The dependence of peak electron density on solar irradiance in the ionosphere of Mars

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? Why are peak densities in the ionosphere of Mars proportional to the cube-root of the solar irradiance?

Introduction

The layer of charged particles in the upper atmosphere of Mars, the ionosphere, interacts with the impinging solar wind. This complex interaction can energize atmospheric particles allowing them to escape the planet. It is therefore crucial to understand the current state of the ionosphere in order to understand the long-term evolution of the atmosphere of Mars. Here we investigate one aspect of the current state of the ionosphere of Mars: how the peak electron density responds to changes in solar irradiance.

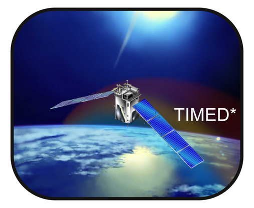
The peak density in the ionosphere of Mars is produced by CO_2 ionization from extreme ultraviolet (EUV) solar photons[1]. Previous studies[2-8] have investigated how the peak density depends on the solar irradiance using the power-law relation:

$$N_m \propto F^k \qquad (1)$$

where N_m is the peak electron density, F is the ionizing solar irradiance, and k is a derived exponent. These studies used the F10.7 index, a measure of the solar radio flux at 10.7 cm, or the E10.7 index, a measure of the solar EUV energy from 1-105 nm, for F in Equation 1. The exponents reported when using these indices are k ≈ 0.35. Here we test Eq. 1 using solar EUV spectra measurements in place of the commonly used F10.7 and E10.7.

Data

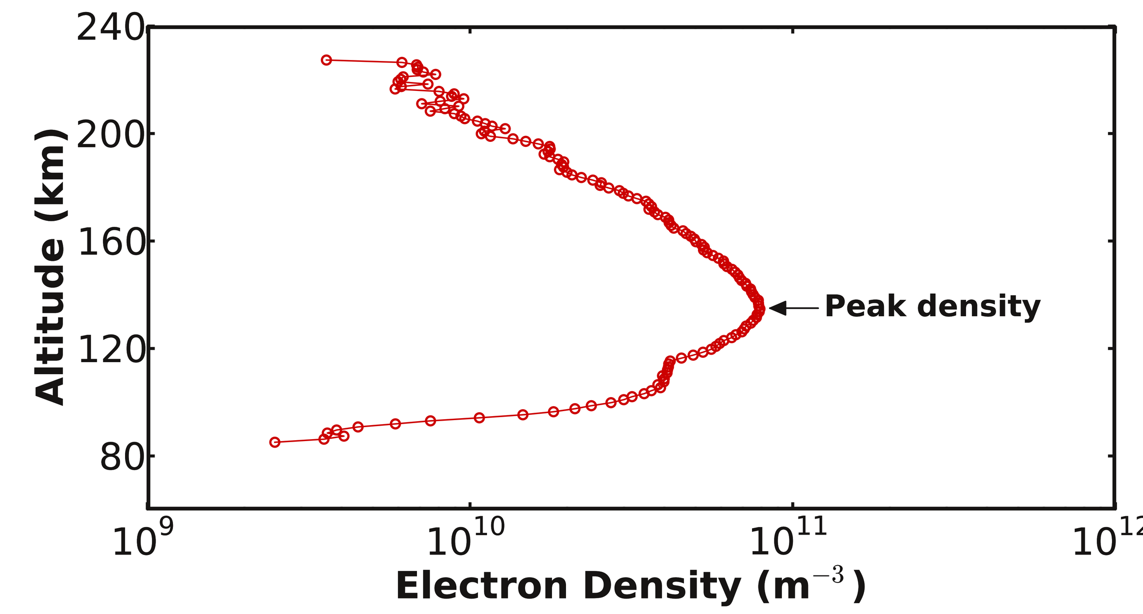
Electron density profiles[9] were obtained between 2002 - 2005 by the radio occultation instrument aboard the Mars Global Surveyor (MGS) spacecraft. Profiles with solar zenith angles (SZA), a measure of the Sun's height above the horizon with 0° directly overhead, greater than 80° were discarded to eliminate day-night effects. In total, 2093 profiles with SZA ranging from 70° - 80° were used in this study.



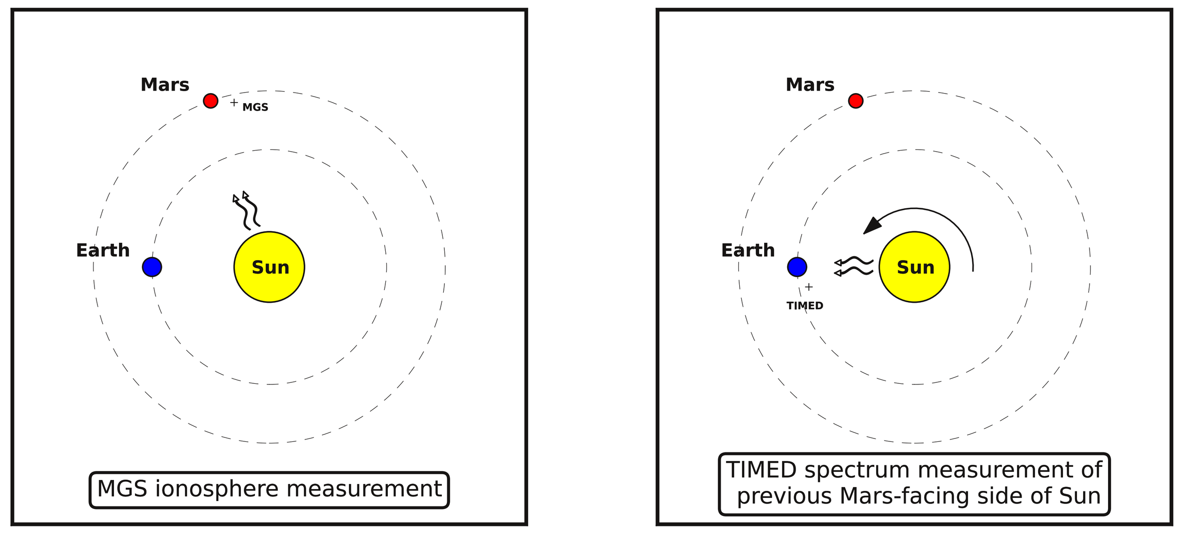
Solar spectra were obtained in Earth orbit by the Solar EUV Experiment[10] (SEE) aboard the TIMED spacecraft.

The EUV solar irradiance is not isotropic and unless Earth and Mars are aligned in their orbits, they receive different solar spectra. Furthermore, Mars is more distant from the Sun than Earth is and receives less irradiance due to the inverse-square law of radiation. This makes it difficult to match an ionospheric measurement obtained at Mars with a corresponding solar spectrum measured at Earth. We attempted to mitigate these difficulties as explained in the Procedure section.

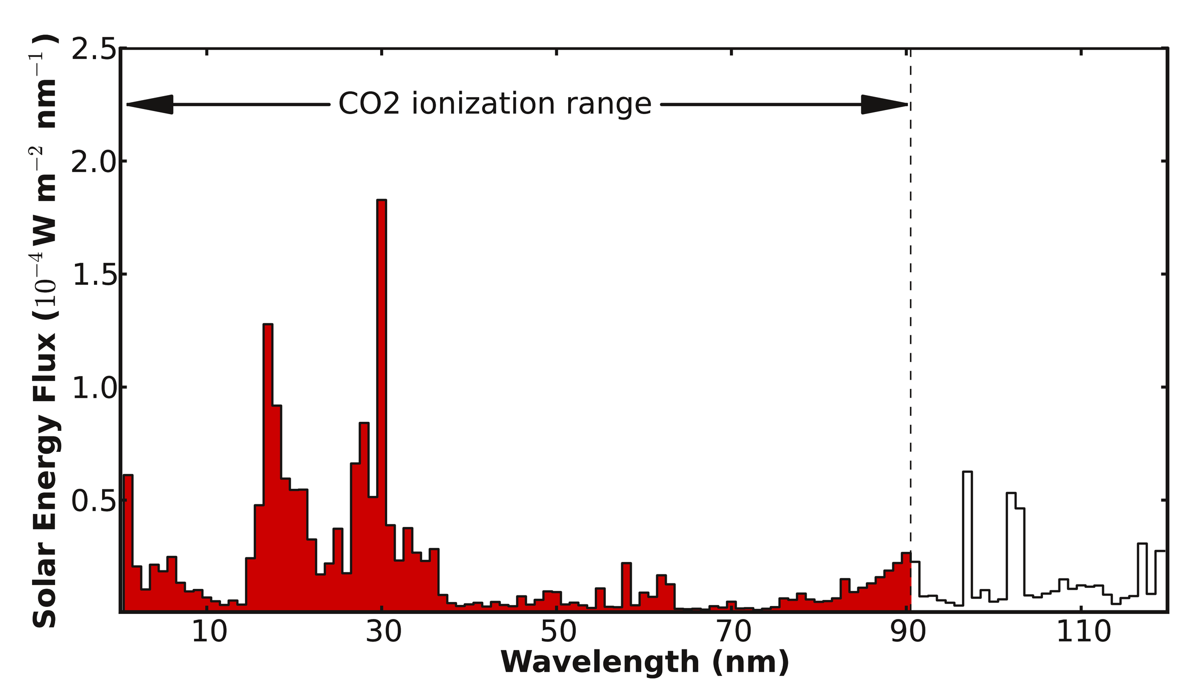
Procedure



First we obtained peak electron densities directly from the electron density profiles (one is shown above). We then multiplied the densities by $[\mathrm{Sec(SZA)}]^{0.5}$. This eliminated any SZA dependence of the peak densities[8].



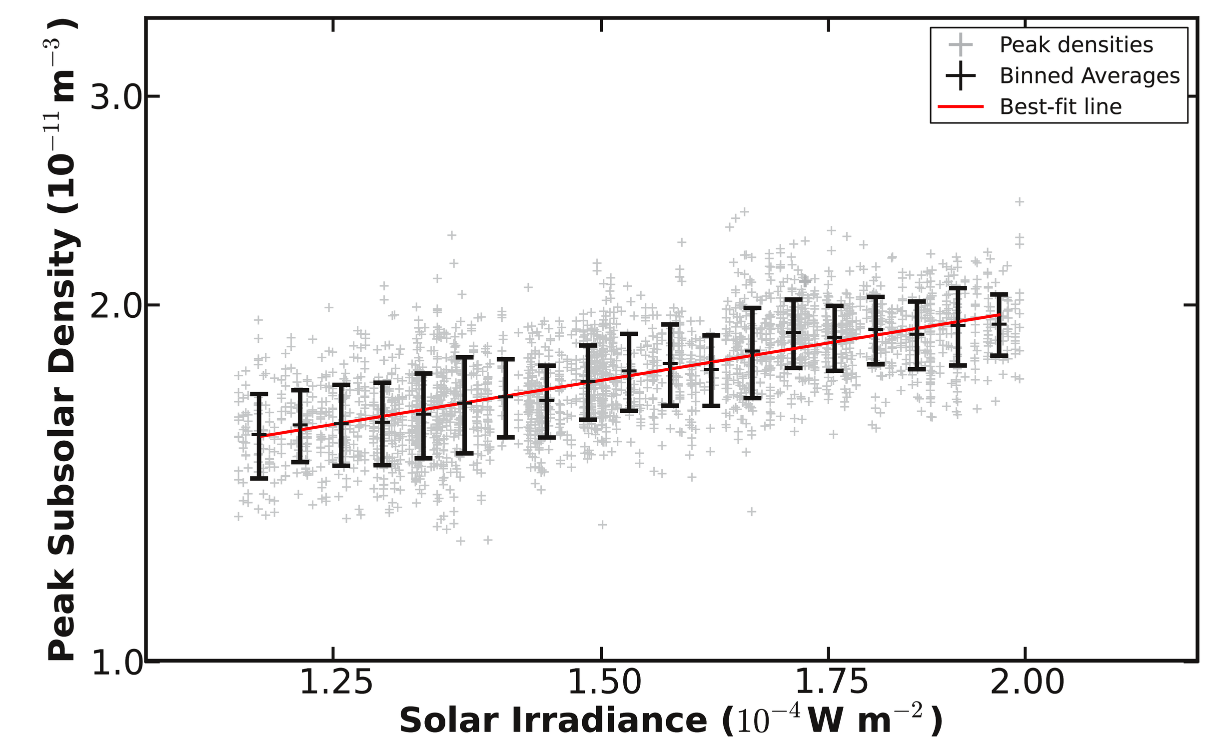
Next we corrected for the anisotropic EUV solar irradiance. For each density, we calculated the date when the Mars-facing part of the Sun during the MGS ionosphere measurement rotated to face Earth and the TIMED spacecraft. An EUV spectrum from this shifted date was then obtained.



Finally, we integrated each EUV spectrum in the wavelength range that ionizes CO_2, then multiplied it by the inverse-square of the Mars-Earth distance. This is our representation for the ionizing solar irradiance, F, in Eq. 1.

Results

$$N_m \propto F^{(0.47 \pm 0.02)}$$



A log-log plot showing the dependence of peak electron density in the ionosphere of Mars on solar irradiance. Peak densities are shown by gray crosses, average densities and their respective 1σ uncertainties after binning are shown by black crosses, and the best-fit line to Eq. 1 is shown in red. The best-fit exponent, the slope of the red line, is k = 0.47 ± 0.02, which is much larger than the k ≈ 0.35 reported by previous studies that used F10.7 or E10.7.

Conclusions

Peak electron densities in the ionosphere of Mars are proportional to the square-root of the ionizing solar irradiance. This is in contrast to the cube-root dependence reported by previous studies that used the F10.7 or E10.7 solar indices, and not solar spectra measurements, for their representation of the ionizing solar irradiance at Mars.

Our derived exponent, k = 0.47 ± 0.2, is close to the theoretical prediction of Chapman theory. This implies that the dependence of peak electron density in the ionosphere of Mars on solar irradiance is in better agreement with Chapman theory than previously recognized.

Our representation of the ionizing solar irradiance may be better suited for Mars than F10.7 or E10.7 are. Although commonly used, F10.7 is a measure of the radio irradiance, not the EUV irradiance that produces the ionosphere. E10.7, however, is a measure of the EUV irradiance, but it includes wavelengths that do not ionize CO_2 (90 - 105 nm).

Although limited by the scarcity of EUV observations, our method for calculating a proxy for the ionizing irradiance can be tailored to the compositions of different planetary atmospheres.

Citations

1. Withers (2009), Adv. Space Res., 44, 277-307
2. Breus et al. (2004), J. Geophys. Res., 109
3. Fox and Yeager (2009), Icarus, 200, 468-479
4. Hantsch and Bauer (1990), Planet. Space Sci., 38, 539-542
5. Morgan et al. (2008), J. Geophys. Res., 113, A09303
6. Nemec et al. (2011), J. Geophys. Res., 116, E07003
7. Withers and Mendillo (2005), Planet. Space Sci., 53, 1401-1418
8. Zou et al. (2006), J. Geophys. Res., 111, A07305
9. Hinson et al. (1999), J. Geophys. Res., 104, 26,997-27012
10. Woods and Esparvier (2006), Adv. Space Res., 37, 219-224
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