Astron. Astrophys. 346, 437–440 (1999)

ASTRONOMY AND ASTROPHYSICS

The EB-type contact binary system BV Eridani

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Received 8 August 1997 / Accepted 1 September 1998

Abstract. Two sets of available photoelectric photometric observational data of the close binary system BV Eri were analyzed with the recent Wilson-Devinney synthetic light curve program. The new absolute parameters of the system were also derived by combining the photometric solutions with the spectroscopic material. The research suggests that BV Eri is a B-type contact binary system, and mass from the primary component is transferring to the secondary component. It may be concluded that BV Eri is a good example following the TRO theory.

Key words: binaries: close – stars: individual: BV Eri

1. Introduction

BV Eri was discovered to be an eclipsing binary by Hoffmeister(1933). The first photoelectric photometric observation of the system was carried out by Baade et al. in 1976 and 1977(Baade et al. 1979). Later, they performed the spectroscopic observations for BV Eri, and published an analysis of photometric light curves and a spectroscopic orbit(Baade et al. 1983). An obvious asymmetry in light curves was found in their photometric observations. In their spectroscopic observations, the spectral lines of the secondary component were not seen. In order to avoid that the asymmetry of the light curve should affect the analysis, they excluded observational data near 2nd Maximum from the light curve analysis. Therefore, their analysis cannot totally reflect all aspects of the system. The theoretical light curves based on their photometric solution do not fit their observational data well, especially on either side of the primary eclipse. Their result had suggested that BV Eri is a semi-detached system in which the secondary component fills its Roche lobe and the primary one is near to it. They thought that BV Eri was experiencing mass reversal during its evolution. In 1986, Yamasaki et al. studied BV Eri from a point of view of evolution, and found it important to binary evolution research.

Because there is no appropriate analysis for BV Eri up to now, we decided to investigate BV Eri again in order to get a better understanding about BV Eri. Our research work is based on both the observation published by ourselves(Gu et al. 1994) and the one by Baade et al.

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2. Light curve analysis

First, we analyzed our own observational data. Our observations have been combined into 55 normal points in the B band and 57 in the V band, respectively. By means of Wilson-Devinney's synthetic light curve program(Wilson & Devinney 1971; Wilson 1992), we have analyzed two normal light curves. System parameters were adopted as follows: based on the spectral type F2 of BV Eri, we let the temperature of the primary component T_1=6850K according to Eaton & Poe's(1984) calibration. A standard gravity-darkening coefficient of $g_1=g_2=0.32$ and a bolometric albedo of $A_1=A_2=0.5$ were adopted. According to Claret & Gimenez's(1990) and Wade & Rucinski's(1985) tables, we assumed a limb-darkening coefficient of $x_{1B}=x_{2B}=0.6$ and $x_{1V}=x_{2V}=0.5$. Because BV Eri is a single-spectrum spectroscopic binary system, no spectroscopic mass ratio is available. Therefore, we had to use the photometric method to determine the mass ratio of the system. Since the secondary eclipse is total, a mass ratio $q(m_2/m_1) > 1$ can be excluded. First, we fixed the mass ratio at 0.2, 0.25, 0.3, 0.35, 0.4, 0.5, 0.7, 0.9, respectively. Using the DC program of Wilson-Devinney, we carried out the differential correction calculation which started from mode 2 (detached mode) for each adopted mass ratio. The fitting residue $\sum W_i(O-C)_i^2$ of the best solution for each mass ratio is displayed in Fig. 1 where the final mode for each mass ratio was also marked. From the $\sum$-q relation curve, we may see that the residue $\sum$ is smallest when q equals 0.25, and the corresponding mode is mode 3 (contact mode). Thus, we chose the initial value of mass ratio q to be 0.25. From our observations, we can also see that there is an O'Connell effect on the light curves, namely, light Max.I $>$light Max.II. Therefore, before proceeding with the calculations, we want to compare the theoretical light curves with the observational ones so that we can decide onto the next step. Using the LC program of Wilson-Devinney, we calculated the theoretical light curves by means of the photometric elements of the best solution at q=0.25 and plotted them together with the observational data. From this diagram we find that the fit is not good on either side of the secondary eclipse and light Max.II. This discrepancy indicates that perhaps there is a hot spot located on the surface of the secondary component near the neck of the binary system, as has often been suggested for this type of contact binary, so we repeated the DC calculations

Table 1. The photometric solution of BV Eri

Element	Value (Gu et al.'s data)	Value (Baade et al.'s data)
i	$79^\circ.350 \pm 0^\circ.265$	$78^\circ.598 \pm 0^\circ.131$
T_1	6850K	6850K
T_2	5592K±14K	5702K±4K
g_1=g_2	0.320	0.320
A_1=A_2	0.500	0.500
Ω_1=Ω_2	2.3263±0.0024	2.3272±0.0012
Ω_{in}	2.3599	2.3576
q	0.253±0.001	0.252±0.001
$L_{1U}/(L_1+L_2)_U$	*	0.9161±0.0006
$L_{1B}/(L_1+L_2)_B$	0.9073±0.0014	0.8981±0.0006
$L_{1V}/(L_1+L_2)_V$	0.8907±0.0013	0.8821±0.0006
x_{1U}=x_{2U}	*	0.647±0.006
x_{1B}=x_{2B}	0.628±0.022	0.600±0.007
x_{1V}=x_{2V}	0.542±0.023	0.517±0.008
r_1(pole)	0.4766±0.0004	0.4763±0.0002
r_1(side)	0.5170±0.0005	0.5164±0.0003
r_1(back)	0.5434±0.0006	0.5427±0.0004
r_2(pole)	0.2568±0.0013	0.2560±0.0007
r_2(side)	0.2684±0.0016	0.2674±0.0009
r_2(back)	0.3080±0.0032	0.3063±0.0017
Latitude$_{spot}$	90°	90°
Longitude$_{spot}$	$7^\circ.100 \pm 1^\circ.199$	$12^\circ.560 \pm 1^\circ.813$
Radius$_{spot}$	$66^\circ.100 \pm 1^\circ.910$	$83^\circ.080 \pm 1^\circ.382$
Temperature factor$_{spot}$	1.116±0.006	1.092±0.001
f	21%	19%

assuming the presence of this hot spot at fixed latitude (90deg). The adjustable parameters were: the inclination i, the surface temperature of the secondary component T_2, the surface potential Ω_1, the mass ratio q, the luminosity L_1, the limb-darkening coefficient x_1, the longitude of the hot spot, the radius of the hot spot, and the temperature factor of the hot spot. Because of the high correlations among these parameters, the parameters were divided into three subsets {longitude$_{spot}$, radius$_{spot}$, temperature factor$_{spot}$},{i,x_1}, and {T_2,Ω_1,q,L_1}, each subset was adjusted separately until the best solution was obtained. Finally, we derived the photometric solution for BV Eri listed in Table 1. Making use of these photometric elements, the theoretical light curves of BV Eri were computed with the LC program and shown along with the observational light curves in Fig. 2. We can see that the theoretical light curves fit the observational ones very well.

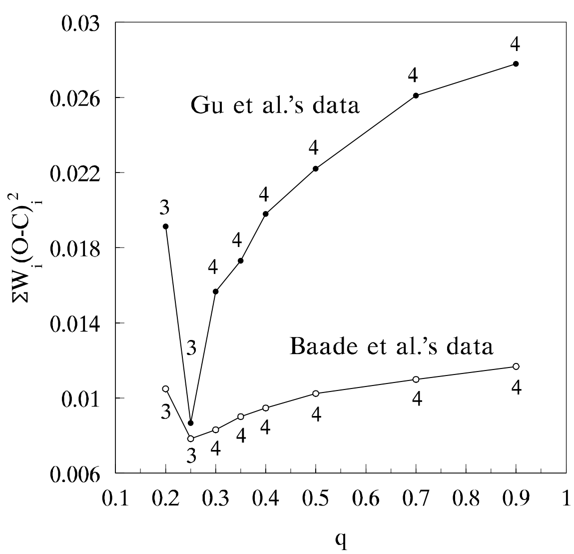

Fig. 1. The $\sum$-q relations for BV Eri.

Secondly, we analyzed Baade et al.'s observational data. Because their observations are of better quality, we didn't make normal points for their data, and the observational light curves were used directly to calculate the photometric elements of the system by using Wilson-Devinney's synthetic light curve program in the same way as we did for our own normal light curves. In the course of searching the mass ratio of the system, we obtained the same result, namely, the initial value of the mass ratio is q=0.25 and the system is a contact system. The fitting residue $\sum W_i(O-C)_i^2$ of the best solution for each mass ratio is also displayed in Fig. 1. We get a similar indication of a hot spot by comparing the observational light curves with the theoretical ones at q=0.25 calculated with the aid of LC program. So we again put a hot spot on the surface of the secondary component, and repeated the DC calculations. The adjustable parameters were the same as those in the above analysis of our own observation. Similarly, because of the high correlations among adjusted parameters, the parameters were again divided into three subsets {longitude$_{spot}$, radius$_{spot}$, temperature factor$_{spot}$}, {i,T_2,Ω_1,q,L_1}, and {x_1}, each subset was adjusted

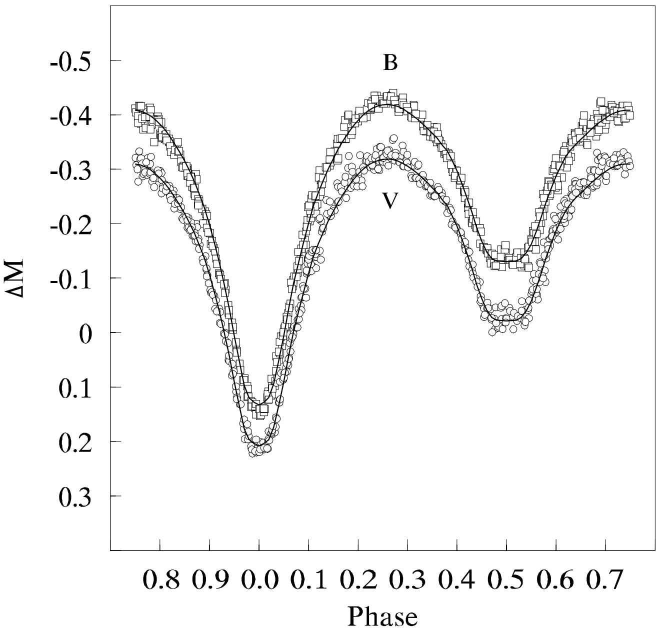

Fig. 2. Observed and theoretical light curves of BV Eri related to our own observations. The symbols "□" and "○" represent the individual observations in the B and V bands respectively, the solid curves represent the theoretical light curves.

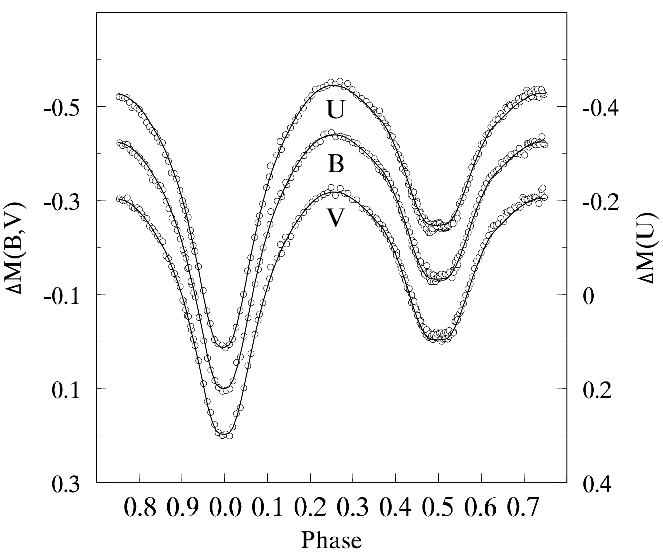

Fig. 3. Observed and theoretical light curves of BV Eri for the observations of Baade et al. The symbol "○" represents the individual observations, the solid curves represent the theoretical light curves.

separately until the best solution was obtained. The final photometric solution of BV Eri based on Baade et al.'s observation has also been listed in Table 1. Using these photometric elements, the theoretical light curves of BV Eri were calculated with the LC program and displayed along with the observational ones in Fig. 3. It may be seen that the theoretical light curves fit the observations very well.

From the above analysis, we may see that no large discrepancy exists between the two results based on our own and Baade et al.'s observations except the parameters of hot spot. Combining two sets of new photometric solutions with the mass function $f(M) = 0.0079$ presented by Baade et al., we have obtained two sets of absolute parameters of the system listed in Table 2 with the aid of several well-known formulae. It is found that the two sets of absolute parameters are very similar. This result suggests that our method is proper and the result is reliable.

Table 2. The absolute parameters of BV Eri

Parameter	Value (Gu et al.'s data)	Value (Baade et al.'s data)
R_1	$1.38R_\odot$	$1.38R_\odot$
R_2	$0.75R_\odot$	$0.75R_\odot$
M_1	$0.81M_\odot$	$0.82M_\odot$
M_2	$0.20M_\odot$	$0.21M_\odot$
$\mathrm{Log}(L_1/L_\odot)$	0.58	0.58
$\mathrm{Log}(L_2/L_\odot)$	-0.31	-0.27

3. Discussion and conclusion

In fact, in the course of Baade et al.'s analysis, they had found that the bolometric albedo of the secondary component is unusual and A_2=2.0. This point also confirms that the part of the surface of the secondary component located near the neck of the binary system is superluminous, and agrees with our result. The hot spot on the secondary component of the contact binary system may be explained as a result of higher temperature matter of the primary component flowing to the secondary component through the neck of the binary system and heating up lower temperature matter of the surface of the secondary component near the neck. On the other hand, it may be also explained as the result of the matter transferring through the neck accelerating toward the secondary component so as to cause an acoustic shock wave, and thus to heat up the photosphere of the secondary component(Samec et al. 1993).

The present study has shown that the system BV Eri is a contact binary with a large temperature difference between the two components. The components are in poor thermal contact phase, the degree of overcontact f is 21% and 19% for the two sets of observational data respectively. The hot spot on the secondary component suggests that mass transfer is in progress, with the mass from the primary component transferring to the secondary through the neck of the binary system. In the H-R diagram of the components of BV Eri, we have found that the primary component is well within the main-sequence and the secondary one is near the ZAMS, so they are main-sequence stars.

More than a decade ago, Kaluzny published a series of papers about this kind of contact binaries: CN And, WZ Cep, FT Lup, AU Ser, AG Vir, and BE Cep(Kaluzny 1983; 1986a,b,c,d). He had found that the light curves of CN And, WZ Cep, AU Ser, and FT Lup can be reproduced theoretically only if one assumes that there is a higher surface brightness(namely, a hot spot) on the secondary component near the neck of the binary system. In his solutions for these systems, he allowed the bolometric albedo of the secondary component A_2 to take values larger than 1.0 in order to simulate a hot spot. From our research work, BV Eri is similar to WZ Cep and AU Ser.

According to the ”Thermal Relaxation Oscillation” theory(Lucy & Wilson 1979), an unevolved W UMa system undergoes oscillation about a state of marginal contact. In the poor thermal contact phase , the system which deviates from an EW-type light curve is at the beginning or end of the contact phase: its light curve is expected to tend toward an EB-type, which is called B-type contact binary. But this binary system is still in the domain of the period-color diagram dominated by conventional W UMa binaries. Moreover, for a W UMa system undergoing such oscillation, the system is in shallow contact and the degree of overcontact f is restricted to be $\leq$30%.

Because BV Eri satisfies all conditions for a B-type contact binary, we conclude that BV Eri is a B-type contact binary system and at the beginning or end of the contact phase; mass transfer is taking place between the two components.

Acknowledgements. I would like to thank the referee Dr. van’t Veer for valuable advice to my manuscript.

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