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Sources of Titan's Ionosphere as Determined by Cassini Data

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Abstract

Model comparisons with Cassini data can be used to contrain the sources, dynamics, and energetics of the ionosphere of Titan. This paper will review models of both the ion composition and the ionospheric energetics (i.e., electron and ion temperatures). Emphasis will be placed on ion density profiles measured by the Cassini Ion and Neutral Mass Spectrometer for relatively primary species such as N^+, CH_3^+, and CH_4^+. This data, combined with relatively simple chemistry, is used to empirically determine ion production rates on both the dayside and nightside of Titan. Calculations and measurements of the electron temperature and density in the ionosphere will also be discussed.

1. Introduction

The following questions are relevant to any ionosphere including Titan's. *What physical and chemical processes control the ionosphere? How does the ionosphere interact with the neutral atmosphere and with external plasma and radiation inputs? What role does transport play in controlling the distribution of plasma and its composition?* Data from several experiments onboard the Cassini Orbiter including the Ion and Neutral Mass Spectrometer (INMS) and the Langmuir Probe (RPWS/LP), combined with theoretical modeling, have allowed us to at least partly answer these questions for Titan. Solar radiation is the dominant ionization (and thermospheric heat) source on the dayside, but ion production on the nightside obviously cannot be due to solar radiation. However, energetic electrons and ions in the outer magnetosphere of Saturn near Titan can ionize Titan's neutral gas if the particles gain access to the atmosphere, which partly depends on the magnetic field topology in the vicinity of Titan.

2. Empirical Ion Production Rates on the Dayside

Ion production by solar radiation of the major neutral species can be represented by reactions such as:

$$h\nu + N_2 \rightarrow N_2^+ + e$$

$$\rightarrow N^+ + N + e \quad (1)$$

$$h\nu + CH_4 \rightarrow CH_4^+ + e \quad (2)$$

The main ion species produced is N_2^+ but this species is rapidly converted first to CH_3^+ and then to $C_2H_5^+$ via the following reactions with the major species CH_4:

$$N_2^+ + CH_4 \rightarrow CH_3^+ + N_2 + H \quad (3)$$

$$CH_3^+ + CH_4 \rightarrow C_2H_5^+ + H_2 \quad (4)$$

Further reaction of $C_2H_5^+$ with HCN produces the most abundant ion species $HCNH^+$ and other reactions with minor neutral species produce complex ion species including higher mass species.

Current ionospheric models produce ionospheres in qualitative agreement with Cassini data, but one major problem is that the absolute electron densities (and densities for some ion species) are about a factor of 2 too large. Ion production and loss processes (mainly dissociative recombination) are now being re-examined. For example, empirical production rates for the main ionization channel (N_2^+ production) can be found using the above simple chemistry and INMS data:

$$P \approx k\,[CH_3^+][CH_4] \quad (5)$$

The INMS measures the densities of [CH_3^+] and [CH_4], and k is the rate coefficient for the fourth reaction above. These production rates will discussed and interpreted.

3. Empirical Ion Production Rates from Magnetospheric Inputs

Energetic protons, oxygen ions, and electrons are observed in Saturn's outer and can precipitate into Titan's atmosphere where they deposit energy and drive ionospheric chemistry. The magnetic topology near Titan strongly affects the transport of electrons from Saturn's magnetosphere into Titan's atmosphere due to the small electron gyroradii. The empirical production rate approach has also been applied to the nightside where particle precipitation is thought to be important. Comparisons will be presented of measured densities with model calculations in which measured magnetospheric electron fluxes are used as inputs

4. Summary

The model and observational results for the ionosphere of Titan will be put into the broader context of the questions listed in the Introduction.

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