Spacecraft-plasma interactions: low energy electron measurement perspective

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Outline

- Summary of effects of Spacecraft-Plasma Interactions on electron measurements
- SPIS: model validation and science data interpretation
- SPIS as a predictive tool for future missions

Summary of effects of Spacecraft-Plasma Interactions on electron measurements (1)

- Positively charged spacecraft
  - Attracts ambient electrons so that
    - measured energy > true energy in ambient plasma;
    - may also modify electron trajectory leading to error in measured direction
  - Surrounded by trapped spacecraft electrons
    - Photoelectrons and secondary electrons with energy < e Vsc
    - Photo/secondary electrons with energy > e Vsc may also enter instrument aperture “contaminating” measurement of ambient plasma
  - May have negatively charged wake
    - In Earth applications the wake perturbation is minimal
  - Spacecraft potential can often be estimated from the electron spectra

Summary of effects of Spacecraft-Plasma Interactions on electron measurements (2)

- Negatively charged spacecraft
  - Repels ambient electrons so that
    - measured energy < true energy in ambient plasma;
    - may also modify electron trajectory leading to error in measured direction
    - Ambient electrons with energy < eVsc are not measured, so if such electrons are present in the plasma, the complete characteristation of the electron plasma is not possible
  - Spacecraft potential cannot be estimated from the electron spectra

SPIS and data interpretation

At MSSL we have direct interests in electron data from

- Cluster (Double Star)
- VEX
- Cassini

SPIS and data interpretation: Cluster

- Spacecraft current balance and s/c potential
- Accurate measurement of spacecraft potential
- Particle trajectories in the vicinity of the spacecraft

SPIS and data interpretation: Cluster

- Spacecraft current balance and s/c potential
  - At the March 2010 SPIS meeting I proposed validation of SPIS current balance/spacecraft potential modelling using Cluster:
    - various plasma environments (recently altitudes of a few 100 km!)
    - eclipses with varying shadow depth
    - active experiments (ASPOC ion beam and EDI electron beam)
    - Potential can be estimated in all cases from PEACE and determined in a subset of cases from EFW
  - Can SPIS deal with all these cases?
    - The Prakash et al. 2007 study of Cluster showed some limitations, but perhaps present day SPIS is better adapted to modelling the Cluster case?
  - Can/will Cluster be used as a Test Case in 2011/2?

SPIS and data interpretation: Cluster

- Accurate measurement of spacecraft potential
  - At the March 2010 SPIS meeting I highlighted the usefulness of the Cully et al. 2007 model :
    - Method to assess true spacecraft potential from measurements made with probes that are not outside the Debye shielded region
    - Some tests against spacecraft potential estimates from PEACE spectra have been encouraging
    - Can todays' SPIS reproduce the Cully et al. result?

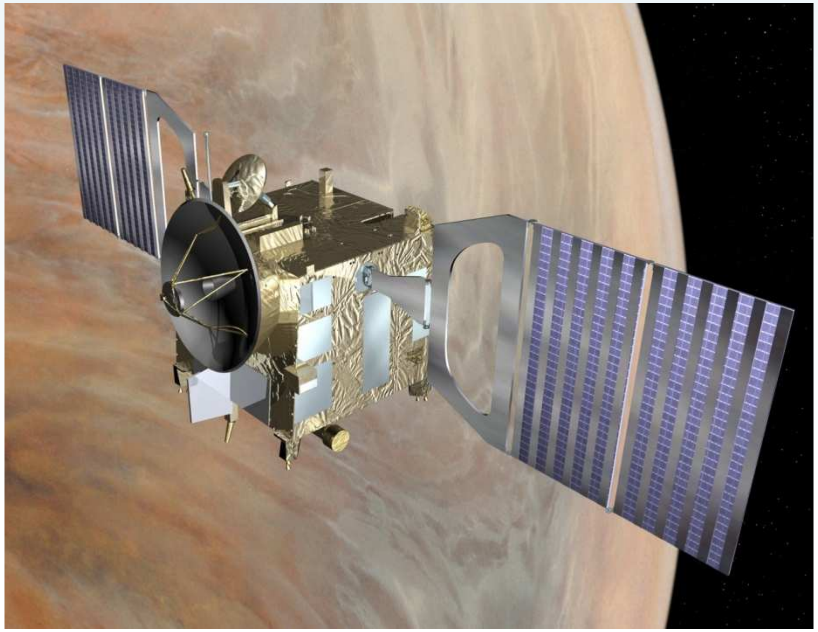
SPIS and data interpretation: Cluster

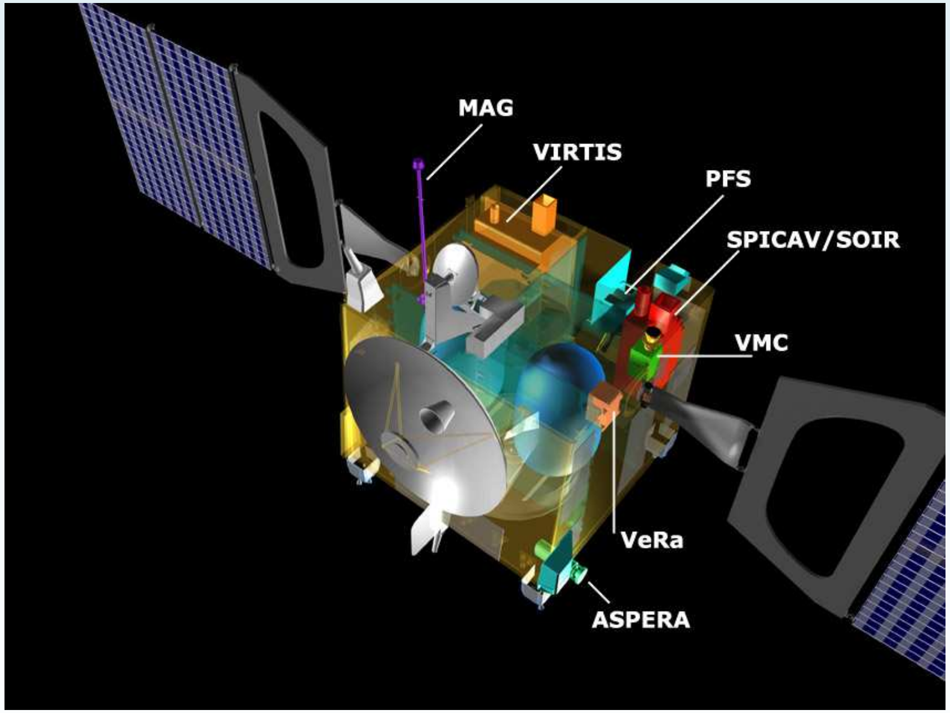
- Particle Trajectories
  - PEACE electron moments calculations assume that particle trajectories are not significantly bent by the potential near the spacecraft
    - Can SPIS backtracking be used to check when trajectory bending of ambient electrons might ever be important?
  - In-orbit tests of PEACE detection of photoelectrons from the EFW probes have been in progress:
    - Can SPIS backtracking be used to help with detailed interpretation of such data, and also of spacecraft electron behaviour within the "sheath"?

SPIS and data interpretation: Venus Express

- Spacecraft current balance and s/c potential

- VEX spacecraft
- Not coated with conductive surface tbc
- Large solar array wings

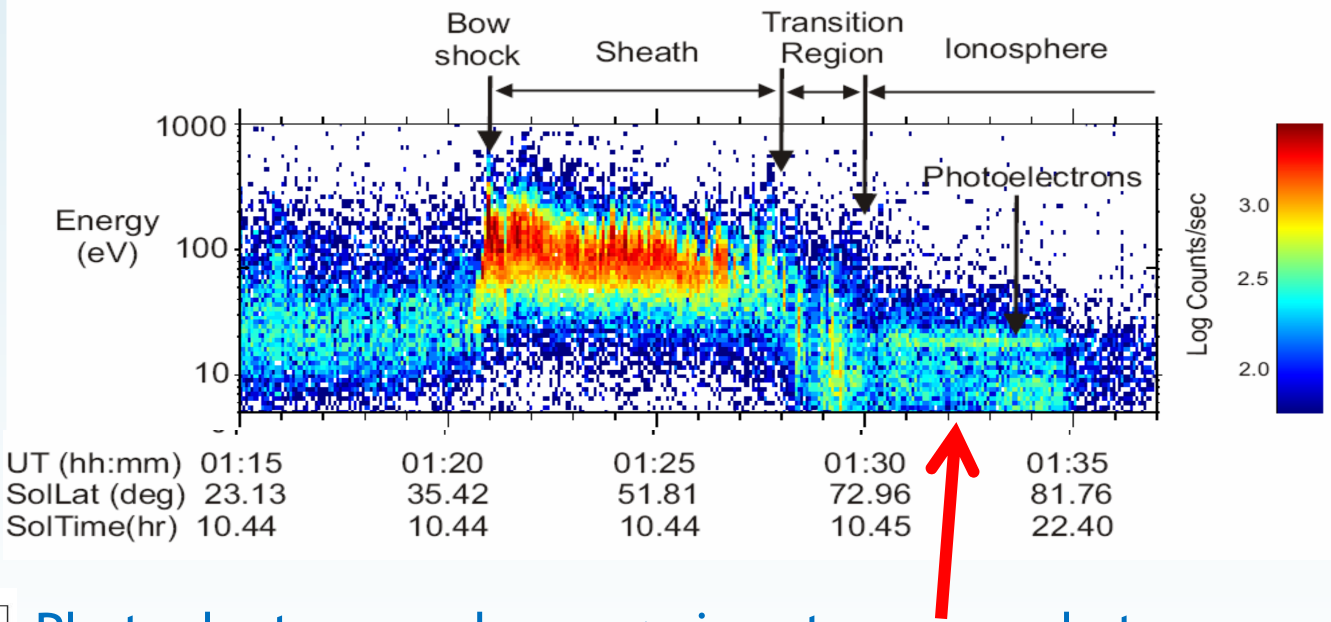


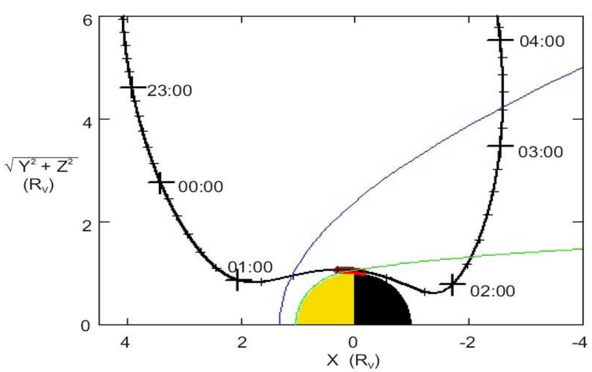


SPIS and data interpretation: Venus Express

- Spacecraft current balance and s/c potential

- VEX-Aspera4-ELS electron data
- A 22 minute interval centred on a **Venus Periapsis** (~200 km closest approach)
- Coates et al PSS 2008





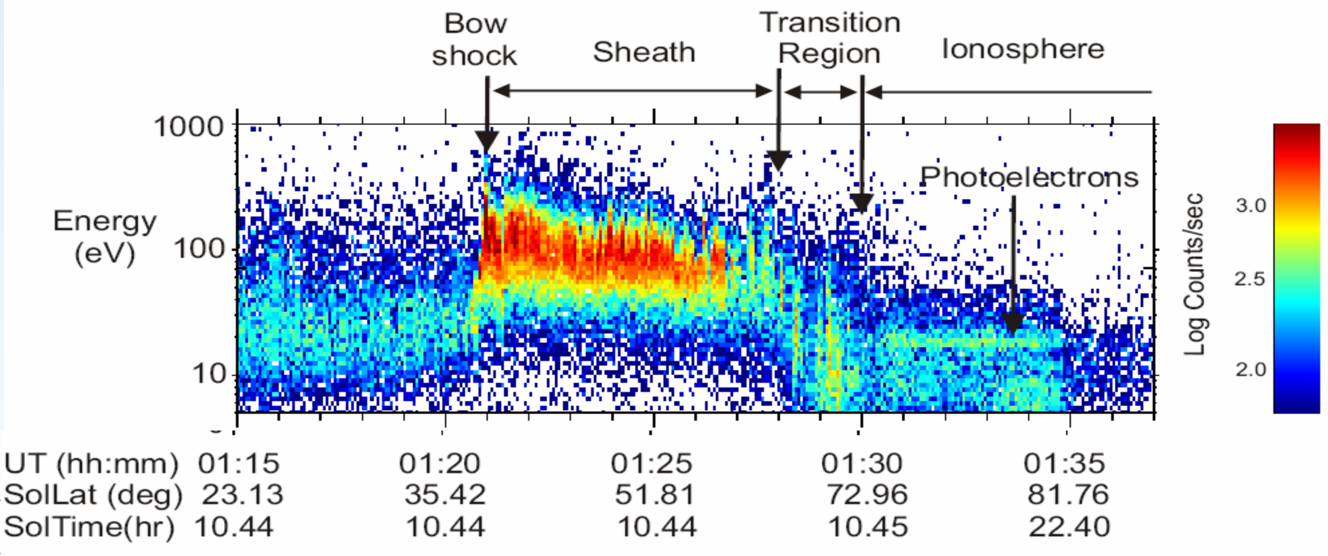
Photoelectron peak energy is not measured at expected value; implies that negative spacecraft potential despite strong sunlight. Infer high ionospheric electron fluxes.

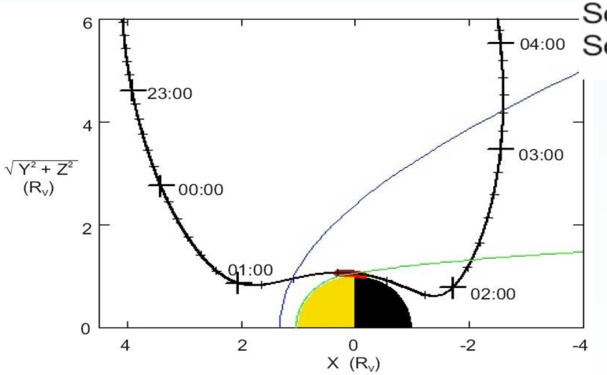
Can SPIS reproduce this potential behaviour accurately for a spacecraft like VEX?

SPIS and data interpretation: Venus Express

- Spacecraft current balance and s/c potential

- VEX-Aspera4-ELS electron data
- A 22 minute interval centred on a **Venus Periapsis** (~200 km closest approach)





VEX electron data is suspected of exhibiting variations between anodes due to effects of solar panel on measurements.

Can SPIS be used to investigate this possibility?

SPIS and data interpretation: Cassini

- See talk by Gethyn Lewis

SPIS : Predictive tool for new missions

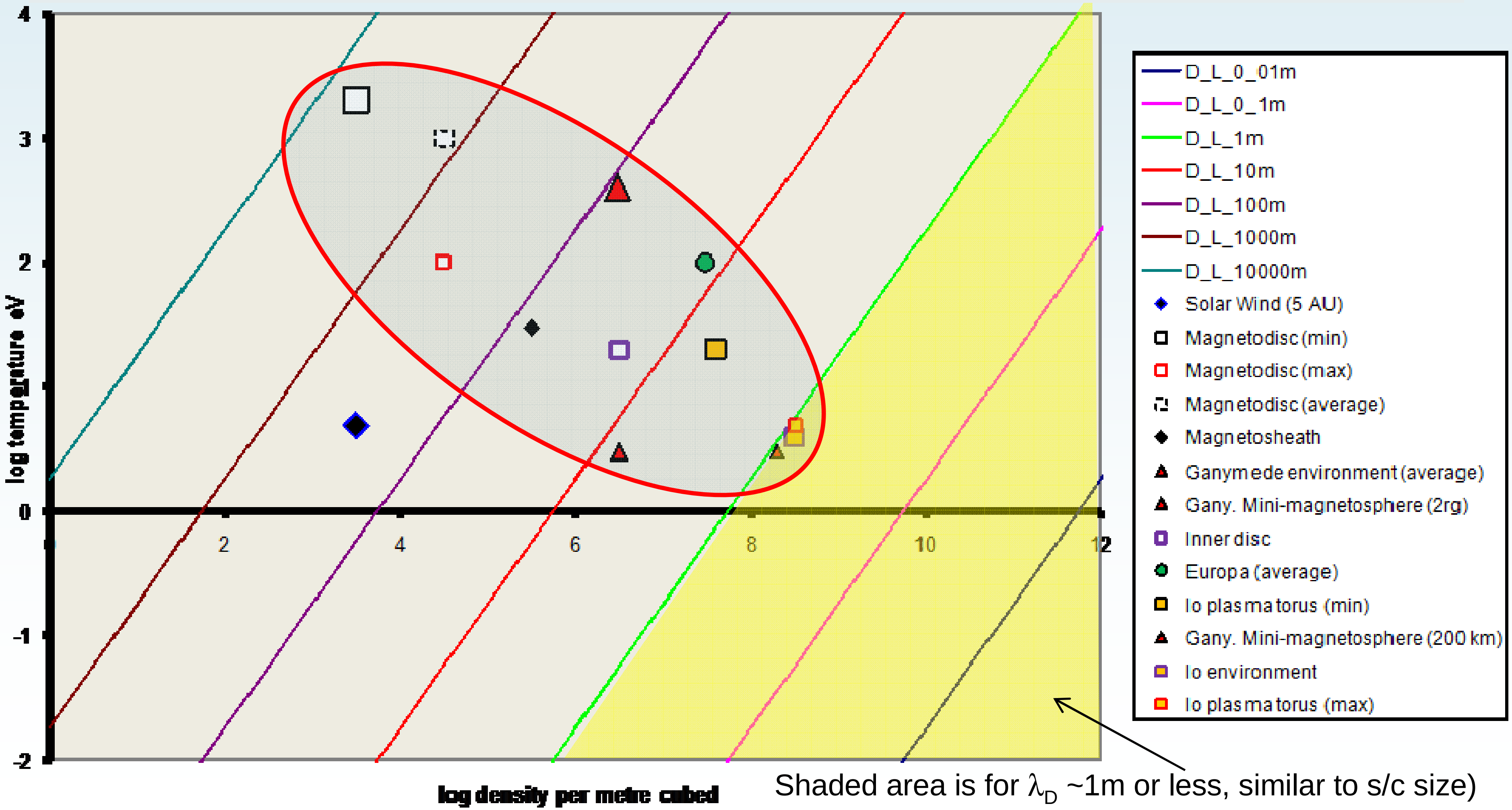
- Validation of SPIS using available datasets is desirable to inspire confidence in application to new missions
- New missions may require SPIS to be applied in parameter ranges outside those it was developed for

SPIS : Predictive tool for new missions

- Debye Lengths and missions of interest
  - SPIS User requirements should capture range of Debye Lengths of interest (in relation to s/c size, which is typically ~ metres)
  - The Debye lengths are often much larger than the spacecraft (highlights the wide relevance of the issue of how best to handle this in SPIS)

SPIS : Predictive tool for new missions

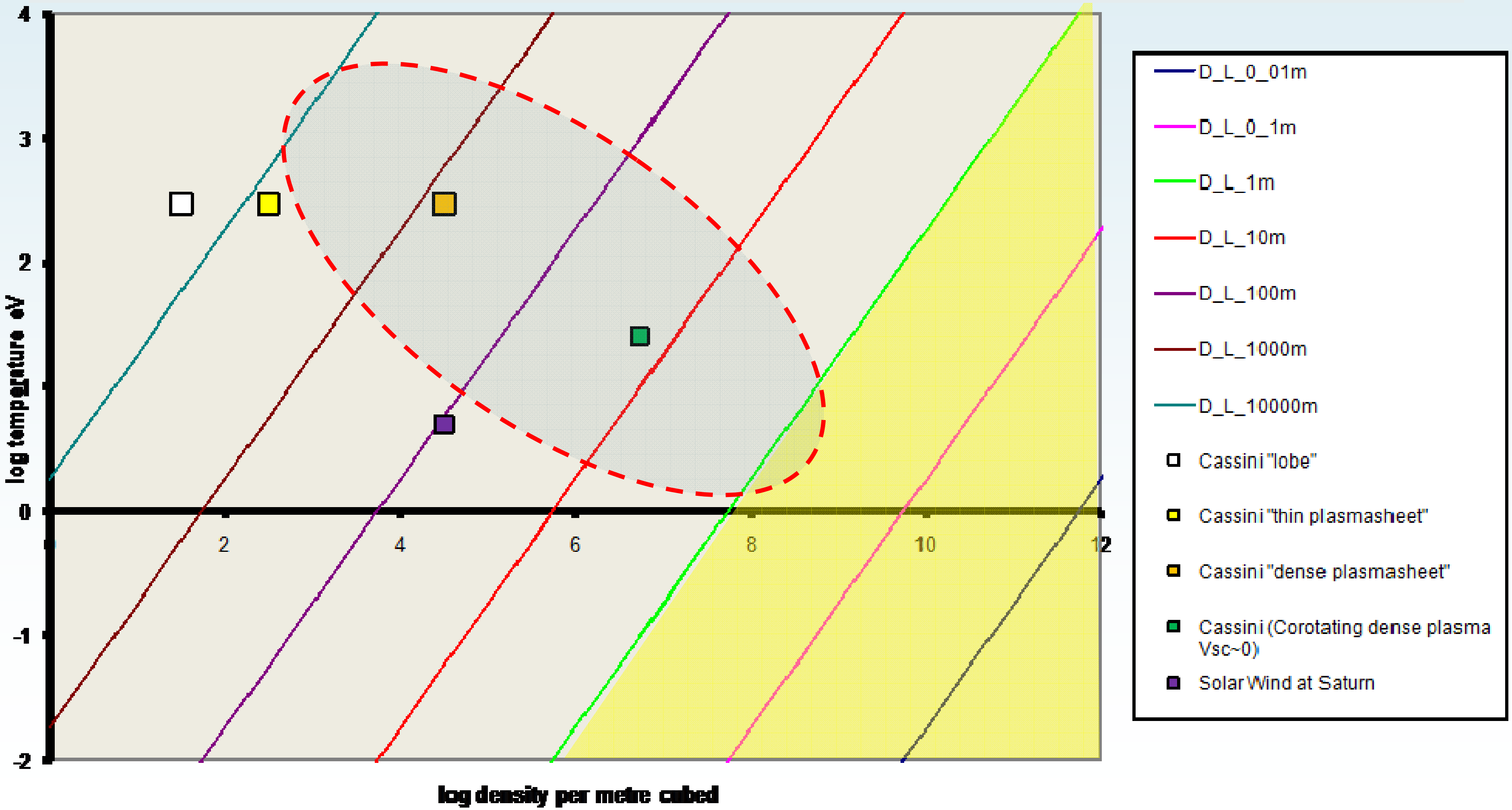
- Debye Length Ranges: Jupiter missions



Shaded area is for λ_D ~1m or less, similar to s/c size)

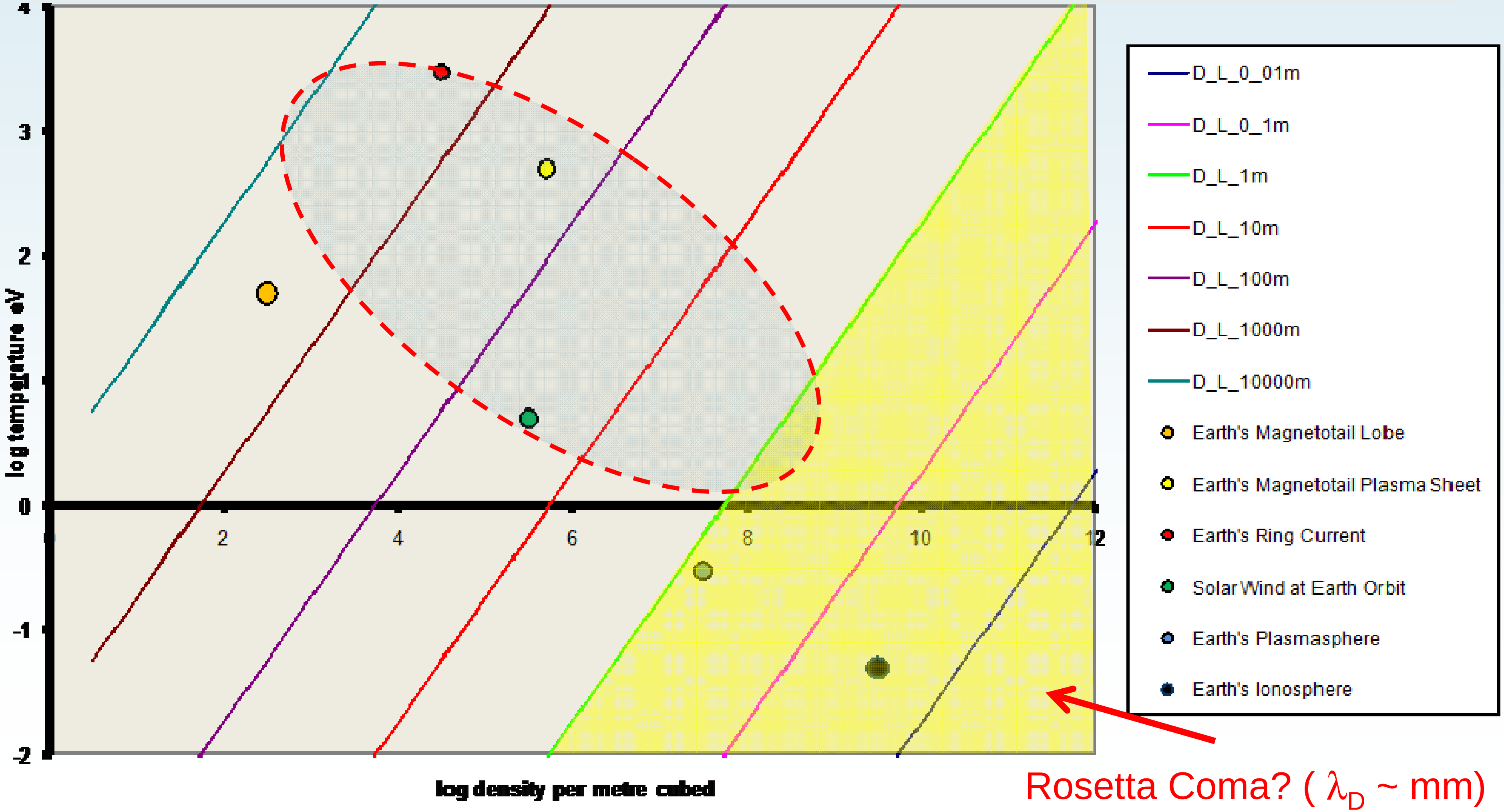
SPIS : Predictive tool for new missions

- Debye Length Ranges: Saturn missions



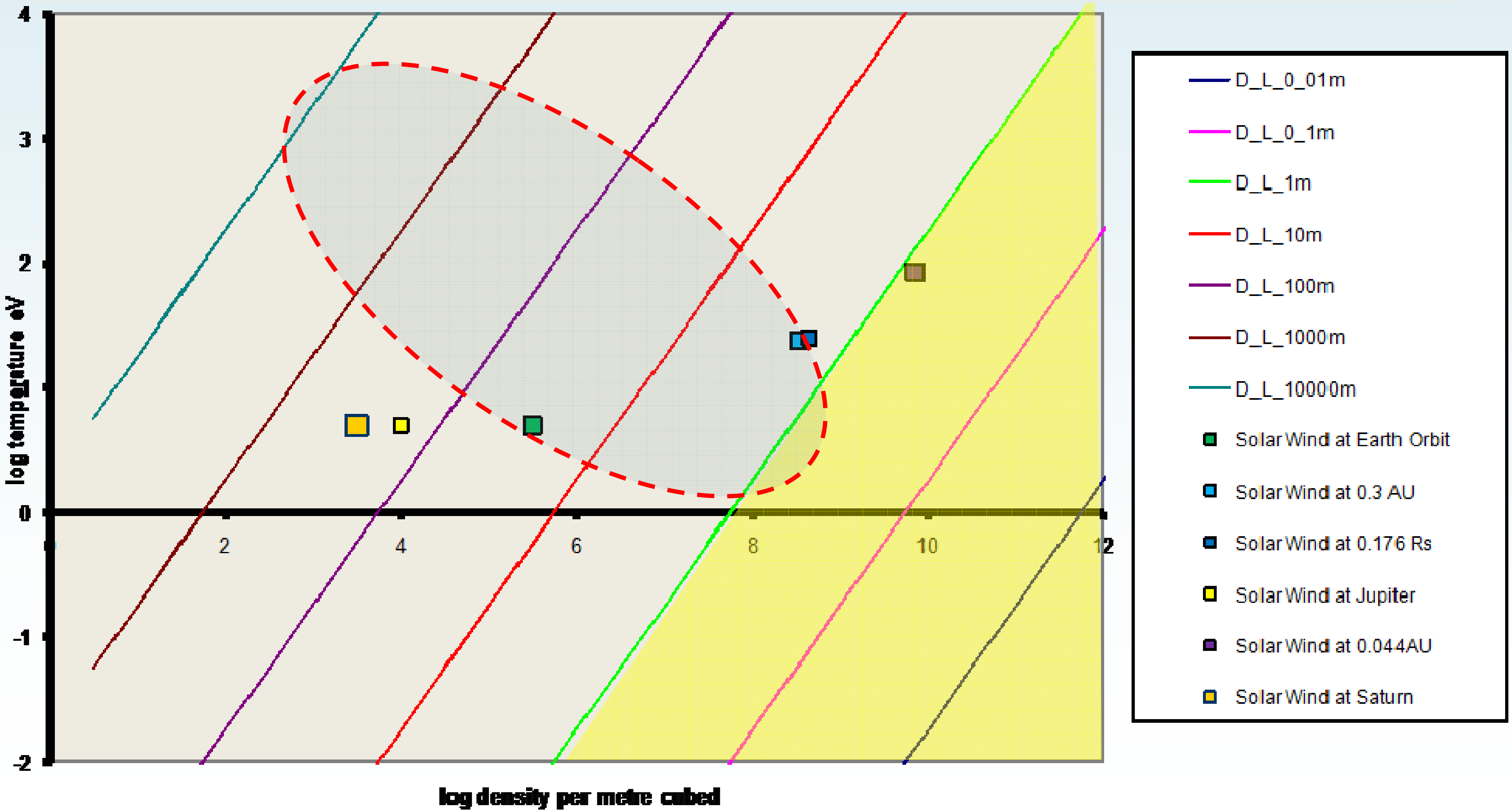
SPIS : Predictive tool for new missions

- Debye Length Ranges: near Earth missions



SPIS : Predictive tool for new missions

- Debye Length Ranges: Solar Wind missions



SPIS : Predictive tool for new missions

- Plasma Wakes and missions of interest

  - SPIS User requirements should capture range of wake conditions of interest (I didn’t try to make a start on that!)

SPIS : Predictive tool for new missions

- Plasma Wakes and missions of interest
  - SPIS User requirements should capture range of wake conditions of interest (I didn't try to make a start on that!)
  - Wakes in solar wind and polar outflow regions of magnetosphere have been studied by IRF group to interpret Cluster data (some use made of SPIS).
  - Little impact expected for Cluster electron observations in the solar wind, though E-field measurements by EFW are affected to some extent (Eriksson et al, Proc 10^{th} Spacecraft Charging Technology Conference, 2007)

SPIS : Predictive tool for new missions

- Plasma Wakes, Solar Orbiter and Solar Probe +

- SWA-EAS is a low energy electron instrument on a 4 m boom behind the spacecraft
  - Ergun et al 2010 modelling for Solar Probe Plus (see “*Spacecraft Charging and ion wake formation in the near-Sun environment*” Phys. Plasmas July 2010) also raises questions about potential environment of boom mounted electron instrument for Solar Orbiter – quite strongly negatively charged wake - may it sometimes prevent good measurements of low energy core solar wind population?
- We need simulations for distances visited by Solar Orbiter for average and extreme solar wind conditions to assess the range of possible negative values of potential in the spacecraft ion wake – important for the Solar Orbiter EAS design work

Plasma Wakes and Solar Orbiter

- Photoelectron emission and collected (thermal) electron current scale roughly as $1/R^2$, so one may expect small positive spacecraft potentials again, but…
- Debye lengths go as $1/R$
- Characteristic energy of photoelectrons and secondary electrons is fixed
- The (negative) potential of an ion wake is expected to be larger than at 1 AU

Helios spacecraft charging at 0.3 AU

- Interpretation of certain Helios charging data was in terms of a deep wake potential and significant electrostatic barriers due to spacecraft photoelectrons

- Results from simulation of Helios-solar wind interactions, from

  Isensee and Maassberg, Adv Space Res, 1, p413-6, 1981.

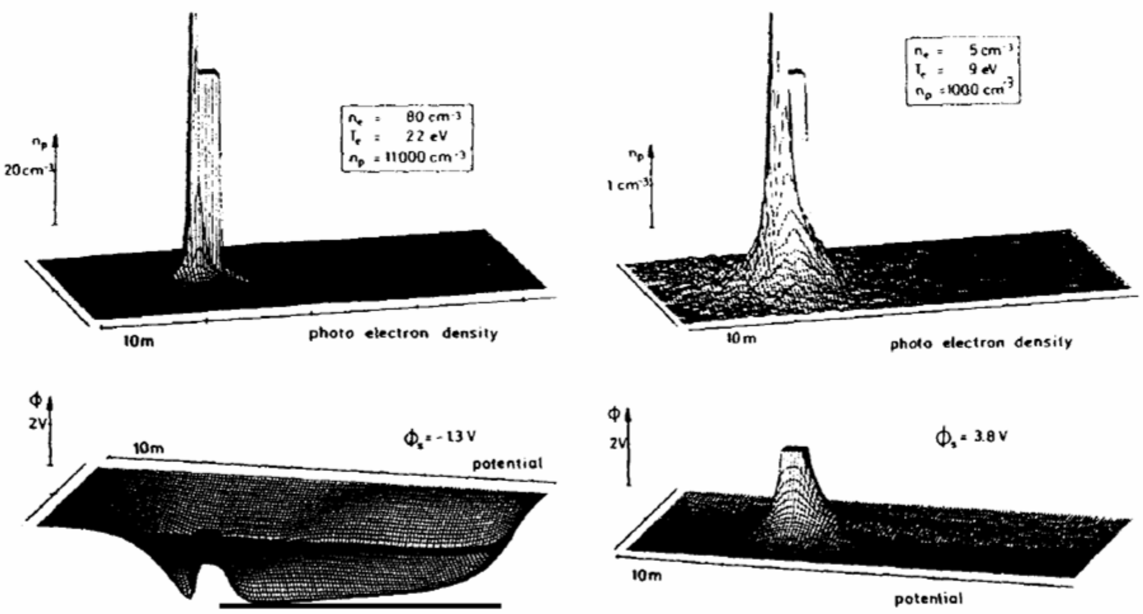


Fig. 1 (O.3 AU) Fig. 2 (1.O AU)

Results from the numerical simulation. The probe with potential ϕ_S is shown by the squares in the middle of the perspective representations. The solar wind is streaming from the left.

Conclusion

- I would be interested to see (and hopefully participate in) work to validate the newly upgraded versions of SPIS against Cluster data
- I would be interested to also see how well SPIS can reproduce potential observations for the similar (but different enough to be a test) case of Double Star, and less similar VEX spacecraft

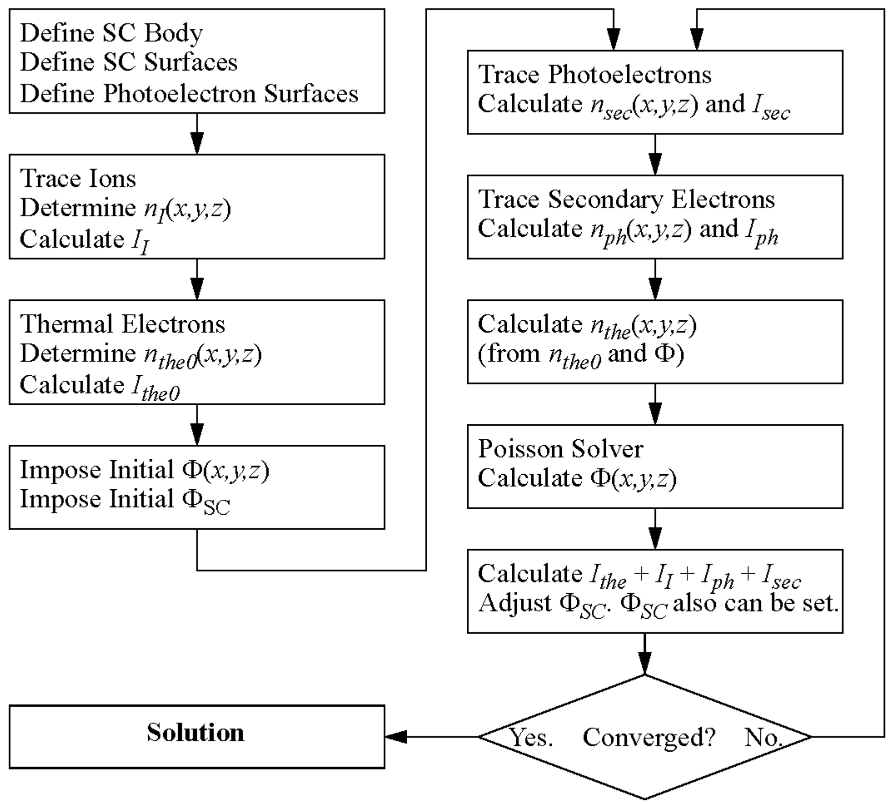
- We would be very keen to see timely application of SPIS to Solar Orbiter, not only at 1 AU (e.g. validation against STEREO) but in particular at perihelion distances and for a realistic range of solar wind conditions there (possible validation against Helios?).

p.s.

- How about modelling Cluster thruster gasses? (they clearly affect PEACE MCPs)
- How about SPIS-DeepCharging for investigating disturbances on the Doube Star spacecraft?

Ergun et al. Simulation - Introduction

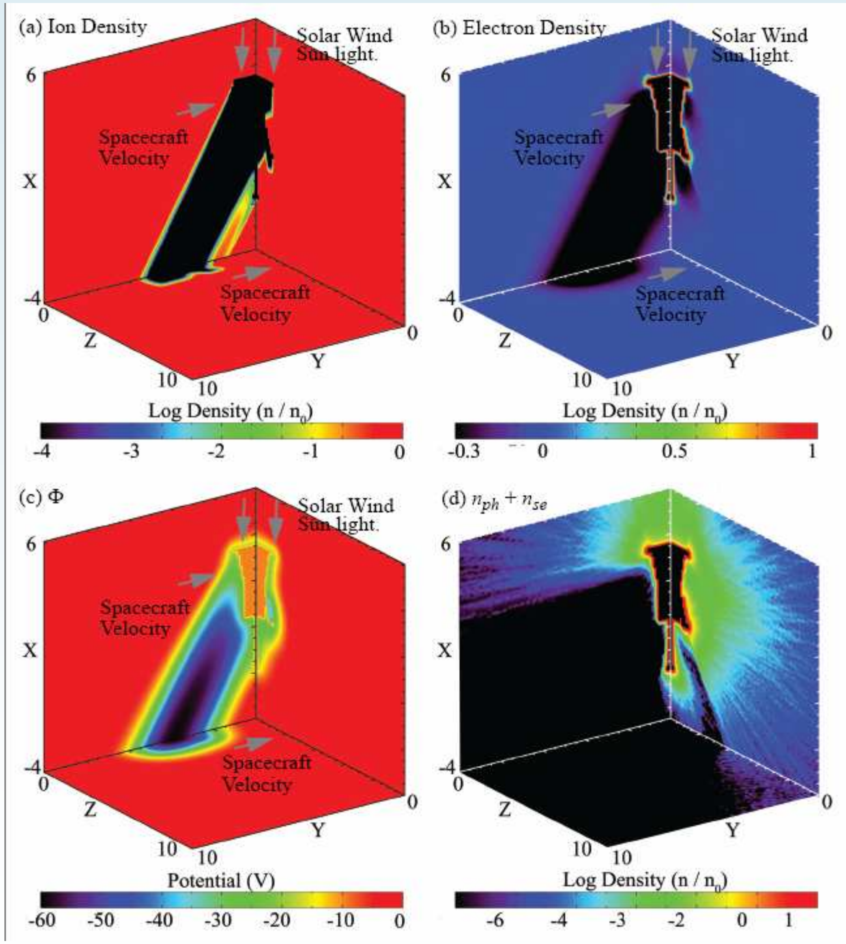
- Full 3-D Poisson solver and particle tracing self-consistent code
- Includes
  - ion wake,
  - Debye shielding,
  - secondary electron emission
  - photoelectron emission
- Similar to earlier work on simulating Cluster
- For Solar Probe Plus used a conducting spacecraft with non-conducting solar arrays



3D Simulation for 9.5 Rs = 0.044 AU (summary)

- Looked at 9.5 Rs (for Solar Probe +)
- Use n = 7,000 cm^{-3}; T_e = 85 eV, T_i = 82 eV, Rsc~1m, λ_{Dph}=0.15m (Rsc >> λ_{Dph})
- Use Vsw = 300 km/s, Vsc = 180 km/s

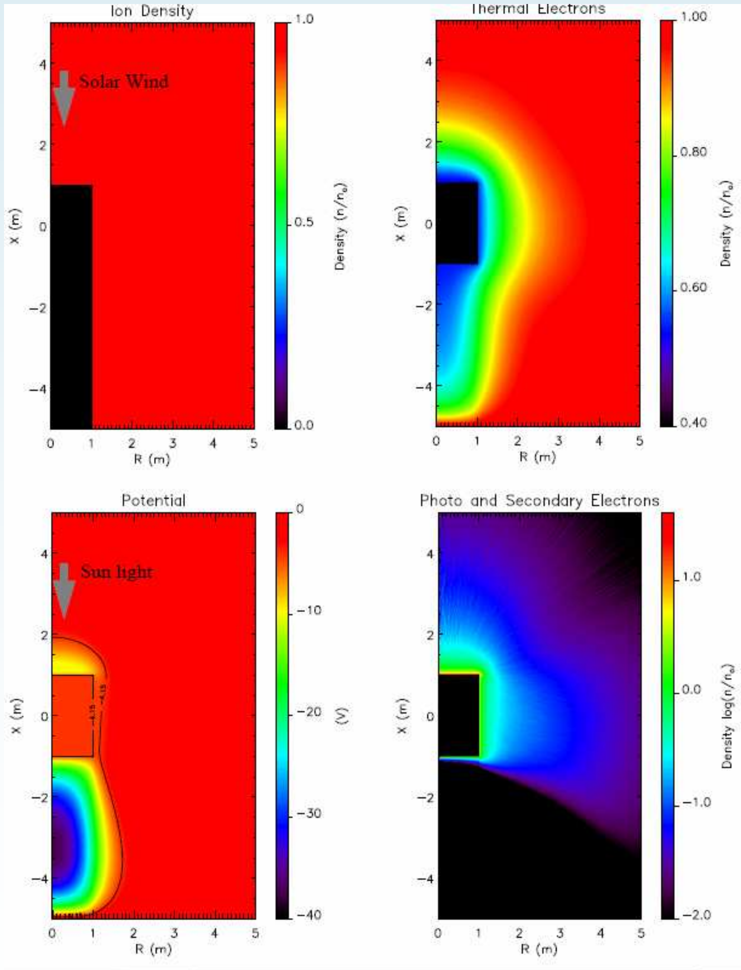
- Wake potential < -60 V
- Wake scale size (>2 m) > Debye length for thermal electrons (λ_{De} = 0.82 m anf)
- A few eV negative potential layer surrounds the spacecraft – thickness ~ λ_{De}: the lower energy (few eV) photoelectrons and secondaries are trapped near the spacecraft. The wake potential reflects all secondaries.



Distances in m. Spacecraft represents SP+

3D Cyl Simulation for 9.5 Rs = 0.044 AU

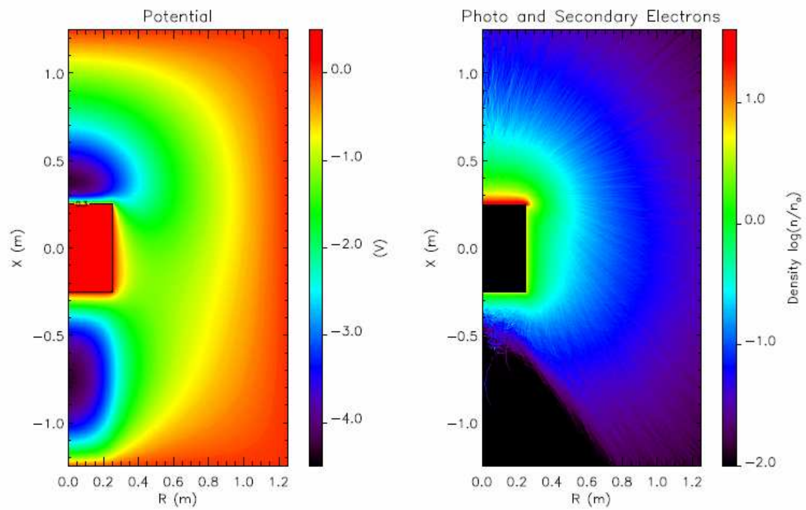
- Looked at 9.5 Rs (for Solar Probe +)
- Use n = 7,000 cm^{-3}; T_e = 85 eV, T_i = 0 eV
- Use Vsw = 300 km/s, Vsc = 0 km/s
- Rsc~1m, λ_{Dph}=0.15m (Rsc >> λ_{Dph})
- S/c Potential = - 4.15 V
- Wake potential ~ -37 V (extreme value)
- Wake scale size (>2 m) > Debye length for thermal electrons (λ_{De} = 0.82 m anf)
- Secondaries can't escape from top or bottom (less extreme than in previous figure so less negative spacecraft potential here)



Distances in m. Spacecraft represents SP+

3D Cyl Simulation for 9.5 Rs, but s/c size/4

- Looked at 9.5 Rs (for Solar Probe +)
- Use n = 7,000 cm^{-3}; T_e = 85 eV, T_i = 0 eV
- Use Vsw = 300 km/s, Vsc = 0 km/s
- Rsc~0.25m, λ_{Dph}=0.15m (Rsc ~ λ_{Dph})
- S/c Potential = + 0.3 V
- Interpretation: If Rsc >> λ_{Dph} as for full size SP+ spacecraft, trapped photoelectrons form a high flux negative charge layer which traps secondaries. Photoelectron and secondary electron currents are reduced, affecting current balance in favour of –ve spacecraft potential. Hotter plasma electrons can cross the barrier to charge the s/c -ve. Similarly the -ve wake.



Distances in m.

Simulation for 38 Rs = 0.176 AU (summary)

- Looked at 38 Rs (part way to 0.28 AU)
- Use n = 440 cm^{-3}; T_e = 25 eV,
- Use Vsw = 300 km/s
- (Rsc ~ λ_{Dph})
- Wake potential < -3 V (tbc) at 4m in –X dir'n
- wake scale size (>2 m) > Debye length for thermal electrons (λ_{De} = 1.8 m)
- Spacecraft potential ~ 2.9 V
- A few eV negative potential layer sunward of the spacecraft – thickness ~ λ_{De}: photoelectrons and secondaries are not trapped near the spacecraft (can exist to the sides). The wake potential reflects some secondaries.