An upper limit for the water outgassing rate of the main-belt comet 176P/LINEAR observed with *Herschel*

P. Hartogh[1], M. de Val-Borro[2], L. Rezac[1], N. Biver[3], D. Bockelée-Morvan[3], J. Crovisier[3], M. Küppers[4], D. C. Lis[5], S. Szutowicz[6], G. A. Blake[5], M. Emprechtinger[5], C. Jarchow[1], E. Jehin[7], M. Kidger[8], L.-M. Lara[9], E. Lellouch[3], R. Moreno[3], and M. Rengel[1]

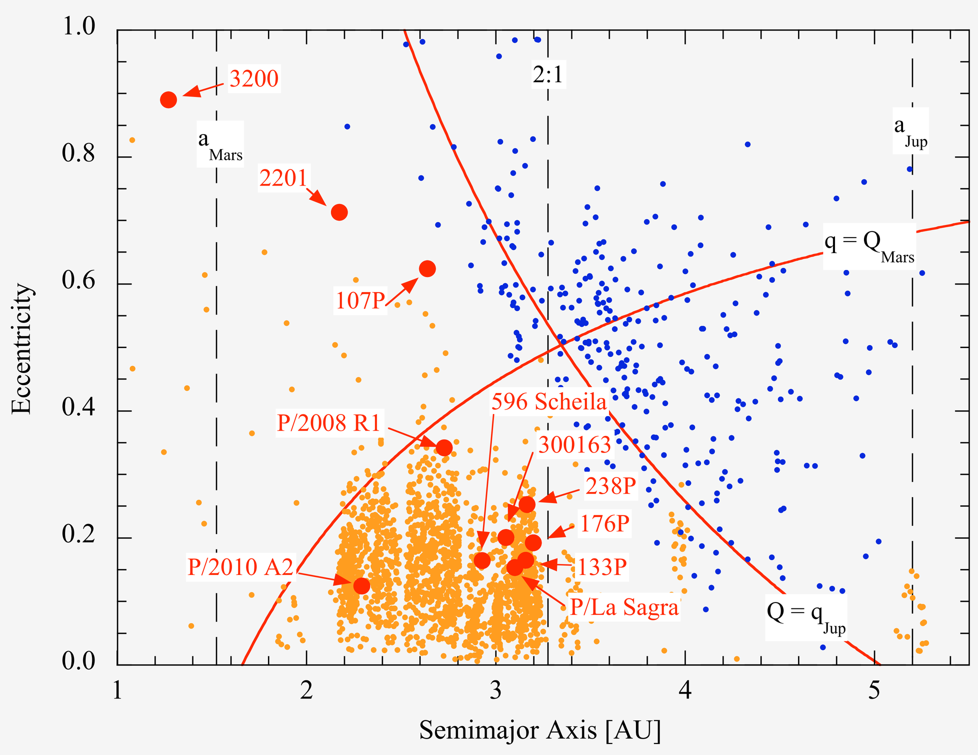
[1]MPS, [2]Princeton University, [3]Observatoire de Paris, [4]ESAC, [5]Caltech, [6]Polish Academy of Sciences, [7]Université de Liège, [8]*Herschel* Science Centre, [9]IAA-CSIC

Abstract

176P/LINEAR is a member of the new cometary class known as main-belt comets (MBCs). It displayed cometary activity shortly during its 2005 perihelion passage, which may be driven by the sublimation of subsurface ices. We have therefore searched for emission of the H_2O 1_{10}–1_{01} ground state rotational line at 557 GHz toward 176P/LINEAR with the Heterodyne Instrument for the Far Infrared (HIFI) onboard the *Herschel* Space Observatory on UT 8.78 August 2011, about 40 days after its most recent perihelion passage, when the object was at a heliocentric distance of 2.58 AU. No H_2O line emission was detected in our observations, from which we derive sensitive 3-σ upper limits for the water production rate and column density of $< 4 \times 10^{25}$ molec. s^{-1} and of $< 3 \times 10^{10}$ cm^{-2}, respectively. From the peak brightness measured during the object's active period in 2005, this upper limit is lower than predicted by the relation between production rates and visual magnitudes observed for a sample of comets at this heliocentric distance. Thus, 176P/LINEAR was most likely less active at the time of our observation than during its previous perihelion passage. The retrieved upper limit is lower than most values derived for the H_2O production rate from the spectroscopic search for CN emission in MBCs.

Main-belt comets

Comets originate in the outskirts of the solar system beyond the snow line, where temperatures in the solar nebula were low enough for water to condense onto icy grains. A new class of bodies has been discovered recently, the so-called main-belt comets (MBCs), which have orbital properties that are indistinguishable from standard asteroids with a Tisserand parameter with respect to Jupiter that is greater than three, and they display cometary activity in the form of a dust tail during part of their orbit. These objects have also been termed "active asteroids". Numerical simulations have shown that these objects are not comets from the Kuiper Belt or Oort Cloud that have been recently transferred to orbits within the main belt, but instead are most likely formed in situ at their current locations. Determining the composition of this class of objects can provide important clues to both the thermal properties that allow water to survive in subsurface layers and the distribution of volatile materials in the solar nebula to constrain planet formation mechanisms. Additionally, MBCs may have played an important role in the delivery of water and other volatiles to the inner solar system, including the Earth.



Orbital eccentricity against semimajor axis for the known main-belt comets (red dots), asteroids (orange dots) and comets (blue dots) from Jewitt (2012).

176P/LINEAR

The MBC 176P/LINEAR was discovered in 1999 and originally categorized as asteroid 118401 LINEAR. This object belongs to the Themis asteroid family. Cometary activity was reported for this object around perihelion in 2005 by the Hawaii Trails project. It displayed a mean photometric excess of $\sim 30\%$ during a month-long active period around its perihelion passage, consistent with an approximate total dust mass-loss of $\sim 7 \times 10^4$ kg (Hsieh et al. 2011). Although ice sublimation is expected to trigger MBC activity, gas emission has never been directly detected in these objects owing to their low activity, which requires very sensitive observations. *Herschel* proves to be the most sensitive instrument for directly observing water in a distant comet. We present the *Herschel* observation of the 1_{10}–1_{01} fundamental rotational transition of H_2O at 557 GHz in 176P, performed within the framework of the *Herschel* guaranteed-time key program "Water and related chemistry in the solar system" (Hartogh et al. 2009). This observation is intended to test the prediction that the observed cometary activity of MBCs is driven by sublimation of water ices and to constrain the production process (de Val-Borro et al. 2012).

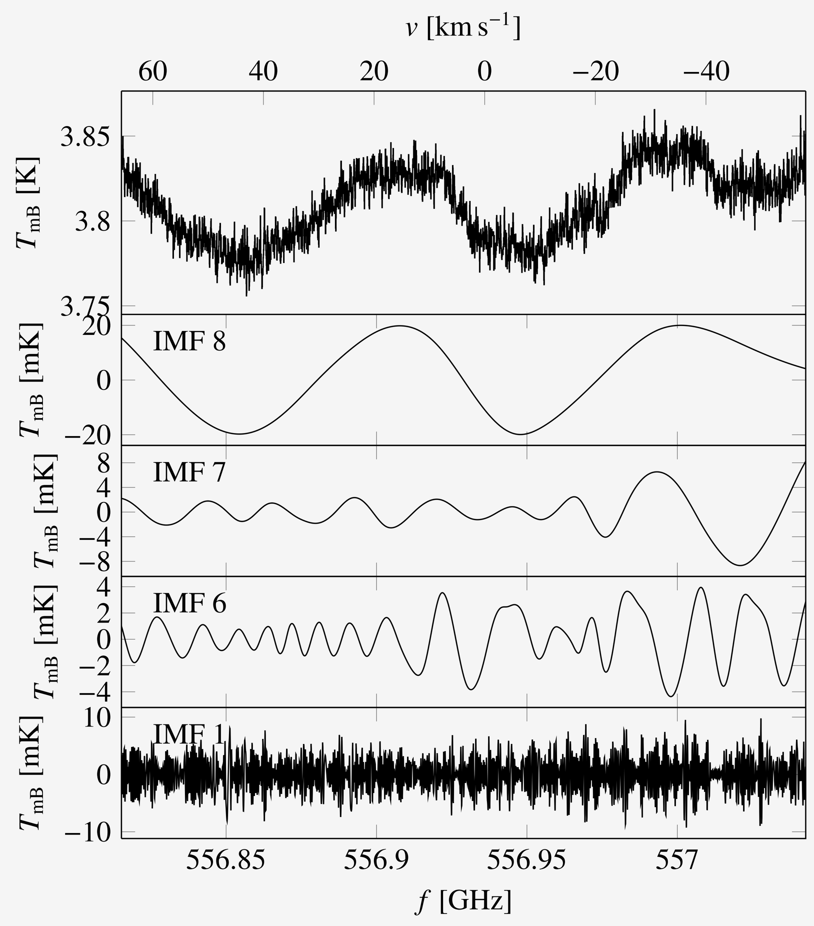
Results

There are several mechanisms that have been proposed to drive mass loss from small bodies, including sublimation of subsurface ices, rotational instability, impact ejection and thermal fracture (see Jewitt 2012, for a review of activation mechanisms). The cometary activity observed in 176P was initially found to suggest the presence of sublimating subsurface ice that may have been exposed by recent collisions. The main results of this work are summarized below:

- From the search for the H_2O 1_{10}–1_{01} rotational line at 557 GHz in 176P, a 3-σ upper limit for the H_2O production rate of $< 4 \times 10^{25}$ molec. s^{-1} is derived from the WBS and HRS data, for gas expansion velocities between 0.4 km s^{-1} to 0.7 km s^{-1} and gas kinetic temperatures between 20 K to 40 K.
- Since the cometary activity in 176P is indicative of ice sublimation with a 30% contribution of the coma to the total brightness, the scaling relation between gas production rates and heliocentric magnitudes from Jorda et al. (2008) predicts a water production rate of approximately 1×10^{26} molec. s^{-1}.
- If ice sublimation is the driving mechanism of 176P's activity, the derived H_2O production rate is too low by about a factor of two to explain the activity level during its 2005 perihelion passage.
- We conclude that water was not detected in our observation because the water production rate was lower than $< 4 \times 10^{25}$ molec. s^{-1} or the object was not active during our observation.

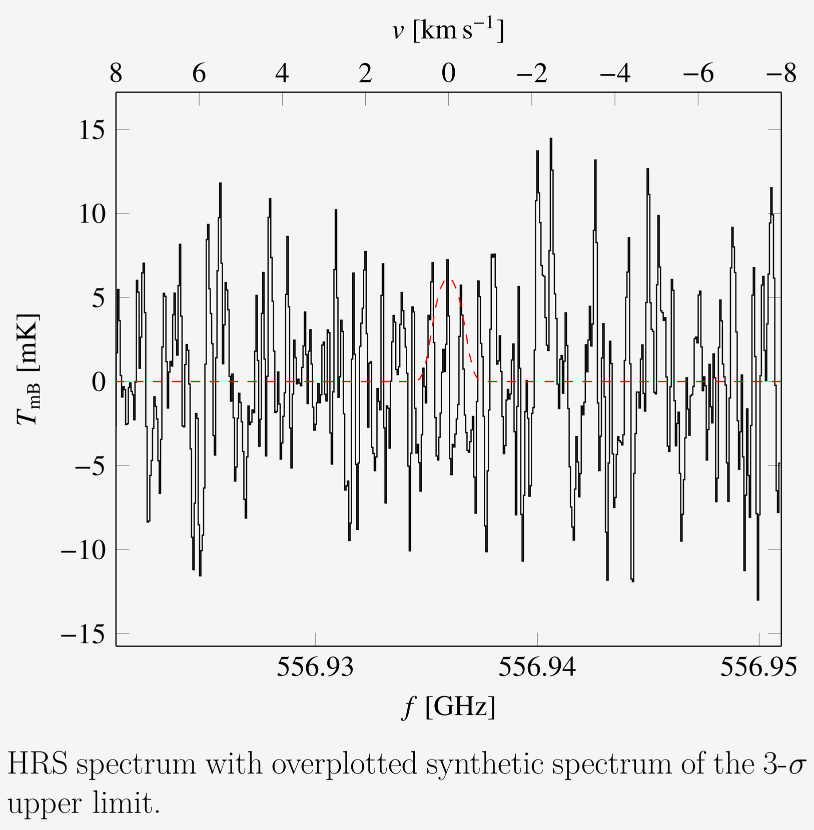
Data analysis

To obtain a reliable estimate of the noise present in the measured data, the baseline has to be removed, which is usually accomplished by fitting a linear combination of sine waves using the Lomb-Scargle periodogram technique. Nevertheless, the instrumental processes responsible for the baseline are in general combinations of linear distortions of different components in the receiver with a small fraction of nonlinear processes, which may cause an aperiodicity in the ripple. Analyzing such contaminated signals by assuming a linear relation among the signal components (a fundamental assumption for all the Fourier-based techniques) is not always suitable, depending on the degree of nonlinearity. We utilize a relatively novel approach specifically developed for analysis of aperiodic and nonlinear signals – the Hilbert-Huang Transform. This approach combines the empirical mode decomposition (EMD) procedure, which decomposes the original signal into its intrinsic mode functions (IMFs; representing the different modes of oscillations) with the Hilbert transform that can be then used in computing the instantaneous frequencies. The EMD technique extracts all the oscillatory modes, including all the baseline ripple components (the smooth low-frequency modes), as well as the highest frequency components, usually the noise. Another important property of IMFs is that they obey a simple additive rule to reconstruct the original signal exactly.



Original HRS spectrum of the H_2O 1_{10}–1_{01} line at 556.936 GHz observed on UT 8.78 August (upper panel), and several low and high frequency components of the spectrum determined using the EMD analysis (four lower panels).

In this work we applied the EMD technique to the measured WBS and HRS spectra to obtain the highest frequency IMFs (dominated by Gaussian noise), which are usually the first modes. There is no evidence of H_2O emission in our observation, although it is expected that the object's dust emission activity is driven by the sublimation of subsurface material as it approaches perihelion. A molecular excitation model based on the publicly available accelerated Monte Carlo radiative transfer code *ratran* is 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. Since the electron density in the coma is not well constrained, an electron density scaling factor of $x_{n_e} = 0.2$ with respect to the standard profile derived from the observations of comet 1P/Halley has been used. The expansion velocity is assumed to be constant in the coma with a value of 0.5 km s^{-1} For low-activity and distant comets an expansion velocity close to 0.5 km s^{-1} is determined from the shapes of the OH line observed with the Nançay radio telescope, but observations $Q_{OH} < 1 \times 10^{28}$ molec. s^{-1} are lacking, and observations at $r_h > 2$ AU are rare. Odin observations of the H_2O 557 GHz line toward the active comet C/2003 K4 (LINEAR) at 2.2 AU from the Sun are consistent with an expansion velocity on the order of 0.5 km s^{-1}.



HRS spectrum with overplotted synthetic spectrum of the 3-σ upper limit.

References

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