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A SuperWASP light curve displaying a single long-duration transit: a Jupiter size exoplanet in a very distant orbit?

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ABSTRACT

We present the SuperWASP light curve of a 10th magnitude A7V star containing a single, well-defined U-shaped transit-like event lasting around 11 days with a depth of 1.1%. The star is otherwise non-variable throughout the 8-year duration of the observations. If the event is modeled as an exoplanet transit, it is compatible with a 1.8 R_J exoplanet in a $\sim$ 205 AU orbit with a period of $\sim$ 2200 years.

1. SUPERWASP AND ZOONIVERSE

The Wide Angle Search for Planets is the world's most successful ground-based exoplanet survey, having discovered almost 200 transiting hot Jupiters to date (Pollacco et al. 2006). *SuperWASP North*, in La Palma, and *SuperWASP South*, in South Africa, observed the entire sky (excluding the Galactic plane) between 2004 and 2013, producing high-candence, long-duration light curves of $\sim$ 31 million sources with magnitude brighter than $V \sim 15$.

To encourage exploitation of the non-exoplanet science from the survey, we have created two citizen science projects on the Zooniverse platform (Lintott et al. 2008) using SuperWASP light curves. The first of these, *SuperWASP Variable Stars*, allows volunteers to classify folded light curves of around 750 000 potentially periodic variable stars (Norton 2018; Thiemann et al. 2021). The results of this may be interrogated via the *SuperWASP Variable Star Photometry Archive* (VeSPA) interface (McMaster et al. 2021). A second project, *SuperWASP Black Hole Hunters*, has recently begun and seeks to identify hidden black holes in binaries via self-lensing. The subjects for this project are SuperWASP light curves that do *not* display periodicities.

2. A LIGHT CURVE WITH A SINGLE LONG-DURATION TRANSIT

A serendipitous discovery in *SuperWASP Black Hole Hunters* occurred when a citizen science volunteer noticed that the light curve of 1SWASP J182438.34+302546.0 (= TYC 2623-1439-1) displayed a single, shallow, U-shaped transit-like event lasting around 11 days, during the first season of observations in 2004. This is noteworthy, as such a long duration transit indicates a very long period orbit for the transiting object. The star's SuperWASP light curve spans 8 years and contains 39 305 data points, mostly acquired during 5 observing seasons (see Figure 1, upper panel).

The otherwise anonymous star has *Tycho* magnitudes $V = 9.70$ and $B = 9.91$ (Høg et al. 2000) and has a *Gaia* parallax of 2.5719 ± 0.0137 mas (Gaia Collaboration 2020), implying a distance of 389 ± 2 pc. Using the extinction model of Amôres & Lépine (2005) (Model A) implemented at GALExtin (Amôres et al. 2021) the extinction to the star is $A_V = 0.19$ mag, so its absolute magnitude is $M_V = +1.56$. The colour and magnitude therefore indicate a spectral type around A7V (Pecaut & Mamajek 2013), but slightly evolved off the ZAMS to higher luminosity.

The assumed stellar spectral type indicates a surface gravity of $\log(g/\mathrm{cm\ s^{-2}}) \sim 4.20$ and effective temperature $T_{\rm eff} \sim 7800$ K. We used these values, and solar metallicity, as priors for the *EXOFAST* transit fitting software (Eastman et al. 2013) at the NASA Exoplanet Archive to fit the event seen in the light curve, assuming a circular orbit. The period is not well constrained, as only a single transit is seen, but nonetheless a convincing MCMC fit is achieved, as shown in the lower panel of Figure 1. The star has a fitted mass and radius of $M_* = 1.73^{+0.10}_{-0.09}$ $M_\odot$

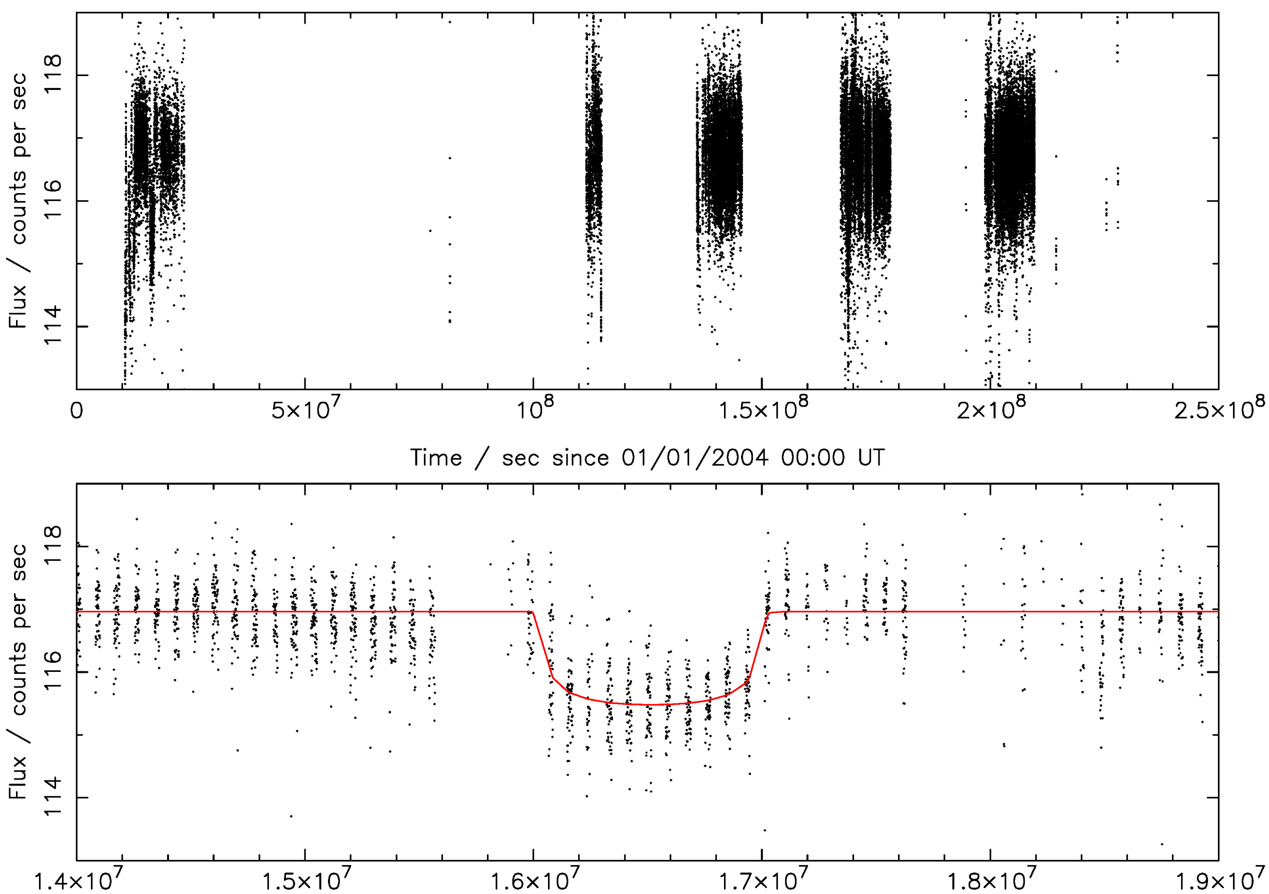

Figure 1. (*upper panel*) The SuperWASP light curve of 1SWASP J182438.34+302546.0 spanning 8 years. (*lower panel*) A zoom-in to $\sim$ 60-days of the light curve during 2004 showing the transit-like event, over-layed with a best-fit transit model.

and $R_* = 1.75^{+0.12}_{-0.11}$ R$_\odot$, and the transit has a depth of 1.10 ± 0.03 % with a total duration of 11.15 ± 0.36 days. The linear and quadratic limb darkening coefficients are 0.27 ± 0.05 and 0.34 ± 0.05 respectively. If the event is due to the transit of an orbiting object, this implies a planet of radius $R_{\rm P} = 1.80^{+0.14}_{-0.12}$ R$_{\rm J}$ in an orbit with a period of $P = 2240^{+510}_{-390}$ years and semi-major axis of $a = 205^{+29}_{-24}$ AU, inclined at 90° to our line of sight. The mid-time of the transit is at BJD 2453197.9 ± 0.2.

3. DISCUSSION

The potential for detecting long-period exoplanets using photometric transit surveys was explored by Osborn (2017) and recent studies have investigated the potential of detecting exoplanets via single transits in *TESS* (Grziwa & Pätzold 2021), *Kepler* (Incha et al. 2021) and *LSST* (Buzasi 2020). However these studies focused on relatively short-duration single transits, indicative of orbital periods of no more than tens of years. Two long-period exoplanets, each exhibiting a single transit in *Kepler* data, have been reported by Quinn et al. (2021) and Giles et al. (2018), but the transit durations are 'only' 45 hours and 54 hours respectively with orbital periods of $\sim$ 10 years in each case.

Long-duration transits, indicative of planets in very long-period orbits, are important as they allow exploration of under-sampled regions of parameter space. Such planets may be expected to exhibit different evolution and migration behaviour to compact, multi-planet systems. The location for the planet inferred here is comparable to that of the scattered disc for our Solar System and the Extrasolar Planet Encyclopaedia (exoplanet.eu) lists only $\sim$ 55 exoplanets with $a > 200$ AU, all detected via direct imaging.

At the inferred distance of 1SWASP J182438.34+302546.0, with the proposed semi-major axis, the maximum observed separation between the star and planet would be $\sim$ 0.5 arcsec implying that the presumed planet may also be detectable via direct imaging. However, since the transit occurred in 2004, it will take another quarter of an orbital period (~ 560 years) for the planet to attain this elongation from the star. Clearly there is also no prospect to detect another transit any time soon, and radial velocity changes or astrometric shifts will also be negligible. Consequently observational follow-up study of this or similarly detected exoplanets is likely to be impossible.

The geometric probability of a transit for this system ($\sim R_*/a$) is $\sim 4 \times 10^{-5}$ so only 1 in $\sim 25\,000$ such systems would be expected to display transits. Moreover, this system has only been observed by SuperWASP for $\sim 5 \times 10^7$ s in total, which is a fraction $\sim 7 \times 10^{-4}$ of its orbit. So the chance of detecting one event from a system such as that seen here is about 1 in 36 million. A search of the entire SuperWASP archive for other single long-duration transit events may allow inferences to be made about the Galactic population of such planets.

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