ULTRAVIOLET AND VISIBLE DAYGLOW EMISSIONS ON MARS: MODELLING PERSPECTIVE.

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Introduction

Since the beginning of space era, the quest for understanding the atmospheres of Earth's neighbour Mars fascinated planetary scientists. The upper atmospheric studies of Mars have been carrying out since sixties. At present, atmospheres of Mars is being investigated by Mars Express. SPICAM (SPectroscopy for the Investigation of the Characteristics of the Atmosphere of Mars) aboard Mars Express observations have provided wealth of information on Martian upper atmosphere and enhanced our understanding regarding the energetics of upper atmosphere of Mars. SPICAM observations span more than a Martian years. These measurements have been very informative and have helped us understand the effect of dust storms, seasonal variations, solar zenith angles etc., on Martian dayglow emissions. SPICAM has also observed for the first time ultraviolet emissions of N_2 on Mars.

Modelling of dayglow emissions, aided by laboratory studies and observations, are essential tool to understand the underlying chemical and physical processes occurring in the upper atmosphere of a planet. Most of the earlier modelling calculations of airglow emissions on Mars were carried out using the available input parameters and model atmospheres. Since then, there has been a significant enhancement in our understanding of Martian atmospheric parameters with the help of recent planetary missions to Mars. Also atomic and molecular parameters, viz., cross sections, Einstein coefficients, and Frank-Condon factors have been updated. With the current continuous measurements of dayglow emissions by SPICAM on Mars, new modelling studies of emission features in the atmosphere of Mars are an essential requirement.

We have developed photochemical model to study the dayglow emissions emanating from upper atmosphere of Mars. The study focuses mainly on CO Cameron band, CO_2^+ ultraviolet doublet, N_2 triplet band and atomic oxygen 2972, 5577 Å, and red doublet (6300, 6364 Å) line emissions on Mars. Since model calculations directly depend on input parameters such as solar EUV flux, model atmosphere, and cross sections. Evaluation of the effect of various input parameters on emissions intensities is also one of the aim of the study. The following sections will discuss the above mentioned emissions.

Model

We have developed a Monte Carlo model for electron energy degradation in a CO_2 atmosphere, which is the dominant constituent in the atmosphere of Mars [1]. The output of Monte Carlo simulation is used to generate the "yield spectra", which embodied all the information related to electron degradation process. The numerical yield spectra have been fitted analytically resulting in an Analytical Yield Spectra (AYS) [1]. The AYS is further employed to calculate photoelectron flux in the atmosphere of Mars.

CO Cameron band

CO Cameron band is brightest ultraviolet dayglow emissions in the atmosphere of Mars [2, 3]. Figure 1 shows the production rates of CO($a^3\Pi$) for low and high solar activity conditions. The major source of this emission on Mars is the electron impact on CO_2, followed by photon impact on CO_2. However, our study demonstrated that the cross section of $a^3\Pi$ state in e-CO process is important in modelling CO Cameron band emission on Mars, and the role of electron impact on CO in Cameron band production on Mars needs to be reconsidered [4, 5, 3]. The contribution of e-CO process in CO Cameron band also depends on the density of CO in the atmosphere; hence, it is difficult to constrain the former without fixing the latter. We suggest that future missions to Mars should focus on measuring the densities of Minor constituents such CO and N_2 on Mars.

CO_2^+ UV doublet

CO_2^+ UV doublet at 2883 and 2896 Å is the second brightest UV emission in the atmosphere of Mars and have been observed on Mars by both Mariner 6 and 7 flybys and recently by SPICAM/MEx. This emission is mainly produced by photoionization of CO_2, which accounts for more than 70% production of UV doublet emission. Second major source of this emission is electron impact ionization of CO_2.

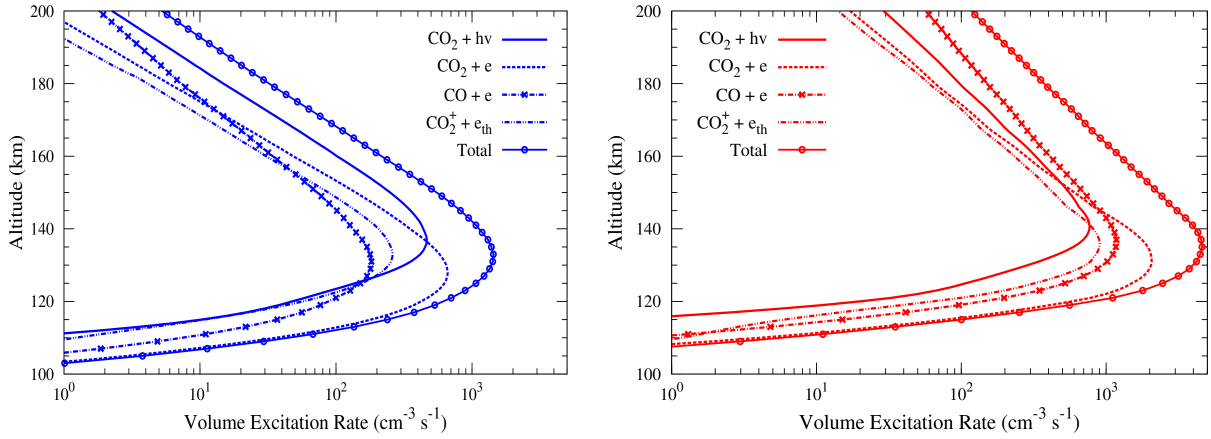

Figure 1: Calculated production rates of the CO($a^3\Pi$) on Mars for low (left panel) and high (right panel) solar activity condition at SZA = 45°.

N_2 triplet bands

Emissions from excited states of N_2 have been studied extensively in the terrestrial airglow and aurora [6]. Recent observations by SPICAM/MEx have, for the first time, observed N_2 triplet band emissions in the dayglow of Mars [2, 7]. The main emission observed are N_2 Vegard-Kaplan (VK) (0, 5) at 2605 Å, (0, 6) at 2762 Å, and (0, 7) at 2937 Å, which originate from triplet $A^3\Sigma_u^+$ state of excited N_2 molecule. The N_2 VK band emissions is mainly produced by the electron impact on N_2. Apart from direct excitation, cascade from higher triplet states and interstate cascading between different states is also important in determining the N_2 (A) population. We have calculated the population of different vibrational levels of triplet $A^3\Sigma_u^+$ state by solving the equation for statistical equilibrium. We have calculated overhead intensities of Vegard-Kaplan ($A^3\Sigma_u^+ - X^1\Sigma_g^+$), First Positive ($B^3\Pi_g - A^3\Sigma_u^+$), Second Positive ($C^3\Pi_u - B^3\Pi_g$), Wu-Benesch ($W^3\Delta_u - B^3\Pi_g$), and Reverse First Positive bands of N_2.

The N_2 triplet band emissions span a wide spectrum of electromagnetic radiation covering EUV-FUV-MUV, visible, and infrared [8, 9]. Major emissions in N_2 VK band lie in the wavelength range 200–400 nm, and a few significant emissions in the visible. N_2 triplet First Positive ($B \rightarrow A$), Wu-Benesch ($W \rightarrow B$), and $B' \rightarrow B$ bands have prominent emissions in the infrared region [8, 3]. Thus, beside observations in the extreme and middle ultraviolet region future mission for Mars should look for the N_2 emissions in far ultraviolet as well as visible wavelengths also.

OI 2972, 5577 Å, and red doublet (6300, 6364 Å)

We have developed a detailed photochemical model for the atomic oxygen ultraviolet (2972 Å; $^1S \rightarrow {}^3P$), green (5577 Å: $^1S \rightarrow {}^1D$), and red doublet (6300, 6364 Å: $^1D \rightarrow {}^3P$) emissions in the dayglow of Mars [3]. All the possible production and loss reactions of O(^{1}S) and O(^{1}D) in the atmospheres of Mars have been considered in the calculation.

Below 120 km the main production source of O(^{1}D) is photodissociation of CO_2, while at higher altitudes dissociative recombination of O_2^+, O(^{1}S) radiative decay, and photodissociation of CO_2 are the major sources. On Mars, during both solar minimum and maximum conditions, the main production mechanism of O(^{1}S) is photodissociation of CO_2. Contrary to the recent suggestion of [10], our calculation and as well as calculation of [11] show that dissociative recombination of O_2^+ is not the major source mechanism for O(^{1}S) production in the 80–170 km region on Mars. Thus, the O(^{1}S) emission cannot be used as a monitor of Martian ionosphere, unlike that mentioned by [10]. We have compared our calculated OI 2972 Å brightness profiles with the SPICAM observed intensity and found a good agreement between them.

Based on the model calculated limb intensity profiles of OI 6300 and 5577 Å emissions, it is suggested that in future Mars missions the search for red doublet emissions should focus at altitudes above 160 km, whereas for observing of OI 2972 and 5577 Å emissions the altitude region below 150 km is more suitable.

Summary

Figure 2 shows the limb intensity profiles of above discussed emissions for both solar minimum and maximum

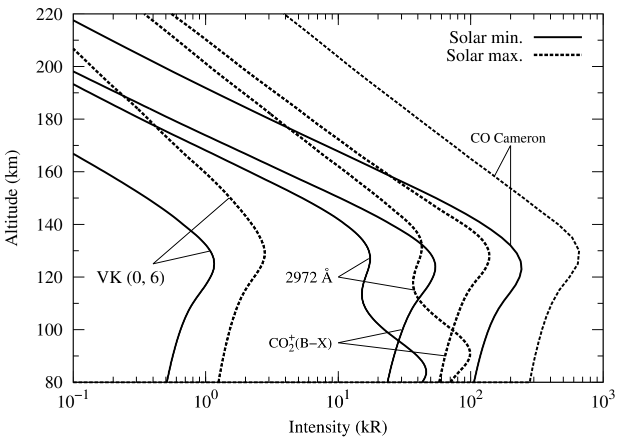

Figure 2: Calculated limb intensities of ultraviolet emission of atomic oxygen (2972 Å), N_2 (VK 0-6 at 2762 Å), CO (Cameron band) and CO_2^+ (UV doublet at 2883, 2896 Å) during high (max.) and low (min.) solar activity period at SZA = 45°

conditions and gives an insight about the relative magnitude of various important ultraviolet emissions in the dayglow of Mars.

The information derived from the present calculation is very useful for the dayglow observations on Mars currently being carried out by SPICAM/Mars Express and will be useful for upcoming MAVEN and Indian Mars orbiter missions.

References

[1] A. Bhardwaj and S. K. Jain, *J. Geophys. Res.* **114** (2009).

[2] F. Leblanc, J. Y. Chaufray, J. Lilensten, O. Witasse and J.-L. Bertaux, *J. Geophys. Res.* **111** (2006).

[3] S. K. Jain, Dayglow Emissions on Mars and Venus, PhD thesis, Cochin University of Science and Technology, (India, 2013).

[4] S. K. Jain and A. Bhardwaj, *Planet. Space Sci.* **63-64**, 110 (2012).

[5] A. Bhardwaj and S. K. Jain, *J. Geophys. Res.* **118** (2013).

[6] R. Meier, *Space Sci. Rev.* **58**, 1 (1991).

[7] F. Leblanc, J. Y. Chaufray and J. L. Bertaux, *Geophys. Res. Lett.* **34** (2007).

[8] S. K. Jain and A. Bhardwaj, *J. Geophys. Res.* **116** (2011).

[9] A. Bhardwaj and S. K. Jain, *Icarus* **217**, 752 (2012).

[10] D. L. Huestis, T. G. Slanger, B. D. Sharpee and J. L. Fox, *Faraday Discussions* **147**, 307 (2010).

[11] G. Gronoff, C. S. Wedlund, C. J. Mertens, M. Barthélemy, R. J. Lillis and O. Witasse, *J. Geophys. Res.* **117** (2012).