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Geometric effects on the flux and polarization signals of Jupiter-sized exoplanets

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Abstract

The direct detection of reflected starlight from exoplanets marks the beginning of a new era in the characterization of extrasolar planetary atmospheres. The flux and in particular the linear polarization signals from such planets are sensitive to atmospheric structure and composition, but other effects may also contribute to observed signals. We investigate the influence of an exoplanet's shape and orbit orientation on its flux and polarization signature, and compare it against the influence of a variable cloud cover.

1. Introduction

The linear polarization of light has played a key role in the characterization of planetary atmospheres at least since its contribution in determining the composition and size of Venus' cloud particles from Earth-based disk-integrated observations across a wide phase angle range, and at a few wavelengths [1]. Since then, the interpretation of polarization observations with simulations of scattering in planetary model atmospheres has been applied successfully to various solar system bodies.

Polarimetry could also be used as a method for determining the composition of exoplanetary atmospheres [see e.g. 4]. Indeed, it has several advantages over photometry when applied to the direct detection of extrasolar planetary systems, as light from the host star tends to be unpolarized, whereas starlight that is scattered in the planetary atmosphere will usually pick up a degree of polarization which facilitates the detection of planetary light. While the outer planets in our solar system present very low polarization signals when observed from Earth because of the illumination and viewing geometries, the illumination and viewing geometries of exoplanets favor relatively high degrees of polarization. In [4], the strong dependence of the linear polarization on the composition and structure of Jupiter-like model planets with purely gaseous atmospheres, or with clouds and hazes added, is shown. The model planets were, however, assumed to be spherical and the effect of inhomogeneous cloud coverage was not considered.

A planet's shape may be oblate (squashed at the poles) due to rotation, but it may also be deformed by tidal interactions with the host star if it is in a close-in orbit. Such tidal forces will give the planet an ellipsoidal shape, the major axis of which will point towards the star under some angle. When in addition, we vary the obliquity of the planet, we also change the cross section of the disk at a given phase angle (i.e. the angle star-planet-observer) and so may introduce a comparable effect to oblateness.

The simulations conducted in this study extend the work in [4] to include ellipsoidal Jupiter-sized planets with non-zero obliquities. In addition, the effect of a spatially extended stellar disk has been included so that scattering simulations could be made for tidally deformed hot-Jupiters orbiting very close (< 0.1 AU) to their host stars (for planets in wide orbits, the incident starlight can be assumed to be unidirectional, see [4]).

2. Results

As demonstrated for self-luminous, hot exoplanets [3], and for directly imaged homogeneous planets [2], increasing oblateness introduces a slight increase in the planet's linear polarization. Figure 1 shows that this effect is minor relative to the effects of varying inhomogeneous cloud cover.

We find that the effect of obliquity on the linear polarization is of the same order of magnitude as oblateness. This is illustrated in Figure 2, showing the linear polarization against the normalized flux for both spherical and oblate models at three obliquities. Note that the flux of the star itself is not included in the signal.

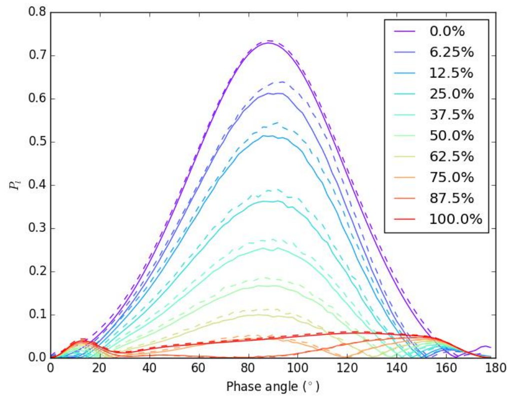

Figure 1: The variation of total linear polarization with percentage inhomogeneous cloud cover for spherical (solid) and oblate (dashed) model planets.

For hot-Jupiters around solar-type host stars, we detect little change in the polarization signal with tidal deformation, but there are some interesting effects as a result of the planet's close proximity to its star (< 0.1 AU). Figure 3 shows an enhanced reflected flux at large phase angles for close-in planets as compared to a planet in a wide orbit. This enhancement is further increased with increasing oblateness (not shown), and may lead to an underestimation of an exoplanet's radius from observations if not taken into account.

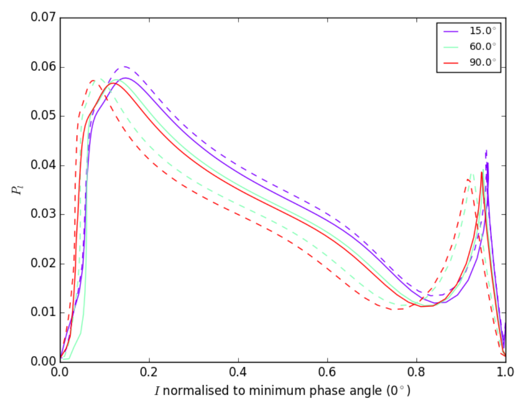

Figure 2: Variation with obliquity of linear polarization plotted against normalized intensity for spherical (solid) and oblate (dashed), 100% cloudy model planets.

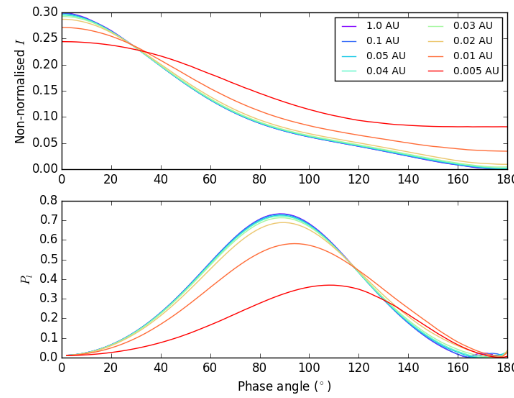

Figure 3: Variation of flux (top) and linear polarization (bottom) with distance from the star.

3. Conclusions

This work demonstrates that geometrical influences on the direct detection of exoplanets in polarized light tend to be at an order of magnitude below the influence of atmospheric composition and structure, so may be ignored in first order characterizations for exoplanets in wide orbits. For close-in planets, the spatial extension of the stellar disk should be taken into account.

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