Detection of dust impacts on spacecraft by antenna instruments

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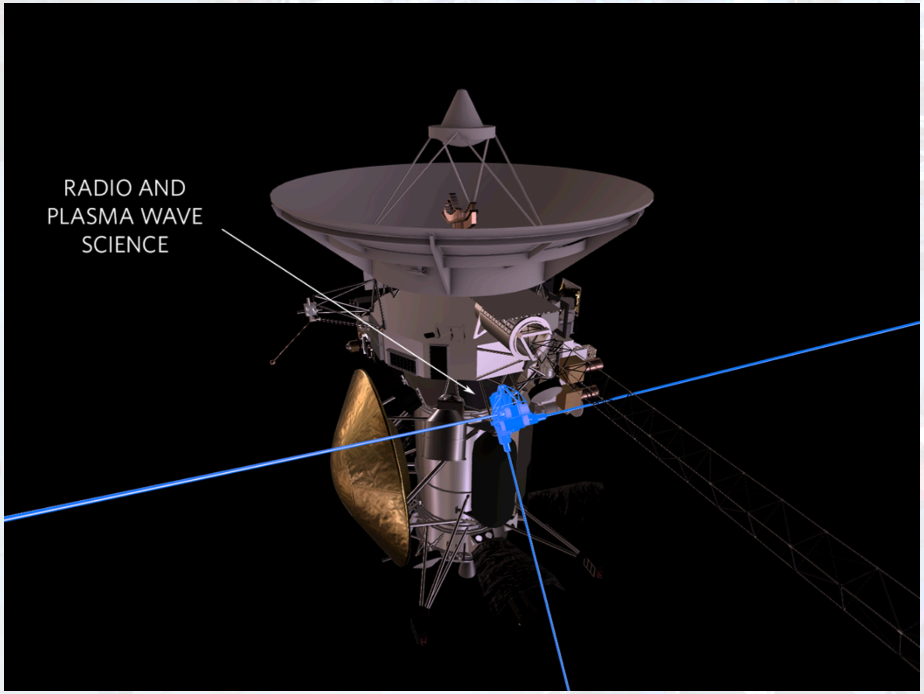
Antennas as dust impact detectors



The RPWS instrument on Cassini

Mission with dust detecting antennas:

Voyager 1&2
Wind
STEREO
Cluster
Cassini
…..

} Serendipitous dust impact detection

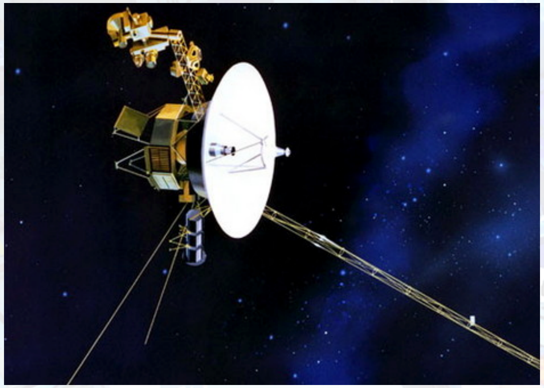
MAVEN (Mars)
JUNO (Jupiter)
SPP (Inner solar system)

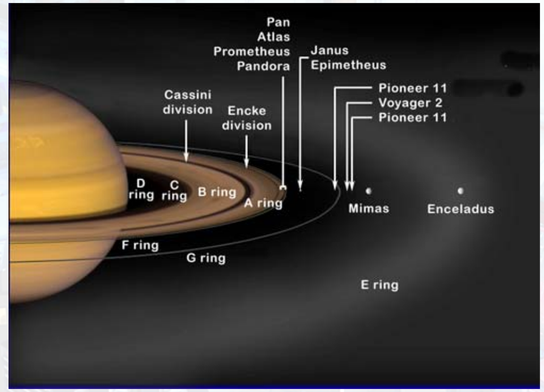
} Planning for using antennas for dust detections

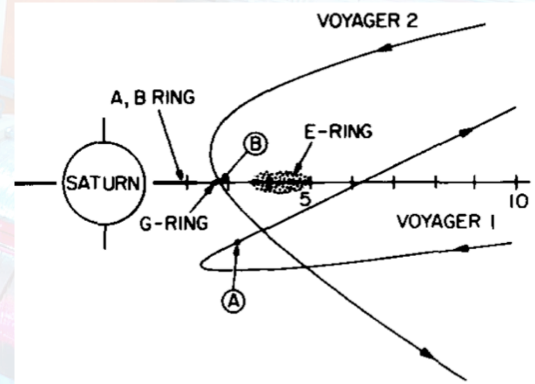
Outline

- Historical overview
- Dust accelerator facility
- Two resent experimental campaigns:
  - Monopole lab setup identifying basic coupling mechanisms
  - Dipole lab setup modeling the Cassini spacecraft

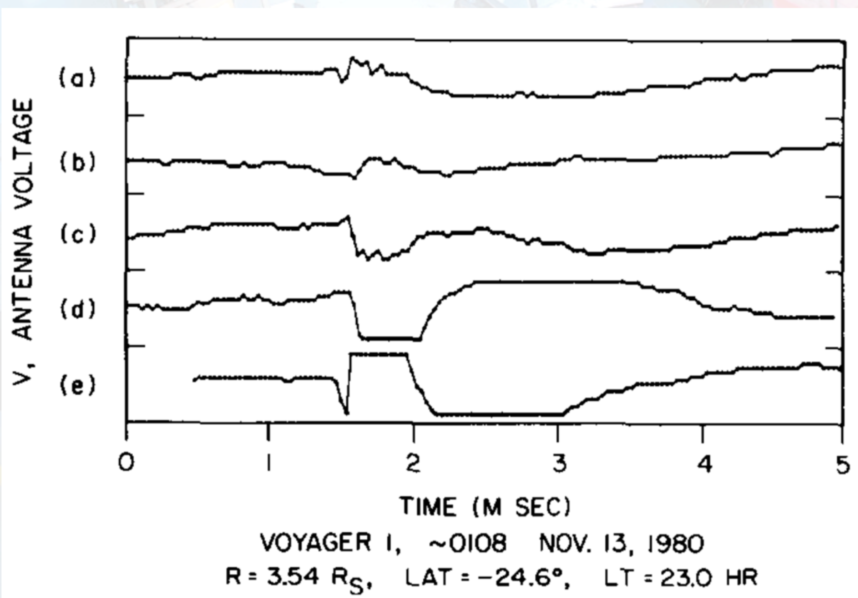
First detections by Voyager 1&2 at Saturn



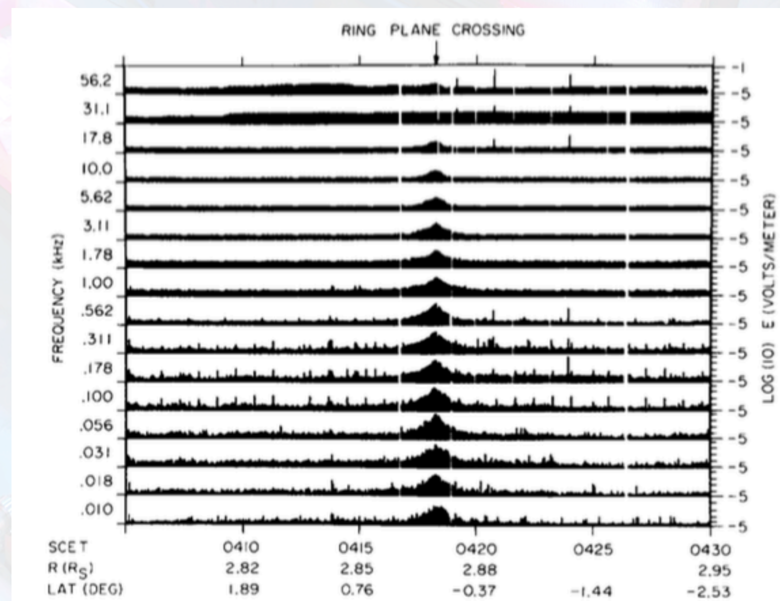




Individual dust impacts identified in the wideband receiver data

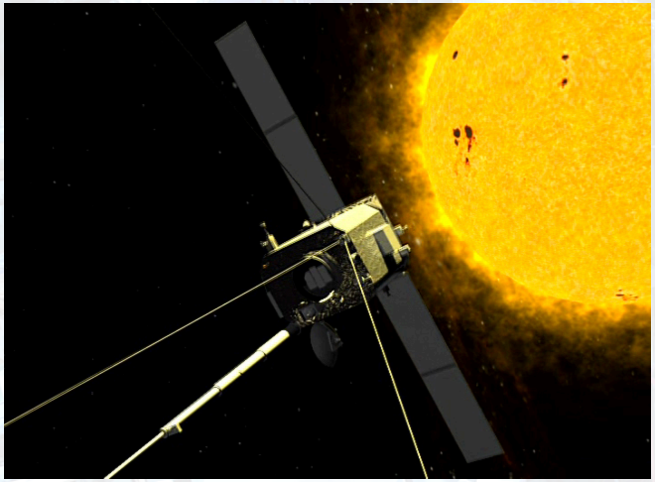


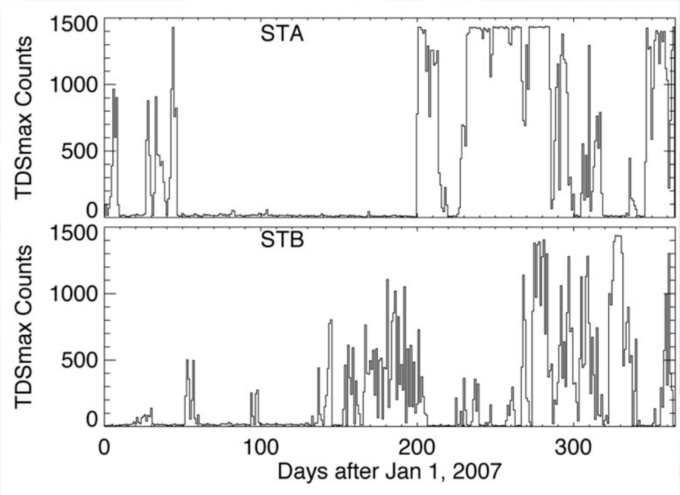
Intense dust bombardment shows up on the **frequency spectrum** of E-field measurements



(Gurnett et al., Icarus, 1983)

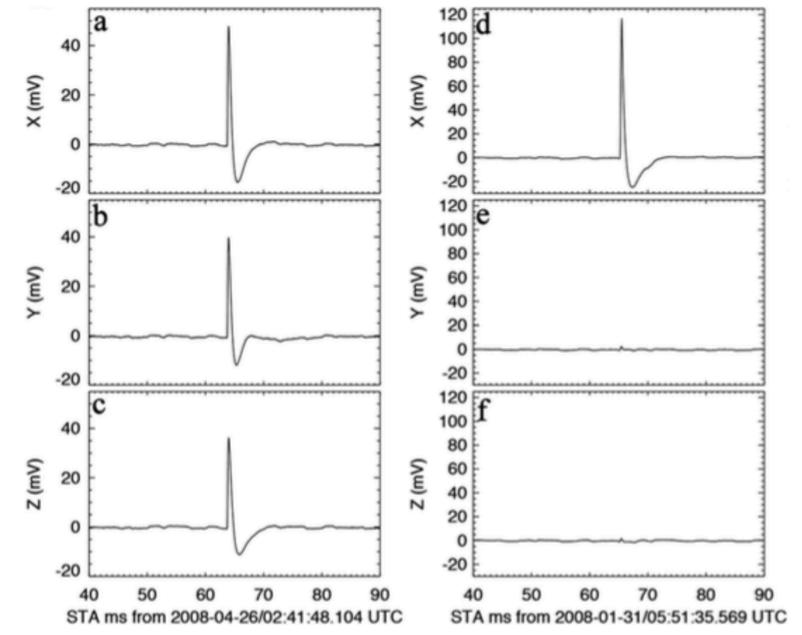
STEREO observes nanodust particles (?)





'Triple hit'

'Single hit'

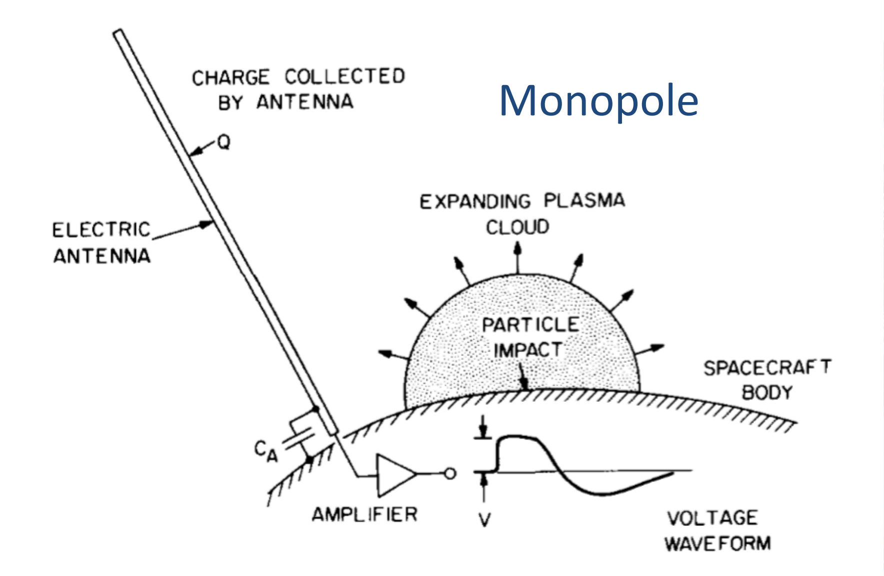


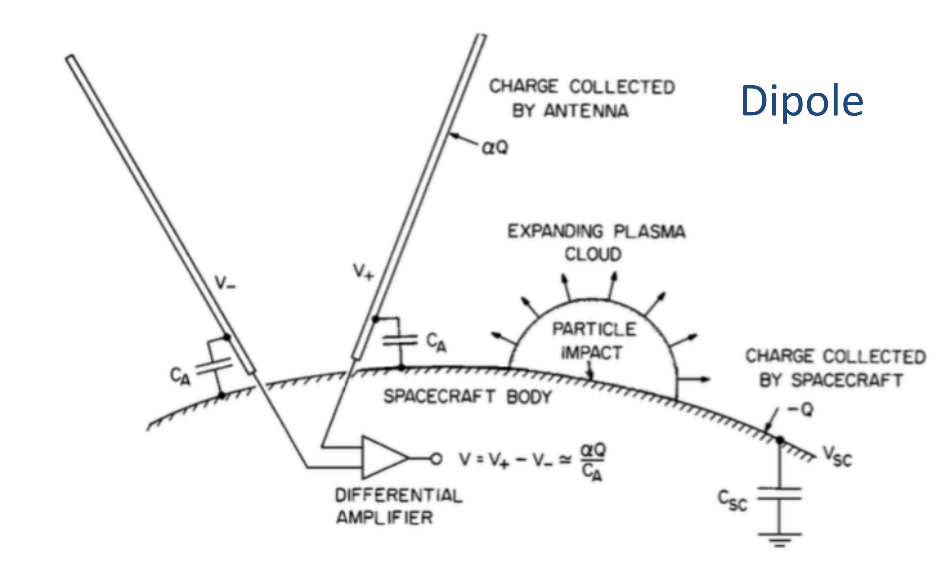
Interplanetary and interstellar dust

'Nano-dust'

(e.g., Zaslavsk yet al., JGR, 2012)

Early coupling mechanism ideas





What is the physical mechanism that generates a measurable voltage signal?

- Impact signal due to dust impact ionization
- Assumes charge collection on antenna (neglects charge collection on SC)
- Assumes dipole signal from uneven charge collection on antennas

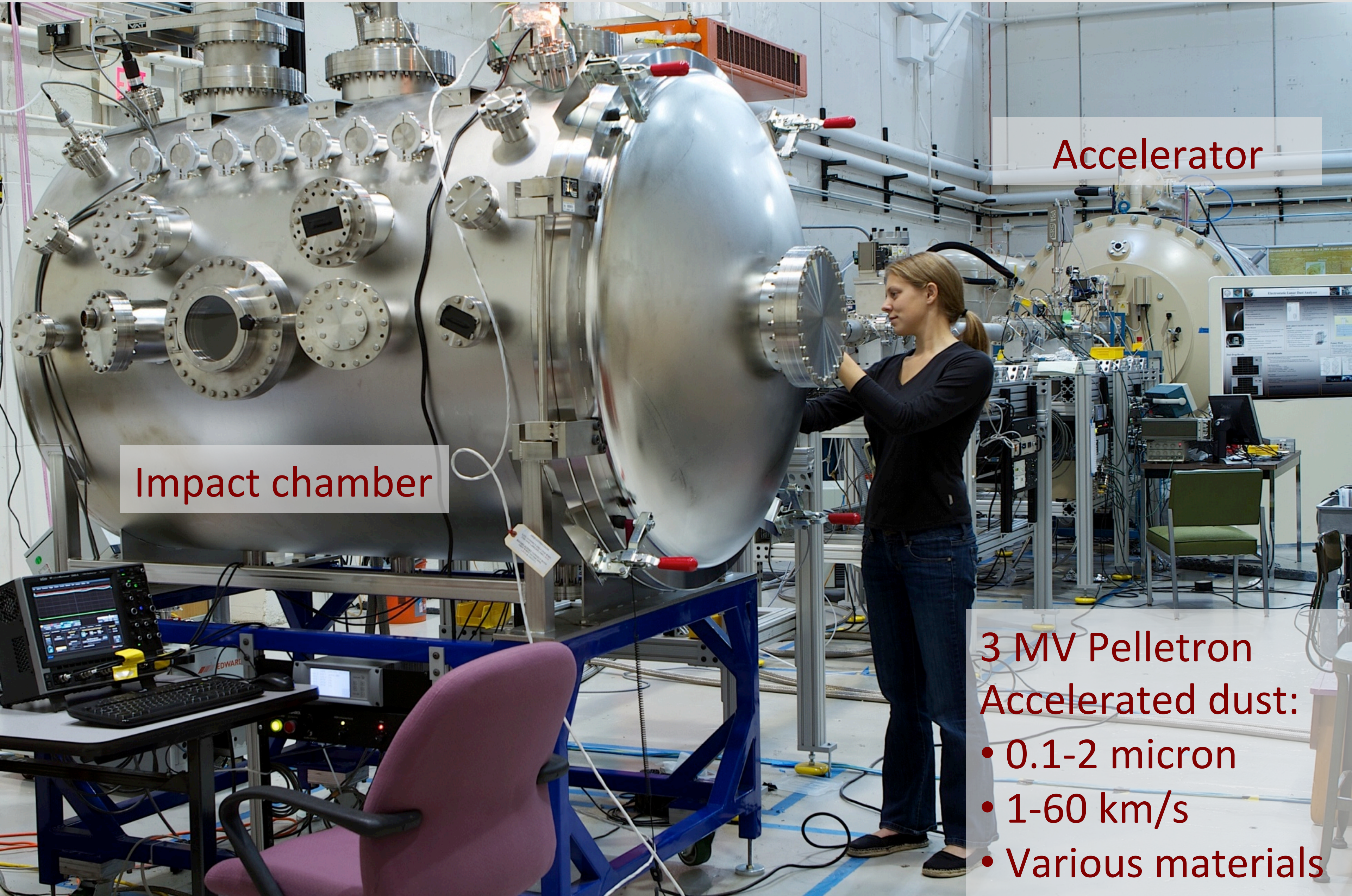
How can we determine the mass and speed of the impacting dust particle?

Gurnett et al., 1983

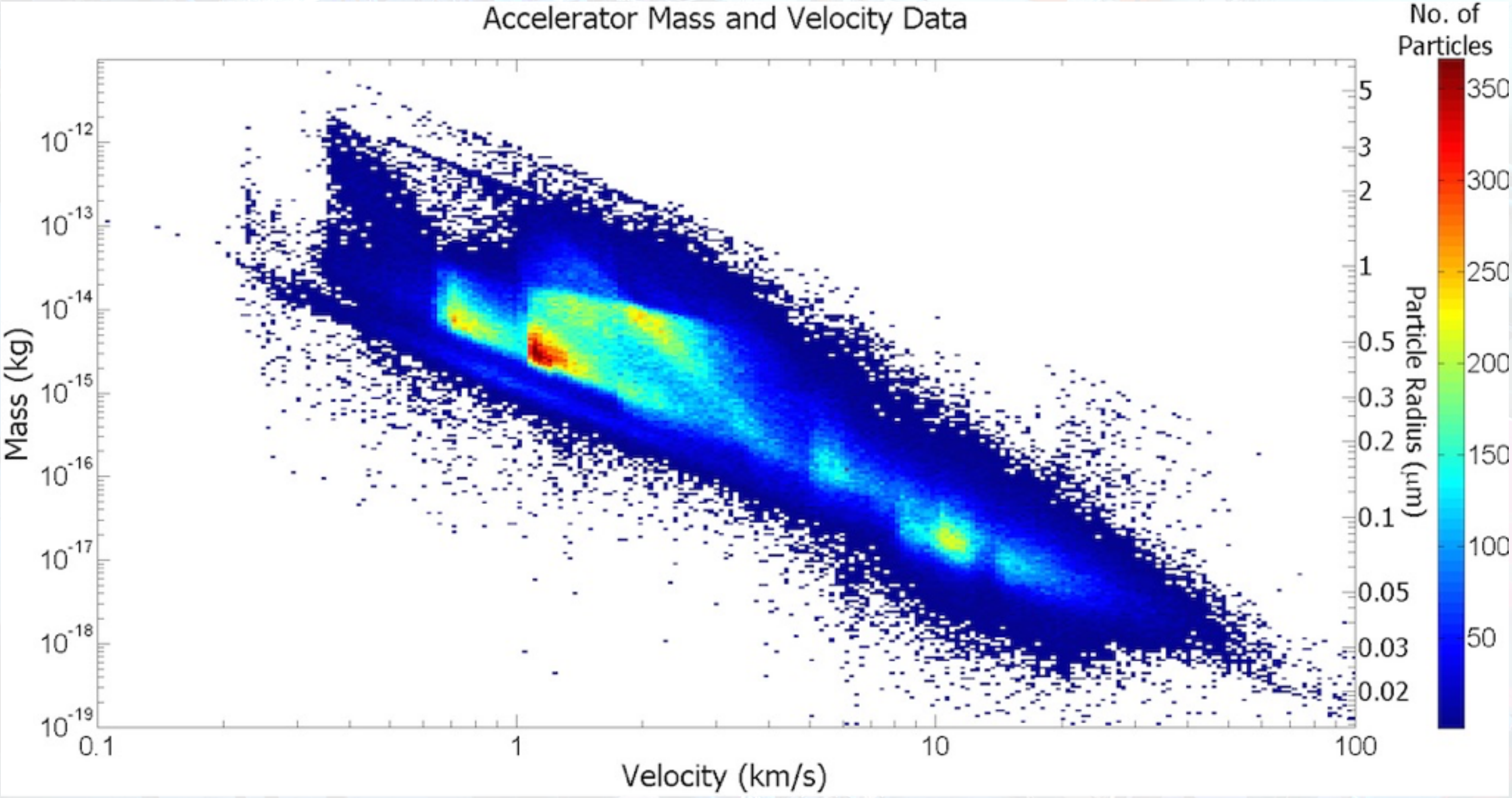
Impact ionization and antenna signal generation

- Impact charge generation, $\boldsymbol{Q_I = \alpha m v^{\beta}}$, α,β depend on materials
- Collected charge on generates voltage (V = Q / C)
- Collected charge depends potential, plasma temperature, etc
- Most basic signal pickup mechanisms :
  (1)<u>SC charging</u>: $\boldsymbol{dV = \Gamma\, Q_I(V_{SC}) / C_{SC}}$, Γ – coupling parameter
  (2)<u>Antenna charging</u>: $\boldsymbol{dV = Q_I(V_A, G) / C_A}$, G –geometry, impact location
  (3)<u>Antenna pickup</u> (induced charging)

Testing and calibration (dust accelerator)



Particle mass vs. velocity distribution



Is the impact plasma really a plasma?

$$d_P = V^{1/3} \geq b\lambda_D$$

Textbook requirement for a plasma, b = 10

$$\lambda_D = \sqrt{\epsilon_0 k_B T / q^2 n}$$

The Debye length

$$d_{P,max} = \frac{q^2}{\epsilon_0 k_B} \frac{1}{b^2} \frac{N}{T} = 4 \cdot 10^{-11} N[m]$$

N = number of elementary charges
T = Te = Ti = 5 eV assumed

- For a typical laboratory 'impact plasma' $N = 10^6$ and thus d_P = 40 microns
- For impacts in space N can be much larger. For $N < 10^{10}$ it will be true that d_P < SC size and d_P << antenna length

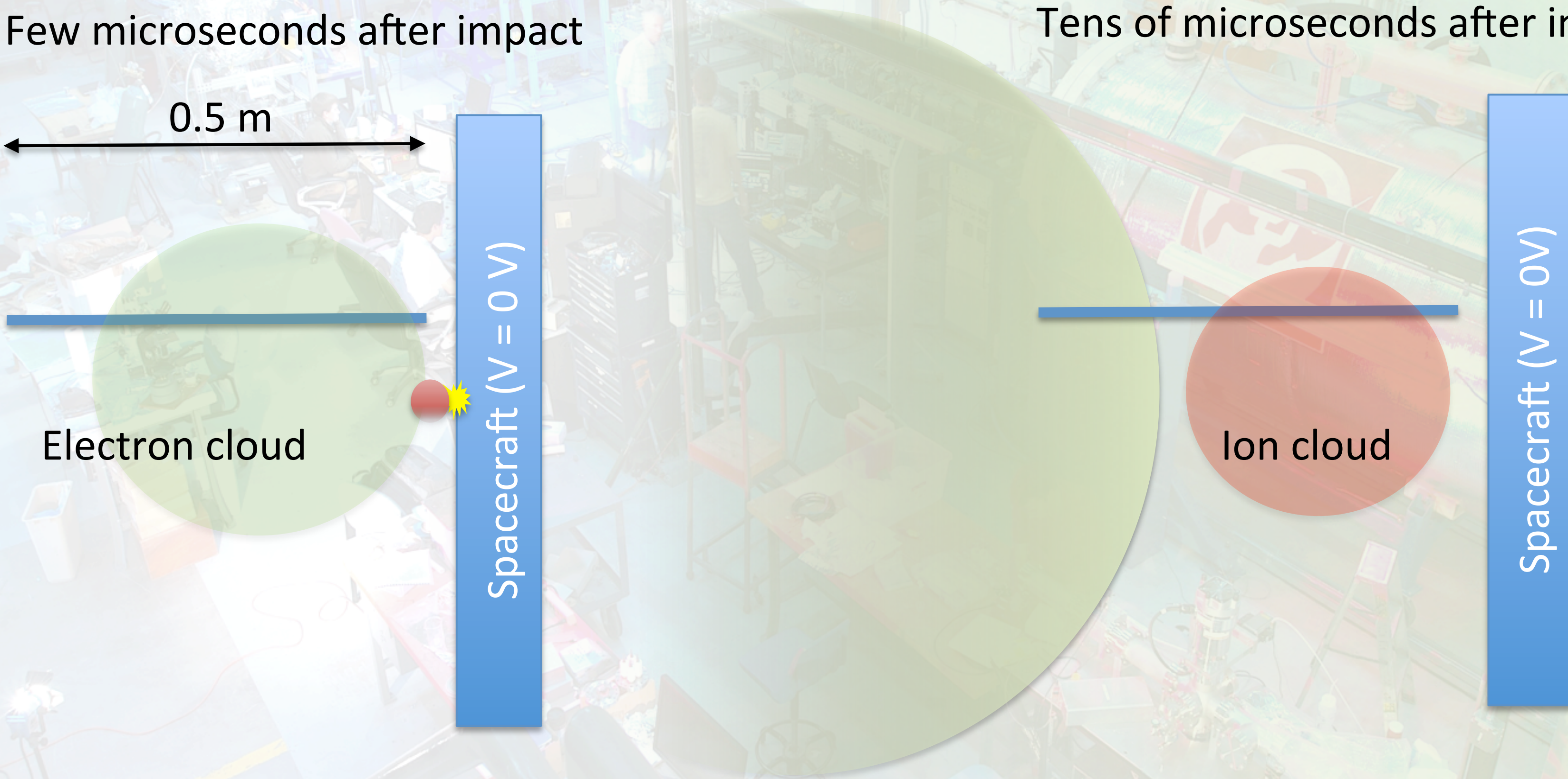
- The limit corresponds to (assuming impacts on common SC materials)
  - 5 km/s < 33 micron radius dust particle
  - 10 km/s < 13 micron
  - 20 km/s < 5.6 micron
  - 300 km/s < 0.18 micron

- **Conclusion:** It is NOT a plasma, but rather an uncoupled population of electrons and ions

The physical picture impact charge dynamics (no/low bias potential)

Few microseconds after impact

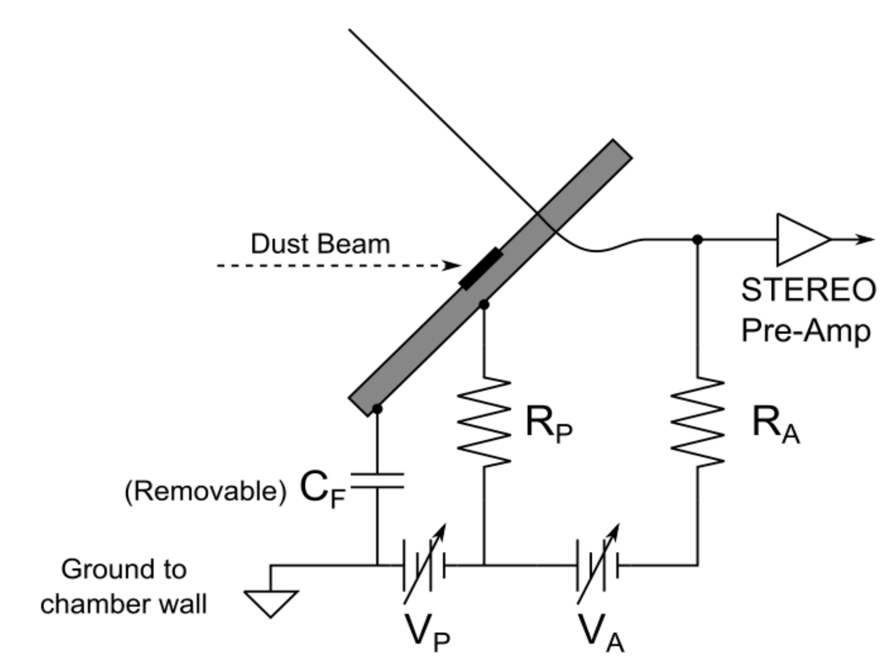
Tens of microseconds after impact

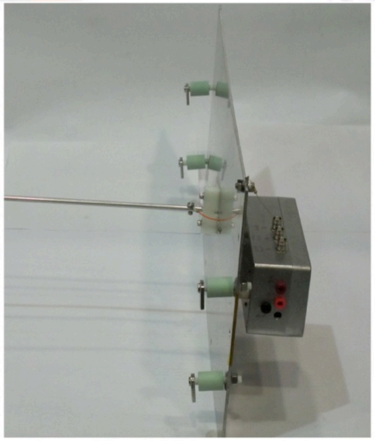


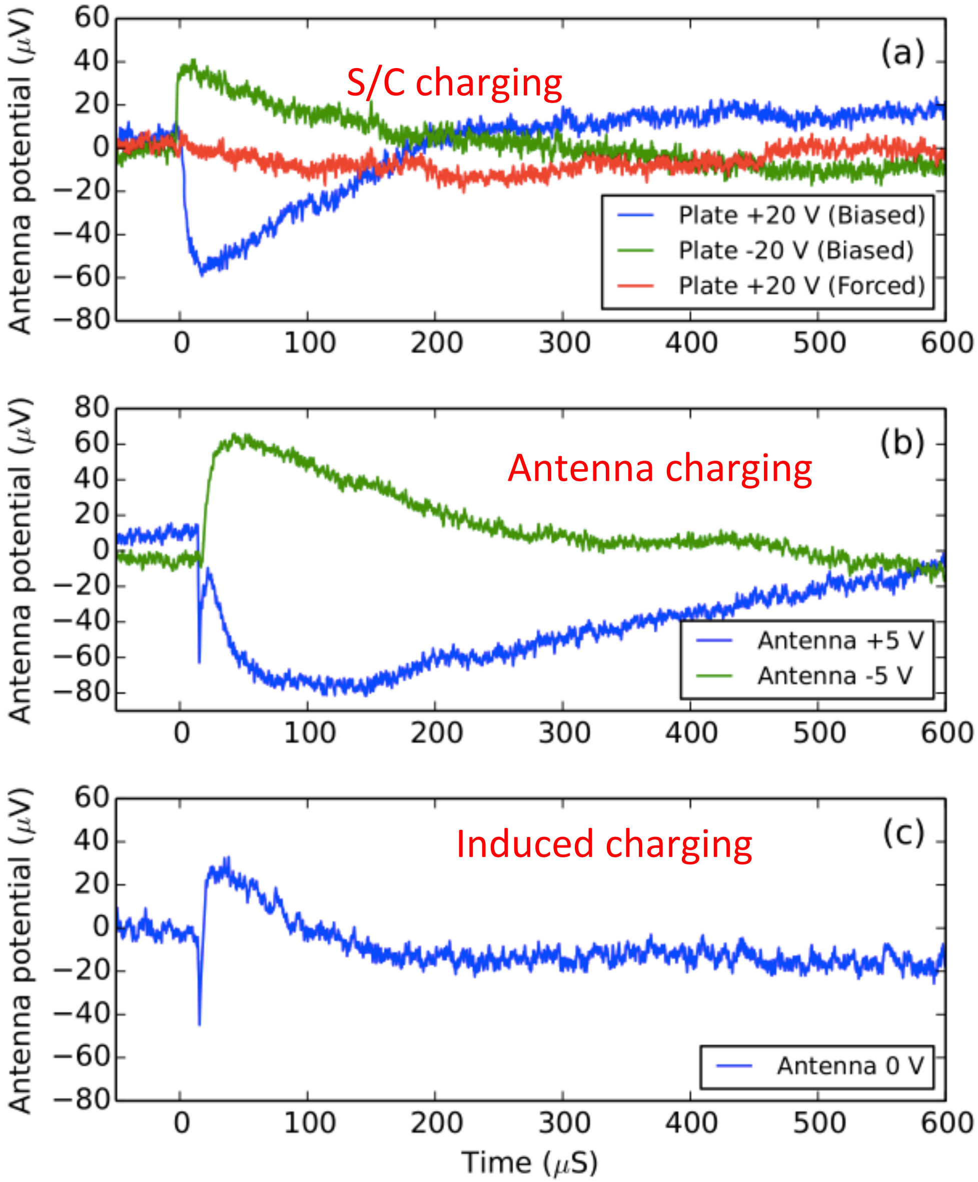
Electron thermal speed 10^6 m/s

Ion thermal speed 5 km/s
(0.5 m/ 5000 = 100 microsec)

Identifying different pickup mechanisms



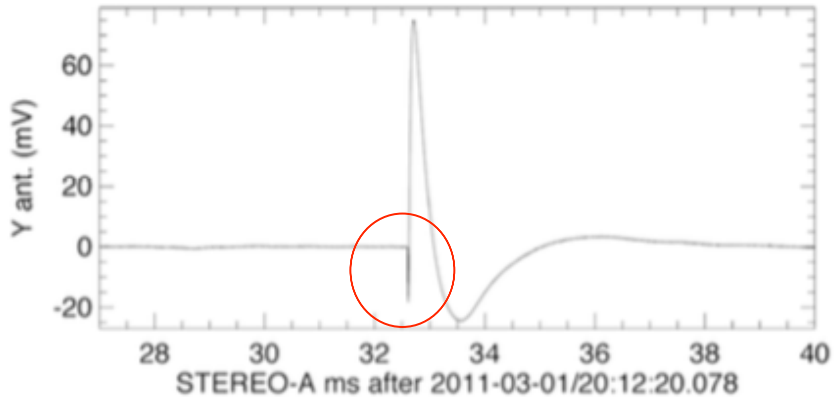


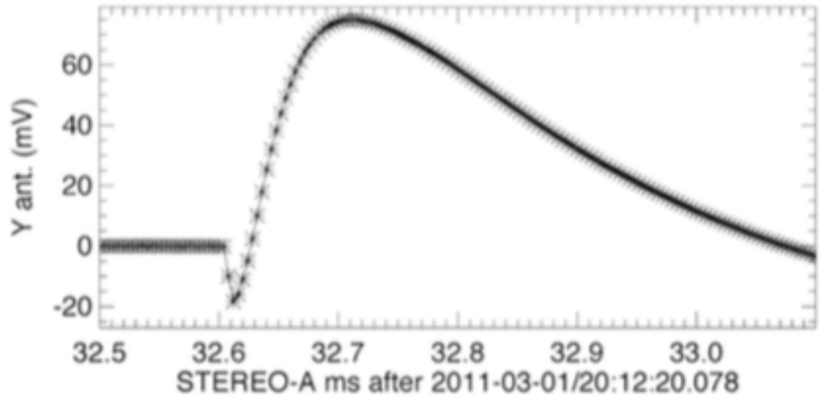


(Collette et al., 2015)

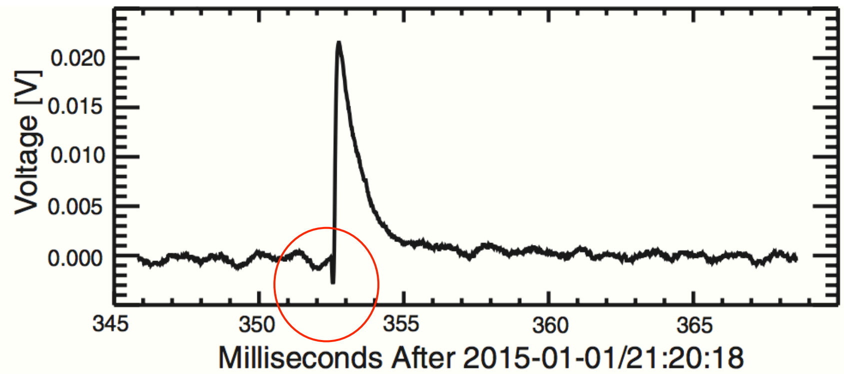
Induced charging in flight data all along

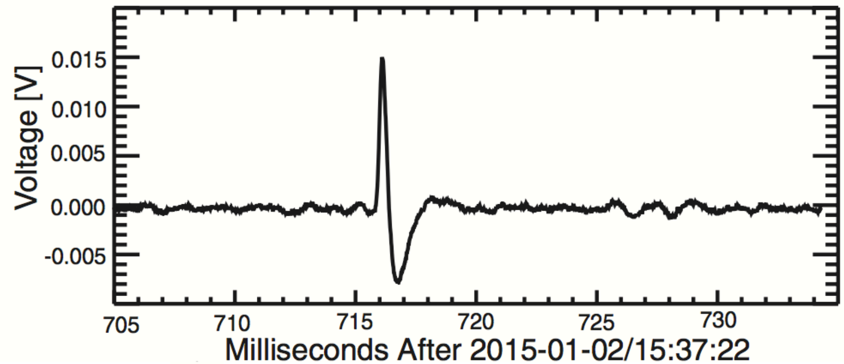
STEREO





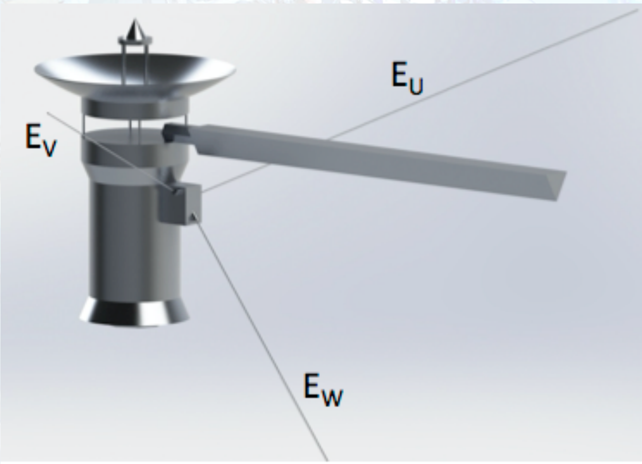
MAVEN

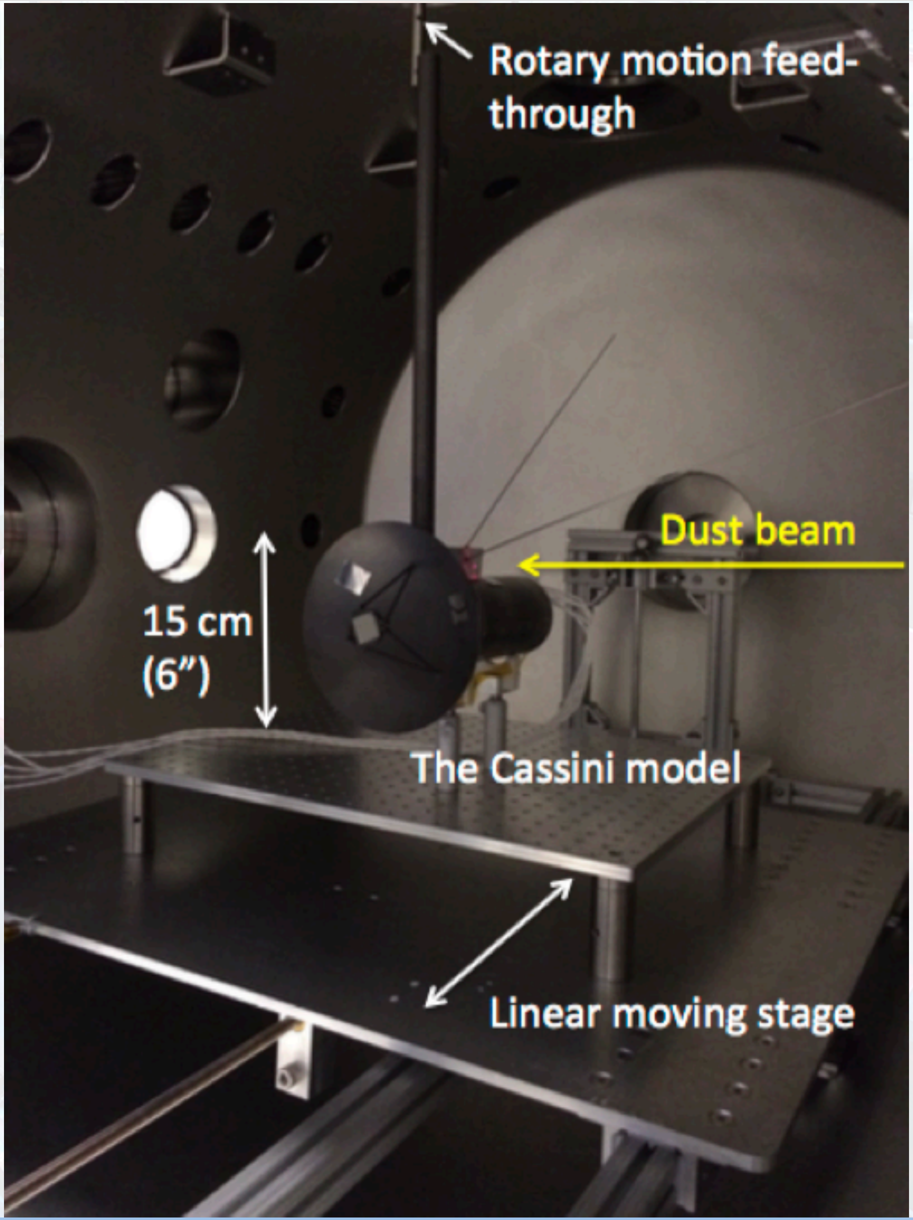




Cassini lab model development

$E_U - E_V$ = dipole config
E_W = monopole config.





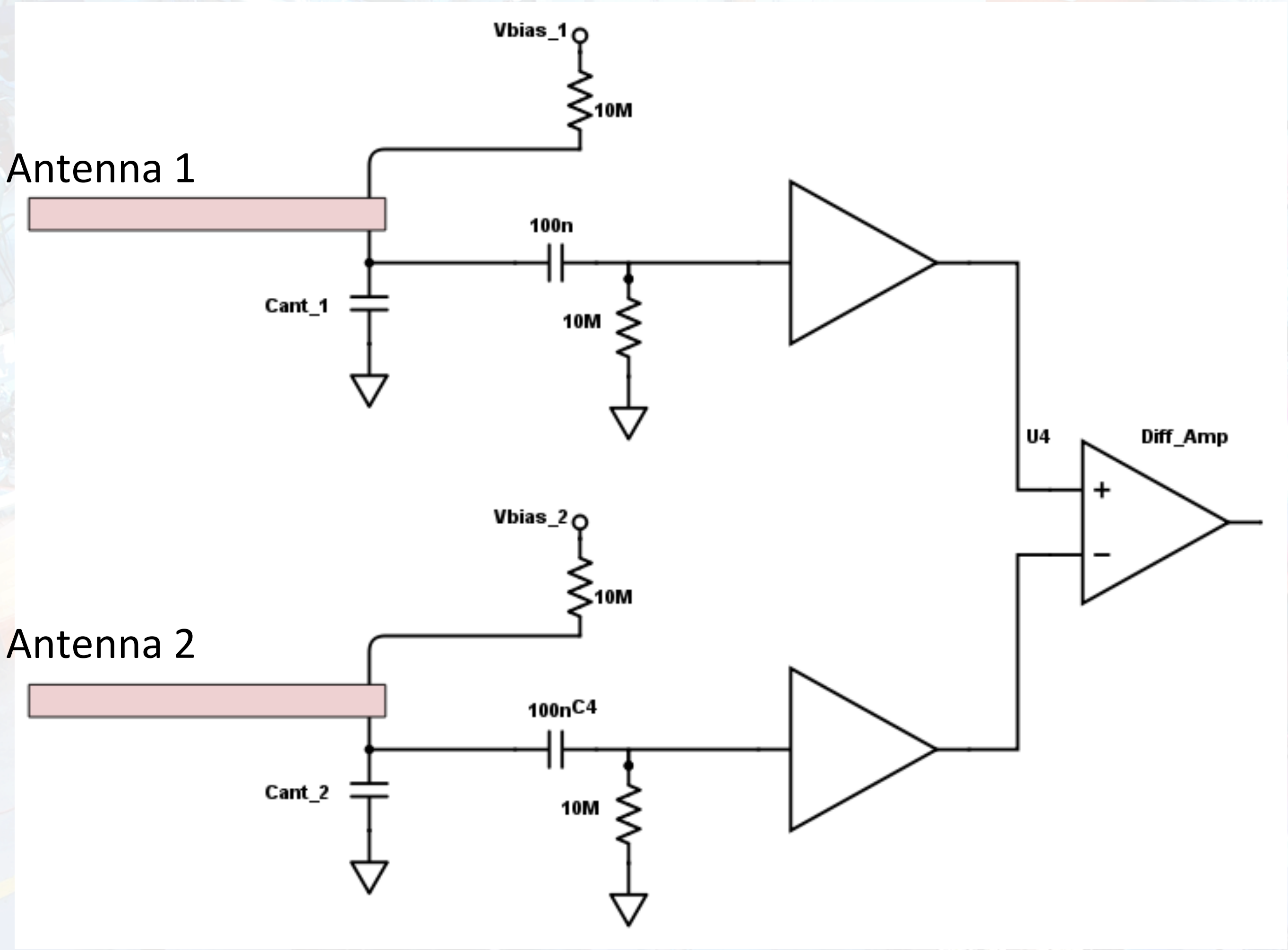
Interesting to shoot at:

- HGA
- SC body
- Antennas

Variations with

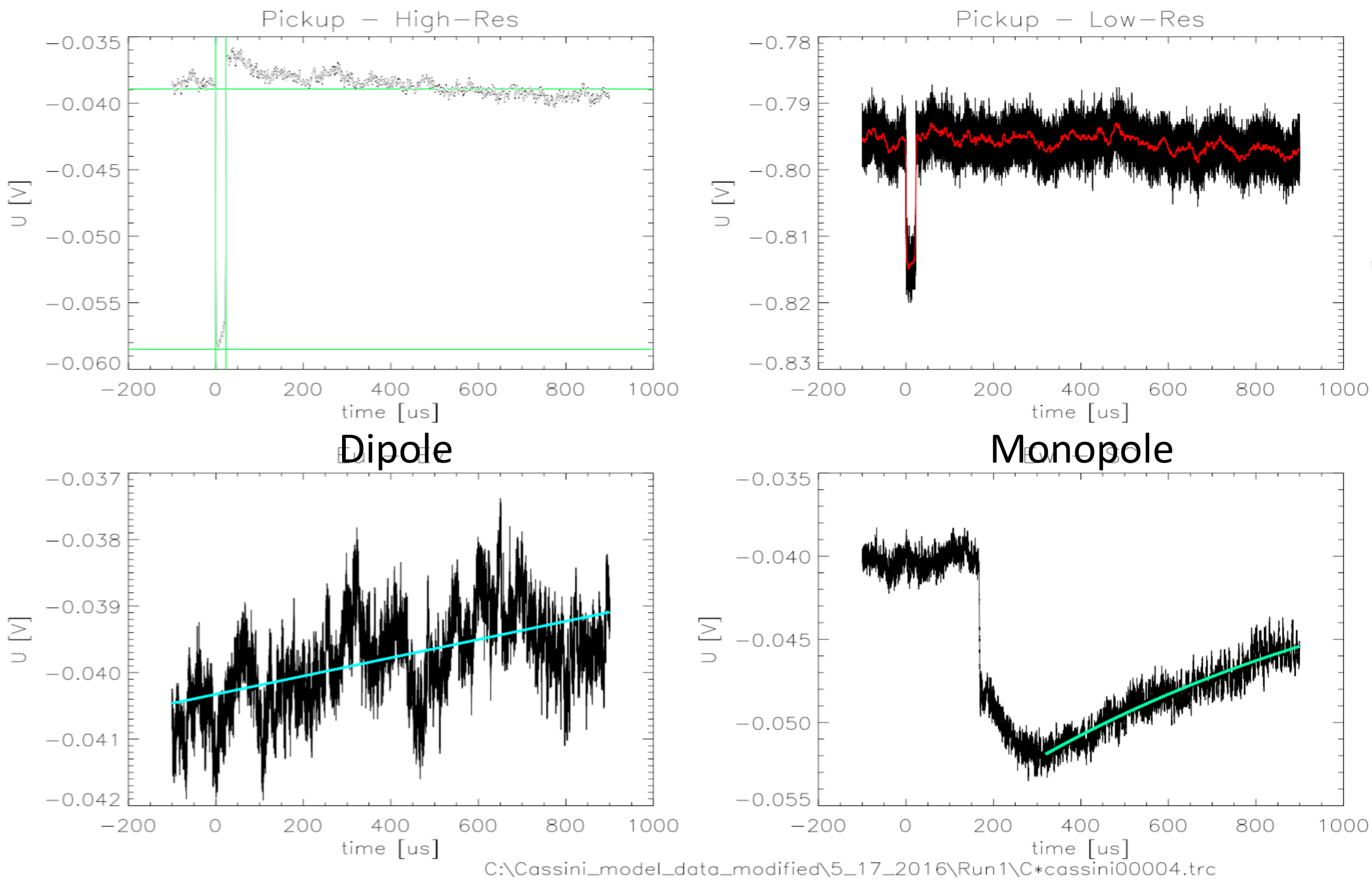
- Bias voltage
- Location

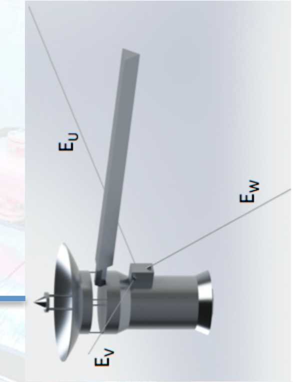
Dipole antenna configuration



Independent biasing of the antennas/SC
Differential amplifier helps to suppress pickup noise and thus improve SNR

Impact on HGA, -10 V (all)

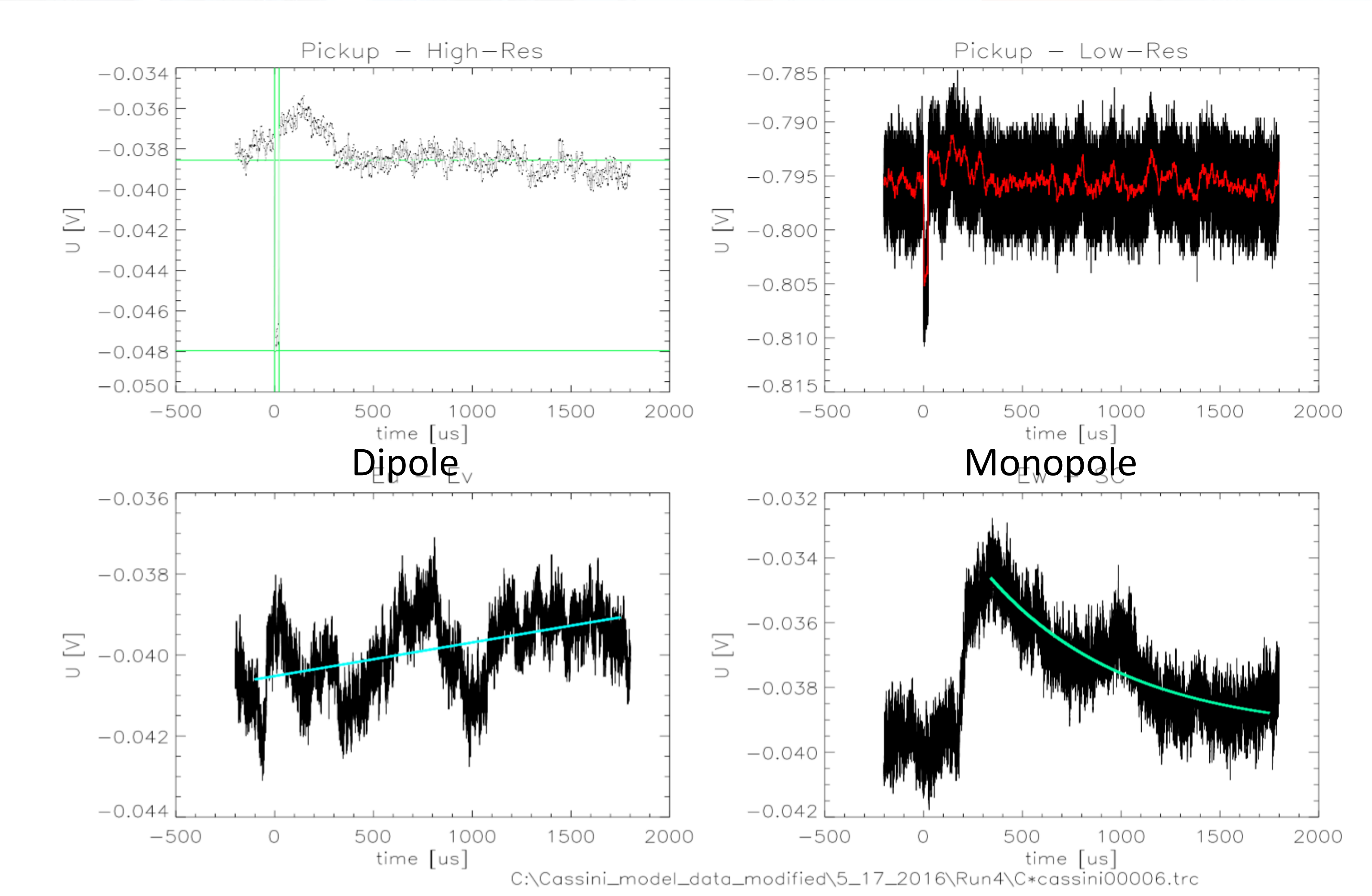




Note:

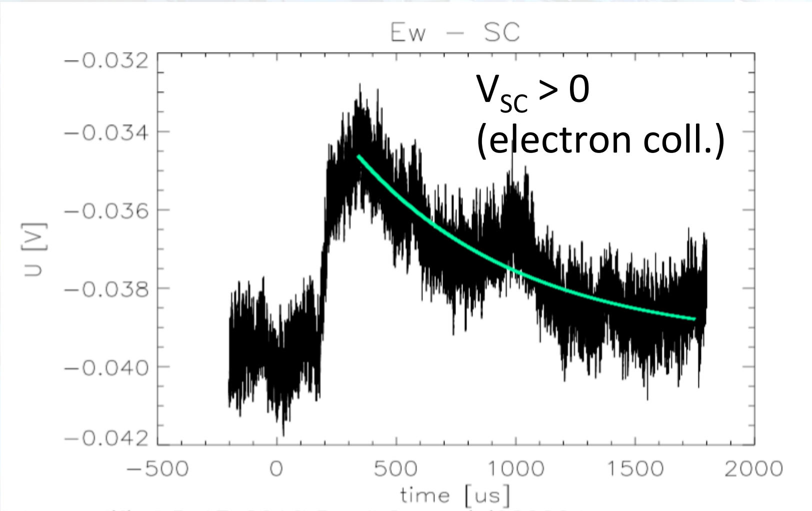
- SC negative, thus collects positive charge, Ew – SC is thus negative
- No signal on the dipole antennas

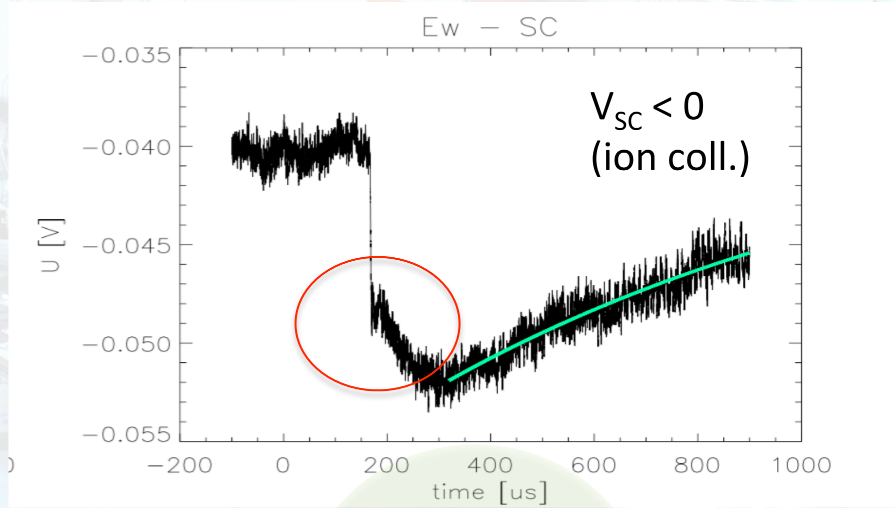
HGA, +10 V (all)



Pickup – High–Res
Pickup – Low–Res
Dipole
Monopole
U [V]
time [us]
C:\Cassini_model_data_modified\5_17_2016\Run4\C*cassini00006.trc

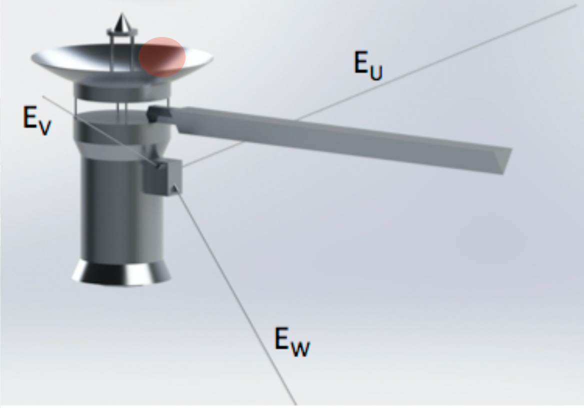
Impact on HGA, variation with bias polarity (monopole)



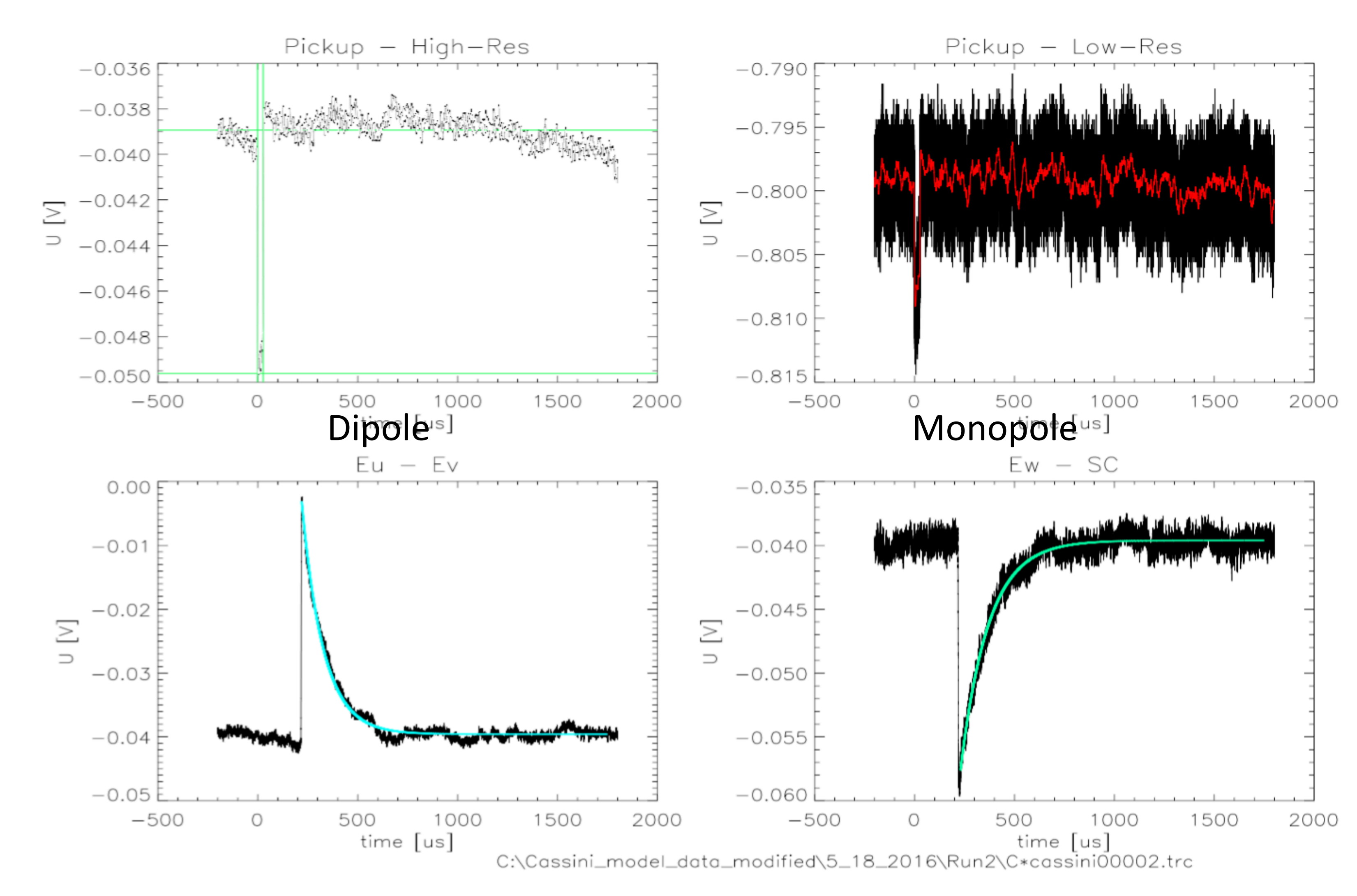


Electron cloud

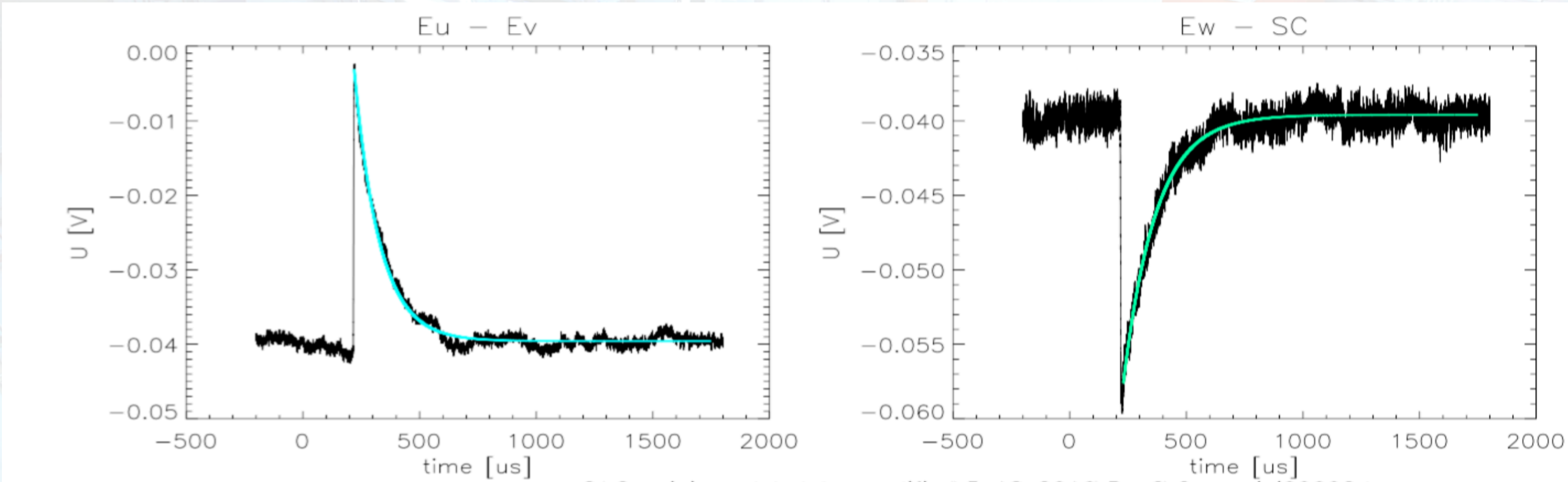
- Signal polarity changes with applied bias voltage
- Different rise times
- 'Pre-peak' observed in negative bias potential case

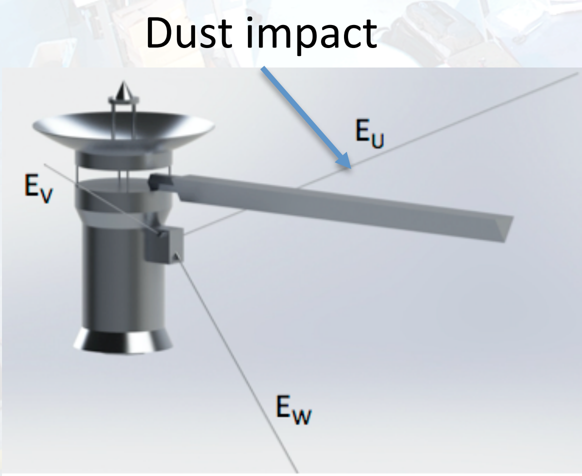


Impact on E_U, -10 V all



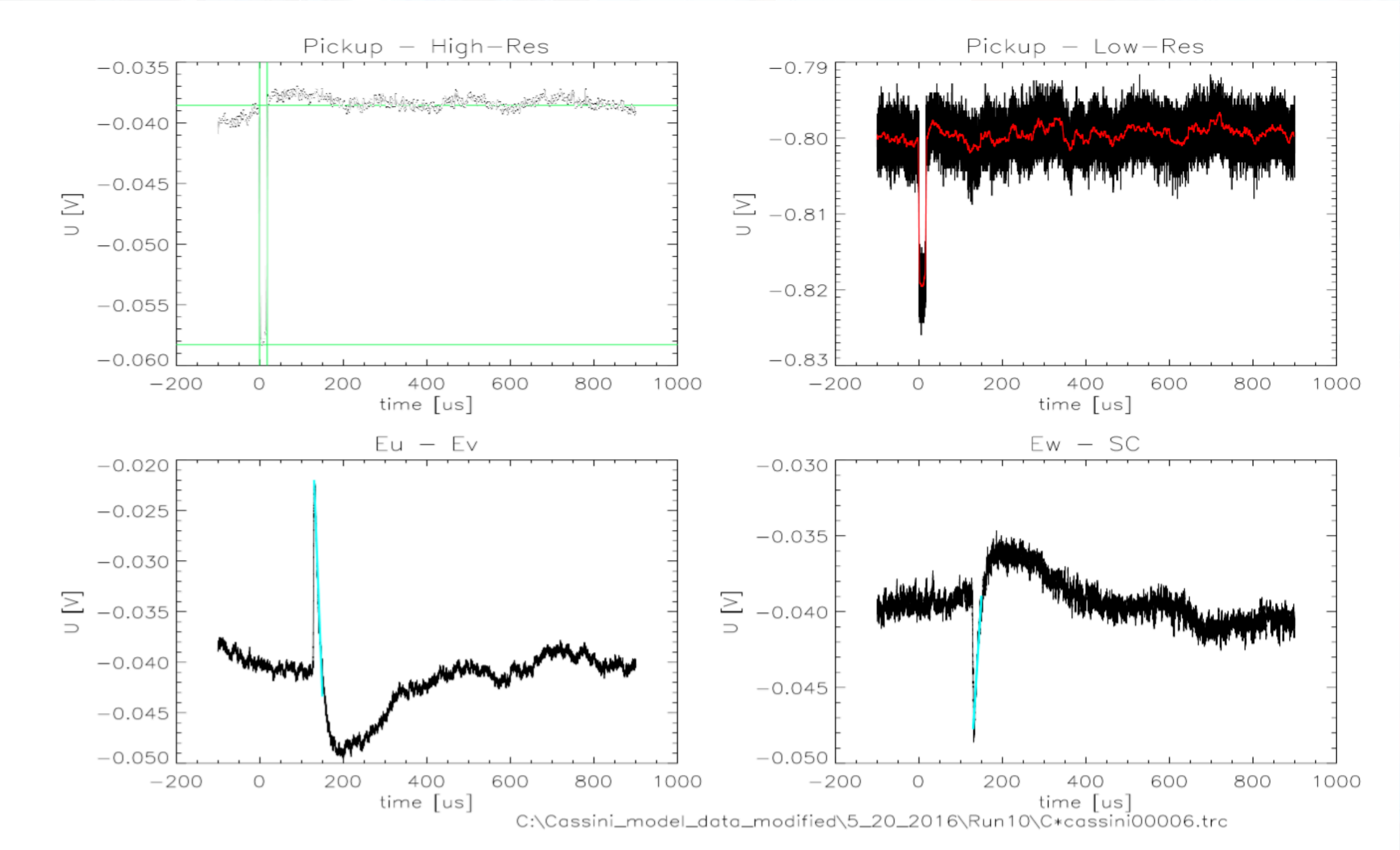
Impact on E_U, -10 V all





- Larger amplitude signals (smaller antenna capacitance ($V = Q_{coll} / C_{Ant}$)
- Monopole antenna measures ~1/3 of the amplitude
- Current explanation for cause is capacitive coupling between SC and antennas

Impact on E_U, 0 V all



Impact on E_U, 0 V all

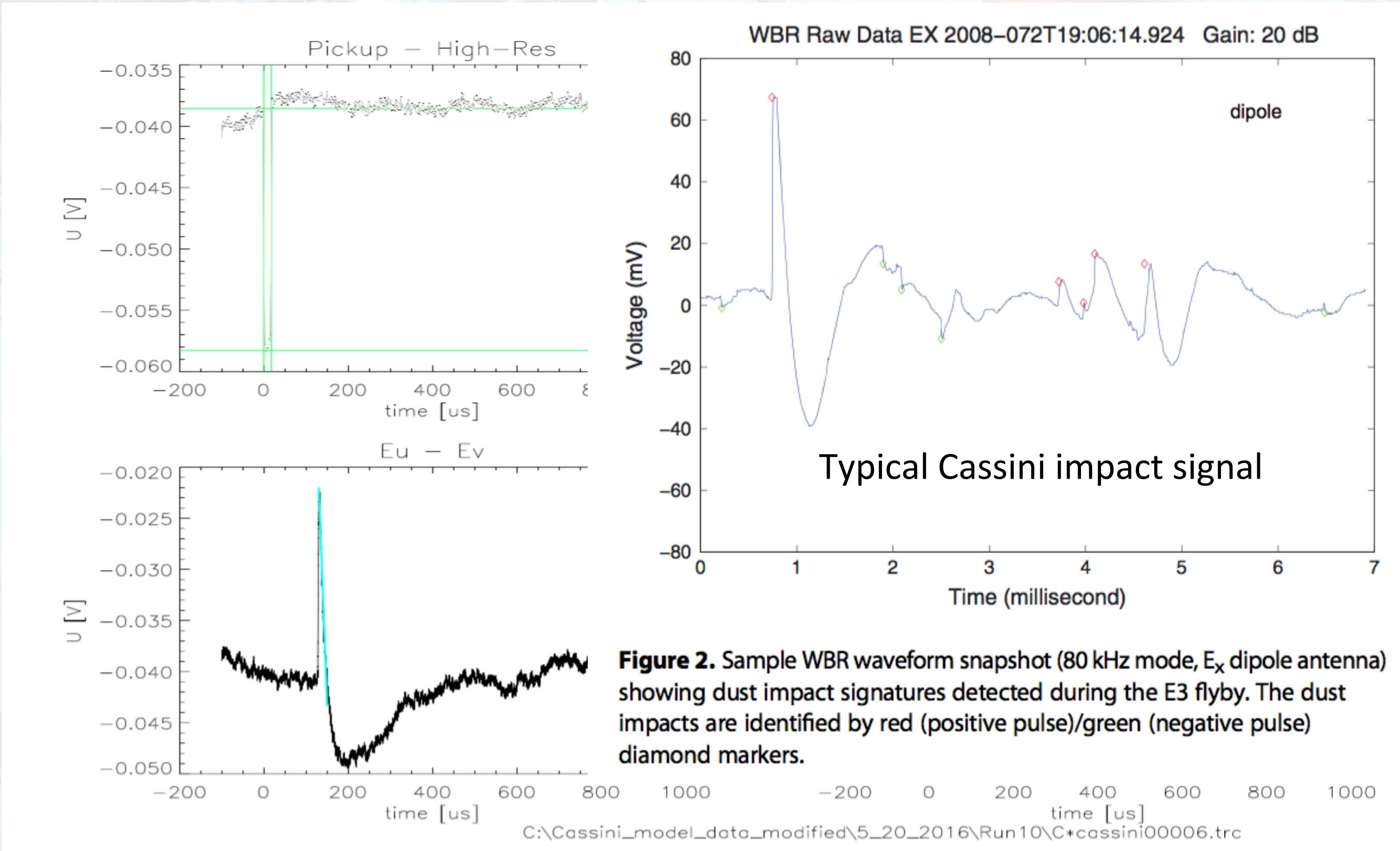


Figure 2. Sample WBR waveform snapshot (80 kHz mode, E_x dipole antenna) showing dust impact signatures detected during the E3 flyby. The dust impacts are identified by red (positive pulse)/green (negative pulse) diamond markers.

Overshoot occurs, not yet explained

Summary/Conclusions

- The ***elementary processes*** relevant to dust impact generated antenna signals ***can be studied*** in the laboratory ***using a dust accelerator***
- Monopole and dipole configurations modeled
- We can simulate the most basic signal pickup mechanisms
- Cassini model data analysis under way….

Temperature of the impact plasma

Linear TOF arrangement

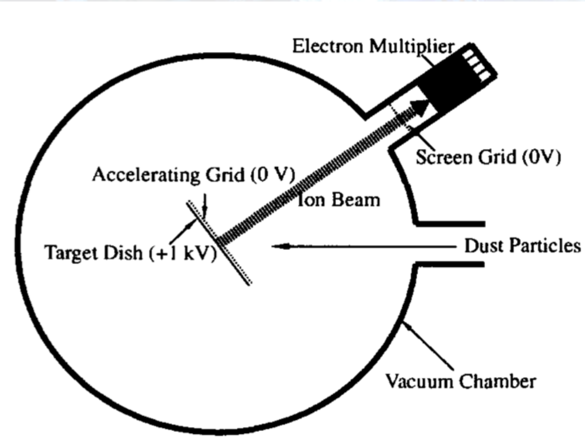
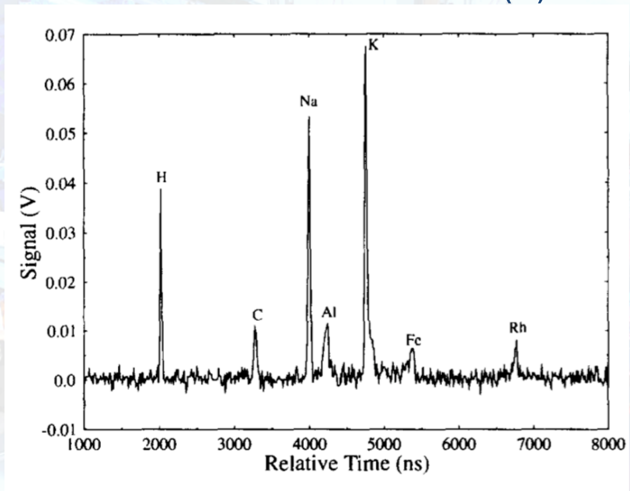
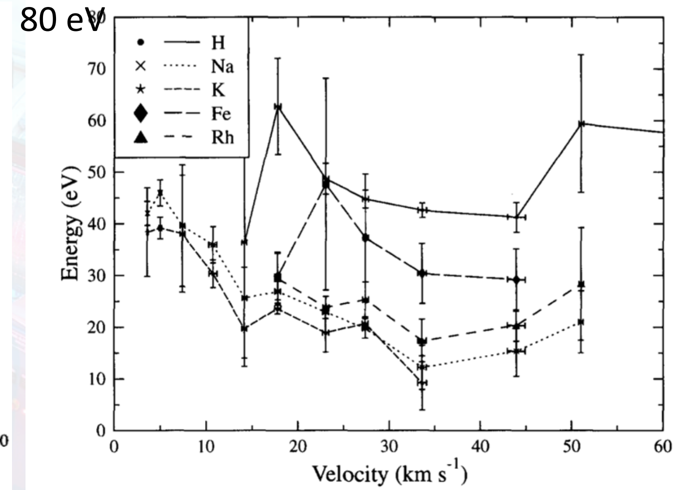


Fig. 2. Experiment configuration.

Mass line width ~ΔE (T)



Impact plasma ‘temperature’



Ratcliff et al. [1997], Fe particle on Rh.

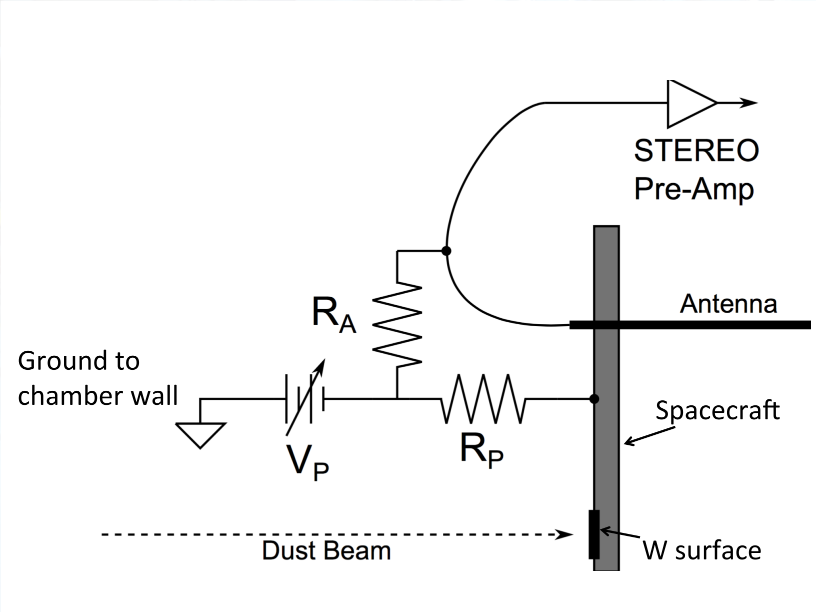
Similar results by:

Ratcliff and Allahdadi, 1996], Boron nitride particles on Ag doped Al

Hillier et al. [2006]

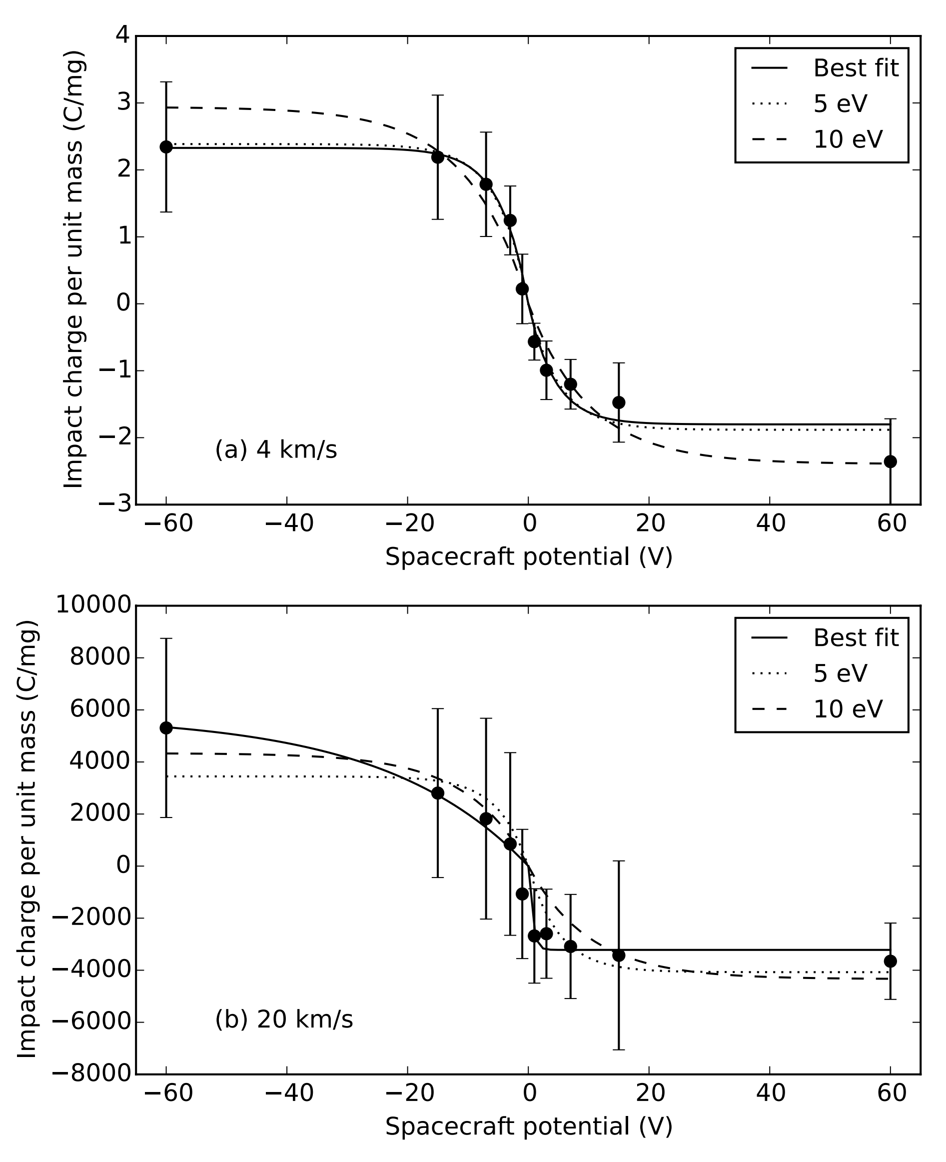
Lee et al. [2012], Fe particles on different targets

Lab Exp. #1: Temperature of the impact plasma



$$Q_{SC} = Q_I(1- \exp (qV_{SC}/T_P))$$

Impact speed [km/s]	Te [eV]	Ti [eV]
4	4	5
10	3	6
20	~1	23



(Collette et al., JGR, in revision)