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Mapping exoplanet clouds with high-dispersion spectro-polarimetry

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Abstract

Polarization is an under-exploited technique in the investigation of exoplanet atmospheres. A polarization detection, particularly if extended over a broad spectral range, will set valuable constraints on the gas and clouds in an exoplanet atmosphere that are impossible through brightness-only observations. In this presentation, I will describe simulations that show that the polarization of a spatially unresolved exoplanet may be detected by cross-correlating high-dispersion linear polarization and brightness spectra of the planet-star system [1]. In this approach, the Doppler shift of the planet-reflected starlight facilitates the separation of the signal from other polarization sources, including the star, the interstellar medium and the terrestrial atmosphere. I will elaborate on the case of close-in giant exoplanets with non-uniform cloud coverage, in which cases the hemispheres east and west of the sub-stellar point will produce different polarizations. The simulations show that high-dispersion spectro-polarimetry can rule out some of the proposed cloud scenarios and, in particular, set additional constraints on the cloud particles' optical properties.

1. Introduction

Whole-disk polarization measurements of reflected sunlight have a long history in the remote sensing of the solar system bodies, their surfaces and atmospheres. Linear polarimetry is potentially more sensitive than brightness measurements to the composition, size, and shape of the scattering particles. The two approaches complement each other in the characterization of the condensate–gas envelope of an atmosphere [2].

The potential and current status of polarimetry for the detection of exoplanets and the characterization of their atmospheres and orbits has been discussed at length [3]. Since polarimetry is a photon-starved technique, most efforts to date have focused on broadband measurements from bright star systems (55 Cancri, τ Boötes, HD 189733). Broadband polarimetry ensures that a large number of photons are collected, which is essential for reaching the required sensitivities of tens of ppms or better. On the other hand, broadband polarimetry also requires the removal of systematics introduced by the telescope-instrument optical system, and the subtraction of the polarization arising in the interaction of the starlight with the ISM or with the terrestrial atmosphere. In practice, the non-planet components of the measured polarization signal may easily bury the polarization attributable to the planet.

2. HDSP: High-dispersion spectro-polarimetry

An alternative to broadband polarimetry is the use of high-dispersion spectro-polarimetry (HDSP) together with some form of cross-correlation. In recent years, the HDS technique (without polarimetry) has become established as a powerful tool in the investigation of exoplanet atmospheres [e.g. 4]. The technique benefits from the spectral separation of the planet and the star due to their relative Doppler shifts. The same idea, i.e. the separation of the starlight from the planet signal due to their different Doppler shifts, can also be used to investigate the planet polarization. The distinct velocity of the planet signal should facilitate its identification against other polarization sources such as the star, the ISM, the terrestrial atmosphere or the telescope.

3. Simulations of Kepler-7b's atmosphere

Figure 1 presents synthetic phase curves for brightness and polarization based on the best fits by Ref. [5] to the brightness measurements of Kepler-7b. Three condensate compositions plausibly explain the measurements, namely: silicate, perovskite and silica. Small changes in the optical properties of the condensates (e.g. the particle size) have no apparent impact on the simulated brightness phase curves. These small changes, however, affect the polarization phase curves significantly. The simulations show the unique diagnostic potential of polarimetry to confirm some of the proposed cloud scenarios.

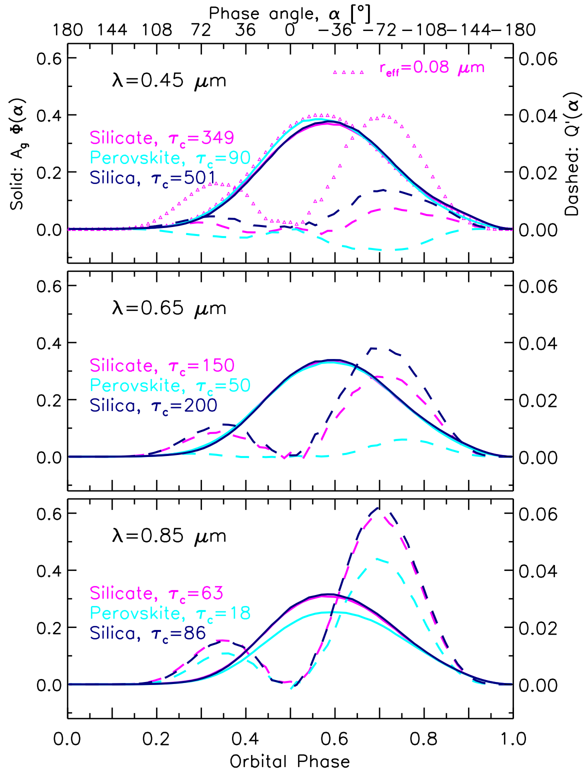

Figure 1. Simulated phase curves (brightness and polarization) for Kepler-7b at three wavelengths. Polarization is much more sensitive than brightness to the optical properties of the condensates in this hot Jupiter's atmosphere. Figure from Ref. [1].

4. The Cross-Correlation Function

Cross-correlating the linear-polarization spectrum of the planet-star system with the measured brightness spectrum of the star reveals the planet signal at the corresponding planet Doppler shift. Figure 2 shows an example of a CCF simulation for Kepler-7b. The planet signal is Doppler-shifted by about 130 km/s with respect to the star for a phase angle of ~70 deg.

5. Summary

Polarimetry is a valuable complement to photometric and spectroscopic measurements in the characterization of exoplanet atmospheres. The HDSP-CC technique offers a built-in way to separate polarization contributions originating with different radial velocities. This feature may be of great advantage to prevent the spurious identification of exoplanet polarization signals. The technique can be tested on a number of targets (e.g. 51 Peg b) orbiting bright stars with currently existing telescopes and instruments.

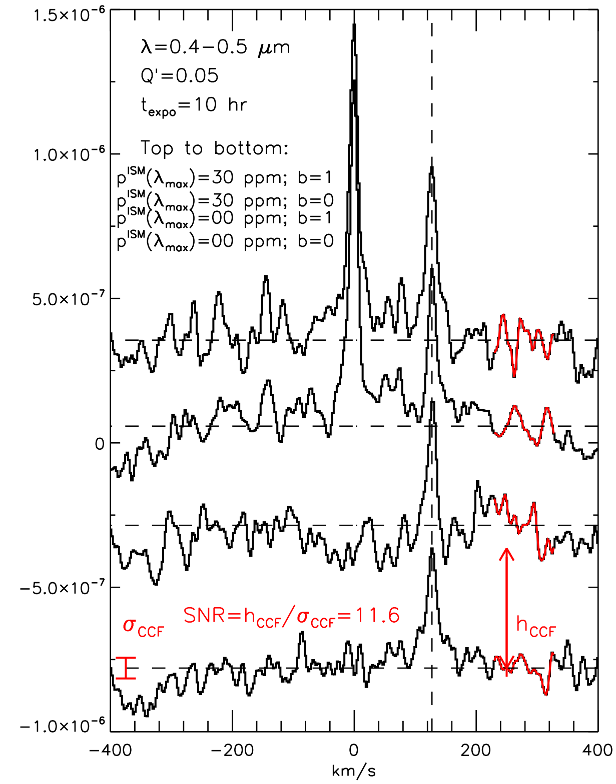

Figure 2. Simulated CCF for Kepler-7b. The planet signal is well-separated in the velocity space from the signal introduced by the star and the ISM. Figure from Ref. [1].

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