

THE THERMAL INFRARED SPECTRA OF COMETS HALE-BOPP AND 103P/HARTLEY 2 OBSERVED WITH THE INFRARED SPACE OBSERVATORY. J. Crovisier¹, K. Leech², D. Bockelée-Morvan¹, E. Lellouch¹, T.Y. Brooke³, M.S. Hanner³, B. Altieri², H.U. Keller⁴, T. Lim^{2,5}, T. Encrenaz¹, A. Salama², M. Griffin⁵, T. de Graauw⁶, E. van Dishoeck⁷ and R.F. Knacke⁸. ¹Observatoire de Paris-Meudon, F-92195 Meudon, France, crovisie@obspm.fr, ²ISO Data Centre Centre, Astrophysics Division of ESA, Villafranca, Spain, ³Jet Propulsion Laboratory, Pasadena, USA, ⁴MPI für Aeronomie, Katlenburg-Lindau, Germany, ⁵Queen Mary and Westfield College, London, UK, ⁶SRON, Groningen, The Netherlands, ⁷Leiden Observatory, The Netherlands, ⁸Penn State Erie, USA.

Introduction: The Infrared Space Observatory (ISO) offered us the opportunity to observe celestial bodies over the full infrared range from 2.4 to 196 μm . This spectral domain is of peculiar interest for comets. Cometary parent molecules, likely to have sublimated from the nucleus ices, can be investigated through their fundamental bands of vibration in the 2.5–12 μm region. With temperatures ranging between 100 and 400 K or more, cometary grains show thermal emission peaking in the 5–200 μm region, where spectral features related to their chemical nature may be expected.

Observations: We report here on spectroscopic observations of comets which were conducted with ISO by an international team of investigators. Other programmes by other teams were aimed at photometric and imaging observations, in order to study cometary dust in the coma, the tails and the trails, and to try to disentangle the emission of the comet nuclei from that of the dust.

Our observations were undertaken in the frame of two programmes. The first one, a guaranteed time programme, had to be planned on advance. It was thus aimed at short-period, predictable comets. The nominal target, 22P/Kopff, was weaker than expected and could not be observed at the moment it was the brightest. Fortunately, it was possible to observe a second comet, 103P/Hartley 2, during the extended lifetime of ISO, when the comet was at its brightest near perihelion [7]. The second programme, an open-time target-of-opportunity programme, was aimed at any bright comet which might appear during ISO's life time. We were lucky to benefit from the apparition of the exceptional comet Hale-Bopp (1995 O1). Unfortunately, because of the visibility constraints of ISO, the comet could only be observed when it was at $r_h > 2.8$ AU from the Sun. Observations were secured pre-perihelion on April 1996 ($r_h = 4.6$ AU) and September–October 1996 ($r_h = 2.8$ AU) and post-perihelion on December 1997 ($r_h = 3.9$ AU) and April 1998 ($r_h = 4.9$ AU) [1], [2], [3], [4], [5], [6].

The observations of gas-phase species will not be discussed in detail here: H₂O, CO₂ and CO were detected, and their production rates, as well as physical

parameters for cometary water, were determined as a function of heliocentric distance ([1], [2], [3], [4], [6], [7]).

Results on comet Hale-Bopp: For the four observing periods of comet Hale-Bopp, low-resolution spectra were observed from 2.5 to 12 μm with the grating spectrometer of the ISO photometer. All spectra show a strong silicate band at 10 μm with a peak at 11.3 μm indicating the presence of crystalline olivine. This constituent is observed to be present whatever the heliocentric distance (4.9 to 2.8 AU), both pre- and post-perihelion.

In September–October 1996, high signal-to-noise ratio spectra of the comet were obtained with the short- and long-wavelength spectrometers of ISO. Beyond 6 μm , the spectrum of comet Hale-Bopp was dominated by dust thermal continuum emission, upon which broad emission features were superimposed, the strongest appearing at 10, 19.5, 23.5 and 33.5 μm . The wavelengths of all these peaks correspond to those of Mg-rich crystalline olivine (namely forsterite, Mg₂SiO₄) [2], [3], [4], [6]. A careful study of the ISO spectrum, complemented by ground-based spectra of the 10- μm region obtained at smaller heliocentric distances, show that amorphous silicates as well as pyroxenes are also present [8] [9]. It is remarkable that the spectrum of comet Hale-Bopp in this spectral domain closely resembles that of the dust discs around some young stars (such as that of HD 100546, an intermediate star between Vega-like objects and Herbig Ae-Be stars) which were also observed by ISO [10]. Thus, the dust contained in such discs should be similar to cometary dust. This contrasts with interstellar silicates, which are amorphous.

In the September–October 1996 spectra, emission features at 44 and 65 μm and possible absorption at 2.9–3.2 μm were detected, characteristic of crystalline water ice. A temperature of 165 K was inferred for this water ice. This suggests that grains of water ice were still present at a distance of 2.9 AU from the Sun and that they could be a significant source of water release in the coma [5].

No sign of PAHs could be found in the spectrum of comet Hale-Bopp (especially in the 6–9 μm re-

COMETS HALE-BOPP AND P/HARTLEY 3 OBSERVED WITH ISO: J. Crovisier et al.

gion, where they are expected to have strong bands not blended with silicate features). However, one cannot exclude that cometary PAHs are revealed at shorter heliocentric distances than those of the ISO observations of comet Hale-Bopp.

Results on comet P/Hartley 2: Whereas Hale-Bopp was a long-period comet presumably coming from the Oort cloud, 103P/Hartley 2 is a Jupiter-family comet supposed to originate from the Edgeworth-Kuiper belt. It was observed in December 1997—January 1998 at $r_h = 1$ AU. A 6—17 μm low-resolution spectrum obtained with the CVF of ISO-CAM showed a weak 10 μm silicate band with an intensity only 15% of the continuum [7]. The presence of a peak at 11.3 μm revealed the presence of crystalline silicates

Conclusion: ISO observations — complemented by ground based spectroscopic observations in the infrared and radio domains — show that there is a great

similarity in the composition of interstellar and cometary ices. This agrees with the hypothesis that comets could have formed from basically unprocessed interstellar matter. However, the presence of crystalline silicates in the dust of both a Oort-cloud comet and a Jupiter-family comet shows that these bodies have also incorporated processed material at some stage of their formation.

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