SPIS and MUSCAT software comparison on LEO-like environment

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Abstract:

Several numerical codes aiming at calculating spacecraft plasma interactions have been developed over the world. They generally calculate plasma dynamics, current emission/collection on spacecraft and spacecraft charging. Among these codes, SPIS and MUSCAT have been developed by ONERA/DESP and KIT respectively.
SPIS, the Spacecraft Plasma Interaction Software, has been developed with ESA support and ameliorated via several CNES R&T contracts so as to provide the community with an open-source software dedicated to the environment effect on satellites. The numerical core and the user interface have been developed by ONERA and ARTENUM respectively [1]. The effect of in-orbit plasma on spacecraft has been modelled in a wide range of configurations: electric propulsion [2], GEO charging, barrier of potential [1]. The ONERA plasma chamber JONAS has also been simulated and the results compared to experiments [3]. SPIS also takes account of all phenomena involved in ESD triggering. It has permitted to confirm a physical model of ESD triggering [4] by numerical simulations [5].
MUSCAT, the Multi-Utility Spacecraft Charging Analysis Tool, has been in development since 2004 and the final version was released in March 2007 [6]. The comparison to experiments has also been achieved in a wide range of configurations [7].

By now, the models have been tested independently. The objective of this work is to provide a first attempt of SPIS and MUSCAT cross validation. It consists in comparing them in a typical LEO-like environment. First simulations were performed in previous work using MUSCAT to solve plasma dynamics around a plate immersed in drifting plasma.[7]. The work presented in this paper consisted in using SPIS in the same configuration. The results show a good qualitative and quantitative agreement with similar plasma sheath, particle dynamics, wake and particle collection. In near future, better quantitative agreement could be achieved by using closer models. The next step would then be to simulate the spacecraft charging at GEO.

[1] J.-F. Roussel et al., "SPIS Open Source Code: Methods, Capabilities, Achievements and Prospects", *IEEE Trans. Plasma Sci.*, Vol. 36, N°5, oct. 2008.

[2] J.-F. Roussel et al., "Modeling of FEEP Electric Propulsion Plume Effects on Microscope Spacecraft," *IEEE Trans. Plasma Sci.*, Vol. 36, N°5, oct. 2008.

[3] J.-C. Matéo-Vélez et al.,"Ground Plasma Tank Modeling and Comparison to Measurements," *IEEE Trans. Plasma Sci.*, Vol. 36, N°5, oct. 2008.

[4] D. Payan, F. Séverin, J.-P. Catani, J.-F. Roussel, R. Reulet, D.Sarrail, "Electrostatic discharges on solar arrays. Physical model of inverted potential gradient electrostatic discharge", 7^{th} SCTC, Noordwijk, The Netherlands, 2001.

[5] L. Girard, D. Payan, J.-F. Roussel, F. Séverin, "SPIS modelling of electrostatic discharge triggering in a solar cell gap", 10^{th} Spacecraft Charging Technology Conference, Biarritz, France, 2007.

[6] T. Muranaka, S. Hatta, J. Kim, S. Hosoda, K. Ikeda, M. Cho, H. O. Ueda, K. Koga, T. Goka, "Final version of multi-utilityspacecraft charging analysis tool (MUSCAT)", 10^{th} SCTC, Biarritz, France, 2007.

[7] S. Hosoda, T. Muranaka, H. Kuninaka, J. Kim, S. Hatta, N. Kurahara, M. Cho, H. O. Ueda, K. Koga, T. Goka, "Laboratory experiments for code validation of Multi-Utility Spacecraft Charging Analysis Tool (MUSCAT)", *IEEE Trans. Plasma Sci.*, Vol. 36, N°5, oct. 2008.

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ONERA THE FRENCH AEROSPACE LAB

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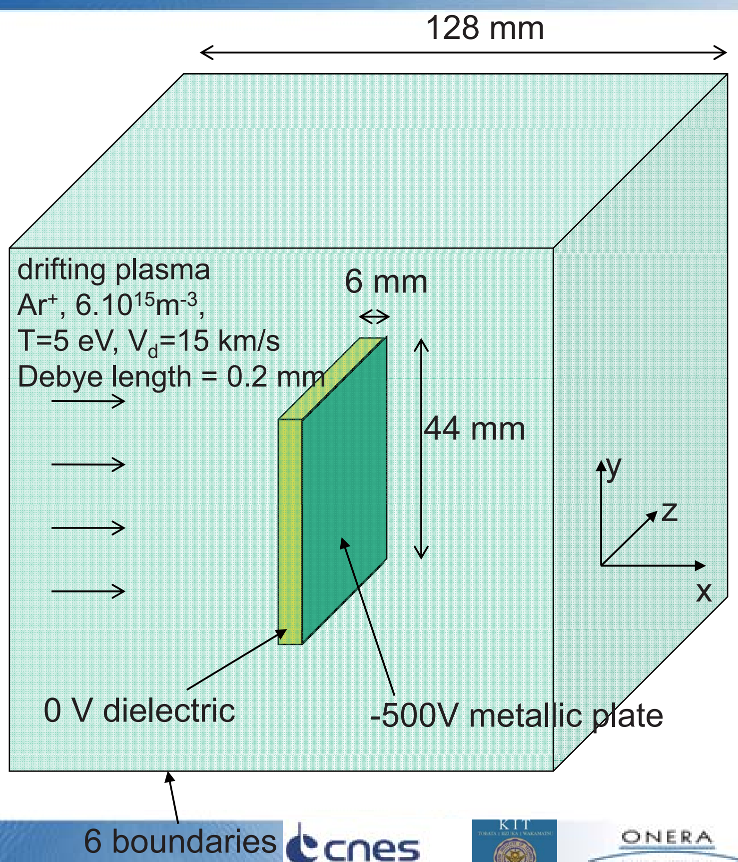
retour sur innovation

Introduction

- Complex interactions between spacecrafts and the environment can be simulated with dedicated numerical tools (SPIS, MUSCAT, NASCAP-2k,…)
- Compare SPIS and MUSCAT
  - SPIS : open source code, development supported by ESA, with multiple improvements through CNES R&D funding
  - MUSCAT : Multi Utility Spacecraft Charging Analysis Tool (JAXA and KIT, Japan)
- CNES R&D funding (2008) for SPIS simulations
- Chosen configuration :
  - Simulation of an experiment already conducted in KIT
  - Reference : Hosoda et al., "Laboratory Experiments for Code Validation of Multi-Utility Spacecraft Charging Analysis Tool (MUSCAT)", IEEE Trans. Plasma Sci., Oct 2008.
  - Simple geometry : a plate
  - LEO plasma environment

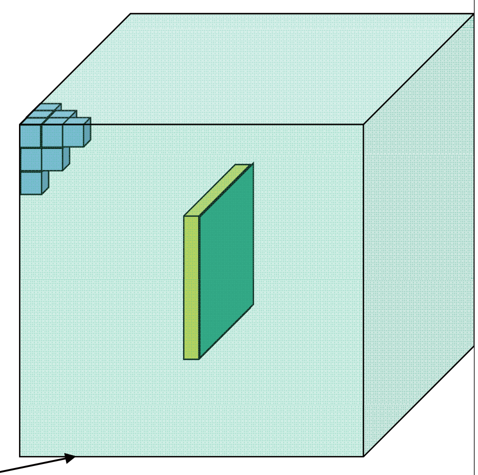
Description of the simulation

- Previous MUSCAT simulation
- Flat plate immersed in a LEO-like drifting plasma
- General model
  - Input data obtained from experiments
  - no change in the plate potential (0V on the dielectric ram face and -500V on the rear side)
  - no charge exchange reaction
- Physics to simulate
  - plasma dynamics (Vlasov-Poisson system)
  - wake effect
  - plasma sheath
  - collection of ions on the -500V rear side



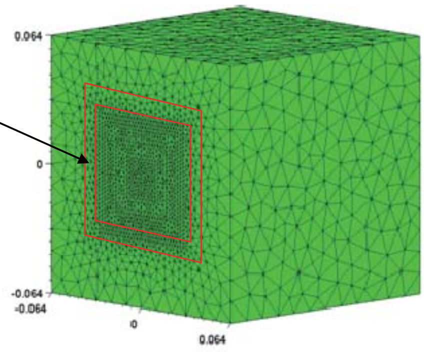
MUSCAT modelling

- Uniform mesh (MUSCAT limitation)
  64 × 64 × 64 = 260,000 cells of 2mm edge
  and ~260,000 nodes
- Electron and ion dynamics
  PIC (Particle-In-Cell)
  64*64*100 particles injected at entrance
- Electric field
  Fast Fourier Transform (because unif. mesh)
- Boundary conditions
  0V on plasma boundary
- Particle collection on the plate
  Forward tracking (particles followed from their injection to their collection on boundaries (plate or external)



SPIS modelling

For statistics: local amplificaton of superparticle number injection (100p/cell instead of 5)



- *Tetrahedral unstructured mesh (Gmsh)*

  155,000 cells – 26,000 nodes
- Ions dynamics

  PIC
- *Electron dynamics (Global equilibrium)*

  Boltzmann distribution $N_e = N_0 \exp\left(\frac{e\phi}{k_B T_e}\right)$
- *Electric potential*

  Non-linear Poisson equation – implicit solving for stability at grid mesh greater than Debye length

$$-\Delta\phi = \frac{e}{\varepsilon_0}\left(N_i - N_0 \exp\left(\frac{e\phi}{k_B T_e}\right)\right)$$

- *Boundary conditions*

  $1/r^2$ potential decay (pre sheath condition)
- Ion collection

  Forward tracking

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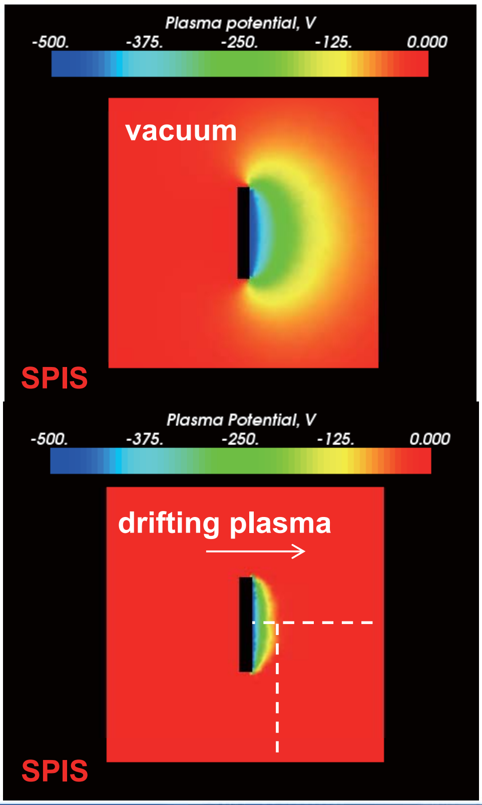
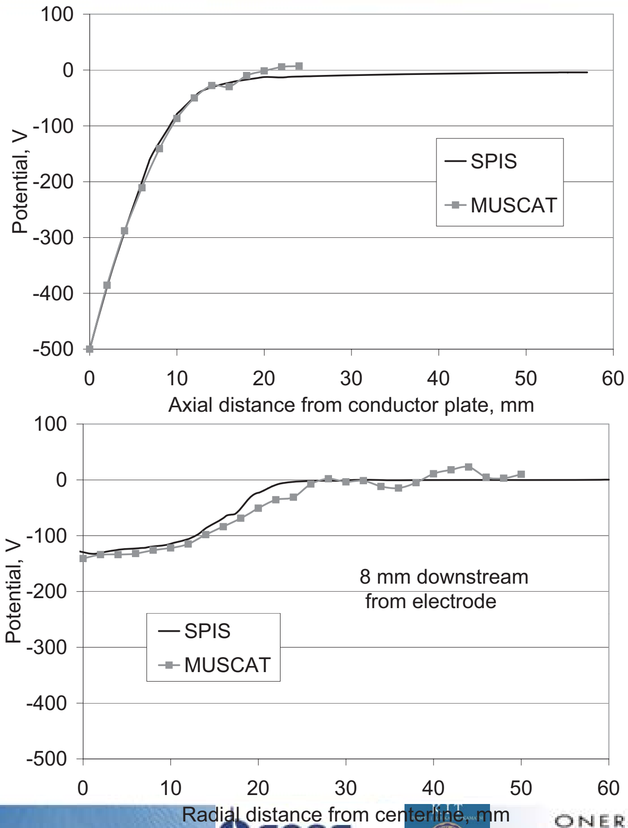
Results – Electrical Potential





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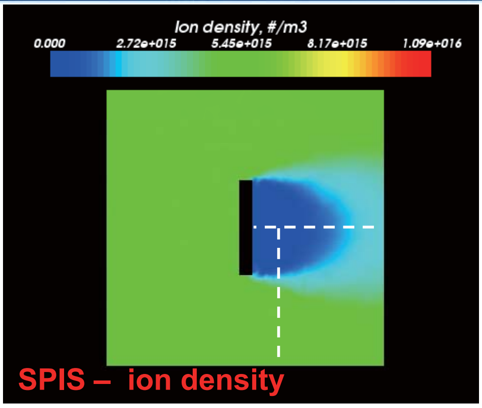
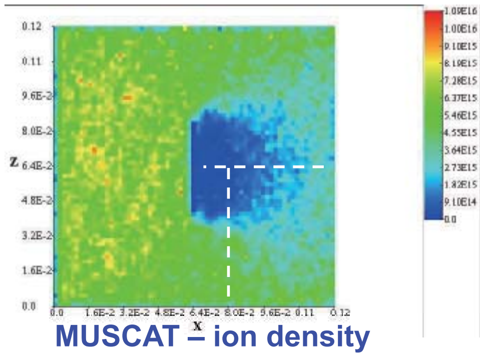
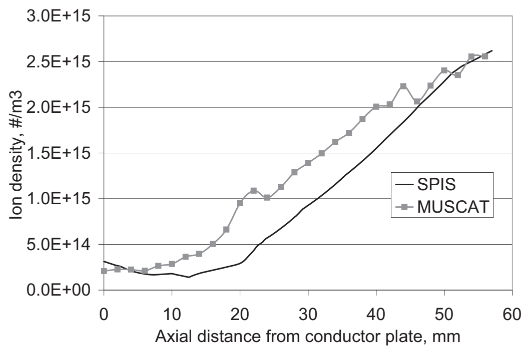
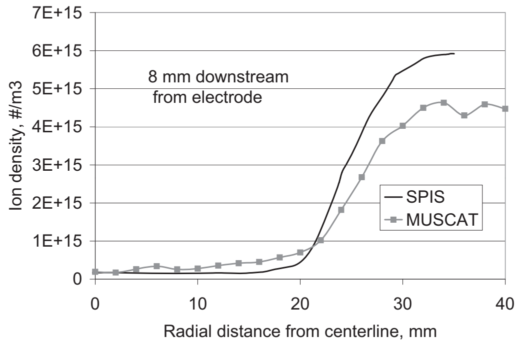
Results - Ions









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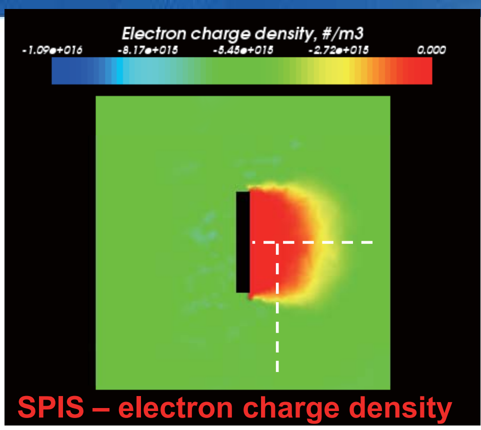
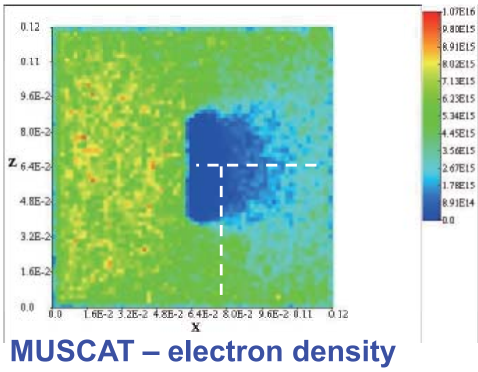
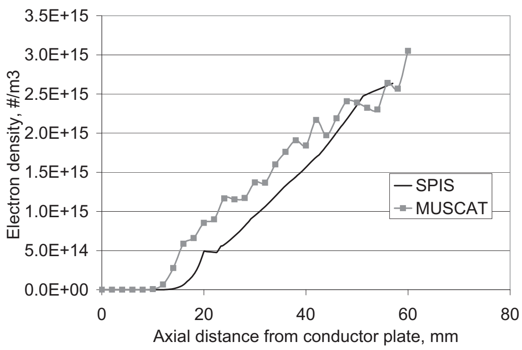
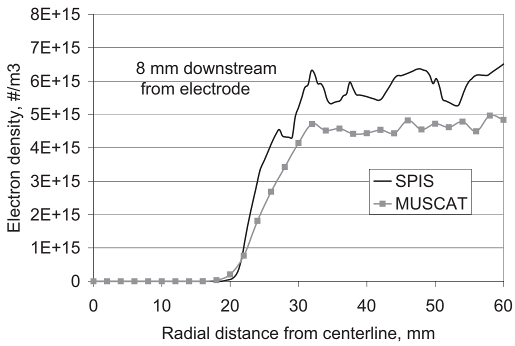
Results - Electrons









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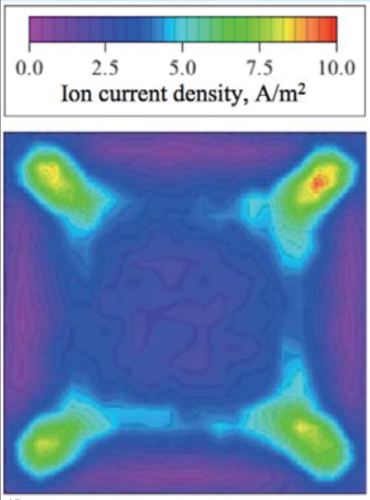
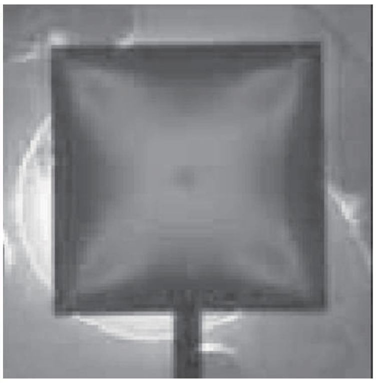
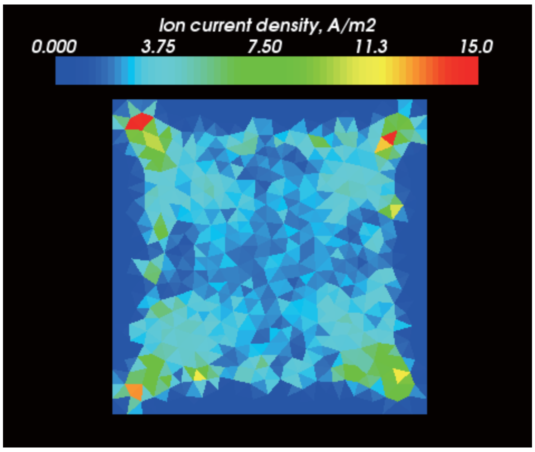
Results - Ion collection on the rear side



MUSCAT



KIT exp.



SPIS

Hosoda et al., "Laboratory Experiments for Code Validation of Multi-Utility Spacecraft Charging Analysis Tool (MUSCAT)", IEEE Trans. Plasma Sci., Oct 2008.

Total collected current = 6.4 mA with MUSCAT
= 5.0 mA with SPIS

Conclusion

- Good comparison between SPIS and MUSCAT on
  - Plasma sheath
  - Particle dynamics and wake
  - Forward tracking for ion collection on the plate
- Probably better agreement with
  - the same boundary conditions (Dirichlet on plasma BC potential now available in SPIS)
  - a higher Debye length case
- Probably to be taken into account for comparison to experiments: (CEX)Charge exchange ions
  - *cf.* ONERA plasma chamber simulation: Mateo-Velez et al., "Ground Plasma Tank Modeling and Comparison to Measurements", IEEE Trans. Plasma Sci., Oct 2008.
- Future comparison: GEO spacecraft satellite?
  - Spacecraft electrical circuit
  - Backtracking on sufficiently big domain to assess which trajectories are filled or not
  - Same boundary conditions