GSC 4552-1643: a W UMa System With Complete Eclipses

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Abstract Observations and analysis of GSC 4552-1642 are presented and the system is shown to be a W UMa system with complete eclipses. The total/annular nature of the eclipses results in a photometric mass ratio that should be reliable but the light curves do have appreciable amounts of third light.

1. Background

GSC 4552-1643 is listed as star 828321 in the Gettel, *et al.* (2006; hereafter GGM) catalogue of overcontact binary stars with an orbital period of about 0.27 day. Visual inspection of the light curve given by GGM showed that it might have complete eclipses. Given the greatly strengthened analysis that complete eclipses can provide, we began observing the system with Johnson B and V and Cousins I filters at the Sonoita Research Observatory in Sonoita, Arizona. We used the 20-inch telescope equipped with a Santa Barbara Instrument Group Research STL 6303 CCD camera. Calibration (bias, dark, flat) and aperture photometry were done with IRAF. Observations were made on six nights in March and April 2011 with a total of 283 observations in the B filter, 459 in V, and 436 in I. GSC 4552-0002 was used as the comparison star and GSC 1399-0059 was the check star. The images were reduced using IRAF to bias and dark subtract the frames before flatfielding, and the calibration frames were created by median-combining at least twenty raw images. Aperture photometry was performed on the images using the IRAF PHOT package. Data from the AAVSO Photometric All-Sky Survey (APASS) (Henden *et al.* 2010) for the stars are shown in Table 1. The comparison minus check star values showed no variability greater than 0.01 magnitude over the course of the observing run.

2. Analysis

We analyzed our observations with the most recent version of the PHOEBE program (Prša and Zwitter 2005) which is based on the Wilson-Devinney program (WD; Wilson and Devinney 1971; Wilson 1979). The J–H value from

2MASS (Skrutskie *et al.* 2006) is 0.40 ± 0.03, which corresponds to an effective temperature of about 5600 K (Kenyon and Hartmann 1995). The B–V value from APASS is 0.78 ± 0.08, corresponding to a temperature of around 5400 K. Since the J–H and B–V values are in good agreement, we set the mean effective temperature of star 1 (the star eclipsed at primary minimum) equal to 5500 K for the light curve solution. The adjusted parameters were the orbital inclination (i), the mean effective temperature of the secondary (T2), the mass ratio (q), the modified surface potential of the common envelope (–1), the heliocentric Julian date of the primary minimum (HJD_0), the orbital period (P), the bandpass luminosity of the primary (L1), and third light (l_3). Unadjusted parameters such as the gravity darkening exponents (g_1, g_2) and bolometric albedos (A_1,A_2) were set to their theoretically expected values for convective envelopes (0.32 and 0.5, respectively). The square root limb darkening law, using the Van Hamme (1993) coefficients (x_1,x_2,y_1,y_2), gave the best fits to the light curves. We used WD mode 3, appropriate for overcontact binaries of this type. The derived parameter values are shown in Table 2. The third light values are the ratio of the third light value to the total system light at quadrature. The fit shows that the slightly deeper eclipse (by 0.01 magnitude in V) is the partial one, technically making this an A-type system, but the light curve clearly shows asymmetries and large scatter, so we cannot make that classification with high confidence. Figure 1 shows the fits to the observations.

In W UMa systems like this, there is an astrophysical interest in the temperature difference of the two components. The primary star's temperature is estimated from the observed B–V and J–H colors with an approximate error of 200 K from the observational errors of the colors. The light curve solution gives the error in T_2, given the assumed T_1 from the observed colors. Thus the true uncertainty in T_2 is similar to the uncertainty in T_1. However, the uncertainty in the temperature difference, T_2–T_1, is similar to the formal solution error in T_2 since T_1 is assumed to be fixed. To illustrate this, we re-did the light curve analysis with T_1 = 5700 K and found T_2 = 5858 K, for a temperature difference of 158 K, compared to a value of 152 K for the solution in Table 1. So, while the individual temperatures are uncertain at the level of 200 K, the uncertainty in their difference is much smaller, of order 10–20 K.

3. Conclusions

Because of its total/annular eclipses and overcontact configuration, we might expect the photometric mass ratio to be well-determined (Terrell and Wilson 2005). However, Terrell and Wilson (2005) did not consider the effect of third light on the mass ratio determination. This system shows appreciable third light, with the flux from the third body comparable to that of the secondary star at quadrature. Simulations like those of Terrell and Wilson (2005) are underway to determine how third light might affect their findings, although we do not expect it to have a large effect on the mass ratio determination. As discussed by Terrell and Wilson (2005), the photometric mass ratio for a totally eclipsing overcontact system is accurate because of the high accuracy to which the ratio of the stellar radii can be determined. Since third light affects the depths of both eclipses, rather than one or the other strongly, we do not expect the ratio of the radii to be strongly affected, and the photometric mass ratio should be reasonably accurate. The luminosity ratio in this system is, however, not so extreme as to preclude the ability to measure a spectroscopic mass ratio, so this system could have its absolute dimensions determined accurately because of the complete eclipses, even if the photometric mass ratio should prove to be inaccurate due to third light issues. A spectroscopic study of this system is sorely needed.

References

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Table 1. Colors of the variable, comparison, and check stars.

	Star	*B–V*
Variable	GSC 4552-1643	0.78 ± 0.08
Comparison	GSC 4552-0002	0.92 ± 0.08
Check	GSC 4552-0059	0.50 ± 0.06

Table 2. Parameters for the light curve solution.*

Parameter	*Value*
i	88.9 ± 0.6°
T_2	5652 ± 10 K
q	0.327 ± 0.004
Ω_1	2.435 ± 0.008
HJD_0	2452500.187 ± 0.002
P	0.2698999 ± 0.0000001 day
$L_1/(L_1+L_2)_B$	0.687 ± 0.010
$L_1/(L_1+L_2)_V$	0.697 ± 0.009
$L_1/(L_1+L_2)_I$	0.705 ± 0.009
$l_{3\ B}$	0.163 ± 0.008
$l_{3\ V}$	0.185 ± 0.007
$l_{3\ I}$	0.212 ± 0.008
A_1, A_2	0.5 (fixed)
g_1, g_2	0.32 (fixed)
x_1, y_1 (B filter)	0.77, 0.09 (fixed)
x_1, y_1 (V filter)	0.46, 0.35 (fixed)
x_1, y_1 (I filter)	0.19, 0.48 (fixed)
x_2, y_2 (B filter)	0.72, 0.14 (fixed)
x_2, y_2 (V filter)	0.43, 0.37 (fixed)
x_2, y_2 (I filter)	0.18, 0.48 (fixed)

* *The quoted errors are the formal errors from the differential corrections solution. Since the primary star's temperature is estimated from the observed B–V and J–H colors with an approximate error of 200 K; the secondary star's uncertainty in temperature is similar. The formal error is more indicative of the precision to which the solution can fit the ratio of the stellar temperatures, rather than the absolute temperatures.*

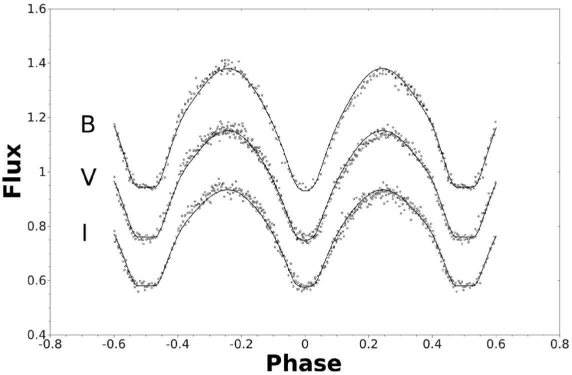

Figure 1. BVI light curves of GSC 4552-1643 and the fits from the Wilson-Devinney solution given in Table 2.