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Modelling of Cassini charging and wake formation in Saturn's Magnetosphere

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Abstract

A self-consistent three-dimensional particle-in-cell code has been employed to explore modifications of the spacecraft (SC) potential and the resultant wake structure in a wide range of distances from the planet (for the dipole shell in the range L~ 4 -10). The plasma parameters derived from the Cassini plasma spectrometer (CAPS) measurements during the Saturn orbit insertion (SOI) period on June 30, 2004 [1], and CAPS data obtained in the inner equatorial magnetosphere in 2005 on Oct. 11 and 29, Nov. 27 and Dec. 24 [2] have been used as input data.

1. Introduction

The primary motivation of this study is to explore the orbiter charging in highly variable near-Saturn plasma environment using the advanced three-dimensional particle-in-cell code, and thus furthering our knowledge about charging of objects in space [3]. Understanding the efficiency of photoemission due to UV radiation, the role of plasma inhomogeneities (density and temperature) and contribution of a few ion species with different flow and thermal energies, can provide new insight into the charging not only of such large objects as SC, but also of small dust particles in Saturn's magnetosphere. Another important aspect of the orbiter charging is a formation of the potential and density distributions around the SC moving through the flowing plasma. The plasma (usually ion) flow around a charged object can lead to a distributed density reduction directly behind the object (wake) and often a more concentrated density enhancement downstream (ion focusing). Keeping in mind multispecies composition of the planetary magnetosphere, the whole system can represent even a more complicated wake structure downstream of SC which has to be examined in a near-Saturn environment. Associated with the wake and developing in the direct vicinity of the SC, variations of the plasma densities and of the electrostatic potential have to be understood and even controlled, since they can affect the measurements onboard Cassini.

2. Results

We study the spacecraft-plasma interactions in the regime relevant for Cassini at SOI trajectory corresponding to spacecraft event time SCET182:16:00 - 24:00h on 30, June 2004. Considering 5 reference points in the range L~ 4-10 and using the plasma parameters consistent with those inferred from CAPS measurements [1], we examine the potential and plasma distributions around the orbiter at different distance from Saturn. Special attention is given to the vicinity of the icy moon Enceladus, where the freshly-produced slow water group ions [2] can significantly modify the SC wake structure. Modeling of the SC charging takes into account plasma fluxes, including a few types of ions and plasma flows, photoemission due to solar UV radiation, and flyby geometry [3].

Simulations show that the spherical model of Cassini spacecraft floats roughly from a few volts positive at distances L>8.5 to ten volts negative in the inner magnetosphere depending on plasma conditions in Saturn's magnetosphere (Fig.1). These numbers and the trend are in reasonable agreement with those deduced from the CAPS data acquired during the SOI period [1].

The main factor defining spatial configurations of the electric potential and the plasma densities around SC is the energy distribution of the surrounding plasmas: we see a transition from a strongly asymmetric potential and electron density distributions (with elongated trails downstream of the SC) in the

Enceladus-Tethys region to a practically spherically symmetric ones in the outer magnetosphere, where the electron and ion temperatures become significantly higher (Fig.2). Potential structures arising around Cassini lead to electric field variations up to a few V/m at distances of ~1 m from the SC surface and are typically in the range of 0.1-0.5 V/m at distances of ~10 m from the orbiter at different distances from Saturn. These quantities can affect the electric field measurements onboard the orbiter.

Results reveal clearly defined ion wakes formed by the water group ions (co-rotating and\or slow freshly-produced) as well as by protons at all reference points of Saturn’s magnetosphere. The wake structures are strongly dependent on the ratio between the ion thermal energy, ion flow energy and the SC potential. In the inner magnetosphere one gets different spatial configurations formed by the water group ions, i. e. from a scattered ion wake (for slow pick up water group ions near Enceladus) to a well-defined pure geometrical wake structure outside of the Enceladus plasma torus. The ion energy characteristics determine also the strength of the ion focusing. Simulations show that inside Rhea's dipole shell the proton density peak arising from ion focusing downstream of the orbiter can be up to 4 times the ambient proton density.

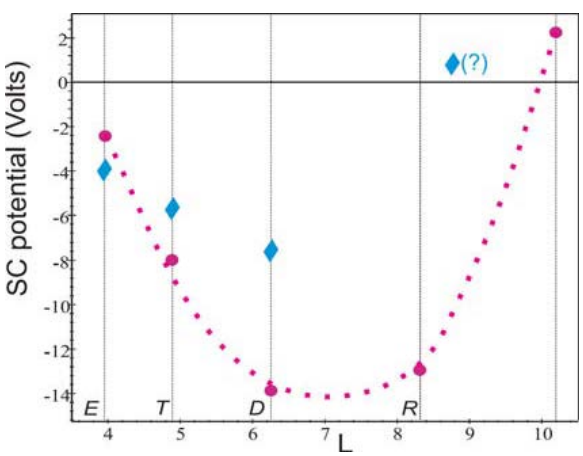

Figure 1: SC equilibrium potential vs. distance from Saturn (circles); average SC potential obtained in [1] (diamonds). CAPS measurements outside Rhea shell, L> 8.5, are marked as diamond with "?". The vertical lines labeled R, D, T and E indicate radial distances corresponding to the time, when SC crossed the dipole L shells of the moons Rhea, Dione, Tethys and Enceladus, respectively.

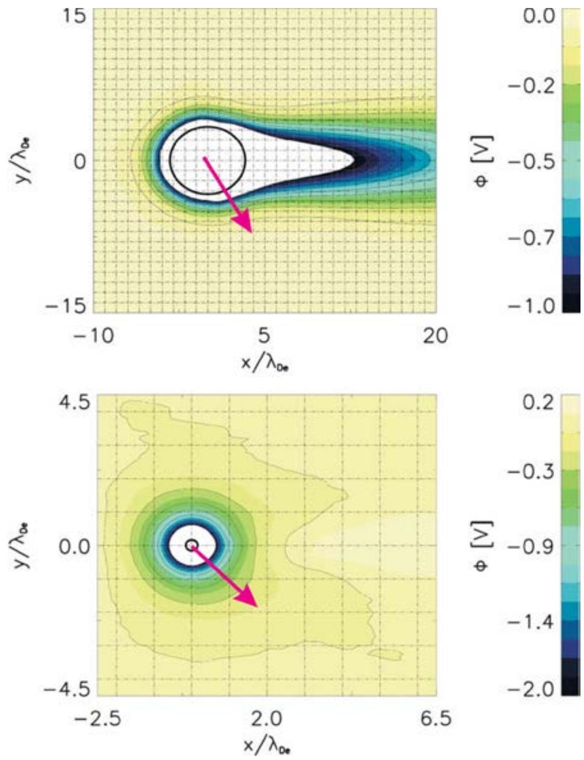

Figure 2: Microstructure of the electric potential in Saturn equatorial plane calculated at L~4 (Enceladus shell), upper panel; and L~8.3 (at Rhea’s shell), lower panel. The ion flow is in x-direction. Arrows indicate direction of SC motion during SOI period. Inside the white area the potential drops to the spacecraft surface potential, which are estimated as -2.5 V (L~4), -12.5V (L~8.3), respectively.

References

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[2] Tokar, R. L., Wilson R. J., Johnson, R.E., et al.: Cassini detection of water group ions in the Enceladus torus: Geophys. Res. Lett., Vol. 35, pp. L14202, 2008

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