SPIS simulations of Langmuir Probes on Cassini and Rosetta

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Work done with two project students, Alex Sjögren (Rosetta) and Thomas Nilsson (Cassini), and Chris Cully

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SPINE meeting, Toulouse, Sep 28-29, 2009

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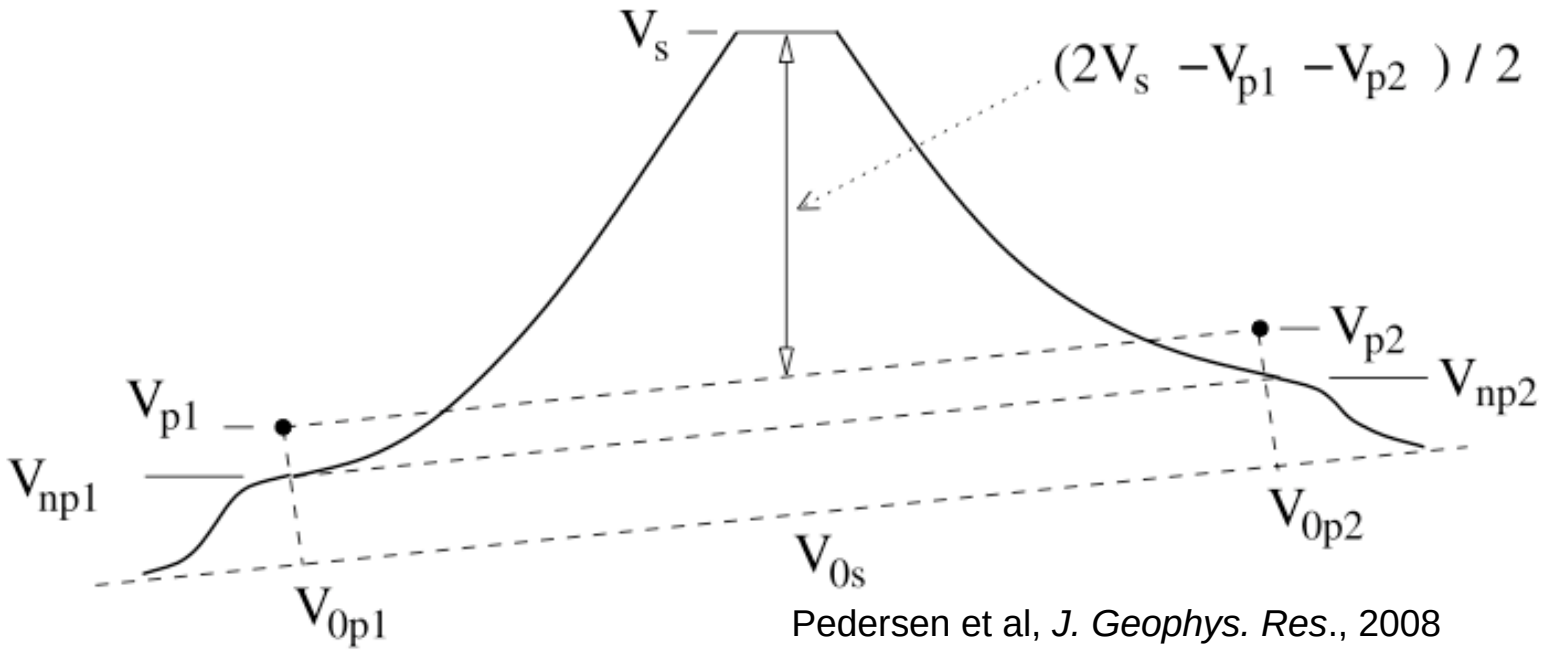
Outline

- Probe measurements
- Cassini simulations
- Rosetta simulations
- Conclusions & outlook

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

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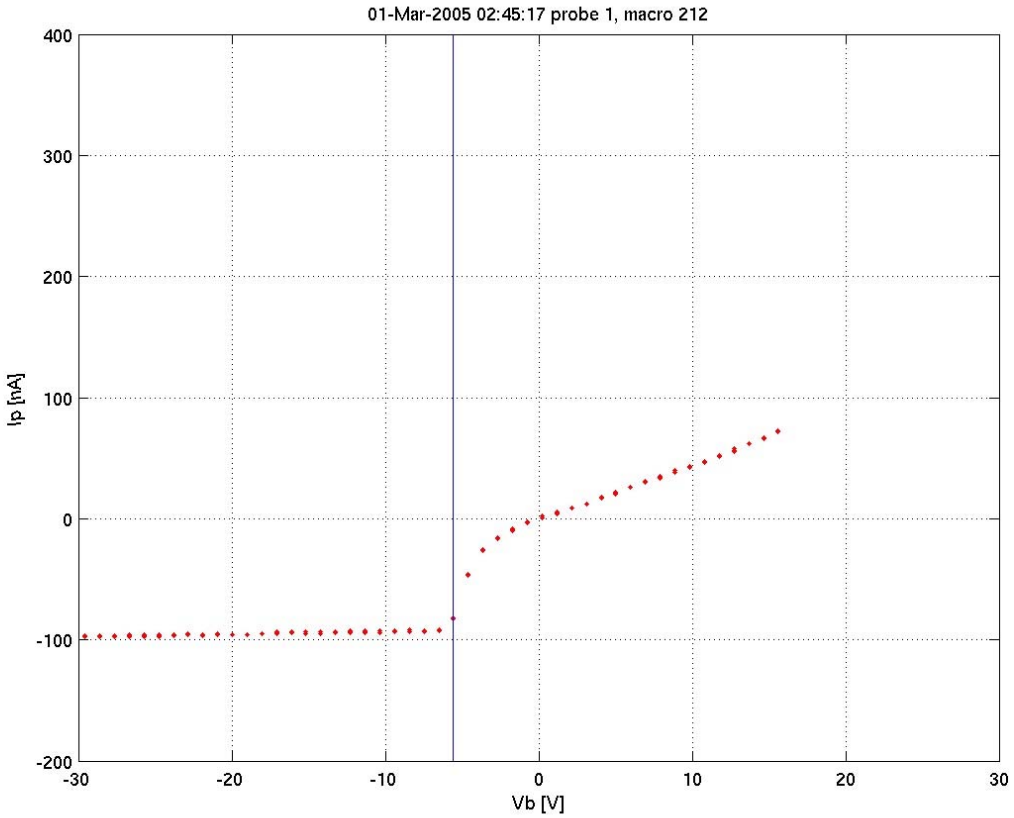
Vsc from electrostatic probes

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



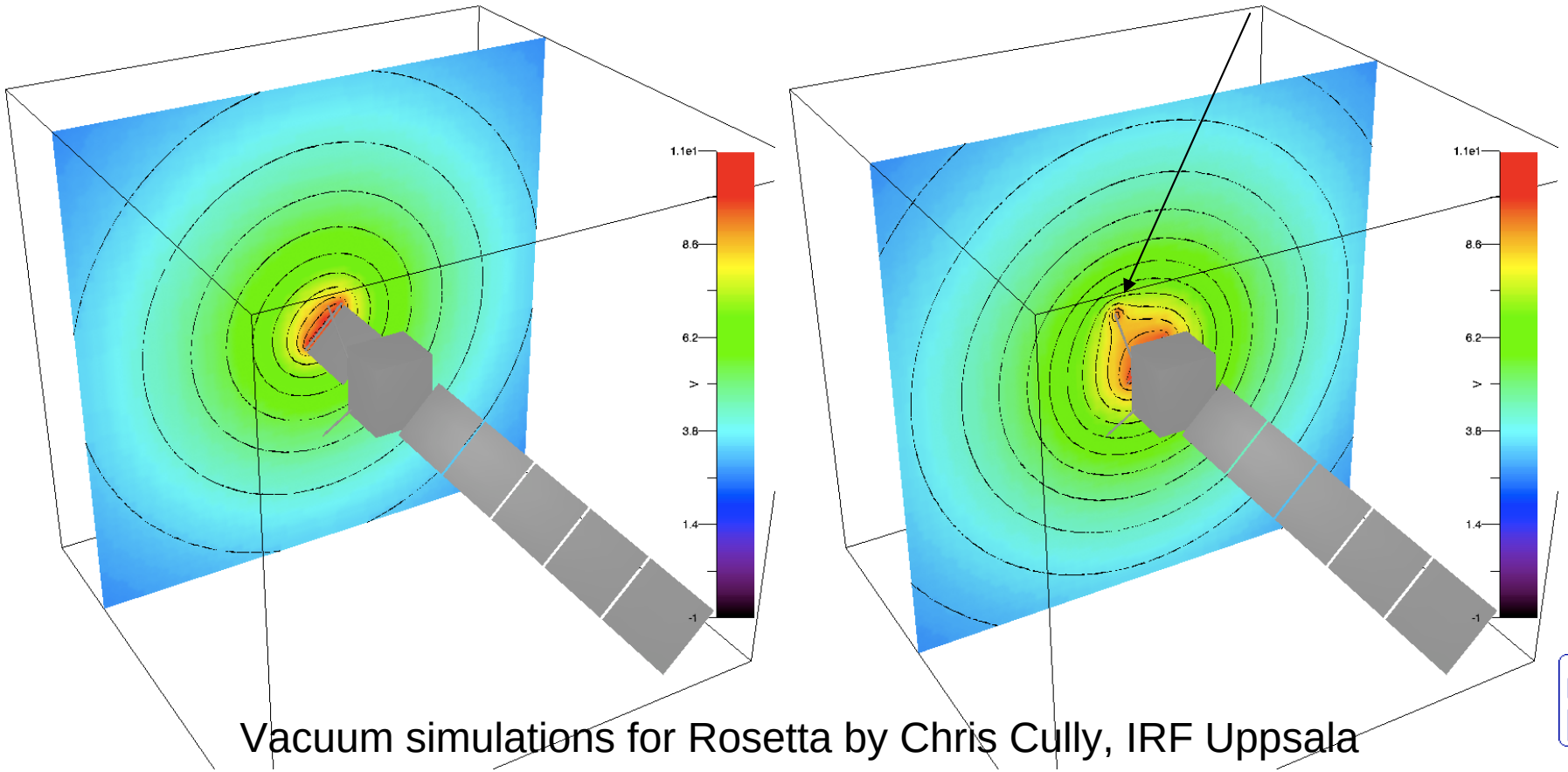
Rosetta RPC-LAP data

1st Earth swing-by

Probes on short booms

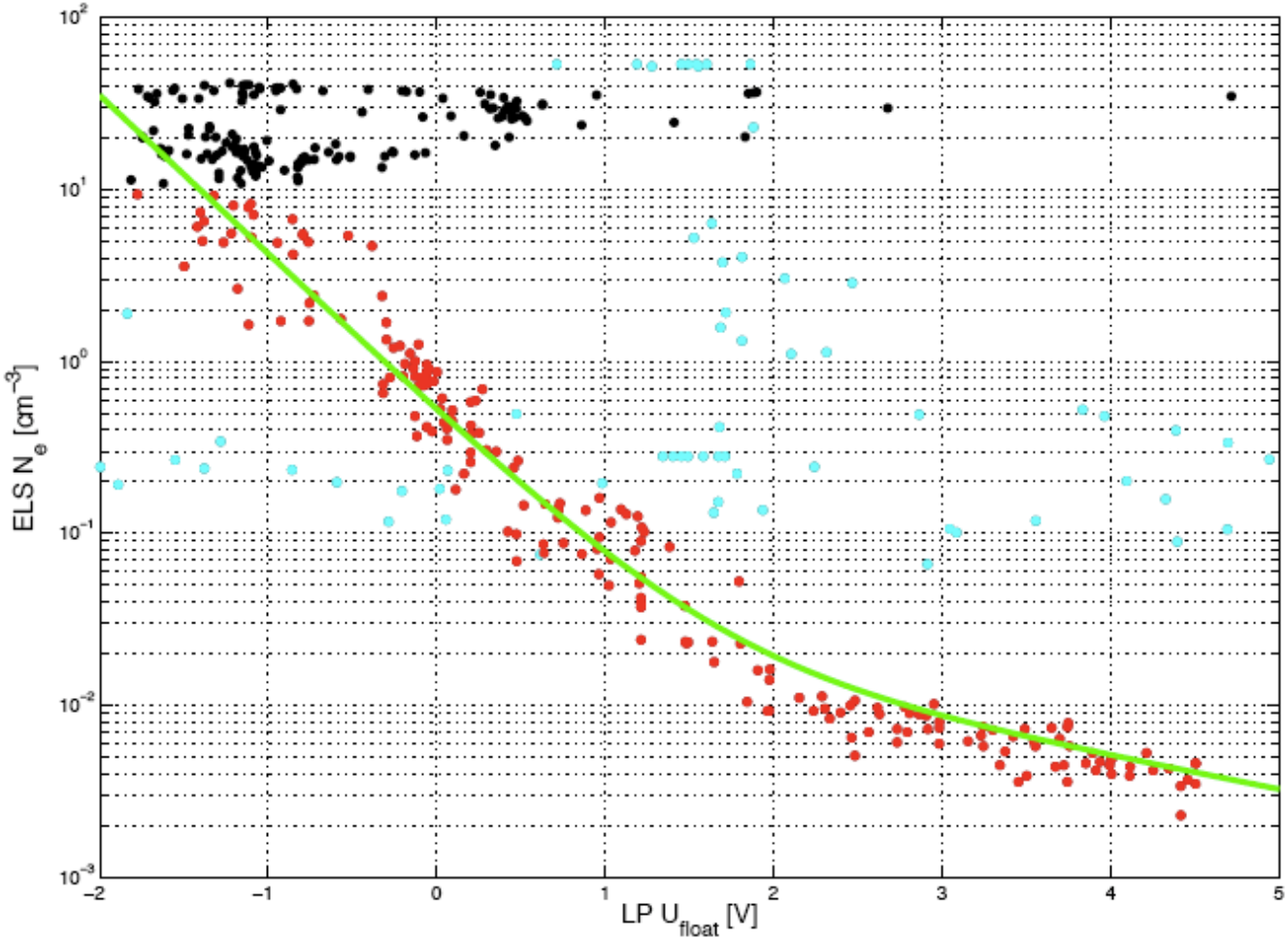
The shorter the boom length is relative to s/c size and Debye length, the more remains of the s/c potential at probe position => smaller fraction of Vsc is measured

Langmuir probe on boom



Vacuum simulations for Rosetta by Chris Cully, IRF Uppsala

Saturn Vps-density relation



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

Morooka et al., *Ann. Geophysicae,* 2009

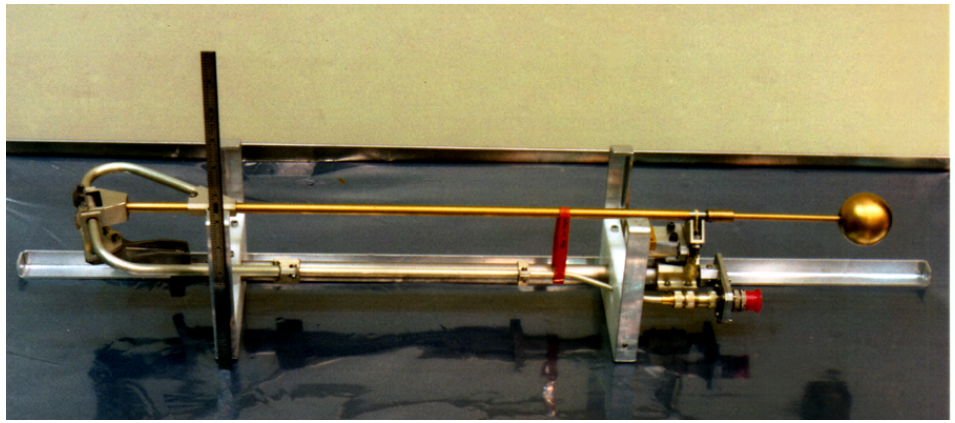
Cassini SPIS simulations

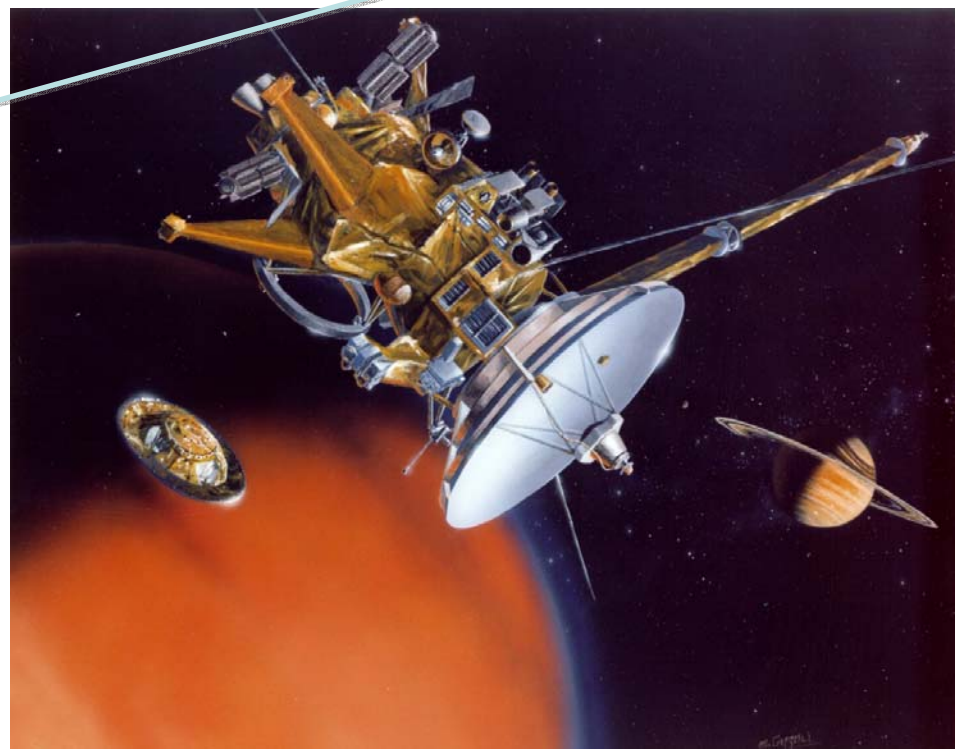
Thomas Nilsson

- Two problems studied:
  - How does the Cassini s/c affect Langmuir probe Vsc measurement?
  - How does the connecting parts (the “stub”) between s/c and the Langmuir probe affect the LP measurements?

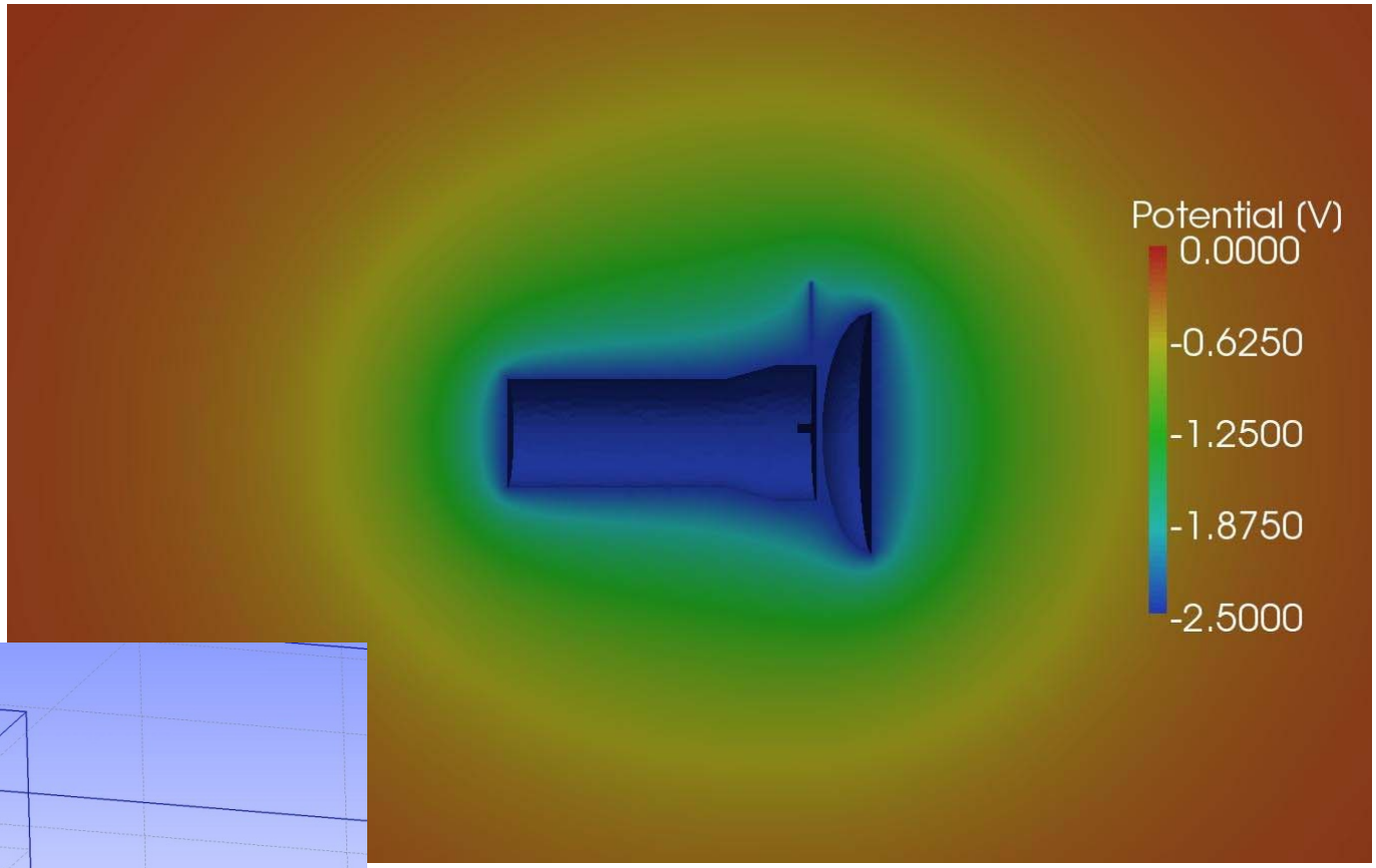
Cassini LP

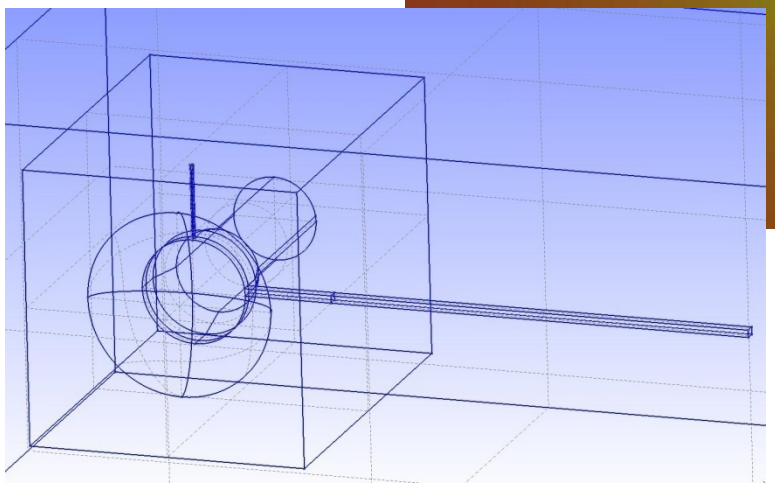
- Probe radius 50 mm
- Stub length 109 mm
- Boom length 1.5 m
- S/c size ~5 m





Cassini s/c potential simulations





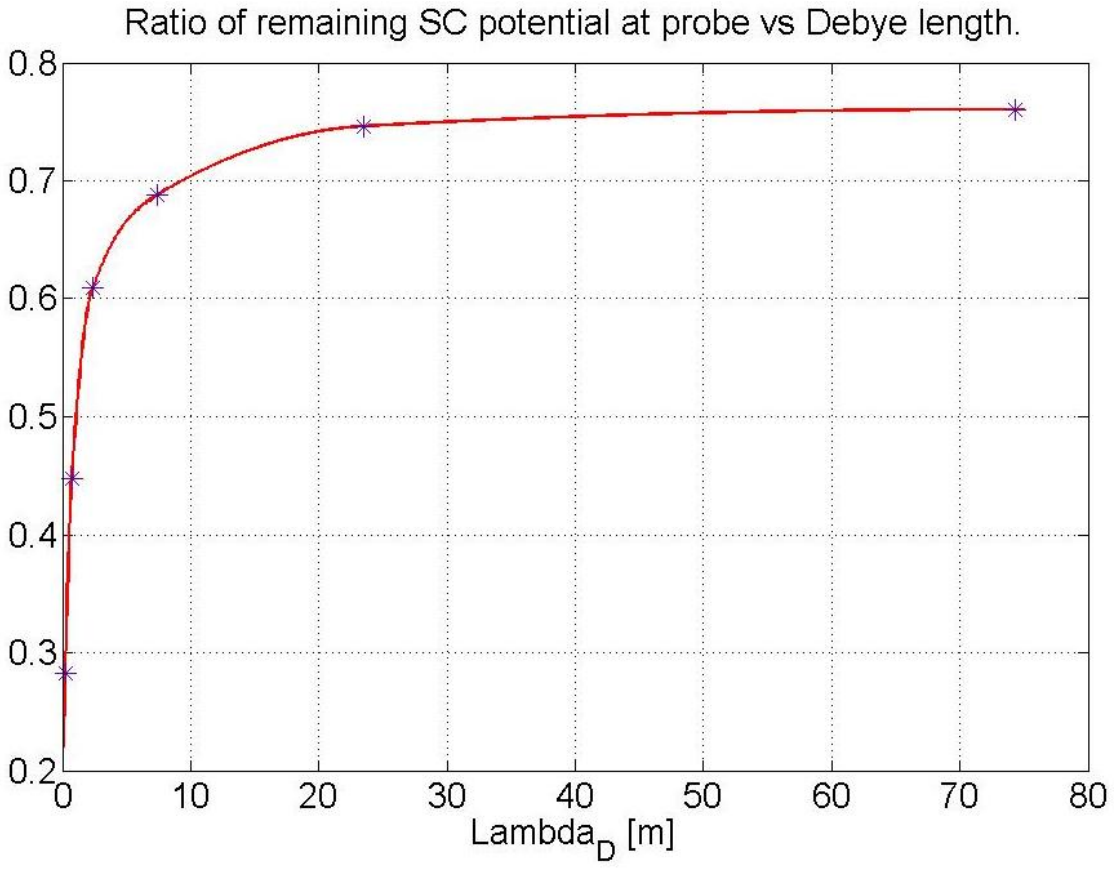
Potential around the spacecraft
n_e = 1 cm^{-3} and T_e = 1 eV

Resulting Vps – Vsc relation

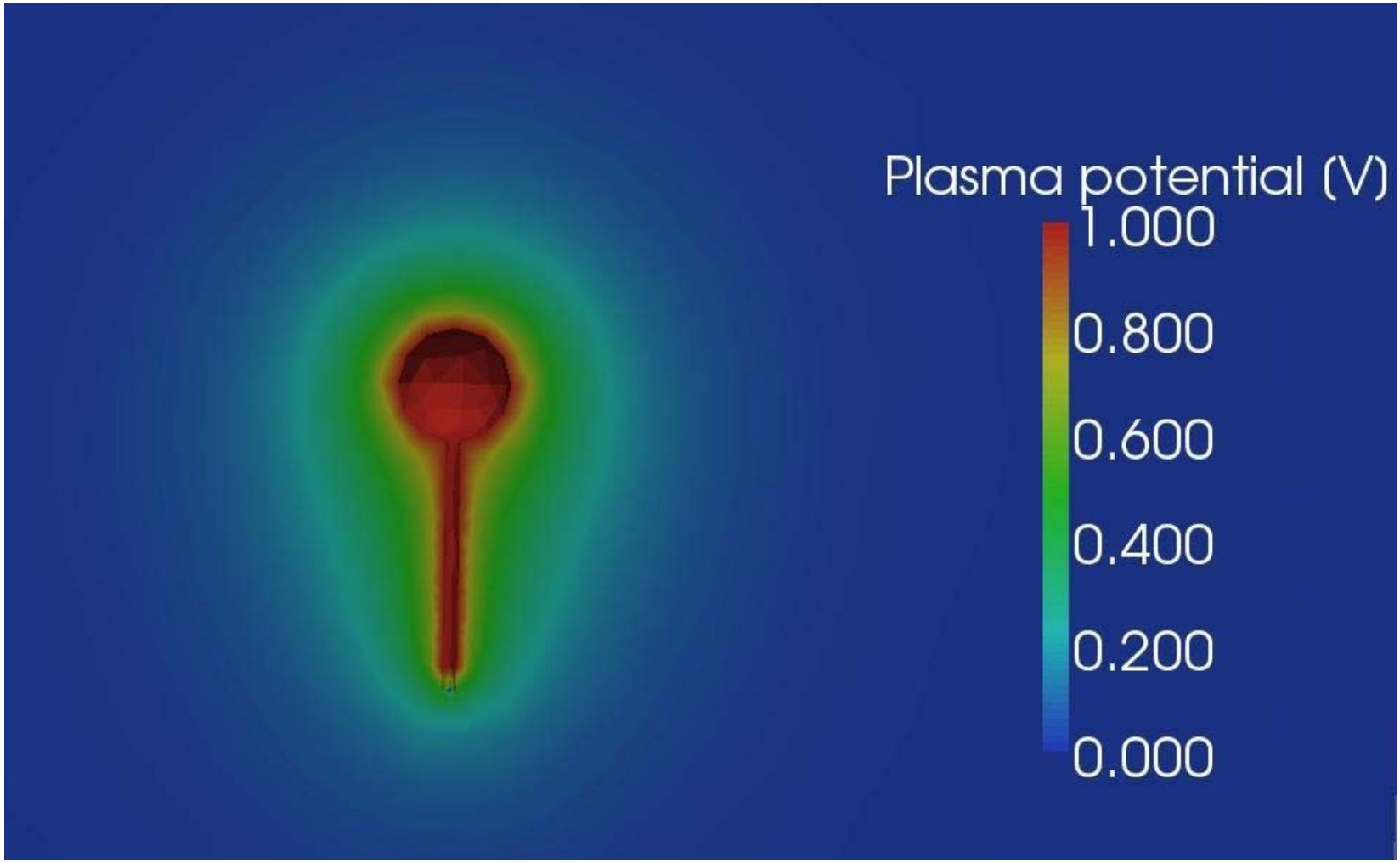
Long Debye length => 76% of the S/C potential remains at the position of the probe.

This means that $V_{sc} \approx 4.16\, V_{ps}$

Empirical value from comparisons to electron spectra: ~5



Probe + stub simulation I



Probe+stub simulation II: $r_p << \lambda_D$

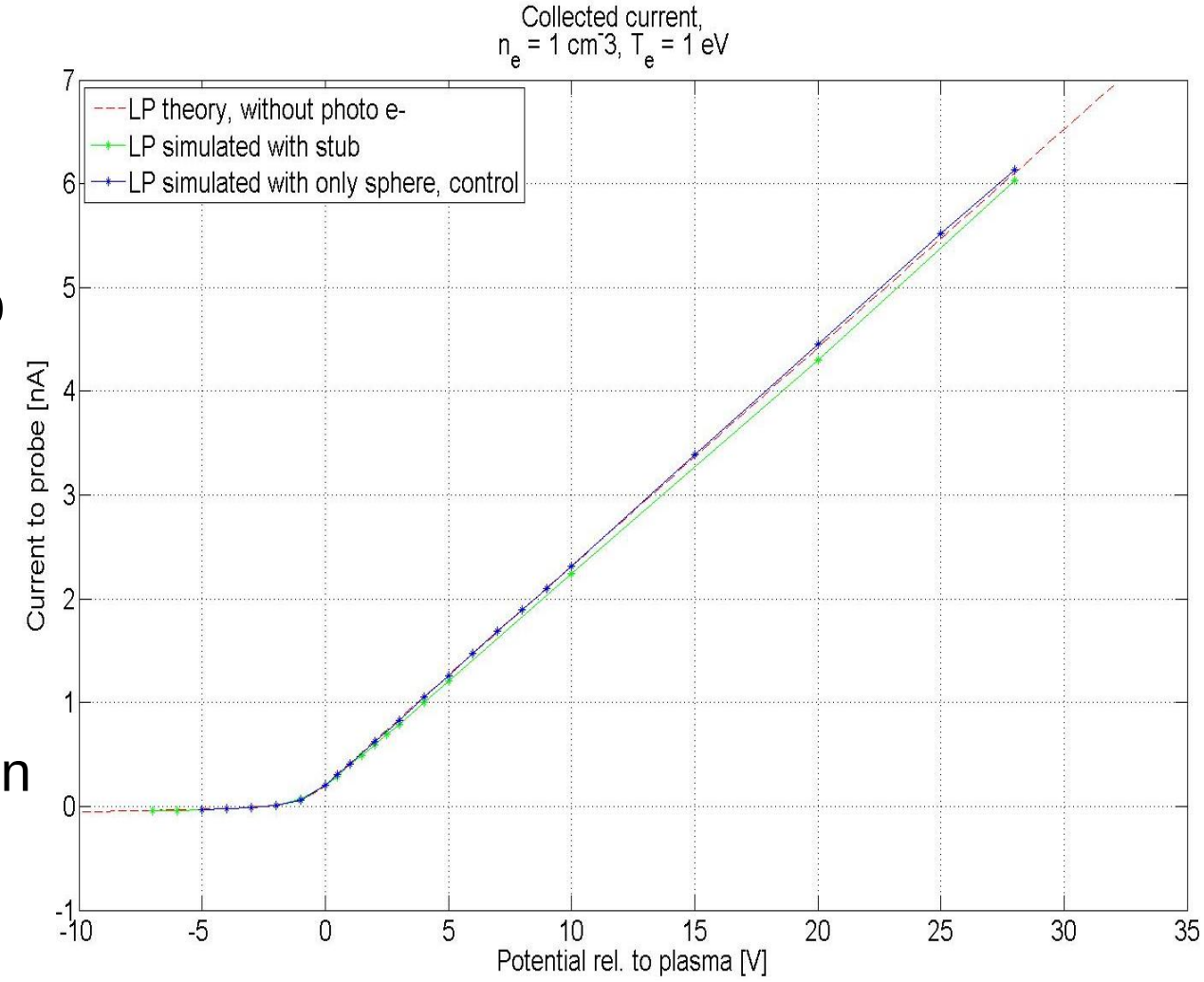
Three curves:

- OML (red)
- SPIS sphere (blue)
- SPIS sphere + stub (green)

SPIS sphere & OML agree perfectly

Sphere current decreases by 4% when stub is attached

-1% expected if $I_p \propto A_p$



Probe+stub simulation III: $r_p \sim \lambda_D$

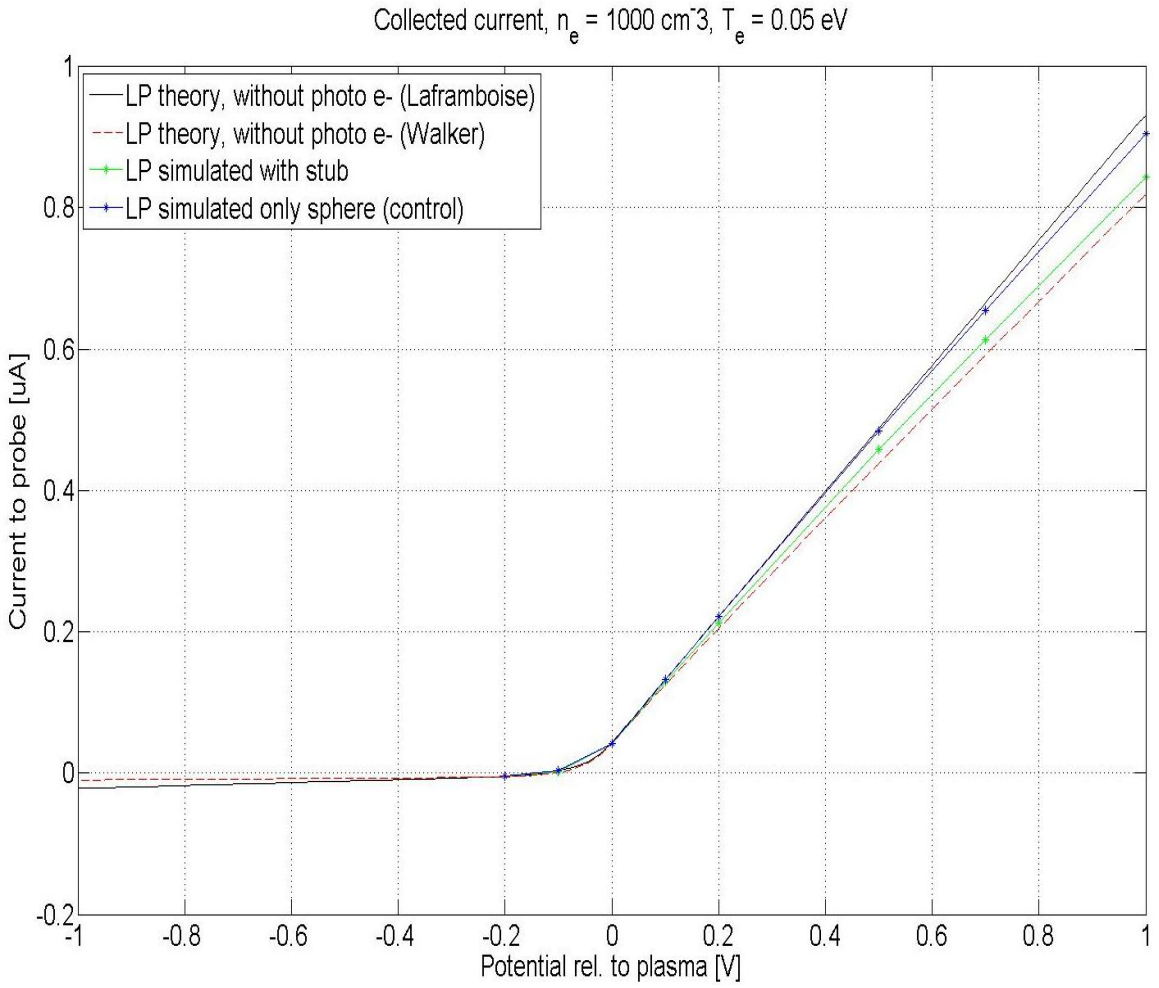
Four curves, from top:

- Laframboise sphere
- SPIS sphere
- SPIS sphere + stub
- Walker sphere

SPIS sphere & Laframboise agree well

Sphere current decreases by 10% when stub is attached (more than in OML case)

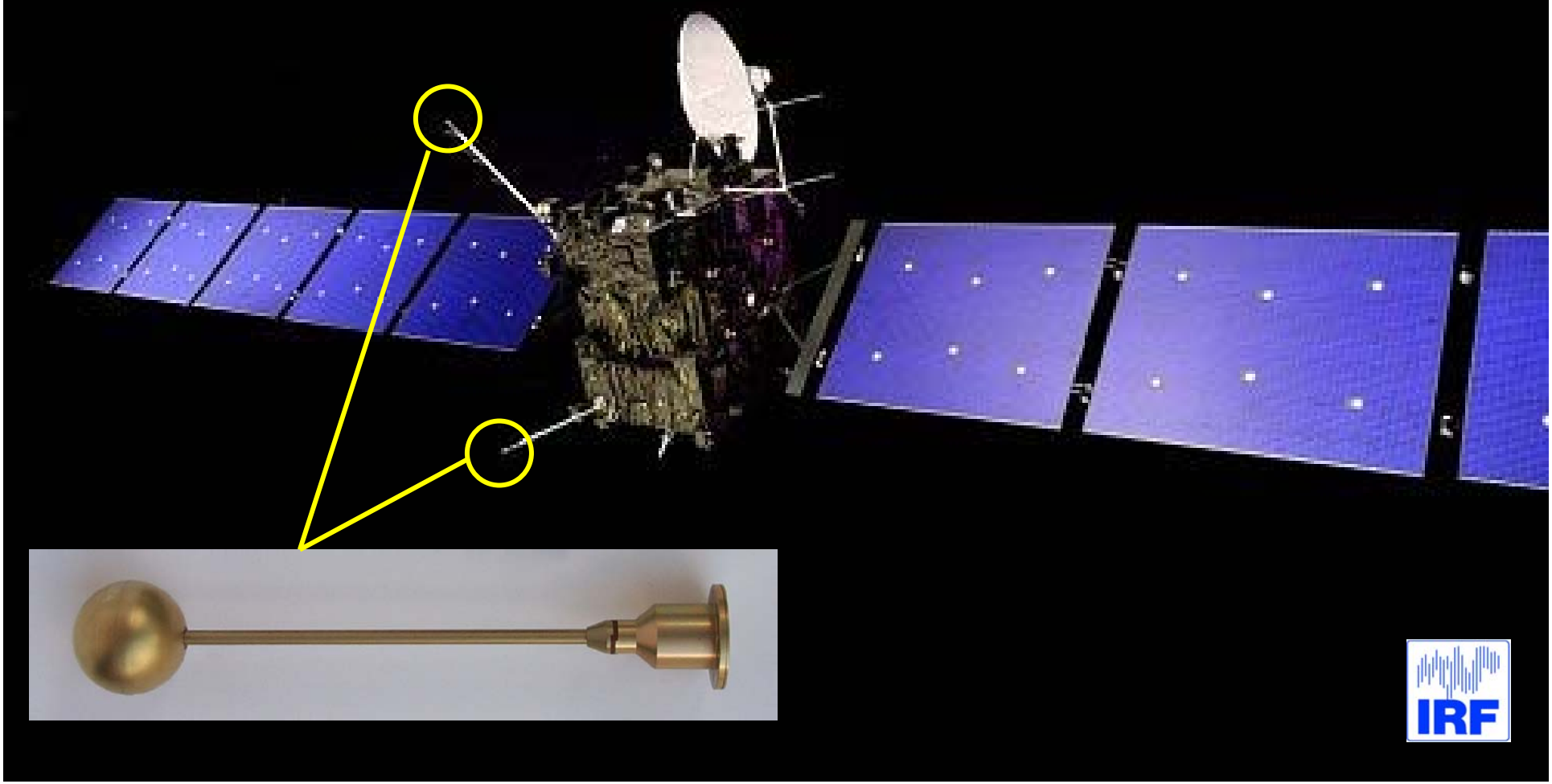
Walker disagrees with Laframboise (well known)



Conclusions from Cassini study

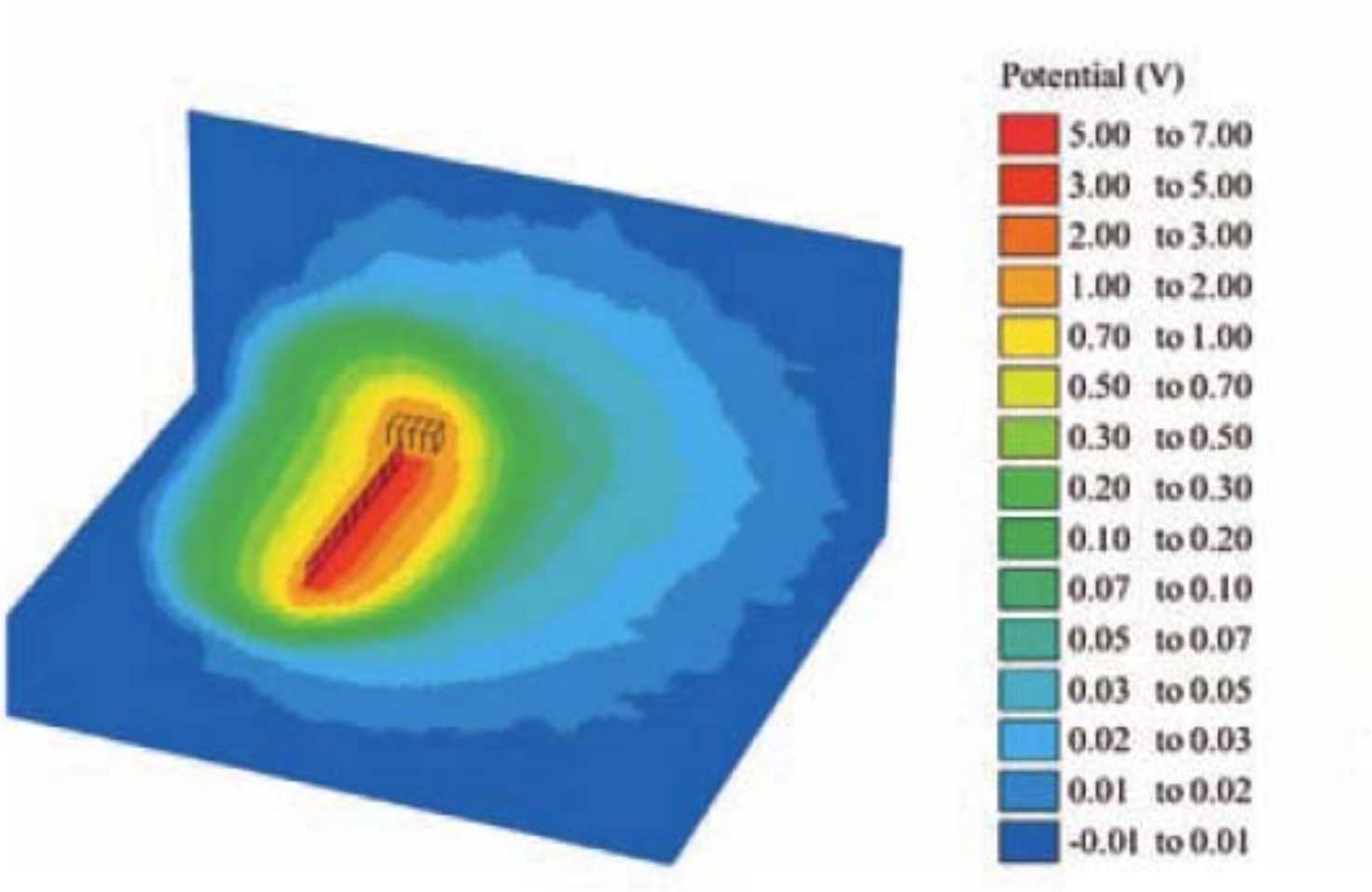
- About 1/4 of Vsc measured by LP in tenuous plasmas
- Presence of stub decreases sphere current by up to 10%
- Direct impact on LP by s/c presence remains to be simulated
  - SPIS 4.0 !?

Rosetta Langmuir probe instrument LAP
SPIS simulations by Alexander Sjögren
(now at Embry-Riddle Aeronautical University)



Rosetta Vsc

Photoelectrons and wake add to potential structure

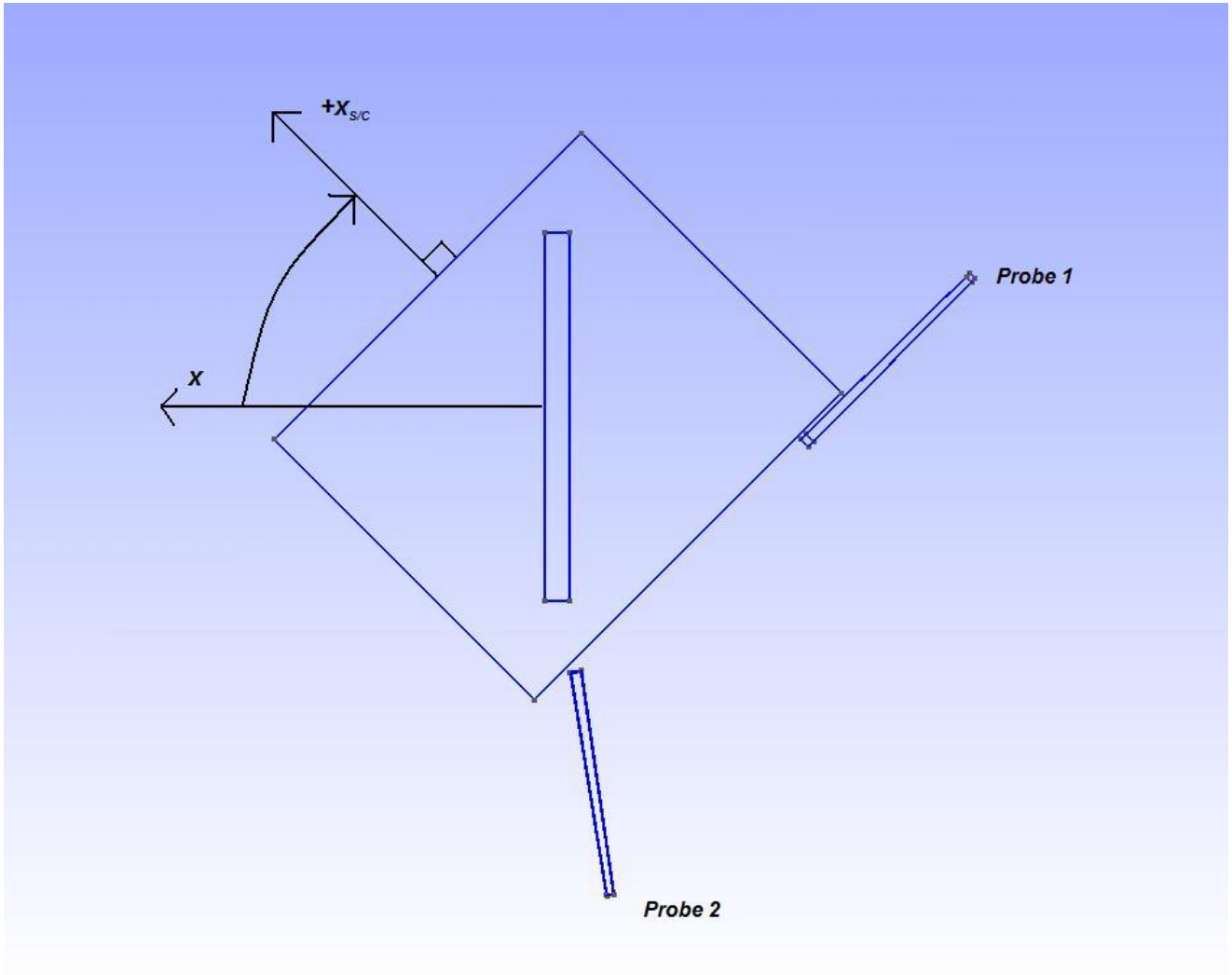


Plasma simulations by Roussel & Berthelier, *J. Geophys. Res.,* 2004

Solar aspect angle

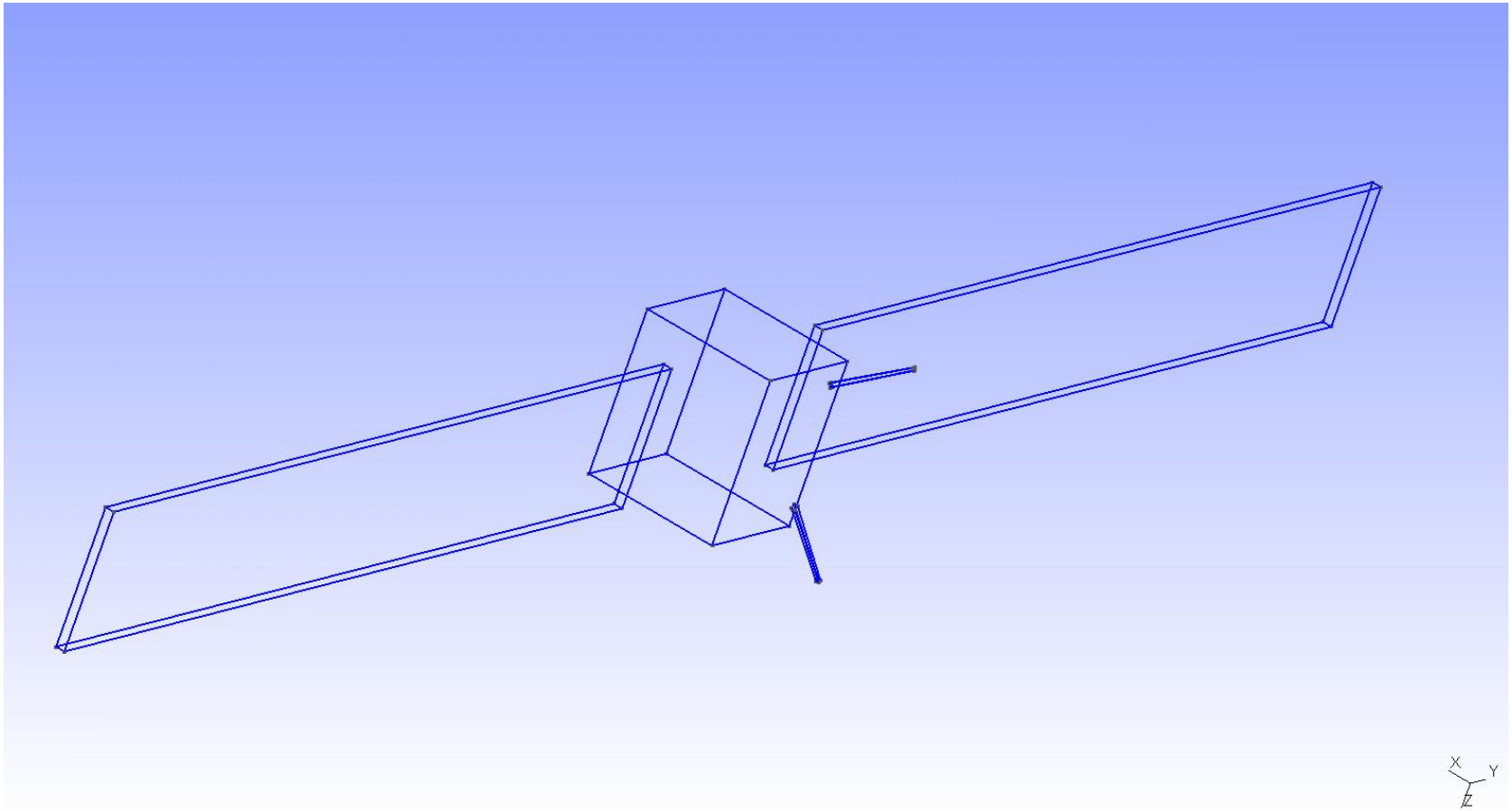
The sole controlling angle in the solar wind, as wind speed and illumination are parallell

Sun



SPIS Rosetta model

- Booms included, but not probes
- Prime output parameter: Potentials at probe positions



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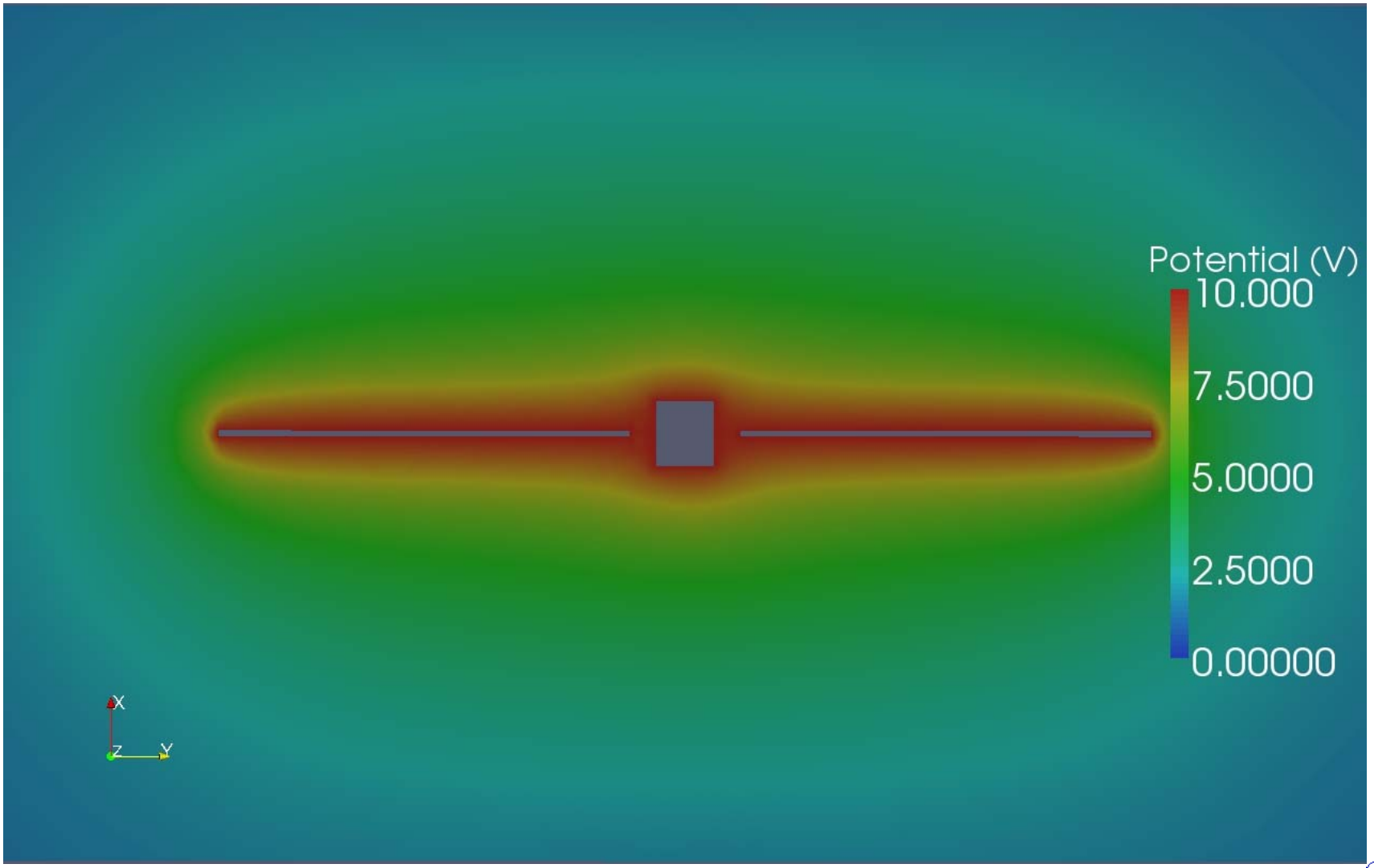
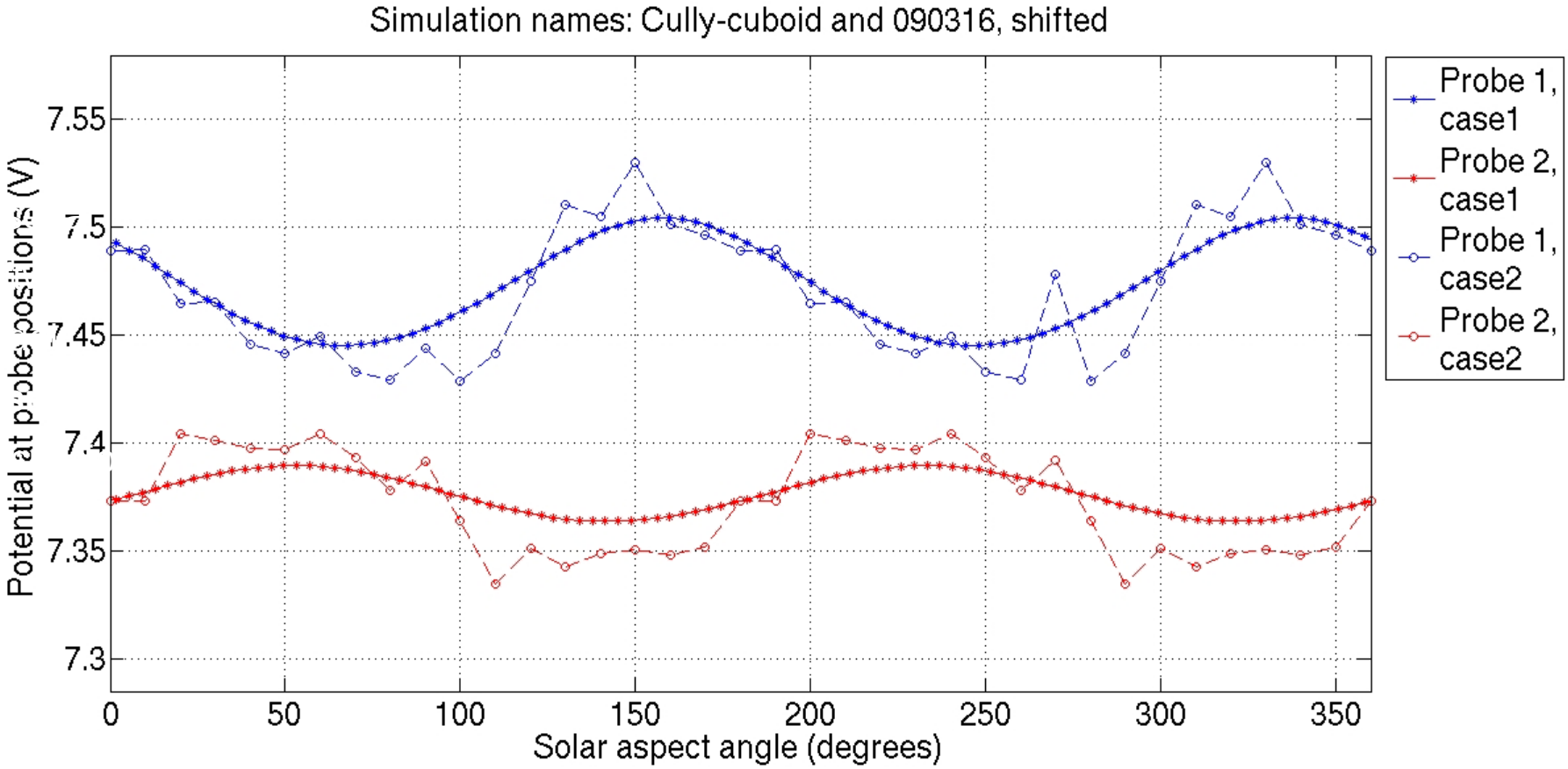
Rosetta in vacuum



Rosetta in vacuum



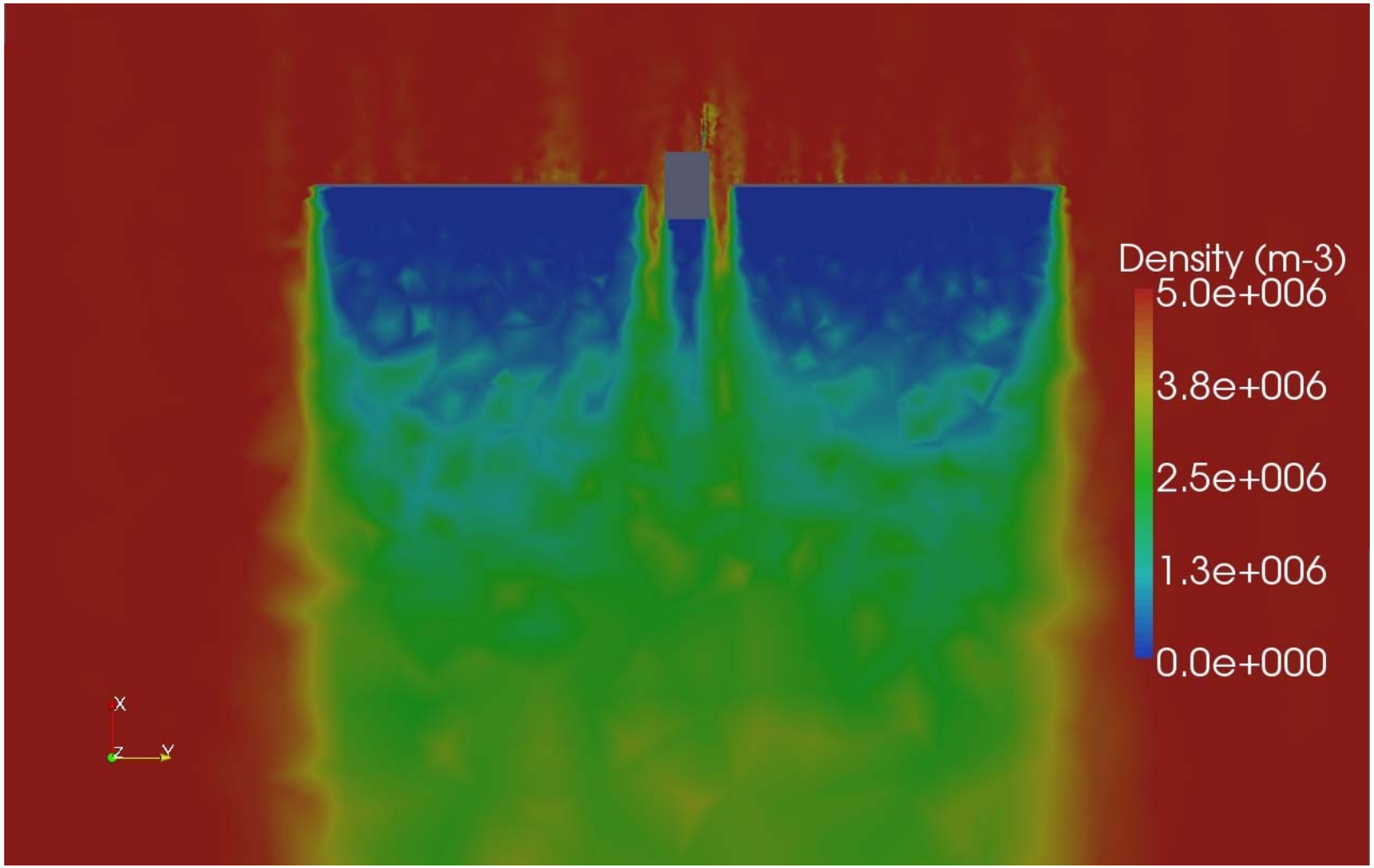
Potentials at probe positions (Vsc = 10 V)

Sinusoids: Chris Cully vacuum code

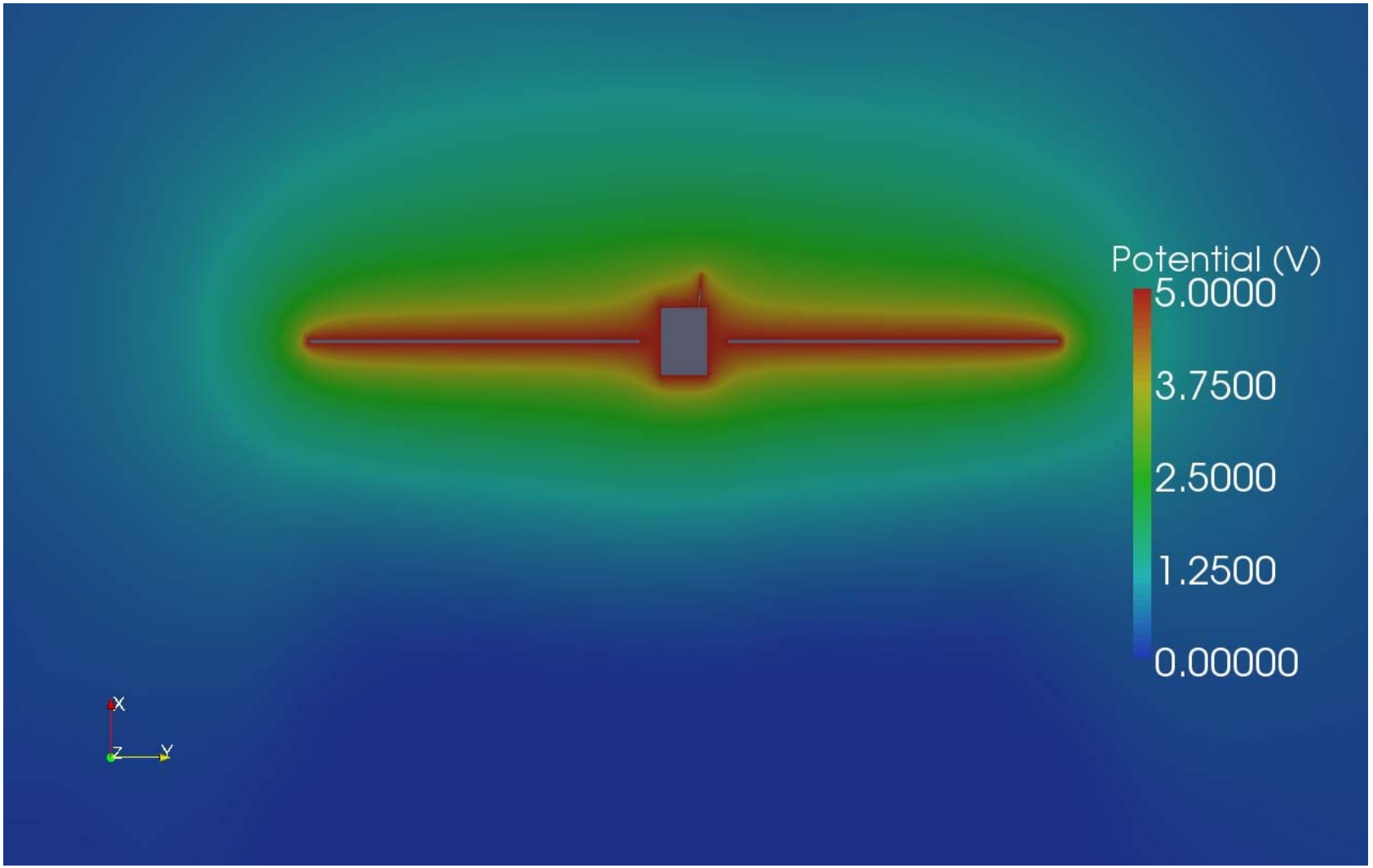
Broken lines: SPIS simulations

Probe 1 blue, probe 2 red

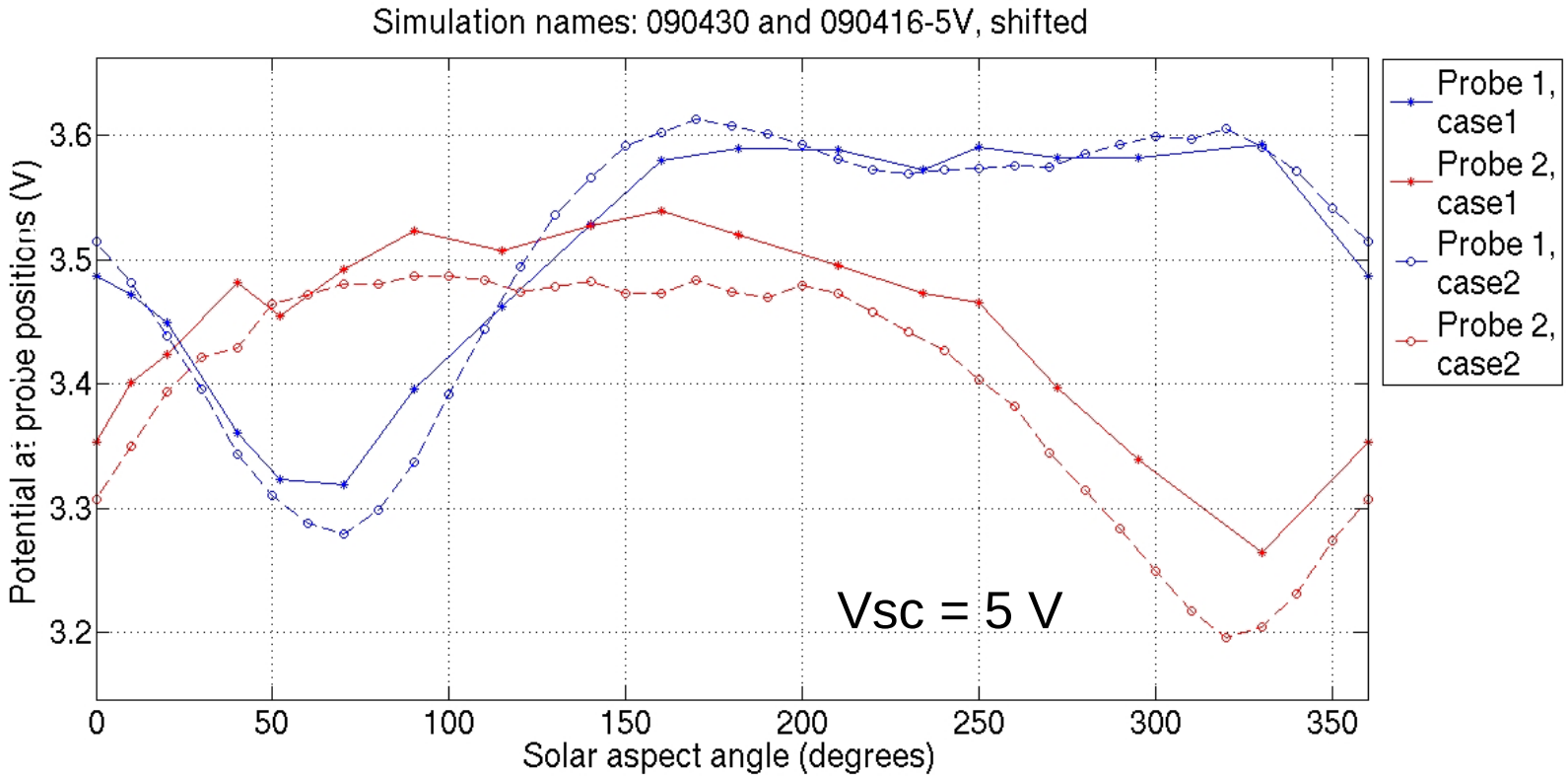
Wake in solar wind: ion density



Wake in solar wind: potential



Wake in solar wind: potential at probes



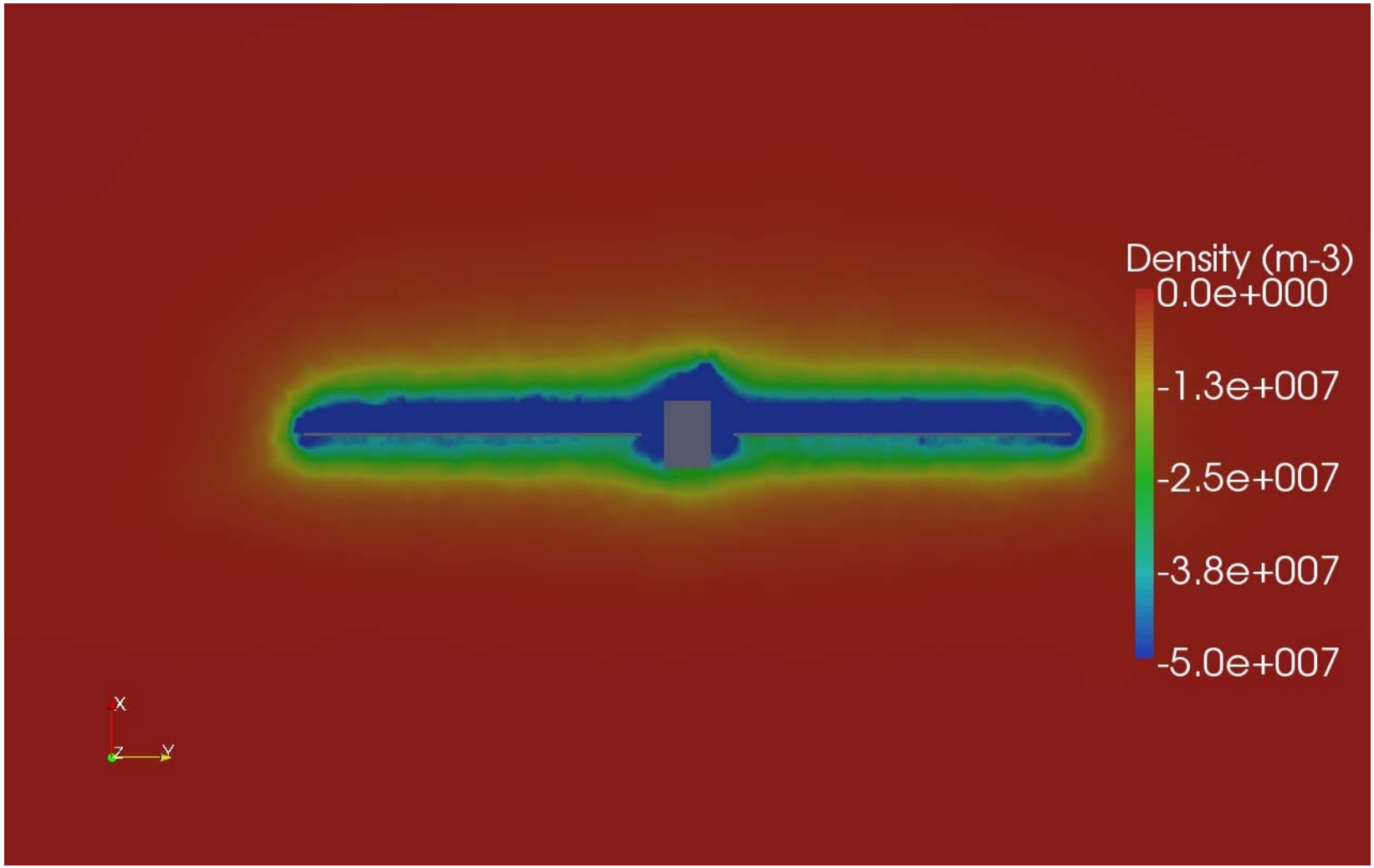
Solid: cuboid s/c with booms

Dashed: spherical s/c w/o booms, shifted +0.7 V

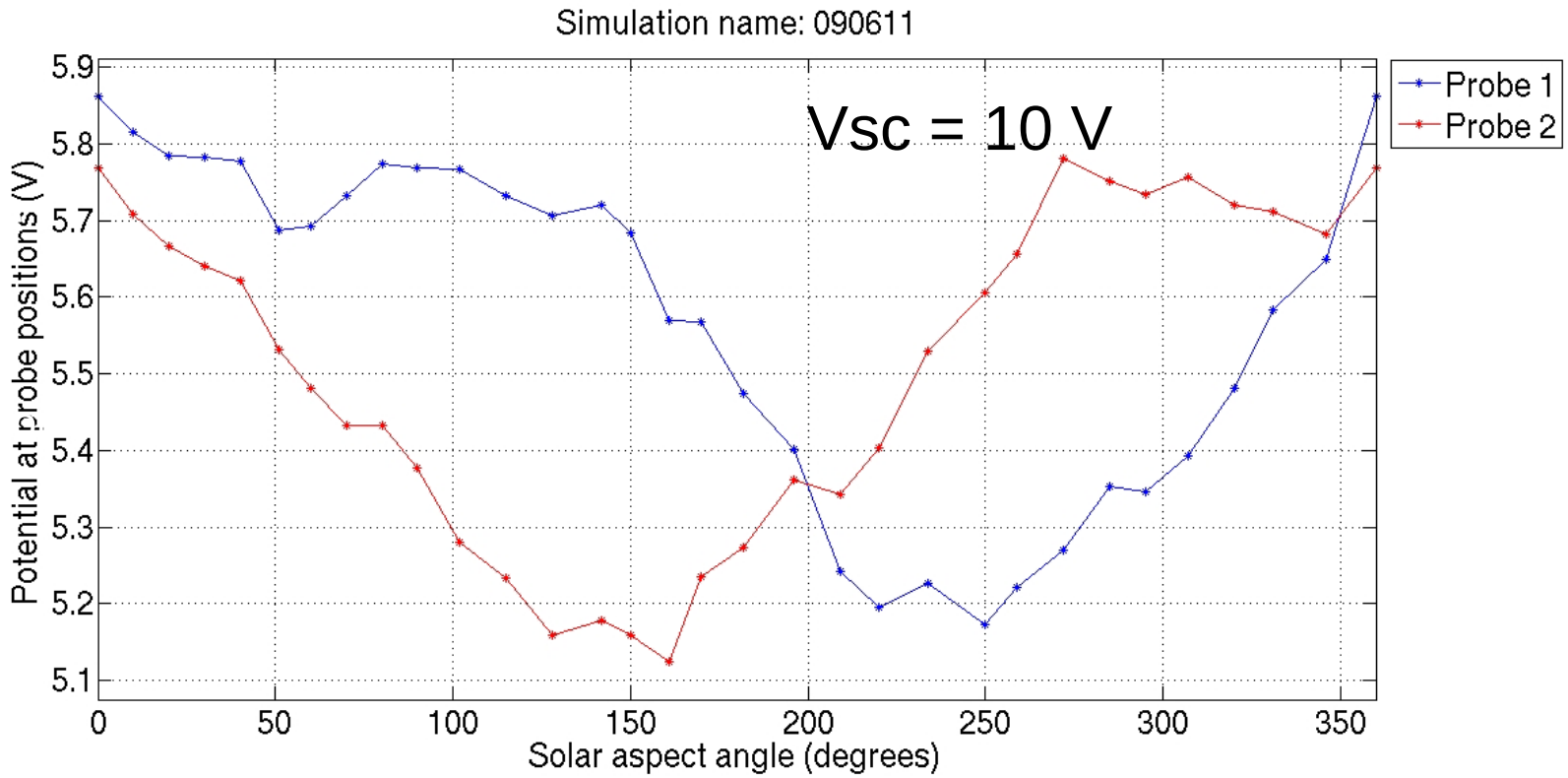
Probe 1 blue, probe 2 red

Vacuum variation almost drowned by wake

With photoemission: e_{ph} density



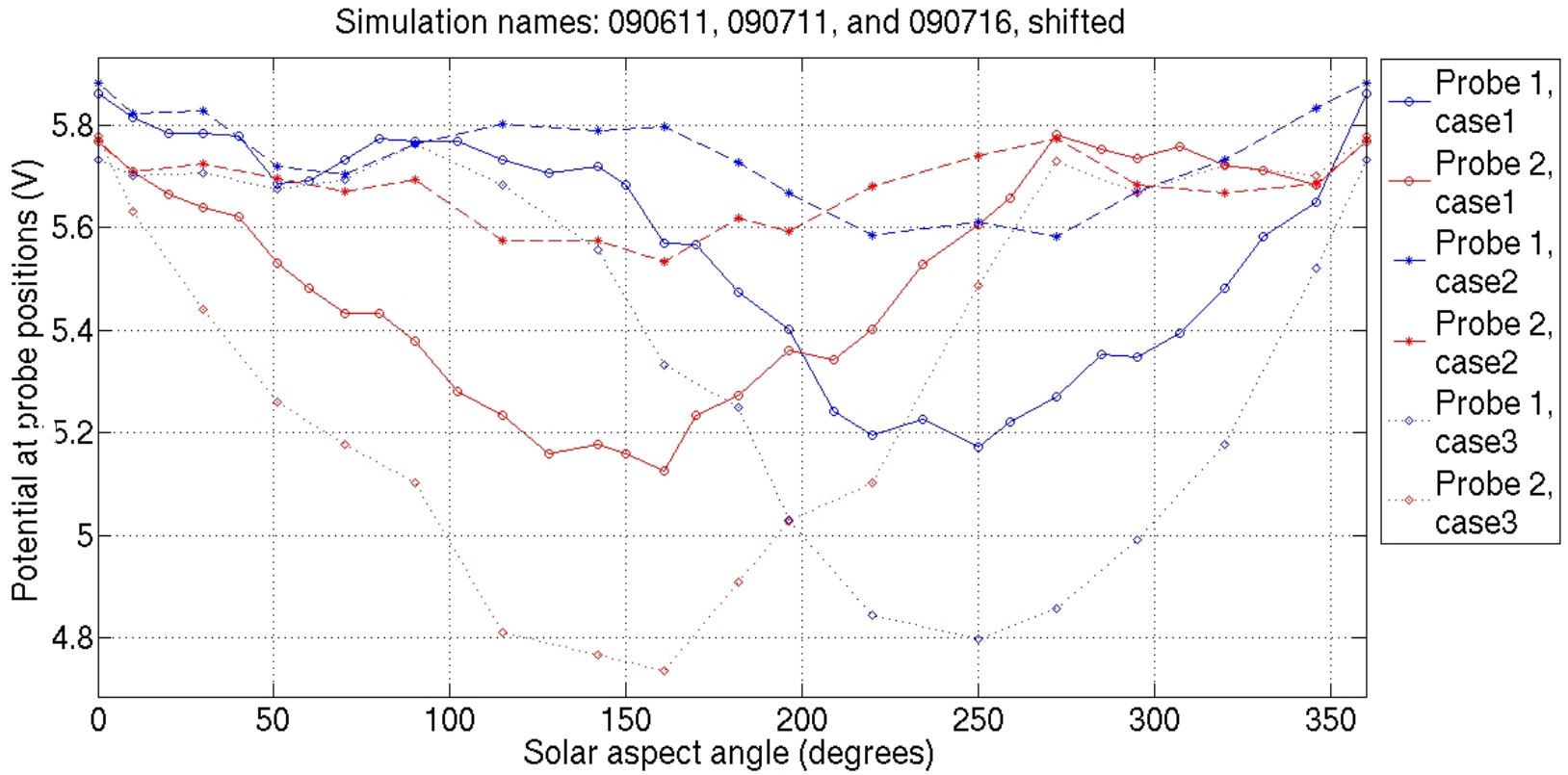
With photoemission: potential at probes



Probe 1 blue, probe 2 red

Wake signature almost drowned by photoelectrons

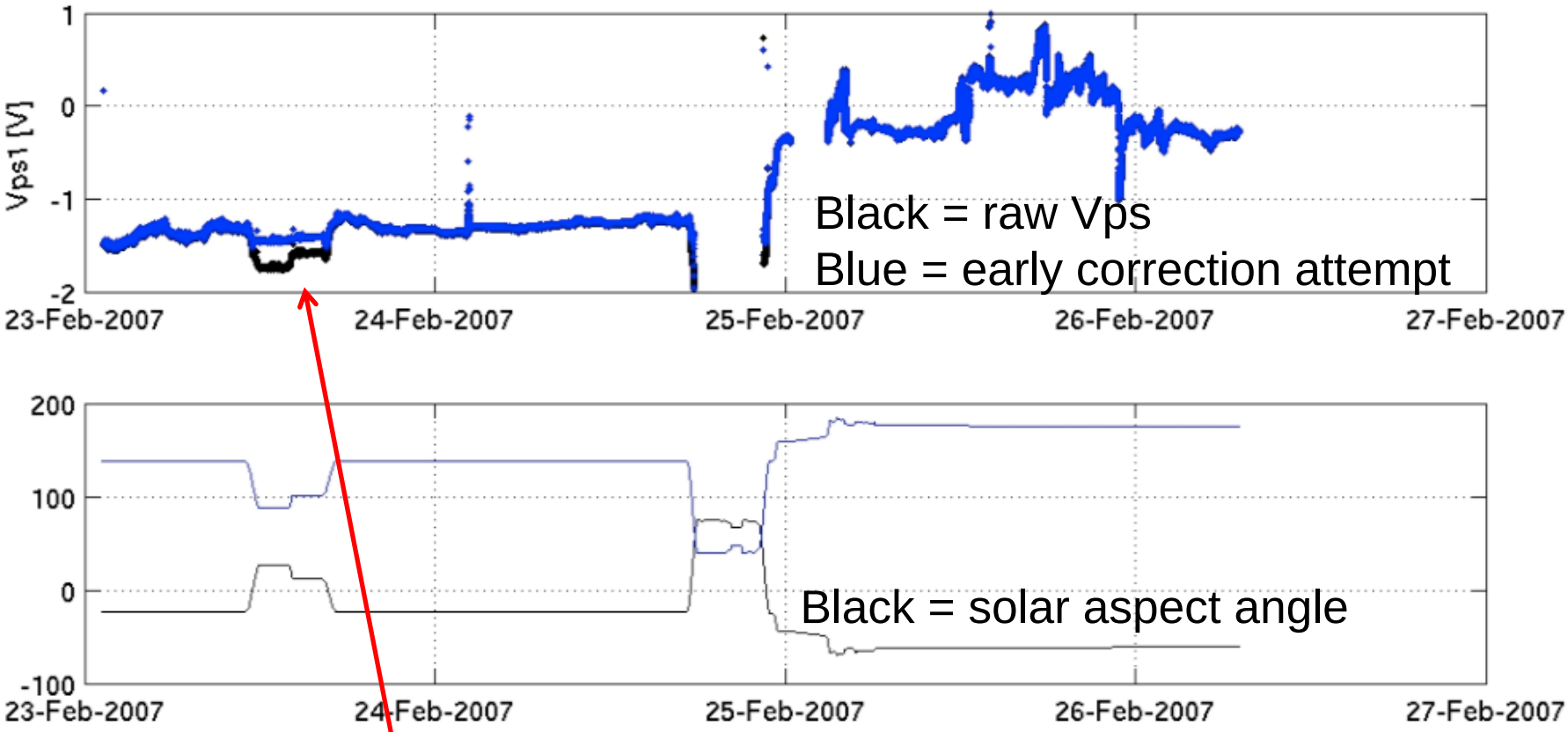
Varying the photoelectron temperature



Dashed: T_{ph} = 1 eV (shifted -0.85 V)
Solid: T_{ph} = 2 eV
Dotted: T_{ph} = 4 eV (shifted +0.75 V)
Probe 1 blue, probe 2 red

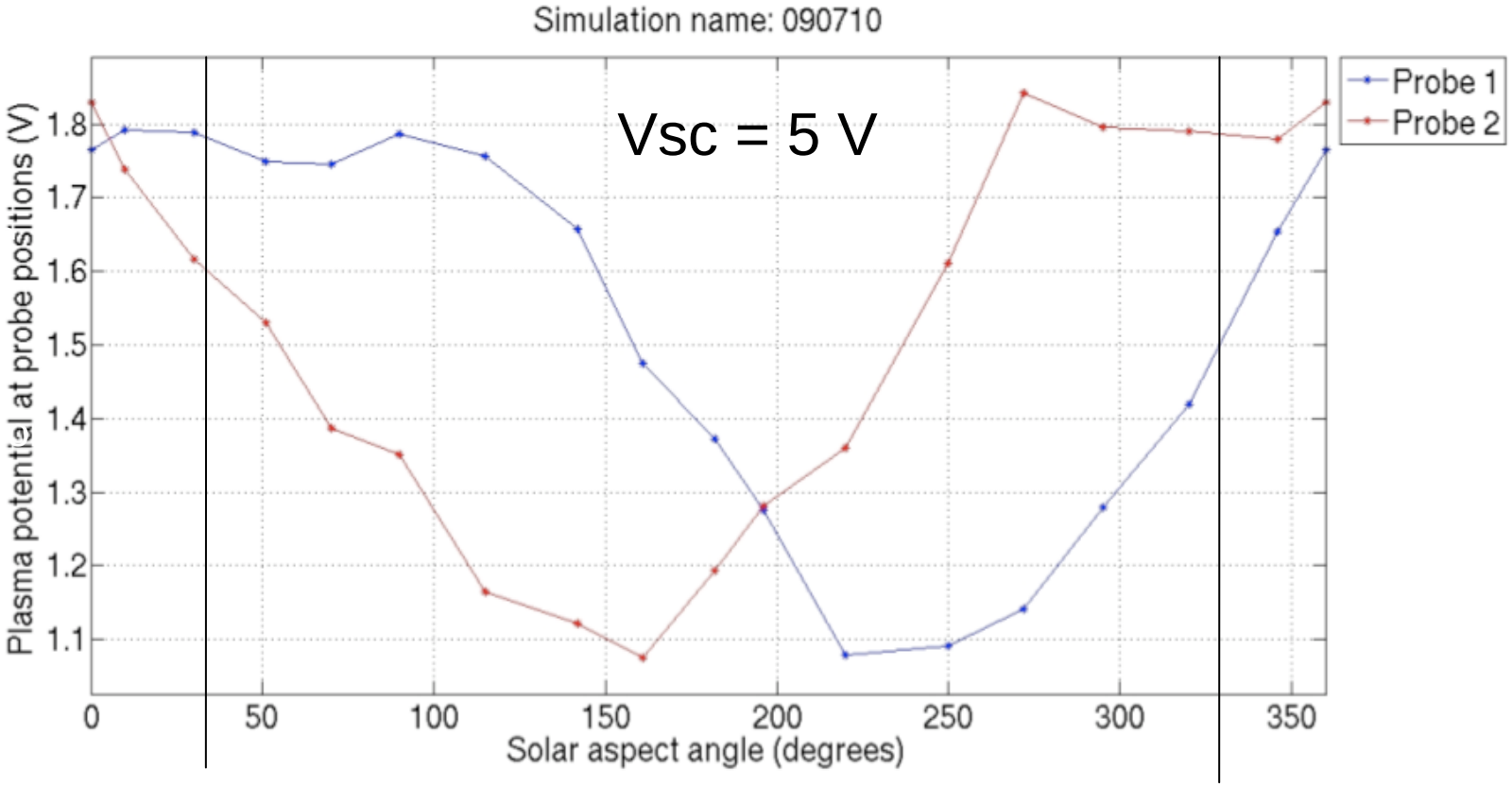
Rosetta LAP data

Rosetta Mars swing-by, Feb 2007



Vps ~0.4 V lower at -25 deg than at +30 deg SAA
Consistent with simulations!

With photoemission: potential at probes



+30 deg

-25 deg

For Vsc = 5 V, simulations suggest Vps = -3.2 V at +30 deg and -3.5 V at -25 deg

Real Vsc apparently was lower in this case

Summary I

- SPIS simulations essential for understanding impact of wake & photoemission on LP measurements
- Cassini:
  - Determined fraction of Vps measured (in absence of wake and photoelectrons)
  - Presence of stub decreases probe current by up to 10%
- Rosetta:
  - Photoelectron effect dominates over wake effect
  - Vacuum effect from turning solar panels still smaller
  - Perturbation magnitude sensitive to Tph
  - Simulations agree qualitatively with data
  - Detailed parametric modelling needed

Summary II

- Full reports available at:
  - http://space.irfu.se/exjobb/2009_alex_sjogren
  - http://space.irfu.se/exjobb/2009_thomas_nilsson
  - Both include appendices on how to run SPIS 3.7
- Future:
  - Simulation of full LP operation, not only looking at potential where the probe should be
    - Possible in SPIS 4.0 using backtracking ability?
    - For Cassini, spacecraft may otherwise be modelled by a wall
  - For Cassini, study wake and photoelectron cloud influence
  - For Rosetta, extended parametric study with comparison to data
- Two new project students (Marco Chiaretta and Christian Hånberg) have started on SPIS simulations in Uppsala