Detecting Extrasolar Planets by High-Precision Polarimetry

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Abstract: We describe a new polarimeter designed to detect the polarisation signature of unresolved extra-solar planets. Results from the first science run, including limited data from τBoo, are presented.

Current detections of extra-solar Planets (EXPs) are *indirect*

- infer the presence of the planet by its effect on the star
- only in the rare cases of transits can information be obtained on the planetary atmosphere

A *direct* detection of the light reflected by the planet will provide information on the planet radius and atmosphere as well as its mass.

The amount of light from the planet, relative to that from the star, is given by:

$$\varepsilon(\alpha,\lambda) = p(\lambda)\, g(\alpha,\lambda)\, (R_p/D)^2$$

$p(\lambda)$ is the geometric albedo, $g(\alpha,\lambda)$ is the phase function describing the amount of light reflected to the observer as a function of orbital phase angle α (α=0 for full phase), R_p is the planet radius, and D is the planet-star distance.

For a Lambert sphere, p = 2/3, and $g(\alpha,\lambda) = [\sin(\alpha)+(\pi-\alpha)\cos(\alpha)]/\pi$ [1,2]. The maximum fractional reflected signal, ε_o, occurring at full phase, is then given by

$$\varepsilon_o = 2/3\,(R_p/D)^2 \quad [\alpha=0,\ g(0,\lambda) = 1]$$

For a hot-Jupiter, typically $R_p = 1.5R_J$, (R_p for HD209458 is $(1.40\pm0.17)R_J$, from transit observations[3], where R_J is the radius of Jupiter), and D = 0.05AU, making $\varepsilon_o \sim 1.5\times10^{-4}$, with a maximum orbital change ~150μmag (*i*=90°).

Assuming Rayleigh scattering, the fractional polarisation P_s of scattered light is given by $\sin^2\theta/(1+\cos^2\theta)$, ranging between 0 and 1 for scattering angles θ of 0° to 90° respectively. The observed fractional polarisation will be $\varepsilon(\alpha,\lambda)g(\alpha,\lambda)P_s$, and will range from zero for α = 0° & 180° to a maximum for α ~70° & ~290° of ~5.5×10^{-5} for a hot-Jupiter (*i*= 90°). The PA of polarisation, as a function of orbital phase, gives *i*. See Figures 1 & 2.

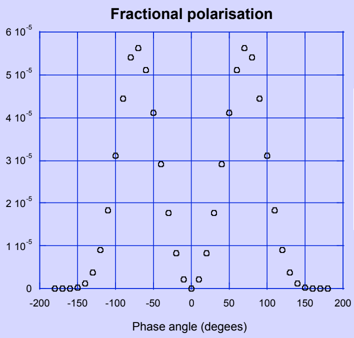


Fig 1. Orbital fractional polarisation assuming Rayleigh scattering. The amplitude of variations scale as $(R_p/D)^2$

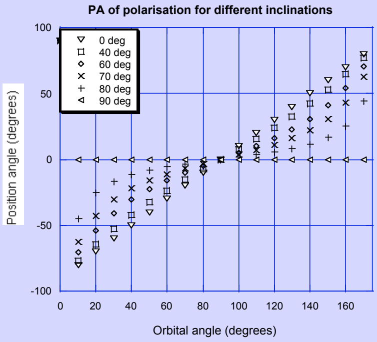


Figure 2. Variation of polarisation PA with orbital angle for different orbit inclinations

More detailed models[2] indicate fractional polarisations of a few x10⁻⁶ (below)

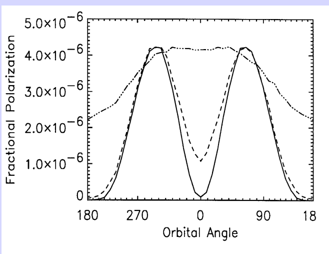


Fig 3. Fractional polarisation for 0.1μm particles, *i*=90° (solid), 82° (dotted), 66° (dashed), 48° (dot-dashed), 21° (dash-triple-dotted).

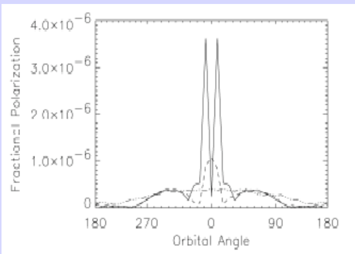


Fig 4. As for Fig 3, for 1μm particles.

To detect the polarisation signature of a hot-Jupiter needs a polarimeter with a sensitivity of 10^{-6} or better.

We have constructed a polarimeter (PlanetPol) to detect the polarisation signature of hot-Jupiters. It has a classical design, employing photoelastic modulators (frequency 20kHz), a triple-wedge calcite Wollaston and single-element Avalanche Photodiodes (NEP <2fWHz⁻), and operates between 450 and 1000nm. There are two identical channels, one for the object and one for the sky (see Figure 5). The instrument is rotated on the telescope to measure both linear polarisation components (Q and U).

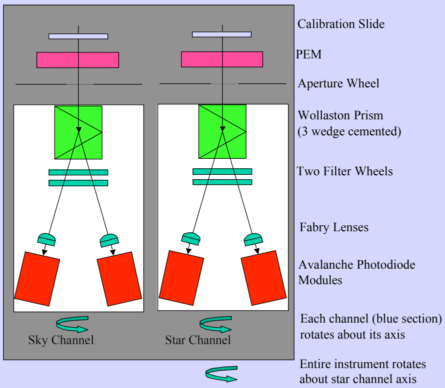


Fig 5. Schematic of PlanetPol

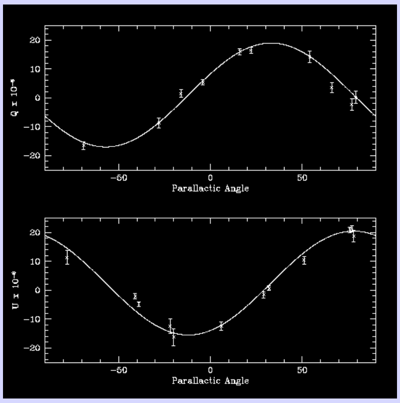
A 7 night run on the WHT in April 2004 was used for science verification of PlanetPol and to make our first observations of a star with a known EXP (τBoo)

Results from the 3_ clear nights are shown below.

Use altazimuth mounted telescopes:

- **telescope tube rotates relative to sky as a source tracks across the sky**
- **this enables telescope and star polarization to be separated.**

Observations of assumed unpolarized stars as a function of parallactic angle are shown in Fig 6.



The sinusoidal Q & U curves have amplitude (2×10^{-5}) and are phase shifted by 45°. This shows that:

(i) the telescope polarization is 2×10^{-5}

(ii) the instrument polarisation is very small, and

(iii) for these stars the intrinsic polarisation and interstellar polarisation is probably $<2\times10^{-6}$.

(iv) we can reach the sensitivities necessary to detect the polarization signature of hot-Jupiters.

Fig 6. Observations of assumed unpolarized stars (units are 10^{-6}) as a function of parallactic angle.

Observations of τBoo

Because of poor weather only limited observations were made of τBoo, covering just parts of the orbital phase, and integration times were limited giving larger errors. Fig. 7 (a) & (b) show the data, with the telescope polarisation subtracted, as a function of planetary phase angle.

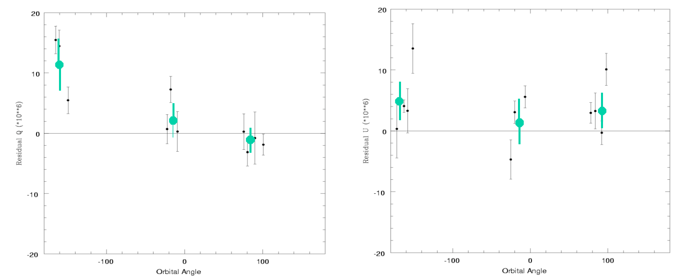


Fig 7(a) Q residuals and (b) U residuals (the green points are the averages of each block of data)

With only patchy data we clearly can't claim to have detected the polarisation signature of τBoo, although there is a polarization residual at a phase angle of -160 degrees, which at first sight is a bit surprising. However, this can be understood in the context of a tidally spun up star model where the star has the same rotation period as the planets's orbital period (and the rotation period of the planet). In that model[4] *i* must be ~40°. Hence, the scattering angle near phase angles of -160 degrees is ~ 50°, enough to give a large polarisation and still provide a lot of flux, especially if we have moderately forward throwing sub-micron grains.

References

1. Russell H. N., 1916, *Astrophysical Journal*, XLIII, No. 3, 173
2. Seager S. Whitney B. A. & Sasselov D. D. 2000, *ApJ*, 540, 504
3. Mazeh T., et al. 2000, *ApJ*, 532, L55-L58
4. Leigh et al, 2003, 344, 1271