Spacecraft potential measurements

Anders Eriksson

Swedish Institute of Space Physics, Uppsala, Sweden

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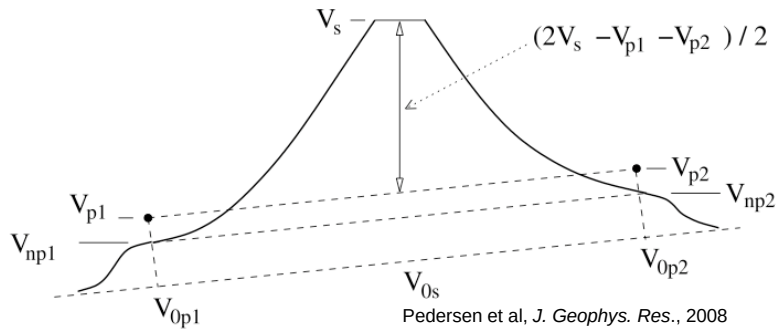
Outline

- What is Vsc?
- Why do we care?
- How to measure Vsc?
- Vsc measurements by electrostatic probes
  - E-field measurements with long booms
  - Langmuir probes on short booms
- Needs for improved understanding

What is Vsc?

- Vsc = spacecraft potential
- But what is this?
- Vsc = *potential of the s/c wrt surrounding plasma*
- "You may think you understand, but just wait until I have explained it"
- Vsc = *potential of the s/c wrt surrounding plasma*? OK if …
  - … the "surrounding plasma" means several Debye lengths away from the s/c
  - … there are no significant E-fields in the plasma on s/c length scales

What is Vsc?



Pedersen et al, *J. Geophys. Res.*, 2008

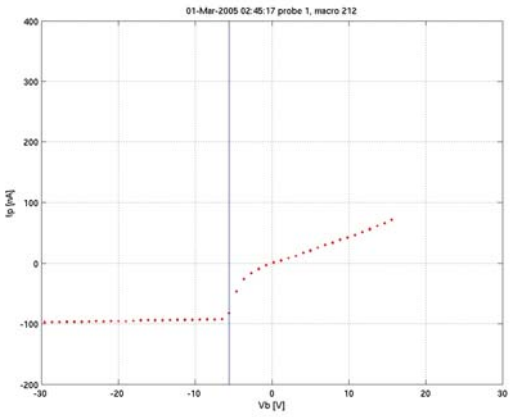
Vsc = *the electrostatic potential of the s/c with respect to what the potential should have been in the plasma at the location of the s/c if the s/c had not been there*

Why measure Vsc?

- Scientific reasons (Earth & solar system missions):
  - Particle measurements: low-energy particles are accelerated/retarded by the s/c potential field before hitting detectors, so correction for Vsc can be necessary
  - Dust measurements I: also influenced by Vsc
  - Dust measurements II: the s/c is like a gigantic dust grain, so s/c potential gives insight to dust grain potential
  - Plasma density: Vsc is a proxy for plasma density in tenuous plasmas (Iph > Ie0)
  - Vsc can also influence E-field measurements
- Technological reasons:
  - Understanding/monitoring s/c charging
  - Backflow/return current control for electric propulsion systems

Vsc from electrostatic probes

- Based on probe current-voltage characteristic
- Two common techniques:
  - Sweep: vary the probe bias voltage, record IV-curve, identify Vsc from knee (caution!)
  - Set bias current, measure probe-to-s/c potential, Vps
- Complication: what is actually measured?



Rosetta RPC-LAP data

1st Earth swing-by

Vsc from Vps

Principle:

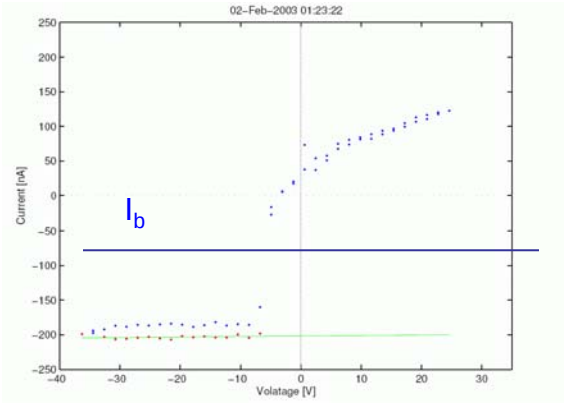
Bias current puts probe close to plasma potential

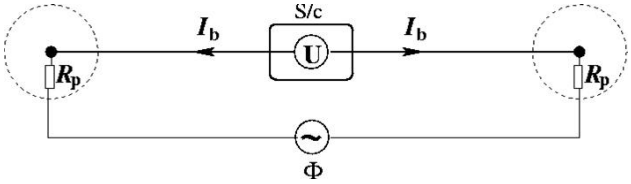
Measure probe-to-s/c voltage Vps

Only voltage drop over probe sheath remains to plasma

Assumption:
Vsc = -Vps + 0.7 V

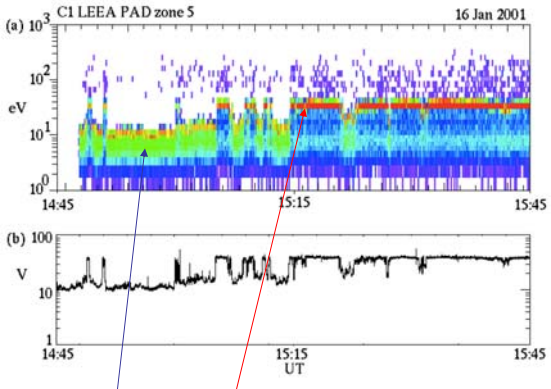
Does it work? Compare to Particle data!





Vsc from particle detectors

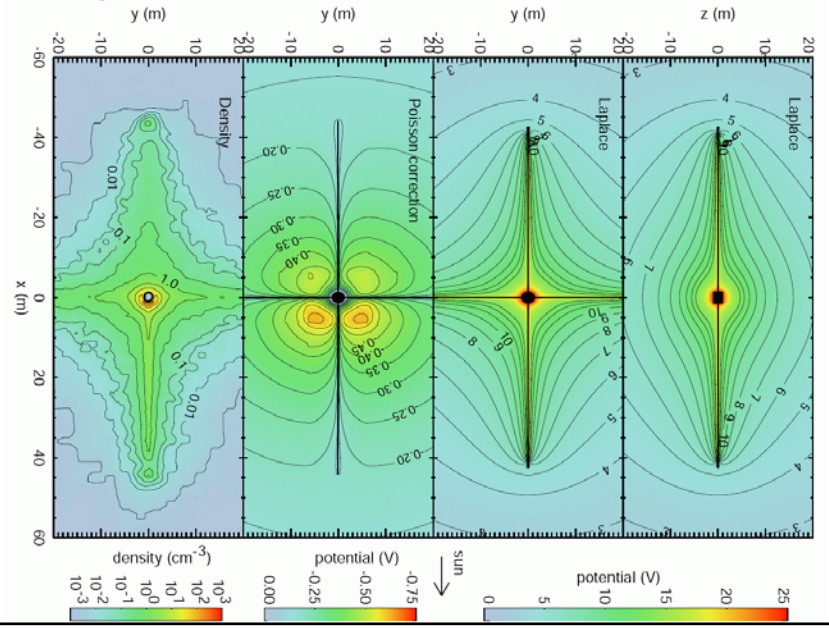
- Cutoff energy of accelerated species can give Vsc
- Voltage resolution limited by detector energy resolution
- Much TM use, or complicated onboard analysis
- Time resolution limited anyway by integration times
- Complications by e.g. photoelectrons
- Agreement with Vps (as well as data allows)



Cluster e- and Vps data showing photo-e- from s/c and probe detected below and at ~Vsc energy, respectively [Szita et al., *Ann. Geophysicae*, 2001]

S/c potential simulations

Cully et al., *J. Geophys. Res.*, 2007



S/c potential simulations

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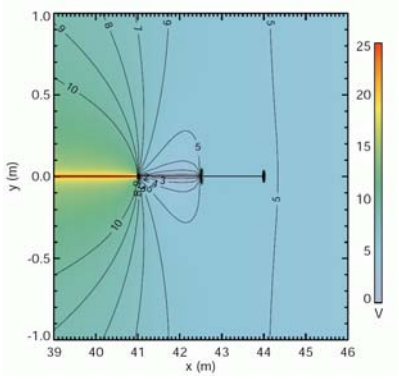
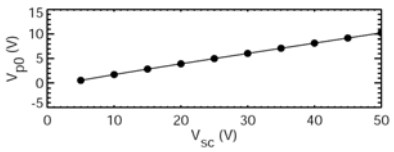
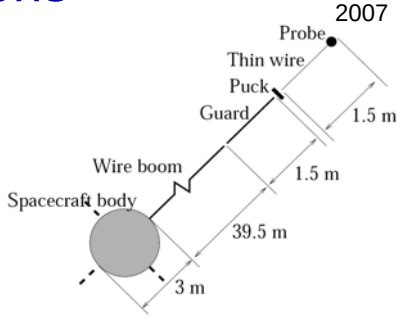






Potential from s/c not decayed to zero at probe location

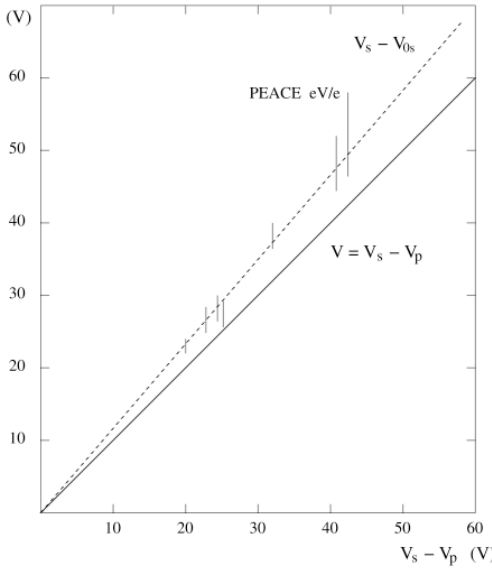
Previously:
Vsc = -Vps + 0.7 V

New result:
Vsc = -1.23 Vps + 0.7 V

Actual factor depends on geometry.

Simulations consistent with data

- Comparison of Cluster Vps and electron data consistent with linear relation

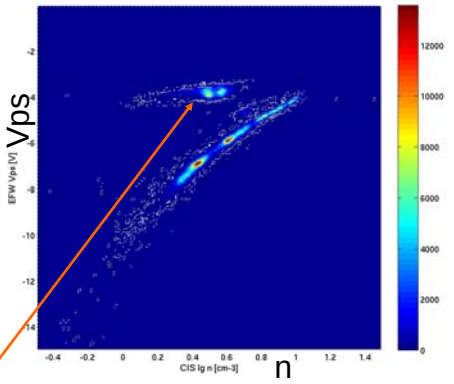


Pedersen et al,
J. Geophys. Res., 2008

Vsc (or Vps) as density proxy

Winkler, student project, Uppsala 2007

- Currents to spacecraft:
  - $-I_e \sim n$: collected plasma e-, scales with density n
  - $-I_{ph}(V_{sc})$: photoemission
    - Saturation for $V_{sc} < 0$
    - Decays for $V_{sc} > 0$
  - $-I_i$: negligible ion current
  - –Current balance $I_e + I_{ph} = 0$ $\Rightarrow V_{sc} = f(n)$ relation
- Vsc thus a proxy for the density
- Works equally well for Vps thanks to linear Vsc(Vps) relation
- Easy to measure down to 10 ms time scale
- Disregard -- relation changes when ASPOC ion emitter is on

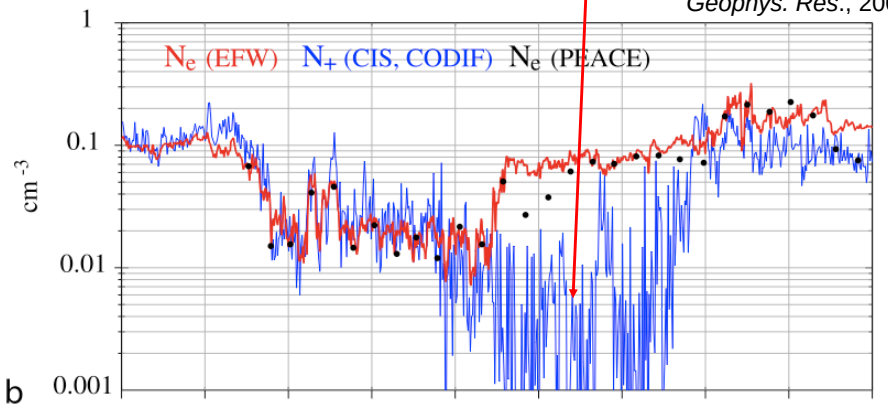


Empirical relation: EFW Vsc vs. plasma density from Cluster CIS ion spectrometer:
1.1 million data points (spins) from Feb-March 2003, 2004 & 2005
(Poster 25)

Vsc (or Vps) as density proxy

- Vps gives ”continuous” density estimate to high time resolution
- Ion spectrometers cannot see energies below energy eVsc -- Vps method gets all plasma
- Methods compare well where expected

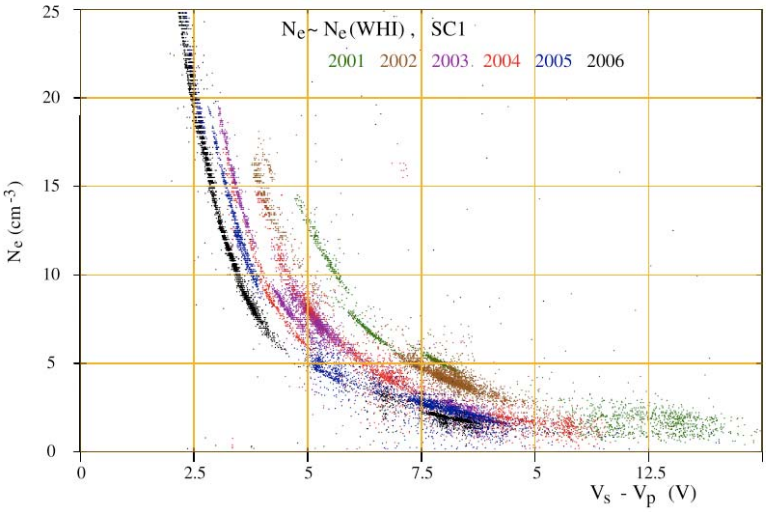
Pedersen et al, *J. Geophys. Res.*, 2008



Density-Vsc relation

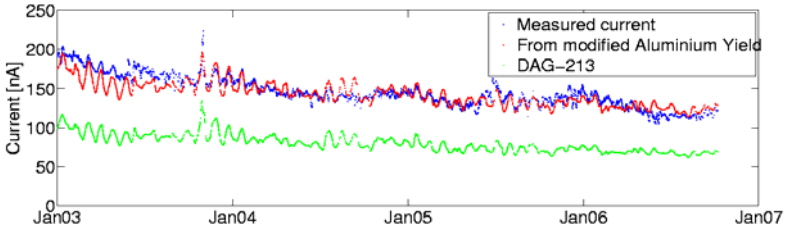
Depends on photoemission, i.e. solar EUV radiation intensity

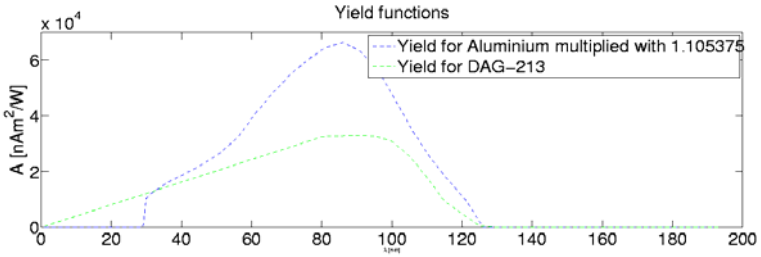
Pedersen et al, *J. Geophys. Res.*, 2008



Influence of solar variations

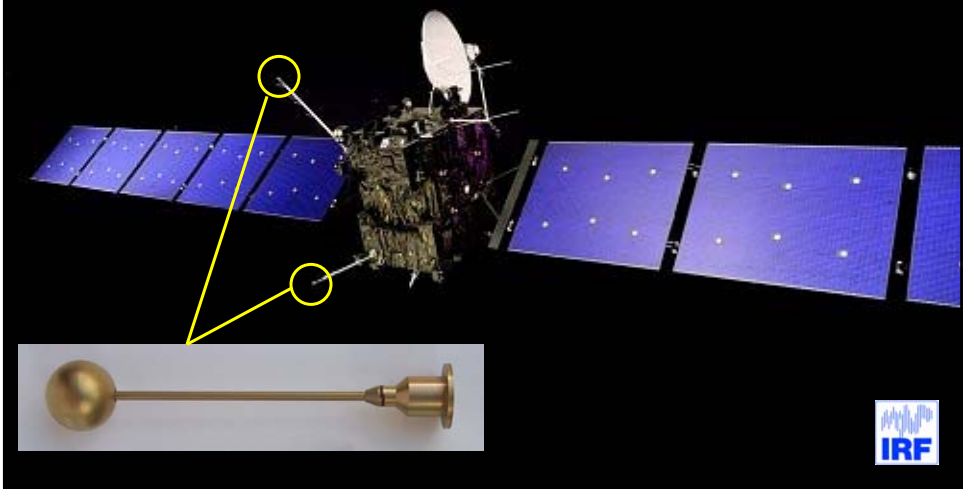
- Dependence on solar UV can be followed to high time resolution
- Comparison to UV measurements reasonable but far from perfect - why?





Eriksson & Winkler, SCTC-10 proceedings, 2007

Probes on short booms: Rosetta Langmuir probe instrument LAP



Probes on short booms

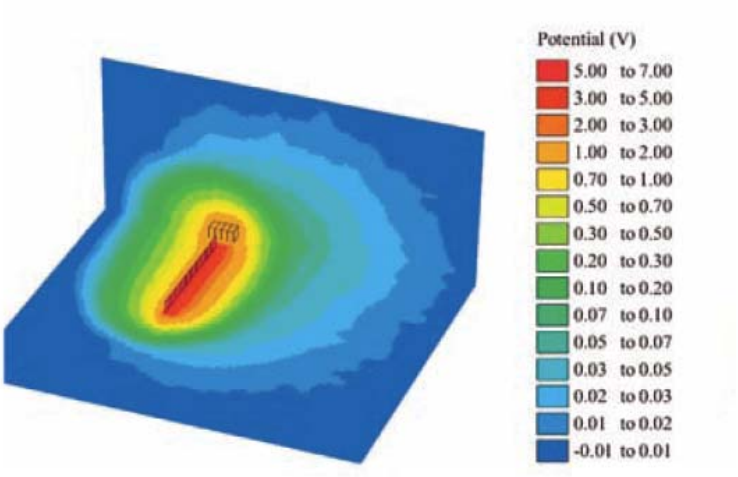
The shorter the relative boom length, the more remains of the s/c potential at probe position => smaller fraction of Vsc is measured

Langmuir probe on boom

Vacuum simulations for Rosetta by Chris Cully, IRF Uppsala

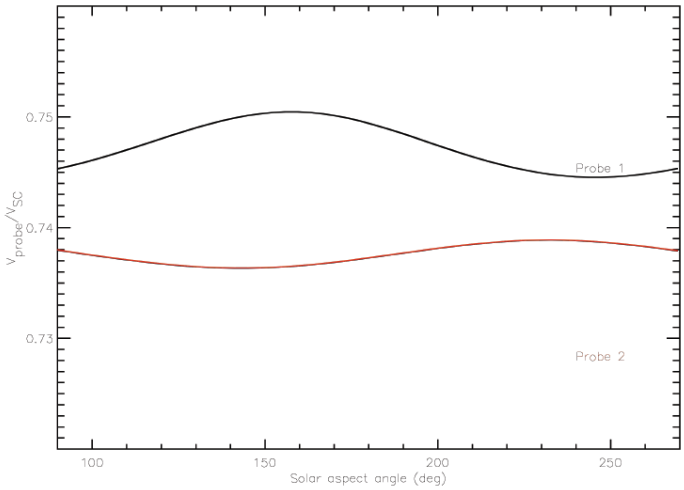
Probes on short booms

Photoelectrons and wake add to potential structure



Rosetta plasma simulations by Roussel & Berthelier, *J. Geophys. Res.,* 2004

Probes on short booms



Some 75% of Vsc remains at Rosetta LAP probe position

⇒Vps ~ -0.25 Vsc

Spin variation due to solar panels

In reality, wake and e_{ph} cloud effects enter as well, so things should be worse than seen here

Vacuum simulations for Rosetta by Chris Cully, IRF Uppsala

Rosetta LAP data

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

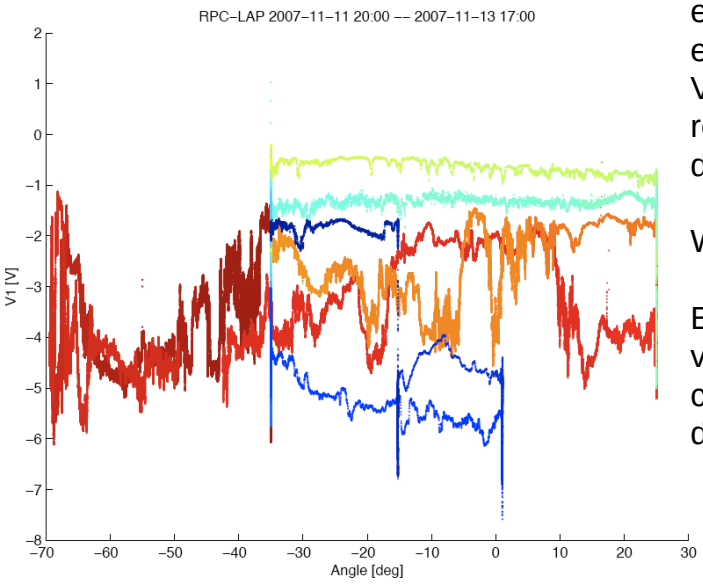
2nd Rosetta Earth swing-by, Nov 2007

Vps data from Langmuir probe run in bias current mode

Varying attitude

Magnetotail data

Rosetta LAP data

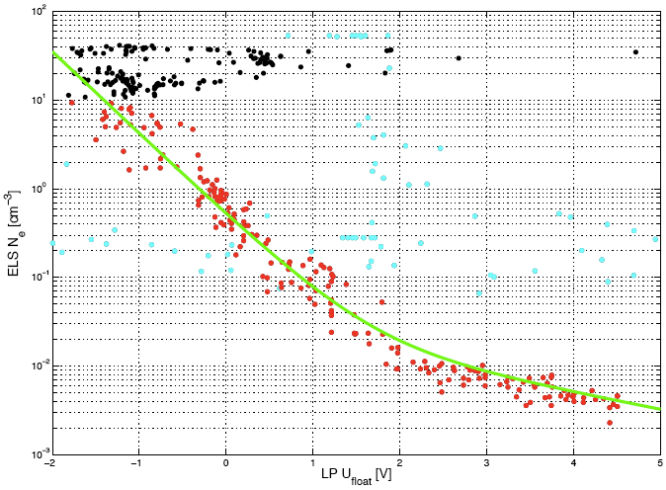


Non-trivial to establish empirical Vps(Vsc,angle) relation from data

Work ongoing!

But: natural variations clearly dominate

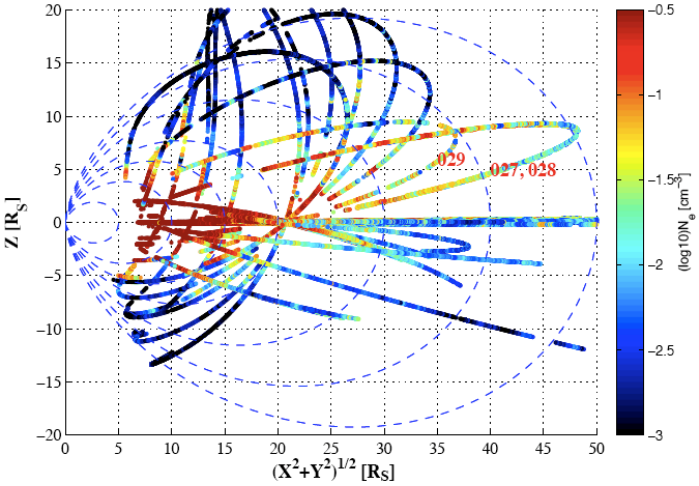
Saturn Vps-density relation



Cassini Langmuir probe (RPWS-LP) and electron spectrometer (ELS) data

Morooka et al., submitted to *Ann. Geophysicae,* 2008

Saturn plasma density from Vps



Cassini Langmuir probe data

Morooka et al., submitted to *Ann. Geophysicae,* 2008

Summary

- Vsc measurements of scientific value
  - Particle measurement corrections
  - Density from Vsc in tenuous plasmas
    - High time resolution
    - Works “always” (except when it doesn’t)
- Electrostatic probes give Vps at high time resolution
  - Vps = a * Vsc + b in tenuous plasma
  - Parameters a and b can depend on angle (and in worst case on n and T through wake)
- Work ongoing for better understanding of attitude dependence
- Dependence on solar UV flux realized in later years
  - Is photoemission as well understood as we believe?