RETRIEVAL OF THE VERTICAL PROFILES OF WATER VAPOUR IN THE MARTIAN ATMOSPHERE USING PACS ONBOARD HERSCHEL.

G. PORTYANKINA[1], **P. HARTOGH**[2], **H. SAGAWA**[2], **and N. THOMAS**[1], [1]*Physikalisches Institut, University of Bern, CH-3012, Bern, Switzerland*, [2]*Max-Planck-Institut für Sonnensystemforschung, Max-Planck-Straße, 2, D-37191 Katlenburg-Lindau, Germany*.

Introduction

The Herschel Space Observatory is an ESA mission that provides high sensitivity observations in the far infrared and sub-millimeter regime. The Photodetector Array Camera and Spectrometer (PACS) is one of the three science instruments of the Herschel Space Observatory. PACS provides capabilities for spectroscopy and imaging photometry in the 55–210 μm range. On 23 June 2010, PACS conducted observations of Mars in the frame of the guaranteed-time key project "Water and related chemistry in the Solar System" (Hartogh et al., 2009) The program dedicates a substantial amount of observation time to Martian atmosphere studies with PACS.

Observations of the Martian atmosphere in the thermal infrared and sub-millimeter allow one to study the atmosphere's vertical structure. The vertical distribution of water vapour in the atmosphere is a key aspect in these studies. Column-integrated amounts of water vapour were estimated by several authors using data from space missions such as Viking (Clark et al., 1976), MGS (Smith, 2002), Mars Express (Fedorova et al., 2006). Their temporal and spatial variations were also described. However, the observational data for vertical profiles of water vapour are very limited.

Our present knowledge of the H_2O vertical profile comes from diverse models of the Martian atmosphere (for example, (Forget et al., 1999; Sonnemann et al., 2010)). The only observational sources are ground-based observations of the H_2O 22 GHz and HDO 226 GHz lines (Encrenaz et al., 1991; Clancy et al., 1996) and solar occultation experiments from the Mars Express orbiter (Fedorova et al., 2009). These observations show that the altitude of the minimum in the water vapour mixing ratio (so-called hygropause) varies between 10 km (aphelion) and 50 km (perihelion). Potentially Herschel has the capability to confirm or disprove this seasonal asymmetry of the water vapour mixing ratio with a sensitivity an order of magnitude higher than the previous measurements. It will be a strong constraint for models describing the general circulation of the Martian atmosphere (Forget et al., 1999; Hartogh et al., 2005).

In the present work we discuss retrievals of water vapour vertical profiles using PACS observations. After reduction and calibration the observational data result in the Martian far-infrared spectra in 55–210 μm range. An example subset of such is shown in Fig. 1.

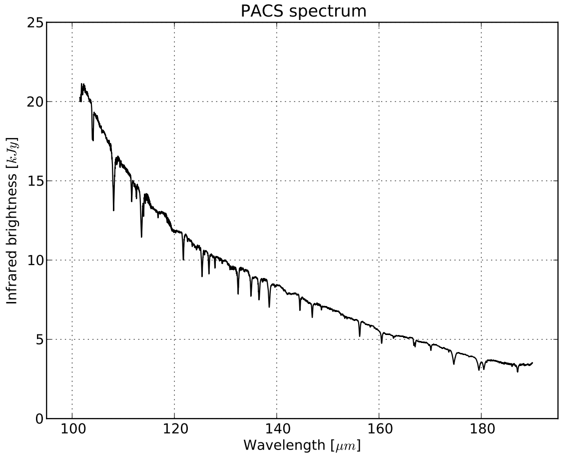

Figure 1: An example subset of PACS spectrum of Martian atmosphere observed on 23 June 2010. A number of spectral features due to CO and H_2O are detected.

Description of the techniques used

We use a forward and inversion model to solve the ill-posed problem of finding the vertical water vapour profile that fits the observed spectra. Our model has been developed on the basis of MOLIERE-5 (Microwave Observation LIne Estimation and REtrieval, Urban et al. (2004)). Being a modular application, the MOLIERE-5 forward model consists of modules describing spectroscopy, radiative transfer, and instrumental characteristics. Besides the "forward model", MOLIERE-5 also provides a "retrieval model" for the retrieval of profile information from radiometric measurements at millimeter and sub-millimeter wavelengths. The theoretical basis of the inverse method for atmospheric sounding is well described for example, Rodgers (1976).

In our model, the atmosphere spans from 0-120.0 km with a vertical resolution of 1.5 km. In this initial analysis, the temperature and pressure profiles are based on the results of Mars Climate database (Forget et al., 1999).

MOLIERE numerically integrates the following expression for each atmospheric layer along the line-of-sight of the considered instrument (in our case PACS):

$$I_\nu(s_r) = I_\nu(s_e)e^{-\tau(s_e,s_r)} + \int_{s_e}^{s_r} \alpha_\nu(s)B_\nu(T)e^{-\tau(s,s_r)}ds. \tag{1}$$

We denote the specific intensity of radiation that reached the sensor at position s_r at a frequency ν as $I_\nu(s_r)$ and that is entering the atmosphere at the position s_e (at the direction of line-of-sight) as $I_\nu(s_e)$. The line-of-sight geometry for simulated PACS observations is calculated according to the Herschel - Mars geometry during the PACS observations (i.e. at UTC 01:46:20 on 23 June 2010, L_s = 108.28°). Spectroscopic data for molecular compounds were taken from the HITRAN 2008 molecular spectroscopic database (Rothman et al., 2009).

The modelled intensity of radiation $I_\nu(s_r)$ that reaches the sensor is then convolved with the antenna response and channel sensitivity of PACS to produce synthetic spectra. Instrument modelling was performed according to the PACS observer manual.

MOLIERE uses the linear least-squares method based on the Optimal Estimation Method (OEM, see e.g., Rodgers (1976)) to combine statistical a priori knowledge of the variability of the searched parameters with the information provided by the measurement (in our case - PACS measured spectra). We calculate the forward model and the OEM inversion model iteratively using the Levenberg-Marquardt scheme, which allows us to solve non-linear inversions.

Preliminary results

Fig. 2 shows an example of a preliminary water vapour vertical profile. We consider this retrieval to be preliminary because of two following reasons: first, we have used a certain wide spectral range of the PACS data, and the spectral features of additional atmospheric compounds such as CO and the instrumental ripples on the continuum are not properly considered in the analysis. Secondly, we have used vertical temperature profiles averaged over 30 sols. We plan in future to use exclusively H_2O spectral lines for the retrievals. Also, we will incorporate vertical temperature profiles more suitable for the date of observation. In addition, we need to improve the accuracy of the continuum level determination of PACS measured spectra, which easily introduce a significant error on the retrieved H_2O profile. Since Mars is a too bright source for a normal operation of the PACS detectors, only a very special observing mode can be applied. Nevertheless the absolute calibration errors are rather high. Note that the original absolute amplitude of PACS measurements are incorrect because of the detector's self-curing effect against too high infrared flux from Mars.

Fig. 3 shows averaging kernels for the preliminary retrieval. The averaging kernels show the sensitivity

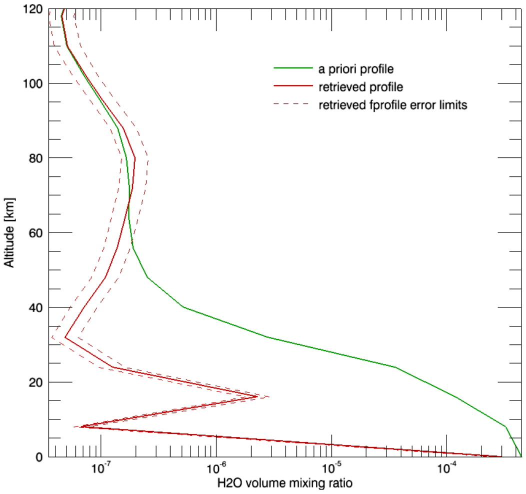

Figure 2: An example retrieval of water vapour vertical profile using PACS spectrum of Martian atmosphere observed on 23 June 2010.

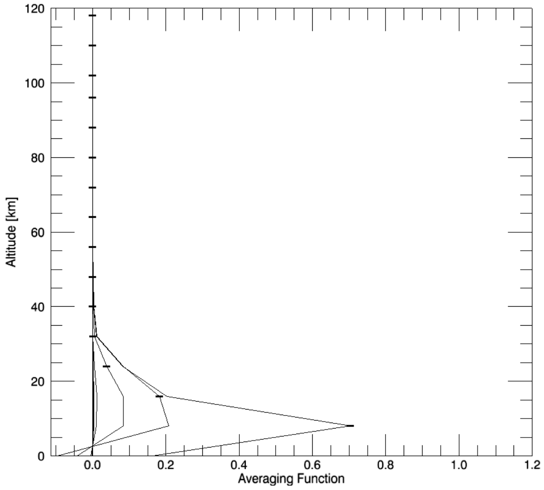

Figure 3: Averaging kernels for the retrieval from Fig. 2.

of the retrieved state to the true state for a particular layer, in other words we can assess the quality of a retrieval from the amplitudes of the averaging functions, and also estimate the effective vertical resolution on the retrieved information from their broadening widths. We can see, that with this first try run we are able to asses the information about atmospheric layers below 30 km. This is mostly limited by the spectral resolution of PACS.

We will present further analysis of PACS data, including by using careful baseline/continuum evaluation for the observed spectrum and more careful model of the instrument.

Bibliography

Clancy, R. T. et al, Jul. 1996. Water vapor saturation at low altitudes around Mars aphelion: A key to Mars climate? Icarus 122, 36–62.

Clark, B. C. et al, Aug. 1976. Argon content of the Martian atmosphere at the Viking 1 landing site - Analysis by X-ray fluorescence spectroscopy. Science 193, 804.

Encrenaz, T. et al, Dec. 1991. The atmospheric composition of Mars - ISM and ground-based observational data. Annales Geophysicae 9, 797–803.

Fedorova, A. et al, Sep. 2006. Mars water vapor abundance from SPICAM IR spectrometer: Seasonal and geographic distributions. Journal of Geophysical Research (Planets) 111, 9.

Fedorova, A. et al, 2009. Solar infrared occultation observations by SPICAM experiment on Mars-Express: Simultaneous measurements of the vertical distributions of H_2O, CO_2 and aerosol. Icarus, 111, 9.

Forget, F. et al, Oct. 1999. Improved general circulation models of the Martian atmosphere from the surface to above 80 km. Journal of Geophysical Research (Planets) 104, 24155–24176.

Hartogh, P., et al, Nov. 2009. Water and related chemistry in the solar system. A guaranteed time key programme for Herschel. Planetary and Space Science 57, 1596–1606.

Hartogh, P. et al, Nov. 2005. Description and climatology of a new general circulation model of the Martian atmosphere. Journal of Geophysical Research (Planets) 110, 11008.

Rodgers, C. D., Nov. 1976. Retrieval of atmospheric temperature and composition from remote measurements of thermal radiation. Reviews of geophysics and space physics 14, 609–624.

Rothman, L. et al., 2009. The hitran 2008 molecular spectroscopic database. Journal of Quantitative Spectroscopy and Radiative Transfer 110 (9-10), 533 – 572, hITRAN.

Smith, M. D., Nov. 2002. The annual cycle of water vapor on Mars as observed by the Thermal Emission Spectrometer. Journal of Geophysical Research (Planets) 107, 5115.

Sonnemann, G. et al., 2010. A new coupled 3d-model of the dynamics and chemistry of the martian atmosphere Adv. Geoscience, 19, 177-194.

Urban, J. et al, 2004. Moliere (v5): a versatile forward and inversion model for the millimiter and submillimiter wavelength range. Journal of quantitative spectroscopy and radiative transfer 83, 529–554.