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Retrieval of CO and Temperature in the upper atmosphere of Venus from infrared non-LTE limb emissions observed by VIRTIS/Venus Express

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Abstract

The upper atmosphere of Venus between 100 and 150 km is a particularly difficult region for remote sounding. Molecular emissions out of Local Thermodynamic Equilibrium (LTE) are useful to sound these altitudes, specially those presenting a strong solar fluorescence. If proper modeling is performed and those daytime emissions are well understood, information about the emitting species as well as about the kinetic temperature could be derived. We present here a study of non-LTE emissions by carbon monoxide at 4.7-μm in the upper atmosphere of Venus, as observed by Venus Express during daytime in a limb geometry. A retrieval method to derive CO abundance and temperature simultaneously, accounting for the non-LTE nature of the emissions is also discussed, and the results compared to the few data available.

1. VIRTIS Measurements

Recent evidences strongly suggest a more variable upper atmosphere in Venus than the classical picture given by VIRA [1,2,7]. Most observations, however, correspond to the nightside of the planet and at altitudes below 100-110 km. Venus Express carries a few instruments on board which are sounding the region of our interest in a limb geometry, namely SPICAV, SOIR and VIRTIS [8]. The first two are occultation instruments while the third is an emission sounder, which is observing interesting and strong non-LTE infrared emissions in the atmospheric limb [3].

This work follows on from previous analysis of the nature and variability of the CO non-LTE emission at 4.7-μm in the Venus atmosphere [3] [4], and from the recent application of a specific non-LTE retrieval method to exploit those data [5,6]. [3] showed that the rotational structure of two CO bands, the fundamental and the first hot bands of the main isotope, can be identified unambiguously in VIRTIS data. [4] further showed how these two bands can be well reproduced with a non-LTE model and a good fit of the VIRTIS spectra (within noise) can be obtained. A proper retrieval of CO abundances and kinetic temperatures was recently performed for the first time by our team [5,6]. Here we summarize these works and their conclusions.

VIRTIS supplies two signals, that (V-H) with the largest spectral resolution was chosen for this study. Figure 1 shows the coverage in altitude, latitude, local time, and solar illumination of a large section of the V-H spectra, each cross being one single spectrum. Regarding the time record, each V-H spectrum is independent from the previous or the following one. 1-D vertical profiles are therefore not available. Let us recall also that the coverage in latitude and local time is far from regular, with large gaps, specially in the Southern Hemisphere. One third aspect to notice is that the large ellipticity of Venus Express makes the field of view (FOV) extremely variable. To simplify the situation, only the data with FOV < 5 km is considered here.

2. Non-LTE retrieval scheme

The retrieval scheme developed by [5,6] is specially suited to the characteristics of V-H data, and could be applied to any optically thin non-LTE emission from sparse limb measurements. The forward model at its core makes use of a non-LTE population model [9] and also of a line-by-line non-LTE radiative transfer forward calculation.

The retrieval scheme follows a two-steps method. The first is a chi-2 minimization of the V-H spectrum of interest. It is obtained by comparison with a set of pre-computed spectra, simulated with the non-LTE forward model mentioned above, forming a 2-

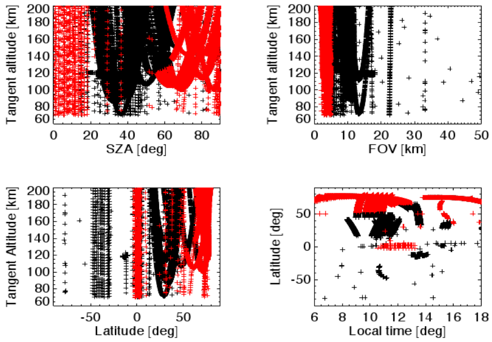

Figure 1: Distribution of VIRTIS-H data with SZA, altitude, latitude and local time. Colors are used to separate two sub-sets, those with FOV larger (black) and smaller (red) than 5 km.

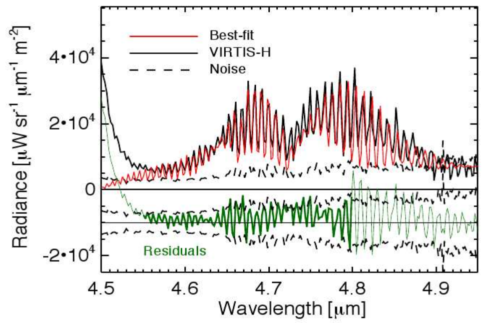

Figure 2: Best-fit spectrum (red) and residuals (green) obtained during the inversion of a particular V-H spectrum (black solid). Dashed lines: noise level. The residual and its noise envelope are shifted downward for clarity. The thick green line shows the actual set of wavelengths selected for the retrieval. See text.

dimensional grid, in CO abundance and kinetic temperature. The result of the first step is to select one of the grid points as a "first-fit" of the method. Then, a second step is to "refine" the solution performing a linear inversion around the "first-fit" in order to obtain the final "best-fit" of the spectrum. For this second step we followed the Optimal Estimation theory.

An example of retrieval and its residuals is shown in Figure 2, for one particular box/average of V-H spectra pointing around 100 km tangent altitude. The vertical resolution of the inversion is typically 20 km. The noise level increases with wavelength and in spite of the boxing it is still large, particularly at the longest wavelengths. In the other extreme of the spectrum, a strong contamination by the CO2 non-LTE emission is clear. The agreement between data and best-fit is good, as shown by the residuals in Figure 2: these are within noise levels between 4.55 and 4.8-μm.

In addition to the non-LTE nature of the emissions object of this study, one of the main difficulties of this work is the large measurement noise. In our work [5,6] we focused only on averages of data, with the aim of increasing the SNR. The retrievals of temperature are particularly sensitive to the noise level, and required specially large averages.

Acknowledgements

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