EPSC Abstracts
Vol. 10, EPSC2015-855, 2015
European Planetary Science Congress 2015

Cassini-plasma interactions in the vicinity of Enceladus

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Abstract

We report the results of a three dimensional particle-in-cell simulation of a plasma structure around a charged spacecraft (SC) traversing the Enceladus torus and the dust-loaded plume. It is found that the plasma perturbations at the orbiter surface can directly impact the ambient plasma density measurements by the Cassini Langmuir probe (LP). Large discrepancy between the electron and ion density observed by LP during all Enceladus flybys may not represent the actual plasma conditions but can be artificially generated by the interactions of the charged spacecraft with the near-Enceladus plasma.

1. Introduction

The geologically active small moon Enceladus represents a significant source of gas from geysers located at the moon's southern pole. It is assumed that the plumes of gas that extend at least ~1000 km into space produce a radially narrow torus of water-group neutral atoms and molecules centered on Enceladus' orbit. The main constituents of weakly ionized plasma in the moon's torus are co-rotating water group ions and thermal electrons. Another medium occurs in the direct vicinity of the eruptive south pole of Enceladus. The plumes of water-vapor interact directly with Saturn's co-rotating plasma, loading the magnetosphere with fresh cold ions and decelerating the plasma flow up to its stagnation [4]. The Enceladus plumes also contain copious amounts of charged nanograins [1]. Modifications of the SC potential and associated plasma perturbations in the two plasma conditions have to be understood and even controlled, since they can affect the measurements onboard Cassini.

2. Model and numerical code

A three-dimensional particle-in-cell DiP3D code [2] has been adapted for the parameter space constrained by the Cassini observations during the Enceladus flybys. Employing a spherical conducting model of the SC, we study the SC-plasma interactions and accompanying plasma distributions in two characteristic regions within the Enceladus proximity: (A) the co-rotational plasma flow in the Enceladus torus (far away from the south-pole plume, plasma density $n_0 \sim 60\ cm^{-3}$); (B) the dense plume with the stagnated ion flow ($n_0 \sim 10^3\ cm^{-3}$). Modeling in the latter case includes the negatively charged nanograins with densities and mass-to-charge ratios consistent with the CAPS measurements during the plume flybys [1].

2. Results

Our numerical analysis has two important consequences. First, it points that even a small amount of charged dust initiates much more complicated plasma and potential distributions around the orbiter than those formed in the conventional electron-ion plasma (Fig. 1). Second, the resulting plasma configuration can directly impact the ambient plasma density measurements by Cassini LP. In the Enceladus torus and in the plume regions with low dust density a considerable domination of the water group ions over the electron population in the ram direction is found due to the formation of the conventional plasma sheath. The possible electron depletion can reach values up to $n_e/n_i \sim 0.3$ at possible LP positions. The latter implies that the ram-oriented LP registers *a priory* non-quasineutral plasma with $n_e < n_i$ instead of $n_e \sim n_i$ (Fig. 2). In the dust-abundant plume the negative dust provides an initial electron depletion which remains the main factor affecting the plasma and potential distribution around the orbiter. The plasma perturbations are reduced at the ram LP positions, and the probe can make relatively accurate measurements of the ambient plasma. In the downstream (wake) direction, the electron depletion at the LP positions decreases in both A and B cases

(Fig. 2). Hence the wake-oriented LP will always sense $n_e \sim n_i$ which is relatively accurate for the plasma in the Enceladus torus, but gives a significantly compromised measurements in the dust-dominated plume (B).

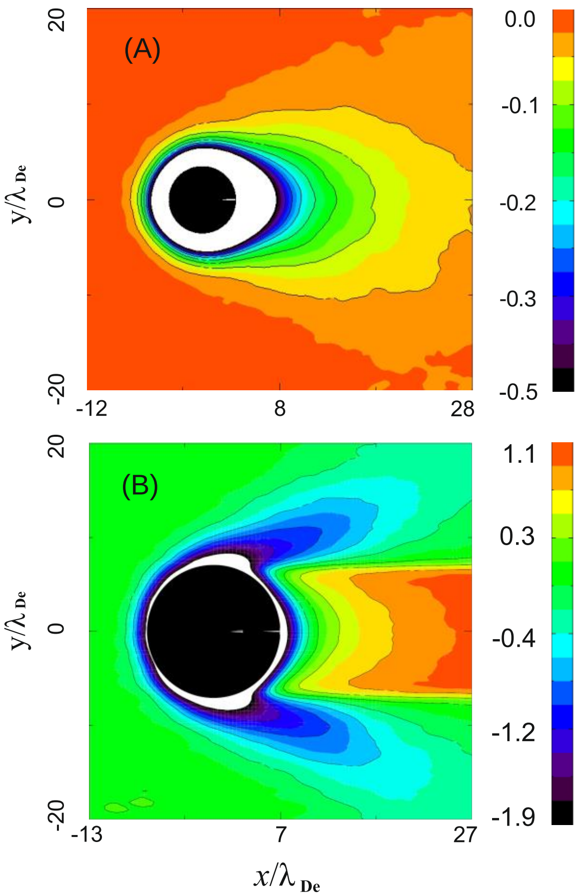

Figure 1: Contour plots of electric potential in the (xy) plane through SC simulated for A and B near-Enceladus conditions. The local coordinate system (xy) is connected to the moving SC so that the axis x is directed along the plasma flow. Length scales are measured in units of the electron Debye length. The arrows indicate a direction of Cassini motion at SCET073:18:51 (Enceladus torus - case A) and SCET073:19:07 (Plume - case B).

3. Conclusions

Our modeling leads to a very important conclusion with broad implications for the interpretation of the Cassini LP data collected near Enceladus: it is demonstrated that a large imbalance between ion and electron densities observed by the Cassini LP [3] may not represent the actual plasma conditions near the moon's plume. Instead, the large discrepancy may be artificially generated by the interactions of the charged spacecraft with Enceladus' plasma environment. The simulation results are qualitatively consistent with the long intervals of the electron-ion imbalance registered by the Langmuir probe far away from the dust-abundant plume during the Cassini plume flybys. In any case, the plasma perturbations associated with the moving Cassini orbiter appear to be an important factor for a reliable interpretation of the LP measurements.

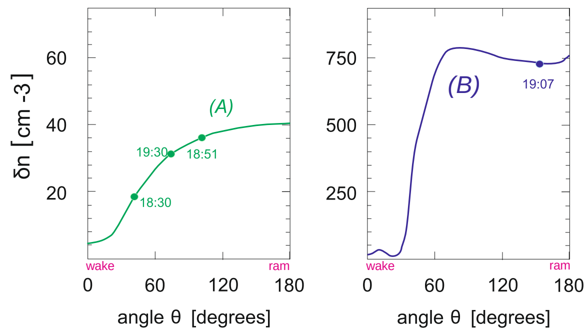

Figure 2: Angular distributions of the plasma imbalance $\delta n = n_i - n_e$ in the (xy) plane calculated at 1.5 m distance from the SC surface. The respective LP orientation in terms of angle θ is marked for E3 flyby at SCET073:18:30 and SCET073:18:51 (case A) and at SCET073:19:07 (case B).

References

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