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Numerical Simulation of Spacecraft Charging Processes in Time-varying Plasma Environment

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Spacecraft charging has been a crucial aspect of design consideration for all modern satellites, and a detailed and comprehensive understanding of the charging process is needed to ensure proper operation of spacecraft system, e.g., correct interpretation of scientific measurements and other information collected in situ. The existing models of the spacecraft charging mostly assume static plasma conditions for space environment, which can be well defined with some macro parameters such as density, temperature, flow speed, and high-energy particle flux. In fact, the space environment is dynamically changing. The time variation effects, e.g., caused by some plasma wave activities, will alter the physics behind the spacecraft charging, when their characteristic time scales are comparable to or shorter than a charging time constant.

Recent observations by Van Allen Probes showed apparent spacecraft potential fluctuations associated with chorus wave detection [1], and a major physical factor of the effect was speculated as photoelectron-escape current modulations due to wave electric field. Although its dependencies on wave frequency and magnetic field strength have been examined experimentally [2,3], there are a number of remaining issues such as effects of wave polarization or configuration of spacecraft chassis and probes. In particular, in-space spacecraft potential measurements are conducted by seeing a potential difference between spacecraft chassis and electrostatic probes, and thus it is necessary to consider the difference of their responses to external wave electric fields.

Based on the particle-in-cell (PIC) method, we numerically model the modulation of a spacecraft potential in the presence of time-varying electric fields of plasma waves. We have confirmed that this model can reproduce the photoelectron-driven spacecraft potential modulations even in case of a circular-polarized wave electric field. We have also constructed a theoretical model to explain the identified potential change in consideration of a photoelectron escaping current though an RF sheath around the spacecraft [4]. We will examine the case of multiple spacecraft bodies corresponding to the spacecraft chassis and the probes, and discuss the difference of potential fluctuations between the bodies, which will elucidate detailed mechanism of detecting spacecraft potential modulations in in-situ observations.

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