Observations of the 18-cm OH lines of comet 103P/Hartley 2 at Nançay in support to the EPOXI and Herschel missions

Jacques Crovisier\textsuperscript{*}, Pierre Colom\textsuperscript{a}, Nicolas Biver\textsuperscript{a}, Dominique Bockelé-Morvan\textsuperscript{a}, Jérémie Boissier\textsuperscript{b,c}

\textsuperscript{a}LESIA – Observatoire de Paris, CNRS, UPMC, Université Paris-Diderot, 5 place Jules Janssen, 92195 Meudon, France
\textsuperscript{b}Istituto di Radioastronomia – INAF, Via Gobetti 101, Bologna, Italy
\textsuperscript{c}ESO, Karl Schwarzschild Str. 2, 85748 Garching bei München, Germany

Abstract

The 18-cm radio lines of the OH radical were observed in comet 103P/Hartley 2 with the Nançay radio telescope in support to its flyby by the EPOXI mission and to observations with the Herschel Space Observatory. The OH lines were detected from 24 September to 15 December 2010. These observations are used to estimate the gas expansion velocity within the coma to \(0.83 \pm 0.08\) km s\(^{-1}\) in October 2010. The water production increased steeply but progressively before perihelion, and reached \(1.14 \pm 0.3 \times 10^{28}\) s\(^{-1}\) just before the EPOXI flyby.

Keywords:
Comets, coma; Comet 103P/Hartley 2; Spectroscopy

1. Introduction

The Jupiter-family comet 103P/Hartley 2 passed perihelion on 28 October 2010 at \(q = 1.059\) AU. It made an exceptional close approach to the Earth just before perihelion on 21 October at \(\Delta = 0.12\) AU, providing us with the best opportunity to observe a Jupiter-family comet since 73P/Schwassmann-Wachmann 3 in May 2006 (Colom et al. 2006, Weaver 2006). It was the target of the EPOXI space mission, with a flyby at 700 km on 4.57 (UT) November 2010 (A’Hearn et al. 2011). For these two reasons, this comet was the object of an international campaign of observations (Colom et al. 2011). It was also the primary target of the cometary programme for the Herschel Space Observatory (Hartogh et al. 2009, 2011).

The observation of the 18-cm radio lines of the OH radical is a convenient way to measure the cometary water production rate and its evolution (Despois et al. 1981, Crovisier et al. 2002). We report here on supporting observations of these lines in comet 103P/Hartley 2 made with the Nançay radio telescope.

2. Observations

The Nançay radio telescope is a meridian instrument with a 3.5 \times 18 arcmin field of view at 18-cm wavelength. The other characteristics of the telescope and the methodology used for the cometary observations and their reduction were described by Crovisier et al. (2002).

Observations of comet 103P/Hartley 2 at Nançay began on 3 August 2010 and were scheduled until the end of January 2011. The first detection of 18-cm OH lines occurred at the end of September with a production rate \(Q[OH] = 0.7 \pm 0.1 \times 10^{28}\) s\(^{-1}\) at a heliocentric distance \(r_h = 1.14\) AU (Crovisier et al. 2010). The comet was detected until 15 December 2010, with episodic gaps due to telescope scheduling, technical problems, or low OH-maser inversion. Excerpts of the results for the 1–21 October period are listed in the top part of Table 1. Results for integrated spectra selected over the entire apparition are listed in the bottom part of Table 1 and shown in Fig. 1. The long-term evolution of the OH production rate is shown in Fig. 2. For a full day-by-day report, see http://www.lesia.obspm.fr/planeto/cometes/basecom/HT/indexht.html.

3. Results and discussion

3.1. Line shape and gas expansion velocity

Our Haser-equivalent model uses standard values of \(0.80\) km s\(^{-1}\) for the OH-parent expansion velocity \(V_p\) and by Crovisier et al. (2010) are based on a Haser-equivalent model (Combi and Delsemme 1980). The excitation of the OH radical assumes the \(r_h\)-dependent maser inversion of the model of Despois et al. (1981) and takes into account collisional quenching. An enhancement of the continuum background as the comet passed across the galactic plane around 15 October was also taken into account as explained by Crovisier et al. (2002).
Table 1: Parameters of the OH spectra of 103P/Hartley 3: individual spectra recorded between 1st and 21 October, and integrated spectra for the entire apparition. For a full log of the spectra, see http://www.lesia.obspm.fr/planete/cometen/basecom/HT/indexht.html.

| date       | \(\Delta\) [AU] | \(r_h\) [AU] | \(\bar{r}_h\) [km/s] | \(i\) (1) | \(i\) (2) | \(T_{bg}\) [K] | \(\int Sdv\) [mJy km/s] | \(S\) [mJy] | \(V_o\) [km/s] | \(\Delta V\) [km/s] | \(Q(\text{OH})\) [10\(^{28}\) s\(^{-1}\)] |
|------------|----------------|--------------|----------------------|--------|--------|-----------|-------------------|------|--------|---------|----------------|
| 10/10/1.00 | 0.18           | 1.12         | -7.9 -0.31 -0.37     | 3.7    | -88 ± 21 -51 ± 10 | 0.71 ± 0.19 | 1.71 ± 0.48 | 0.7 ± 0.2 |
| 10/10/2.00 | 0.18           | 1.12         | -7.7 -0.31 -0.37     | 3.6    | -68 ± 19 -46 ± 9  | -0.15 ± 0.20 | 1.64 ± 0.50 | 0.7 ± 0.2 |
| 10/10/3.01 | 0.17           | 1.11         | -7.4 -0.31 -0.37     | 3.6    | -112 ± 23 -49 ± 10 | -0.07 ± 0.21 | 2.09 ± 0.51 | 0.9 ± 0.2 |
| 10/10/4.01 | 0.17           | 1.11         | -7.2 -0.31 -0.37     | 3.6    | -134 ± 18 -74 ± 10 | 0.08 ± 0.11  | 1.48 ± 0.27 | 0.9 ± 0.1 |
| 10/10/6.03 | 0.16           | 1.10         | -6.6 -0.30 -0.35     | 3.6    | -94 ± 20 -52 ± 9  | -0.06 ± 0.17 | 2.01 ± 0.43 | 0.9 ± 0.2 |
| 10/10/7.03 | 0.15           | 1.10         | -6.4 -0.29 -0.34     | 3.6    | -138 ± 17 -62 ± 8  | -0.18 ± 0.15 | 2.20 ± 0.37 | 1.1 ± 0.1 |
| 10/10/9.05 | 0.15           | 1.09         | -5.8 -0.27 -0.32     | 3.6    | -141 ± 17 -77 ± 9  | -0.11 ± 0.11 | 1.77 ± 0.27 | 1.1 ± 0.1 |
| 10/10/10.06| 0.14           | 1.09         | -5.6 -0.26 -0.31     | 3.7    | -162 ± 15 -87 ± 7  | -0.21 ± 0.08 | 1.86 ± 0.20 | 1.4 ± 0.1 |
| 10/10/11.07| 0.14           | 1.09         | -5.3 -0.25 -0.30     | 3.8    | -88 ± 18 -62 ± 13  | -0.07 ± 0.15 | 1.54 ± 0.35 | 0.8 ± 0.2 |
| 10/10/12.08| 0.13           | 1.08         | -5.0 -0.24 -0.29     | 3.9    | -186 ± 19 -75 ± 9  | 0.14 ± 0.13  | 2.27 ± 0.34 | 1.6 ± 0.2 |
| 10/10/13.09| 0.13           | 1.08         | -4.7 -0.23 -0.27     | 3.8    | -101 ± 16 -68 ± 9  | -0.06 ± 0.12 | 1.71 ± 0.29 | 1.2 ± 0.2 |
| 10/10/14.10| 0.13           | 1.08         | -4.4 -0.22 -0.26     | 3.8    | -134 ± 21 -82 ± 9  | -0.16 ± 0.11 | 1.68 ± 0.27 | 1.6 ± 0.2 |
| 10/10/15.10| 0.13           | 1.07         | -4.1 -0.21 -0.24     | 4.2    | -123 ± 18 -70 ± 8  | -0.04 ± 0.11 | 1.73 ± 0.26 | 1.4 ± 0.2 |
| 10/10/17.12| 0.13           | 1.07         | -3.5 -0.18 -0.20     | 3.6    | -99 ± 17 -61 ± 9   | -0.11 ± 0.15 | 1.66 ± 0.37 | 1.7 ± 0.3 |
| 10/10/18.13| 0.13           | 1.07         | -3.2 -0.16 -0.18     | 3.7    | -79 ± 15 -47 ± 8   | 0.03 ± 0.16  | 1.83 ± 0.39 | 1.6 ± 0.3 |
| 10/10/19.13| 0.12           | 1.07         | -2.9 -0.14 -0.15     | 3.5    | -64 ± 20 -50 ± 11  | -0.11 ± 0.14 | 1.09 ± 0.33 | 1.2 ± 0.4 |
| 10/10/20.14| 0.12           | 1.06         | -2.6 -0.12 -0.12     | 3.5    | -72 ± 15 -43 ± 8   | -0.50 ± 0.14 | 1.61 ± 0.35 | 1.7 ± 0.4 |
| 10/10/21.15| 0.12           | 1.06         | -2.2 -0.10 -0.10     | 3.5    | -109 ± 13 -47 ± 6  | -0.16 ± 0.14 | 2.04 ± 0.35 | 2.5 ± 0.3 |

The display of the Table follows that used by Crovisier et al. (2002). The respective columns are the date of the observation (or the date range for the integrated spectra listed in the bottom part of the table); the geocentric distance \(\Delta\); the heliocentric distance \(r_h\); the heliocentric radial velocity \(\bar{r}_h\); the expected inversion \(i\) of the OH maser according to (1) Despois et al. (1981) and (2) Schleicher and A. Heard (1988); the background brightness temperature \(T_{bg}\); the integrated line area \(\int Sdv\); the results of a Gaussian fit to the line: line intensity \(S\), line central velocity \(V_o\), and line width at half-maximum \(\Delta V\); the OH production rate \(Q(\text{OH})\) according to the Haser-equivalent model with collisional quenching described in Crovisier et al. (2002).
and 0.95 km s$^{-1}$ for the OH ejection velocity at photodissociation (Crovisier et al. 2002). However, $V_p$ may be smaller for this weakly productive comet, leading to an over-evaluation of the OH production. Indeed, from Tseng et al. (2007) who undertook a statistical study of the OH line shapes from the Nançay data, we expect $V_p \approx 0.71$ km s$^{-1}$ for a comet with $Q_p \approx 10^{28}$ s$^{-1}$ at $r_h \approx 1.09$ AU. The real value may still be smaller since we are sampling a smaller inner region in this close-by comet.

We thus re-evaluated $V_p$ following the trapezium method of Bockelée-Morvan et al. (1990), from the average spectrum of 4–15 October obtained at $r_h = 1.09$ AU and $\Delta = 0.14$ AU (Fig. 3) (this method requires a line shape observed with a high signal-to-noise ratio and can
rate, 9P/Tempel 1 was then at ∆ = 0 (Biver et al. 2007). With a comparable OH production at Nançay which could only integrate one hour per day to a long integration (Howell et al. 2007), but not at detected with the 100-m Green Bank telescope thanks and maser inversion around 5 July 2005. It could be then detected with the Herschel with the three instruments of (Knight and Schleicher 2012), of H from the Ly-α line ob-

3.2. The radio OH observations at the time of the EPOXI flyby

Comet 103P/Hartley 2 could be detected in the period 30 October–2 November, just after perihelion and just before the EPOXI flyby, when \( \dot{r}_h \approx 1.1 \text{ km s}^{-1} \), corresponding to a weakly positive OH inversion (0.04–0.10). The OH production rate is then estimated to \( 1.7 \pm 0.3 \times 10^{28} \text{ s}^{-1} \).

No observation was possible on 3 and 4 November due to a technical failure. At the very time of the EPOXI flyby (4 November 2010), the expected OH inversion is small and its predictions differ between the [Despois et al. (1981)] and [Schleicher and A’Heen (1988)] models (0.02 and 0.05, respectively). The interpretation of the radio OH observations in terms of production rates is thus difficult at this moment.

Indeed, the detection of comet 103P/Hartley 2 at Nançay at the end of October was favoured by the small geocentric distance. For comparison, comet 9P/Tempel 1 (the target of the Deep Impact mission) had similar \( \dot{r}_h \), and maser inversion around 5 July 2005. It could be then detected with the 100-m Green Bank telescope thanks to a long integration (Howell et al. 2007), but not at Nançay which could only integrate one hour per day (Biver et al. 2007). With a comparable OH production rate, 9P/Tempel 1 was then at at \( \Delta = 0.90 \text{ AU} \), whereas 103P/Hartley 2 was much closer at \( \Delta = 0.14 \text{ AU} \).

3.3. Comparison with other production rates

The water production was directly measured in this comet from submillimetric rotational transitions from space with Odin (Biver et al. 2010, 2011) and with the three instruments of Herschel (Lis et al. 2010; Hartogh et al. 2011; Meech et al. 2011), from ro-vibrational lines in the infrared from the ground (Dello Russo et al. 2010, 2011; Munna et al. 2010, 2011). It was indirectly measured from the observation of its photodissociation products: of OH in the near-UV (Knight and Schleicher 2012), of H from the Ly-α line observed by SOHO/SWAN (Combi et al. 2011).

Published water production rates from these concurrent observations, for dates close to the EPOXI flyby, are listed in Table 2. They range from 0.6 to \( 1.6 \times 10^{28} \text{ s}^{-1} \). The Nançay measurement is on the high side of this spread. The importance of the spread may be attributed to the short-term variation of the comet activity linked to its rotation (see below), but also to the idiosyncrasies of the various models used to interpret the different methods of observation. The large Nançay beam is also more sensitive to water outgassed from icy grains.

3.4. Short- and long-term variations

From many contemporaneous observations — visible imaging, spectrophotometry and radar monitoring — a comet rotation period of 17–18 hours was derived (Jehin et al. 2010; Harmon et al. 2011; Knight and Schleicher 2011; Samarasinha et al. 2011). A strong modulation of the production rates of gas species was observed with the same period (Drahus et al. 2011). For water, the modulation had an amplitude of nearly a factor of two, as was observed by e.g. Odin (Biver et al. 2011).

The short-term variation of the OH production rate observed at Nançay in October 2010 is shown in Fig. 4. One can see a steady increase of the production rate as the comet was approaching the Sun, but no sign of a periodic modulation. This is not unexpected: with a 1-hour observation every day at Nançay, the time variation of the OH production rate was badly sampled. Moreover, temporal variations are averaged over the large beam of Nançay (\( 3.5 \times 18 \text{ arcmin} \)) and smoothed by the progressive photodissociation of water which has a lifetime of approximately one day. It is thus delusive to try to recover a period of the order of one day from the Nançay data, although the 7-day period of comet 1P/Halley could be successfully retrieved in the past (Colom and Gérard 1988).

In the month preceding perihelion, the water production was steeply increasing (Figs 2 and 4), roughly following an \( r_{13}^{-1} \) law. The post-perihelion evolution shows a similarly steep decrease (but not so well constrained due to larger errors). These variations can difficultly be explained by the small variation in the heliocentric distance. A seasonal effect may be suspected, which could be further investigated when the rotational state of the comet and especially its pole orientation will be precisely known.

Figure 4: Evolution of the OH production rate of 103P/Hartley 2 between 1 and 21 October 2010 (this period has been selected because the signal on a single day of observation had a significant signal-to-noise ratio). A power-law model \( r_{13}^{-1} \) is superimposed.

Published water production rates from these concurrent observations, for dates close to the EPOXI flyby, are listed in Table 2. They range from 0.6 to \( 1.6 \times 10^{28} \text{ s}^{-1} \). The Nançay measurement is on the high side of this spread. The importance of the spread may be attributed to the short-term variation of the comet activity linked to its rotation (see below), but also to the idiosyncrasies of the various models used to interpret the different methods of observation. The large Nançay beam is also more sensitive to water outgassed from icy grains.
The water production rate preceding perihelion measured by SOHO/SWAN also shows an increase by a similar amount. But this increase appears to be almost entirely due to a sudden jump — by a factor \( \approx 2.5 - 27 \) days before perihelion (Combi et al. 2011). This jump is not present in the Nançay data for which the rise is progressive.

4. Conclusion

- The 18-cm lines of OH were monitored in comet 103P/Hartley 2 with the Nançay radio telescope from August 2010 to January 2011. They were detected from 24 September to 15 December 2010.

- From the line shapes, we derive an expansion velocity \( V_p = 0.83 \pm 0.08 \) km s\(^{-1}\) for the gas coma in October. This is comparable to what is observed for comets with comparable gas production rates at similar heliocentric distances.

- The water production rate is estimated to \( 1.9 \pm 0.3 \times 10^{28} \) s\(^{-1}\) just before the EPOXI flyby.

- The timing of our meridian observations was not appropriate to retrieve a possible modulation of the comet activity by its rotation if the period is as short as \( \approx 1 \) day. The water production was observed to increase steeply, but progressively, in the month preceding perihelion.

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