Radiative transfer of the oxygen 130 nm triplet in atmospheres containing oxygen and carbon monoxyde

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Abstract

The radiative transfer of the of the oxygen 130nm triplet is of great importance to measure remotely the oxygen profile in atmospheres. This triplet is optically thick and resonant with sun and stars radiation. To use the angle average partial redistribution, which is the most useful in atmospheric radiative transfer, the RII function has to be rewritten. In addition to this the 130nm triplet overlaps with CO fourth positive band lines. The effects of this overlapping have to be taken into account in the interpretation in term of oxygen concentrations and profiles especially in the cases of Mars and Venus but also in the cases of super Earth exoplanets.

1. Introduction

The problem of the atomic oxygen concentration in the terrestrial planets atmospheres is crucial to understand the upper atmospheric mechanisms. This had never been directly measured for Mars and Venus. The oxygen 130 nm triplet is optically thick in those atmospheres and is resonant with the sun. The instruments SPICAV and SPICAM are able to measure the intensity of this triplet. Due to these points, it is important to calculate accurately the intensity of this triplet in such planetary atmospheres. In a recent paper Chaufray et al [1] used Monte Carlo radiative transfer calculation of this triplet in the case of Mars. They showed an exobase oxygen density of $1.2_{-0.5}^{+1.2} \times 10^{7} \, cm^{-3}$ and suggested the existence of a hot oxygen population.

However recent radiative transfer simulations showed that overlapping between lines in a planetary atmosphere could modified strongly the intensity and line shape of optically thick lines [2],[3]. In the atmosphere of Mars and Venus an overlapping between the O 130 nm triplet and lines of the CO fourth positive band has never been taken into account but if we consider ±0.3Å of each line of the triplet, 21 CO lines are in coincidence with the O 130nm triplet. This leads to a coupling through the radiative transfer. If we consider the temperature in the upper atmosphere of Mars (ie T=200K to 300K), we found that only 4 lines of CO are at less than 3σ of the lines centres of the triplet (table 1).

9-0 P(6)	λ= 130.211nm	-0.0055nm
9-0 Q(8)	λ= 130.221nm	+0.0052nm
9-0 Q(19)	λ= 130.489nm	+0.0031nm
9-0Q(22)	λ= 130.604nm	+0.0006nm

Table 1: CO line in coincidence with the oxygen 130nm triplet

On the dayside of Venus the exospheric temperatures are expected to be between 200K and 300K depending of the solar activity, which means that the same set of line is involved in the radiative transfer problem.

For hot exoplanets most of the previous 21 lines have to be taken into account.

The CO fourth positive band is the transition between $A^{1}\Pi$ et $X^{1}\Sigma^{+}$. A quasi-exhaustive study of the transitions characteristics of this band could be found in Kurucz[4]. In the calculation we consider the rotational levels populations are at thermal equilibrium. We calculate the radiative transfer through a Feautrier method with angle average partial redistribution function.

As in previous calculation in the jovian cases [2][3], we consider the RII function which is more accurate than the complete redistribution function. In the present problem, the redistribution on the other lines of the triplet suggests to rewrite the angle average RII function with the following equation:

$$R_{II,A,j} = \sum_{i=1}^{3} \frac{A_i}{\sum A_i} \pi^{-\frac{3}{2}} \int_{|x'-\Delta_{i,j}-(x-\Delta_j)|/2}^{\infty} du \exp(-u^2) \left[\left(\tan\left(\frac{\min(|x-\Delta_j|,|x'-\Delta_{i,j}|)+u}{a} \right) \right)^{-1} - \left(\tan\left(\frac{\max(|x-\Delta_j|,|x'-\Delta_{i,j}|)-u}{a} \right) \right)^{-1} \right]$$

Where the sums are on the absorbed photons (i) and the reemitted ones (j). Δ is representing the separation of the transitions in Doppler unit as defined in [2]. Each photons absorbed on a transition can be redistributed on another transition and redistributed through the partial redistribution function. The equation is a translation of this fact and takes into account both phenomena by summing on each absorbing transition (i) and each reemitting transition (j). It is important for the separation between the transitions to distinguish between Δ_j which represents the separation between the line centre (ie the centre of one arbitrary line of the triplet; in our case the 130.4 nm line) and the emission and Δ_{ij} represents the separation between the absorption and the re emission.

Using this new expression of the redistribution function we can consider than this O triplet is an isolated system. No other allowed transition from the upper level exists. In this sense we can consider that the single scattering albedo of the system is 1.

This is not the case for the CO fourth positive system. The selection rules for dipolar electrical transitions allowed to have $\Delta J=\pm 1,0$. Δv can take all entire values. This contributes to get a very large fluorescence spectrum for each transition. Due to this the single scattering albedo is very low but not equal to 0.

3. Results and discussion

We show that these effects are really important for the cases of Mars, Venus and every atmosphere containing O and CO in similar quantities.

This leads us to reassess the conclusion linked to the analysis of SPICAM data. Especially the presence of hot oxygen has to be more discussed.
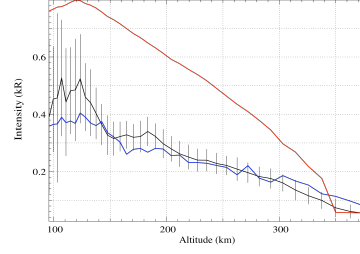

Figure 1: Red curve: curve with taking into account CO effects. Blue curve: with CO effects. Black error bars: Spicam data; Ls=101°; sza ~30°; f10.7 =80. The code runs with conditions close to Spicam ones (ie same f10.7, same season, same sza).

4. Summary and Conclusions

We showed that the effects of the overlapping have to be taken into account when interpreting O 130 nm data. For any atmospheres, containing O and CO, it could lead to really important changes on both temperatures and concentrations.

References

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