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PHOTOELECTRIC OBSERVATIONS AND PERIOD STUDY OF ECLIPSING BINARY VZ CEP

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ABSTRACT

Photoelectric observations of the neglected eclipsing binary VZ Cep were made on four nights during the observing season of 1984 at Sobaeksan Astronomy Observatory. The UBV light curves were secured incompletely with the gap in 0.35-0.75 phases. From the observations three times of minimum lights were determined in three band-passes, which formed one weighted minimum epoch (JD Hel 2446009.0453). With our observations, an improved light elements for VZ Cep is determined using all the photoelectric and CCD times of minimum lights published so far. The (O-C) residuals calculated with our light elements show small varying scatters which cannot be negligible. From the analyses of all the times of minima with the Scargle's (1982) period-searching and a curve fitting methods, we found possible periodic oscillations of the (O-C) residuals with the period of $1.^{y}26$ and the amplitude of $0.^{d}0032$. These results, however, have to be considered as a preliminary values until complete analysis for the minimum lights of VZ Cep with enough observational data. Future observations of this binary system are urgently prompted.

1. INTRODUCTION

The light variability of VZ Cep (BD +70°1199, V=$9.^{m}74$, P=$1.^{d}183$) was first reported by Beyer (1950) and confirmed by Romano (1962). The first photoelectric observations of VZ Cep were made by Rössiger (1978) who found that it is an eclipsing binary system with an orbital period of $1.^{d}18336$. However, they presented only a mean light curve of VZ Cep without any analysis of the light curves. After Rössiger's study, the color index (Lacy 1992), mean spectral type of F2-5 and the lower mass limit of 2.4 $M_{\odot}$ (Popper 1996) for the system have been reported. A number of times of minimum lights have been published (Braune *et al.* 1983, Rössiger 1984, Braune & Hübscher 1987, Hübscher & Lichtenknecker 1988, Hübscher *et al.* 1990, Agerer & Hübscher 1995, BBSAG observers 1997). Until now the properties for VZ Cep are little known. This paper is intended to catch out some more dynamical characteristics through analyses of the observed times of minimum lights of the binary system.

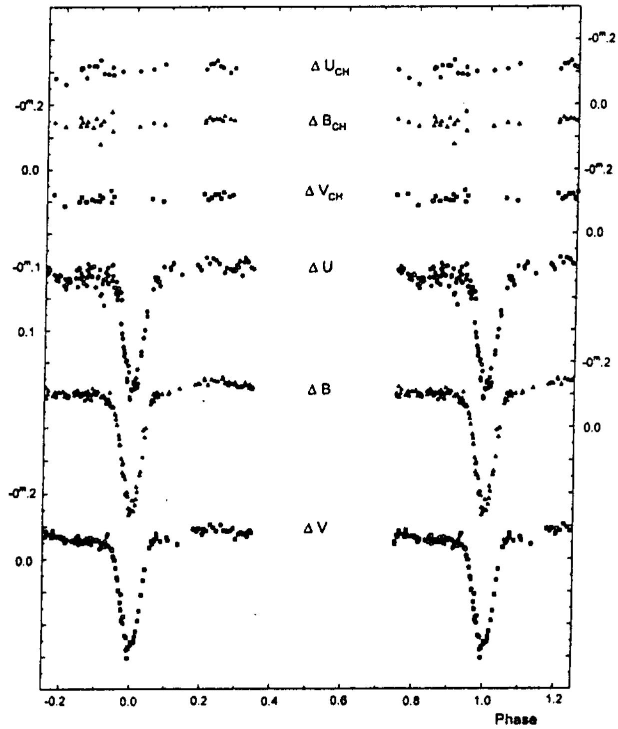

Figure 1. *UBV* light curve of VZ Cep and the check star (BD +70° 1195).

2. OBSERVATIONS AND LIGHT CURVES

The observations of VZ Cep in this study were made photoelectrically for four nights during the observing season in 1984, with a 61 cm reflector at Sobaeksan Astronomy Observatory in Korea. The single channel photometer has an 1P21 photomultiplier tube refrigerated with dry ice and a set of standard *UBV* filters recommended by Johnson (1963). The output photocurrent of the PM tube was fed into a strip chart recorder. More details of the observational system have been described by Han & Kim (1988). The comparison and check stars were BD +70°1200 and BD +70°1195, respectively. The comparison star is the same one used by Rössiger (1978), but the check star was selected by us to check of the light variability of the comparison star.

Extinction coefficients were nightly determined from the observations of the comparison star and small differential corrections applied to data reduction procedure. Mean standard errors of each individual observations were calculated as $0.^{m}017$ for U, $0.^{m}018$ for B, and $0.^{m}011$ for V from the analysis of the magnitude differences in terms of the data from check minus comparison stars.

A total of 469 measurements (153 for U, 157 for B, and 159 for V) for VZ Cep and 82 (27 for U, 28 for B, and 27 for V) for the check star were obtained, which were listed in Table 1 and Table 2, respectively. The *UBV* light curves of VZ Cep and the check star were drawn in Figure 1. As shown in the Figure 1, our light curves show a gap between $0.^{p}35$ and $0.^{p}75$, unfortunately.

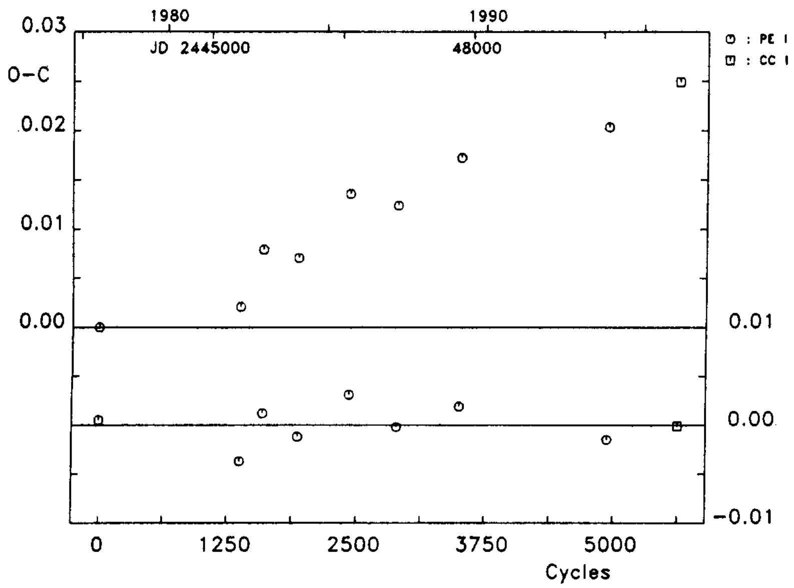

Figure 2. The (O-C) diagram of VZ Cep. The upper and lower diagram were drawn with Rössiger's and our light elements, respectively.

3. PERIOD STUDY

From our observations three primary times of minimum lights for VZ Cep were determined as JD Hel 2446009.0444 ($\pm 0.^d0016$) for U, JD Hel 2446009.0443 ($\pm 0.^d0010$) for B and 2446009.0469 ($\pm 0.^d0014$) for V, respectively by the method of Kwee & van Woerden (1956). A weighted mean timing for these times of minima was calculated as JD Hel 2446009.0453 ($\pm\ 0.^d0013$). The observed times of minima for VZ Cep available to us have been collected and listed in Table 3. The (O-C) residuals for VZ Cep was calculated and plotted in Figure 2 with the light elements of Rössiger (1978) as:

$$Min\, I = JD\; Hel\, 2443720.420 + 1.^d18336\, E. \qquad (1)$$

As shown at the upper part in Figure 2, the times of minimum lights have been deviated from Rössiger's light elements. Therefore a new light elements was determined, using a least-squares method, as:

$$Min\, I = JD\; Hel\, 2443720.4194 + 1.^d18336453\, E. \qquad (2)$$

$$\pm 4 \qquad\qquad \pm 13$$

The (O-C) residuals calculated with equation (2) were listed in third column of Table 3 and drawn at the lower part in Figure 2.

As shown at the lower diagram in Figure 2, all the minima for VZ Cep were well represented by Eq. (2). However we note that the residuals have fluctuated around the zero line with the semi-amplitude of about $0.^d004$. These small scatters seem not to be considered as observational errors

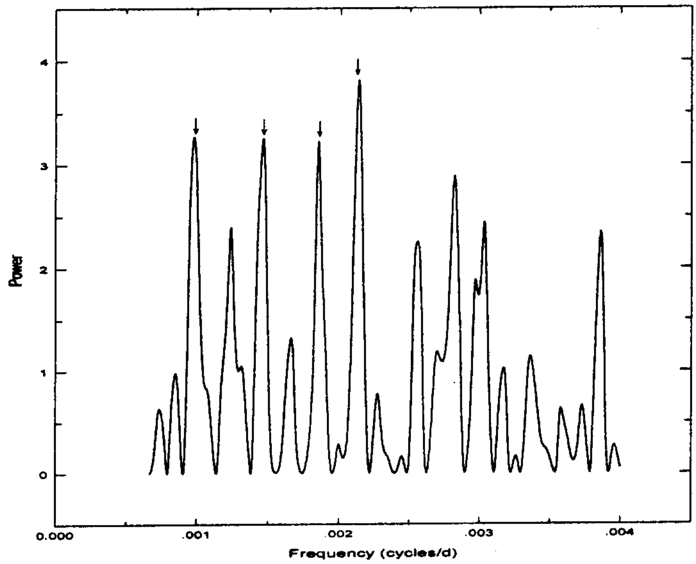

Figure 3. A power spectrum for (O-C) residuals of VZ Cep. Four large peaks were appeared as indicated by arrows.

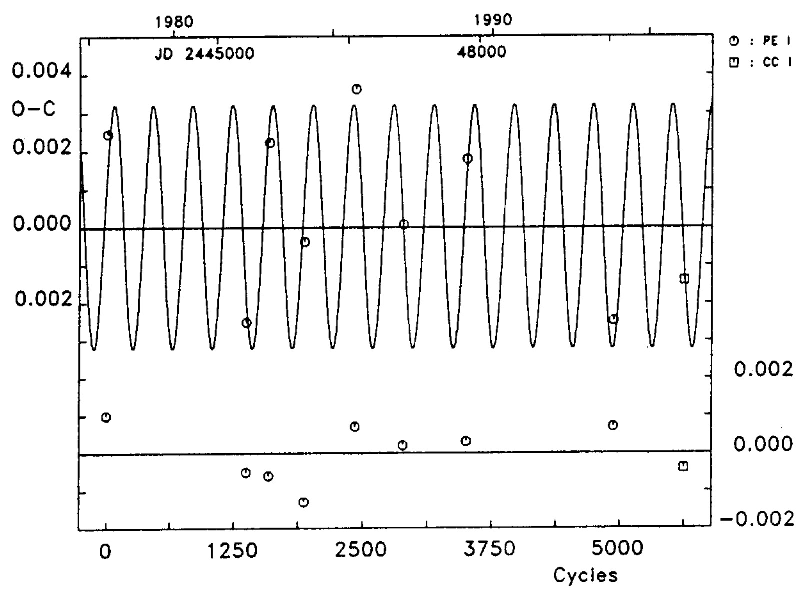

Figure 4. The (O-C) diagram of VZ Cep. The residuals and theoretical curve were drawn with solution 4 (see text).

Table 1. Photoelectric observations of VZ Cep.

JD Hel 2446000+	ΔU	JD Hel 2446000+	ΔB	JD Hel 2446000+	ΔV	JD Hel 2446000+	ΔU	JD Hel 2446000+	ΔB	JD Hel 2446000+	ΔV
8.9361	-.1158	8.9349	-.1142	8.9341	-.0934	9.9683	-.0687	9.9630	-.0992	9.9617	-.0751
8.9401	-.1179	8.9395	-.1385	8.9387	-.0867	9.9728	-.0580	9.9670	-.0996	9.9636	-.0663
8.9463	-.1062	8.9453	-.1521	8.9445	-.1049	9.9745	-.0543	9.9689	-.1089	9.9675	-.0887
8.9474	-.1078	8.9481	-.1378	8.9489	-.1039	9.9800	-.0730	9.9734	-.0938	9.9693	-.0786
8.9525	-.1007	8.9532	-.1256	8.9539	-.0934	9.9823	-.0707	9.9808	-.1077	9.9760	-.0688
8.9560	-.0896	8.9553	-.1389	8.9546	-.0951	9.9942	-.0394	9.9829	-.1079	9.9815	-.0690
8.9693	-.1534	8.9684	-.1969	8.9678	-.1408	9.9960	-.0597	9.9948	-.1108	9.9835	-.0680
8.9703	-.1535	8.9710	-.1760	8.9716	-.1298	10.0004	-.0294	9.9967	-.1092	9.9952	-.0697
8.9794	-.0846	8.9801	-.0856	8.9808	-.0487	10.0021	-.0429	10.0009	-.0936	9.9973	-.0636
8.9868	-.1217	8.9862	-.1117	8.9857	-.0845	10.0065	-.0533	10.0028	-.0997	10.0014	-.0653
8.9874	-.0871	8.9880	-.1261	8.9884	-.0722	10.0085	-.0623	10.0071	-.1022	10.0033	-.0659
9.0171	.1718	9.0163	.1057	9.0124	.4223	10.0127	-.0604	10.0091	-.0960	10.0078	-.0508
9.0263	.2514	9.0256	.1995	9.0150	.4214	10.0142	-.0502	10.0132	-.0912	10.0096	-.0517
9.0272	.2591	9.0281	.2041	9.0156	.1070	10.0347	-.0880	10.0150	-.0984	10.0136	-.0597
9.0360	.3074	9.0354	.2446	9.0250	.1754	10.0439	-.0951	10.0340	-.0982	10.0155	2.9421
9.0367	.3145	9.0374	.2658	9.0287	.2347	10.0454	-.0910	10.0445	-.1014	10.0283	-.9437
9.0481	.2664	9.0476	.2202	9.0350	.2790	10.0520	-.0764	10.0459	-.1030	10.0299	-.4229
9.0617	.2775	9.0610	.2171	9.0381	.3042	10.0533	-.0606	10.0524	-.1044	10.0334	-.0564
9.0630	.2664	9.0637	.1944	9.0471	.2543	10.0572	-.0657	10.0537	-.0943	10.0449	-.0608
9.0730	.1792	9.0722	.1440	9.0604	.2520	10.0593	-.0607	10.0578	-.0997	10.0463	-.0662
9.0738	.1670	9.0746	.1339	9.0644	.2220	10.0712	-.0877	10.0600	-.1042	10.0528	-.0719
9.0804	.1239	9.0811	.0903	9.0716	.1890	10.0731	-.1070	10.0704	-.1068	10.0542	-.0691
9.0842	.0996	9.0834	.0086	9.0755	.1583	10.0783	-.0932	10.0725	-.1016	10.0585	-.0570
9.0902	.0412	9.0893	.0299	9.0816	.1084	10.0802	-.0956	10.0790	-.1115	10.0604	-.0547
9.0912	.0561	9.0922	.0028	9.0828	.1099	10.0858	-.0685	10.0807	-.1002	10.0695	-.0514
9.1099	-.0282	9.1078	-.0711	9.0885	.0647	10.0876	-.0671	10.0863	-.1020	10.0719	-.0523
9.1155	-.0651	9.1092	-.0831	9.0929	.0311	10.0989	-.0341	10.0882	-.0986	10.0796	-.0576
9.1163	-.0579	9.1149	-.1016	9.1085	-.0345	10.1058	-.0628	10.0983	-.1056	10.0812	-.0581
9.1218	-.0528	9.1170	-.0794	9.1143	-.0556	10.1076	-.0677	10.1065	-.1005	10.0869	-.0494
9.1237	-.0630	9.1225	-.0923	9.1175	-.0472	10.1127	-.0890	10.1080	-.1037	10.0888	-.0501
9.1289	-.0512	9.1244	-.1057	9.1230	-.0548	10.1224	-.0455	10.1133	-.1100	10.0975	-.0457
9.1329	-.0379	9.1296	-.1057	9.1251	-.0602	10.1243	-.0573	10.1231	-.0926	10.1071	-.0564
9.1453	-.0968	9.1320	-.0926	9.1303	-.0772	10.1319	-.0606	10.1251	-.0960	10.1084	-.0609
9.1667	-.0950	9.1447	-.1018	9.1312	-.0655	10.1340	-.0799	10.1312	-.0970	10.1139	-.0607
9.1674	-.0889	9.1661	-.1024	9.1442	-.0544	10.1393	-.0941	10.1334	-.0977	10.1236	-.0558
9.1761	-.1092	9.1682	-.1070	9.1655	-.0667	10.1413	-.0706	10.1383	-.0909	10.1257	-.0321
9.1772	-.1062	9.1754	-.1259	9.1688	-.0574	10.1550	-.0559	10.1407	-.0856	10.1306	-.0470
9.9288	-.0865	9.1777	-.1383	9.1749	-.0908	10.1586	-.0693	10.1545	-.0755	10.1328	-.0388
9.9322	-.0822	9.9294	-.1010	9.1784	-.1106	10.1618	-.0327	10.1560	-.0656	10.1375	-.0443
9.9380	-.0958	9.9315	-.0934	9.9299	-.0522	10.1642	-.0335	10.1625	-.0604	10.1401	-.0381
9.9390	-.0764	9.9372	-.1241	9.9309	-.0450	10.1727	.0040	10.1649	-.0619	10.1539	-.0425
9.9434	-.0837	9.9395	-.0903	9.9363	-.0723	10.1744	-.0092	10.1720	-.0424	10.1556	-.0403
9.9456	-.0898	9.9441	-.1024	9.9401	-.0673	10.1877	.0788	10.1738	-.0392	10.1632	-.0325
9.9604	-.0736	9.9462	-.1145	9.9448	-.0856	10.1915	.1095	10.1883	.0518	10.1656	-.0305
9.9665	-.0578	9.9611	-.0970	9.9480	-.0754	10.1988	.1817	10.1907	.0527	10.1713	-.0084

Table 1. Continued.

JD Hel 2446000+	$\triangle U$	JD Hel 2446000+	$\triangle B$	JD Hel 2446000+	$\triangle V$	JD Hel 2446000+	$\triangle U$	JD Hel 2446000+	$\triangle B$	JD Hel 2446000+	$\triangle V$
10.1995	.1616	10.1983	.1359	10.1733	.0018	29.0135	-.0712	28.9742	-.1121	28.9917	-.0541
26.9554	-.0733	10.2001	.1456	10.1890	.0960	29.0241	-.0976	28.9776	-.1150	29.0014	-.0493
27.0070	-.1032	26.9537	-.1182	10.1900	.0938	29.0270	-.0987	28.9889	-.0980	29.0047	-.0571
27.0129	-.0974	27.0056	-.1297	10.1978	.1531	29.0498	-.0084	29.0023	-.0830	29.0125	-.0503
27.0195	-.0870	27.0140	-.1319	10.2007	.1879	29.0525	-.0133	29.0039	-.1047	29.0155	-.0643
27.0368	-.1246	27.0203	-.1322	26.9529	-.0449	29.0619	.0218	29.0117	-.0889	29.0260	-.0571
27.0473	-.1070	27.0358	-.1489	27.0047	-.0916	29.0731	-.0489	29.0146	-.1007	29.0289	-.0661
27.0590	-.1224	27.0378	-.1438	27.0150	-.0853	29.0761	-.0445	29.0251	-.0844	29.0343	-.0576
27.0702	-.1171	27.0483	-.1288	27.0210	-.0931	29.0881	-.1013	29.0280	-.1200	29.0370	-.0579
27.0803	-.1056	27.0601	-.1462	27.0346	-.0750	29.0909	-.1035	29.0351	-.1017	29.0606	-.7891
27.0987	-.0780	27.0713	-.1419	27.0387	-.0917	29.1007	-.0151	29.0378	-.1118	29.0641	-.5549
27.1041	-.0931	27.0811	-.1402	27.0492	-.0857	29.1037	-.0511	29.0742	-.0749	29.0752	-.0512
27.1177	-.0891	27.0960	-.1470	27.0609	-.1056	29.1088	-.0246	29.0772	-.0721	29.0783	-.0549
27.1274	-.0829	27.0978	-.1537	27.0721	-.0960	29.1120	-.0306	29.0840	-.0856	29.0827	-.0699
27.1311	-.0887	27.1051	-.1344	27.0819	-.0851	29.1200	-.0182	29.0871	-.1067	29.0861	-.0768
27.1359	-.0847	27.1071	-.1373	27.0969	-.1042	29.1225	.0050	29.0999	-.0637	29.0989	-.0320
27.1400	-.1023	27.1168	-.1269	27.1066	-.0868	29.1273	.1248	29.1099	-.0254	29.1017	-.0291
27.1450	-.0954	27.1186	-.1387	27.1161	-.0863	29.1306	.1516	29.1130	-.0080	29.1026	-.0276
27.1484	-.1128	27.1283	-.1322	27.1192	-.0838	29.1392	.1984	29.1192	.0227	29.1110	.0033
27.1586	-.0691	27.1299	-.1324	27.1292	-.0857	29.1418	.1943	29.1217	.0344	29.1139	.0269
27.1640	-.1111	27.1369	-.1309	27.1378	-.0934	29.1469	.2107	29.1283	.0936	29.1184	.0552
27.1674	-.1238	27.1389	-.1374	27.1467	-.0601	29.1495	.2308	29.1314	.1123	29.1209	.0624
27.1725	-.1171	27.1459	-.1279	27.1568	-.0758	29.1578	.2827	29.1382	.1454	29.1294	.1321
27.1759	-.1113	27.1474	-.1218	27.1657	-.0811	29.1605	.2868	29.1409	.1561	29.1322	.1557
27.1785	-.1108	27.1559	-.1211	27.1742	-.0752	29.1652	.2602	29.1479	.1950	29.1373	.1786
27.1878	-.0938	27.1577	-.1245	27.1805	-.0779	29.1700	.2819	29.1504	.2082	29.1401	.1962
27.1971	-.0895	27.1648	-.1243	27.1860	-.0674	29.1740	.2499	29.1569	.2583	29.1487	.2380
28.9675	-.0625	27.1734	-.1365	27.1895	-.0828	29.1778	.2220	29.1596	.2481	29.1513	.2402
28.9731	-.0351	27.1750	-.1326	27.1951	-.0866			29.1658	.2532	29.1561	.2702
28.9786	-.0623	27.1795	-.1281	27.1997	-.0797			29.1696	.2536	29.1588	.2751
28.9898	-.0580	27.1869	-.1190	28.9651	-.0552			29.1749	.2350	29.1660	.2627
28.9926	-.0466	27.1887	-.1298	28.9753	-.0574			29.1783	.1794	29.1692	.2551
29.0030	-.0396	27.1961	-.1164	28.9766	-.0517					29.1754	.2554
29.0056	-.0661	27.1985	-.1214	28.9881	-.0458					29.1787	.2383
29.0107	-.0775	28.9663	-.1085	28.9908	-.1067						

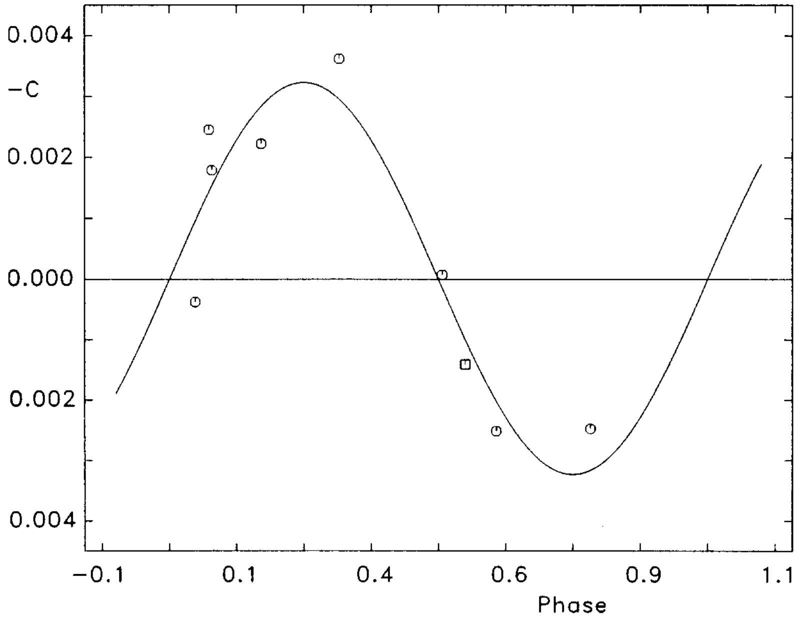

Figure 5. (O-C) versus phase for VZ Cep. The curve represents the sine term of solution 4 (see text).

Table 2. Photoelectric observations of the check star (BD +70°1195).

JD Hel 2446000+	△ *U*	JD Hel 2446000+	△ *B*	JD Hel 2446000+	△ *V*	JD Hel 2446000+	△ *U*	JD Hel 2446000+	△ *B*	JD Hel 2446000+	△ *V*
8.9235	-.1362	8.9243	-.0781	8.9252	-.1207	10.1819	-.1015	27.0265	-.1430	27.0401	-.1058
8.9650	-.1137	8.9643	-.1775	8.9637	-.1349	27.0287	-.1074	27.0278	-.1502	27.0500	-.1122
9.0570	-.1029	9.0565	-.1322	9.1028	-.1088	27.0418	-.1241	27.0410	-.1600	27.0623	-.1213
9.1014	-.1088	9.1022	-.1433	9.1402	-.1009	27.0521	-.1251	27.0512	-.1518	27.0735	-.1231
9.1414	-.1236	9.1409	-.1382	9.9213	-.1196	27.0640	-.1342	27.0632	-.1559	27.0833	-.1087
9.9201	-.1069	9.9207	-.1543	9.9567	-.1224	27.0753	-.1171	27.0744	-.1548	27.0915	-.1282
9.9552	-.0803	9.9560	-.1448	9.9915	-.0865	27.0849	-.1124	27.0841	-.1487	27.1109	-.1146
9.9901	-.0620	9.9909	-.1323	10.0399	-.0991	27.1091	-.0968	27.0908	-.1638	27.1242	-.1198
10.0411	-.1077	10.0405	-.1332	10.0417	-.0997	27.1260	-.1113	27.1101	-.1541	28.9823	-.1149
10.0425	-.1128	10.0420	-.1606	10.0649	-.0994	28.9801	-.1119	27.1250	-.1501	28.9964	-.0998
10.0664	-.1189	10.0655	-.1470	10.0946	-.1034	28.9939	-.0820	28.9811	-.1459	29.0168	-.1071
10.0933	-.1173	10.0940	-.1573	10.1191	-.1130	29.0188	-.1186	28.9952	-.1353	29.0425	-.1019
10.1181	-.0951	10.1187	-.1489	10.1502	-.0974	29.0676	-.0927	29.0178	-.1295	29.0913	-.1160
10.1511	-.0906	10.1506	-.1178	27.0257	-.1235			29.0417	-.1383		

Table 3. Observed times of minimum lights for VZ Cep.

JD Hel (2400000+)	Cycles	(O-C)	Type	Method	Reference
2443720.420	0	0.0005	I	PE	Rössiger (1978)
2445346.3587	1374	-0.0037	I	PEV	Braune *et al.* (1983)
2445605.5204	1593	0.0012	I	PE	Rössiger(1984)
2446009.0453	1934	-0.0012	I	PE	This Paper
2446592.4483	2427	0.0031	I	PEV	Braune & Hübscher(1987)
2447140.3428	2890	-0.0002	I	PE	Hübscher & Lichtenknecker(1988)
2447863.3806	3501	0.0019	I	PE	Hübscher *et al.* (1990)
2449567.4221	4941	-0.0015	I	PE	Agerer & Hübscher (1995)
2450380.395	5628	-0.0001	I	CCD	BBSAG observers(1997)

Table 4. The major frequencies obtained by the Scargle's (1982) period-searching method.

frequency (cycles/d)	power	period (d)
0.0009775	3.272	1023
0.0014625	3.238	684
0.0018469	3.226	541
0.0021322	3.818	469

because they are quite larger than the mean accuracy of about $0.^d0005$ for modern photoelectric and CCD observations. Assuming these changes to be real, we made an attempt to find whether any periodicities in the scatters exist or not. Scargle's (1982) period-searching technique was used in this procedure. In application of the method to the (O-C) residuals listed in Table 3 and shown at the lower part in Figure 2, we need reliable limitations of the periods that has to be found. Namely, the period-searching was made only for periods between 250^d as a lower limit and 1500^d as an upper one. The upper and lower period limits were selected from the (O-C) behaviors of four times of minima (JD2445346.3587, JD2445605.5204, JD2446009.0453, and JD2446592.4483, see Table 3) which are relatively close in time and of which (O-C) residuals vary alternatively from positive to negative sign. The upper limit of 1500^d was taken as slightly larger than the time-interval (about 1246^d) between JD2445346.3587 and JD2446592.4483. The lower period limit of 250^d was simply chosen as one sixth of the upper period limit. The frequencies corresponding to the upper and lower period limits are 4.0×10^{-3} and 6.7×10^{-4} (cycle/day), respectively. The resulting power spectrum is drawn in Figure 3 where we see that there are four large peaks discriminating when compared with other peaks. The frequencies, powers and periods corresponding to the four peaks are listed in

Table 5. Final solutions for Eq. (3).

Elements	Solution 1	Solution 2	Solution 3	Solution 4
T_o (JD Hel)	2443720.4180	2443720.4187	2443720.4205	2443720.4175
	± 10	± 13	± 13	± 7
P (d)	1.18336507	1.18336479	1.18336417	1.18336511
	± 32	± 41	± 43	± 23
A (d)	0.0028	0.0021	0.0023	0.0032
	± 16	± 19	± 22	± 11
ω (deg/P)	0.3981	0.5948	0.7947	0.9260
	± 95	± 172	± 119	± 52
ω_o (deg)	136.5	142.2	237.2	26.4
	± 28.0	± 49.6	± 42.0	± 16.4
P (y)	2.930	1.961	1.468	1.260
	± 70	± 57	± 22	± 7
χ^2	0.000954	0.001495	0.001638	0.000464

Table 4.

Finally, we made attempts to fit the observed times of minima to a light elements with a sine term as

$$C = T_o + P\,E + A \sin\,(\omega\,E + \omega_o) \tag{3}$$

In this attempt, the periods listed in Table 4 were used as initial parameters for ω in Eq. (3). The final four solutions are listed in Table 5 where the error measure χ^2 denotes sum of residuals for the fit. As listed in Table 5, the solution 4 shows the best among the other solutions sets because it has the smallest in χ^2 and the largest in amplitude, **A**. An (O-C) diagram of VZ Cep with the linear light elements of solution 4 is plotted in Figure 4 where the curve is drawn with the sine terms of solution 4. The (O-C) residuals subtracting with the sine terms were drawn at the lower part in Figure 4. Scatters of the residuals seem to be the result of observational errors because the probable error of the residuals is calculated as about $0.^d0005$ corresponding to a mean timing accuracy for normal photoelectric observations. Figure 5 shows the (O-C) values versus the phase of the theoretical sine curve.

4. DISCUSSIONS

According to the solution 4, the period of VZ Cep have varied in a sinusoidal pattern with the period of $1.^y26$ and the amplitude of $0.^d0032$. If the period variations are assumed as a result of the light-time effects produced by an unseen third-body, the resulting mass function is estimated as 0.10711 $M_\odot$, based on the calculated values from the Table 3. In this case, the minimum mass of the third-body turned out as 1.1 $M_\odot$ which is relatively large. In these calculations, the lower limit of 2.4 $M_\odot$ was used as the binary mass of the system, which was given by Popper (1996) from his spectroscopic observations. The discussions in this study has to be considered as preliminary results partly because the solution 4 was derived from only nine times of minimum lights that may cause uncertainties to some extents, and partly because the binary mass of 2.4 $M_\odot$ that could have some uncertainties mainly due to lack of spectroscopic observational data. Future photometric and spectroscopic observations are urgently prompted.

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