ISO OBSERVATIONS OF SOLAR-SYSTEM OBJECTS

CH. LEINERT
Max-Planck Institüt für Astronomie
Königstuhl 17, D-69117 Heidelberg, Germany

AND

TH. ENCRENAZ
DESPA, Observatoire de Paris
F-92195 Meudon, France

1. Introduction

The Solar System is characterized by a large variety of objects, with sizes ranging from more than a hundred thousand km down to less than a μm. All solar-system IR spectra are the sum of two components: at short wavelengths, the reflected sunlight provides information upon the albedo and the chemical composition of the body; at longer wavelengths (typically above 3 to 5 μm), the thermal emission provides information on the temperature of the surface or the atmosphere, and on the vertical distribution of atmospheric constituents.

Observations with ISO have been performed on all classes of solar-system objects. Only Venus was unobservable due to the solar elongation constraint of the satellite (60 degrees); this constraint also made the observation of Mars very difficult. Extensive programs were devoted to the study of giant planets, comets and zodiacal light; the highlights of these programs are presented below. In addition, ISO observations, still under reduction, have been performed on Titan, the Galilean satellites and a number of asteroids.

2. The Giant Planets

The thermal structure of the giant planets is characterized by a troposphere, dominated by convection, where the temperature decreases as the altitude increases. The minimum temperature, which ranges from 110 K in Jupiter to 50 K in Neptune, is reached at the tropopause, at a pressure level of about 100 mbar. Above this level, in the stratosphere, the temperature increases with height due to sunlight absorption, reaching values of several hundred K at pressure levels of 0.01-1 μbar. In the thermal regime, molecular signatures appear in emission (from the stratosphere) or in absorption (from the troposphere), depending upon the region where they are formed.

2.1. THE D/H RATIO IN JUPITER AND SATURN

The measurement of D/H in Jupiter and Saturn has important cosmological and cosmogonical implications, as it is likely to reflect the value of D/H in the primordial solar nebula, 4.5 billion years ago. As first suggested by Bézard et al. (1986), the observation of the rotational HD lines provide a direct and homogeneous method for inferring the D/H ratio in all the giant planets. First ISO determinations of D/H have been obtained on Jupiter, using the R(2) line at 37.7 μm (Encrenaz et al., 1996) and on Saturn using the R(1) line at 56 μm (Griffin et al., 1996). The observations were made with the Fabry-Perot modes of SWS for Jupiter (R = 31000) and SWS for Saturn (R = 8500). The Jupiter measurement was later refined by Lellouch et al. (1996) who derived D/H = 1.8 (+1.1, -0.5) 10^{-5}. The measured D/H in Saturn was D/H = 2.3 (+1.2, -0.8) 10^{-5} (Griffin et al., 1996). Both results are in good agreement with the estimated value of D/H in the primordial nebula, derived from ^{3}He measurements in the solar wind.

J. Andersen (ed.), Highlights of Astronomy, Volume 11B, 1151–1153.

https://doi.org/10.1017/S1539299600019833 Published online by Cambridge University Press

2.2. DISCOVERY OF OXYGEN COMPOUNDS IN THE STRATOSPHERES OF THE GIANT PLANETS

An unexpected discovery from ISO was the first detection of water emission lines in the stratospheres of Saturn, Uranus and Neptune, with SWS in the grating mode, between 30 and 45 μm; about 6 lines were detected on each planet (Feuchtgruber et al., 1997). Simultaneously, CO_2 was detected at 15 μm in Saturn (de Graauw et al., 1997) and Neptune (Feuchtgruber et al., 1997), also with the grating mode of SWS.

Because of the low temperature of the tropopause, which acts as a cold trap, H_2O cannot come from the interior of the planets, and has to be of external origin. Two possible sources have been proposed by Feuchtgruber et al (1997): an interplanetary source (flux of meteorites) or a local source (rings and/or icy satellites). The presence of stratospheric CO_2 can be due either to direct external flux or to atmospheric chemistry in presence of H_2O. The discovery of oxygen compounds in the stratospheres of the giant planets has important implications with regard to the population of the outer solar system, as it may provide constraints on the injection rates and possible activity of distant comets.

Because Jupiter is too bright for SWS-grating observations beyond 25 μm, the presence of stratospheric water in Jupiter is still uncertain. The reduction of H_2O Fabry-Perot observations of Jupiter is in progress. In the case of Titan, SWS grating data in the 30-45 μm range are also under reduction.

2.3. DETECTION OF HYDROCARBONS IN THE STRATOSPHERE OF SATURN

The stratospheres of the giant planets are subject to active photochemistry due to the dissociation of methane by the solar UV radiation. In addition to C_2H_2 and C_2H_6 previously detected, the SWS grating spectrum of Saturn has shown evidence for C_3H_4 (methylacetylene, CH_3C_2H) and C_4H_2 (diacetylene) in Saturn's stratosphere, in the vicinity of 16 μm (de Graauw et al., 1997). These two species, which had been previously identified on Saturn's satellite Titan by the IRIS instrument aboard Voyager, had not been seen on any giant planet before. The ISO result will allow us to better understand the complex photochemistry of these planets.

2.4. DETECTION OF H_2O IN THE TROPOSPHERE OF SATURN

In the 5-μm range, the deep troposphere of Saturn is probed, at pressure levels of about 5 bars. The ISO SWS-grating spectrum of Saturn has provided the first detection of tropospheric water, through the detection of 3 absorption lines. An important result is that the derived H_2O abundance is significantly lower than its saturation value, assuming a cosmic value of O/H (de Graauw et al, 1997). A similar depletion is observed in the hot spots of Jupiter which have been found to be very dry from the observations of the Galileo probe. This suggests comparable circulation models in Jupiter and Saturn, with ascending motions in the colder zones and descending motions in the dry hot spots of the belts.

3. Comets and cometary dust

3.1. ISO OBSERVATIONS OF COMET HALE-BOPP

Cometary observations with ISO have greatly benefited from the unexpected apparition of comet Hale-Bopp, which was chosen as a target of opportunity. Due to the visibility constraints of the satellite, the comet was observable only in a few occasions, far from perihelion. Observations took place in April 1996 and September-October 1996, when the comet was at 4.6 and 2.9 AU from the Sun respectively. In both cases, a PHT-S spectrum was recorded in the 2.5-12 μm range; in the second case, full SWS and LWS grating spectra were also obtained. CO_2 was detected as early as April 1996 (Crovisier et al., 1996); from the September 1996 observations, the H_2O lines at 2.7 μm were identified by the SWS grating and modelled (Crovisier et al, 1997); the whole SWS grating spectrum between 10 and 45 μm has shown clear evidence for magnesium-enriched olivine, a specific crystalline silicate (Crovisier et al., 1997). These results are discussed in deeper detail by Keller et al. (1997).

3.2. THE COMETARY TRAIL OF COMET KOPFF

Cometary trails were first detected by the IRAS satellite (Davies et al., 1984; Sykes et al., 1986). These cometary grains are located along the orbits of ancient comets, ahead and behind their cometary nuclei, as a result of repeated outgassing at multiple perihelion passages. The cometary trail of comet P/Kopff was observed by ISOCAM on March 26, 1996 (Davies et al., 1997). Scans were made across the trail at positions behind the comet corresponding to anomalies of 0.5 and 1 degree, with the LW10 filter (IRAS band 1, at 12 μm). Observations show that the trail, which has a width of about 50 arcsec, has varied since the time of the IRAS observations in 1983. It also shows substructures, which will allow to study the history of dust emission processes. The conclusion that much mass resides in the particles of the trail, and that the dust-to-gas ratio in comets appears to be larger than unity, is confirmed by these observations (Davies et al., 1997).

4. The zodiacal light

4.1. SPECTROSCOPIC SIGNATURE OF THE ZODIACAL LIGHT

Thanks to its high sensitivity, the ISOCAM instrument in the CVF mode is a powerful tool for achieving low-resolution spectroscopy of faint extended sources. The CVF mode of ISOCAM has been used by Reach et al. (1996) and Reach (1996) to obtain a spectrum of the zodiacal light between 5 and 16 μm, with a resolving power of about 40. The spectrum is generally smooth and follows a blackbody curve of about 260-270 K, except for a hump at 9-11 μm which might indicate a possible contribution from small silicate particles; this interpretation, however, has to await final calibration. Complementary observations were made by ISOPHOT in the spectroscopic mode PHT-S, in the 5-11 μm range, with a resolving power of about 100 (Abraham and Leinert, private comm.) They fully confirm the CAM-CVF observations, with no measurable change between different viewing directions.

4.2. MAPPING OF THE ZODIACAL LIGHT TOWARD THE NORTH GALACTIC POLE

In order to search for potential structures in the zodiacal light, Abraham et al. (1997) have used ISOPHOT to map a 45x45 arcmin field of the North Galactic Pole with a 3 arcmin diaphragm at 25 μm. No structures were seen, and an upper limit for the underlying rms brightness fluctuations of 0.2% was found. This emphasises the smoothness of the zodiacal light and suggests that the remaining graininess in the zodiacal light brightness will not adversely affect programs searching for very faint extragalactic sources.

References

Abraham, P., Leinert, Ch. and Lemke, D. (1997) Search for brightness fluctuations in the zodiacal light at 25 μm with ISO *Astron. Astrophys.*, (in press)

Bézard, B., Gautier, D., and Marten, A. (1986) Detectability of HD and non-equilibrium species in the upper atmospheres of the giant planets from their submillimeter spectrum, *Astron. Astrophys.*, **161**, 387-402

Crovisier, J. et al. (1996) The infrared spectrum of comet C/1995 O1 (Hale-Bopp) at 4.6 AU from the Sun, *Astron. Astrophys.*, **315**, L385-L388

Crovisier, J. et al. (1996) The spectrum of comet Hale-Bopp (C/1995 O1) observed with the Infrared Space Observatory at 2.9 AU from the Sun, *Science*, **275**, 1904-1907

Davies, J. K., Green, S., Stewart, B., Meadows, A. J. and Aumann, H. H. (1984) The IRAS fast moving object search, *Nature*, **309**, 315-319

Davies, J. K. et al. (1997) ISOCAM observations of the Comet P/Kopff Dust Trail, *Icarus*, **127**, 251-254

de Graauw, Th. et al. (1997) First results of ISO-SWS observations of Saturn: detection of CO_2, CH_3C_2H, C_4H_2 and tropospheric H_2O, *Astron. Astrophys.*, **321**, L13-L16

Encrenaz, Th. et al. (1996) First results of ISO-SWS observations of Jupiter, *Astron. Astrophys.*, **315**, L397-L400

Feuchtgruber, H. et al (1997) External source od oxygen in the atmospheres of the giant planets, *Nature*, **389**, 159-162

Griffin, M. J. et al. (1996) First detection of the line of HD in Saturn's atmosphere *Astron. Astrophys.*, **315**, L389-L392

Keller, H. U. et al. (1997), This Conference

Lellouch, E. et al. (1997) Determination of the D/H ratio on Jupiter from ISO-SWS observations, *Communication presented at the AAS-DPS Annual Conference*, Tucson, October 1996

Reach W T (1996) The structured zodiacal light: IRAS, COBE and ISO observations, *Proceedings of the IRTS Conference*, Tokyo, November 1996

Reach, W. T. et al. (1996) Mid-infrared spectrum of the zodiacal light, *Astron. Astrophys.*, **315**, L381-L384

Sikes, M. V., Hunten, D. M. and Low, F. J. (1986) Preliminary analysis of cometary dust trails, *Adv. Space Res.*, **6**, 67-78