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Evidence of Hot Hydrogen in the Exosphere of Mars

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Abstract

Analysis of earlier martian exospheric Lyman α emission from the Hubble Space Telescope (HST) and Mars orbiters had revealed temperatures that were much higher than the thermospheric temperatures recorded at Mars. This paved the way for the hypothesis that an energetic population of hydrogen atoms was mixed in with the thermal hydrogen atoms in the exosphere of Mars, thereby raising the average temperature of the total population of H atoms. However, no direct observational evidence or in-situ measurements have yet been obtained for the presence of such a population as the scale height of the thermal H atoms is quite large at Mars owing to its low gravity resulting in an exosphere which extends to altitudes beyond 10 Mars radii. Here we present HST observations of resonantly scattered solar Lyman α emission from the exosphere of Mars obtained under specific conditions which reveal a change in the scale height of the exosphere as it transitions from being thermally dominated to non-thermally dominated at higher altitudes, a definite observational signature for the presence of energetic H atoms. A radiative transfer model analysis reveals that fitting the data with only thermal H cannot reproduce the observed intensities at high altitudes.

1. Introduction

Mars has a highly expansive hydrogen exosphere which is visible at Lyman α as it resonantly scatters solar Lyman α photons. Attempts at characterizing this layer in the past decade have revealed large seasonal changes [1,2,3] as well as temperatures that are much higher than the martian thermospheric temperatures [1,2,3,4,5]. This discrepancy between the temperatures derived for the exosphere and the lower atmosphere was hypothesized to be due to the presence of an energetic population of H atoms. Such populations of energetic H atoms have been detected in the exospheres of Venus and Earth [6,7]. However, due to the large scale height of Mars' exosphere the same has been difficult to detect at Mars. Recently, HST observations of the martian exosphere were conducted under optimal conditions in order to detect the population of hot hydrogen atoms in the exosphere of Mars. The presence of such a population can alter the escape rate of H and thereby water from the martian atmosphere by almost a factor of ~2 thereby impacting the water escape history timeline of Mars [5,8,9].

2. Observations

The HST observations were a focused campaign tailored towards discovering an observational signature for the presence of energetic H at Mars. Since the scale height of the martian thermal H population is large in general, these observations were conducted when Mars was close to aphelion and the solar activity was low which resulted in colder temperatures and therefore a decreased scale height for thermal H. Also, the Earth-Mars distance was large during these observations (1.58 – 1.96 AU) so that the martian dayside exosphere could be imaged to very high altitudes (~10 R_M or 33000 km) where the non-thermal H population becomes dominant and therefore detectable.

3. Figures

Figure 1 shows the Lyman α intensity profile with altitude of the dayside martian exosphere. As is evident from the figure, the intensity profile drops off very fast with altitude up to ~ 8000 km after which the slope of the intensity profile changes dramatically to a much more gradual decrease with altitude. This suggests that the thermal H population dominates at lower altitudes but transitions to non-thermal H dominated region above ~18000 km. A radiative transfer model [5] fit to the data with an average dayside temperature of 170 K, derived from Mars

Global Circulation Model (MGCM) [10] simulation, cannot reproduce the observed intensities at high altitudes (red curve).

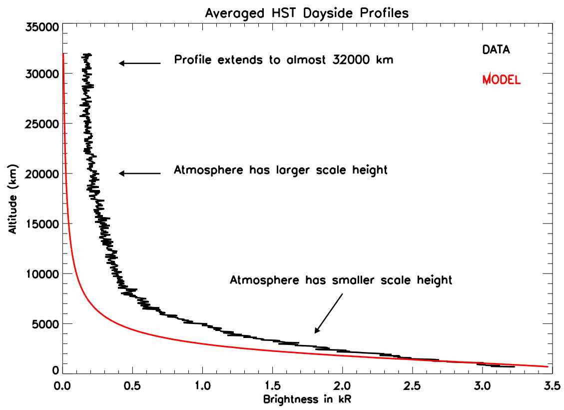

Figure 1: Averaged dayside radial intensity profiles with altitude of the Martian hydrogen Lyman α emission as observed by HST during 2017-2018.

4. Tables

Table 1 details the HST observational conditions

Table 1: HST Observational Conditions for Imaging Hot H at Mars

Date of Observation	Solar Longitude (L_s in degrees)	Earth-Mars Distance (AU)	$F_{10.7}$ index at Earth
12/31/2017	108°	1.96	71
01/13/2018	114°	1.85	71
02/10/2018	128°	1.58	78

5. Summary and Conclusions

At present, we have strong observational evidence for the presence of hot H atoms in the exosphere of Mars. A radiative transfer model fit to the data which accounts for the multiple scattering of solar Lyman α photons by the H atoms in the martian exosphere cannot reproduce the observed intensities at higher altitudes when only thermal H is considered in the modeling process.

Acknowledgements

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