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Saturn's Equatorial Ionosphere as Observed by Cassini: Composition and Flow

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Abstract

The Cassini Orbiter measured the upper atmosphere and ionosphere of Saturn in 2017. Molecular hydrogen and helium were the major neutrals seen by the Ion and Neutral Mass Spectrometer (INMS) but important minor species were also seen including water, methane, ammonia, and organics. INMS in its ion mode measured light ion species (H^+, H_2^+, H_3^+, He^+) and the Radio and Plasma Wave Science (RPWS) instrument measured electron densities in the ionosphere. The spacecraft (s/c) velocity with respect to Saturn during the proximal orbits was 31 km/s, which corresponds to 25 times higher kinetic energy per nucleon for incident molecules than during the Titan encounters. Heavier neutral species, or even grains, break up in the closed source antechamber at these speeds and INMS ion measurements were limited to species with mass numbers less than 8 Daltons (i.e., only lighter ions). The chemistry and dynamics of Saturn's ionosphere will be discussed using Cassini data and simple theory.

1. Photochemical Analysis

Photochemistry plays a key role in the main ionospheric layer of Saturn. Analysis shows that photoionization of molecular hydrogen is the main source of plasma. The H_2^+ ions produced react with H_2 to produce H_3^+ and H_3^+ ions can dissociatively recombine. But theoretical H^+ and H_3^+ densities greatly exceed the measured densities unless another chemical loss process is operating. A quantitative explanation of the measured H^+ and H_3^+ densities requires that they chemically react with one or more heavy neutral molecular species that have mixing ratios of about of 100 parts per million (Cravens et al.,2018, and Moore et al., 2018). This is consistent with the neutral measurements made by INMS showing the presence in the upper atmosphere of neutral species (e.g., methane) and/or grains thought to originate in the rings (Waite et al.,2018 and Perry et al., 2018).

A photochemical analysis of the INMS and RPWS data indicates that the major ion species near the ionospheric peak must be heavy and molecular with a short chemical lifetime (e.g.,CH_3^+).

2. Dynamical Analysis of the Ionosphere

Photochemical lifetimes increase with increasing altitude in the ionosphere whereas ion transport times become shorter. Understanding the distribution of ionospheric plasma requires the inclusion of transport effects. INMS data shows that H^+ is the major ion species in the topside Saturn ionosphere at high altitudes, and RPWS data shows interesting structure associated either with altitude and/or latitude. During one of the Cassini proximal orbits energy scans were performed using the INMS ion optics which allowed H^+ flow speeds along the spacecraft track to be measured. This data will be presented and shows a flow along the magnetic field from the northern hemisphere to the southern hemisphere.

A simple numerical dynamical model of the ionosphere is used to interpret INMS and RPWS data. Single species fluid equations are numerically solved along magnetic field lines and the model includes chemical production and loss, and ion-neutral collisions. The effects of ring shadowing (Hadid et al. 2018) are included in the model and are necessary to explain the data.

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