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THE SUDDEN PERIOD CHANGE OF VV CEPHEI

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VV Cep (HD 208816, HR 8383) is known as a massive eclipsing binary consisting of an M supergiant and a Be companion showing strong Balmer and [FeII] emission lines (Cowley 1969). The orbital period, based on photometric data, is $7430^{\rm d}$ (Gaposchkin 1937, Saitō et al. 1980) and the eclipses are apparently total. Wright (1977) has found the spectroscopic orbits of both components from the radial velocity measurements of some neutral atomic lines of the M component and the Hα emissions from an envelope of the hot companion. Assuming the inclination 77° he calculated the masses and sizes of both components concluding that M supergiant does not fill up its Roche lobe. However, quite large eccentricity ($e = 0.346$) indicates that some mass transfer events may exist near the periastron passage, when temporary Roche-lobe overflow drives a stream which forms an accretion disk around the Be companion (Wright 1977, Stencel et al. 1993).

The nature of the hot companion has attracted much attention over the last years. In particular the spectral type and temperature of the B star remain very uncertain. Estimates range from early B or even O (Hutchings & Wright 1971, Stencel et al. 1993) to as late as A0 (Hack et al. 1989).

We have observed VV Cep as a part of a project of UBVRI photometric monitoring of long period binaries. We used one-channel photometer with the 60-cm Cassegrain telescope at the Piwnice Observatory. The UBV realization was very close to the original Johnson's response curves, while R and I bands were centered at *shorter* effective wavelengths of 638 nm and 740 nm, respectively. As the comparison star 20 Cep has been used.

Figure 1 presents our light curves of VV Cep in the UBV bands, covering the period from 1991 to the end of 1998. The large scatter of the observed magnitudes is due to intrinsic variability of both components: semiregular pulsations of the M supergiant (visible in B and V light curves) and random fluctuations of the hot component (seen mainly in U light curve). The amplitudes of the variations were about $0\overset{\rm m}{.}3$ in the UBV bands and about $0\overset{\rm m}{.}2$ in the I and R bands. The eclipse is very well seen in ultraviolet and blue light. In the V light the eclipse is difficult to detect because the amplitude of the M supergiant's pulsations is over three times larger than the depth of the minimum. The period of the semiregular pulsation over the whole eclipse is about 114 d and corresponds very well to the previously reported periods which range from 110 to 118 d (Saitō et al. 1980).

We have analyzed the U$-$B, B$-$V, V$-$R colour curves. This allows us to remove much of the intrinsic variations of the supergiant, in particular its pulsations.

The eclipse duration was calculated using U−B, B−V curves where the eclipse is clearly visible. The eclipse began just after JD 2450541 and ended just before JD 2451177 in both colours. The totality phase seems not to be longer than 450 d in U−B and 477 d in B−V colour. This indicates that the 1997/98 eclipse was similar to the 1957/58 one (Larsson-Leander 1957, 1959) in the duration of totality phase and partial phases (Fig. 2). The previous 1977/78 eclipse (Fig. 3) seems to be different in some aspects: it was asymmetric, with shorter totality phase and longer total duration (Saitō et al. 1980).

The most surprising feature of the eclipse is the disagreement between the observed time of mid-eclipse and the predicted time based on the Gaposchkin's (1937) ephemeris (Fig. 4). The ephemeris gives JD 2450790 for the mid-eclipse time, while the observations (Fig. 2, 3) clearly show that it occurred at around JD 2450855. This means that the mid-eclipse occurred 65 d *later* than expected from the ephemeris. There are two probable reasons for such event: (i) inappropriate Gaposchkin's elements; (ii) the secular or even sudden change of period in VV Cep. We inspected diagram O−C (Fig. 4) for the past five eclipses observed since 1890 and recalculated the times of minima, but we did not find any systematic deviation from the Gaposchkin's elements (see e.g. Saitō et al. 1980). This means that a sudden increase of about 1% in the orbital period occurred between the two last eclipses!

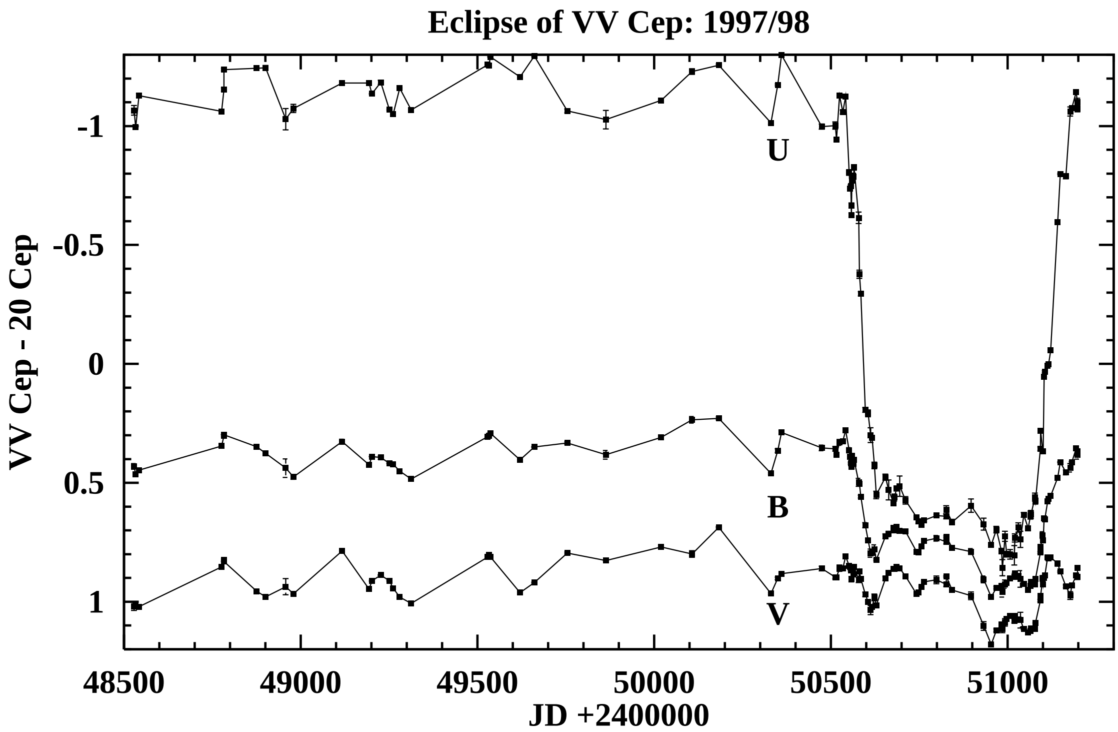

Figure 1. The latest part of the UBV light curves of VV Cep including the 1997/98 eclipse. The comparison star was 20 Cep and its variability was smaller than reported by Saitō (1978). The B and V light curves are shifted by +0.2 mag. and +1.0 mag. respectively. The errors of individual observations are drawn with bars and for most of the nights are smaller than 0.006 for B, V and 0.010 for U band.

The well-known reasons for the period change in binaries are: 1) mass transfer between components, 2) ejection of some amount of mass from a system, or 3) presence of a third body. The sudden increase of the period suggests the first possibility (that is the mass transfer between less massive donor to more massive gainer) or the second one.

Assuming, that the change in the period is caused entirely by a rapid mass-loss event from the M star (the second scenario) we can calculate the total mass ejected during the period of last 20 years. There are two dynamical solutions conceivable in the case of VV Cep system. The first one is the result of the Wright's spectroscopic orbit of the hot component. It is a massive system ($40M_\odot$) with the mass ratio $q = M_{\rm M}/M_{\rm B}$ very close to unity. In this case we obtained the value of the total ejected mass of the order of 0.1 solar mass! This gives the lower limit of the mass loss rate of $\dot{M} = 5\times10^{-3}M_\odot\,{\rm yr}^{-1}$. We propose the second possibility: the *medium mass model* with mass ratio $0.2 \leq q \leq 0.3$. In such a case, rejecting questionable spectroscopic solution for the hot component and using well-defined mass function for the M star $f(m) = 4.68\pm0.44$, we get the mass of a B star of about $8M_\odot$ (typical for early B main-sequence star) and the mass of M star about $2.5M_\odot$ (it corresponds to early AGB phase rather than to supergiants). This gives the total mass ejection of about $0.008M_\odot$ and mass loss rate of $\dot{M} = 4\times10^{-4}M_\odot\,{\rm yr}^{-1}$ which is consistent with the estimates of the upper limits of mass loss rate from the M-component in VV Cep (Stencel et al. 1993, Kawabata & Saitō 1997). Assuming that the change of period is caused by a mass transfer (the first scenario) we get the mass transfer rate of $5\times10^{-2}M_\odot\,{\rm yr}^{-1}$ for $q = 1$ and $5\times10^{-4}M_\odot\,{\rm yr}^{-1}$ for $q = 0.3$. These calculations also advocate the low mass model of the VV Cep system.

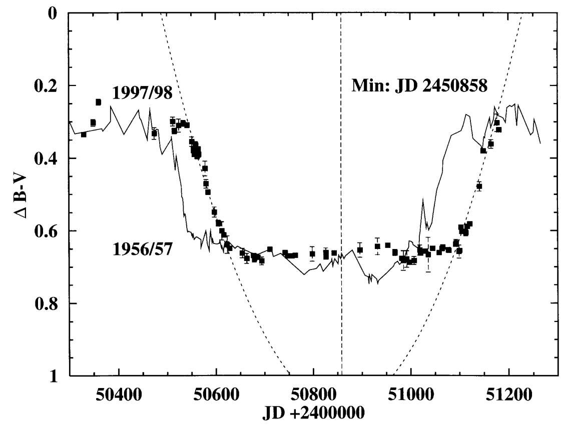

Figure 2. The 1997/98 eclipse in B$-$V (points) and the 1956/57 eclipse in similar P$-$V (solid line, Larsson-Leander 1957, 1959) shifted according to Gaposchkin's ephemeris by $+2\times7430^{\rm d}$. The dashed line is a simple parabolic fit to the shoulders of the eclipse setting the time of mid-eclipse at JD 2450858. Note that both eclipses are symmetric and of similarity in the depth and shape.

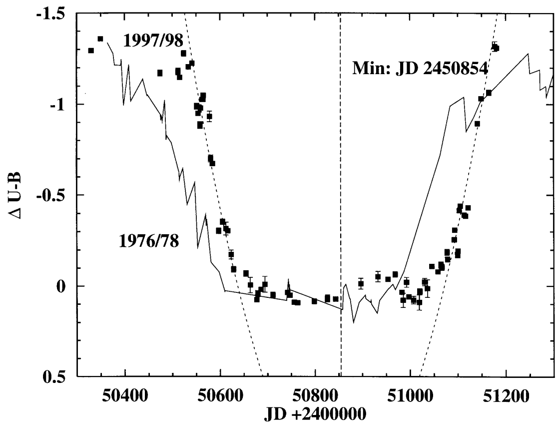

Figure 3. The 1997/98 eclipse in U$-$B (points) and 1976/78 eclipse in 3500 Å–4170 Å colour (solid line, Saitō et al. 1980) shifted by $+7430^{\rm d}$. The dashed line is a parabolic fit to observed shoulders and the time of mid-eclipse is JD +2450854. The minima are slightly different in the shape and the duration of the totality.

Table 1 reports colours and V magnitudes of VV Cep and 20 Cep. The depth of the eclipse does not differ significantly from the last one in 1977 (Saitō et al. 1980). The colours of the B component corresponds to B1 V main sequence star with $E({\rm B}-{\rm V}) = 0.63$. However, this reddening seems to be overestimated in the case of M component.

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Table 1: Colours and V magnitudes for the both components of VV Cep and the comparison star 20 Cep. The colours of VV Cep during totality were adopted for the M component. The UBVR magnitudes of 20 Cep were transformed to Johnson system from Argue (1966, 1967).

Star	U−B	B−V	V−R	V
VV Cep, outside eclipse	0.43	1.73	1.45	5.14
VV Cep, M component	1.82	2.07	1.52	5.25
VV Cep, B component	−0.52	0.36	∼0.4	7.68
20 Cep	1.78	1.41	1.10	5.27

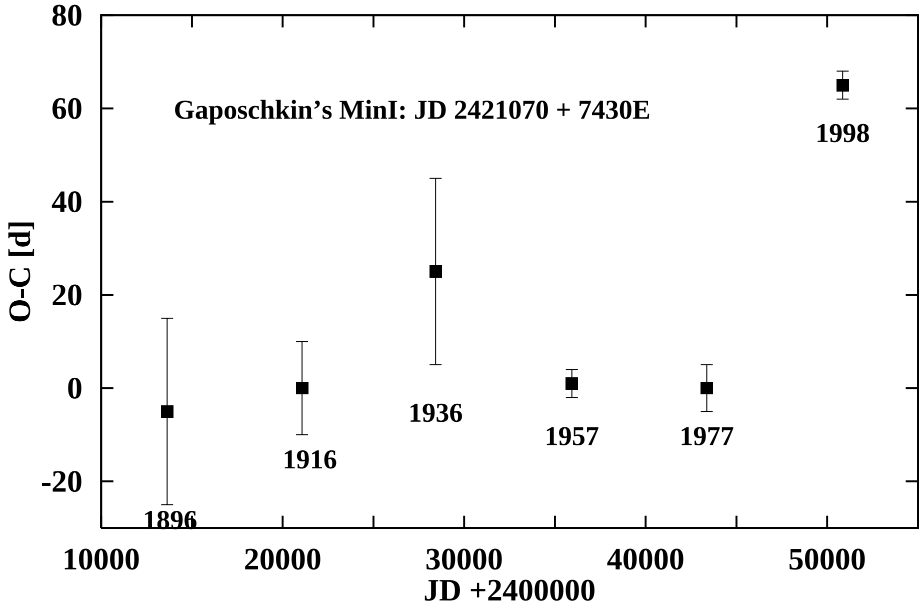

Figure 4. The O−C diagram for the orbital period of the VV Cep system. The times and errors of the first three eclipses were estimated graphically using published photographic light curves by Gaposchkin (1937). The O−C of 1997/1998 eclipse obviously indicates a sudden large change in the orbital period between the last two minima.

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