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# Large-Scale Particle Simulations on Space Plasma Interaction with Scientific Spacecraft
科学衛星と宇宙プラズマの電磁的相互作用に関する大規模粒子シミュレーション

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Electric and magnetic field perturbations around the Solar Probe Plus (SPP) spacecraft is examined by large-scale particle simulations using our original code called EMSES. We consider important physical effects such as spacecraft charging, photoelectron and secondary electron emission, solar wind plasma flow, and the background magnetic field. Our simulation results show that both photoelectrons and secondary electrons from the spacecraft are magnetized in the spatial scale of several meters, and make drift motion due the presence of the background convection electric field. This effect leads to non-axisymmetric distributions of the electron density and the resultant electric potential near the spacecraft.

## 1. Introduction

It is necessary to assess the nature of spacecraft–plasma interactions in extreme plasma conditions for future space explorations. As one of such activities, we study on the spacecraft interaction with near-Sun plasma environment. The spacecraft environment immersed in the solar corona is characterized by the small Debye length due to dense (7000 /cc) plasmas and a large photo-/ secondary electron emission current emitted from the spacecraft surfaces [1-3]. We applied our original electromagnetic particle-in-cell (PIC) simulation code called EMSES to the problem and focus on the field perturbation around the Solar Probe Plus (SPP) spacecraft.

## 2. Numerical Model and Setup

2.1 *Simulation code*

EMSES is an electromagnetic PIC code designed particularly for spacecraft–plasma interaction study [4]. The basic algorithms are based on the standard PIC method [5]. EMSES employs inner boundary treatments for electric field at the interface between a plasma and a conducting spacecraft body, and has capability of simulating spacecraft charging process in space using the capacitance matrix method [6] in an electrostatic aspect. In addition, a radiation component of an electric field, introduced by the electromagnetic field solver, is also cancelled out on the spacecraft conducting surface [4]. EMSES also includes numerical models of photoelectrons and secondary electron emission.

2.2 *Simulation Model*

We simulate the plasma environment near the SPP spacecraft at perihelion. For manageability in the Cartesian grid code, we use a simplified spacecraft geometry as shown in Figure 1. The entire simulation domain, except for the interior of the SPP spacecraft, is initially filled with background solar wind electrons and protons at the SPP perihelion. In addition to the solar wind velocity along z-axis, we take into account a spacecraft orbital velocity of 195 km/s near perihelion (see Figure 1). We also assume a static magnetic field of magnitude 2 $\mu$T pointing toward the Sun.

In the series of simulations, a sunlit face of the spacecraft shield emits photoelectrons throughout the simulations. The present analysis also takes into account the secondary electron emission triggered by electron impact on the spacecraft surface. We assume the photo- and secondary electron temperatures of 3 and 2 eV, respectively.

## 3. Simulation Results

Table I summarizes the SPP floating potentials computed with the three different environments of near-Earth, near-Mercury, and its perihelion (0.04 AU from the Sun). In all environments, the photoelectron yield from the SPP heat shield dominates over the influx of the background solar wind electrons. This results in the positive floating potentials as predicted for the near- Mercury and Earth environments. The situation, however, is totally different at the SPP perihelion from the other two environments; i.e., the spacecraft potential is negative. This result is caused by the formation of the potential barrier in front of the spacecraft sunlit surface, which reflects approximately 87% of emitted electrons back to the spacecraft. That is, the photoelectron emission current is in a space-charge-

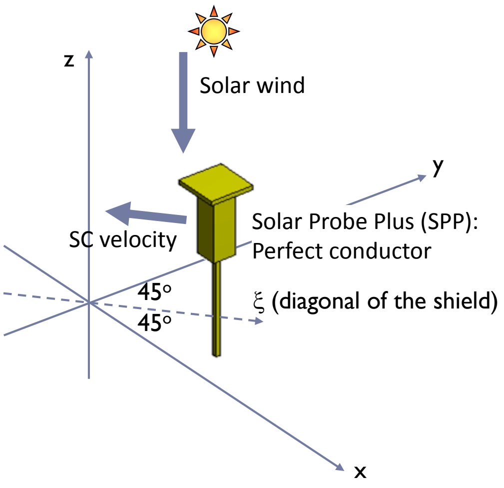


Fig.1. Model of Solar Probe Plus with simplified geometry

limited regime with a non-monotonic potential profile.

We next focus on the spatial profiles of field quantities for the SPP perihelion case. Figure 2 shows photoelectron density and electric potential, as obtained at the steady state. The oblique plasma flow in this case produces the proton wake at +ξ side of the spacecraft. This leads to strong asymmetry of the resultant potential distribution downstream of the spacecraft. Although shown less clearly here, the potential profile shows weak asymmetry also upstream of the spacecraft. The slight asymmetry is due in part to the asymmetry in the photoelectron distributions, as shown in panel b. Although the majority of photoelectrons is reflected back to the spacecraft by the potential barrier, some electrons emitted with energies larger than the barrier can escape from the spacecraft. These photoelectrons are seen as a radial diffusion pattern of its density upstream of the spacecraft. The region downstream of the spacecraft contains electrons emitted near the edge and missing the shield after being reflected by the barrier. The notable feature is apparent left-right asymmetry mainly seen downstream of the spacecraft. This is due to the $E_C \times B_0$ drift to +ξ direction, where $E_C \sim 390$ mV/m represents the motional electric field. Although not shown clearly, the $E_C \times B_0$ drift contributes also to the asymmetry in the photoelectron density upstream of the spacecraft. This slight asymmetry results in the potential asymmetry upstream of the spacecraft.

## 6. Summary

Our electromagnetic full-particle simulation analysis shows that plasma and field environments around SPP show considerable asymmetry both up-stream and downstream of the spacecraft. The motional electric field exerts the $E_C \times B_0$ drift on the photo electron dynamics. The resultant asymmetric distributions of these electrons cause the asymmetry in the electric potential profile. The simulations also predict a spurious electric field of a few hundreds of mV/m observed by the probe measurement on the spacecraft. The further assessment of the impact of such field perturbations on scientific measurements should be followed in the future study.

Table I. Simulation results on SPP floating potential

| Near-Earth | Near-Mercury | SPP perihelion |
|---|---|---|
| +12.8 V | +9.9 V | −20.5 V |

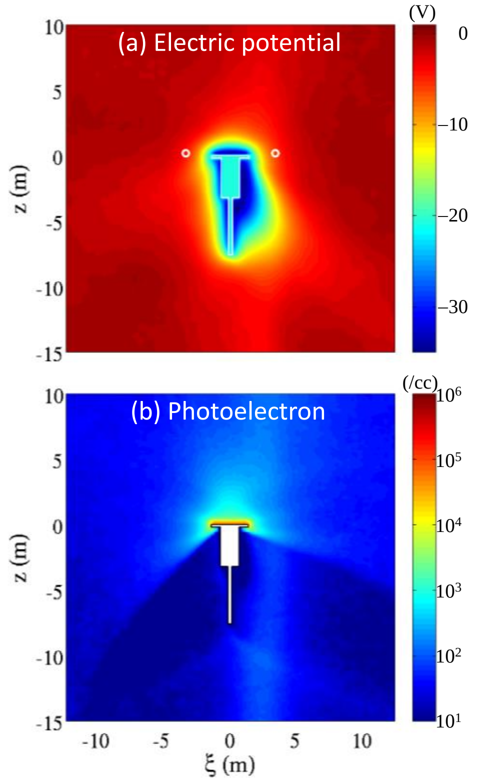


Fig.2. 2-dimensional profiles of (a) electric potential, and (b) photoelectron density

### References

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