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On accuracy of eclipsing binary system parameters determination from light curve modeling

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Abstract. Based on multicolour observations of two contact systems with flat bottom minima, we investigate the consistency of derived photometric mass ratio parameters. Applying the Wilson-Devinney code, we derived the best solutions using the Monte Carlo search method for GSC 2723-2376 and GU Ori. We found discrepancies in $q_{\rm phot}$ among our solutions and those previously published for the two systems, reaching more than 10%. This will lead to similar differences in the physical parameters.

Key words: binaries: eclipsing – stars: modelling

1. Introduction

The parameters of contact binaries can be reliably obtained if both spectroscopic and photometric data are available. Surveys such as Kepler and TESS have provided a vast number of binary light curves, however spectroscopic data of sufficient quality to derive mass ratios are only available for a tiny fraction of systems. Terrell & Wilson (2005) showed that the photometric mass ratio ($q_{\rm phot}$) could only be reliably derived for systems showing a flat-bottomed minimum, as for partial eclipses nearly identical fits can be obtained for a wide range of mass ratios. This is especially important for contact binaries since differences in derived $q_{\rm phot}$ lead to inconsistencies in the physical parameters.

We investigated the consistency of light curve solutions by modelling photometric light curves collected during different observing seasons for two contact binaries with flat-bottomed minima: GSC 2723-2376 and GU Ori. These results are compared with previously published ones.

2. Targets and Observations

GSC 2723-2376: the single previous study of this system was by Alton and Stepien in 2018 (Alton & Stepien, 2018), based on BVI data. They derived the ephemeris $M = 2458051.7941 + 0.28570290E$ and modelled the system using PHOEBE (Prša & Zwitter, 2005). They assumed the primary temperature to be 5430 K based on the system $B-V$ colour and concluded that the system was in a contact configuration, with a fill-out factor of about 14% and $q_{\rm phot} = 0.53$. The model did not include a spot as no asymmetry was seen in the light curve.

GU Ori: this system has a longer history of observations dating back to 1930, when Hoffmeister identified it as an RR Lyr type star. Subsequently, only minima times were published until light curve modelling by Yang et al. (2017), who determined the system spectral type to be G0V and derived the ephemeris $M = 2455581.9658 + 0.47067725E$, and by Zhou et al. (2018). Both groups presented parameters determined using the Wilson-Devinney code.

We observed the two systems photometrically using two 50 cm telescopes located at the Jagiellonian University Astronomical Observatory in Kraków, Poland. The CCD images were calibrated using IRAF for bias, dark and flat field (only sky flats were used). Differential aperture photometry was then performed using CMunipack (Motl, 2011), which is based on DAOPHOT (Stetson, 1987).

GSC 2723-2376 was observed over two seasons. A complete light curve in the $BVRI$ bands was collected in 2018, and in VRI in 2019. GSC 2327-2128 was used as the comparison star, and GSC 2327-2362 and NOMAD1 1235-0584368 as check stars. GU Ori was observed in the $BVRI$ bands in 2017 and 2020. TYC 738-883-1 was used as the comparison, with GSC 00738-00513, 2MASS 06095077+1254152 and TYC 738-2484-1 as the check stars.

3. Light Curve Modelling Using the New Photometric Data

We modelled the light curves separately for each observing season to check consistency of the results. The Wilson-Devinney (Wilson & Devinney, 1973) code was used, extended with a Monte Carlo search to ensure that the fit converged on the global minimum (Zola et al., 1997). Observed differential magnitudes were converted to flux units. The light curve for each filter was normalized to 1 at quadrature and binned into about 200 points.

For GSC 2723-2376, we used the $BVRI$ data collected in 2018 to calculate two models with different assumed temperatures for the primary star. One was taken from the Gaia DR2 (Gaia Collaboration et al., 2018) catalogue (5018 K) and the other (5430 K) corresponded to the system $B - V$ colour as derived by Alton and Stepien. We used a model without a spot due to the lack of any noticeable difference in the heights of the maxima of the light curve.

For GU Ori we assumed the primary temperature to be 5920 K based on the system spectral type of G0V and the calibration published by Mamajek (2022). Asymmetries in the light curve required a model with one cool spot. Consistency of the resulting photometric mass ratio was checked by separate modelling of the light curves taken in two observing seasons. The resulting best fits are shown in Fig. 1.

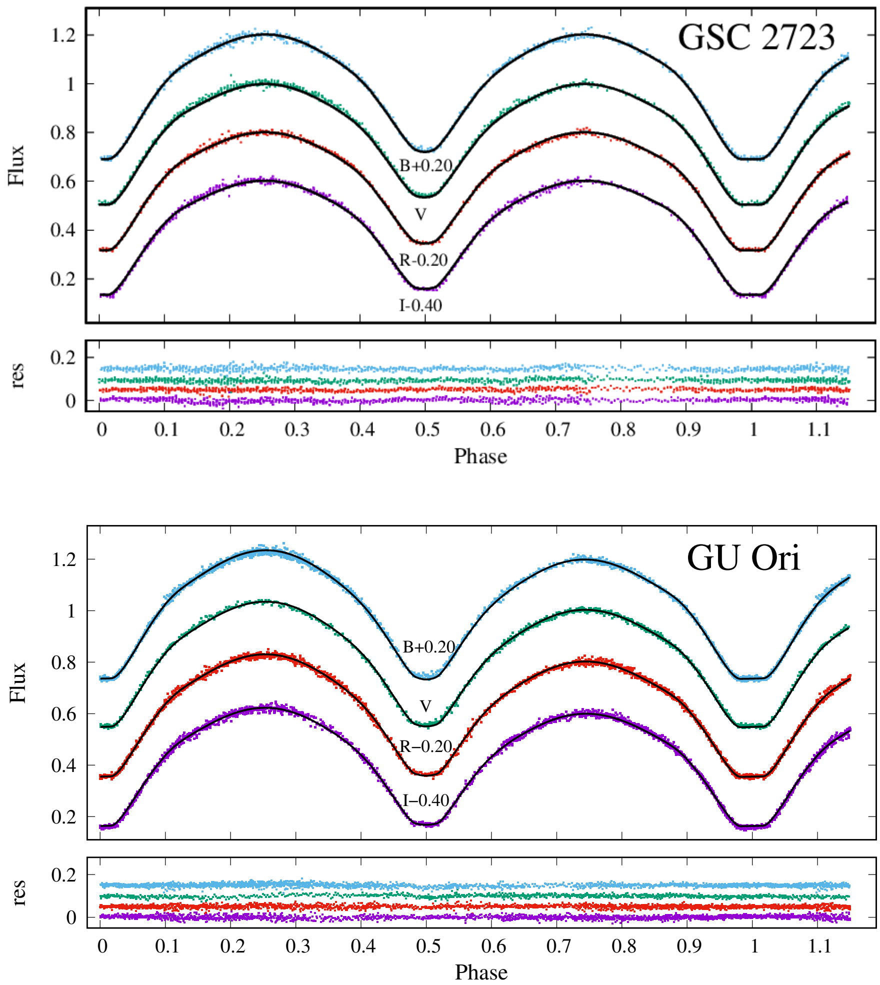

Figure 1. Comparison between data and models for GSC-2723-2376 and GU Ori

4. Results and Conclusions

We investigated the consistency of the determination of the photometric mass ratio $q_{\rm phot}$ based on data from two contact binary systems, considering two possible influences on the models: the assumed fixed temperature of one of the components and the accuracy of the observed light curves. For GSC 2723-2376 we modelled the $BVRI$ light curve from 2018 for two assumed values of the primary temperature. For GU Ori, we modelled the $BVRI$ light curves observed in 2017 and 2020, and compared our results between seasons and with those derived by Yang et al. and Zhou et al. The results are shown in Table 1.

Table 1. Results of modelling GSC 2723-2376 and GU Ori

GSC 2723-2376	Alton and Stepien		This work	
assumed T_1	5430 K		5430 K	5018 K
q_{phot}	1.894±0.004		2.118±0.010	2.173±0.010
GU Ori	Yang et al.	Zhou et al.	This work	
			2017	2020
assumed T_1	5920 K	6050 K	5920 K	5920 K
q_{phot}	0.455±0.020	2.32±0.05	2.207±0.010	2.209±0.013

Looking at the results obtained for GSC 2723-2376, the assumed temperature seems to only have a small impact on q_{phot}: an approximately 400 K (∼8%) difference in the temperature of the primary resulted in only a 2% difference in q_{phot} for the same data. On the other hand, despite the same assumed temperature there is a much higher (11%) difference between our result and that of Alton and Stepien, which may be explained by their data, collected with a smaller telescope (28 cm diameter vs. 50 cm). These differences would lead to inconsistencies in the other derived physical parameters in the range of 2–6%.

For GU Ori, we found consistent values for the derived q_{phot} from both two sets of data collected 3 years apart. Our result is about 5% smaller than that of Zhou et al., while Yang et al. obtained the inverse of our value. This appears to be due to poor quality data leading to misidentification of which was the flat minimum (see fig. 2 of Yang et al.). The models included one (Yang et al. and our work) or two dark spots (Zhou at al.) due to the asymmetric light curve.

The presence of spots in models may increase the scatter of the derived values of q_{phot}. However, we argue that accuracy of the underlying photometric data has more of an impact on the reliability of the photometric mass ratio. Rucinski (2024) noted that photometrically-determined mass ratios for contact systems tend to have smaller values compared to the spectroscopic determinations. Neither of the two systems presented here has a spectroscopically determined mass ratio as yet, therefore we cannot confirm if they also follow this trend.

Our results and those previously published for these two systems are based on the Roche geometry. Very recently, Rucinski challenged its application in case of two binary systems thought to be in contact configuration: AW UMa and ϵ CrA (Rucinski, 2024), arguing that high resolution spectroscopic observations do not agree with the traditional Lucy (1968a,b) model.

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