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Trajectories of charged nanograins in the plume of Enceladus: Modelling and Cassini CAPS observations

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Abstract

Plumes from the south pole of Enceladus are produced through active cryovolcanic processes and contain both gaseous and dusty components. The Cassini-Huygens mission has confirmed that these plumes are a major source of gas and dust for Saturn's magnetosphere. Cassini CAPS data shows evidence for charged nanograins in the plume on Enceladus and in this paper we describe modelling work aimed at understanding fine structure in these nanograin observations. In particular we show that the stagnation of the flow near the plume is important in preventing the dispersion of the plume in the immediate vicinity of Enceladus and present results of a Monte Carlo model of the plume and compare these with CAPS observations.

1. Introduction

On three separate encounters with Enceladus the sensors of the Cassini Plasma Spectrometer (CAPS) were oriented such that they directly sampled the plume material. High-energy negatively (positively) charged particles were measured by electron (ion) sensor on CAPS which enter the instrument at the ram velocity of the spacecraft through the plume, thus facilitating a measurement of the mass-to-charge ratio of the particles. Jones et al. (2009) studied the energy and resulting mass spectrum of the plume particles detected by CAPS and concluded that the particles were nanometre-sized grains thus bridging the gap between previously detected gaseous species and larger micron-sized ice grains observed by other instruments. Jones et al. also studied fine-scale structuring inside the plume and concluded that discrete plume sources, inferred from remote sensing observations, were the origin for this fine structure.

Figure 1 shows observations of these nanometer dust grains from Cassini's E3 flyby of Enceladus.

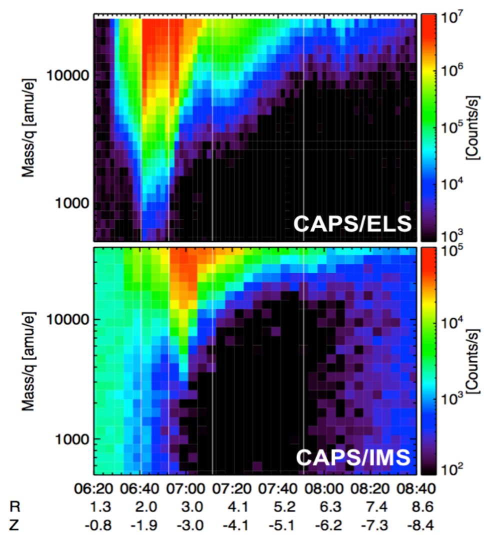

Figure 1: Negative and positive grain observations from Cassini CAPS. The top (bottom) panel shows a spectrogram (in counts/s) of negative (positive) dust grain observations as a function of grain mass-to-charge. The ephemeris show the minutes and seconds from 19:00 UT on 12 March 2008, the radial distance from Enceladus and the vertical distance from Saturn's equator (in R_{En}).

2. Modelling

The positive and negative grain charging observations show timing differences that have yet to be fully resolved. An example is in figure 1 where one can see that negative grains are observed before the positive grains. To understand these timing differences we model the trajectories of the grains. Previous work on grain motion has concentrated on the trajectories of the larger ice grains [e.g., Kempf et al., 2010]. In our study we examine the motion of the charged nanograins discussed by Jones et al. and solve the equation of motion, for both negatively and positively charged grains, emerging (already charged) from discrete vents on Enceladus. We use the following expression for the acceleration of a grain:

$$\mathbf{a} = \mathbf{a}_{Sat}(\mathbf{r}_s) + \mathbf{a}_{En}(\mathbf{r}) + \frac{\mathbf{E}}{m/q} + \frac{\mathbf{v}\times\mathbf{B}}{m/q} \quad (1)$$

which is identical to that used by Kempf et al. (2010) and takes into account the gravitational field from both Saturn and Enceladus, the background magnetospheric field, and the motional electric field introduced by the azimuthal convection of Saturn's magnetospheric plasma. However in our study we also take into account the slowing and stagnation of the magnetospheric plasma near the moon and its plume. The benefit of the functional form of (1) is that each term is proportional to some power of the mass-to-charge ratio (m/q) which is the observable obtained from the CAPS observations. Hence the m/q parameter can be chosen to reflect the CAPS observations. All calculations are carried out in the Enceladus interaction coordinate system (ENIS) where X is along the corotation direction, Y points to Saturn and Z completes the right-handed set.

3. Flow stagnation

Figure 2 illustrates the importance of flow stagnation in the Enceladus plume. At full corotation the relative flow velocity between Saturn's magnetospheric plasma and Enceladus is 26 km s^{-1}. The resulting convection electric field produces very rapid acceleration of the plume nanograins out of the plume region. Under these conditions the nanograins would not be observable by Cassini.

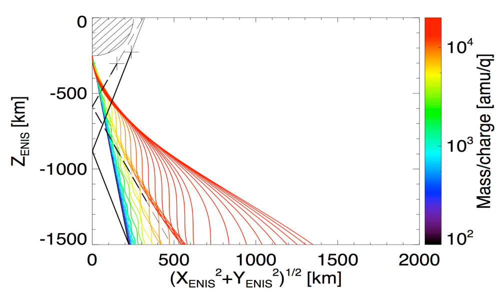

Figure 2: Negative dust grain trajectories for a highly stagnated magnetospheric plasma flow. The coloured curves indicate different grain mass-to-charge ratios and the black lines show Cassini's trajectory on the E3 (solid) and E5 (dashed) encounters. The bold regions of these trajectories indicate where nanograins were detected.

We find it necessary to reduce the background plasma flow to around 0.1 km s^{-1} in order to have nanograin trajectories near to the region of observation.

4. Current work

To study the fine structure and flow stagnation in more detail we are constructing a Monte Carlo model of the plume and discrete sources on Enceladus. With this model the grains from many vents can be tracked and synthetic CAPS spectra can be constructed – including all grains and grains from only particular vents. Timing differences and fine structure can then be understood by comparing the observations to the model. We are also accounting for stagnation within the plume in a more comprehensive fashion by using models of the plume-plasma interaction.

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