ON THE NATURE OF ASYMMETRY OF THE LIGHT CURVES OF BM Cas – A LONG PERIOD ECLIPSING SUPERGIANT BINARY

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ABSTRACT. We report results of the analysis of $UBVR$ light curves of the long period eclipsing binary BM Cas obtained between 1967 and 1996 in Tallinn observatory. The asymmetry of the light curves and color variations are discussed and interpreted in terms of a hot extended region close to the neck connecting the critical Roche lobes of the components.

Key words: stars:binaries:close - stars: individual: BM Cas

1. Introduction

A long period eclipsing binary BM Cas with a primary A5-A7 supergiant and invisible secondary component was an observational target for photometric study at Tallinn Observatory where a number of seasonal light curves of this peculiar system in UBVR colors were obtained between 1967 and 1996. A complete light curve (see Figure 1) was calculated according to

$$C = 2449051.17 + 197.275 * E - 2.847 \cdot 10^{-5} * E^2$$

Analysis of the O-C diagram based on these observations and a brief discussion of the observed properties of BM Cas as well as of its probable evolutionary history were published two years ago in our earlier paper (Kalv, Harvig, Pustylnik, 2005). Results of detailed spectroscopic investigation and of some photometric data of BM Cas by Fernie and Evans (1997) generally agree with our earlier conclusions about the probable range of physical parameters of the binary.

Here we summarize the main results of a semi-quantitative analysis of our seasonal light curves (some examples are demonstrated in Figures 2–6). Because of a pronounced intrinsic variability and asymmetry of the light curves as well as of anomalous radial velocity curves available only for the primary component up to now nobody proposed a quantitative model of BM Cas nor determined reliable physical parameters of the components and the binary orbit (an earlier detailed model assuming the extended scattering envelope elaborated by Barwig (Barwig 1976) contradicts the recent IUE data in UV which do not confirm the presence of circumbinary envelope claimed by Barwig).

2. Peculiarities of the $UBVR$ light curves

Individual $UBVR$ light curves manifest the following peculiarities:

2.1. Temporal variations of the depths of both minima.

There are significant differences between individual light curves in the depths of both minima and to a smaller extent in their duration. The average values of light in units of the total luminosity normalized to the local maximum at the bottom of the primary minimum range between 0.56 and 0.61 for the primary and between 0.86 and 0.89 for the secondary minimum in all four colors, the average semi-widths of the primary minimum range between $0.14P$ and $0.17P$. In some cases the primary minimum is even more shallow – the brightness at the bottom of the primary minimum 0.667 in B color and 0.70 in V was obtained from one partial light curve obtained in 1974.

2.2 Sporadic displacements of the moment of the primary minimum.

Sporadic displacements of the moment of the primary minimum from the predicted ephemerides amounting up to $0.02P$ have been detected (despite the fact that no significant systematic period variations have been found in our earlier paper). The same applies to the secondary minimum but because of a conspicuous asymmetry and scattering of observed points it is virtually impossible to give even the approximate numerical estimates.

2.3 The absence of contribution to the total light from the secondary component.

Spectroscopic data do not show the evidence for the presence of the spectrum of a companion either in the visible or UV (see Fernie and Evans 1997 for a more detailed discussion). Our multicolor photometric data

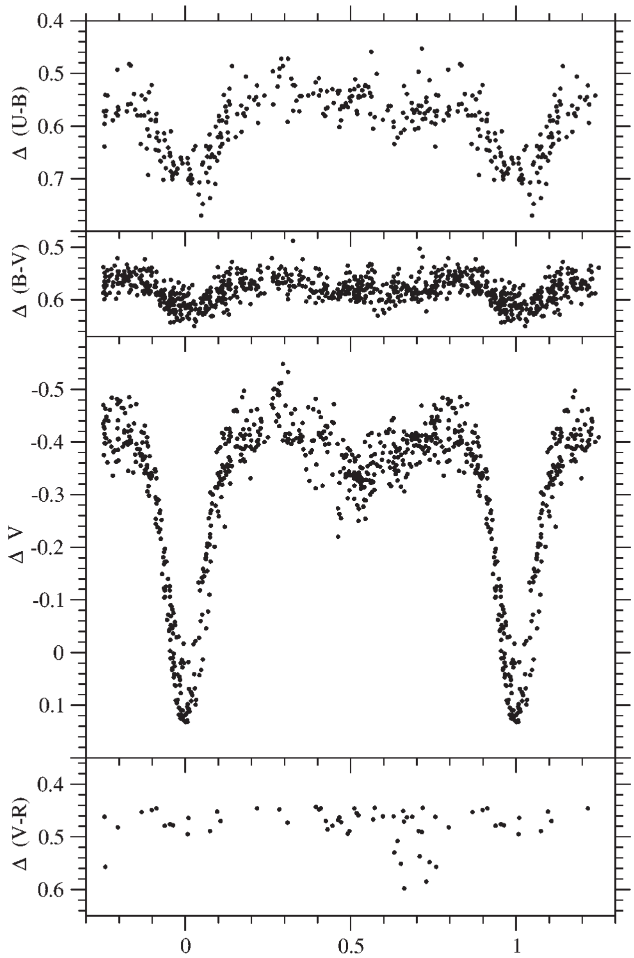

Figure 1: Light and colour curves of eclipsing binary system BM Cas (all observations). The mean–square–root error of a single measurement has been determined from the measurements of comparison and the check stars: $\sigma V = \pm 0.^{m}009$ and $\sigma(B-V) = \pm 0.^{m}01$.

supports this conclusion: a) assuming that the primary A5 supergiant is very close to its critical Roche lobe one can with a satisfactory accuracy reproduce the observed light variations as caused by a combined effect of the transient eclipse by a dark smaller body of an invisible secondary component and the ellipticity of the primary. The secondary minimum is caused solely by the ellipticity of the primary, b) within the uncertainties imposed by intrinsic variability the depths of both minima and their widths are roughly the same in all four colors.

3. Probable nature of asymmetry of the light curves and colour changes with phase

Over more than 25 years of our time series asymmetry of the seasonal light curves preserved in all colours the same pattern: the ascending branch dur-

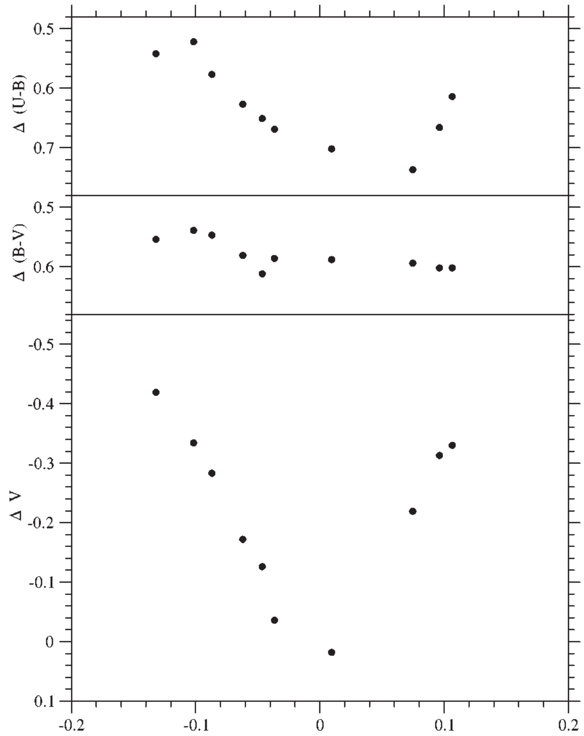

Figure 2: Light and colour curves of eclipsing binary BM Cas E=-19 (JD=2445303±40d).

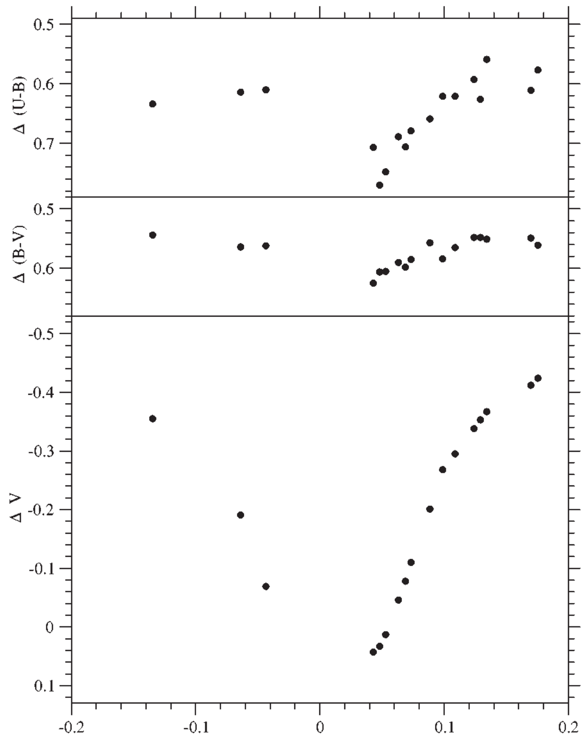

Figure 3: Light and colour curves of eclipsing binary BM Cas E=-11 (JD=2446884±40d).

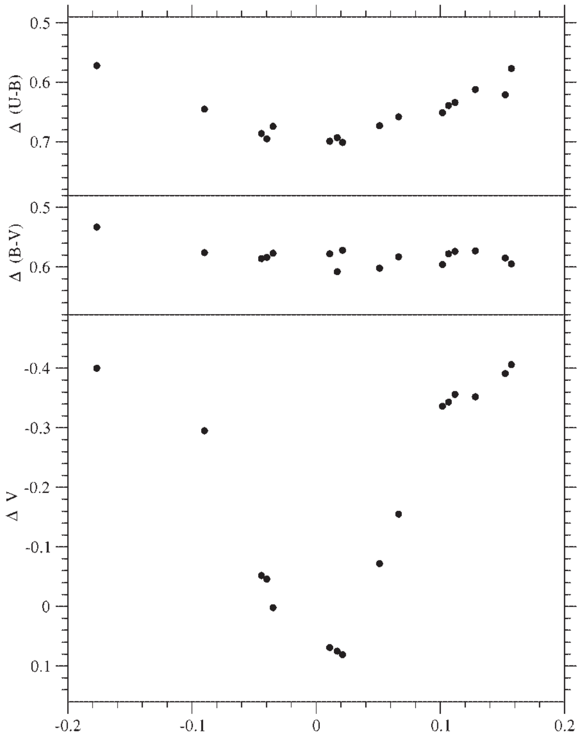

Figure 4: Light and colour curves of eclipsing binary BM Cas E=-10 (JD=2447079±40d).

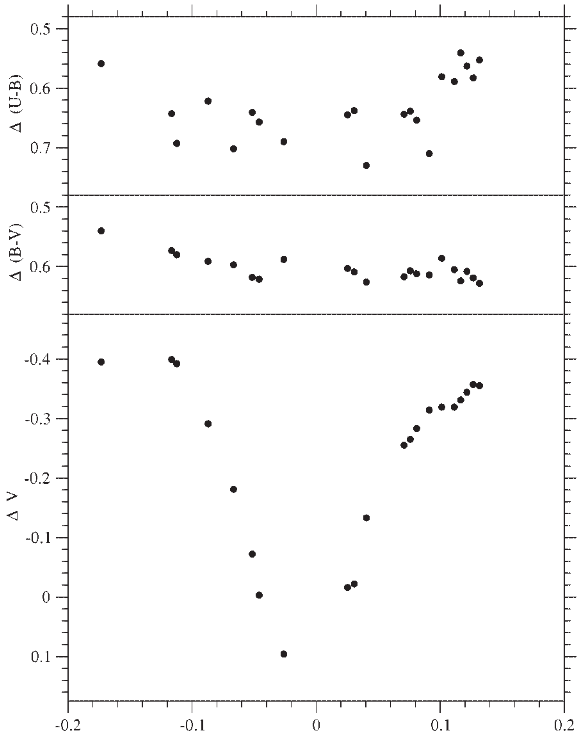

Figure 5: Light and colour curves of eclipsing binary BM Cas E=-9 (JD=2447274±40d).

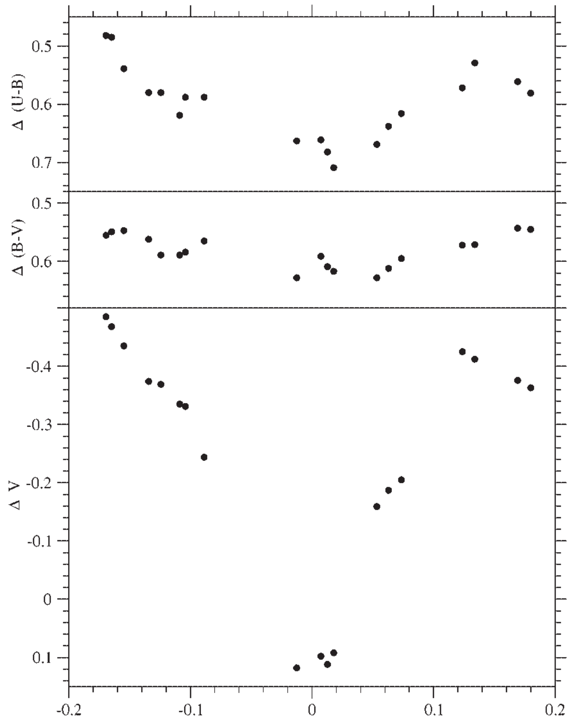

Figure 6: Light and colour curves of eclipsing binary BM Cas E=-8 (JD=2447472±40d).

ing primary minimum was systematically slightly more steep than the descending branch (a similar trend is in evidence in the published light curve of BM Cas by Fernie and Evans 1997) and statistically the maximum preceding the primary minimum is slightly (by $0.^{m}01 - 0.^{m}02$) higher than the following maximum (with the phase corresponding to the light maximum shifted from elongation – $0.75P$ to the orbital phase of $0.78P - 0.80P$).

We made an attempt to interpret both the observed pattern of asymmetry of the light curves and color variations from maxima to minima (see Figures 1–6, i.e. BM Cas looks more blue in the maximum light than in minimum, see also similar evidence from a brief note by Shao and Gaposchkin 1962). We postulated the presence of a rather extended, off–center hot region located close to the neck connecting the Roche lobes of both components superimposed upon A5 supergiant. Making use of the commercially available Binary Maker computer code we have found that the following parameters of the hot region result in the asymmetry of the light curve pretty similar to the observed pattern: the temperature contrast

$\Delta T/T_{1sg} \sim 0.2 - 0.25 (T_{1sg} = 8700K)$, the angular radius of the hot region

$R_{\rm sp} = 12° - 15°$, the central co-latitude $l = 88°$, the central longitude 350°, inclination angle of orbit $i = 70.5°$, the relative radii of the components $r1 = 0.438$ and $r2 = 0.338$ (in the units of semi–

major axis), the temperature of the invisible companion $T_2 = 4500K$. In relative measure (again in the units of semi–major axis of orbit) our value of $R_{\rm sp}$ is close to the radius of the cross–section at the inner Lagrangian point determined by the isothermal density drop–off of the gas stream (see formula in Meyer and Meyer–Hofmeister 1983). The same hot region can explain the small amplitude color changes up to

$\Delta(B-V) \sim 0.05 - 0.08$ from minima to maxima. In $U-B$ the amplitude of color excess amounts even to $0.^{\rm m}15$ and in the black body approximation of the hot source energy distribution we cannot match the observed color curves. This may be partially due to the influence of emission lines (H emission lines are present in BM Cas spectra, with maximum at the phase of the best visibility of the putative hot region, for more details see Barwig 1976) on the light curve in U.

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