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

Zachary Girazian, Paul Withers, Kathryn Fallows
Boston University

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. Previous studies have investigated how the peak density depends on the solar irradiance using the power-law relation:

\[ N_m \propto F^k \quad (1) \]

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 flux of 1-105 nm, for $F$ in Equation 1. The exponents reported when using these indices are $k \approx 0.35$. Here we test Eq. 1 using solar EUV spectra measurements in place of the commonly used F10.7 and E10.7.

Procedure
First we obtained peak electron densities directly from the electron density profiles (one is shown above). We then multiplied the densities by $[\text{Sec(SZA)}]^\frac{1}{2}$. This eliminated any SZA dependence of the peak densities.

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 ionosonde 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
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 $k = 0.47 \pm 0.02$, 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, $k = 0.47 \pm 0.02$, 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
3. Fox and Yaker (2003), Icarus, 164, 484-479
4. Hanstech and Bauer (1990), Planet. Space Sci., 38, 539-542
7. Withers and Marsh (2009), Planet. Space Sci., 57, 1401-1418

Contact information
You can email Zachary Girazian at: ZRG@BU.EDU

*Courtesy NASA/JPL-Caltech