Photometric Analysis of Three ROTSE Contact Binary Systems

Surjit S. Wadhwa
Astronomical Society of NSW, Sydney, NSW, Australia; surjitwadhwa@gmail.com

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Abstract Ground-based photometry of three ROTSE contact binary systems was analyzed using the Wilson-Devinney method. One system with a very low mass ratio below q = 0.06 and one with high mass ratio with a complete eclipse and edge-on inclination were found and represent candidates for further study.

1. Introduction

The W Ursae Majoris (W UMa) group of short-period contact eclipsing binaries are important test beds for theories of stellar evolution. Numerous new contact systems have been discovered recently through the automated sky survey programs and dedicated amateur observing efforts. Quite a large percentage of the new discoveries remain largely un-analyzed even though data are of sufficient quality to yield at least basic physical information. In a previous paper published in this journal I have demonstrated how analysis of amateur observations of a contact binary star for which little other information is available can yield a satisfactory photometric solution (Wadhwa 2004). In this first paper I present photometric solution for three binary systems discovered by the The Robotic Optical Transient Search Experiment (ROTSE) that have had follow up ground-based observations published.

GSC 963-246 (R.A. $16^h\ 27^m\ 44.9^s$, Dec.+11° 03' 38" (2000)) was discovered by the ROTSE mission and catalogued as a contact system by Gettel *et al.* (2006). Ground-based dual-band (R and V) photometry was reported in 2007 (Blättler and Diethelm 2007). Preliminary analysis confirmed the contact binary nature of the system with the following basic elements: JD (min I, hel) = 2453898.3997 + 0.337043 × E; magnitude (R) variation of 0.41 mag. for the primary eclipse and 0.36 mag. for the secondary eclipse. The photometry data are available publically (http://ibvs.konkoly.hu/pub/ibvs/5701/5799-t4.txt). The R band data were analyzed to determine mass ratio and other parameters in the present study.

Ground-based observations of GSC 3034-299 (R.A. 14^h $05^m\ 08.985^s$, Dec. +38° 54' 18.74" (2000)) were reported in Blättler and Diethelm (2006). Preliminary analysis confirmed the contact binary nature of the system with the following basic elements: JD(min I, hel) = 2453382.6919 + 0.395010 × E; unfiltered (near R) yielded a magnitude range of 11.46–12.20 mag. (primary eclipse) and 11.46–12.13 mag. (secondary eclipse). The photometry data are available publically (http://ibvs.konkoly.hu/pub/ibvs/5601/5699-t10.txt). The data although unfiltered are reported to be near-red bandpass and were analyzed as R band data.

GSC 2587-1888 (R.A. $16^h\ 29^m\ 19.89^s$, Dec. +35° 40' 02.90" (2000)) is another ROTSE variable with ground-based photometry in both the R and V bands reported in 2007 (Blättler and Diethelm 2007). Preliminary analysis confirmed the contact binary nature of the system with the following basic elements: JD(min I, hel) = 2453877.4694 + 0.310726 × E; primary and secondary eclipses have a magnitude variation of 0.17 in the R band. The photometry data are available publically (http://ibvs.konkoly.hu/pub/ibvs/5701/5799-t2.txt). The R band data were analyzed in this study.

2. Light curve analysis

The mass ratio of a contact binary system is usually determined by radial velocity studies. The mass ratio is then used to determine other features of the system such as the inclination, degree of contact, and temperature variations. However, where radial velocity data are not available, under certain circumstances, such as when the system exhibits at least one total eclipse, a systematic search of the parameter space for various values of the mass ratio can be employed to determine the correct mass ratio for the system (Terrell and Wilson 2005). This is sometimes referred to as the grid search method and has previously been employed on many data sources, including data obtained through automated sky patrols (Wadhwa 2004, 2005).

As radial velocity data were not available for any of the systems analyzed in this paper, the grid search method as described in the above-referenced articles was employed. In addition, very few basic data are available for the systems and certain assumptions with respect to the temperature of the primary were required as outlined below. In each case the available data indicated a probable convective envelope, therefore gravity brightening was set at 0.32 and bolometric albedos were set at 0.5. Black body approximation was used for the stars' emergent flux and simple reflection treatment was applied. The maximum magnitude of the stars is not well known, therefore the photometric data were normalised to the mean magnitude between phases 0.24 and 0.26 in each case. This methodology has previously been applied to the analysis of All Sky Automated Survey and ground-based amateur observations (Wadhwa 2004, 2005).

3. Individual systems

3.1. GSC 963-246 = ROTSE1 J162744.97+110336.5, V1179 Her

The SIMBAD database gives a B–V value of 0.54 for the system leading to a calibrated temperature of 6100 K. The mass ratio search grid (Figure 1) demonstrated a nice clear minimum with the mass ratio at 0.14. Based on this, other parameters of the photometric solution are summarized in Table 1. As can be seen, the temperature of the secondary is similar to that of the primary, indicating good thermal equilibrium, however, it

Table 1. Photometric Solution for GSC 963-246.

Parameter	*Value*
Mass Ratio (q)	0.14 + 0.004
T2	6122 K + 49 K
Potential	2.021 + 0.01
Inclination (i)	78.15 + 1.4
Fillout	60.3%

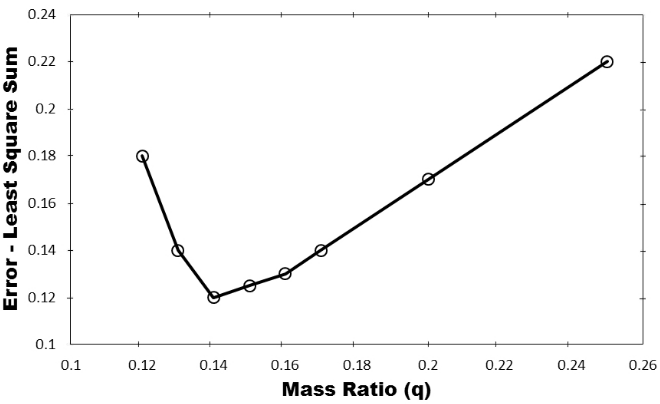

Figure 1. Mass ratio search grid for GSC 963-246. The best fit as indicated by the least sum of squares occurs at q = 0.14.

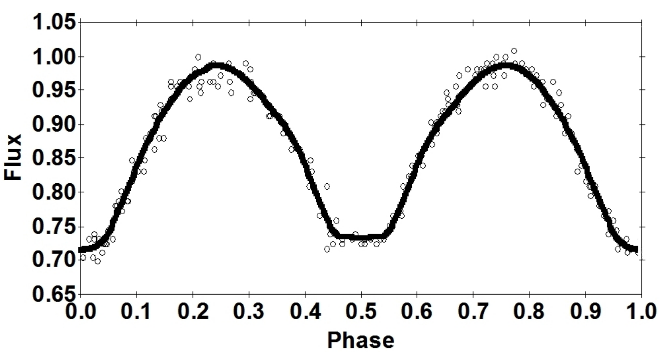

Figure 2. GSC 963-246 light curves. Solid line = fitted curve; Open circles = observed curve.

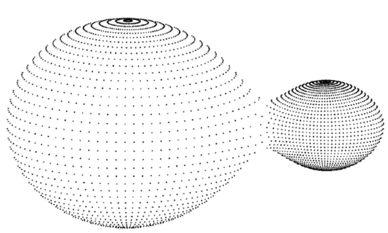

Figure 3. Three dimensional model of GSC 963-246.

Table 2. Basic photometric elements for GSC 3034-299.

Parameter	*Value*
Mass Ratio (q)	0.50 + 0.01
T2	5664K + 25K
Potential	2.813 + 0.02
Inclination(i)	90.00
Fillout	21.0%

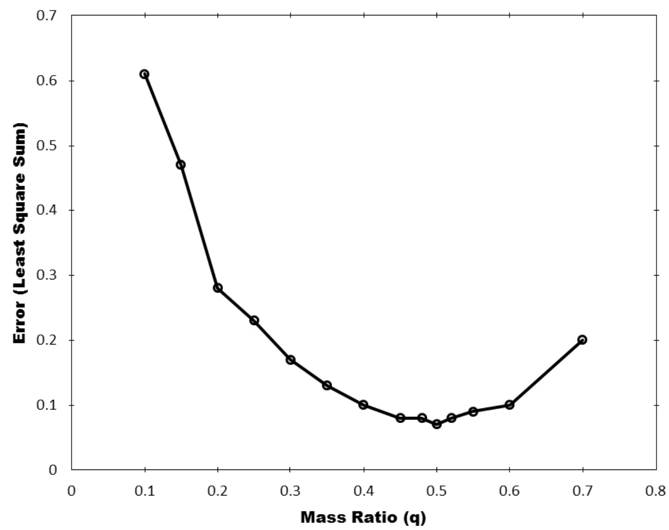

Figure 4. Mass ratio search grid for GSC 3034-299. There is a clear minimum at q = 0.5.

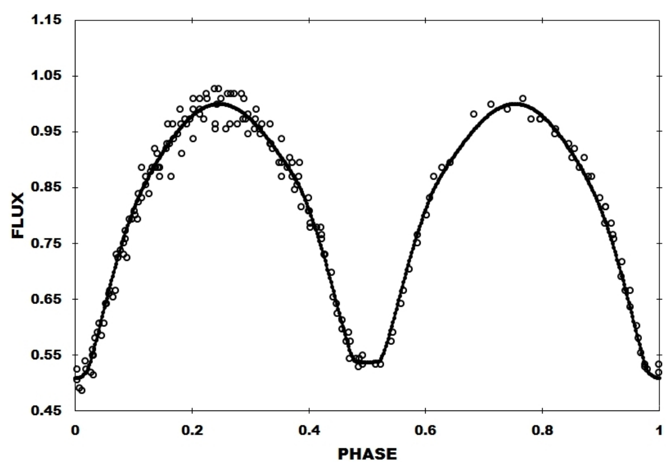

Figure 5. Fitted (solid line) and observed (open circles) light curves for GSC 3034-299.

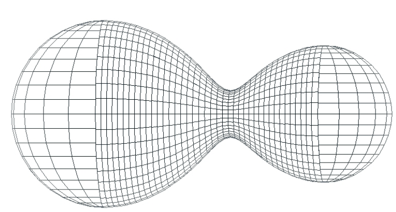

Figure 6: 3D representation of GSC 3034-299.

is somewhat difficult to classify the system as either A or W type. Based purely on the values of the photometric solution the system would be of W-Type. The fitted light curves are shown in Figure 2, while a three-dimensional representation (Bradstreet 1993) is shown in Figure 3.

3.2. GSC 3034-299 = ROTSE1 J140509.23+385417.9, GN CVn

This system has an effective temperature of 5660 K based on a B–V of 0.63 as per the SIMBAD database. The light curve has relatively deep minima, suggesting a higher mass ratio than usual for contact binary systems. The presence of a complete eclipse would suggest a high almost edge-on inclination. As with the previous example the grid search method was applied to search for the mass ratio of best fit. As illustrated in Figure 4 the system has a clearly defined minimum error at q = 0.5. The remainder of the photometric solution is summarized in Table 2, confirming an edge-on inclination and good thermal contact with no difference in the temperatures between the stars. Observed and fitted light curves are shown in Figure 5 while the three-dimensional representation (Bradstreet 1993) is shown in Figure 6.

Since the initial analysis of this system the author has become aware that the system had been analyzed previously by Samec *et al.* (2012). The 2012 analysis reached a very similar solution with a mass ratio of 0.48 with good thermal contact, high inclination of 89.6 degrees, and 24% fillout. The closeness of the two solutions adds further confidence that analysis of amateur observations can yield high quality and useful scientifically valid analysis.

3.3. GSC 2587-1888 = NSVS 7913634, TYC 2587-1888-1

GSC 2587-1888 is another ROTSE variable and is largely unstudied. The SIMBAD database yields a B–V of 0.48 corresponding to an effective temperature of 6393 K. Visual inspection of the light curve (Figure 7) clearly indicates a total eclipse. Prior to starting the mass ratio search grid manual light curve fitting was used to get an approximate starting point. During this process it became clear that the system most likely had a very low mass ratio, as all attempts to manually fit the light curves with q > 0.1 yielded non-physical systems. The automated differential corrections would also only lead to either very poorly fitting or non-physical systems when the mass ratio was greater than 0.1. Similarly very low mass ratios (q < 0.05) also yielded poorly fitting solutions, which is not surprising given that as calculated by Ruciński (1993) the maximum amplitude for systems with mid-range contact and mass ratios less than 0.05 would be less than 0.14 magnitude. Our system exhibits amplitude well in excess at 0.17 magnitude, which suggests a mass ratio above 0.05 but below 0.09.

A reasonable manual fit was made at the high end of this range at q = 0.09 and the other parameters adjusted to yield the best solution for this mass ratio. The mass ratio was then allowed to be an adjustable parameter and differential corrections iterations performed again. The mass ratio quickly drifted down with marked improvement in the fitting profile. The best fit (Figure 7, Table 3) was achieved with a possible record low mass ratio for a contact system of q = 0.059 with the secondary star considerably hotter than the primary. A three-dimensional representation (Bradstreet 1993) is shown in Figure 8.

Table 3. Basic photometric elements for GSC 2587-1888.

Parameters	*Value*
T2	6727 K + 73 K
Inclination (i)	66.23 + 1.13
Potential	1.815 + .01
Mass Ratio (q)	0.059 + .02
Fillout	19.15%

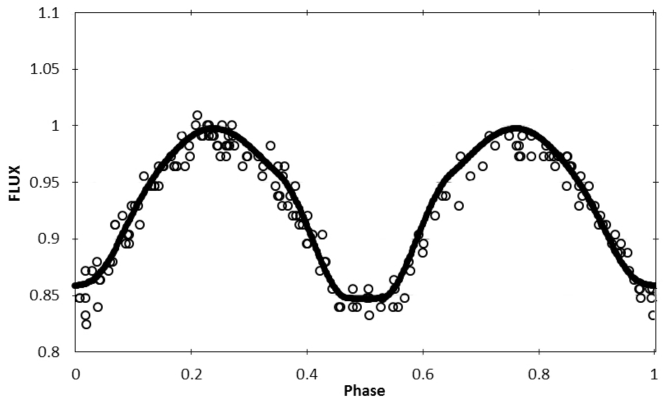

Figure 7. The best fit (solid line) and the observed (open circles) light curves for GSC 2587-1888.

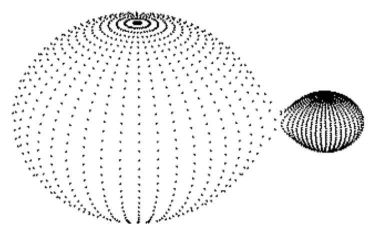

Figure 8. Three-dimensional representation of GSC 2587-1888 showing the extremely small secondary in shallow contact with its much larger primary.

The mass ratio of 0.059 is significantly smaller than the theoretical lower limit of 0.07 (Li and Zhang 2006). The theoretical limit, however, is valid for stars in good thermal equilibrium and with high degree of contact (> 70%). Our system is somewhat different, with a very shallow contact of 19% and poor thermal equilibrium. Although a very rare event it is possible that GSC 2587-1888 is a newly formed low mass contact system having only recently moved from the semi-detached to the contact phase. Unfortunately the confidence in the low mass ratio must be tempered as the analysis was performed on a small photometric sample with moderate error. However, the system clearly deserves a more thorough study.

4. Conclusion

An analysis of the ground-based photometry of three ROTSE variables has identified GSC 2587-1888 as a possible very low mass ration system which is in the early phase contact. The study again highlights the importance of analysis of all data regardless of whether they are professional or amateur in deepening our understanding of contact binary astronomy.

5. Acknowledgements

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