Sensitive Upper limits of gaseous H_2O on Asteroids (65) Cybele and (24) Themis using Herschel HIFI

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The detection of water ice on Asteroids (65) Cybele and (24) Themis and comet-like activity on some asteroids have provided evidence for water ice in the outer asteroid belt. This supports the suggestion that water in the Earth's oceans may have been delivered from the outer asteroid belt. We used the Herschel HIFI Instrument (Wide Band Spectrometer (WBS) and High resolution Spectrometer (HRS)) to observe (65) Cybele on the 21st December 2012 and (24) Themis on the 30th January 2013. In both cases, the line emission from the fundamental ortho-H2O 1_{1-0} - 1_{0-1} line of ortho-water at 556.936 GHz was searched for in the upper sideband of the HIFI band 1a mixer. Although for both asteroids no water signal was detected, very sensitive 3σ upper-limits were obtained in each case.

1. Background

The detection of water ice on Asteroids (65) Cybele and (24) Themis and comet-like activity on some asteroids have provided evidence for water ice in the outer asteroid belt. This supports the suggestion that water in the Earth's oceans may have been delivered from the outer asteroid belt.

On both (24) Themis and (65) Cybele, rotationally resolved near-IR spectra published by Campins et al (2010)`, Rivkine et al (2010) and Licandro et al (2011) indicated the possible presence of widespread ice on their surfaces (Fig. 1) although an alternative interpretation of the absorption at 3.1 microns has since been suggested.

Observations performed on these two asteroids using ground-based ultraviolet and radio telescopes in the search for sublimation of this ice through OH emission were published in late 2010. However the OH observations could not confirm an exosphere but rather served to provide an upper limit of 10^{28} molec./sec on this emission. Further observations on Themis since then e.g. McKay et al (2016), also have not found evidence but do provide upper limits on water production (4.5 x 10^{27} mol/s).

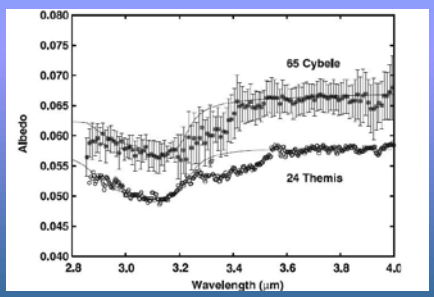

Figure 1: Reflectance spectrum of Cybele and Themis in albedo units. Within the noise, both spectra are very similar. Over-plotted on the spectrum of Themis and Cybele is the spectral model included in Fig. 1 of Rivkin & Emery (2010). These models include a thin coating of H2O ice on surface grains. Notice that models fit very well the left part of the band while at longer wavelengths there are additional absorptions indicative of a difference in the composition of the organics in both asteroids.

3. Our observations

An OT1 proposal from Herschel was accepted to observe these two asteroids. We used the Herschel HIFI Instrument (Wide Band Spectrometer (WBS) and High resolution Spectrometer (HRS)) to observe (65) Cybele on the 21st December 2012 and (24) Themis on the 30th January 2013,. In both cases, the line emission from the fundamental ortho-H2O 1_{1-0} - 1_{0-1} line of ortho-water at 556.936 GHz was searched for in the upper sideband of the HIFI band 1a mixer.

The observations were performed in the Frequency Switching mode with No Reference. This mode has been used with success in a number of different observation campaigns on asteroids & MBCs e.g.. O'Rourke et al, 2013.

4. Data Processing

The HRS and WBS data was taken at level 0 from the Herschel Science Archive and processed in both the HIPE and CLASS data analysis software packages. Steps applied included baseline subtraction, averaging and smoothing the datasets.

Detailed information on all steps performedwill be included in the paper that is now under preparation (O' Rourke et al, 2016, under preparation).

5. HIFI Results

Examples of the averaged spectra for the HRS of both (65) Cybele and (24) Themis are shown in Figure 2

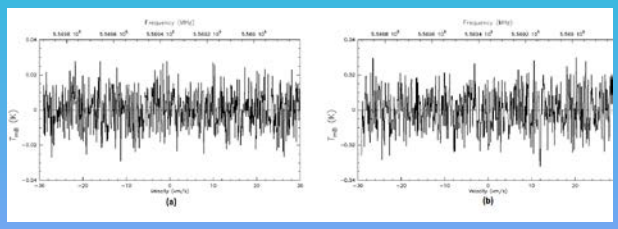

Figure 2 – (a) (65) Cybele and (b) (24) Themis - Averaged spectra of the two orthogonal polarizations of the H_2O line 1_{10}–1_{01} at 556.936 GHz with the HRS spectrometers. The vertical axis is the calibrated main beam brightness temperature and the horizontal axis is the asteroidal centric Doppler velocity.

6. Models - Water Production Rates

We used a molecular excitation model to calculate the population of the rotational levels of water as a function of asteroidal centric distance as well as to derive the production rates.

To derive the production rates, the code includes collisional effects as well as infrared fluorescence by solar radiation. This same version of this model has been utilized to analyze both *Herschel* and ground-based cometary observations (Hartogh et al. 2010, 2011;).

Input parameters to this model included : Gas kinetic temperature (range from 10 to 20K used) and expansion velocity (assumed constant in the coma - an expansion velocity of 0.5 km s^{-11} has been used (Biver et al. 2007, O'Rourke et al 2013)

7. Our Results

	Tmbdv mKkm/s	Water production rate (Q) Molecules/s
(65) Cybele	< 9.3	< 5.4 x 10^{26}
(24) Themis	< 9.6	< 3 x 10^{26}

Although for both asteroids no water signal was detected, very sensitive 3σ upper-limits were obtained in each case – these are presented in table 1.

The final values for these upper limits are being cross-checked at the time of the EPSC/DPS as the values below are being "improved upon" using the most recent calibration and HIPE data analysis.

References: : Campins et al., 2010, Nature, 464, 1320 * Rivkin & Emery, 2010, Nature, 464,1322; * Licandro et al., 2011, A&A 525, A34 *Mckay et al, 2016, Icarus, submitted * O'Rourke et al, 2013, ApJ, 774:L13 * Hartogh et al, 2010, AA, 518, L150 * Biver, N., et al. 2007, P&SS, 55, 1058 * O'Rourke et al, 2013, A&A 560, A101