Spacecraft-plasma interactions: An MSSL perspective

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Measuring low energy plasma electrons & ions

- Spacecraft plasma instruments will ideally measure the 3-dimensional velocity distribution function of ions & electrons near the spacecraft.
- Ideally, the arriving ions and electrons would not be affected by the spacecraft, i.e. the spacecraft-plasma potential difference, V_{sc}, would ideally take a stable value V_{sc} ~0 V (and have no assymmetry)

Measuring low energy plasma electrons & ions

- In practice, environement is a key element in defining V_{sc}. Near Earth, V_{sc} ~10's V in sunlight and in eclipse V_{sc} <0 V is possible. In other environments, negative values of V_{sc} can be expected even in sunlight.
- For non-zero V_{sc}, part of the plasma distribution *cannot be measured,* due to electrostatic repulsion in the spacecraft potential. *This may prevent determination of density or velocity of the full population.*
- For non-zero V_{sc}, the particle population measured energies typically appear at higher/lower energies than the true energy. Cold populations measured at higher energies, where instrument energy resolution is poorer, are not properly resolved, and may be effectively undetectable.
- Measurements of plasma electrons above the potential may also sometimes be contaminated by secondary electron emission or photo-electrons emitted into the analyser.
- (Also in some environments measurements are affected by penetrating radiation; thruster gases and gas from leaking batteries)

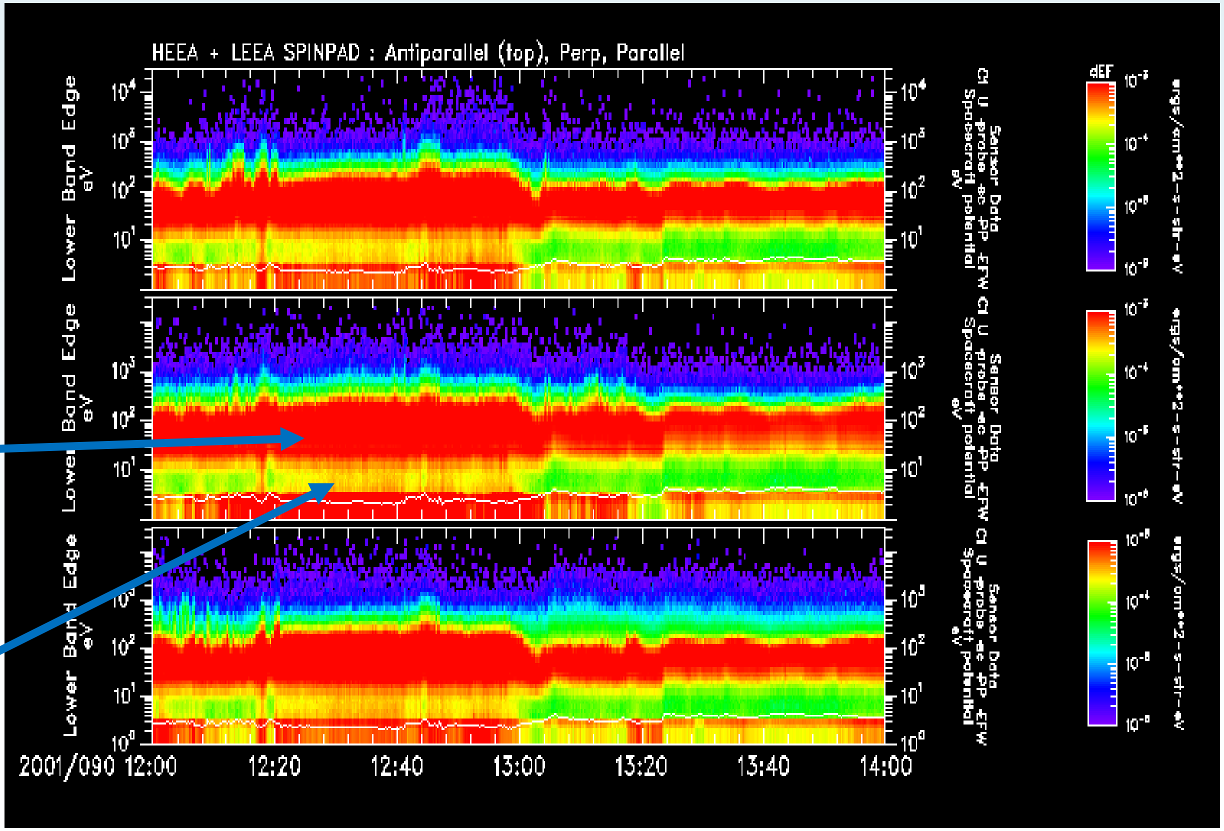
Measuring low energy plasma electrons & ions

- In order to calculate accurate plasma moments, it is necessary to correct for acceleration of ions/electrons in the spacecraft potential. This is not done onboard the spacecraft for Cluster, but it IS done onboard for the recently launched THEMIS spacecraft.
- However, onboard removal of counts associated with secondary electrons, radiation or photo-electrons observed above the potential is not considered possible at present.

- The best situation is therefore to design a spacecraft which maintains its potential near zero, and symmetrical, in all environments, and which has low emission coefficients for secondary electrons.
- Design work using advanced simulations methods may help towards this goal; active potential control devices (positive and negative particle sources) would also be valuable.

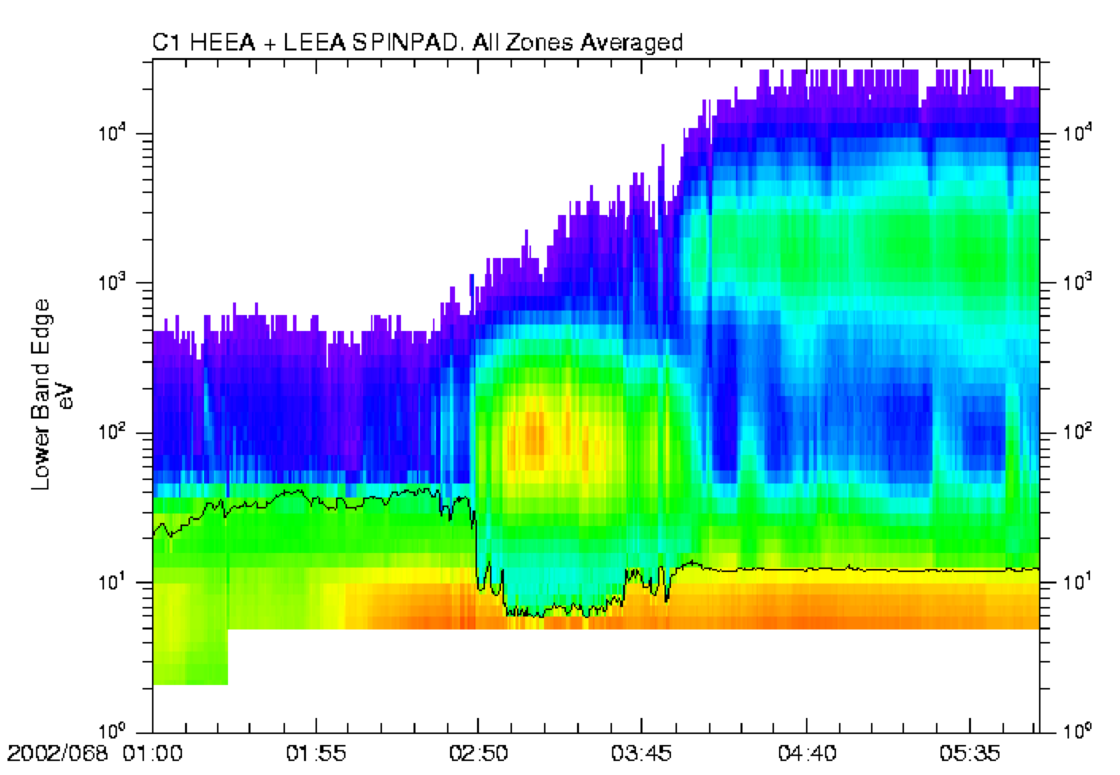
Secondary Electrons

- Cluster-PEACE electron data
- A 2 hour interval in the **magnetosheath**
- Very high fluxes of ~100 eV electrons (magnetosheath) appear to generate fluxes of secondary electrons appearing above the potential



Determining V_{sc} without a direct measurement

- Knowledge of spacecraft-plasma potential is essential for accurate determination of plasma parameters from electrostatic analysers
- The Cluster EFW experiment usually (not always) provides a good proxy.
- On Double Star and Cassini there is no routine availability of V_{sc} data
- Determining a good estimate of the correct V_{sc} from particle data is often possible but it can be difficult. Example:



In this Cluster example, the black line is the potential from EFW. Note that:

- some “green” fluxes do not lie above the potential (photoelectrons),

- yet others do (cold magnetospheric electrons).

It is quite hard to write a computer code to automatically determine a highly reliable potential estimate

Spacecraft potential and current balance

The spacecraft electrostatic potential is controlled by a balance of currents flowing to and from the spacecraft, typically

(i) collected electron and ion currents

(ii) photoelectron emission current

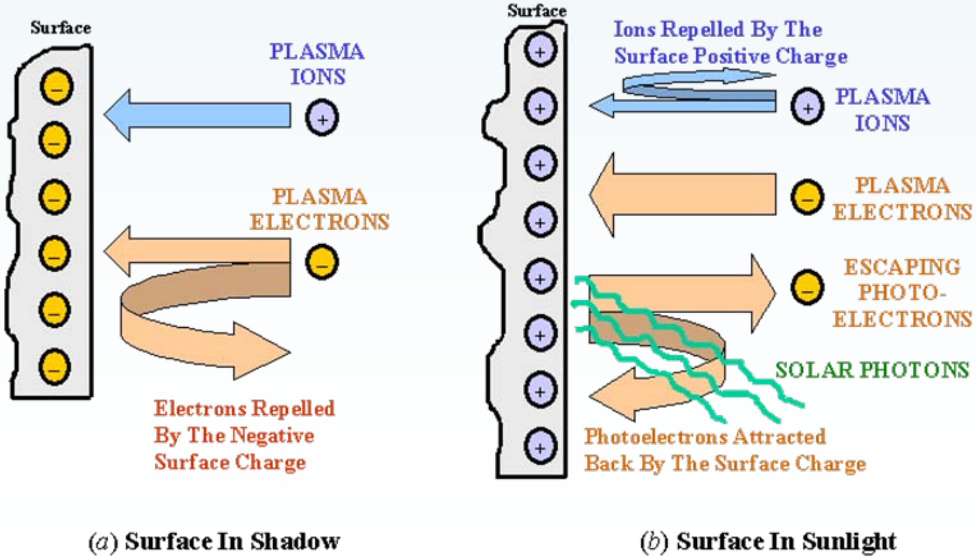
(iii) secondary electron and ion emission currents

The emission characteristics of the spacecraft depend on surface materials, and on ageing of the materials over time in space.

Active spacecraft experiments may contribute additional currents or transient potential changes during plasma wave sounding.

The following slides illustrate these points with a variety of examples

Figure from http://www.eas.asu.edu/~holbert/index.html

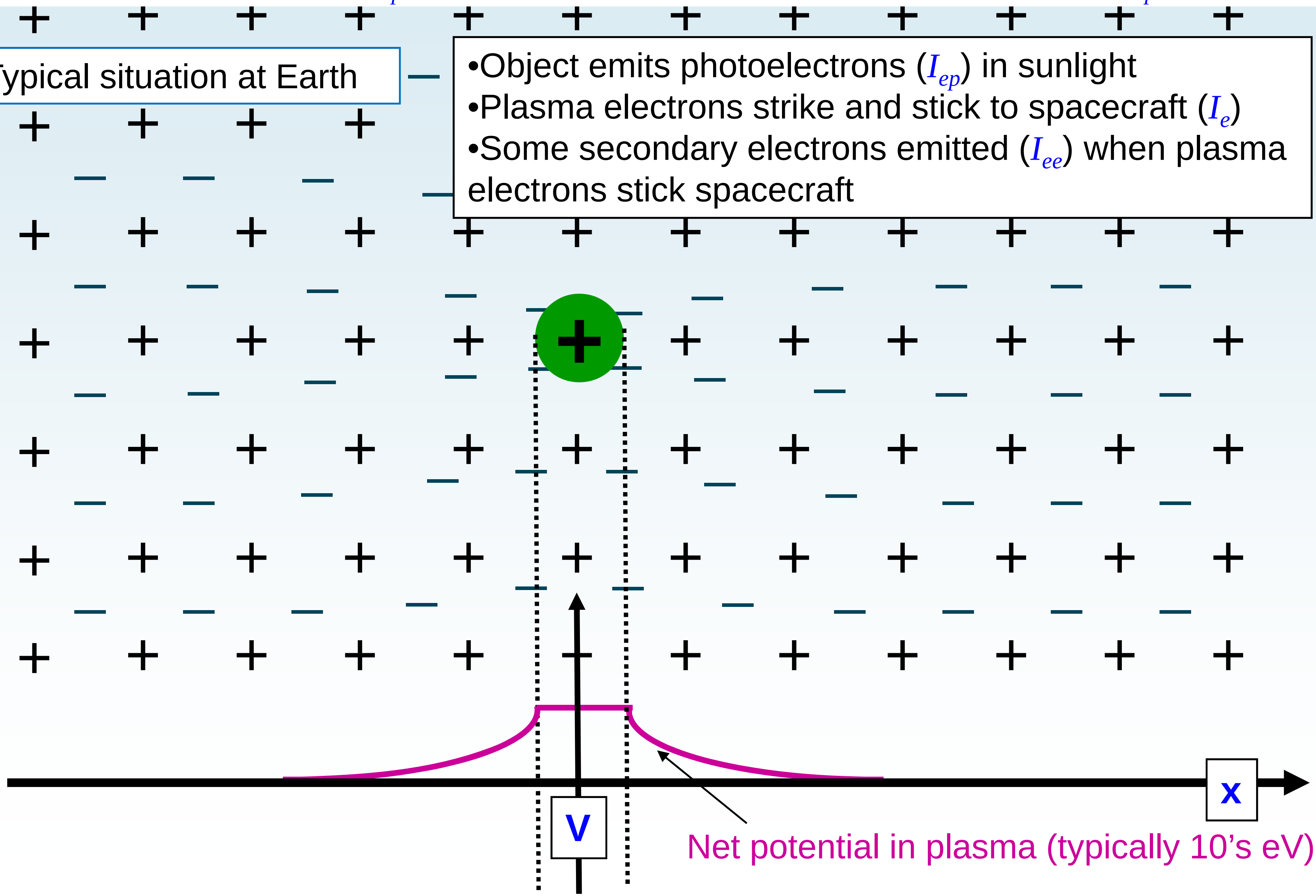


V_{sc}, current balance and environment

Spacecraft in light: initially I_{ep} (+I_{ee}) > I_e charges positive 'til current balances I_{ep} (+I_{ee}) = I_e

Typical situation at Earth

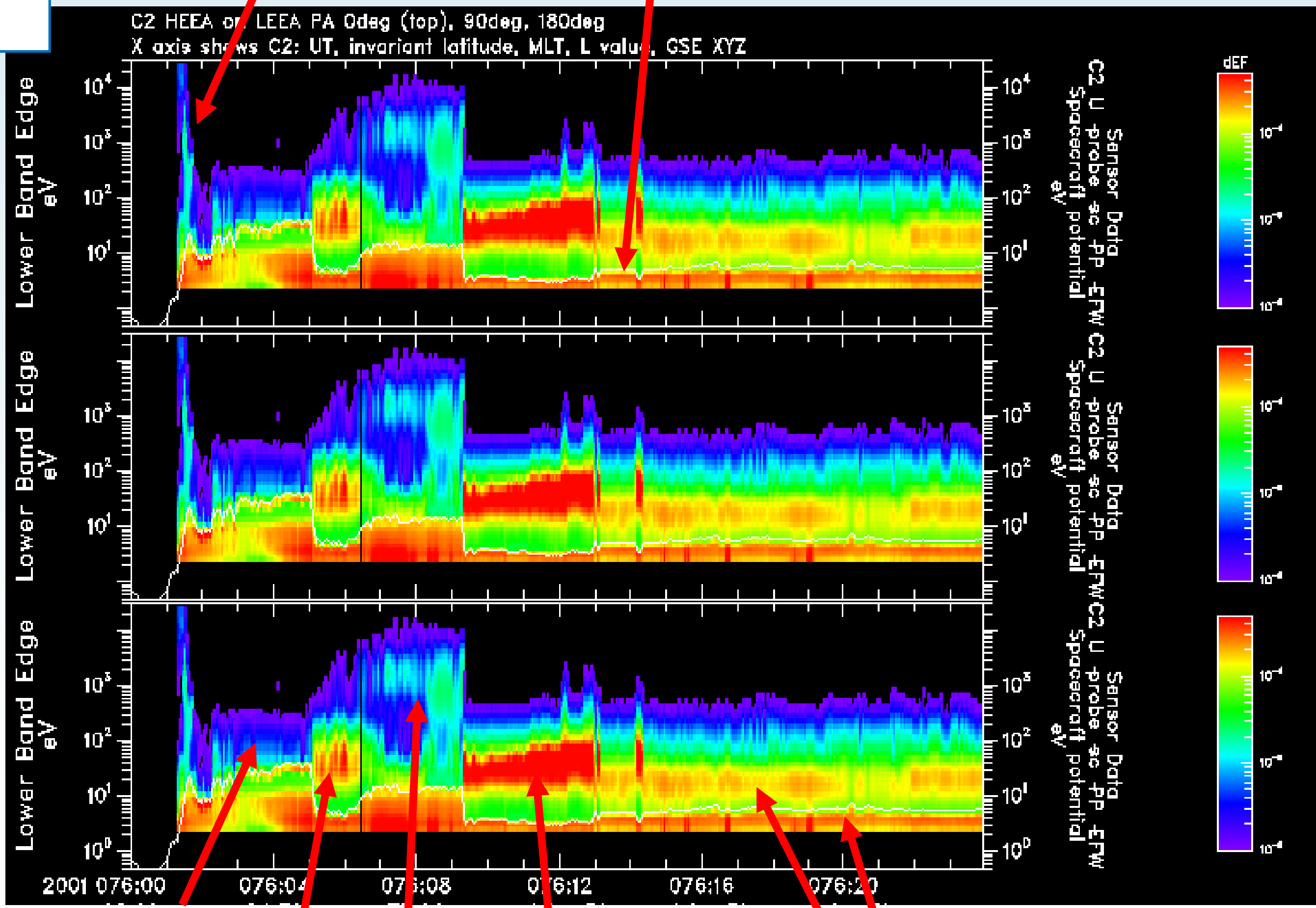
- Object emits photoelectrons (I_{ep}) in sunlight
- Plasma electrons strike and stick to spacecraft (I_e)
- Some secondary electrons emitted (I_{ee}) when plasma electrons stick spacecraft



V_{sc}, current balance and environment

Typical sunlit situation at Earth

- Cluster-PEACE electron data
- A 1 day interval showing a dayside outbound pass
- V_{sc} is 20-30 eV in the polar cap, but less than 5 eV in the magnetosheath
- V_{sc} is always no more than a few 10s eV positive, but varies according to local plasma fluxes

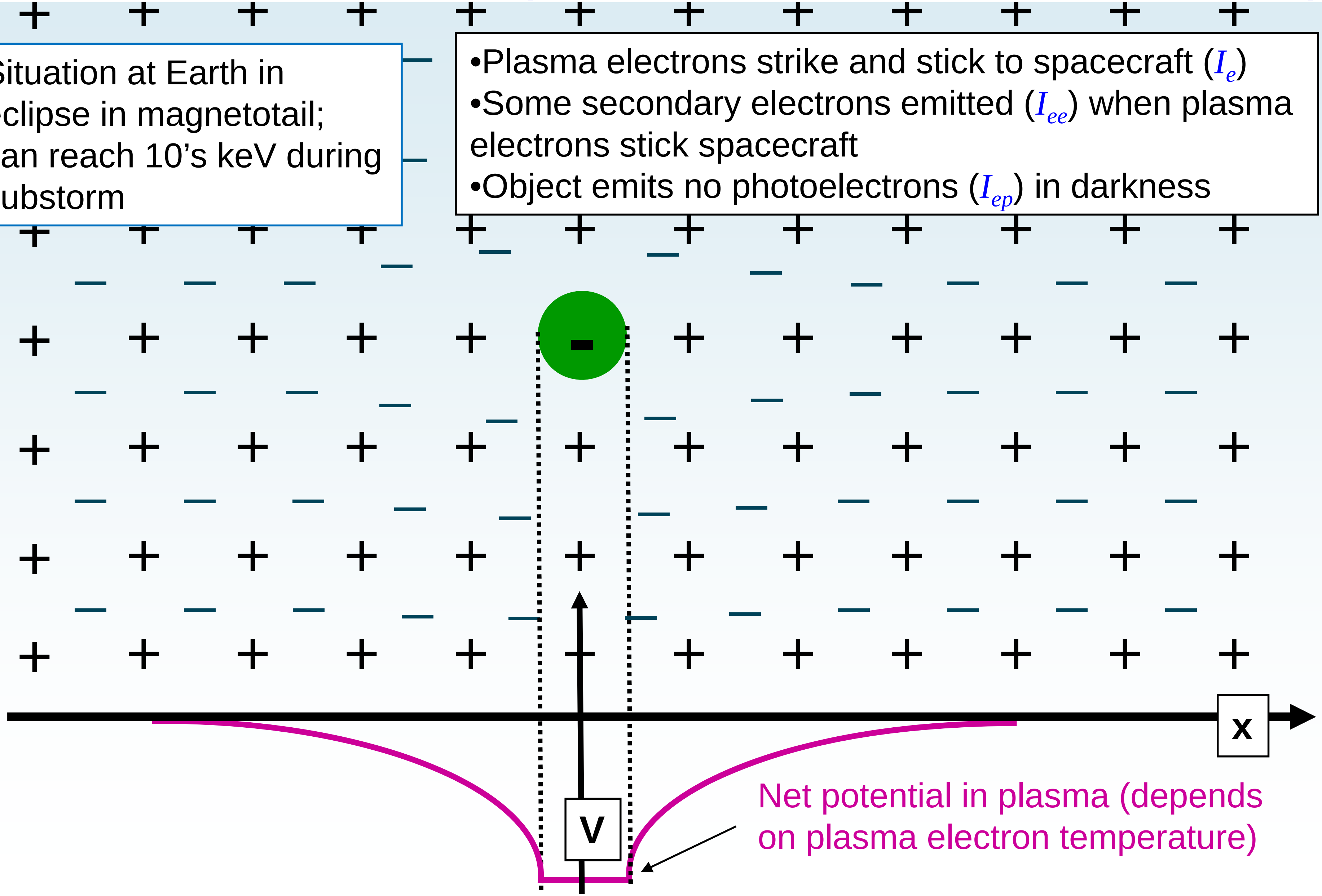


V_{sc}, current balance and environment

Spacecraft in dark: initially $I_e > I_{ee}$ ($+I_{ep}$), charges negative 'til current balances $I_e = I_{ee}$ ($+I_{ep}$)

Situation at Earth in eclipse in magnetotail; can reach 10's keV during substorm

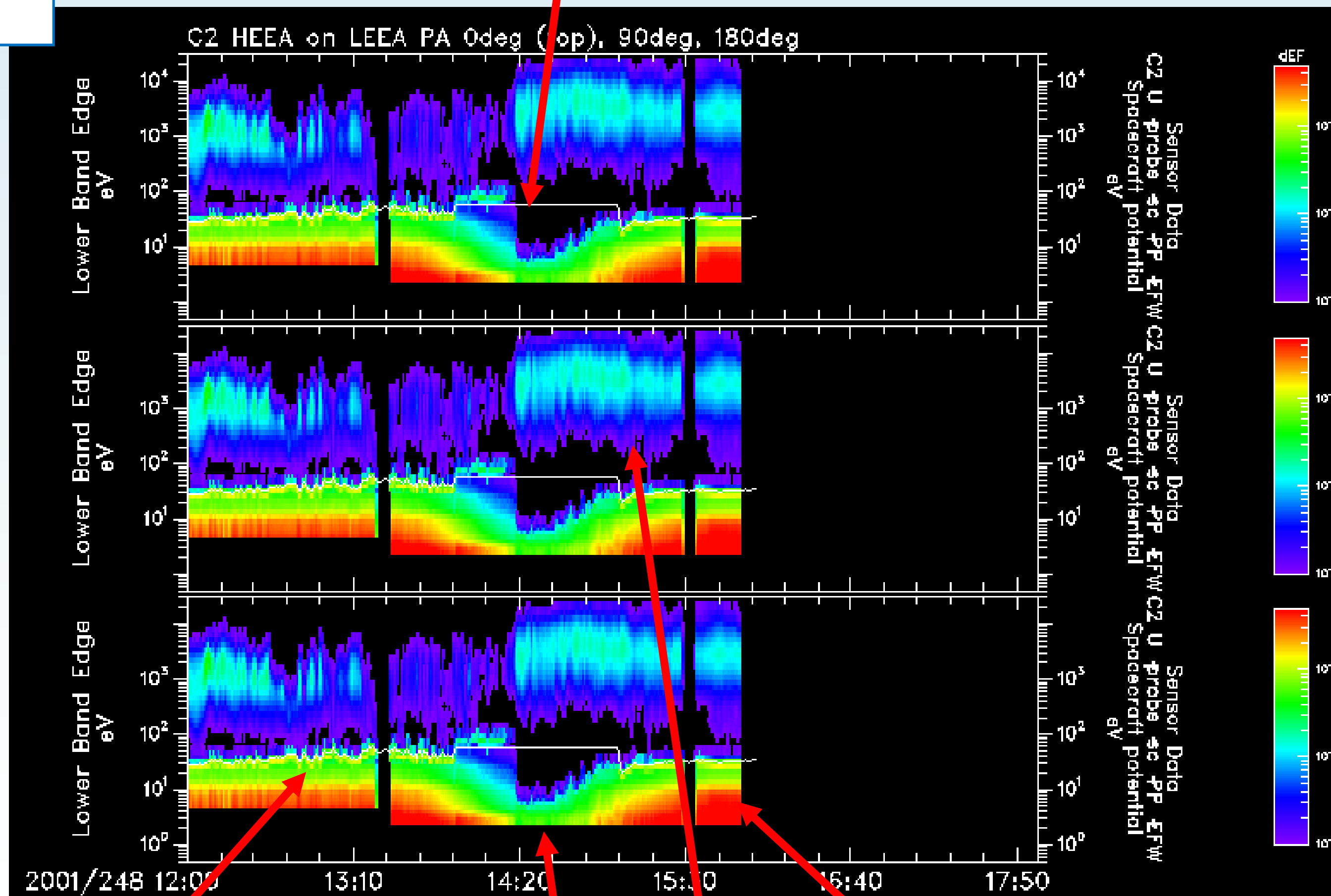
- Plasma electrons strike and stick to spacecraft (I_e)
- Some secondary electrons emitted (I_{ee}) when plasma electrons stick spacecraft
- Object emits no photoelectrons (I_{ep}) in darkness



V_{sc}, current balance and environment

Situation at Earth in eclipse in magnetotail

- Cluster-PEACE electron data
- A 4 hour interval centred on a spacecraft **eclipse**
- Photoelectron fluxes near the spacecraft are clearly declining in reduced sunlight levels. V_{sc} ~ or < 0V
- V_{sc} is not well measured during the eclipse by EFW

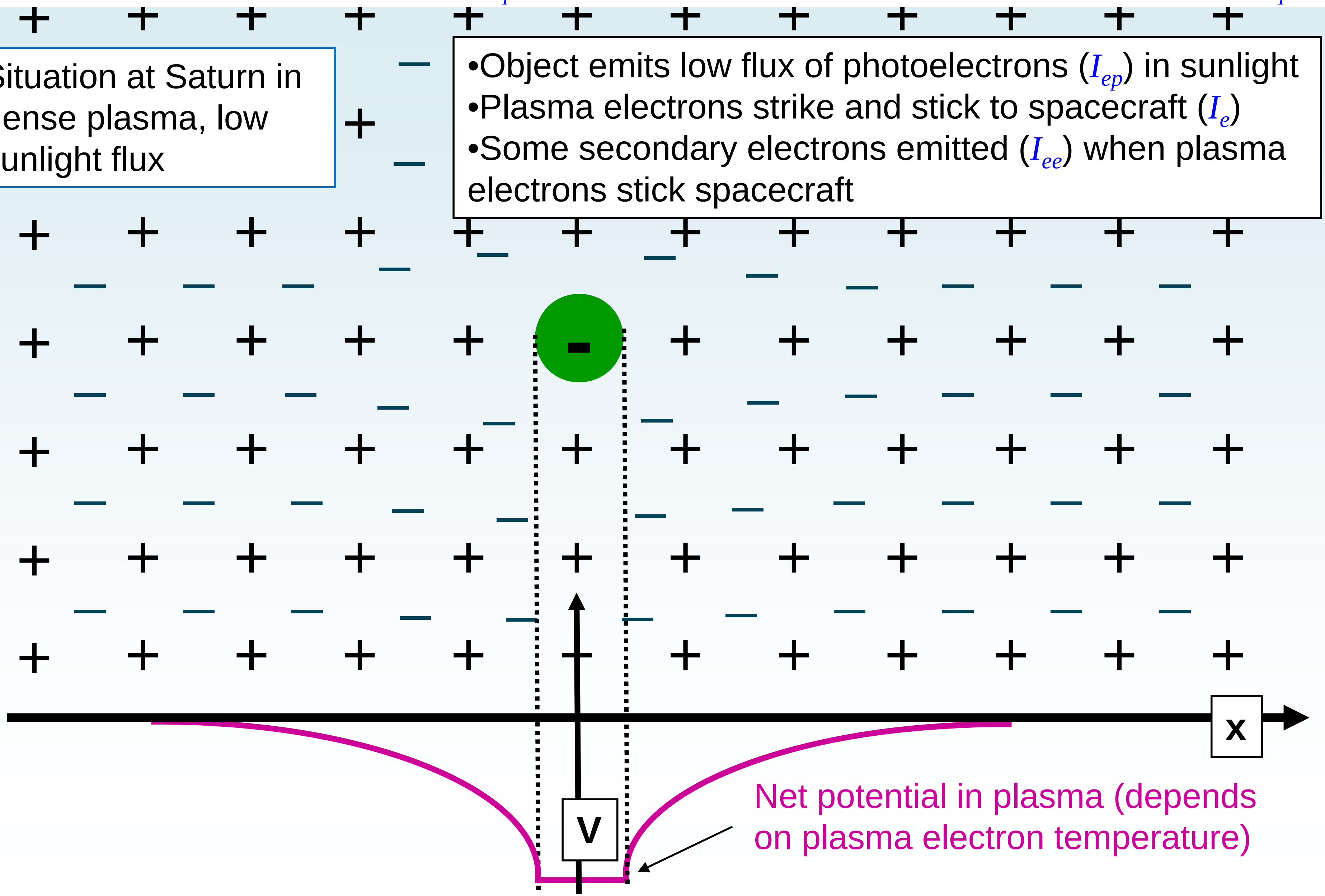


V_{sc}, current balance and environment

S/c *weakly sunlit*: initially $I_e > I_{ee}$ ($+I_{ep}$), charges negative 'til current balances $I_e = I_{ee}$ ($+I_{ep}$)

Situation at Saturn in dense plasma, low sunlight flux

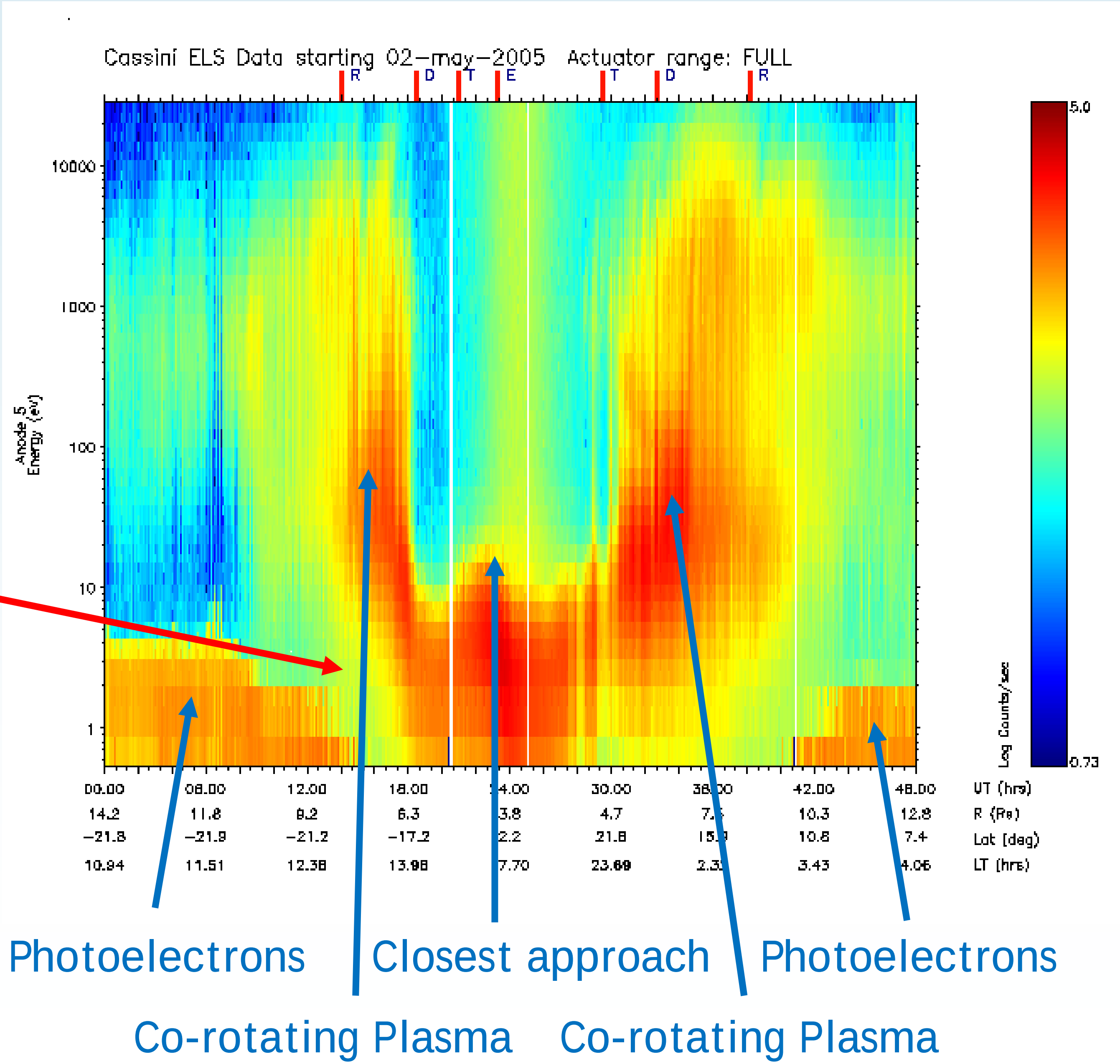
- Object emits low flux of photoelectrons (I_{ep}) in sunlight
- Plasma electrons strike and stick to spacecraft (I_e)
- Some secondary electrons emitted (I_{ee}) when plasma electrons stick spacecraft



V_{sc}, current balance and environment

Situation at Saturn in dense plasma, low sunlight flux

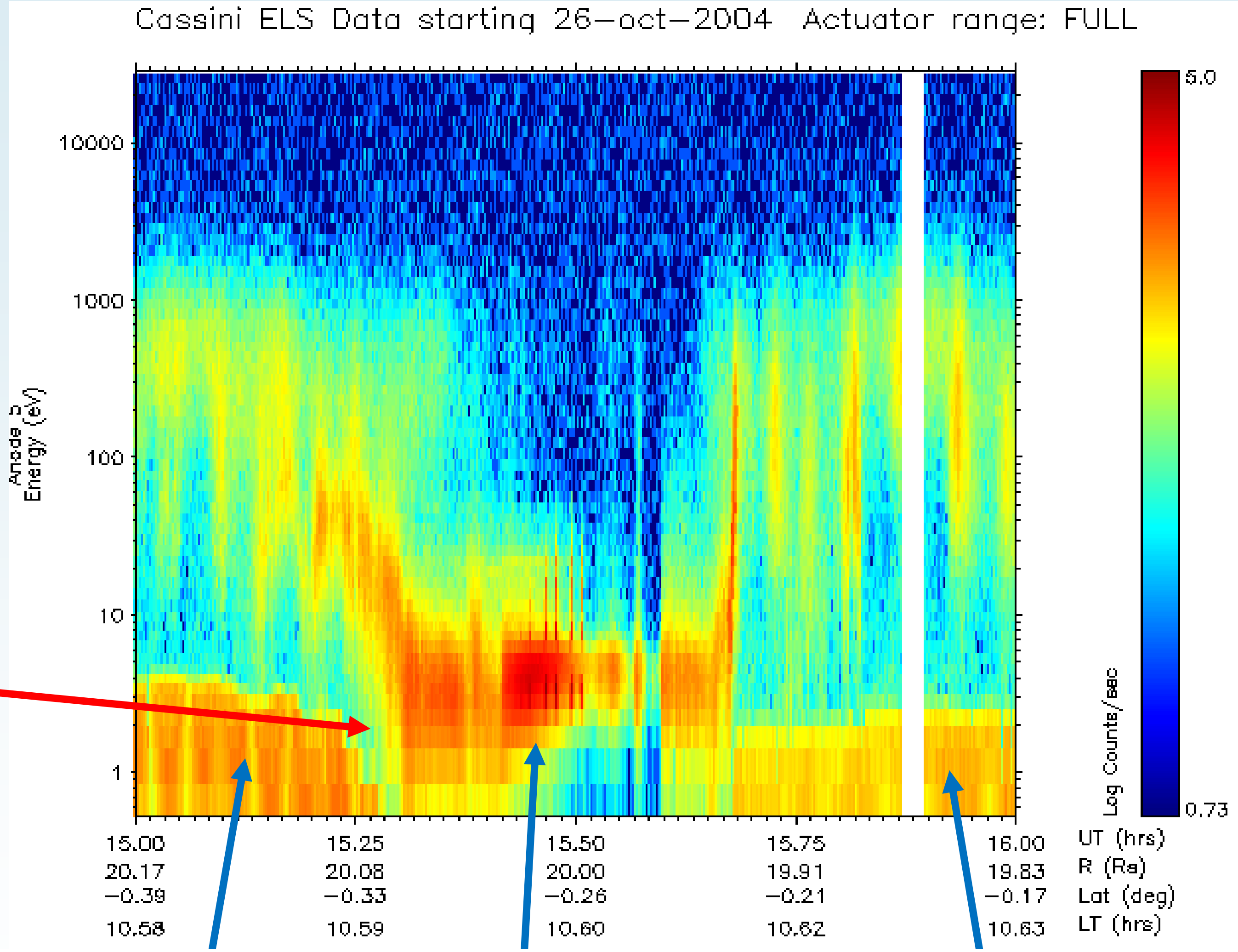
- Cassini-CAPS-ELS electron data
- A two day interval centred on a **Saturn Periapsis**
- Photoelectrons disappear before, during and after closest approach, in presence of dense plasma
- SC potential has become negative



V_{sc}, current balance and environment

Situation at Saturn (Titan) dense plasma, low sunlight flux

- Cassini-CAPS-ELS electron data
- A one hour interval centred on a **Titan Flyby** (1,200 km closest approach)
- Photoelectrons disappear before, during and after closest approach, in presence of dense plasma
- V_{sc} is negative



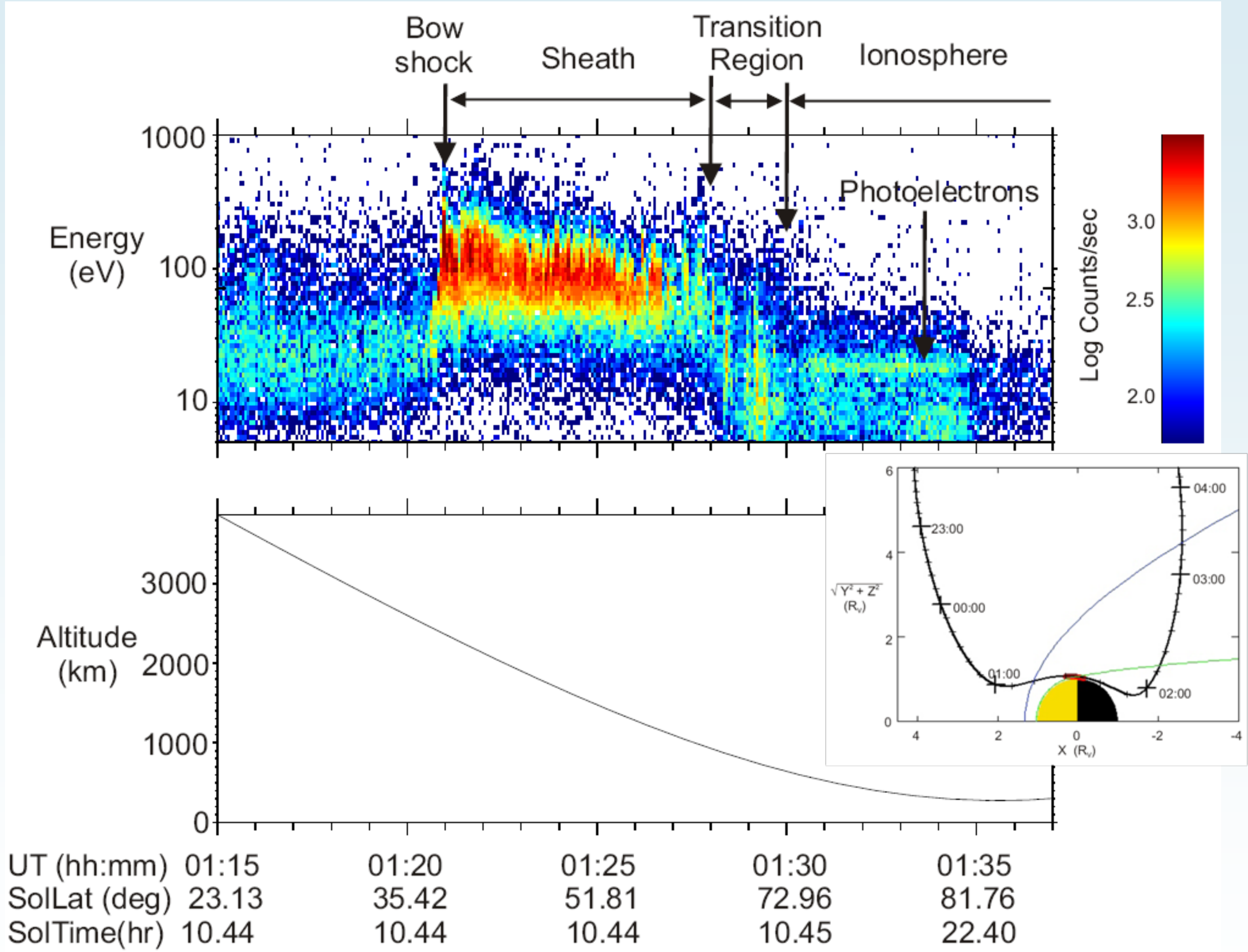
Photoelectrons Titan's ionosphere Photoelectrons

Density comparisons with plasma wave instrument only agree if the potential is treated as being negative

V_{sc}, current balance and environment

Situation at Venus in dense plasma, high sunlight flux

- VEX-Aspera4-ELS electron data
- A 22 minute interval centred on a **Venus Periapsis** (~200 km closest approach)
- Ionopsheric (not spacecraft) photoelectrons
- V_{sc} is negative, despite strongly sunlit spacecraft



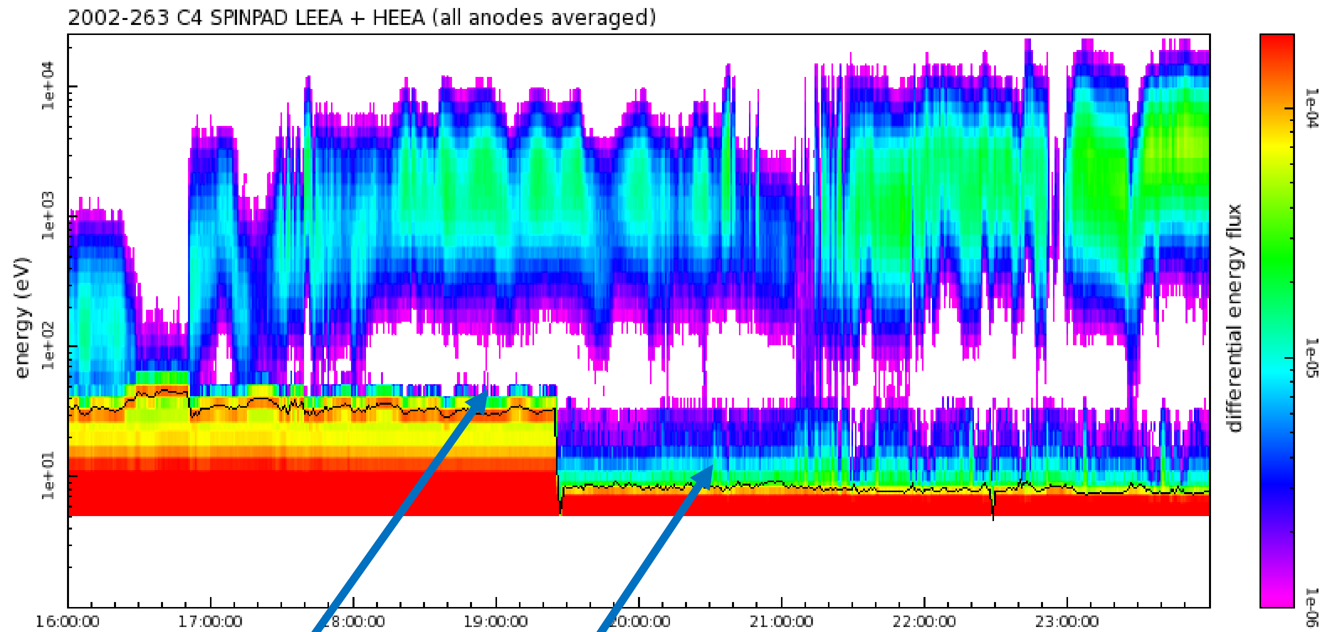
Photoelectron peak energy is not measured at expected value; makes sense if the potential is treated as being negative. Infer high ionospheric electron fluxes.

V_{sc}, current balance and active experiments

Active Spacecraft Potential Control, ASPOC

Good for plasma measurements

- Cluster-PEACE electron data
- An 8 hour interval in the **magnetotail plasmasheet**
- The ASPOC ion beam emission starts at ~19:30 UT
- SC potential falls from 30-40 eV, to ~8 eV as ASPOC turns on & remains quite stable



PEACE can only measure cold electrons with good energy resolution when ASPOC is on

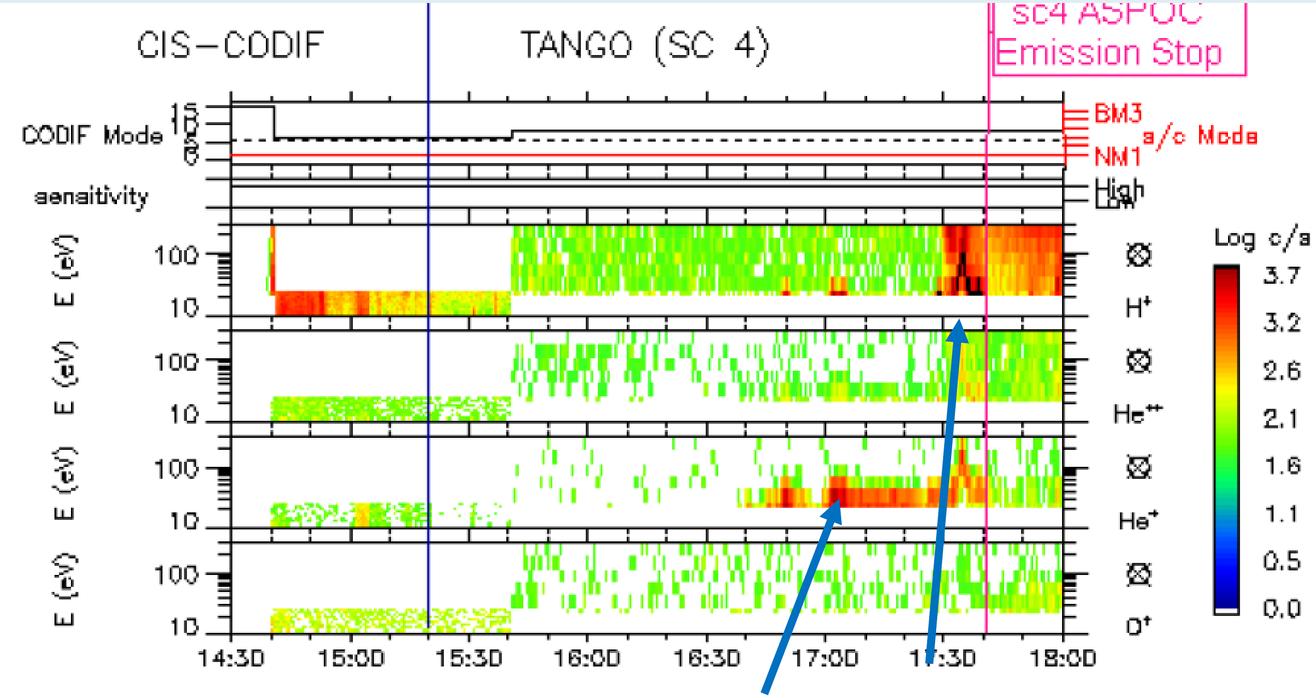
When ASPOC is off, cold electrons are measured only in 1 or 2 energy bins just above V_{sc} (black line) but not adequately resolved to be the basis for good moments data

V_{sc}, current balance and active experiments

Active Spacecraft Potential Control, ASPOC

Good for plasma measurements

- Cluster-CIS ion data (CODIF/RPA)
- An 3.5 hour interval in the **polar cap**
- The ASPOC ion beam emission ends at ~17:41 UT
- Cold ions (H^+ and He^+) with energies of a few 10's of eV can be seen until ASPOC turns off



CIS (RPA) can only measure cold electrons with good energy resolution when ASPOC is on

When ASPOC is turned off, such ions are immediately no longer seen

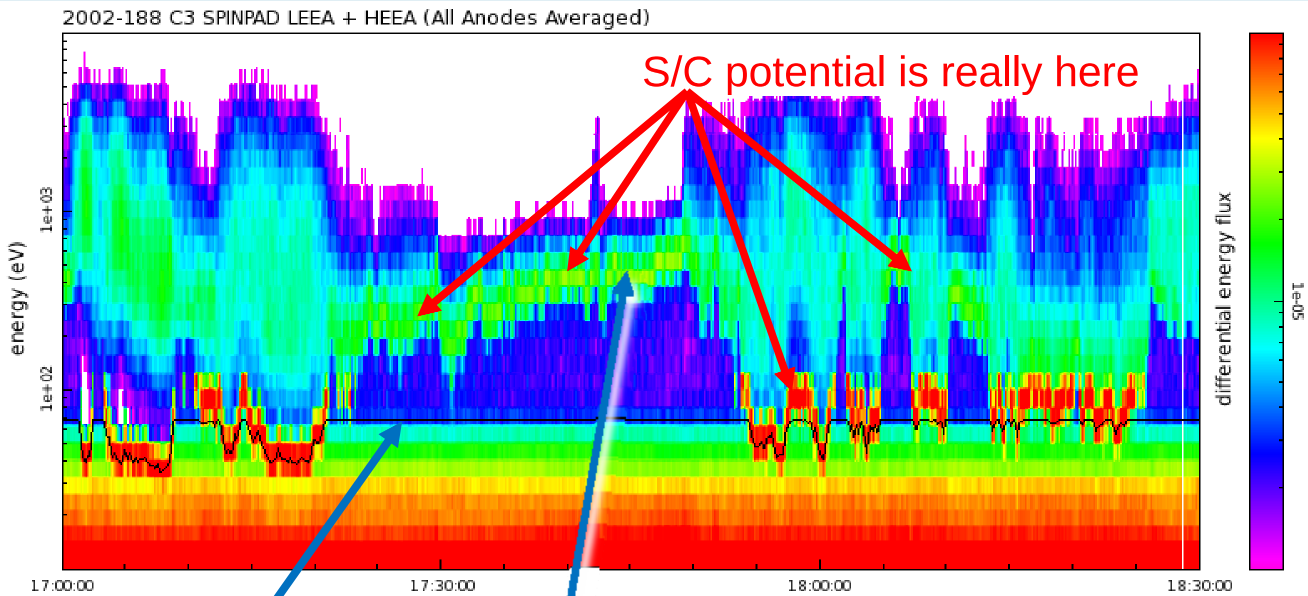
(example from Reme et al. 2001)

V_{sc}, current balance and active experiments

Electron Drift Instrument, EDI (case of strong current)

Bad for plasma measurements

- Cluster-PEACE electron data
- A 1.5 hour interval in the **magnetotail plasmasheet boundary layer**
- EDI electron beam emission is active throughout, on high current mode
- SC potential rises from 30-40 eV, fluctuates, reaches ~1 keV at times



Fluctuations in the current balance drive the spacecraft highly positive in tenuous plasma. *Effective plasma measurements are difficult…*

The EFW experiment which measures something close to V_{sc} saturates at 80 V: the black trace goes no higher

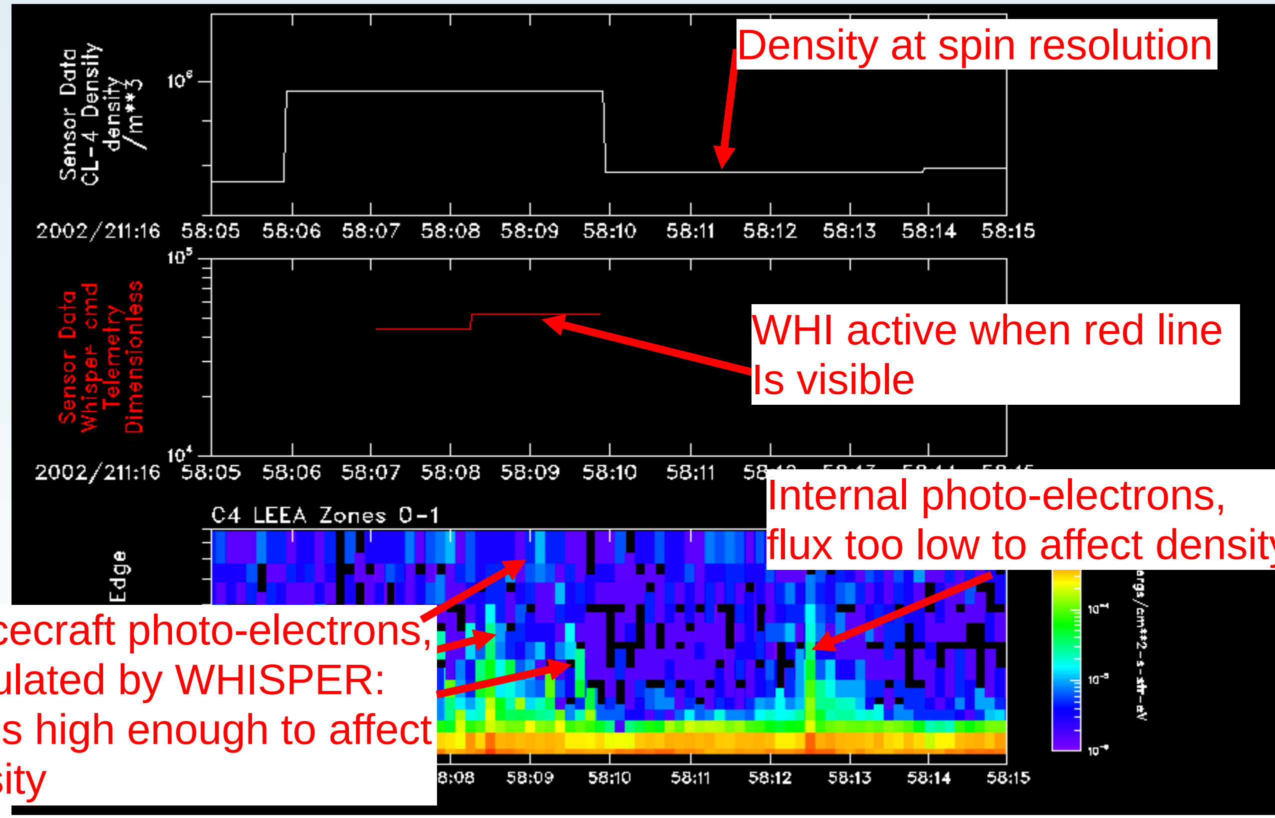
The high fluxes at the true potential are either cold plasma from the environment or emission from the EFW booms

V_{sc}, current balance and active experiments

WHISPER Instrument, WHI (case of active sounding)

Bad for plasma measurements

- Cluster-PEACE electron data
- A 10 second interval in the **magnetotail plasmasheet**
- WHI sounder radio emission emission is briefly active. ASPOC is on throughout
- SC potential fluctuates rapidly (faster than PEACE samples)

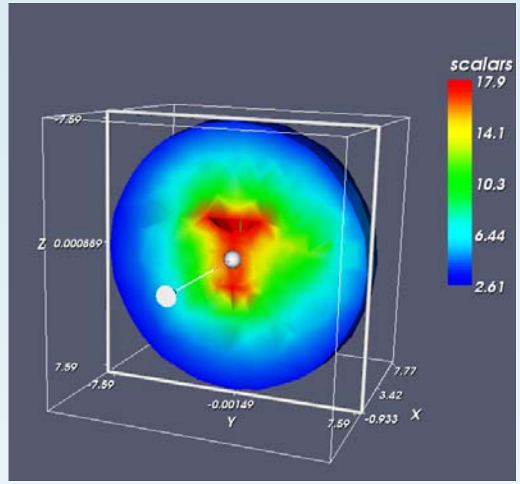


Rapid fluctuations in the current balance during WHI active operations drive photoelectrons to higher energies than Vsc, where they contaminate measurements of the un-perturbed plasma electrons. Leads to errors in density moments

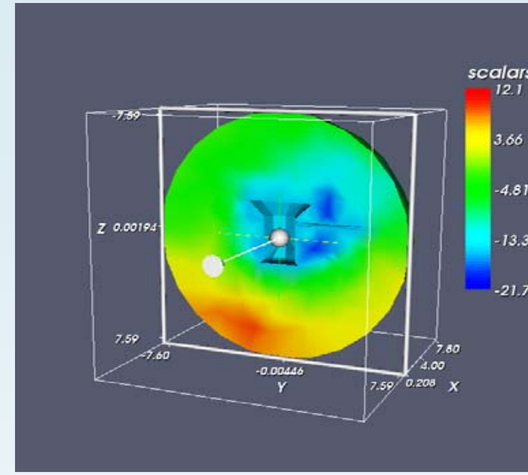
Modelling Efforts

SPIS (SPINE)

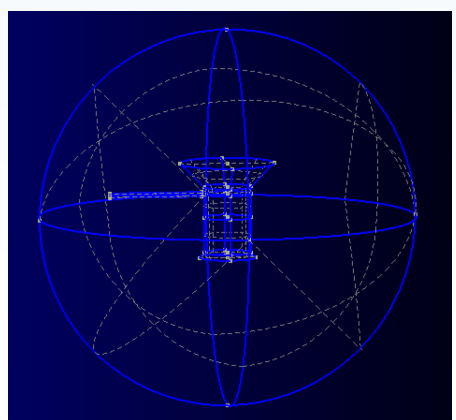
- Cassini spacecraft
- Model potential variations in different plasma environments at Saturn
- **Current model fairly crude description of complex spacecraft form, but it is still able to illustrate the situation**



n_e = 10 cm^{-3}
n_i = 10 cm^{-3}
V_{ix} = 400 km/s
Final V_{sc} = ~ +18 V



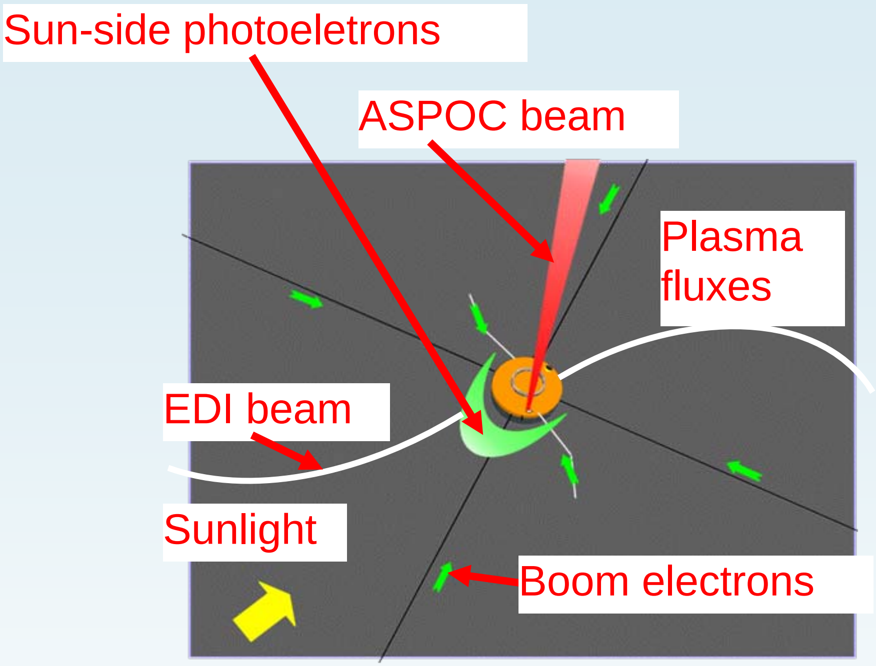
n_e = 5,000 cm^{-3}
n_i = 5,000 cm^{-3}
V_{ix} = 30 km/s
Final V_{sc} = ~ -20 V

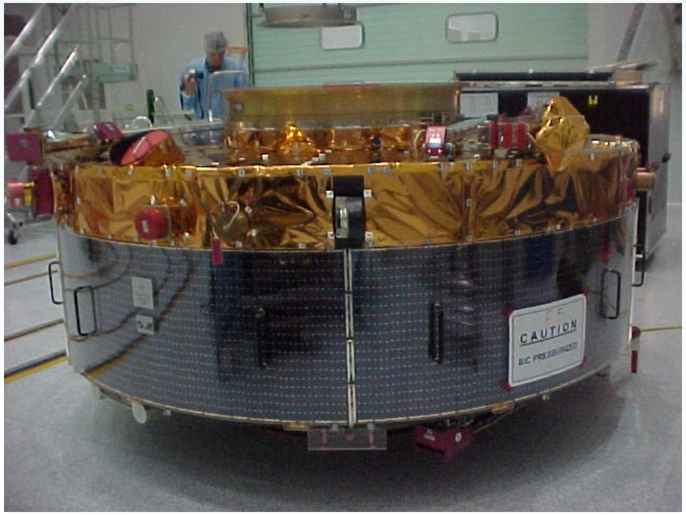


Modelling Challenge

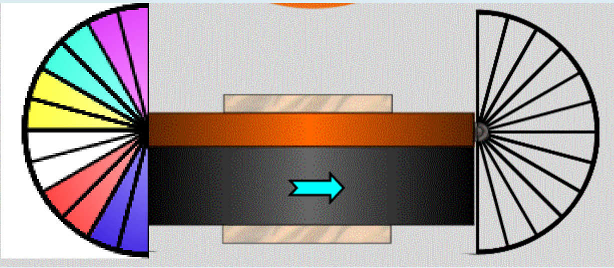
Future SPIS

- Cluster spacecraft
- Try to model potential variations in different plasma environments, with and without active experiments working, and compare to real data
- Investigate contribution of secondary electrons to current balance
- **Validate improved models for use in design of future missions**

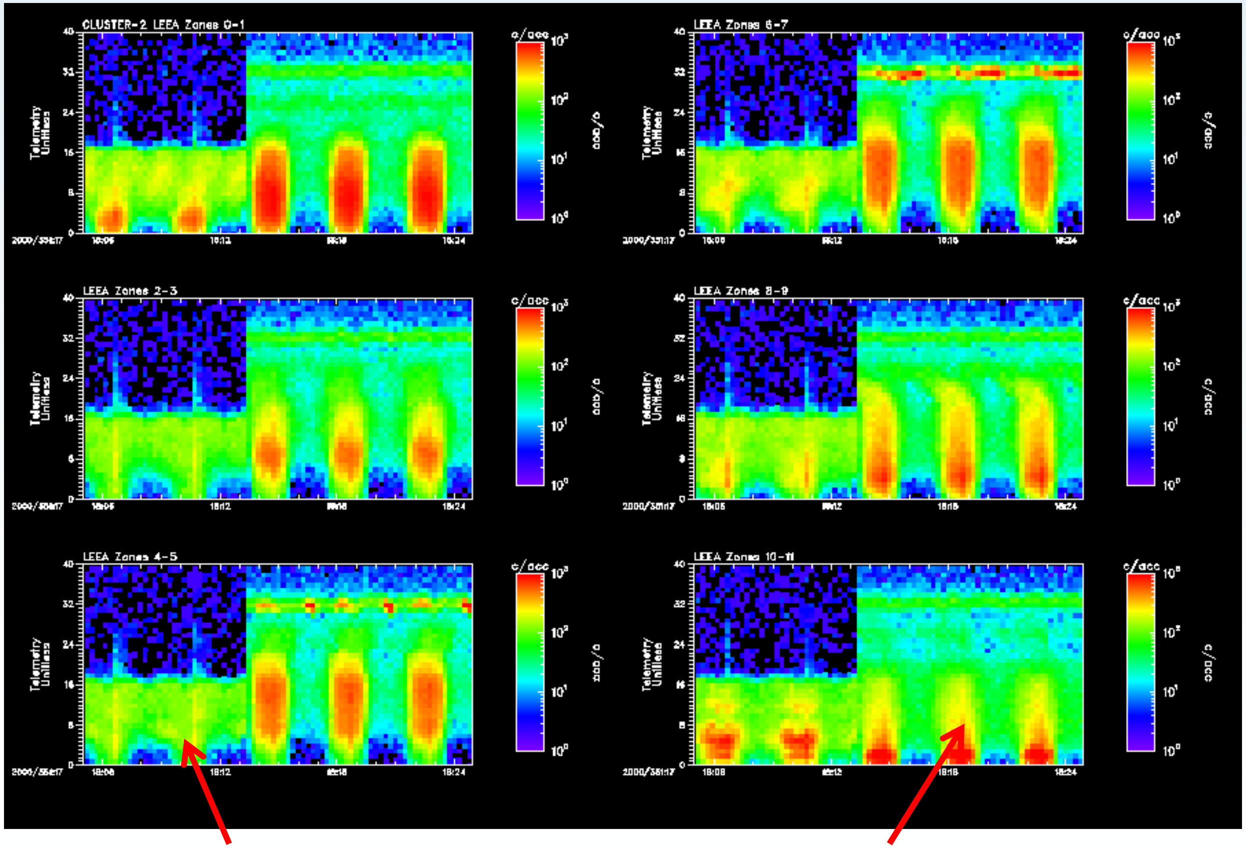




Modelling Challenge



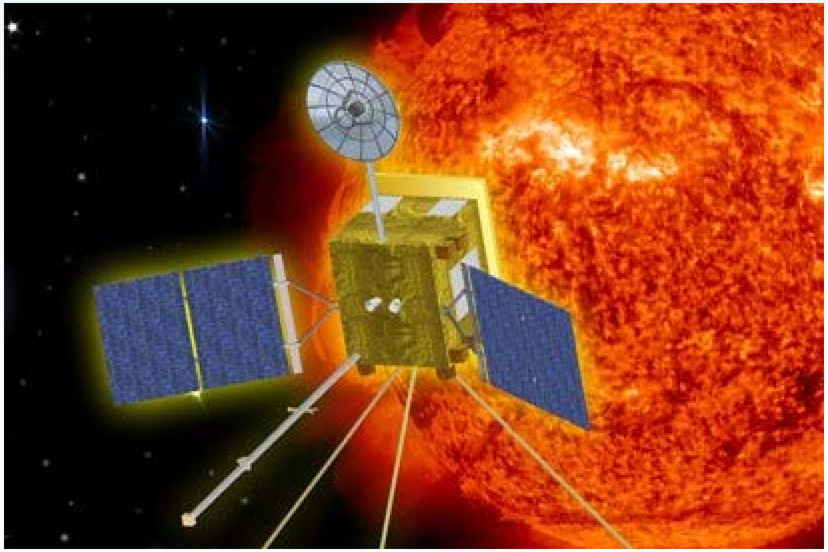
- Cluster-PEACE data, from 6 anode pairs
- A 5 spin interval in a low density plasma with ASPOC current strong then weak.
- Sensitive test of model if one can reproduce the measurement of non-escaping photo-electrons detected below the potential, as well as predict the potential change



ASPOC High current ASPOC low current

Modelling work for Future Missions

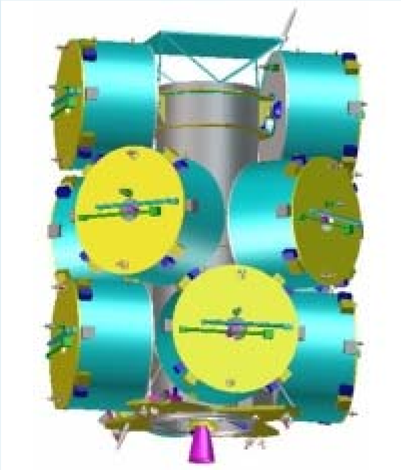
- Solar Orbiter
  - Strong variation in orbital distance from the sun drives strong variation in environment – plasma fluxes and photon flux – how will secondary and photoelectron emission work?
  - How does spacecraft charging work on this non-spinner? Differential charging? Boom instruments in shadow?
  - Is boom mounting likely to allow better measurements than body mounting?
  - Penetrating radiation
  - Thruster contamination

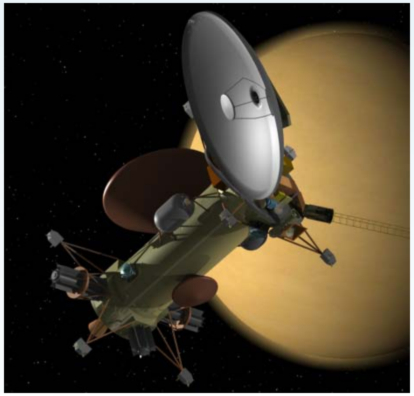


Modelling work for Future Missions

Cross-Scale

- Expect issues similar to Cluster;
- Can we design for more benign spacecraft-plasma interaction effects on measurements?
- Active potential control?





Europa Jupiter System Mission (EJSM) /Titan Saturn System Mission (TSSM)

- Expect issues similar to Cassini
- Can we design for more benign spacecraft-plasma interaction effects on measurements?
- Active potential control?
- High radiation environment for EJSM