RETRIEVAL OF AR, N_2, O, AND CO IN THE MARTIAN THERMOSPHERE USING DAYGLOW LIMB OBSERVATIONS BY EMM EMUS

J. S. Evans, *Computational Physics, Inc (CPI), Springfield, VA, USA (evans@cpi.com)*, **J. Deighan**, **S. Jain**, *Laboratory for Atmospheric and Space Physics (LASP) at University of Colorado, Boulder, CO, USA*, **J. Correira**, **V. Veibell**, *Computational Physics, Inc (CPI), Springfield, VA, USA*, **H. Almatroushi**, *Mohammed Bin Rashid Space Center (MBRSC), Dubai, UAE*, **H. Almazmi**, *United Arab Emirates Space Agency, Abu Dhabi, UAE*, **M. Chaffin**, *Laboratory for Atmospheric and Space Physics (LASP) at University of Colorado, Boulder, CO, USA*, **S. England**, *Virginia Polytechnic Institute and State University, Aerospace and Ocean Engineering, Blacksburg, VA, USA*, **M. Fillingim**, *Space Sciences Laboratory (SSL), University of California, Berkeley, CA, USA*, **G. Holsclaw**, *Laboratory for Atmospheric and Space Physics (LASP) at University of Colorado, Boulder, CO, USA*, **R. Lillis**, *Space Sciences Laboratory (SSL), University of California, Berkeley, CA, USA*, **F. Lootah**, *Mohammed Bin Rashid Space Center (MBRSC), Dubai, UAE.*

Introduction:

The Emirates Ultraviolet Spectrometer (EMUS) onboard the Emirates Mars Mission (EMM) Hope probe (Amiri *et al.*, 2021) images Mars at wavelengths extending from approximately 100 to 170 nm. We report the first limb scan observations at Mars of extreme-ultraviolet (EUV) emissions Ar I 106.6 nm, N I 120 nm, and carbon monoxide (CO) Hopfield-Birge (B – X). We use EMUS transition phase limb scan observations from February and March 2021 to retrieve vertical number density profiles of atomic argon, molecular nitrogen (N_2), atomic oxygen, and CO in the upper atmosphere of Mars. CO is a sensitive tracer of the thermal profile and winds in Mars' middle atmosphere, as well as the chemistry that balances CO_2 in the whole atmosphere of Mars. However, the altitude range 100 – 160 km in the upper atmosphere is largely unconstrained by observations. CO number densities retrieved from EMUS observations enable us to fill a significant gap in knowledge of the abundance of CO and its variability in the Martian thermosphere.

Observations:

The orbit of the EMM Hope probe has an apoapsis at 42,650 km and periapsis at 19,970 km with a 54.5 hour period. This high altitude orbit affords a synoptic view of Mars with full local time coverage every 9 – 10 days. High and very high resolution slits have angular widths of 0.18° and 0.05°, respectively, and spectral widths of 1.3 nm and 0.3 nm, respectively (Holsclaw *et al.*, 2021). EMUS remotely senses the thermosphere at 100 – 200 km altitude, observing extreme- (EUV) and far-ultraviolet (FUV) emissions (see Figure 1) from hydrogen (H I 121.6 nm), nitrogen (N_2 LBH), oxygen (O I 115.2 nm and O I 135.6 nm), and carbon monoxide (CO HB B – X). The first data

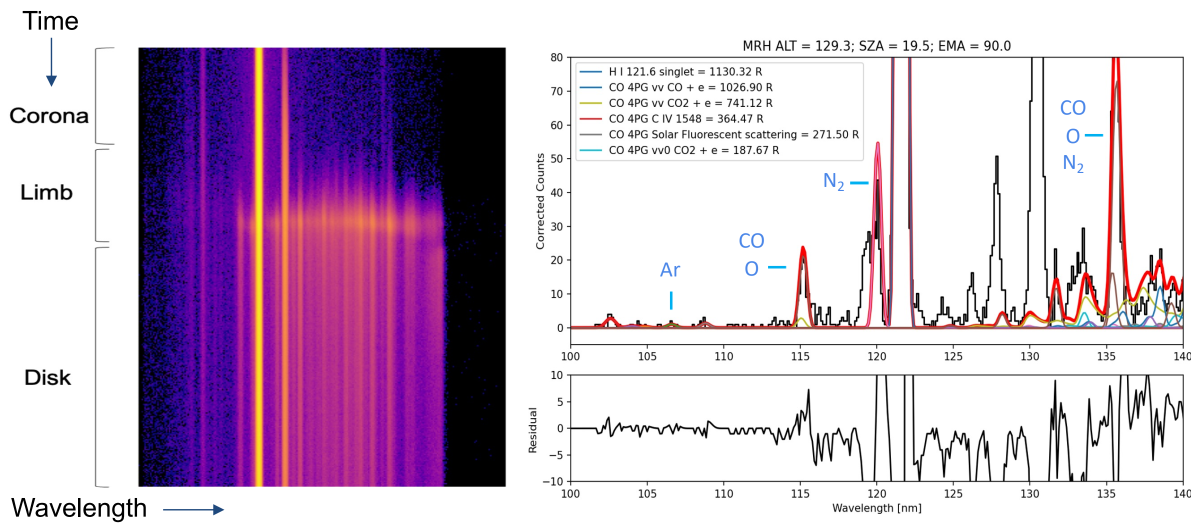

Figure 1. Left: Spectrogram of transition phase observation by EMUS on February 25, 2021. The motion of the instrument slit is from top to bottom (from the limb onto the disk) and the wavelengths increase in the horizontal direction from left to right. Upper right: EMUS spectrum measured on March 2, 2021 shown in black with multiple linear regression (MLR) fit shown in red. Sources contributing to the total fit are shown in the legend. Lower right: The difference (counts/bin) between the measured spectrum and MLR total fit.

release, covering February 10, 2021 to May 23, 2021, was delivered in early October 2021. For the present analysis, we utilize EMUS transition phase limb scan observations covering February 25, 2021 to March 9, 2021.

Retrieval Algorithm:

We infer atmospheric composition from EMUS limb scan observations using the Generalized Retrieval and ANalysis Tool (GRANT). This tool merges AURIC with OPTimal estimation (hereafter OPT) retrieval algorithms (Lumpe *et al.*, 2007). The GRANT tool has been applied to dayglow observations of Titan for the retrieval of N_2 and methane (Stevens *et al.*, 2015) and Mars for the retrieval of density profiles of CO_2, N_2, and O (Evans *et al.*, 2015). For the present study, we extend the Mars algorithm in order to retrieve Ar, N_2, O, and CO densities using EMUS transition phase limb scan observations of Ar I 106.6 nm, N I 120 nm, O I 135.6 nm, and CO HB (B – X) emissions, respectively. Our forward model calculations assume that the atmosphere is spherically symmetric along the line of sight, which is a safe approximation at Mars for solar zenith angles below ~85°. The *a priori* abundances used to initiate the retrievals are mean densities as a function of altitude from the Mars Climate Database (Forget *et al.*, 1999).

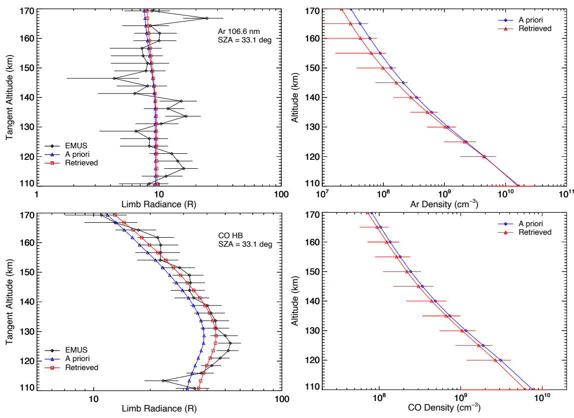

Figure 2. Top left: Ar I 106.6 nm intensity profile observed by EMUS on February 26, 2021 (black) and best fit from optimal estimation retrieval (red). Top right: The *a priori* Ar density profile used to initiate the optimal estimation retrieval is shown in blue whereas the retrieved Ar density profile is shown in red. Bottom: Same as top but for CO HB (B – X) intensity (left) and retrieved CO density (right).

Results:

Figure 2 provides sample retrievals of Ar and CO density profiles in the thermosphere of Mars using remote sensing limb scan observations of Ar I 106.6 nm and CO HB (B – X) emissions, respectively, by EMUS on February 26, 2021. Density retrievals for all eight transition phase observations by EMUS are provided in Figure 3 for Ar, CO, N_2, and O. Estimated uncertainties in the EMUS observations and the *a priori* abundances are formally propagated to determine uncertainties in the retrieved densities. Mean uncertainties for retrieved densities over the altitude range 120 – 160 km are 85%, 35%, 20% and 10%, respectively, for Ar, CO, N_2, and O. Figure 4 shows CO volume mixing ratios (VMR) corresponding to the retrieved CO density profiles shown in Figure 3. The estimated uncertainty in the CO VMR over the altitude range 120 – 160 km is ~35%.

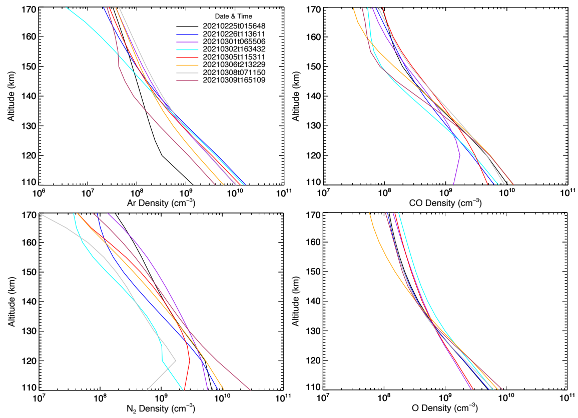

Figure 3. Retrieved density profiles of Ar, CO, N_2, and O for all eight transition phase observations by EMUS. Time stamps for the eight EMUS observations are provided in the upper left.

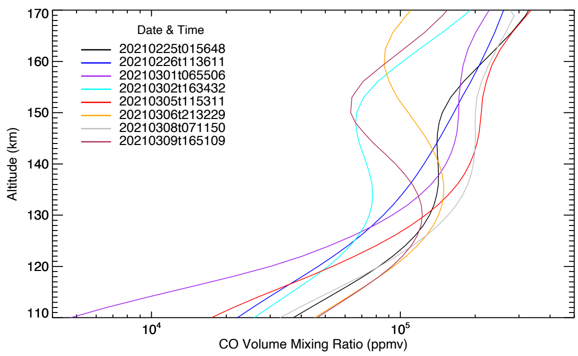

Figure 4. Retrieved CO volume mixing ratio for all eight EMUS transition phase observations.

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