EPSC Abstracts
Vol. 6, EPSC-DPS2011-1862, 2011
EPSC-DPS Joint Meeting 2011

The Plumes of Enceladus: Measuring slow Particles by combining Numerical Simulations and Infrared Spectra

P. Strub (1), S. Kempf (2), U. Beckmann (1)
(1) Max-Planck-Institut für Sonnensystemforschung, Katlenburg-Lindau, Germany (strub@mps.mpg.de / Fax: +49-5556-979-240), (2) LASP, University of Colorado, Boulder, CO, USA

Abstract

The south pole region of Saturn's icy moon Enceladus is known for its volcanic activity, emitting a stream of ice particles and water vapor into the Saturnian system. After the discovery by the Cassini spacecraft [2, 3, 8, 10], the ice particles' dynamics and density distribution in the vicinity of the moon have been described using numerical models [8, 7, 1].

Here we make use of numerical simulations to predict the light scattering properties of the jets and compare them to spatially resolved near-infrared spectra taken by the VIMS camera. We identify a component of systematically larger, slower particles in the spectra that does not show up in the simulations. We argue that this constitutes the diffuse particle population as seen in optical close-up images and as proposed to explain the chemical segregation of the plume particles [6].

1. Introduction

The activity of Saturn's moon Enceladus has been studied extensively in various respects. The dynamics of the ice particles constituting the plumes has been modeled, and detailed analyses of the scattered light from the plume and the jets have been presented [8, 7, 1, 4]. While these studies have modeled with great effort the field they are focused on, either the dynamics or the analysis of light scattering has only been treated in a simplified manner.

2. Modeling approach

Here we present a model that treats the particle formation, the particle dynamics, and the light scattering in a comprehensive way, taking into account all known relevant factors.

The assumed condensation process is based on the approach described by [7]. It describes the formation of ice particles by homogeneous nucleation from the gas phase. This model leads to a velocity-size-distribution that exhibits systematically lower velocities for larger particles, which is required to explain the observations. The parameters were adjusted such that the dust distribution's slope and normalization reproduce in-situ measurements by the Cosmic Dust Detector (CDA) on board Cassini.

The resulting size-velocity-distribution is used as a weight function to calculate the dust density from the numerical integration of an ensemble of dust particle trajectories [1, 5]. All relevant forces have been taken into account for the integration. The jet base points shown in [9] have been used as the initial conditions.

The resulting size-dependent dust densities are then converted to spectral intensity of the scattered light using a Mie model for the geometry in the VIMS near-infrared observations by [4]. Furthermore, spectra are calculated at different heights above the active south pole of Enceladus, matching the height intervals of the existing VIMS observations.

3. Results

The choice of simulated observing conditions allows us to analyze the VIMS spectra and the simulated spectra in a side-by-side comparison. While both share some basic properties, there are distinct differences in the spectral shape and the height dependence. This can be solved by introducing two dust components in addition to the simulated jets (Fig. 1).

One component can be understood as a contribution of scattered light from the E-ring as a background in the exposures. Using an additional E-ring particle size distribution as measured by CDA, which is normalized independent of the height above Enceladus, a much better agreement between observed and simulated spectral shape can be achieved.

The other component is concentrated towards the surface of Enceladus. Its scale height is $68 \pm 7\,\mathrm{km}$, while the average observed scale height of the plume is $152 \pm 13\,\mathrm{km}$. This implies a generally slower velocity for these particles. The spectral shape is not well constrained due to ambiguities in the determination of the E-ring background. However, fits suggest that this component is well characterized by a power law size distribution $n(s) \sim s^{-k}$ between 0.6 and $3.4\,\mu\mathrm{m}$, $k = 2.5$. This is much flatter towards large particles than the assumed jet size distribution, which has $k \simeq 5$.

We suggest to identify the second component with a diffuse component of larger particles which are systematically slower than the simulated jets. The simulated jets are based on particles condensed from the gas phase. Salt-rich particles, as observed close to the surface [6], cannot originate from this process, and therefore are not included in the simulation. Thus it seems plausible to identify this second component with the salt-rich population of grains.

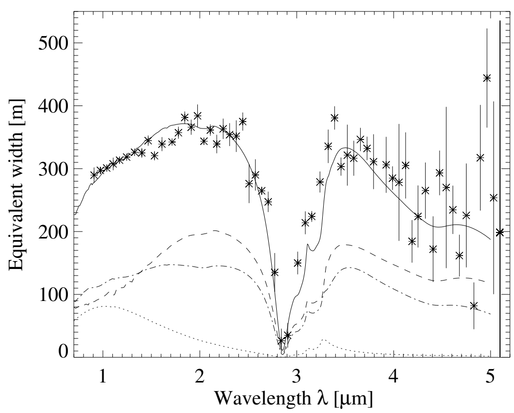

Figure 1: VIMS spectrum of the Enceladus plume at 80 km above the surface (data points), overlaid with the corresponding model spectrum (solid line). The dashed line shows the simulated jet component. The dotted line and the dash-dotted line show the additional E-ring background and the diffuse component, respectively, as discussed in the text.

4. Summary and Conclusions

We have taken an integrated approach to model the dust jets of Enceladus from dynamics to simulated observations. The simulated spectra show distinct differences in comparison to near-infrared observations of the VIMS camera on board the Cassini spacecraft. These differences hint towards an additional dust component concentrated close to the moon's surface, consisting of systematically larger and slower grains. This is in good agreement with expectations from models of the formation and chemical composition of the observed grains.

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