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A photometric study of contact binaries V3 and V4 in NGC 2539

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Abstract. CCD photometric observations of the eclipsing contact binaries (EW type) V3 and V4 of the cluster NGC 2539 were made in the B and V bands using the 2m telescope at the IUCAA-Girawali Observatory in India. The light curves have been obtained and using the Wilson-Devinney code, the combined photometric solutions have been presented here. The photometric solutions have revealed that both V3 and V4 are W-type contact binary systems with mass ratios of 0.806 and 1.001 respectively. Revised orbital periods, absolute masses and radii of the components have been obtained. New ephemerides indicate that the orbital periods of the variables have not changed much during the time span of the observations from 2003 to 2009. The estimated absolute parameters for the two variables V3 and V4 are in close agreement with the field EW-type binaries (Gazeas & Stepien 2008). The distance estimate for V3 is 1712±48pc indicating that this could be a field star in the background of the cluster, while that for V4 is 1183±32pc, suggesting it to be a possible member of the cluster. No third light is found in the systems.

Keywords : stars: binaries: eclipsing – stars: binaries: general – stars: distances – open clusters and associations: general

1. Introduction

NGC 2539 (IAU designation $C0808 - 126$; $l = 233^{\circ}.7, b = +11^{\circ}.1$; Trumpler class II-1m) is an intermediate sparse open cluster towards the south of the constellation Puppis. Pesch (1961) obtained photoelectric UBV data for 59 stars in the cluster field and derived a mean colour excess $E(B - V) = 0.10$ mag, distance modulus $V_o - M_v = 10.5 \pm 0.5$, corresponding to a distance,

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d=1290±290pc. Becker & Fenkart (1971) re-analysed Pesch's data and found a true distance modulus $V_o - M_v = 10.60$ which corresponds to a distance of 1320pc. Joshi & Sagar (1986) obtained UBV photometry of 88 stars in the region of NGC 2539 and derived the following parameters: $E(B - V) = 0.08 \pm 0.02$, distance 1050 ± 150pc and the age of the cluster to be 540 Myr. Clariá & Lapasset (1986) determined the following cluster parameters: mean reddening $E(B - V) = 0.08 \pm 0.02$, distance modulus $V_o - M_v = 9.8 \pm 0.5$ ($d = 910 \pm 210$pc) and age of 640 ± 80Myr. Later Clariá, Lapasset & Minniti (1989) deduced the metallicity $[Fe/H] = 0.03 \pm 0.09$, by studying the red giants and found it to be of solar type. Lapasset, Clariá & Mermilliod (2000) found 169 stars brighter than V=15.0 to be probable members of the cluster with a mean reddening E(B-V)=0.06 and a true distance modulus $V_o - M_v = 10.42$ ($d = 1210$pc). They derived an age of 630 Myr by using the main sequence fitting method by theoretical isochrones. Choo et al. (2003) observed the cluster in Johnson UBV and Cousins I bands and discovered seven new variables. They classified the variables V3 to V7 as eclipsing contact binaries (EW type).

W UMa over-contact binaries are divided into two categories A and W types. As per Binnendijk (1970), the A-type systems are found among the more massive stars of earlier spectral type (A-F) with longer periods, and in these systems the deeper minimum is a transit - i.e., the smaller star has a relatively lower surface temperature. The W-type systems are found among the less massive systems of later spectral type (G-K) with shorter periods, and in these W-type systems the deeper minimum is an occultation - that is, the smaller star has a relatively higher surface temperature. As per Hobart, Peña & de la Cruz (1998), the mass ratios q ($=m_2/m_1$) is rather small for the A-type systems; they are usually < 0.4 and extend to very small values of 0.07 for AW UMa. Mochnacki (1985) found a well-defined period-colour relation, with the redder W-type systems having the shorter periods (0.22-0.40 d), while the bluer A-types have longer periods (0.4-0.8 d). There are several unanswered questions regarding the evolution of contact binaries like: i) what are the initial conditions in particular masses and separation that leads to the evolutionary scenarios of A and W type binaries, ii) is there an evolutionary link between them and iii) do both A and W type evolve in their own way from the formation of contact configuration to a probable merging of both components into a single rapidly rotating star? Large number of contact binaries are discovered in open and globular clusters (Rucinksi 1998, 2000 and references therein). The observation of binaries in an open cluster provides us an important astrophysical tool to estimate the distance to the cluster and various evolutionary phases of the binaries itself. Rucinski (1993) found that the relative frequencies of occurrence seem to be much higher than the field stars, indicating action of multi-body collision processes, possibly intertwined with nuclear and angular momentum evolution of individual components.

We note that no attempts were made to obtain the light curve solutions of EW variables in NGC 2539, and hence we carried out an observation campaign in B and V bands on this cluster. The short period EW variable stars that we could find in the frame of $10' \times 10'$ are V3 and V4. The aim of the present paper is to derive the photometric elements of the selected two W UMa systems V3 and V4 using the W-D Code (version 2003) and compare these with binaries studied earlier.

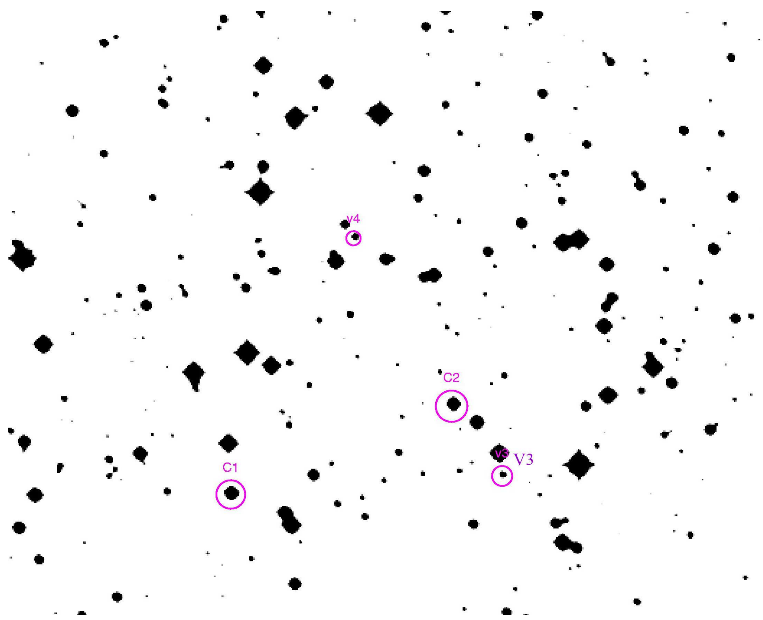

Figure 1. The variable stars V3 and V4, comparison star (C1) and check star (C2) are shown in the field.

2. Observations and data reduction

The observations of open cluster NGC 2539 were carried out at the IUCAA-Girawali Observatory (IGO) using the 2m telescope. The description of the telescope and its backend instruments and their capabilities are described in Das et al. (1999) and Gupta et al. (2002). The observations in B and V bands were carried out on four nights, during 2010 February 06 – 09. Considering the magnitude range during the observations, the exposure time was set to 360s in B band and 180s in V band. The observations were taken with the field centered at $\alpha_{J2000} = 08^h 10^m, \delta_{J2000} = -12°50'$ as shown in Fig. 1. For the selection of comparison star (C1) and the check star (C2), we chose several stars which are relatively bright. It was found that the magnitude of C1 was constant. The coordinates of the variable stars, C1 and C2 are given in Table 1. The cluster was observed at various air-mass values ranging from 1.1-2.0. In total, we obtained 111 frames in B band and 102 frames in V band. Due to the variations in the sky conditions, we could not do the transformation of the magnitudes.

In Tables 2 and 3, we list the time of observations in HJD and the differential magnitudes of the variable stars (ΔV3 and ΔV4 in B and V bands). The reduction procedures adopted for deriving the magnitudes are described in Sriram & Vivekananda Rao (2010). The probable errors obtained for the two variables are ±0.008 mag in B band and ±0.006 mag in V band. The times of minima (Table 4) were determined from the data using the method given by Kwee & van Woerden (1956). The revised epoch and period of each variable studied in the present work are

Table 1. The co-ordinates of the variable stars, comparison star (C1) and check star (C2).

Star	α(J2000)	δ(J2000)
V3	$08^h10^m46^s$	$-12°53'14''$
V4	$08^h10^m39^s$	$-12°50'18''$
Comp. star	$08^h10^m33^s$	$-12°53'28''$
Check star	$08^h10^m44^s$	$-12°52'24''$

derived by using the epoch and period given in Choo et al. (2003). Table 5 shows the result of the new epochs and periods. Using the new epoch and period, the eclipse timing residuals are calculated. It is found that the eclipse timing residuals do not show any significant variation, indicating that the period has remained constant during the years 2003 to 2009 for the observed binaries. However, since our observations span only for 4 days, our determined periods do not differ from that of Choo et al. (2003). The phases for obtaining the light curves are calculated using the relationship given by Deb et al. (2010).

3. Photometric solutions

In our study, we consider component 1 as high temperature (primary) star and component 2 as low temperature (secondary) star. The light curves were analysed using the 2003 version of the Wilson-Devinney code (Wilson & Devinney 1971; Wilson 1979, 1990; van Hamme & Wilson 2003; Wilson et al. 2010). Initially we started the analysis with mode 2 which is for the detached systems. Since this mode did not yield a converged solution, we adopted mode 3 which is for overcontact binaries. Tables 2 and 3 of Choo et al. (2003) give the colours of the variables V3=0^m.739 and V4=0^m.749. The reddening value E(B−V) is taken as 0.08±0.03 by averaging the values obtained by Pesch (1961), Clariá & Lapasset (1986), Joshi & Sagar (1986), Lapasset et al. (2000) and Choo et al. (2003). From these we obtained the dereddened colour $(B\text{-}V)_o$ for the two variables V3=0.659±0.03 and V4=0.669±0.03. The effective temperature of the primary component T_1 was obtained using the tables given in Cox (2000) and it is kept as a fixed parameter. The initial value for the effective temperature of the secondary component T_2 was assumed to be slightly less than the T_1. Because of the convective nature of heat transportation in envelopes, the gravity darkening exponents for the system were taken as $g_1 = g_2 = 0.32$ (Lucy 1967). The rotation and revolution for the variable was assumed to be synchronized, hence we chose the rotation parameter (ratio of the angular rotation to the synchronous rate) $F1 = F2 = 1$. Assuming the circular orbits, the eccentricity e was fixed at 0. From Rucinski (1969), the values of the bolometric albedo $A_1 = A_2$ were fixed at 0.5. The wavelengths assumed were 4455Å and 5497Å for B and V bands respectively The limb-darkening coefficients were taken as $x_1 = x_2 = 0.610$ for B band and $x_1 = x_2 = 0.549$ for V band. The y_1 and y_2 coefficients were 0.072 for B band and 0.180 for V band (van Hamme 1993). The adopted adjustable parameters are: the orbital inclination i, the temperature of secondary component T_2, the dimensionless potential of the primary star Ω_1 and the monochromatic luminosity of the primary star L_1.

Since no spectroscopic observations are available for both the variables, we used the grid

Table 2. B-band CCD observations of variables V3 and V4 of NGC 2539.

H.J.D 2455200+	ΔV3 mag	ΔV4 mag	H.J.D 2455200+	ΔV3 mag	ΔV4 mag	H.J.D 2455200+	ΔV3 mag	ΔV4 mag
34.25830	3.745	2.462	35.32009	3.532	2.525	36.39021	3.735	2.773
34.26455	3.685	2.460	35.30828	3.564	2.496	36.38882	3.727	2.772
34.27913	3.593	2.473	35.32564	3.529	2.545	36.39438	3.764	2.768
34.28469	3.566	2.484	35.33120	3.537	2.574	36.39577	3.772	2.763
34.29163	3.541	2.497	35.33259	3.539	2.576	37.13395	3.861	2.481
34.29719	3.532	2.521	35.36870	3.756	2.771	37.14297	3.922	2.466
34.33677	3.668	2.732	35.37425	3.795	2.760	37.14436	3.928	2.464
34.34163	3.696	2.748	35.37981	3.847	2.743	37.15686	3.901	2.463
34.34371	3.707	2.755	35.38120	3.856	2.741	37.15825	3.894	2.462
34.35066	3.761	2.771	35.39370	3.932	2.648	37.16797	3.819	2.470
34.36108	3.836	2.729	35.39648	3.936	2.630	37.16936	3.806	2.478
34.36663	3.867	2.707	35.40481	3.911	2.580	37.18325	3.693	2.513
34.37983	3.881	2.615	35.40620	3.897	2.574	37.18464	3.683	2.512
34.38121	3.873	2.596	36.12633	3.888	2.462	37.19436	3.615	2.542
34.38399	3.864	2.590	36.12771	3.887	2.461	37.19575	3.607	2.545
34.39649	3.781	2.532	36.13744	3.848	2.463	37.25408	3.662	2.681
34.40135	3.744	2.519	36.13883	3.843	2.468	37.25547	3.663	2.679
34.40274	3.736	2.515	36.15758	3.715	2.493	37.26450	3.722	2.624
34.40482	3.719	2.507	36.15896	3.707	2.492	37.26589	3.734	2.620
35.12218	3.838	2.464	36.16799	3.645	2.521	37.27769	3.813	2.558
35.12843	3.782	2.475	36.16938	3.637	2.526	37.27908	3.826	2.551
35.12981	3.769	2.478	36.27077	3.931	2.516	37.28881	3.878	2.523
35.21037	3.653	2.704	36.27216	3.933	2.515	37.29019	3.883	2.522
35.21176	3.661	2.698	36.28118	3.902	2.489	37.30200	3.871	2.489
35.21315	3.671	2.690	36.28257	3.893	2.486	37.31380	3.793	2.463
35.22565	3.757	2.626	36.29438	3.798	2.463	37.31519	3.784	2.464
35.22703	3.766	2.613	36.29577	3.789	2.466	37.32978	3.684	2.461
35.22842	3.774	2.598	36.30480	3.714	2.460	37.33117	3.674	2.462
35.24509	3.875	2.538	36.30618	3.702	2.461	37.34089	3.609	2.476
35.24648	3.886	2.532	36.33674	3.537	2.511	37.34228	3.604	2.478
35.24787	3.885	2.527	36.33813	3.535	2.525	37.35408	3.551	2.512
35.26176	3.853	2.487	36.34716	3.532	2.549	37.35547	3.549	2.508
35.26315	3.842	2.481	36.34854	3.533	2.564	37.36519	3.529	2.553
35.26453	3.833	2.483	36.36035	3.558	2.622	37.36658	3.531	2.548
35.29578	3.626	2.468	36.36174	3.566	2.635	37.39158	3.608	2.704
35.30134	3.593	2.478	36.37146	3.614	2.700	37.39297	3.616	2.706
35.30689	3.572	2.489	36.37285	3.623	2.706			

Table 3. V-band CCD observations of variables V3 and V4 of NGC 2539.

H.J.D 2455200+	ΔV3 mag	ΔV4 mag	H.J.D 2455200+	ΔV3 mag	ΔV4 mag	H.J.D 2455200+	ΔV3 mag	ΔV4 mag
34.27566	2.959	1.801	35.33676	2.891	1.921	36.40479	3.173	2.036
34.27705	2.953	1.802	35.33814	2.897	1.937	36.40618	3.187	2.026
34.28677	2.899	1.820	35.38328	3.216	2.049	36.40757	3.194	2.018
34.29024	2.885	1.829	35.38467	3.222	2.043	37.14714	3.265	1.795
34.32288	2.919	1.967	35.38606	3.236	2.033	37.14853	3.267	1.794
34.32427	2.924	1.970	35.38953	3.257	2.004	37.15061	3.271	1.794
34.32774	2.946	1.984	35.40759	3.227	1.895	37.15200	3.260	1.793
34.33052	2.958	2.014	35.40898	3.220	1.891	37.17145	3.131	1.812
34.34719	3.079	2.093	35.41037	3.211	1.885	37.17284	3.121	1.814
34.34858	3.086	2.098	36.14091	3.176	1.797	37.17978	3.051	1.829
34.35205	3.112	2.096	36.14230	3.161	1.795	37.18117	3.066	1.834
34.35552	3.138	2.087	36.14994	3.117	1.808	37.19714	2.927	1.878
34.38260	3.207	1.926	36.15133	3.111	1.809	37.19853	2.943	1.881
34.38746	3.188	1.898	36.17285	2.956	1.860	37.20408	2.909	1.904
34.39094	3.163	1.883	36.17424	2.948	1.868	37.20547	2.893	1.909
35.15829	2.921	1.878	36.18119	2.906	1.889	37.26797	3.097	1.929
35.16245	2.898	1.889	36.18258	2.902	1.894	37.26936	3.107	1.924
35.16384	2.889	1.901	36.28466	3.213	1.812	37.27492	3.144	1.895
35.16523	2.887	1.906	36.28605	3.203	1.810	37.27631	3.152	1.893
35.23051	3.132	1.919	36.28743	3.192	1.809	37.29158	3.219	1.845
35.23190	3.144	1.915	36.28882	3.184	1.806	37.29297	3.223	1.842
35.23328	3.159	1.908	36.30827	3.025	1.794	37.29853	3.223	1.828
35.23467	3.165	1.901	36.30966	3.018	1.795	37.29992	3.210	1.824
35.23606	3.171	1.898	36.31105	3.003	1.797	37.31728	3.101	1.794
35.23745	3.181	1.892	36.31243	2.991	1.798	37.31867	3.101	1.794
35.26453	3.169	1.813	36.35063	2.868	1.895	37.32700	3.044	1.795
35.26662	3.154	1.810	36.35202	2.867	1.902	37.32839	3.031	1.795
35.26801	3.149	1.808	36.35341	2.874	1.907	37.34436	2.930	1.818
35.26940	3.137	1.807	36.35479	2.876	1.914	37.34575	2.912	1.824
35.31037	2.892	1.826	36.37493	2.964	2.049	37.35061	2.901	1.833
35.31176	2.881	1.833	36.37632	2.969	2.057	37.35200	2.894	1.837
35.31314	2.877	1.839	36.37771	2.986	2.061	37.38741	2.924	1.993
35.31662	2.873	1.849	36.37910	2.995	2.066	37.38880	2.929	2.006
35.33537	2.886	1.915	36.40340	3.159	2.044	37.40269	3.020	2.088

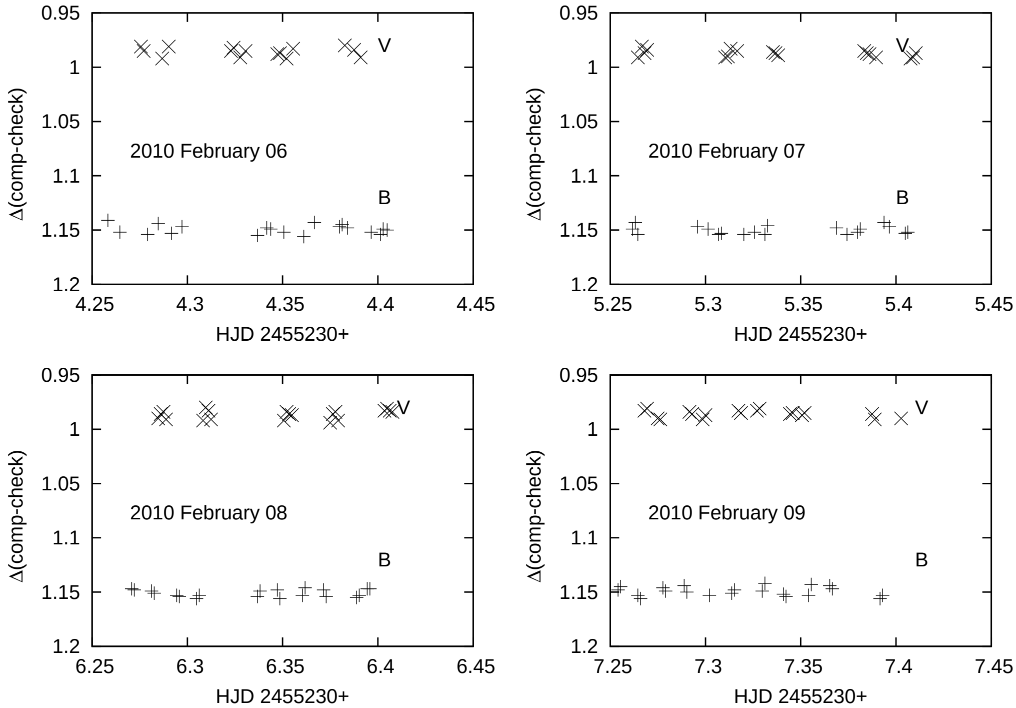

Figure 2. The four panels show the magnitude differences between the comparison and check stars versus HJD for observations for four nights.

Table 4. CCD times of light minima for the observed variables V3 and V4 of NGC 2539.

Variable	J.D. Hel.	Min[a].	E	(O-C)	Reference
V3	2451591.025	I	0	0	Choo et al. (2003)
	2455234.374	II	12481.5	−0.00115	The present study
	2455235.251	II	12484.5	0.00045	The present study
	2455235.397	I	12485	0.0007	The present study
	2455236.272	I	12488	−0.0003	The present study
	2455237.149	I	12491	0.0011	The present study
	2455237.298	II	12491.5	0.00415	The present study
V4	2451596.060	I	0	0	Choo et al. (2003)
	2455234.351	I	10704	0.0011	The present study
	2455235.196	II	10706.5	−0.00305	The present study
	2455235.369	I	10707	−0.0005	The present study
	2455236.389	I	10710	−0.0002	The present study

[a]I Primary II Secondary

Table 5. New epoch and period of variables V3 and V4.

Variable	Epoch (JD Hel.)	Period (days)
V3	2455235.3972(23)	0.2919997(35)
V4	2455235.3692(42)	0.3399994(36)

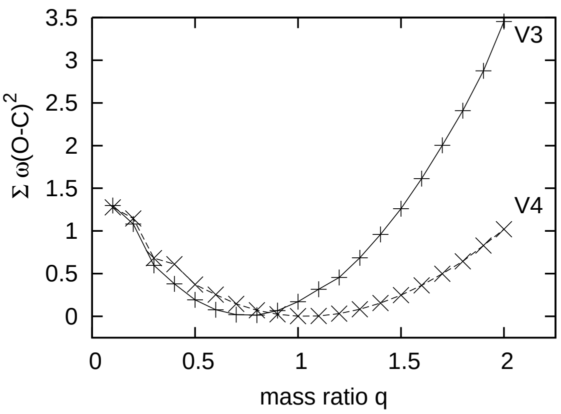

Figure 3. Sum of the squares $\sum \omega(O-C)^2$ as a function of mass ratio q for variables V3 and V4.

search method to constrain the most important parameter the mass ratio q ($=m_2/m_1$). In order to find the best value of the mass ratio, we executed the differential code (DC) for various assumed values of mass ratio (from 0.1−2.0 with a stepwise increase of 0.1), simultaneously changing the corresponding values of the surface potential ($\Omega_1 = \Omega_2$). The resulting sum $\sum \omega(O-C)^2$, of the weighted square deviations of the converged solutions for each value of q are given in Table 6 and shown in Fig. 3. Finally we executed the program, freeing the parameter mass ratio q along with other free parameters viz. inclination i, secondary component temperature T_2, surface potential Ω_1 and monochromatic luminosity of the primary component L_1. The results of the final analysis are shown in Table 7. The uncertainties of the values are the standard errors. Applying these parameters in the LC code, the theoretical light curves were computed and plotted in Fig. 4.

Table 6. Obtained values of q and $\sum \omega(O-C)^2$ for variables V3 and V4.

q	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
V3: $\sum \omega(O-C)^2$	1.299	1.082	0.596	0.380	0.194	0.077	0.019	0.014	0.067	0.171
V4: $\sum \omega(O-C)^2$	1.276	1.147	0.682	0.611	0.372	0.255	0.146	0.071	0.024	0.002
q	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
V3: $\sum \omega(O-C)^2$	0.318	0.455	0.686	0.959	1.261	1.614	2.003	2.409	2.876	3.452
V4: $\sum \omega(O-C)^2$	0.005	0.032	0.082	0.155	0.249	0.363	0.498	0.645	0.830	1.021

Initially the temperature T_1 is fixed at 5625 K for V3 and 5600 K for V4 and the values for

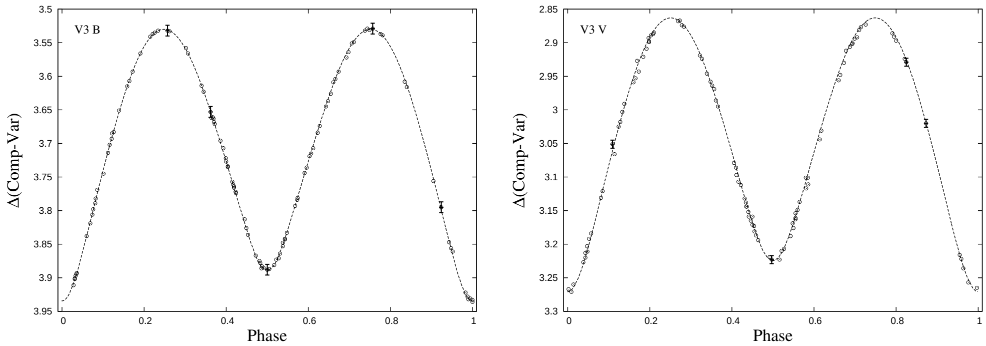

Figure 4. Best fit in the B and V bands light curves for variable V3. The points represent the observed data and lines represent the best fits. Error bars are shown for a few data points in each panel.

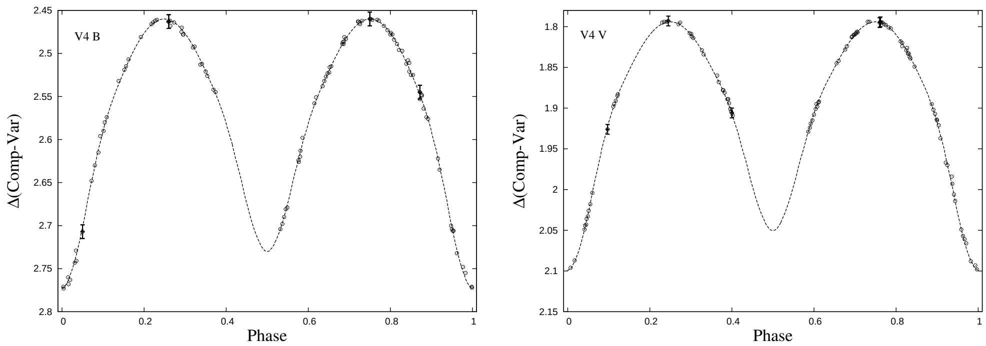

Figure 5. Best fit in the B and V bands light curves for variable V4. The points represent the observed data and lines represent the best fits. Error bars are shown for a few data points in each panel.

parameters T_2, i , q, Ω, L_{1B}, L_{1V} etc were obtained. Since $(B-V)_o$ has an error of ±0.03, the value of fixed parameter T_1 also would have an error of ±100 K. If we vary the temperature of T_1 by 100 K and keep it fixed at 5725 K and 5525 K for variable V3, the corresponding changes in the other parameters is very small and within the standard errors. Similar results for the variable V4 were obtained when we kept the temperature T_1 fixed at 5700 K and 5500 K.

For the two variables V3 and V4, the absolute magnitude M_v is obtained from the relation $M_v=-4.44\log P+3.02(B\text{-}V)_o+0.12$ (Rucinski & Duerbeck 1997). The apparent magnitude m is taken as 15.652 for V3 and 14.584 for V4 with an error of 0.043 (Choo et al. 2003). Applying the error propagation formula over the distance modulus equation $m-M_v=5\log d-5$, the distance d is derived. The results of each of the systems are discussed below:

3.1 Variable V3

The mean depths of the primary and secondary minima are not equal and the effective temperatures of the two components show a difference of $\triangle T = 230K$. The best combination of q and i is 0.806 and 62°.60 respectively. The fill out factor of 0.187 shows that the contact is low. The period of this system is $0^d.292$ and the dereddened colour $(B-V)_o$=0.659±0.03. The M_v, m−M_v and the distance d derived for the variable V3 are 4.484±0.09, 11.168±0.10 and 1712±48pc respectively.

3.2 Variable V4

The mean depths of the primary and secondary minima are not equal and the effective temperatures of the two components show a difference of $\triangle T = 200K$. The best combination of q and i is 1.001 and 62°.11 respectively. The fill out factor of 0.226 shows that the contact is low. The period of this system is $0^d.340$ and the dereddened colour $(B-V)_o$=0.669±0.03. The M_v, m−M_v and the distance d derived for the variable V4 are 4.221±0.09, 10.363±0.10 and 1183±32pc respectively.

4. Discussion

Based on a good quality sample of 112 contact binaries, Gazeas & Stepien (2008) found a strong correlation between Primary component (M, R, L) i.e. mass, radius, luminosity and the orbital period (P) resulting in three empirical relations. Later Gazeas (2009) extended this study to obtain a three dimensional correlation among (M,R,L) of primary's, period and mass ratio with an error less than 5%. We obtained the masses and radii of the components using the equations given by Gazeas (2009). Since the physical parameters of WUMa type contact binaries obey the basic relations resulting from the Roche lobe, using the Kepler's equations and the expression for orbital angular momentum (Gazeas & Stepien 2008) we obtained a and H. These are listed in Table 8 and the uncertainties of the values are the standard errors. We find that these do not show large discrepancies with respect to field contact binaries (Gazeas & Stepien 2008).

Based on high mass ratios of V3 and V4 they can be classified as W-type W UMa systems. In general, for A-type contact binaries the mass ratio values are often found to be low (Gazeas & Stepien 2008). The mass ratio close to unity derived for V4 (q = 1.001) is rare for W UMa type binary. However, so far only one field W UMa type binary V803 Aql has been found with mass ratio equal to unity (Samec, Su & Dewitt 1993), but some hot overcontact binaries (not W UMa's) have unit mass ratios. The discovery of more number of W UMa systems with mass ratio close to unity can help us in understanding the evolution of contact binaries. In such cases, two evolved components have almost the same masses and radii and therefore little mass exchange. If both the components can evolve into the sub-giant stage, the system will merge directly into a single star.

Table 7. Photometric elements obtained for the variables V3 and V4 by using the W-D method.

Element		$V3_B$	$V3_V$	$V3_{combined}$	$V4_B$	$V4_V$	$V4_{combined}$
Period (days)		0.2919	0.2919	0.2919	0.3399	0.3399	0.3399
$T_1{}^a$ K		5625	5625	5625	5600	5600	5600
T_2 K		5369±69	5375±63	5394±74	5383±78	5407±75	5398±79
q (= m_2/m_1)		0.787±0.006	0.812±0.006	0.806± 0.006	0.988±0.008	0.998±0.005	1.001±0.005
i°		61.02±0.57	62.12±0.23	62.60±0.19	62.15±0.17	62.21±0.15	62.11±0.11
Ω		3.122±0.021	3.219±0.011	3.201±0.010	3.738±0.013	3.759±0.007	3.761±0.008
fill out factor		0.182	0.185	0.187	0.211	0.223	0.226
r_1	pole	0.4282±0.004	0.3973±0.002	0.3994±0.002	0.3836±0.002	0.3829±0.001	0.3835±0.001
	side	0.4649±0.004	0.4232 ±0.002	0.4260±0.002	0.4029±0.002	0.4021±0.001	0.4025±0.001
	back	0.5375±0.011	0.4658±0.004	0.4700±0.004	0.4355±0.003	0.4344± 0.002	0.4351±0.002
r_2	pole	0.3922±0.004	0.3603±0.002	0.3625±0.002	0.3836±0.002	0.3829±0.001	0.3835±0.001
	side	0.4236±0.005	0.3874±0.002	0.3846±0.003	0.4029±0.002	0.4021±0.001	0.4025±0.001
	back	0.5121±0.015	0.4285±0.004	0.4332±0.005	0.4355±0.003	0.4344± 0.002	0.4351±0.002
$\frac{L_1}{L_1+L_2}B$		0.6080±0.013	-	0.6142±0.014	0.5680±0.034	-	0.5590±0.023
$\frac{L_2}{L_1+L_2}B$		0.3920	-	0.3858	0.4320	-	0.4510
$\frac{L_1}{L_1+L_2}V$		-	0.5856±0.013	0.6155±0.023	-	0.5689±0.034	0.5493±0.023
$\frac{L_2}{L_1+L_2}V$		-	0.4144	0.3845	-	0.4311	0.4507
Spectral type		F9	F9	F9	G0	G0	G0

[a] Fixed parameters

Table 8. Estimated absolute elements for variables V3 and V4 of NGC 2539.

Parameter	V3	V4
$M_1(M_\odot)$	0.968±0.022	1.060±0.033
$M_2(M_\odot)$	0.778±0.011	1.061±0.011
$a(au)$	1.541±0.027	1.598±0.041
$H_{orb}\,(cgs\,units)$	5.37 $\times 10^{51}$	7.62 $\times 10^{51}$
$R_1(R_\odot)$	0.891±0.008	0.996±0.011
$R_2(R_\odot)$	0.813±0.011	0.996±0.011

Our solutions show that both the variables have high end mass ratio values with a slight difference, temperature of the respective primary and secondary components were found to be same. The period of the variable V3 and V4 are different which is a measure of angular momentum in the respective systems. Primarily the period and slight difference in the mass ratio values of V3 and V4 suggest that the variables are at different stages of Thermal Relaxation Oscillation (TRO) cycle. This could be due to the fact that the TRO primary driving parameter is the mass/energy transfer from one component to another. Assuming conservation of mass and angular momentum, TRO models (Lucy 1976; Flannery 1976; Robertson & Eggleton 1977) predicted oscillation between semi-detached and slightly overcontact configurations. In the contact stage, the direction of mass transfer is opposite to that of the energy transfer and causes a rapid increase in separation. The system then reaches a configuration with the primary filling its lobe and transferring material to the secondary. Qian (2001) studied overcontact binaries and found that there exist a critical mass ratio (q = 0.4) where period increase (q>0.4) or decrease (q<0.4) occurs. However, the sample was small and hence this kind of study should be extended to other contact binaries to know the real dependency of mass ratio and period change. Our study shows that both the variables have mass ratio > 0.4 and should have period increase trend. Incidentally, no such trend has been observed in these variables during the interval 2003-2009.

The photometric mass ratios of variables in Be 33, NGC 6791, Be 39 and NGC 7789 suggest that most of them are W-type with mass ratio q >1 or intermediate mass ratio values (q~0.4−0.7), independent of the respective cluster age (Rukmini & Vivekananda Rao 2002; Rukmini, Vivekananda Rao & Sriram 2005; Sriram, Ravi Kiron & Vivekananda Rao 2009; Sriram & Vivekananda Rao 2010). This work along with our previous ones suggests that the frequency of W-type systems exceeds the frequency of A-type in clusters. Gazeas & Stepien (2008) showed that contact binaries with periods 0.5−0.7d have an age of about 5−6 Gyr, but the variables V3 and V4 have much shorter periods which probably are members of the cluster of young age (~0.6 Gyr).

Future photometric and spectroscopic observations would be useful to know the possible period changes and constrain the mass ratio of member variables and also would be important for understanding the evolutionary status of these systems.

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