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OBSERVATIONS OF SOLAR SYSTEM SMALL BODIES WITH THE INFRARED SPACE OBSERVATORY

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ABSTRACT

A summary of the observing programs of Solar System small bodies by the Infrared Space Observatory and the highlights of the first results are presented.

THE ISO SATELLITE

The Infrared Space Observatory (ISO) was launched on 17 November 1995. Its expected lifetime is about two years. It consists in a 60-cm telescope contained in a liquid helium cryostat (Kessler *et al.*, 1996). It is equipped with four instruments: a camera (CAM; Cesarsky *et al.* 1996) and a photometer (PHT; Lemke *et al.*, 1996), both with low-resolution spectroscopic capabilities, and two high-resolution spectrometers: the long-wavelength spectrometer (LWS; Clegg *et al.*, 1996) covering 45-196 μm and the short-wavelength spectrometer (SWS; de Graauw *et al.*, 1996) covering 2.5-45 μm. ISO can only observe the 60-120° solar elongation region and at more than 77° from Earth's limb. Objects with large proper motions cannot be tracked. These are stringent constraints for Solar System observations.

At the time of the ACM conference (July 1996), only a small part of the Solar System program of ISO has been achieved and very limited results could be presented. Much more observations were obtained by the end of the year 1996. However, a fraction only of these observations have been reduced and their results made available. The present review is thus limited to an exposition of the goals of the main ISO programs concerning Solar System small bodies and to the highlights of the first results.

ASTEROIDS

Asteroids are used as calibrators for ISO and the largest ones are to be extensively observed all over the ISO mission (Schulz *et al.* 1996). The IR spectra of dedicated objects will be observed in order to precise their composition and their relation with comets.

A peculiarly promising program concerns the observations of Kuiper Belt objects with PHT. It could allow one to determine their albedo and to precise their size (Thomas *et al.*, 1997).

COMETS

The "central program" and the open-time observations of ISO could only be aimed at known comets, i.e. short-period comets. The brightest target of this kind during ISO's lifetime is 22P/Kopff. A first image of this comet was obtained by CAM on 18 January 1996 during the performance verification phase of ISO (Sibille *et al.*, 1996). The first photometric observations of 22P/Kopff from 3.6 to 160 µm by PHT were presented by Peschke *et al.* (1996). An extensive observation program of 22P/Kopff — photometry, imaging and spectroscopy — was achieved by the end of 1996.

Other short-period comets were the subject of PHT and CAM observations as part of the "central program" and of several open-time programs, including 46P/Wirtanen, the nominal target of the ROSETTA Mission. Weaker than 22P/Kopff, they were observed by PHT and CAM and could not be studied spectroscopically.

More flexible is the "target-of-opportunity comet" program, which could be aimed at unexpected comets. Comet C/1996 B2 (Hyakutake), which had exceptional observational conditions due to its close approach to Earth at the end of march 1996, could not be observed by ISO, however, because of unfavourable visibility windows and of its too large proper motion. Comet C/1995 O1 (Hale-Bopp), which is an exceptional bright object (intrinsically more than 100 times brighter than P/Halley) discovered in July 1995 at 7 AU from the Sun, was selected as a target-of-opportunity comet to be observed by ISO.

The first observations of comet Hale-Bopp, with PHT, took place in March-April 1996. A 2.5-12 µm low-resolution spectrum was observed by PHT-S on 27 April when the comet was still at 4.6 AU from the Sun (Crovisier *et al.* 1996). The 2.5-5 µm region (Figure 1), which includes several of the most intense fundamental vibrational bands of molecules, showed the ν_3 band of carbon dioxide at 4.25 µm. The CO_2 production rate was about 1.3×10^{28} molecules s^{-1}, which is about one third of the CO production rate observed in the radio and of the water production rates derived from the UV and radio observations of the OH radical. This shows that CO_2 is an important contributor to cometary activity at 4.6 AU from the Sun. The 6-12 µm region showed thermal continuum emission and a strong emission at 9-12 µm which may be attributed to silicates. A sharp feature at 11.2 µm is observed, indicative of crystalline olivine.

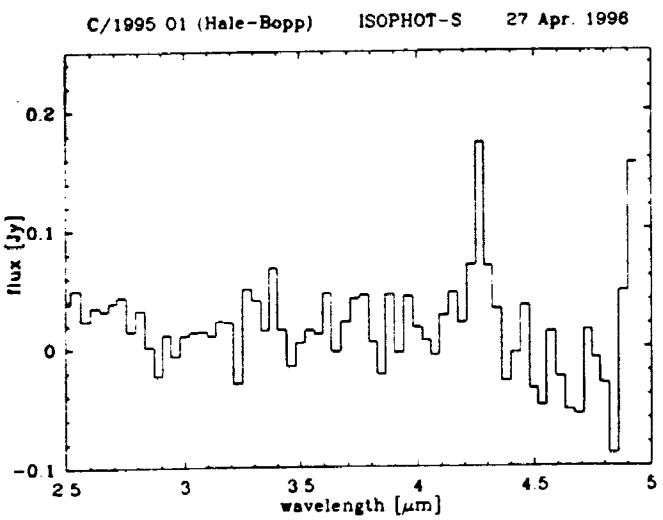

Fig. 1. The 2.5-5 µm spectrum of comet C/1995 O1 (Hale-Bopp) observed with PHT-S on 27 April 1996, when the comet was at 4.6 AU from the Sun. One can see the 4.25 µm band of CO_2. From Crovisier *et al.* (1996).

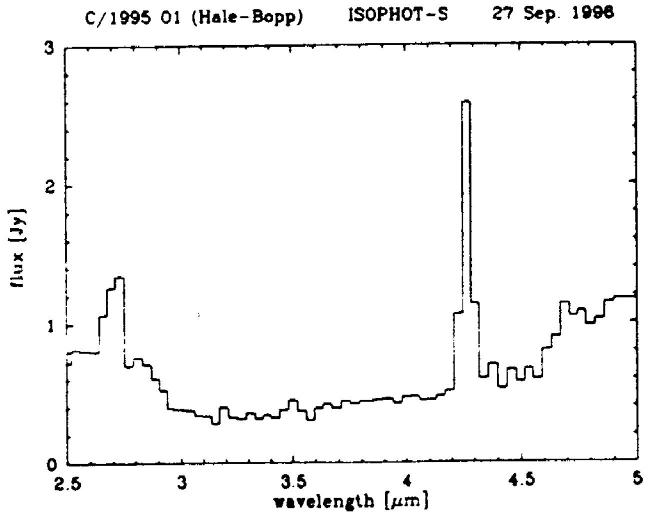

Fig. 2. The same spectrum observed on 27 September 1996, when the comet was at 2.9 AU from the Sun. One can see the 2.7 µm band of H_2O, the 4.25 µm band of CO_2, and the 4.67 µm band of CO. From Crovisier *et al.* (1997).

A second series of observations of comet Hale-Bopp, with all instruments of ISO, took place in September-October 1996 when the comet was at 2.9 AU from the Sun. In the 2.5-5 μm spectral region, PHT-S detected the bands of water at 2.7 μm, of carbon dioxide at 4.25 μm, and of carbon monoxide at 4.67 μm (Fig. 2). Thus the main observed volatiles sublimated from the nucleus ices are H_2O, CO and CO_2 in a ratio (by number) of 10:6:2. The 2.6-2.9 μm region observed at high resolution by the SWS revealed the fully resolved ν_3 band of water and lines of the ν_1 and several hot bands of water. Several rotational lines of water were also observed by the LWS around 180 μm. Several broad emission features were observed in the 7-45 μm region investigated by the SWS. The strongest ones are at 10, 19.5, 23.5 and 33.5 μm. They point to the presence of silicates, and especially to magnesium-rich crystalline olivine. (Crovisier *et al.*, 1997). Ground-based observations of the 9-11 μm feature already revealed crystalline olivine in 1P/Halley and a few other comets. The analyses of the PHT (broad filters) and CAM observations are still in progress.

Comet Hale-Bopp could not be observed at less than 2.8 AU from the Sun, unfortunately, due to the solar elongation constraint of ISO.

INTERPLANETARY DUST

Zodiacal light is a tool of investigation for interplanetary dust specialists, but it is a mere nuisance for other ISO observers! Its space distribution and IR spectrum are the subject of detailed investigations with PHT and CAM that will complete the pioneering work made by IRAS.

Using CAM, Reach *et al.* (1996) observed the 5-16.5 μm spectrum of the zodiacal light towards ecliptic longitude 196°.6 and latitude -2°.4, at a solar elongation of 104°.3. They found that the spectrum of interplanetary dust, integrated over the whole line of sight, is close to that of a blackbody at $T = 261.5 \pm 1.5$ K. Departures from the blackbody curve are less than 15% and there is some evidence of a 9-11 μm feature indicative of silicates. A more detailed investigation of zodiacal light using PHT is in progress.

The discovery of cometary trails was an important outcome of the IRAS observations. They are due to large dust particles diffusing along the orbit of the comets. ISO provides the second opportunity to study these objects. The trail of 22P/Kopff was imaged by CAM on 26 March 1996 (Davies *et al.* 1997). This allowed the authors to determine the width of the trail (50 arcsec, corresponding to 50 000 km) and to show that its brightness has decreased since the IRAS observations more than ten years before, which may be related to a decrease of activity of the comet.

EXTRASOLAR ICES AND DUST

ISO spectrometers could assess the composition of interstellar ices. It was observed that H_2O, CO and CO_2 are their main constituents, with contributions from CH_4, CH_3OH, H_2CO, X-CN and OCS (d'Hendecourt *et al.*, 1996; Whittet *et al.*, 1996).The composition of interstellar ices is thus strikingly similar to that of cometary nucleus ices.

The spectra of circumstellar disks — as those around Vega-like objects — showed spectral features very similar to those observed in comet Hale-Bopp (Crovisier *et al.*, 1997) and attributed to dust grains composed of crystalline silicates (Waters *et al.*, 1996; Waelkens *et al.*, 1996). This conforts our idea that these objects are akin to our solar pre-planetary nebula. The absorption features in absorption in the interstellar medium, however, indicate that interstellar silicates are amorphous (Lutz *et al.*, 1996).

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