Spacecraft charging analysis with iPic3D & comparison of model predictions applied to Solar Probe Plus

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SEVENTH FRAMEWORK PROGRAMME

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We present the first results on the analysis of spacecraft charging with the implicit particle-in-cell code **iPic3D**, designed for running on massively parallel supercomputers *[Deca et al. 2013]*. Secondly, five spacecraft-plasma models, including **iPic3D**, are used to simulate the interaction of the SPP satellite with the space environment under representative solar wind conditions near perihelion *[Marchand et al. 2013, submitted to P&SS]*. Although the numerical approaches are rather different, good agreement is found, raising the level of confidence in the codes to predict and evaluate the complex plasma environment around spacecraft.

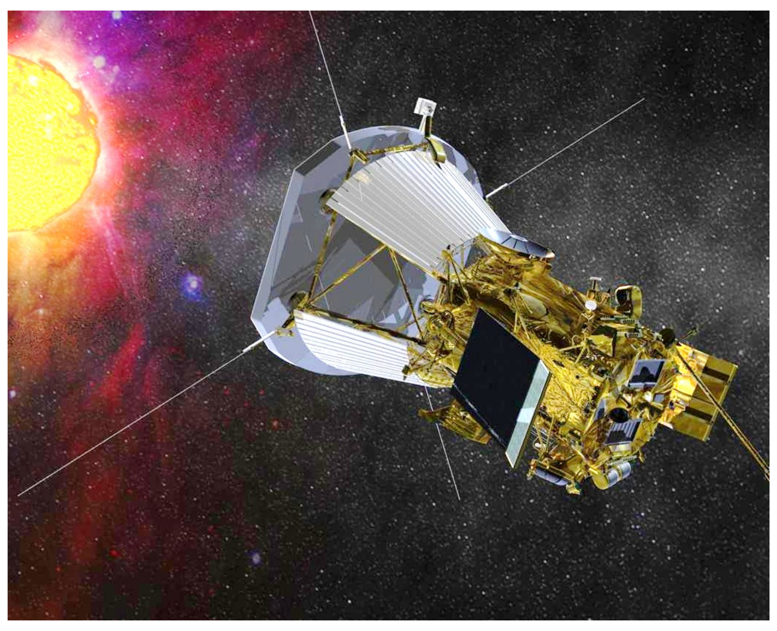


Figure courtesy: NASA

SOLAR PROBE PLUS (SPP) will study the Solar corona as it extends out into space, the last region of the solar system to be visited by a spacecraft.

- 8.5 solar radii above the Sun's surface.
- In-situ measurements of the region where some of the most hazardous solar energetic particles are energized.
- Improve our ability to characterize and forecast the radiation environment in which future space explorers will work and live.

iPic3D for spacecraft charging

- Fully kinetic, fully parallelized PIC code based on the implicit moment method *[Markidis et al. 2010]*.
- Electrostatic Poisson solver with immersed boundary method:

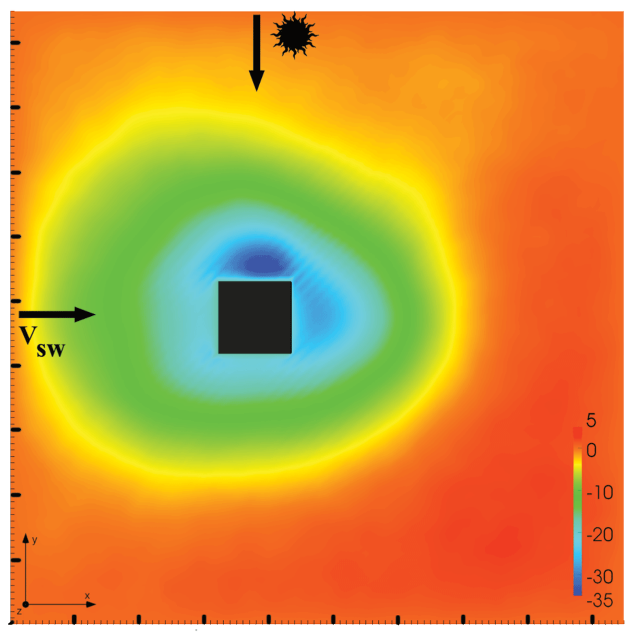
$$\nabla \cdot \epsilon \nabla \phi = -\rho,$$

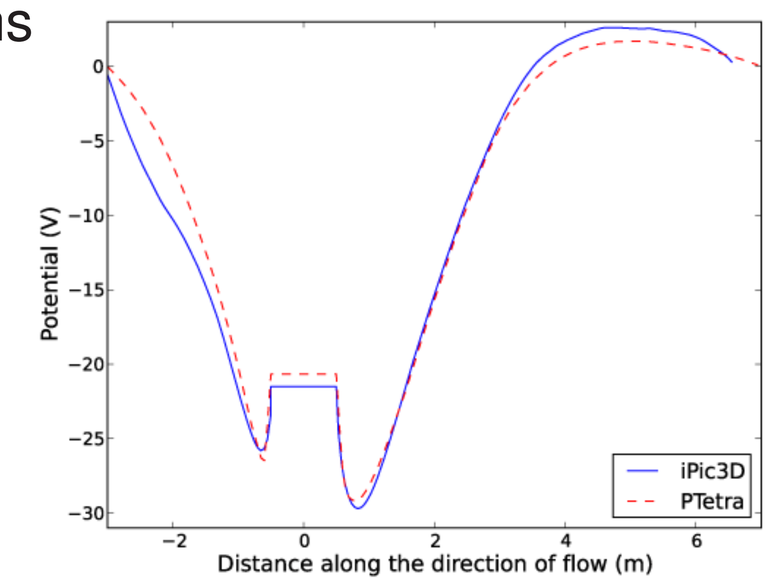
with $\epsilon = 10^5$ inside the spacecraft and $\epsilon = 0$ elsewhere for a perfect conducting body.
- Easy implementation of complex spacecraft geometries.
- Open boundary conditions.
- Photoelectron and secondary electron emission and
- static background magnetic field possible.

Code verification: CubeSat (1m×1m×1m)

Five cases considered and compared with Ptetra, under solar wind conditions applicable to SPP *[Deca et al. 2013]*.

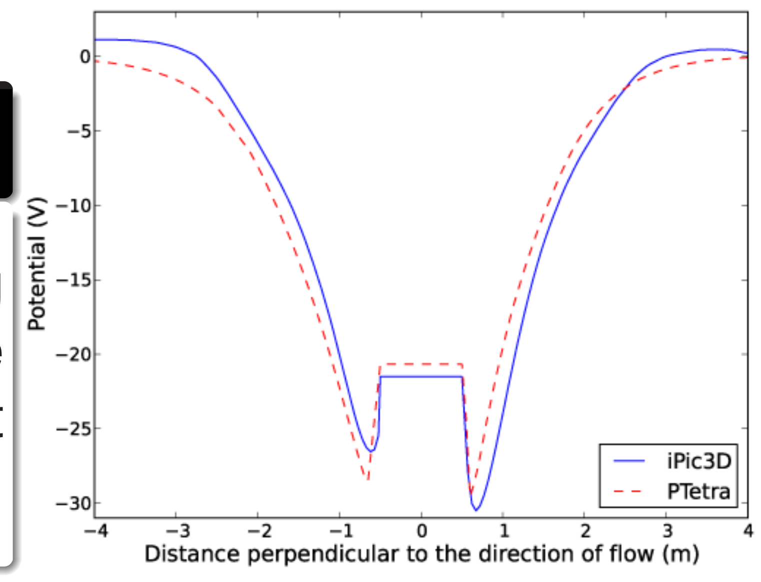
Case	1	2	3	4	5
Flow	X	X	X	X	X
Photoemission		X		X	X
Sec. elec. em.			X	X	X
background ***B***					X
$\phi_{SC,iPic3D}$ (V)	-228.2	-32.9	-17.1	-16.2	-21.5
$\phi_{SC,PTetra}$ (V)	-226.0	-33.6	-16.5	-15.4	-20.7





Saturated emission regime

When the photoelectron and/or secondary electron emission yield is strong enough to create a potential barrier higher than the average energy of the emitted particles, emitting more particles has little effect on the spacecraft charge/floating potential.



Cross-comparison of model predictions applied to SPP near perihelion

Simulation results are compared with increasing levels of complexity in the physics of interaction between the solar environment and SPP. We show the most advanced case.

Five models, five different numerical approaches

- EMSES (EM, expl., PIC) *[Miyake&Usui 2009]*.
- iPic3D (ES, impl., PIC) *[Deca et al. 2013]*.
- LASP (ES, Time. Stat., hybrid) *[Ergun et al. 2010]*.
- PTetra (ES, expl., PIC) *[Marchand 2012]*.
- SPIS (ES, expl., PIC) *[Roussel et al. 2008]*.

Space environment and adopted simulation parameters.

$n_e = n_i$	$7 \times 10^9\,m^{-3}$	orbital speed	195 km/s
ions	100% H^+	J_{ph}	16 mA/m^2
T_e	85 eV	T_{ph}	3 eV
T_i	82 eV	secondary em.	model dependent
B	2 μT radial	T_{se}	2 eV
v_{sw}	300 km/s radial	particle albedo	5% (SPIS, LASP)
			0% (other models)

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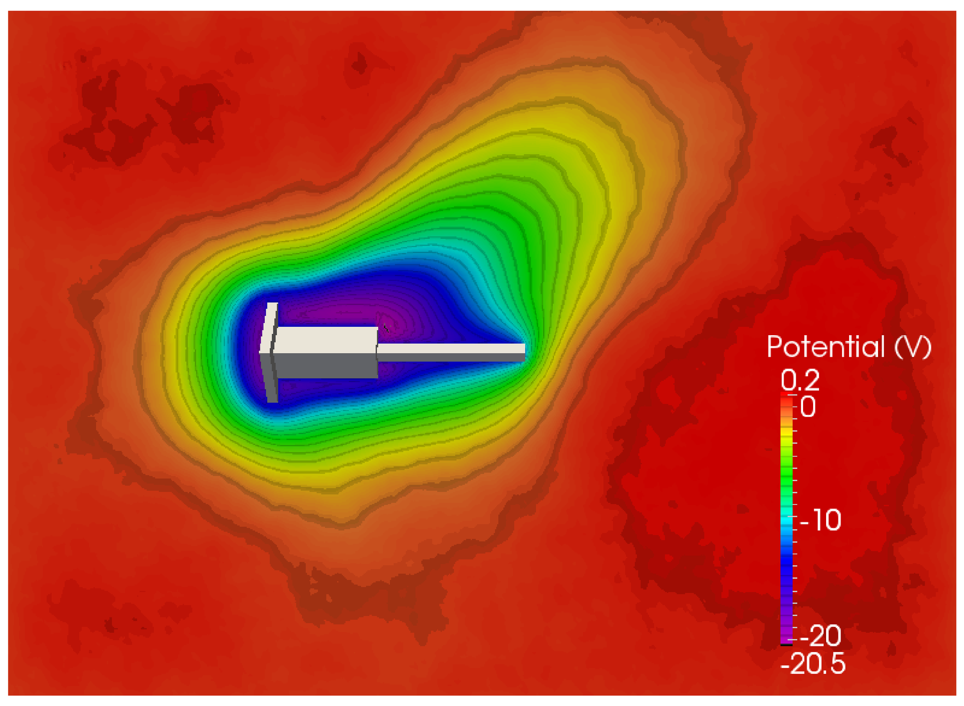
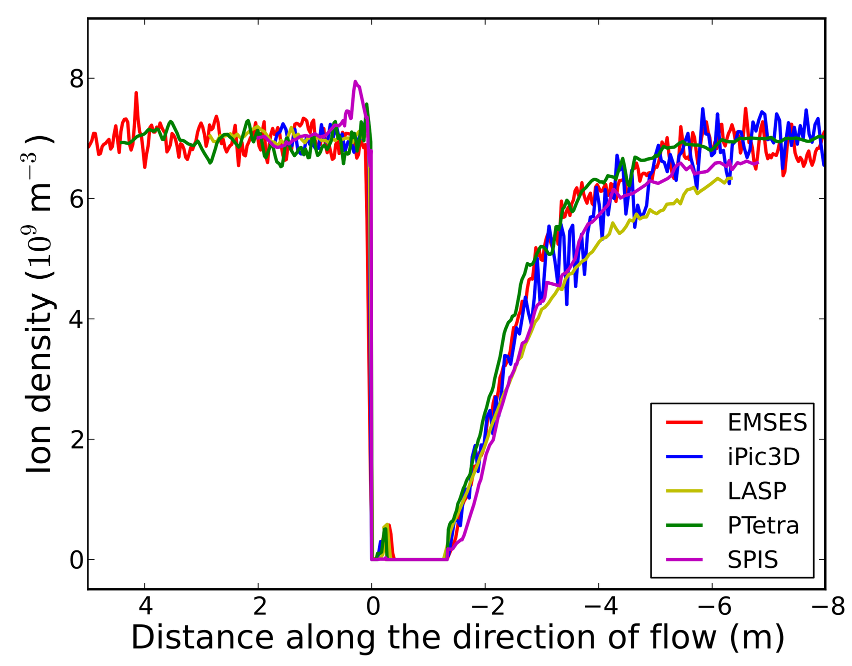
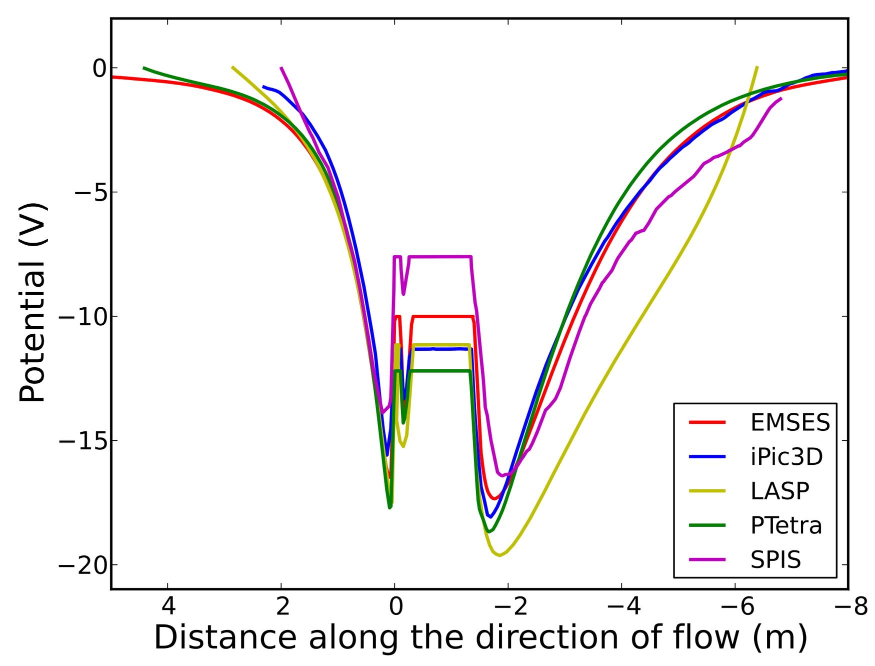


- SPP will operate in an emission saturated regime, surrounded by a dense negative low energy (2-3 eV) electron sheath which reflects most of the electrons emitted from the surface.
- A major difficulty in making predictions stems from the uncertainty in the parametrization of material properties in space.

Excellent agreement!

Excellent agreement between the models indicates a high level of skill for these models to predict spacecraft-environment interactions.





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