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Simulation of the H_2O measurement in the Jupiter's atmosphere in forecast of the Juno mission

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Abstract. In view of a possible Italian participation to the NASA New Frontiers mission Juno to Jupiter, whose launch is planned for 2011, Italy proposes to extend its contribution by the addition of JIRAM (Jovian InfraRed Auroral Mapper) to the scientific payload. In order to show the possibilities of JIRAM in observing the Jupiter atmospheric water content, we simulated the H_2O measurements inside a hot spot that, for its particular dynamical structure, is characterized by low optical depths. This fact allows to an imaging spectrometer like JIRAM to sound the tropospheric layers in deeper levels than on the rest of the planet. The simulation of the H_2O measurements has been realized using a radiative transfer model named ARS. This code is based on the spectroscopic archives HITRAN (HIgh TRANsmission molecular absorption database), and uses the line-by-line technique to compute transmissivity calculations. The simulation regards the atmospheric emission, in the spectral interval between 4.5 and 5.3 μm, that comes from the inner regions of the planet. In order to calculate the characteristics emission/absorption of the atmosphere we have been taken in consideration other gases in trace beyond water like CH_4, PH_3 e NH_3 that are active in the sounded spectral interval.

Key words. LBL synthetic spectrum, transmittance, contribution functions, Jupiter, hot spot.

1. Introduction

The understanding of formation and composition of the giant planets, and their atmospheres, can be consider as a very important element for all Solar System understanding. In the last decades, the atmosphere of Jupiter has been investigated with earth-based remote sensing but the analysis of *in situ* measurements by the Galileo Probe has played a very important role to obtain this main goal.

The entry probe location was in a 'dry hot spot', where the cloud opacity is low and the region is relatively cloud free. It is well known that the 5 μm spectrum of Jupiter gives the opportunity to sound the deeper atmospheric layers and our goal is to simulate the thermal emission of the Jovian atmosphere, in the nearinfrared spectral region, using three different water mixing ratio profile, to retrieve the right O/H ratio by future possible observation taken by JIRAM. JIRAM would be an image spectrometer working in the $2.0 \div 5.0\,\mu m$ spectral range, with a spectral resolution of approximately 10 *nm*.

2. The simulation

So far, we have modeled the atmosphere as a mixture of 4 gases using ARS, a radiative transfer code developed by N.I. Ignatiev (2005), based upon the spectroscopic database HITRAN 2004.

We considered the emission of the planet as modulated by the absorption of four molecules (H_2O, CH_4, NH_3, PH_3), in the spectral range $4.5 \div 5.4\,\mu m$. We have chosen the temperature-pressure profiles, showed in Fig.1, from the Galileo probe data (Seiff et al., 1998) taken in the entry probe site. Fig.2 shows the mixing ratio versus pressure of the four gases which have been considered in the first simulation.

The water vapor mixing ratio profile that we used shows constant values at pressure values higher than 6 *bar*, where the mixing ratio is set to 2.67×10^{-3}. The values of the profile have been obtained modifying those ones in M.Roos-Serote et al. (2004), where the mixing ratio is set to 1.38×10^{-3}, that corresponds to solar O/H ratio given by Cameron et al. (1982), with a constant mixing ratio at pressures higher than 6 *bar*.

Next, we have synthesized a Line-By-Line (LBL) spectrum, using a 400.000 points grid with a resolution of 0.001 cm^{-1}, and we have calculated the absorption coefficient for every species in the mixture. A Voigt line shape function with truncated wings has been assumed. The cutoff has been chosed at 50 cm^{-1} from the line center.

Then the radiance, computed by ARS at high spectral resolution, has been convolved with a Gaussian function, with 10.0 *nm* FWHM, gridded on the instrument's channel wavenumbers and then adapted to the wavelength units, in order to have the resulting spectrum in equally spaced wavelengths as expected for the image spectrometer. The gaussian simulates the instrumental transfer function of JIRAM. The convolved radiance profile is showed in Fig.3. The simulated spectrum is compared, in Fig.4., with an average spectrum of Jupiter taken by VIMS (Visible Infrared Mapping Spectrometer). The VIMS observa-

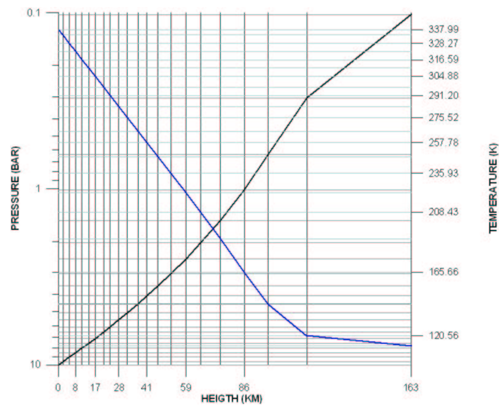

Fig. 1. Temperature and pressure versus altitude profiles taken from the Galileo probe data (Seiff et al., 1998).

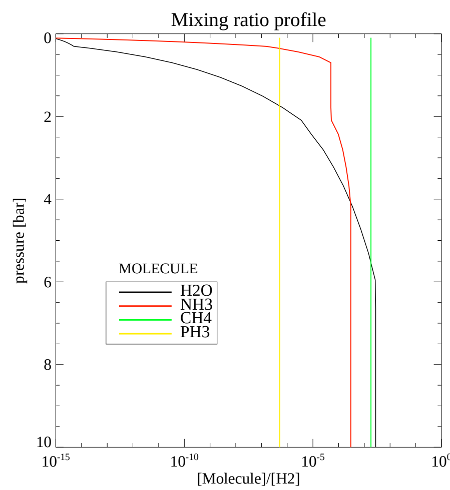

Fig. 2. Mixing ratio profiles of all the molecules used in the simulation. H_2O profile was obtained from M.Roos-Serote et al. (2004) while NH_3 profile from Fouchet et al. (2000). For the CH_4 and PH_3 profile however, we have used a constant value of 1.81×10^{-3} for the methane (Seiff et al., 1998) and 6.0×10^{-7} for phosphine (Carlson et al., 1993).

Table 1. Main physical parameters used for the simulation.

Molecules	H_2O, CH_4, NH_3, PH_3	-
Wavelength range	4445 ÷ 5405	[nm]
LBL wavenumber range	1850 ÷ 2250	[cm^{-1}]
LBL resolution	0.001	[cm^{-1}]
Wings cutoff	50.0	[cm^{-1}]
LBL grid points	400.000	-
Instrument channels	97	-
Gaussian FWHM	10.0	[nm]

tions have been taken during the Cassini fly-by of Jupiter which took place in December 2000.

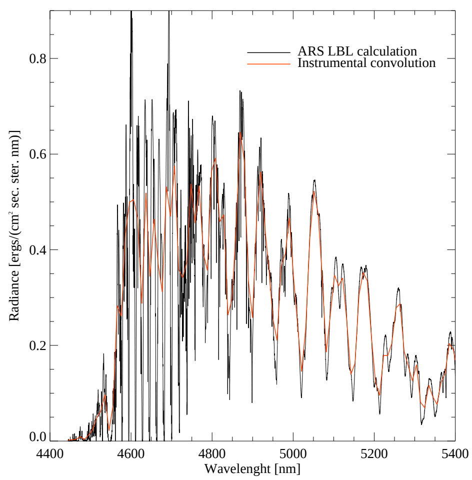

Fig. 3. The black line is the ARS radiance calculated for every single point of the grid. The red line is the convolution using the Gaussian function as a response.

For this first trial a setting as simple as possible for the radiative transfer (RT) model inputs has been chosen, to verify the goodness of our parameter choices.

The conditions of the RT model for the calculations are summarized in Table 2 and are the same for all of the simulations where the values of the pressure, temperature and height can be read in Fig.1.

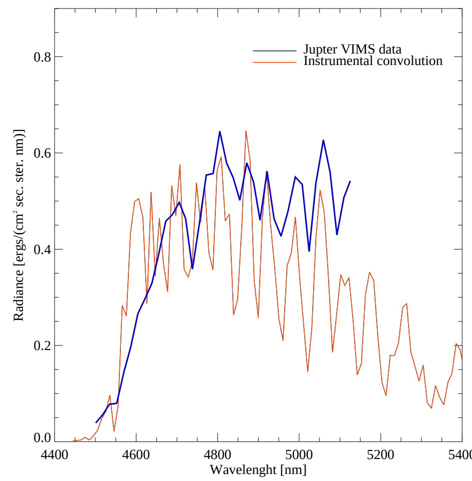

Fig. 4. The ARS radiance, convoluted on the instrument channels, is now compared with the VIMS spectrum of Jupiter (blue line).

For understanding the atmospheric levels where the maximum signal comes from, we have defined the transmittance and the weighting or contribution functions (CF) for all of the four species. The CF comes from the convolved transmittance, on the 97 channels.

In Fig.5, we show the color-coded CF for the 97 instrument channels. The white color shows the position of the maximum of the CF respect to its pressure level. As seen in the figure, some channels are 'double peaked'. The double peak might be due to the stratification (number and height of the layers) of the atmosphere, however similar effects can be observed in the presence of clouds (M.Roos-

Table 2. RT conditions. Note that an altitude of 40 *km* level of has been attributed to the pressure level of 10 *bar* for convenience in the calculations. The level of 0.1 *bar* corresponds to about 200 *km*.

no clouds
no solar source (planet emission only)
nadir looking
34 atmospheric layers (from 10 to 0.1 *bar*)
constant layering step of 5 *Km*

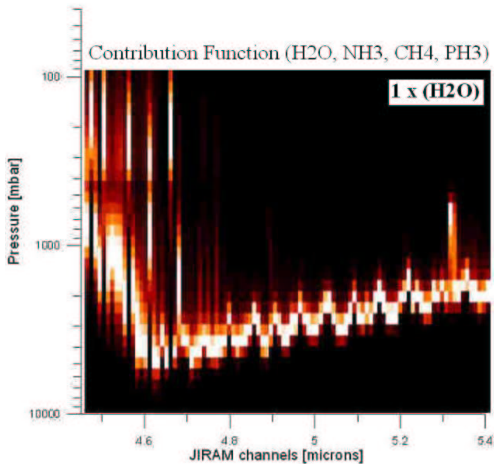

Fig. 5. Total CF (for all of the molecules used for the simulation) with 1× (H_2O) profile as reported in Fig.2.

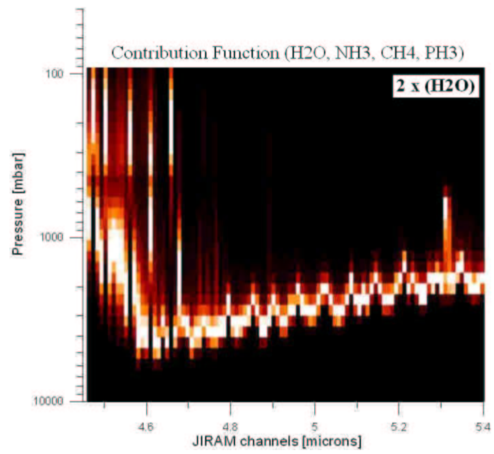

Fig. 6. CF for 2× (H_2O).

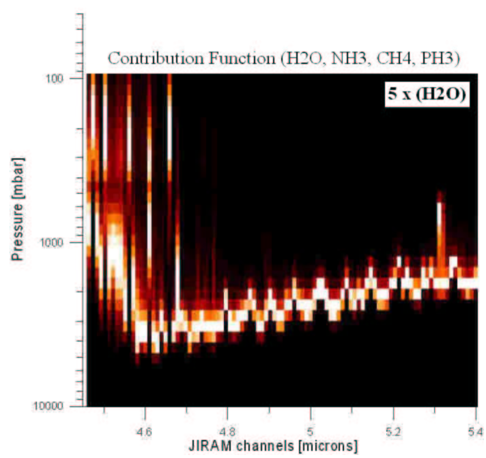

Fig. 7. CF for 5× (H_2O).

Serote et al., 1998). The introduction of the clouds is planned for the next simulations.

In order to evaluate the depth of the sounding as a function of the water vapor content in the atmosphere, the calculation of new Contribution Functions has been done increasing the water vapour mixing ratios of a factor of 2 and 5 at all the pressure levels, in respect to the values given in Fig.2. The concentrations for the remaining gases have not been changed. The effect of the increasing of the water vapor mixing ratio of a factor 2 or 5 on the trasmissivity of the atmosphere and, consequently, the new maximum values of the CF, are reported in Fig.6 and Fig.7 respectively.

The result of the H_2O concentration increased of a factor 5, results in a decreasing of about 1 *bar* in the depth of the sounding. The

Table 3. Output values for the three different simulation, 1×, 2× and 5× (H_2O).

Simulation	Pressure max [*bar*]
1× (H_2O)	4.8
2× (H_2O)	4.1
5× (H_2O)	3.7

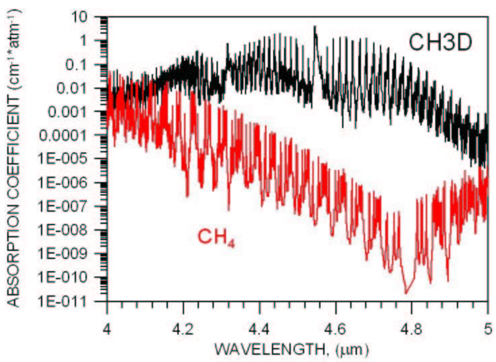

Fig. 8. CH_3D absorption coefficient spectrum. Note the absorption feature centered around 4.6 μm.

figures show such a decrease by a shift of the CF maximum toward up. The value of pressure of the deeper level reached by each simulation, is summarized in Table 3 as a function of the water vapor concentration. The numbers in the table give the lowest levels of the maximum of the respective cumulative CF considering the all spectral range between 4.5 and 5.4 μm, as show in the figures.

3. Future development

CH_3D has not been taken into consideration in the current simulation. In order to get a better simulation of the Jovian emission, CH_3D contribution has to be introduced in the next step.

The contribution of CH_3D in the absorption will be around 4.6 μm (see Fig. 8) and it will consequently significantly change the position of the maximum of the CF around that part of the spectrum.

The effect of the introduction of the monodeuterated methane in the calculation, can be also estimated comparing the simulated spectrum with the Cassini-VIMS one (see Fig.4), where it's clear that the shape of the spectrum is modulated by the absorption of this compound at that wavelength.

An estimation of the CH_3D concentration can be used for the estimation of the abundance of Deuterium in the Jovian atmosphere. No contribution to the absorption from HDO there is in the considered spectral range.

A further development of the simulation is the introduction of thin clouds, of different optical depths, in order to also evaluate their role in the atmospheric radiative transfer from Jupiter to JIRAM.

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