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Photoelectric photometry of the Beta Cephei star BW Vulpeculae (1988 - 1991) ⋆

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Abstract. — BW Vul, the β Cephei star with the largest-known amplitude, has been observed through several cycles of pulsation. The data, obtained at three observatories, were homogenized, and are presented in tabular form. Times of minimum and maximum light were derived, and a contemporary value for the period is deduced. Our data do not reveal any sudden period change in the time span 1988–1991.

Key words: photometry — β Cephei stars — BW Vul — period changes

1. Introduction

BW Vul (HD 199140 = HR 8007, B2III, $V = 6.55$) has the largest known amplitude of light variation and radial velocity variation among the β Cephei stars. The light curve is marked by a stillstand phase, the beginning of which precedes time of maximum by about $0^{\rm d}.05$. The duration of the stillstand is close to $0^{\rm d}.03$. The peak-to-peak amplitude of the light variation is approximately $0^{\rm m}.2$ in the visual domain and increases to about $1^{\rm m}.2$ at ultraviolet wavelengths (see Sterken et al. 1987, fig.3). The period of the variation is approximately 5^h, and is now secularly increasing at a rate of the about 2 seconds/century.

BW Vul was the subject of several photometric campaigns. This paper presents photometric observations obtained at three observatories during the time span 1988-1991. An analysis of part of these data has been published by Jiang & Liu (1991). A full discussion of the period history of this star will be the subject of a subsequent paper.

2. The observations

2.1. *The equipment*

At Jungfraujoch Observatory (Long. = 7°59′06″, Lat = 46° 32′54″, Alt. = 3600m) measurements were obtained with a 76-cm reflector telescope and the Geneva P1 photoelectric photometer. A Lallemand S-11 photomultiplier, refrigerated at about -23°C, was used as detector. The system was equipped with a DC amplifier and a strip chart recorder.

At Białków station (Long. = 16°39′36 ″, Lat. = 51°28′32″, Alt. = 130m) a 60 cm reflecting telescope and a conventional photoelectric photometer were used. The detector was an unrefrigerated EMI 6256S photomultiplier tube. The signal was fed through pulse-counting electronics, and the output was recorded on magnetic disk.

The observations at Xinglong (Long. = 117°34′35″, Lat. = 40°23′36″, Alt. = 960m) were obtained with the 50 cm reflector to which a sequential photometer was attached. The detector was an EMI6256 photomultiplier, used in DC mode.

Figure 1 gives a schematic representation of the combined transmission curves of the filters and the response curves of the photocathodes used. Table 1 gives the journal of observations.

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⋆ Based on observations collected at Hochalpine Forschungsstation Jungfraujoch (Switzerland), Białków observing station of Wroclaw University, and Xinglong observing station of Beijing Observatory

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Table 1. The journal of observations. J = Jungfraujoch, B = Białków, X = Xinglong. The observer designation stands for the authors' initials. DB is D. Boratyn, GB is G. Busarello, MD is M. Dumont and co-workers, and MJ stands for M. Jerzykiewicz

Date	HJD244	Site	Observer	Quality
15 June 88	7328	J	CS	good
18 June 88	7331	J	CS	medium
23 July 88	7366	B	AP	medium
25 July 88	7368	B	AP	medium
26 July 88	7369	B	AP	good
28 July 88	7371	B	MJ	acceptable
19 Sep 88	7424	J	CS	medium
20 Sep 88	7425	J	CS	medium
21 Sep 88	7426	J	CS	medium
9 June 89	7687	B	AP	medium
13 June 89	7691	J	CS	acceptable
17 June 89	7695	J	CS	medium
21 July 89	7729	B	AP	good
30 Aug 89	7769	J	MD	good
6 Sep 89	7776	J	MD	medium
21 Sep 89	7791	J	CS, GB	good
28 Sep 89	7798	X	LZ	medium
30 Sep 89	7800	X	LZ	medium
1 Oct 89	7801	X	LZ	medium
17 Nov 89	7848	B	AP	medium
29 Aug 90	8133	B	AP	medium
9 Oct 90	8174	B	AP	good
28 Aug 91	8497	B	AP	reas/good
5 Sep 91	8505	X	LZ	good
6 Sep 91	8506	J	CS, DB	medium
7 Sep 91	8507	J	CS, DB	good
8 Sep 91	8508	J	CS, DB	medium

2.2. *The observing scheme*

The observations were carried out according to the scheme $C_1, P, C_2, P, C_1, \ldots$ or $C_1, P, C_2, C_1, P, C_2, C_1, \ldots$, where P, C_1 and C_2 denote measurements of the program and comparison stars, respectively. At Jungfraujoch each datapoint consisted of a measurement of about 50 seconds to 1 minute duration. Sky background was measured about once every one to two cycles. Comparison stars were the same as C_1 and C_2 used by Sterken et al. (1986), viz. HD 198820 = HR 7996 (B3III, $V = 6.44$) and HD 198527 = SAO 089185 (B9.5V, $V = 7.0$), but on all nights indicated with CS in Table 1, the scheme $C_1, P, C_1, P, C_1, \ldots$ was applied. All measurements were taken through the V_1 filter of the Geneva system.

At Białków, the same comparison stars were used in a similar observing sequence as at Jungfraujoch, with the exception that the sky measurements were performed after every star measurement. Observations covered either eight 8-s or 10-s integrations for each measurement. All measurements were taken through a Strömgren y filter.

At Xinglong station, measurements of BW Vul were sandwiched between measurements of two comparison stars. In 1989 the above-mentioned comparison star C_2 = HD 198527 was used together with C_3 = HD 199102 = SAO 89259 (B9.5V, $V = 7.6$), and the measurements were carried out through a Strömgren b filter. In 1991 the comparison stars were C_1 and C_2, and a Johnson B filter was used.

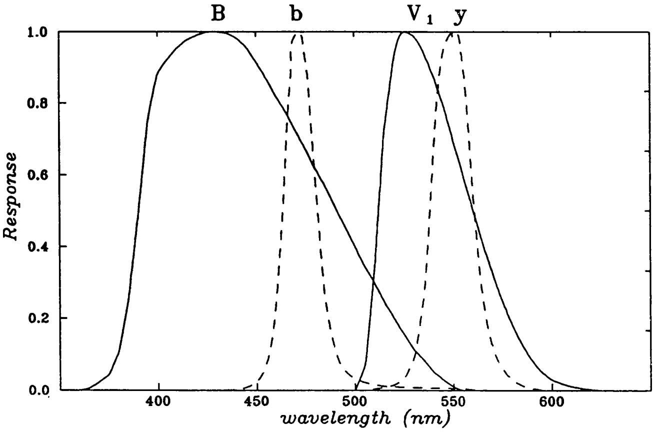

Fig. 1. Standard response curves for the y, b, B and V_1 passbands

2.3. *The reductions*

The data were corrected for sky background contribution, and for the effect of atmospheric extinction, and then differential magnitudes ΔP = 'P *minus* a mean of C_1 and C_2' or 'P *minus* C_1' or 'P *minus* C_2' were formed.

The determination of the atmospheric extinction coefficients needs some explanation. For the Białków observations (on all those nights two comparison stars were observed), the nightly extinction coefficients were derived from a linear regression of the points in the diagram constructed with raw magnitudes Δm = 'C_1 *minus* C_2' against the corresponding air mass diffferences ΔX (see for example Jerzykiewicz et al. 1984, and Jerzykiewicz & Sterken 1990), the air mass range being extended by the use of the mean value of the out-of-atmosphere magnitude $\Delta C = C_1 - C_2$ obtained from the nights of best quality. For the Jungfraujoch and Xinglong observations, nightly extinction coefficients were determined by the classical Bouguer method applied to the measurements of each comparison star. Both methods, of course, were only employed when the data covered a reasonable range of differential air masses ΔX, or a broad range of air mass X. From an inspection of these diagrams and from the goodness of the linear fits, the data of different nights with similar extinction coefficients were grouped together. It turned out that both for Jungfraujoch and for Białków, three such groups could be recognized, whereas for Xinglong all nights of acceptable quality could be grouped together. Very short nights, covering extremely small air mass ranges (most likely those nights that yielded less data due to poor weather conditions) were classified with those having —for each site— the largest k-values. Listed in Table 2 are the adopted extinction coefficients.

Table 2. Adopted extinction coefficients k

Site	HJD						k
Jungfrau	7328	7426	7769	7776	7791	8506	0.10
	7425	7691	7695	8507	8508		0.17
	7331	7424					0.32
Białków	7368	7369	7729	7848	8174	8497	0.28
	7366	7687					0.55
	8133						0.80
Xinglong	7798	7800	7801	8505			0.25

It is apparent from Table 2 that the range of adopted k-values is much lower for Jungfraujoch than it is for Białków. This, as well as the obvious difference in mean value of k for each site, clearly is a consequence of the extreme difference in altitude between both observatories.

2.4. *The results*

The mean magnitude differences between C_1 and C_2 (in the sense C_1 *minus* C_2) turned out to be $-0\overset{m}{.}759 \pm 0\overset{m}{.}001$ in y (Białków) and $-0\overset{m}{.}769 \pm 0\overset{m}{.}001$ in V_1 (Jungfraujoch). The difference in the B band (Xinglong, one night) equals $-0\overset{m}{.}502$, whereas the $C_2 - C_3$ differences in b (Xinglong) show a larger scatter and yield a mean value amounting to $-0\overset{m}{.}654 \pm 0\overset{m}{.}006$. The large scatter is caused by the fact that the $C_2 - C_3$ value for the night of 28 Sep 1989 is about $0\overset{m}{.}02$ lower than are the corresponding values on Sep 30 and Oct 1, 1989, which yield a mean difference of $-0\overset{m}{.}660 \pm 0\overset{m}{.}005$. It is not clear to what the origin of this discrepancy must be ascribed, but both star C_2 and star C_3 measurements clearly showed a strong increase in apparent brightness (about $0\overset{m}{.}1$) during the first couple of hours that night. Whether this apparent brightening is due to an atmospheric effect, or is caused by an instrumental problem, is not clear. Though all doubtful measurements were eliminated, there remains an unaccountable difference of about $0\overset{m}{.}02$ between C_2 and C_3, a difference that also showed up when comparing the BW Vul light curve of that night and the one obtained during the two consecutive nights of observation. The discrepancy could be due to a sudden fading of C_2, for example caused by an eclipse, though this is less likely, since also the $P - C_2$ light curve of that night is shifted with respect to the light curves of the other nights, the mean shift amounting to approximately $0\overset{m}{.}04$. We exclude the explanation of an atmospheric origin of this difference, and accept as a likely reason for the discrepancies of the Sep 28, 1989 data that the measuring system may have responded non-linearly during that night. Indeed, the systematic differences among the light curves follow very well the trend of increasing magnitude when going from C_3 to C_2 and to P. In order to make all Xinglong b-observations mutually consistent, we have applied to all BW Vul *minus* C_2 differences of that night a correction of $-0\overset{m}{.}04$.

From an evaluation of the extinction plots, and from the differences between the extinction-corrected magnitudes of the comparison stars, we have assigned weights ranging from 1 to 5. Weight 5 was given to the data collected in the nights labeled "good" in Table 1, weight 3 was assigned to nights with a "medium" indication, and data from other nights were assigned weight 1. In addition, for stars observed at an air mass lower than 1.6, the weight was preserved. For data taken at air masses between 1.6 and 2.0 the weight was decreased by 2 units. Only four observations were taken at air mass greater than 2.0, and these results were always given weight 1. Because of all the uncertainties involved, all data of the night of September 28, 1989 have been given weight 1. Though our scheme of weights is internally consistent, it does not qualitatively match the system of weights assigned by Sterken et al.(1986), where really long series of "excellent" nights (with weight 5) were available. It must also be pointed out that our datapoints with weight 1 still represent data of acceptable quality.

Tables 3 and 4, respectively, give the differential values BW Vul *minus* C_1 for the Jungfraujoch and Białków data. Table 5 gives the observations obtained at Xinglong, viz. BW Vul *minus* C_2 for the b data, and BW Vul *minus* C_1 for the B data. Fig. 2 shows the corresponding phase diagrams for all data ($P = 0\overset{d}{.}2010443$; see Sect. 3).

3. The actual period of BW Vul

From the data displayed in Tables 3–5, we derived times of minimum light and times of maximum light using the method outlined by Sterken et al. (1987). Table 6 lists the results.

Sterken et al. (1987) argued that there are two reasons for using $T_{\min}$ instead of $T_{\max}$ for determining the pulsation period of BW Vul. First, due to the occurrence of the stillstand phenomenon (until about 0.1 phase before the time of maximum light), the time base of data useful for determining the time of maximum is more than two times smaller in the case of light minimum than it is in the case of light maximum. In addition, the disturbance of the stillstand on the shape of the light curve progressively increases towards infrared wavelengths (see Fig. 3 of Sterken et al. 1987). We have, therefore, determined the actual period of BW Vul from the $T_{\min}$ of Table 6,

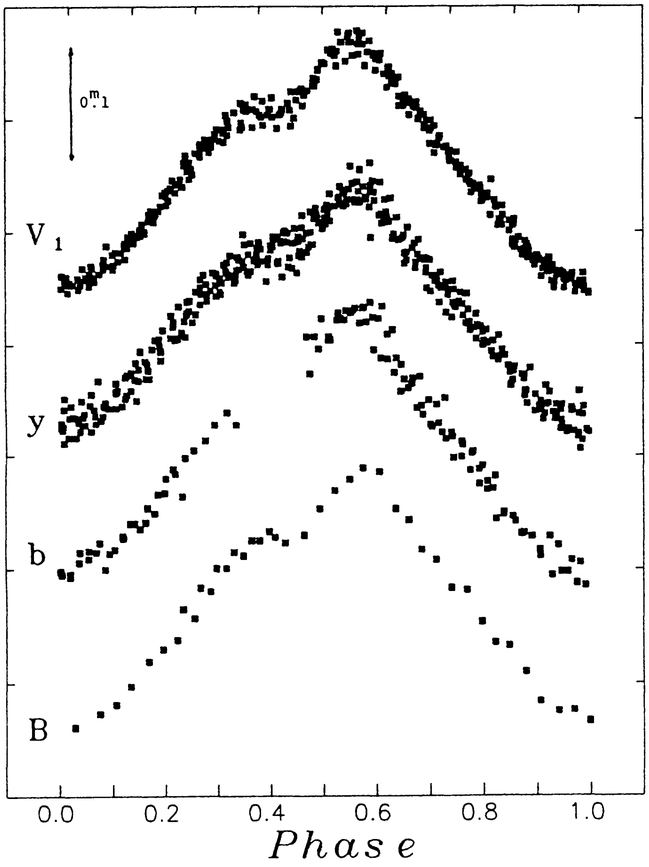

Fig. 2. Phase diagrams for all data. The period is $0^d.2010443$

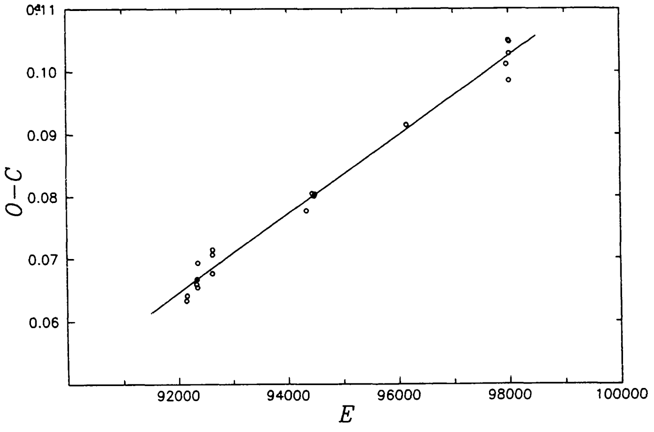

Fig. 3. O-C diagram for the times of minimum obtained from data presented in this paper. The solid line is a least-squares linear fit

obtained $P = 0^d.2010443 \pm 0^d.0000002$. An O-C diagram is given in Fig. 3. The figure clearly illustrates that the new data do not reveal any sudden period change in the time span 1988–1991. Our value for P agrees (within the 2σ level) with the period derived by Chapellier & Garrido (1990). The actual period is about $0^s.11$ larger than the one given by Sterken et al. (1987).

Table 6. Heliocentric times of light minimum ($T_{\rm min}$) and light maximum ($T_{\rm max}$) of BW Vul

$T_{\rm min}$	$T_{\rm min}$	$T_{\rm max}$	$T_{\rm max}$
7328.4729	7791.4807	7366.3821	7800.0327
7331.4893	7798.1145	7368.3981	7801.0438
7366.4717	7801.1304	7369.3980	7848.2857
7368.4829	8133.4573	7425.4866	8174.3840
7369.4868	8497.5467	7426.4951	8497.4625
7371.5011	8505.1900	7695.4919	8505.1018
7424.3724	8506.3898	7729.4696	8506.5099
7425.3806	8507.3993	7776.5137	8507.5097
7426.3865	8508.4064	7791.3921	
7769.5647		7798.0308	

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Table 3. Heliocentric Julian Date, V_1 magnitude difference BW Vul *minus* HD 198820 and weights for observations obtained at Jungfraujoch

HJD	ΔV_1	p	HJD	ΔV_1	p	HJD	ΔV_1	p	HJD	ΔV_1	p	HJD	ΔV_1	p	HJD	ΔV_1	p
7328.4365	0.166	5	7424.3911	0.212	3	7426.3681	0.236	3	7695.5045	0.060	3	7791.3427	0.096	5	8506.5493	0.171	3
7328.4419	0.194	5	7424.3956	0.226	3	7426.3729	0.236	3	7695.5080	0.066	3	7791.3504	0.087	5	8506.5559	0.178	3
7328.4468	0.214	5	7424.3998	0.205	3	7426.3757	0.243	3	7695.5118	0.083	3	7791.3546	0.093	5	8507.3242	0.062	5
7328.4515	0.223	5	7424.4046	0.193	3	7426.3792	0.249	3	7695.5156	0.089	3	7791.3587	0.096	5	8507.3314	0.079	5
7328.4567	0.240	5	7424.4095	0.185	3	7426.3830	0.254	3	7695.5195	0.105	3	7791.3632	0.096	5	8507.3376	0.105	5
7328.4614	0.250	5	7424.4136	0.165	3	7426.3879	0.247	3	7695.5240	0.123	3	7791.3671	0.092	5	8507.3437	0.119	5
7328.4652	0.250	5	7424.4213	0.132	3	7426.3920	0.243	3	7695.5292	0.137	3	7791.3709	0.075	5	8507.3512	0.142	5
7328.4700	0.248	5	7425.2865	0.049	3	7426.3966	0.240	3	7695.5333	0.149	3	7791.3757	0.068	5	8507.3568	0.160	5
7328.4744	0.255	5	7425.2924	0.034	3	7426.4004	0.233	3	7695.5372	0.158	3	7791.3792	0.050	5	8507.3618	0.169	5
7328.4784	0.254	5	7425.2994	0.048	3	7426.4042	0.229	3	7695.5410	0.173	3	7791.3827	0.042	5	8507.3660	0.192	5
7328.4825	0.251	5	7425.3053	0.069	3	7426.4084	0.212	3	7695.5445	0.185	3	7791.3865	0.032	5	8507.3730	0.206	5
7328.4865	0.248	5	7425.3105	0.085	3	7426.4122	0.205	3	7695.5528	0.212	3	7791.3903	0.032	5	8507.3775	0.220	5
7328.4905	0.237	5	7425.3147	0.093	3	7426.4160	0.199	3	7695.5566	0.221	3	7791.3934	0.028	5	8507.3837	0.226	5
7328.4954	0.233	5	7425.3199	0.106	3	7426.4202	0.184	3	7695.5611	0.230	3	7791.3973	0.031	5	8507.3891	0.233	5
7328.5002	0.224	5	7425.3244	0.124	3	7426.4243	0.168	3	7695.5674	0.244	3	7791.4014	0.042	5	8507.3948	0.246	5
7328.5048	0.204	5	7425.3282	0.129	3	7426.4299	0.153	3	7769.3680	0.247	5	7791.4045	0.054	5	8507.4039	0.241	5
7328.5089	0.190	5	7425.3320	0.154	3	7426.4341	0.144	3	7769.3774	0.230	5	7791.4080	0.063	5	8507.4098	0.241	5
7328.5127	0.181	5	7425.3372	0.161	3	7426.4382	0.125	3	7769.3927	0.201	5	7791.4115	0.084	5	8507.4165	0.234	5
7328.5166	0.172	5	7425.3424	0.172	3	7426.4431	0.113	3	7769.4066	0.163	5	7791.4150	0.090	5	8507.4216	0.215	5
7328.5209	0.157	5	7425.3480	0.190	3	7426.4479	0.101	3	7769.4201	0.124	5	7791.4202	0.108	5	8507.4272	0.205	5
7328.5247	0.153	5	7425.3539	0.208	3	7426.4531	0.086	3	7769.4368	0.093	5	7791.4236	0.115	5	8507.4326	0.192	5
7328.5287	0.133	5	7425.3584	0.221	3	7426.4584	0.080	3	7769.4458	0.091	5	7791.4268	0.129	5	8507.4378	0.178	5
7328.5331	0.124	5	7425.3626	0.225	3	7426.4639	0.091	3	7769.4548	0.099	5	7791.4313	0.144	5	8507.4450	0.172	5
7328.5379	0.120	5	7425.3674	0.236	3	7426.4709	0.086	3	7769.4621	0.071	5	7791.4348	0.156	5	8507.4495	0.144	5
7328.5443	0.109	5	7425.3716	0.237	3	7426.4771	0.079	3	7769.4757	0.032	5	7791.4393	0.166	5	8507.4542	0.138	5
7328.5489	0.107	5	7425.3758	0.244	3	7426.4823	0.056	3	7769.4826	0.041	5	7791.4459	0.189	5	8507.4589	0.121	5
7328.5530	0.105	5	7425.3806	0.244	3	7426.4879	0.038	3	7769.4916	0.068	5	7791.4511	0.207	5	8507.4646	0.112	5
7328.5582	0.108	5	7425.3858	0.251	3	7426.4941	0.024	3	7769.4982	0.082	5	7791.4542	0.216	5	8507.4693	0.100	5
7328.5634	0.106	5	7425.3900	0.237	3	7426.4993	0.034	3	7769.5048	0.101	5	7791.4573	0.222	5	8507.4738	0.102	5
7328.5680	0.088	5	7425.3987	0.220	3	7426.5042	0.044	3	7769.5208	0.148	5	7791.4608	0.224	5	8507.4799	0.094	5
7328.5733	0.065	5	7425.4042	0.214	3	7426.5092	0.062	3	7769.5274	0.170	5	7791.4639	0.230	5	8507.4854	0.089	5
7331.4536	0.154	3	7425.4094	0.203	3	7426.5146	0.088	3	7769.5333	0.185	5	7791.4674	0.239	5	8507.4910	0.074	5
7331.4577	0.177	3	7425.4143	0.191	3	7426.5195	0.085	3	7769.5447	0.226	5	7791.4709	0.244	5	8507.4962	0.059	5
7331.4621	0.189	3	7425.4199	0.172	3	7691.4657	0.053	5	7769.5503	0.235	5	7791.4743	0.247	5	8507.5008	0.042	5
7331.4664	0.215	3	7425.4254	0.160	3	7691.4741	0.043	5	7769.5562	0.237	5	7791.4778	0.253	5	8507.5069	0.037	5
7331.4709	0.222	3	7425.4292	0.149	3	7691.4796	0.044	5	7769.5628	0.244	5	7791.4809	0.250	5	8507.5114	0.037	5
7331.4753	0.223	3	7425.4355	0.129	3	7691.4855	0.062	5	7769.5691	0.241	5	7791.4841	0.245	5	8507.5167	0.037	5
7331.4793	0.235	3	7425.4396	0.119	3	7691.4987	0.096	5	7769.5763	0.240	5	7791.4872	0.241	5	8507.5213	0.052	5
7331.4838	0.242	3	7425.4431	0.107	3	7691.5008	0.122	5	7769.5833	0.224	3	7791.4907	0.242	5	8507.5263	0.079	5
7331.4879	0.249	3	7425.4480	0.103	3	7691.5060	0.125	5	7769.5923	0.210	3	7791.4952	0.237	5	8507.5315	0.104	5
7331.4918	0.239	3	7425.4556	0.098	3	7691.5109	0.143	5	7769.6003	0.184	3	7791.4993	0.230	5	8507.5379	0.110	5
7331.4961	0.247	3	7425.4598	0.098	3	7691.5164	0.165	5	7769.6086	0.161	3	7791.5035	0.218	5	8507.5423	0.126	5
7331.4997	0.232	3	7425.4633	0.094	3	7691.5223	0.168	5	7769.6159	0.138	3	7791.5084	0.210	5	8507.5470	0.145	5
7331.5032	0.232	3	7425.4671	0.076	3	7691.5275	0.191	5	7769.6232	0.123	3	7791.5125	0.201	5	8507.5530	0.151	5
7331.5074	0.229	3	7425.4709	0.073	3	7691.5331	0.208	5	7769.6305	0.114	3	7791.5209	0.176	5	8507.5576	0.171	5
7331.5122	0.218	3	7425.4754	0.064	3	7691.5380	0.217	5	7776.4269	0.210	3	7791.5243	0.165	5	8507.5636	0.184	1
7331.5169	0.204	3	7425.4796	0.051	3	7691.5432	0.233	5	7776.4366	0.181	3	8506.3666	0.205	3	8507.5684	0.198	1
7331.5213	0.198	3	7425.4844	0.040	3	7691.5480	0.235	5	7776.4495	0.141	3	8506.3752	0.231	3	8507.5732	0.216	1
7331.5251	0.189	3	7425.4903	0.044	3	7691.5532	0.240	5	7776.4554	0.123	3	8506.3849	0.246	3	8507.5784	0.226	1
7331.5300	0.167	3	7425.4949	0.053	3	7691.5584	0.237	5	7776.4644	0.112	3	8506.3934	0.240	3	8507.5854	0.243	1
7331.5339	0.154	3	7425.4990	0.057	5	7691.5640	0.240	5	7776.4717	0.107	3	8506.4007	0.246	3	8508.3203	0.030	3
7331.5383	0.138	3	7425.5032	0.072	5	7695.4104	0.203	1	7776.4783	0.096	3	8506.4079	0.233	3	8508.3282	0.055	3
7331.5426	0.130	3	7425.5077	0.088	5	7695.4153	0.187	1	7776.4922	0.083	3	8506.4134	0.220	3	8508.3350	0.076	3
7331.5464	0.118	3	7425.5115	0.096	5	7695.4194	0.177	1	7776.4991	0.071	3	8506.4196	0.210	3	8508.3405	0.093	3
7331.5510	0.109	3	7425.5171	0.106	5	7695.4254	0.158	3	7776.5068	0.044	3	8506.4246	0.200	3	8508.3459	0.102	3
7424.3036	0.079	3	7425.5209	0.130	3	7695.4299	0.146	3	7776.5158	0.034	3	8506.4312	0.179	3	8508.3505	0.121	3
7424.3088	0.099	3	7425.5265	0.134	3	7695.4347	0.128	3	7776.5224	0.047	3	8506.4363	0.161	3	8508.3560	0.138	3
7424.3133	0.101	3	7425.5317	0.145	3	7695.4392	0.118	3	7776.5283	0.060	3	8506.4422	0.147	3	8508.3607	0.156	3
7424.3227	0.138	3	7425.5362	0.162	1	7695.4431	0.109	3	7776.5349	0.086	3	8506.4473	0.123	3	8508.3668	0.169	3
7424.3275	0.149	3	7426.2983	0.024	3	7695.4479	0.094	3	7776.5404	0.108	3	8506.4533	0.114	3	8508.3712	0.182	3
7424.3327	0.172	3	7426.3077	0.055	3	7695.4514	0.092	3	7776.5453	0.122	3	8506.4597	0.100	3	8508.3779	0.202	3
7424.3386	0.194	3	7426.3118	0.080	3	7695.4549	0.091	3	7776.5505	0.137	3	8506.4653	0.092	3	8508.3829	0.210	3
7424.3428	0.199	3	7426.3157	0.086	3	7695.4587	0.084	3	7776.5561	0.145	3	8506.4713	0.090	3	8508.3891	0.223	3
7424.3480	0.220	3	7426.3190	0.100	3	7695.4622	0.081	3	7776.5613	0.159	3	8506.4764	0.088	3	8508.3963	0.236	3
7424.3518	0.223	3	7426.3233	0.110	3	7695.4660	0.091	3	7776.5672	0.177	1	8506.4831	0.087	3	8508.4010	0.244	3
7424.3560	0.231	3	7426.3268	0.117	3	7695.4719	0.076	3	7776.5741	0.193	1	8506.4906	0.075	3	8508.4064	0.244	3
7424.3598	0.245	3	7426.3309	0.128	3	7695.4757	0.075	3	7776.5790	0.211	1	8506.4966	0.058	3	8508.4107	0.242	3
7424.3633	0.243	3	7426.3351	0.141	3	7695.4795	0.057	3	7776.5845	0.226	1	8506.5027	0.046	3	8508.4158	0.235	3
7424.3675	0.254	3	7426.3396	0.157	3	7695.4833	0.039	3	7776.5887	0.230	1	8506.5097	0.036	3	8508.4204	0.225	3
7424.3709	0.249	3	7426.3441	0.168	3	7695.4872	0.023	3	7776.5936	0.239	1	8506.5184	0.066	3	8508.4248	0.223	3
7424.3758	0.240	3	7426.3483	0.178	3	7695.4910	0.026	3	7776.5988	0.244	1	8506.5255	0.088	3	8508.4289	0.212	3
7424.3814	0.247	3	7426.3545	0.194	3	7695.4945	0.022	3	7776.6054	0.243	1	8506.5322	0.113	3	8508.4627	0.107	3
7424.3866	0.244	3	7426.3604	0.214	3	7695.5007	0.042	3	7791.3330	0.122	5	8506.5422	0.140	3	8508.4687	0.094	3

Table 4. Heliocentric Julian Date, y magnitude difference BW Vul *minus* HD 198820 and weights for observations obtained at Białków

HJD	Δy	p	HJD	Δy	p	HJD	Δy	p	HJD	Δy	p	HJD	Δy	p	HJD	Δy	p
7366.3416	0.072	3	7368.4846	0.244	3	7371.4145	0.041	1	7729.4690	0.041	3	8133.3576	0.054	3	8174.3801	0.027	5
7366.3483	0.085	3	7368.4927	0.242	3	7371.4221	0.056	1	7729.4740	0.039	3	8133.3617	0.040	5	8174.3841	0.030	5
7366.3545	0.074	3	7368.4987	0.238	3	7371.4295	0.088	1	7729.4793	0.055	3	8133.3658	0.032	5	8174.3882	0.035	5
7366.3611	0.067	3	7368.5045	0.227	3	7371.4370	0.094	1	7729.4845	0.072	3	8133.3699	0.044	5	8174.3923	0.041	5
7366.3672	0.052	3	7368.5101	0.211	3	7371.4443	0.142	1	7729.4895	0.095	3	8133.3740	0.075	5	8174.3967	0.057	5
7366.3734	0.046	3	7368.5158	0.200	3	7371.4521	0.125	1	7729.4962	0.093	3	8133.3780	0.054	5	8174.4008	0.066	5
7366.3795	0.033	3	7368.5215	0.176	3	7371.4594	0.157	1	7729.5014	0.118	3	8133.3821	0.075	5	8174.4049	0.077	5
7366.3851	0.041	3	7368.5280	0.165	3	7371.4665	0.180	1	7729.5068	0.133	3	8133.3863	0.073	5	8174.4092	0.095	5
7366.3907	0.025	3	7368.5337	0.150	3	7371.4741	0.211	1	7729.5125	0.152	3	8133.3904	0.080	5	8174.4132	0.106	5
7366.3965	0.061	3	7368.5391	0.125	3	7371.4875	0.229	1	7729.5181	0.171	3	8133.3947	0.106	5	8174.4181	0.121	5
7366.4026	0.089	3	7368.5442	0.123	3	7371.4957	0.233	1	7729.5238	0.183	3	8133.3988	0.113	5	8174.4225	0.125	5
7366.4086	0.094	3	7368.5498	0.115	3	7371.5030	0.225	1	7729.5293	0.202	3	8133.4029	0.126	5	8174.4265	0.143	5
7366.4144	0.109	3	7368.5552	0.108	3	7371.5107	0.214	1	7729.5347	0.223	3	8133.4071	0.132	5	8174.4308	0.169	5
7366.4207	0.114	3	7368.5606	0.096	3	7371.5198	0.204	1	7729.5400	0.229	3	8133.4111	0.150	5	8174.4542	0.213	3
7366.4264	0.139	3	7368.5661	0.097	3	7371.5275	0.186	1	7729.5453	0.235	3	8133.4152	0.154	5	8174.4583	0.228	3
7366.4320	0.159	3	7368.5716	0.102	3	7687.4309	0.087	3	7729.5502	0.246	3	8133.4193	0.176	5	8174.4624	0.227	3
7366.4380	0.162	3	7368.5773	0.088	3	7687.4371	0.054	3	7729.5554	0.256	3	8133.4233	0.175	5	8174.4669	0.226	3
7366.4439	0.190	3	7368.5831	0.067	3	7687.4423	0.060	3	7729.5605	0.259	3	8133.4276	0.194	5	8174.4713	0.228	3
7366.4498	0.191	3	7369.3469	0.107	5	7687.4473	0.047	3	7729.5658	0.240	3	8133.4316	0.197	5	8497.3907	0.166	4
7366.4556	0.207	3	7369.3523	0.091	5	7687.4527	0.026	3	7848.2191	0.164	3	8133.4357	0.230	5	8497.3946	0.163	4
7366.4618	0.224	3	7369.3579	0.081	5	7687.4577	0.035	3	7848.2239	0.140	3	8133.4398	0.224	5	8497.3987	0.143	4
7366.4683	0.212	3	7369.3632	0.079	5	7687.4628	0.057	3	7848.2282	0.134	3	8133.4438	0.233	5	8497.4025	0.125	4
7366.4744	0.218	3	7369.3687	0.074	5	7687.4681	0.077	3	7848.2324	0.122	3	8133.4479	0.246	5	8497.4065	0.127	4
7366.4809	0.220	3	7369.3741	0.071	5	7687.4733	0.084	3	7848.2366	0.115	3	8133.4522	0.232	5	8497.4105	0.106	4
7366.4871	0.202	3	7369.3795	0.066	5	7687.4785	0.102	3	7848.2407	0.108	3	8133.4575	0.241	5	8497.4145	0.104	4
7366.4973	0.199	3	7369.3848	0.049	5	7687.4839	0.120	3	7848.2451	0.101	3	8133.4616	0.235	5	8497.4184	0.105	4
7366.5032	0.176	3	7369.3901	0.036	5	7687.4890	0.135	3	7848.2495	0.094	3	8133.4654	0.235	5	8497.4225	0.099	4
7366.5089	0.166	3	7369.3956	0.035	5	7687.4951	0.157	3	7848.2537	0.096	3	8133.4696	0.228	5	8497.4264	0.099	4
7366.5150	0.144	3	7369.4010	0.034	5	7687.5002	0.167	3	7848.2582	0.096	3	8133.4738	0.226	5	8497.4303	0.098	4
7366.5211	0.132	3	7369.4071	0.042	5	7687.5054	0.181	3	7848.2626	0.093	3	8133.4779	0.212	5	8497.4340	0.101	4
7366.5274	0.108	3	7369.4124	0.060	5	7687.5105	0.205	3	7848.2671	0.092	3	8133.4821	0.215	5	8497.4379	0.091	4
7366.5338	0.111	3	7369.4175	0.075	5	7687.5156	0.216	3	7848.2712	0.081	3	8133.4864	0.202	5	8497.4417	0.083	4
7366.5399	0.110	3	7369.4231	0.090	5	7687.5210	0.225	3	7848.2756	0.050	3	8133.4906	0.200	5	8497.4454	0.062	4
7366.5468	0.096	3	7369.4286	0.109	5	7687.5262	0.231	3	7848.2796	0.047	3	8133.4950	0.184	5	8497.4494	0.048	4
7366.5523	0.093	3	7369.4346	0.121	5	7687.5313	0.249	3	7848.2840	0.045	3	8133.5019	0.136	5	8497.4536	0.030	4
7366.5580	0.071	3	7369.4399	0.134	5	7687.5364	0.264	3	7848.2885	0.042	3	8133.5060	0.131	5	8497.4576	0.012	4
7366.5637	0.078	3	7369.4457	0.153	5	7687.5416	0.247	3	7848.2927	0.048	3	8133.5102	0.112	5	8497.4613	0.015	4
7368.3382	0.131	3	7369.4515	0.167	5	7687.5467	0.254	3	7848.2972	0.062	3	8133.5150	0.106	5	8497.4650	0.009	4
7368.3435	0.125	3	7369.4572	0.189	5	7729.3465	0.238	3	7848.3015	0.076	3	8133.5193	0.099	5	8497.4688	0.026	4
7368.3492	0.113	3	7369.4624	0.197	5	7729.3512	0.248	3	7848.3058	0.098	3	8174.2780	0.232	5	8497.4726	0.040	4
7368.3551	0.105	3	7369.4696	0.221	5	7729.3560	0.247	3	7848.3099	0.102	3	8174.2820	0.234	5	8497.4853	0.095	4
7368.3609	0.114	3	7369.4754	0.224	5	7729.3615	0.236	3	7848.3142	0.120	3	8174.2859	0.222	5	8497.4893	0.114	4
7368.3669	0.110	3	7369.4809	0.230	5	7729.3662	0.242	3	7848.3189	0.133	3	8174.2900	0.213	5	8497.4930	0.119	4
7368.3724	0.106	3	7369.4891	0.245	5	7729.3712	0.241	3	7848.3237	0.146	3	8174.2942	0.197	5	8497.4970	0.137	4
7368.3778	0.081	3	7369.4945	0.236	5	7729.3762	0.227	3	7848.3278	0.144	3	8174.2984	0.192	5	8497.5010	0.151	4
7368.3833	0.063	3	7369.4998	0.224	5	7729.3812	0.225	3	7848.3321	0.155	3	8174.3037	0.174	5	8497.5301	0.237	4
7368.3888	0.045	3	7369.5049	0.225	5	7729.3860	0.201	3	7848.3367	0.168	3	8174.3078	0.157	5	8497.5344	0.237	4
7368.3945	0.044	3	7369.5101	0.211	5	7729.3908	0.187	3	7848.3411	0.184	1	8174.3120	0.150	5	8497.5388	0.249	4
7368.4003	0.029	3	7369.5153	0.195	5	7729.3958	0.175	3	7848.3454	0.195	1	8174.3161	0.149	5	8497.5431	0.253	4
7368.4061	0.052	3	7369.5206	0.185	5	7729.4009	0.153	3	7848.3507	0.201	1	8174.3205	0.123	5	8497.5470	0.249	4
7368.4115	0.076	3	7369.5260	0.165	5	7729.4060	0.142	3	7848.3551	0.215	1	8174.3245	0.116	5	8497.5514	0.254	4
7368.4172	0.097	3	7369.5314	0.154	5	7729.4111	0.119	3	7848.3599	0.223	1	8174.3285	0.109	5	8497.5557	0.248	4
7368.4229	0.123	3	7369.5367	0.143	5	7729.4161	0.106	3	7848.3645	0.246	1	8174.3325	0.097	5	8497.5598	0.248	4
7368.4285	0.115	3	7369.5421	0.125	5	7729.4210	0.104	3	7848.3690	0.229	1	8174.3366	0.092	5	8497.5641	0.234	4
7368.4340	0.124	3	7369.5476	0.117	5	7729.4261	0.095	3	8133.3241	0.103	3	8174.3407	0.090	5	8497.5685	0.227	2
7368.4401	0.165	3	7369.5528	0.110	5	7729.4330	0.084	3	8133.3285	0.080	3	8174.3448	0.081	5	8497.5728	0.218	2
7368.4464	0.181	3	7369.5581	0.096	5	7729.4381	0.086	3	8133.3330	0.096	3	8174.3490	0.082	5	8497.5769	0.220	2
7368.4530	0.207	3	7369.5635	0.090	5	7729.4432	0.078	3	8133.3372	0.077	3	8174.3531	0.080	5	8497.5814	0.193	2
7368.4588	0.212	3	7369.5696	0.083	5	7729.4485	0.074	3	8133.3414	0.069	3	8174.3573	0.080	5	8497.5857	0.171	2
7368.4658	0.232	3	7369.5751	0.079	5	7729.4533	0.070	3	8133.3455	0.079	3	8174.3614	0.076	5	8497.5900	0.164	2
7368.4722	0.242	3	7369.5807	0.055	5	7729.4590	0.049	3	8133.3496	0.071	3	8174.3655	0.058	5	8497.5943	0.159	2
7368.4785	0.250	3	7371.4071	0.041	1	7729.4640	0.039	3	8133.3536	0.057	3	8174.3696	0.057	5			

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Table 5. Heliocentric Julian Date, b magnitude difference BW Vul *minus* HD 198527 and B magnitude difference BW Vul *minus* HD 198820 with weights, for observations obtained at Xinglong

HJD	Δb	p	HJD	Δb	p	HJD	Δb	p	HJD	Δb	p	HJD	Δb	p	HJD	Δb	p
7798.0168	-0.514	1	7798.0924	-0.339	1	7798.1703	-0.424	1	7800.0621	-0.447	3	7801.0572	-0.498	3	7801.1217	-0.308	3
7798.0206	-0.533	1	7798.0957	-0.322	1	7798.1738	-0.438	1	7800.0650	-0.438	3	7801.0602	-0.479	3	7801.1250	-0.298	3
7798.0245	-0.538	1	7798.1002	-0.305	1	7798.1786	-0.449	1	7800.0680	-0.439	3	7801.0634	-0.480	3	7801.1283	-0.296	3
7798.0289	-0.542	1	7798.1036	-0.308	1	7798.1821	-0.438	1	7800.0706	-0.425	3	7801.0661	-0.481	3	7801.1312	-0.305	3
7798.0329	-0.534	1	7798.1075	-0.318	1	7800.0182	-0.517	3	7800.0734	-0.408	3	7801.0694	-0.460	3	7801.1343	-0.306	3
7798.0363	-0.544	1	7798.1106	-0.316	1	7800.0211	-0.517	3	7800.0765	-0.409	3	7801.0725	-0.456	3	7801.1379	-0.325	3
7798.0402	-0.523	1	7798.1150	-0.308	1	7800.0238	-0.533	3	7800.0799	-0.397	3	7801.0756	-0.462	3	7801.1412	-0.319	3
7798.0434	-0.492	1	7798.1186	-0.303	1	7800.0266	-0.517	3	7800.0833	-0.385	3	7801.0784	-0.427	3	7801.1442	-0.325	3
7798.0474	-0.475	1	7798.1221	-0.316	1	7800.0298	-0.532	3	7800.0862	-0.380	3	7801.0819	-0.423	3	7801.1475	-0.310	3
7798.0511	-0.455	1	7798.1257	-0.326	1	7800.0325	-0.532	3	7800.0895	-0.354	3	7801.0857	-0.412	3	7801.1511	-0.327	3
7798.0551	-0.436	1	7798.1297	-0.333	1	7800.0356	-0.540	3	7801.0246	-0.484	3	7801.0885	-0.398	3	7801.1544	-0.337	3
7798.0589	-0.431	1	7798.1334	-0.324	1	7800.0383	-0.529	3	7801.0279	-0.506	3	7801.0915	-0.387	3	7801.1571	-0.350	3
7798.0623	-0.431	1	7798.1384	-0.339	1	7800.0409	-0.530	3	7801.0316	-0.514	3	7801.0945	-0.392	3	7801.1607	-0.345	3
7798.0665	-0.420	1	7798.1430	-0.350	1	7800.0437	-0.505	3	7801.0353	-0.538	3	7801.0977	-0.360	3	7801.1636	-0.364	3
7798.0704	-0.414	1	7798.1472	-0.351	1	7800.0464	-0.498	3	7801.0383	-0.540	3	7801.1020	-0.352	3	7801.1676	-0.376	3
7798.0740	-0.401	1	7798.1507	-0.359	1	7800.0488	-0.497	3	7801.0417	-0.542	3	7801.1052	-0.342	3	7801.1707	-0.390	3
7798.0780	-0.381	1	7798.1546	-0.377	1	7800.0513	-0.485	3	7801.0450	-0.543	3	7801.1083	-0.339	3	7801.1736	-0.398	3
7798.0819	-0.358	1	7798.1586	-0.394	1	7800.0538	-0.468	3	7801.0476	-0.547	3	7801.1113	-0.327	3	7801.1770	-0.374	3
7798.0854	-0.356	1	7798.1624	-0.408	1	7800.0566	-0.471	3	7801.0506	-0.533	3	7801.1148	-0.339	3			
7798.0887	-0.341	1	7798.1658	-0.415	1	7800.0597	-0.453	3	7801.0540	-0.519	3	7801.1181	-0.331	3			

HJD	ΔB	p	HJD	ΔB	p	HJD	ΔB	p	HJD	ΔB	p
8505.0333	0.155	5	8505.0969	0.041	5	8505.1516	0.184	5	8505.2143	0.223	5
8505.0401	0.136	5	8505.1020	0.031	5	8505.1568	0.187	5	8505.2212	0.201	5
8505.0462	0.119	5	8505.1081	0.034	5	8505.1630	0.210	5	8505.2268	0.190	5
8505.0530	0.105	5	8505.1141	0.067	5	8505.1685	0.236	5	8505.2322	0.182	5
8505.0597	0.095	5	8505.1190	0.077	5	8505.1753	0.245	5	8505.2388	0.163	5
8505.0663	0.087	5	8505.1239	0.103	5	8505.1811	0.244	5	8505.2450	0.139	5
8505.0724	0.097	5	8505.1294	0.112	5	8505.1870	0.254	5	8505.2510	0.119	5
8505.0795	0.090	5	8505.1352	0.136	5	8505.1933	0.259	5	8505.2576	0.108	5
8505.0855	0.067	5	8505.1409	0.138	5	8505.2026	0.247	5	8505.2638	0.095	3
8505.0912	0.051	5	8505.1466	0.166	5	8505.2088	0.239	5	8505.2695	0.092	3