A review of spacecraft plasma interaction effects on plasma measurements

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- 1. Introduction
- 2. Contamination by charged particles
- 3. Surface charge effects
- 4. Space charge effects
- 5. Conclusions

1. Introduction

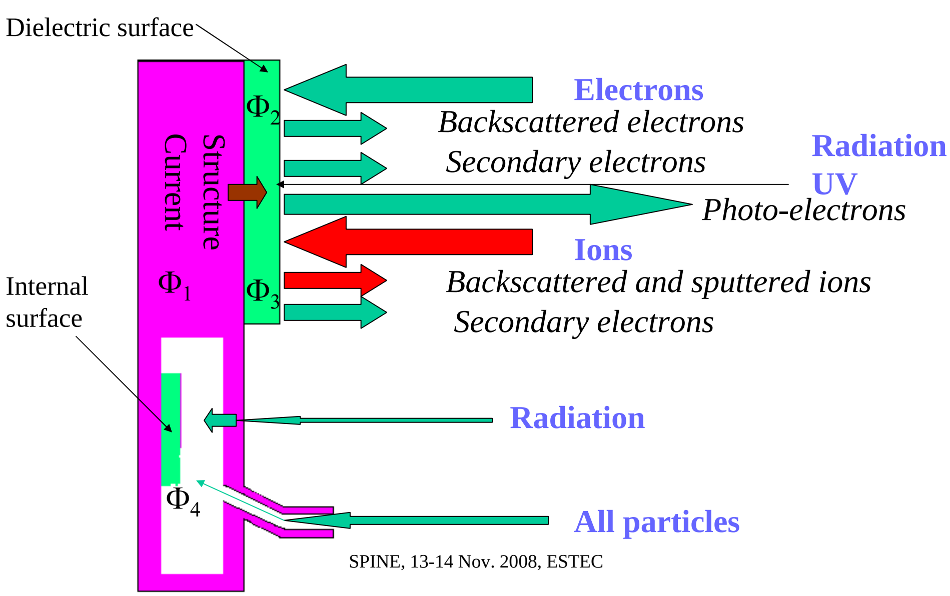
Spacecraft effects on plasma measurements:

- Thermal, High energy radiation, etc…
  - Affect electronic, materials and structure
- Micro-particle impact induced transient environment
- Magnetic and EMC
- Contaminants from passive and active sources
  - Create background and disturbances
- Surface and space charge induced E-field
  - Affect particle trajectories
  - Other disturbances

Scope of this presentation

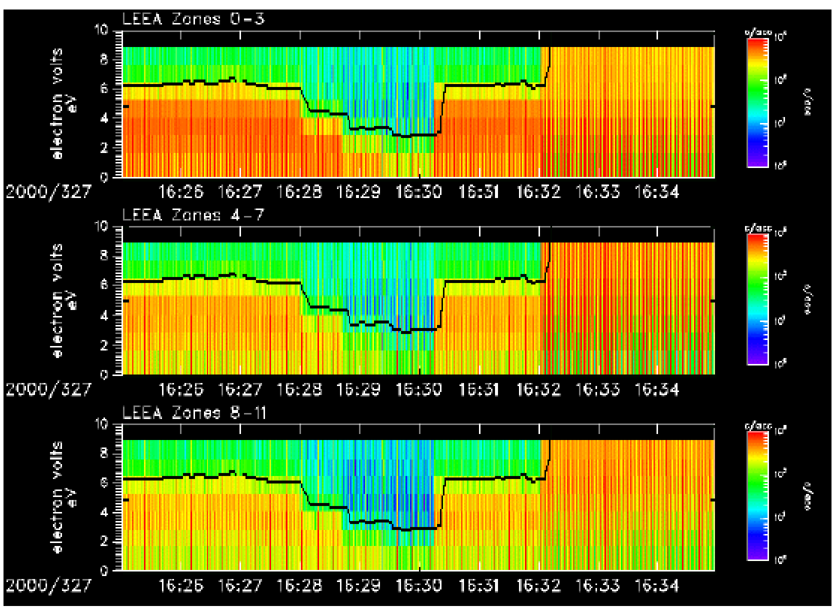
- The following effects on plasma particle detectors are addressed:
  - Contamination by secondary and injected particles
  - Surface charge effects
  - Space charge effects
- Specific requirements for scientific instruments (particle detectors, Langmuir probes):
  - smaller magnitude effects matter

Key features and glossary

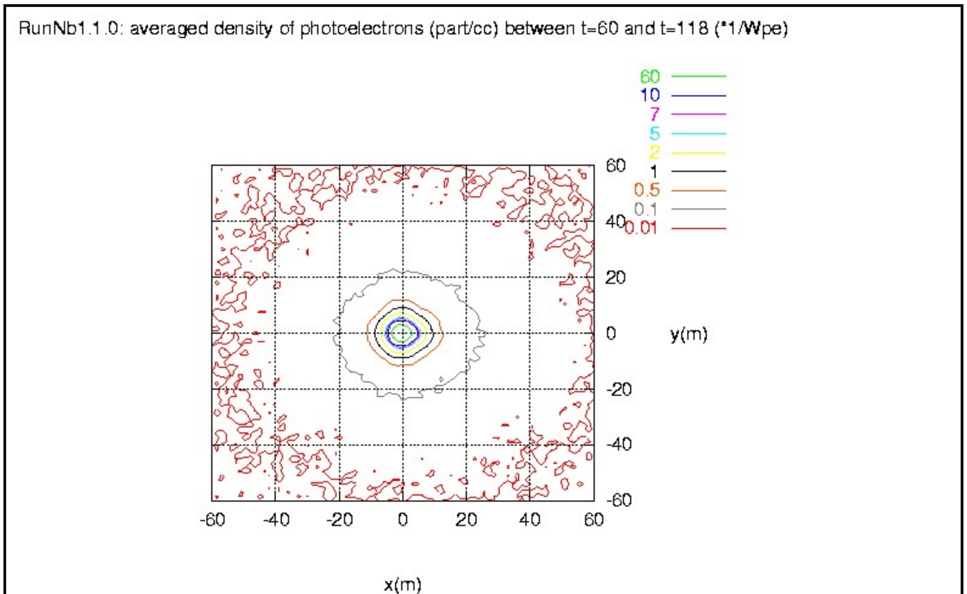


2. Contamination by induced or injected particles

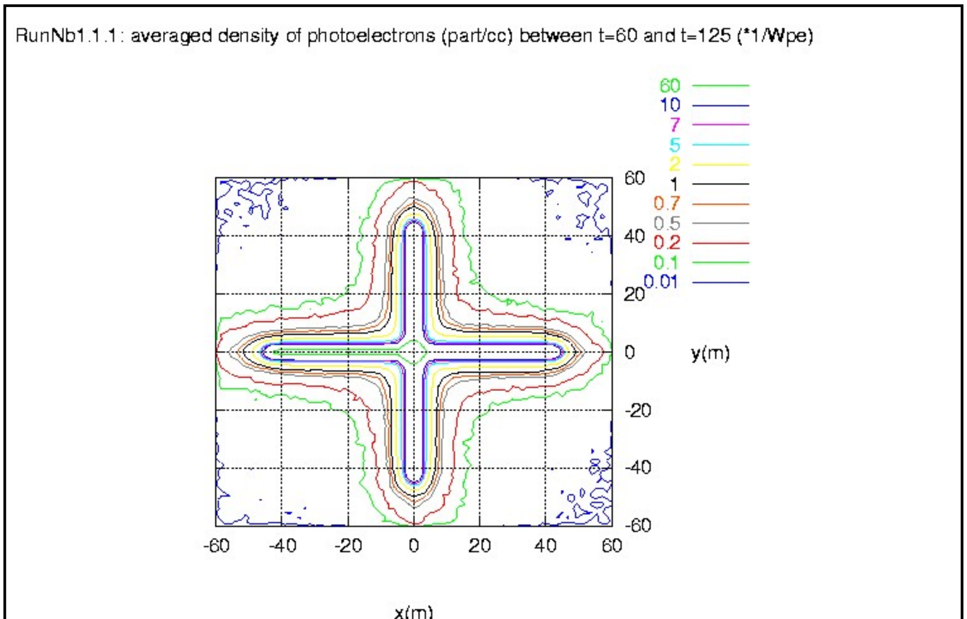
- Secondary particles and photo-electron generated on surface
  - Example: ISIS (Wrenn and Heikkila), Viking (Hilgers), Cluster (Szita, ESA unpublished)
- Particles from active sources
  - Primary ions or charge-exchange ions from E-thruster
    - Example: DS-1, SMART-1 (Capacci, Tajmar, Hilgers).
  - Secondary ions created by charge-exchange, CIV, or photo-ionisation of neutrals.



Cluster/PEACE spectrograms (from Torkar et al. 2001)

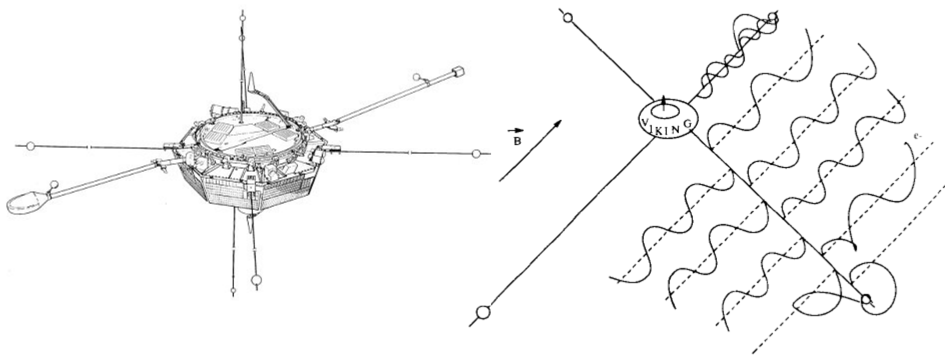


PIC simulation of half-emitting spacecraft (Thiébault et al., 2005)



PIC simulation of photo-e along booms (Thiébault et al., 2003; Cully et al. 2007)

Viking Polar orbiting Spacecraft 1986-1992



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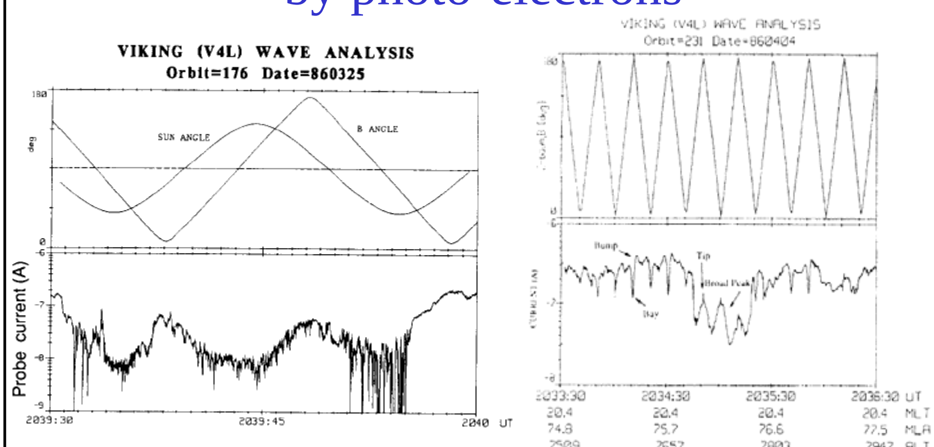
Contamination of Langmuir probe by photo-electrons



Contamination by photo-electrons (Hilgers et al., 1992, 1993)

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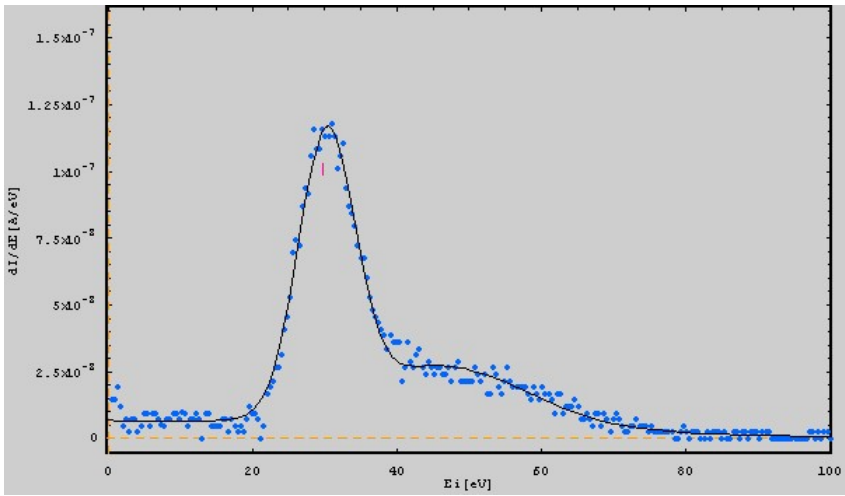
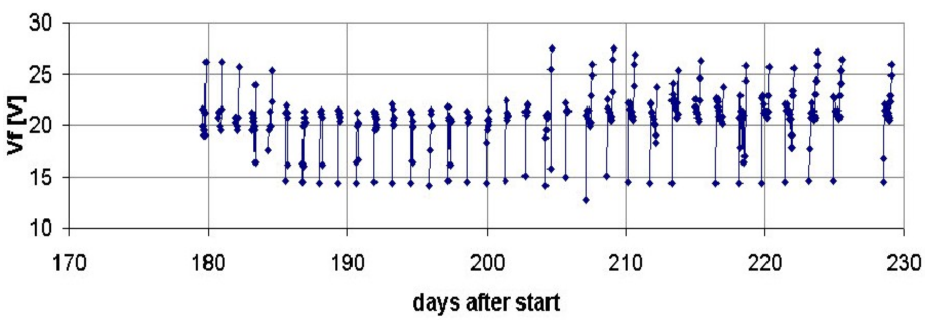
Detection of E-thruster ions



RPA analyser on SMART-1 (Capacci, 2003)

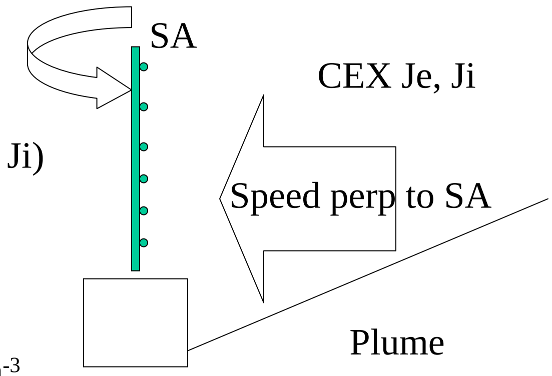
Indirect evidence:
Variation of SMART-1 Floating Potential



Sketch of CEX ions interaction with SA

“wake”

CEX η(Je, Ji)



Ji ~0.01 A m^{-2}
Je ~0.3 A m^{-2}

For ni=ne=10^{13} m^{-3}
Te=1 eV
Ei=12 eV

Mitigation techniques

- Choice of material depending on emissivity
- Choice of location of detector
- Use of potential barriers

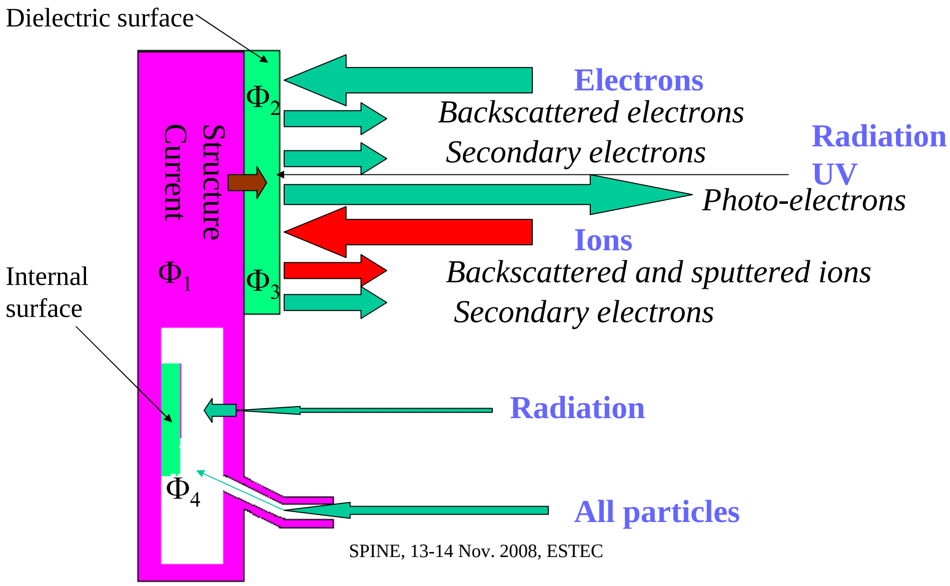
Remaining issues

- Spectrum of secondary and photo-emitted particles not well known.
- Related surface properties not well characterised for all materials in use.
- Not much observation of the environment of active sources in space.
- Modelling of antennas challenging due to small transverse side.

3. Surface charge effects

- Negative charging
  - Example: Freja (Wahlund, Eriksson, Hilgers), DMSP (Many AFRL papers), ISEE-1 in sun light (Olsen and Whipple, 1988)
- Positive charging
  - Example: Interball-2 (Hamelin et al.), Rosetta (cf Berthelier), Ulysses (Scime et al.)
- Active voltage source
  - Example solar array

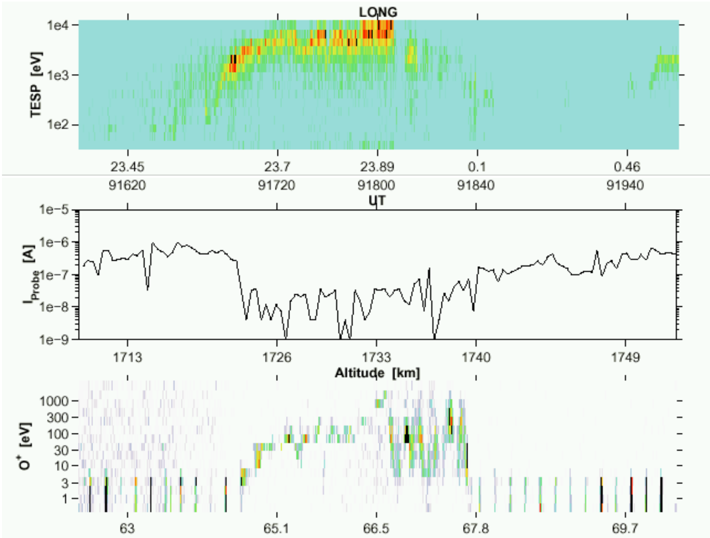
Surface effects in brief



Negative surface charging

- Often slightly negative in dense ionospheric plasma but also a few tens of volts, sometimes up to several kilovolts, in magnetospheric plasma:
  - in eclipse
  - under irradiation by > 1keV electrons fluxes
  - in low density regions (typically less than 100 cm^{-3})
- Few example of high level charging in daylight explained by potential barriers due to negative parts of the spacecraft (on the non-sunlit side) or negative space charge.

Kilo-Volt Negative Charging



Blind sensor
ESD risk
Contamination
…

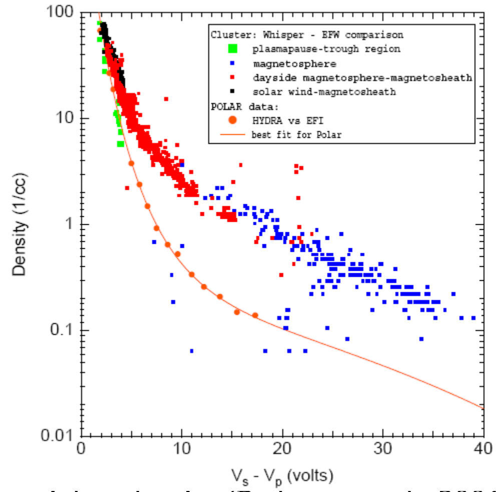
1-10 keV
electrons is
A concern

(e.g, Sasot et al.)

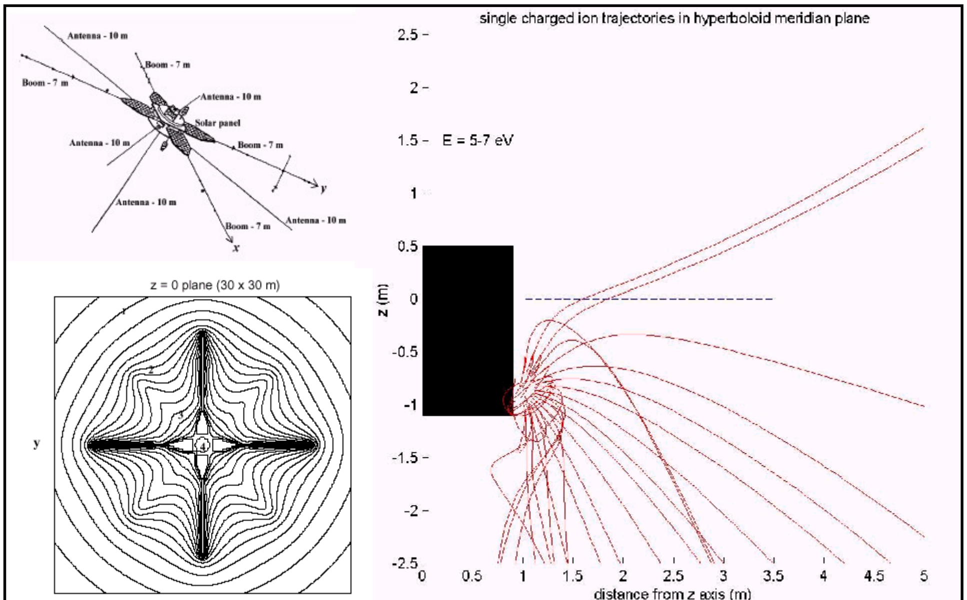
Positive charging

- Often a few volts positive driven by photo-electron emission in the low density magnetosphere, sometimes a few tens of volts in depleted regions, e.g., lobes, auroral acceleration regions.

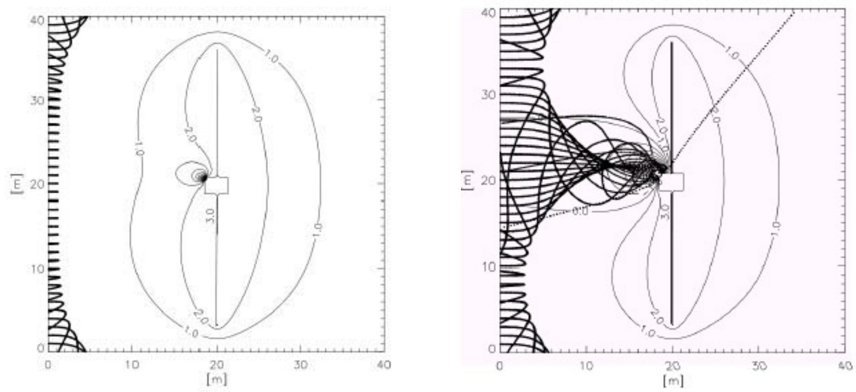
Spacecraft Potential in the magnetosphere



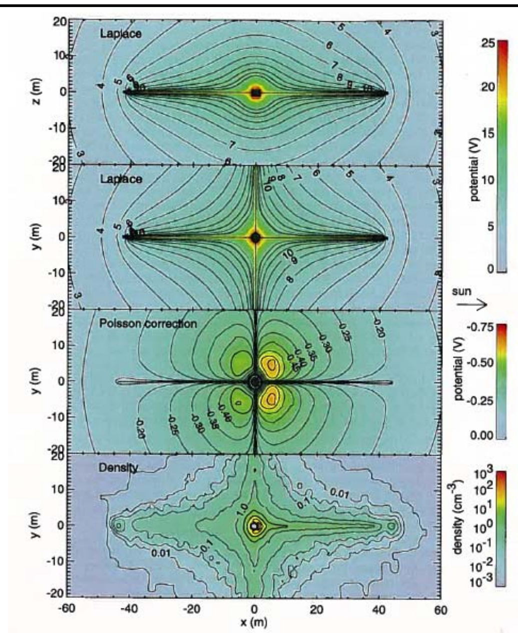
spacecraft potential vs density (Pedersen et al., 2001)



Interball geometry, contours of equipotentials and trajectory of ions reaching the HYPERBOLOID particle detector (from Hamelin et al., 2001).



Simulation of cometary ion collection by a detector on Rosetta at +3V with a grid at 0V (left) and a grid a –50 V (right) (from Nyffenegger et al., 2001).



boom potential effect (Cully et al., 2007)

Mitigation techniques

- Choice of material with high secondary electron emission and good conductivity.
- Reduce potential via active particle emission.
- Adapt entrance potential of detector.
- Location of detector (possibly on boom).
- Inverse method to retrieve plasma parameters (e.g., Genot et al., Geach. et al.)

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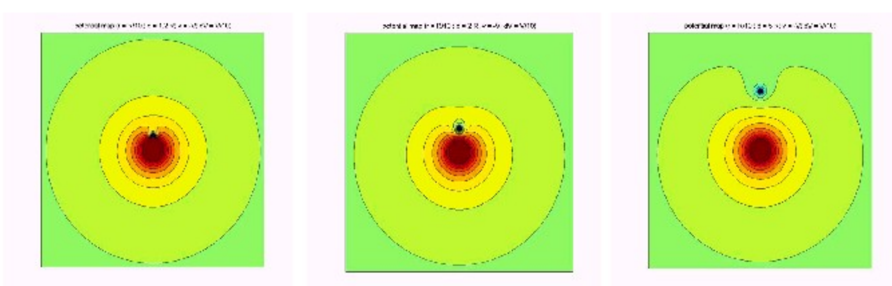

Investigation of potential distribution around a spacecraft at +10 V and a detector at –10 V mounted on a boom at various distances (from Hamelin et al., 2001).

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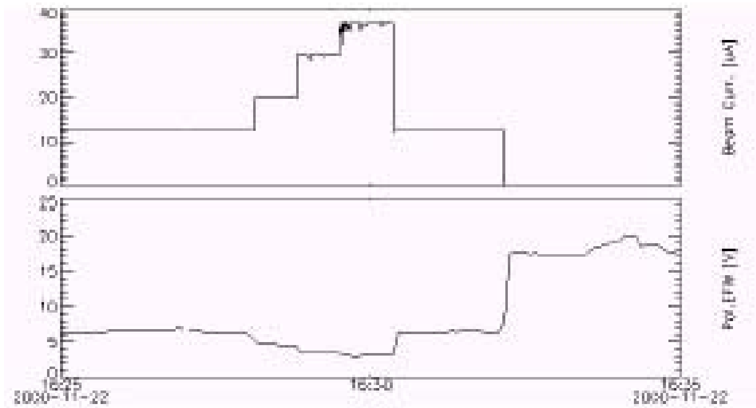


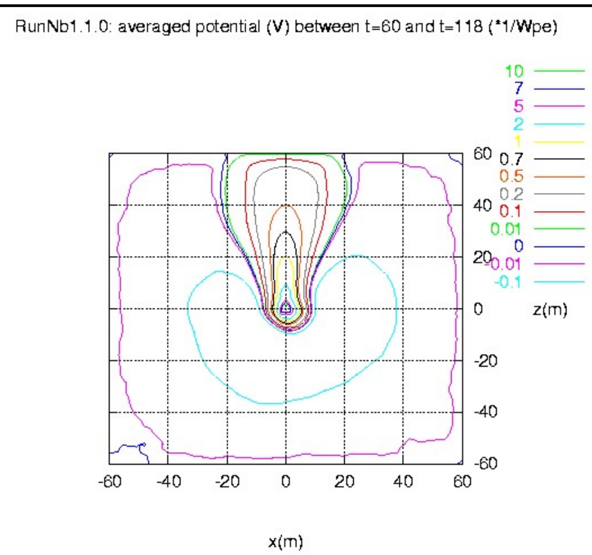
CLUSTER/ASPOC ion emission current (upper panel) and variation of spacecraft potential (lower panel) from Torkar, 2001.

Remaining issues

- Spectrum of secondary and photo-emitted particles not well known.
- Related surface properties not well characterised for all used materials.
- Not much observation of the actual sheath.
- Trade-off with other instruments requirements.

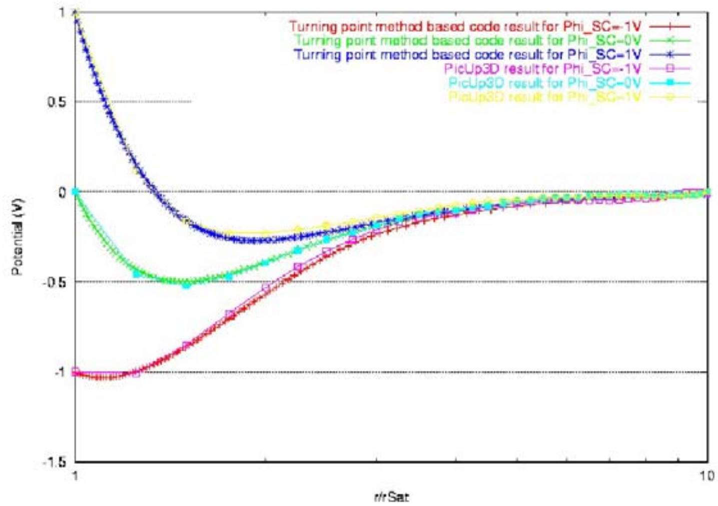
4. Space charge effects

- Wake
  - Examples: (Cooke, Samir, …), ISEE-1 (A. Pedersen, 1984), Cluster (Engwal et al. , Anderson et al.)
- Active source environment
  - Example: Polar (Singh et al., 2001), Cluster (ESA unpublished), SMART-1
- Secondary electron induced potential barriers
  - Example: ATS-6 (Whipple), Cluster(Zhao, ESA unpublished), Rosetta (ESA unpublished)



Preliminary results of potential distribution around an ASPOC like ion plume on a cylindrical spacecraft (Thiébault et al., 2003).

Simulation of potential barrier for biased conductor at 100 cc and 1eV (Thiébault et al., 2004).



Mitigation techniques

- Reduce number of injected particles.
- Use of modelling and inverse methods.
- Choice of location of detectors.

Remaining issues

- Very little detailed observations exists.
- Active sources characteristics poorly known.
- Simulations difficult to fully validate.
- Trade-off with other instruments requirements.

Conclusions

- There are several spacecraft effects which may limit significantly the scientific return of plasma instruments.
- Some mitigation techniques exist but optimisation is necessary.
- Other science instrument may be affected (e.g, X-ray detectors).
- Significant effort is required for optimising the set-up and/or retrieving a 'clean' signal.
- Plasma simulation and detailed space-based observation for validation are useful methods for this.
- Ground testing and list of surface materials with conductivity and secondary electron emission properties.
- Actions are taken in ESA TR&D plan and world-wide.

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