An Average Empirical FUV Model of Airglow for Oxygen OI 135.6 nm Emission Line in the Martian Atmosphere for Emirates Mars Ultraviolet Spectrometer Instrument Simulator

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Introduction:

The Emirates Mars Mission (EMM), to be launched by 2020, is the first Arab Islamic planetary mission to explore a planet other than Earth. Its goal is to explore the dynamics in the atmosphere of Mars on a global scale while sampling contemporaneously both diurnal and seasonal timescales using three instruments on an orbiting spacecraft called Hope Probe. The three instruments are (1) Emirates eXploration Imager (EXI), (2) Emirates Mars InfraRed Spectrometer (EMIRS), and (3) Emirates Mars Ultraviolet Spectrometer (EMUS). The EMUS instruments is a far ultraviolet spectrometer that is designed to determine the abundance and spatial variability of key neutral species in the thermosphere and to determine the three-dimensional structure and variability of key species in the exosphere and their variability both on seasonal and sub-seasonal timescales. It will have a spectral range of 100-170 nm to make the required observations of ultraviolet emissions of hydrogen (H), oxygen (O), carbon (C) and carbon monoxide (CO).

The Martian atmosphere, nowadays, is considered a very thin and cold atmosphere filled with more than 95% of CO_2. However, studies have shown that around 4 billion years ago Mars used to have warm thick atmosphere that was enough to support oceans of liquid water. Yet, because Mars is further away from the sun referenced to Earth and it has a weak magnetic field to protect it, the temperature became too cold and the atmosphere became too thin to support the existence of liquid water on the surface of Mars. EMM is designed to reveal the connection between the conditions in the lower atmosphere and the escape of hydrogen and oxygen from the upper atmosphere, a process that may have been responsible for Mars' transition, over billions of years.

As per Curiosity Rover latest measurements, the Martian atmosphere at the surface consists of 0.146% of Oxygen [1], one of the essential elements of life besides Hydrogen. Atomic oxygen is considered one of the main neutral species in the upper thermosphere and the low exosphere of Mars (~200–500 km) and it is important for several processes in the Martian upper atmosphere [2]. The EMUS instrument will be able to detect two atomic oxygen emission lines which are OI 135.6 nm (optically thin) and OI 130.4 nm (optically thick). However, in this research, we focus on modeling the OI 135.6 nm oxygen emission line in the Martian atmosphere.

Research Objective:

The objective of this research is to develop an average empirical FUV model of airglow for oxygen emission line OI 135.6 nm utilizing data from IUVS instrument onboard the MAVEN mission. The model is developed to calculate the brightness of the OI 135.6 nm emission taking into consideration observation geometry parameters like emission angle (EA), solar zenith angle (SZA) and planet distance from the sun (Ds). This model will aid in simulating EMUS disk data to the best accuracy possible to be utilized as an input to the EMUS instrument simulator which aims to (1) predict the behavior of the instrument under different types of conditions and familiarize the science team on how the data will look like, (2) verify if the science requirements for the instrument are met with the current design and observation strategies, (3) aid the design and instrument calibration, (4) and build and test a data pipeline in the early phases of the mission before spacecraft launch.

MAVEN IUVS Data:

The average empirical FUV model is being developed based on data from Imaging Ultraviolet Spectrograph (IUVS) on board of Mars Atmosphere and Volatile Evolution Mission (MAVEN). MAVEN arrived to Mars in September 2014 and is designed to explore the planet's upper atmosphere and ionosphere and examine their interaction with the solar wind and solar ultraviolet radiation. Using FUV measurements by IUVS will lead to a more consistent estimation of the emission line brightnesses that EMUS will observe. It is important to note that IUVS wavelength coverage extends from 120 to 330 nm with a spectral resolution of 0.6nm (115-190nm) and 1.2nm (180-330nm). These parameters are similar to EMUS as it is designed to take thermospheric measurements at 1.3nm spectral resolution. In this research, L1C level of data from IUVS are utilized as it contains a disk image acquired during an entire apoapse segment and is binned into 2×2 longitude and latitude grid to provide cylindrical projection in the latitude-longitude coordinates [3].

Research Methodology:

To build the average empirical FUV model of airglow for OI 135.6 nm, data from the MAVEN IUVS instrument is used since it is expected to be similar to the EMUS data that will be captured after launch in 2021, with the exception that the coverage is not the same and the EMUS instrument will cover Lyman Beta hydrogen emission line that was not captured in IUVS. However, within the scope of this research, the IUVS data is used to model the oxygen emission line at 135.6 nm. The emission line brightnesses are normalized by the distance from Sun at the time of acquisition to reduce the impact of being near or far from the sun on the brightness value. Second, the relationship between the brightness and EA and SZA are examined for at least 11 MAVEN orbits (2 Martian days) and the validity of the plane-parallel approximation is examined for EA less than 80 degree. In addition, the variability of the airglow is identified and an average empirical model is constructed. This model shall be able to calculate the average brightness with a variability given at any SZA, EA, and distance from the sun (Ds).

Selection of Results:

The MAVEN IUVS L1C data were examined closely for 16 consecutive orbits (548 to 562) which represent 3 Martian days in the Northern hemisphere Winter Solstice (i.e. Solar Longitude is 270). Figure 1 shows the brightness data of orbit 550, as an illustration, mapped into its geographic location at Mars. These brightness values are normalized by multiplication factor of Ds [AU]/1.52368. Note also that the data had been preprocessed in which missing data, negative values, or instances where EA is greater than 80 degrees are filtered out.

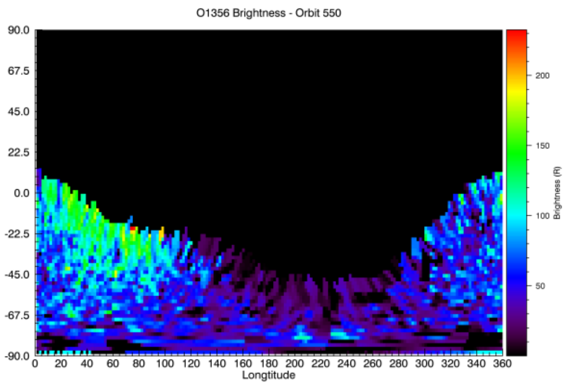

Fig. 1: OI 135.6 nm brightness values mapped to Mars geographic location.

Comparing the OI 135.6 nm brightness values across all 16 orbits, it was observed that there is no direct correlation or heavy dependency between Mars geographic longitudes and latitudes with the brightness values. Instead, values were changing with respect to changes in EA and/or SZA as illustrated in Figure 2. The brightness is witnessed to be the highest when SZA values are low and EA values are high, while it is the lowest when SZA values are high and EA values are low. However, it should be noted that the standard deviation for each bin of SZA and EA is not the same. From Figure 3, it is noticed that the standard deviation value ranges between ~12.5 and 50 R except for SZA=40 and EA=35 bin, the value shoots to around 111 R which indicates possible existence of outliers in the data.

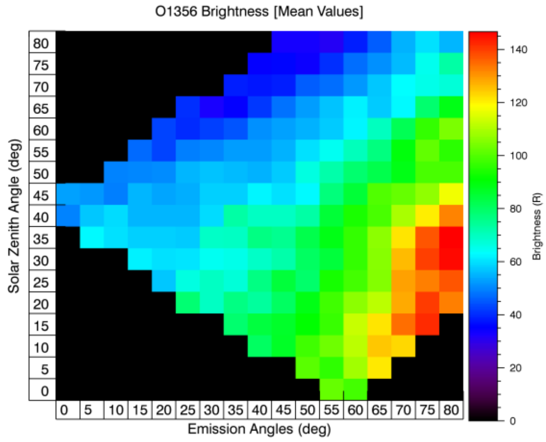

Fig. 2: Mean OI 135.6 nm brightness values mapped to binned values of SZA and EA.

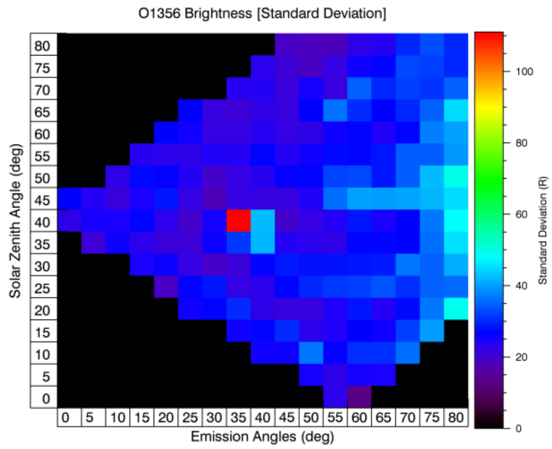

Fig. 3: Standard deviation for OI 135.6 nm brightness values for each bin of SZA and EA.

To examine further the correlation between the brightness, SZA, and EA, the brightness dependence on the emission angle is plotted in Figure 4 for selected SZA values against the expected curve for the optically thin OI 135.6 nm plane-parallel approximation. The brightness lines, as seen, follow similar trends or behavior compared to each other, however, they do not behave as the plane-parallel approximation curve especially at higher emission angles. If normalized, the brightness lines exhibits significantly lower values at higher emission angles. Sources of these variations are investigated and shall be quantified for the model's development.

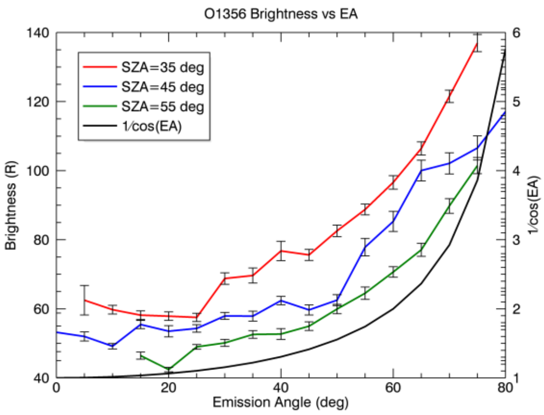

Fig. 4: OI 135.6 nm plane-parallel approximation verification

Summary and Future Work:

OI 135.6 nm emission line is optically thin and its brightness values were found to be dependent on solar zenith angle, emission angle, and the distance from the sun. The correlation between these variables are examined and investigated compared to optical thin plane parallel approximation. The brightness has a positive correlation with EA and a negative correlation with SZA. The plane parallel approximation is yet to be verified for higher EA and sources of these variations are investigated. Upon verification and validation of the OI 135.6 nm FUV model, we plan to build an average empirical FUV model for OI 130.4 nm emission line utilizing MAVEN IUVS data as well.

References:

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