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Photometric observations of BW Vulpeculae

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Abstract. Photometric observations of β Cephei star BW Vul, secured on five nights, in B and V filters are given. A new ephemeris for the maxima of the star and its rate of change of period has been derived.

Key words : β Cephei stars—BW Vul—photometry

1. Introduction

The well-known β Cep variable BW Vul (B2III) has been extensively studied on account of the peculiarities in its light and velocity curves and the secular increase in its period. Petrie (1954) found an increase at a rate of 3.7 s century^{-1} on the basis of radial velocity data. Odgers (1956) confirmed the increase in period but found a lower rate of increase. Cester (1957) derived a period increase of 2.8 s century^{-1} for the star based on photometric data. Percy (1971), using the formula given by Petrie, obtained an irregular rate of period increase with a mean value of about 4 s century^{-1}. Cherewick & Young (1975) from fifteen photometric maxima found a rate of period increase of 1.89 s century^{-1}. Margrave (1979) has given a rate of 2.24 s century^{-1} for the increase in the period of the star. In this paper we give five epochs of photometric maxima of the star obtained by us and derive an ephemeris for the maxima of the star taking an initial epoch about 5050 days later than the epoch taken by Margrave (1979). We have also determined a rate of change of the period which is similar to that given by Margrave (1979).

2. Observations

The photometric observations of the star BW Vul were secured on five nights during 1962 November (four nights) and 1964 November (one night) through the 38-cm reflector of the Uttar Pradesh State Observatory. An unrefrigerated IP21 photomultiplier, UBV filters of Johnson and Morgan system, and standard d.c. recording techniques were employed for these observations. HD 199139 (F0) was used as a comparison star on 1962 November 2 and HD 198820 (B3III) on the remaining nights. Nightly extinction corrections were applied to the observed magnitudes. The standard deviations of the comparison stars on all the five nights are less than $\pm 0^{m}.02$ in both B and V filters. The light curves in the instrumental system were plotted for all the five nights in the sense Δm (variable comparison) against UT. The UT of individual observations have been converted into heliocentric Julian days and are given in table 1. In table 2 we give the observed epochs of maxima determined by us from the light curves by graphical method. The uncertainities in the observed times of maxima are estimated to be within $\pm 0^d.004$.

Table 1. Observed differential magnitudes of BW Vul

$JD_\odot$	Δm_V	$JD_\odot$	Δm_V	$JD_\odot$	Δm_V
2437971.1166	0.168	2437971.2779	0.273	2437973.2453	0.165
.1179	0.165	.2789	0.242	.2463	0.157
.1194	0.164	.2802	0.268	.2473	0.159
.1205	0.169	.2812	0.325	.2483	0.164
.1326	0.146	2437973.0648	0.202	.2633	0.213
.1339	0.122	.0658	0.216	.2646	0.215
.1351	0.124	.0669	0.202	.2658	0.225
.1428	0.117	.0672	0.209	.2682	0.248
.1441	0.105	.0680	0.207	.2697	0.232
.1451	0.116	.0818	0.227	.2706	0.209
.1461	0.135	.0827	0.235		
.1475	0.097	.0835	0.235	2437974.1087	0.233
.1585	0.097	.0843	0.229	.1096	0.227
.1597	0.097	.0940	0.268	.1105	0.211
.1610	0.098	.0950	0.271	.1114	0.211
.1621	0.098	.0963	0.252	.1124	0.229
.1631	0.097	.0976	0.261	.1136	0.231
.1644	0.096	.1510	0.123	.1147	0.222
.1725	0.077	.1519	0.122	.1151	0.212
.1736	0.071	.1529	0.116	.1160	0.212
.1744	0.058	.1537	0.104	.1288	0.195
.1755	0.054	.1611	0.100	.1290	0.186
.1762	0.070	.1621	0.099	.1315	0.178
.1863	0.050	.1632	0.098	.1323	0.178
.1867	0.051	.1657	0.100	.1441	0.130
.1887	0.050	.1678	0.093	.1448	0.121
.1906	0.045	.1699	0.074	.1454	0.116
.1933	0.044	.1710	0.076	.1464	0.134
.1945	0.051	.1720	0 075	.1470	0.128
.1957	0.058	.1733	0.073	.1469	0.119
.1970	0.059	.1855	0.035	.1491	0.128
.2061	0.088	.1868	3.033	.1504	0.116
.2073	0.095	.1888	0.038	.1513	0.122
.2086	0.099	.1898	0.035	.1521	0.104
.2105	0.102	.1919	0.023	.1533	0.114
.2141	0'126	.1936	0.010	.1889	0.057
.2154	0.115	.1948	0.008	.1899	0.089
.2164	0.129	.1958	0.007	.1905	0.055
.2177	0.116	.2064	0.068	.1915	0.053
.2185	0.121	.2077	0.065	.1923	0.071
.2341	0.189	.2089	0.079	.1932	0.040
.2357	0.192	.2098	0.090	.1956	0.052
.2366	0.189	.2113	0.076	.1965	0.050
.2379	0.199	.2126	0.098	.1977	0.040
.2389	0.186	.2274	0.133	.1984	0.033
.2512	0.191	.2286	0.132	.1995	0.044
.2522	0.174	.2299	0.146	.2004	0.057
.2433	0.176	.2312	0.147	.2014	0.061
.2543	0.190	.2399	0.168	.2117	0.059
.2646	0.277	.2410	0.157	.2126	0.051
.2658	0.279	.2418	0.153	.2136	0.064
.2668	0.273	.2426	0.155	.2146	0.075
.2679	0.271	.2434	0.169	.2156	0.064

(*Continued*)

Table 1.—*Continued*

$JD_\odot$	Δm_V	$JD_\odot$	Δm_V	$JD_\odot$	Δm_V
2437974.2178	0.054	2437974.2356	0.113	2437974.2542	0.145
.2189	0.065	.2366	0.109	.2568	0.143
.2192	0.053	.2375	0.106	.2579	0.161
.2200	0 065	.2399	0.118	.2662	0.179
.2210	0.057	.2412	0.126	.2672	0.182
.2223	0.082	.2503	0.149	.2681	0.174
.2317	0.108	.2513	0.143	.2690	0.154
.2328	0.088	.2521	0.139	.2701	0.197
.2341	0.099	.2532	0.151	.2709	0.189

$JD_\odot$	Δm_B	$JD_\odot$	Δm_B	$JD_\odot$	Δm_B
2437971.1173	0.169	2437971.2662	0.291	2437973.2132	0.077
.1189	0.168	.2672	0.271	.2279	0.134
.1200	0.167	.2684	0.276	.2289	0.138
.1213	0.168	.2783	0.280	.2303	0.182
.1334	0.135	.2793	0.288	.2318	0.145
.1344	0.127	.2806	0.300	.2474	0.174
.1356	0.129	.2819	0.309	.2484	0.164
.1433	0.129			.2492	0.149
.1443	0.125	2437973.0655	0.219	.2502	0.168
.1453	0.122	.0665	0.223	.2519	0.181
.1466	0.114	.0676	0.234	.2529	0.148
.1490	0.103	.0688	0,238	.2539	0.161
.1590	0.112	.0697	0.239	.2547	0.191
.1603	0.108	.0824	0.247	.2555	0.151
.1616	0.102	.0832	0.252	.2637	0.232
.1626	0.100	.0840	0.248	.2650	0.207
.1639	0.107	.0847	0.248	.2663	0.209
.1649	0.102	.0944	0.247	.2685	0.236
.1723	0.070	.0969	0.252	.2700	0.228
.1733	0.065	.0979	0.251	.2711	0.219
.1743	0.070	.1221	0.173	2437977.0877	0.225
.1755	0.070	.1233	0.197	.0882	0.220
.1768	0.072	.1249	0.175	.0887	0.225
.1879	0.065	.1272	0.171	.0890	0.220
.1887	0.036	.1274	0.172	.0995	0.243
.1895	0.047	.1307	0.139	.1001	0.240
.1908	0.046	.1320	0.137	.1005	0.238
.1942	0.062	.1411	0.139	.1010	0.244
.1950	0.050	.1419	0.138	.1060	0.263
.1963	0.068	.1514	0.202	.1066	0.261
.1976	0.062	.1523	0.198	.1072	0 260
.2067	0.091	.1532	0.199	.1078	0.262
.2078	0.099	.1625	0.116	.1131	0.247
.2096	0.100	.1638	0.110	.1136	0.249
.2110	0.112	.1692	0.024	.1141	0.240
.2150	0.114	.1703	0.032	.1146	0.244
.2161	0.124	.1714	0.030	.1157	0.243
.2169	0.109	.1727	0.021	.1240	0.238
.2182	0.121	.1739	0.010	.1246	0.244
.2194	0.138	.1893	0.037	.1250	0.235
.2347	0.181	.1903	0.047	.1254	0.232
.2360	0.177	.1924	0.042	.1260	0.234
.2370	0.160	.1949	0.031	.1268	0.231
.2383	0.183	.1959	0.035	.1321	0.235
.2393	0.180	.1968	0.042	.1334	0.234
.2518	0.175	.2071	0.066	.1340	0.233
.2526	0.187	.2084	0.067	.1347	0.232
.2537	0.173	.2095	0.065	.1487	0.190
.2546	0.196	.2105	0.077	.1493	0.192
.2653	0.272	.2121	0.077	.1498	0.181

(*Continued*)

Table 1.—*Continued*

$JD_{\odot}$	Δm_B	$JD_{\odot}$	Δm_B	$JD_{\odot}$	Δm_B
2437977.1548	0.178	2437977.2065	0.048	2438727.0596	0.950
.1554	0.181	.2071	0.057	.0619	0.935
.1561	0.174	.2177	0.038	.0640	0.931
.1567	0.164	.2185	0.032	.0750	0.903
.1668	0.122	.2191	0.027	.0774	0.906
.1675	0.109	.2197	0.022	.0798	0.888
.1681	0.108	.2203	0.026	.0820	0.883
.1687	0.109	.2209	0.034	.0844	0.880
.1695	0.106	.2280	0.066	.0984	0.931
.1700	0.105	.2283	0.064	.1011	0.932
.1766	0.113	.2389	0.061	.1057	0.954
.1774	0.109	.2304	0.063	.1204	1.008
.1780	0.110	.2310	0.077	.1230	1.016
.1786	0.105	.2316	0.079	.1256	1.016
.1842	0.093	.2326	0.092	.1280	1.017
.1846	0.098	.2424	0.157	.1303	1.017
.1849	0.095	.2430	0.144	.1462	1.063
.1853	0.160	.2433	0.142	.1481	1.073
.1955	0.085	.2437	0.139	.1503	1.074
.1961	0.079	.2440	0.144	.1526	1.079
.1969	0.075	.2637	0.260	.1649	1.074
.1977	0.073	.2645	0.264	.1669	1.075
.2040	0.070	.2650	0.259	.1692	1.080
.2044	0.066	.2654	0.256	.1713	1.076
.2047	0.063	.2689	0.305	.1833	1.098
.2050	0.051	.2695	0.306	.1847	1.095
.2059	0.061	2438727.0576	0.954	.1869	1.099

Table 2. Observed times of maxima of BW Vul

Date UT	Max. $JD_{\odot}$	Filter
Nov. 2, 1962	2437971.188	V, B
Nov. 4, 1962	2437973.195	V, B
Nov, 5, 1962	3437974.201	V
Nov. 8, 1962	2437977.218	V, B
Nov. 28, 1964	2438727.085	B

3. Results and discussion

Using the epoch of maxima at $JD_{\odot}$ 2433853.3980 (Nikonov & Nikonova 1952) as an initial epoch and a period of $0^d.2010298$ the $O - C$ values for 41 observed maxima (taken from Margrave 1979, Valtier 1976 and our observed maxima) were calculated taking due care in counting the number of cycles in accordance with the $O - C$ trend. Where several maxima of the star have been given by an author within a small interval of time (within few days) we have dropped some of the maxima. But on the other hand, where there are large gaps in the observations of the photometric maxima we have adopted the available maxima of the star obtained from spectroscopic observations. This is because for this study we are interested in having the maxima at sufficiently spaced interval of a few thousand cycles.

These $O - C$ values were then plotted against time. A smooth parabolic curve (figure 1) was thus obtained. The parabola can be represented by

$$O - C = -2.37612 \times 10^{-3} + 3.04167 \times 10^{-6} E + 7.2332 \times 10^{-11} E^2.$$

If P be the instantaneous period of the star and P_1 the period at the initial epoch $JD_{\odot}$ 2433853.398 and P_0 the assumed constant period equal to $0^d.2010298$, we have

$$P = P_1 + \alpha t \text{ where } \alpha = \frac{dP}{dt} \qquad \ldots(1)$$

$$P_1 = P_0 + \Delta P \qquad \ldots(2)$$

and $$O - C = (\mathrm{Max}_{(0)}^{P_1} - \mathrm{Max}_{(0)}^{P_0}) + \Delta PE + \frac{\alpha}{2} P_0 E^2 \qquad \ldots(3)$$

and $$\frac{\alpha}{2} P_0 \simeq \frac{\alpha P_1}{2}. \qquad \ldots(4)$$

With these relationships the above quadratic solution gives

$$\Delta P = 3.04167 \times 10^{-6}$$

$$\frac{\alpha}{2} P_0 \simeq \frac{\alpha P_1}{2} = 7.23317 \times 10^{-11} \text{ and } \alpha = 7.196 \times 10^{-10} \text{ days/day}$$

$$= 2.27 \text{ s century}^{-1}$$

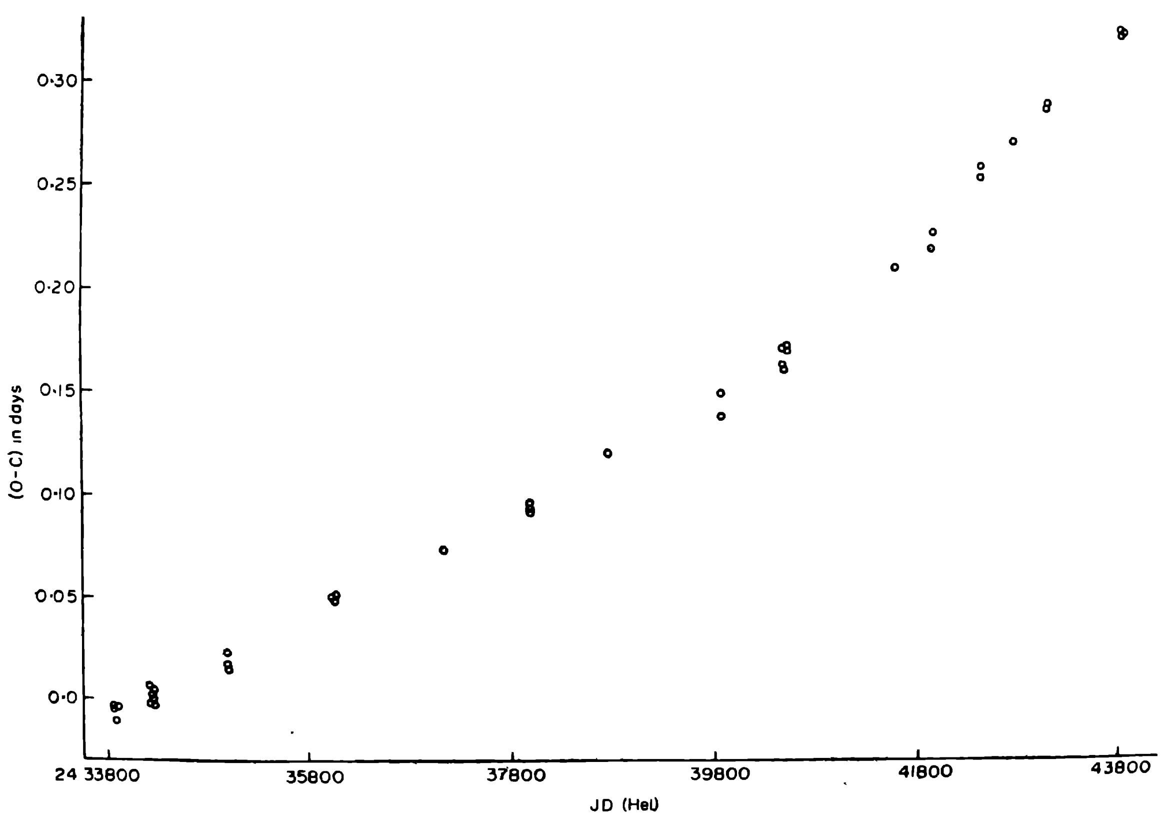

Figure 1. ($O-C$) diagram for BW Vul.

and $O - C$ value at the initial epoch $= -2^d.37612 \times 10^{-3}$.

Taking the initial observed epoch as the starting point the emphemeris for the star can be written as

$$JD_{\odot}\ \mathrm{Max}_{(0)} = 2433853.3980 + 0.20103284\,E + 7.2332 \times 10^{-11}\,E^2 \quad ...(5)$$

Using this relation the standard deviation for the $O - C$ values of the 41 maxima considered by us is $\pm\ 0^d.0049$ (table 3).

Table 3. $(O - C)$ values calculated on the basis of derived ephemeris

Sl No.	$JD_{\odot}$	Reference	$O - C$
1	2433859.4260	Valtier (1976)	$+0^d.0003$
2	33868.4710	,,	−0.0009
3	33892.3880	,,	−0.0069
4	33896.8160	,,	−0.0016
5	33898.4250	,,	−0.0008
6	34221.8930	,,	+0.0051
7	34232.9400	,,	−0.0047
8	34247.8210	,,	−0.0002
9	34257.8700	,,	−0.0028
10	34262.7000	,,	+0.0024
11	34263.8980	,,	−0.0058
12	35003.9140	,,	+0.0063
13	35009.9388	,,	+0.0012
14	35015.7670	,,	−0.0017
15	36032.4110	,,	+0.0095
16	36052.5120	,,	+0.0071
17	36067.3910	,,	+0.0095
18	37136.8920	,,	+0.0090
19	37971.1880	Present work	+0.0077
20	37973.1950	,,	+0.0043
21	37974.2010	,,	+0.0051
22	37977.2180	,,	+0.0066
23	38727.0850	,,	+0.0054
24	39828.5560	Valtier (1976)	−0.0002
25	39829.5500	,,	−0.0035
26	40432.8649	,,	−0.0096
27	40433.8788	,,	−0.0009
28	40449.7596	,,	−0.0020
29	40474.6879	,,	−0.0025
30	40475.6910	,,	−0.0045
31	41537.7728	,,	−0.0063
32	41871.9023	,,	−0.0028
33	41891.8023	,,	−0.0051
34	42350.7854	,,	+0.0059
35	42356.8112	,,	+0.0006
36	42678.8780	,,	+0.0028
37	43002.9543	Margrave (1979)	+0.0037
38	43012.8081	,,	+0.0066
39	43724.8816	,,	+0.0026
40	43729.9141	,,	+0.0002
41	43755.8486	,,	+0.0004

This rate of increase is similar to the increase obtained by Margrave (1979) by taking his initial epoch at $JD_{\odot}$ 2428802, some 5050 days earlier than the epoch taken by us. This shows that prior to our initial epoch also the rate of increase of the period has been about 2.2 s century^{-1}. This lends confirmation to an approximately uniform rate of increase of period by 2 2 s century^{-1} for the star.

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