Inversion of vertical profiles of CO2 in the Mars daylight thermosphere from its limb non-thermal emission at 4.3 um

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Introduction

The two European missions to Mars and Venus, Mars Express and Venus Express, have provided a unique set of infrared observations of their upper atmospheres in a limb geometry [1] [2]. These observations should allow for a first-time exploitation of the non-thermal CO2 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 um spectral region. Although spectroscopically well characterized and theoretically well understood and modeled [3] [4] [5], the practical exploitation of these emissions is difficult for several reasons. Some of these are common to previous similar investigations and IR remote sounding on the Earth upper atmosphere and some of them specific to a CO2 atmosphere like the Martian case (and the Venusian one).

One of the goals of the UPWARDS project [6] is 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-local thermodynamic models and retrieval suite) , the datasets selected, the major difficulties found in the retrieval process and a sample of the results obtained so far.

The Mars Express datasets

The two IR sounders on board Mars Express, PFS and OMEGA, performed limb observations in the IR region, detecting the strong 4.3 um CO2 emissions [1] [7]. 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 were actually uncorrelated, and their inversion should rather proceed independently from each other dataset. For this study we selected the OMEGA qubes as our primary goal due to the much larger number of vertical profiles that one can build from its 2D limb-projected data qubes. The PFS dataset, on the other hand, presents tangential tracks with large horizontal extensions, more suitable for atmospheric variability studies.

The non-thermal retrieval scheme

Our team at the Instituto de Astrofísica de Andalucía (IAA/CSIC) has experience in the simulation of CO2 emissions in the upper atmospheres of the three terrestrial planets under conditions of non-local thermodynamic equilibrium [5][8][9]. In addition, our team has helped develop, in partnership with the University of Karlsruhe, a line-by-line radiative transfer model (KOPRA) [10] used to simulate emission and absorption spectra primarily of the Earth's atmosphere. This was used to perform retrievals of CO2 densities in the Earth's atmosphere in the infra-red [11][12]. And this is the scheme extended and applied to the Martian case. The results are being cataloged for dissemination and discussed at length in an manuscript in preparation [13], and the present talk is the first presentation of these results.

Extensions and future applications

One of the major difficulties of the study has been the strong and non-linear dependence of the CO2 non-thermal emission on the CO2 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. At present, for operational reasons, we are deriving densities only at thermospheric altitudes. A first extension is therefore to extend the scheme to the Martian mesosphere, which we will attempt with a two-steps/layers strategy.

A second application is the similar dataset of limb emissions by VIRTIS/Venus Express in the other CO2 neighbor atmosphere, Venus.

And finally, 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 is presented in a companion contribution to this workshop [14]

Keywords: Mars Express, OMEGA, PFS, ExoMars TGO, NOMAD, ACS, inverse methods, Mars, remote sounding, CO2, non-thermal emissions.

References:

[1] Piccialli et al., *J. Geophys. Res.* Vol. 121, 1066-1086, 2016, doi: 10.1029/2015JE004981
[2] Gilli et al., *J. Geophys. Res.,* Vol. 114, E00B29, 2009, doi:10.1029/2008JE003112
[3] Lopez-Valverde et al., *Planet. Space Sci.,* Vol. 55, 1757-1771, 2007, doi:10.1016/j.pss.2007.01.008
[4] Wolff et al., Chapter 4, in Mars Atmosphere and Climate,Cambridge Univ. Press, 2016
[5] López-Puertas, M. and Taylor, F., Non-LTE radiative transfer in the atmosphere. *Ed. World Scientific* (2001)
[6] *Understanding Planet Mars With Advanced Remote-sensing Datasets and Synergistic studies,* http://www.upwards-mars.eu/
[7] Formisano et al., Icarus, Vol. 182, 51-67, 2006, doi: 10.1016/j.icarus.2005.12.022
[8] Gilli et al., *Planet. Space Sci.* 59, 1010 - 1018, 2011, doi: 10.1016/j.pss.2010.07.023.
[9] López-Valverde, M. A. et al., *Planet. Space Sci.* 59, 988–998, 2011, doi: 10.1016/j.pss.2010.02.001
[10] Stiller G. P. (Editor), Clarmann T. v., et al., *Wissenschaftliche Berichte,* Bericht Nr. 6487, 2000.
[11] Funke B. et al., *J. Geophys. Res.* Vol. 110, 2005, doi: 10.1029/2004JD005225
[12] Jurado Navarro A. A., Lopez-Puertas M. et al., *Ph.D., Univ. of Granada, Spain* . ISBN: 9788491254164, 2016.
[13] Jimenez-Monferrer et al., 2018, *in preparation*
[14] Hill et al., 2018 (this workshop)

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