MAVEN/IUVS DAYGLOW OBSERVATIONS: MARTIAN THERMOSPHERIC RESPONSE TO SOLAR EUV AND XUV.

S. K. Jain, A. I. F. Stewart, J. I. Deighan, N. M. Schneider, M. M. J. Crismani, M. S. Chaffin, W. E. McClintock, E. M. B. Thiemann, F. Eparvier, B. M. Jakosky, *Laboratory for Atmospheric and Space Sciences, University of Colorado, Boulder, CO, United States, (Sonal.Jain@lasp.colorado.edu)*, **M. H. Stevens,** *Space Science Division, Naval Research Laboratory, Washington DC*, **J. S. Evans,** *Computational Physics Inc., Springfield, Virginia, United States*, **P. C. Chamberlin,** *NASA Goddard Space Flight Center, Greenbelt, Maryland, USA*.

Introduction

The energetics of a planet's upper atmosphere is mainly governed by absorption of solar extreme ultraviolet (EUV) radiation. Thus, understanding the response of a planet's upper atmosphere to the daily, short, and long term variation in solar flux is very important to quantify the energy budget of an upper atmosphere. In the current analysis, we report on a comprehensive study of Mars dayglow observations made by the Imaging Ultraviolet Spectrograph (IUVS) instrument aboard the Mars Atmosphere and Volatile EvolutioN (MAVEN) spacecraft, focusing on upper atmospheric response to solar EUV flux.

Observation and data processing

The MAVEN satellite is in an elliptical orbit with apoapsis near 6,000 km altitude and periapsis near 160 km (*Jakosky et al.*, 2015). The IUVS instrument carries two detectors: FUV detector (115-190 nm) with a spectral resolution of ∼0.6 nm and MUV detector (180-340 nm) with a spectral resolution of ∼1.2 nm. In its limb-observing mode, IUVS measures the Martian UV airglow layer in the altitude region of 80 to 220 km with vertical resolution of ∼5 km (see *McClintock et al.*, 2014; *Jain et al.*, 2015, for more details about the IUVS periapse observations). *Jain et al.* (2015) used observations from two time periods, viz., Oct. 18-22, 2014 (L_s = 218°) and May 2 - June 2, 2015 (L_s = 345°), creating altitude profiles of CO_2^+ Ultraviolet doublet (UVD) band emission at 289 nm to retrieve the neutral atmosphere scale height and temperature using a exponential fit to the UVD emission profile (*Jain et al.*, 2015; *Stiepen et al.*, 2015). IUVS has taken more dayglow observations since *Jain et al.* (2015) published their study and the data set chosen for this study span between Oct. 18, 2014 (L_s = 218°) and June. 06, 2016 (L_s = 140°). Table 1 shows the IUVS dayglow observation considered in the present analysis. Figure 1 shows the detector images of MUV and FUV detectors taken during the April-May 2016 time period, when IUVS took high spectral resolution data. Images are co-addition of ∼180 orbits data. The horizontal axis represents wavelength and vertical axis depicts the altitude from 80 to 200 km in 5 km bins. Bottom panel shows the averaged MUV and FUV spectra at 130 km. We fit the CO_2^+ UVD profile using a Chapman function to retrieve the scale height. Similar methodology has been used by *Lo et al.* (2015) in their analysis of non-migrating tides in Martian atmosphere.

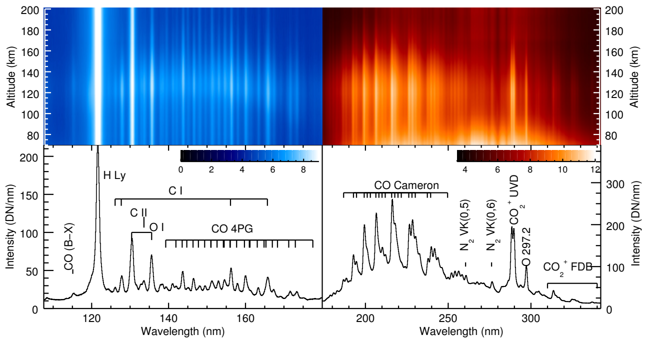

Figure 1: (top) The co-added (from orbits 2957-32) high spectral resolution (1024 pixels) image of FUV and MUV channel. The data is in uncalibrated unite (DN/nm) with log scaling. (bottom) FUV and MUV spectrum is in uncalibrated unite (DN/nm) with square root scaling at 130 km. Left panel shows image and spectrum from FUV channel and right panel shows image and spectrum from MUV channel.

Table 1: Characteristics of IUVS sampling periods.

Orbits	Number of orbits	Ls (deg)	D_{S-M} [a] (AU)	SZA [b] (deg)	SH[c] (km)
109 – 128	19	218	1.40	32 - 72	13.4 ± 1.3
866 – 896	22	308	1.44	52 - 75	13.3 ± 0.7
973 – 988	14	318	1.46	26 - 74	12.9 ± 1.0
1051	1	320	1.48	33 - 60	13.0 ± 0.6
1160 – 1309	43	345	1.52	12 - 73	11.6 ± 1.0
2023 – 2150	93	61	1.66	49 - 75	10.0 ± 1.0
2957 – 3221	185	140	1.56	15 - 75	10.7 ± 0.7

[a] Mars-Sun diastance
[b] Minimum and maximum values of solar zenith angle
[c] Scale height

Effect of solar EUV flux

Figure 2 shows a time series of retrieved scale heights. Simultaneous observations of solar irradiance at 0-7 nm, 17-22 nm, and Lyman alpha channels measured by the

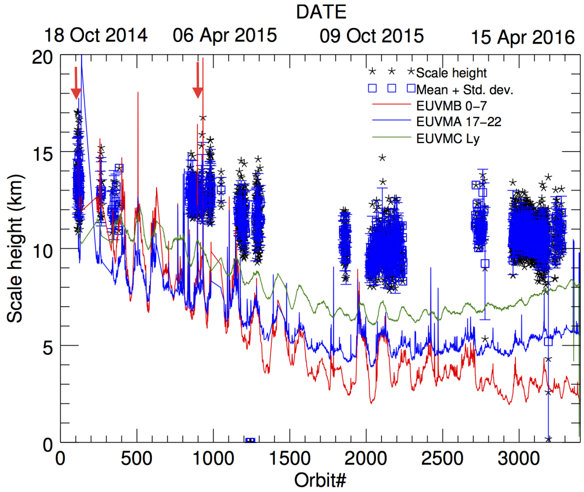

Figure 2: Time series of retrieved scale heights for IUVS dayglow observations. Black symbols show scale for all the scans in given orbit. Blue symbols shows mean orbital scale height along with standard deviation. Red, blue, and green curves show 0-7 nm, 17-22 nm, and Lyman alpha irradiance, respectively, measured by EUV monitor onboard MAVEN. The two red arrows indicate solar flare events.

EUV Monitor onboard MAVEN are also shown in Figure 2. Since MAVEN's orbit precesses around Mars, IUVS does not observe the sunlit atmosphere at all times which is why there are gaps in the scale heights calculations (some gaps are due communication constrains, such as solar conjunction). Figure 2 shows the dependence of scale height on incoming solar radiation. There is an overall decrease in the solar flux reaching the top of Martian atmosphere, however, the heliocentric distance of Mars is also increasing (see Table 1), contributing to the decrease of the upper atmospheric scale heights (and temperature).

Effect of solar x-ray flare

The solar EUV photons (5-105 nm) deposit most of their energy around the airglow peak, but more energetic photons (such as soft x-rays) deposit their energy well below the airglow peak (*Jain*, 2013). Solar ï‹Çares are transient events in the solar corona that result in emissions which span the electromagnetic spectrum from X-ray to radio wavelengths (*Thiemann et al.*, 2015). Solar flare events result in a sudden enhancement in solar ionization photons, which then dissipate their energy in the atmosphere affecting its heat budget (*Thiemann et al.*, 2015). These events also result in enhanced solar soft x-ray flux (0-5 nm), which deposit their energy deep in the atmosphere. Although EUVM has reported multiple solar flare events (*Thiemann et al.*, 2015), there are only a few which occurred during the times when IUVS limb scans were on the dayside. We report two such solar flare events: one on 19 Oct. 2014 and second on 24 March 2015 (see red arrows on Figure 2). Figure 3 shows the altitude profiles of CO_2^+ UVD during the multiple orbits in and around the solar flare events of 19 Oct. 2014. A flare occurred at the time when IUVS limb scans were in the sunlit atmosphere during orbit 112. The altitude profile of CO_2^+ UVD during orbit 112 shows enhancement in UVD emission well below the airglow peak (< 120 km) caused by high energy secondary photoelectrons. The overall increase in UVD intensity during a flare event was around ∼20% (below airglow peak). We also noticed a similar enhancement in the UVD profile during the 24 March 2015 solar flare event.

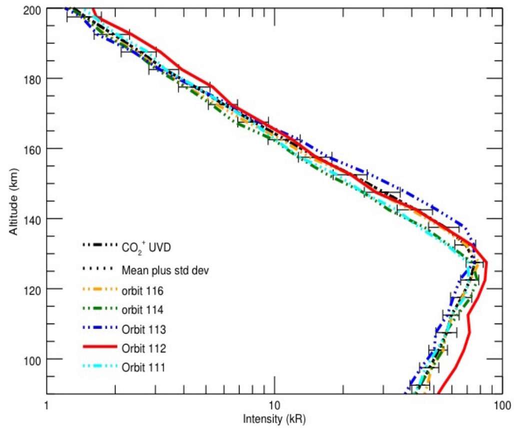

Figure 3: Altitude profiles of CO_2^+ UVD emission during orbits 111 to 116 (excluding orbit 115), along with mean CO_2^+ UVD profile. The UVD emission profile during orbit 112 shows enhancement below airglow peak (<110 km) during solar flare event on 19 Oct. 2014.

Results

- MAVEN/IUVS dayglow observations show the scale height's dependence on solar ionizing flux at Mars.
- For a given small time period, upper atmospheric scale heights (and temperatures) show large variability, indicating coupling from the lower atmosphere, but for a larger time period, average upper atmospheric temperatures are governed by solar EUV flux and the heliocentric distance of Mars.
- The effect of solar x-ray flares have been observed on dayglow emission.
- We will show the results of model calculation in explaining IUVS dayglow observations.

References

Jain, S. K. (2013), Dayglow Emissions on Mars and Venus, Ph.D. thesis, Cochin University of Science and Technology, India, https://dyuthi.cusat.ac.in/jspui/handle/purl/3688.

Jain, S. K., et al. (2015), The structure and variability of Mars upper atmosphere as seen in MAVEN/IUVS dayglow observations, *Geophys. Res. Lett.*, *42*, 9023–9030, doi:10.1002/2015GL065419.

Jakosky, B. M., et al. (2015), The Mars Atmosphere and Volatile Evolution (MAVEN) Mission, *Space Sci. Rev.*, doi: 10.1007/s11214-015-0139-x.

Lo, D. Y., et al. (2015), Tides in the Martian Atmosphere as Observed by MAVEN IUVS, *Geophys. Res. Lett.*, *42*, 9057–9063, doi:10.1002/2015GL066268.

McClintock, W. E., N. M. Schneider, G. M. Holsclaw, J. T. Clarke, A. C. Hoskins, I. Stewart, F. Montmessin, R. V. Yelle, and J. Deighan (2014), The Imaging Ultraviolet Spectrograph (IUVS) for the MAVEN Mission, *Space Sci. Rev.*, doi:10.1007/s11214-014-0098-7.

Stiepen, A., J.-C. Gérard, S. Bougher, F. Montmessin, B. Hubert, and J.-L. Bertaux (2015), Mars thermospheric scale height: CO Cameron and CO_2^+ dayglow observations from Mars Express, *Icarus*, *245*, 295–305, doi: 10.1016/j.icarus.2014.09.051.

Thiemann, E. M. B., et al. (2015), Neutral density response to solar flares at Mars, *Geophys. Res. Lett.*, *42*, 8986–8992, doi:10.1002/2015GL066334.