A reanalysis of ISO-SWS Jupiter observations using NEMESIS: first results

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Introduction

- Determining the abundances of chemicals species and their isotopic ratios is fundamental to understand how and when the planets formed, in what conditions and what processes happen in their atmosphere. Jupiter still has some unanswered questions in this regard. The apparent low-temperature origin of the elements that formed the planet, the detailed meteorological processes that happen in its atmosphere remain largely unknown and the chemistry responsible for the colours of clouds of Jupiter is one of its oldest mysteries (Taylor et al.). With this work, we hope to contribute to the progress of unravelling some of these questions.

Methodology

- We used observations of Jupiter from the ESA mission Infrared Space Observatory (ISO) (Kessler et al. 1996) in the 793.65-3125 cm^{-1} (3.2-12.6 μm) region using the Short-Wave Spectrometer (SWS) (de Graauw et al., 1996). Our work is focused on the 793.65-1492.54 cm^{-1} (6.7-12.6 μm) region of the spectrum. Even though this data set is old, it was an important step in the study of Jupiter's atmosphere and with the advancements in atmospheric models and line data, we argue that it warrants a revisit and reanalysis.
- We used the NEMESIS radiative transfer suite (Irwin et al. 2008) to reproduce the results from Encrenaz et al. 1999 as a way to verify the validity of our method. This study was done using the CIRS NEMESIS template as a base adapted to the ISO-SWS data. We used correlated k-tables compiled for NH_3, PH_3, $^{12}CH_3D$, $^{12}CH_4$, $^{13}CH_4$, C_2H_2, C_2H_6, He, H_2, C_2H_4 and C_4H_2, with our results showing good agreement (Fig(1)).

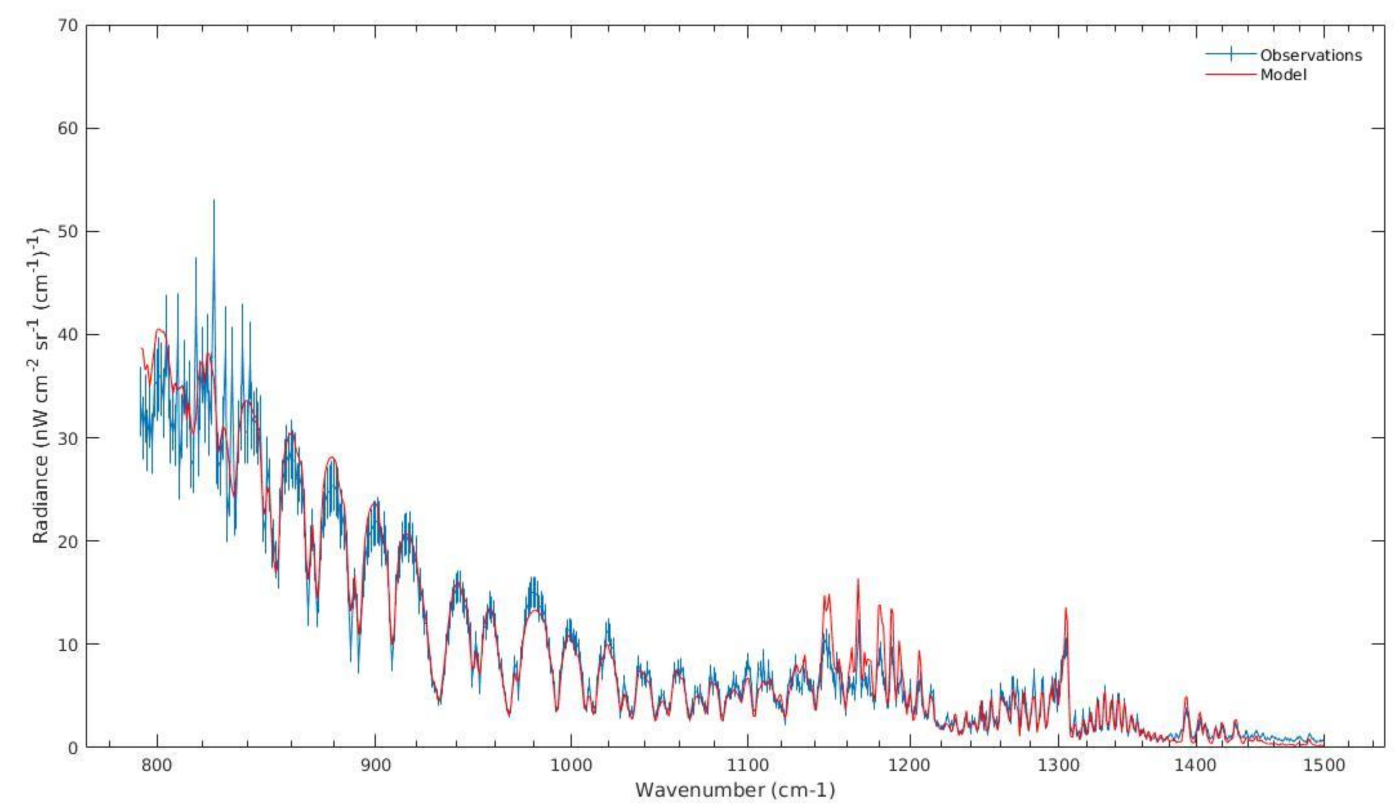

Figure 1: Plot of ISO-SWS data used in this work and NEMESIS best fit model for $^{12}CH_4$ retrieval with χ^2/N = 7.54

- The quality of our fit is determined by the reduced χ^2 value (χ_{red}):

$$\chi_{red} = \left(\sum \left(\frac{L_{measured} - L_{fit}}{\sigma_{measured}} \right)^2 \right) / N$$

- Where $L_{measured}$ is the measured radiance, L_{fit} is the model radiance, $\sigma_{measured}$ is the measured radiance error and N is the total number of wavenumber values in the spectrum.
- Our initial results (Fig(1)) gave us a χ_{red}= 7.54 when for an excellent fit χ_{red} should be less than 1.
- Our current best fit is for a retrieval of NH_3, $^{12}CH_3D$, $^{12}CH_4$, $^{13}CH_4$, C_2H_2, C_2H_6 and H_2, with a χ_{red}= 1.63 for the 793.65-1200.00 cm^{-1} region (Fig(2)).

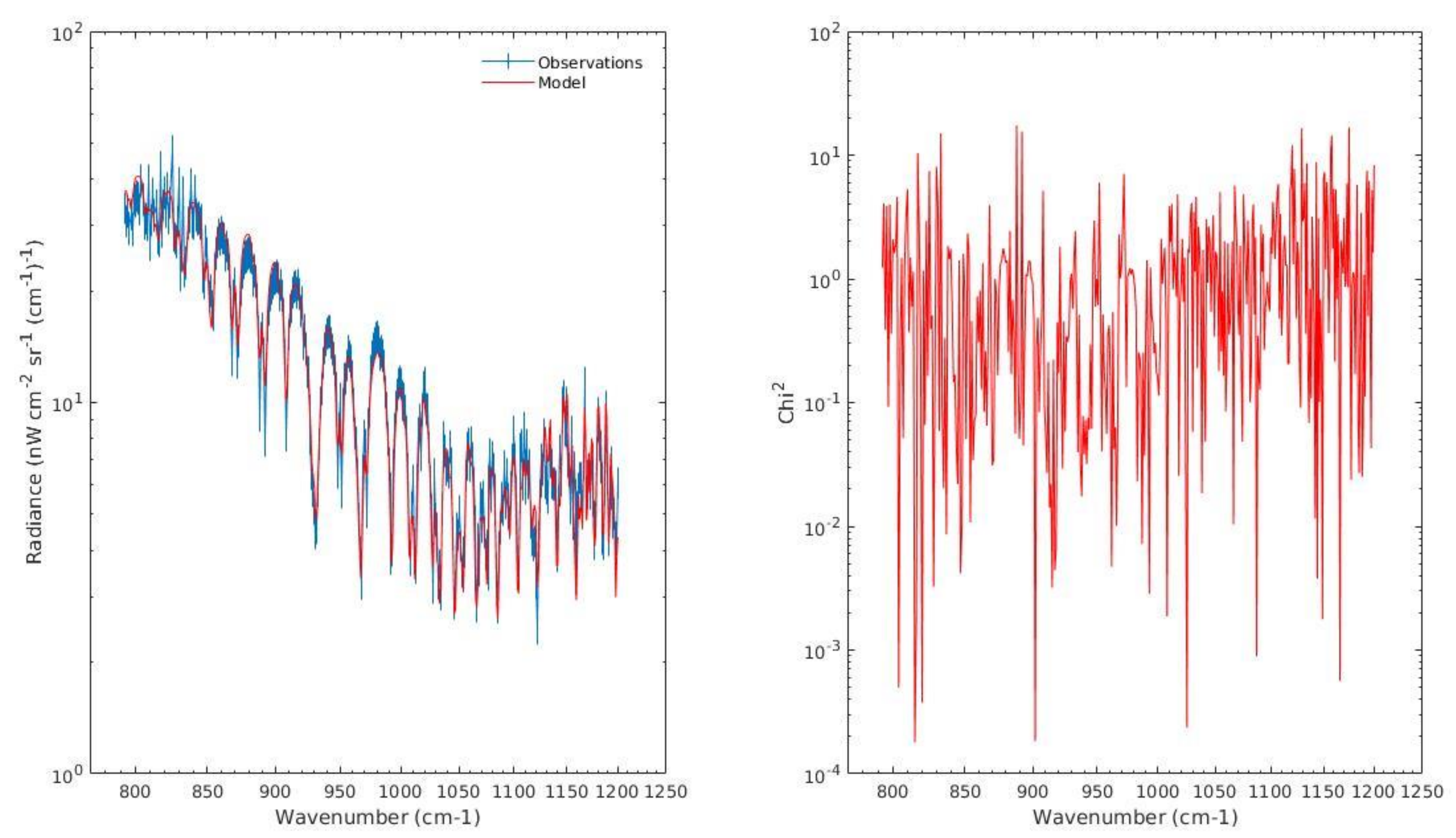

Figure 2: Plot of ISO-SWS data and current best model fit (left) and the variation of the χ^2 with wavenumber (right)

Abundance study

- Having verified our method, we present here our first results of the study of abundances of $^{12}CH_3D$, $^{12}CH_4$, $^{13}CH_4$, C_2H_2 and C_2H_6 of Jupiter's atmosphere using the NEMESIS suite to determine the abundances as a function of pressure (Fig (3)).

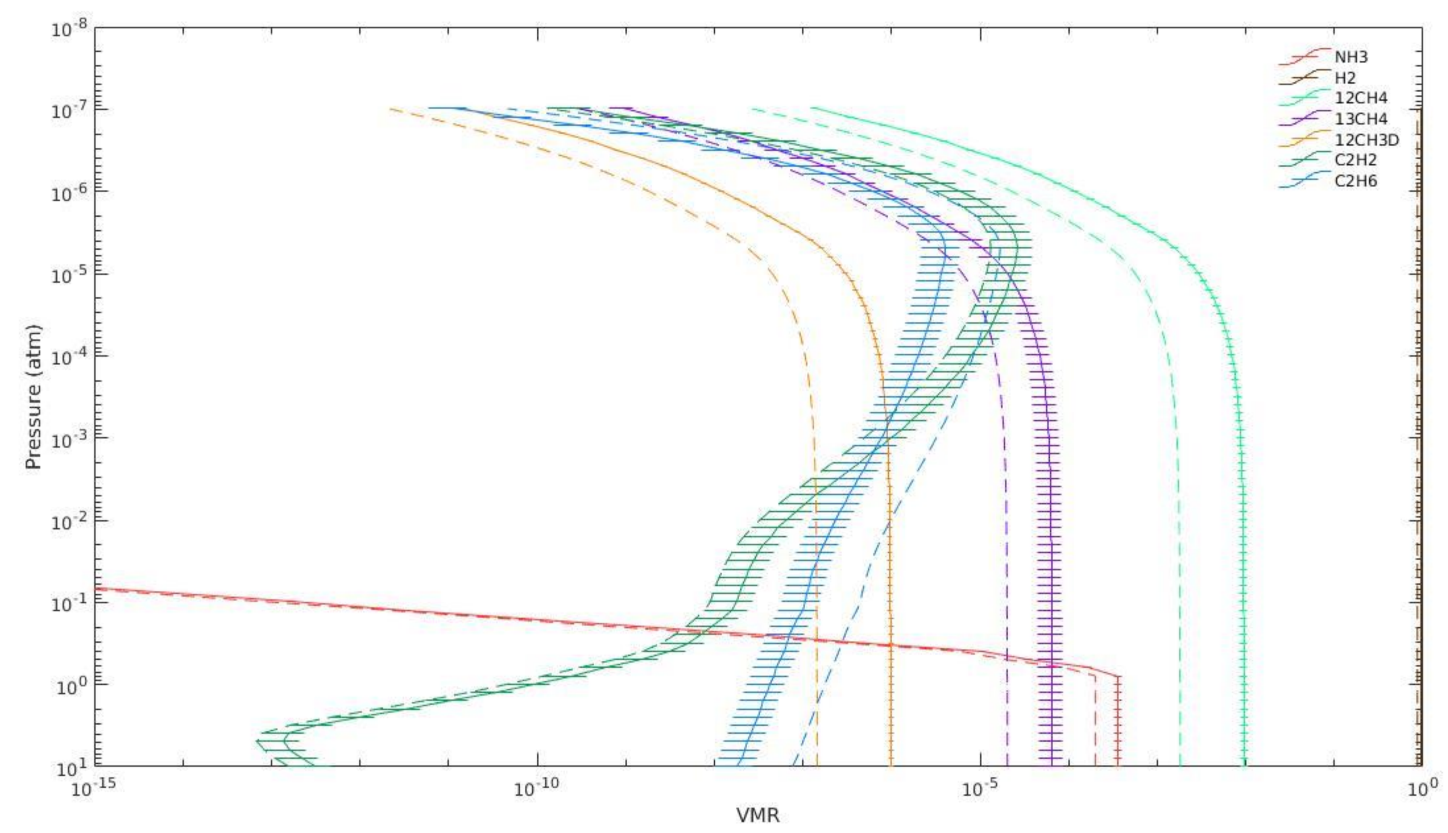

Figure 3: Plot of the volume mixing ratio of NH_3, PH_3, $^{12}CH_3D$, $^{12}CH_4$, $^{13}CH_4$, C_2H_2, C_2H_6 and H_2 as it varies with atmospheric pressure for the a priori model (dashed lines) and best fit (continuous with error bars)

- The volume mixing ratio of NH_3 goes to 0 near 0.1atm and the volume mixing ratio of H_2 is a constant 0.96±0.01 over all pressure levels.

Pressure-Temperature profile study

- We present our initial study of the pressure-temperature profile of Jupiter, retrieved using the NEMESIS suite (Fig (4)).

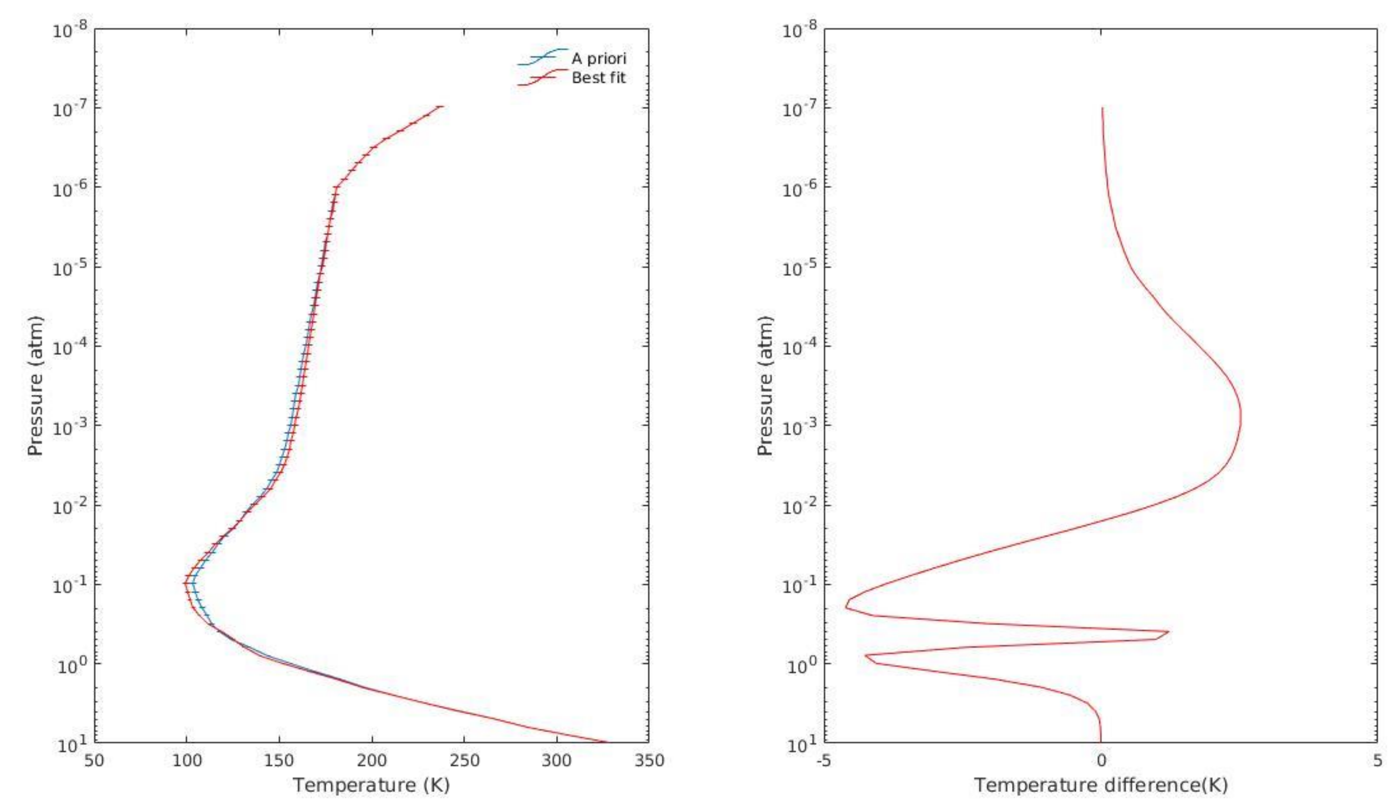

Figure 4: Plot of the a priori pressure-temperature profile of Jupiter and of the best fit pressure-temperature profile retrieved with NEMESIS (left) and plot of the temperature difference between the a priori and the best fit profile (right)

Isotopic study

- From the study of abundance of $^{12}CH_3D$, $^{12}CH_4$, $^{13}CH_4$ we obtained a preliminary $^{12}C/^{13}C$ ratio of 29±9 and an H/D ratio of (7.7±0.8) × 10^3.

Future work

- Despite the ISO-SWS data used being global, with this preliminary work we hope to further advance the knowledge about the chemical processes that happen in Jupiter, as well as the chemical and temperature vertical distribution. As future work, we expect to extend our frequency domain to the range of ISO/SWS observations and study the $^{15}N/^{14}N$ ratio.
- New k-tables are being generated using spectral line database of Fletcher et al. 2018 (https://arxiv.org/abs/1809.00572)
- Obtain the best fit for the rest of 1200-1500 cm^{-1} region and 793.65-3125 cm^{-1} region.
- Constrain the Pressure-Temperature profile, abundances and isotopic ratios for a fit with a χ_{red} less than 1 .

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References

- de Graauw et al., Observing with the ISO short-wavelength spectrometer, A&A 315, L49-L54, 1996
- Encrenaz et al., The atmospheric composition and structure of Jupiter and Saturn form ISO observations: a preliminary review, Planetary and Space Science 47, 1225-1242, 1999
- Fletcher et al., Mid-infrared mapping of Jupiter's temperatures, aerosol opacity and chemical distributions with IRTF/TEXES, Icarus 278, 128–161, 2016
- Fouchet et al., ISO-SWS Observations of Jupiter: Measurement of the Ammonia Tropospheric Profile and of the 15N/14N Isotopic Ratio, Icarus 143, 223–243, 2000
- Irwin et al., The NEMESIS planetary atmosphere radiative transfer and retrieval tool, Journal of Quantitative Spectroscopy & Radiative Transfer 109, 1136–1150, 2008
- Kessler et al., The Infrared Space Observatory (ISO) mission, A&A 315, L27, 1996
- Neimann et al., The composition of the Jovian atmosphere as determined by the Galileo probe mass spectrometer, Journal of Geophysical Research Atmospheres 103(E10):22831-45, 1998
- Taylor et al., Jupiter, The Planet, Satellites and Magnetosphere, Ch.4, Cambridge Planetary Science, Eds. Bagenal, Dowling, McKinnon, 2006
- Fletcher et al., A Hexagon in Saturn's Northern Stratosphere Surrounding the Emerging Summertime Polar Vortex, Nature Communications 9, 2041-1723, 2018

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