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A Photometric Study of the W UMa-type Eclipsing Binary System GSC 0445–1993 *

Yuan-Gui Yang[1,2,3], Sheng-Bang Qian[1,2] and M. D. Koppelman[4]

[1] National Astronomical Observatories /Yunnan Observatory, Chinese Academy of Sciences, Kunming 650011; *yygcn@163.com*
[2] United Laboratory of Optical Astronomy, Chinese Academy of Sciences (ULOAC), Beijing
[3] Graduate School of Chinese Academy of Sciences, Beijing 100039
[4] Starhouse Observatory, 1523 Valders Ave N, Golden Valley, MN USA

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Abstract Several new light minimum times for the eclipsing binary GSC 0445–1993 have been determined from the observations by Koppelman et al. and the orbital period of this system was revised. A photometric analysis was carried out using the 2003 version of the Wilson-Devinney code. The results reveal that GSC 0445–1993 is a W-type eclipsing binary with a mass ratio of $q = 0.323(\pm 0.002)$ and an over-contact degree of $f = 22.8\%(\pm 4.2\%)$. A small temperature difference between the components of $\Delta T = 135\,\mathrm{K}$ and an orbital inclination of $i = 65.7^\circ(\pm 0.3^\circ)$ were obtained. The asymmetry of its light curve (i.e., the O'Connell effect) for this binary star is explained by the presence of a dark spot on the more massive component.

Key words: stars: binaries: close — stars: binaries: eclipsing — star: individual: GSC 0445–1993

1 INTRODUCTION

The variable GSC 0445–1993 in the galactic cluster NGC 6633 (=NSV10892=BD+06 3809, $B_{\max} = 9.97^{\rm m}$, $V_{\max} = 9.44^{\rm m}$, spectral type G from SIMBAD database) was noted by Hilnter et al. (1958). Their observed magnitude and colors for this system are $V = 8.74^{\rm m}$, $B-V$=$+0.27^{\rm m}$ and $U-B = +0.22^{\rm m}$. However, Koppelman et al. (2002) gave the color indices $B-V = +0.65^{\rm m}$, $V - R_c = +0.32^{\rm m}$ and $V - I_c = 0.69^{\rm m}$. GSC 0445–1993 is an EW-type binary with a period of $0.375296^{\rm d}$ and an amplitude of $0.36^{\rm m}$. Now, the geometrical and physical parameters of eclipsing binaries derived from their light and velocity curves, can offer accurate physical properties

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of the star at various evolutionary stages. Therefore we have undertaken for GSC 0445–1993 a photometric analysis based on its V-band light curve and determined its photometric parameters.

2 ORBITAL PERIOD REVISED

Photometric data were obtained by Koppelman et al. (2002) from 2002 June 15 to August 7. Two comparison stars (GSC 0445–1017 and GSC 0445–1293) were used. Four primary and five secondary light minimum times were derived from the observations using a quadratic polynomial fitting method. Taş et al. (2004) published three photoelectric light minimum times in the U, B, V, and R bands. The $(O-C)_1$ values of 12 light minimum times are listed in the fourth column of Table 1 with the linear ephemeris given by Koppelman et al. (2002),

$$\mathrm{Min.I} = \mathrm{HJD}\,2452454.7107 + 0.375296 \times E\,. \tag{1}$$

A linear least-square fitting gave a new ephemeris:

$$\mathrm{Min.I} = \mathrm{HJD}\,2452798.4897(4) + 0.3753161(8) \times E\,. \tag{2}$$

The corresponding residuals $(O-C)_2$ are listed in the sixth column of Table 1.

Table 1 New Times of Light Minimum for GSC 0445–1993

HJD +2452000	Error (d)	Min.	$(O-C)_1$ (d)	Epoch	$(O-C)_2$ (d)	Ref.[a]
434.8144	0.0003	I	−0.0056	−53.0	+0.0007	[1]
441.7576	0.0002	I	−0.0054	−34.5	+0.0005	[1]
453.7658	0.0004	II	−0.0067	−2.5	−0.0014	[1]
454.7054	0.0003	I	−0.0053	+0.0	−0.0001	[1]
456.7702	0.0003	II	−0.0046	+5.5	+0.0005	[1]
463.7127	0.0018	I	−0.0051	+24.0	−0.0004	[1]
476.6600	0.0007	II	−0.0055	+58.5	−0.0015	[1]
478.7253	0.0004	I	−0.0043	+64.0	−0.0004	[1]
488.6738	0.0005	II	−0.0012	+90.5	+0.0022	[1]
795.4934	0.0004	I	+0.0139	+908.0	+0.0009	[2]
798.4949	0.0005	I	+0.0131	+916.0	−0.0001	[2]
802.4350	0.0004	II	+0.0126	+926.5	−0.0008	[2]

[a]: [1] this paper; [2] Taş et al. (2004).

3 PHOTOMETRIC ANALYSIS

Our photometric analysis of GSC 0445–1993 was carried out using the 2003 version of the Wilson-Devinney program (Wilson & Devinney 1971; Wilson 1990, 1994, 2003). We chose the observed light curve of Koppelman et al. for the photometric solution. The phases were calculated with a new revised period of 0.3753161^{d} and 1459 individual observations were combined into the 99 normal points listed in Table 2, where the number of individual observations for each

Table 2 Normal Points of V-band Observation of GSC 0445–1993

Phase	Mag.	N	Phase	Mag.	N	Phase	Mag.	N
0.0001	9.720	14	0.3305	9.401	14	0.6604	9.432	15
0.0100	9.710	15	0.3399	9.419	15	0.6701	9.415	16
0.0200	9.690	14	0.3497	9.425	16	0.6797	9.412	8
0.0299	9.684	15	0.3600	9.440	16	0.6899	9.414	9
0.0391	9.672	9	0.3702	9.457	16	0.7001	9.402	8
0.0507	9.629	12	0.3800	9.485	23	0.7097	9.392	8
0.0601	9.621	15	0.3894	9.492	16	0.7187	9.391	7
0.0702	9.591	14	0.4000	9.524	16	0.7438	9.377	2
0.0800	9.560	14	0.4101	9.541	14	0.7504	9.386	8
0.0892	9.543	11	0.4199	9.565	15	0.7598	9.395	6
0.1003	9.528	7	0.4300	9.585	15	0.7687	9.390	9
0.1099	9.510	7	0.4398	9.611	14	0.7815	9.398	5
0.1201	9.492	8	0.4508	9.630	18	0.7894	9.400	8
0.1303	9.467	7	0.4601	9.650	30	0.8002	9.404	8
0.1399	9.449	7	0.4702	9.670	26	0.8103	9.411	14
0.1501	9.443	8	0.4799	9.682	29	0.8200	9.414	15
0.1604	9.435	7	0.4901	9.694	30	0.8299	9.425	16
0.1699	9.422	7	0.5001	9.693	23	0.8400	9.439	16
0.1802	9.401	8	0.5098	9.698	25	0.8502	9.455	16
0.1904	9.393	7	0.5202	9.676	33	0.8601	9.467	15
0.2000	9.386	7	0.5302	9.670	30	0.8701	9.480	15
0.2102	9.385	8	0.5402	9.652	31	0.8796	9.491	9
0.2204	9.371	7	0.5502	9.627	39	0.8904	9.523	7
0.2300	9.358	7	0.5602	9.610	29	0.9000	9.525	7
0.2407	9.371	9	0.5697	9.579	36	0.9103	9.557	8
0.2501	9.364	15	0.5806	9.563	33	0.9205	9.568	7
0.2597	9.361	15	0.5898	9.547	35	0.9300	9.590	14
0.2702	9.360	14	0.5997	9.529	34	0.9402	9.621	16
0.2800	9.369	17	0.6101	9.507	23	0.9505	9.646	14
0.2903	9.371	8	0.6199	9.489	22	0.9601	9.678	14
0.2998	9.362	8	0.6294	9.476	21	0.9698	9.690	14
0.3093	9.384	8	0.6396	9.467	14	0.9799	9.703	15
0.3197	9.405	7	0.6497	9.448	8	0.9901	9.712	15

point was taken as the weight for the point. The light curve (magnitude versus orbital phase) is shown by the filled points in Fig. 1. The curve shows typical O'Connell effect. To quantify this effect, a parabolic least-square fitting was made around the two maxima. The result indicates that the light at phase 0.25 (Max. I) is 0.023 mag brighter than that at phase 0.75 (Max. II). The light around the eclipses varied all the time, indicating that this is a system of partial eclipses.

Starting with the assumption that the system is detached (Mode 2), the differential corrections always converged to a mode 3 solution (the contact mode). The following parameters were set fixed in the calculation: temperature for Star 1 (the more massive component eclipsed at the transit minimum), $T_1 = 5790\,\mathrm{K}$, calculated from the color index of $B-V = 0.65^{\mathrm{m}}$ (Koppelman et al. 2002) using the Flower (1996) fitting formulae; the linear limb darkening coefficients in the V-band, $x_1 = x_2 = 0.68$ (Díaz-Cordovés et al. 1995); the gravity darkening exponents, $g_1 = g_2 = 0.32$ (Lucy 1967) and the bolometric albedos, $A_1 = A_2 = 0.5$ (Rucinski 1973). The adjustable parameters are the orbital inclination, i, the mass ratio, q, the mean temperature of Star 2, T_2, the potential of the components, $\Omega_1 = \Omega_2$, and the monochromatic luminosity of Star 1, L_1. The reflection effect was computed with the detailed model of Wilson (1990). The relative brightness of Star 2, L_2, was calculated by the stellar atmosphere model.

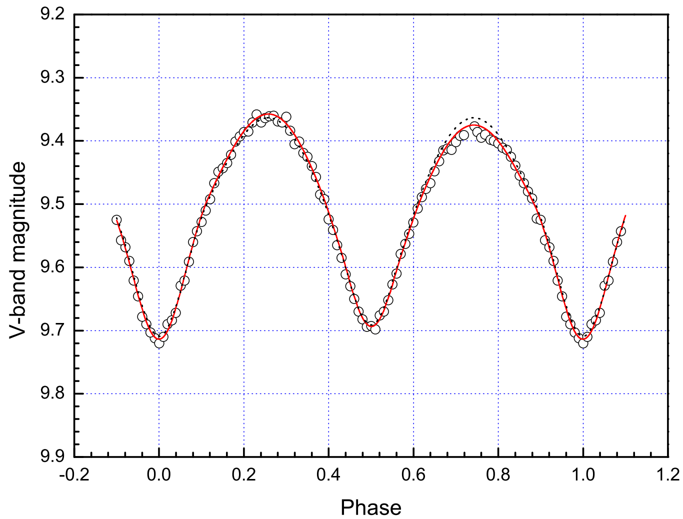

Fig. 1 V-band light curve of GSC 0445–1993. Open circles show the observations. The solid and dotted lines are the theoretical light curves, given by the spotted solution and the unspotted solution, respectively.

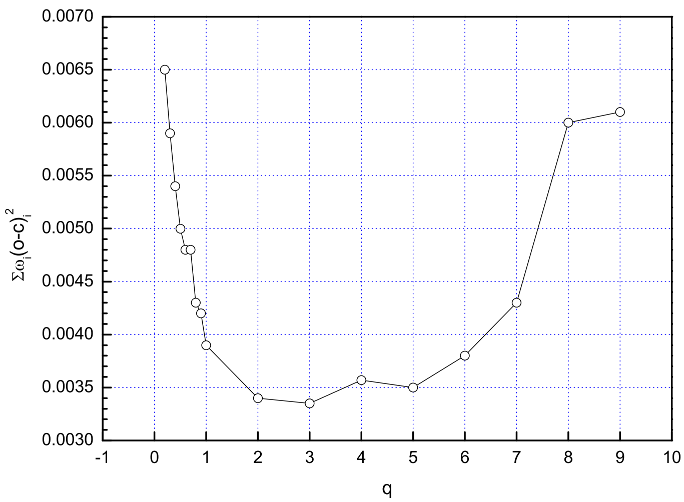

Fig. 2 Variance of the computed fit of GSC 0445–1993 as a function of the mass ratio q.

Table 3 Photometric Solutions of the Eclipsing Binary GSC 0445–1993

Parameters	Spotted Sol.	Unspotted Sol.
$i(^\circ)$	65.7($\pm$0.3)	65.1($\pm$0.3)
$g_1 = g_2$	0.32	
$A_1 = A_2$	0.5	
$\Omega_1 = \Omega_2$	2.4829($\pm$0.0086)	2.4923($\pm$0.0073)
$\Omega_{\rm in}$	2.5293	2.5388
$\Omega_{\rm out}$	2.3256	2.3325
f	22.8%($\pm$4.2%)	22.5%
T_1 (K)	5655 $\pm$ (23)	5673($\pm$22)
T_2 (K)	5790	
$q = M_2/M_1$	0.323($\pm$0.002)	0.333($\pm$0.001)
$L_1/(L_1 + L_2)$	0.7066($\pm$0.0026)	0.7086($\pm$0.0026)
r_1 (pole)	0.4581($\pm$0.0016)	0.4568($\pm$0.0010)
r_1 (side)	0.4938($\pm$0.0022)	0.4922($\pm$0.0015)
r_1 (back)	0.5230($\pm$0.0029)	0.5213($\pm$0.0026)
r_2 (pole)	0.2785($\pm$0.0021)	0.2788($\pm$0.0012)
r_2 (side)	0.2916($\pm$0.0025)	0.2918($\pm$0.0015)
r_2 (back)	0.3329($\pm$0.0047)	0.3326($\pm$0.0026)
$\phi(^\circ)$	90.1($\pm$3.2)	-
$\theta(^\circ)$	272.2($\pm$2.5)	-
$\gamma(^\circ)$	14.3($\pm$0.5)	-
T_s/T_*	0.91($\pm$0.03)	-
$\sum(\omega_i(O-C)_i^2)$	0.0017	0.0034

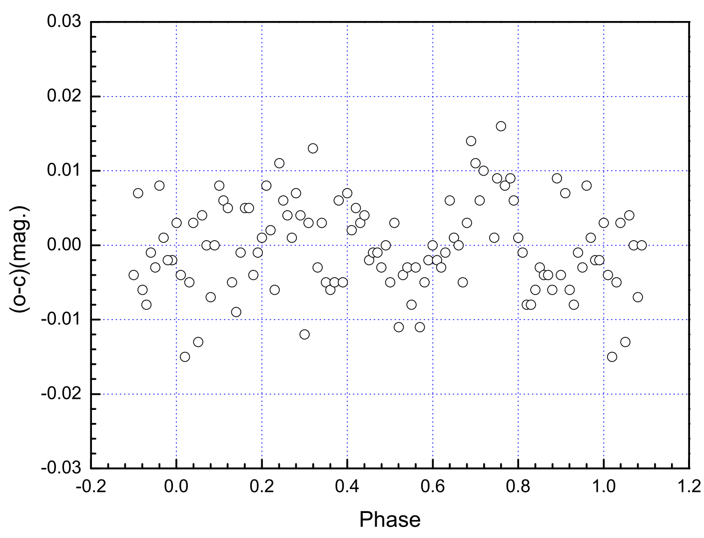

Fig. 3 Residuals $(O-C)$ of the spotted solution of GSC 0445–1993.

First we find a preliminary value of the photometric mass ratio using the grid method, i.e., solutions are obtained for a series of trial values of the mass ratio in the range 0.2–9.0. The weighted sum of the squared residuals, $\Sigma(\omega_i(O-C)_i^2)$, as a function of the trial value, is shown in Fig. 2. The curve shows a minimum at $q = 3.0$. Then q is taken as another adjustable parameter. The final solution without spots is listed in the third column of Table 3. The computed light curve is shown by the dotted line in Fig. 1. The distortion in the observed light curve may come from a cool spot on Star 2 (the more massive component). The solution with a cool spot is listed in the second column of Table 3, and the corresponding light curve is displayed by the solid line in Fig. 1. To show the quality of the solutions, the residuals $(O - C)$ are plotted against the orbital phase in Fig. 3. For about 90% of all the normal points the residuals range from −0.01mag to +0.01mag, which indicate that the spotted solution fits the observations fairly well. Therefore, the O'Connell effect for this system can be attributed to starspot activity.

4 DISCUSSION AND CONCLUSIONS

We have derived, for the first time, a photometric solution for the eclipsing binary GSC 0445–1993. It indicates that the binary could be a W-type contact system with a mass ratio of $q = 0.323(\pm 0.002)$. It is a partial-eclipsing binary star with an orbital inclination of $i = 65.7°(\pm 0.3°)$. The less massive component has a temperature up to $\Delta T = 135$K higher than the more massive one, while contributing less light. The degree of geometrical contact, defined by $f = (\Omega_{\rm in} - \Omega)/(\Omega_{\rm in} - \Omega_{\rm out})$, is 22.8%(±4.2%), meaning that the system is an overcontact binary. The observed light curve of GSC 0445–1993 is quite asymmetric: there is a marked O'Connell effect, which could be caused by a dark spot on the surface of the more massive component. We found that the observed light curve is indeed well accounted for by a photometric solution that includes the cool spot model as shown in Fig. 3. It is, of course, well-known that such spot activity appears in many W UMa binaries including UY UMa (Yang & Liu 2001), ST Ind (Zola et al. 1997), FG Hya (Qian & Yang 2004), AD Cnc (Yang & Liu 2002) and GSC 0619–0232 (Yang et al. 2005). The spot parameters of these systems are listed in Table 4. For GSC 0445–1993, the spot is up to 1.54% of the surface area of the star, a typical value. However, this paper presents only a photometric solution of the system, spectroscopic observations would be necessary for a determination of its absolute physical parameters.

Table 4 Spot Parameters of Several W UMa-type Binaries

Star	Position[a]	$\phi(°)$	$\theta(°)$	$\gamma(°)$	T_s/T_*	Spot area(%)	Ref.[b]
UY UMa	Pr.	95.6	278.9	13.3	0.84	1.34	[1]
ST Ind	Se.	95.8	261.8	18.6	0.80	2.61	[2]
FG Hya	Pr.	90.0	101.8	10.0	0.85	0.76	[3]
AD Cnc	Pr.	80.8	284.2	9.5	0.91	0.69	[4]
GSC 0619–0232	Pr.	88.8	267.5	14.9	0.86	1.68	[5]
GSC 0445–1993	Pr.	90.1	272.2	14.3	0.91	1.54	[6]

[a]: Pr. and Se. refer to the more massive component and the less massive one.
[b]: [1] Yang & Liu (2001); [2] Zola et al. (1997); [3] Qian & Yang (2004); [4] Yang & Liu (2002); [5] Yang et al. (in press); [6] this paper.

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References

Díaz-Cordovés J., Claret A., Giménez A., 1995, A&AS, 110, 329

Flower P. J., 1996, ApJ, 469, 355

Hiltner W. A., Iriarte B., Johnson H. L., 1958, ApJ, 127, 539

Koppelman M. D., West D., Price A., 2002, IBVS, 5327

Lucy L. B., 1967, Z. Astrophysics, 65, 89

Qian S.-B., Yang Y.-G., 2004, MNRAS, 356, 765

Rucinski S. M., 1973, Acta Astro., 23, 79

Taş G., Sipahi E., Dal H. A. et al., 2004, IBVS, 5548

Wilson R. E., 1990, ApJ, 356, 613

Wilson R. E., 1994, PASP, 106, 921

Wilson R. E., Devinney E. J., 1971, ApJ, 166, 605

Wilson R. E., Van Hamme W., 2003, Computing Binary Stars Observables

Yang Y.-L., Liu Q.-Y., Leung K.-C., 2001, A&A, 370, 507

Yang Y.-L., Liu Q.-Y., 2002, Chin. J. Astron. Astrophys., 2, 369

Yang Y.-G., Qian S.-B., Gonzlez-Rojas D. J. et al., 2005, Ap&SS, in press

Zola S., Kolonko M., Szczech M., 1997, A&A, 324, 1010