SPIS simulations in support of science projects and their limitations

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SPINE, Uppsala, Sweden
17-19/01/2011

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Introduction

- SPIS has been called upon to aid the design of scientific spacecraft
  - To quantify the disturbance to the environment caused by the spacecraft
  - To assess contamination of measurements from the presence of the spacecraft and active sources
  - To optimise the location of instruments
  - To aid in the interpretation of observations.

- Despite success, there have been difficulties in using SPIS for this purpose
- Some examples from Swarm, Cluster and MMS are given

- Probe simulations have shown unexpected differences to theory

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SWARM

- SWARM - a multi-satellite mission to survey Earth’s geomagnetic field and its temporal evolution
- 3 satellites in three different polar orbits between 400 and 550 km altitude.
- High-precision and high-resolution measurements of the strength and direction of the magnetic field will be made
- Electric fields can influence measurements taken by the sensitive magnetometers on board.

- Goal of SPIS simulation: to help quantify the disturbance that would be experienced by the Langmuir probe on the SWARM spacecraft

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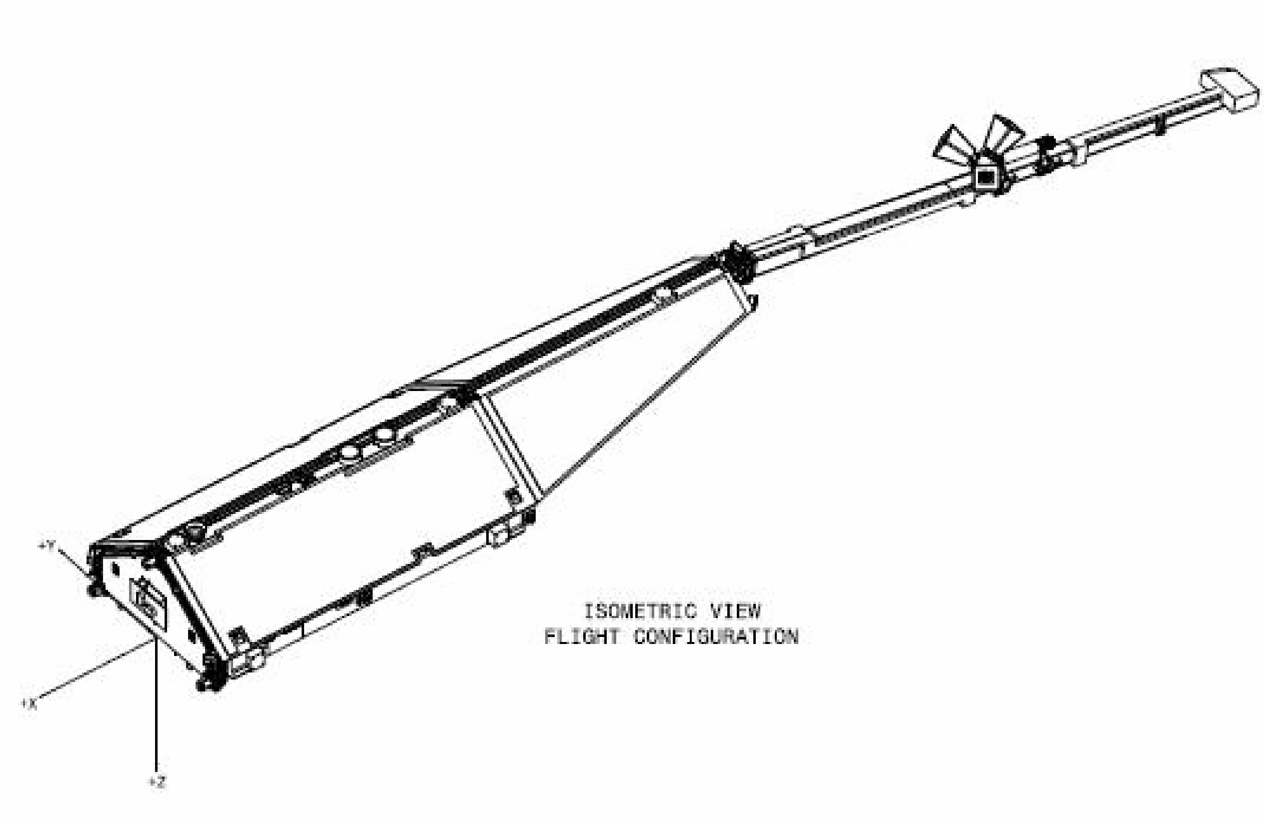
SWARM



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SWARM

- We could not directly simulate the behaviour of the Langmuir probe

- Sources of interference of Langmuir probe
  a. Geometrical blocking due to nearby spacecraft
  b. Electric field due to presence of spacecraft
- Point a was not addressed
- Point b was addressed
  - Depends on s/c surface potential and geometry
  - Depends on mainly plasma characteristics and the current collection on conductive elements
    - Metallic plate on ram (of size to be determined)
    - Metallic interconnects of solar array
- SPIS could not simulate the thousands of tiny solar array interconnects, so the same area was used in larger patches

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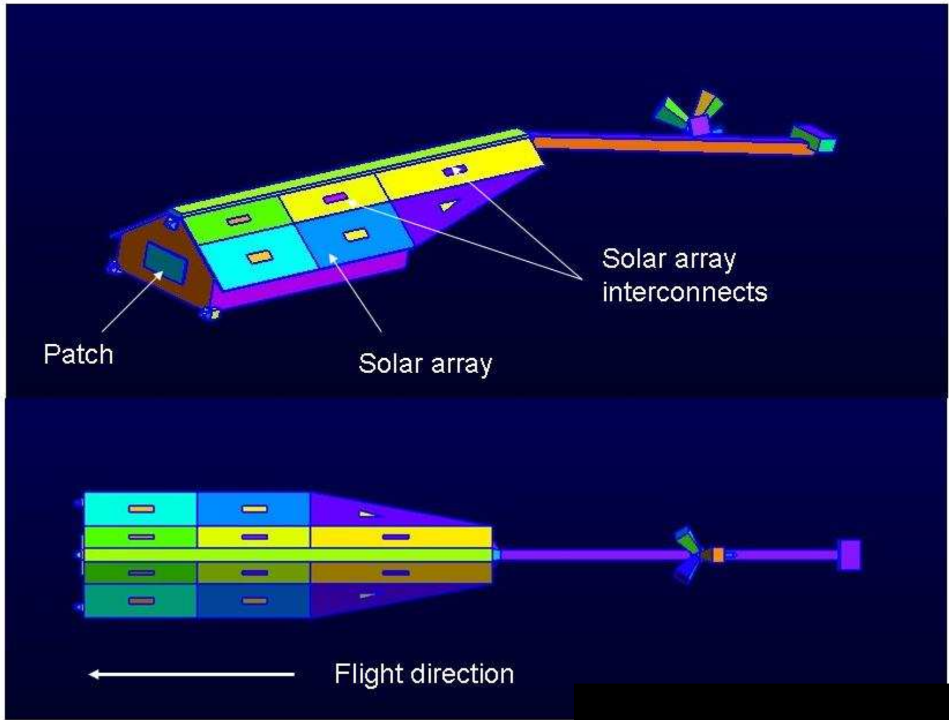

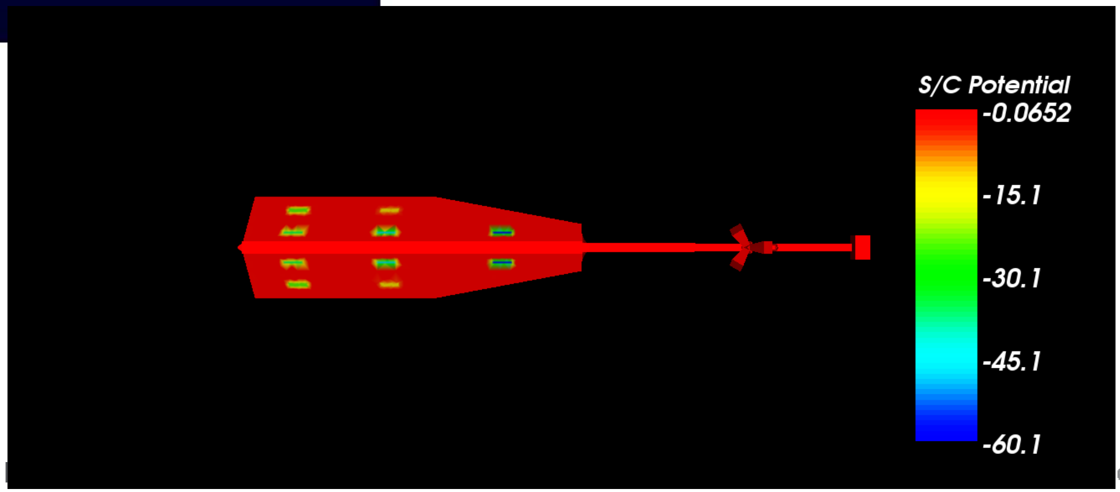

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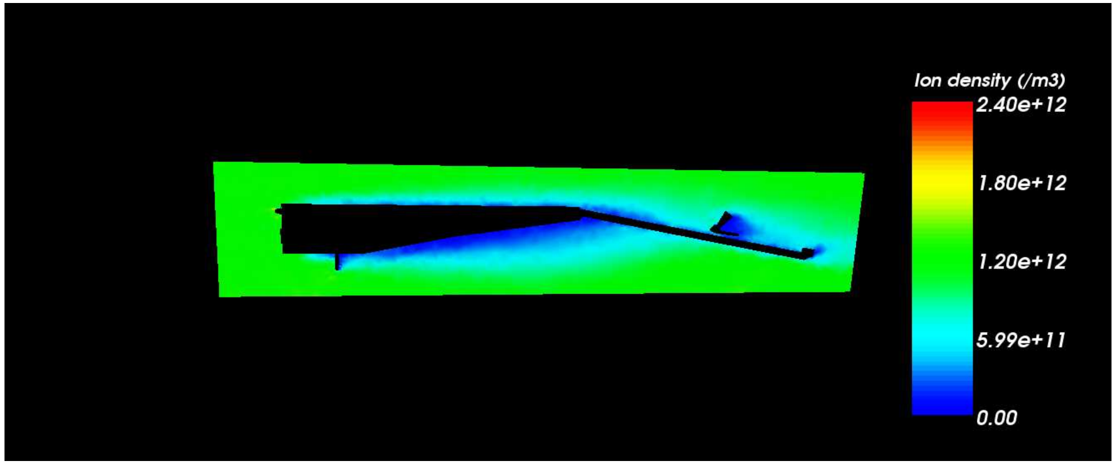

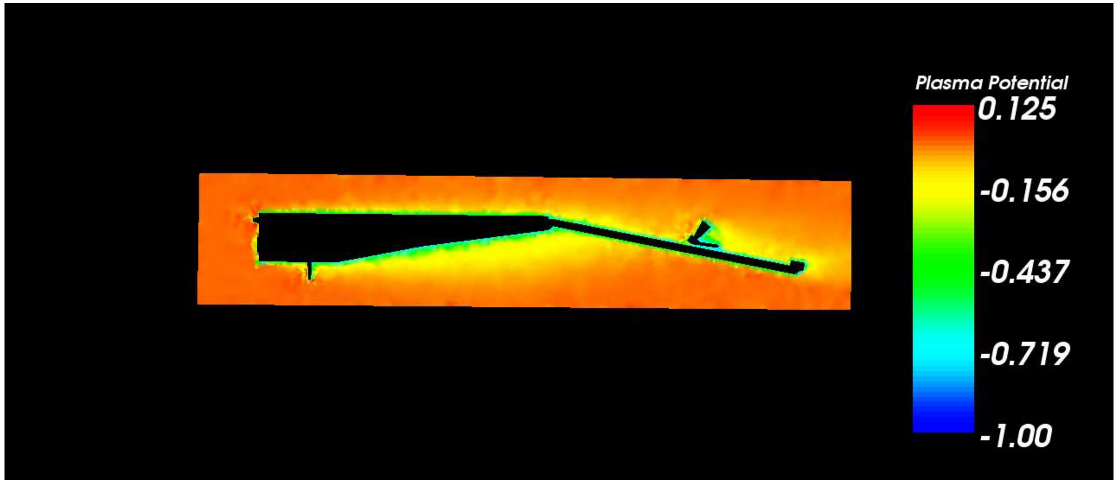

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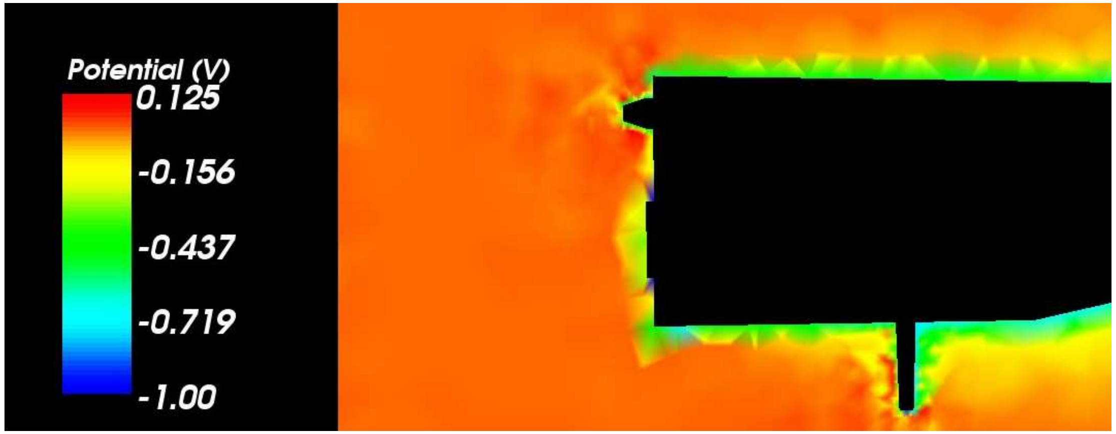


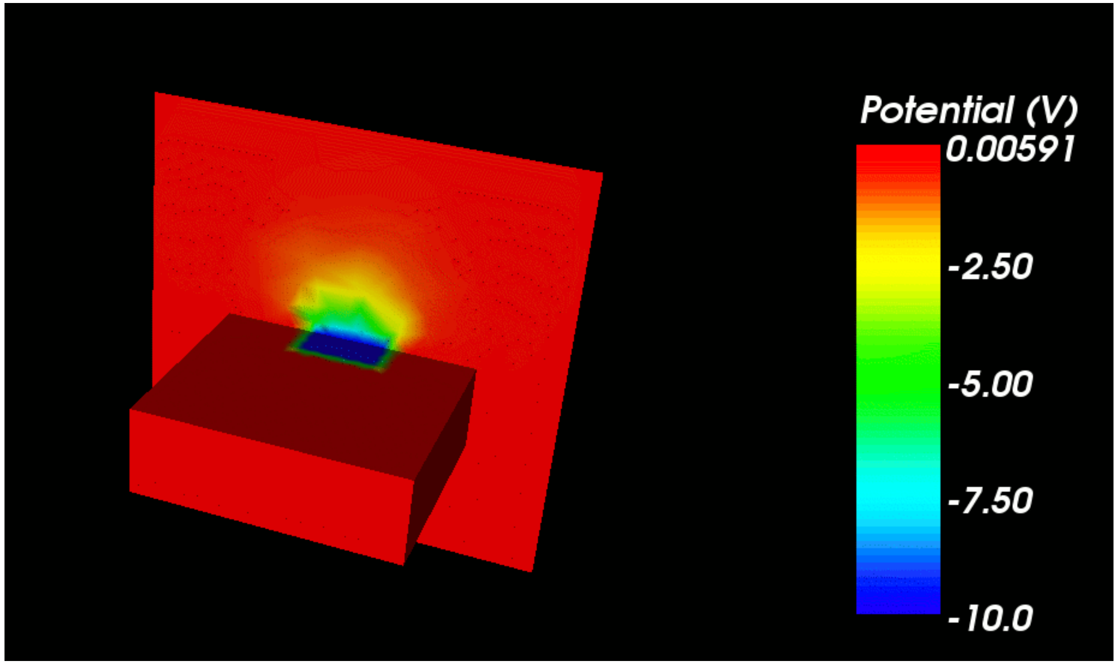
n=9E4cm-3, Te=0.237, Ti=0.144, Debye length 12mm
Vel=7.7km/s, Species O+

Floating potential:
-0.50V with a 0.35m^2 ram plate
-0.49V with no ram plate

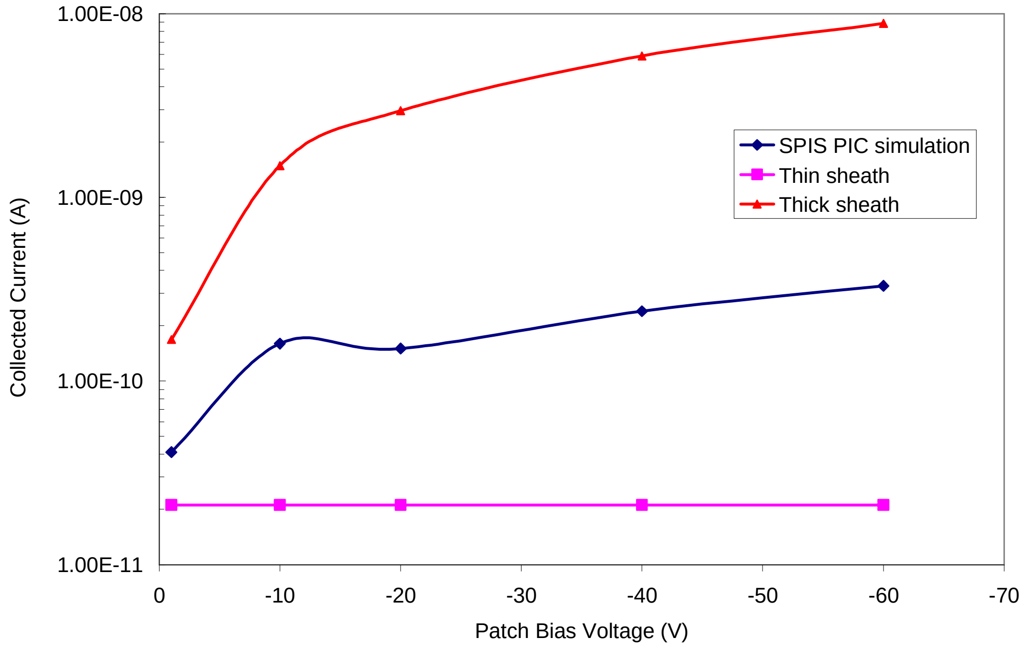
How accurate are these SPIS results given the interconnect approximation?

Interconnects were mostly 2mmx2mm in size

Equilibrium is negative, and so isotropic electrons are well simulated by Boltzmann equation



Combining small interconnects into larger surfaces moves ion current collection from the thick sheath case towards thin sheath.



Ion Current-Voltage curve lies between thin and thick sheath approximations

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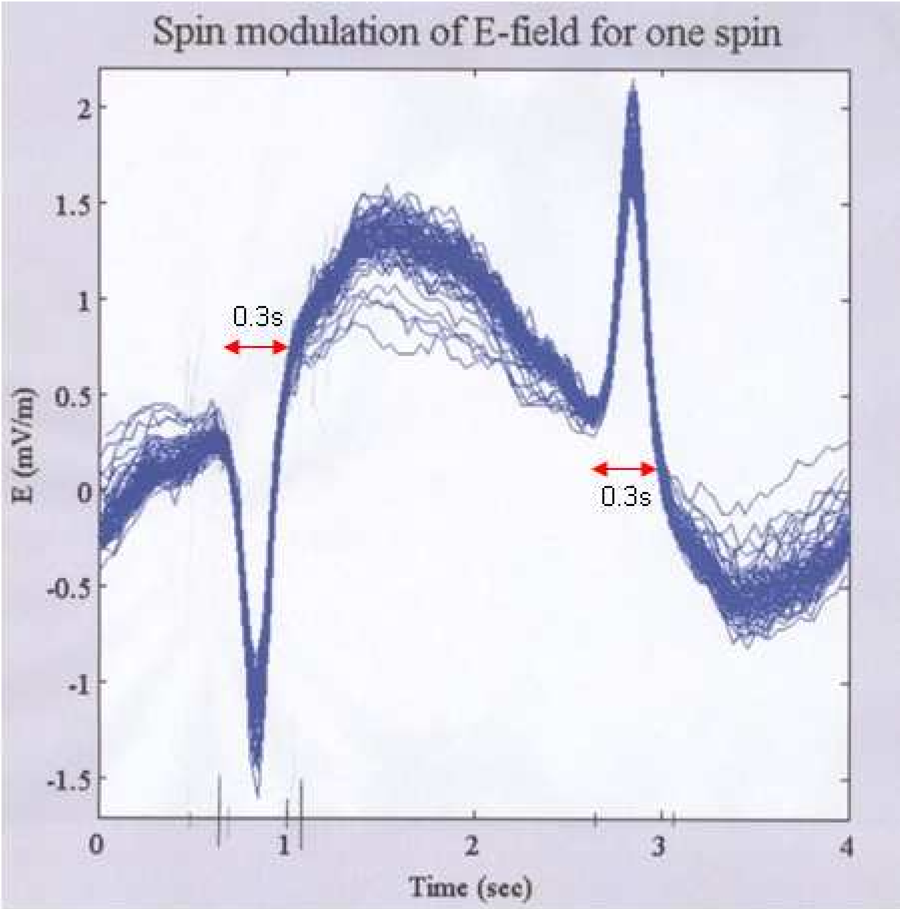
SWARM

- Comparison of SPIS with theoretical calculations

Ram plate cm^2	SPIS V	Thin V	Thick/10 V
0.35	-0.5	-0.55	-0.51
0	-0.49	-0.48	-0.18

- Better to include I-V curves of solar arrays in SPIS

Cluster



- Cluster wake crossings contaminate electric field measurements
- A pulse of duration 0.3s and amplitude 1.5V occurs twice per rotation

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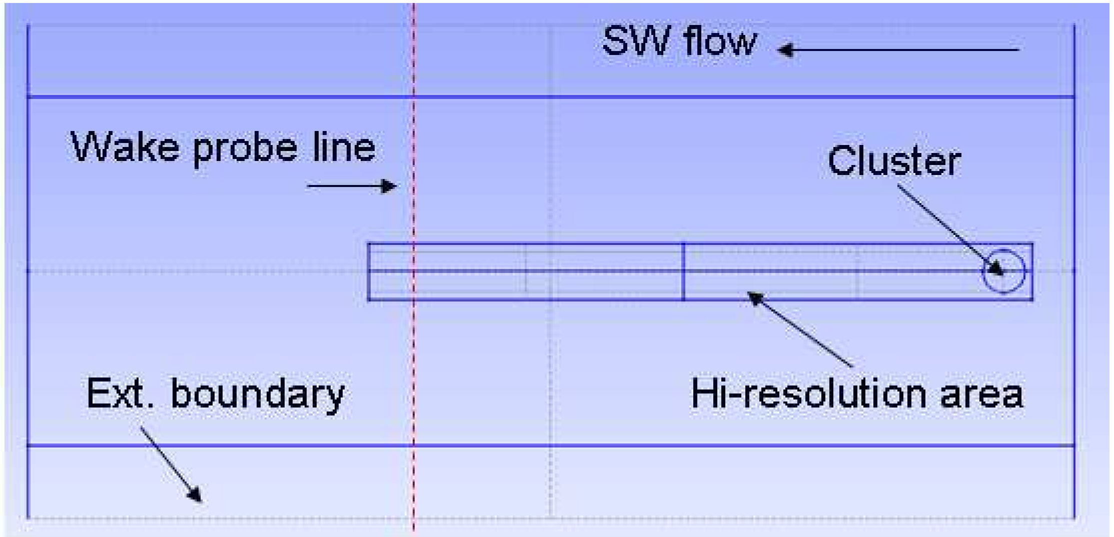
Cluster

Electron Temp (eV)	8.61
Ion Temp. (eV)	10.34
Ion/Electron density (m^{-3})	8.7×10^6
Drift (km/s)	468



- The full wake region could not be simulated in high resolution

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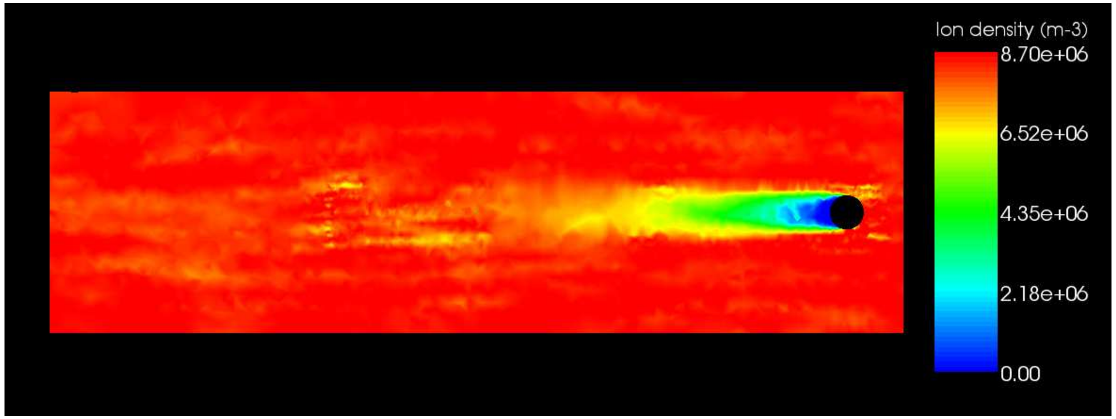
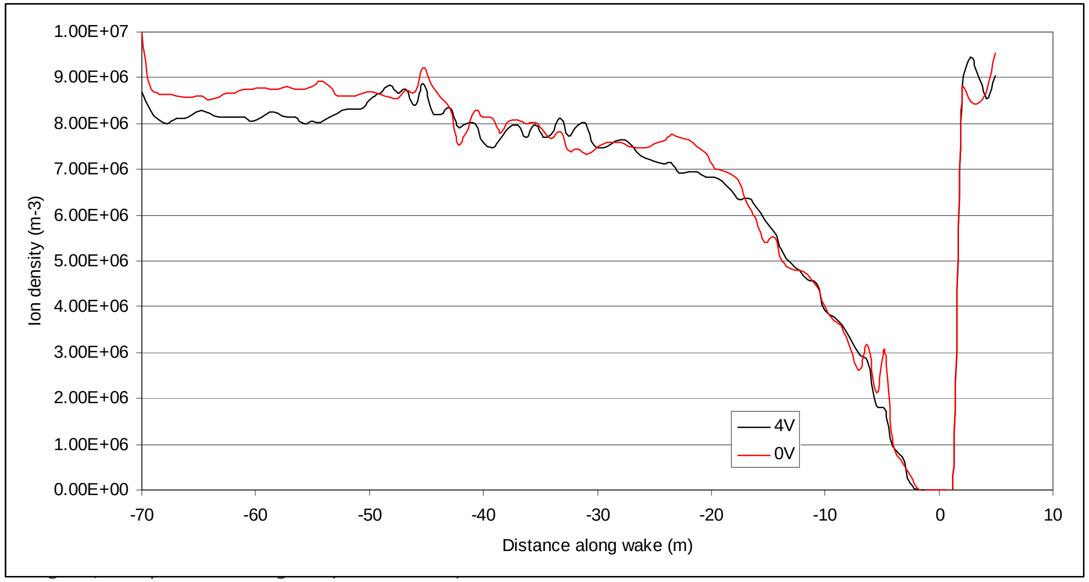
Cluster

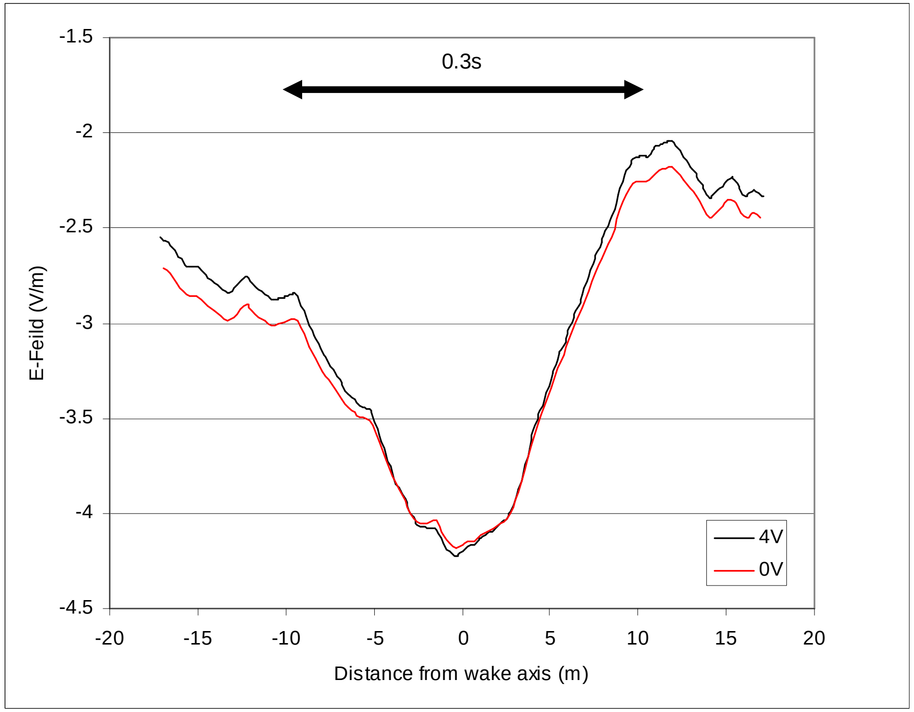


Ion density (m-3)
8.70e+06
6.52e+06
4.35e+06
2.18e+06
0.00



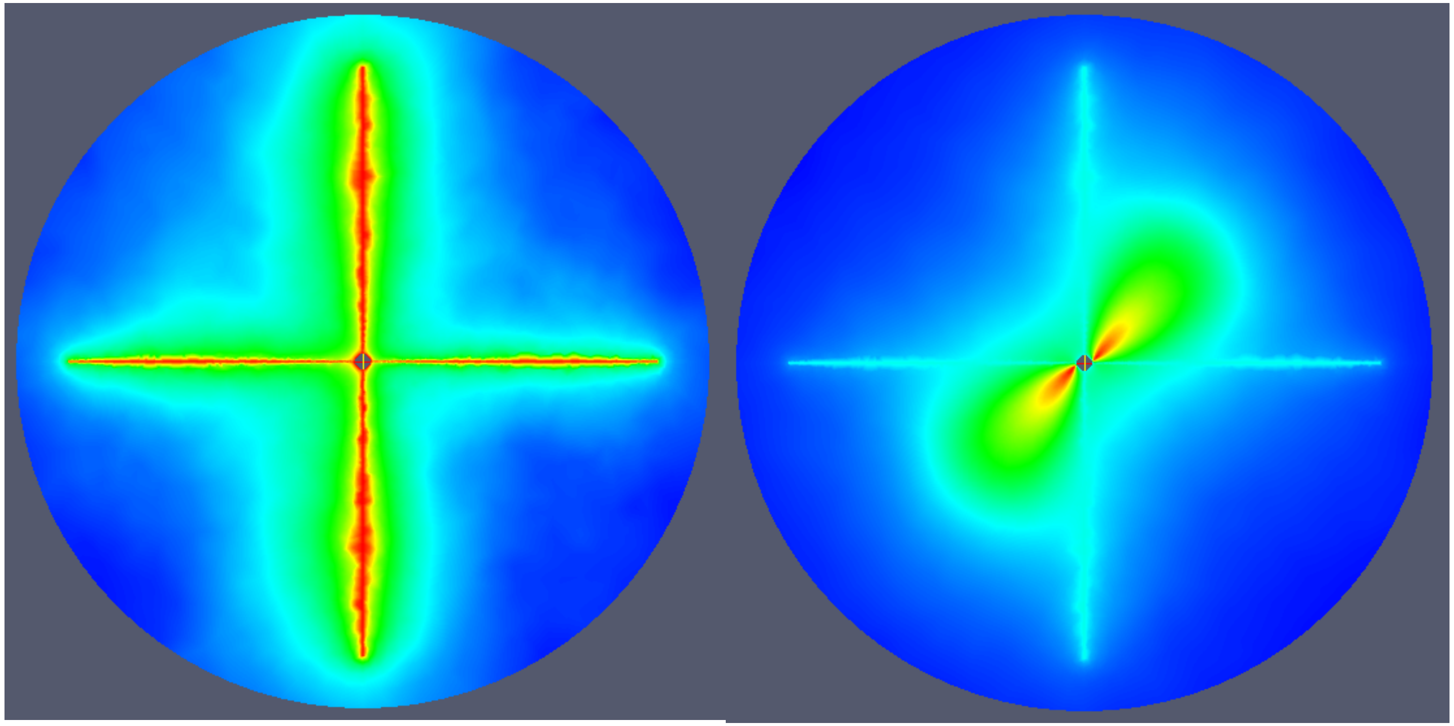
1.00E+07
9.00E+06
8.00E+06
7.00E+06
6.00E+06
5.00E+06
4.00E+06
3.00E+06
2.00E+06
1.00E+06
0.00E+00
Ion density (m-3)
-70
-60
-50
-40
-30
-20
-10
0
10
Distance along wake (m)
4V
0V

Cluster

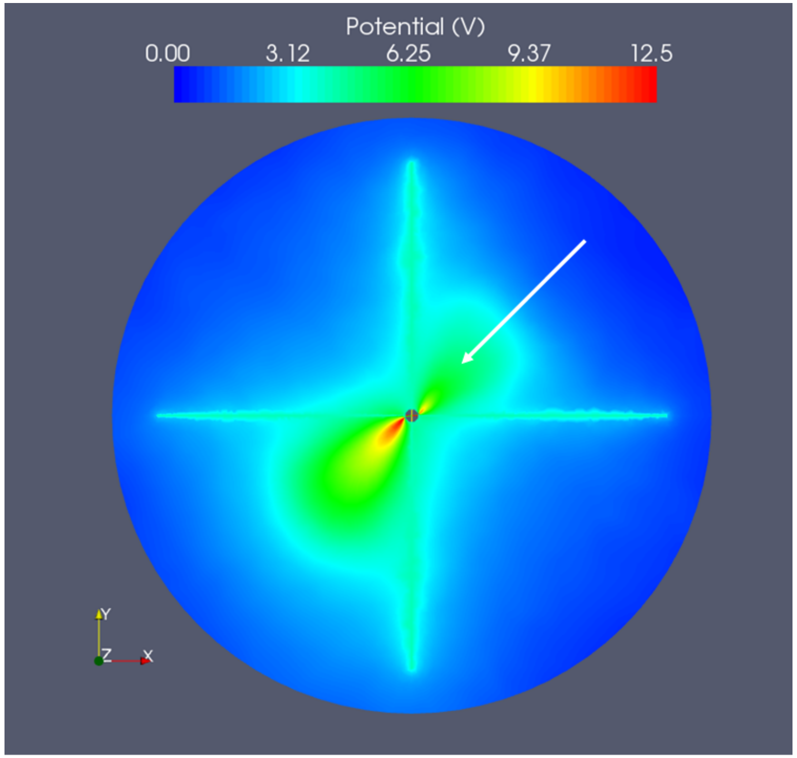


- E-field is calculated as V/88m
- Pulse of 0.3s duration and about 1.5V/m is predicted
- However, a background potential was produced which may be artefact of coarse wake simulation and narrow simulation volume

MMS



MMS

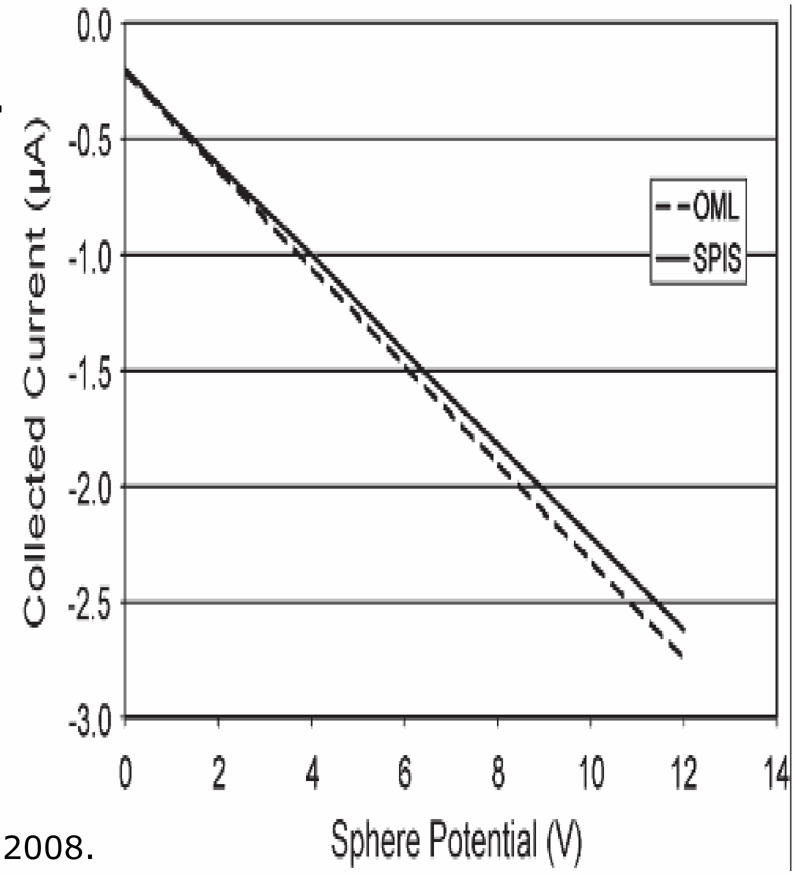


Spherical probe simulation

Validation test case

Sphere in large Debye length regime:
- A systematic difference of 5% found.
- No explanation.

Quantity	Symbol	Value	
Temperature	T	1.0	eV
Electron density	n	10^7	m^{-3}
Debye length	λ	~2.35	m
Potential	ϕ	[0,12]	V
Sphere radius	ρ	0.25	m
Number of tetrahedrons		~30,000	
Simulation box diameter		20	m
Number of macro-particles		~300,000	



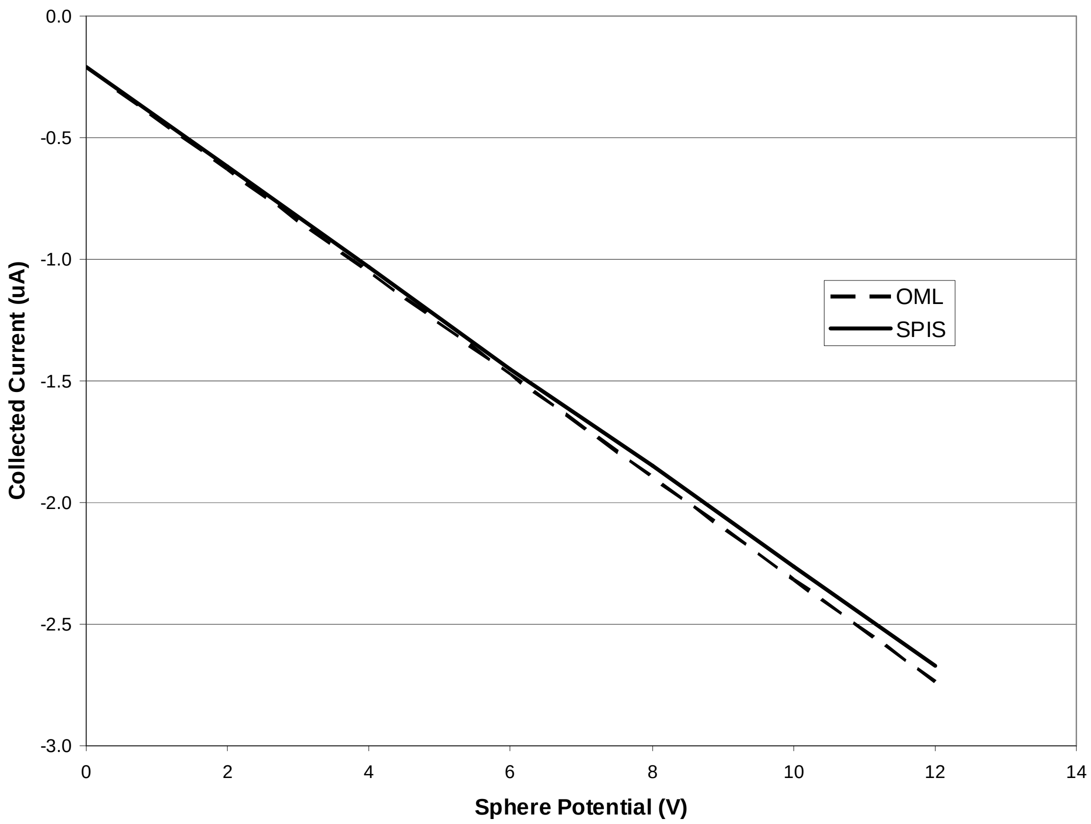
Ref.: Hilgers et al., IEEE Trans. Plasma Sc., 36, 5, 2008.

Spherical probe simulation

Backtracking
(SPIS v4.3)

12000 particles tracked

Sphere in large Debye length regime:
- At 0V virtually exact
- At higher voltages up to 2.5% error



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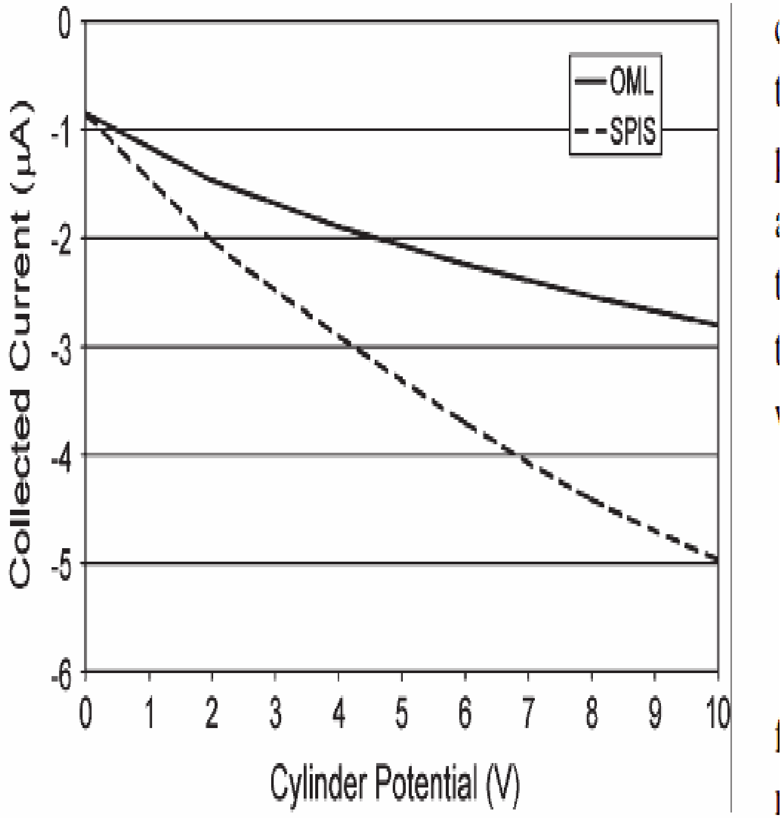
Cylindrical probe in Large Debye length regime

Cylinder in large Debye length regime:
- Very large difference is found.
- Finite length effect
- Is trajectory calculation accurate enough?

Quantity	Symbol	Value	
Temperature	T	1.0	eV
Electron density	n	10^7	m^{-3}
Debye length	λ	~2.35	m
Potential	ϕ	[0,12]	V
Cylinder radius	r	0.26	m
Cylinder length		16	m
Central node length		2.0	m
Number of tetrahedrons		~60,000	
Simulation box diameter		20	m
Number of macro-particles		~300,000	

Ref.: Hilgers et al., IEEE Trans. Plasma Sc., 36, 5, 2008.



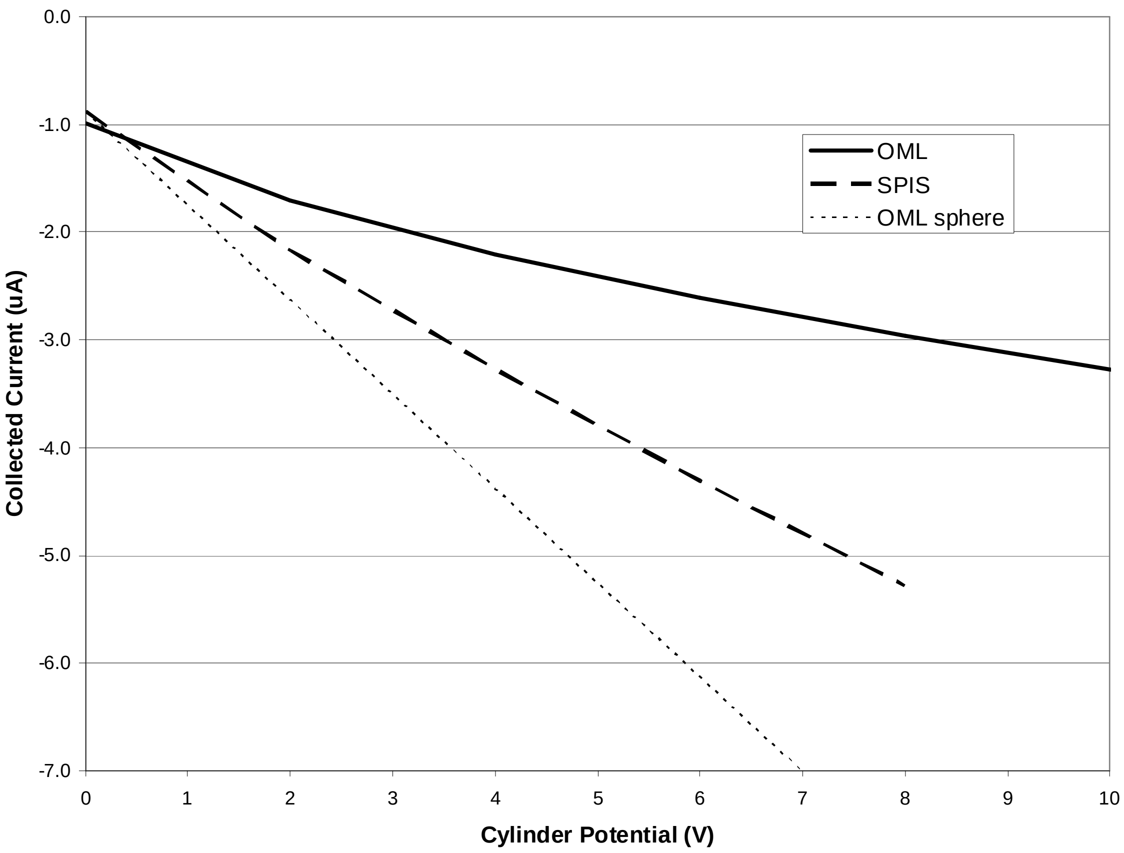
Cylindrical probe simulation

Backtracking

(SPIS v4.3)

49000 particles backtracked

Difference to OML is even larger



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Conclusion

- SPIS has allowed the effects of the spacecraft presence on measurements to be investigated.
- Not all the details that are wanted could be simulated (e.g. interconnects and high resolution everywhere)
- In particular the induced potential due to spacecraft floating potential at the instrument location can be assessed
- There is uncertainty in the neutralisation of ion plumes

- We want to simulate what the instrument itself measures, e.g. current for Langmuir probes, particle distributions for electrostatic analysers.
- By developing the reverse trajectory analysis capabilities of SPIS, this may be possible
- BUT we need to understand differences with probe theory

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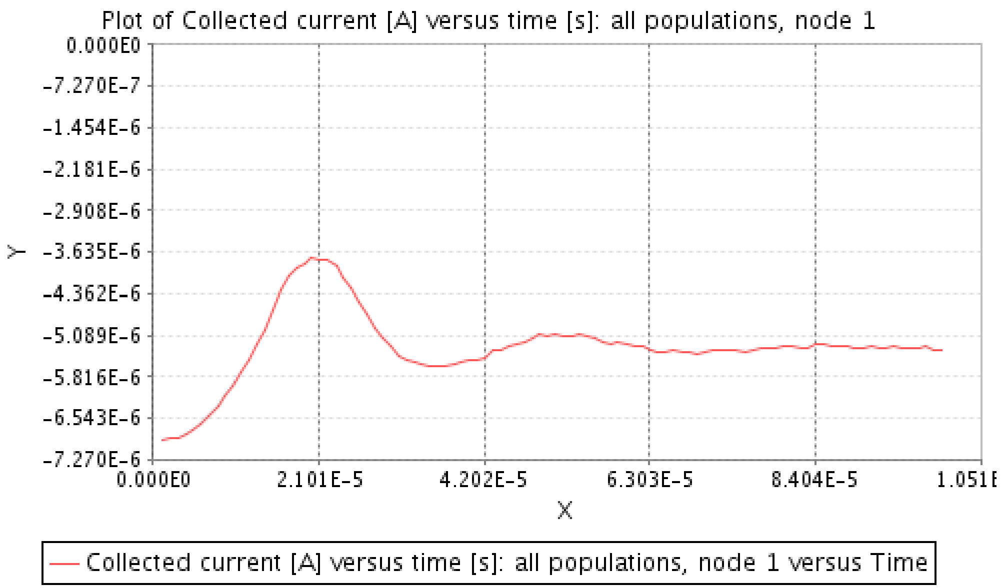

Cylindrical probe with +8V

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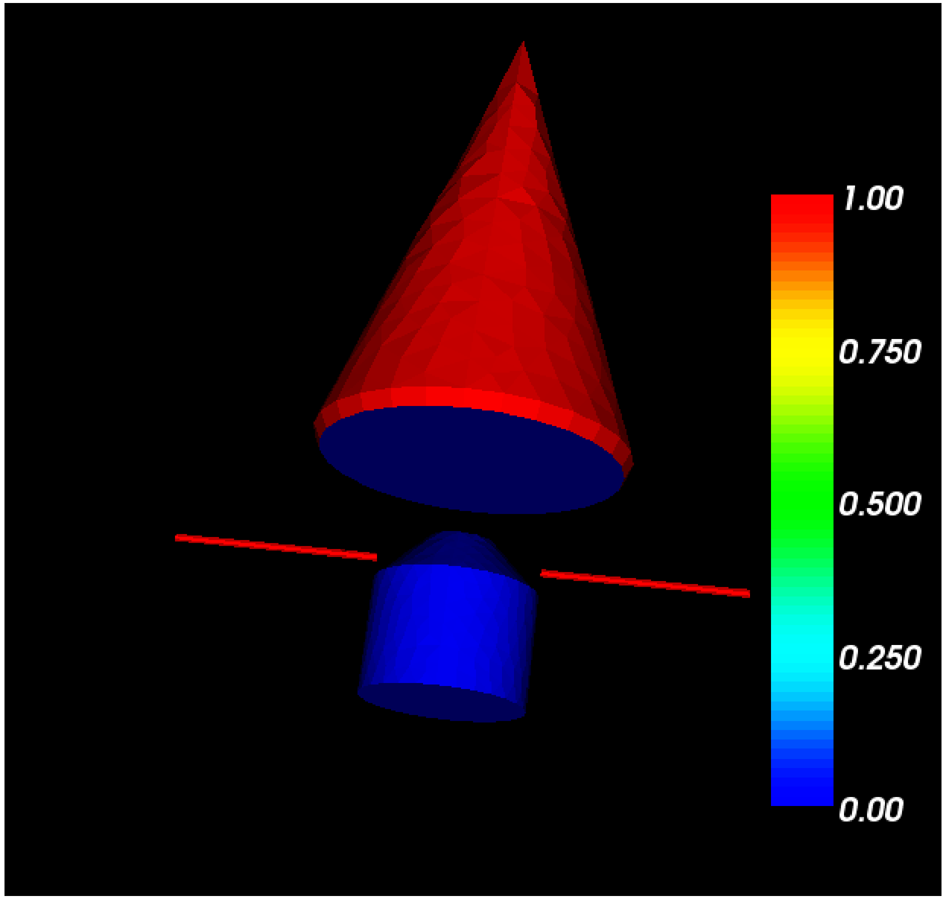
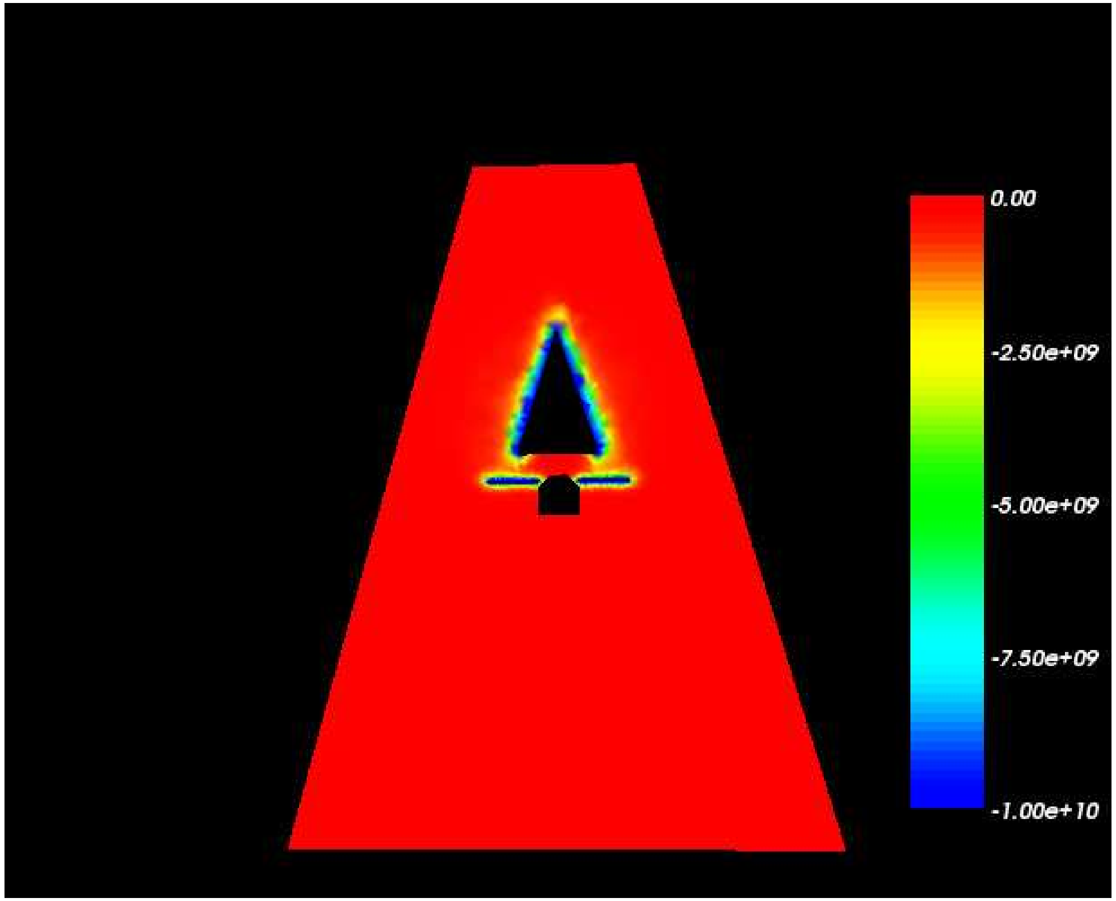
Solar probe



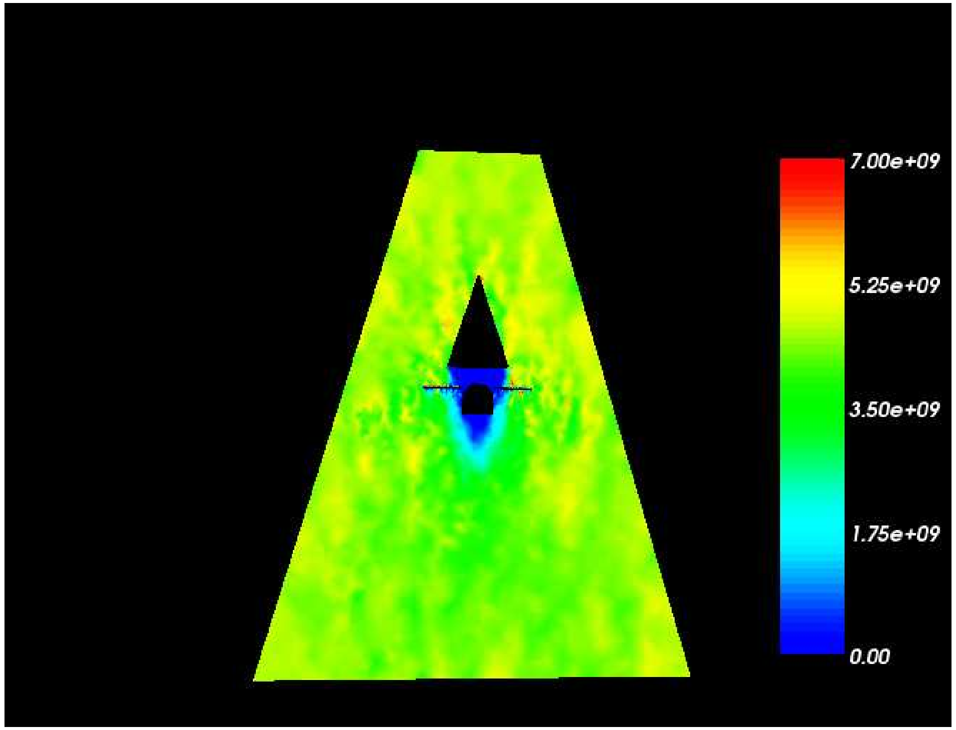
- Spacecraft is in shadow and sensors on booms extend beyond a sun-shield.

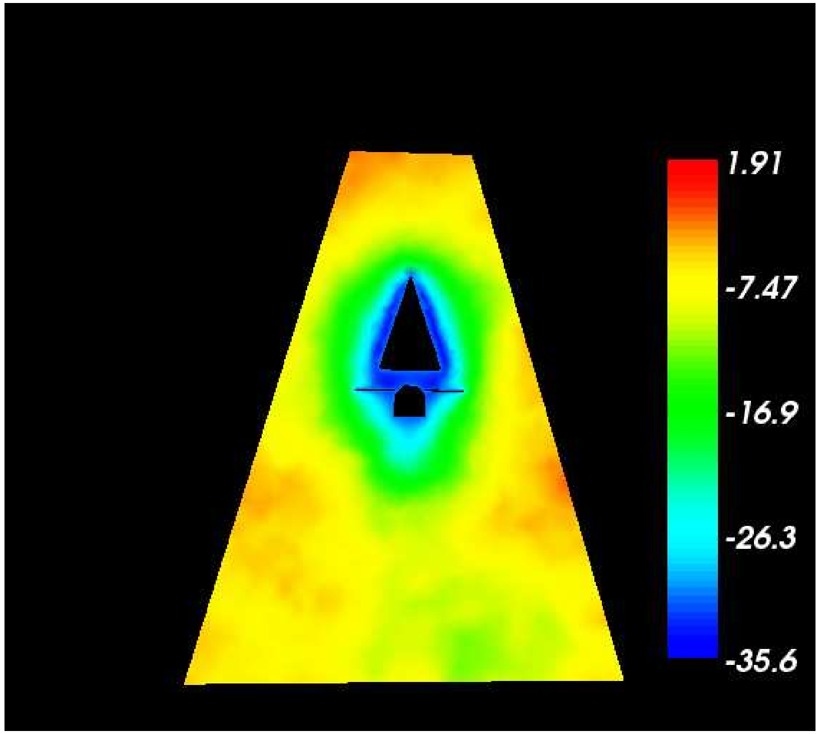
Solar probe



- Smaller simulation space than for Cluster allows better statistics
- Forcing shadowed surfaces to have no photoemission was difficult

Solar probe





- Instruments on short booms are out of the wake but influenced by the spacecraft potential

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