EPSC Abstracts
Vol. 10, EPSC2015-535, 2015
European Planetary Science Congress 2015


# CO concentration in the upper stratosphere and mesosphere of Titan: non-LTE analysis of VIMS dayside limb observations at 4.7 $\mu$m

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## Abstract

During the last 20 years, many works have focused on the atmospheric concentration of CO on Titan, giving contradictory results. In particular, no measurement of the CO abundance above 300 km has been done yet, due to the faint emission of CO above that altitude. On the other hand, such a study is particularly awaited as a confirmation of photochemical models that predict a uniform volume mixing ratio of CO in the whole Titan's atmosphere. Moreover, given that CO is the main reservoir of oxygen in Titan's atmosphere and its presence is linked to water, the matter is of astrobiological interest too.

The analysis of VIMS (Visual & Infrared Mapping Spectrometer, onboard Cassini) daytime limb measurements of Titan at 4.7 $\mu$m, corresponding to the vibrational bands of CO, allows such a study: CO molecules are significantly excited by solar radiation and the otherwise faint infrared signal of the upper atmosphere is large, allowing to probe this region too. On the other hand, the strong non-LTE behavior of CO infrared emission above 200 km, strongly coupled to $N_2$ and $CH_4$ vibrational levels, represents an extra complexity of the data analysis.

In order to deal with CO non-LTE emission, we have developed a non-LTE excitation/de-excitation model for the first two CO vibrational levels of the two most abundant isotopologues. We consider the contribution of absorption of radiation in the fundamental, first hot and first overtone bands and evaluate the possible contribution of different collisional processes, mainly the coupling with the first excited state of $N_2$ and with several levels of $CH_4$. The solution of the non-LTE problem is obtained through GRANADA [1], a non-LTE population algorithm based on *Lambda iteration* resolution strategy, eventually coupled to a Curtis-Matrix type approach. The result shows a significant over-population of the first vibrational level above 300 km and of the second level in the whole atmosphere. The possibility of further pathways for CO(1) (de)-excitation, mainly through vibrational energy transfer from/to the excited states of $CH_4$, through the route $CH_4(\nu^*) \Leftrightarrow N_2(1) \Leftrightarrow$ CO(1), is explored and seems to be crucial for establishing its population.

We then analyze the spectra acquired by VIMS between 2004 and 2013 in the 4.7 $\mu$m region, for daytime conditions. Considering the non-LTE populations obtained above, the retrieval of CO concentration is performed with the aid of Geofit Broad Band, a non-LTE *line-by-line* radiative transfer code coupled to a bayesian inversion method, initially developed for the Earth's atmosphere and later adapted to other planetary atmospheres [2]. The low signal-to-noise ratio and spectral resolution of the instrument considerably complicate the data analysis. Moreover, the scattered solar radiation is not negligible below 350 km and dominates over atmospheric emission below 200 km, and hence it is taken into account as well.

CO relative abundance profiles are finally obtained and discussed in the light of photochemical models predictions.

## References

[1] B. Funke *et al.*, *Journal of Quantitative Spectroscopy & Radiative Transfer* **113**, 1771 (2012).

[2] A. Adriani *et al.*, *Icarus* **214**, 584 (2011).