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Analysis and modelling of PFS/MEx limb observations of 4.3-µm CO2 non-LTE emission

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Abstract

We present PFS-MEX limb observations of CO_2 and CO non-local thermodynamic equilibrium (non-LTE) emission at 4.3 µm in the atmosphere of Mars collected in more than three Martian years. With unprecedented spatial and temporal coverage, and relatively high spectral resolution, this unique dataset promises to improve our understanding of the upper atmosphere of Mars. The spectral resolution of these spectra allow unambiguous identification of several emission bands. The complete spatial and temporal coverage allow analyses of the emission as a function of tangent altitude, solar zenith angle (SZA), local time, latitude, and season. We compare careful selections of measurements to simulated spectra to improve non-LTE calculations and develop a forward model to fit the emission spectra observed by PFS, and eventually build retrieval algorithm to derive isotopic abundances and key parameters of the middle and upper atmosphere of Mars (e.g., pressure and temperature).

1. Introduction

Non-LTE processes play a key role in the cooling and heating rate of the mesosphere and lower thermosphere of Mars. The knowledge of this mechanism is extremely important for the study of the upper atmospheric layers, which may also affect the lower part of the atmosphere. Indeed, the meteorological processes on Mars appear to have a considerably larger vertical extension, probably involving the top of the neutral atmosphere up to 120 km [1].

At these altitudes the radiative budget of the atmosphere is determined by the direct absorption of sunlight in the near-IR region between 1 and 5 micron and the cooling via non-LTE emission of the CO_2 15 µm bands [2]. Particularly important is the absorption of the solar radiation in the range 1.2 - 2.7 µm because a major part of this energy is reemitted in cascade at 4.3 µm and 10 µm [3]. Vibrational-vibrational (V-V) collisions – where vibrational quanta are exchanged between the colliding molecules – redistribute the absorbed solar energy in a variety of vibrational states [3] providing also its partial thermalization. These processes need to be understood in details in order to perform meaningful simulations of the radiative balance of the middle and upper atmosphere of Mars and to extend the present parameterizations of the infrared radiative cooling/heating currently in use in Martian GCMs.

2. Dataset and Models

An accurate analysis of the non-LTE emissions measured by PFS requires the combined solution of the problem of ro-vibrational relaxation for a large number of excited vibrational states of CO_2 and CO isotopic molecules and the radiative transfer equation for very large number of ro-vibrational lines. To test the available theoretical tools, a complete dataset of observations of the upper Martian atmosphere is extremely important.

We collected all the currently available PFS-MEX limb observations of CO_2 and CO non-LTE emission at 4.3 µm and 4.7 µm, respectively. This dataset covers more than three Martian years, with unprecedented coverage and spectral resolution. More than sixty eight thousands spectra have been collected for this analysis. The advantage of limb measurements is twofold. First, it is possible to locate the height above the surface where the non-LTE emission occurs [4]. Secondly, they allow to detect the emission from weaker transitions compared to the nadir data, which are useful to put more stringent constraints on the models [4]. Observed altitudes range from 60-300 km, for all latitudes and for different SZAs, local times, and seasons. In order to maximize the spectral details, the zero-padding procedure has been applied to the interferograms. An example of emission spectra for different altitudes is shown in Figure 1. In this example, we selected measurements acquired during the fall season, and for SZAs ranging from 65° to 75°.

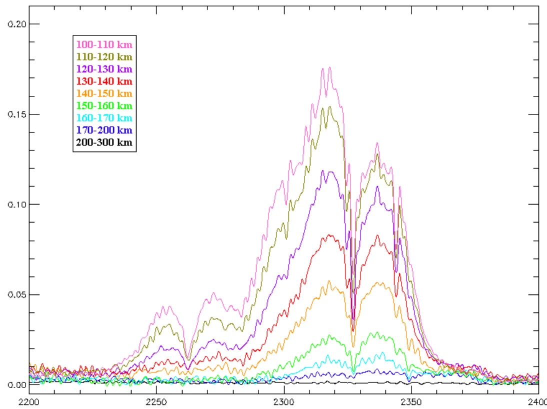

Figure 1: Example of PFS non-LTE emission spectra observed at different altitudes.

Given the high number of measurements collected, we can average tens or even hundreds of spectra for fixed parameters (altitude, SZA, latitude, etc.) and obtain high SNRs. The large amount of information contained in the high quality, resolution, and wide range of PFS spectra will allow us to uniquely validate our theoretical understanding of the non-LTE processes in the upper atmosphere, and suitable models can be used to invert the radiances and determine important quantities like pressures and temperatures, and the non-LTE model collisional parameters.

We compare selected PFS spectra to model calculations. The calculations were performed using the ALI-ARMS research code package described in [5]. The input atmosphere was set on 0–200 km altitude grid with 1 km vertical step. Pressure, temperature, volume mixing ratios of atomic oxygen and CO_2 are extracted from the LMD GCM [6]. We involved two models to the simulation: a) a standard one involving 60 vibrational levels of five CO_2 isotopes, 20000 optical transitions from HITRAN database and b) an extended one with 300 vibrational levels of seven CO_2 isotopes and 300000 optical transitions from HITEMP database. The simulation was performed in the following way. The populations of all CO_2 vibrational levels involved in the problem are first calculated by solving the non-LTE task. The populations of these levels are then used for calculating the radiance on limb paths in 50–200 km altitude region. Finally, the monochromatic radiances are convolved to the PFS resolution.

6. Summary and Conclusions

We will report the progress made recently in the modeling and understanding of the rotational-vibrational non-LTE processes in the CO_2 atmosphere of Mars (Figure 2), based on the analysis of the new data from PFS/MEX. We compare measured and simulated spectra to improve/validate the non-LTE model and develop a retrieval algorithm to derive isotopic abundances and key parameters of the middle and upper atmosphere of Mars (e.g., pressure and temperature).

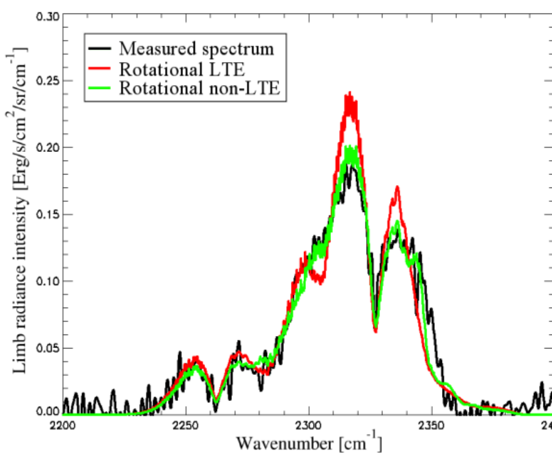

Figure 2: Rotational non-LTE plays an essential role on the formation of the 4.3-µm CO_2 emission spectra.

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