Broadband Linear Polarimetry of Exoplanet Upsilon Andromedae b: Constraints on the orbital and physical parameters

Yasir Abdul Qadir[1], Andrei V. Berdyugin[1], Vadim Kravtsov[1], Vilppu Piirola[1], Takeshi Sakanoi[2], Masato Kagitani[2], and Juri Poutanen[1]

[1]Tuorla Observatory, Department of Physics and Astronomy, FI-20014 University of Turku, Finland (e-mail: yasir.abdulqadir@utu.fi)

[2]Graduate School of Sciences, Tohoku University, Aoba-ku, 980-8578 Sendai, Japan

Abstract

Advancements in astronomical polarimetry have enabled the detection and characterization of some exoplanets. Our study focused on a non-transiting gas giant named υ And b, that we observed using the DiPol-2 polarimeter and the T60 telescope. The data analysis successfully revealed a polarimetric signal related to the planetary orbital period. Applying the Rayleigh-Lambert model, we derived key orbital parameters of the exoplanet. However, an irregular polarization signal from the host star, as indicated by the analysis of photometric data and limitations of a 60 cm telescope, add high uncertainties to these preliminary results. Future observations with a larger telescope later this year will improve data precision and should provide better estimations of orbital parameters and planetary albedo.

Data Analysis

We conducted polarimetric observation of υ And b over a period of three years from 2016 to 2019 using DiPol-2 polarimeter (Piirola et al. 2014) and T60, a 60 cm telescope at Haleakalā Observatory, Hawaii. Our broadband polarimetric observations in B, V, and R passbands captured data at various orbital phases. We obtained a total of 114 data points, revealing significant polarimetric variations, as shown in Fig. 1.

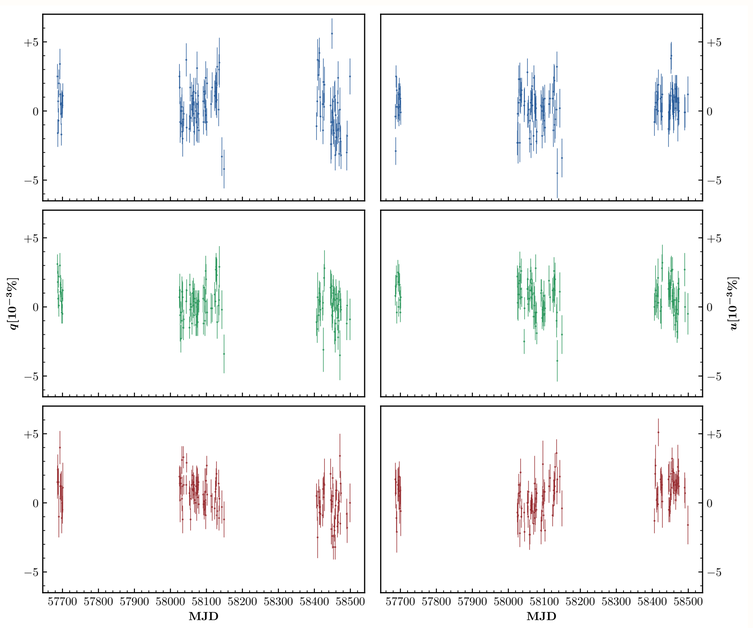

Figure 1: Stokes q and u (left and right panels) observations in B, V, and R passbands (top to bottom panels) with 1σ uncertainties.

To find any periodic signals, we analyzed the polarimetric data of υ And using a Lomb-Scargle algorithm. There seems to be a signal at around 2.3 d (see Fig. 2), half of its known orbital period of 4.6 d (Piskorz et al. 2017). False Alarm Probability for the apparent planetary orbital peaks in the periodograms was above 50%, which can be expected from such noisy data.

To validate the signal's authenticity, we filtered the periodograms, retaining only frequencies related to the planetary orbital period and stellar rotational period of 7.3 d (Simpsons et al. 2010), two phenomenons that could most likely produce linear polarization. The cleaned periodograms confirmed the presence of a clear periodic signal corresponding to the planetary orbital period, with no significant peaks at other periods, as shown in Fig. 3.

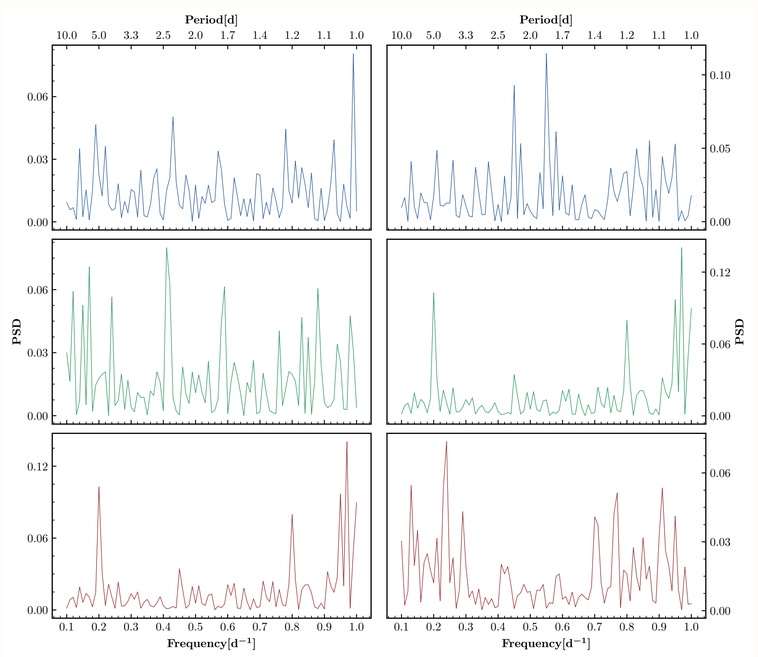

Figure 2: Lomb-Scargle periodograms of Stokes q (left column) and u (right column) of υ And in B, V, and R passbands (top, middle, and bottom panels respectively).

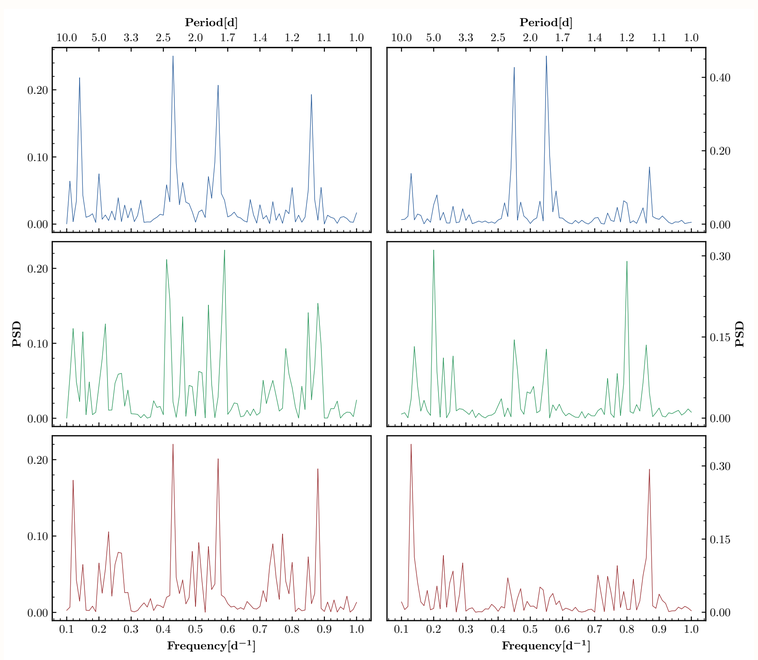

Figure 3: Same as Figure 2 but for cleaned data.

Next, we analyzed the photometric data of υ And, obtained by the Transiting Exoplanet Survey Satellite (TESS). This data consists of 31,747 measurements that were collected over two observation periods in 2019 and 2022. Lomb-Scargle periodograms revealed three significant periodic signals at 9.29 d, 2.76 d, and 4.67 d (see Fig. 4).

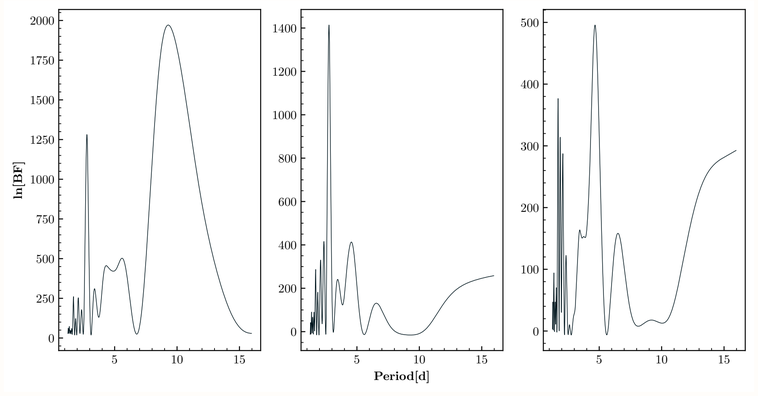

Figure 4: Lomb-Scargle periodograms for the photometric data of υ And. Bayesian factor estimation was used to find these signals.

The presence of these periods, seemingly related to the planetary orbital period, is unexpected as υ And is a non-transiting exoplanet. Further analysis through phase folding the data at these periods (see Fig. 5) suggests that the slight dips in magnitude are most likely due to the presence of stellar spots. Therefore, we can conclude that the observed polarimetric signal is due to the exoplanet, but the signal may have been contaminated by the polarization arising from the starspots.

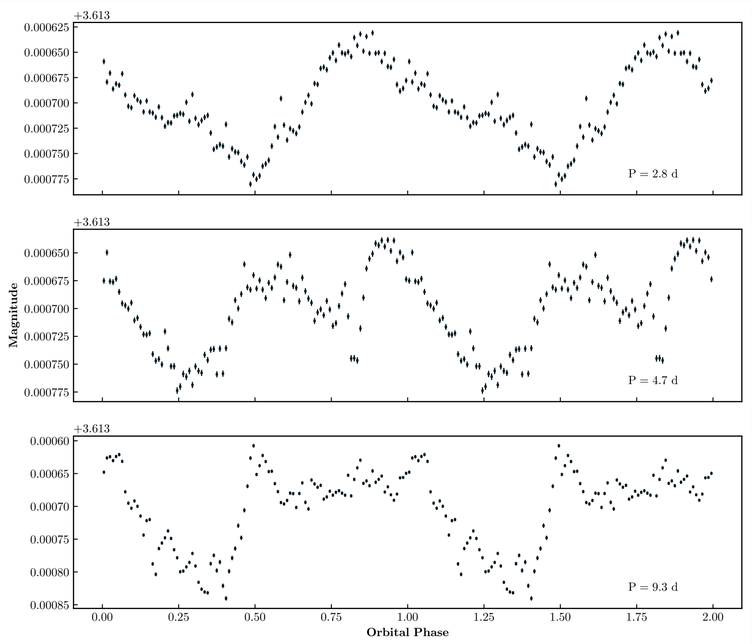

Figure 5: Folded photometric data of υ And with periods of 9.3 d (top panel), 2.8 d (middle panel), and 4.7 d (bottom panel). Data points with error bars represent the average values of individual observations and the standard errors of the mean calculated with phase interval of 0.008.

We used Rayleigh-Lambert (RL) approximation (Seager & Whitney 2000; Wiktorowicz 2009; Fluri & Berdyugina 2010) to model the signal and derive orbital parameters. Bayesian inference was used to fit the model to the binned data, where the standard errors of the mean were calculated for the orbital phase bin size of 0.053. This helped derive the values of orbital inclination (i), periastron longitude (ω), longitude of ascending node (Ω), geometrical albedo (p) albeit with high uncertainties, and constant polarization offsets of Z_q and Z_u for Stokes q and u respectively. We used RL radius $R_{RL} = 1.8\ R_J$ given by Deitrick et al. (2015) to estimate planetary albedo p as our model can only fit one of these two parameters. The results are given in Table 1.

Table 1: Derived orbital parameter values with 1σ uncertainties, where $\chi^2/\mathrm{dof} = 183/114$.

	B	V	R
R_{RL} $[R_J]^{a,b}$	–	1.8	–
i [deg]^b	–	103^{+13}_{-10}	–
ω [deg]^b	–	249^{+11}_{-12}	–
Ω [deg]^b	–	254^{+12}_{-14}	–
p [%]	26^{+15}_{-13}	23^{+14}_{-12}	22^{+16}_{-13}
Z_q $[10^{-4}\%]$	3^{+2}_{-2}	1^{+1}_{-2}	2^{+2}_{-2}
Z_u $[10^{-4}\%]$	1^{+1}_{-1}	1^{+1}_{-1}	1^{+2}_{-1}

(a)Fixed parameter.

(b)Same for all passbands.

Conclusions

We detected a polarization signal from υ And b, but the estimated parameters have high uncertainties due to noise in data and should be considered preliminary results. The low albedo suggests irregular polarization from the host star, possibly caused by stellar spots, as it was indicated by the photometric data. Further observations with a 1 m telescope later this year will provide more accurate results and should also enable estimation of additional parameters such as planetary mass, density, and surface gravity.

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