Astron. Astrophys. 343, L87–L90 (1999)

ASTRONOMY AND ASTROPHYSICS

LETTER

Letter to the Editor

Infrared spectral observations of comet 103P/Hartley 2 by ISOPHOT*

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Received 15 December 1998 / Accepted 14 February 1999

Abstract. Spectral observations in the 2.5–12 μm range of comet 103P/Hartley 2 were performed on 1 Jan. 1998 by the ISOPHOT instrument, on board the Infrared Space Observatory. The obtained spectrum evidences intense bands at 2.66 and 4.26 μm, attributable to H_2O and CO_2, respectively. The derived molecular production rates are Q(H_2O) = $(3.1 \pm 0.2) \times 10^{28}$ molec. s^{-1} and Q(CO_2) = $(2.5 \pm 0.3) \times 10^{27}$ molec. s^{-1}. This leads to a CO_2/H_2O abundance ratio of $\sim$ 8%, showing that P/Hartley 2 is a relatively CO_2 abundant comet, with respect to 1P/Halley and several other comets. A feature has been detected at 3.69 μm, whose attribution is rather puzzling. The long wavelength part of the spectrum is well fitted by a black–body profile at 285 K colour temperature. No significant silicate emission feature around 10 μm is observed, within observation errors.

Key words: comets: individual: 103P/Hartley 2 – infrared: solar system

1. Introduction

Infrared spectroscopy is a powerful tool to study the chemical composition of comets and, thus, to derive information about formation and evolution mechanisms and on the materials from which they originated. The Infrared Space Observatory (ISO) has represented a unique facility to observe infrared sources – and comets in particular – in a wide spectral range and under conditions not achievable by ground-based telescopes (for a description of the ISO mission see Kessler et al., 1996). Thanks to ISO it has been possible to evidence typical gas and dust features, whose identification has allowed us to shed light on chemical and structural properties of components present in comets (e.g. Crovisier et al., 1997; 1999a; 1999b).

Within the ISO observational programs called EXTRACT (EXtended Remote Analysis of Coma and Trails) our team has performed both ISOCAM and ISOPHOT observations of the short period comet 103P/Hartley 2, an Edgeworth-Kuiper belt object. The combination of observations by ISO instruments for comets pertaining to the Jupiter family was aimed at gaining information on dynamics and morphology of solid particles distributed in the coma and in the trails and about the chemical properties of gas and dust ejected from the nucleus. In the present paper we report the results of the spectroscopic observations by ISOPHOT.

2. Observations

Observations were performed by ISOPHOT–S (Lemke et al., 1996), which allows the simultaneous observation in the two spectral ranges 2.5–5 μm (hereafter SW) and 6–12 μm (hereafter LW) with two 64–element detector arrays. The spectral resolution achievable by this observing mode is not very high, $\lambda/\Delta\lambda \sim 85$ in the SW and ~ 95 in the LW, but sufficient to identify typical features of gas and dust components. The field of view is a 24$''$ x 24$''$ square. The integration time of the observations was 4096 s. The observations were carried out on 1 Jan. 1998 at 22:58:04 UT (starting time of observation), at RA (J2000) = 23h 34m 16s and dec. (J2000) = –7d 18$'$ 2$''$, when the comet was at geocentric distance R = 1.043 AU and heliocentric distance D = 0.824. The spectrum of the background was taken on 5 Jan. 98 at 19:23:59 UT with the same instrument parameters and on the same sky position. The background spectrum is used to remove the background sky contribution. The data reported in the present paper are the output of the ISOPHOT auto–analysis data reduction (pipeline vers. 7.0, see Laureijs et al., 1996 for more details). Thus, they must be considered pre-

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* Based on observations with ISO, an ESA project with instruments funded by ESA Member States (especially the PI countries: France, Germany, the Netherlands and the United Kingdom) and with participation of ISAS and NASA.

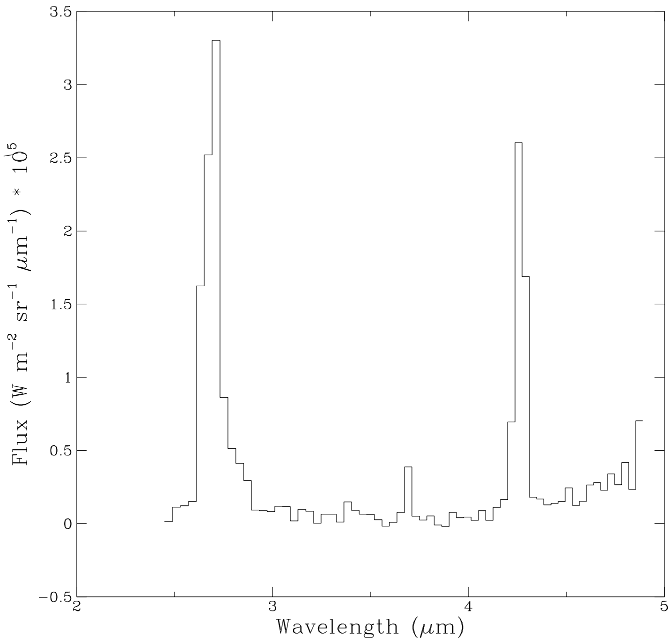

Fig. 1. The 2.5–5 μm spectrum of comet 103P/Hartley 2 obtained with ISOPHOT–S on 1 January 1998. The percent errors on the band peak intensity are of the order of 20%

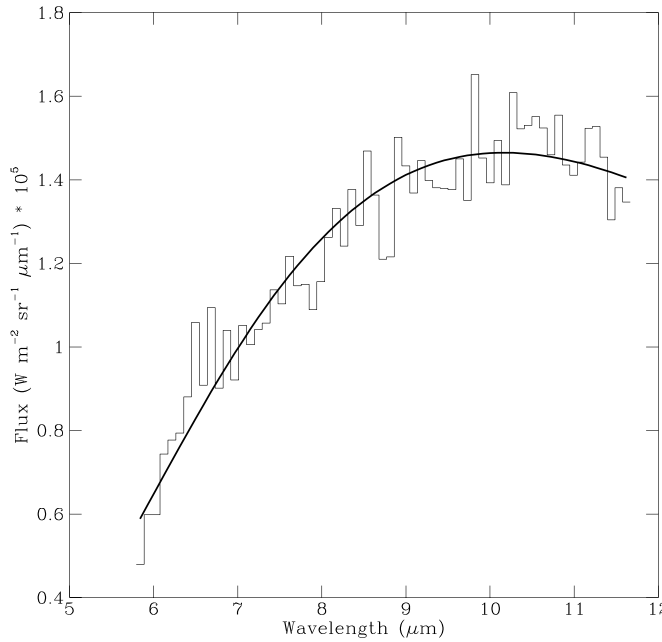

Fig. 2. The 6–12 μm spectrum of comet 103P/Hartley 2 obtained with ISOPHOT–S on 1 January 1998. The percent error on the flux is about 20%. The thick solid line is a 285 K blackbody fitted to the data

liminary and need a further more careful analysis for intensity calibration.

In order to correctly interpret the comet observation, we have to consider the actual position of the comet with respect to the pointing position. In this respect, the parallel ISOCAM observations, which will be presented in a forthcoming paper, can help us. The spot of the ISOPHOT observation is well centred on the comet positions. The spectrum of 103P/Hartley 2 is shown in Figs. 1 and 2. The SW portion presents well pronounced features and first evidence of the thermal continuum emission at the longest wavelengths; the reflected sunlight contribution is negligible. The LW range is characterised by a featureless thermal emission, with no evident emission features.

3. Discussion

The SW spectrum of 103P/Hartley 2 is characterised by typical vibrational bands of volatile species present in the coma. The band positions and intensity are listed in Table 1. Here following we concentrate on their attribution and interpretation.

The band observed in our spectrum at 2.7 μm, with a shoulder around 2.8 μm, is mostly attributable to the ν_3 transition of water molecules. The shoulder at 2.8 μm is also presumably due to hot bands of water (Bockelèe-Morvan and Crovisier 1989). The presence of the H_2O molecule in comet 1P/Halley was determined by detecting the IR band at 2.66 μm in observations from the Kuiper Airborne Observatory (Mumma et al., 1986) and by in situ infrared spectroscopy (Moroz et al., 1987) and gas mass spectroscopy, by the NMS instrument onboard Giotto (Krankowsky et al., 1986). By neglecting the emission excess in the shoulder present in our spectrum, that anyway represents only less than 10% of the entire band flux, we have derived the water production rate, Q(H_2O), from the integrated band intensity. We have considered an expansion velocity of 0.8 km s^{-1} (resulting from an hydro–dynamic model, Combi and Smyth, 1988). The computed Q(H_2O) = (3.1 $\pm$ 0.2) $\times$ 10^{28} molec. s^{-1} value is higher than that, (1.24 $\pm$ 0.2) $\times$ 10^{28} molec. s^{-1}, derived by Crovisier et al. (1999a) from SWS observations of P/Hartley 2 performed on 31 Dec. 1997. As the two observations are close in time, the difference could be explained with a sudden change of H_2O emission. The values reported above are smaller than Q(H_2O) $\sim$ 6.3 $\times$ 10^{28} molec. s^{-1}, based on UV observations performed with the Faint Object Spectrograph (FOS) of the Hubble Space Telescope, during the previous passage of the comet, in September 1991, when the comet was at heliocentric distance $\sim$ 1 AU (Weaver et al., 1994). This result was derived from the brightness analysis of several bands of the hydroxyl radical, which is believed to be the primary daughter product of the photo-dissociation of H_2O. Actually, the shoulder at 2.8 μm, present in our spectrum, could be due to the rather weak OH ν(1-0) resonance.

Our SW spectrum presents a well defined band at 4.26 μm, due to carbon dioxide. CO_2 cannot be directly observed in the IR from ground, due to telluric absorption. It was first identified in comet 1P/Halley by in situ gas mass spectrometry (Krankowsky et al., 1986) and infrared spectroscopy (Combes et al., 1988). Weaver et al. (1994) detected in P/Hartley 2 several bands of the Cameron system of CO, almost certainly due to photo–dissociative emission of CO_2. By assuming an expansion velocity of 0.8 km s^{-1}, we have derived, directly from our integrated band flux, the production rate Q(CO_2) = (2.5 $\pm$ 0.3) $\times$ 10^{27} molec. s^{-1}. This value is quite consistent with Q(CO_2)

Table 1. Bands observed in 103P/Hartley 2 with PHT–S.

Band position (μm)	Flux (W m^{-2})	Attribution	Band	g (s^{-1})	Q (s^{-1})
2.66	$(4.9 \pm 0.3) \times 10^{-14}$	H_2O	ν_3	2.6×10^{-4}	$(3.1 \pm 0.2) \times 10^{28}$
4.26	$(2.7 \pm 0.2) \times 10^{-14}$	CO_2	ν_3	2.9×10^{-3}	$(2.5 \pm 0.3) \times 10^{27}$
4.67	$< 4.1 \times 10^{-15}$	CO	ν(1-0)	2.6×10^{-4}	$< 4.4 \times 10^{27}$ (^{1})

g: emission rate, assuming resonant fluorescence excited by the Sun at 1 AU
Q: production rate computed by assuming a molecule distribution with expansion velocity of 0.8 km s^{-1}
(^{1}) The upper limit is calculated for 3σ

= (2.6×10^{27}) molec. s^{-1}, inferred by Weaver et al. (1994) at almost the same heliocentric distance. The relative abundance CO_2/H_2O derived from our observations is $\sim$ 8%, well compatible, within errors, with the $\sim$ 10%, obtained by Crovisier et al. (1999a) from SWS (for H_2O) and CAM-CVF (for CO_2) spectra. These direct determinations are a bit higher than that inferred by Weaver et al. (1994), likely due to the decrease in the water production rate, and reveal that P/Hartley 2 has a relative CO_2 abundance higher than 1P/Halley and several other comets (Feldman et al., 1997).

The attribution of the band falling at 3.69 μm is rather puzzling and various interpretations could be proposed. A ν_1 band of the deuterated water HDO, due to the OD stretch, falls at 3.68 μm and could match the observed band, within the spectral resolution limits of the ISOPHOT–S spectrum (in this spectral region, the ISOPHOT–S $\Delta\lambda$ is 0.04 μm). HDO has been detected in comet C/1996 B2 (Hyakutake), through its rotational transition at 464.925 GHz (Bockelèe–Morvan et al., 1998), and in comet Hale–Bopp (Meier et al. 1998) with a similar abundance. Unfortunately, we cannot be sure of the attribution of the 3.69 μm band in our spectrum. Actually, a more intense ν_3 band (OH stretch) would be expected at 2.7 μm, but it could not be resolved from the more intense water band at 2.66 μm and a ν_2 band, expected at 7.13 μm, is not evident in our LW spectrum. Moreover, if we derive the production rate of HDO by assuming that the 3.69 μm is entirely due to this molecule, the resulting D/H(H_2O) ratio is too high with respect to the measured values for comets 1P/Halley (Eberhardt et al., 1995) and Hyakutake (Bockelèe–Morvan et al., 1998). Finally, contrarily to our observed spectrum, the band width should spread over more pixels, even for a cold (5–10 K) rotational temperature (Crovisier, *private communication*). Alternatively, the 3.69 μm band could be attributed to the methyladyne radical (CH), whose ν(1-0) band falls at 3.66 μm and is, however, expected to be broad.

Carbon monoxide is probably a major volatile cometary component, but its abundance is highly variable from comet to comet. The ν(1-0) band at 4.67 μm of CO is not observed in our SW spectrum. Our derived upper limit for Q(CO) (see Table 1) is in agreement with the 9×10^{26} molec. s^{-1} measured by Weaver et al. (1994).

The spectral region from 3.1 to 3.6 μm displays some weak and wide features, not very much evident above the noise level, that could be interpreted with the presence of C-H bearing molecules, already observed in several comets (e.g. Moroz et al., 1987; Brooke et al., 1990; Brooke et al., 1991). Recently, methanol and/or ethanol have been proposed among the potential contributors to these bands (Disanti et al., 1995; Mumma et al., 1996). No attempt of specific attribution is possible for our very faint structures.

Finally, the feature at 4.87 μm, which is as bright as the 3.69 μm feature, corresponds to a notoriously bad pixel of the instrument (it has been already seen in other ISOPHOT-S observation), so we consider it as an instrumental effect.

The LW spectrum of P/Hartley 2 presents a featureless profile that can be fitted by a black–body at colour temperature T_c = 285 K (Fig. 2). This result is similar to the T_c = 295 K value, determined by Crovisier et al. (1999a) from CAM spectra. The slight difference could be due to the different spectral ranges used to derive T_c and/or to the fact that the real spectrum departs from a pure black–body spectrum. For comparison, T_c = 309 K is derived by scaling to the P/Hartley 2 heliocentric distance the power law obtained from pre– and post–perihelion observations of 1P/Halley (Tokunaga et al. 1988). The equilibrium blackbody temperature would be 272 K. We conclude that grains in P/Hartley 2 are hot, as expected for very small particles, but not as much as typical of P/Halley–like dust. After subtraction of the blackbody profile, our residual spectrum does not show any 10 μm silicate emission band, in contrast with the finding by Crovisier et al. (1999a), who detected a broad 10 μm band, with evidence of a sharp feature at 11.3 μm, attributable to amorphous and crystalline silicate grains respectively. We notice that the silicate emission in their spectrum is about 20% of the continuum in intensity and, thus, it is too faint to be detected above 3σ in our spectrum, but should be (faintly) observable above 1σ. We note however that the 10 μm silicate emission in the same comet was not seen by Fomenkova et al. (1998) on 24 January, while Lynch et al. (1998) reported it on 9 February.

4. Conclusions

In the present work we have reported the infrared spectrum of comet 103P/Hartley 2, observed with the medium resolution ISOPHOT–S instrument on 1 Jan. 1998. The analysis of the 2.5–5 μm range evidences relevant spectral features. Vibrational bands of water (2.66 μm) and carbon dioxide (4.26 μm) were both directly measured by infrared spectroscopy for this comet. A strong out–gassing of carbon dioxide was observed, leading to confirm a CO_2/H_2O ratio of about 8%, consistent with data inferred from UV observations. A feature at 3.69 μm appears difficult to attribute clearly. The 6–12 μm spectrum is well fitted by a blackbody emission at a colour temperature of 285 K.

Acknowledgements. We warmly thank Dr. J. Crovisier for helpful discussion and for providing information on his ISO results prior to publication. This work has been supported under ASI, CNR and MURST contracts.

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