EPSC Abstracts
Vol. 7 EPSC2012-782-1 2012
European Planetary Science Congress 2012

The Cassini INMS view of ions and neutrals in Saturn's inner magnetosphere

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1. Introduction

Although designed for the higher densities in Titan's upper atmosphere, the Cassini Ion Neutral Mass Spectrometer (INMS) can observe the low-density particles in Saturn's inner magnetosphere (IM). Over the past five years, planning and implementing INMS observations of neutral molecules and water-group ions near the equatorial plane have steadily improved such that INMS now provides unique information on Saturn's dynamic IM.

INMS observations in Saturn's IM include aspects that are not available by other means. Most other observations of neutral distributions are indirect, relying on inferences from data sets such as OH ultraviolet images. In contrast, INMS measurements are *in situ*, directly measuring the neutral targets. For ions, INMS can differentiate between the dominant water-group species, O^+, OH^+, and H_2O^+, unambiguously, a task that is difficult for the Cassini Plasma Spectrometer (CAPS), which has provided excellent, detailed data on almost every other aspect of low-energy plasmas in Saturn's IM.

INMS provides data on the three-dimensional distribution of neutrals and ion fractions in the IM, results that are particularly useful as constraints and benchmarks for models of the magnetosphere and of neutral-ion interactions. The INMS data have sufficient quality to resolve densities in a single observation, enabling assessment of changes from one Cassini orbit to the next and investigation of the time dependence of neutrals and ion fractions. For both neutrals and ions, INMS collects its best IM data between 3.5 R_S and 6 R_S. Closer to Saturn, increased background due to radiation swamps the signals, and farther from Saturn, the densities are too low.

2. *Neutral measurements*

Two factors complicate analysis of neutrals in Saturn's IM: 1)background noise that is comparable to the neutral count rate, and 2)the tendency of H_2O molecules to adhere to the walls of the INMS inlet aperture [1-2]. The steps, below, describe data-reduction for INMS neutrals:

- Use time histories of the data to quantify the outgassing background for mass 18 AMU. Use other mass channels (with no expected signal) to quantify the radiation background.
- Use the time history of volatile species to determine the spatial profile of the neutral density.
- Since H_2O adheres to the instrument walls, calculate the total amount of water measured by INMS during the pass by summing the entire 18-AMU signal during the extended observation.
- Combine total water with the spatial profile to calculate the water density and errors.
- When there is sufficient signal, calculate CO_2 density.

Using this technique, the INMS detection limit for neutral water is about 10^3 molecules/cm^3, which is the approximate equatorial density near 6 R_S. In the densest part of the neutral cloud that is outside of the Enceladus plumes and north of Enceladus, INMS measures 10^5 molecules/cm^3.

Figure 1 displays data gathered in a single Cassini pass through Saturn's IM near the equatorial plane. From 4.2 R_S, just outside the orbit of Enceladus, to 7 R_S, neutral water density drops a factor of ten as it becomes photo-ionized, disassociated by ion impact, and distributed by neutral-neutral collisions [3].

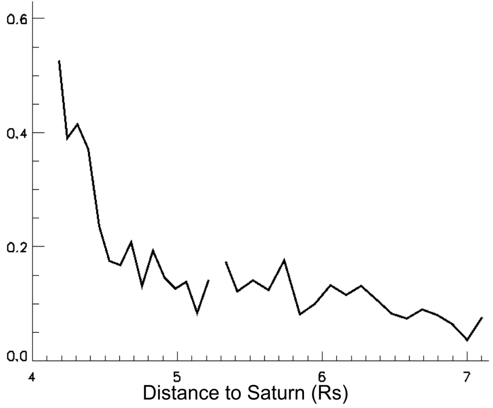

Figure 1. Relative density of neutrals from a recent INMS observation along the equatorial plane that shows the decline in density as distance increases from the orbit of Enceladus at 4 R_S. There are other observations that show vertical (north/south) and azimuthal dependence.

3. *Ion measurements*

There is no outgassing background for ions, and we treat radiation background using the same process as for neutrals. The primary difference in analysis is due to the lack of molecular sticking (ions never contact the aperture walls) and INMS's restriction of measuring only one velocity at a time. We convert counts, c, to density of an ion at the measured velocity using

$$n = \frac{c}{tSu} 10^{-5}$$

where n is the density of ions at velocity u (km/s) with respect to the spacecraft, t is the duration of an IP, and S is the sensitivity in counts/s/(particle/cm^2/s).

The velocity phase space density measured by INMS is determined by the half-angle, θ, of the field-of-view in radians, and the spread in velocities, Δv, in km/s. The phase space density, in units of s^3/cm^6, is

$$F_i = n \big/ \left[\pi(\theta v)^2 \Delta v\right]$$

Since INMS measures only a small portion of velocity phase space in a single measurement, we use the velocity phase-space distributions measured by CAPS to interpret the INMS results [4-5]. We examine the species fractionation at different locations in coordinate system with V_{PERP} (perpendicular to the magnetic field) and V_{PAR} (along the magnetic-field lines).

INMS resolves the species within the water group and observes H_2O^+, OH^+, and O^+, as expected from magnetosphere models based first on the OH observations and later on a water source at Enceladus. The data show that the H_2O^+ density falls relative to the other two species with increasing distance from the orbit of Enceladus at 4 R_S.

Figure 2 shows the behavior that is predicted by model, the clear decay of H_2O^+ at the expense of OH^+ and O^+ densities. The water-group distribution is comprised almost entirely of H_2O^+ near 4 R_S and transitions to a region beyond 5.5 R_S that is poor in H_2O^+. Another INMS observation shows that the OH^+ fraction increases above H_2O^+ at about 5.5 R_S, which is about 1 R_S closer to Saturn than the 6.5 R_S location of the crossover in the model. The model parameters can be adjusted to match the INMS data. Other INMS observations investigate how these fractions depend on phase space, vertical and azimuthal dimensions, and time.

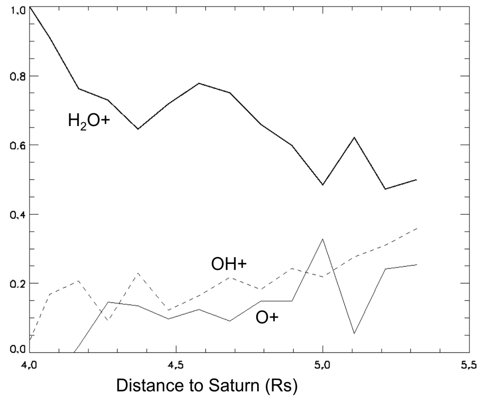

Figure 2. The water-group ions are composed almost entirely of H_2O^+ at the orbit of Enceladus, as expected since the population is dominated by recently picked-up ions. The rate that O^+ and OH^+ increase as they move away from Enceladus provides a quantitative value to benchmark ion models, where these fractions are sensitive probes of the transport and loss processes.

References

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