A NEW UNDERSTANDING OF THE INTERACTION BETWEEN SATURN AND ITS RINGS.
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Introduction: The first *in situ* measurements of Saturn's exosphere and upper atmosphere reveal a complex and varied flux of molecules and particles flowing into Saturn from its rings. Combining data from the Cassini Ion and Neutral Mass Spectrometer (INMS) [1] with data from the Charge-Energy-Mass Spectrometer (CHEMS) and the Ion and Neutral Camera (INCA) instruments on the Magnetospheric Imaging Instrument (MIMI) [2], we have taken the first steps toward a new understanding of the interactions between rings and the body that they orbit.

Before Cassini's 2017 passage through Saturn's exosphere, the dominant, non-gravitational interaction between Saturn and its rings was a transfer of water molecules from the inner rings to the mid latitudes of Saturn. Connerney and Waite (1984) [3] were the first to propose an influx of water to explain the low electron densities measured during Pioneer and Voyager radio occultation experiments. Charge exchange of the H^+ ions with the heavier, minor species, at mixing ratios of $1x10^{-4}$, depleted the H^+ ions by provided a faster path to electron recombination. With ice the primary constituent of the rings, water was the most likely in-falling molecule. Northrop and Connerney 1986 [4] proposed a mechanism for that precipitation: molecules sputtered from the inner rings travel along the magnetic field lines to the middle latitudes of Saturn, a process dubbed "ring rain." Later, Moore et al. 2010 [5] proposed and quantified an additional flux of neutral water at low latitudes to explain the early RSS Cassini occultation results, which showed that electron densities were lowest for latitudes within 30 degrees of the ring plane.

Although the present work concentrates on nanoparticles and neutral molecules, INMS also measured the light ions, H^+, H_2^+, H_3^+, and $4u^+$ (He^+ and HD^+), which show that Saturn's atmosphere is in photochemical equilibrium (PCE) [6, 7]. This balance provides constraints on the minor species that we use in interpreting the neutral measurements.

INMS measurements: The INMS data were acquired using the Closed Source Neutral (CSN) mode, where molecules enter the CSN aperture at 29-31 km/s and impact the antechamber walls before they are ionized and counted. There are INMS observations at three different altitudes, from 1,500 km above the 1-bar level to 4,000 km, just inside the inner edge of the D-ring. At every altitude, the most abundant minor species in the H_2 atmosphere is not the expected water, but methane (CH_4). At the highest altitudes, only a few other species, CO_2 and a species at 28u, are above the noise level. Water is present but at lower abundance. At the mid latitudes, only a few more species are above the noise level. At the lowest altitudes, the count rates are hundreds of times higher, with many more species observed.

MIMI measurements: Both INCA and CHEMS were designed to measure high-energy particles using start and stop foils. During the proximal orbits, though, both instruments detected much heavier particles that were detectable because of the high speeds that provided sufficient energy to sputter particles from the start foils.

INCA measured particles with masses larger than approximately 20,000u, both neutrals and ions, during three orbits at approximately 3,000 km altitude [8]. The distribution of particles was remarkably stable and narrow. CHEMS measured positively charged nanoparticles between 40 and 230 keV. Since the fraction of nanoparticles with a positive charge is less than 10^{-2} [9], only the lowest altitudes, with the highest density of particles, have a sufficient amount of positive particles to be measured by CHEMS. The particle distribution has both a latitude and atmospheric-density dependence, consistent with an equatorial source of particles that are not yet fully diffused into Saturn's atmosphere.

Discussion: The latitudinal dependence of the minor species in the high and mid altitude indicates that the source of the molecules is near the equatorial plane. At high altitudes, the minor species were observed primarily at zero latitude, where the 28u mixing ratio was six times higher than at 5° latitude. At lower altitudes, the species is diffused and fully mixed into Saturn's H_2 atmosphere. The lighter molecule, CH_4, diffuses more rapidly than the 28u species.

From pass to pass, the abundances and distribution of the minor species varied a factor of three about the average mixing ratio, which can be explained by a variable or spatially dependent source. The distribution within a single pass could also show variation: the CH_4 distribution of orbit 288 is consistent with a source that reduced by a factor of two within a diffusion time scale, which is tens of minutes for the local conditions.

Some of the initial discoveries include the identification of CH_4 as the primary influx species, the high density of nanoparticles, the concentration of molecules and particles at the ring plane, and the variability in the molecular flux. We report on several avenues of research including comparison between the INMS and CHEMS data to the larger particles measured by the Cassini Dust Analyzer [10, 11], the total mass flux based on INMS and CHEMS data, the diffusion ratios of molecules with different masses, the abundance of neutral molecules measured by INMS compared to the mixing ratios determined by PCE, and characteristics of the transport processes that deliver the molecules and particles from the rings to Saturn's upper atmosphere.

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