OBSERVATIONS OF THE WATER LINE AT 557 GHz

IN COMETS

WITH THE ODIN SATELLITE

Nicolas Biver[1,2], **Alain Lecacheux**[3], **Jacques Crovisier**[4], **Dominique Bockelée-Morvan**[5], **Hans Rickman**[6], **Urban Frisk**[7], **Åke Hjalmarsson**[8], **Lennart Nordh**[9], **Michael Olberg**[10], **Aage Sandqvist**[11], **Fredrik von Scheele**[12] and **the ODIN Science Team**

[1] *LESIA, CNRS FRE 2461, Observatoire de Paris, 5 pl. J. Janssen, F-92195 Meudon Cedex, France – E-mail:Nicolas.Biver@obspm.fr*
[2] *and ESA-ESTEC, SCI-SB, Keplerlaan 1, NL-2200 AG, Noordwijk, The Netherlands*
[3] *as (1) above – E-mail: Alain.Lecacheux@obspm.fr*
[4] *as (1) above – E-mail: Jacques.Crovisier@obspm.fr*
[5] *as (1) above – E-mail: Dominique.Bockelee@obspm.fr*
[6] *Uppsala Astronomical Observatory, Box 515, SE-751 20 Uppsala, Sweden – E-mail: hans.rickman@astro.uu.se*
[7] *Swedish Space Corporation, PO Box 4207 SE-171 04 Solna, Sweden – E-mail: ufr@ssc.se*
[8] *Onsala Space Observatory, SE-439 92 Onsala, Sweden – E-mail: hjalmar@oso.chalmers.se*
[9] *Swedish National Space Board, Box 4006 SE-171 04 Solna, Sweden – E-mail: lennart.nordh@snsb.se*
[10] *as (8) above – E-mail: olberg@oso.chalmers.se*
[11] *Stockholm Observatory, S-133 36 Saltsjobaden, Sweden – E-mail: aage@astro.su.se*
[12] *as (7) above – E-mail: fvs@ssc.se*

ABSTRACT

ODIN is a small astronomical/aeronomical satellite which was launched in February 2001. One of its capacities is the observation of the 1_{10}–1_{01} line of water at 557 GHz with a high spectral resolution (corresponding to 80 m s^{-1}) and a spatial resolution of 2 arcmin. The measurement of the 557 GHz line intensity in comets provides an estimation of the water production rate. The line width gives a direct evaluation of the coma expansion velocity. The line centre position and shape are affected by the anisotropy of the outgassing and by optical depth effects.

INTRODUCTION

ODIN is a small (240 kg) dual-mission satellite for both astronomical and atmospheric measurements at submillimetre/millimetre wavelengths. The main instrument on ODIN is a radiometer equipped with 4 receivers tunable in the 486–580 GHz frequency range, and a fixed-tuned receiver at 118.8 GHz dedicated to the O_2 line. These receivers are based on Schottky mixers cooled at 140 K. The system temperature of the submillimetre receivers is about 3000 K. All receivers can operate simultaneously and are fed by a 1.1 m off-axis telescope. Two reference beams, about 30° aside the main beam, can be used for the subtraction of the background signal during observations in the "Dicke switching" mode. In the submillimetre range (0.5 mm), the main beam size is about 2.2' and the beam efficiency is about 85%, as measured on Jupiter maps. ODIN was successfully launched on Feb. 20.3, 2001 from Svobodny in eastern Russia, on a Start-1 rocket. It is orbiting the Earth on a 97 min Sun-synchronous polar orbit at 600 km altitude.

Half of the time is used for observation of the Earth atmosphere and the other half for astronomical programmes. Astronomical targets can be observed when in the 60–120° elongation range from the Sun, and about 60 min per orbit.

The back-end is composed of three spectrometers: one acousto-optical spectrograph (AOS, 1.05 GHz bandwidth, 1.0 MHz resolution) and two splittable autocorrelators, with a maximum total bandwidth of 800 MHz at 1.2 MHz resolution, or 100 MHz at 140 kHz resolution.

COMETARY OBSERVATIONS

One of the astronomical objectives of ODIN is to observe with high spectral resolution the fundamental $1_{10} - 1_{01}$ H_2O line at 556.936 GHz in comets. Water is the main constituent of cometary nuclear ices, and its sublimation drives the

activity of comets close to the Sun. Its observation from the ground is difficult due to the terrestrial atmospheric opacity. The 557 GHz H_2O line is the strongest cometary line in the radio spectrum.

The configuration generally adopted for comet observations uses two receivers at 556.9 GHz in parallel, alternately observing the target and the reference beam. Each receiver is hooked up to an autocorrelator at its highest resolution setting (corresponding to 80 m s^{-1}). One receiver also is connected to the AOS. The rms typically achieved in one orbit is 0.14 K km s^{-1} in the main beam brightness temperature scale (T_{mB}) over the width of a cometary line. This sensitivity enables the 5-σ detection of a comet with a water outgassing rate of 10^{28} molec. s^{-1} at 1 AU from the Sun and the Earth. Such an outgassing rate is typical of active short-period comets. The H_2O 557 GHz line was first detected in comets in 1999, by the Submillimeter Wave Astronomical Satellite SWAS [1]. ODIN offers higher spatial resolution and higher sensitivity.

After one year in orbit and long commissioning activities, ODIN successfully detected and mapped three comets, two of which (C/2001 A2 and C/2000 WM1 (LINEAR)) being newly discovered comets with remarkable activity. The intensity of the water line in C/2001 A2 (LINEAR) [2] was one of the strongest among all astronomical targets available for ODIN observations in late June 2001. This line was used as a pointing source calibrator during commissioning activities. A summary of the comets observed until March 2002 is given in Table 1. Thanks to the high sensitivity of ODIN, these comets were detected with high signal-to-noise ratios.

The ODIN observations were coordinated with millimetre and submillimetre observations of HCN lines at the 10-m telescope of the Caltech Submillimeter Observatory (CSO) and at the 30-m telescope of the Institut de Radioastronomie Millimétrique (IRAM). The 18-cm lines of OH were also monitored on a daily basis with the Nançay radio telescope at the time of the ODIN observations. OH is the main photodissociation product of water in cometary coma. Its observation permits us to monitor the water outgassing rate of comets.

Table 1: Cometary observations by the ODIN satellite

Dates UT	Comet	Remarks
2001/04/27	C/2001 A2 (LINEAR)	First astronomical observation
2001/06/20–07/07	C/2001 A2 (LINEAR)	Maps as part of commissioning activities
2001/09/22–24	19P/Borrelly	In support of Deep Space 1 flyby
2001/11/05	19P/Borrelly	
2001/12/07	C/2000 WM1 (LINEAR)	Map, simultaneous with CSO observations
2002/03/12	C/2000 WM1 (LINEAR)	

RESULTS

Figure 1 shows the spectrally resolved H_2O $1_{10} - 1_{01}$ line in comet C/2001 A2 (LINEAR). The frequency scale has been converted in relative Doppler velocity with respect to the comet nucleus velocity. The line width is indicative of gas outflow velocities on the order of 0.8 km s^{-1}. The superimposed HCN J(3–2) line observed with the CSO in Hawaii is relatively symmetric, which indicates that the outgassing of the comet nucleus is almost isotropic. In contrast, the water line is strongly asymmetric and displays a mean velocity offset of about +0.2 km s^{-1}. Such asymmetry was expected from modelling, which predicts a line optical depth of about 4 and self-absorption in the foreground of the coma.

The brightness distribution of the H_2O line was mapped in comets C/2001 A2 and C/2000 WM1. This was possible because of the close proximity of the comets, the good spatial resolution (2.2 arcmin) of ODIN, and the strength of the line in these comets. The water line was detected up to 6 arcmin (about 3 beams) from the nucleus position in comet C/2001 A2. A map of comet C/2000 WM1 is shown in Fig. 2. The variation of the line intensity with beam offset, together with the line shape, provide us with complementary information on radiation trapping effects and collision processes which affect the excitation of cometary water and its emission. Available models are still approximate and will have to be improved to fit these observational constraints.

Preliminary analysis lead to water production rates in good agreement with measurements obtained with other techniques.

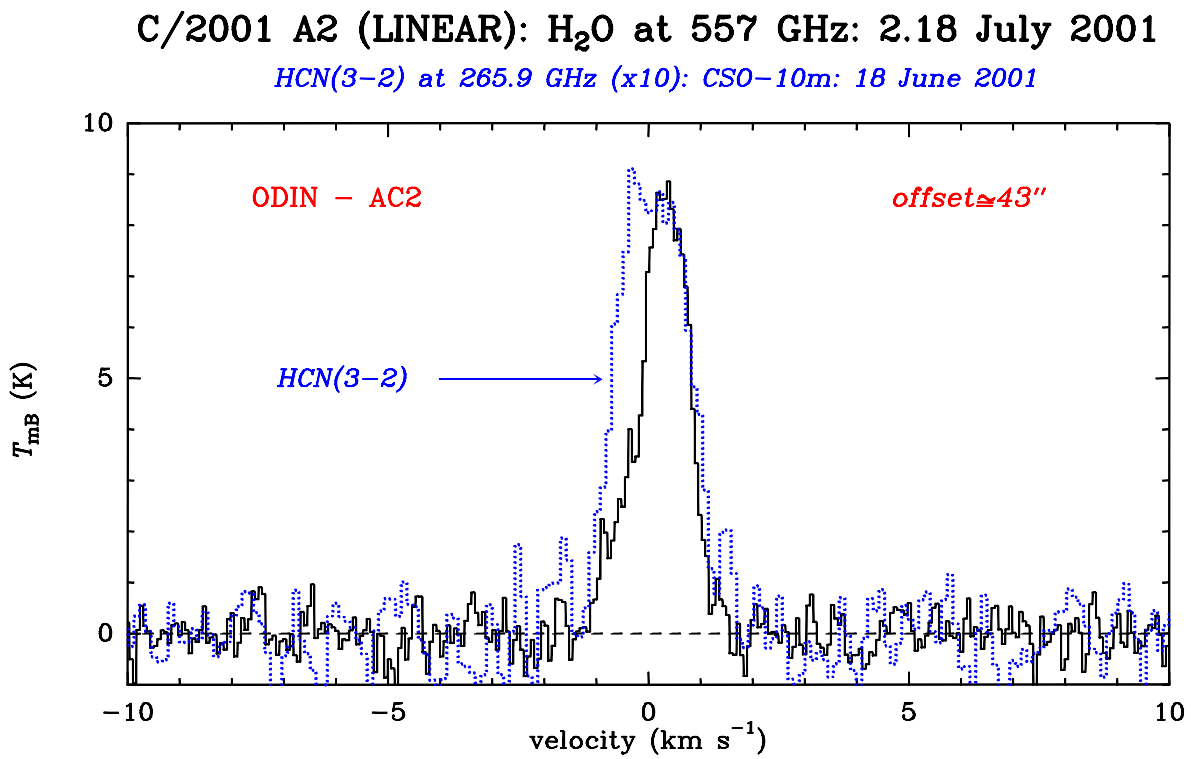

Figure 1: Comparison of the optically thick (red-shifted by self-absorption) water line in comet C/2001 A2 (LINEAR) observed by ODIN and optically thin HCN J(3–2) line at 265.9 GHz observed from the ground with the CSO telescope.

ACKNOWLEDGEMENTS

ODIN (http://www.snsb.se/odin/odin.html) is a Swedish-led satellite project funded jointly by the Swedish National Space Board (SNSB), the Canadian Space Agency (CSA), the National Technology Agency of Finland (Tekes) and Centre National d'Etudes Spatiales (CNES, France). The Swedish Space Corporation has been the industrial prime contractor. The french participants acknowledge the scientific and technical support provided by the CNES.

REFERENCES

[1] D.A. Neufeld, J.R. Stauffer, E.A. Bergin, S.C. Kleiner, B.M. Patten et al., " Submillimeter Wave Astronomy Satellite observations of water vapor toward Comet C/1999 H1 (Lee)", *Astrophys. J. Letters*, vol. 539, L151–L154, 2000.
[2] A. Lecacheux, "Comet C/2001 A2 (LINEAR)", *IAU Circ*, 7706, 2001.

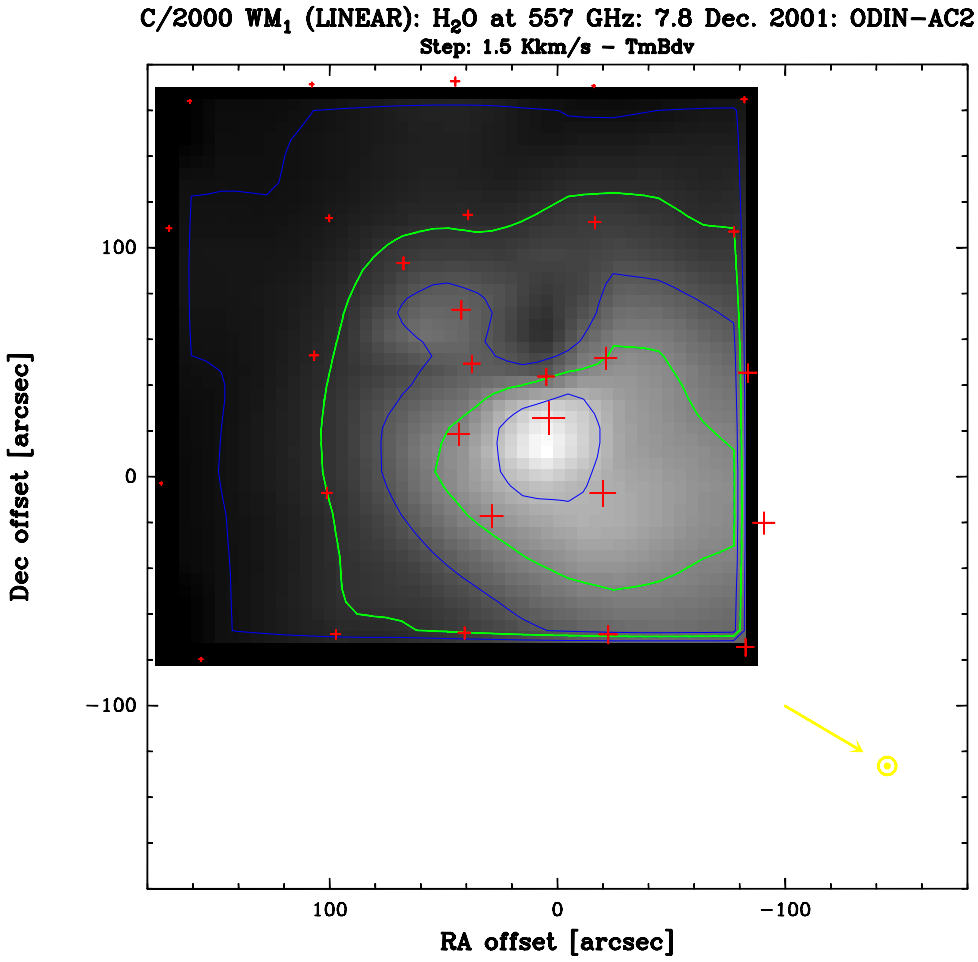

Figure 2: Re-gridded and interpolated map of the 557 GHz water line in comet C/2000 WM1 (LINEAR) observed with the ODIN satellite. Crosses show the position of the individual measurements. Their size is proportional to the line integrated intensity. The depleted feature at a declination offset of +70 arcsec is likely due to the irregular map gridding.