Cold and Hot Plasma and Electric field Measurements in the Jovian System: Possibilities and Challenges

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SPINE meeting, ESTEC, Nov 13, 2008

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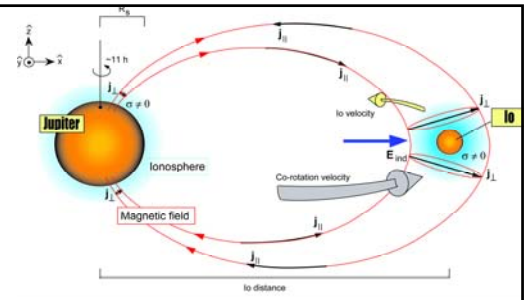
Outline

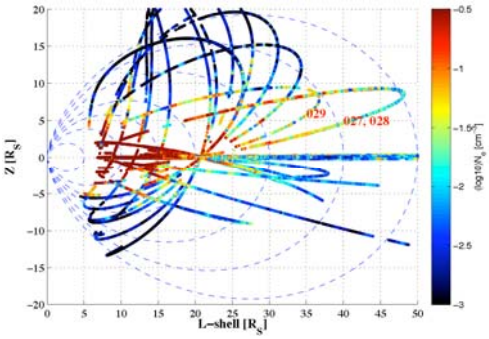
Plasma around Jupiter and the Galilean moons

Possibilities with a dual Langmuir probe instrument

SPINE relevance for Laplace (and Tandem)

Note: Focus here is on Laplace, but all applies to Tandem as well





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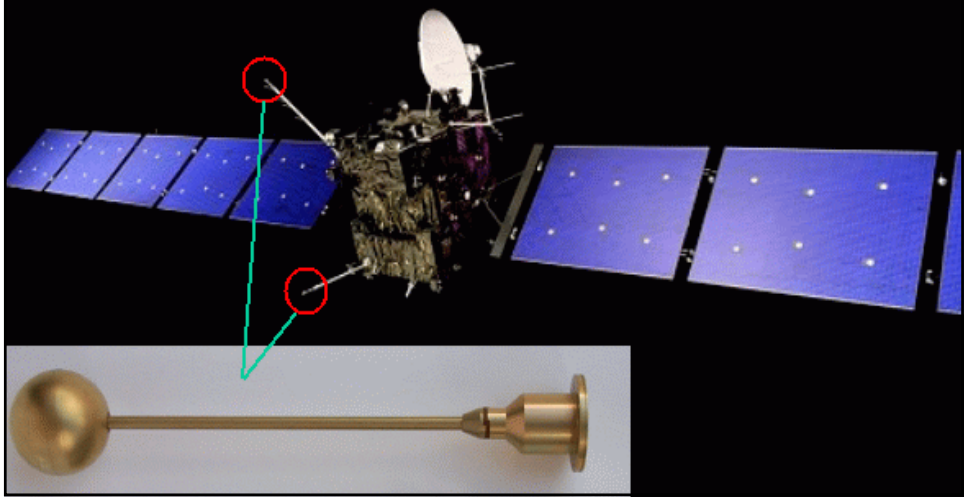
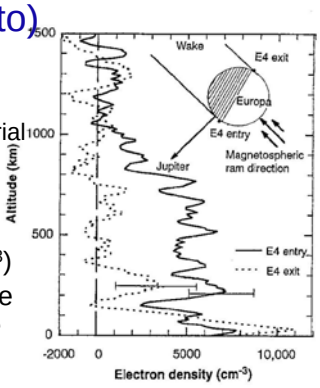
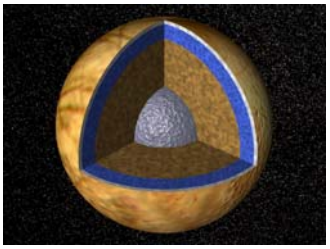
Example instrument:
Rosetta dual Langmuir probes (LAP)

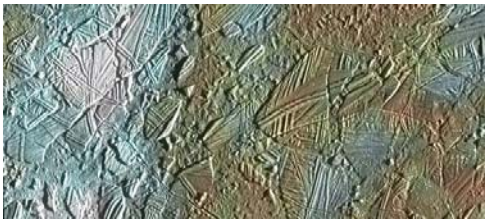


Ionospheres of Icy Galilean Moons
(Europa, Ganymede, Callisto)

- H_2O-products released fr. surface:
  - Magnetospheric particle sputtering
  - Sub-surface breaching of oceanic material
  - Diffusion from interior
  - Meteoritic impact evaporation
  - Solar radiation decomposition
- Leads to O_2^+-rich ionospheres (10^4 cm^{-3})
- Interaction with Jupiter's magnetosphere leads to high variability: need to resolve dynamics



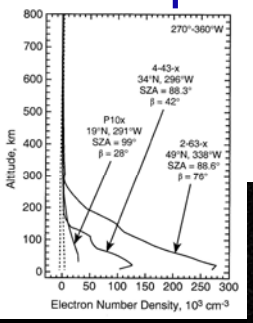




Io's Atmosphere/Ionosphere

- Volcanic sources (SO_2)
- Surface sublimation of SO_2-frost
- Magnetospheric bombardment ⇒ surface sputtering ⇒ Na^+

- *Ionosphere dynamics* reflects changes in atmosphere & magnetosphere co-rotational flow



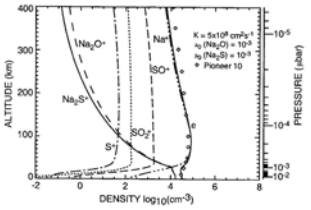
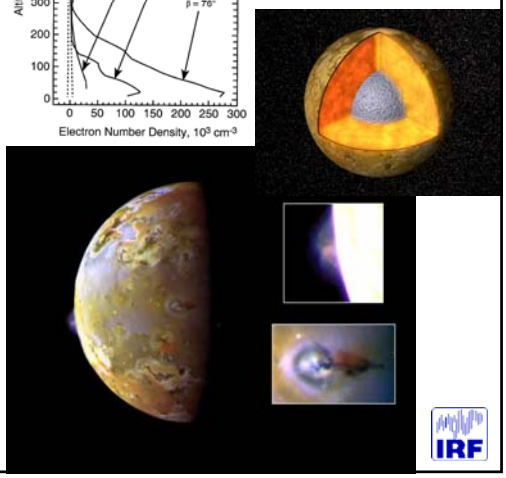
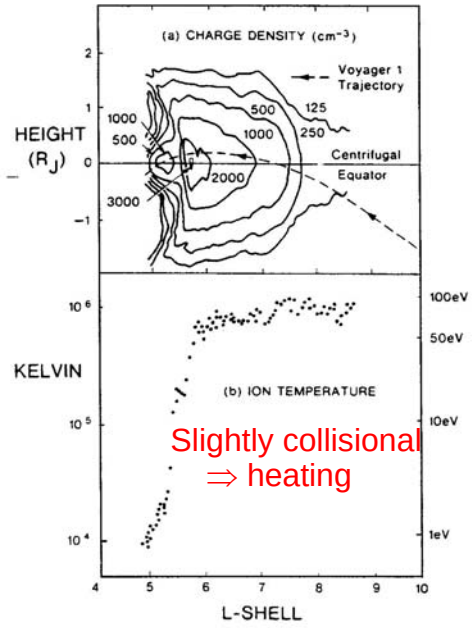
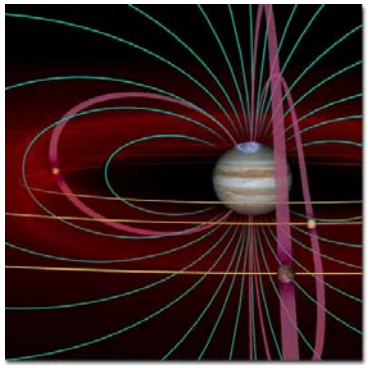


Figure 15. Density profiles from an ionospheric model of Io (from Summers and Strobel, 1996).



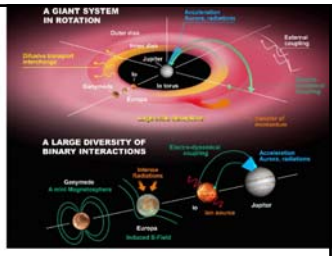
Io Plasma Torus

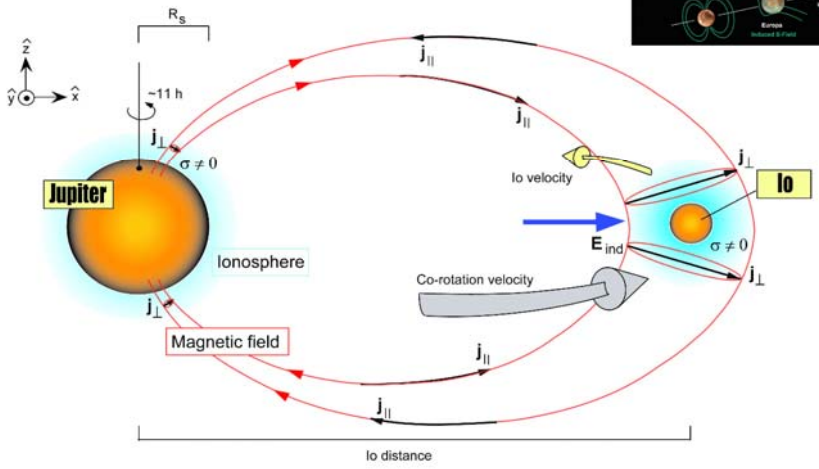




- Important plasma source
  - Exospheric SO_2 escape ⇒ ionization/dissociation ⇒ $q_i n_i(\mathbf{E}+\mathbf{B}\times\mathbf{v}_i)$ picked-up ⇒ supply 10^{28}-10^{29} ions/s ⇒ forms large torus

Jupiter-moon interactions (Io)



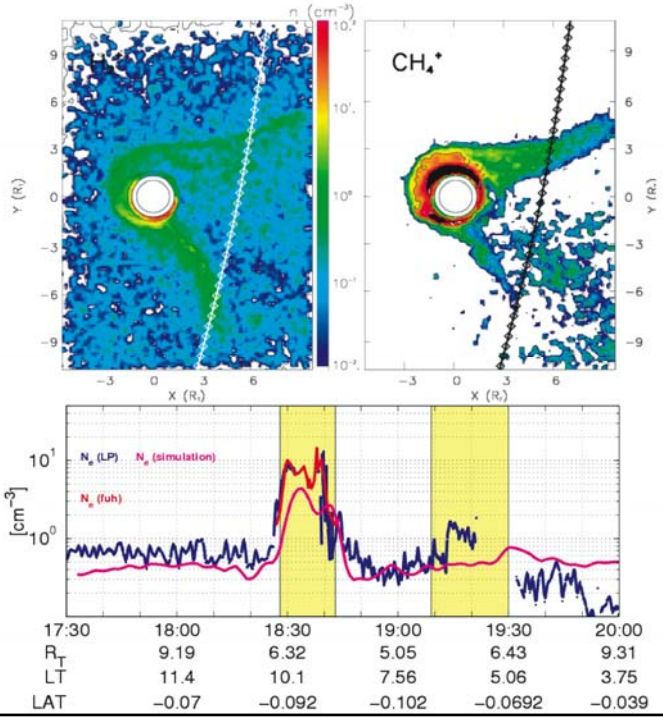


Crucial plasma parameters

- Crucial parameters for investigations of Jovian plasma dynamics:
  - Magnetic field
  - Plasma density
  - Plasma flow and E-field
  - Plasma waves E & B
  - Particle distributions
- Large-scale convection and high-accuracy E-field measurements in the Jovian magnetosphere requires long booms on a spinning s/c
- Still, a dual LP instrument on booms ~several meters gives the parameters in red

How to measure plasma density?

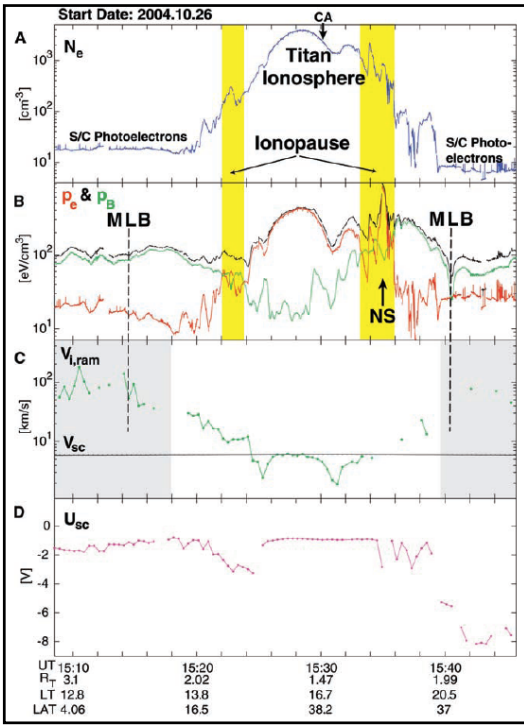
- Ion spectrometer?
  - Vsc problems at low energy & density
  - Noise integration in low densities
  - Low time resolution
  - Field of view
- Electron spectrometer?
  - Vsc problems at low energies
- Natural waves?
  - Wave identification
  - Existence
- Sounder/impedance?
  - Time resolution
  - Excitation problems
- Langmuir probes?
  - Probe current/probe characteristic at high densities
  - Density from Vsc at low density
  - Also LF wave E-field if two probes
  - High time resolution



Cassini LP @ Titan

Titan simulation and Cassini LP density

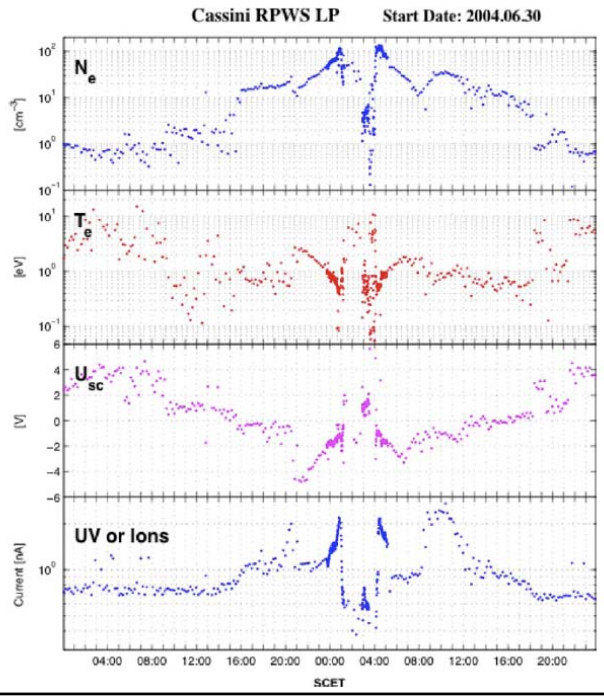
[Modolo et al., *Geophys. Res. Lett.*, 2007]



Cassini LP @ Titan

- Cheap way to get
  - Magnetospheric density (by Vps)
  - Ionospheric ne, Te, mi, vi
  - UV flux
- Few kg, few W, few kpbs
- High TRL

[Wahlund et al., *Science*., 2005]



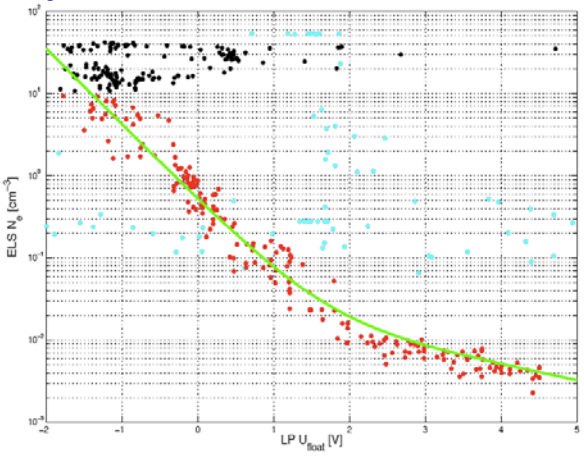
Cassini LP @ Saturn

- Cheap way to get
  - Magnetospheric density (by Vps)
  - Ionospheric ne, Te, mi, vi
  - UV flux
- Few kg, few W, few kpbs
- High TRL

[Wahlund et al., *Adv. Space. Res*., 2005]

Vsc as density proxy

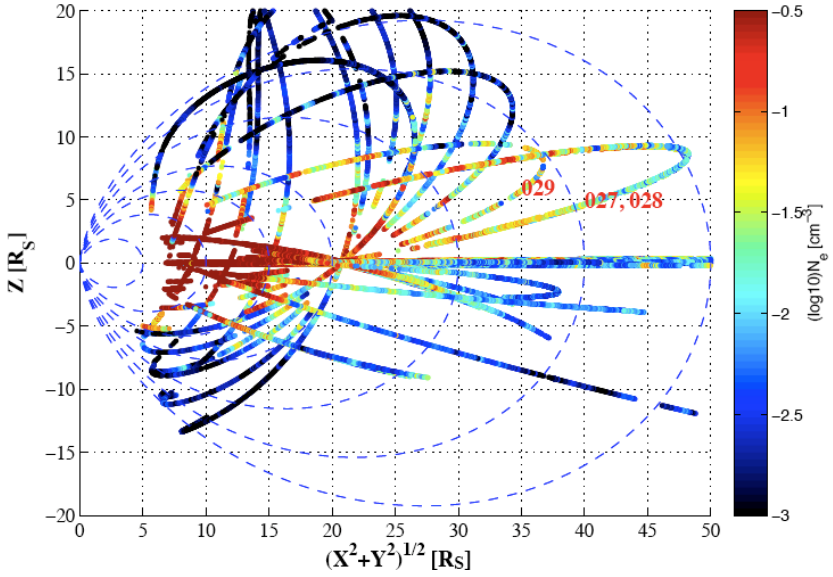
- Currents to spacecraft:
  - $I_e \sim n$: collected plasma e-, scales with density n
  - $I_{ph}(V_{sc})$: photoemission
    - Saturation for $V_{sc} < 0$
    - Decays for $V_{sc} > 0$
  - I_i: negligible ion current
  - Current balance $I_e + I_{ph} = 0 \Rightarrow V_{sc} = f(n)$ relation
- V_{sc} a proxy for the density
- Easy to measure down to 10 ms time scale

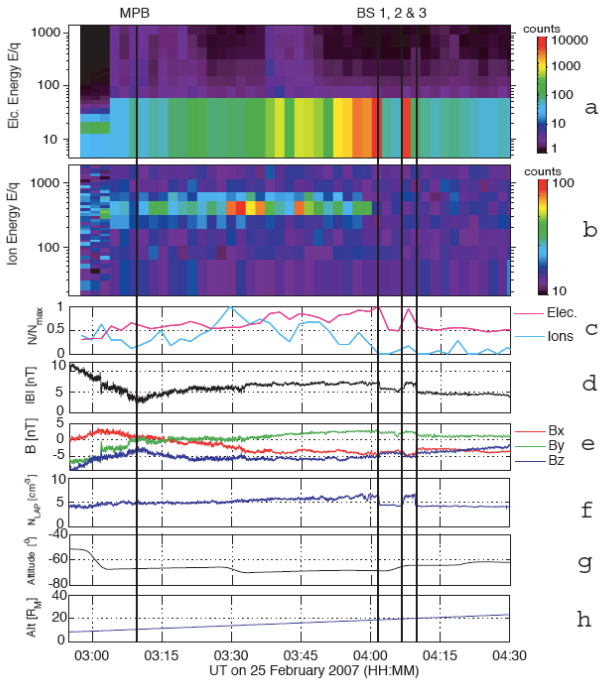


Empirical relation: Cassini density from ELS electron spectrometer vs. LP Vps.
[Morooka et al., *Ann. Geophysicae*, in review, 2008]

Cassini LP @ Saturn: Density from Vsc

[Morooka et al., *Ann. Geophysicae*, in review, 2008]





Rosetta LAP Vps at Mars

Rosetta Vps calibrated to MEX plasma density in the solar wind

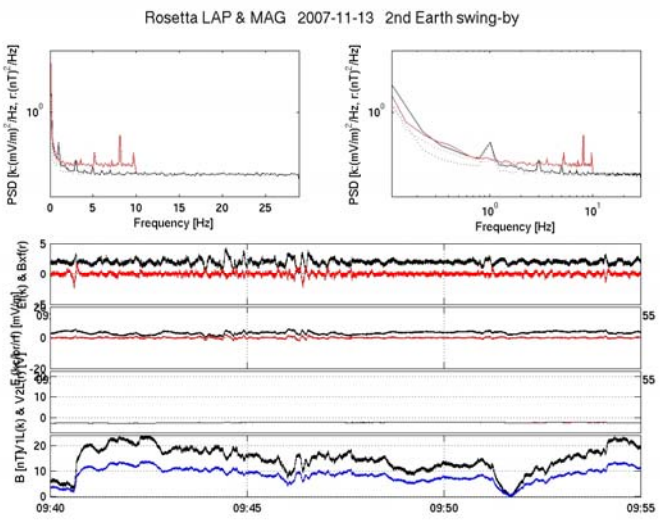
Agrees with Rosetta particle data

High time resolution makes boundary studies possible

[Edberg et al., *Planet. Space Sci.*, accepted, 2008]

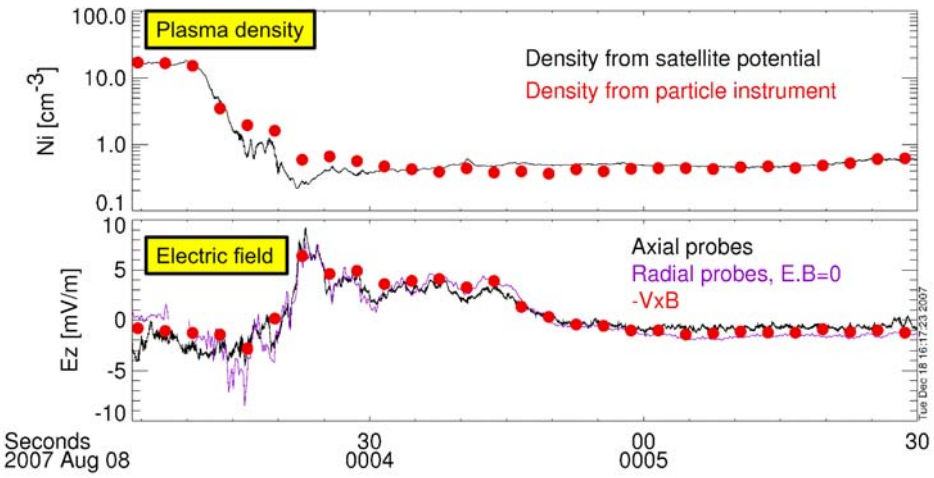
Dual probes as E-field instrument

- Rosetta E & B data at Earth
- Asymmetric booms, longest is 2 m
- Still reasonable E-field (correlate to B, only possible check)



Dual probes for E-field

THEMIS. Symmetric booms, length 3 m.



So where does SPINE enter?

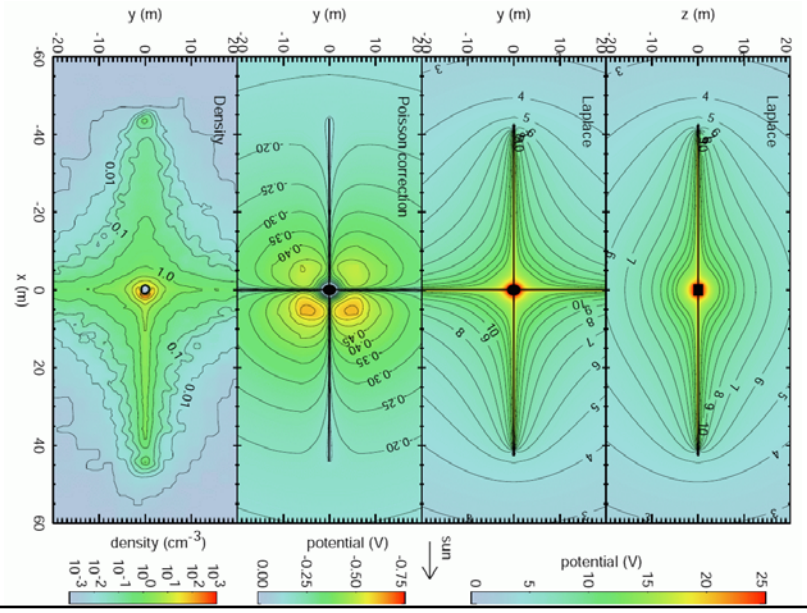
- Methods still improving
- Many issues to resolve, particularly for short booms on asymmetric s/c with varying attitude
- Improved understanding requires improved simulations
- Examples:
  - First-principles calibration of Vsc to actual plasma density for large and asymmetric s/c
  - First-principles calibration of measured Vps to actual Vsc for probes on short booms on large and asymmetric s/c
  - First-principles calibration of quasi-DC E-field (how?)

S/c potential: Work needed

- We want Vsc, which relates to ne reasonably simply
- The measured probe potential Vps relates linearly to Vsc: Vsc = a – b Vps
- Simulations needed to understand (establish analytic models for) effects of short booms on large asymmetric s/c

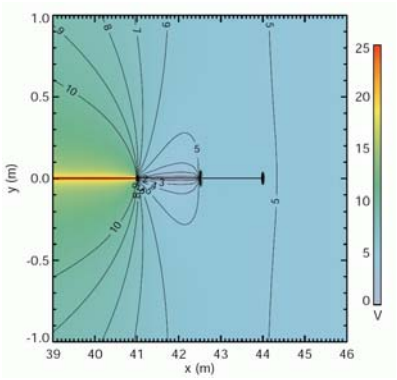
S/c potential simulations

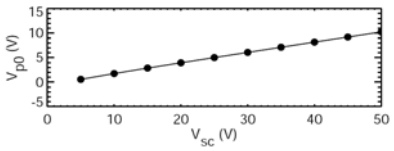
Cluster [Cully et al., *J. Geophys. Res.*, 2007]

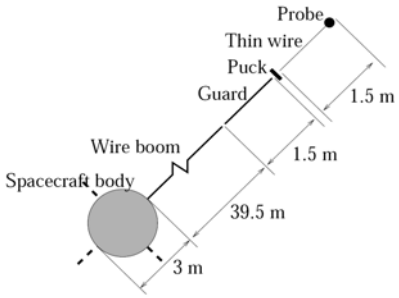


S/c potential: vacuum simulations

Cluster [Cully et al., *J. Geophys. Res.*, 2007]







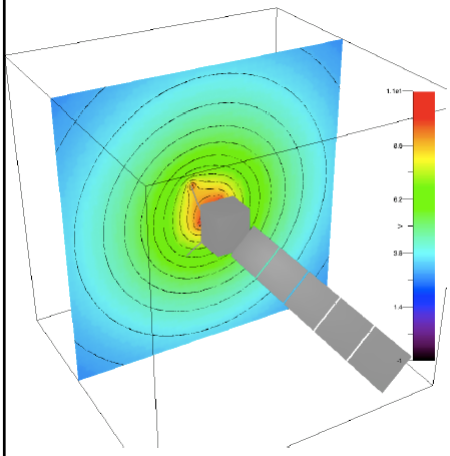
Previously:
Vsc = -Vps + 0.7 V

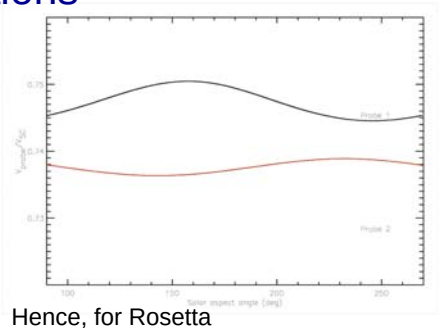
New result:
Vsc = -1.23 Vps + 0.7 V

Actual factor depends on geometry: For Rosetta LAP, see next slide…

S/c potential measurement: Rosetta vacuum simulations

Chris Cully, IRF Uppsala





Hence, for Rosetta
Vsc ≈ V0 – 4 Vps
where V0 is the potential drop over the probe sheath

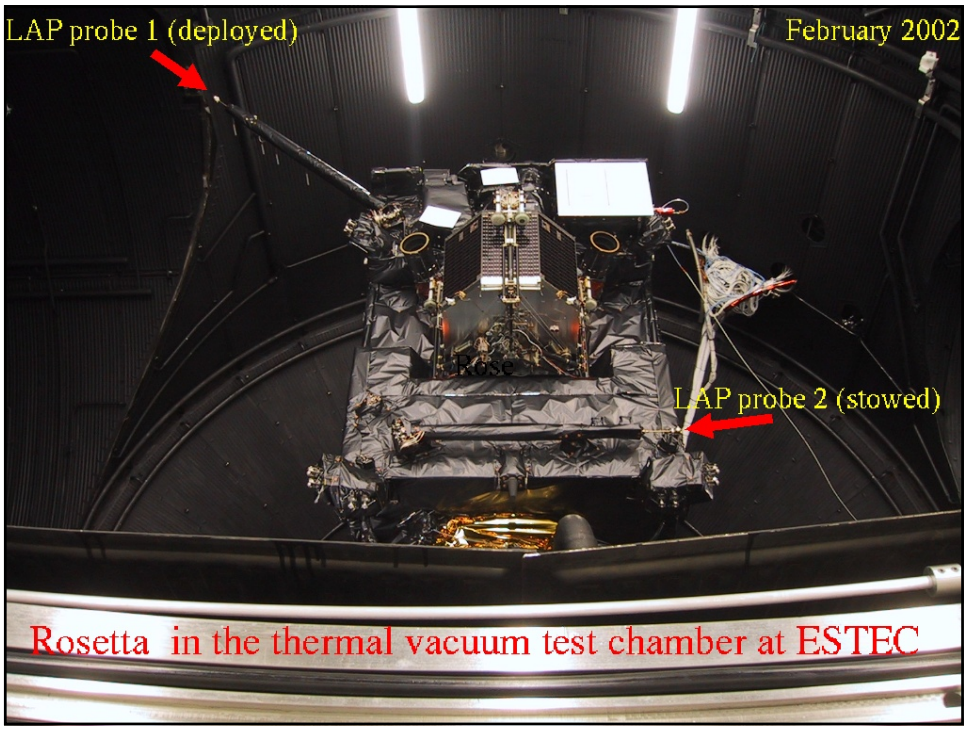
Observed attitude dependence show discontinuities apparently due to wake and/or inhomogeneous photoelectron cloud. Need plasma model!

Conclusions

- A dual LP instrument is very mass- and power-efficient for Laplace/Tandem/similar missions:
  - N, Te, v in dense plasmas
  - N from Vps in tenuous plasmas
  - LF E-field (10^{-1} – 10^{5} Hz)
  - Dynamics to ms timescale
- Method works well but often relies on empirical calibrations (e.g. density-Vps relation)
  - Increased understanding and better models for data reduction require theoretical and simulation work

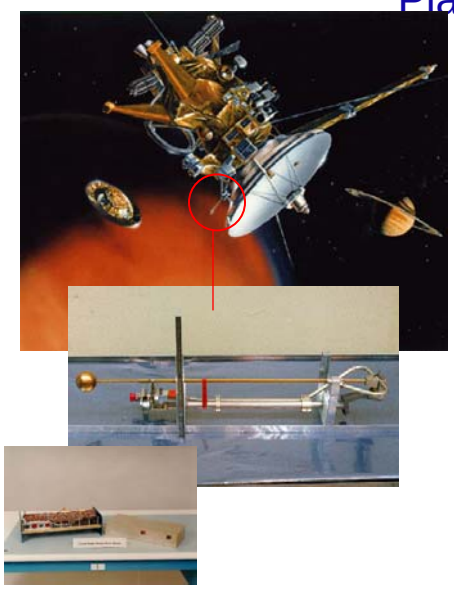
Dual Langmuir probe allows estimates of...

- ✔ cold plasma $n_e, T_e, |V_i|, <m_i>$
- ✔ total plasma density at high time resolution
  n=0.01-10⁶cc
- ✔ velocity of plasma structures by interferometry
  v<100km/s
- ✔ satellite potential
  allows corrections to particle measurements
- ✔ one component of electric field E
  allows measuring E at DC/LF frequencies covering ion gyrofrequencies, lower hybrid range.
- ✔ conductivity
- ✔ solar UV emission



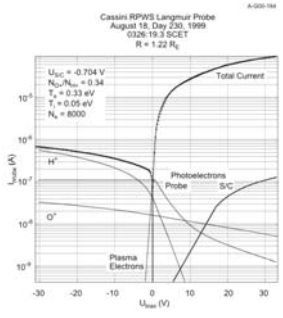
S/c potential: Total plasma density in tenuous plasmas

- S/c emits photoelectrons at constant rate…
- …and collects plasma e- in proportion to density n_e
- Current equilibrium sets V_{sc}, so that…
- $n_e = f(V_{sc})$
- Vsc best measured by electrostatic probes:
  - From bias voltage sweeps
  - Or from probe-to-s/c potential Vps for an E-field probe (bias current)



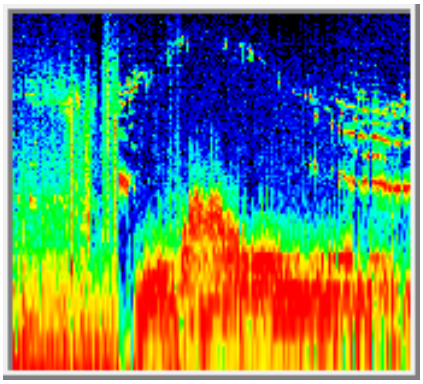
Cassini RPWS LP Measurements of Cold Plasma

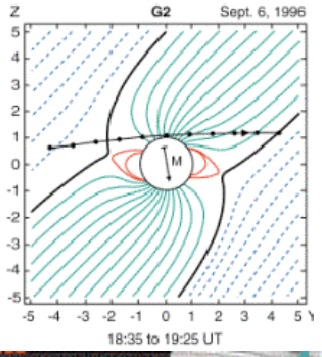
- The Langmuir Probe (LP)
  - TiN coated sensor (5 cm)
  - Voltage Sweeps +/-32 V
    - Every ~20 s
  - **High t-res.** N_e (fix U_{bias})
    - mostly 20 Hz [~300 m res.] at Titan
    - δN/N at 7 kHz
    - δN/N-"interferometry" using 2 antennas

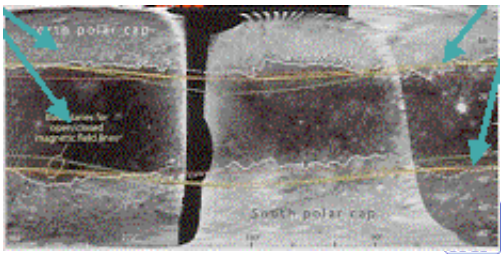


Ganymede

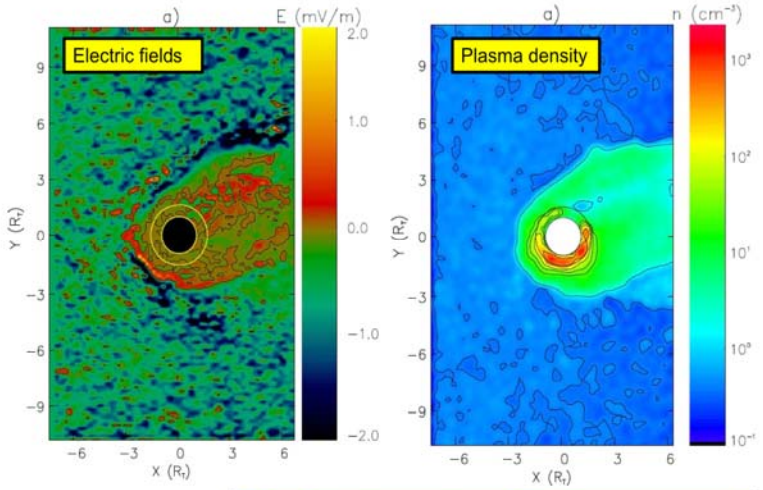
- … has an internal **B**-field (700 nT)
- Affects ionosphere dynamics
- Energetic particles reach surface near the poles
- Change surface ice properties







LP-PWI instrument can explore...



Also ... plasma temperature, velocity, plasma waves ...

Numerical simulations of Titan environment. Courtesy R. Modolo.

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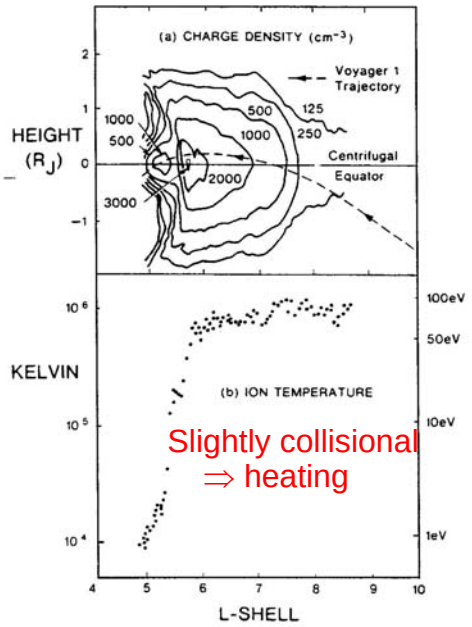
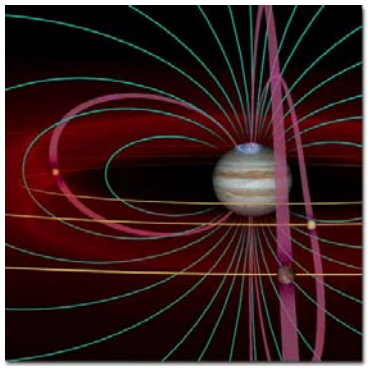
Io Plasma Torus





- Important plasma source
  - Exospheric SO_2 escape ⇒ ionization/dissociation ⇒ $q_i n_i(\mathbf{E}+\mathbf{B}\times\mathbf{v}_i)$ picked-up ⇒ supply 10^{28}-10^{29} ions/s ⇒ forms large torus

Science Objectives: Double-LP

- **(Exo-)Ionospheres: Structure, dynamics, sources, & losses**
  - Cold plasma profiles (Ne, Te, v_i, $<m_i>$) - aeronomical pathways
  - Ionization sources (particles, UV)
  - Sub-surface ocean outgasing from icy moons
  - Surface weathering processes (sputtering)
- **Energy deposition in Galilean ionospheres**
  - Magnetospheric particle impacts & solar UV radiation
  - Heating & cooling
- **Magnetosphere-Ionosphere interactions**
  - Dynamics, energy transport, atm erosion
  - Plasma waves (dn/n component)
  - Co-rotation speed determination (interferometry & sweep-slope)
- **A cold plasma monitor - never sent to Jupiter before**

S/c potential measurements

Principle:

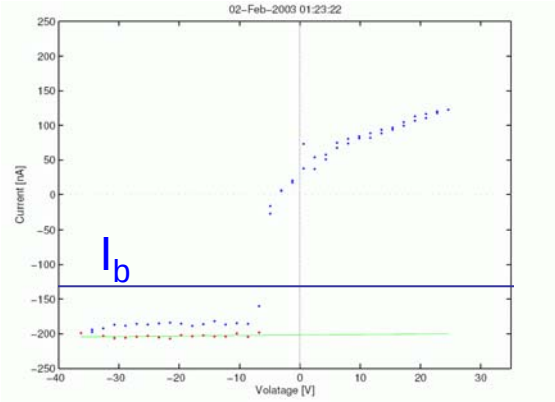
Bias current puts probe close to plasma potential

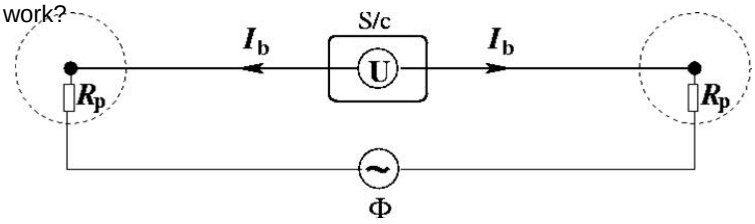
Measure probe-to-s/c voltage Vps

Only voltage drop over probe sheath remains to plasma

Vsc = -Vps + 0.7 V

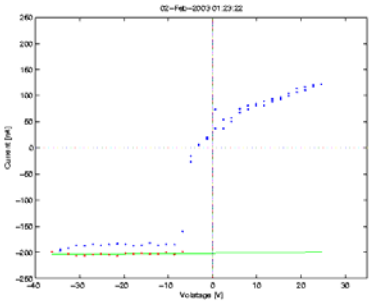
Does it work?

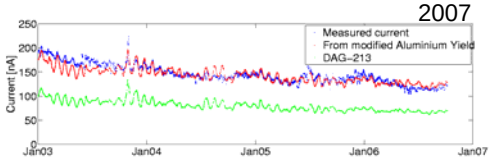


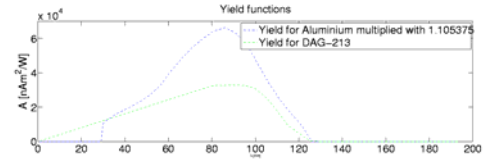


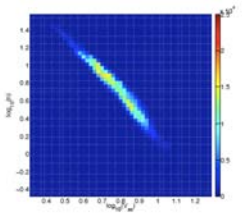
Density-Vsc relation and UV flux

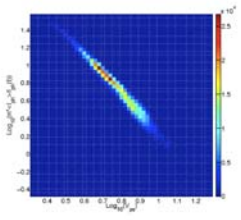
Winkler, student project, 2007











Cluster photoemission measured in bihourly bias sweeps

Can be used for calibrating the density-Vsc relation, decreases spread