ISO FAR-INFRARED SPECTROSCOPIC OBSERVATIONS OF JUPITER

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ABSTRACT

We present the far-infrared spectrum of Jupiter that was measured with the Short and Long Wavelength Spectrometers (SWS and LWS) aboard the Infrared Space Observatory (ISO). The region between 38 and 44 μm was observed in grating mode, where the SWS provides a spectral resolution of about 1300. For longer waves up to 197 μm the LWS-FP (Fabry-Perot) was used to achieve a resolution of several thousand. The observations were made between 23 and 26 May 1997 during ISO's revolutions 554, 556 and 557.

The Jovian spectrum in the far-infrared is compared to an atmospheric radiative transfer model using expected values for the vertical profiles of the atmospheric constituents. Rotational transitions of ammonia and phosphine are responsible for the absorption features observed: Strong ammonia absorption manifolds are obvious against the background continuum slope, appearing at 39, 42, 46, 51, 56, 63, 72, 84, 100 and 125 μm in both the data and the model. Also PH_3 features are present at the expected wavelengths of 113 and 141 μm in both the data and the model. This is the first time that most of these far-infrared features have been detected. The ISO observations are therefore of interest for the preparation of the planned submillimeter studies of the atmospheres of the Jovian planets with FIRST.

Key words: Infrared observations – Jupiter: atmosphere – Spectroscopy

1. INTRODUCTION

The far-infrared and submillimeter range contains many transitions of species known or thought to be present in the stratospheres and tropospheres of the giant planets. Whereas in the submillimeter bands observations could be made from the ground (Davis et al. 1997) and with balloon-borne instruments (Goldin et al. 1997), our knowledge of the far-infrared spectrum of Jupiter was before ISO only based on the results of Voyager observations. Its Infrared Interferometer Spectrometer and Radiometer instrument covered the 4–56 μm range with a low spectral resolution of 4 cm^{-1}. However, with the two complementary ISO spectrometers (SWS and LWS), it has become possible to obtain complete spectra from 2–200 μm, both with medium spectral resolution in grating mode and with high spectral resolution, using Fabry-Perot interferometers (Kessler et al. 1996, Salama et al. 1997 and Swinyard et al. 1998). During the ISO mission, a large data set of high spectral resolution observations of all Jovian planets has been acquired.

In this paper the complete spectrum of Jupiter between 38 and 200 μm is shown. Data were acquired by SWS (in grating mode) below 45 μm and by LWS (in FP mode) above. These data have been compared with a synthetic model including absorption by H_2, NH_3 and PH_3. Dedicated scans over NH_3 rotational multiplets and a PH_3 rotational band allowed a characterization of these features with high signal-to-noise ratio.

2. OBSERVATIONS AND DATA ANALYSIS

2.1. SWS

AOT S06 observations of Jupiter in band 4 (29–45 μm) have been obtained on May 25, 1997. The integration time was 2796 s. The resolving power around 40 μm was about 1300.

The 20″ × 33″ slit was centered on the planet and aligned with the North-South axis, i.e. making a 21° angle with the central meridian (North Pole P.A. = 339°). Pointing errors for these observations were of the order of 1″.

SWS data of Jupiter in band 4 were strongly saturated: For most of the spectral range, only 3 samples (out of 24) of a reset interval were not affected by this phenomenon. As a result, the removal of the detector and instrumental response function was problematic, leading to artifacts below 30 μm and above 44 μm. The two NH_3 multiplets (J = 11 and 12) that we show in section 4, however, lie within the more reliable part of the range covered by band 4.

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2.2. LWS

Ten large LWS FP scans have been performed with Astronomical Observation Template (AOT) L03; they were executed in revolutions 554, 556 and 557, i.e. between May 23 and 26, 1997, and had a spectral resolution of ≈ 8000. Three dedicated LWS FP observations, again with AOT L03, were used to observe NH_3 and PH_3 lines, covering the wavelength ranges 80–90 μm, 99–104 μm and 139–143 μm. Jupiter had an apparent diameter of 40″ and was always fully included in the LWS field of view.

The starting point of the processing were Standard Processed Data obtained with pipeline version 8. The LWS Interactive Analysis (LIA, Sidher et al. 1998) was used to subtract the stray current, to shift the grating centre and to perform a velocity correction on all observations. With the ISO Spectral Analysis Package we fitted then second order polynomials to the continuum around those lines for which dedicated scans were available. The baseline was removed in order to facilitate the comparison with the model.

Fabry-Perot observations with the LWS are implemented as a series of miniscans. Each miniscan samples the grating response profile, which had to be removed from the data with LIA. This removal of the grating response profile is difficult because of non-repeatability of unknown origin in the grating position. When the grating profile is not completely removed from the Fabry-Perot data, however, the result can be a spectrum that is significantly skewed, and there may be some effect on the slope of the continuum (`http://www.iso.vilspa.esa.es/manuals/HANDBOOK/IV/lws_hb/`).

For this reason we can discuss in the following only global properties of the spectrum and the strong, broad features from ammonia and phosphine. Discontinuities and small-scale variations that appear at certain wavelengths in our data are most likely processing artifacts.

3. Modelling

The far-infrared flux of Jupiter was modelled using a radiative transfer code (Fouchet et al. 2000) including absorption by H_2 (H_2-H_2 and H_2-He collision pressure induced spectrum), NH_3 and PH_3. No cloud contribution was taken into account. The thermal profile and the NH_3 and PH_3 vertical distributions were derived from ISO SWS observations around 10 μm (see figures 1 and 2). In the lower troposphere, the NH_3 and PH_3 show enrichment factors (wrt the solar value) of 3 and 1, respectively. Both NH_3 and PH_3 distributions exhibit a strong cut-off in the upper troposphere due to photodissociation and, in the case of NH_3, saturation. Spectroscopic data were taken from Jacquinet-Husson et al. (1999). The synthetic spectrum was calculated for the entire disk, assuming a mean air-mass factor of 1.6. The SWS data, which did not fully cover the entire disk, were normalized to fit the synthetic spectrum at 40 μm.

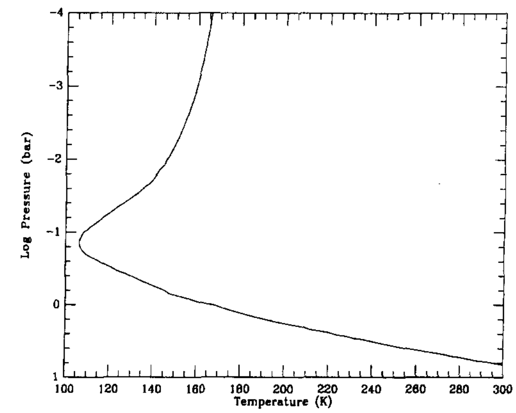

Figure 1. Temperature profile of Jupiter (Fouchet et al. 2000)

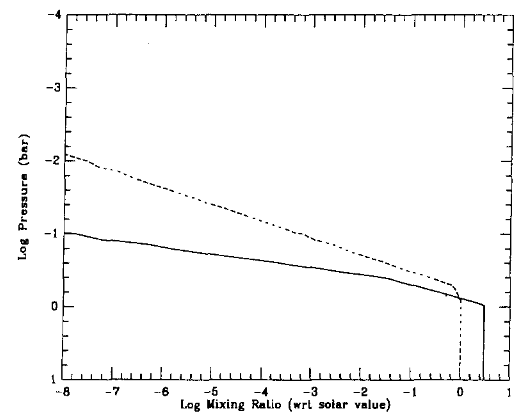

Figure 2. Vertical distribution of ammonia (solid line) and phosphine (dashed line) on Jupiter (Fouchet et al. 2000)

4. Results and Discussion

The ISO spectrum of Jupiter between 38 and 197 μm is shown in Figures 3 (SWS) and 4–6 (LWS) and compared to the model spectrum.

Strong ammonia absorption manifolds are obvious against the background continuum slope, appearing at 39, 42, 46, 51, 56, 63, 72, 84, 100 and 125 μm in both the data and the model. Also phosphine absorption features are present at the expected wavelengths of 113 and 141 μm. Beyond 150 μm, the signal to noise is not sufficient for a clear identification of NH_3 or PH_3 features (figure 6). Figures 7–9 show the NH_3 features at 84 and 100 μm and also the PH_3 line at 141 μm as observed in the dedicated scans with LWS. The ISO data shown in this paper provide the first complete far-infrared spectrum of Jupiter from 50 until 200 μm with high spectral resolution (for a low resolution spectrum see Oldham et al. 1997). The fine structure of the NH_3 multiplets was observed for the first time, as well as the PH_3 bands.

There is good agreement between the continuum slope of the data and the model. Some ammonia features appear somewhat weaker in the observations than in the model,

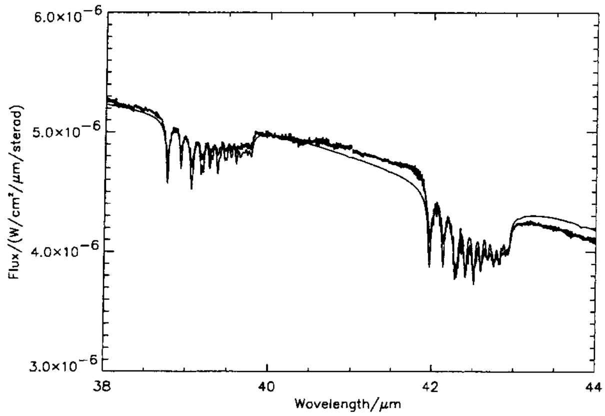

Figure 3. Jupiter's spectrum between 38 and 44 micron. The measurement with the SWS is plotted in black, the model spectrum in red.

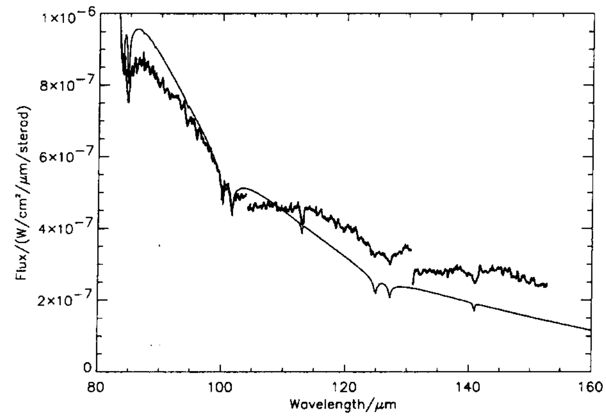

Figure 5. Jupiter's spectrum between 85 and 153 micron. The measurement with the LWS is plotted in black, the model spectrum in red.

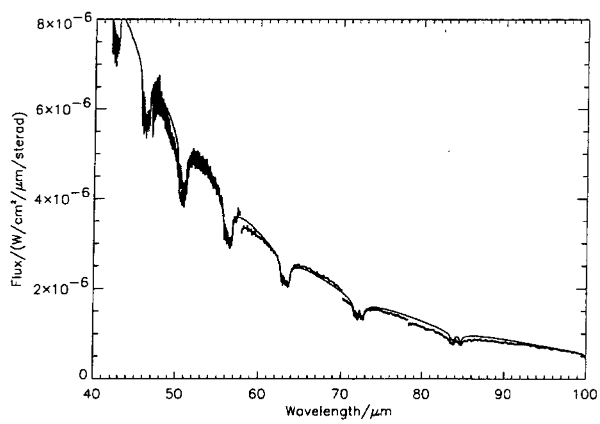

Figure 4. Jupiter's spectrum between 47 and 100 micron. The measurement with the LWS is plotted in black, the model spectrum in red.

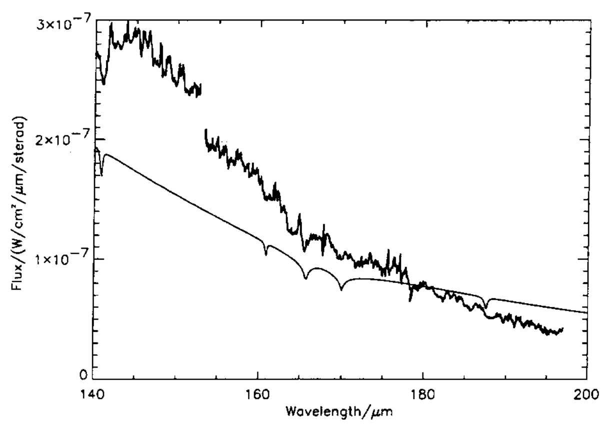

Figure 6. Jupiter's spectrum between 140 and 197 micron. The measurement with the LWS is plotted in black, the model spectrum in red.

especially at 100 μm (figure 8), but at 84 μm (figure 7) the agreement is very good. At 42 μm, the depth of the observed NH_3 band is also in good agreement with the model, but the continuum is poorly fitted, probably because of saturation problems. The measured depth of the phosphine feature at 141 μm agrees with the model, but the line is broader than expected and shows an unexpected emission wing (figure 9). It needs to be investigated further whether this too big line width is an artifact of the data processing.

At first order, the observed far-infrared spectrum of Jupiter appears to be in reasonable agreement with the model, but no precise information can be presently derived about the PH_3 vertical distribution.

New information will be provided by the far-infrared spectra which have been recorded with the CIRS (Composite Infra-Red Spectrometer) instrument aboard the Cassini spacecraft during its Jupiter flyby (December 2000).

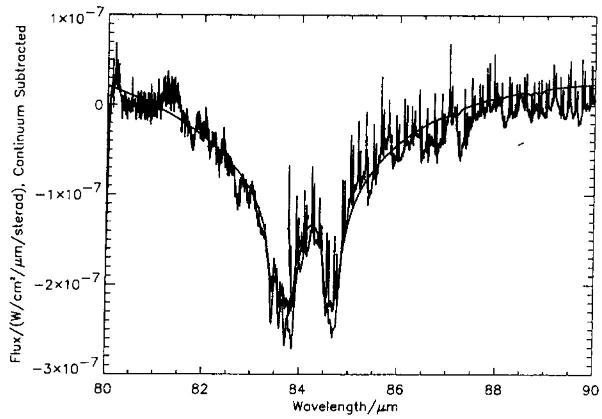

Figure 7. Ammonia Feature on Jupiter at 84 micron. The measurement with the LWS is plotted in black, the model spectrum in red.

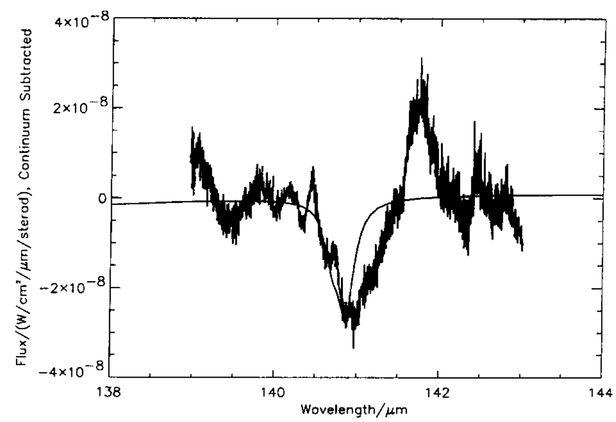

Figure 9. Phosphine Feature on Jupiter at 141 micron. The measurement with the LWS is plotted in black, the model spectrum in red.

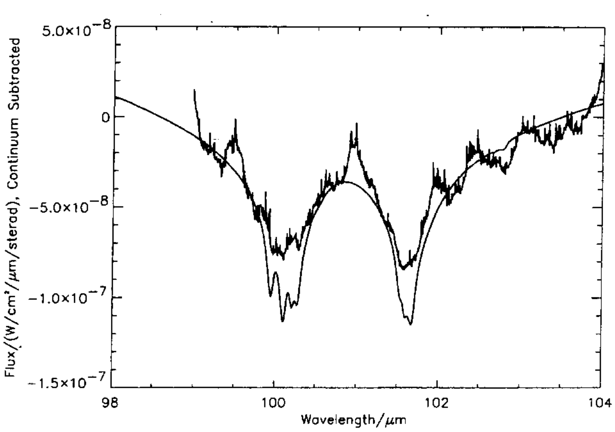

Figure 8. Ammonia Feature on Jupiter at 100 micron. The measurement with the LWS is plotted in black, the model spectrum in red.

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