PHOTOMETRIC ELEMENTS OF V364 CASSIOPEIAE

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Abstract. The *UBV* photometric observations of the eclipsing binary V364 Cas have been discussed. Two sets of photometric elements, one based on the Russell and Merrill methods and the other based on Kopal's new method of the analysis of the light curves of eclipsing binary stars in the frequency-domain, have been derived. Using the observed colour indices $U - B$ and $B - V$, the spectral types of the systemic components are estimated. An examination of all the available times of minimum light of V364 Cas does not reveal any change in its orbital period.

1. Introduction

The photographic light curve of the eclipsing binary V364 Cas has been given by Perova (1957). He also gave its finding chart and determined the photographic magnitude to be $11^{m}_{.}3$–$12^{m}_{.}0$. Diethelm (1977) observed the star photovisually and derived a time of minimum light. No radial velocity study has been done so far.

We selected V364 Cas (BD + 49°226, BV = 1) for three colour photoelectric photometry because neither the photoelectric light curve nor the photoelectric times of minimum light have ever been published. It has already been reported that the orbital period given by Perova (1957) is half of the actual orbital period of the system (Chaubey and Singh, 1984) and the secondary minimum occurs at $0^{P}_{.}5$. The purpose of this paper is to present our *UBV* observations, solve the light curves and discuss some more findings on the system.

Throughout this paper subscript h refers to the hotter star which is eclipsed at primary minimum. Subscript c refers to the cooler star which is eclipsed at secondary minimum.

2. Observations

During October–December, 1980 the 56 cm reflector of Uttar Pradesh State Observatory equipped with a photometer having a refrigerated (to − 20 °C) 1P21 photomultiplier and standard U, B, and V filters of the Johnson and Morgan system, was used for the observations. The comparison star used was BD + 49°225. For all the observations, a diaphragm of 13 arc sec diameter was used to exclude the nearby stars. The observational technique and data reduction procedures were the same as used earlier (Chaubey, 1982).

In addition, nine standard stars (HD 18992, HD 19373, HD 19909, HD 20123, 32 Per, λ Per, μ Per, ν Per, and τ Per) taken from Blanco *et al.* (1968) have been observed to reduce the data to the standard *UBV* system. The standard errors of our observations, in U, B, and V filters are $0^{m}_{.}03$, $0^{m}_{.}02$, and $0^{m}_{.}02$, respectively.

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TABLE I

Observed differential magnitudes of V364 Cas in U, B, and V filters

J. D. (Hel.) 2444000.0 +	Phase	ΔU	ΔB	ΔV
519.1277	0.034	$-0\overset{m}{.}192$	$0\overset{m}{.}720$	$1\overset{m}{.}505$
519.1402	0.042	0.315	0.703	1.495
519.1520	0.050	0.404	0.605	1.328
519.1547	0.052	0.409	0.589	1.247
519.1581	0.054	0.507	0.583	1.230
519.1732	0.064	0.550	0.583	1.067
519.1763	0.066	0.549	0.496	1.087
519.1880	0.073	0.600	0.481	1.120
519.1912	0.075	0.596	0.483	1.118
519.1951	0.078	0.572	0.489	1.119
519.2050	0.084	0.585	0.453	1.079
519.2081	0.086	0.581	0.466	1.089
519.2170	0.092	0.612	0.458	1.051
519.2756	0.130	0.551	0.443	1.096
519.2787	0.132	0.578	0.443	1.106
519.2888	0.139	0.580	0.461	1.080
519.3301	0.165	0.552	0.409	1.108
519.3329	0.179	0.550	0.427	1.093
519.3735	0.194	0.587	0.433	1.066
519.3756	0.195	0.545	0.432	1.066
528.2219	0.928	0.589	0.428	1.091
528.2263	0.930	0.573	0.440	1.088
528.2517	0.946	0.487	0.462	1.144
528.2544	0.949	0.459	0.474	1.274
528.2648	0.950	0.386	0.548	1.361
528.2673	0.957	0.216	0.673	1.361
528.2708	0.959	0.197	0.660	1.430
528.2808	0.966	+0.069	0.752	1.450
528.2839	0.968	0.140	0.779	1.453
528.3173	0.989	0.170	1.036	1.468
528.3220	0.993	0.174	1.063	1.660
528.3360	0.001	0.171	1.101	1.752
528.3383	0.002	0.155	1.087	1.770
528.3406	0.004	0.125	1.079	1.770
528.3445	0.007	0.133	1.054	1.772
528.3462	0.008	0.083	1.039	1.722
528.3483	0.009	0.085	1.028	1.715
528.3514	0.011	0.043	1.003	1.686
528.3550	0.013	+0.031	1.022	1.712
528.3572	0.016	0.055	0.988	1.651
528.3594	0.017	0.068	0.774	1.617
528.3727	0.025	0.184	0.826	1.590
528.3768	0.028	0.186	0.806	1.491
528.3792	0.030	0.256	0.781	1.476
528.3881	0.035	0.268	0.720	1.400
528.3901	0.036	0.408	0.706	1.397
528.4087	0.048	0.498	0.618	1.271
528.4775	0.054	0.586	0.561	1.268

Table I (continued)

J. D. (Hel.) 2444000.0 +	Phase	ΔU	ΔB	ΔV
528.4203	0.056	−0.574	0.533	1.248
540.2305	0.710	0.590	0.412	1.117
540.2339	0.712	0.593	0.410	1.133
540.2372	0.714	0.608	0.407	1.133
540.2728	0.737	0.606	0.410	1.102
540.2742	0.739	0.590	0.405	1.102
540.2813	0.742	0.599	0.426	1.100
540.2929	0.749	0.572	0.429	1.125
540.2985	0.753	0.572	0.417	1.090
540.3027	0.756	0.572	0.425	1.105
540.3126	0.763	0.583	0.412	1.094
540.3169	0.765	0.570	0.442	1.127
540.3211	0.767	0.566	0.422	1.110
540.3256	0.772	0.523	0.432	1.119
544.2460	0.312	0.608	0.418	1.129
544.2486	0.314	0.628	0.428	1.143
544.2559	0.318	0.586	0.415	1.143
544.2584	0.321	0.579	0.423	1.113
544.3169	0.359	0.582	0.410	1.113
544.3189	0.361	0.574	0.429	1.104
545.1177	0.877	0.565	0.432	1.049
545.1194	0.879	0.600	0.435	1.096
545.1215	0.880	0.600	0.418	1.057
555.0912	0.340	0.596	0.429	1.072
555.0957	0.344	0.585	0.418	1.069
555.0980	0.345	0.570	0.425	1.071
555.1096	0.352	0.584	0.438	1.075
555.1127	0.354	0.600	0.431	1.072
555.1155	0.356	0.602	0.429	1.070
555.1574	0.383	0.596	0.417	1.068
555.1605	0.385	0.585	0.410	1.065
555.1695	0.391	0.583	0.427	1.067
555.1738	0.394	0.580	0.429	1.065
555.1768	0.396	0.591	0.429	1.053
555.1847	0.401	0.588	0.429	1.045
555.1964	0.408	0.543	0.416	1.061
555.1983	0.409	0.570	0.431	1.073
555.2018	0.412	0.545	0.420	1.072
555.2093	0.417	0.548	0.427	1.082
555.2147	0.420	0.571	0.430	1.052
555.2233	0.426	0.573	0.420	1.104
555.2270	0.428	0.563	0.427	1.106
555.2317	0.431	0.566	0.454	1.092
555.2427	0.438	0.485	0.429	1.101
555.2462	0.441	0.477	0.437	1.129
555.2495	0.443	0.420	0.558	1.128
555.2556	0.448	0.354	0.593	1.267
555.2633	0.452	0.354	0.615	1.279
555.2650	0.453	0.357	0.625	1.303

Table I (continued)

J. D. (Hel.) 2444000.0 +	Phase	ΔU	ΔB	ΔV
555.2735	0.458	−0.208	0.669	1.375
555.2797	0.462	0.213	0.701	1.473
555.2830	0.464	0.162	0.703	1.492
555.2929	0.471	0.120	0.876	1.480
555.3085	0.481	0.063	0.908	1.543
555.3127	0.484	0.042	0.962	1.601
555.3250	0.492	+0.018	0.991	1.680
555.3283	0.494	0.056	1.022	1.710
555.3332	0.497	0.057	1.058	1.720
555.3371	0.499	0.059	1.066	1.704
555.3454	0.504	0.042	1.053	1.710
555.3463	0.506	0.021	0.993	1.680
555.3496	0.508	0.003	1.034	1.690
555.3572	0.513	−0.008	1.001	1.503
555.3608	0.515	0.015	0.958	1.514
555.3640	0.517	0.103	0.916	1.648
555.3727	0.523	0.170	0.852	1.564
555.3768	0.526	0.183	0.735	1.453
558.0911	0.284	0.578	0.432	1.065
558.1019	0.292	0.565	0.422	1.072
558.1066	0.294	0.565	0.418	1.077
558.1181	0.302	0.541	0.442	1.079
558.1231	0.305	0.571	0.427	1.084
558.1358	0.314	0.564	0.406	1.090
558.1401	0.316	0.556	0.435	1.058
558.1437	0.318	0.569	0.424	1.063
558.1522	0.324	0.609	0.404	1.066
558.1558	0.326	0.599	0.440	1.070
558.1730	0.337	0.559	0.439	1.089
558.1767	0.339	0.576	0.387	1.086
558.1781	0.341	0.577	0.407	1.085
558.1841	0.345	0.581	0.438	1.082
558.1876	0.347	0.586	0.409	1.078
558.1915	0.351	0.556	0.432	1.085
558.1997	0.355	0.558	0.450	1.091
558.2101	0.362	0.550	0.391	1.064
558.2176	0.366	0.556	0.416	1.074
558.2208	0.368	0.578	0.406	1.094
558.2654	0.394	0.582	0.421	1.097
558.2749	0.403	0.566	0.416	1.081
558.2786	0.406	0.576	0.429	1.085
558.2812	0.408	0.586	0.439	1.098
559.0975	0.937	0.538	0.446	1.093
559.1005	0.939	0.456	0.456	1.077
559.1044	0.941	0.430	0.500	1.079
559.1129	0.946	0.384	0.525	1.183
559.1211	0.952	0.311	0.606	1.198
559.1334	0.960	0.229	0.688	1.231
559.1370	0.963	0.209	0.698	1.449

Table I (continued)

J. D. (Hel.) 2444000.0+	Phase	ΔU	ΔB	ΔV
559.1463	0.969	−0.146	0.775	1.458
559.1513	0.972	0.061	0.820	1.484
559.1685	0.983	+0.015	0.920	1.631
559.1726	0.986	0.025	0.933	1.632
559.1810	0.992	0.153	1.008	1.632
559.1834	0.993	0.155	1.039	1.743
559.1871	0.996	0.165	1.058	1.759
559.1973	0.000	0.173	1.075	1.759
559.1997	0.003	0.172	1.062	1.763
559.2035	0.005	0.163	1.062	1.735
559.2074	0.008	0.139	1.005	1.683
559.2112	0.010	0.112	1.001	1.675
559.2153	0.013	0.098	0.988	1.662
559.2195	0.016	−0.021	0.947	1.598
559.2233	0.018	0.026	0.896	1.511
559.2265	0.021	0.104	0.868	1.518
559.2362	0.027	0.107	0.717	1.392
559.2393	0.029	0.112	0.708	1.441
559.2687	0.048	0.315	0.572	1.167
559.2717	0.050	0.355	0.560	1.130
559.2747	0.051	0.398	0.554	1.112
559.2811	0.055	0.480	0.484	1.118
559.2851	0.059	0.530	0.484	1.092
559.2916	0.062	0.583	0.407	1.085
559.3164	0.079	0.590	0.417	1.082
559.3192	0.085	0.572	0.384	1.081
559.3225	0.086	0.580	0.414	1.070
559.3285	0.087	0.596	0.404	1.083
559.3376	0.092	0.581	0.435	1.064

The individual observations are listed, in differential form, in Table I, wherein phases have been computed with the ephemeris (Chaubey and Singh, 1984)

$$\text{J.D. (Hel.)} = 2444519.0752 + 1\overset{\text{d}}{.}5430694E\,. \qquad (1)$$

The last three columns contain the differential magnitudes U, B, and V in the sense variable minus comparison. They are plotted against phases in Figure 1.

3. Photometric Solutions

3.1. Russell and Merrill method

Assuming the light outside the eclipse to be of the form

$$l = A_0 + A_1 \cos\theta + A_2 \cos 2\theta\,, \qquad (2)$$

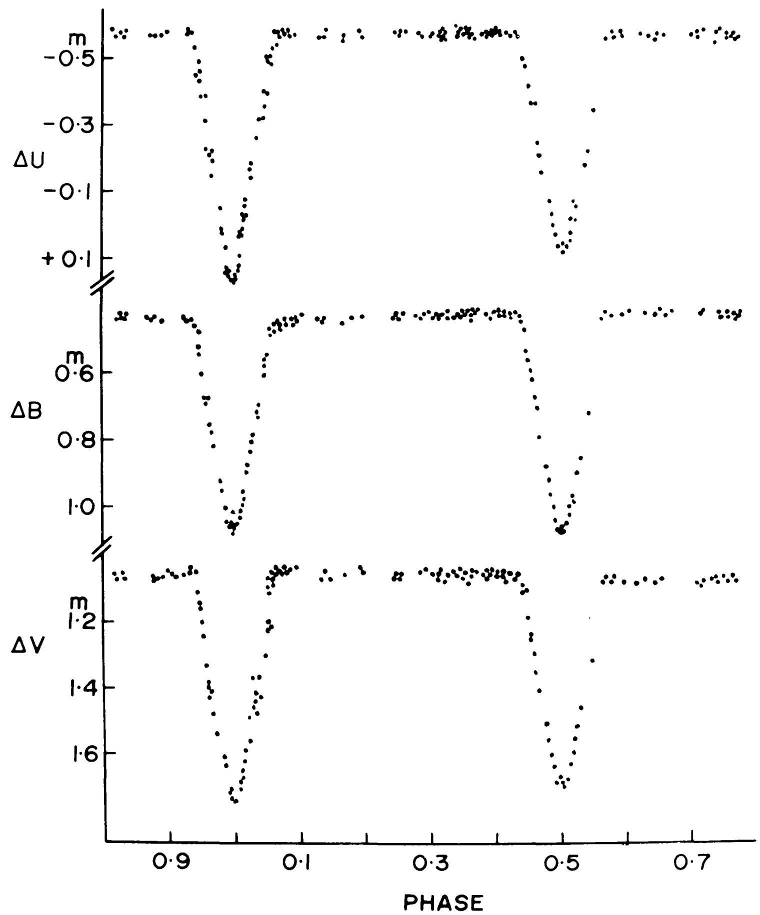

Fig. 1. Observed *UBV* light curves of V364 Cas.

TABLE II

Photometric solution for V364 Cas by Russell and Merrill's method

	U	B	V
Δm at $I = 1$	$-0^m.595$	$+0^m.425$	$+1^m.085$
x (assumed)	0.6	0.6	0.6
A_0	0.9592	0.9731	0.9701
A_1	−0.0011	−0.0024	−0.0019
A_2	0.0010	0.0001	0.0000
α_0^{occ}	1.000	1.000	1.000
α_0^{tr}	1.012	1.013	1.013
r_h	0.221	0.223	0.223
r_c	0.194	0.189	0.192
L_h	0.563	0.553	0.550
L_c	0.437	0.447	0.450
θ_e	$24^\circ.4$	$24^\circ.2$	$24^\circ.3$
θ_i	$2^\circ.5$	$2^\circ.6$	$2^\circ.5$
i	$87^\circ.4$	$87^\circ.1$	$87^\circ.1$

the Fourier coefficients A_0, A_1, and A_2 were determined by a least-squares fit using a computer program. The magnitudes corresponding to unit light and the resulting coefficients in all three colours are given in Table II. Using these values of A_0, A_1, and A_2 the actual rectifications, conversion of l to l^r and of θ to θ^r, were carried out using the procedure given by Russell and Merrill (1952).

In order to get the orbital elements, the normalized rectified intensity of primary and secondary minima were reflected about 0° and 180°, respectively, and plotted on a large scale. The χ values for the secondary and the primary eclipse were, respectively, 0.292, 0.312, 0.308, and 0.198, 0.215, 0.204 in the U, B, and V filters, showing that $\chi^{\text{pri}} < \chi^{\text{sec}}$, which indicates that the secondary eclipse is an occultation and the primary eclipse a transit. The nomographic solution (Russell and Merrill, 1952) suggests that the secondary eclipse is total. The orbital elements, derived with the help of tables of eclipse of Merrill (1950), are listed in Table II.

3.2. Kopal's frequency-domain method

The moments of the light curves, as defined by the equation (Kopal, 1977):

$$A_{2m} = \int_0^{\theta_e} (1 - l) d \sin^{2m} \theta \,, \tag{3}$$

where θ_e, outer contact angle; l, normalised intensity at phase angle θ; and m, any non-negative integer; were computed for the secondary minima of the U, B, and V light curves for m = 0, 1, 2, and 3. These moments of the light curves are listed in Table III.

TABLE III

Photometric solutions for V364 Cas in Kopal's frequency-domain method

	U	B	V
Δm at $l = 1$	$-0^{m}.595$	$+0^{m}.425$	$+1^{m}.085$
A_0	0.4372	0.4473	0.4502
A_2	0.02016	0.02083	0.02204
A_4	0.002367	0.001690	0.003939
A_6	0.000169	0.000165	0.000180
r_h	0.220	0.221	0.221
r_c	0.195	0.194	0.196
L_h	0.5628	0.5527	0.5498
L_c	0.4372	0.4473	0.4502
i	87°.2	87°.2	87°.1

Further, the four moments A_0, A_2, A_4, and A_6 of each light curve have been used to extract the orbital elements. In order to do this, we carried out some calculations in accordance with the precepts of Kopal (1982) by means of the following equations:

$$A_0 = L_1 \alpha_0 , \tag{4}$$

$$A_2 = L_1 \{C_3 + (1 - \alpha_0) \cot^2 i\} , \tag{5}$$

$$A_4 = L_1 \{C_3^2 + C_2^2 - (1 - \alpha_0) \cot^4 i\} , \tag{6}$$

$$A_6 = L_1 \{C_3^3 + 3C_2^2 C_3 + C_1 C_2^2 + (1 - \alpha_0) \cot^6 i\} ; \tag{7}$$

where L_1 is the luminosity of the eclipsed star, expressed in terms of the total light of the system taken as unity; α_0 is the maximum fractional loss of light of the eclipsed star; i is the angle of inclination of the orbital plane to the plane of the sky; and

$$C_3 = \{r_2^2 \operatorname{cosec}^2 i - \cot^2 i\} \sum_{n=0}^{N} \frac{1!\, C^{(n)}}{(\frac{1}{2}n + 1)} ; \tag{8}$$

$$C_2 = r_1^2 r_2^2 \operatorname{cosec}^4 i \sum_{n=0}^{N} \frac{2!\, C^{(n)}}{(\frac{1}{2}n + 1)(\frac{1}{2}n + 2)} ; \tag{9}$$

$$C_1 C_2^2 = r_1^4 r_2^2 \operatorname{cosec}^6 i \sum_{n=0}^{N} \frac{3!\, C^{(n)}}{(\frac{1}{2}n + 1)(\frac{1}{2}n + 2)(\frac{1}{2}n + 3)} . \tag{10}$$

In the above equations, r_1 and r_2 are the fractional radii of the eclipsed and the eclipsing stars, respectively, expressed in terms of their separation; and $C^{(n)}$ are the functions specifying the distribution of brightness over the apparent disc of the eclipsed star, characterized by the limb darkening coefficient $u_1, u_2, u_3, \ldots, u_n$ and given by the relation:

$$C^{(n)} = \frac{1 - u_1 - u_2 - u_3 - \cdots - u_n}{1 - \sum_{l=0}^{N} \frac{l u_1}{l + 2}} \quad \text{for} \quad n = 0 \tag{11}$$

and

$$C^{(n)} = \frac{u_n}{1 - \sum_{l=0}^{N} \frac{l u_1}{l + 2}} \quad \text{for} \quad 0 < n \leq N . \tag{12}$$

In our calculations, the linear law of limb darkening for the distribution of the brightness over the apparent disc of the eclipsed star were assumed. The values of the limb darkening coefficients 0.6, 0.73, and 0.58, respectively, in the U, B, and V filters have been taken from Grygar *et al.* (1972). The resulting elements are given in Table III.

4. Spectral Types and Period Variation

From the observed colour indices, $U - B$ and $B - V$ outside the eclipses and within the eclipses, we have determined the colour indices of the individual systemic components.

TABLE IV

Observed minima of V364 Cas

n	J. D. (Hel.) 2400000.0 +	Cycles	O–C (in days)	Observing method[b]	Type of minima[c]	Reference[a]
1	16711.446	− 18021	+ 0.024	pg	P	1
2	24825.623	− 12762	− 0.029	pg	S	2
3	25081.821	− 12591	+ 0.019	pg	S	2
4	25108.786	− 12579	+ 0.013	pg	P	2
5	25169.736	− 12539	− 0.021	pg	S	2
6	28847.708	− 10156	+ 0.007	pg	P	2
7	28871.600	− 10140	− 0.020	pg	S	2
8	29583.696	− 9679	− 0.011	pg	P	2
9	29868.419	− 9494	− 0.016	pg	S	1
10	29905.498	− 9470	+ 0.061	pg	S	1
11	30224.835	− 9263	− 0.017	pg	S	2
12	30340.625	− 9188	+ 0.043	pg	S	2
13	30619.860	− 9007	− 0.018	pg	S	2
14	30640.672	− 8994	− 0.037	pg	P	2
15	30667.733	− 8976	+ 0.020	pg	S	2
16	31005.693	− 8757	+ 0.048	pg	S	2
17	31032.686	− 8740	+ 0.035	pg	P	2
18	31383.677	− 8512	− 0.020	pg	S	2
19	31407.602	− 8497	− 0.013	pg	P	2
20	31439.259	− 8476	+ 0.011	pg	S	1
21	33033.300	− 7438	+ 0.062	pg	S	1
22	33154.387	− 7365	+ 0.018	pg	P	1
23	33178.288	− 7349	+ 0.001	pg	S	1
24	33212.277	− 7327	+ 0.043	pg	S	1
25	34333.281	− 6601	+ 0.007	pg	P	1
26	34457.478	− 6520	− 0.013	pg	S	1
27	42782.349	− 1125	− 0.001	V	S	3
28	44519.075	0	0.000	pe	P	4
29	44528.334	+ 6	0.000	pe	P	4
30	44555.337	+ 23	0.000	pe	S	4
31	44559.195	+ 26	+ 0.001	pe	P	4

[a] (1) Perova (1957); (2) Strohmeier and Bauernfeind (1968); (3) Diethelm (1977); (4) present study.
[b] pg is photographic; V is visual; pe is photoelectric.
[c] P is primary minimum; S is secondary minimum.

A plot of the colour indices $U - B$ and $B - V$ of both stars, in a colour-colour diagram suggests that both stars are equally reddened, $E(B - V) = 0\overset{m}{.}28$, A6V and A9V stars, respectively. This spectral type of the hotter star is in good agreement with A7, the classification given by Wood *et al.* (1980).

In order to see the variations in the orbital period of the system V364 Cas, we have compiled a list of the 31 minima (Table IV) from the literature known to us, and examined the O–C residuals computed with the ephemeris given in Section 2. A plot of these O–C residuals against cycles given in Figure 2, which shows that the orbital period of the system is constant at least during the last fifty years.

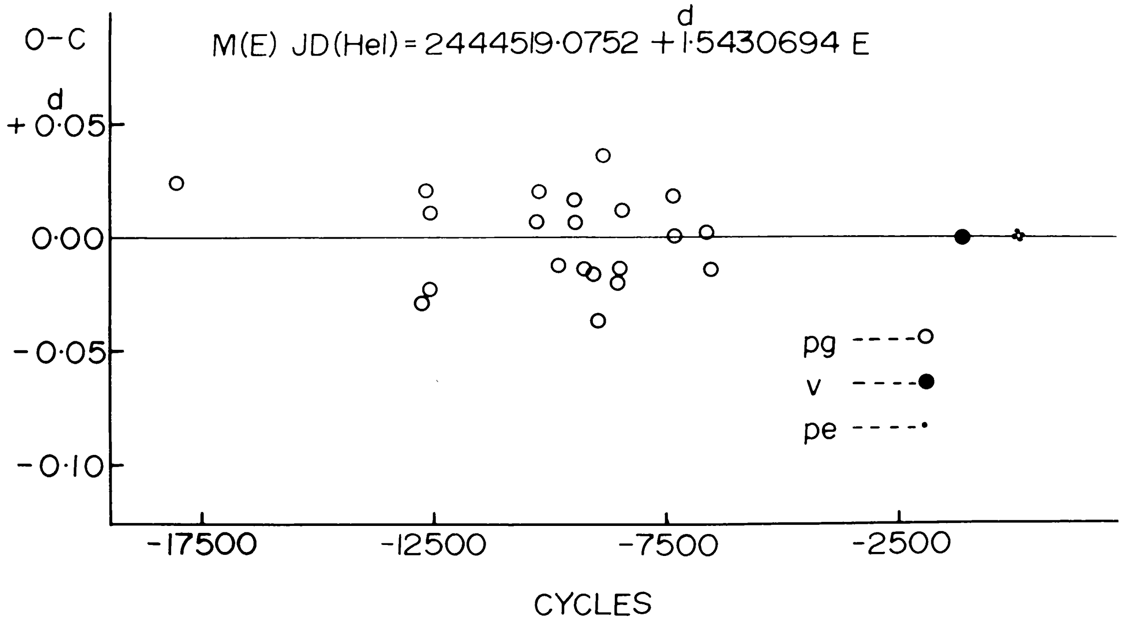

Fig. 2. The O–C curve of V364 Cas. Points are the residuals of the observed minima of V364 Cas based on the ephemeris: $M(E)$ J.D. (Hel.) 2444519.0752 + $1^{d}.5430694E$.

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References

Blanco, V. M., Demers, S., Dauglass, G. G., and Fitzgerald, M. P.: 1968, *Photoelectric Catalogue*, U.S. Naval Observatory, 2nd Series, Vol. 21, Washington.

Chaubey, U. S.: 1982, *Astrophys. Space Sci.* **82**, 283.

Chaubey, U. S. and Singh, M.: 1984, *Bull. Astron. Soc. India* **12**, 40.

Diethelm, R.: 1977, *B.B.S.A.G. Bull.* **33**.

Grygar, J., Cooper, M. L., and Jurkevich, I.: 1972, *Bull. Astron. Inst. Czech.* **23**, 147.

Kopal, Z.: 1977, *Language of the Stars*, D. Reidel Publ. Co., Dordrecht, Holland, p. 148.

Kopal, Z.: 1982, *Astrophys. Space Sci.* **82**, 123.

Merrill, J. E.: 1950, *Princeton Contr.*, No. 22.

Perova, N. B.: 1957, *Variable Stars* **12**, 124.

Russell, H. N. and Merrill, J. E.: 1952, *Princeton Contr.*, No. 26.

Strohmeir, W. and Bauernfeind, H.: 1968, *Veröff. der Remeis Sternw. Bamberg* **7**, No. 72.

Wood, F. B., Oliver, J. P., Florkowski, D. R., and Koch, R. H.: 1980, *A Finding List for Observers of Interacting Binary Stars*, Pennsylvania Press, p. 59.