OBSERVING FAR-ULTRAVIOLET OXYGEN AURORA IN THE MARTIAN NIGHT-SIDE ATMOSPHERE WITH MAVEN-IUVS.

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Introduction

There are at least three types of aurora on Mars; discrete, diffuse, and proton. Discrete aurora were first discovered by the Mars Express SPICAM instrument and are further supported by MAVEN IUVS observations, Figure 1 panel A shows a typical discrete aurora emission. These aurora are defined by their small, short-lived patches of emission usually related to the strong crustal field region in the southern hemisphere (Bertaux et al. (2005)). Diffuse aurora were first discovered by MAVEN IUVS and are defined by emission that spans much of the Martian nightside atmosphere (Schneider et al. (2015); Jakosky et al. (2015); Schneider et al. (2018)). Figure 1, Panel B shows an example of a diffuse aurora. These emissions are caused by solar energetic particles (SEPs), specifically electrons and protons accelerated to energies of roughly 100 keV. Lastly, MAVEN IUVS also discovered proton aurora which occur on the Martian day side and are caused by penetrating protons from the solar wind (Deighan et al. (2018); Halekas et al. (2017); Ritter et al. (2018)).

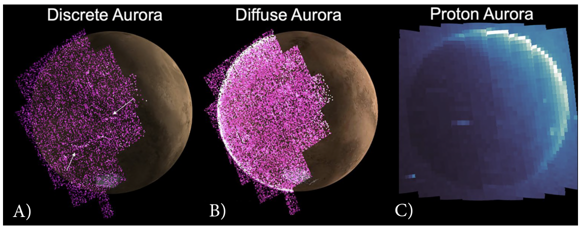

Figure 1: Three types of aurora on Mars. Mars Atmosphere and Volatile Evolution (MAVEN)/Imaging UltraViolet Spectrograph (IUVS) apoapse images.

The focus of the present study is to showcase new analysis of MAVEN IUVS night side observations in the Far-Ultraviolet (hereafter FUV) wavelength range, specifically emissions at 130.4 nm and 135.6 nm. Until now, discrete aurora have been extensively studied in the Mid-Ultraviolet (hereafter MUV) range and it has been shown that strong aurora occur at 190 - 270 nm which correspond to CO Cameron Band emissions and at 298 & 299 nm which correspond to CO_2^+ UVD Doublet emissions. Ritter et al. (2019), studied oxygen emissions at 130.4 nm and 135.6 nm on the Martian day side and showed that these features are strongly correlated and behave similarly to each other there, and can provide an understanding of the variability of the day side Martian atmosphere. There have also been significant results from the Emirates Mars Misssion (EMM) EMUS instrument showing strong discrete aurora in the Far-Ultraviolet. Due to the sensitivity and high vantage point of EMUS observations, their detection of aurora shows variations with solar wind, interplanetary magnetic field conditions, and local time (Lillis et al. (2021)). The current study focuses on these emissions on the Martian night side using MAVEN IUVS for the first time and so far has revealed that Mars's atmosphere still has new things to teach us.

Observations and Analysis

We have analyzed MAVEN IUVS periapse data, now in the FUV, ranging in time from January 2015 to near the present in February 2021. We have found 47 examples of emissions at 130.4 nm or 135.6 nm. Both of these emissions are due to electron impact on atomic oxygen and carbon dioxide molecules. The 130.4 nm triplet is caused by the OI^3S transition to the ground state emitting at 130.22, 130.49, and 130.60 nm, but we refer to it here as 130.4 nm, which is an allowed transition subject to resonance scattering. The 135.6 nm quintet-triplet is caused by the OI^5S^0-^3P transition which is a forbidden quintet-triplet transition to the ground state at 135.56 and 135.85 nm, but we refer to it here as 135.6 nm, and features no resonance scattering (Ritter et al. (2019)).

We define a detection of an aurora via statistical tests and a by-eye analysis. Emissions at 130.4 nm pass our statistical tests if the observation consists of more than 10 pixels that have a signal-to-noise ratio greater than 2 sigma. Emissions at 135.6 nm pass our tests if they have more than 5 pixels with a signal-to-noise ratio greater than 1.5 sigma. The discrepancy between 130.4 nm and 135.6 nm is due to the fact that the emission at 135.6 nm is far fainter than those at 130.4 nm. Both emissions must also have a solar zenith angle greater than 105 degrees to ensure that no daylight scattering corrupts the observation. The MUV emissions pass our statistical tests if at least 5 pixels show a signal-to-noise ratios greater than 4 sigma and 3 sigma for CO Cameron bands and CO_2^+ UVD Doublet, respectively. After a scan passes our statistical tests, a by-eye analysis is required to further refine the detections versus non-detections.

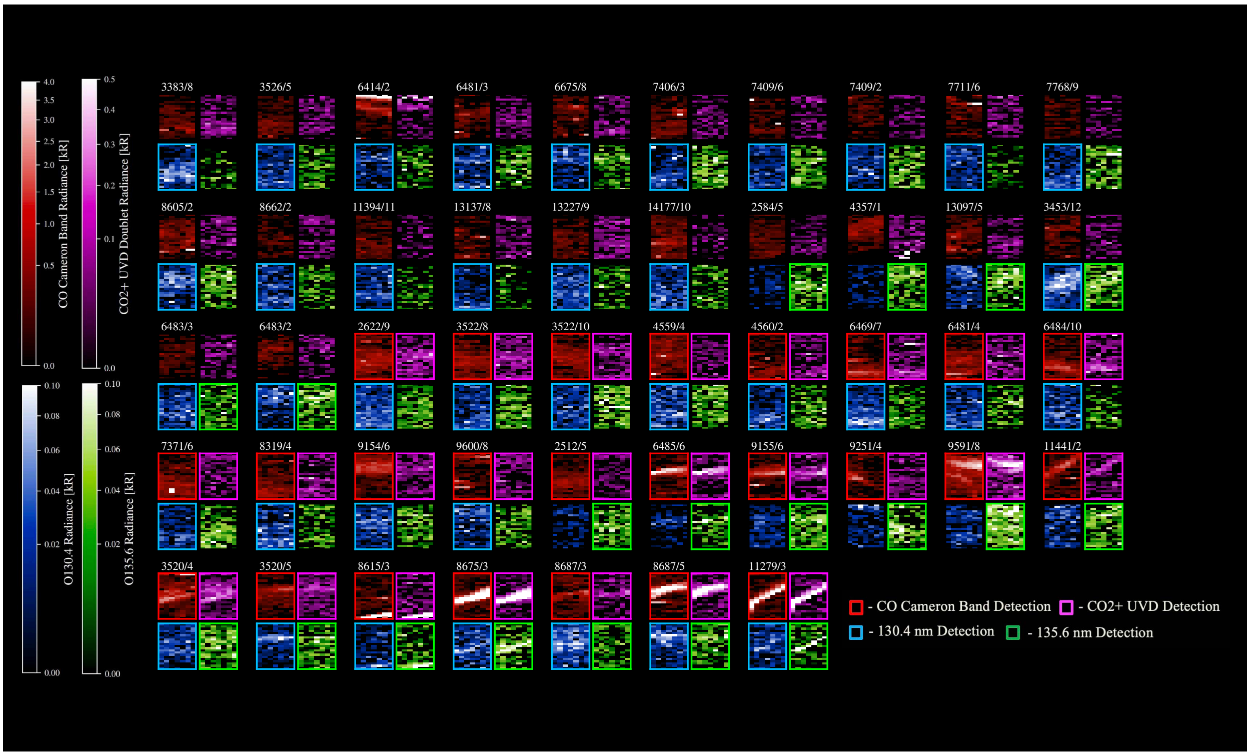

Figure 2: A "family portrait" of all FUV aurora detections in snapshots which show all four auroral emissions. Within each snapshot there are four scan images, the top left shows the CO Cameron Band, top right shows the CO_2^+ UVD Doublet, bottom left shows the 130.4 nm, and bottom right shows the 135.6 nm. The border color of each scan image corresponds to whether or not a statistical detection was made at that wavelength. The CO Cameron band and the UVD Doublet scan images are bordered in red and pink, the 130.4 nm scan image is bordered in blue, and the 135.6 nm scan image is bordered in green if there is a detection at this wavelength.

Most observations that pass our statistical tests do not pass the by-eye analysis, as a variety of factors are required to make a positive detection. For example, it is not only necessary for there to be a certain number of bright pixels, but those pixels must be relatively spatially coherent and they must be observed far away from the terminator.

When considering the underlying physics of aurora, one would assume that the mechanisms generating the MUV aurora would always allow for FUV aurora, and vice versa. However, this is not what we have found. 47% of our FUV aurora occur with no measurable MUV counterpart (Fig. 2, first and second row). Roughly 10% of detections have very bright and spatially coherent FUV aurora with no measurable MUV counterpart (Fig. 2, orbit 3383 scan 8, orbit 8605 scan 3, and orbit 3453 scan 12). For detections of concurrent MUV and FUV aurora, they tend to be very bright and spatially coherent (Fig 2, last row), this amounts to about 15% of the detections. Additionally, more than 93% of MUV aurora have no simultaneous FUV aurora. The process which causes emission bright enough to be detected in one wavelength range but not in the other is not yet understood.

There are unique optical depth processes affecting the detection of FUV aurora with MAVEN IUVS. The Martian atmosphere has unit optical depth equal when horizontal column densities exceed approximately 10^{17} cm^{-2}. This occurs when densities for CO2 densities at the tangent point approximately equal to 10^{10} cm^{-3} and this local density occurs at an altitude of 125 km. We assume that all FUV light is absorbed by the atmosphere anywhere below 115 km. In periapse mode, there are three points of interest along the line of sight: the nearside intercept point, the tangent point, and the farside intercept point. The instrument only reports the tangent point but the aurora could be located at any point along the line of sight through the limb of the atmosphere. For those detections at a tangent point altitude below 115 km, the aurora must occur at the nearside intercept point because the atmosphere is optically thick to FUV emission at the tangent point (and the farside point).

Unlike the MUV aurora, there is no clear correlation between FUV aurora and their proximity to the strong crustal field region, defined to be from 50 to 210 degrees longitude and from -60 to -30 degrees latitude. That is to say, FUV aurora can be and have been detected at all latitudes and longitudes. However, the FUV aurora with an MUV counterpart are more likely to occur near the strong crustal field region, which is expected because the brightest MUV detections occur within the strong crustal field region. Variations in detection frequency and brightness with solar longitude, local time, and solar zenith angle are negligible.

Conclusions

The existence of strong aurora in the FUV wavelength range with no simultaneous aurora in the MUV suggests that there is an interesting phenomena in the Martian atmosphere to be understood. A possible explanation for the differences lies in the energy distribution of precipitating electrons. The oxygen mixing ratio increases at higher altitudes where less energetic electrons are able to penetrate, rather than lower down where they get scattered or absorbed. In this case, electron impact on O atoms is favored rather than collisions with CO2 which could allow for more detections of FUV aurora at higher altitudes, but this has not yet been proven. Another avenue of investigation is how these differences vary over the solar cycle, we are lucky to have data that spans from solar maximum of solar cycle 24 in 2015 to the rise of solar cycle 25 in 2021. Studying the effects of solar activity will help to prove if there is a correlation between the distribution of energetic particles and the detection frequency of FUV aurora, as there are more energetic particles hitting Mars when the sun is more active. Future work on this study will also involve modeling of the Martian atmosphere, in order to simulate the conditions that allow for the observations we see to help us understand the physical mechanisms behind these unique night side FUV aurora.