OPTIMAL ESTIMATION RETRIEVAL OF NEUTRAL AND ION COMPOSITION IN THE MARTIAN THERMOSPHERE USING DAYGLOW OBSERVATIONS FROM THE IMAGING ULTRAVIOLET SPECTROGRAPH ON MAVEN: PRELIMINARY RESULTS. J. S. Evans[1], J. D. Lumpe[1], M. H. Stevens[2], N. M. Schneider[3], A. I. Stewart[3], J. Deighan[3], S. K. Jain[3], W. E. McClintock[3], G. M. Holsclaw[3], J. T. Clarke[4], and B. M. Jakosky[3], [1]Computational Physics, Inc., 8001 Braddock Road, Suite 210, Springfield, VA 22151 (email: evans@cpi.com), [2]Naval Research Laboratory, 4555 Overlook Ave., SW, Washington, DC 20375, [3]Laboratory for Atmospheric and Space Physics, 3665 Discovery Drive, Boulder, CO 80303, Space Science Division, [4]Astronomy Department, Boston University, Boston, MA 02215

Introduction: The retrieval of neutral and ion composition from remote sensing observations allows for a global-scale characterization of upper atmospheric variability that is not possible from *in situ* measurements or occultations. Only when the basic state of the Martian upper atmosphere and the sources of its variability are quantified can we begin to determine the present and historical rate of escape of the Martian atmosphere. Here we present preliminary results from a first attempt to use optimal estimation techniques to directly retrieve neutral and ion composition in the Martian thermosphere from far- and mid-UV remote sensing observations between 100–200 km altitude by the Imaging Ultraviolet Spectrograph (IUVS) on NASA's Mars Atmosphere and Volatile Evolution (MAVEN) mission.

IUVS Observations: IUVS is designed to provide global 3-D maps of major molecules, atoms and ions in the atmosphere [1, 2]. IUVS is a UV imaging spectrograph with a 10 x 0.06 degree slit and occultation apertures at each end. There are two fields-of-regard for nadir or limb viewing. Nadir viewing allows for disk maps near apoapsis while limb viewing allows for scans near periapsis. Nominal periapsis is near 150 km. IUVS measures the FUV airglow on Mars between 1100–1900 Å at ~5 Å resolution and the MUV airglow between 1800–3400 Å at ~11 Å resolution. The vertical resolution is one scale height for each species and the accuracy is 25%. Targeted neutral species include: C, O, CO, N_2 and CO_2. Profiles of ions C^+ and CO_2^+ are obtained from the ionospheric peak to 400 km with 60 km resolution and 25% accuracy.

Retreival Algorithm: The Generalized Retrieval and ANalysis Tool (GRANT), developed by Computational Physics, Inc. (CPI), infers atmospheric composition from terrestrial and extraterrestrial dayglow observations. This tool merges CPI's Atmospheric Ultraviolet Radiance Integrated Code (AURIC) [3] and OPTimal estimation (hereafter OPT) retrieval algorithms [4-6]. The GRANT framework uses AURIC as a forward model driver for the optimal estimation routines in OPT, deriving an optimal atmospheric state solution by minimizing the difference between forward model calculations and measurements.

The OPT retrieval algorithms provide a generic and flexible implementation of the optimal estimation constrained linear inversion technique. This technique is quite general and has been widely applied to retrieval problems in atmospheric and geophysical remote sensing [7]. To apply the algorithms to a particular retrieval problem an appropriate forward function must be defined, as well as the necessary interface subroutines to define the data and retrieval space vectors. The forward model function defines the mathematical and physical mapping between the model and data space, and therefore completely defines the particular problem to be solved.

Accurate retrieval of atmospheric abundances requires forward model brightnesses to be consistent with observations, meaning the forward model must include any instrument effects that are not accounted for by instrument calibration. This can be achieved with a suitable instrument model that is coupled with the forward model within the retrieval loop. In the spectral dimension we convolve AURIC 1 Å resolution model spectra corresponding to each tangent altitude with an IUVS point spread function as well as a slit function. To ensure consistency with IUVS observed limb profiles, we sum over all AURIC model spectral bins associated with selected atomic lines and/or molecular bands to capture the full intensity. For spatial smoothing we use a box-car average, which yields an effective vertical resolution of ~5 km. Our forward model calculations assume isotropy, which is a safe approximation for solar zenith angles below 60°.

Forward Model: The AURIC software package was developed by CPI for upper atmospheric radiance modeling from the FUV to the NIR. Many enhancements have been made to AURIC since its inception, including a more comprehensive chemistry model (for neutral and ionospheric species), new radiative transfer capabilities, the option of performing photoelectron energy degradation with or without vertical transport, updates to electron impact cross sections [1, 8], and the addition of new emission features. Upgrades made to allow modeling of the Martian atmosphere include: 1-D Mars photochemistry and molecular transport; and the addition of the following molecular band systems: CO Cameron; CO Fourth Positive Group; CO_2^+ Fox–Duffendack–Barker; CO_2^+ UV Doublet; CO Hopfield-Birge (B-X); and CO^+ First Negative Group.

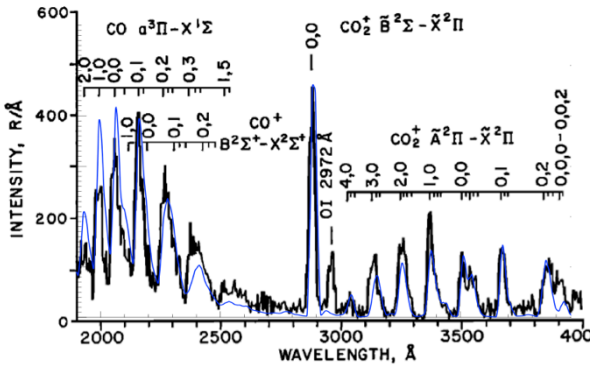

Figure 1. *UV spectrum of Mars upper atmosphere from 1900 – 4000 Å at 20 Å resolution observed by Mariner 6 & 7 as reported by Barth et al. [9] (black) compared with results from AURIC (blue). The Mariner spectrum was obtained by summing four 3-second individual observations for tangent altitudes between 160 and 180 km. The AURIC spectrum was obtained by summing spectra smoothed to 20 Å resolution for all tangent altitudes in the given range.*

AURIC has been validated against numerous published rocket and satellite data, and shown to have good overall agreement with the measurements (Figure 1).

Results and Future Work: Retreived limb profiles are calculated from CO_2 densities obtained by modifying an *a priori* guess until a best fit solution is found. Figure 2 shows a GRANT retrieved CO_2^+ UVD limb radiance profile (red curve) compared against an IUVS observed limb radiance profile (green curve). The model limb radiance profile corresponding to the *a priori* guess is shown in blue. The *a priori* guess is the mean of density profiles taken from the Mars Climate Database [10] sampled over a full Martian year. The agreement between retrieved limb radiance profiles and the data is good at nearly all altitudes.

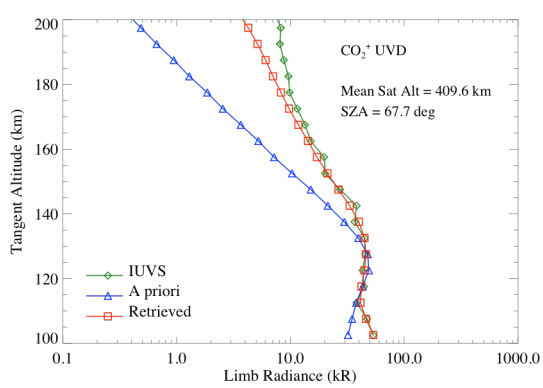

Figure 2. *CO_2^+ UVD intensity profile observed by IUVS (green) from MAVEN Orbit 109. Also shown are radiance profiles corresponding to a priori (blue) and retrieved (red) CO_2 density profiles.*

A quantitative and thorough understanding of the relevant emission cross sections and XUV solar irradiance producing CO_2^+ UVD allow for direct CO_2 retrievals in the Martian upper atmosphere (Figure 3). Furthermore, simultaneous observations of the CO_2^+ UVD feature along with other FUV and MUV emission features allows for a self-consistent yet decoupled direct retrieval of Martian thermospheric composition through careful consideration of the dependencies of atomic and molecular emission on atmospheric constituents.

Future work includes the retrieval of number densities of N_2 from the N_2 VK bands, CO from the CO 4PG bands, C from C I 1561 Å and 1657 Å, CO_2^+ from the CO_2^+ Fox–Duffendack–Barker bands, and C^+ from C II 1335 Å.

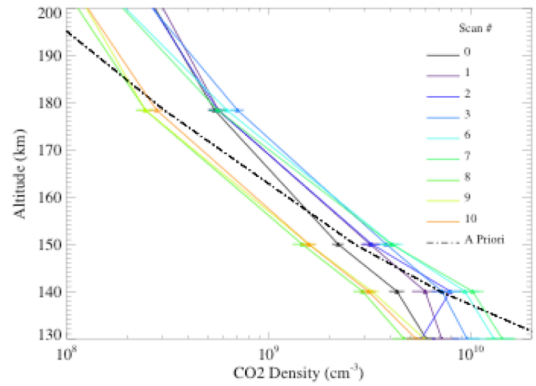

Figure 3. *Retrieval of CO_2 density profiles using nine IUVS limb scan observations from MAVEN Orbit 109. The adopted a priori CO_2 density profile, shown in black, is a mean of density profiles from the Mars Climate Database sampled over a Martian year.*

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