EPSC Abstracts
Vol. 11, EPSC2017-259, 2017
European Planetary Science Congress 2017

Mars proton aurora: energy deposition and Lyman-α line profile

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Abstract

We present the result of a model calculation of the brightness and line shape of Lyman-α emission produced in the Martian proton aurora recently discovered with the IUVS instrument on board MAVEN. This emission is produced by the interaction of solar wind protons with the Martian upper atmosphere.

1. Introduction

Two types of electron aurora have been observed on the Mars nightside. One is the discrete aurora confined to regions with residual magnetic field. The second one is the diffuse aurora (Schneider et al., 2015) which is more widespread and extends to lower altitudes, below the homopause. They occur during outbursts of highly energetic solar electrons. In addition, enhancements of the Lyman-α emission have been occasionally observed in the Mars dayside atmosphere with the Imaging UltraViolet Spectrograph (IUVS) instrument on board MAVEN (Deighan et al., 2016). This excess emission superimposes on the Ly-α resonance scattering background and is located between 100 and 140 km with a maximum near 120 km. It reaches as much as a 50% increase over the background level. These enhancements are generally coincident with periods of increased solar wind activity and last up to a few hours (Connour et al., 2017). They are likely caused by penetration of a fraction of solar wind protons into the Mars corona where they charge exchange with the ambient particles and produce fast neutral H_f atoms. The H^+/H_f population ratio in the auroral beam is controlled by the equilibrium between charge transfer and electron stripping during collisions with the ambient atoms and molecules. Measurements made with the SWIA instruments (Halekas et al., 2016) illustrated in the following figure indicated that the peak of the energy spectrum of protons penetrating the atmosphere is similar to that in the enhanced solar wind.

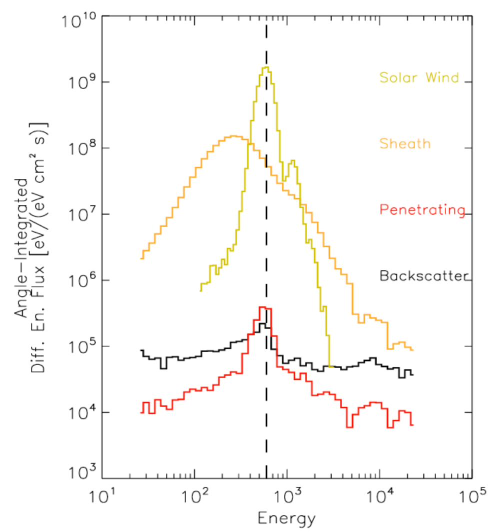

Figure 1 : angle-integrated energy spectra of protons measured by the SWIA instrument on board MAVEN in the solar wind, the sheath and those penetrating the atmosphere. Note the similarity in the peak energy suggesting the solar wind origin of the energetic protons. Energies are given in eV (from Halekas et al., 2015).

2. Monte Carlo model

The Monte Carlo code, based on the Direct Simulation Method (DSM), has been applied under different versions to calculate the interaction between a H^+- H beam with the neutral gas in the atmosphere of the Earth (Gérard et al., 2000), Jupiter (Bisikalo et al., 1996) and Mars (Shematovich et al., 2011). It is used here to calculate the energy degradation of the energetic H^+/H incident beam as it penetrates into the Martian upper atmosphere. The processes describing the interactions of energetic H^+ and H and the atmosphere may be written as:

$$H^+(H) + M \rightarrow \begin{cases} H_{f'}^+(H_{f'}) + M^* \\ H_{f'}^+(H_{f'}) + M^+ + e \\ H_{f'}\left(H_{f'}^+\right) + M^+(M) + (e) \end{cases}$$

where M denotes CO_2, N_2 or O, and M* an excited state of species M. Part of the fast H hydrogen atoms $H_{f'}$ may be in the H(2p) excited state which radiates Doppler shifted Lyman-α photons. The vertical temperature and the neutral density profiles of CO_2, CO, N_2 and O are taken from the Mars Global Ionosphere-Thermosphere Model (M-GITM) for mid-latitude dayside conditions. The cross sections used in these calculations to calculate the H^+/H interactions with the atmosphere have been described in Shematovich et al. (2011).

3. Model simulations

We simulate the Lyman-α line profile excited by proton and H atom precipitation from the magnetosheath. For this purpose, we first calculate the altitude distribution of the velocity distribution function of the fast H(2p) atoms in the Martian proton aurora. The Lyman-α line profile is obtained by integrating the projection of the H atom velocity vector along the line of sight to simulate a limb observation. Since the line is optically thick in the central core, we use the resonance line radiative transfer model developed by Gladstone (1985) that is based on the Feautrier method with angle-averaged partial frequency redistribution and taking the atmospheric curvature into account. We show that only the central core of the line is optically thick but that most of the broader line profile remains optically thin. We then calculate the line profile of the emerging auroral Lyman-α radiation and the fraction of the Ly-α photons emerging from the atmosphere for a given viewing geometry.

Finally, we quantitatively discuss the relationship between the observed intensity enhancement caused by the aurora and the proton energy deposition.

4. Conclusions

Observations of transient dayside enhancements of Ly-a limb intensity have been interpreted as signatures of energetic H+ and H precipitation. We describe the results of calculations of the interaction of the incident beam with the Mars upper atmosphere. The altitude of the emission peak and the emerging intensity are discussed.

Acknowledgements

This research was funded by the PRODEX program of the European Space Agency, managed The PRODEX program is managed in collaboration with the Belgian Federal Science Policy Office (BELSPO). B.H. is supported by the National Fund for Scientific Research (FNRS).

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