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Resonance lines radiative transfer for non-maxwellian velocity distribution function

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Abstract

We present the theory and a numerical model to describe the resonant emission lines in the planetary upper atmospheres for any velocity function distributions. The algorithm of the numerical model is based on a Monte Carlo approach. The model is applied to describe the emission lines of the sodium D_2 lines in the exosphere of Mercury. The very general approach of this tool makes it efficient to study the impact of non-maxwellian effects in emission lines of planetary upper atmospheres / exospheres.

1. Introduction

Surface bounded exospheres are formed by several surface processes [1]. Some of these processes are non-thermal and because a surface-bounded exosphere is collisionless, the interactions restoring equilibrium, mostly due to surface interaction are very weak. Then non-maxwellian velocity distribution functions are expected for species in the surface-bounded exosphere. The model is presented for a general transition (Fig. 1) and applied to sodium D_2 lines in the exosphere of Mercury.

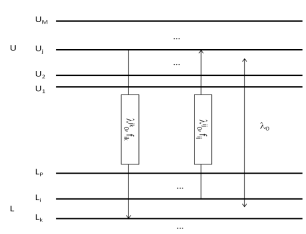

Fig. 1 Schematic representation of a system of lines involving two electronic states L and U. λ_0^{ij} and f_{ij} are the wavelength and the oscillator strength of the transition ij. λ_0 is the wavelength of the centroid of the system

2. Model description

The model is based on a Monte Carlo approach in which photons are followed from the sun through a planetary upper atmosphere based on [2] but contrary to [2] velocity distribution functions are not necessary maxwellian. Absorption and emission of photon (resonant scattering) are described using the statistical properties of the atoms in the planetary upper atmosphere. The statistical properties of the atoms are represented by their velocity function distribution f(**r**,**V**). Noting **n** the propagation direction of the photon, at a position **r**, the relative number of atoms with a velocity V_n along **n** is given by:

$$g(\boldsymbol{r}, Vn) = \frac{1}{n(\boldsymbol{r})} \iint_{Vm,Vl} f(\boldsymbol{r}, Vn, Vm, Vl) dVmdVl \quad (1)$$

The absorption cross section of a transition *ij* in the direction **n** is proportional to the relative number of atoms able to be excited by the photon through the transition *ij*. If we neglect the natural width of the line it is given by

$$\sigma^{ij}(\boldsymbol{r}, \lambda) = \frac{c}{\lambda_0^{ij}} \sigma_{tot}^{ij} g\left(\boldsymbol{r}, V_n^{ij}\right) \quad (2)$$

Where, V_n^{ij} is the velocity component along n satisfying

$$V_n^{ij} = -\frac{c}{\lambda_0}(\lambda - \lambda_0^{ij}) \quad (3)$$

The frequency redistribution function p(λ'/**n**, **p**, λ) is the probability for a photon with a wavelength λ, propagating in the direction **n** and scattered in the direction **p** to have a wavelength λ' after the scattering. We develop an algorithm to describe this redistribution process for any velocity distribution functions.

3. Validation of the code

Average dayside spectral line obtained with the new algorithm for maxwellian distributions is compared to result from maxwellian RT models to validate the algorithm presented above (Fig. 2).

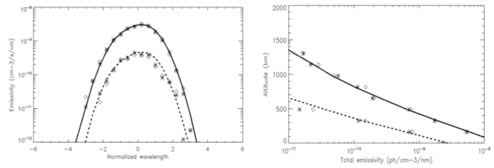

Fig. 2 Left : Average dayside spectral profile of the sodium D_2 line from algorithm used by [2] which inherently assumes maxwellian distributions (first scattering profile : solid line, multiple scattering profile : dotted line) and new algorithm used with Maxwell distributions with a velocity resolution ~ 1.1 km/s (diamonds) and 0.5 km/s (stars). Right : Same legend as left for altitude brightness variations.

The radiative model presented above has been coupled to a model of sodium in the exosphere of Mercury [3]

4. Summary and Conclusions

A new model taking into account non-maxwellian velocity distribution function has been developed and applied to describe the Sodium D_2 emission lines in the exosphere of Mercury. This model is coupled to an exospheric sodium model to describe in a consistent way the recent THEMIS observations [4] of Mercury sodium exosphere. The algorithm developed is very general and can be applied to any velocity distribution functions in any planetary upper atmospheres and easily coupled to exospheric models. It could be possible for example to investigate the effect of truncated maxwellian distribution function predicted by classical exospheric theory [5] as well as the presence of hot population in planetary upper atmospheres on the spectral profile line.

References

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