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Hybrid simulations of dust-plasma interactions at Enceladus and comparison with Cassini data

H. Kriegel (1), S. Simon (2), U. Motschmann (1,3), J. Saur (2) and F. M. Neubauer (2)
(1) Institute of Theoretical Physics, TU Braunschweig, Germany, (2) Institute of Geophysics and Meteorology, University of Cologne, Germany, (3) Institute for Planetary Research, German Aerospace Center (DLR), Germany
(h.kriegel@tu-bs.de)

Abstract

The interaction between Enceladus' south polar plume and Saturn's magnetosphere gives rise to a magnetic field perturbation, in particular an Alfvén wing. We study the structure and properties of plume and Alfvén wing by means of the hybrid simulation code A.I.K.E.F. (adaptive ion kinetic electron fluid). Our plume model is adapted to data from the INMS (neutral plume) and CDA (dusty plume) instruments. We show that our simulations can explain the shape of the magnetic field draping observed by the Cassini magnetometer (MAG), but the non-detection of a field decrease downstream of the plume is still puzzling.

1. Introduction

It has previously been shown that the influence of the electron-absorbing dust grains in the plume has to be taken into account. It explains the orientation of the magnetic field perturbations in the Alfvén wings [7, 4]. In these studies, the plume was adjusted only to MAG data but not to measurements of the plume itself. This gap is filled in the present work.

2. Hybrid Code A.I.K.E.F.

Within our hybrid simulation code A.I.K.E.F. [5], charged dust is included in the model as a negatively charged ion species. With respect to our previous studies [3, 4], we also improved the model of the ion-neutral chemistry such, that we now consider the different water group ions (O^+, OH^+, H_2O^+, H_3O^+) and hydrogen with individual reaction and production rates.

3. Plume model

To use a realistic density profile of the plume, we carry out Monte-Carlo simulations of both, gas and dust plume. Since a neutral or dust particle needs $\sim$ 1 h to travel through the plume, while the plasma interaction takes place in only a few minutes, it is not efficiently possible to combine both time scales in one simulation. Instead, the plume is computed within a pre-simulation which is used as a stationary input for the plasma simulation.

The particles are started from the eight observed jets as well as from eighty sources distributed along the tiger stripes. The motion of the neutrals is given by

$$m_{H_2O}\frac{d\underline{v}_{H_2O}}{dt} = \underline{F}_{G,En} + \underline{F}_{G,S} + \underline{F}_{inertia} \quad , \quad (1)$$

where the forces denote the gravitation of Enceladus and Saturn and inertia forces due to the orbital movement of Enceladus. The resulting profile is in very good agreement with Cassini INMS observations (fig. 1). For the dust, a grain size distribution according to

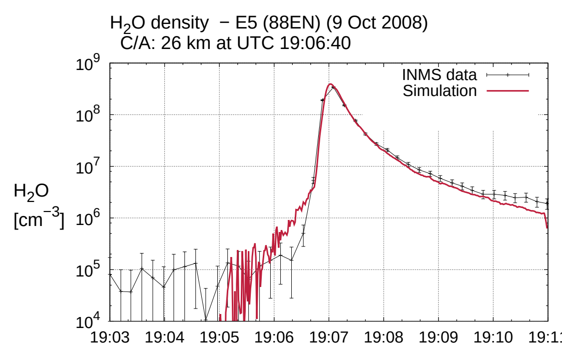

Figure 1: Simulated neutral plume compared to INMS data for the E5 flyby (see also [1]).

a power law ($n(R) \sim R^{-\mu}$) is considered. Thus, the dust charge density is dominated by nanograins. Since these small grains are also subject to the Lorentz force, the simulations of dust plume and plasma interaction are performed iteratively:

Dust simulation:
motion of nanograins affected by $\underline{E}$ and $\underline{B}$

↑ ↓

Plasma simulation:
$\underline{E}$ and $\underline{B}$ influenced by dust charge density

The dust parameters are adjusted to CDA measurements [6] as well as recent CAPS observations [2].

4. Results

Our simulations predict an ion density in the plume of the order of 10^3 cm^{-3}, which is also the upper limit of the dust charge density. The magnetic field B_x component, which is mainly determined by the neutral gas density, and the B_y component (determined by the charged dust) are in excellent agreement with the observations for the E7 flyby (fig. 2). B_z, however, appears to be puzzling. As clearly visible in fig. 3, our simulation predicts a region of positive ΔB_z, i.e. a reduced $|\underline{B}|$ downstream of the plume (blue). This is caused by pickup and Pedersen currents within the plume. But during *all 20* Enceladus flybys so far, Cassini did *not* detect a decrease of the magnetic field. This contradiction clearly points towards a southward/downstream shift of the plume which is not covered by our present model.

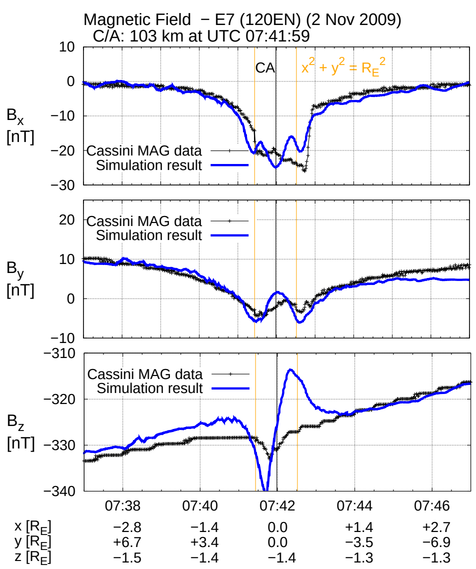

Figure 2: Simulated magnetic field components compared with Cassini MAG data for the E7 flyby

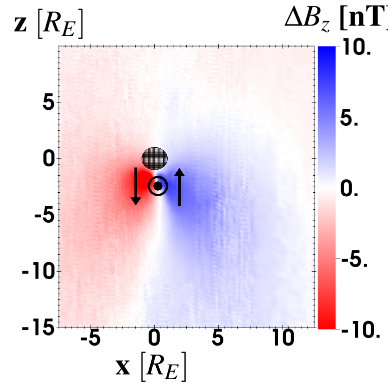

Figure 3: Simulated ΔB_z in the $y = 0$ plane. The blue region of reduced magnetic field ($\Delta B_z > 0$) for $x > 0$ has not yet been observed by Cassini.

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