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3D numerical simulations of radiative transfer in the cometary coma

V.V. Zakharov (1,2), J.-F. Crifo (3), D. Bockelée-Morvan (1), N. Biver (1)
(1) LESIA, Observatoire de Paris, Paris, France, (2) Gordien Strato S. A. R. L. Verrieres le Buisson, France, (3) LATMOS, CNRS, Guyancourt, France, (vladimir.zakharov@obspm.fr / Fax: +33145077144)

Abstract

We report about the resent advances in the development of our 3D model of water excitation in cometary atmosphere in which radiation transfer is treated on the base of the accelerated Monte Carlo method.

1. Introduction

Because water is the main constituent of cometary nucleus ices, its observation in cometary atmospheres is of paramount importance for measuring the outgassing rate, monitor overall comet activity and determine relative abundances of minor gaseous constituents for chemical comparisons between comets. The recent advent of space-based detectors at far infrared and submillimetre wavelengths opened up the possibility of observing cometary water from its rotational transitions. The 1_{10}-1_{01} fundamental line of ortho H_2O at 557 GHz was detected in several comets by the Submillimeter Wave Astronomical Satellite, Odin satellite and the ESA Herschel Space Observatory. This line as well as $H_2{}^{17}O$ and $H_2{}^{18}O$ lines will be observed by the ESA Rosetta probe.

The European Space Agency Rosetta Spacecraft was launched on March 2, 2004 toward comet 67P/Churyumov-Gerasimenko. One of the scientific instruments on the Rosetta orbiter is a millimeter/submillimeter radiometer and spectrometer named MIRO (Microwave Instrument for the Rosetta Orbiter). This instrument will be used to study the evolution of four volatile species – CO, CH_3OH, NH_3 and three isotopologues of water, $H_2{}^{16}O$, $H_2{}^{17}O$ and $H_2{}^{18}O$ in comet 67P as a function of heliocentric distance. The MIRO experiment will use these species as probes of the physical conditions within the coma. The basic quantities measured by MIRO are the sub-surface temperature, gas production rates and relative abundances, and velocity and excitation temperature of each species, along with their spatial and temporal variability. This information will be used to infer coma structure and outgassing processes, including the nature of the nucleus/coma interface.

2. The Model

The main excitation mechanisms of the H_2O molecule are collisional excitation and radiative pumping of the fundamental bands of vibration by the solar infrared flux. The former mechanism dominates in the inner coma and leads to thermal equilibrium. The latter leads to a rotationally cold fluorescence equilibrium in the outer coma. In general case optical depth effects cannot be neglected.

Several models have been developed to prepare and interpret observations of water rotational lines in cometary atmospheres (e.g. [1-3,5]). The models [1-3] were developed for spherically symmetric atmospheres. Radiation transfer was treated with the local approximation using the escape probability method [1] or on the base of the accelerated Monte Carlo method [2,3]. Extension in 3D of the former method is not evident, the latest method is readily extensible in 3D (therewith it is more exact from a physical point of view), but it is much more CPU time-demanding. In the model [5] gas distribution was obtained from 3D gas dynamical simulations but the excitation state of the water molecules corresponds to the local thermodynamical equilibrium distribution.

In the present 3D model the radiation transfer in cometary atmosphere is treated on the base of the accelerated Monte Carlo method [4]. The distributions of water density and velocity in the coma were taken from gas dynamical 3D calculations performed for 67P at 3 AU from the Sun for a mixture of CO and H_2O with total gas production rate ~10^{26}-10^{27} s^{-1} [6]. The excitation model takes in to account the seven lowest rotational levels of ortho-water, which are the primarily populated levels in the rotationally cold coma. Collisions with water and electrons (via scaling of observational data of 1P/Halley), and infrared pumping, were considered.

3. Summary

We present the results of numerical simulations of the emergent line profiles (the synthetic line profiles) of the fundamental rotational line 1_{10}-1_{01} of water, $H_2^{17}O$ and $H_2^{18}O$ that could be obtained by MIRO during the approach of comet 67P. Simulations were provided for several spacecraft-nucleus surface distances for nadir and limb viewing. The aim of the study was to reveal the influence of gas coma structure on the synthetic line profiles and thereby to assist in analyzing of observations.

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