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Spectroscopy and planetary atmospheres/Spectroscopie et atmosphères planétaires

Infrared spectroscopy of planetary atmospheres

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Abstract

Spectroscopy is at the root of modern planetology, in that it gives access remotely to the possibility to analyze the physical properties of planets. Today, the spectacular advance in techniques and models available to planetology reach an accuracy giving access to new domains in planetary physics, as meteorology, physico-chemical processes, etc. This article is centred on the infrared spectroscopy techniques. It will describe some of the physical observables accessible to modern instrumentation, in space or from the ground. The theoretical as well as instrumental limitations will be given, and the expected progress in short or medium term will be described. ***To cite this article: P. Drossart, C. R. Physique 6 (2005).***

Résumé

Spectroscopie infrarouge des atmosphères planètes. La spectroscopie a véritablement fondé la planétologie moderne en permettant d'analyser les propriétés physiques des planètes à distance. Aujourd'hui, les progrès spectaculaires des techniques et des modèles disponibles atteignent aujourd'hui une précision qui rend accessible des pans entiers de la physique planétaire (météorologie, processus physico-chimiques, etc.) Cet article, centré sur les techniques de spectroscopie infrarouge, décrira quelques unes des observables physiques accessibles par les instruments actuels, dans l'espace ou au sol, les limitations tant théoriques qu'instrumentales, et les avancées à attendre à court et moyen terme. ***Pour citer cet article : P. Drossart, C. R. Physique 6 (2005).***

Keywords: Infrared spectroscopy; Planets; Abundances; Isotopic ratios

Mots-clés : Spectroscopie infrarouge ; Planètes ; Abondances ; Rapports isotopiques

1. Introduction

Spectroscopy is one of the most useful tools for the astrophysicist observing remotely physical properties of the bodies studied. In that sense, it has given planetology many opportunities, well before the space age. The detection of methane and ammonia on Jupiter and Saturn in 1932 [1] can therefore be considered as the foundation of physical planetology, aimed at understanding planets beyond a phenomenological description. This paper intends to give an overview of some recent results obtained from space or ground-based observatories, about different planets. An exhaustive description of the questions raised by spectroscopic measurements is out of scope of this paper, but several questions will be introduced, in order to indicate the present limitations, both technological and spectroscopic. This frontier in planetary research will give the reader an idea of the current and future efforts which will be necessary to go forward.

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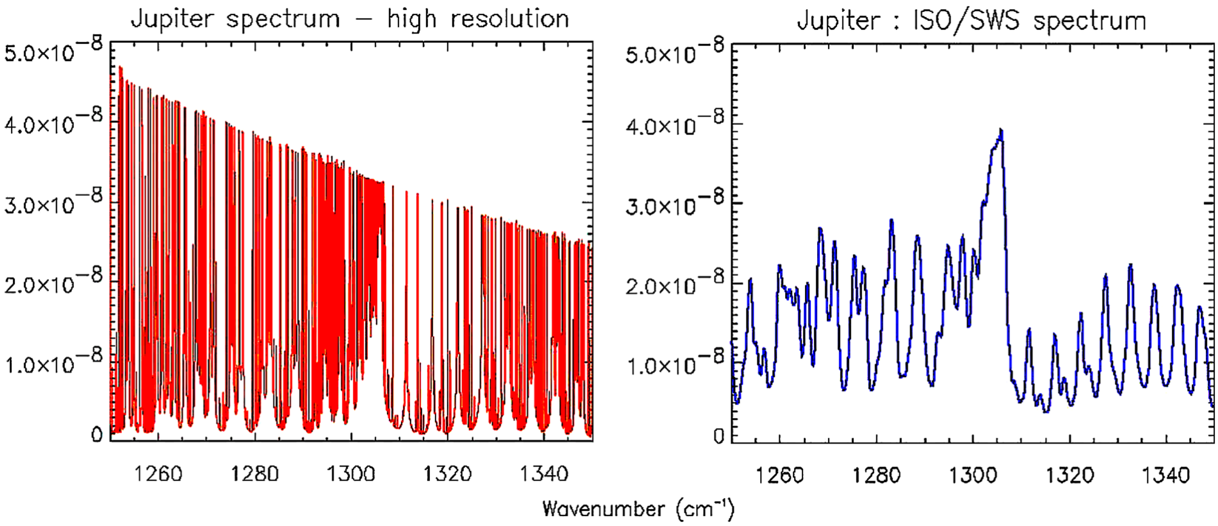

Fig. 1. Synthetic spectrum at high resolution of thermal emission of methane on Jupiter. Left: calculated spectrum at $\sim 0.001\ \mathrm{cm}^{-1}$. Right: convolved spectrum at a spectral resolution equivalent to ISO/SWS instrument ($1\ \mathrm{cm}^{-1}$).

2. Scientific objectives

There are many parameters directly or indirectly accessible to spectral analysis in planetary spectra: composition, pressure, temperature, thermal equilibrium, cloud structure, wave activity, etc. Almost every physical phenomenon of influence on the radiative transfer of a planet can be used, then possibly measured, from a variation of a dedicated spectral features. The remaining difficulties are to extract quantitative information, combining spectral, instrumental and astrophysical expertises. Two main limitations to spectral observations can increase the difficulties:

– spectral heterogeneity (Fig. 1): high spectral resolution planetary spectra have by essence a high intrinsic complexity. Even if low spectral resolution observations, due to instrumental limitations, seem to reduce this complexity, it is, in fact, only masking the real details, with a risk of ambiguity in the interpretation;
– spatial heterogeneity (Fig. 2): planetary spectra averaged over the full disk are integrating very inhomogeneous regions. Non-linearity in the observed physical phenomena can make an accurate inversion of a real physical parameter impossible, when it is processed from an averaged observation.

The combination of a highly resolving instrument, both spectrally and angularly, remains exceptional, and compromises are often needed. Such a combination can, nevertheless, be expected to produce new developments in planetary spectroscopy, as some recent instrumentation developments anticipate.

Although the spectral domain of planetary interest covers all the electromagnetic range, from radio waves to X-rays, this paper will be limited to the infrared spectroscopy domain. The different spectral ranges cover spectral transitions of different origins: electronic bands in ultraviolet, vibrational in the infrared and rotational in millimetre range. The infrared domain has the advantage of a great accessibility in ground-based observations, compared to UV, and is not limited to polar molecules with a rotational spectrum in the millimetre range. The planetary phenomena and the interpretation models are anyway similar between the different domains, and their complementarities give access to planetary atmospheres at very different depths, from different wavelengths range.

2.1. Radiative transfer methods

Radiative transfer techniques for planetary atmospheric studies were derived from Earth observation spectral models, as developed in the 1960s, after the first space observations [2]. Nevertheless, several simplifications have in general to be introduced in the models, depending on the needed accuracy, or also, unfortunately, the level of knowledge in the existing spectral data available. The radiative transfer equation in its most elementary form can be reduced to an integral over the radiative intensity of the external solar flux, in the solar reflected component domain, below approximately 4 microns, or over the intrinsic thermal flux beyond. The usual basic approximation takes a classical approach for radiative flux (thus neglecting interference effects), with quantum effects included only in the molecular absorption/emission processes. As will be seen from some examples,