Retrieval of Jupiter's atmospheric parameters using far infrared spectra measured with PACS onboard the Herschel Space Observatory

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Abstract

On October 31, 2009, the Photodetector Array Camera and Spectrometer (PACS) onboard the Herschel Space Observatory (fig. 1) observed far infrared (FIR) spectra of Jupiter in the wavelength range between 55 and 210 μm in the framework of the program 'Water and Related Chemistry in the Solar System' [Hartogh et al., 2009]. We aim at inferring the abundances of the trace constituents and the atmospheric temperature profile using these data, a line-by-line radiative transfer tool [Villanueva et al. 2018] and the least-squares fitting and retrieval techniques.

Early model preparations and an earlier presentation of the preliminary spectra are given in Sagawa et al. [2010a,b]. Now, we perform a more comprehensive data analysis. PACS's spectral resolution ($R=\lambda/\Delta\lambda$) depends on wavelength and grating order of the measurements and ranges from 990 to 5500. However, the effective spectral resolution was determined using detected, but unresolved spectral lines of stratospheric water, and varies between 500 and 3800. Strong spectral features of methane (CH_4), ammonia (NH_3) and phosphine (PH_3) are clearly visible in the data. Features from other species, such as water, hydrogen deuteride (HD), hydrogen sulfide (H_2S) and some hydrogen halides, such as hydrogen chloride (HCl), are also present in the data and might be used to retrieve upper limits for the relative abundances of these species. We assume a constant CH_4 abundance due to vertical mixing and the lack of methane cloud condensation.

Inferring atmospheric parameters from compositional measurements will not only help to characterize the atmosphere of Jupiter but will also contribute to a better understanding of a plethora of physicochemical processes in the atmosphere.

Figure 1: Artistic impression of PACS in operation [Source: ESA]

Introduction

Jupiter has always sparked strong interest in many branches of Astrophysics and Planetary Science. Its chemical composition plays a vital role in the studies of the origin of the Solar System and the formation of planets. Recently, Jupiter has played a key role as a benchmark planet for extrasolar giant planets that have now been discovered in the thousands. The atmospheric dynamics and composition of Jupiter are central to the understanding of Jupiter for these different purposes, since it is the only directly measurable part of the planet that must be used for models of the entire planet. Hence, both ground-based telescopes and space-borne spectrographs have been used to investigate Jupiter's atmosphere. Here, we focus on the far-infrared spectra measured by PACS onboard Herschel in 2009. The initial analysis of the data set presented here concerns the quality and effective spectral resolution of the measured spectra as well as preliminary results of the CH_4 abundance. After this data analysis, the goal of this project is to retrieve atmospheric profiles and minor constituents' abundances. The molecules in the Jovian atmosphere, for which abundance profiles or upper limits will be determined, are the ones that create visible spectral lines in the data. A list of these molecules and some of their spectral lines are shown in figure 2.

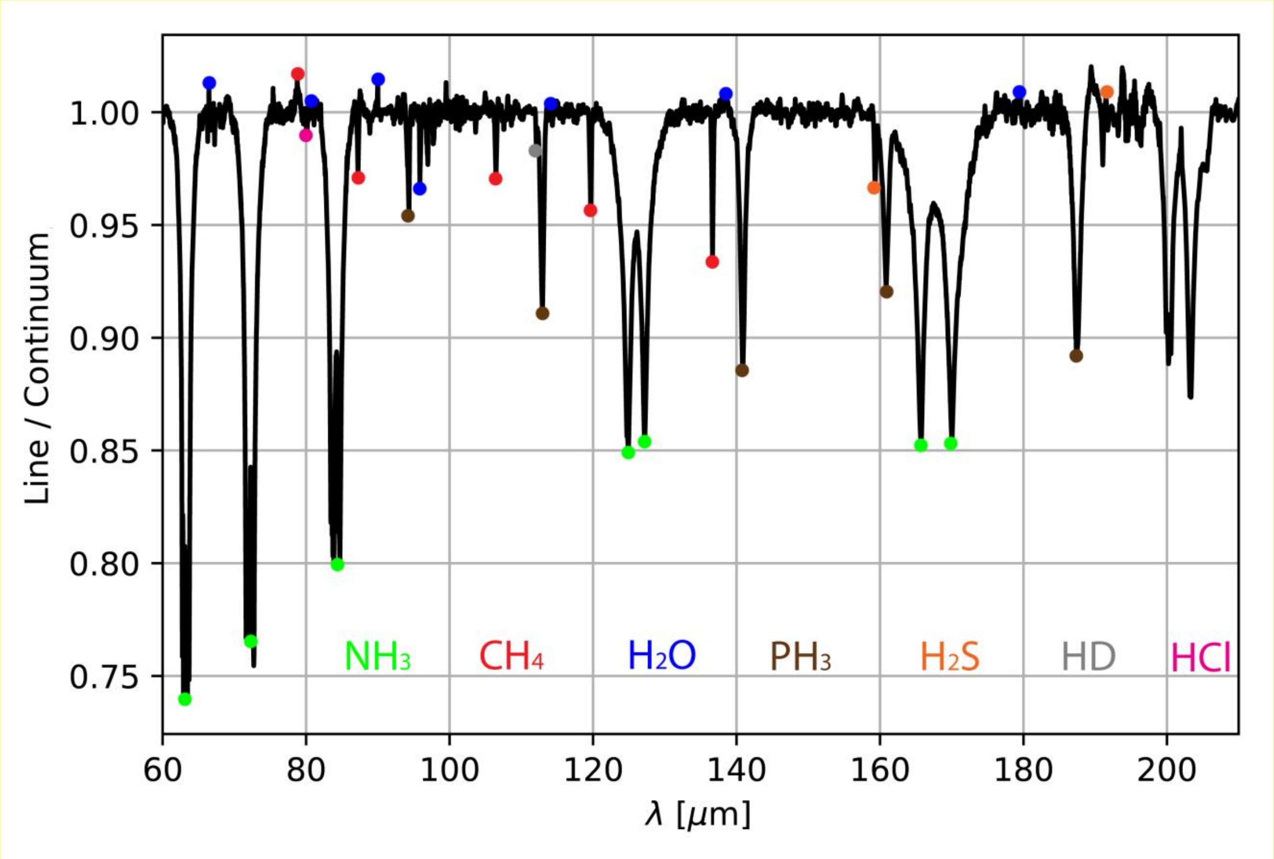

Figure 2: PACS spectrum of Jupiter, expressed in line-to-continuum ratios. Colored dots indicate the signatures attributable to different molecules in the atmosphere.

PACS data analysis

PACS covers the spectral range between 55µm and 201µm in three different filters: A third-order blue filter which operates from 55µm to 73µm, a second-order blue filter from 68µm to 105µm and a first-order red filter from 102 to 210µm. Both the resolution and the grating order of the measurements vary between filters.

The spectral resolution R of the data at different wavelengths is essential to analyze the shape of spectral lines in the spectra. In the PACS user's manual, it is given for point sources for all three filters (see fig. 4, dashed lines). However, Jupiter was spatially resolved in the measurements and its rotation and other factors influenced the spectral resolution. So, we determined the spectral resolution empirically using the FWHM of visible, but unresolved stratospheric H_2O-lines in the spectra. Some of the water lines that were used for this analysis are shown in figure 3 and both the spectral resolution given for point sources in the users' manual and the resolution determined with the water lines are shown in figure 4.

The spectral resolution of the spectra is generally lower than the resolution given in the users' manual, with values between 500 and 3800.

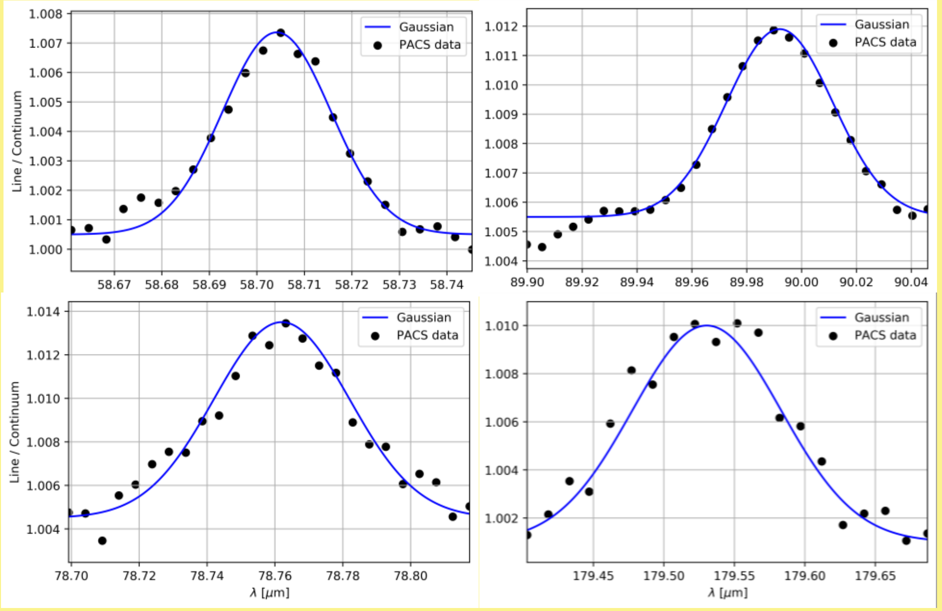

Figure 3: H_2O lines used to estimate the spectral resolution. For each line there is a Gaussian curve with the same FWHM plotted in blue for comparison.

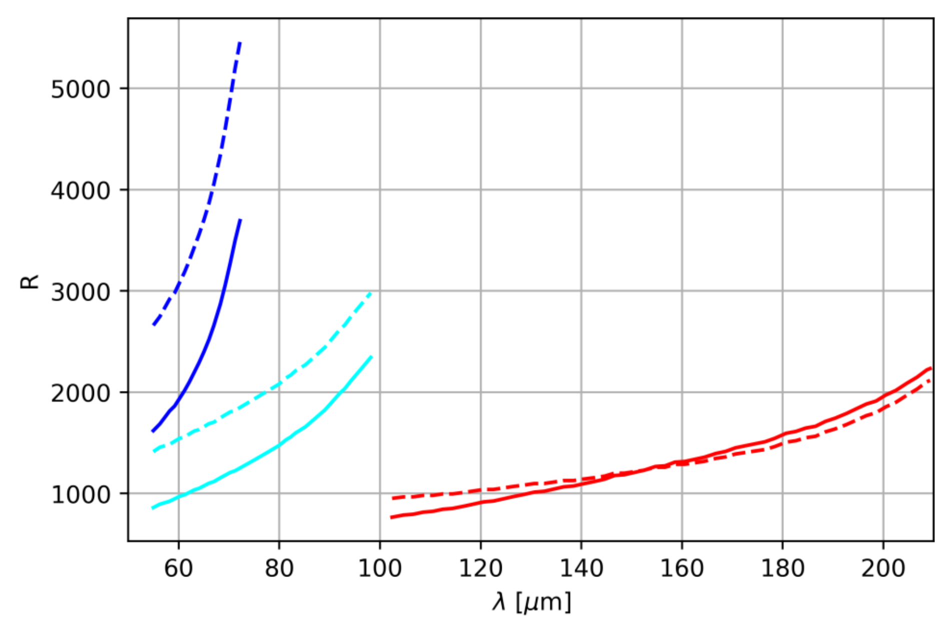

Figure 4: Spectral resolution of the three filters estimated using the H_2O-lines shown above. The dashed lines represent the spectral resolution given in the user's manual for point sources.

Preliminary methane abundance

We assume the CH_4 abundance of Jupiter's atmosphere to be constant vertically and in all latitudes. To determine it from the data, we used the line-by-line radiative transfer forward model PSG [Villanueva et al. 2018]. PSG uses a Jupiter model with a temperature-pressure model from Moses et al. [2005] and models the planet's spectrum. A constant CH_4 abundance was integrated into the composition model of Jupiter, varied and the resulting spectra were compared to the PACS data.

The resulting synthetic spectra were compared to the PACS data using a χ²-test. An example of a comparison between a synthetic PSG spectrum and the PACS data and the χ²-test for a CH_4 line are shown in figures 5 and 6. The best-fit CH_4 abundance from this line is $(1.59 \pm 0.05) \cdot 10^{-3}$. This abundance is lower than the CH_4 abundance found by the Galileo Probe $(1.81 \cdot 10^{-3})$ [Niemann et al., 1998].

There are many more CH_4 lines visible in the PACS data and in the next step, more lines will be used to compute a CH_4 abundance that simultaneously fits all the identified lines. This will give a more robust value for the CH_4 abundance measured by PACS.

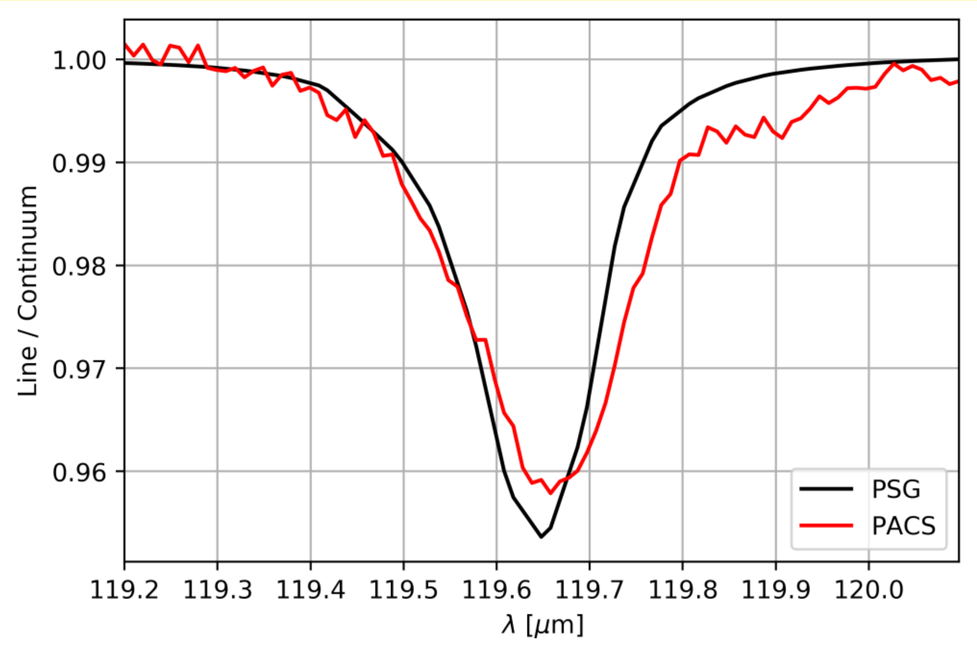

Figure 5: PACS-data of a CH_4-line together with a synthetic spectrum calculated with PSG. The CH4-abundance used for the synthetic spectrum is $1.5 \cdot 10^{-3}$.

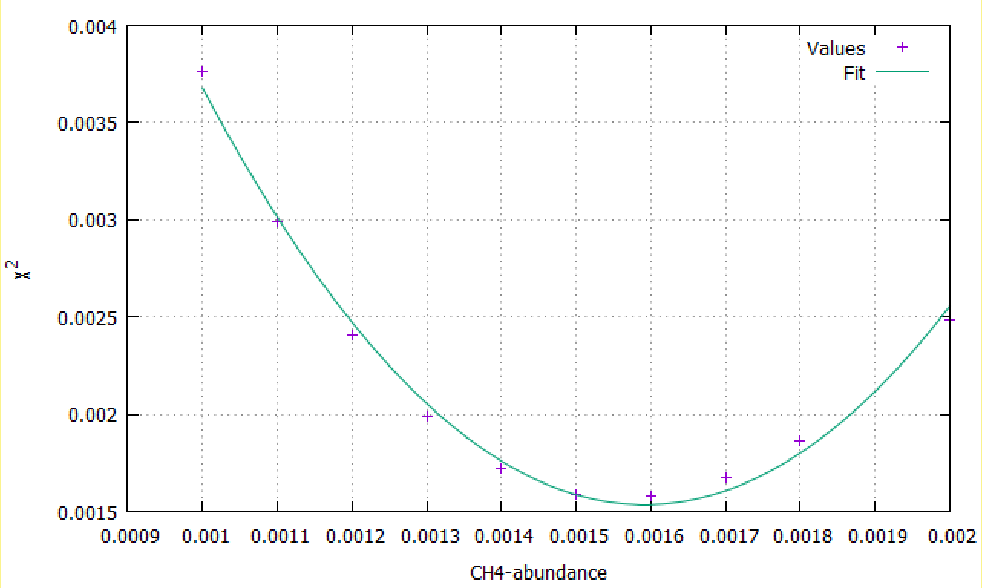

Figure 6: χ²-test for the CH_4-abundance of that line.

Conclusions

With a spectral resolution between 500 and 3800, the PACS data are high-quality data. With further investigation of the data, we expect to be able to retrieve profiles and abundance profiles of some molecules such as NH_3 and PH_3 as well as upper limits for minor constituents such as H_20, H_2S, HD and HCl.

Acknowledgements

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On this poster, we discussed observations performed with the ESA Herschel Space Observatory to do spectroscopy using PACS. PACS has been developed by a consortium of institutes led by MPE (Germany) and including UVIE (Austria); KU Leuven, CSL, IMEC (Belgium); CEA, LAM (France); MPIA (Germany); INAF-IFSI/OAA/OAP/OAT, LENS, SISSA (Italy); IAC (Spain). This development has been supported by the funding agencies BMVIT (Austria), ESA-PRODEX (Belgium), CEA/CNES (France), DLR (Germany), ASI/INAF (Italy), and CICYT/MCYT (Spain).
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