A reanalysis of ISO-SWS Jupiter observations: preliminary results

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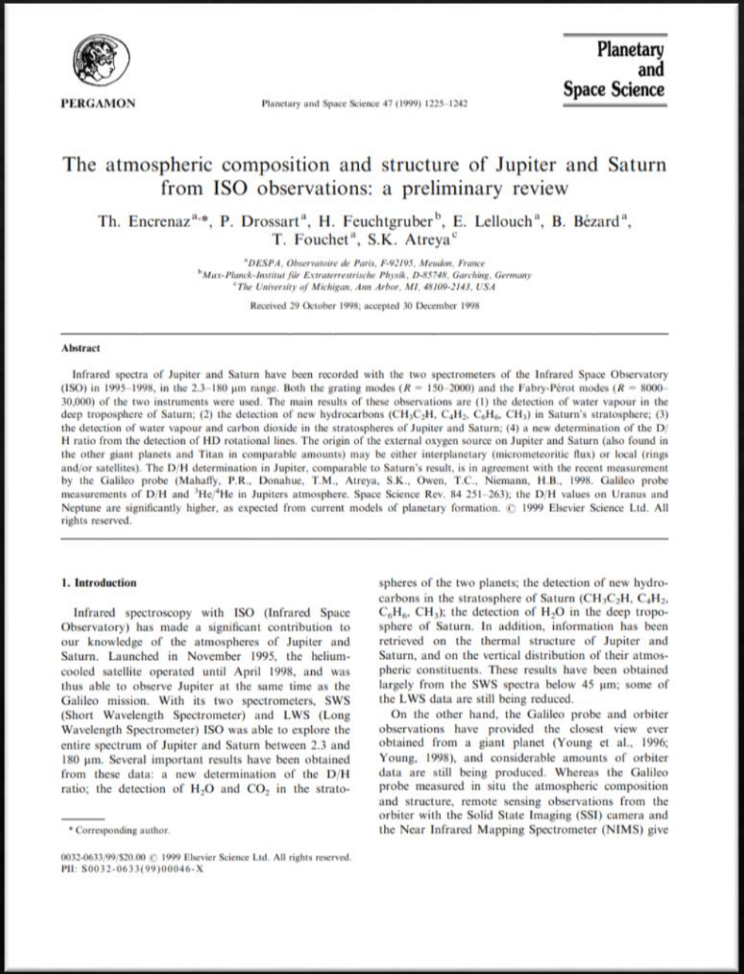
Methodology

- Observations of Jupiter from the ESA mission Infrared Space Observatory (ISO) in the 793.65-3125 cm^{-1} (3.2-12.6 μm) region using the Short-Wave Spectrometer (SWS).

- Our work is focused on the 793.65-1492.54 cm^{-1} (6.7-12.6 μm) region of the spectrum.



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Planetary and Space Science

The atmospheric composition and structure of Jupiter and Saturn from ISO observations: a preliminary review

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Abstract

Infrared spectra of Jupiter and Saturn have been recorded with the two spectrometers of the Infrared Space Observatory (ISO) in 1995–1998, in the 2.3–180 μm range. Both the grating modes ($R = 150$–2000) and the Fabry-Pérot modes ($R = 8000$–30,000) of the two instruments were used. The main results of these observations are (1) the detection of water vapour in the deep troposphere of Saturn; (2) the detection of new hydrocarbons (CH_3C_2H, C_4H_2, C_6H_6, CH_3) in Saturn's stratosphere; (3) the detection of water vapour and carbon dioxide in the stratospheres of Jupiter and Saturn; (4) a new determination of the D/H ratio from the detection of HD rotational lines. The origin of the external oxygen source on Jupiter and Saturn (also found in the other giant planets and Titan in comparable amounts) may be either interplanetary (micrometeoritic flux) or local (rings and/or satellites). The D/H determination in Jupiter, comparable to Saturn's result, is in agreement with the recent measurement by the Galileo probe (Mahaffy, P.R., Donahue, T.M., Atreya, S.K., Owen, T.C., Niemann, H.B., 1998. Galileo probe measurements of D/H and $^3He/^4He$ in Jupiters atmosphere. Space Science Rev. 84 251–263); the D/H values on Uranus and Neptune are significantly higher, as expected from current models of planetary formation. © 1999 Elsevier Science Ltd. All rights reserved.

1. Introduction

Infrared spectroscopy with ISO (Infrared Space Observatory) has made a significant contribution to our knowledge of the atmospheres of Jupiter and Saturn. Launched in November 1995, the helium-cooled satellite operated until April 1998, and was thus able to observe Jupiter at the same time as the Galileo mission. With its two spectrometers, SWS (Short Wavelength Spectrometer) and LWS (Long Wavelength Spectrometer) ISO was able to explore the entire spectrum of Jupiter and Saturn between 2.3 and 180 μm. Several important results have been obtained from these data: a new determination of the D/H ratio; the detection of H_2O and CO_2 in the stratospheres of the two planets; the detection of new hydrocarbons in the stratosphere of Saturn (CH_3C_2H, C_4H_2, C_6H_6, CH_3); the detection of H_2O in the deep troposphere of Saturn. In addition, information has been retrieved on the thermal structure of Jupiter and Saturn, and on the vertical distribution of their atmospheric constituents. These results have been obtained largely from the SWS spectra below 45 μm; some of the LWS data are still being reduced.

On the other hand, the Galileo probe and orbiter observations have provided the closest view ever obtained from a giant planet (Young et al., 1996; Young, 1998), and considerable amounts of orbiter data are still being produced. Whereas the Galileo probe measured in situ the atmospheric composition and structure, remote sensing observations from the orbiter with the Solid State Imaging (SSI) camera and the Near Infrared Mapping Spectrometer (NIMS) give

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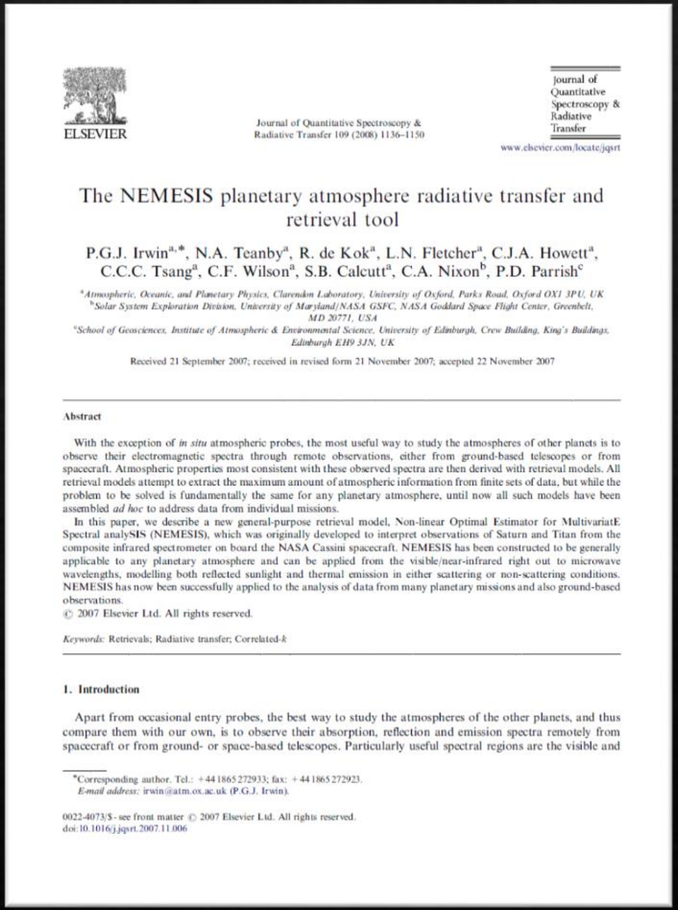
Methodology

- For doing all these analyses, the NEMESIS suite will be used, which covers both reflection and emission from planetary atmospheres.
- NEMESIS is a is general purpose correlated-k retrieval code.
- Line-by-line model calculations are accurate but extremely slow.
- For this reason, the correlated-k method is used and k-tables must be prepared before using NEMESIS to simulate observations.



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The NEMESIS planetary atmosphere radiative transfer and retrieval tool

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Abstract

With the exception of *in situ* atmospheric probes, the most useful way to study the atmospheres of other planets is to observe their electromagnetic spectra through remote observations, either from ground-based telescopes or from spacecraft. Atmospheric properties most consistent with these observed spectra are then derived with retrieval models. All retrieval models attempt to extract the maximum amount of atmospheric information from finite sets of data, but while the problem to be solved is fundamentally the same for any planetary atmosphere, until now all such models have been assembled *ad hoc* to address data from individual missions.

In this paper, we describe a new general-purpose retrieval model, Non-linear Optimal Estimator for MultivariatE Spectral analySIS (NEMESIS), which was originally developed to interpret observations of Saturn and Titan from the composite infrared spectrometer on board the NASA Cassini spacecraft. NEMESIS has been constructed to be generally applicable to any planetary atmosphere and can be applied from the visible/near-infrared right out to microwave wavelengths, modelling both reflected sunlight and thermal emission in either scattering or non-scattering conditions. NEMESIS has now been successfully applied to the analysis of data from many planetary missions and also ground-based observations.

Keywords: Retrievals; Radiative transfer; Correlated-*k*

1. Introduction

Apart from occasional entry probes, the best way to study the atmospheres of the other planets, and thus compare them with our own, is to observe their absorption, reflection and emission spectra remotely from spacecraft or from ground- or space-based telescopes. Particularly useful spectral regions are the visible and

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First results

- We used the NEMESIS radiative transfer suite 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.

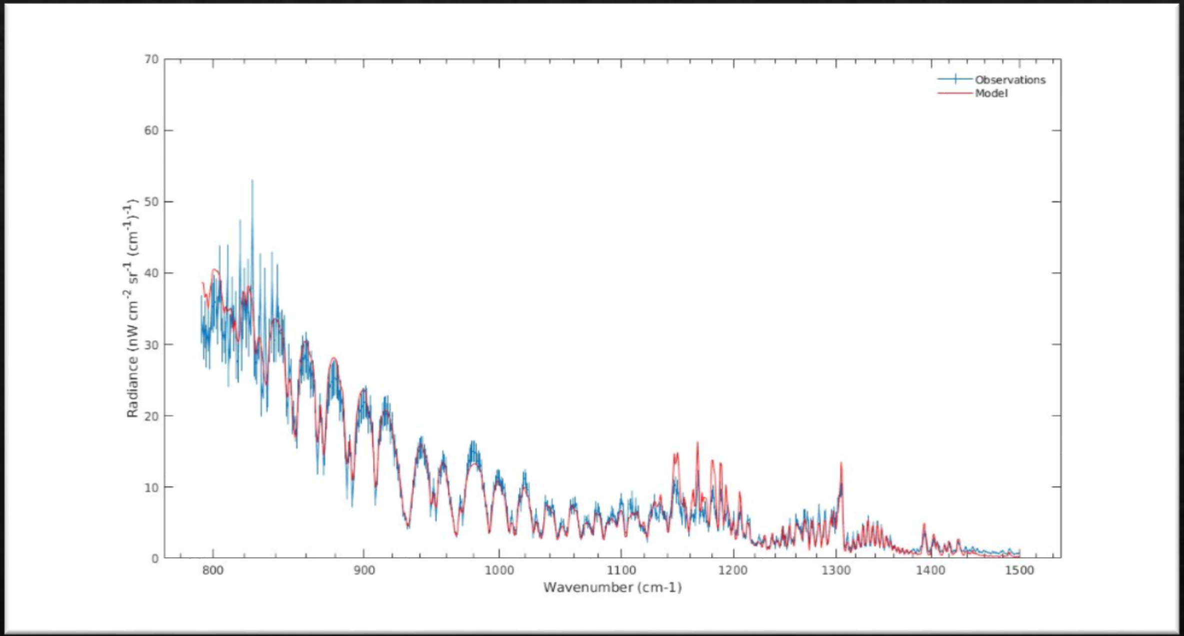

Figure 1: Plot of ISO-SWS data used in this work and NEMESIS best fit model for $^{12}CH_4$ retrieval with $\chi^2/N = 7.54$

Improved results

- The quality of our fit is determined by the reduced χ^2 value (χ^2/N):

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

- Our initial results (Fig(1)) gave us a $\chi^2/N = 7.54$ when for an excellent fit χ^2/N 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 $\chi^2/N = 1.34$ for the 793.65-1200.00 cm^{-1} region (Fig(2)), using k-tables generated from the spectral line database of Fletcher et al. 2018 (https://arxiv.org/abs/1809.00572).

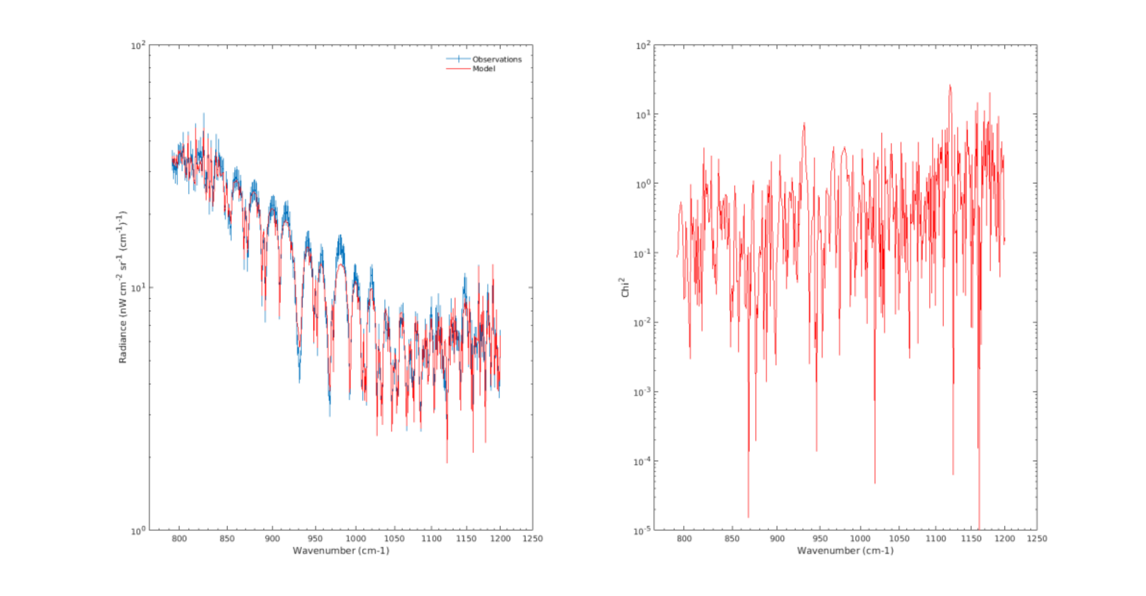

Figure 2: Plot of ISO-SWS data and current best model fit (left) and the variation of the χ^2 with wavenumber (right)

Molecule abundance study

- 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 (Fig (3)).
- The volume mixing ratio of NH_3 goes to 0 near 0.1atm and the volume mixing ratio of H_2 is a constant 1.32±0.02 over all pressure levels.

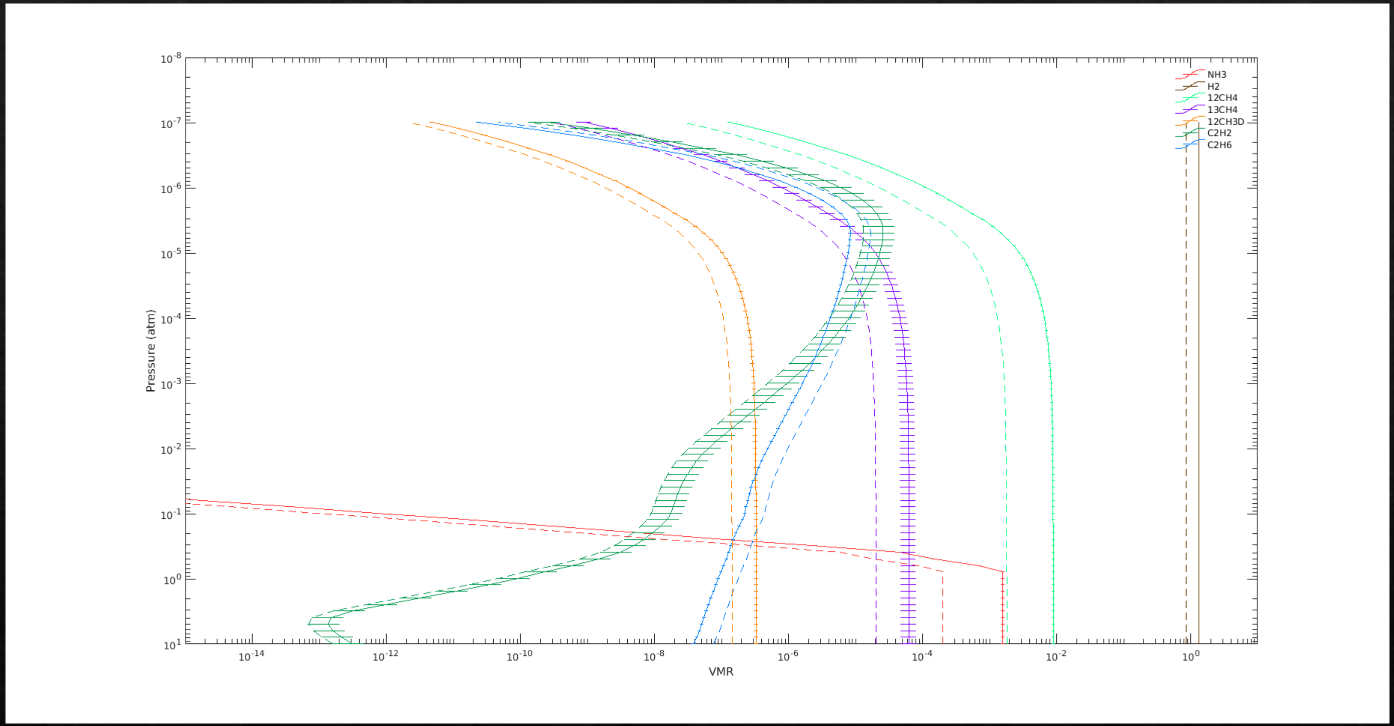

Figure 3: Plot of the volume mixing ratio of NH_3, $^{12}CH_3D$, $^{12}CH_4$, $^{13}CH_4$, C_2H_2, C_2H_6 and H_2 as it varies with atmospheric pressure for the a priori model (dashed lines) and best fit (continuous with error bars)

Pressure-Temperature profile study

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

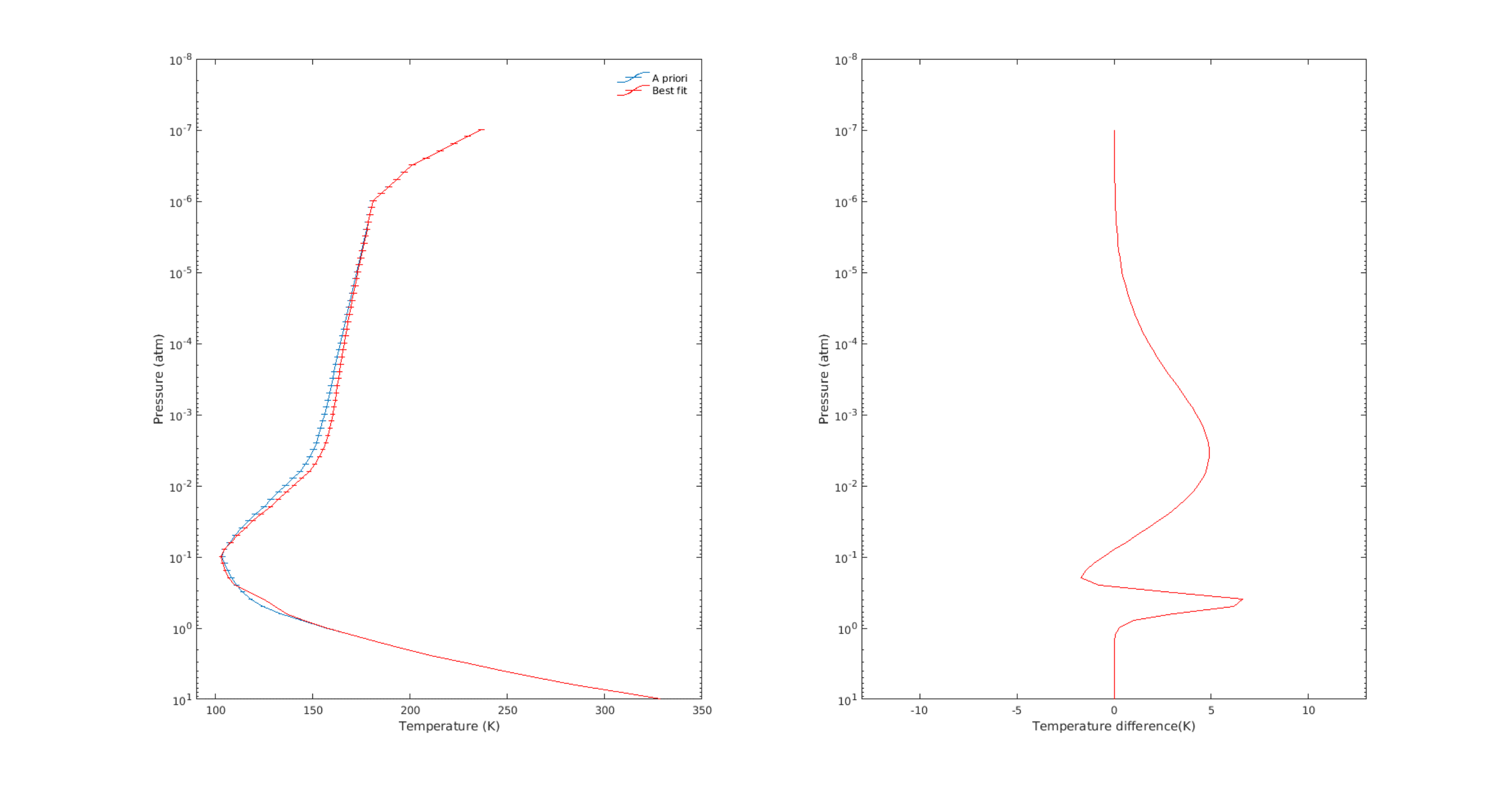

Figure 4: Plot of the a priori pressure-temperature profile of Jupiter and of the best fit pressure-temperature profile retrieved with NEMESIS (left) and plot of the temperature difference between the best fit and the a priori profile (right)

Isotope ratio 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 28±8 and an H/D ratio of $(2.2\pm0.1)\times10^4$.

$$^{12}C/^{13}C = \frac{vmr_{12CH4} + vmr_{12CH3D}}{vmr_{13CH4}}$$

$$H/D = \frac{4vmr_{12CH4} + 3vmr_{12CH3D} + 4vmr_{13CH4}}{vmr_{12CH3D}}$$

Future Prospects

- Improve our understanding of Jupiter:
  - We expect to study the 15N/14N ratio.
  - 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^2 /N less than 1.

- Expand methodology to other targets (Saturn, Uranus, Neptune, Titan)