

Water Ortho-to-Para Ratio in Comet 67P/Churyumov-Gerasimenko from VIRTIS/Rosetta Observations

V. Debout (1), D. Bockelée-Morvan (1), S. Erard(1), C. Leyrat(1), F. Capaccioni(2), G. Filacchione(2), P. Drossart(1), G. Arnold(3), N. Biver(1), J. Crovisier(1), T. Encrenaz(1), E. Quirico(4), B. Schmitt(4), and the VIRTIS team .

(1) LESIA, Observatoire de Paris/CNRS/UPMC/Université Paris-Diderot, Meudon, France, (2) IAPS-INAF, Via del Fosso del Cavaliere 100, I-00133 Rome, Italy, (3) Institute for Planetary Research, Deutsches Zentrum für Luft- und Raumfahrt (DLR), Berlin, Germany, (4) Laboratoire de Planétologie de Grenoble (LPG) - University Joseph Fourier, Grenoble, France.

Abstract

The ν_3 vibrational band of H_2O at 2.67 μm was observed with the high spectral-resolution channel of the Visible InfraRed Thermal Imaging Spectrometer (VIRTIS-H) onboard Rosetta. The spectral resolution is adequate to resolve the rovibrational structure of the band. High signal-to-noise ratios allow us to measure both the rotational temperature and the ortho-para ratio of water (OPR) in comet 67P/C-G. The measured OPR value will be presented and compared to measurements obtained in other comets from ground-based and space telescopes.

1. Introduction

Molecules with H atoms at symmetrical positions may exist in different nuclear-spin species, e.g. ortho and para species for molecules with two H atoms. The ortho-para ratio (OPR) of water has been measured in several comets from high and medium resolution spectroscopy in the infrared [2, 6, 7]. Most measurements indicate a spin temperature within 25–35 K, though some comets exhibit higher spin temperatures, corresponding to an equilibrated OPR. No relationship was found between the spin temperature and the comet dynamical origin, or with the heliocentric distance at which the comets were observed, and their volatile composition. Unequilibrated spin temperatures might be related to the temperature environment of the species in the nucleus or even before, i.e., they could indicate that molecules formed at ~30 K or were last processed at about 30 K [2]. However, quantum mechanics calculations show that the inter-conversion between para and ortho H_2O states is very fast inside the ice [3], so that the actual spin temperatures measured in cometary atmospheres might depend both on the ice temperature and of the evaporation history of the ice. Thermal desorption might be more efficient for para-

water than for ortho-water according to [8]. Experiments show that thermal desorption could clear the memory of the OPR stabilized at low ice temperature (see review of [9]).

2. VIRTIS-H observations

Since July 2014, the Visual IR Thermal Imaging Spectrometer (VIRTIS) onboard the ESA's Rosetta spacecraft has intensively observed comet 67P/Churyumov-Gerasimenko [4]. VIRTIS is composed of two channels, –M for mapping and –H for high resolution, working in the 0.25–5 μm and 2–5 μm wavelength domains, respectively [5]. Limb observations were carried out to obtain spectra of the coma, and to detect fluorescence emissions of gas phase species. The ν_3 vibrational band of H_2O at 2.67 μm was detected in mid-October 2014 using VIRTIS-H, and is observed regularly since then [1] including from VIRTIS-M [3].

A sample VIRTIS-H spectrum of the water band acquired when the water production rate was typically 10^{26} mol/s is shown in Fig. 1. This spectrum is an average of the observations acquired from December 2014 to January 2015 and has a signal-to-noise on the band area larger 100 [1]. Similar SNRs were obtained in March 2015 for typical total integration times of 3–4 h due to the increasing activity of the comet and increased fluorescence emission related to closer distance to the Sun.

3. Ortho/para ratio

Determining the OPR from the VIRTIS-H spectrum requires modelling the fluorescence emission of the water ν_3 band, following, e.g., [6, 7] who determined the OPR in comets C/1995 O1 (Hale-Bopp) and 103P/Hartley 2 from observations with the Infrared Space Observatory of the same water band with

similar spectral resolution as VIRTIS-H. Weak water bands present rovibrational lines blended with v_3 lines (Fig. 1), and their contribution requires to be considered for best accuracy in the OPR determination. A model considering the optical thickness of the v_3 water lines is used for analysing observations obtained near perihelion. The OPR inferred value and possible variations in the coma will be presented and compared to values measured in other comets.

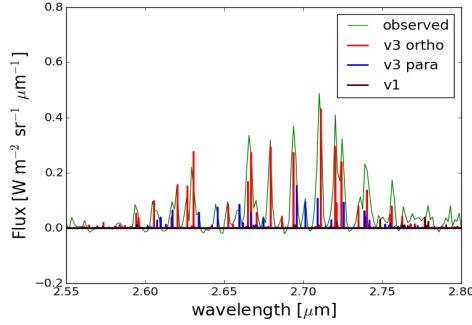


Figure 1: VIRTIS-H spectrum of the $2.7\text{ }\mu\text{m}$ band of water (green). Data from 4 December 2014 to 24 January 2015. A fluorescence spectrum with infinite spectral resolution is shown with ortho and para lines in red and blue, respectively. This range presents also lines of the water v_1 band (black) and of water hot bands.

Acknowledgements

The authors would like to thank the following institutions and agencies, which supported this work: Italian Space Agency (ASI-Italy), Centre National d'Etudes Spatiales (CNES, France), Deutsches Zentrum für Luft und Raumfahrt (DLR, Germany), National Aeronautic and Space Administration (NASA-USA) Rosetta Program, Science and Technology Facilities Council (UK). VIRTIS has been built by a consortium, which includes Italy, France and Germany, under the scientific responsibility of the Istituto di Astrofisica e Planetologia Spaziali of INAF, Italy, which guides also the scientific operations. The VIRTIS instrument development has been funded and managed by ASI, with contributions from Observatoire de Paris financed by CNES, and from DLR.

References

- [1] Bockelée-Morvan, D., Debout, V., Erard, S. et al. : First observations of H_2O and CO_2 vapour in comet 67P/Churyumov-Gerasimenko with VIRTIS onboard Rosetta, *A&A*, submitted, 2015.
- [2] Bonev, B. P., Mumma, M. J., Villanueva, G. L., et al. A Search for Variation in the H_2O Ortho-Para Ratio and Rotational Temperature in the Inner Coma of Comet C/2004 Q2 (Machholz), *ApJ* 661, L97, 2007.
- [3] Buntkowsky, G., Limbach, H. H., Walaszek, B., et al. 2008, *Z. Phys. Chem.* 222, 1049
- [4] Capaccioni, F. et al.: The organic-rich surface of comet 67P/Churyumov-Gerasimenko as seen by VIRTIS/Rosetta, *Science* 347, 2015.
- [5] Coradini, A., Capaccioni, F., Drossart, P., et al.: An Imaging Spectrometer for the Rosetta Mission, *Space Science Reviews*, 128, 529, 2007.
- [6] Crovisier, J., and 11 colleagues: ISO spectroscopic observations of short-period comets. The Universe as Seen by ISO 427, 161, 1999.
- [7] Crovisier, J., Leech, K., Bockelee-Morvan, D., et al.: The spectrum of Comet Hale-Bopp (C/1995 01) observed with the Infrared Space Observatory at 2.9 AU from the Sun. *Science* 275, 1904-1907, 1997.
- [8] Dulieu, F.: Water Ice Formation and the O/P Ratio. *IAU Symposium* 280, 405, 2011.
- [9] Hama, T., Watanabe, N.: Surface Processes on Interstellar Amorphous Solid Water: Adsorption, Diffusion, Tunneling Reactions, and Nuclear-Spin Conversion. *Chemical Reviews* 113, 8783, 2013.