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Inversion of vertical profiles of CO_2 in the Mars daylight thermosphere from its non-thermal emission at 4.3 μm

Sergio Jiménez-Monferrer, Miguel Ángel López-Valverde, Bernd Funke,
Manuel López-Puertas, Francisco González-Galindo, Maya García-Comas
Instituto de Astrofísica de Andalucía (IAA/CSIC), Granada, Spain (sjm@iaa.es)

Introduction

Several instruments on board Mars Express (MEx) have observed daytime atmospheric emissions in the IR, although the data at high altitudes and in a limb geometry have not been sufficiently exploited so far [1, 2, 3]. Exploiting atmospheric emissions in a limb geometry is a real challenge because this geometry favours optically thick conditions, difficult to handle. In addition, the emissions of CO_2 and CO at the low pressures at these altitudes are no longer in LTE (local thermodynamic equilibrium), i.e. they cannot be described by the local kinetic temperature. This is a limitation and a complication because the state populations, i.e., the emission observed is not analytically related to the temperature in a simple manner. These observations should allow for a first-time exploitation of the non-thermal CO_2 emission in a terrestrial planet other than Earth, in at least the strongest system of ro-vibrational bands of this molecules, that in the 4.3 μm spectral region.

Although spectroscopically well characterised and theoretically well understood and modelled [4, 5, 6], the scientific exploitation of these non-LTE emissions is difficult for several reasons. Some of these are common to previous similar investigations and IR remote sounding on the Earth upper atmosphere (sensitivity to rate coefficients not well determined in the lab, propagation of errors in the temperature retrievals, etc.) and some of them specific to a CO_2 atmosphere like the Martian case (large number of CO_2 bands contributing, lower spectral resolution of spectrometers on Mars orbit, larger optical thickness of a CO_2 atmosphere, stronger limitations from lab data available).

One of the goals of the UPWARDS project [7] was the exploitation of these limb emissions as captured by OMEGA and PFS on Mars Express and the delivery of the major results obtained (densities and temperatures at thermospheric altitudes) to open repositories for its scientific dissemination.

In this presentation we will describe the essential tools used (non-LTE models and retrieval suite), the datasets selected, the major difficulties found in the retrievals and a sample of the results obtained so far.

The Mars Express datasets

The two IR sounders on board Mars Express, OMEGA and PFS, performed limb observations in the IR region, detecting the strong 4.3 μm CO_2 emissions [1, 3]. The two instruments have different spectral resolutions, spatial and temporal mapping of the limb, and very different FoV and sampling rates. Although their joint analysis presents a very interesting challenge, their measurements are actually uncorrelated, and their inversion should rather proceed independently from each other.

For this study we selected the OMEGA *qubes* as our primary goal due to the much larger number of vertical profiles that can be built from the 2D limb-projected data. The PFS dataset, on the other hand, presents tangential tracks with large horizontal extensions, more suitable for atmospheric variability studies.

The non-LTE retrieval scheme

Our team at the Instituto de Astrofísica de Andalucía (IAA/CSIC) has experience in the simulation of CO_2 emissions in the upper atmospheres of the three terrestrial planets, under conditions of non-LTE [2, 6, 8]. In addition, our team has helped to develop, in partnership with the University of Karlsruhe, a line-by-line radiative transfer model (KOPRA) [9], used to simulate emission and absorption spectra primarily of the Earth's atmosphere. This was used to perform retrievals of CO_2 densities in the Earth's atmosphere in the infrared [10, 11]. And this is the scheme extended and applied to the Martian case. The results have been catalogued for dissemination and discussed at length in an manuscript in preparation [12], and this talk will focus on the presentation of these preliminary results.

Extensions and future applications

One of the major difficulties of the study has been the strong and non-linear dependence of the CO_2 non-thermal emission on the CO_2 density (target of the inversion). This dependence enters twice into the iterative process, making the inversion time consuming and very sensitive in the upper mesosphere. For operational reasons, we are deriving densities only at thermospheric altitudes at the moment. A first extension is therefore to cover the Martian mesosphere with our scheme, which will probably involve a revisit to the non-LTE model. A second application is the similar dataset of limb emissions by VIRTIS/Venus Express in the other CO_2 neighbour atmosphere, Venus. And another effort in parallel, regarding ExoMars, an obvious extension is the application of the retrieval scheme to solar occultation observations by NOMAD and ACS, on board the Exomars 2016 TGO, which are essential and systematic data of such mission. These instruments offer unique capabilities to study the Martian thermosphere with unprecedented vertical resolution. The adaptation of this retrieval scheme to the two instruments will be presented elsewhere [13].

Keywords: Mars Express, OMEGA, inverse methods, remote sounding, CO_2, non-LTE, ExoMars TGO, clustering techniques, Mars, NOMAD, PFS, ACS.

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