Photometric observations of two very long period eclipsing binaries: AZ Cas and EE Cep

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1 Introduction

Light curves of eclipsing systems with long periods, even during the minima, are very difficult to obtain. Therefore, multisite campaigns needs to be organized to achieve good coverage of their light curves. These systems consist of a cool, evolved component (supergiant) and a hot companion and are important for understanding the evolution of stars with moderate and high masses. Such binary systems as well as other members of the VV Cep/ζ Aur types can provide reliable determination of masses and radii of the evolved supergiants as well as information about mass loss during their evolution off the Main Sequence. Some are unique systems showing evidence of harbouring dark discs (ϵ Aur as an example) or thermonuclear events (several eclipsing symbiotic stars).

In this paper we report photometric observations of minima of two very long-period eclipsing systems: AZ Cas (P=3402^d) and EE Cep (P=2050^d). Both systems have had the primary minima in 2003. We show unpublished observations of the AZ Cas primary minimum taken in 1994 and 2003, the latter being still in progress as the primary minimum has not yet reached the third contact. The predicted time of this moment is 27 October, a few days after this conference. This system seems to be a twin to VV Cep, whose last eclipse was late by about 1% (2 months) of the orbital period, caused probably by a significant mass loss from the supergiant (Graczyk et al. 2003). EE Cep is an unique system, being a cousin of ϵ Aur, where the eclipsing body is probably a dark extended disc around an invisible companion (Mikolajewski & Graczyk 1999). The 2003 minimum of EE Cep finished in the second half of June. The observations of EE Cep were conducted at several observatories as part of an international campaign which was the respond to the appeal published at the very beginning of the eclipse (Mikolajewski et al. 2003). The light curves obtained in several filters have extremely good time coverage and accuracy, not achieved during observations of the previous 10 eclipses between 1947 and 1997.

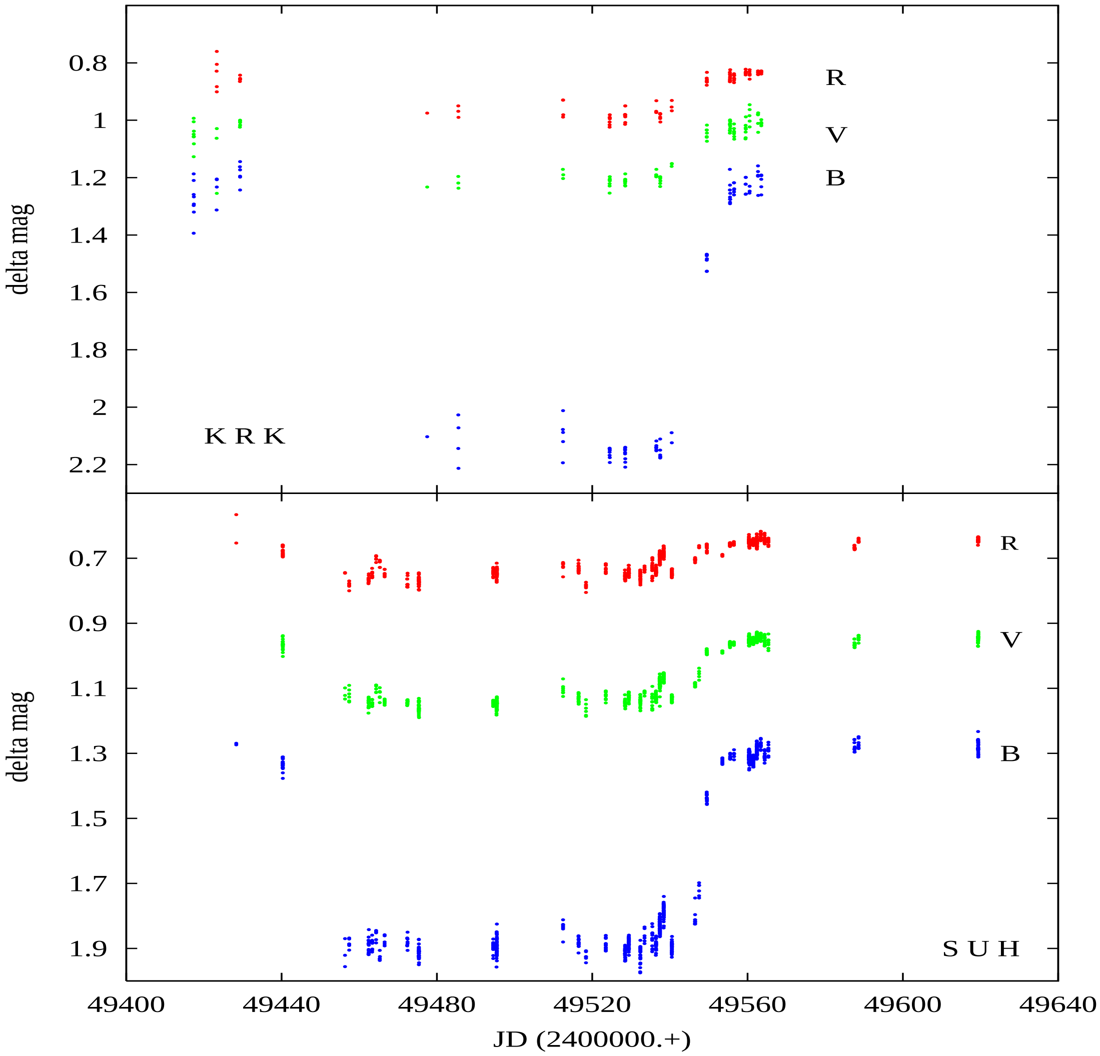

Figure 1: Photoelectric observations of AZ Cas in BVR filters taken at Mt. Suhora and Krakow Observatories in 1994

2 AZ Cas

AZ Cas consists of an M-type supergiant and a hot B-type component (Cowley & Hutchings 1977). Its orbital period is 9.3 years, the light curve shows flat-bottom minima of more than 100 days duration. The minima have been observed by several investigators. Cowley and Hutchings (1977 and references therein) summarized photometric data taken since AZ Cas was discovered by Ashbrook (1959) until the primary minimum which occurred in mid 70s. Observations made in UBV filters, outside the primary minimum (1985 Oct - 1990 Feb) have been reported by Nha (1994). He found no light variations in the V filter, however, a gradual decrease of light in the shorter (UB) passbands was observed. AZ Cas was also observed by Lee & Gim (1994) during three seasons: 1990 to 1993 in the RI filters. They found no significant light variations outside eclipse phases ranging from 0.54 to 0.87 in the near infrared.

Spectrograms of AZ Cas covering the whole orbital period were analyzed by Cowley & Hutchings (1977). The derived orbital parameters revealed a very eccentric orbit (e=0.55). The mass function $f(m)$=2.2 $M_{\odot}$ was found from the radial velocity curve of the cool M-type component. The spectral type of the hot component was estimated as B0V. Cowley & Hutchings argued that the masses of components were 13 and 18 solar masses for the B and M star, respectively. Kang (1994) analyzed the IUE spectra of AZ Cas and from the energy distribution

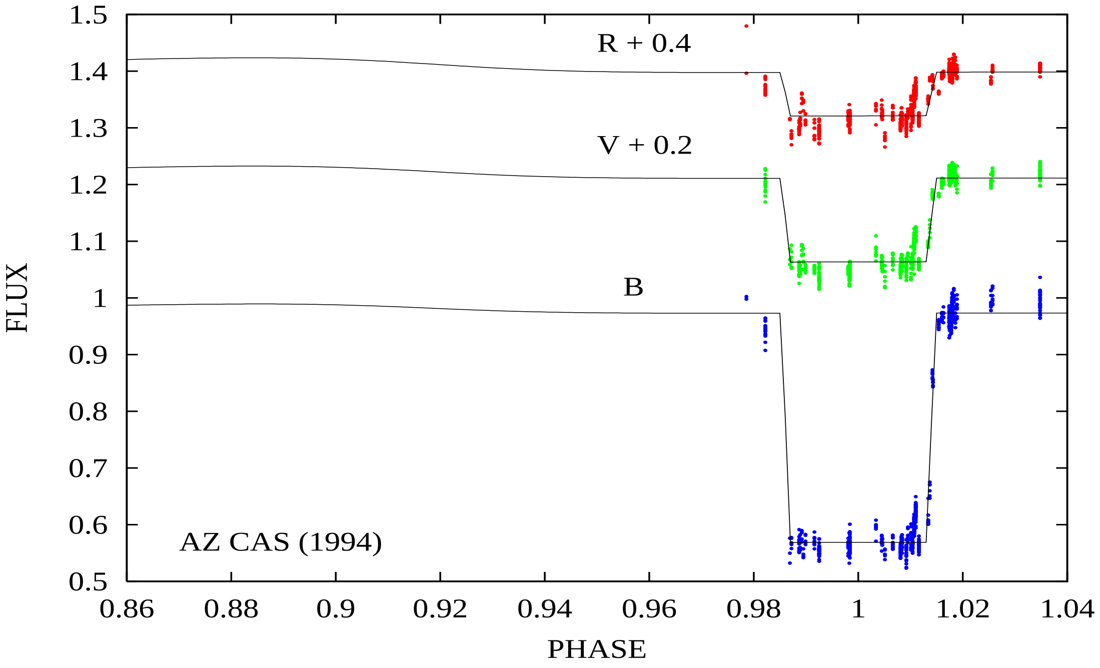

Figure 2: Comparison between the theoretical and observed light curves (BVR filters, Mt. Suhora data)

inferred the temperature of the B-type star in the range between 15000 K and 20000 K. He also revised parameters of the components: the temperature of components were reduced to 16000 K and 3800 K, the radii of stars were 10 and 320 $R_\odot$. Kang obtained an even somewhat higher eccentricity (e=0.61), while the result for periastron angle was $10\overset{\circ}{.}5$.

The primary minimum in 1994 was observed at two observatories: Mt. Suhora observatory (SUH) using the 60 cm Cassegrain telescope and a two-channel photometer equipped with the $UBVR$ filters and the Astronomical Observatory of the Jagiellonian University (KRK) with a single channel photometer through BVR filters. BD+60°0321 was used as the comparison star. Unfortunately, due to bad weather no observations were obtained during the descending branch. The BVR data taken at Mt. Suhora Observatory and those from Krakow are shown in Fig. 1.

Photometric observations of the current (2003) minimum are in progress, data has been obtained during 11 nights so far, all in the flat bottom phase. They are being made at the Astronomical Observatory in Torun using the 60 cm reflector and a single channel photometer with a cooled C31034 photomultiplier through the wide band $UBVRI$ and H_β filters. BD+60°0306 is being used as the comparison star while BD+60°0317 as the check star.

We made the preliminary light curves modeling using BV observations taken by Larson-Leander (1959) and $UBVR$ data obtained during the minimum in 1994. Computations were performed simultanously for 6 light curves with the Wilson-Devinney code. Due to the fact that these data cover only the phases in the vicinity of the primary minimum several parameters had to be fixed. Following Cowley & Hutchings we assumed the primary component to be a B0 type star, while the secondary the M0I star. Therefore their temperatures corresponding to these spectral types were fixed at 30000 K and 3200 K for the primary and the secondary, respectively. Furthermore, if the hot star has not evolved off the Main Sequence (Cowley & Hutchings), its mass should be $14M_\odot$, which with known mass function, gives a mass ratio q=1.5 (M_{M0}/M_{B0}). After Cowley & Hutchings, the orbit eccentricity and the longitude of periastron were fixed (e=0.55, ω=10°). The free parameters were: the phase shift, inclination, potentials of components and the luminosity of the primary. After several attempts, it turned out that for the star as described above it was not possible to obtain a good fit to observations. By adding a third light into the list of free parameters the theoretical light curves matched the observed depth of the primary minimum. The best fit was obtained for inclination i=$82\overset{\circ}{.}6\pm2.0$ and the fractional radii of components

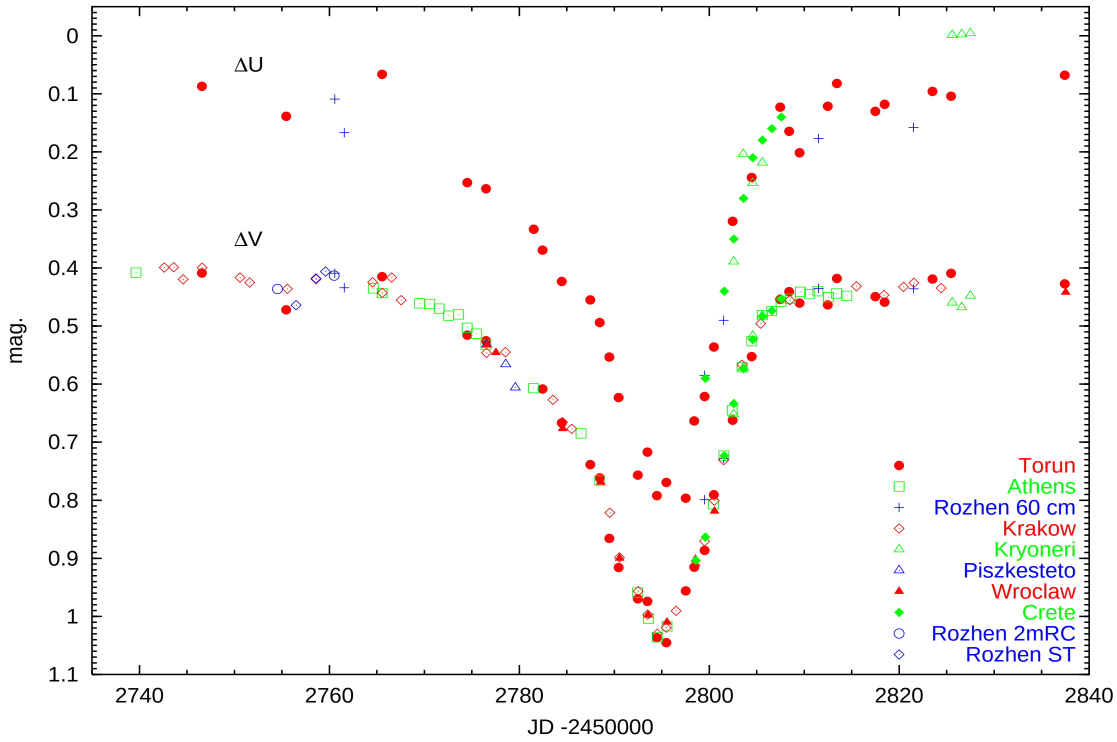

Figure 3: Observations of EE Cep obtained during the 2003 campaign (U and V filters)

r_1=0.0052, r_2=0.1488. The resulting third light was: 15% in the U filter, 53% in B, 80% in V and almost 83% in the R filter. The theoretical light curves corresponding to the best fit along with observed ones in the BVR filters (Mt. Suhora data) are shown in Fig. 2. We conclude that a third light is needed to obtain theoretical light curves resembling observations of AZ Cas. Its contribution to the total light of the system is very large and growing towards the long wavelenghts, reaching more than 80% in the R filter. Its amount needed to obtain a good fit can be lowered if the temperature of the primary is significantly lower than that corresponding to the B0V spectral type. A more extensive parameter search is in progress using the Monte Carlo search method and the final results will be published elsewhere.

3 EE Cep

Two first minima of EE Cep with a depth of more than 1.5^m have been discovered in 1947 and 1952 (Romano 1956, Weber 1956). The eclipsing nature of these minima with the period of 5.6 years was established after three subsequent events in 1958, 1964 and 1969 by Meinunger (1973). So far, there have been no traces of any secondary eclipse. Very few low-resolution spectroscopic observations were available until now. The spectrum was classified as that typical of a Be-type star with the B5 III spectral type (Baldinelli et al. 1981), however we cannot be sure that Hα and Hβ emissions indeed belong to the visible primary. No stellar spectrum of the secondary was ever detected even during the deep (about 1.5^m) minima. Any orbital parameters and the mass function remain absolutely unknown.

The most striking features of the EE Cep minima are large changes of their shape (Graczyk et al. 2003). The observed depths range from about $2^{\rm m}$ in 1958 and 1964 to about $0\overset{\rm m}{.}6$ in 1969. Also, the total duration of particular eclipses changes from about 3 weeks in 1992 to about 2 months (in 1969). Multicolor $UBVRI$ observations of the previous eclipse in 1997 (Mikolajewski & Graczyk 1999) showed that the contribution of the secondary in the red RI bands is negligible. In their preliminary model the obscuring body is a dark disc around a low-luminosity companion, likely an invisible low-massive close binary system. The observed changes of the depths of the

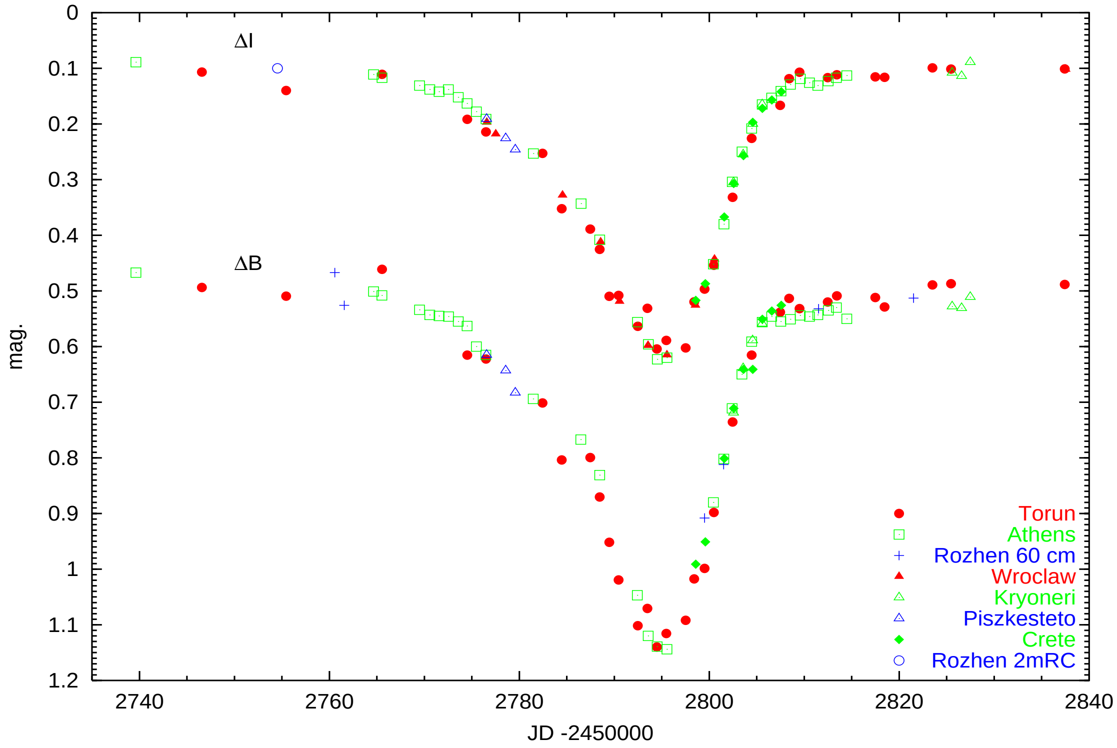

Figure 4: Observations of EE Cep obtained during the 2003 campaign (B and I filters)

minima can be understood if the disc has varying inclination to the line of sight during different eclipses, for example due to precession. If the disc is not transparent, the deeper eclipses could be observed when it is visible closer to a pole-on configuration, whereas the shallower ones, when it is seen almost edge-on.

We collected photometric observations during the recent eclipse of EE Cep between May and July 2003 obtained with ten different telescopes (with diameters from 40 cm to 2 m) in eight observatories from four countries: Poland (Torun, Krakow and Wroclaw), Greece (Athens, Kryoneri and Crete), Bulgaria (Rozhen) and Hungary (Piszkesteto). Most of these telescopes were equipped with CCD cameras. Only two 60 cm reflectors, at Torun and Rozhen, worked with one-channel aperture photometers equipped with a photomultiplier. All observations were shifted to the same comparison star, BD+55°2690.

Most of our observations were carried out with standard $UBV(RI)_C$ broad band filters. The preliminary reduced data (U and V filters) is shown in Fig. 3. During the whole eclipse there are only two nights when we gathered no observations. This time-coverage and good accuracy of observational points allows one to notice the characteristic shape of the minimum (Fig. 5). This light curve can be easy understood if the projection of an eclipsing body is not circular but has an extremely oblong shape, just as a visible edge-on dark disc (Graczyk et al. 2003). The outer regions of such a disc should be semitransparent and they are responsible for low-inclination ingress and egress phases. The central parts of the minimum show characteristic four contacts similar to those observed in Algols, where a flat-bottomed phase reflects the transit of a spherical body. Instead, the slope-bottom phase in EE Cep eclipses seem to be appropriate to the transit of a flat, extended object. Changing space orientation of such a flat object varies both the inclination to line of sight and the tilt into direction of motion. For extremely rare configuration, when inclination is close to 90°and tilt is close to 0°, the eclipse should be shallow with a flat-bottom phase, just as observed in 1969.

Unlike the latter, the currently observed eclipse had moderate duration (about 44 days) and was rather shallow, from about 0.7^m to 0.5^m, U and I bands, respectively. The following characteristic phases of the eclipse can be distinguished: (i) a relatively extended atmospheric part of ingress - 17 days; (ii) a 9 days-long phase of ingress into occultation by an opaque

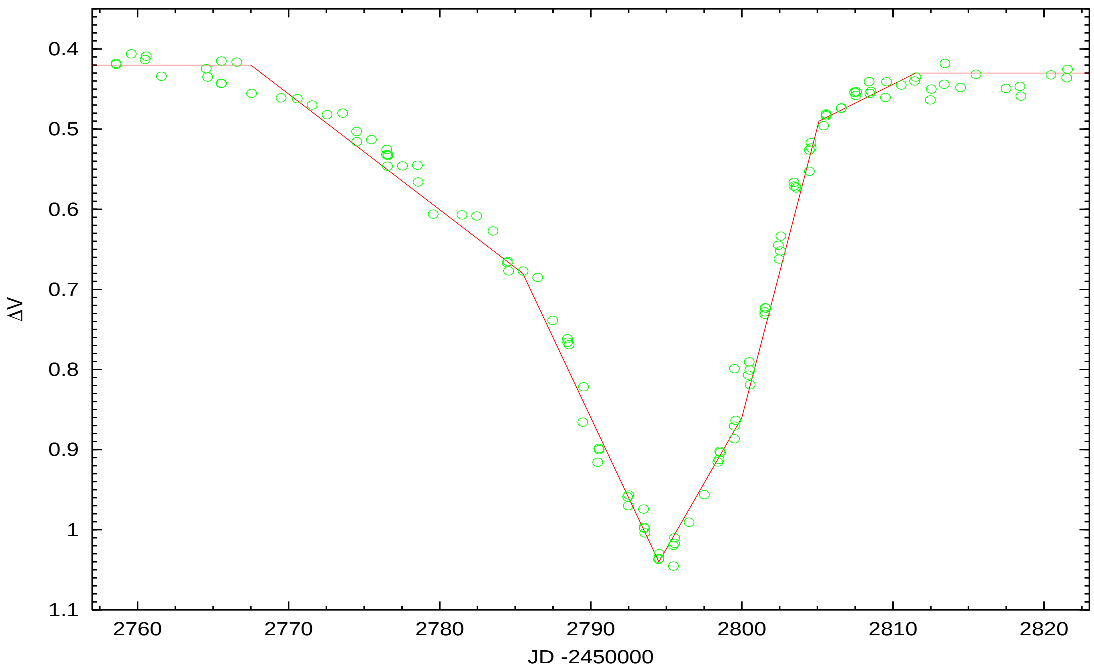

Figure 5: The schematic shape of the primary minimum of EE Cep in 2003

body; (iii) a short, slope-bottom phase - about 6 days; (iv) very sharp egress - 5 days; (v) short atmospheric egress - 7 days. During the 2003 eclipse the spatial orientation of the disc should be characterised by an incliniation close to 90°and a relatively large tilt into the direction of motion. Very broad (20–30 days) weak wings best visible in the shorter wavelenghts (BU) were also observed. Spectacular spectral changes in the NaI $D_{1,2}$ doublet (Mikolajewski et al. 2003) about one month before the start of the eclipse suggest the existence of significant amount of circumstellar matter in the system.

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