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ON THE ORBITAL PERIOD OF THE EXOPLANET WASP-39 b†

MACIEJEWSKI, G.[1]; GINSKI, CH.[2,3]; GILBERT, H.[2]; MUGRAUER, M.[2]; NEUHAEUSER, R.[2]

[1] Centre for Astronomy, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University, Grudziadzka 5, 87-100 Toruń, Poland, e-mail: gmac@umk.pl

[2] Astrophysikalisches Institut und Universitäts-Sternwarte, Schillergässchen 2–3, D–07745 Jena, Germany

[3] Sterrewacht Leiden, PO Box 9513, Niels Bohr weg 2, NL–2300RA Leiden, the Netherlands

The WASP-39 system is composed of a G8 main-sequence star and a bloated Saturn-mass planet on a 4.06 d circular orbit (Faedi et al. 2011). Ricci et al. (2015) acquired three new light curves with 0.8-2.2 m telescopes and refined system parameters. In Maciejewski et al. (2016), we have revisited the system parameters by modelling two new high-precision light curves obtained with 2 m telescopes. We have found that the orbital period of WASP-39 b is shorter by 3 seconds compared to the value determined by Ricci et al. (2015). In this research note, we present a new transit light curve acquired in 2016, i.e. about 200 epochs after observations of Ricci et al. (2015) and about 380 epochs after observations of Maciejewski et al. (2016). In addition, we also present an unpublished transit light curve acquired in 2011. We used those data together with the literature ones to verify the orbital period of WASP-39 b and refine its transit ephemeris.

The new transit light curve was acquired on 2016 April 29 with the 0.6 m Cassegrain telescope located at the Centre for Astronomy of the Nicolaus Copernicus University in Piwnice, near Toruń (Poland). An SBIG STL-1001 CCD camera with 1024×1024 24-μm size pixels was used as detector. The instrumental setup offers the field of view of $11\farcm8 \times 11\farcm8$. To achieve a higher precision for transit timing, the observations were carried out without any filter (in so called white light). The maximum of a spectral response was found to fall between V and R bands. The sky conditions were photometric. The archival light curve was obtained on 2011 April 19 with the 0.9/0.6 m Schmidt Teleskop Kamera (Mugrauer & Berthold 2010) at the University Observatory Jena (Germany). The sky was clear, and observations were done through a Bessel R filter. The detailed log of observations is given in Table 1.

We used the AstroImageJ package (AIJ, Collins et al. 2016) to process the data. The scientific exposures were corrected with dark current and flat field calibration frames. Timestamps were converted to barycentric Julian dates in barycentric dynamical time (BJD_{TDB}). Differential aperture photometry was applied to produce the light curves. The aperture radius and a set of comparison stars were optimized to achieve the smallest photometric scatter for the target star. The light curves were simultaneously detrended against the airmass, position on the matrix, time, and seeing. The light curve of 2016

†Partly based on observations obtained with telescopes of the University Observatory Jena, which is operated by the Astrophysical Institute of the Friedrich-Schiller-University.

Table 1: Details on individual observing runs.

Date	UT start - end	Airmass	$t_{\rm exp}$ [s]	$N_{\rm exp}$	Γ	pnr	$T_{\rm mid}$ (BJD$_{\rm TDB}$)
2011 Apr 19	20:56 - 01:03	$2.45 \rightarrow 1.71 \rightarrow 1.80$	60	196	0.82	4.10	$2455671.4470^{+0.0010}_{-0.0011}$
2016 Apr 29	20:58 - 01:40	$2.04 \rightarrow 1.81 \rightarrow 2.62$	15	789	3.02	3.33	$2457508.48959^{+0.00063}_{-0.00063}$

Date is given for the beginning of a run. Airmass shows changes of the airmass during a run. $t_{\rm exp}$ is the exposure time used. $N_{\rm exp}$ is the number of exposures. Γ is the median number of exposures per minute. pnr is the photometric scatter in parts per thousand of the normalized flux per minute of observation, based on a definition given in Fulton et al. (2011). $T_{\rm mid}$ is the mid-transit time.

April 29 was also detrended against a meridian flip close to the middle of the transit. The fluxes in both time series were normalized to unity for out-of-transit brightness. The mid-transit times were determined with the Transit Analysis Package (TAP, Gazak et al. 2012). In the fitting procedure, we used the system parameters (the orbital inclination, scaled semi-major axis, and planet-to-star radii ratio) from Maciejewski et al. (2016) as Gaussian priors with their uncertainties as 1-σ penalties. The limb darkening coefficients of the quadratic law were interpolated from tables of Claret & Bloemen (2011) and allowed to vary under Gaussian penalty of $\sigma = 0.1$. To account for possible trends in a total error budget, the intercept and slope of the out-of-transit brightness were free parameters. The best-fitting values and their 1-σ uncertainties were calculated as median and the 15.9 and 85.1 percentile values of marginalized posteriori probability distributions of ten Markov chain Monte Carlo walks with 10^6 steps each. New light curves[1] with the best-fitting models are plotted in Fig. 1.

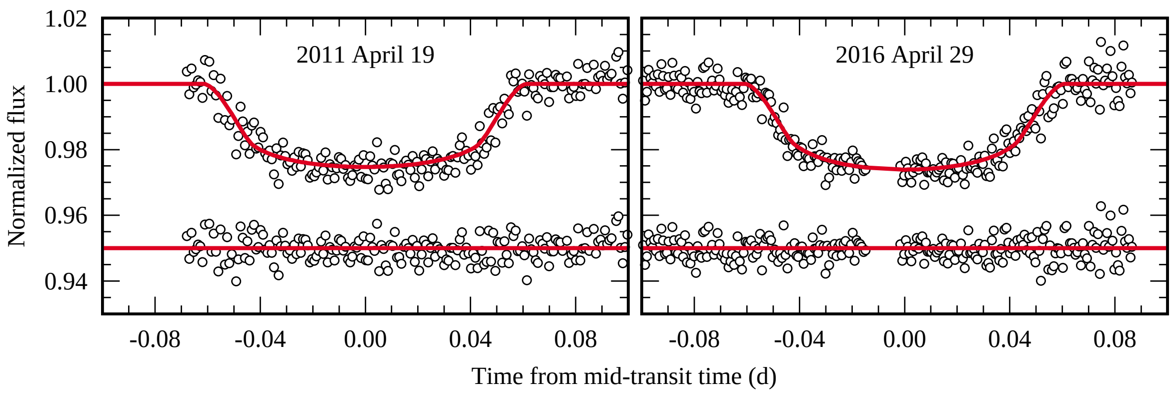

Figure 1. New transit light curves for WASP-39 b. The original light curve acquired on 2016 April 29 was binned into 1 minute intervals.

New mid-transit times, given in Table 1, were combined with the literature determinations from Faedi et al. (2011) and Maciejewski et al. (2016) in order to refine the transit ephemeris. Using the least-squares method, we derived

$$T_{\rm mid}({\rm BJD_{TDB}}) = (2455342.96933 \pm 0.00033) + (4\overset{\rm d}{.}0552807 \pm 0\overset{\rm d}{.}0000015) \times E, \quad (1)$$

where E is a transit number starting from the initial epoch given by Faedi et al. (2011). The goodness of the fit $\chi^2_{\rm red}$ was found to be equal to 1.11. The mid-transit time for epoch 0 is 1.5 times more precise than that one reported in Maciejewski et al. (2016).

[1]The photometric time series are available online at `http://www.home.umk.pl/~gmac/TTV`

The orbital period was found to be longer by 0.35 s and 2.3 times more precise than the value given in Maciejewski et al. (2016). A plot of residuals for transit timing is shown in Fig. 2. The mid-transit times of Ricci et al. (2015) are 11-14 σ outliers, and were skipped in calculations.

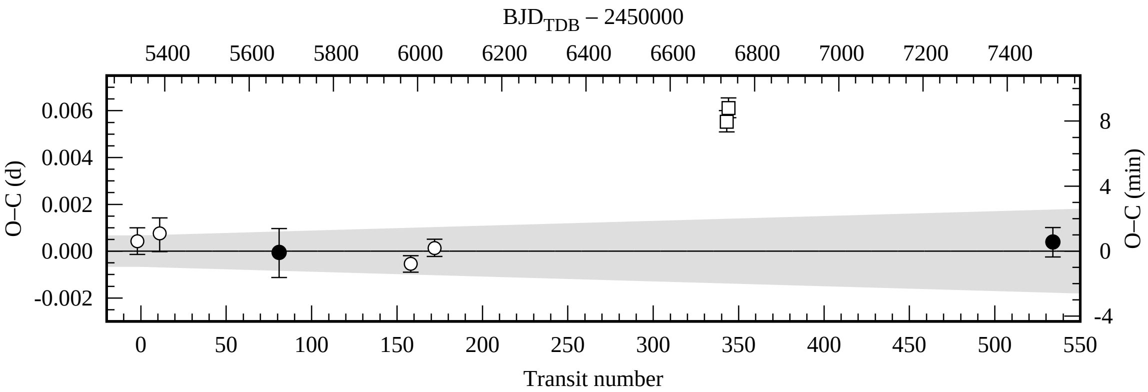

Figure 2. Transit timing residuals from a linear ephemeris. Filled dots are two new determinations reported in this note. Open circles mark the literature points from Faedi et al. (2011) and Maciejewski et al. (2016). Open squares show outlying mid-transit times of Ricci et al. (2015). The gray area shows propagation of the ephemeris uncertainties at a 95.5% confidence level.

Our new observations refined the transit ephemeris for WASP-39 b and confirm that the orbital period is shorter than that one reported in Ricci et al. (2015). The mid-transit times of Ricci et al. (2015) are shifted by some systematic effect, the source of which could be an incorrect time survey during observing runs or errors in the conversion of timestamps. We found that the linear ephemeris reproduces observed mid-transit times satisfactorily, giving no hint of any variations in transit timing.

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