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Dust-plasma interaction in the Saturn plasma disc & Enceladus' plume

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Abstract

We present several independent *in-situ* measurements from the RPWS instrument on board the Cassini spacecraft, which provide evidence that negatively charged sub-micron sized dust in the E-ring interacts collectively with the dense surrounding plasma disk of Saturn, i.e., form a system of dust-plasma interaction where the charged dust is an inseparable part of the plasma and is governed by a common dynamics (e.g., *Wahlund et al.*, 2005; *Wahlund et al.*, 2009). The region of collective interaction occurs out to about 7-8 R_S (Saturn radii) near the equatorial plane of Saturn, and implies a relationship between Saturn's rotation (about 10.7h period) and its whole magnetospheric dynamics (*Morooka et al.*, 2010). Furthermore, we show that a large quantity of ionized gas is produced within the moon Enceladus southern exhaust plume, and that this plasma similarly is a strongly coupled dust-plasma system (*Farrell et al.*, 2009; *Shafiq et al.*, 2010). This type of interactions, which cause a deceleration of the plasma toward the gravitational bound dust motion (*Farrell et al.*, 2010; *Morooka et al.*, 2010), has not been considered before and fundamentally changes the view on how the interaction of the rotating planet, its magnetic field, and plasma disc with Enceladus and the E ring occurs.

1. Introduction

Plasma in the Kronian magnetosphere is strongly controlled by the planetary rotation through the magnetic field, which originates from the dynamo within the planet itself, and the associated induced co-rotation electric field in its magnetosphere. One problem has been to relate the planet's rotation period to the dynamics in the magnetosphere and the associated periodicity of Saturn Kilometric Radiation (SKR) bursts. Here we put forward a model that may link the rotation of Saturn to the quasi-periodic nature of its magnetosphere, by taking into account the dust-plasma interaction in the plasma disk that cause a large part of the plasma there to move with the negatively charged dust, i.e., with a Keplerian motion. The conditions in the plasma disk near the equatorial plane are such that $r_d << d_g << \lambda_D$, where r_d, d_g and λ_D are the typical grain radius, the inter-grain distance and the plasma Debye length, respectively. In the case where $d_g < \lambda_D$, the charged dust participates in the screening process and therefore in the collective behavior of the ensemble, which is the case here.

2. E-ring results

Radio and Plasma Wave Science (RPWS) Langmuir Probe (LP) observations, that measure the cold plasma (<10 eV) properties, clearly indicate that negatively charged E ring dust causes a significant slowdown of the plasma compared to rigid co-rotation in the near equatorial plasma disc (*Wahlund et al.*, 2009). These observations identified a cold (< 1 eV) ion population in addition to the rather hot nearly co-rotating ion population. This colder ion component dominates the plasma at times and rotates with near Keplerian speed around Saturn. Closest to the equatorial plane, where the E ring dust is densest, the ion charge densities were in excess of the electron densities. Despite the nearly parallel alignment of the magnetic dipole and the planetary spin axis, many observations show strong planetary rotational modulations of the Saturnian magnetospheric plasma. New results presented here suggest that dusty plasma in the E ring dominates the electrodynamics and is responsible for the plasma slippage causing the rotation periodicities.

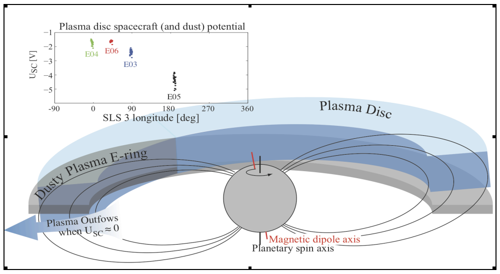

Figure 1: Saturn's magnetic dipole has a very slight tilt and northward shift compared to the planets spin axis, which makes the magnetodisc plasma to wobble with respect to the E ring and the interaction with the dusty plasma of the E ring will be enhanced once each planetary spin period. When the centre of the E ring and the centre of the plasma disc coincide near 0° SKR longitude, the dust potential becomes least negative. The dust potentials will become positive at a radial distance of about 7-8 Saturn radii, and this will occur closest to the plasma disc near 0° SKR longitude. At this point the plasma is most prone to be released by the electro-dynamic coupling of the dust and start to flow outward to the surrounding magnetosphere at a specific SKR longitude, and there creates a spiral pattern of cold plasma.

3. Enceladus dust-plasma plume

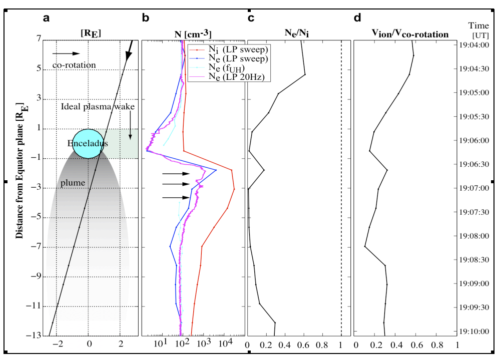

Figure 2: **a**, Spacecraft trajectory flyby geometry in the frame of Enceladus. The E03 flyby of Cassini was steep across the equatorial plane of Saturn, and behind Enceladus with regard to the ideal co-rotation. Cassini thereafter encountered the Enceladus south-pole plume. The corresponding observation times are displayed on the right of panel d. **b**, Plasma densities estimated from several RPWS techniques. Plume ion density reaches 30,000 cm^{-3} and the electron density reaches 4,000 cm^{-3} based on the LP measurements. The upper hybrid band is masked by dust impacts during this time, hence, cannot be used to confirm this high electron density. The ideal wake region shows a largely unaffected ion density of 100 cm^{-3}, while the electrons are depleted down to a few cm^{-3}. Several electron density peaks in the plume are detected in the 20 Hz Langmuir probe data (magenta), which corresponds well with the footprint of "tiger stripes" exhaust structures (arrows). **c**, The LP electron to ion density ratio show a significant depletion of electrons during the flyby. A ratio below 0.01 is reached within the plume, indicating that the dominant part of the negative charge is carried by the water rich dust particles and relatively few free electrons are encountered. That is a collective dust-ion plasma. **d**, Ratio of the observed ion speed to the rigid co-rotation speed, both in the spacecraft frame of reference. The ion speed is inferred from the Langmuir probe ion flux measurements assuming water group ions. A significant slowdown of the plasma compared to rigid co-rotation is detected in the neighborhood of Enceladus.

References

[1] Farrell, W. M. et al. Electron density dropout near Enceladus in the context of water-vapor and water-ice. *Geophys. Res. Lett.* **36**, doi:10.1029/2008GL037108, (2009).

[2] Farrell, W. M., et al., Modification of the Plasma in the Near-Vicinity of Enceladus by a Large Dust Cloud and Its Active Source, submitted, 2010.

[3] Morooka, M. W., et al., *In-situ* Detection of Dust-Plasma Interactions in the vicinity of Enceladus, submitted, 2010.

[4] Shafiq, M., et al., Characteristics of the dust-plasma interaction near Enceladus South Pole, submitted, 2010.

[5] Wahlund, J. -E. et al. Detection of dusty plasma near the E ring of Saturn. *Planet Space Sci*. **57**, 14-15, 1795-1806, (2009).