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Investigation at 1.27 µm, in the upper atmosphere of Venus, using VIRTIS/Venus Express

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Abstract

Venus Express gives the opportunity to study in great detail the O_2 nightglow in the IR spectral range, thanks to the extensive dataset acquired by VIRTIS, the Visible and Infrared Thermal Imaging Spectrometer on board the orbiter. The variability of the nightglow intensity has been debated in various papers [1, 2, 3, 4], and recently in [5]. One puzzle to solve is the unsatisfactory fit between data and synthetic spectrum at about 1.28 µm and thus we have further investigated the spectral properties of the emission. The spectral region around 1.27 µm is characterized by the presence of the bright (a−X)(0,0) O_2 band, the most intense nightglow emission observed on the night side of Venus. Another band, the (a−X)(1,1) O_2 band, is expected to occur at 1.28 µm, although it cannot be independently resolved from the (0-0) with VIRTIS, because of the relatively low spectral resolution. We find that the inclusion of this emission significantly improves the spectral fit around 1.27-1.28 µm. We also report the discovery of the presence of the (1-1) band and describe its vertical distribution.

1. Introduction

Several emissions due to O_2, OH and NO have been detected up to now in the Venus night side upper atmosphere by VIRTIS. In the infrared spectral range, the O_2 IR bands at 1.27 and 1.58 µm [5], the hydroxyl emissions [6, 7, 8] at 1.46 and 2.81 µm and the nitric oxide [9] at 1.22 µm have been observed for the first time, if we exclude the O_2 (0-0). In the visible spectral range, the oxygen emissions known as the Herzberg II system were also observed [10]. Atomic oxygen emissions were not detected yet in VIRTIS spectra, maybe because of the very low intensity.

Variability in the spectral shape was observed in VIRTIS spectra around 1.27 µm. Spectra acquired at different altitudes, in the range 90-100 km, show a kind of "shoulder" at longer wavelengths than 1.27 µm. Any attempt to satisfactorily reproduce the O_2 emission with the (0,0) band available in the spectral range 1.2-1.32 µm has failed.

From a photochemical point of view, other oxygen emissions are expected to be present in the planetary atmospheres, both in the visible and infrared spectral ranges. Emissions at 1.06 and 1.28 µm are predicted [11], though no observations have been reported so far, even in the case of the Earth. The energy level scheme of molecular O_2 consists of a triplet ground state, labeled X, and two excited states, $a^1\Delta_g$ and the $b^1\Sigma_g$ singlet states. Vibrational-rotational transitions are associated to these two electronic transitions, giving rise to two band systems, one in the IR, called atmospheric infrared bands, and one in the visible spectral range, called the red bands.

We propose a method to reproduce the O_2 emission around 1.27 µm, by comparing the VIRTIS spectra in the 1.2-1.3 µm spectral range, to a simulation taking into account both the (0,0) and the (1,1) O_2 bands .

2. Method

We used PGOPHER software to generate line intensities of the O_2 molecule emission at 1.27 µm, due to the (0,0) transition. Lines are computed considering a rotational temperature of 185 K [8]. In addition, the O_2 emission due to the (1,1) transition was included in the simulation. Unfortunately, no spectroscopic information is available for this transition, and the rotational structure of the (1,1) band was assumed to be of the same as that of the (0,0) O_2 transition. Being the intensity of the (1,1) band unknown, we multiplied the rotational line intensities by a numerical factor, in order to obtain the best match between the simulation and the observed spectra. This approximation is quite reasonable, in absence of spectroscopic information on the $a^1\Delta_g$ (v=1) state.

The simulated spectrum was then convolved assuming a Gaussian line shape, with a full width at half maximum (FWHM) of 14 nm, with a spectral resolution equal to the VIRTIS one, in order to compare simulated and observed spectra.

We focus on limb observations of the night side of Venus, acquired with VIRTIS, and selected in the altitude range 90-100 km, where the O_2 nightglow is usually observed. The VIRTIS spectra are obtained by selecting and averaging spectra in this altitude range.

The best match between the observed and simulated spectra is obtained when the difference between the two sets is less than 10%. Some results are discussed in the following section.

3. Results

The (0,0) O_2 band alone is not sufficient to explain the emission observed on VIRTIS data around 1.27 µm, as one can see in Figure 1 (red curve). The inclusion of the (1,1) O_2 band centred at 1.28 µm significantly increases the agreement of the observed spectrum with the simulated one. The case of VIRTIS spectrum acquired on 2007-03-14 (orbit number 327) is discussed in this work, as an example. It is obtained by adding a contribution corresponding to the (1,1) O_2 band, with an intensity of 5.4 MR, to the (0,0) O_2 band, and convolved considering a FWHM equal to 14 nm. The vertical profile of this additional emission was also derived (Figure 2). Its profile is quite similar to the (0,0) O_2 emission, with a peak maximum altitude equal to 95.5 km.

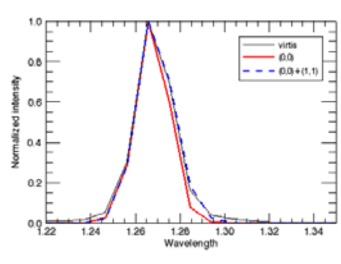

Figure 1. Comparison between the VIRTIS observed spectrum (black curve) and synthetic spectra of pure (0,0) O_2 band (red curve) and (0,0) and (1,1) O_2 bands (blue).

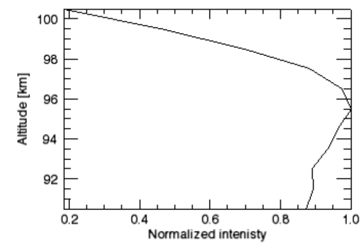

Figure 2. Vertical profile of the (1,1) O_2 band, derived in the case of data acquired on 2007-03-14 by VIRTIS. The emission peak is observed at about 96 km height.

4. Summary and Conclusions

We propose some simulations of the O_2 emission around 1.27 µm, to explain the extra signal observed on VIRTIS spectra, acquired in limb mode, at longer wavelengths than 1.27 µm. The inclusion of another O_2 emission, centred at 1.28 µm, allows to better reproduce the observed spectra, in the altitude range 90-100 km height. This emission was never observed on planetary atmospheres, though its influence on the 1.27 µm oxygen emission was discussed in [12], deriving an upper limit equal to the 15% of the (0,0) O_2 emission. Though VIRTIS does not allow to spectrally separate the (0,0) and (1,1) O_2 emissions, the proposed method demonstrates that the (1,1) O_2 band can be detected by VIRTIS.

Acknowledgements

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References

[1] Crisp, et al., 1996; [2] Ohtsuki et al., 2005; [3] Ohtsuki et al., 2008; [4] Bailey et al., 2008; [5] Piccioni et al., 2009; [6] Piccioni et al., 2008; [7] Gérard et al., 2010; [8] Soret et al., 2010; [9] Garcia-Munoz et al., 2009a; [10] Garcia-Munoz et al., 2009b; [11] Goody, R.M., and Y. L. Yung, 1989; [12] Connes et al.,1979.