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Thermosphere and Ionosphere on Mars: a Closely Coupled System

Laila Andersson (1), Marcin Pilinski (1), Scott Thaller (1), Hassanali Akbari (1), Robert R. Ergun (1), William K. Peterson (1), Gina A. DiBraccio (2), Mehdi Benna (2), and David Mitchel (3)
(1) Laboratory for Atmospheric and Space Physics, University of Colorado Boulder, USA (2) NASA Goddard Space Flight Center, USA (3) Space Sciences Laboratory, University of California Berkeley, USA (laila.andersson@lasp.colorado.edu)

Abstract

The Martian ionosphere provides insights to many fundamental properties of the generation region. This is the region where electrons are coupled to the magnetic field while ions are not. One aspect that has, up to now, not been completely taken into consideration is the close coupling between the ionosphere and thermosphere where not only are the winds important but also the photochemical reaction rates. In this study the latest observations are put into context of previous works.

1. Introduction

With the NASA MAVEN mission, the Martian ionosphere and thermosphere is sampled in-situ on par with aeronomic satellite missions sampling the ionosphere-thermosphere (I-T) region at Earth. The MAVEN mission reaches down to the equivalent Earth E-region (Mars is almost devoid of an F-region equivalent). This result in both opportunities: (a) analyze the generation region of an ionosphere but also complexity (b) separate out the thermospheric dynamics from the ionospheric dynamics.

2. Thermospheric Coupling

Mars has a strong day night asymmetry with a large density gradient and corresponding background winds. Additionally, the thermosphere contains both tidal waves of the order of 20% fluctuations and of ‘gravity waves’ of similar magnitude. Below ~200 km the ions are demagnetized and the ionosphere can respond to a ~20% change in the thermosphere in less than ~1 hour. Therefore, to first order, the ionosphere will move with the thermosphere. As a result, any discussion of the ionospheric dynamics below 200 km needs to be put in the context of neutral pressure levels. The thermosphere below ~180 km is dominated by CO2. This gas efficiently cold down the plasma and controls indirectly the chemical reaction rates via electron temperatures.

3. Ionosphere

Using data from the MAVEN mission, three features have been observed at Mars: (a) the morning overshoot, (b) the electron temperature spike, and (c) the ionosphere is warmer than expected. The ionospheric density profiles are highly variable and the effects of tidal waves, gravity waves and forcing from the solar wind all can be identified to various degrees.

The morning overshoot is similar to the overshoot observed at Earth which takes ~1-2 hours. At Mars due to the large density gradient, the morning overshoot takes ~6 hours since both the ionosphere and thermosphere need to reach equilibrium.

The cause of the electron spike not known yet but it is a ~300 K electron temperature spike where the thermosphere becomes optically thick (~120-150 km) and there is a ~15 K fluctuation in the neutral temperature. The presence of this feature observed near the subsolar point indicates that the Martian circulation pattern and the atmosphere itself is not completely understood.

There were no measurements of electron temperatures below 200 km prior to MAVEN and the electron temperature at lower altitudes was therefore assumed based on theoretical considerations. The observations indicate those assumption were largely incorrect and we will discuss why that is the case.

4. Ionospheric Dynamics

Wind measurements exist in the Martian ionosphere but are challenging to make. However, the observed electron temperatures indicate that significant heat flux is occurring on regular basis.

The ionosphere below 200-230 km is, to first order, independent of the magnetic field since the ions are demagnetized. Where this occurs can sometimes be clearly seen in the magnetic field. Below that region, the magnetic field provides global information and cannot be used to clearly identify currents.

Field-aligned-current can be seen often at low altitudes with ~100 eV electron precipitation, at the edge of closed-open magnetic fields in regions of the crustal fields. The FAC observations are associated with changes in atmospheric chemistry. These active currents are frequently narrow being less than 10 km in horizontal direction.

Above ~230 km, where the ions are magnetized, plasma processes dominate the ionosphere. The influence of the thermosphere is almost absent resulting in a lack of an equivalent Earth F-region. It is above this region where the impacts of crustal fields are observable and energy (particles and Poynting flux) driven by the solar wind is absorbed.

5. Summary and Conclusions

Several unexpected dynamics in the Martian ionosphere have been identified. The most important understanding is that the ionosphere cannot be studied in isolation but needs to be put into context of thermospheric behavior. The Martian ionosphere has demonstrated several unexpected features indicating that the aeronomy of Mars is not yet understood.

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