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The challenge and scientific application of the CO2 4.3 μm atmospheric limb emission of Mars

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Abstract

The atmospheric fluorescent emissions of CO2 at 4.3-um have been observed in the daytime upper atmosphere of Mars from a limb geometry by the instruments OMEGA and PFS on board Mars Express [1, 8]. Initial analysis using non-local thermodynamic equilibrium (NLTE) models show that the emissions are well understood [7, 3, 6]. Yet they have not been exploited to derive important thermospheric parameters, like CO2 densities and temperatures. Our major goals are to improve current NLTE models with a joint study of OMEGA and PFS data, and to build an ambitious state-of-the-art NLTE retreival scheme for Mars. Recent progress has been made in these directions on Mars, Venus and Earth. We will present a summary of these efforts and the difficulties and expectatives for its application to the Mars Express data.

1. Introduction

Infrared NLTE emissions by atmospheric molecules, specially under fluorescent or solar-pumping situations, are powerful tools to sound the upper layers of a planetary atmosphere [5]. Limb observations, in addition, are specially suited for a proper vertical sounding. The particular emissions by the ro-vibrational bands of CO_2 around 4.3 μm share these two advantages and are among the strongest molecular emissions in the infrared in the three terrestrial planets [6]. The instruments OMEGA and PFS have been performing systematic observations of these emissions on board Mars Express since 2003 and form a dataset which needs to be properly exploited. However, their scientific exploitation has a couple of difficulties, inherent to the NLTE nature of the emissions. One of them is the need to develop a suitable NLTE forward model (based on the theoretical NLTE population models) which produce simulated radiances in sufficiently good agreement with the observations. Another difficulty is linked to the inherent uncertainties in the microscopic description of the NLTE populations involved in a CO2 atmosphere like that of Mars. Specifically, the lack of laboratory information on collisional energy exchanges between CO2 states at high vibrational states and with isotopes. Actually, when spectral resolution and sensitivity are good enough, insight into and retrieval of some collisional rate coefficients are possible from remote souding [4]. A third difficulty is the large optical thickness of these emissions in a limb geometry, which may produce variations in the actual location of the "emitting region" along the line-of-sight. Retrievals under optically thin conditions, free from this last difficulty because the emitting region is at the tangent point, have recently been carried out for CO at 4.7 μm in the upper atmosphere of Venus [2]. A careful evaluation of all these conditions and difficulties, and a proper fit of the OMEGA and PFS data with a NLTE forward model are needed in order to evaluate the ability to investigate the upper Martian atmosphere using these datasets, and are the focus of an ongoing effort in our teams.

2. Recent NLTE results

2.1. Mars upper atmosphere

The OMEGA and PFS datasets seem to obey the expected NLTE behaviour of the emissions regarding the two most important aspects: spectral shape and absolute magnitude of the emitted radiance. Also the variation of these with altitude and solar illumination seem to be understood, at least in a global or averaged sense [7, 3]. In order to explain the spectral shape measured by OMEGA, however, changes in vibrational-vibrational exchanges between $CO_2(\nu_3)$ states was needed; a solution which also improved similar measurements by VIRTIS/Vex in the Venus thermosphere

[6]. An extended study using both OMEGA and PFS is needed, in particular the PFS higher spectral resolution, can be very useful to settle this question.

2.2. Venus upper atmosphere

In the Venus upper atmosphere, the 4.3 μm emissions by CO_2 present similar difficulties. A simpler retrieval (optically thin situation) was applied to the limb fluorescent emissions by CO at 4.7 μ from VIRTIS/Venus Express, obtaining both CO abundance and temperatures simultaneously [2]. CO observations in Mars, at least available from PFS, should also be exploited, and a joint retrieval with CO_2 at 4.3 μm shall be particularly useful to obtain the total carbon content in the Martian thermosphere.

2.3. Earth upper atmosphere

An interesting study in the Earth's upper atmosphere using MIPAS/Envisat observations has been recently conducted in the Granada group [4]. Jurado-Navarro and colleagues not only derived CO_2 but also rate coefficientes of a few vibrational-to-vibrational and vibrational-to-translation energy transfer routes involving CO_2 states. Unfortunately the OMEGA and PFS spectral resolutions are not as good as those of MIPAS, but the NLTE retrieval scheme used by these authors should be applied to the Martian case to examin the possibility of similar derivations. In the case of Mars, or Venus, the collisional exchanges driving the populations are slighlty different, and offer new insight into the governing NLTE mechanisms in a CO_2 atmosphere.

3. Summary and Conclusions

The NLTE limb emissions of CO2 at 4.3 um observed by Mars Express are a unique dataset to extend our description of the upper mesosphere and the thermosphere of Mars. The understanding of the emissions, their correct simulation and the NLTE retrieval of densities and temperatures are our major objectives. A further strategy behind this work is the preparation of suitable retrieval tools for the analysis of the upcoming ExoMars Trace Gas Orbiter (EMTGO), specifically to exploit infrared measurements of the upper atmosphere subject to NLTE features in a completely different observing mode (atmospheric absorption) from two of the EMTGO instruments: NOMAD and ACS.

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