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The dynamics of nanoparticle influx at Saturn

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Abstract

During Cassini's final months, *in situ* instruments made the first direct measurements of nanoparticles, finding an exceptionally large flow from the rings into Saturn's atmosphere. Cassini's Ion and Neutral Mass Spectrometer (INMS) measured material in three altitude bands and found a global-integrated flux of 2–20 × 10^4 kg/s that is dominated by hydrocarbon material [1, 2]. Magnetospheric Imaging Instrument (MIMI) measurements at two altitude bands provided data for the larger range of nanoparticles, 10,000u to 40,000u [3]. Due to their relatively large area-to-mass ratio, nanoparticles are susceptible to atmospheric drag by Saturn's tenuous exosphere that reaches the inner edge of the D-ring. We model this drag process and use the results to constrain the density of the hydrogen exosphere, the transport timescales, and the spatial distribution of material in the D-ring.

1. Introduction

From the depressed electron densities in Saturn's ionosphere, measured during Pioneer and Voyager radio frequency occultations, Connerney and Waite deduced the existence of ring material entering Saturn's atmosphere [4]. The posited transport mechanism is via charged material—ions and particles—traveling along magnetic field lines and entering Saturn's atmosphere primarily in the mid latitudes. Analyses of subsequent Earth-based observations supported this mechanism [5], and during Cassini's last orbits, the Cosmic Dust Analyzer measured these particles and confirmed that this process provides material to Saturn's upper atmosphere. [6].

INMS and MIMI data revealed a different process acting on a different particle population. The INMS- and MIMI-measured particles were smaller, neutral, and confined within a few degrees of the equatorial plane. The flux was also two or three orders of magnitude larger than expected.

Atmospheric drag preferentially acts on smaller particles for two reasons: 1) the area-to-mass ratio is larger for nanoparticles; and 2) charging time scales are longer for smaller particles. Larger and heavier particles are relatively unaffected by collisions with the atomic hydrogen that reaches the D-ring, whereas particles that are 1 or 2 nanometers in radius or smaller will begin their descent with just one or two collisions. The larger particles will also charge more quickly either by solar photons or local plasma, and once charged, the particles are controlled by the magnetic field and are resistant to atmospheric drag.

2. INMS and MIMI data

We group INMS data by orbit into high, middle, and low bands that are based on the orbit periapsis altitudes, which range from 1,370 to 3,600 km. Contrary to expectations based on the 95% water composition of Saturn's rings, INMS mass spectra are dominated by CH_4, species at 28u, and other carbon-bearing compounds. At the highest altitudes, the strongest signals are within only two degrees of the equatorial plane, as are the MIMI measurements at the middle altitudes. At the lowest altitudes, both INMS and MIMI data are spread further and extend approximately ten degrees north and south of the equator. Mixing ratios are highest at the highest altitudes, as expected for material entering Saturn's exosphere from above.

During the proximal orbits, the low-altitude mixing ratios varied independently of the H_2 density. This is particularly evident in CH_4, where the mixing ratio varied by a factor of 3 from pass to pass [1, 2], and in the total integrated mass, which varied by a factor of 4. At least a portion of this variability appears to be linked to the clumps of material [7] in the D68 ringlet, the assumed source of the influx material.

3. Model

The Monte Carlo model traces one ring particle at a time from its initial location in the inner edge of the D-ring (68,000 km from Saturn's center) to the bottom of the exosphere at an altitude of 2,800 km (63,000 km). Collisions are elastic, with random impact parameters and a frequency that is random based on the probability associated with the particle size and local exosphere density. Particles are initially on the equatorial plane and have circular orbital velocity.

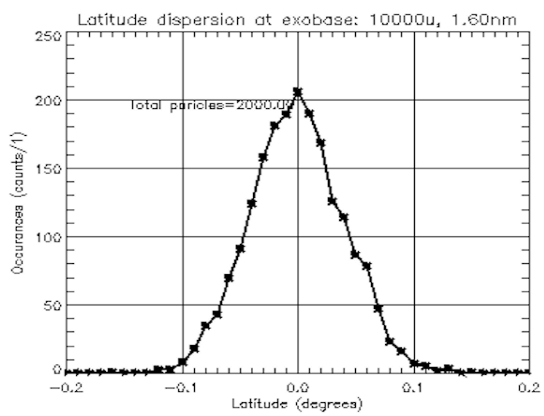

Fig. 1. Using the baseline parameters, the spread in 10,000u particles in the middle-altitude band is ±0.5 degrees, about 1/3 of the width measured by MIMI.

4. Initial results

The baseline model does not produce the observed dispersion in particles at the mid-altitude band (Fig. 1). Two possible reasons for this are that the material in the D68 ringlet has a broader distribution north and south than the narrow confinement of the baseline assumption. Another possibility is that the higher plasma density in the lower exosphere charges some of the neutral influx and the particles are then spread along the north-south magnetic field lines. Some of the MIMI data support this latter explanation and we will add charging to the model.

Both horizontal (parallel to the equatorial plane) and vertical velocities depend on the density distribution of atomic hydrogen in the upper exosphere and on the particle mass (Fig. 2). The density of atomic hydrogen is poorly constrained by observational data, including INMS, so matching the results of high-fidelity modeling to MIMI data provides an important constraint. The interaction between competing processes is complex but well captured in the model. These initial results indicate that to match MIMI data, the hydrogen density is lower than many predictions.

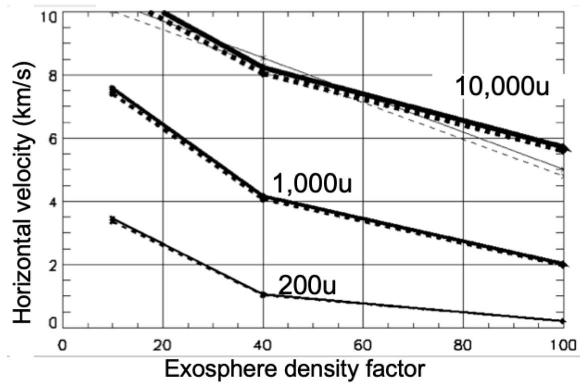

Fig. 2. The horizontal velocity relative to Saturn's atmosphere of particles at the exobase vs. the density of atomic hydrogen in the exosphere.

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