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Laboratory and theoretical work applied to planetary atmospheres

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Abstract. We look at applications of recent work in theoretical and experimental spectroscopy for the analysis of IR data concerning giant planets, Titan and possibly exoplanets.

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1. Introduction

The study of planetary atmospheres has various aims which include the :

- Cartography of the chemical composition therein with high precision
- Detection of new components with low abundance levels (including isotopes)
- Determination of the origin and evolution of the planetary bodies

For this, there is strong need for spectroscopic measurements at the right p, T conditions to be able to perform the spectroscopic analysis of data provided by different instruments on board of space missions or from telescopic ground-based observations. In the case of dense planetary atmospheres in the outer solar system (gas giants and Titan) what is needed is:

- Long atmospheric paths (at scale heights of a few tens of km)
- Temperatures difficult to achieve in a laboratory (for Titan : 70-94 K in troposphere; less than 200 K in stratosphere).

Spectroscopic data available in the infrared range for outer solar system objects include acquisitions by Voyager/IRIS, ground-based telescopes and ISO, Galileo, and more recently Cassini-Huygens (CIRS, VIMS, DISR, etc). The latter space mission has been exploring the Saturnian system since 2004 and will continue until 2017, providing a large amount of data on all the objects and in particular the planet and its main satellite, Titan. Hereafter we focus at the infrared spectrum of Titan and the giant planets and look at how theoretical and experimental spectroscopic data can help determine their composition for the objectives hereabove.

We study the physical properties in the atmosphere of the giant planets and Titan with radiative transfer calculations using a line-by-line code solving for : opacity sources; chemical abundances (gas and solid); haze/aerosols; clouds; and the temperature structure (Coustenis *et al.*, 2010; 2015). Spectroscopic data come from various sources but essentially from GEISA and HITRAN.

2. Titan and the giant planets

Titan is a satellite essentially composed of N_2, CH_4, and H_2, with an atmospheric pressure on the surface of 1,5 bar with a temperature of 94 K. In the thermal IR, Cassini Titan data are essentially derived from CIRS : 7μm-1mm (resolution up to 0.5 cm^{-1}).

In the near-IR the spectro-imager VIMS covers the 0,35-5,2 μm region (resolution 7-16 nm). Also, from the Huygens probe with DISR we get the images and spectra in the 0.48-1.7 μm region (resolution: 5-17 nm). For the current chemical composition of Titan see Table 2 in Coustenis, A. (2014) and references therein.

Several breakthroughs have been made in the determination of the chemical composition of Titan in recent years thanks to new spectroscopic data made available to the community. Examples are propane (for which multiple bands were identified in CIRS spectra, Nixon *et al.*, 2012), ethane (Coustenis *et al.*, 2010), isotopes and methane.

Isotopes. For isotopes we have the detections of C_2HD and of several isotopes of ^{13}C in HC_3N (Cyanoacetylene formed by substitution of -CN (from HCN) into C_2H_2 and C_2H_4), with a strong ν_2 band at 663.4 cm^{-1} due to bending of CH and $H^{13}CCCN$ = 658.7 cm^{-1} ; $HC^{13}CCN$ = 663.1 cm^{-1} ; $HCC^{13}CN$ = 663.1 cm^{-1}. Also isotopes of CO_2, with essentially the ν_5 band at 667 cm^{-1} but also $^{13}CO_2$ at 648.5 cm^{-1} (6-σ detection) and probably the $C^{18}O^{16}O$ emission at 662.5 cm^{-1}.

Methane. Titan's near-IR spectrum contains information on the lower atmosphere and the surface of the satellite. It is equivalent to a 20 km cell with 75 mbar of CH_4 in 1.5 bar of N_2 and at T= 85 K. One needs to obtain the CH_4 absorption spectrum in Titan conditions in the several transparency windows at 0.83, 0.94, 1.075, 1.28, 1.6, 2.0, 2.6-2.8, and 4.9 μm. In recent efforts, with the goal to determine the transmission in these transparency windows at 80 K (in some cases, the different band models that existed before showed large disagreements in fitting the Cassini data) a combination of astronomer and experimental teams have produced new data to help in the analysis of the observations. On the basis of new experimental developments, as a first step the room-temperature (RT) and liquid-nitrogen temperature (LNT) spectra of CH_4 have been recorded in the full 1.2-1.6 μm region. They will be used on Titan to:

- re-measure the CH_3D/CH_4 ratio from much higher resolution ground-based spectra
- re-measure the CO abundance and vertical profile in Titan's atmosphere
- look for other minor atmospheric constituents
- study variations of the CH_4 mixing ratio over Titan with ground-based observations
- measure the surface albedo and its variations over the surface using VIMS data and ground-based data
- re-analyze DISR data (e.g. to study albedo variations near the Huygens site)

Giant planets. Other applications concern Uranus and Neptune (clouds levels, gaseous abundances, spatial variations). Simulations of Uranus spectra at 1.6 μm using the new datalist WKMC from Grenoble. The new linelists were also applied to Uranus in the 1.55 μm window (Bailey *et al.*, 2012) on data from IRIS2 on the Anglo-Australian telescope at a resolving power of about 2400.

The new linelists for methane also apply to exoplanets.

We clearly need more adequate spectroscopic data for the analysis of the large sum of data that we retrieve from observations of the bodies in the outer solar system.

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