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Herschel/HIFI determination of an upper limit for the water outgassing rate of active main-belt comet P/2012 T1 (PANSTARRS)

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1. Introduction: Recently, several objects showing cometary activity around perihelion have been found on asteroidal orbits in the asteroid main-belt ([1] Hsieh & Jewitt 2006; [2] Jewitt et al. 2009; [3] Moreno et al. 2010). They are called main-belt comets (MBCs) of which 7 have now been discovered. The seventh, P/2012 T1 (PANSTARRS), being discovered in October 2012.

While sublimation of water ice in main-belt objects is strongly implied by MBC activity, gas has never been directly observed via spectroscopy, though attempts have been made ([4] Hsieh et al. 2012a,b, [5] de Val-Borro et al. 2012a). Given the difficulty of detecting weak, distant, and transient gas emission, these non-detections do not rule out the presence of gas. A bright and actively sublimating MBC offers the unique opportunity to unambiguously confirm the presence of sublimating volatile material in a main-belt object, and thus confirm the plausibility of ice in all of the other MBCs. This would strongly validate the potential MBCs are believed to have, for tracing the volatile content of the inner solar system.

The MBC P/2012 T1 (Panstarrs) was discovered on the 6th October by the 1.8 m Pan-STARRS1 (PS1) survey telescope on Haleakala with follow up images confirming the object to be cometary in nature with a 10"-15"-long tail ([6] Wainscoat et al. 2012).

2. Observations performed on MBC P/2012 T1 (PANSTARRS) : The MBC P/2012 T1 was observed with the Heterodyne Instrument for the Far Infrared (HIFI; [7] de Graauw et al. 2010), one of the three instruments onboard the ESA Herschel Space Observatory ([8] Pilbratt et al. 2010), using 5 hours of Director Discretionary Time (DDT). On the basis of its obvious and ongoing activity following its perihelion passage, the MBC was observed by Herschel on UT 16.31 January 2013 with a total on-target integration time of 4.8 h, when it was at a heliocentric distance of 2.5 AU and a distance of 2.06 AU from the satellite (Herschel ObsID 1342259756). The object was tracked using an up-to-date ephemeris provided by the JPL Horizons system. It had passed its perihelion in early September 2012. The line emission from the fundamental ortho-H_2O 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 observation was performed in the frequency-switching observing mode with a frequency throw of 94.5 MHz, using both the wide band spectrometer (WBS) and the high-resolution spectrometer (HRS).

In addition to the Herschel DDT observation, we also requested and were awarded DDT to take a context broad band image of the MBC on the 15th January 2013 using the VLT FORS2 detector, in support of the Herschel observation. The image had a duration of 3x300s integration time with a V band exposure. The resultant image showed the comet to be still clearly active (Figure 1).

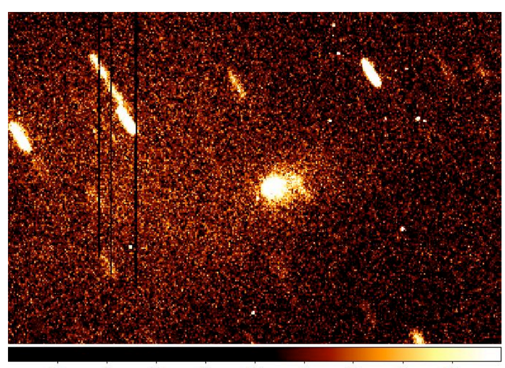

Figure 1 : VLT FORS2 observation of MBC P/2012 T1 (PANSTARRS)

3. Summary of data processing : The data analysis was performed using the Herschel interactive pro-

cessing environment (HIPE) software package ([9] Ott 2010). The standard HIFI processing pipeline v9.2 was used to reduce the data to calibrated level-2 data products. We averaged the horizontal and vertical polarization spectra to increase the signal-to-noise ratio. The frequency switching observing mode introduces a strong baseline ripple. To obtain a reliable estimate of the noise present in the measured data, the baseline has to be removed, which is usually accomplished by a least-squares fitting of a linear combination of sine waves. We applied the Lomb-Scargle periodogram method (initially proposed by [10] Lomb 1976, and additionally developed by [11] Scargle 1982) to the HRS and WBS spectra and fitted the baseline ripple using the strongest peaks in the frequency spectrum.
The reduction methods applied to the baseline removal and denoising of the Herschel/HIFI data is described in detail in [5] de Val-Borro et al 2012. We show the baseline subtracted HRS spectrum in Figure 2.

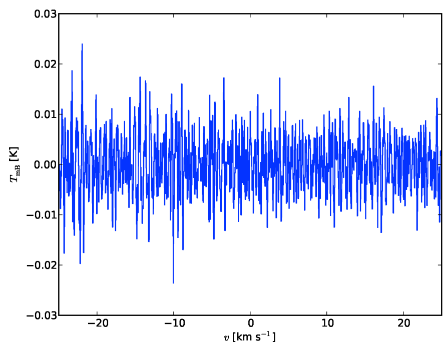

Figure 2 : Baseline subtracted HRS spectrum obtained by averaging the two orthogonal polarisations for the HIFI observation of MBC P/2012 T1 (PANSTARRS). The vertical axis is the calibrated main beam brightness
temperature and the horizontal axis is the cometocentric velocity.

4. Data Analysis : Upon analysing our data, we found no detection of H2O in our observation, although it was expected that the objects dust emission activity would be driven by the sublimation of subsurface material. The VLT image shows that the comet was still active at the time of our observation.
A molecular excitation model based on the publicly available accelerated Monte Carlo radiative transfer code ratran ([12] Hogerheijde & van der Tak 2000) has been used to calculate the population of the rotational levels of water as a function of the nucleocentric distance. The code includes collisional effects and infrared fluorescence by solar radiation to derive the production rates.

We used the one-dimensional spherically symmetric version of the code following the description outlined in [13] Bensch & Bergin (2004) that has been used to analyse Herschel and ground-based cometary observations (see e.g. [14] Hartogh et al. 2011; [15,5] de Val-Borro et al. 2010, 2012). The model input parameters are the gas kinetic temperature, which controls the molecular excitation in the collisional region, and the electron density. We assume a gas kinetic temperature in the range of 10 to 20K. In addition, we used the following excitation parameters as input to the model : Expansion velocity of v_{exp}=0.5 km/s, an electron density scaling factor (x_{ne}) = 0.2, beta0(H_2O)=1.36E-5 and a pointing offset = 3.5".
For a low expansion velocity characteristic of weak comets, with a gas kinetic temperature of 20K, we derive a first approximation (with analysis continuing) for the water production rate of < 7.3 x 10^{25} mol s^{-1} from the WBS and HRS data, with a column density < 1.54E^{11} cm^{-2}**.**

5. Conclusions: recognising that (a) the MBC was determined to be active at the time of the Herschel observation (b) Herschel did not detect gaseous H_2O water (c) an upper limit has been provided, it is our conclusion that if ice sublimation occurred at the time of our observation, the water production rate was < 7.3 x 10^{25} mol s^{-1}.

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