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Absolute parameters for the F-type eclipsing binary BW Aquarii

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BW Aqr is a bright eclipsing binary star containing a pair of F7V stars. The absolute parameters of this binary (masses, radii, etc.) are known to good precision so they are often used to test stellar models, particularly in studies of convective overshooting (e.g., Clausen 1991; Claret & Torres 2018).

Maxted & Hutcheon (2018) analysed the Kepler K2 data for BW Aqr and noted that it shows variability between the eclipses that may be caused by tidally induced pulsations. The authors warn that they had "not attempted to characterise the level of systematic error" in the parameters they derived. Lester & Gies (2018) analysed the same data together with new radial velocity (RV) measurements. The binary star model they used gave a poor fit to the light curve through the secondary eclipse so the radii they derive may be subject to significant systematic error. The standard errors they quote on the stellar masses based on $N = 14$ pairs of RV measurements are clearly underestimated. The RMS (root-mean square) of the residuals from their spectroscopic orbit fit to these RVs is $\sigma \approx 3.6\,\mathrm{km\,s^{-1}}$ so the semi-amplitudes of the spectroscopic orbit are expected to have errors $\sigma_K \approx \sigma/\sqrt{N/2} = 1.4\,\mathrm{km\,s^{-1}}$ (Montgomery & O'Donoghue 1999), cf. the quoted errors of $0.27\,\mathrm{km\,s^{-1}}$.

Table 1 shows the absolute parameters for BW Aqr derived from an improved analysis of the Kepler K2 light curve plus the RV measurements from both Imbert (1979) and Lester & Gies (2018). The light curve data used are identical to those shown in Maxted & Hutcheon (2018). We used ellc version 1.8.0[2] to model the light curve using the power-2 limb darkening law, $I_\lambda(\mu) = 1 - c\,(1-\mu^\alpha)$, with the same parameters c and α for both stars and with Gaussian priors on the parameters $h_1 = 1 - c\,(1-2^{-\alpha}) = 0.78 \pm 0.02$ and $h_2 = c2^{-\alpha} = 0.44 \pm 0.10$ (Maxted 2018). The "default" grid size in ellc was used so that numerical noise is less than 60 ppm. Other details of the fit to the light curve are similar to those described in Maxted & Hutcheon (2018).

Each pair of consecutive primary and secondary eclipses in the K2 light curve were analysed separately using the emcee algorithm to determine the median of the posterior probability distributions (PPDs) for the model parameters. The results shown in Table 1 are calculated from the mean and its standard error from these 10 median values. The RV measurements were fit simultaneously with the times of mid-eclipse from Lester & Gies (2018) and Volkov & Chochol (2014) using the model omdot to account for apsidal motion (Maxted et al. 2015). The values in Table 1 with their robust error estimates from the standard deviation of the mean are consistent with the values and errors from Maxted & Hutcheon (2018) based on the PPD calculated using emcee for a fit to the entire K2 light curve.

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Facility: Kepler

Software: ellc (Maxted 2016), emcee (Foreman-Mackey et al. 2013)

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Table 1. Model parameters and absolute parameters for BW Aquarii.

Parameter	Units	Value	Standard error	Notes
Model parameters, ELLC				
$P_{\rm s}$	d	6.719695		Siderial period (fixed value for light curve analysis only)
$(R_1+R_2)/a$		0.17916	0.00024	Sum of stellar radii relative to orbital semi-major axis
R_2/R_1		1.1948	0.0049	
$S_{\rm Kp}$		0.9291	0.0014	Surface brightness ratio in the Kepler bandpass
i	$^{\circ}$	88.65	0.03	Orbital inclination
f_c		−0.09415	0.00014	$\sqrt{e}\cos\omega$
f_s		0.41081	0.00047	$\sqrt{e}\sin\omega$
h_1		0.7974	0.0066	
h_2		0.251	0.070	
y		0.1	0.2	Monochromatic gravity darkening exponent
σ_f	%	0.017	0.005	Standard error of K2 flux measurements
Quantities derived from ELLC model parameters				
e		0.17763	0.00036	Orbital eccentricity
ω	$^{\circ}$	102.91	0.03	Longitude of periastron
R_1/a		0.08163	0.00028	Radius of star 1 relative to orbital semi-major axis
R_2/a		0.09753	0.00010	Radius of star 2 relative to orbital semi-major axis
$\ell_{\rm Kp}$		1.326	0.011	Flux ratio in the Kepler bandpass
Model parameters, OMDOT				
$\rm T_0$		2456990.46693	0.00008	Reference time of mid-eclipse, BJD (TDB)
$\rm P_a$	d	6.71971325	0.00000057	Anomalistic orbital period
e		0.1771	0.0042	Orbital eccentricity
ω_0	$^{\circ}$	103.0	0.3	Longitude of periastron at time $\rm T_0$
$\dot{\omega}$	$\rm d^{-1}$	0.0000197	0.0000006	Apsidal motion rate, radians per siderial period
γ	$\rm km\,s^{-1}$	9.73	0.25	Systemic radial velocity
$\rm K_1$	$\rm km\,s^{-1}$	83.93	0.45	Semi-amplitude of spectroscopic orbit, star 1
$\rm K_2$	$\rm km\,s^{-1}$	78.42	0.47	Semi-amplitude of spectroscopic orbit, star 2
$\sigma_{RV,1}$	$\rm km\,s^{-1}$	3.12		RMS of residuals for all radial velocity data, star 1
$\sigma_{RV,2}$	$\rm km\,s^{-1}$	2.78		RMS of residuals for all radial velocity data, star 2
σ_t	d	0.00055		RMS of residuals for times of mid-eclipse
Quantities derived from OMDOT model parameters				
U	y	5880	180	Apsidal motion period
Absolute parameters				
$\rm T_{eff,1}$	K	6450	100	Effective temperature, star 1 (Clausen 1991)
$\rm T_{eff,2}$	K	6350	100	Effective temperature, star 2 (Clausen 1991)
M_1	$\mathcal{M}^{\rm N}_{\odot}$	1.373	0.018	Mass, star 1
M_2	$\mathcal{M}^{\rm N}_{\odot}$	1.469	0.018	Mass, star 2
R_1	$\mathcal{R}^{\rm N}_{\odot}$	1.7332	0.0091	Radius, star 1
R_2	$\mathcal{R}^{\rm N}_{\odot}$	2.0708	0.0086	Radius, star 2
$\log g_1$	$\rm cm\,s^{-2}$	4.0982	0.0040	Surface gravity, star 1
$\log g_2$	$\rm cm\,s^{-2}$	3.9731	0.0025	Surface gravity, star 2
$\log \rm L_1$	$\rm L_{\odot}$	0.669	0.027	Luminosity, star 1
$\log \rm L_2$	$\rm L_{\odot}$	0.796	0.028	Luminosity, star 2

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