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BVRI PHOTOMETRY OF VV CEPHEI[1,2]

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ABSTRACT

UBV observations of VV Cep were made in 1988-1992 as a part of the *Ten-year Observing Program for Long Period Eclipsing Binary Stars* (1982-1992) at Yonsei University Observatory. In addition to these the observations in the longer passbands in *R* and *I* are also made in the 1991-1992 season at the same observatory. Atmospheric extinction coefficients determined by a comparison star 20 Cep for *B* and *V* each night have been deduced a linear relation, $k_B = 0.159 + 1.066k_V$. In this paper, light curves of this star in *BVRI* passbands for the 1991-1992 season only are presented. Two periodic light variations of both long-term and short-term are found as for 90 days and 20 days, respectively.

1. INTRODUCTION

VV Cep (HD 208816, $V = 5.10$, M2 I aep + B8Ve, P = 7430 days = 20.36 years) has been known to have two most interesting characteristics aside from many fascinating features common '. all Zeta Aurigae-type stars. The first of these is the longest orbital period and the other the complicated light variations outside eclipse.

The latest eclipse of VV Cep was lasted for two years in 1976-1978, which implies the next eclipse should take place from 1997 Feb to 1998 Aug. Photometric observations have thus been repeated every 20 years for each eclipse in the past, but never been attempted to cover the phases outside eclipse except by Hill *et al.*(1980) who made photoelectric monitoring for five years, 1971-1975, prior to the last eclipse of 1976-1978. Hill *et al.* have investigated intrinsic light variations of VV Cep to check the periodicities proposed by the previous

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investigators; periods of 58 days (Baldinelli *et al.* 1979), 118 days (McCook and Guinan 1978), 150 days (Hayasaka *et al.* 1977), and 349 days and 13.7 years (Fredrick 1960). Conclusion derived by Hill *et al.* gives negative to two shorter periods and positive for the 150 day period. In addition to this long period, they also deduced 25 ± 1 day period, for which they termed "outbursts" in ultraviolet.

At the present time our monitoring, which was initiated in 1988, has been completed one-fifth of its 20 year period of VV Cep in *UBV* passbands. During the last season, 1991-1992, *R* and *I* passbands were included, excluding the *U* data because of cell detector insensitive to this bandpass. Therefore, the present investigation is planned to report the light curves of only the last season, 1991-1992, in order to testify the long term monitoring to complete the whole light curve until AD 2008 for VV Cep.

2. OBSERVATIONS AND REDUCTIONS

Photoelectric photometry of VV Cep in *UBV* has been carried out for four years since the 1988 as a part of the first *Ten-year Observing Program for Long Period Eclipsing Binary Stars* (1982-1992) at Yonsei University Observatory (YUO).

During the first two years, 1988-1990, photometric system used was the same as that given by Nha and Kang (1982). In the third year, 1990-1991, the photometer was replaced by the home-made pulse counting system by Jeong *et al.* (1990), in which an uncooled RCA C31034A photomultiplier with *UBVRI* filters were mounted. However, this photometer had a defect at the filter rotating wheel, and thus replaced again by SSP-3A photometer, which has *UBVRI* filters and 1P21 photomultiplier. For the observations throughout four years, the 61-cm Goto Cassegrain telescope at the Ilsan Station of YUO was used.

BD+62°2010 (HR 8388, $V = 5.93$, M3IIIab) served as a comparison star during the first three years, but due to its variability in brightness this star was replaced by 20 Cep (HR 8426, $V = 5.27$, K4III) and BD+62°2010 was observed as a new variable star during the last year. The photometric behavior of BD+62°2010 during our four year monitoring will be presented elsewhere (Nha and Im 1992).

Instrumental differential magnitudes in the sense $\Delta m =$ VV Cep - 20 Cep are made for only *BVRI* passbands and are corrected by differential extinction. Determination of the atmospheric extinction coefficiencts in *B* and *V* is made by the airmass diagram of 20 Cep each night. These coefficients are listed in Table 1 and are plotted in Figure 1 in a way k_B versus k_V. We found a strong correlationship between the two coefficients as

$$\begin{array}{ccccc} k_B & = & 0.159 & + & 1.066\,k_V. \\ & & \pm.012 & & \pm.031 \end{array} \qquad (1)$$

For *R* and *I* passbands, on the other hand, attempt has been made for the determination of the atmospheric extinction coefficients of each night but fixed values 0.35 and 0.30 for *R* and *I*, respectively, were adopted for the differential extinction corrections.

Table I. Atmospheric extinction coefficients at the Ilsan Station of YUO in 1991-1992. Coefficients were derived by the *B* and *V* magnitudes of 20 Cep. Three nights have double entries because of the variable sky conditions.

Date	k_V	k_B	Date	k_V	k_B
1991 Sep 21	0.382	0.520	Nov 12	0.340	0.540
Sep 28	0.538	0.725	Nov 13	0.200	0.384
Sep 30	0.400	0.520	Nov 14	0.230	0.400
Oct 05	0.140	0.314	Nov 16	0.658	0.970
Oct 08	0.135	0.313	Nov 23	0.235	0.381
Oct 09	0.141	0.320	Nov 23	0.270	0.422
Oct 10	0.206	0.382	Nov 26	0.436	0.652
Oct 11	0.170	0.360	Nov 30	0.450	0.595
Oct 12	0.532	0.803	Dec 01	0.572	0.757
Oct 13	0.209	0.390	Dec 11	0.435	0.600
Oct 17	0.312	0.475	Dec 19	0.442	0.492
Oct 18	0.255	0.440	Dec 21	0.440	0.500
Oct 20	0.270	0.460	Dec 29	0.400	0.590
Oct 20	0.336	0.532	1992 Jan 01	0.569	0.805
Oct 22	0.266	0.482	Jan 02	0.345	0.515
Oct 22	0.422	0.644	Jan 03	0.490	0.680
Oct 23	0.333	0.556	Jan 04	0.605	0.821
Oct 25	0.738	0.928	Jan 09	0.781	0.931
Oct 28	0.210	0.383	Jan 10	0.431	0.550
Oct 31	0.420	0.684	Jan 18	0.412	0.577
Nov 03	0.251	0.421	Jan 19	0.340	0.521
Nov 04	0.347	0.553	Jan 22	0.503	0.662
Nov 05	0.437	0.657	Jan 23	0.534	0.730
Nov 06	0.680	0.972	Jan 25	0.480	0.631
Nov 10	0.335	0.537			

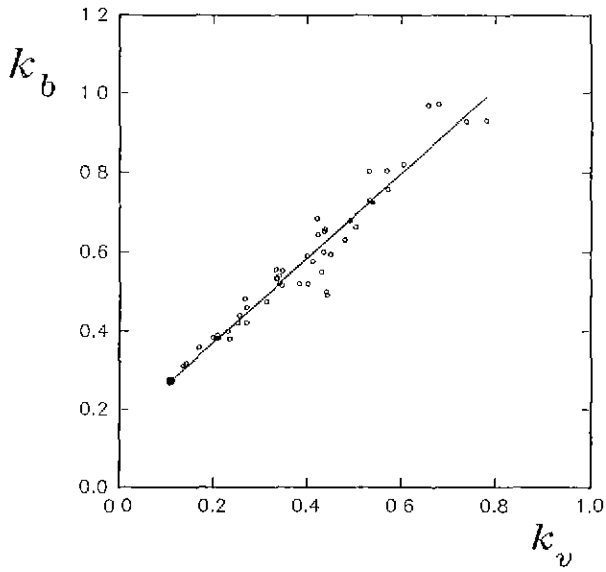

Figure 1. The k_V vs. k_B relation in the season of 1991-1992. Comparison star 20 Cep was used for the determination of k_s. A large closed circle at the left end of the straight line represents a pure Rayleigh scattering.

3. LIGHT CURVES

Standardized *B*, *V* and color curves of 20 Cep are made in Figure 2. As are clear in the figure all three curves show that the comparison star 20 Cep was in constant brightness during the period of observations. Average values of *V* and *B*-*V* of 20 Cep are 5.280± 0.026 and +1.436± 0.021, respectively. These are given in Table II with the collected values available from literature.

Table II. Standardized *V* and colors of 20 Cep.

V	*B*-*V*	*U*-*B*	Reference
5.30	+1.46	+1.76	Nakagiri (1977)
5.28	+1.48	+1 83	Saito *et al.*(1980)
4 91	+1.77	+0.39	Hoffleit (1982)
5.28	+1.44	+1.78	Huang & Guo (1987)
5.28	+1.436	—	Nha & Im (this paper)

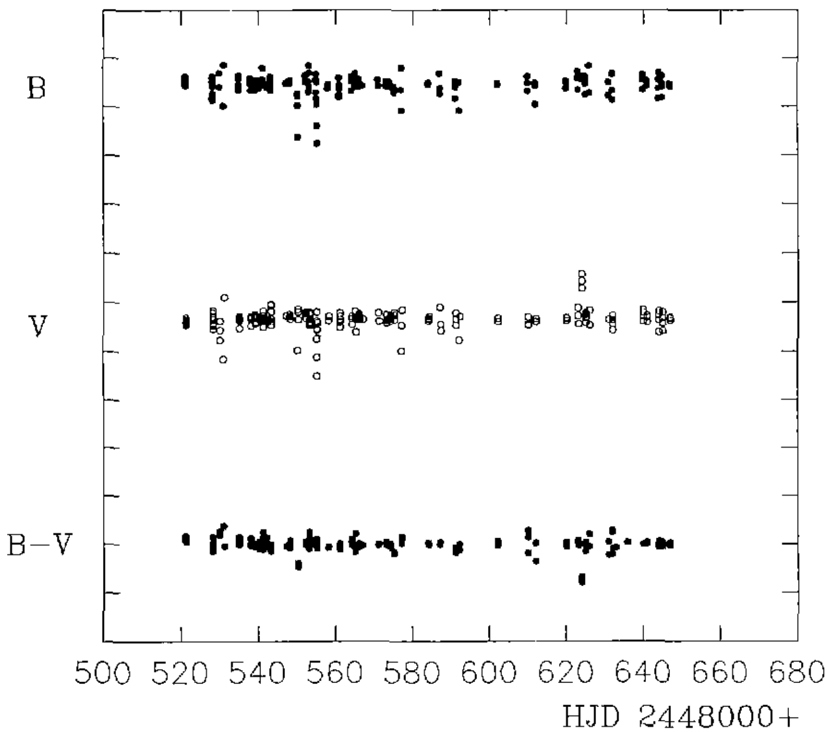

Figure 2. Standardized B, V, and $B-V$ curves of 20 Cep for the 1991–1992 season.

B AND *V* CURVES OF VV CEP

Because of the reasons mentioned earlier, the *U* observations in the 1991–1992 season were discarded, and thus only *B* and *V* obsevations are discussed. A total of 435 observations (213 in *B* and 222 in *V*) is made for 46 nights, and the differential instrumental magnitudes are plotted with respect to Julian dates in Figure 3 below. Since the constant brightness of the comparison star 20 Cep is guaranteed, the light variations of VV Cep exhibited in Figure 3 are solely responsible to the intrinsic variations of the one of/or both components of VV Cep. The light variations of this star show a larger amplitude with shorter wavelength.

The light variations of VV Cep were analysed by many investigators already mentioned in the Introduction. Due to multiple periods for the light variations of this star, the shapes of the light curves are resulted by the beat effects of two or more periods as those seen in Figure 3. As the results of this, gradual long-term light variations of semi-regular with different amplitudes are apparent in Figure 3.

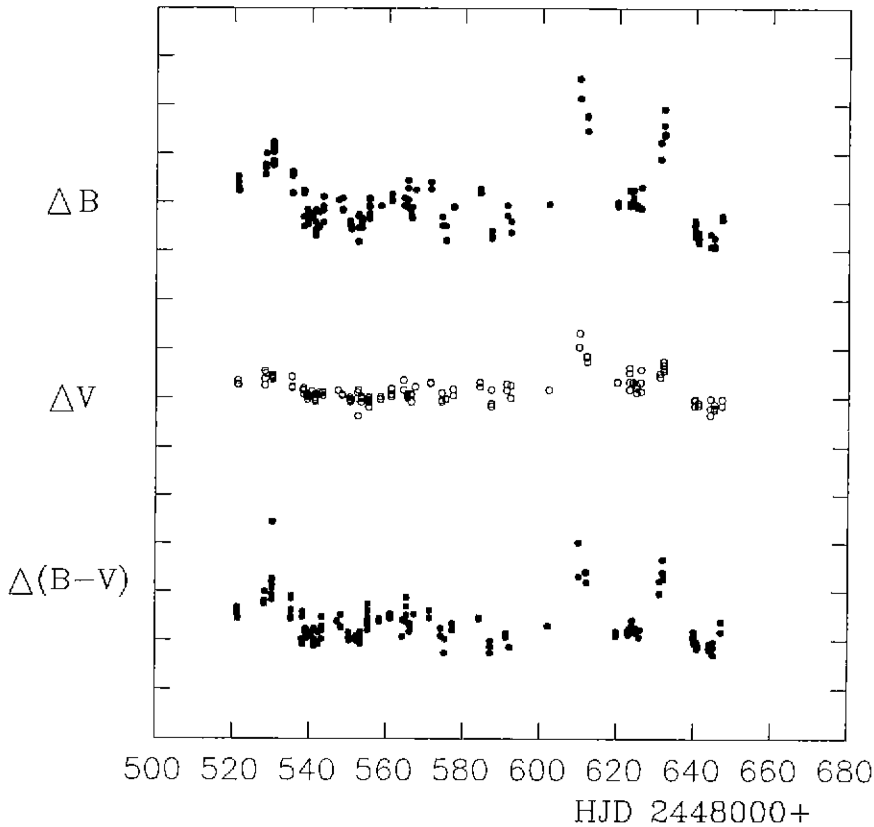

Figure 3. Instrumental ΔB, ΔV, and color curves of VV Cep (1991–1992).

Significant outbursts are also noted on JD 2448530, JD 2448610.0 ~ 1.9, and JD 2448630.9 ~ 1.9. Sharp increases of brightness, particularly in the last two dates separated for nearly 20 days, show the light amplitude more than 0.4 mag in *B*.

R AND *I* CURVES OF VV CEP

The present *R* and *I* filters have passbands comparable to those of Johnson system. To our knowledge, no one has attempted the observation of VV Cep in these wavelength regions so far. With instrumental differential magnitudes, *R*, *I*, and color curves of VV Cep are made with respect to Julian dates in Figure 4 with a same scale as in Figure 3. Scatter of data both in *R* and *I* is greater than that of *V* observations in Figure 3. The overall shape of light variations is, however, comparable to those of *B* and *V* curves missing only the first outburst on JD 2448530. Two outbursts on JD 2448610.0 ~ 1.9 and JD 2448630.9 ~ 1.9 mentioned for *B* are present, but the amplitudes are much smaller. At least one additional outburst, which is missing in *B* and *V*, is clearly appeared on JD 2448587.0 on both *R* and *I* curves.

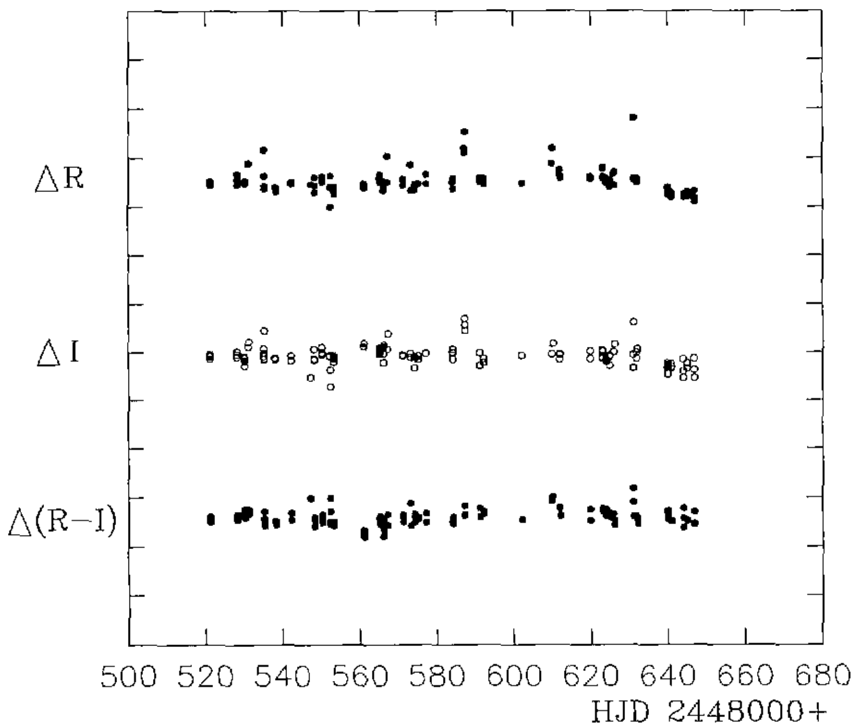

Figure 4. Instrumental ΔR, ΔI, and color curves of VV Cep (1991–1992).

4. DISCUSSION

It is interesting with the present photometric data to investigate the periodicities of light variations of VV Cep reported by previous investigators mentioned earlier. There are suggestions for the periodicities in a wide range from 25 days(the shortest) to 13.7 years(the longest). The time span of the present observations in the 1991-1992 season is, however, rather short about 120 days to give any definitive period longer than about 100 days for the light variations. For the shorter periods, on the other hand, the *B* and *V* light curves in Figure 3 show very pronounced outbursts at the three different epochs. The interval between the last two is nearly 20 days. In the *R* and *I* curves in Figure 4 shows an additional outburst at an epoch prior to the second outburst in the *B* and *V* by about 20 days. Based on these four outbursts, three in *B* and *V* and one in *R* and *I*, one can deduce a period of occurence of the outbursts in the VV Cep of the order of about 20 days. These epochs are indicated with vertical lines in Figures 3 and 4.

There are strong indications of periodic variations longer than 20 days in *B* curve. However, due to the complexity of the light variations particularly in *B*, it is difficult to give any numerical value of it. It is fortunate to have *V* curve, the least scattered light curve, which gives a clear shape of longer period of light variation. It is, therefore, easy to figure it out a period of about 90 days in the *V* curve and possibly in *B* and *R* curves. In the *I* curve, no attempt is possible because the light curve shows no appreciable variation other than those of outbursts mentioned already.

Hill *et al.* (1980) studied critically the periodicities of intrinsic variations of VV Cep and deduced 25 day and 150 day periods, but rejected 58 days by Baldinelli *et al.* (1979) and 118 days by McCook and Guinan (1978). They claimed the 25 day variations as the "*outbursts*". The interval by them is longer than ours by 5 days. It is hoped, however, that our future investigation based on our previous unreduced data of three years, 1988-1991, and those of future monitoring will conceive fruitful results regarding the periodicities of light variations of this interesting close binary system.

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