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In-situ measurements of ions and neutrals near Saturn's F-ring

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1. Introduction

Each week from December 2016 until April 2017, Cassini dove through a gap in the F-ring. During several of those traverses, the orientation of Cassini's Ion and Neutral Mass Spectrometer (INMS [1]) enabled *in situ* measurements of both ions and neutrals, providing data that contribute to improving our understanding of the rings, their interaction with Saturn, and the influence of the magnetosphere. The Enceladus plumes, Saturn's atmosphere, and ring sputtering (photolysis and radiolysis) are all potential sources of F-ring particles.

2. Major neutrals

INMS found two neutrals with remarkable consistency during the F-ring passes: H_2 and a species at 28u (Figure 1). The scale height, or the half-width-half-max of the INMS counts, for both of these species was approximately 3,000 km, or 0.05 Saturn radii (R_S). This parameter and the total counts were nearly identical in each pass.

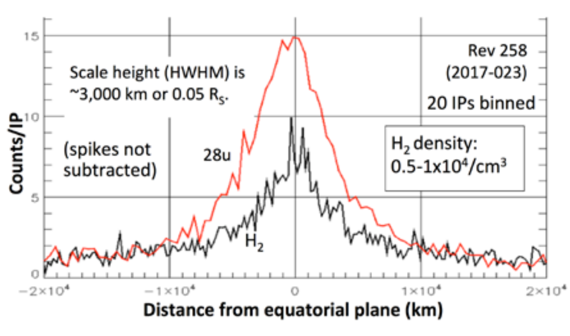

Figure 1: the major neutrals measured by INMS in the F-ring. Twenty measurements (integration periods or IPs) were binned for this plot.

Although H_2 was expected in this area of the rings, models and Earth-based observations predicted a larger scale height for H_2 from Saturn's atmosphere, and the narrow distribution of the observed H_2 suggests that it is more liked to originate in the rings [2]. Atomic hydrogen is not measured by INMS due to instrumental noise at 1u.

A complication for INMS neutral observations is the high speed of Cassini relative to the ring particles. At 20 km/s, the molecules carry 2.1 eV per nucleon, which is sufficient energy to cause some dissociation in the INMS antechamber, particularly for larger molecules. If a molecule dissociates, only volatile products are measured. Without considering dissociation, the density of the H_2 is 0.5-1x10^4 cm^{-3}.

3. Other neutrals and 28u

CH_4 (16u) and CO_2 (44u) are the only other measured species. They both have a count rate that is approximately 20% of H_2's rate. CH_4 is confirmed by the presence of 15u counts at the correct 'cracking' ratio, the amount produced from CH_4 in the INMS ionization chamber. CO_2 is not a common dissociation product and may be a native species. It exists on the surface of several icy moons [3]. Count rates for both CH_4 and CO_2 are depressed due to dissociation and they may be more abundant than indicated by the measurements. There are small amounts of 26u and 27u, which are expected products from ionization of C_2H_4, one possibility for the 28u measurements. However, the count rates for these two cracking products are lower than expected if the entire 28u signal was produced by C_2H_4. This deficiency implies that another species such as CO may contribute to the 28u signal.

Several expected neutrals are missing, most notably H_2O and O_2. Since water is temporarily adsorbed onto the walls of the INMS inlet, H_2O counts are suppressed and delayed [4]. Combined with the radiation background increases after passing through the equatorial plane, INMS would not detect low densities of H_2O, particularly after some loss due to high-velocity dissociation. Modeling by Tseng et al.

[2, 5] shows that O_2 could be abundant, but that densities decrease a factor of 1,000 approaching the location of Cassini's trajectory; moreover, much of the O_2 would be lost due to dissociation.

4. Ions

INMS observed only water-group ions in the F-ring. Unlike the neutrals, the ion densities were not symmetrical with respect to the equatorial plane, varying in both total density and the relative fractions within the water group (Figure 2). The predominance of O^+ vs. the other water-group ions indicates that there may be a source of O^+ other than as a byproduct of water [6].

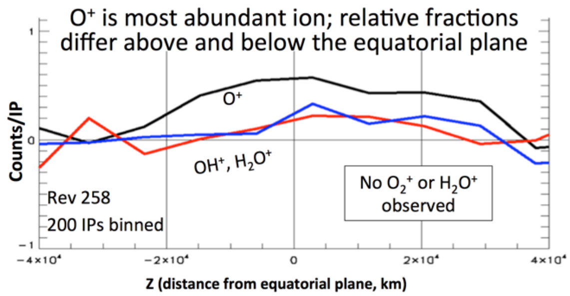

Figure 2: Distribution of water-group ions south and north of the equatorial plane. O^+ comprises a higher fraction of the ions in the south.

The velocity distribution of the ions (Figure 3) shows that the ions are cold, with a mean velocity below the pickup velocity of 8 km/s, corresponding to a temperature of approximately 3 eV. These results are consistent with analyses and modeling of data from the Cassini Plasma Spectrometer (CAPS) [7].

The lack of O_2^+, which INMS observed during Cassini's insertion into orbit about Saturn, is likely due to the INMS energy limit: at the F-ring speeds, O_2^+ exceeds the INMS limit for ions. The lack of H_2^+ is surprising and not yet explained. As with neutrals, noise prevents INMS measurement of H^+ at 1u.

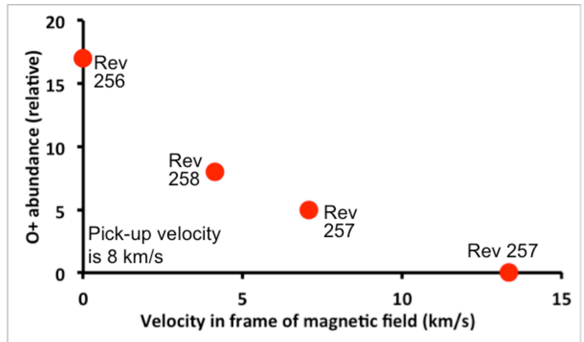

Figure 3: The distribution of ions in the rest frame of the magnetic field. Ions are concentrated near the core, as expected for cold ions.

References

[1] Waite J. H. et al. (2004) *SSR, 114,* 113. [2] Tseng W. L. et al. (2013) *Planet. and Space Sci. 85,* 164. [3] Teolis B. D. et al. (2010) *JGR 115*, A09222. Hedman M. M. et al. (2013) *Icarus 223,* 105-130. [4] Teolis B. D. et al. (2010) *JGR, 114,* A09222. [5] Tseng et al. (2010) *Icarus 206,* 382. [6] Teolis et al. (2017) *J. Geophys. Rev.* submitted. [7] Elrod et al. (2014) *Icarus 242*, 130.