# Simulation needs for fields instruments

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# Why this talk?

- Introductory overview of area: background for speakers
- Point to issues/projects not covered by speakers
- Bring up other codes: what do they offer that SPIS does not?
- Requirements on SPIS upgrade: set the scene for upcoming presentations and discussions
- This is in much <u>my view</u> (with some input from others)
  - To be improved by your presentations and the discussions at this meeting

# Why this workshop?

- Obviously there are simulation needs among instrumenters
- Important to get community input on what these needs are before setting user requirements on SPIS upgrade

# SPINE XIV, ESTEC 2008

## SPIS simulations in support of plasma instruments forCosmic Vision

| | |
|---|---|
| A. Hilgers (ESA) | A review of spacecraft plasma interactions effects on plasma measurements |
| A. Masson (ESA) | Electron density measurements in the magnetotail with different instruments |
| M. Capacci (Laben) | Observation of SMART-1 plume plasma environment with the EPDP plasma diagnostic package and future activities |
| M. Capacci (Laben) | Charging active control: PLEGPAY experiment onboard ISS results; activities on future systems |
| D. Rodgers (ESA) | Plasma measurements onboard CHAMP spacecraft |
| H. Laakso (ESA) | Observation of spacecraft plasma interactions with Cluster |
| D. Kataria (MSSL) | Spacecraft-plasma interactions: an MSSL perspective |
| A. Eriksson (IRFU) | Cold plasma and electric field measurements in the Jovian system: possibilities and challenges |
| A. Hilgers (ESA) | Modelling of plasma environment of Cluster electrostatic sensors |
| A. Eriksson (IRFU) | Wakes in cold tenous plasmas: nuisance and blessing |
| S. Clucas (ESA) | MMS electrostatic environment simulation |
| D. Rodgers (ESA) | Champ and Swarm plasma environment modelling |

# Contents

- Fields instruments
  - Types
  - Issues
  - Design issues
  - Data interpretation
- Missions
- Codes
  - Use of SPIS
  - Other codes

# Fields instruments

- Instruments for measuring continuous fields
- Traditional/practical grouping:
  - DC B-field (limit ≈ 100 Hz)
  - DC E-field (limit ≈100 Hz)
  - Langmuir probes (plasma density & temperature)
  - AC B-field (limit ≈100 Hz)
  - AC E-field (limit ≈100 Hz)
  - Radio/radar (≈MHz)
  - Active instruments: sounders, impedance probes

# S/c-plasma issues for simulation (1/2)

- DC B-field measurements
  - Usually quite insensitive to s/c-plasma issues
  - In dense magnetized plasmas, the polarization current on wake edge can give a DC B signal (Swarm)
- DC E-field measurements & Langmuir probes
  - Relies on electric coupling to plasma, sensitive to s/c-plasma issues
  - Asymmetric antenna or s/c configuration
  - Photoelectron clouds and currents
  - Wake potential, asymmetric shielding
  - Presentations by e.g. Cully, Marchand, Wahlund, Nilsson, Morooka, Hånberg, Capacci, Brunner

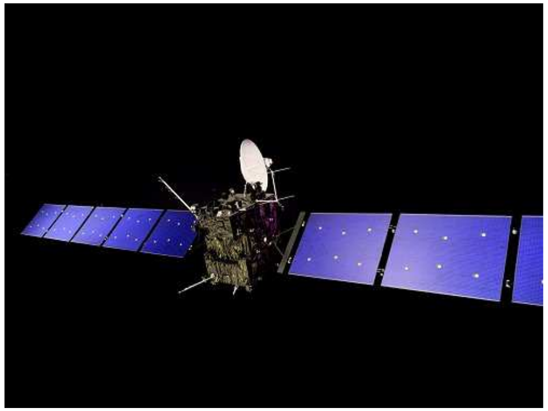
# S/c-plasma issues for simulation (2/2)

- AC E- and B-field instruments
  - Antenna diagrams
  - Wave scattering on s/c surfaces and plasma inhomogeneities
  - Waves and noise generated by wake, Mach cone etc
  - Presentations tomorrow by e.g. Maksimovic and Krasnoselskikh

# Missions and needs

- Some missions needing instrument simulations:
  - In space: Rosetta, Cassini, Cluster, THEMIS
  - Upcoming: Swarm, BepiColombo, MMS
  - Design phase: JGO/JEO, Solar Orbiter, SP+
- In most cases, wide ranges of plasma parameters are encountered
  - Example: Debye lengths for Rosetta vary from a fraction of a mm (fully developed inner coma) to tens of meters (tenuous solar wind & magnetosphere at Earth swingby)
  - No single simulation setup can cover all this with just a change of parameter values
- Some include thin (mm) and long (tens of m) wire booms challenging to model
  - Cluster, THEMIS, MMS, BepiColombo MMO

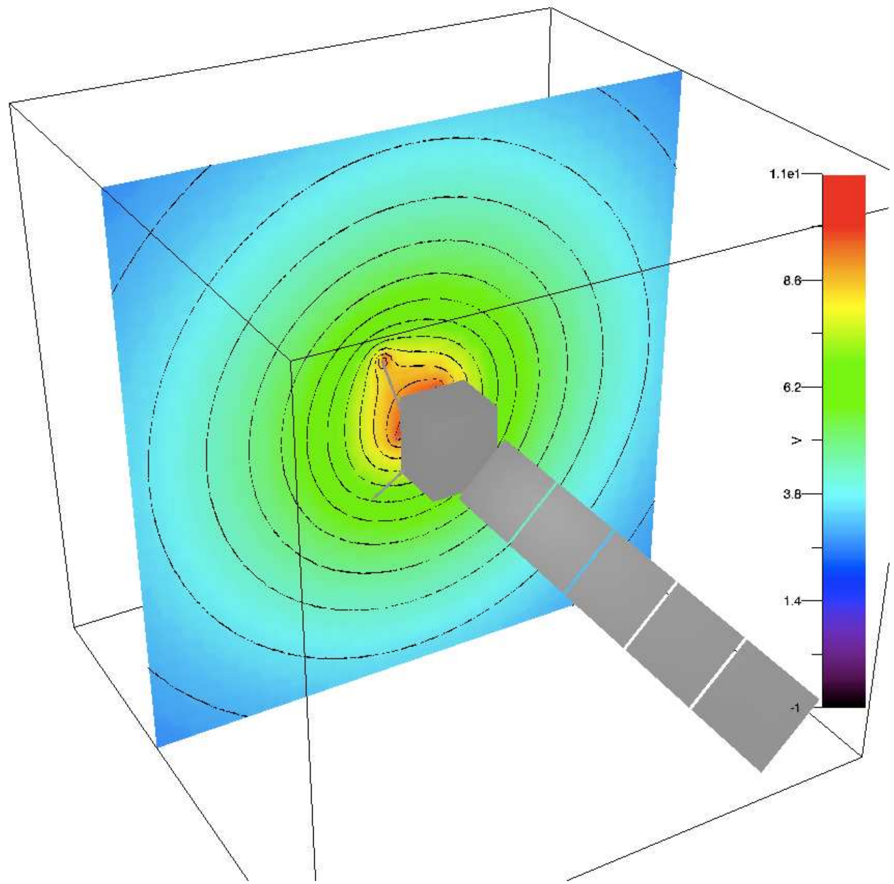
# Rosetta



- In space, ops at target comet from 2014
- Presentations by Schläppi and Hånberg
- S/c-plasma interaction simulated by Roussell and Berthelier (2004) and by Sjögren et al (2009, 2010)
- S/c plasma issues for density, E-field and s/c potential measurements:
  - Wake and photoelectron cloud in solar wind/early comet phase
  - Wake formation in dense plasma at fully developed comet
  - Contamination/inhibition of probe current

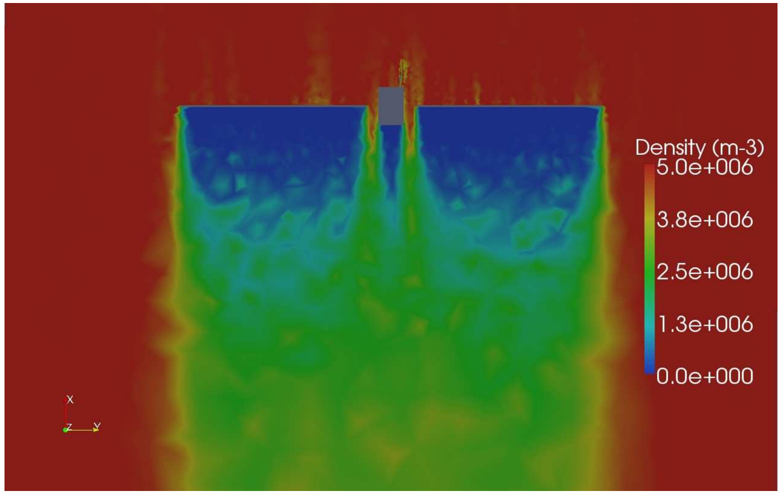
# Rosetta Langmuir probe instrument

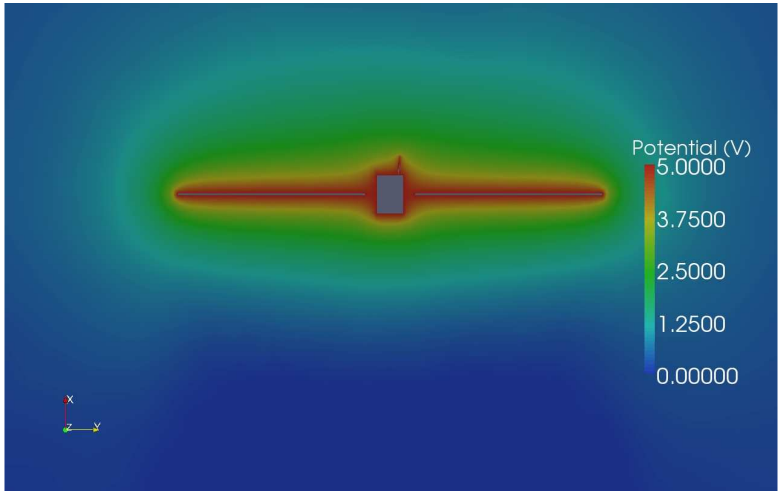
- In tenuous plasmas, much of s/c potential remains at boom position
- Need simulations to see how measured potential relates to real s/c potential



# Rosetta: Wake and photoelectrons

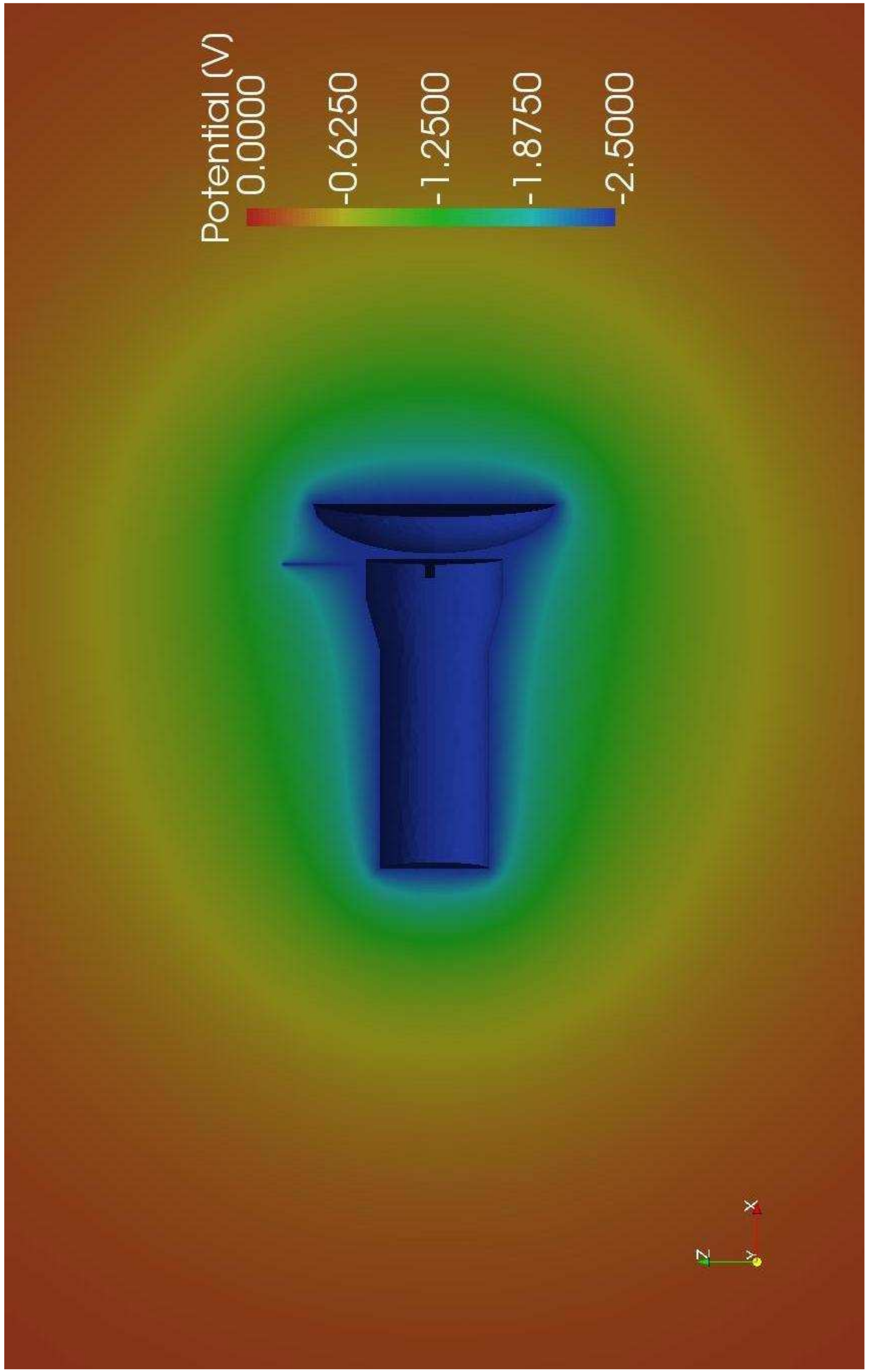
- Wake and cloud of photoelectrons build up potentials of the scale we wish to measure
- SPIS simulations quite adequate for impact on Vsc measurements
- Sjögren (2009, 2010)
- Modelling by Hånberg (tomorrow)
- Present SPIS cannot simulate Langmuir probe operations (c.f. Cassini)



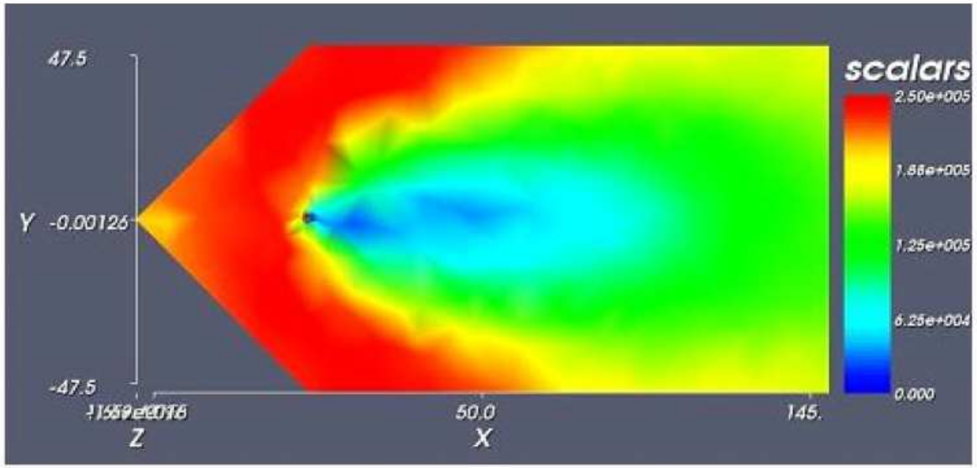
# Cassini

- In space, at Saturn since 2004
- Presentations by Wahlund, Lewis, Morooka and Nilsson
- S/c-plasma interaction simulated by Nilsson (SPIS,2009) and Olson (2010, other code)
- Issues for density and s/c potential measurements:
  - Photoemission in tenuous plasmas (Saturn msph – within current SPIS capacity)
  - LP current collection influence from s/c-plasma issues (current SPIS not sufficient)

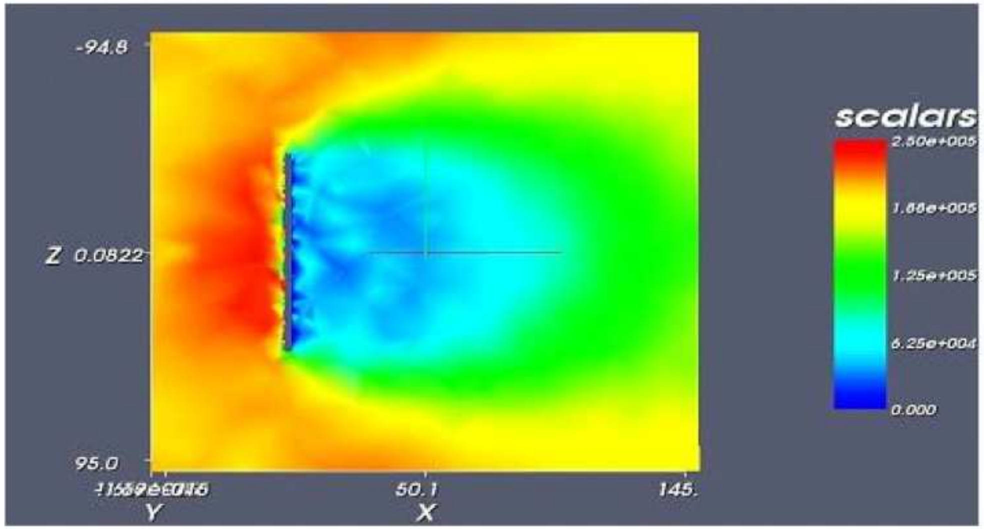


# Cluster, THEMIS, MMS, Bepi MMO

- Missions with long wire boom electric fields
- SPIS has some capability to model these, but dedicated codes (see Cully presentation) with different philosophy can be more useful
  - When plasma densities increase, SPIS PIC capacities would be useful
- SPIS simulations by Prakash (2007)
- Problem:
  - Large scale size disparity (mm to hundreds of m)
  - Enormous number of particle needed in strict PIC approach
  - Backtracking, also of photoelectrons, could much improve SPIS in this respect

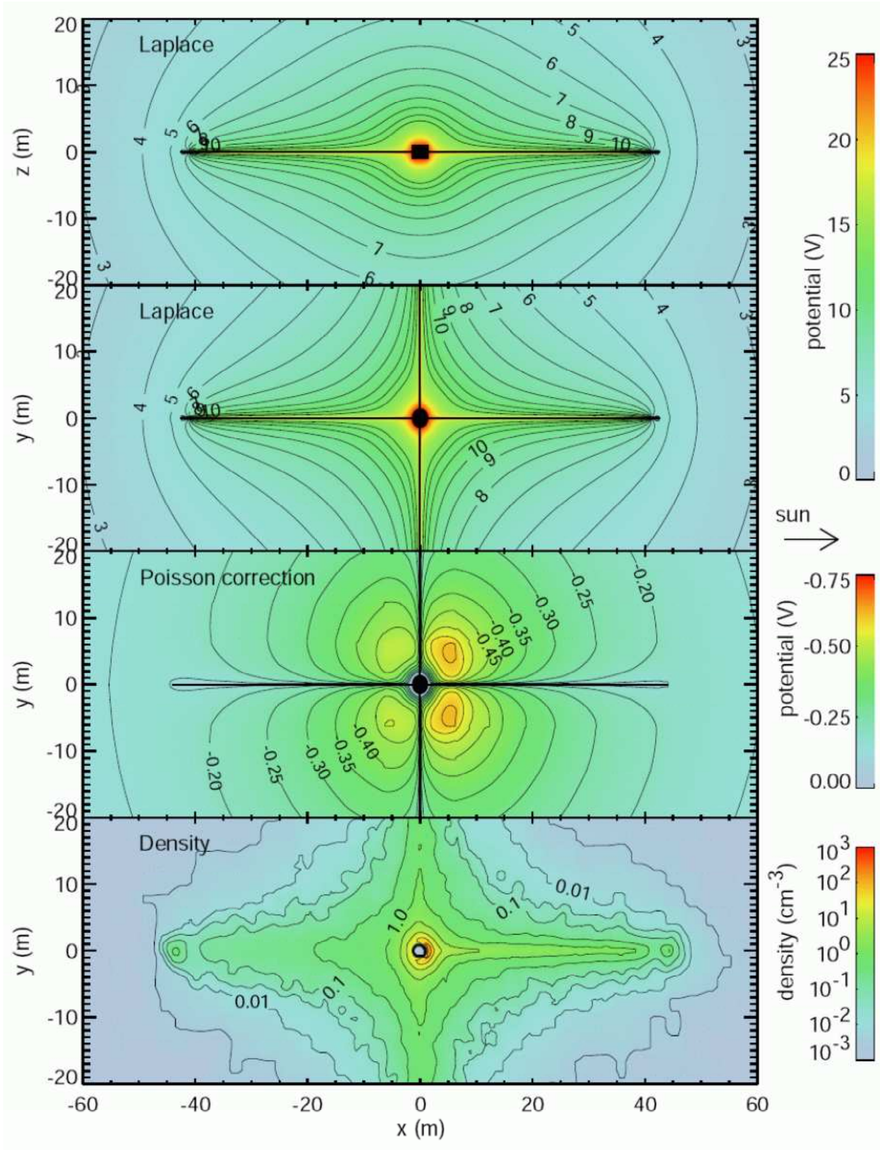



(a): Ion density in XY plane (Grid points in m)




(b): Ion density in XZ plane (Grid points in m)

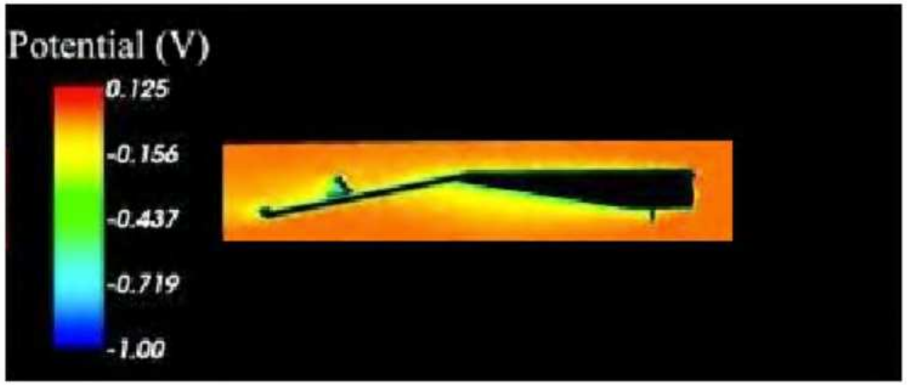
Prakash SPIS sim of Cluster wire booms in a plasma flow

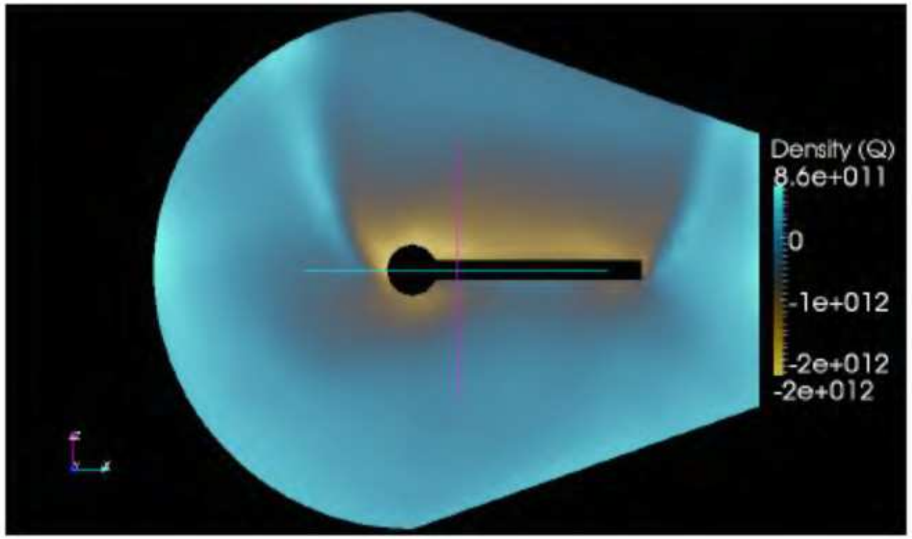



Cully Daedalus simulation of Cluster photoemission and its impact

# Swarm

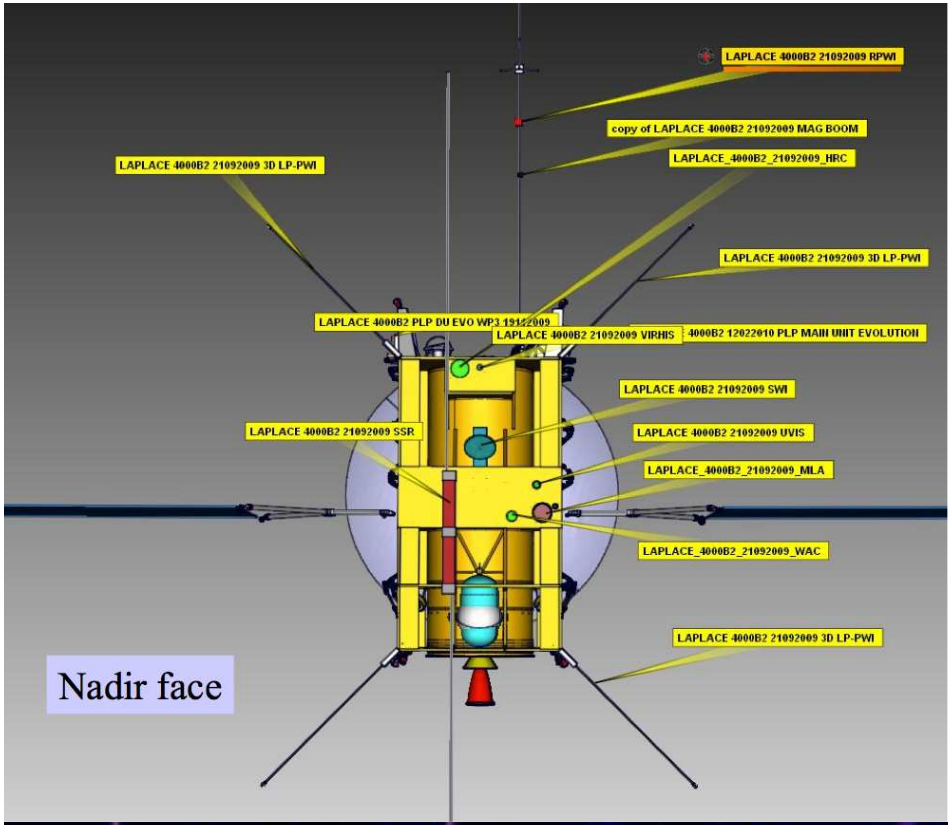
- Ionospheric mission with Langmuir probe and thermal ion instrument
- Simulated by:
  - Rodgers (s/c potential, SPIS)
  - Marchand (ion measurement, own code, includes B)
  - Chiaretta (LP, SPIS, presented at SPINE XVI)
- Chiaretta LP SPIS simulation
  - Simulated influence on LP from adjacent elements
  - Could not simulate s/c influence on LP in current SPIS
  - Would be able to if SPIS version used included backtracking to given surface (probe) for improving statistics
  - Similar problem for Cassini (Nilsson presentation tomorrow), Rosetta, JGO etc
- Magnetic field effects should be modelled!



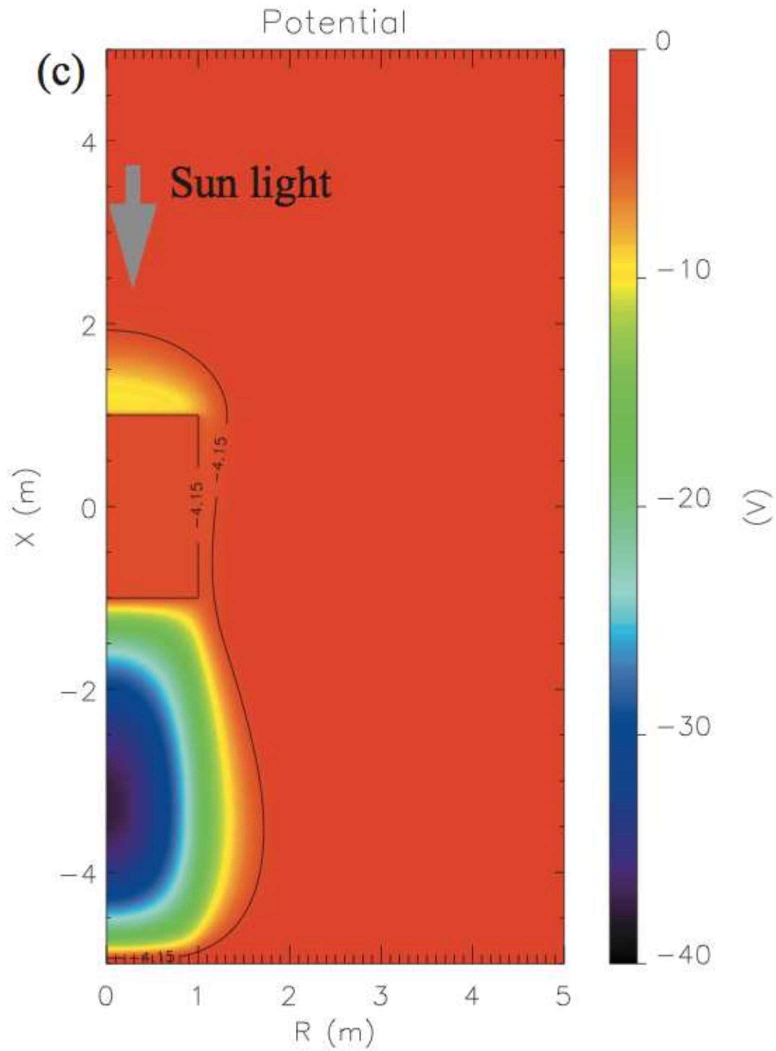
# JGO

- Jupiter Ganymede Orbiter
- Presentations by Wielders and Wahlund tomorrow
- Initial instrument simulations by Cully
- S/c-plasma issues quite similar to Cassini and Rosetta
- Added influence of high-energy impact (radiation secondaries etc)




# Solar Orbiter
# Solar Probe+

- Missions to the near-solar environment
- Presentations by Maksimovic and Krasnoselskikh tomorrow
- Environment with high Te and high density
- For DC Langmuir probes/E-fields, current SPIS should be sufficient
- AC perturbations may need better tools (Krasnoselskikh, Maksimovic)




Ergun Solar Probe+ simulation

# Other simulation tools used

- PicUp3D (SPIS predecessor, homogeneous Cartesian grid)
- Presentations by:
  - Richard Marchand (code including B)
  - Chris Cully (boundary element code with backtracking)
  - Stefano Markidis (independent PIC code)
- Many PIC codes can be adopted to do at least parts of what SPIS does. Recent examples:
  - Olson et al (Phys. Plasmas 17, 102904, 2010) used two PIC codes (2D and 3D) by W. J. Miloch (crude Cassini model, no photoemission)
  - Ergun et al (Phys. Plasmas 17, 072903, 2010) used an own code for investigating the s/c potential of Solar Probe+ in the near-sun environment
- High-frequency codes operating in the frequency domain
  - Beghin et al (Radio Sci., 40, RS6008, 2005) simulated the response of the Cluster electric antennas in space above ≈1 kHz
  - Several simulations and lab investigations by e.g. the Graz group
  - Frequency domain simulations considered to be outside the scope of SPIS

# Input from Jean-Jacques Berthelier

- 1- **Including magnetic field** and testing the results first in the case of a simple Langmuir probe with a plasma at rest. There are a few papers in the litterature such as those of Laframboise (JGR 1993 I believe), Singh (also in JGR but I do not remember the exact year, probably 1994 or 1995) and certainly a few from San Martin which I do not know about. Comparing the SPIS results with published results in a "simple" case is mandatory to be sure of what SPIS is doing. **In particular the extent of the sheath along and perpendicular to B would be very important.** In a second step it should be important to check the variation of the wake, if any, depending on the magnetic field direction and intensity.
- 2- Increasing the size of the simulation box to several tens of meters (minimum 40 m) for a satellite like DEMETER, i.e. with dimensions less than 1 mx1mx1m and for Debye length ~ 10cm (max 20 cm). Most important is the length on the rear side of S/C of at least 30 m. Transverse dimensions may be ~ 8-10m. I understand this is very demanding for memory but we have observed a new phenomenon on DEMETER that is related to wake effects at long distance from S/C and to be quantitative a model with a long simulation box is needed.
- Wish you a happy and successfull New Year and a good meeting, JJ

# When is present SPIS insufficient? (1/2)

- Simulating a small instrument on a big s/c
  - Issue: current to instrument noisy because few PIC particles hit it unless the total macroparticle number is impractically large
  - Can be fixed by allowing backtracking from given elements, in this case an electrostatic probe, also of photoelectrons
  - Assumes SPIS solution for potential is good even though the macroparticle number in small tetrahedra around a finely resolved instrument, which often is a good approximation

# When is present SPIS insufficient? (2/2)

- Magnetic field effects can be very important, and need a SPIS-like tool in complex geometries
  - Integration time for particle trajectories increases
  - Combination with backtracking could allow a relatively low macroparticle number at least in some cases
- Importance of outgassing and subsequent ionization?
  - Can be important for recently launched s/c in tenuous plasmas: see presentation by Schläppi tomorrow
- High-energy particle impact?
  - Particularly for JGO. Is this important or not?
- Dusty plasmas and dust grain impacts?

# This workshop

- Looking forward to getting your inputs
- Your chance to influence SPIS development
- Make your thoughts very clear to us
- Suggestion: end your presentation by stating what you what like SPIS to do, or how it should be modified