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On the Characteristics of Charged Dust in Saturn's Equatorial Ionosphere – Implications from Cassini RPWS/LP data

J.-E. Wahlund (1), E. Vigren (1), M. W. Morooka (1), L. Z. Hadid (1), W. M. Farrell (2), A. M. Persoon (3), W. S. Kurth (3), D. A. Gurnett (3), D. G. Mitchell (4), M. E. Perry (4), J. H. Waite Jr. (5), L. Moore (6), T. E. Cravens (7), M. Galand (8) and A. F. Nagy (9)
(1) Swedish Institute of Space Physics, Box 537, SE-751 21 Uppsala, Sweden (jwe@irfu.se)
(2) NASA/Goddard Space Flight Center, Greenbelt, Maryland, USA
(3) University of Iowa, Iowa City, Iowa, USA
(4) John Hopkins University Applied Physics Laboratory, Laurel, Maryland, USA
(5) Southwest Research Institute, San Antonio, Texas, USA
(6) Center for Space Physics, Boston University, Boston, Massachusetts, USA
(7) Department of Physics and Astronomy, University of Kansas, Lawrence, Kansas, USA
(8) Department of Physics, Imperial College London, London, UK
(9) Department of Atmospheric, Oceanic and Space Sciences, University of Michigan, Ann Arbor, Michigan, USA

Abstract

The Cassini spacecraft observations close to Saturn have revealed that 1-100 nm-sized dust grains precipitate from the D-ring into the atmosphere. RPWS Langmuir probe ion number density measurements suggest that the charged dust has a profound effect on the ionospheric structure, enhancing the ion number density well above photochemical equilibrium levels, while the electrons tend to become attached to the dust population. We present model calculations of Saturn's equatorial ionosphere and include the effect of charged dust grains that break down into smaller grains/clusters deeper in the atmosphere at an altitude near the ionospheric peak. The model is constrained as far as possible by input from Cassini INMS, RPWS and INCA/CHEMS measurements, and then compared with observed electron and ion number densities by RPWS. From these dust-ionosphere model calculations it is clear that a layer of small singly negatively-charged sub-nm-sized dust grains can explain the RPWS Langmuir probe measurements.

1. Introduction

The Cassini spacecraft in-situ measurements monitored the ring material, Saturn's ionosphere and thermosphere. The Radio and Plasma Wave Science (RPWS) observations of ionospheric electron densities [1-4] are determined to high accuracy with two independent measurement methods and showed an ionospheric peak electron density of 4000-12000 cm^{-3} just above 1500 km altitude. The positively charged ion density was greatly enhanced with N_e/N_i around 10-20% toward the lowest altitudes. These large ion densities (10^4-10^5 cm^{-3}) were clearly not in agreement with photochemical equilibrium models.

2. Dust Ionosphere Model

We compare here the RPWS Langmuir probe (LP) measured electron and ion densities in Saturn's ionosphere with an ionosphere model, calculating the ionization production (q) directly from Cassini INMS measurements, using measured electron temperatures for rate constants, and including a dust component, based on MIMI and CDA estimates, that we self consistently charge up according to the surrounding plasma. The results show that a greatly enhanced ion number density can be reproduced with similar amounts as RPWS LP observes. We conclude from the model comparison that the equatorial ionosphere of Saturn can be dominated by sub nm-sized grains/cluster ions, probably similar to those encountered in the Earth's polar mesosphere (Figure 1). Our ionosphere model follows the theory/methods employed by [5-7] and solves a set of coupled continuity equations for the temporal evolution of electrons, ions, singly positive charged grains, and up to 10 charge states of negatively charged grains until equilibrium is reached.

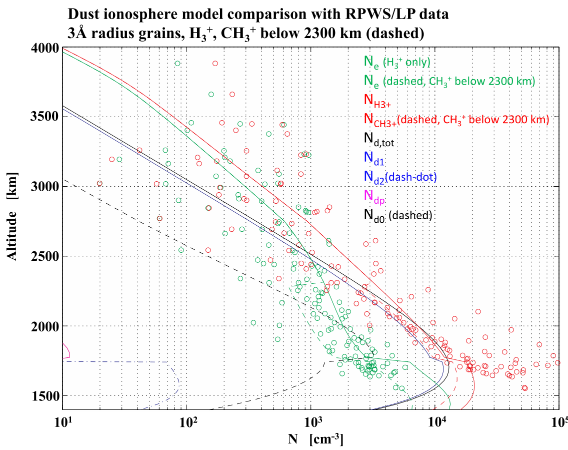

Figure 1: Example model runs with negatively-charged grains of 6Å size, where H_3^+ ions are dominant (solid green and red), but CH_3^+ is also important below an altitude of 2300 km (dashed green and red). The peak total grain number density (*N_0*, solid black) is 13,000 cm^{-3} at 1700 km.

3. Summary and Conclusions

We have identified a valid natural explanation for the observed electron and ion number densities by RPWS/LP in Saturn's ionosphere. A "rain" of nm-sized ring-dust deposited in the equatorial region can accumulate a dense layer of sub-nm-sized grains/clusters with a number density of 10,000-15,000 cm^{-3} near 1700 km altitude. This particulate ring rain is different from that predicted previously by Connerney and Waite (1984), originating instead from the D-ring and its strong interaction with the enveloping, co-rotating ionosphere. The dropout in the electron density by a factor of 10 below 2000 km is also not due to electron loss via the H cycle, but instead it is due to electron attachment to the aerosol congregation in the ionosphere. The impact of the electrons from the H cycle is actually diminished due to this electron loss via this aerosol attachment. Such a dust layer, we show, becomes pre-dominantly singly negatively charged when immersed in the ionospheric plasma, and significantly alters the electron and ion number densities from their photochemical equilibrium values. Electrons will become partly attached to the grains and the relatively stable negatively-charged grain population causes the ion number density to increase, resulting in an N_e/N_i-ratio to approach 10-20% in the deeper observed parts of Saturn's ionosphere (1500-2000 km altitude above 1-bar level).

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