Photometry of VV Cep stars

By: A. S. Miroshnichenko and A. S. Ivanov

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Abstract:

Photometric *UBVRI* and *UBVRIJHL* observations of 17 VV Cep stars were carried out from the end of 1989 to the beginning of 1993. For six of the stars, this *was* the first *UBVRI* photometry ever. The mean brightness level of the objects studied was found to be the same as that observed at the end of the 1960s. The observed features of the star PZ Cas were analyzed, and they were found to be more typical of binary systems of the VV Cep type than of isolated M supergiants. Observational data for NS Vul were considered, and these indicate that its components may not be physically related.

Article:

Introduction

VV Cep stars are binary systems consisting of an M supergiant and a hot dwarf or giant, which is, as a rule, of spectral type B. These stars were identified by Bidetman (1954) via their spectra, which have multiple FeII emission lines in addition to TiO absorption bands. VV Cep stars were described in detail in Cowley's survey (1969), which mentions 13 objects of this type known at that time. In a study of M supergiants, Lee (1970) gave averaged results of *UBVRUHKL* photometry of 10 VV Cep stars obtained over a short period of time at the end of the 1960s. The majority of these objects proved to be bright infrared sources, both because of the late spectral type of the primary components and because approximately half have dust envelopes. The latter was subsequently verified by data obtained with the IRAS satellite (Olnon and Raymond, 1986): emission bands of silicate dust grains were detected in their spectra at 10 and 18 μ. Lee (1970) also identified several possible candidates for this group on the basis of an ultraviolet excess. These stars (Cas 61, PZ Cas, BD + 32°1113, BD -6°4827) were, however, subsequently not placed in the group. Abramyan (1983), who studied the variability in the *UBV* bands and the polarization of the radiation of late supergiants, included seven VV Cep stars in his program.

Snow and Buss (1988) carried out an interesting study of 24 objects of this type, Using IRAS data, they divided these stars into three groups, according to the ratios of their radiation fluxes at 12 and 25 μ: with dust envelopes, with gaseous envelopes, and without envelopes. They concluded, however, that the dust distribution around an M supergiant is (to a first approximation) spherical. The energy distribution in the spectra of some VV Cep stars was modeled by Rowan-Robinson and Harris (1982), within the framework of the model of a late star with a spherical dust envelope, without taking into account the possible contribution of the hot components of the system. At present, about 30 objects in the Galaxy are in this category. All of these are stars brighter than $10^m.5$ in the V band, and most are known to be variables. Eclipses have been observed in only two systems: VV Cep and AZ Cas. The orbital periods of these are about 20 years and 40 years, respectively, It is assumed that eclipses may also be observed in WY Gem (Cowley, 1969).

Despite the considerable attention devoted to these objects, a number of pertinent problems remain, including a) the relationship between the optical variability and the infrared variability on different time scales; b) long-term variability (years, decades) and, in particular, the possibility of eclipses in the systems; c) the characteristics of the dust envelopes of these stars, and in particular the effect of hot companions on their structure; d) observable features differentiating VV Cep stars from symbiotic stars.

TABLE I. Observational Data for VV Cephei Stars

Star	JD 244..	*U*	*B*	*V*	*R*	*I*	*J*	*H*	*K*
TV Gem	8553.39	10.63	8.91	6.65	4.71	3.22			
(BS 2134)	8554.40	10.70	8.88	6.62	4.67	3.19			
	8932.40	10.73	9.20	6.97	4.75	3.31			
WY Gem	8553.41	9.32	8.92	7.28	5.45	3.92			
(BS 2134)	8554.42	9.38	8.95	7.30	5.46	3.97			
	8932.41	9.43	9,01	7.28	5.35	3.98			
	8551.32	11.28	10.95	9.20	7.33	5.84			
	8552.24	11.15	11.06	9.26	7.31	5.82			
	8553.25	11.10	11.05	9.29	7.36	5.88			
BD + 57°641	8554.27	—	11.06	9.27	7.34	5.91			
(BS 825)	8556.24	11.18	11.05	9.24	7.36	5.85			
	9000.08	11.20	10,92	9.27	7.35	5.75			
	9001.07	11.31	10,97	9.35	7.29	5.64			
	8554.11	11.44	10,75	9.01	7.04	5.55			
BD + 54°2698	8932.16	11.60	10,87	9.30	7.22	5.47			
(BS 8506)	8933.14	11.53	10,81	9.05	7.08	5.53			
	8935.21	—	10,86	9.16	7.10	5.51			
5 Lac	8555.14	6.97	5.94	4.22	2.62	2.10			
(BS 8632)	8935.20	7.20	6.02	4.31	—	—			
XX Per	8555.28	12.03	10.17	8.11	5.83	4.12			
(BS 621)	8556.25	11.77	10.18	8.12	5.81	4.08			
	8932.33	11.61	9.89	7.79	5.52	3.94			
	8933.23	—	10,09	7.99	5.53	3.89			
	8932.35	11.66	10,83	9.45	8.03	6.84			
	8933.26	11.81	10,94	9.53	8.01	6.81			
	8935.27	11.59	10,90	9.45	8.05	6.88			
BD + 59° 420	8995.09	11.47	10,82	9.39	7.97	6.74			
(BS 641)	8996.12	11.46	10,83	9.42	7.95	6.72			
VV Cep	7789.28	7.06	6.85	5.08	3.28	1.91	1.01	0.19	−0.15
(BS 8428 — *UBVRI*,	8109.40	7.01	6.69	4.89	3.10	1.76	1.04	0,22	−0,09
BS 8162 — *JHK*)	8555.13	7.38	6.99	5.31	3.37	1.81	—	—	—
FR Sct	8111.23	—	12.52	10.33	7.74	5.85	3.90	2.74	2.24
(BS 6884 — *UBVRI*,	8112.20	—	12.55	10.47	7.82	5.89	4.02	2.78	2.24
BS 6973 — *JHK*)	8113.22	—	—	—	—	—	4.04	2.83	—
BD + 61° 219	8113.47	12.69	11.80	9.61	7.23	5.46	4.20	3.14	2.72
V554 Cas	8551.25	12.80	11.72	9.56	7.19	5.43	—	—	—
(BS 253)	8552.22	12.27	11.69	9.51	7.11	5.39	4.14	3.01	2.76
	8553.22	12.50	11.65	9.43	7.15	5.42	—	—	—
	8929.21	12.87	11.95	9.82	7.26	5.53	—	—	—
	8933.20	12.85	11.80	9.71	7.23	5.51	—	—	—
	9003.09	12.59	11.71	9.63	7.20	5.49	—	—	—
	8113.48	—	—	—	—	—	—	4.55	4.15
	8552.16	12.00	11.27	9.52	7.83	6.47	—	—	—
	8554.20	11.95	11.31	9.58	7.86	6.47	—	—	—
KN Cas	8932.25	12.00	11.33	9.70	7.89	6.51	—	—	—
(BS 244)	8933.22	12.11	11.35	9.70	7.85	6.49	—	—	—
	8934.30	11.92	11.42	9.76	7.87	6.50	—	—	—
	8998.10	11.93	11.40	9.80	7.80	6.24	—	—	—
AZ Cas	8115.47	11.29	11.03	9.30	7.59	6.32	5.32	4.48	4.12
(BS 511)	8933.27	12.09	11.04	9.37	7.62	6.36	—	—	—
	8552.17	11.12	10.16	8.04	5.85	4.28	—	—	—
	8554.21	11.37	10.16	8.02	5.81	4.18	—	—	—
	8932.24	10,89	10.20	8.34	5.95	4.32	—	—	—
V641 Cas	8933.21	10,95	10.27	8.36	5.95	4.31	—	—	—
(BS 60)	8934.28	10,98	10.28	8.34	5.93	4.26	3.30	—	1.82
	8997.09	10,97	10.30	8.38	5.95	4.25	—	—	—
	9000,06	10,99	10.32	8.42	5.87	4.18	—	—	—
KQ Pup	8555.42	6.71	6.41	4.95	3.31	2.07	—	—	—
(BS 3064)	8933.50	6.52	6.49	4.89	3.17	1.94	—	—	—
	8934.47	6.62	6.49	4.87	3.18	1.93	1.26	0.40	0.27
	9000.24	6.60	6.42	4.90	3.17	1.93	—	—	—
W Cep	7813.24	10.23	9,72	7.61	5.89	4.64	3.64	3.07	2.53
(BS 8538 — *UBVRI*,	8109.47	10.31	10.06	8.21	—	—	3.84	3.28	2.71
BS 8707 — *JHK*)	8554.14	—	9.64	7.84	6.10	4.69	—	—	—
	8555.16	10.32	9.54	7.67	6.11	4.87	—	—	—
	8932.18	10.35	9.53	7.45	5.74	4.70	—	—	—
	9002.05	10.03	9.44	7.50	5.81	4.78	—	—	—
U Lac	7814.23	12.78	11.02	8.79	6.30	4.44	3.02	2.12	1.58
(BS 8688 — *UBVRI*,	8112.40	—	10,98	8.66	6.22	4.39	3.07	2.23	1.67
BS 8707 — *JHK*)	8109.46	12.61	10,87	8.59	6.12	4.26	3.09	2.25	1.66
	8495.33	—	11.24	8.88	6.16	4.14	3.19	2.42	1.89
	8496.34	—	11.20	9.10	6.33	4.35	3.26	2.35	1.78
	8554.16	—	11.14	8.80	6.35	4.52	—	—	—
	8932.19	12.50	11.25	9.04	6.34	4.50	—	—	1.48
	8934.17	12.19	11.11	8.91	6.19	4.45	3.13	2.38	1.77
NS Vul	8402.41	9.09	8.75	7.76	4.78	2.50	0.45	−0.42	−0.86
(BS 7506 — *UBVRI*,	8409.38	9.12	8.77	7.69	4.79	2.43	0.74	−0.29	−0.61
BS 7525 — *JHK*)	8934.08	8.92	8.83	8.05	4.79	2.49	0.76	−0.28	−0.61
PZ Cas	8932.22	12.77	11.99	9.47	6.26	4.27	—	—	-
(BS 8707)	8934.26	—	12.40	9.58	6.27	4.25	2.73	1.70	1.14

Note. The column giving the name of the star also gives the names of the comparison stars and the bands which were calibrated.

Moreover, several objects variously assumed to be VV Cep stars remain unstudied: CPD —61°3575 (Cowley, 1969) and BD +59°420 (Humphreys, 1969).

The purpose of our work is to obtain new photometric data for the majority of northern VV Cep stars, in the visible range and in the near infrared, over an extended time interval, including the photometry of objects previously not observed in this region, and to analyze the material accumulated so far concerning certain individual objects.

Observations. From September 1989 through January 1993, 66 *UBVRI* and 24 *UBVRIJHK* (Johnson system) quasi-synchronous photometric observations of 18 VV Cep objects and candidates were carried out. These observations were made with a 1-meter telescope at the Assay high-altitude station (Zailiiskii Altau) of the Kazakh Academy of Sciences. A two-channel FPZU photometer —polarimeter was used (Bergner et al,, 1988), As comparison stars, stars from the BS Catalog (Hoffleit and Jaschek, 1982) were observed, these being located no more than 3° from the object being studied, The observational data are given in Table I, The measurement errors in the *UBVRI* bands did not exceed $0^m.02$, in the JHK bands $0^m.03$, and for stars fainter than 11^m in the *U* band $0^m.07$. For technical reasons, observations were not obtained in the infra-red for all objects in the program.

Discussion. The above program yielded the following results:

a) new photometric data in a uniform system were obtained for 18 VV Cep Stars and candidates for this group;

b) for the first time, simultaneous *UBVRI* observations were obtained for W Cep, V641 Cas, BD +57°641, and BD +54°2698, as well as *UBVRIJHK* observations for V554 Cas;

c) the first *UBVRI* photometry of BD +59°420 was obtained, the analysis of which (since there was no infrared source close to the optical position of the object) via an infrared survey of the sky at 2 μ (Low, 1970) and IRAS data (Gezari et al., 1987) leads to the conclusions that there is no dust envelope around this star and that it may be a ζ Aur star (a K supergiant with a hot companion);

d) a good fit was obtained with the results of Lee (1970) for all the common objects, indicating stability of the characteristics of the stars and their envelopes a time scale of more than 20 years.

Let us consider in more detail some of the results obtained so far for individual objects of this type.

PZ Cas. This year is classified as a supergiant of spectral type M2-4 (Kholopov et al., 1985); OH maser condensations are observed nearly (te Lintel Hekkert et al., 1989). Its *U* — *B* color index varies from $0^m.2$ to $1^m.2$ (Lee, 1970; Abramyan, 1983) and is on the average much less than those of isolated M supergiants (~$2^m.0$). It varies by $1^m.1$ in the *V* band (Abramyan, 1983). These variations are quasiregular with a period of 801.3 days (Kudashlcina, 1985). The infrared spectrum of PZ Cas includes a strong emission line at 10 μ (Olnon and Raymond, 1986), while IRAS photometry (Gezari et al., 1987) indicates that the flux at 25 μ exceeds the flux at 12 μ. The latter is more typical of early-type stars and optically un-identified OH/infrared objects with optically thick dust envelopes, The silicate emission band and the bright visual luminosity of PZ Cas ($V = 8^m.5$-$9^m.5$) point to a small optical depth of its circumstellar dust. The energy distribution in the 10-30 μ region may be due to the contribution of the hot component in this system. Unfortunately, however, we could not find in the literature any information about the composite spectrum of PZ Cas. On the other hand, the radiation of a hot star can show up only in the ultraviolet, as in the case of, for instance, TV Gem (Underhill, 1984).

Using the data of Abramyan (1983), we studied the *UBV* variability of some isolated M supergiants in VV Cep systems. These objects vary by up to $1^m.5$, and the variations can be divided into two kinds: irregular variations of small amplitude ($0^m.1$-$0^m.2$), and stronger slow quasiregular variations with periods of several hundred days, For stars with variability only of the first type, the correlations of the variations in different bands are not very pronounced, whereas for stars with a pre-dominant variability of the second type these variations are synchronous. In the latter case, the color index decreases as the star dims, as a rule, while it increases as the star brightens. After considering various features of this variability, we concluded that for VV Cep stars and isolated M supergiants, different dependences between the luminosity variations in the *U* and V bands are observed, For stars with a quasiregular variability we used the method of least squares to determine the coefficients of the dependences of *U* and *V(k)* and we constructed the graph of *k* as a function of *U* — *B* shown in Fig. 1. It is seen from the graph that PZ Cas lies in the region occupied by VV Cep stars. The separation of double and isolated stars in this case can be attributed to the presence in a binary system of a hot source, which is its main contributor of radiation in the *U* band, Therefore, in many respects PZ Cas can be classified as a VV Cep star. This object obviously warrants closer study.

NS Vul. In contrast to other VV Cep stars, this object has a considerably lower *B* — V color index (see Table I), which suggests a greater contribution of the hot star to the total energy distribution in the spectrum. Moreover, NS Vul is known to be a visual binary with components of spectral types M4-5 and A0-2 with an angular separation of 0".7 = 0".8. For the cooler star, the luminosity class has been estimated to be II-III (Snow and Buss, 1988) or III (Kholopov et al., 1987), and for the hot star it is II (Snow and Buss, 1988). A silicate emission band is observed in the infrared spectrum (Olnon and Raymond, 1986), and Walker and Wolstencroft (1988) attribute to it to the early component.

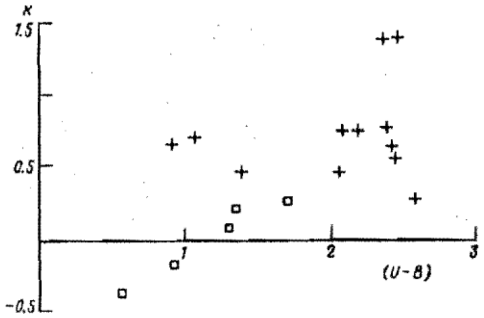

FIG. 1. Dependence of k on mean color index $U-V$ for objects with high amplitude of variability, according to Abramyan (1983). Crosses denote isolated supergiants, and square VV Cep stars.

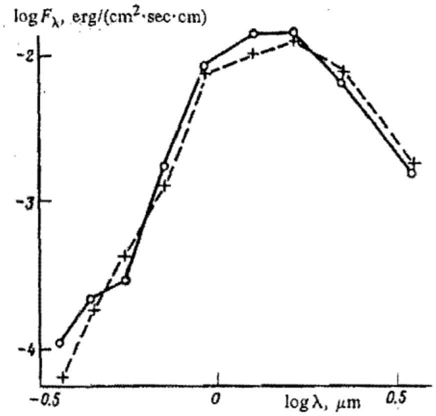

FIG. 2. Spectral distribution of NS Vul: points show observed energy distribution, and crosses show calculated distribution for system consisting of an M5 III star and an A1 V star with $A_V = 3^m.4$.

Despite meager observational data on NS Vul, we can still try to decide whether this system is a VV Cep and whether its components are physically related. Let us analyze the observed spectral energy distribution (Lee, 1970; this work), assuming that in the range from 0.3 to 3.5 μ is determined by radiation from the stellar components and by interstellar absorption. The color index in the near infrared suggests that the contribution of radiation from the dust shell is very small; the energy distribution at longer wavelengths (Gezari et al., 1987) shows that its optical depth is small and, consequently, that it has only a slight effect on the energy distribution in the visible part of the spectrum.

To calculate the energy distribution of the system with the indicated assumptions, and assuming a normal color index for the stars (Straižis, 1977; Koorneeff, 1983), we used the wave-length dependence of interstellar absorption given by Savage and Mathis (1979). Using the given estimates of the spectral types of the stars and assuming interstellar absorption to be the same for both, we were unable to obtain a satisfactory fit between the calculated and observed energy distributions over the spectrum (Fig. 2). The energy distribution in the 0.3-0.55 μ range can be explained only by assuming the presence of an earlier hot star. This may well be because the stars are not physically related, so that interstellar absorption differs between the two. On the other hand, if we use the data of Walker and Wolstencroft (1988) for the hot component of the system [$M_V = 1^m.2$, D = 229 pc (where D is the distance to the star)] then the angular distance between the components will correspond to a distance of $3.4 \cdot 10^{15}$ cm. This is approximately ten times the distance between the components of VV Cep eclipsing binaries, estimated on the basis of the observed orbital periods. Nevertheless, if the cool star is classified as M5 III, then for $M_V = -0^m.1$ (Strains and Kurilene, 1981) its distance is found to be about the same as that of the A star. However, calculations of the energy distributions for stars of different spectral types reveal that for any combination of the latter the best fit with the observed energy distributions is obtained by assuming interstellar absorption of the order of 201. In the ultraviolet spectrum of NS Vul (Snow and Buss, 1988), the absorption band at 2200 Å is appreciable, confirming that there is interstellar absorption. However, at distances of 0.2- 0.3 kpc from the sun values of $A_V \sim 2^m$ are rarely encountered. In this case, if NS Vul is indeed a physical binary, then the spectral type of the cool component is atypical of VV Cep stars. With an increase in the luminosity of the components, the estimated linear distance between them becomes so great that it is difficult to consider them to be gravitationally bound.

Consequently, there are a number of factors which lead us to doubt that the stars of the NS Vul system are physically related and that they are indeed VV Cep stars. Further observations of this object, as well as a more accurate luminosity classification of the components, are needed in order to answer these questions.

KN Cas. This is a fairly stable object, whose fluctuations of luminosity and color index did not exceed $0^m.2$ from September 1973 through August 1976 (Abramyan, 1983), in September—November 1976 exhibited a synchronous increase in $U — B$ and $B — V$, together with a drop in visual brightness. It is quite possible that this was an eclipse of the hot component, Our observations recorded an ordinary brightness and color state of the star. Further monitoring of this object would be useful for the detection of possible eclipses.

Having completed this study, the authors hope to continue their investigation of VV Cep stars and, above all, of their dust shells and variability.

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