ISO SPECTROSCOPIC OBSERVATIONS OF SHORT-PERIOD COMETS*

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ABSTRACT

Two Infrared Space Observatory programmes (guaranteed time and open time) were devoted to high-resolution spectroscopic observations of short-period comets. 22P/Kopff was observed on October–December 1996 with SWS and LWS. Due to the weakness of the object, only the ν_3 ro-vibrational lines of water were detected, with SWS. Comet 103P/Hartley 2 was observed close to its perihelion (at 1.04 AU from Sun and 0.82 AU from Earth) on January 1998 with SWS, LWS and CAM. The bands of H_2O and CO_2 at 2.7 and 4.3 μm are detected, with $[CO_2]/[H_2O] = 10$ %. The 2.7 μm band of H_2O is observed with a high signal-to-noise ratio with SWS, which permits to evaluate the rotational temperature of water to 16–20 K and its ortho-to-para ratio to ≈ 2.7, corresponding to a spin temperature of ≈ 35 K. The 5–17 μm spectrum of comet Hartley 2 observed with CAM-CVF shows the 9–12 μm signature of silicates. Silicate emission around 10 μm is present at a level of about 20 % of the continuum, with a peak at 11.3 μm indicative of crystalline silicates. This is the first time crystalline silicates are found in a short-period comet. The ISO observations of the Jupiter-family comet P/Hartley 2, presumably originating from the Edgeworth-Kuiper belt, are compared to those of comet Hale-Bopp which came from the Oort cloud.

Key words: comets; 22P/Kopff; 103P/Hartley 2; dust; ISO; molecules; spectroscopy.

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1. INTRODUCTION

According to current scenarios of cometary formation and dynamical evolution, there are two reservoirs of comets. The Oort cloud is composed of comets formed within Neptune's orbit, which were ejected to the verge of the Solar System by planetary perturbations. Following stellar perturbations, these comets can be reinjected in the inner Solar System, as new comets, dynamically evolving sometimes into Halley's family comets. Comets formed beyond Neptune's orbit have more stable orbits and compose the Edgeworth-Kuiper belt. They can evolve subsequently into Jupiter family comets which have short periods and low inclinations.

During the life time of the Infrared Space Observatory (ISO), we had the chance to observe a Oort-cloud comet of exceptional brightness, C/1995 O1 (Hale-Bopp), in the scope of a target-of-opportunity programme (Crovisier et al. 1996, 1997a, b). But Jupiter family, short-period comets, were the goal of guaranteed time programmes. We present here the results of spectroscopic observations of two Jupiter-family comets with ISO.

2. OBSERVATIONS

Short-period comets were the goal of two ISO spectroscopic programmes:

- a guaranteed time programme, specifically aimed at comet 22P/Kopff, which appeared to be the best target during the nominal life time of ISO; during the prolonged life of ISO, this program could be extended to comet 103P/Hartley 2;
- an open time programme aimed to complementary spectroscopic observations of 22P/Kopff.

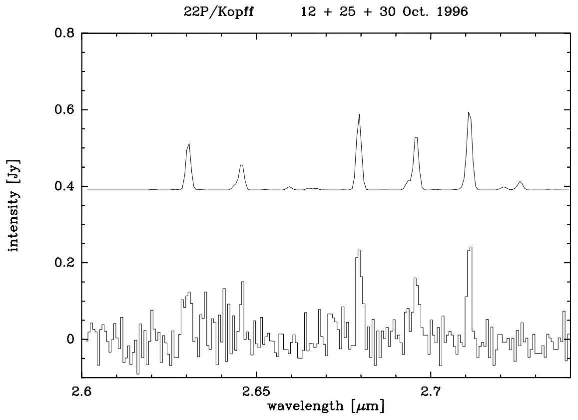

Figure 1. The 2.7 mm water spectrum of comet 22P/Kopff observed with SWS (bottom). This is the sum of three observations corresponding to 10275 sec of integration. At the top is shown a synthetic spectrum computed for $T_{\rm rot}$= 5 K and OPR = 2.5.

The programmes of observation of 22P/Kopff consisted in spectra with the full range of the SWS and LWS, as well as SWS spectra dedicated to the 2.7 μm (H_2O), 3.3 μm, 4.25 μm (CO_2) and 6.5 μm (H_2O) regions. For 103P/Hartley 2, full SWS and LWS spectra were taken as well as special SWS spectra dedicated to the 2.7 μm (H_2O) region; in addition, it was imaged with ISOCAM, and CVF spectra were obtained in the 5–17 μm region and the 2.7 μm (H_2O) and 4.25 μm (CO_2) bands. Only part of these observations are analysed here. Their log is given in Table 1.

Table 1. Summary of the ISO observations of comets 22P/Kopff and 103P/Hartley 2 presented here.

Date dd/mm/yy	r [AU]	Δ [AU]	instrument
22P/Kopff			
12/10/96	1.87	1.27	SWS
25/10/96	1.94	1.45	SWS
30/10/96	1.96	1.52	SWS
103P/Hartley 2			
31/12/97	1.04	0.82	SWS, CAM-CVF
19/01/98	1.11	0.83	SWS, CAM

Because of ISO visibility constraints, 22P/Kopff could not be observed in the best conditions when it was close to the Earth and Sun. It was observed on October–December 1996, several months after its perihelion. It was weaker than expected and could not be detected in the full SWS and LWS spectra, nor in the SWS special spectra dedicated to the 3.3 μm, 4.25 μm (CO_2) and 6.5 μm (H_2O) regions. Only the water band at 2.7 μm could be detected after a long integration (Figure 1).

Comet 103P/Hartley 2 was observed on 1st January 1998, close to perihelion, which corresponded to the best observing conditions. Other observations were also obtained on 19 January. Figure 2 shows an image of the comet observed in the thermal infrared on January 19.

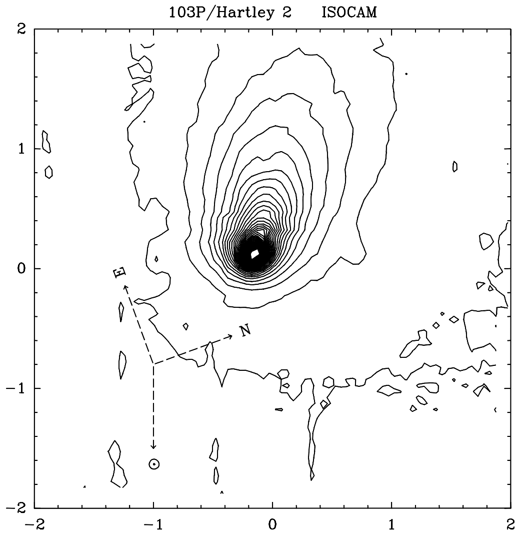

Figure 2. ISOCAM image of comet 103P/Hartley 2 observed with the LW7 filter (9.7 μm) on 19 January 1998. This image is a mosaic covering a 4 × 4 arcmin field (or 143 000 km at the comet) with 3 arcsec pixels.

3. RESULTS

3.1. Molecular Production Rates

The molecular production rates are derived from the SWS spectra for H_2O (Figs 1 and 3) and the CAM-CVF spectrum for CO_2 (Fig. 4), using standard models of molecular fluorescence emission and an expansion velocity of 0.8 km s^{-1} (which is the velocity retrieved from cometary radio line shapes in similar conditions). They are listed in Table 2.

$[CO_2]/[H_2O]$ in P/Hartley 2 is about 10 %, which is larger than what was observed in P/Halley during the Vega flyby (3%; Combes et al. 1988) or indirectly by the HST during the 1991 passage of P/Hartley 2 (4–9 %; Weaver et al. 1994). This ratio is smaller than what was observed in comet Hale-Bopp at 2.9 AU (20%; Crovisier et al. 1997); however, $[CO_2]/[H_2O]$ varies with heliocentric distance because of the difference of volatility of the two molecules. The observed $[CO_2]/[H_2O]$ does not reflect directly the true abundance ratio in cometary ices.

3.2. Water Temperatures

The 2.7 μm water band is rotationally resolved in the high-resolution spectra (Figs 1 and 3). For the high

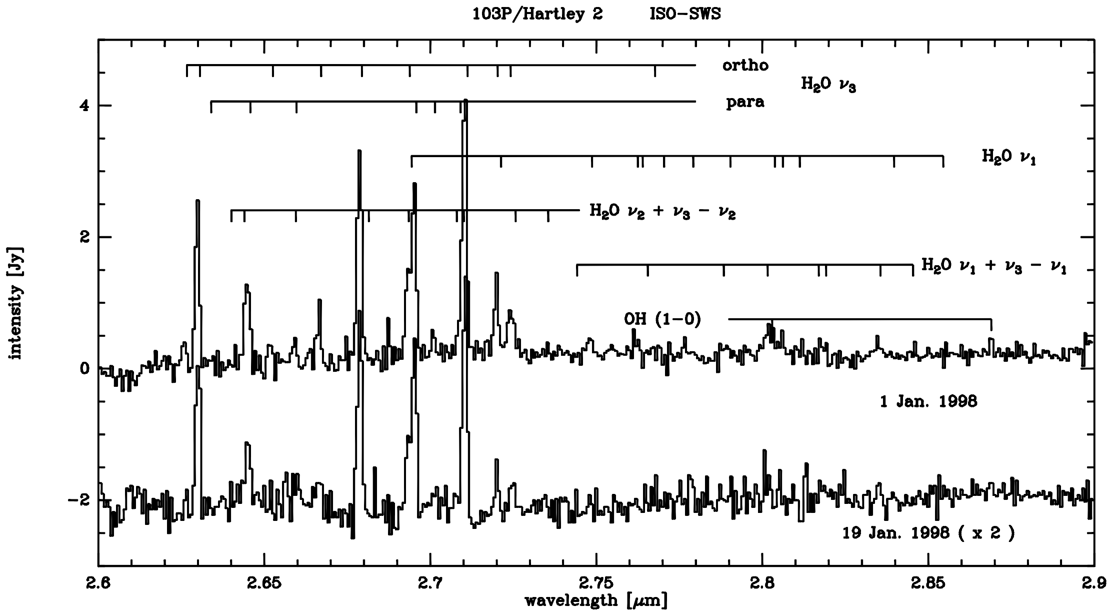

Figure 3. The spectrum of comet 103P/Hartley 2 observed with SWS on 1 and 19 January 1998 in the 2.7 μm region with a resolution $\lambda/\delta\lambda \approx 1500$, showing water lines of the ν_1 and ν_3 group (and at least one OH line).

Table 2. Molecular production rates.

Comet Date	molecule	Q [molec. s^{-1}]
22P/Kopff		
12 + 25 + 30/10/96	H_2O	$3.7 \pm 0.2 \times 10^{27}$
103P/Hartley 2		
31/12/97	CO_2	1.2×10^{27}
01/01/98	H_2O	$1.24 \pm 0.2 \times 10^{28}$
19/01/98	H_2O	$0.54 \pm 0.2 \times 10^{28}$

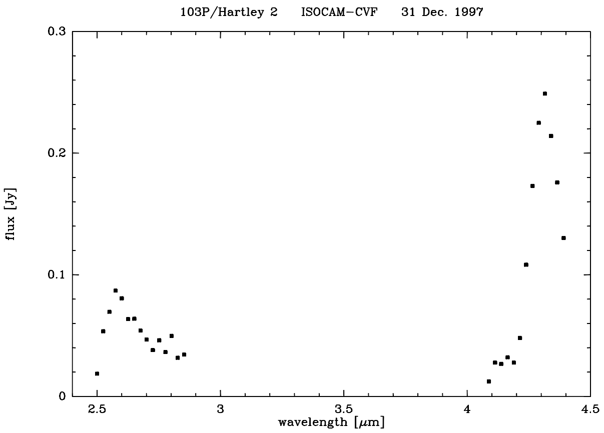

Figure 4. Two parts of the 2.5–4.4 μm spectrum of comet 103P/Hartley 2, observed with ISOCAM-CVF on 31 Dec. 1997, covering the bands of H_2O and CO_2 at 2.7 and 4.25 μm. The field of view is 6×9 arcsec

S/N SWS spectra of 103P/Hartley 2, this allows an analysis of the water rotational temperature averaged over the field of view, and of its spin temperature from the ortho-to-para ratio (Table 3 and Figure 3). The model of Bockelée-Morvan (1987) and Bockelée-Morvan & Crovisier (1989), which takes into account infrared radiative excitation, collisions and optical depth effects, has been used.

The $T_{\rm rot}$ of 6–20 K measured in P/Hartley 2 are smaller than in Hale-Bopp (28 K) at 2.9 AU from the Sun when its water production rate was 3.3×10^{29} s^{-1} (Crovisier et al. 1997). It decreased from 1 to 19 January while Q[H_2O] decreased by more than a factor of two. For P/Kopff, $T_{\rm rot}$, although ill-determined due to the poor S/N, is < 11 K, showing that water is rotationally relaxed and close to fluorescence equilibrium (where water is concentrated on the two lowest ortho and para rotational levels). This agrees with thermodynamical models which predict that not only the heliocentric distance, but also the gas production rate is an important factor in determining the temperature. This will permit to relate kinetic and rotational temperatures to these parameters and to constrain thermodynamical models of the coma.

The OPR in P/Hartley 2 is significantly lower than 3.0, the high-temperature limit, but not as low as that observed by ISO in comet Hale-Bopp (2.45 ± 0.10; Crovisier et al. 1997). The observed value is ≈ 2.7 and corresponds to a spin temperature of about 35 K. It is believed that this spin temperature has a primordial signification: it could be the temperature at the formation of water, or it could reflect the secular equilibrium temperature of ice within the nucleus.

Table 3. Water T_{rot} and OPR.

Comet Date	T_{rot} [K]	OPR
22P/Kopff		
12 + 25 + 30/10/96	< 11	–
103P/Hartley 2		
01/01/98	20.3 ± 0.8	2.76 ± 0.08
19/01/98	16.5 ± 1.6	2.63 ± 0.18

3.3. Minerals

The 5–17 μm spectrum (Figure 5) of 103P/Hartley 2 shows thermal continuum emission and the 9–12 μm silicate emission feature, which is about 20% of the continuum in intensity. This 10 μm silicate emission band has also been reported in the same comet on 9 February with a similar intensity (about 15 %) relative to continuum (Lynch et al. 1998), but it was not seen by Fomenkova et al. (1998) on 24 January.

The shape of the band observed by ISO shows the presence of an emission at 11.3 μm, which is indicative that silicates are partly crystalline. Crystalline silicates have already been observed in a number of comets (including comet Hale-Bopp from ISO spectra and from the ground — Crovisier et al. 1996, 1997a, b; Hanner et al. 1998), but it is the first time they are found in a short-period, Jupiter-family comet. From ground-based observations of three Jupiter-family comets (19P/Borrelly, 4P/Faye and 24P/Schaumasse), Hanner et al. (1996) could only detect the silicate feature in the first two comets; they could not conclude on the presence or not of crystalline silicates. Our ISO results show that both Oort-cloud comets and comets from the Edgeworth-Kuiper belt were able to incorporate crystalline silicates in their grains.

4. DISCUSSION AND CONCLUSION

Jupiter-family comets have well-known orbits and their observations can be easily scheduled ahead. However, they are weak objects. In the ISO extended life time, it was possible to observe 103P/Hartley 2 at the best observing conditions. The fluorescence spectrum of water in this comet could be observed with a S/N similar to that of comet Hale-Bopp, a much brighter comet, but which could not be observed by ISO so close to Earth and Sun. Comets Hale-Bopp and P/Hartley 2 both showed the presence of crystalline silicates, a high content of CO_2, and a low water ortho-to-para ratio.

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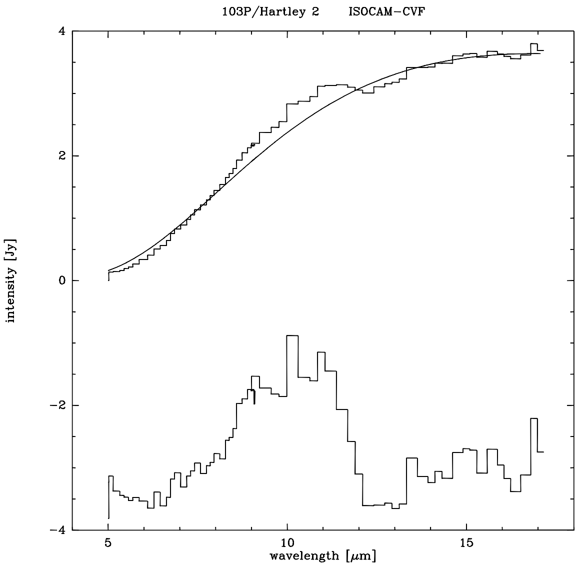

Figure 5. The 5–17 μm spectrum of comet 103P/Hartley 2 observed with ISOCAM CVF on 31 Dec. 1997. The field of view is 9×9 arcsec. The raw spectrum is shown at the top, with a black-body spectrum for $T = 295$ K. At the bottom is the spectrum (multiplied by 5) obtained after subtracting the black-body, showing the silicate band at 9–12 μm.

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