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On a recent theoretical model for the subdwarf binary system LB 3459

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Summary. The theoretical model for the evolved close binary system LB 3459 recently proposed by Paczynski & Dearborn has several major flaws; it does not reproduce the well-defined shape of the primary eclipse nor the observed colour changes at primary and secondary eclipses and it assumes a mass ratio of unity which is very unlikely. The model predicts a velocity curve amplitude several times greater than that observed.

1 Introduction

Paczynski & Dearborn (1980) have recently proposed an evolutionary model for the remarkable eclipsing binary system LB 3459. As part of that model, Paczynski & Dearborn (hereafter PD) have presented an alternative interpretation of the light curve to that given by Kilkenny, Penfold & Hilditch (1979; hereafter KPH). The PD model assumes a mass ratio of unity for the system and proposes an evolutionary scheme relating LB 3459 to the close binary system AS Eri. It is the purpose of this communication to demonstrate that their model is invalid since (a) the interpretation of the published photometry is incorrect and (b) their assumption regarding the mass ratio does not conform to recent spectroscopic data. Consequently, a new evolutionary model is necessary.

2 The light curve and colour-index variations

Paczynski & Dearborn have obtained a solution to the light curve by considering only the times of contact of the well-defined primary eclipse (Kilkenny, Hilditch & Penfold 1978; hereafter KHP), the depths of both eclipses and the size of the reflection effect (0.05 mag in B light). They obtain relative radii of 0.201 and 0.054 with an orbital inclination of $82^\circ.05$. In their model, the smaller star is the hotter one, contributing 30 per cent of the total B light of the system, and is totally eclipsed at primary minimum. This model does successfully account for the durations and depths of both eclipses and the size of the reflection effect but it fails totally to reproduce two important features which are accurately defined by the published photometry (KHP, KPH):

(i) The detailed shape of the primary eclipse, defined by observations to ±0.005 mag, cannot be matched by the PD model. The theoretical curves of the PD and KPH models are

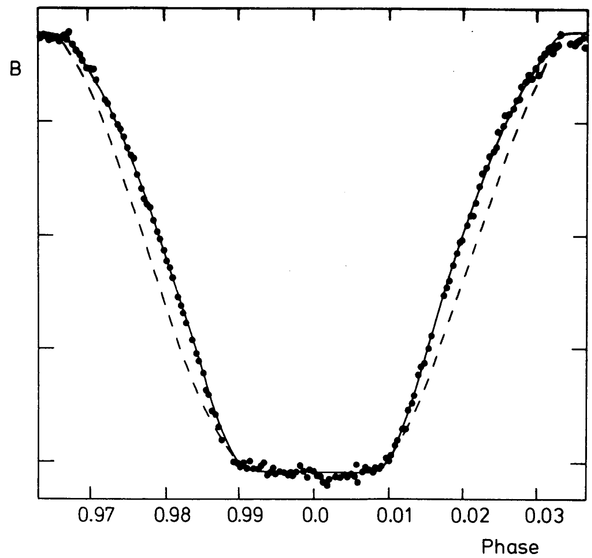

Figure 1. Primary eclipse of LB 3459 taken from Fig. 2 of KPH. Filled circles are observational data from KPH and the solid line is the eclipse solution from the KPH model with a linear limb-darkening coefficient $u_1 = 0.03$. The broken line is the eclipse calculated from the PD model. The B magnitude scale is in units of 0.1 mag with an arbitrary zero-point.

compared with the observations in Fig. 1 (from Fig. 2 of KPH). These curves were calculated using an eclipse routine for spherical stars based on Kitamura's (1965) method for analysing light curves. The PD model is systematically different from the observations by up to 0.045 mag throughout the partial phases of the eclipse.

(ii) The PD model demands significant changes in the colour indices of the system at primary eclipse, the precise amounts depending on the adopted temperatures of the components. We have calculated the expected colour changes (using a preliminary version of the LIGHT program written by Hill 1979) for the three sets of temperatures given in PD, and list these in Table 1. We also give the colour changes predicted by the KPH model and the actual observed values. The PD model is clearly systematically in error whereas the KPH model is in very good accord with the observational results.

We conclude that the PD model does not reproduce the published photometry; the KPH model fits all the photometric data with the important exception of the observed reflection effect, a point which was emphasized strongly in the KPH paper. We have made many

Table 1. Observed and theoretical colour-index variations (relative to quadrature values)

Model	PD	PD	PD	KPH	Observed (sd) values
T_1(K)	31 800	19 800	13 700	45 000	
T_2(K)	126 000	62 000	33 000	20 000	
(a) primary eclipse					
$\Delta(u-b)$	+0.101	+0.259	+0.378	+0.014	-0.015 ± 0.029
$\Delta(v-b)$	+0.012	+0.026	+0.038	+0.001	0.000 ± 0.008
$\Delta(b-y)$	+0.013	+0.021	+0.027	+0.003	-0.001 ± 0.010
(b) secondary eclipse					
$\Delta(u-b)$	−0.016	−0.023	−0.028	−0.034	-0.039 ± 0.008
$\Delta(v-b)$	−0.002	−0.004	−0.003	−0.004	-0.003 ± 0.008
$\Delta(b-y)$	−0.001	−0.001	−0.003	−0.004	-0.007 ± 0.010

attempts to match the light variation outside eclipse using the Hill (1979) program, but so far have been unable to obtaine a satisfactory solution. We have tried solutions similar to the PD model (i.e. primary eclipse as an occultation rather than a transit) but, as noted above, cannot reproduce the eclipse well. Increasing the temperature of the primary component beyond 100 000 K still results in insufficient reflection.

Preliminary work on recent *IUE* satellite observations (Lynas-Gray, Kudritzki & Kilkenny, in preparation) indicate that the $U-V$ continuum is best matched by a (non-LTE) model with a temperature near 45 000 K, thereby precluding any explanation of the reflection effect by an extreme stellar temperature for *either* component. A temperature near 45 000 K for the primary star also agrees will with observed *uvby* colour indices and preliminary analysis of the line profiles using non-LTE models and spectra at 22 Å mm^{-1} (Kudritzki *et al.* in preparation).

3 The velocity curve and mass ratio

Preliminary results for the velocity curve have been given by Kilkenny, Lynos-Gray & Hilditch (1979); more extensive data by Kilkenny, Hill & Penfold (1980) are in close agreement with the preliminary conclusions. The semi-amplitude of the velocity curve of the primary is $K_1 = 32.5 \pm 1.5$ km s^{-1}, in complete contradiction to the PD model which predicts component velocities of the order of 150 km s^{-1}.

The range of solutions permitted by the published photometry and observed radial velocity curve indicate that, for the mass ratio to be unity, the stellar masses must be less than $0.005\,M_\odot$, a value which is unlikely in view of the parallax restrictions (Churms & Thackeray 1971) on the lower limit to the luminosity of the primary star. Note that we cannot rule out a very low mass on evolutionary grounds because it is highly probable that large mass exchange or loss from the system has occurred on at least one occasion during the lifetime of this very close binary system. The most internally consistent results for the component parameters (radii, surface gravities, etc.) are obtained with a mass ratio ~ 0.1 and a primary mass $\sim 0.5\,M_\odot$ (Kilkenny *et al.* 1980).

4 Conclusions

The PD model of the LB 3459 system does not reproduce the well-defined shape of primary eclipse nor does it match the colour changes during primary and secondary eclipses. For these reasons, we prefer the KPH model (where primary eclipse is a transit of the smaller cooler star in front of the larger hotter star) even though we cannot reproduce the observed reflection effect outside of eclipse.

The radial velocity curve suggests a mass ratio near 0.1 rather than the adopted value of unity in the PD model; the semi-amplitude of the curve is much smaller than this model predicts.

The qualitative picture of LB 3459 as an evolved system, similar to AS Eri but after another stage of mass loss/exchange, is very plausible and we note that the PD model suggests mass loss to have occurred more than 10^6 yr ago. In this context, we find no evidence for P Cygni profiles in the visual or ultraviolet spectra, nor is there any indication of circumstellar material around LB 3459 on a UK Schmidt Hα plate of the LMC region.

References

Churms, J. & Thackeray, A. D., 1971. In *IAU Symp., 42,* 21.
Hill, G., 1979. *Publs Dom. Astrophys. Obs.*, **XV**, 298.
Kilkenny, D., Hilditch, R. W. & Penfold, J. E., 1978. *Mon. Not. R. astr. Soc.*, **183**, 523.

Kilkenny, D., Hill, P. W. & Penfold, J. E., 1980. *Mon. Not. R. astr. Soc.*, submitted.
Kilkenny, D., Lynas-Gray, A. E. & Hilditch, R. W., 1979. In *IAU Colloq.*, *53*, 255.
Kilkenny, D., Penfold, J. E. & Hilditch, R. W., 1979. *Mon. Not. R. astr. Soc.*, **187**, 18.
Kitamura, M., 1965. *Adv. Astr. Astrophys.*, **3**, 37.
Paczynski, B. & Dearborn, D. S. 1980. *Mon. Not. R. astr. Soc.*, **190**, 395.