Secondary Electron Emission and the Exploration of Space

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Overview

Secondary electrons are important to the spacecraft charging process and analysis of space system operation in plasma environments

- Spacecraft charging
  - Charging as a current collection phenomenon
  - Why do we care about charging
- Secondary electron currents
  - Impact generated secondary electrons
  - Photoelectrons
- Examples of charging
  - Geostationary orbit and critical electron temperature/energies for charging onset (LANL)
  - Auroral charging (DMSP)
  - Bootstrap charging..........potential barriers (DSCS)
  - Photoelectron dominated charging (Geotail, Cluster)
- Charging and lunar exploration
  - Spacecraft potentials in lunar orbit
  - Lunar surface charging environments
  - Charged dust
- Summary

The Charging Current Balance Process

- Current balance phenomenon

$$dQ/dT = I_i(V) - I_e(V) + I_{ph,e}(V) + I_{s,e}(V) - I_{s,i}(V) + I_{bs,e}(V) + \sigma E(V)$$

- Surface charging
  - Current balance to spacecraft surface
- Bulk charging
  - Penetrating (MeV) electrons generate charge density within materials

(Garrett and Minow, 2004)

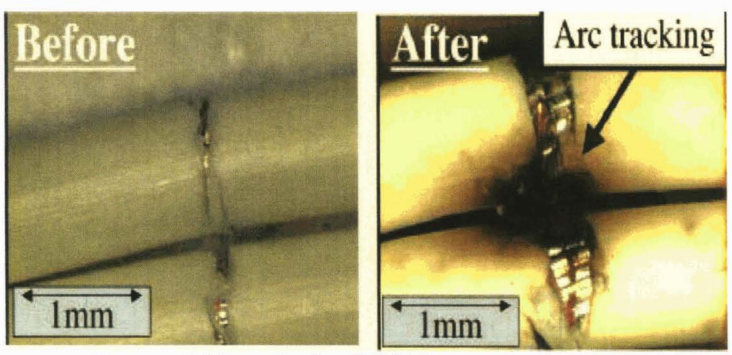
Spacecraft Charging Impacts Space Systems

Space Environment Impacts on Space Systems (Koons et al., 2000)

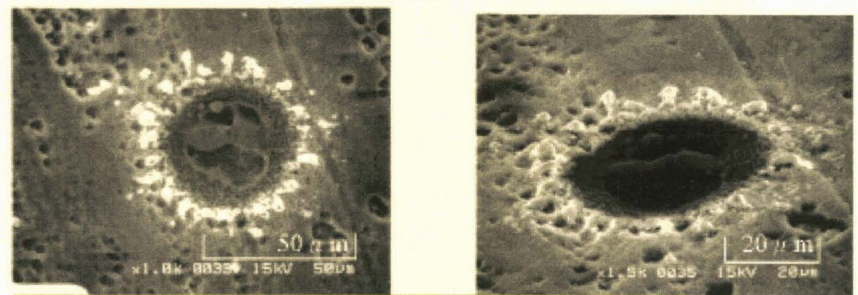
Anomaly Diagnosis	Number	%
ESD-Internal Charging	74	24.7
ESD-Surface Charging	59	19.7
ESD-Uncategorized	29	9.7
SEU (GCR, SPE, SAA, etc.)	85	28.4
Radiation Dose	16	5.4
MMOD	10	3.3
Atomic oxygen	1	0.3
Atmospheric drag	1	0.3
Other	24	8.0
Total	299	100.0%

Risks to Spacecraft

- Phantom commands
- Discharge currents damage materials, electronics systems
- Damage to thermal control coatings, solar cells, power cables
- Trigger arcs on power systems lead to sustained arcing



Kawakita et al., 2005



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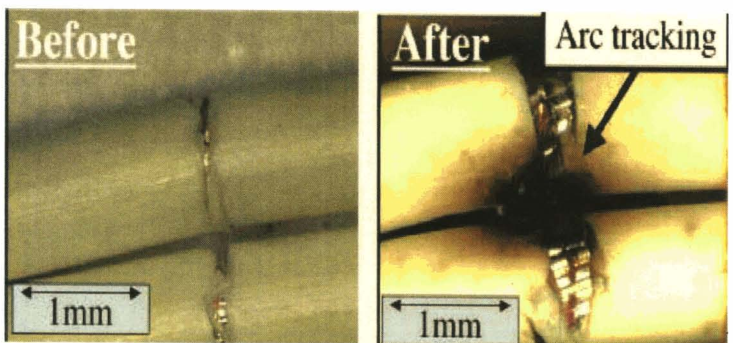

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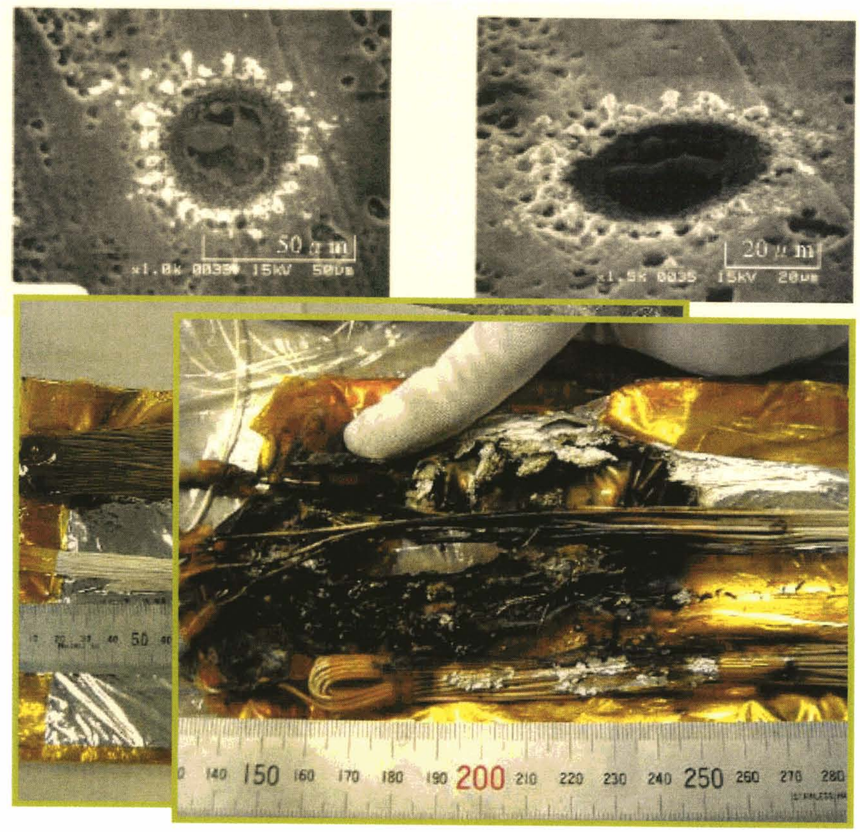

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Risks to Spacecraft

- Phantom commands

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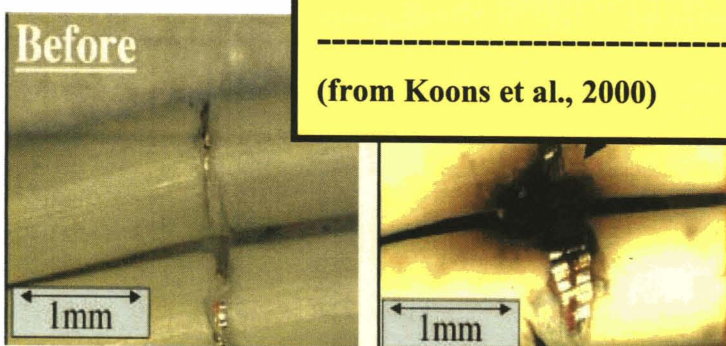
lead to sustained arcing

Spacecraft Lost/Missions Terminated Due to Charging

Spacecraft	Date	Cause
DSCS II	Jun 1973	Surface ESD
GOES 4	Nov 1982	Surface ESD
Feng Yun 1	Jun 1988	ESD
MARECS A	Mar 1991	Surface ESD
Anik E2	Jan 1994	ESD?
Telstar 401	Jan 1997	ESD?
INSAT 2D	Oct 1997	Surface ESD
ADEOS-II	Oct 2003	ESD

(from Koons et al., 2000)



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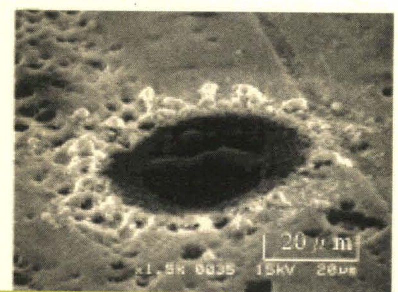
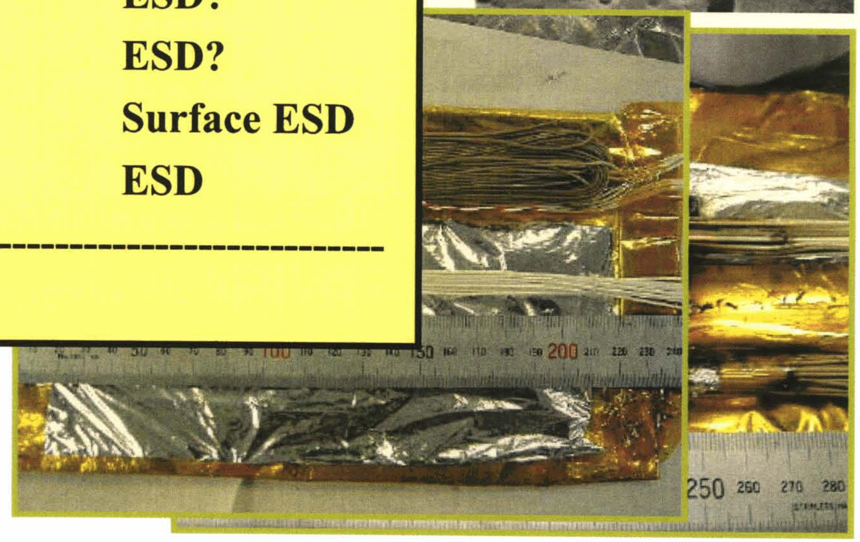
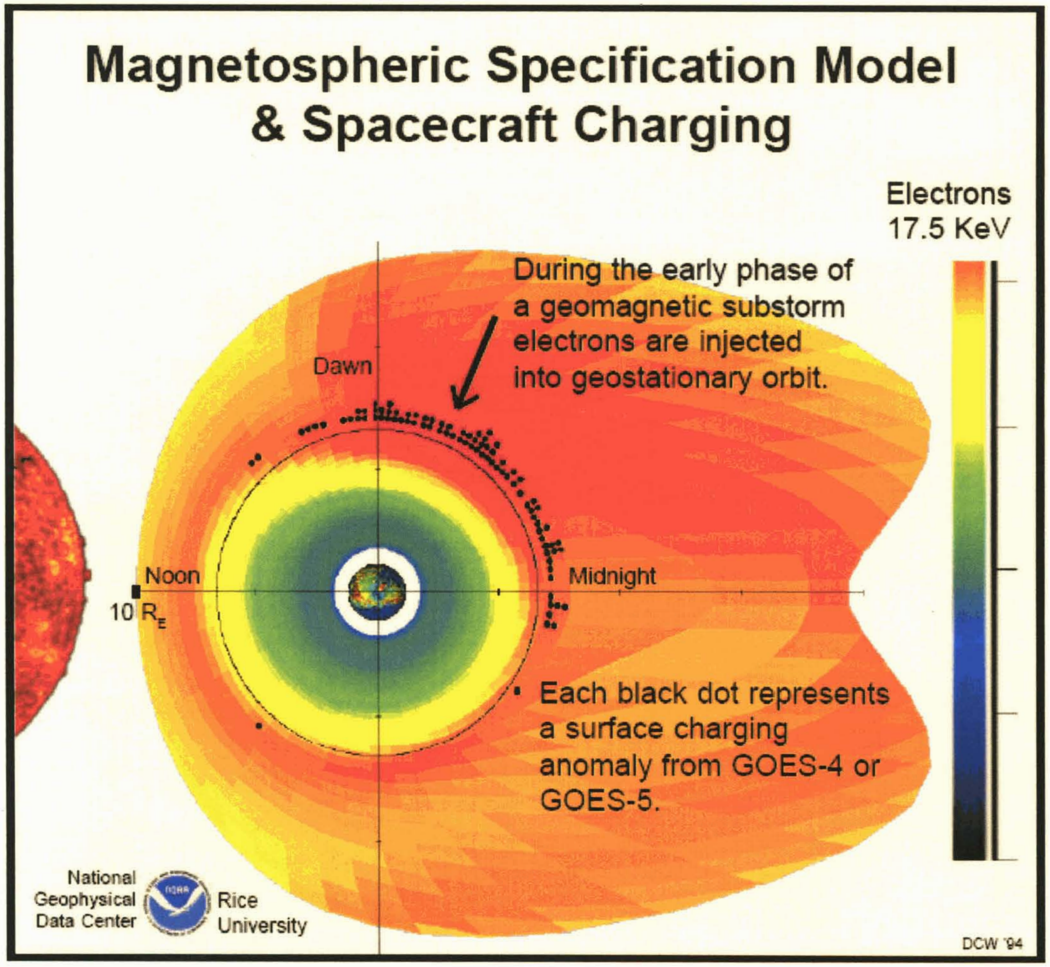
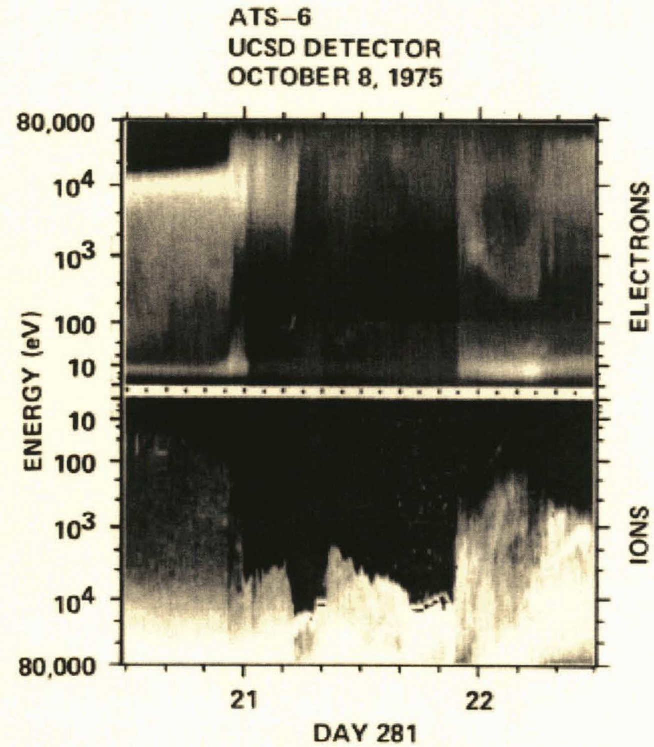




Kawakita et al., 2005

GEO Surface Charging

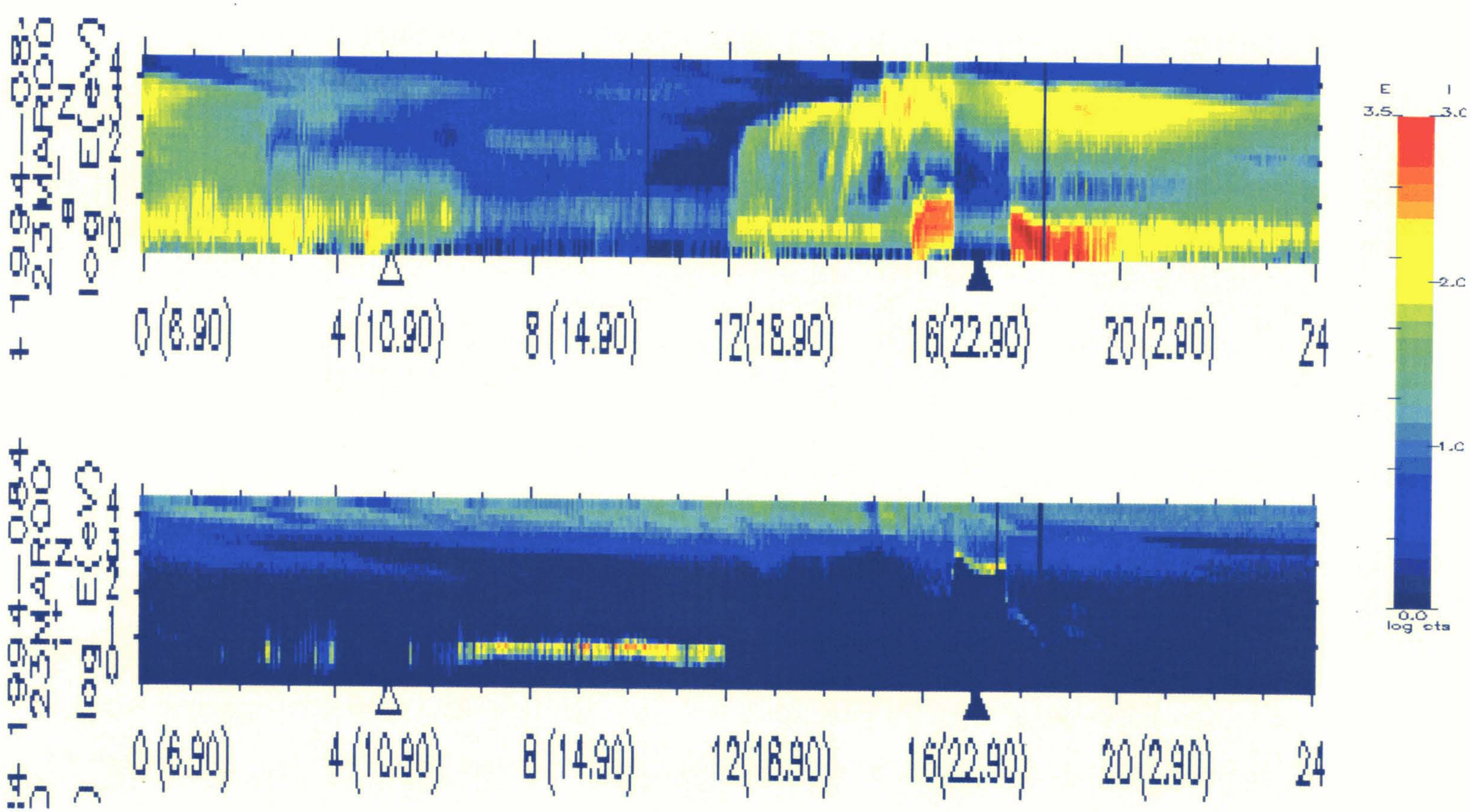




Olsen [1983]

Anomalies typically occur in midnight to dawn sector where hot plasma is injected during geomagnetic substorms

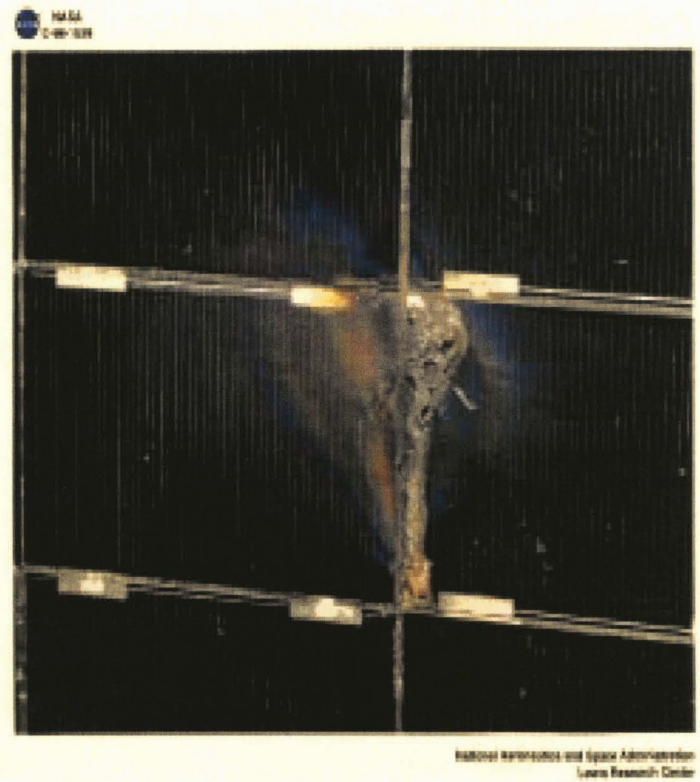
GEO Surface Charging



Eclipse charging events typically reach kilovolt potentials

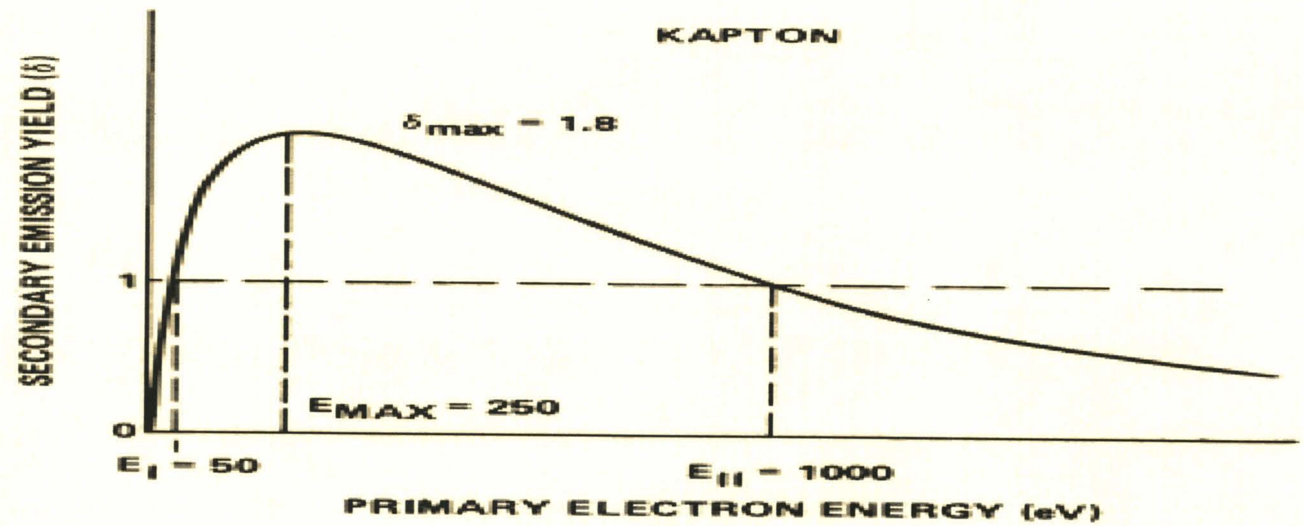
Solar Array Arc Damage

Sustained arc initiated by trigger arcs on charged solar array panels



(Ferguson, 2001)

Secondary Electron Yields



From Leung et. al., 1981

LEO

T~0.1 to 0.5 eV

V~ -0.5 to 1 V

Auroral charging

T~1- 10 keV

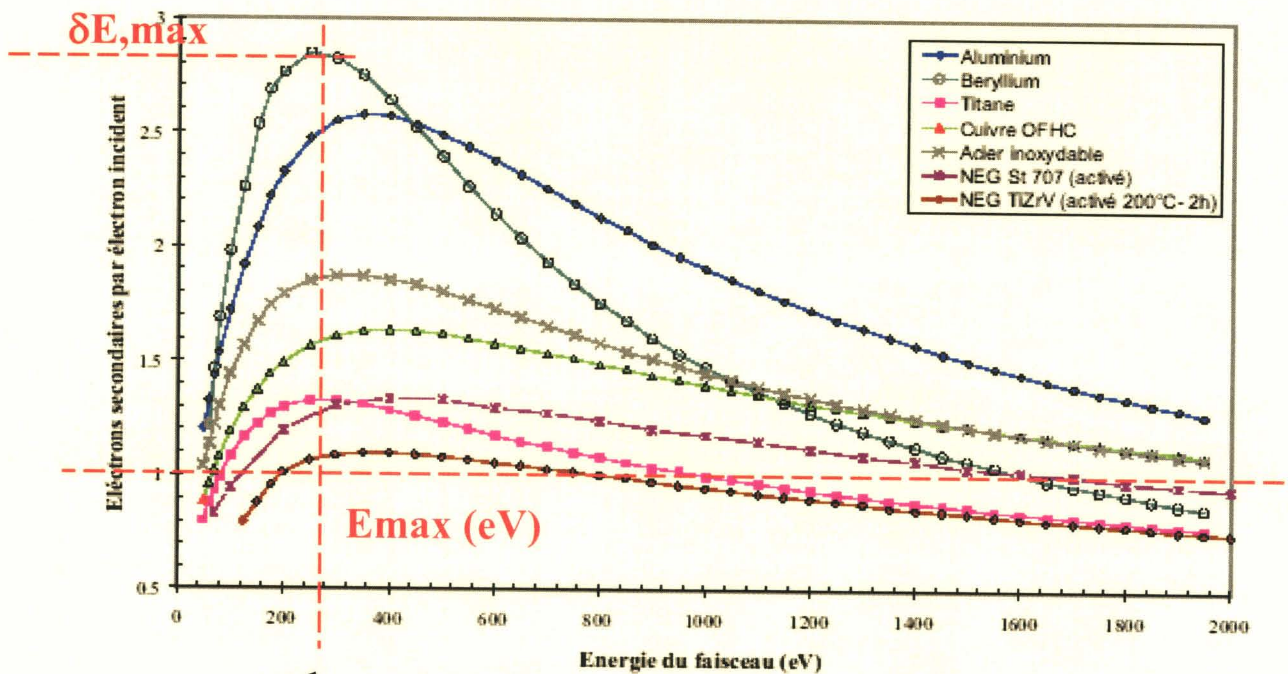
V ~ 0 to -1500 V

GEO charging

T~10's keV

V ~ 100- 10,000 V

Secondary Yields are Material Dependent



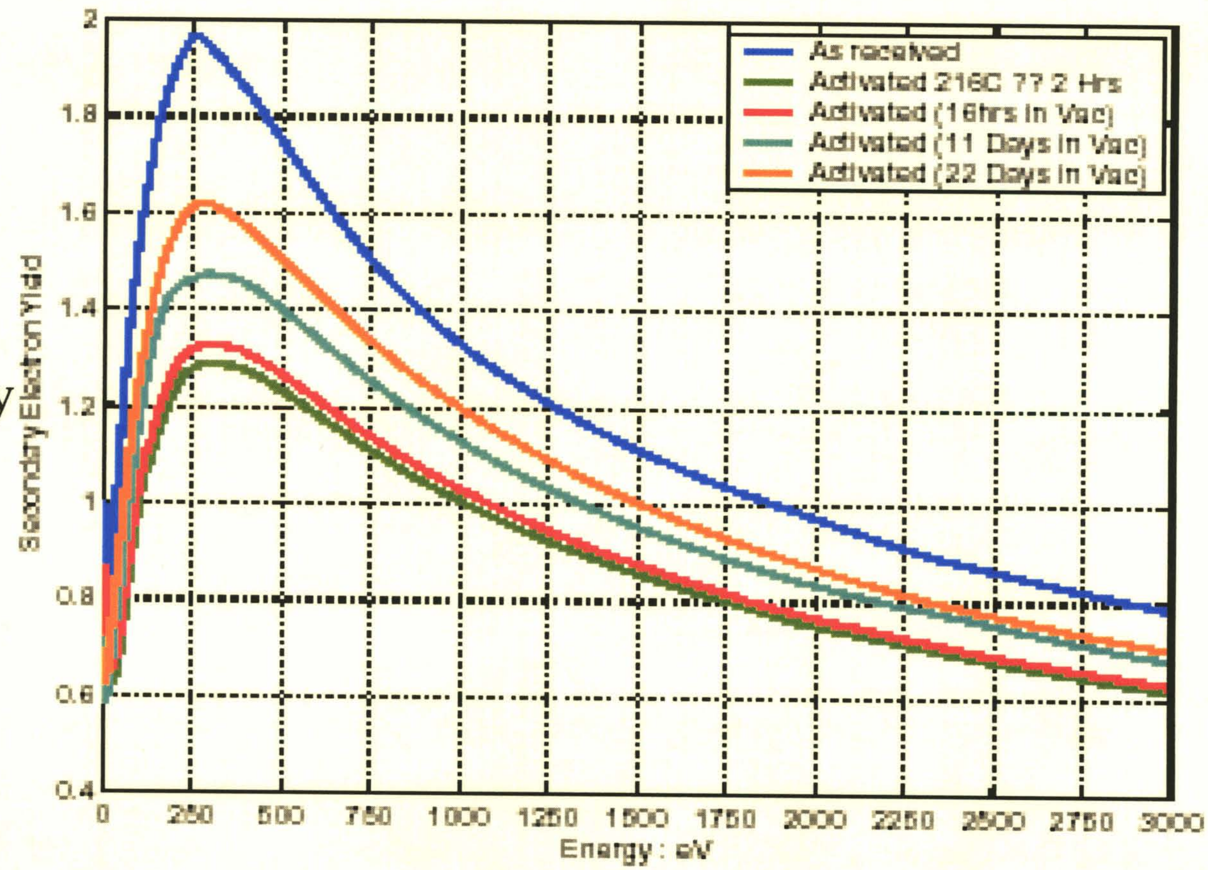
(from Pimpec et al., LCC-0128, SLAC-TN-03-052, 2003)

Model secondary yield curves are used to parameterize electron yields as function of incident electron energy (Sternglass, 1954)

$$\delta_e(E,\theta) = \delta_{e,\max} \frac{E}{E_{\max}} \exp\left(2 - 2\sqrt{E/E_{\max}}\right) \exp[2(1-\cos\theta)]$$

Time Dependent SEY

- Direct launch trajectories through radiation belts
- Rapid changes in secondary yields potentially important early in spacecraft life



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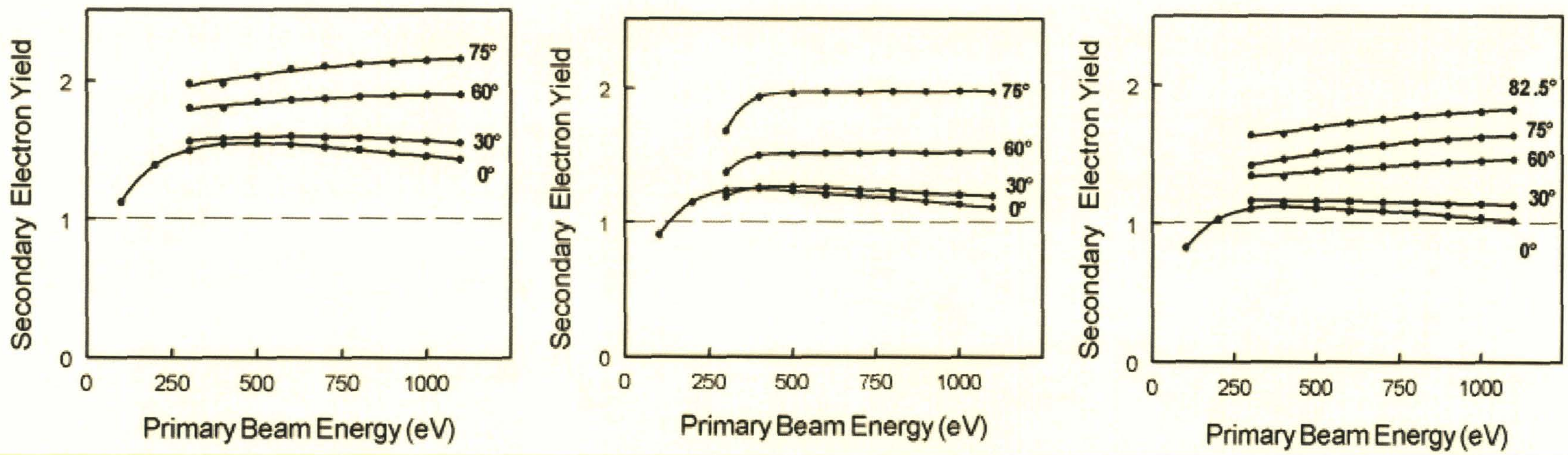
SEY Dose Dependence

(from Kirby and King, SLAC-PUB-8212, 2000)



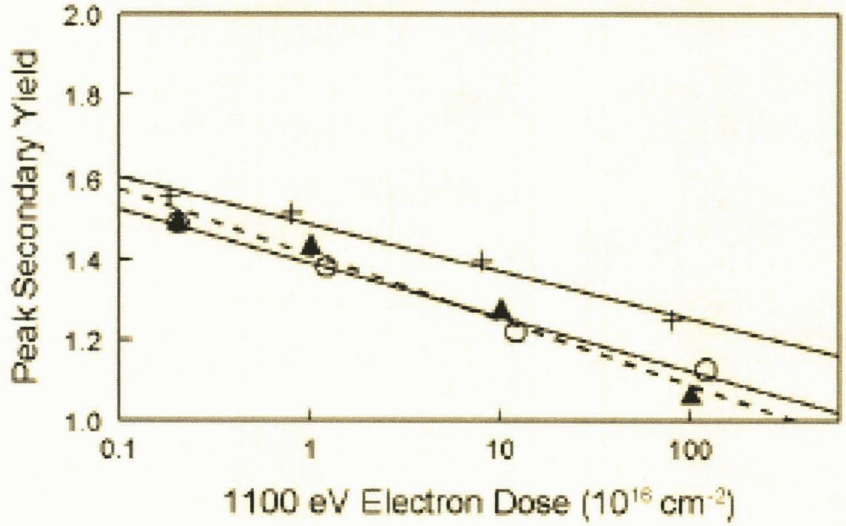
a) Before e^- exposure b) After 0.8×10^{18} e^-/cm^2 c) After 1.8×10^{18} e^-/cm^2

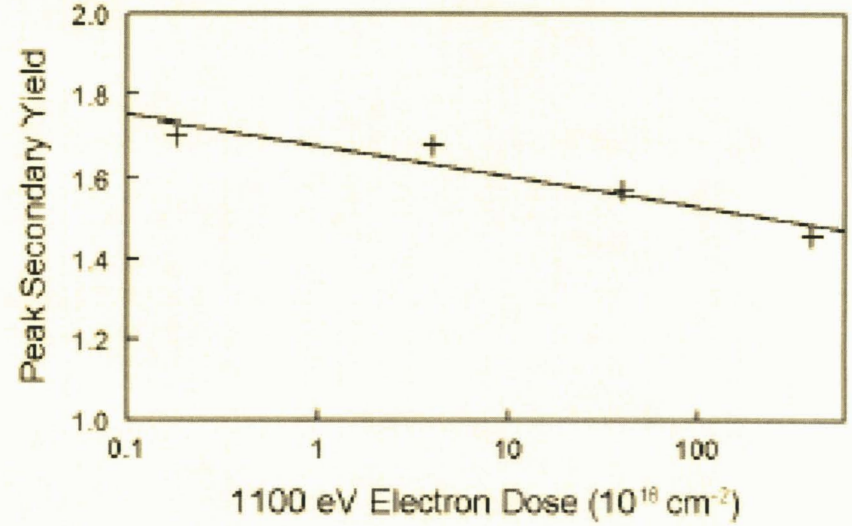
- SEY of TiN coated Al alloy before and after electron beam exposures
    - 5 nA/cm^2 beam current for 1 hour ~ 1.125×10^{14} e^-/cm^2
- Decrease in secondary yield with dose predicts greater charging (consistent with ED31 laboratory results).
- Yield depends on angle:
    - SEY values greater at larger incidence angle, predicts reduction in charging

Dose Dependent SEY

•What fluence gives SEY<1?

•At this point no primary electron impacts will yield seconfaries and spacecraft charges for ALL electrons…….spacecraft charges negative under all conditions





(from Kirby and King, SLAC-PUB-8212, 2000)

a) 1100 eV e^- dose x 10^{16} e^-/cm^2

+,O TiN-coated Al alloy extrusions

▲ TiN-coated Al sheet

b) 1100 eV e^- dose x 10^{18} e^-/cm^2

HER copper extrusion

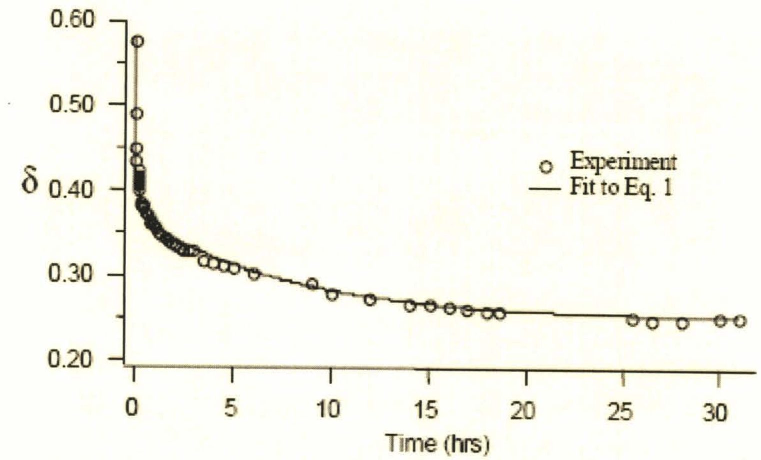
- Demonstrates dose dependent changes in peak secondary electron yield

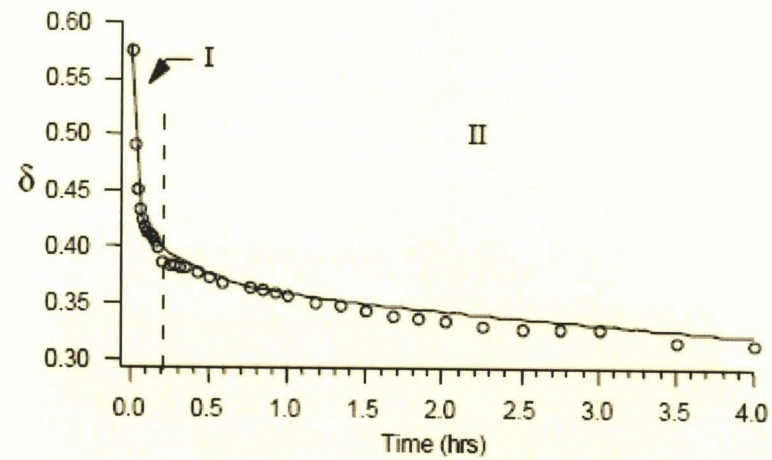
Time Dependent SEY

Oxidized aluminum and PTFE coated wire samples irradiated with 1-3 keV electrons for 30 hours

- δ reduced 30% due to removal of oxide layer and deposition of contaminant layer

- Reduced SEY increases charging threat

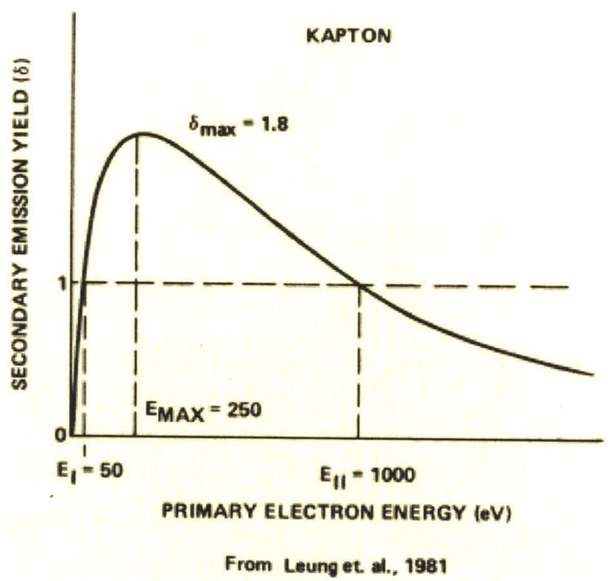


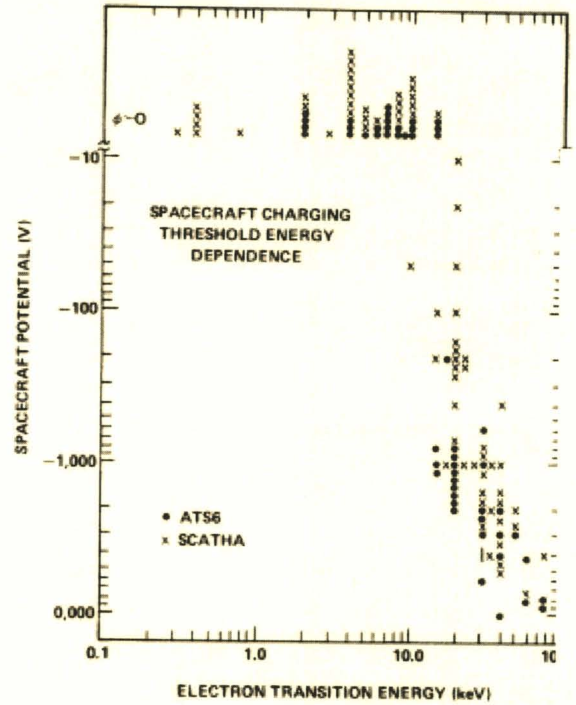


(Davies and Dennison, 2000)

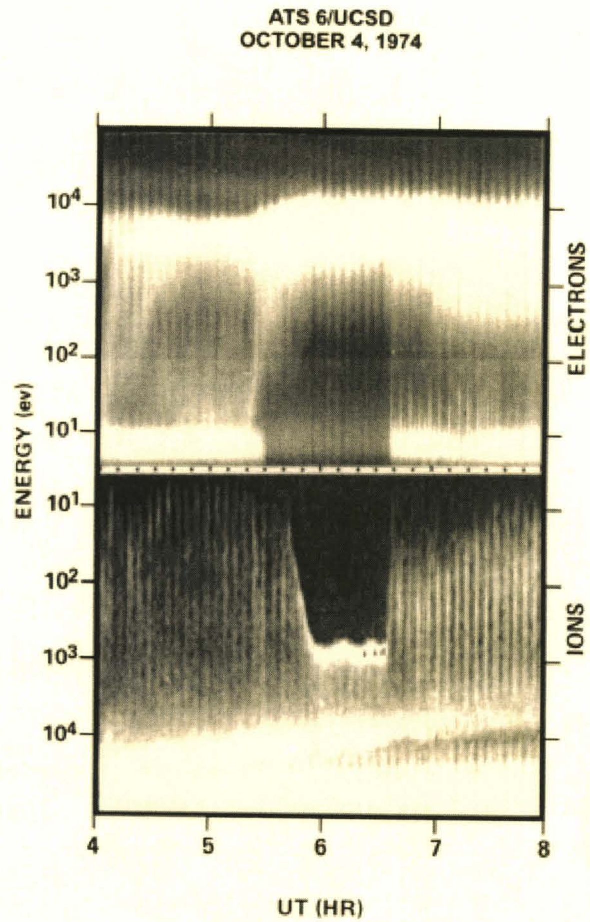
Threshold Temperature for Charging Onset

Temperature threshold for onset of charging is due to second crossover point of secondary electron yield curves (Olsen, 1983)



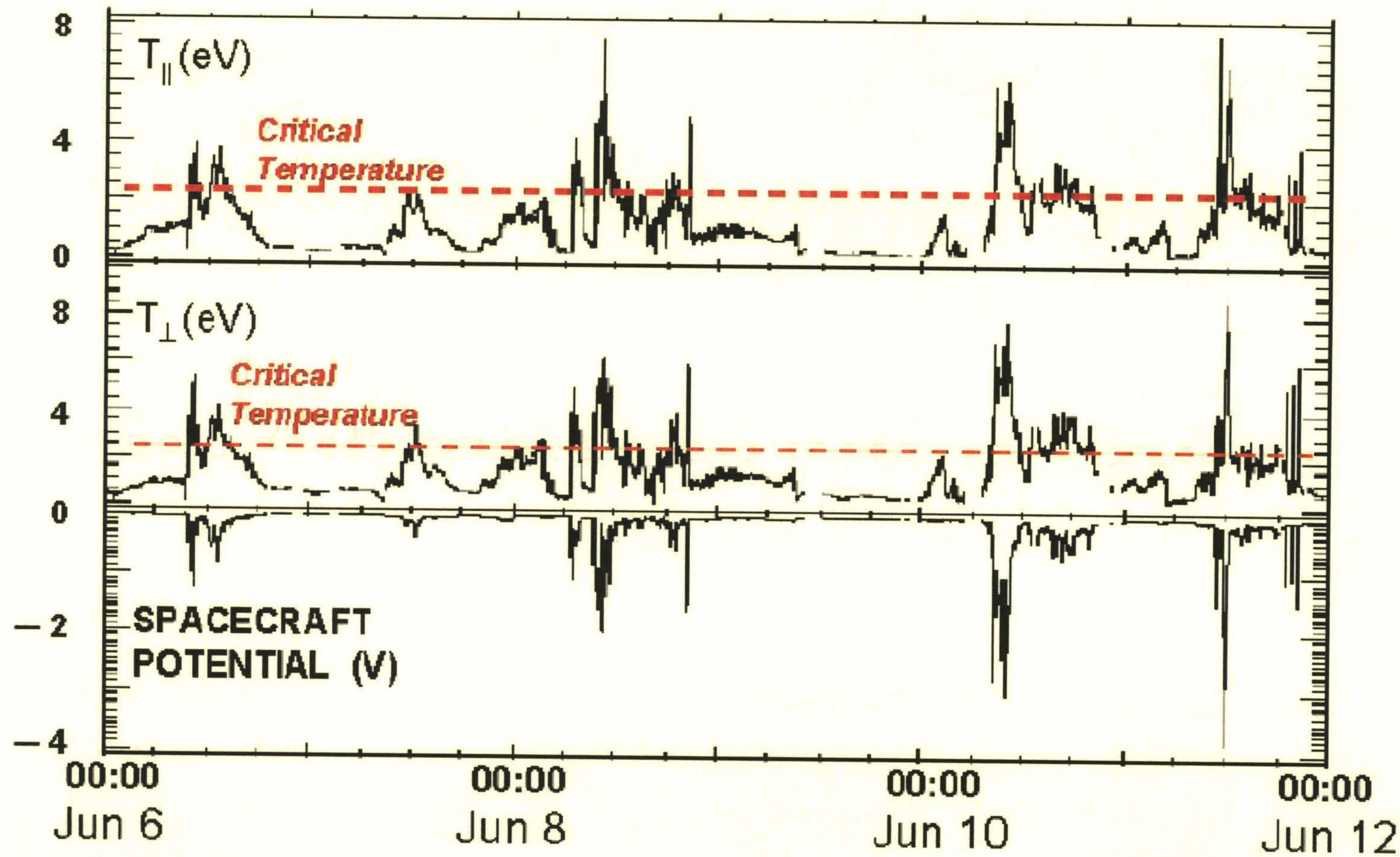


Olsen [1983]



Olsen [1983]

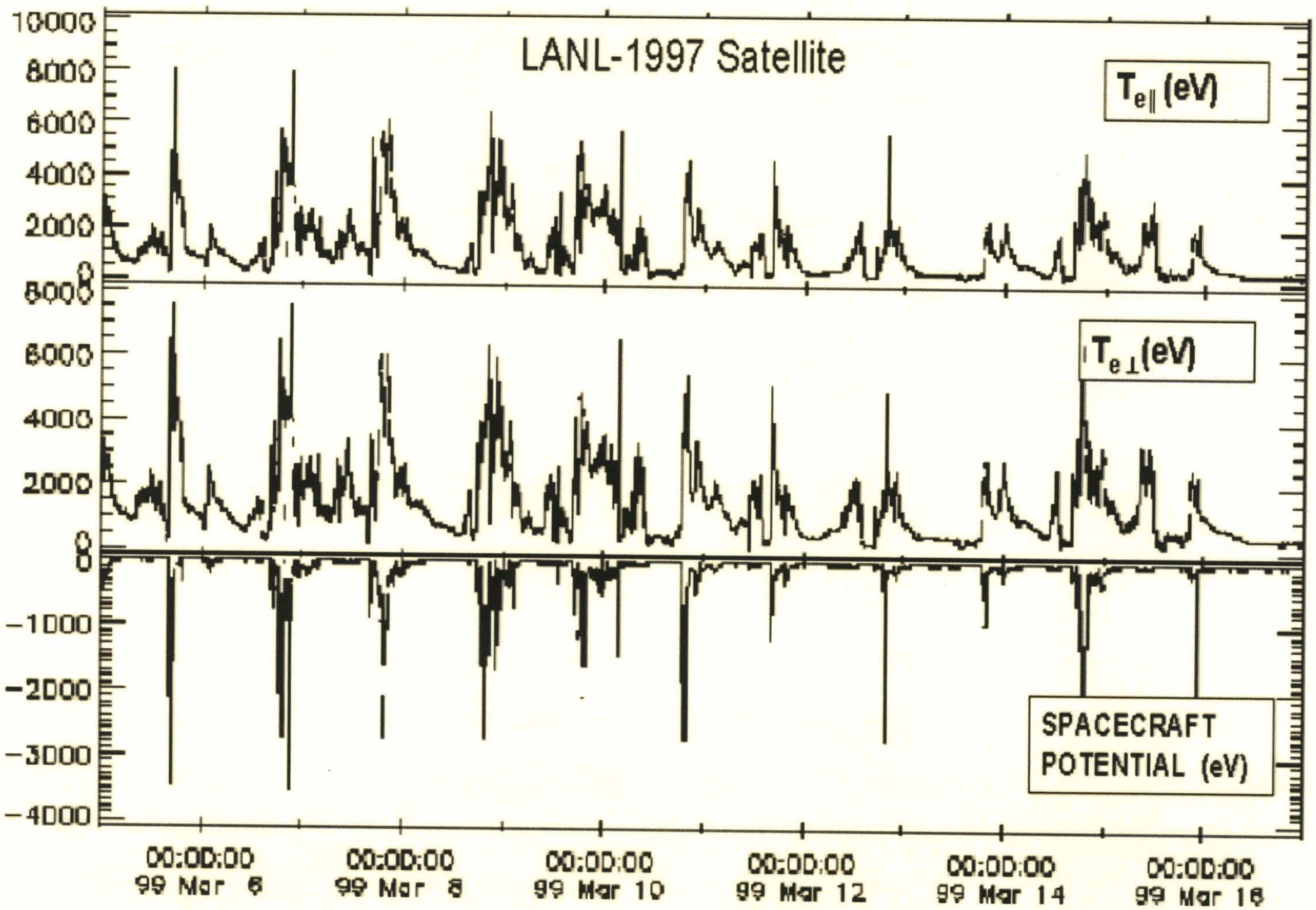
Examples of T_{crit} Onset



- Examples for onset of charging at a critical temperature

(Lai, 2003) 8th SCTC

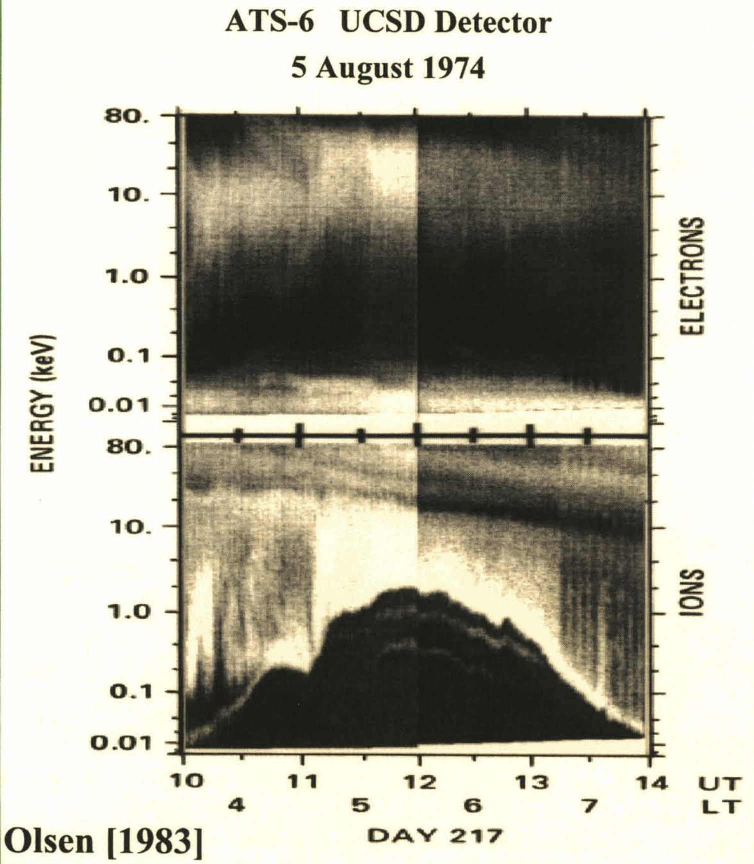
Te Threshold



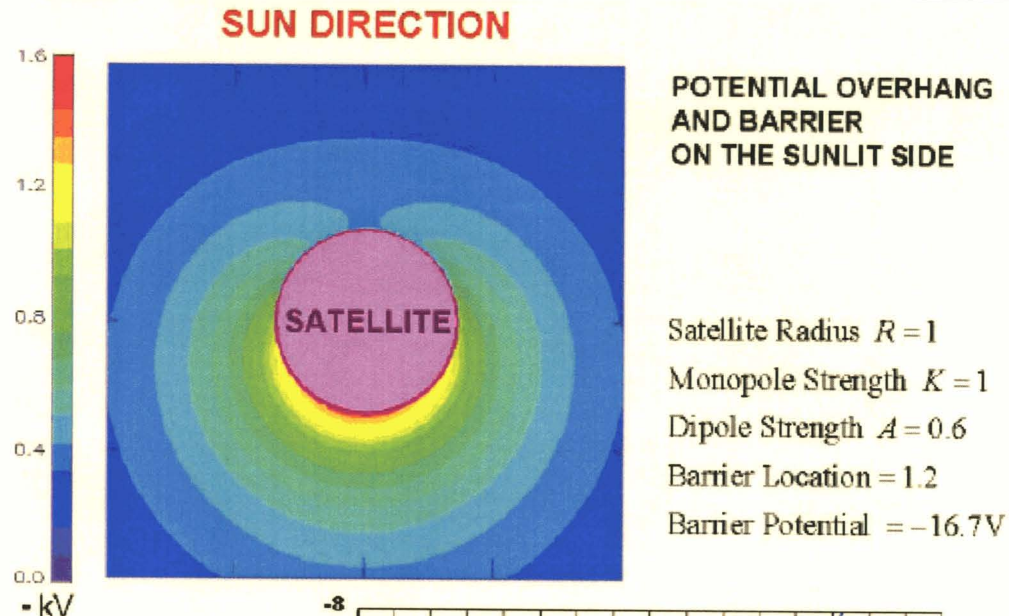
(Lai et al, 2003)

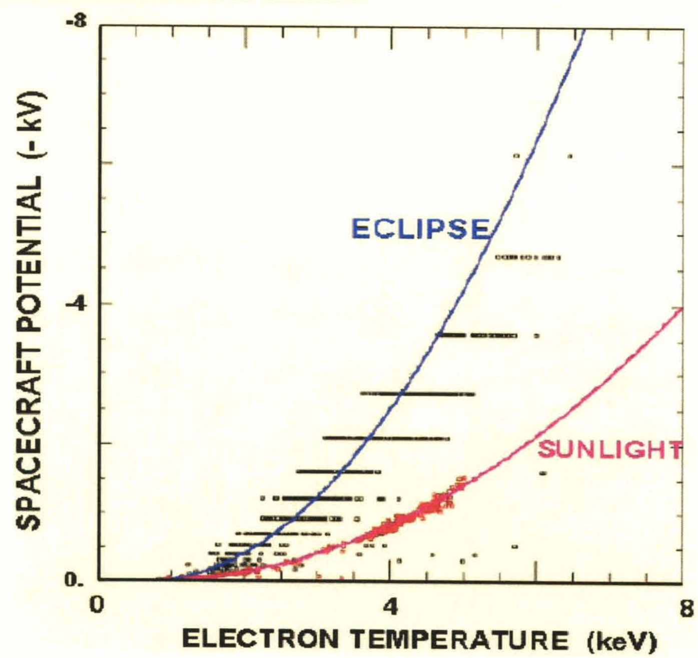
Trapped Photoelectrons and Sunlight Charging

- Sunlight charging in GEO
- Dielectrics in sunlight can also charge to negative potentials



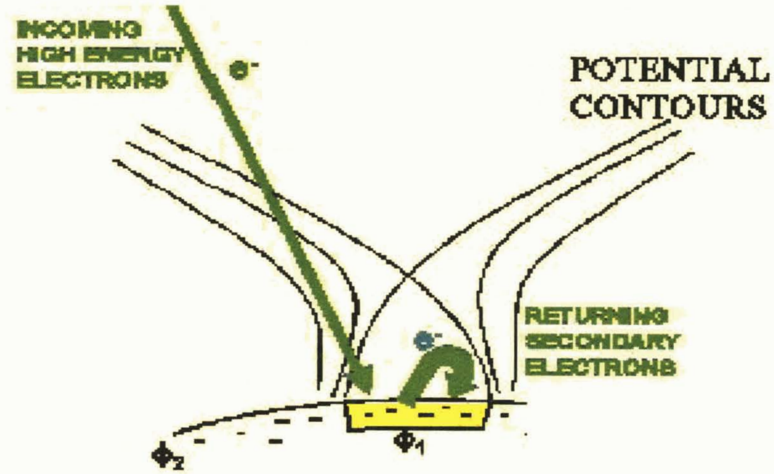
Olsen [1983]

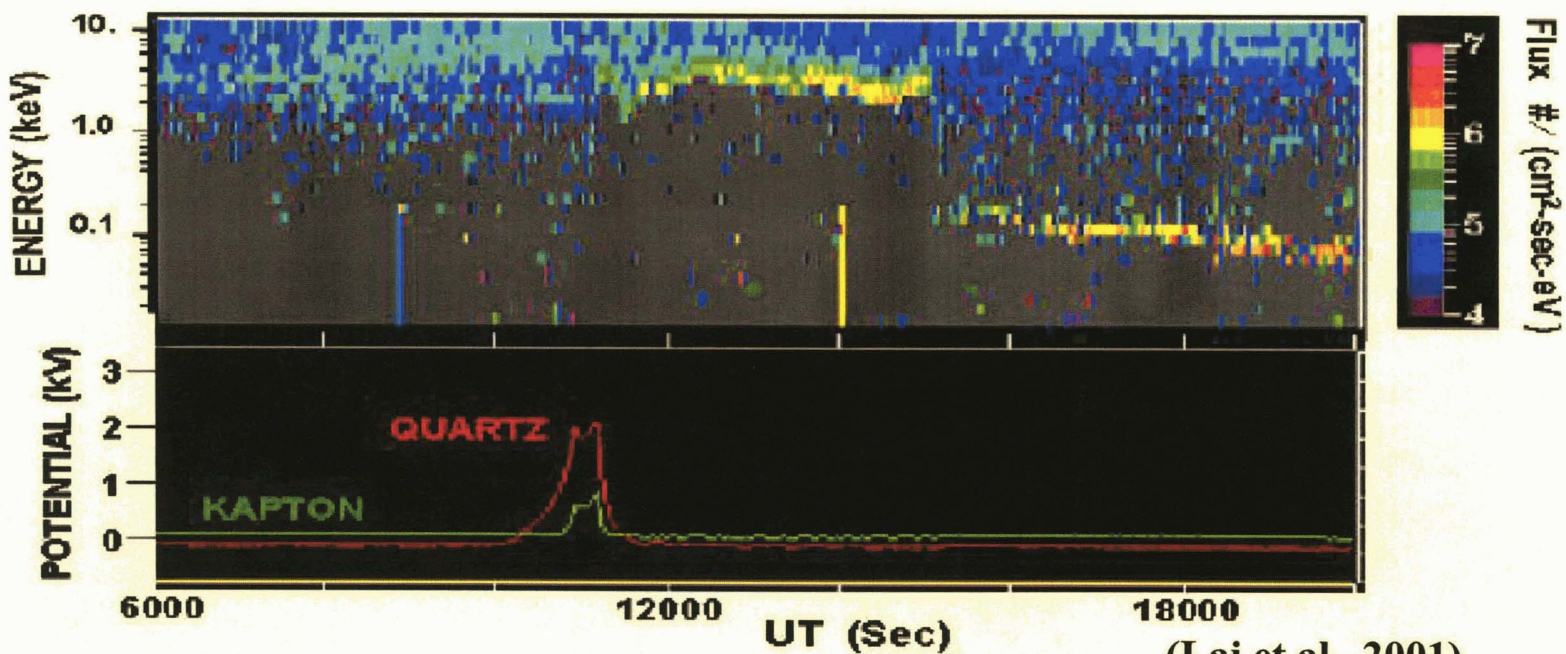




Bootstrap Charging

- Bootstrap charging results from secondary electrons trapped in potential barriers





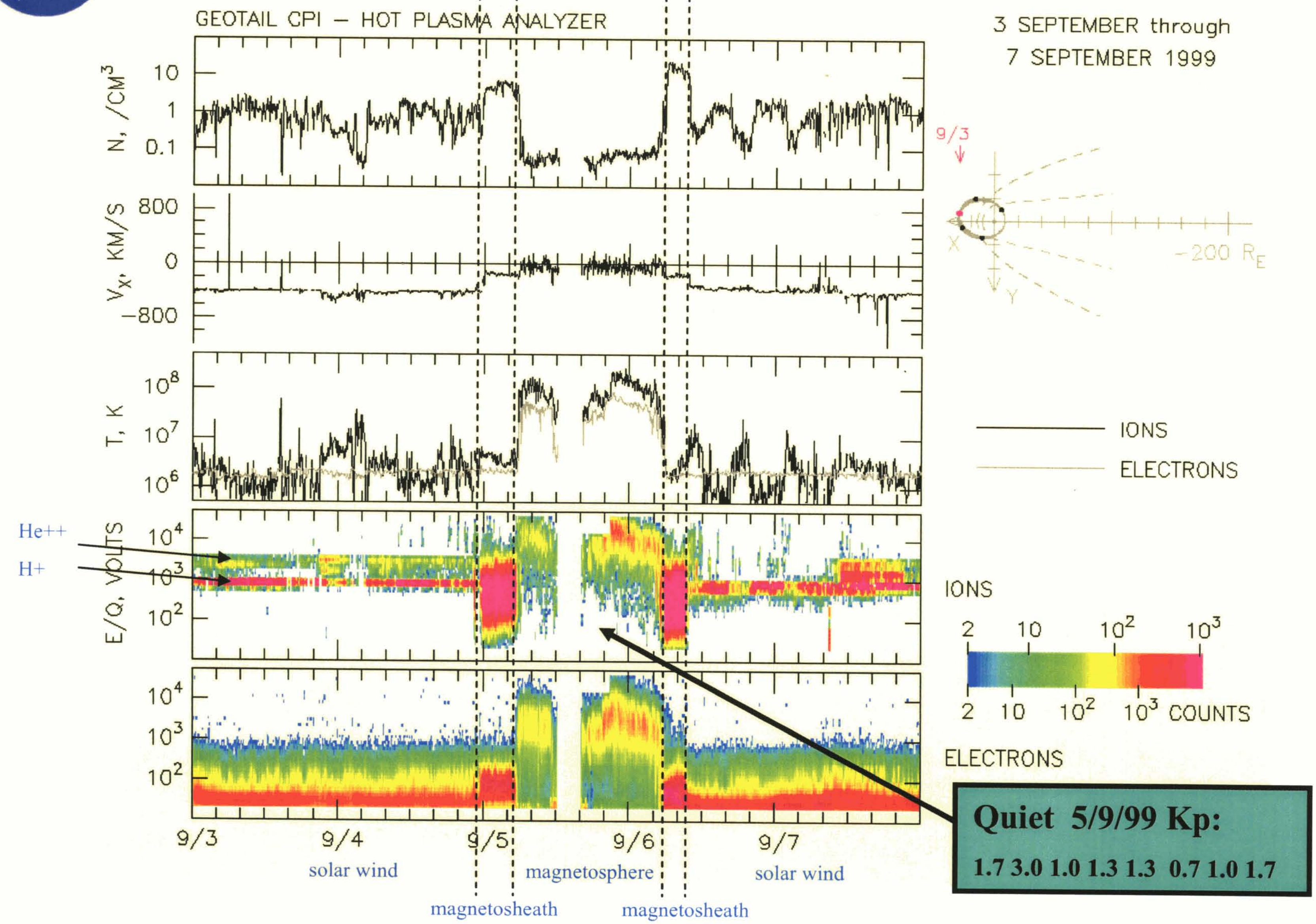
(Lai et al., 2001)

Auroral. Solar Wind Charging

- Secondary electron currents can be larger than primary plasma currents
  - Yields >1
  - Auroral charging case
    - Show one with ~1 keV accelerated auroral electrons (Y>1) so there is no charging (or charged +)
    - Shown example with ~10 to 30 keV electrons where Y<1

- Solar wind charging…photoelectron currents dominate the current balance process and spacecraft charge positive
  - Ions ~ 1 keV   Y>1
  - Electrons low energy
  - Compute incident currents as well as secondary currents
  - Nascap-2k example
  - Example from Geotail

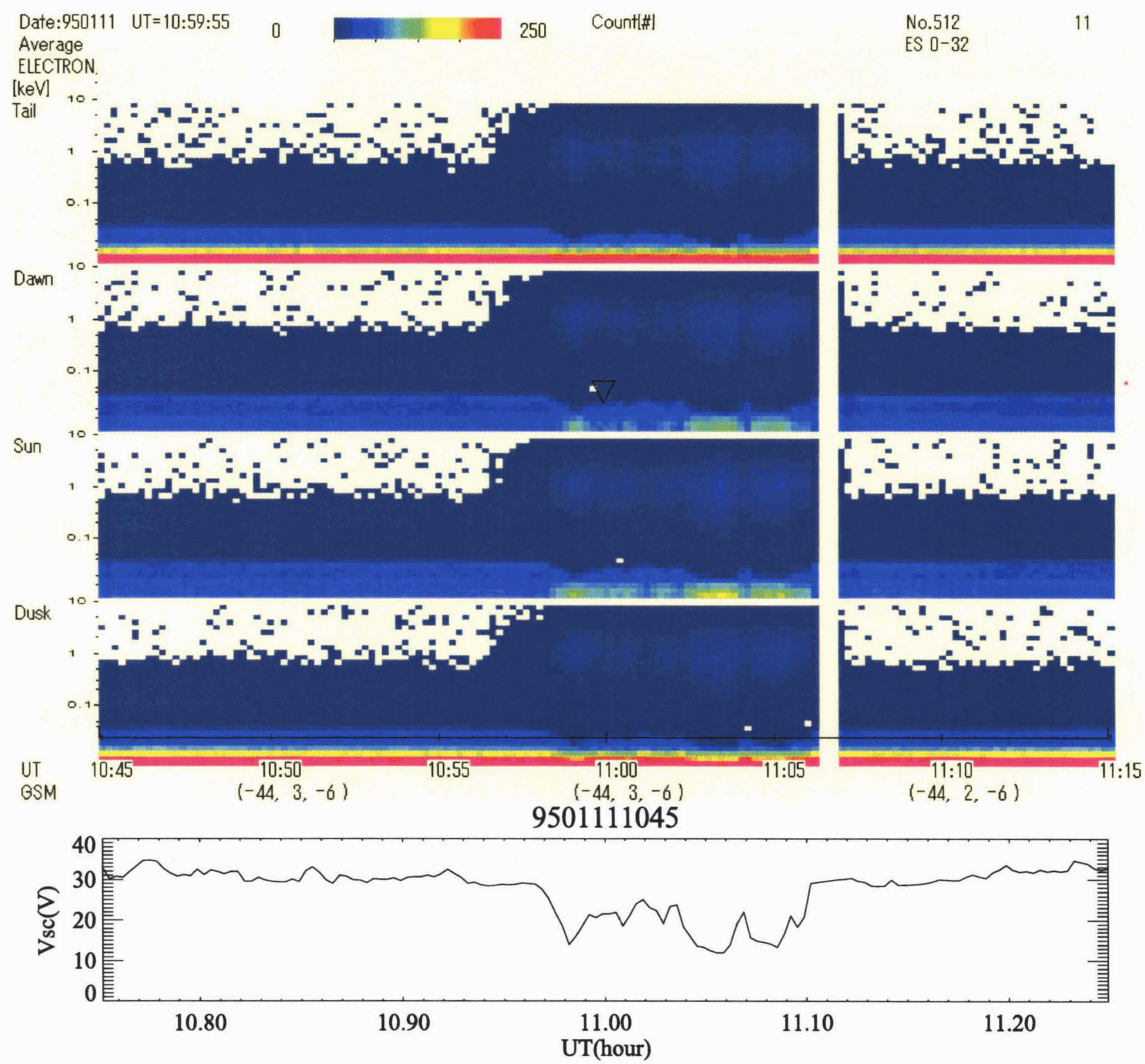
Near Earth Plasma Regimes



J. Minow [256] 544-2850

Photoelectrons

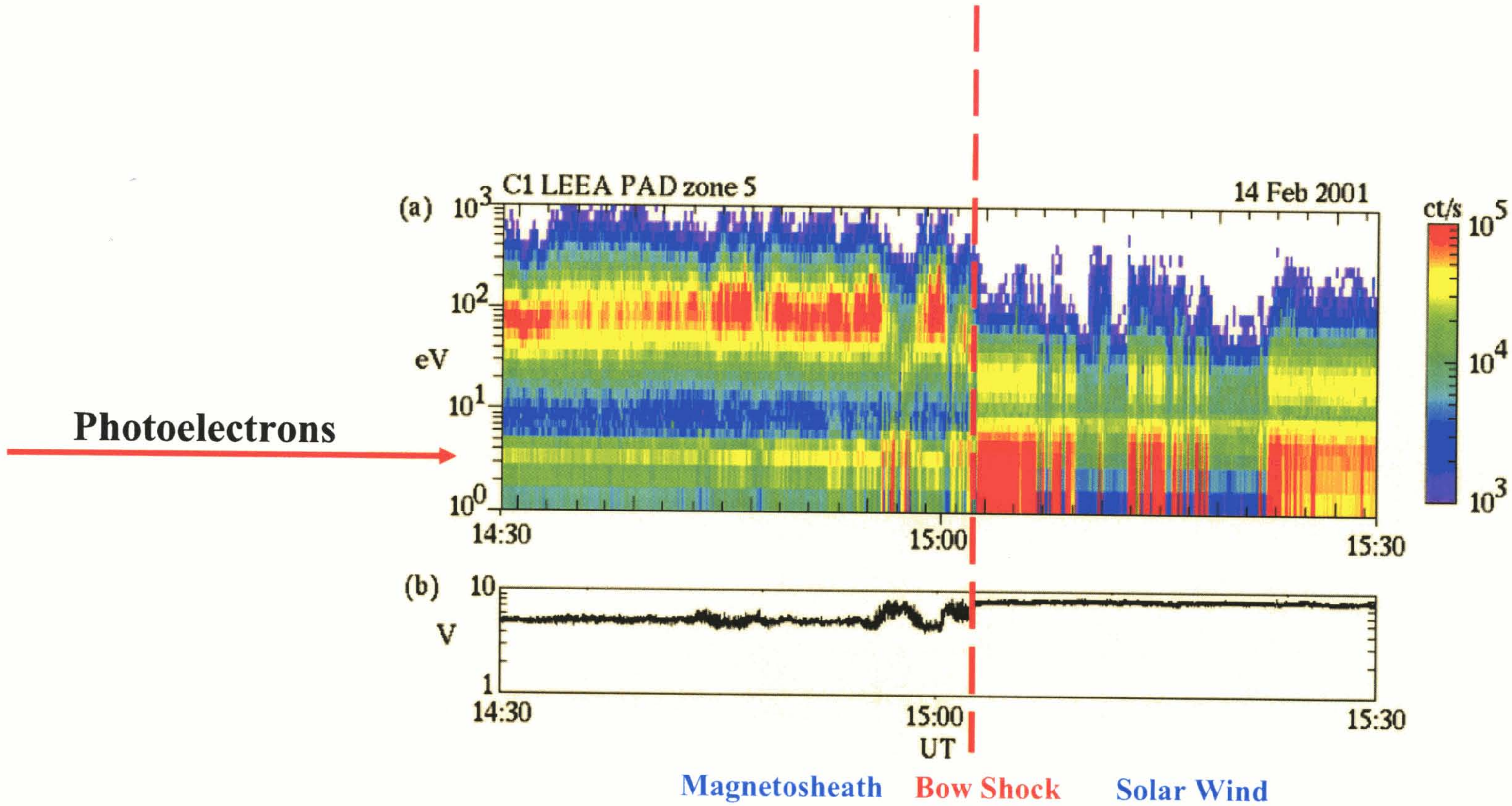
- Photoelectron currents can dominate the charging process in low density environments
- Geotail spacecraft is in interplanetary space where $J_{ph} > J_{plasma}$



Shimoda et al., 9th SCTC

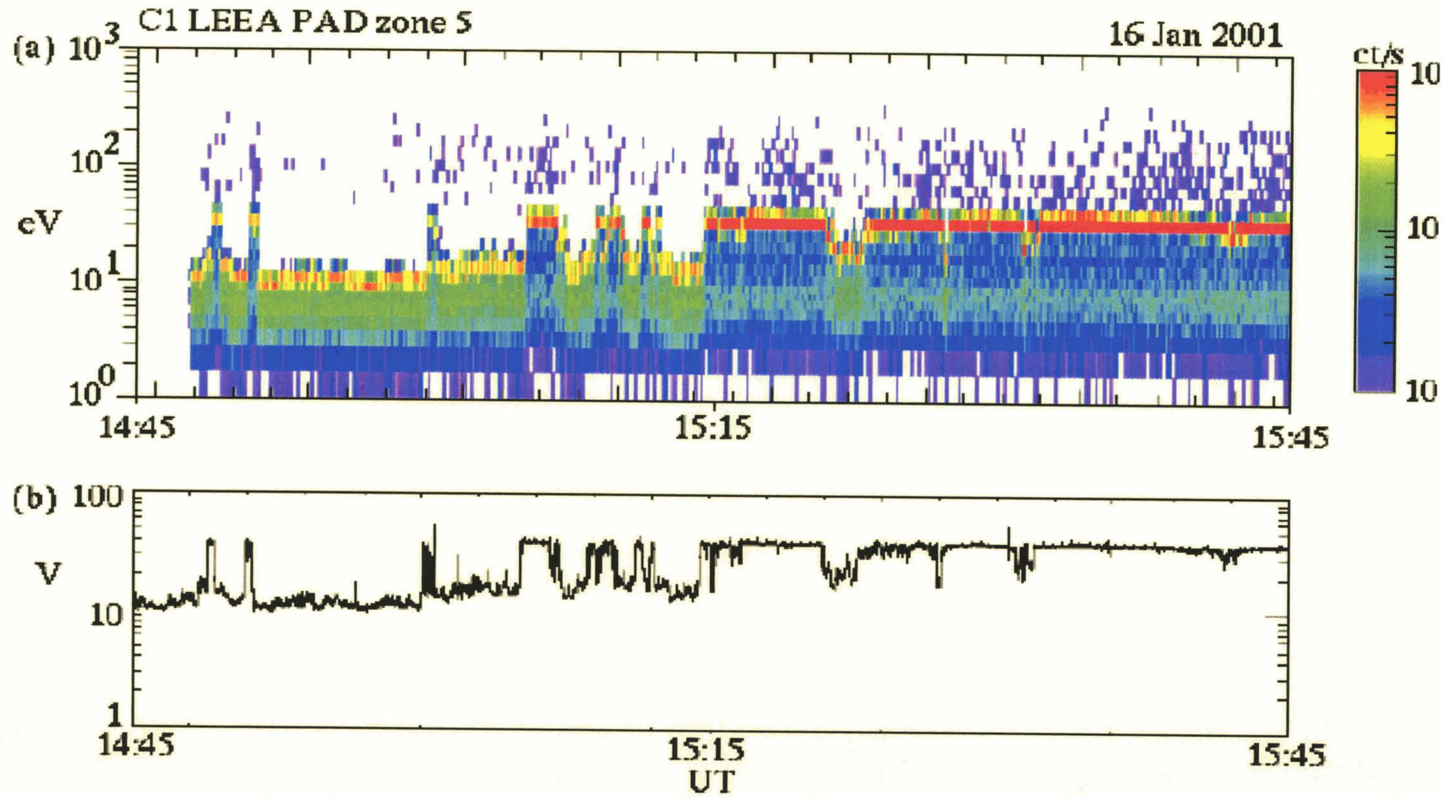
Magnetosheath, Solar Wind

- Cluster spacecraft outbound from magnetosheath into solar wind
- Szita et al. 2001



[from Szita et al., 2001]

Cluster Example

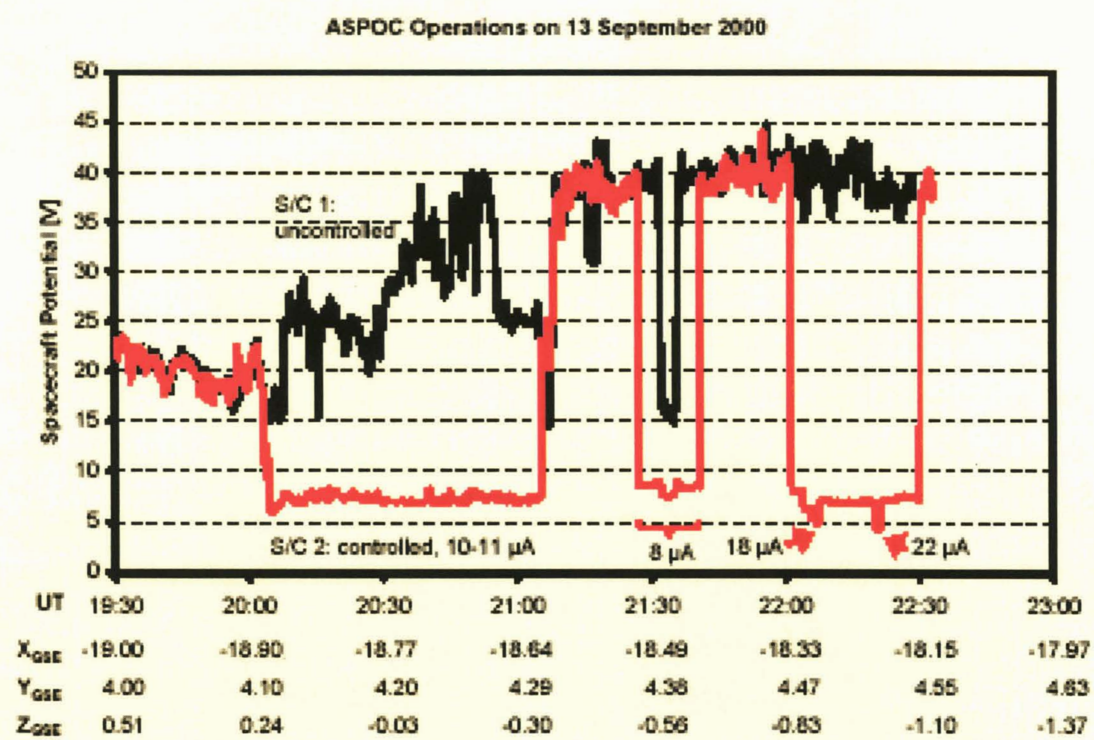


(from Szita et al., 2001)

Photoelectron Charging

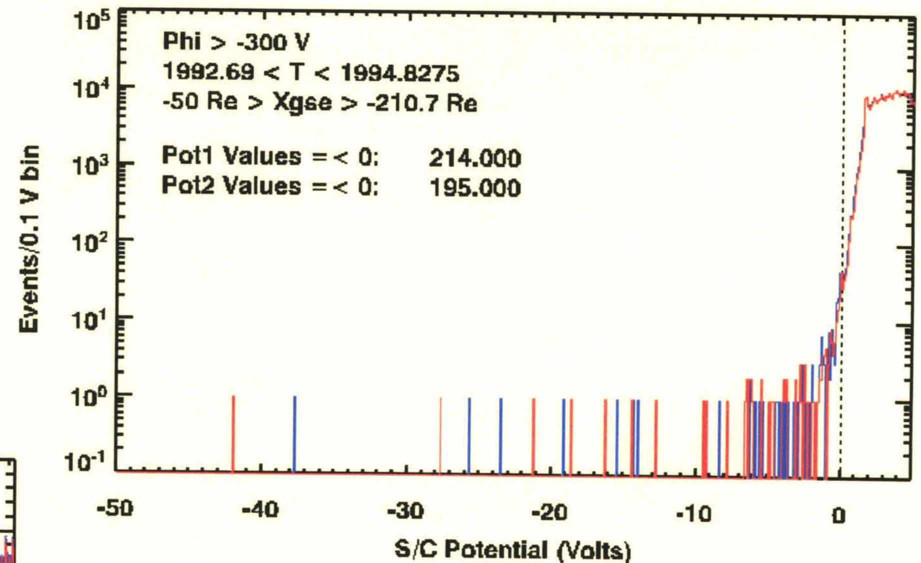
- Cluster S/C 1 and 2 demonstration of spacecraft potential control:
  - Reduction of positive spacecraft potential to allow measurements of low energy ions that would be reflected by hi
spacecraft dominated by
  - Magnetotail environmen ~1000 km (~0.16 Re) an S/C 2.

(from Torkar et al., 2001)

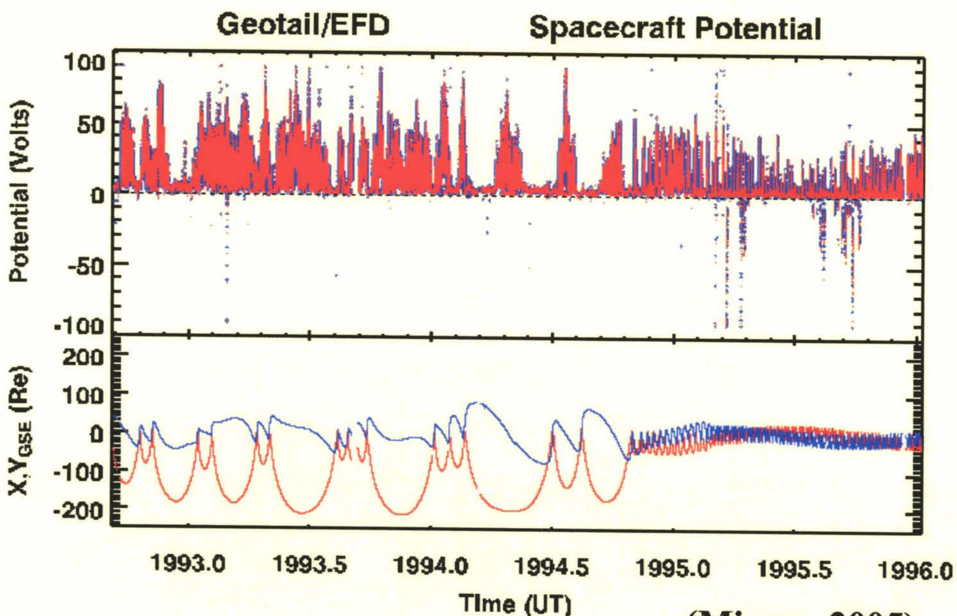


Geotail Spacecraft Potential

- Photoelectron current dominant charging current in distant magnetotail driving spacecraft potential $\Phi_{s/c} > 0$



(Minow, 2005)



(Minow, 2005)

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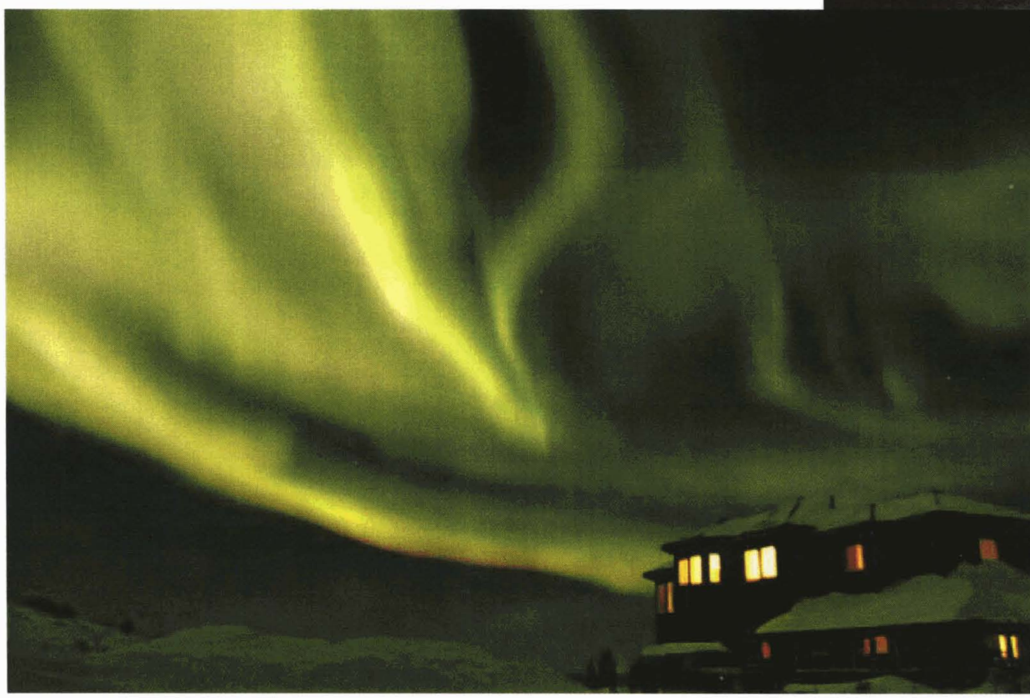
CAARI 2006, Ft. Worth, TX

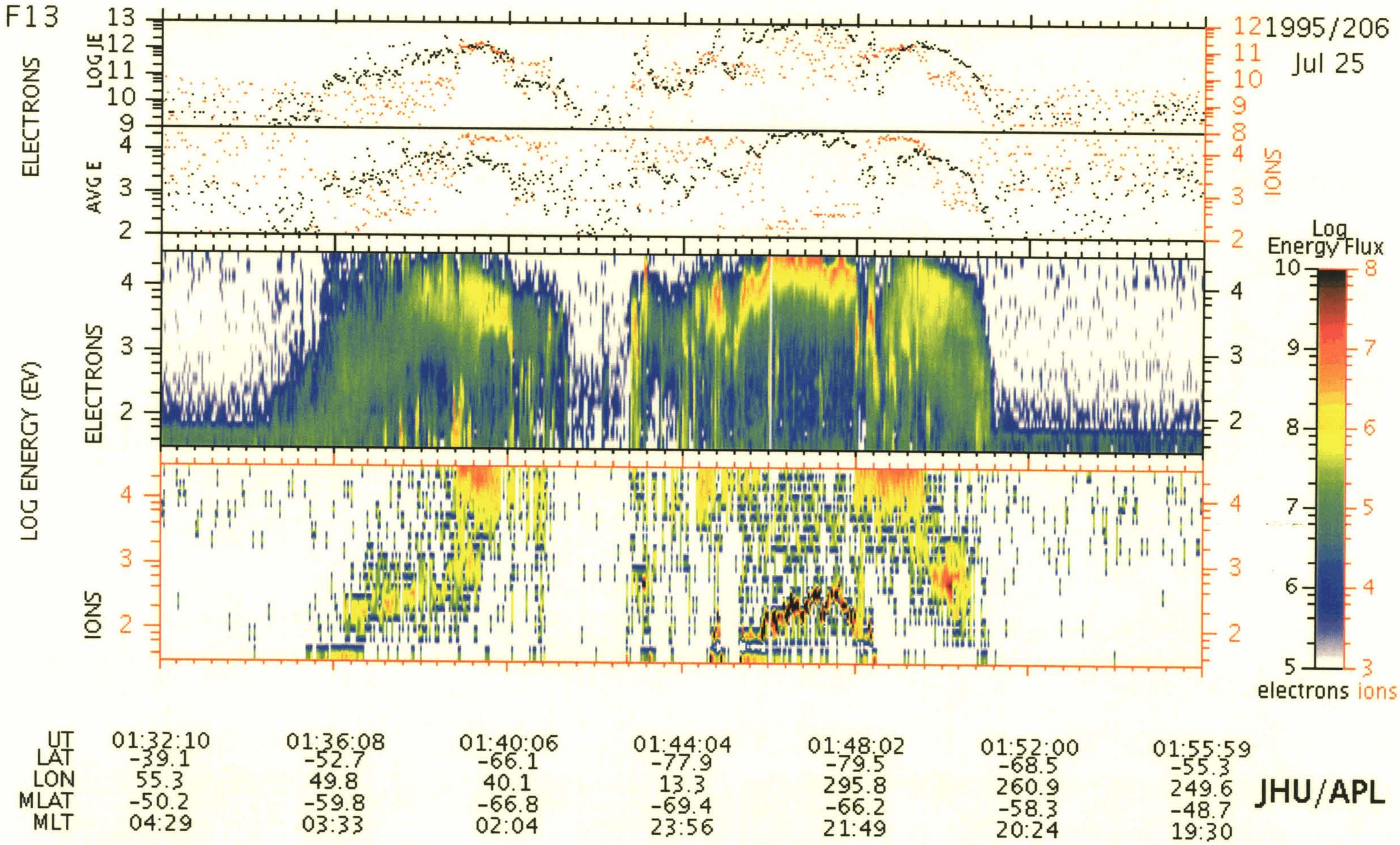
Auroral Charging

- Auroral charging is strongly controlled by secondary electron yields

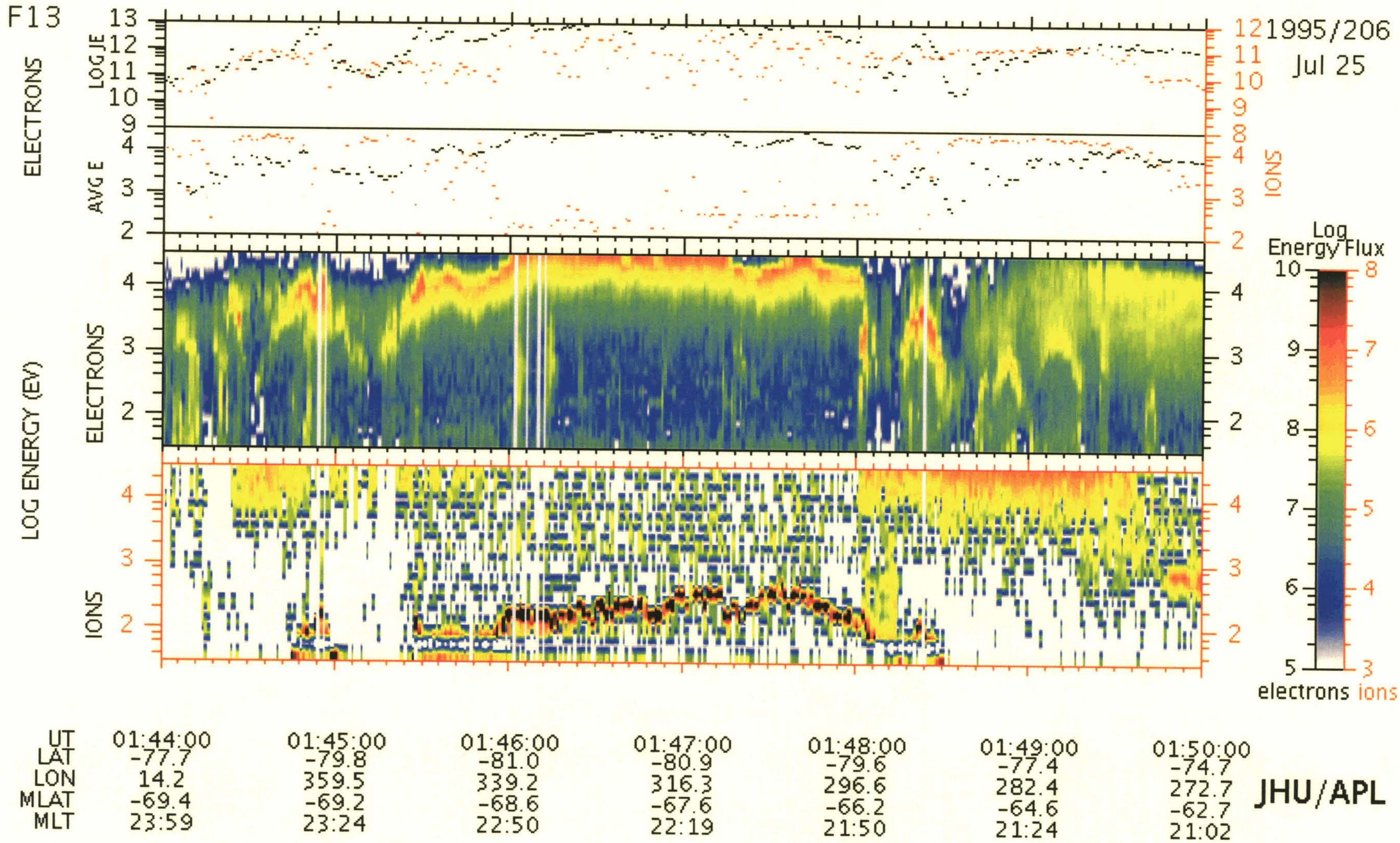


- Primary auroral electrons typically few keV to 10's keV

Auroral Charging



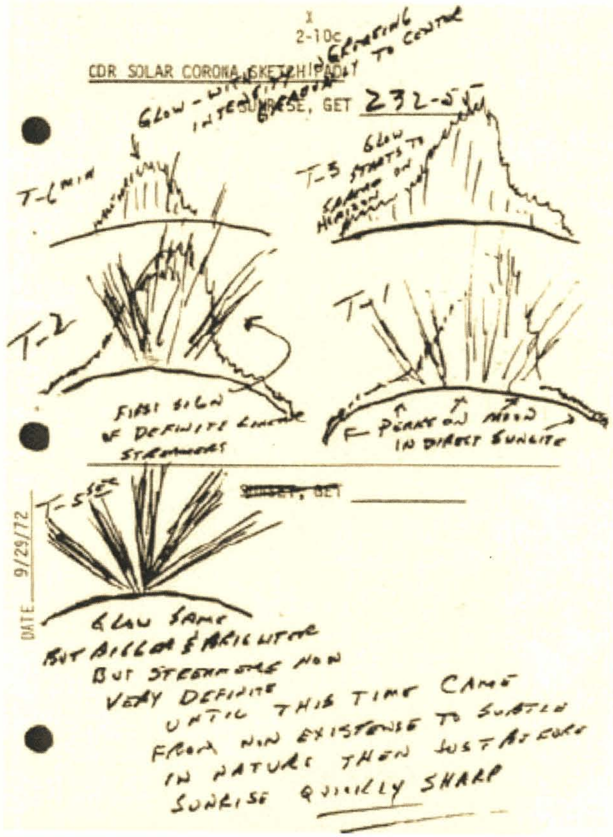
Auroral Charging

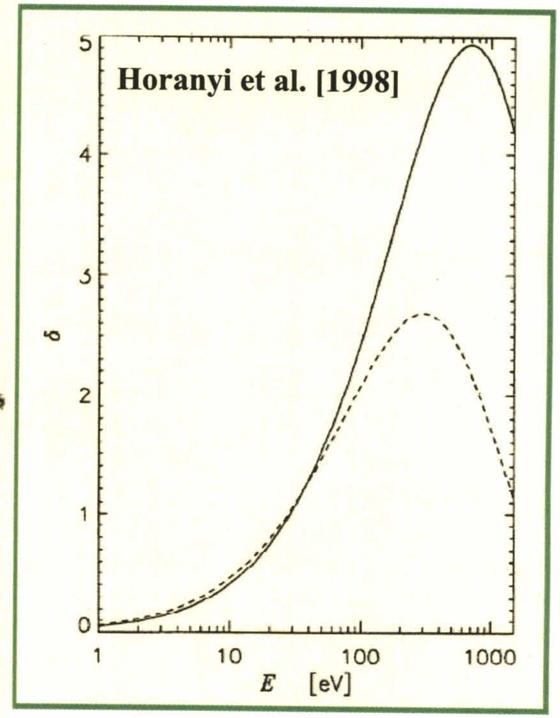


Lunar Dust Charging

Evidence for charged lunar dust

- Apollo 17 astronaut observations (scattered light)
- Surveyor 5,6,7 images of transient horizon glows (scattered light)
- Clementine images (scattered light)
- Apollo 17 Lunar Ejecta and Meteorite Experiment (temperature anomaly)





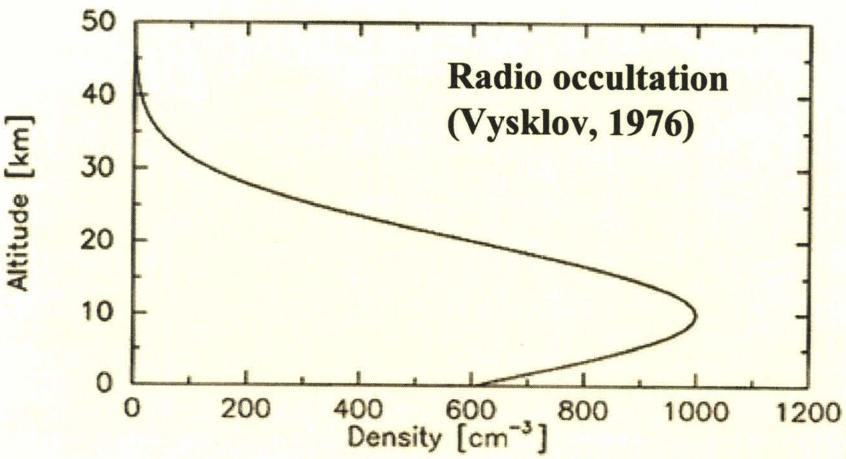
Surveyor 7
Sunset view looking west

- Large secondary yield may reduce charged dust in lunar night

Lunar Secondary Electron Environments

- **Lunar photoelectron sheath**
  - Vysklov (1976) reported lunar "ionosphere" using radio occultation technique from Luna 22 with peak electron densities of 500-1000 #/cm^3 at altitudes of 5-10 km above sunlit lunar surface
  - In-situ measurements from Apollo 12, 15, 15 Suprathermal Ion Detector Experiment (SIDE) and Apollo 14 Charged Particle Lunar Environment Experiment (CPLEE) show 10^4 #/cm^3 up to altitudes of 100 m (Reasoner and Burke, 1972)
  - For comparison.....
    - Solar wind ~6 e-/cm3, large values of 50 to 100 in shocks
    - Magnetosheath at lunar distances
    - Magnetotail at lunar distances

- **Lunar Debye length ~1 meter**
  - ~130 electrons/cm3 density at surface (Feuerbacher et al., 1972)
  - Photoelectrons dominate daytime charging environments within a few meters of surface



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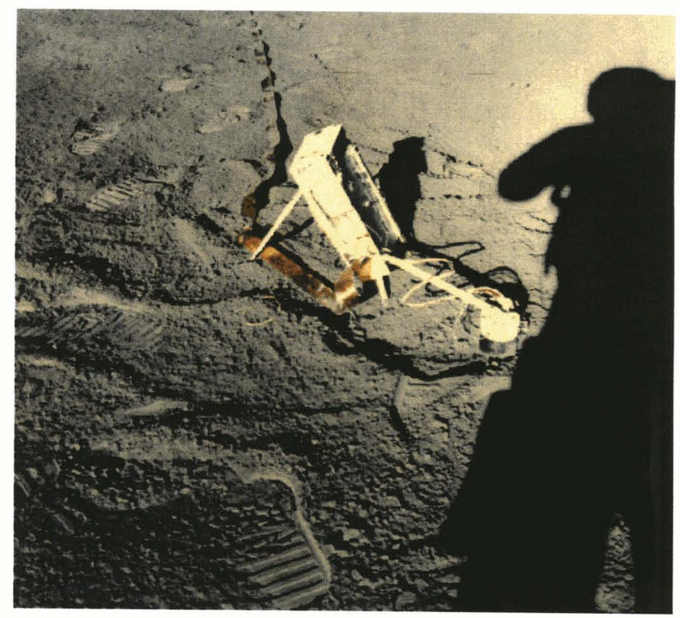
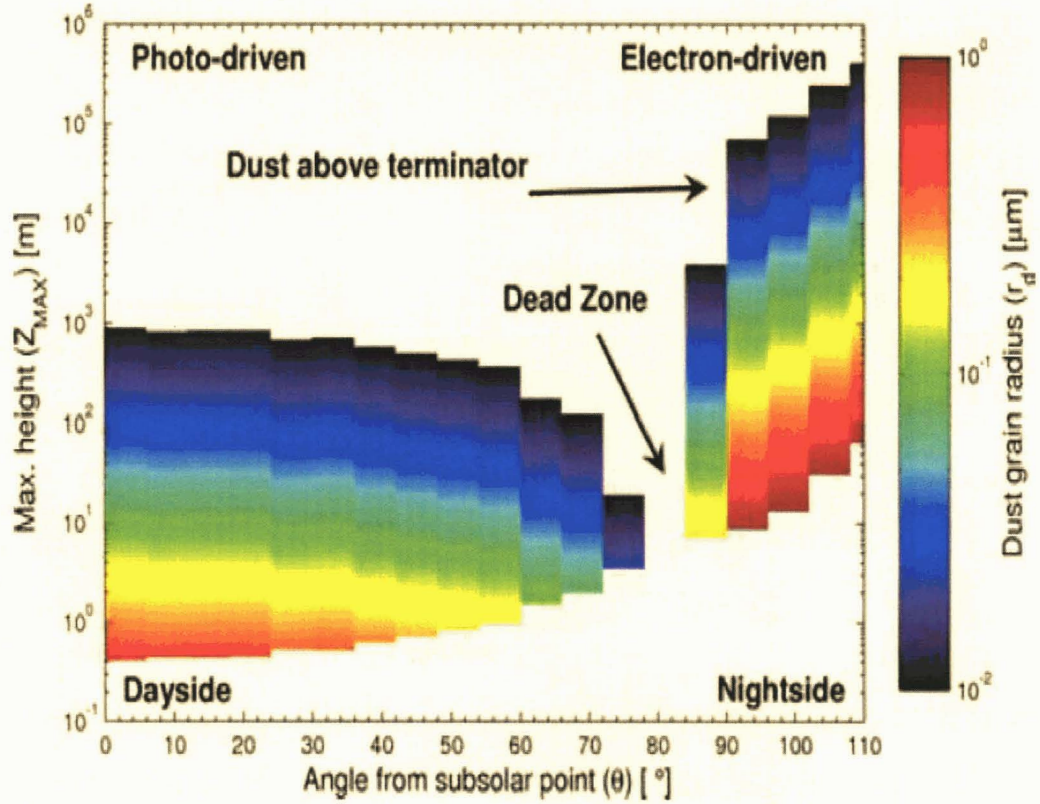


Lunar Dust Charging Models

- Stubbs et al. [2005]
  - Dynamic fountain model
  - Current collection dominated by photoelectron currents in sunlight and plasma currents in darkness
  - But secondary electron currents are neglected in the current model



SEY Properties of Lunar Dust, Simulants

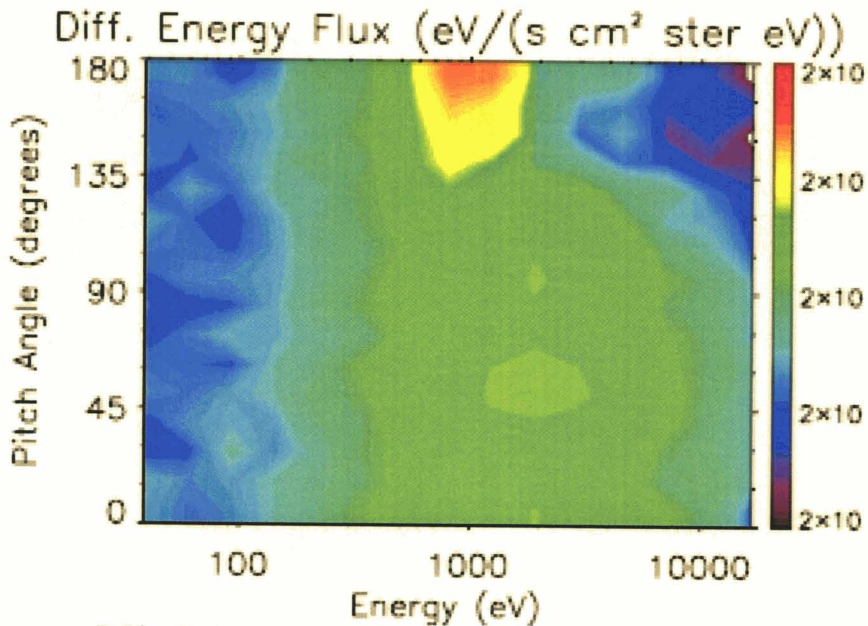
- Sternglass (1954) for normal incidence:

$$\delta_e(E,\theta) = 7.4\delta_{e,\max}\frac{E}{E_{\max}}\exp(-2\sqrt{E/E_{\max}})$$

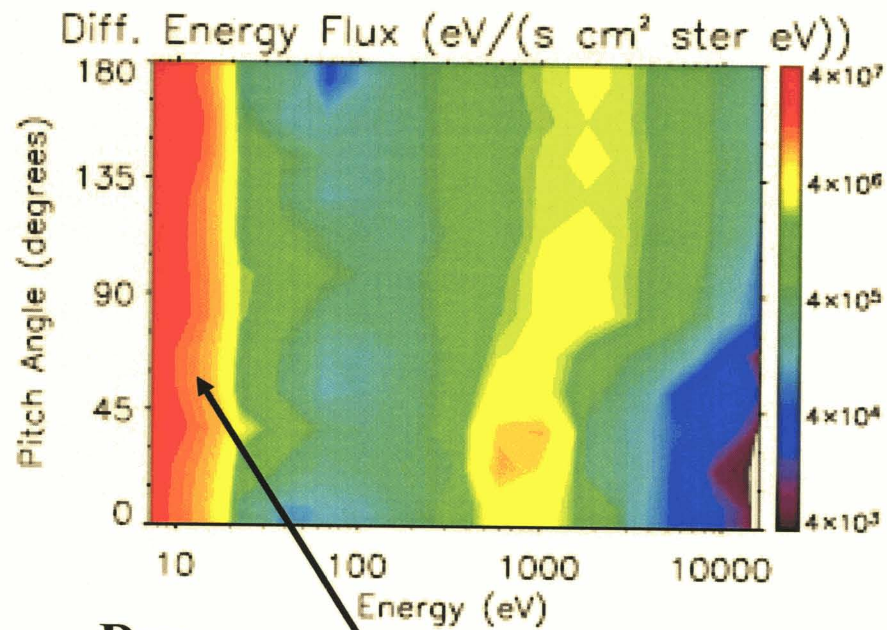
Reference	Material	$\delta_{e,m}$	E_m
-			
Willis et al., 1973	lunar fines	1.5±0.1	0.30-0.70 keV
Horanyi et al. 1998	Apollo 17 soil	3.2	0.4 keV
	JSC-1	3.4	0.4 keV
	MLS-1	3.1	0.4 keV

- Sickafoose et al. [1998] argues yields are too small to be significant in the charging process for solar wind plasma electrons incident with Te~22.5 eV

Lunar Prospector



Night



Day

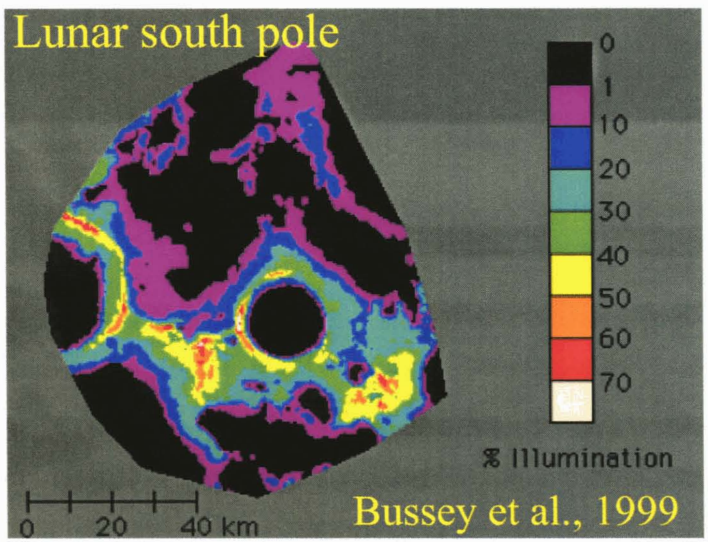
- Halekas et al. 2005

Photoelectrons

Most common when
$\Phi s/c > 0$ and
photoelectrons
emitted by boom
near ER instrument
trapped

Lunar South Pole

- Lunar south pole interesting destination for lunar exploration
- Permanent shadowed regions:
  - May collect volatiles (including water ice)
  - T ~ 40K (Watson et al., 1961; Arnold, 1979;, Ingersoll et al., 1992]
  - Challenging spacecraft charging issues due to lack of sunlight (no photoelectron currents to discharge cold dielectric materials integrating charge for long periods….)



- Permanent illuminated regions
  - Photoelectron currents charge materials, structures positive
  - Minimize charging concerns for lunar habitats, operations

Summary

- Spacecraft charging is an important phenomenon to spacecraft operating in plasma environments
  - Numerous failures attributed to charging

- Secondary electron currents are a significant contribution (sometimes primary contribution) to current balance condition

- Analysis of spacecraft potentials in charging environments require good measurements of secondary electron yields as a function of energy for all materials used on spacecraft surfaces