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Spectroscopic characterization of exoplanets' atmospheres

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Abstract

The increasing number of exoplanets' detections by transit opens the possibility of characterizing their atmospheres in terms of thermal structure and composition, by using infrared spectroscopy at the time of primary and secondary transits. In the case of secondary transits, it is important, whenever possible, to measure both the reflected/scattered stellar component and the thermal emission simultaneously, in order to determine both the thermal profile and the vertical distributions of atmospheric species. It is also important to measure several bands of different intensities to probe the atmosphere at different altitude levels. This requires the simultaneous observation of the whole infrared range, ideally from 1 to 20 microns, with a spectral resolving power of a few tens to a few hundred. The EChO mission, preselected by ESA as a candidate for the Cosmic Vision M3 mission, is designed for this purpose.

1. The different types of exoplanets

It is possible to estimate, to first order, the effective temperature of an exoplanet simply by knowing its distance to its host star and the spectral type of this star, and making an assumption about its albedo. The other important parameter is the mass estimate, derived from velocimetry and transit. Objects with masses above about 10 terrestrial masses are expected to be "super-Earths", either rocky (Mars-Venus type) or icy (Titan-type), depending on their temperature. More massive objects can be classified as icy giants (Neptune-type) or gaseous giants (hot, warm or cold Jupiters) [1].

In the case of super-Earths and temperate Neptunes and Jupiters, a typical albedo of 0.3 can be assumed, due either to surface or cloud features. In the case of warm and hot Jupiters and Neptunes, a low albedo (0.03) can be assumed, as a possible effect of Rayleigh/Mie scattering.

2. The infrared spectrum of an exoplanet

The spectrum of an exoplanet shows two main components, the reflected/scattered stellar component (which dominates at short wavelengths) and the thermal emission (which dominates at longer wavelengths). The peak of the reflected stellar component only depends upon the spectral type of the host star; the peak of the thermal emission depends upon the exoplanet's effective temperature, hence upon its albedo a, its distance to the host-star and the stellar type of this star. Figure 1 shows the spectral blackbody distributions of the two components in the case of M-type stars. These stars are of special interest as temperate exoplanets (possibly in the habitable zone) are expected to be found near their host stars and repeated transits can be observed; in addition, the population of M-type stars in the solar neighbourhood is about 90% of the total stellar population.

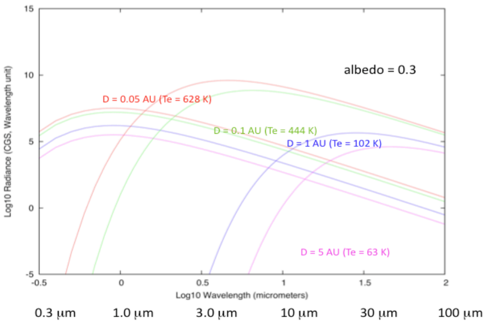

Figure 1: Reflected/scattered stellar light and thermal emission in the case of M-type stars. Examples of exoplanets are shown with their effective temperatures. The assumed albedo is 0.3.

Table 1 shows a comparison of the two spectral components for different types of exoplanets, as a function of their mass and their effective temperature. It can be seen that the 1-2 μm range is important for observing the reflected component of exoplanets.

Table 1: Reflected/scattered vs thermal emission for different types of exoplanets. λ_0 is the wavelength at which both components are expected to be equal. The numbers indicated for the F, G and M stars are the estimated exoplanet's distance to its host star, in AU.

Type of exoplanet	**Jupiter** a = 0.03 (hot, warm) a = 0.3 (temperate)	**Neptune** a = 0.03 (hot, warm) a = 0.3 (temperate)	**Super-Earth** a = 0.3 (hot, warm) a = 0.3 (temperate)
λ_0 **Hot** **> 700K**	< 1 μm F: <0.25 G: <0.1 M: <0.025	< 1 μm F: <0.25 G: <0.1 M: <0.025	< 1.6 μm F: <0.5 G: <0.2 M: <0.05
λ_0 **Warm** **400 K - 700 K**	1 – 1.6 μm F: 0.25-0.5 G: 0.1-0.3 M: 0.025-0.05	1 – 1.6 μm F: 0.25-0.5 G: 0.1-0.3 M: 0.025-0.05	1.4 - 2 μm F: 0.25-0.5 G: 0.1-0.3 M: 0.05-0.1
λ_0 **Temp.** **250 K – 350 K**	1.2–2.5 μm F: 1 - 2 G: 0.7 - 1.5 M: 0.07 - 0.1	1.2–2.5 μm F: 1 - 2 G: 0.7 - 1.5 M: 0.07 - 0.1	3 - 5 μm F: 1 - 2 G: 0.7 - 1.5 M: 0.07 - 0.1

2. Constraints on the spectral range and resolving power

Before and after secondary transits, the direct emission of the exoplanet can be measured on the dayside. The reflected/scattered component gives information about the nature and the abundance of the absorbers. In the thermal regime, the spectrum can show emission or absorption features, depending on the gradient of the thermal profile. In order to determine both the thermal profile and the vertical distributions of the atmospheric constituents, it is important, whenever possible, to observe both the reflected and thermal components, and also to observe simultaneously, for a given species, molecular bands of different intensities. This requires the simultaneous observation of the whole infrared range, ideally from 1 to 16 μm.

Figure 2 shows absorption spectra of a few important molecules (H_2O, CO, CO_2, CH_4, NH_3) between 2 and 18 μm, for temperatures of 300 K and 1200 K respectively. It can be seen that the bands are significantly broadened at high temperatures, and this effect is going to be important in the case of hot and warm exoplanets. The unambiguous detection of a given molecule requires the resolving power to be sufficient for separating two adjacent lines, which depends upon the Bo value of the molecule. It can be seen that a resolving power of 300 is sufficient in most of the cases for $\lambda < 11$ μm.

The EchO mission, preselected by ESA as a candidate for the Cosmic Vision M3 mission, is designed for the infrared characterization of exoplanets using primary and secondary transits. It includes a 1.2-1.4 m telescope and a spectroscopic device which, ideally, will cover simultaneously the 1-16 μm range, with a resolving power of 300 below 11 μm and 20 above. In addition, an optical channel will observe the exoplanet's visible spectrum and monitor the stellar activity.

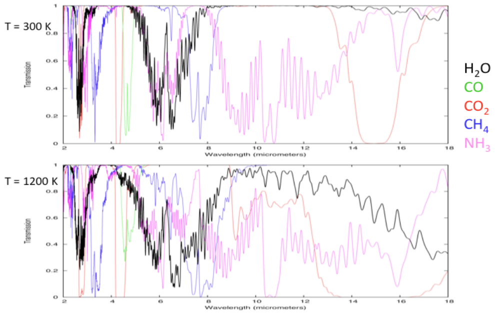

Figure 2: Absorption spectra of H_2O, CO, CO_2, CH_4 and NH_3 between 2 and 18 μm, for a column density of 10 cm-am, a pressure of 1 bar, and temperatures of 300 K and 1200 K respectively. The spectral resolution is 10 cm^{-1} ($R = 100$ at 10 μm).

References

[1] Encrenaz, T., Characterizing Exoplanets Atmospheres and Surfaces, in "Pathways Toward Habitable Planets", ASP Conference Series Vol. 430, edts. V. Coudé du Foresto, D. M. Gelino and I. Ribas, pp. 65-76 (2010)