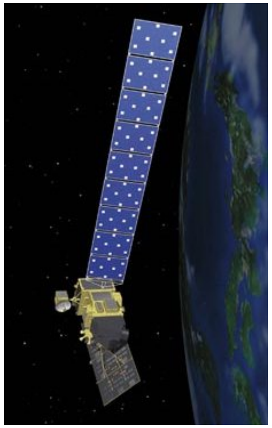
# Modeling ADEOS-III Failure

- **E = 10kV/m**
- **Assume magnetic field penetration into slots and holes pictured; magnetic flux links into cable**
- **Changing magnetic flux →emf→ current**
- **Produces open circuit voltage ~1V**

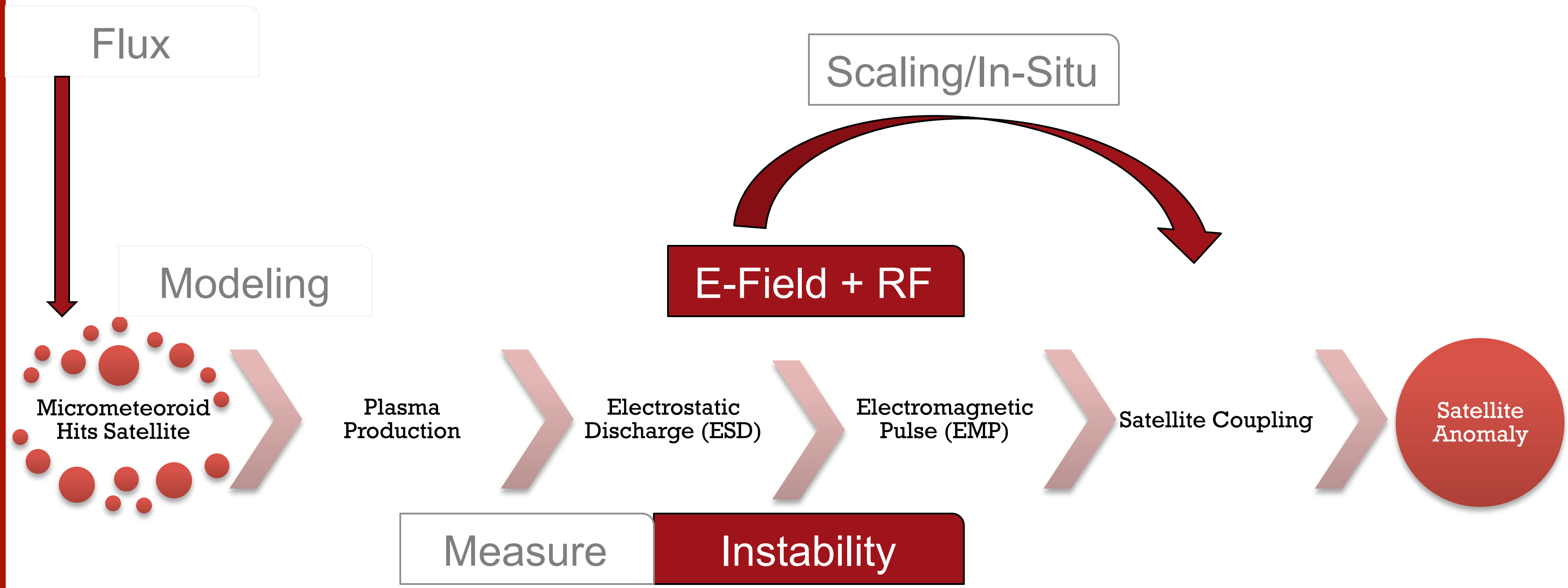


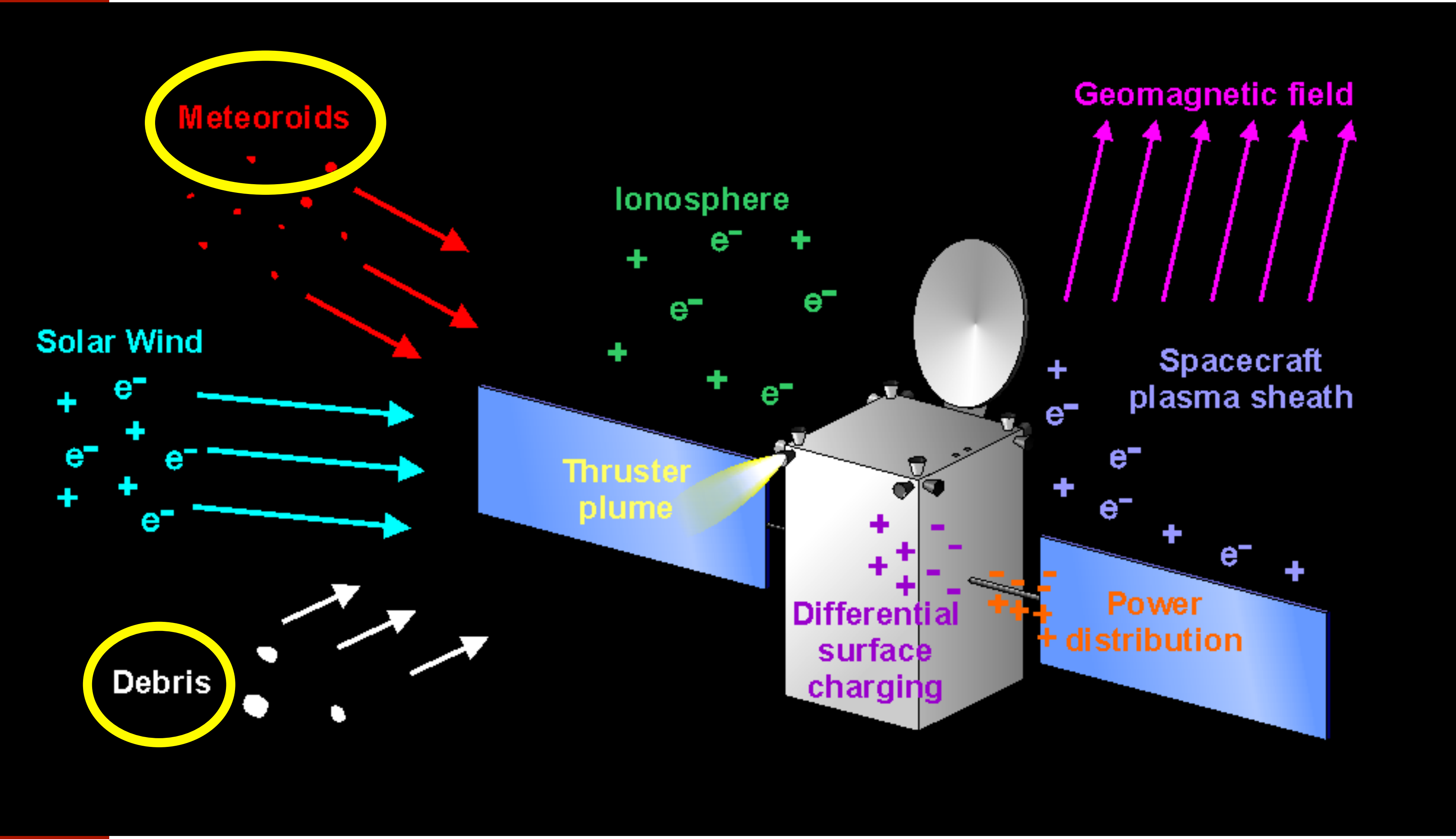
# Spacecraft Anomalies

| Olympus 1993 | Landsat 5 2009 | JASON-1 2005 | ADEOS II 2003 | ALOS 2011 |
|---|---|---|---|---|
|  |  |  |  |  |
| ESA | NASA | NASA | JAXA | JAXA |

| NGDC Database: Anomaly Diagnosis |
|---|
| Electron Caused EM Pulse (Deep Dielectric Charging) - 490 |
| Electrostatic Discharge (Surface Charging) – 1072 |
| Single Event Upset - 822 |
| Radio Frequency Interference – 8 |
| Unknown - 2587 |


Flux
Scaling/In-Situ
Modeling
E-Field + RF
Micrometeoroid Hits Satellite
Plasma Production
Electrostatic Discharge (ESD)
Electromagnetic Pulse (EMP)
Satellite Coupling
Satellite Anomaly
Measure
Instability

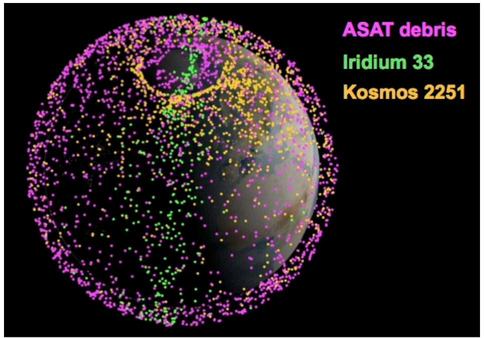
# Spacecraft Environment



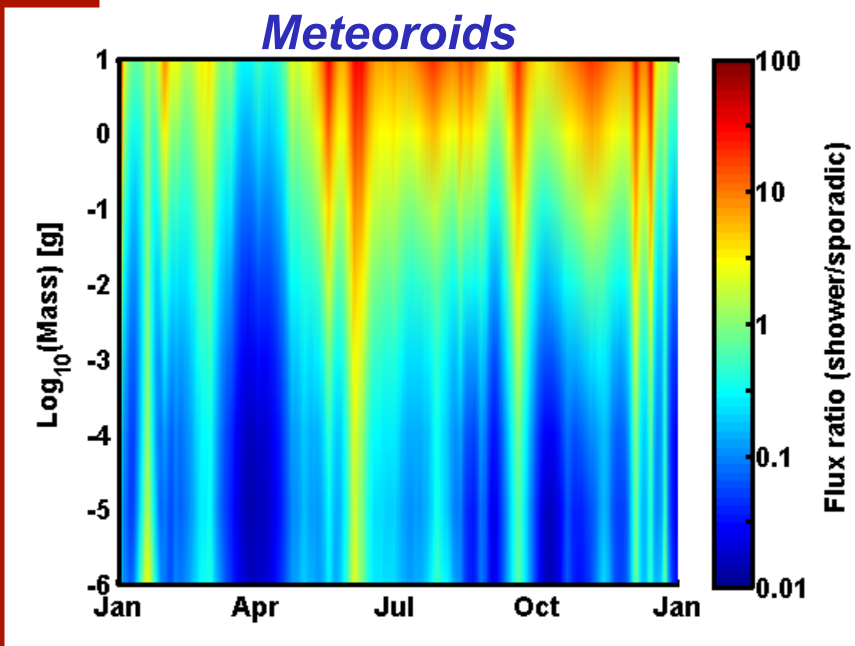
# Hypervelocity Particles

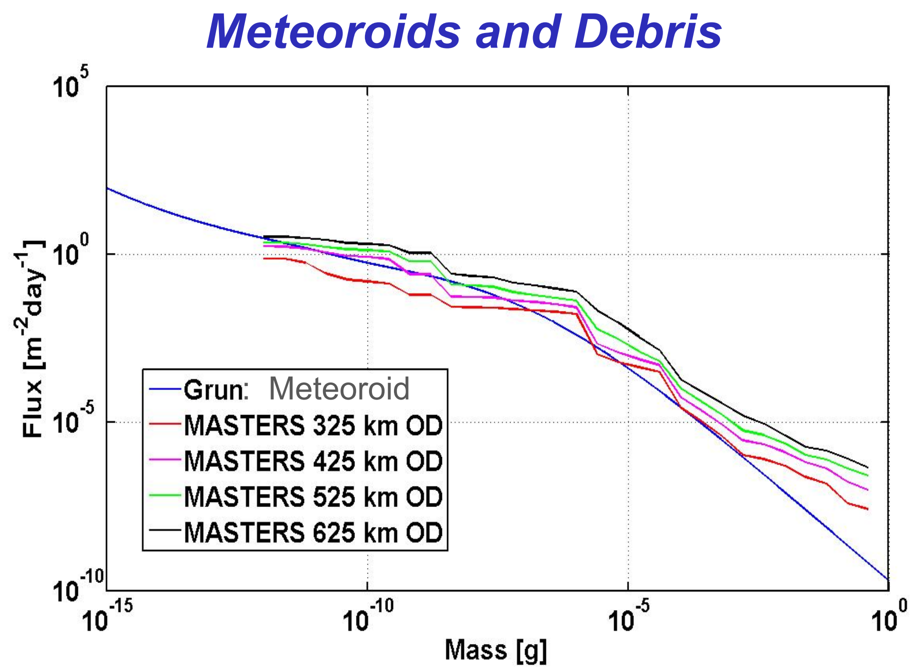
- Meteoroids
  - Speeds
    - 11 to 72.8 km/s (interplanetary)
    - 30-60 km/s (average)
    - ~5% > 72.8 km/s (interstellar?)
  - Densities
    - ≤1 g/cm$^3$ (icy) or > 1 g/cm$^3$ (rocky/stony)
  - Sizes
    - < 0.3 m (meteoroid)
    - < 62 $\mu$m (dust)

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

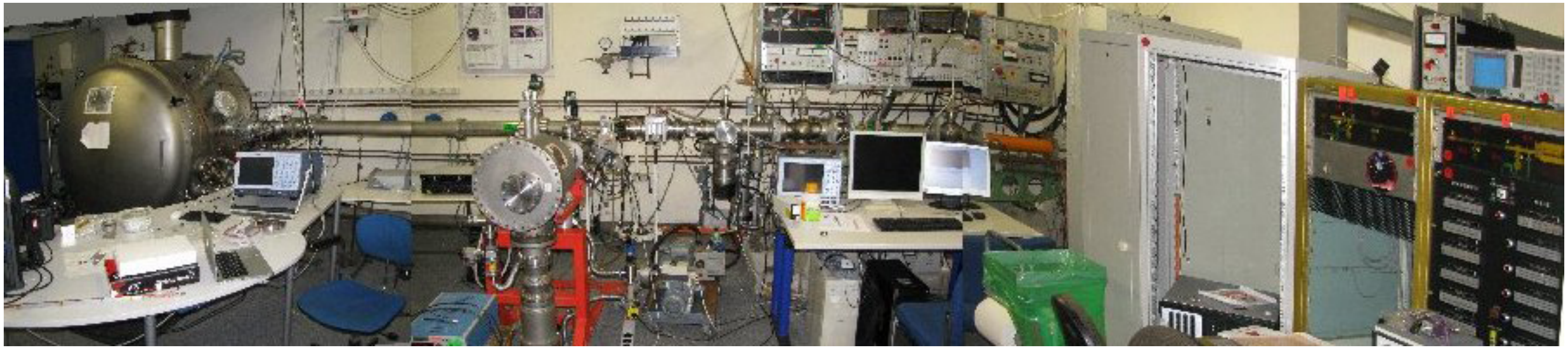


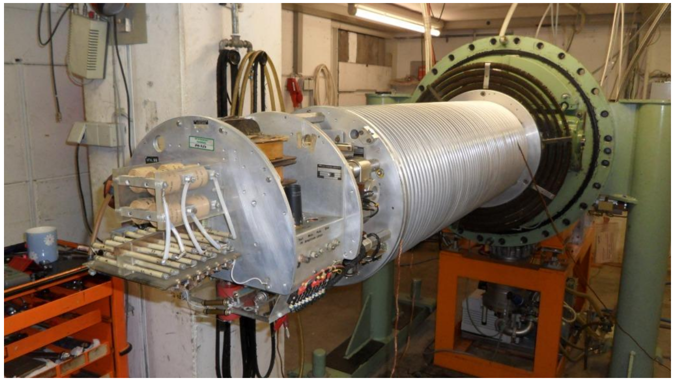
# Flux

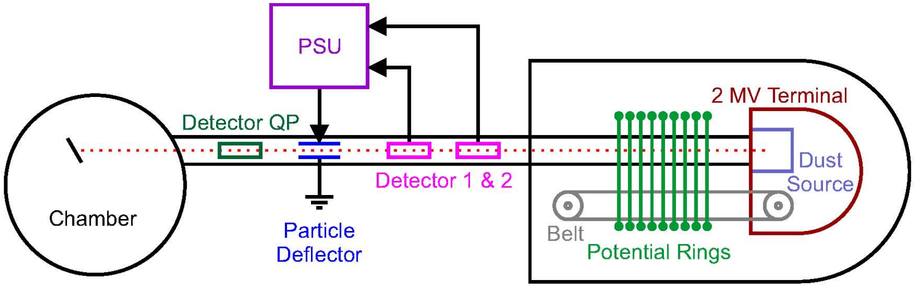

Meteoroids
Log$_{10}$(Mass) [g]
1
0
-1
-2
-3
-4
-5
-6
Jan
Apr
Jul
Oct
Jan
100
10
1
0.1
0.01
Flux ratio (shower/sporadic)


Meteoroids and Debris
Flux [m$^{-2}$day$^{-1}$]
$10^{5}$
$10^{0}$
$10^{-5}$
$10^{-10}$
$10^{-15}$
$10^{-10}$
$10^{-5}$
$10^{0}$
Mass [g]
Grun: Meteoroid
MASTERS 325 km OD
MASTERS 425 km OD
MASTERS 525 km OD
MASTERS 625 km OD

# Max Planck Institute (MPI) Dust Accelerator

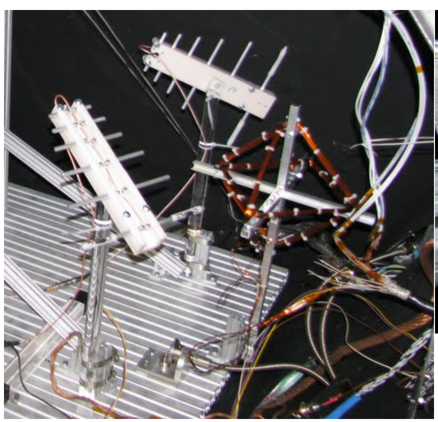


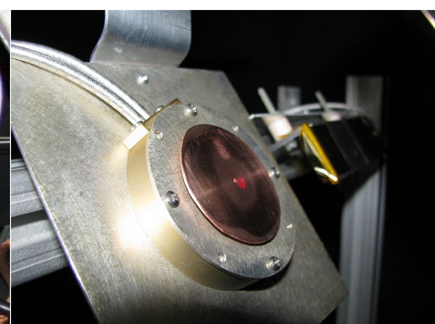


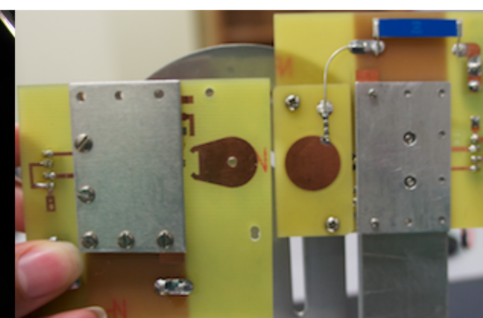


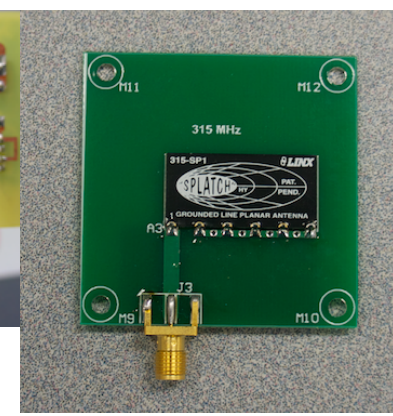
# E-Field/RF Sensors in Ground Experiments

- **Explore generation of EMP from hypervelocity micrometeoroid impacts**
  - **Facility:** Van de Graff Dust accelerator, $10^{-6}$ torr
  - **Sensors:** Electric Field Sensors, Patch Antenna, LPA Antenna, VLF Antenna
  - **Biased Targets:** bare metal, spacecraft surfaces, and active sensors

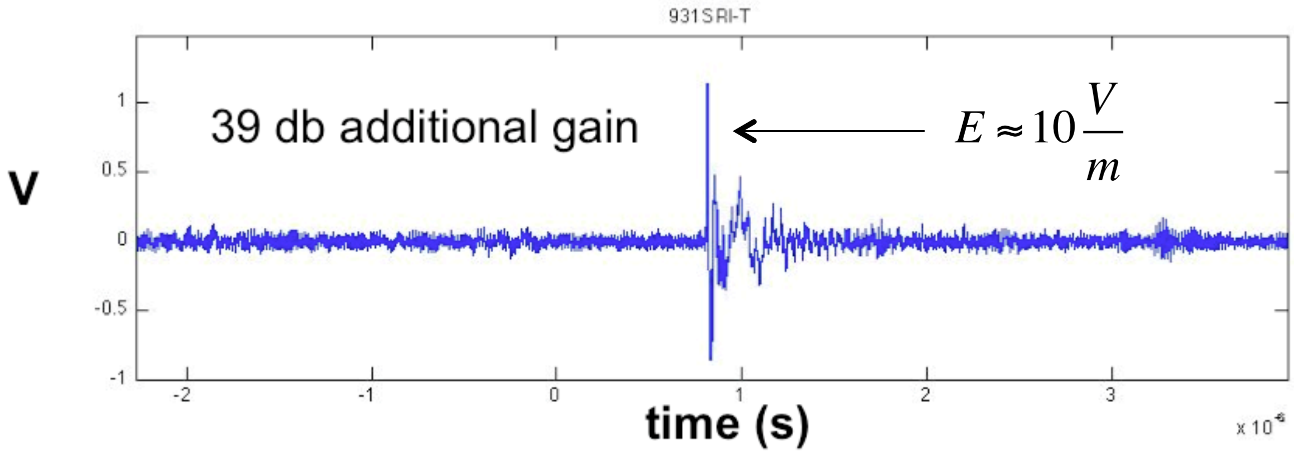


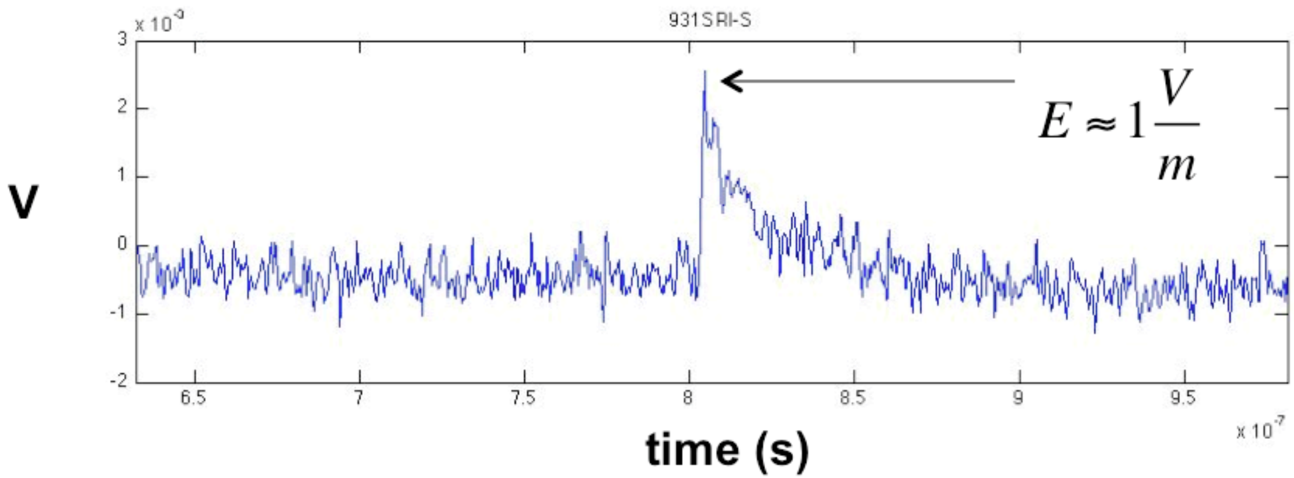






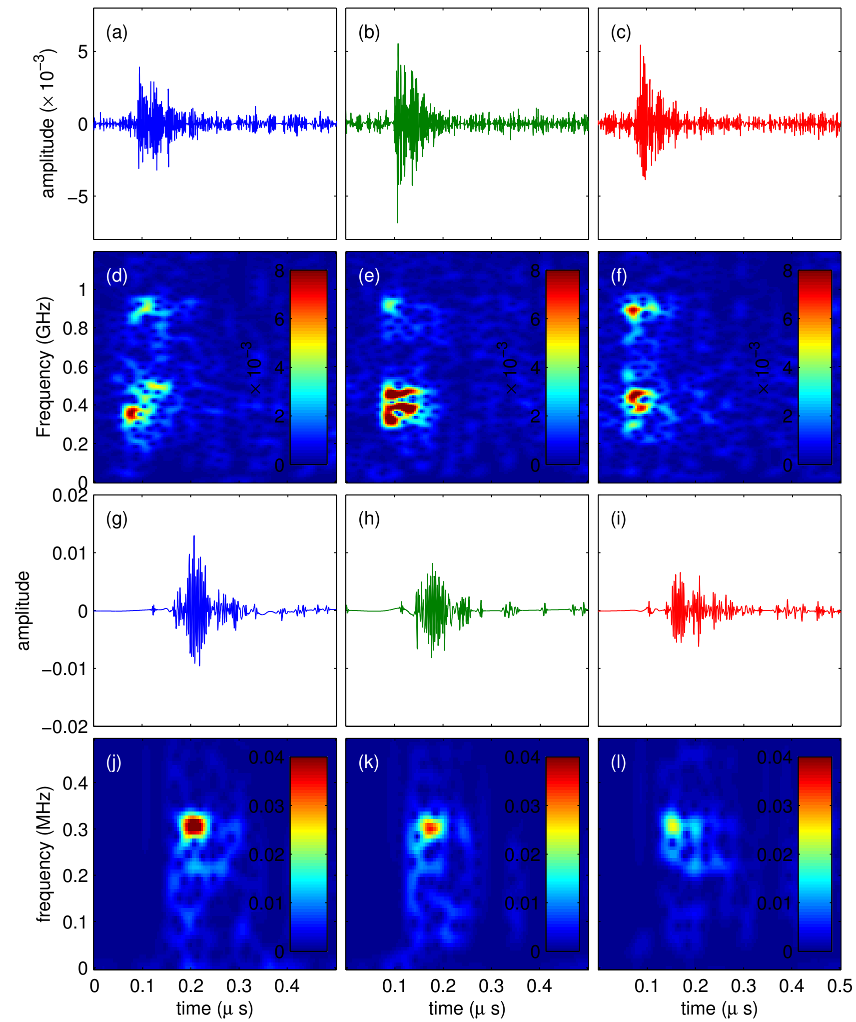
# Hypervelocity Impact ESD: Electric Field




1-2 ns delay between target and side

# Hypervelocity Impact EMP: RF Emission

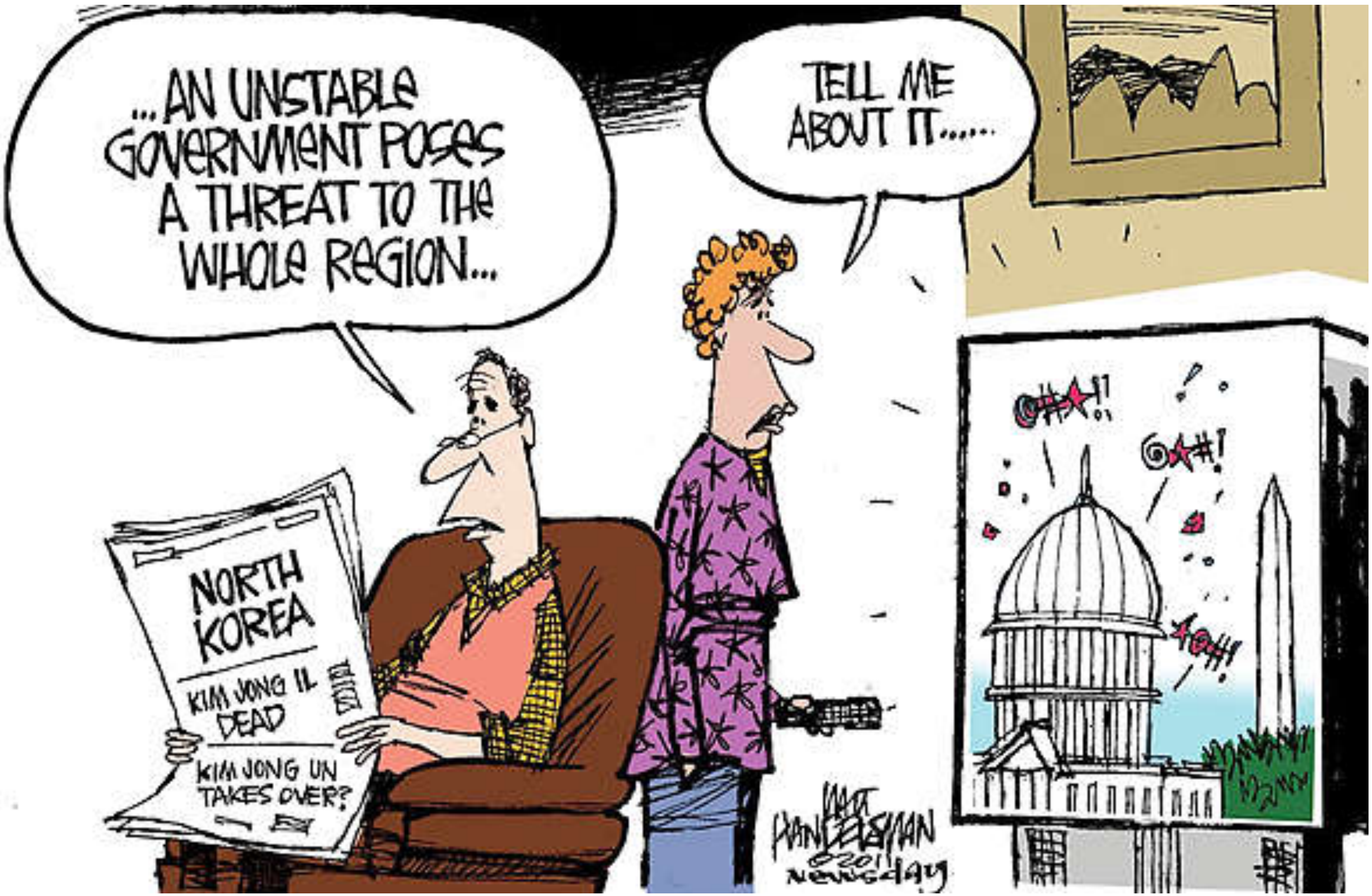


# Case Closed?

| Target | Bias (V) | Velocity (km/s) | PMT | E-field target | E-field side | RPA | Patch ant. | Error | Total |
|---|---|---|---|---|---|---|---|---|---|
| **E-field (active)** | +1000 (on grid) | < 15 | 42.6% | 28.7% | 35.6% | 29.7% | 0.0% | - | 101 |
| | | > 15 | 68.2% | 59.1% | 63.6% | 40.9% | 13.6% | 4.68% | 66 |
| **Tungsten (passive)** | -1000 | < 15 | 92.3% | n/a | n/a | 87.5% | 6.3% | 3.32% | 16 |
| | | > 15 | 100% | n/a | n/a | 100% | 64.7% | 6.52% | 17 |

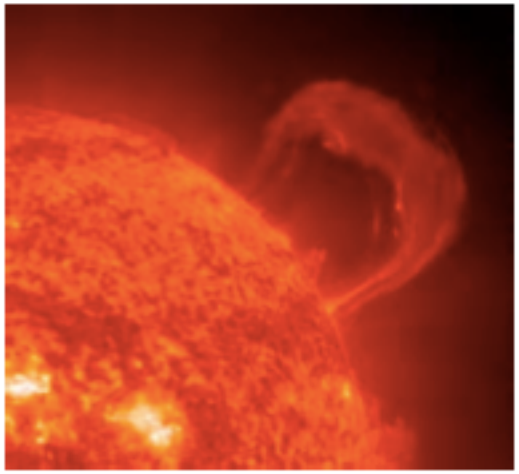
Table 1. Occurrences using 200 confirmed hypervelocity micro particle impacts on the biased targets.

# What about instabilities?

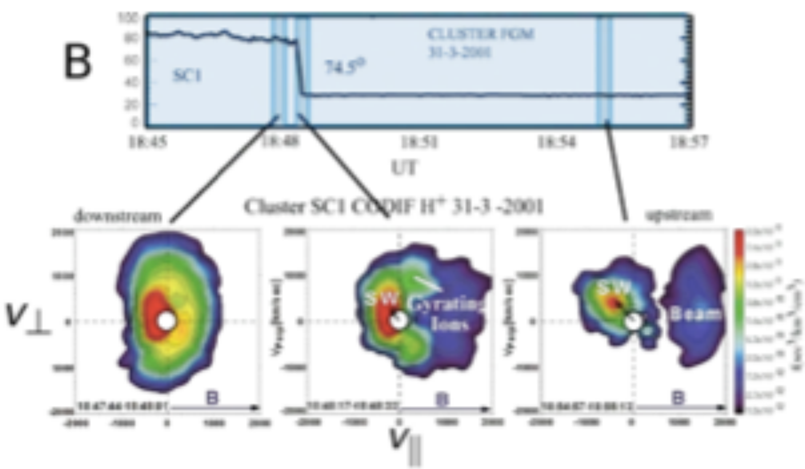


# Beam-Plasma Instability

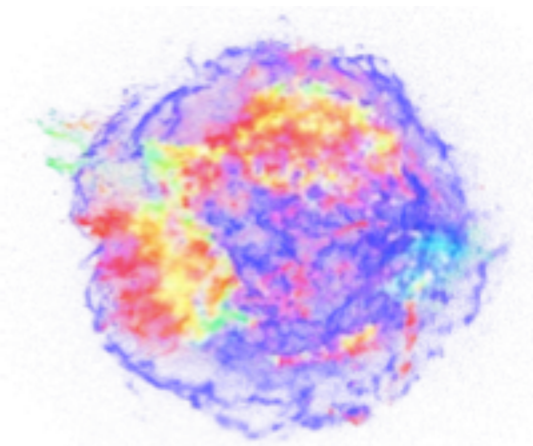
- beam is a minority population of high energy particles
- diverse energy sources in space
- energy not dissipated by collisions
- wave-particle interactions dominate



SOHO (ESA & NASA)




Kucharek 2004 Ann. Geophys.



NASA/CXC/MIT/UMass Amherst/M.D.Stage et al.

# Beam-Plasma Dispersion Relation

- beam energy converted to wave energy
  - phase velocity is much larger than the electron thermal speed
  - beam electron density is much smaller than the background electron density

Dispersion Relation

$$1 = \frac{\omega_{pe}^2}{\omega^2} + \frac{\omega_b^2}{(\omega - kV)^2}$$

Beam perturbation

$$\delta^3 = \frac{1}{2}\omega_{pe}\omega_b^2$$

Unstable mode

$$\delta = \frac{-1 + i\sqrt{3}}{2}\omega_0, \text{ at } kV \simeq \omega_{pe}$$

Growth Rate

$$\gamma_{\max} = \frac{\sqrt{3}}{2}\omega_0 = \frac{\sqrt{3}}{2}\left(\frac{n_b}{2n_0}\right)^{1/3}\omega_{pe}, \quad kV \simeq \omega_{pe}.$$

# Other possible instability mechanism(s) for RF EM emission

Weibel instability

- present in homogeneous or nearly homogeneous electromagnetic plasmas
- anisotropy in momentum (velocity) space (two temperatures in different directions)
- Suppose a field B = B cos ($k_x$) spontaneously arises from noise. The Lorentz force then bends the electron trajectories
- The resulting current sheets generate magnetic field that enhances the original field and thus perturbation grows

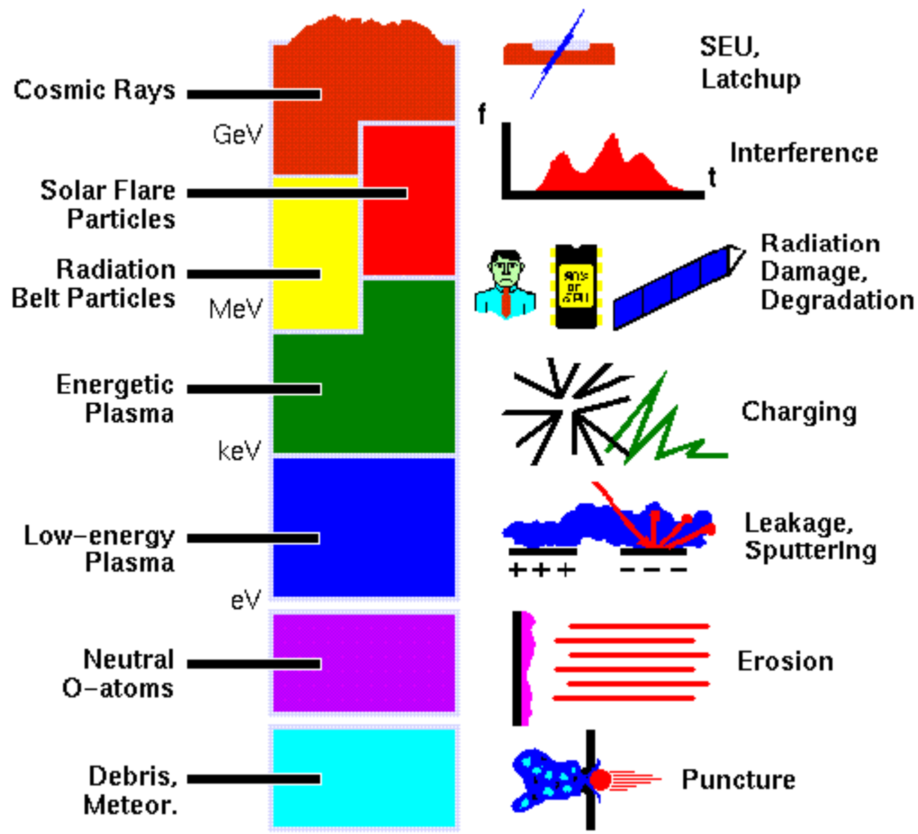
# Langmuir Solitons

- Electrostatic plasma waves grow to very large amplitudes such that the normal modes of the system are modified
- Wave radiation pressure creates growing density depressions
- Formation of Langmuir solitons (i.e. trapping of plasma waves)
- Langmuir soliton collapse, emitting an enhanced level of electromagnetic radiation

# Diagnostic Techniques

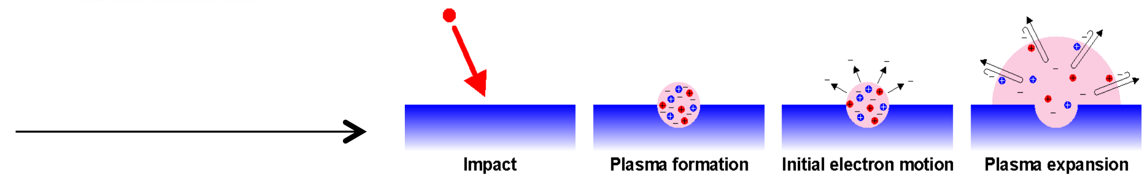
- **Langmuir Probe**
  - Triple
  - Fast
- **Incoherent Scatter Radar… in a Chamber**
- **Radar REMPI**
  - Resonant Enhanced Multiphoton Ionization (REMPI)
  - Microwave scattering (Radar)
  - AFOSR and DARPA
- **Laser Interferometry (Poster METR-11)**

# Space Environment Hazards

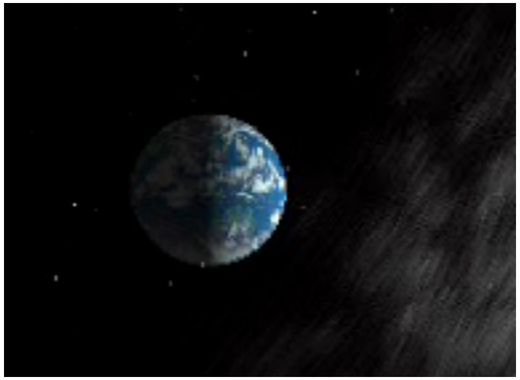



**ESD/EMP**

**Debris/meteoroids**



- Acknowledgements
  - DoE/Los Alamos National Laboratory
  - Lockheed Martin
  - NASA Ames
  - NSF
  - Max Planck Institute

# Thank You!