The Vertical Structure of the Martian Ionosphere

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AAS 2011, Boston, MA
May 22-26, 2010

Abstract

The vertical structure of the Martian ionosphere consists of two main layers. Maximum electron densities are produced in the M2 layer, which occurs at approximately 140 km, and is created by extreme-ultraviolet solar photons[1]. The weaker M1 layer occurs at approximately 120 km and is produced by solar soft X-rays and associated electron impact ionization[1]. Interpreting the vertical shape of the Martian ionosphere is a key tool for understanding ionosphere behavior and the physical processes involved. The vertical structure of the dayside M2 layer usually consists of a shape similar to idealized Chapman layer theory. However, deviations from this theory are expected as a result of the over-simplified assumptions made by idealized Chapman layer theory. We have investigated 485 vertical electron density profiles from the MaRS radio occultation instrument aboard Mars Express from 2004 to 2010. We will report observations of the vertical structure of the ionosphere of Mars that deviate substantially from the predictions of idealized Chapman layer theory. The examples of unusual M2 layer shapes that we will show include a flat-topped layer, a sharply pointed layer, and a wavy layer. These shapes have not been reproduced by current models of the ionosphere of Mars, which implies significant gaps in our present understanding of the ionosphere of Mars.

Introduction

The ionosphere of Mars can readily be studied by current spacecraft. Two instruments aboard Mars Express, MaRS and MARSIS, are conducting radio occultation and radar sounding experiments respectively. This new influx of data has allowed the Martian ionospheric properties to be studied in unprecedented detail, leading to the discovery of unusual features. These recent large data sets of electron density profiles have allowed the general trends of the vertical structure of the M2 layer to be studied and many investigators have concluded that the M2 layer is "Chapman-like"[1,2,3,4,5].

Chapman theory[6] uses an idealized atmosphere and radiative transfer to derive the number density of electrons as a function of vertical height. The theory assumes an isothermal atmosphere made up of a single molecular constituent that is ionized by monochromatic radiation. It is also assumed that the only loss mechanism is dissociative recombination. Therefore, deviations from the theory are expected. However, this idealized theory provides a basic understanding of how the ionosphere behaves. Using Chapman theory, the electron density n at a height z is given by

$$n = n_o \exp\left[\frac{1}{2}\left(1 - \frac{z - z_m}{H} - \exp\left(-\frac{z - z_m}{H}\right)\right)\right]$$

Where n_o is the peak electron density at a given solar zenith angle, H is the scale height of the neutral atmosphere, and z_m is the height of maximum electron density for a given solar zenith angle. Figure 1 shows an example of a normal M2 layer with a fitted Chapman layer in red over plotted.

Data

The Mars Express spacecraft has been accumulating measurements of the ionosphere using the MaRS radio occultation instrument since 2004[7]. A radio signal is sent from the spacecraft towards Earth as it passes behind the disk of the planet. The signal is refracted as it passes through the atmosphere and ionosphere of the planet, causing a measurable shift in frequency. This frequency shift allows atmospheric and ionospheric properties to be measured. The data is then processed into electron density profiles, 485 of which we investigated. These profiles were obtained between 2004 and 2010. A typical electron density profile has a vertical resolution of about 1 km and uncertainties of approximately 10^9 m^{-3}.

Discussion

Three examples of electron density profiles in which the M2 layer deviates substantially from a Chapman layer are shown. All three examples look similar to Chapman layers except near the peak of the M2 layer. Figure 2 shows an electron density profile in which the peak of the M2 layer has a wave-like structure which forms a double peak in the M2 layer. Figure 3 shows a flattop profile. A flat, constant electron density occurs for about 30 km near the peak and then it becomes Chapman-like again. In the final example, Figure 4, the usually smooth and rounded peak of the M2 layer is pointy.

Examples of other non-Chapman electron density profiles were also found, including: broad M2 layers, bulges in the upper M2 layer, and wave-like structures in the M1 layer. Although deviations from Chapman theory are expected due to the underlying assumptions, these unusual features show significant anomalies in the vertical structure of the ionosphere of Mars. In addition, current models of the Martian ionosphere[5] do not reproduce these unusual structures. This implies a significant gap in our knowledge of the physical processes involved in the ionosphere of Mars.

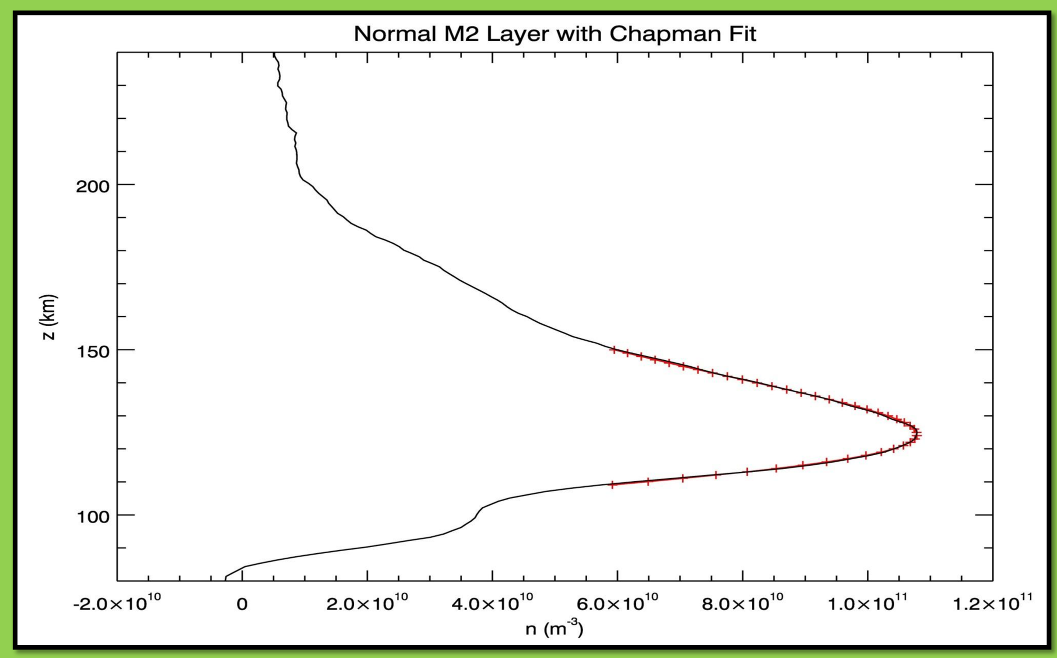

FIGURE 1: A normal M2 layer with a Chapman fit in red

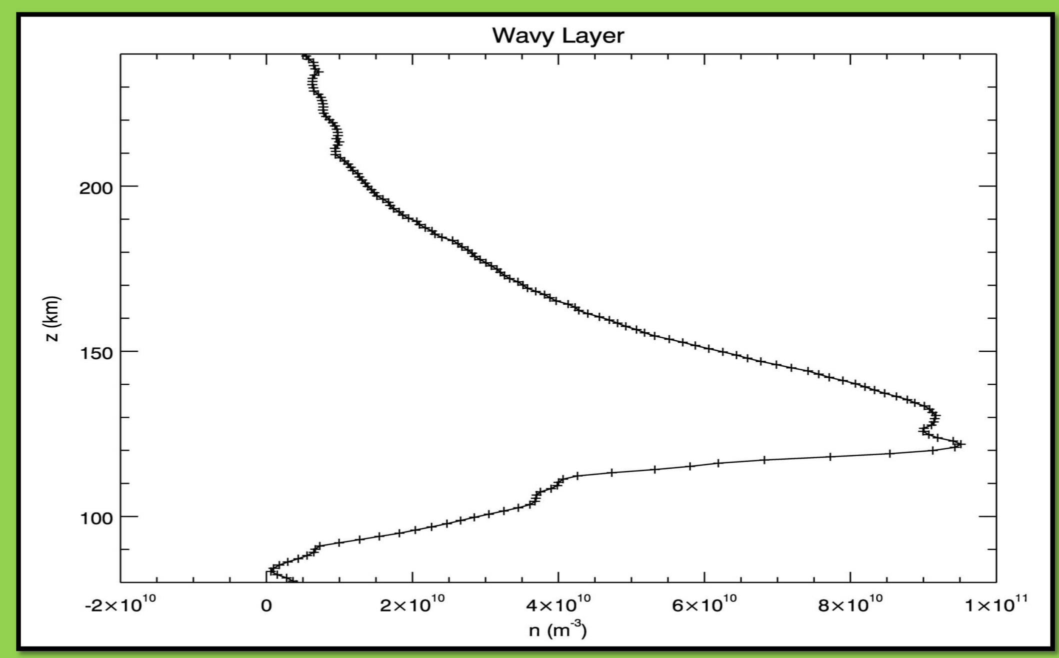

FIGURE 2: A wavy electron density profile

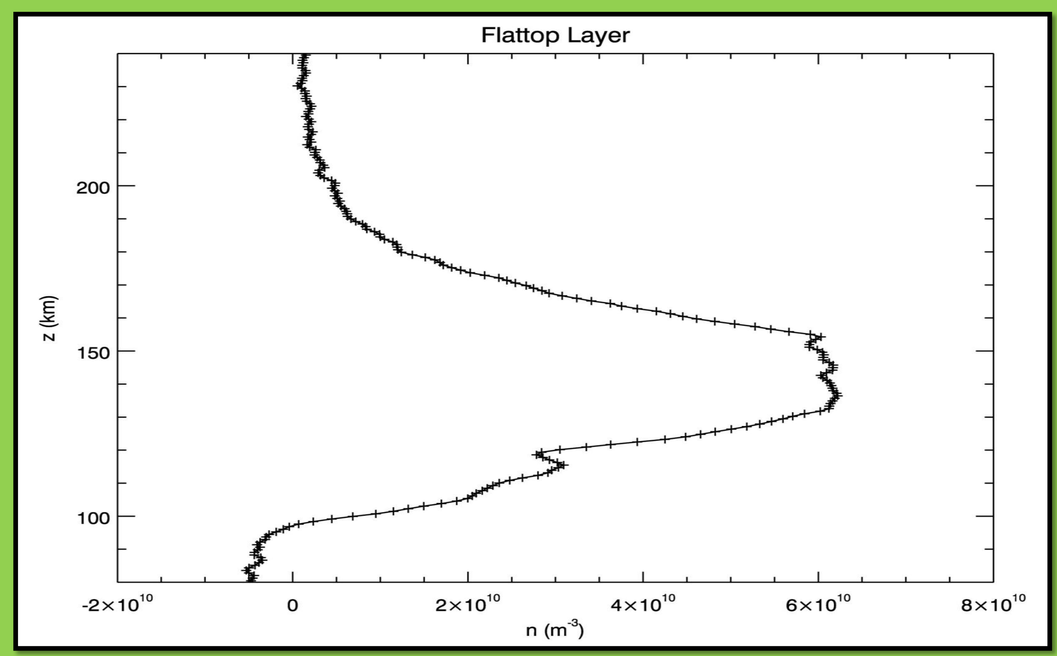

FIGURE 3: A flattop electron density profile

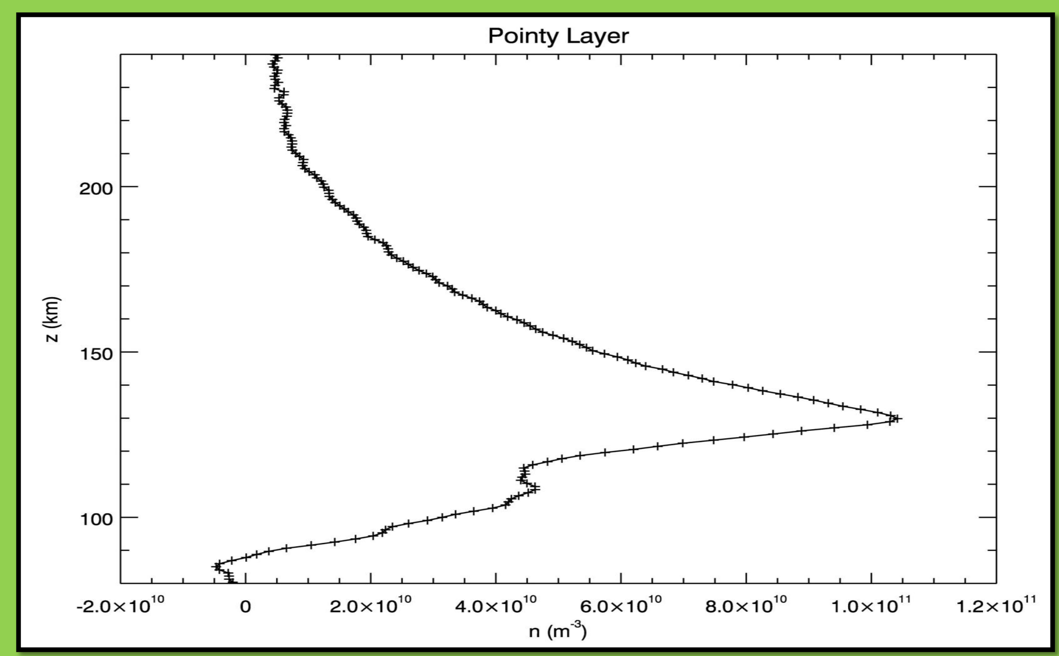

FIGURE 4: A pointy electron density profile

Conclusion

Although the dayside Martian ionosphere behaves similar to an idealized Chapman layer, significant deviations do exist. The deviations cannot be reproduced by current ionospheric models, implying a significant gap in our knowledge in the underlying physical processes. Future work will look into possible explanations such as variations in the solar flux or various plasma instabilities. Similar features in the ionosphere of Venus will also be investigated which will allow comparisons to our proposed explanations.

References

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