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

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Abstract. This paper reports new photometric observations of minima of two very long-period eclipsing systems: AZ Cas (P=3402^d) and EE Cep (P=2050^d). In order to match the observed depth of the primary minimum of AZ Cas we had to introduce a third light component. For EE Cep, the shape of the eclipse can be explained by a model that includes a dark precessing disk in the system.

1. The 1994 and 2003 eclipses of AZ Cas

AZ Cas consists of an M0I supergiant and B0V hot component (Cowley, Hutchings, & Popper 1977). Its orbital period is 9.3 years and the light curve shows flat-bottomed minima of about 100 days duration. Cowley et al. (1977 and references therein) summarized the photometric data taken since AZ Cas was discovered by Ashbrook (1959) until the primary minimum which occurred in mid 70s. No significant light variations in *UBVRI* outside the eclipse have been found (Nha 1994; Lee & Gim 1994). The spectroscopic orbital parameters for the cool component revealed a very eccentric orbit ($e = 0.55$) and the mass function $f(m) = 2.2\ M_\odot$ (Cowley et al. 1977). Assuming this mass function and the mass of $14 M_\odot$ for the hot component (a B0 Main Sequence star) the estimated mass ratio is $q = 1.5$ (M_{M0}/M_{B0}).

The primary minimum in 1994 was observed at two observatories: Mt. Suhora observatory using the 60 cm Cassegrain telescope and a two-channel

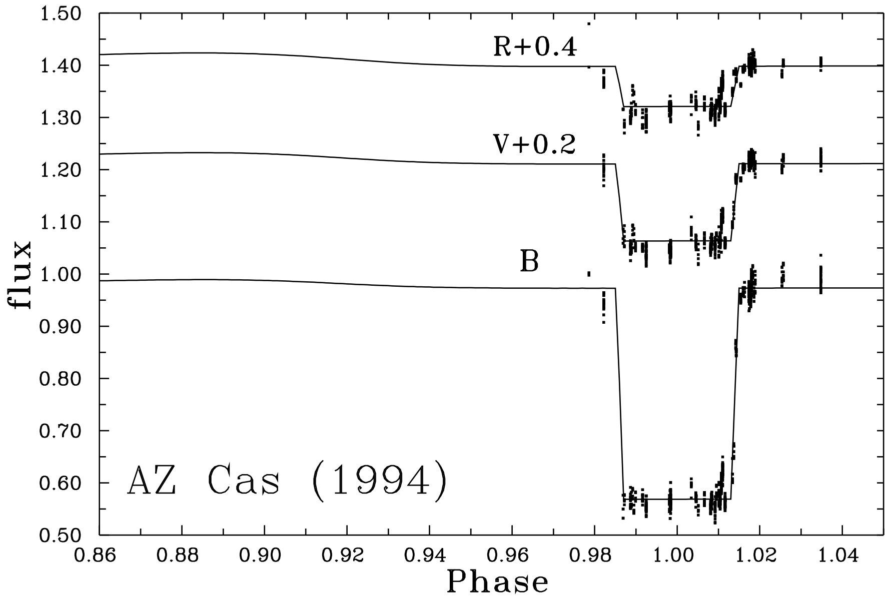

Figure 1. Comparison between the theoretical and observed light curves (BVR filters, Mt. Suhora data)

photometer equipped with $UBVR$ filters, and the Astronomical Observatory of the Jagiellonian University with a single channel photometer through BVR filters. BD+60°0321 was used as the comparison star. Multicolor $UBV(RI)_C$ photoelectric observations of the current (2003) minimum are being carried out at Torun Observatory using the 60 cm telescope equipped with a single-channel photometer and a CCD camera attached to an achromatic (128/2.8) objective (V band only). BD+60°0306 is being used as the comparison star.

We performed the preliminary light curve modelling using BV observations taken by Larsson-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 et al. (1977) we assumed surface temperatures of 30000 K and 3200 K for the primary and the secondary, respectively, the mass ratio $q = 1.5$ (M_{M0}/M_{B0}), the orbital eccentricity $e = 0.55$ and the longitude of periastron $\omega = 10°$. The free parameters were: the phase shift, inclination, potentials of components and the luminosity of the primary. After several attempts, it turned out that it was not possible to obtain a good fit to observations. By adding a third light component 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 $i = 82\overset{\circ}{.}6 \pm 2.0$ and the fractional radii of components $r_1 = 0.0052$, $r_2 = 0.1488$. The synthetic light curve is shown in Fig. 1.

We conclude that, assuming the spectroscopic parameters given by Cowley et al. (1977), a third light component is needed to obtain theoretical light curves resembling the observations of AZ Cas. Its contribution to the total light is large and grows towards the longer wavelengths, reaching about 80 % in the R filter.

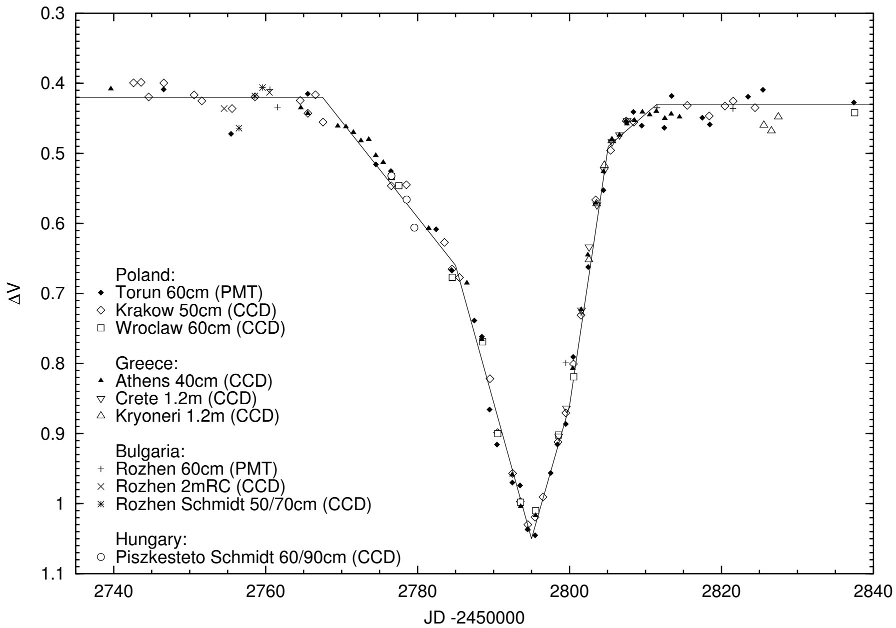

Figure 2. Observations of EE Cep obtained during the 2003 campaign (V filter) along with a schematic shape of the eclipse.

2. The 2003 eclipse of EE Cep

The eclipsing nature of the minima of EE Cep, with a period of 5.6 years, was established after three successive events in 1958, 1964 and 1969 by Meinunger (1973). No trace of the secondary eclipse was found. Very few low-resolution spectroscopic observations were available until now. The spectrum is dominated by the B5 III primary, with the stellar spectrum of the secondary never being detected even during the deep (about 1.5^m) minima (Mikolajewski et al. 2003 and references therein). The most striking features of the EE Cep minima are large changes of their shape (Graczyk et al. 2003). The observed depths of minima range from about $2^{\rm m}$ to about $0\overset{\rm m}{.}6$. Also, the total duration of particular eclipses changes from about 3 weeks to about 2 months. Multicolor $UBVRI$ observations of the 1997 eclipse (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 the low-luminosity companion, likely an invisible low-mass close binary system. The observed changes of the minima depths can be understood if the disc has a varying inclination to the line of sight, for example due to precession.

We collected photometric observations during the recent eclipse of EE Cep between May and July 2003 obtained with ten different telescopes in eight observatories from four countries (Fig. 2). Most of these telescopes were equipped with CCD cameras, but two 60 cm reflectors worked with one-channel photometers. All observations were corrected to the same comparison star: BD+55°2690. Most of our observations were carried out with standard $UBV(RI)_C$ broad band filters. During the whole eclipse there were only two nights when we gathered no observations.

Unlike the former, the recently observed eclipse had moderate duration (about 44 days) and was rather shallow, from about 0.7^m to 0.5^m, in U and I bands, respectively. The characteristic phases of the eclipse are schematically distinguished in Fig. 2. This light curve can be easily understood if the projection of the eclipsing body is not circular but has an extremely oblong shape, such as a disk seen edge-on (Graczyk et al. 2003). Changing the spatial orientation of such a flat object varies both the inclination to the line of sight and the tilt into the direction of motion. The outer regions of such a disc should be semi-transparent and they are responsible for mild ingress and egress phases. The central parts of the minimum show the characteristic four contacts similar to those observed in Algols, while in EE Cep the asymmetric eclipse phases reflect the transit of a tilted, flat object.

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