Pulsation of the δ Scuti star VZ Cancri

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Abstract. After the “O – C” technique is used to study the pulsation of the δ Scuti star VZ Cnc with the times of maximum light listed in the literature and a newly-determined time based on new photometry for this star, some high-quality photometry light curves in the literature are analysed by the Fourier decomposition, showing that there are more than 2 frequencies in the pulsation of this star, which might be one possible explanation of the existence of the large scatter in the “O – C” diagram.

Key words: δ Sct variable — VZ Cnc — oscillations

1. Introduction

The variability of VZ Cnc (HD 73857) was discovered by Whitney (1950). Since then this star has been referred to as a RR Lyrae or a Cluster-Type variable (Joy & Wilson 1950; Guman 1955; Fitch 1955), as a supershort-period Cepheid (Berdnikov 1975) and as dwarf Cepheid (e.g., Percy et al. 1980) or δ Scuti-type variable (Cox et al. 1984; López de Coca et al. 1990). Ferro et al. (1994) refer to VZ Cnc as a large amplitude δ Scuti star. Fitch (1955) and Cox et al. (1984) identify two periodicities in the light variations of VZ Cnc: 0.17836376 and 0.1428041 days as the first and second overtone respectively. A beat period of 0.716292 days is also indicated.

With the observed times of maximum light and the “O – C” technique, many authors have studied the period variations of VZ Cnc (Todoran 1976; Percy et al. 1980; Jiang & Yang 1982; Cao & Jiang 1991; Ferro et al. 1994). Four different interpretations are suggested by researchers as: a sloping linear fit, a sinusoidal fit, abrupt period changes, and long-term effects of nonlinear combinations of short frequencies. However, due to the large scatter in the (O – C) residuals, it is difficult to favor a

case although the latter two possibilities are regarded to be unrealistic by Ferro et al. (1994).

2. New observations and data reduction

As a new attempt to study its possible period variation by the “O – C” technique, photometry on VZ Cnc was made at Xinglong station of Beijing Astronomical Observatory with a 60 cm reflector plus a CCD camera on December 19, 1995. The filter used was a Johnson V. After careful extinction correction on the raw magnitudes of the variable star, one new time of maximum light is determined thus: $T_{\max} = \text{HJD } 2450071.2820$. This new time is combined with the times listed in the literature and 138 times of maximum light are collected and then listed in Table 1.

Besides this, some high-quality observation data for VZ Cnc are collected from the literature. Table 2 lists the journal of these observations.

3. “O – C” calculation

The “O – C” calculation for the collected times of maximum light of VZ Cnc was performed with the computer program OMC (Fu et al. 1998). First, a linear fit is made by the formula of $C_1 = T_1 + P_1 E$. The results of fitting are: $T_1 = \text{HJD } 2431550.7187$, $P_1 = 0.178363665$ days, and $\sigma_1 = 0.0062$ days. Then, a quadratic curve is used to fit the times as $C_Q = T_2 + P_2 E + 0.5\beta E^2$. The fitting parameters are: $T_2 = \text{HJD } 2431550.7199$, $P_2 = 0.178363585$ days, $\beta = 7.9 \cdot 10^{-13}$ days/cycle, and $\sigma_2 = 0.0062$ days. The (O–C)₁ diagram and the fit curve using the quadratic function are shown in Fig. 1.

From Fig. 1, it may be found that the “O – C” calculation does not provide reasonable explanation on the period variation of VZ Cnc with the existence of large scatter for the fitting, and there may be more frequencies in the pulsation of this star since large scatter is present even in one

Table 1. Times of light maxima of VZ Cnc

No.	HJD	E	(O-C) ₁	Ref.	No.	HJD	E	(O-C) ₁	Ref.	No.	HJD	E	(O-C) ₁	Ref.
	2400000.0+		(day)			2400000.0+		(day)			2400000.0+		(day)	
1	31550.7100	0.0	-0.0087	Wh	47	34476.4195	16403.0	0.0016	Gu	93	42099.5045	59142.0	0.0019	Ha
2	33631.8630	11668.0	-0.0029	Fi	48	34667.6237	17475.0	0.0000	Gu	94	42100.3915	59147.0	-0.0029	Ha
3	33633.8220	11679.0	-0.0059	Fi	49	34708.6487	17705.0	0.0013	Gu	95	42128.3910	59304.0	-0.0065	To
4	33647.9205	11758.0	0.0018	Fi	50	34738.9668	17875.0	-0.0024	Fi	96	42132.3295	59326.0	0.0080	To
5	33655.7721	11802.0	0.0054	Fi	51	34740.9363	17886.0	0.0051	Fi	97	42161.3885	59489.0	-0.0063	To
6	33679.8396	11937.0	-0.0062	Fi	52	34742.8946	17897.0	0.0014	Fi	98	42453.5485	61127.0	-0.0060	To
7	33685.7355	11970.0	0.0037	Fi	53	34745.9325	17914.0	0.0071	Fi	99	42474.4160	61244.0	-0.0070	To
8	33686.7967	11976.0	-0.0053	Fi	54	34746.8148	17919.0	-0.0024	Fi	100	42476.3790	61255.0	-0.0060	To
9	33711.7755	12116.0	0.0026	Fi	55	34746.9902	17920.0	-0.0054	Fi	101	42485.4855	61306.0	0.0039	To
10	33714.6261	12132.0	-0.0006	Fi	56	34747.8852	17925.0	-0.0022	Fi	102	42487.4465	61317.0	0.0029	To
11	33722.6478	12177.0	-0.0052	Fi	57	34748.9582	17931.0	0.0006	Fi	103	42508.3195	61434.0	0.0074	To
12	33730.6729	12222.0	-0.0065	Fi	58	34758.9482	17987.0	0.0023	Fi	104	42531.3285	61563.0	0.0075	To
13	33739.4205	12271.0	0.0013	Gu	59	34770.3620	18051.0	0.0008	Gu	105	42756.4113	62825.0	-0.0047	To
14	33740.3175	12276.0	0.0064	Gu	60	34770.5355	18052.0	-0.0041	Gu	106	42771.3955	62909.0	-0.0030	To
15	33741.3750	12282.0	-0.0062	Gu	61	34772.3240	18062.0	0.0008	Gu	107	42785.4980	62988.0	0.0088	To
16	33743.3340	12293.0	-0.0092	Gu	62	34775.8918	18082.0	0.0013	Fi	108	42837.3865	63279.0	-0.0066	To
17	33744.4125	12299.0	-0.0009	Gu	63	34776.7873	18087.0	0.0050	Fi	109	42867.3600	63447.0	0.0018	To
18	33746.3685	12310.0	-0.0069	Gu	64	34779.2770	18101.0	-0.0024	Gu	110	42871.2775	63469.0	-0.0047	To
19	33758.6827	12379.0	0.0002	Fi	65	34779.4590	18102.0	0.0012	Gu	111	42873.4160	63481.0	-0.0065	To
20	33768.6686	12435.0	-0.0023	Fi	66	34780.5255	18108.0	-0.0024	Gu	112	43140.6090	64979.0	-0.0023	Ce
21	33773.6640	12463.0	-0.0011	Fi	67	34781.7825	18115.0	0.0060	Fi	113	43161.4850	65096.0	0.0051	Ce
22	34015.8857	13821.0	0.0028	Fi	68	34781.9528	18116.0	-0.0021	Fi	114	43181.4547	65208.0	-0.0019	BS
23	34032.8216	13916.0	-0.0059	Fi	69	34798.3657	18208.0	0.0014	Gu	115	43528.3807	67153.0	0.0068	BS
24	34034.7904	13927.0	0.0009	Fi	70	34798.5395	18209.0	-0.0032	Gu	116	43528.5520	67154.0	-0.0003	BS
25	34036.7564	13938.0	0.0049	Fi	71	34798.7203	18210.0	-0.0007	Fi	117	43539.4268	67215.0	-0.0057	BS
26	34036.9293	13939.0	-0.0005	Fi	72	34798.9030	18211.0	0.0036	Fi	118	46094.1411	81538.0	0.0059	CJ
27	34038.8948	13950.0	0.0030	Fi	73	34841.7061	18451.0	-0.0006	Fi	119	46095.0223	81543.0	-0.0048	CJ
28	34039.7848	13955.0	0.0012	Fi	74	35901.5400	24393.0	-0.0036	PO	120	46095.2003	81544.0	-0.0051	CJ
29	34039.9578	13956.0	-0.0042	Fi	75	36598.4200	28300.0	0.0096	Ah	121	47501.6092	89429.0	0.0063	Pi
30	34040.5005	13959.0	0.0034	Gu	76	36603.4100	28328.0	0.0054	Ah	122	47968.0200	92044.0	-0.0039	CJ
31	34043.8915	13978.0	0.0055	Fi	77	36608.4100	28356.0	0.0112	Ah	123	48206.3268	93380.0	0.0090	CJ
32	34044.7806	13983.0	0.0028	Fi	78	36613.4000	28384.0	0.0070	Ah	124	48221.3070	93464.0	0.0067	CJ
33	34046.7455	13994.0	0.0057	Fi	79	38357.9670	38165.0	-0.0010	FW	125	48237.3499	93554.0	-0.0031	CJ
34	34063.3487	14087.0	0.0210	Gu	80	38369.0310	38227.0	0.0045	FW	126	48240.2019	93570.0	-0.0050	CJ
35	34064.7567	14095.0	0.0021	Fi	81	38408.9880	38451.0	0.0080	FW	127	48240.3776	93571.0	-0.0076	CJ
36	34066.9020	14107.0	0.0071	Fi	82	39159.8940	42661.0	0.0030	FW	128	49027.6840	97985.0	0.0016	Fe
37	34068.8593	14118.0	0.0024	Fi	83	39852.6396	46545.0	-0.0159	Ha	129	49027.8720	97986.0	0.0112	Fe
38	34071.7099	14134.0	-0.0008	Fi	84	39878.5006	46690.0	-0.0176	Ha	130	49028.7540	97991.0	0.0014	Fe
39	34109.7031	14347.0	0.0009	Fi	85	39879.3958	46695.0	-0.0142	Ha	131	49030.7280	98002.0	0.0134	Fe
40	34356.5508	15731.0	-0.0067	Gu	86	39903.4730	46830.0	-0.0161	Ha	132	49034.6360	98024.0	-0.0026	Fe
41	34393.4925	15938.0	0.0137	Gu	87	40622.3014	50860.0	0.0067	Po	133	49036.7780	98036.0	-0.0010	Fe
42	34393.6558	15939.0	-0.0014	Gu	88	40676.3384	51163.0	-0.0005	Po	134	49037.6690	98041.0	-0.0018	Fe
43	34453.3980	16274.0	-0.0110	Gu	89	40677.4203	51169.0	0.0112	Po	135	49038.7490	98047.0	0.0080	Fe
44	34455.3600	16285.0	-0.0110	Gu	90	40686.3272	51219.0	-0.0001	Po	136	49071.7415	98232.0	0.0032	Fe
45	34456.4470	16291.0	0.0058	Gu	91	40694.3473	51264.0	-0.0063	Po	137	49074.7643	98249.0	-0.0061	Fe
46	34457.3370	16296.0	0.0040	Gu	92	40890.5484	52364.0	-0.0053	Po	138	50071.2820	103836.0	-0.0062	pp

*Ah: Ahnert (1959)

*BS: Balona & Stobie (1983)

*Ce: Cester et al. (1977)

*CJ: Cao & Jiang (1991)

*Fe: Ferro et al. (1994)

*Fi: Fitch (1955)

*FW: Fitch et al. (1966)

*Gu: Guman (1955)

*Ha: Hahn et al. (1975)

*Pi: Piersimoni et al. (1993)

*PO: Ponsen & Oosterhoff (1966)

*Po: Popovici (1971)

*pp: present paper

*To: Todoran (1976)

*Wh: Whitney (1950).

Table 2. Journal of the observations for VZ Cnc in the literature

Publication	Year	Site	Telescope	Filter	Nights	points	σ	Filename
Ferro et al. (1994)	1993	Loluz Obs.	0.57 m	V	12	627	0.1707	VZ1
Jiang et al. (1982)	1962-1963	Beijing	0.15 m	V	6	177	0.1711	VZ2a
				B	6	169	0.2363	VZ2b
				U	5	119	0.2406	VZ2c
Spinrad (1960)	1959	Leuschner & Lick Obs.	20 inch	V	12	675	0.1844	VZ3
Fitch (1955)	1950-1951	Yerkes Obs.	12 inch	V	15	295	0.2055	VZ4a
	1951-1952	Steward Obs.	36 inch	V	17	519	0.1995	VZ4b
	1953-1954	Steward Obs.	36 inch	V	16	622	0.2126	VZ4c

Fig. 1. The (O - C) diagram and the fit curve by a parabolic function. Large scatter is found between the observation points and the fit curve

observation season. In this case, the high-quality observation data sets listed in Table 2 are used to do multiple frequency analysis to study the pulsation of VZ Cnc.

4. Multiple frequency determination

4.1. Multi-frequency analysis

Among the data sets listed in Table 2, VZ2a, VZ2b, VZ2c have few points and VZ4a, VZ4b, VZ4c, although they include more measurements, show mainly increasing segments with few decreasing parts (see Fig. 7), which are not available to deep multiple frequency analyses due to the artificial sampling effect. So the data set VZ1 and VZ3 are used to do Fourier transformation.

The multiple-frequency analyses were performed with the computer program MFA (Hao 1991). After the non-equal spacing Fourier transformation (Deeming 1975) was done, the highest power peak was chosen automatically, or the peak was chosen by hand, then both linear and nonlinear least square fits (Hao 1991) were used to determine the best frequency and corresponding amplitude and phase. The data were then prewhitened with that frequency and the process repeated to search for the next frequency automatically. Step by step, the best frequencies and fit results were obtained. To check the reliability of the results, the theoretical light curves were calculated using the following formula,

$$m(t) = m_0 + \sum_i A_i \cos[2\pi f_i(t - t_0) + \phi_i]$$

Table 3. Results of the Fourier analysis for VZ1

No.	Frequency (c/d)	Frequency (μ Hz)	Amplitude (mag)	Phase	Mark
f_1	5.6066	64.891	0.2003	0.537	ν_0
f_2	11.2128	129.777	0.0748	0.492	$2\nu_0$
f_3	7.0022	81.043	0.0688	0.996	ν_1
f_4	16.8188	194.662	0.0345	0.444	$3\nu_0$
f_5	12.6095	145.943	0.0302	0.828	$\nu_0 + \nu_1$
f_6	1.3957	16.154	0.0250	0.203	$\nu_1 - \nu_0$

Table 4. Results of the Fourier analysis for VZ3

No.	Frequency (c/d)	Frequency (μ Hz)	Amplitude (mag)	Phase	Mark
F_1	5.6063	64.888	0.2063	0.423	ν_0
F_2	11.2132	129.782	0.0882	0.242	$2\nu_0$
F_3	7.0029	81.052	0.0637	0.326	ν_1
F_4	16.8177	194.649	0.0475	0.122	$3\nu_0$
F_5	12.6070	145.914	0.0308	0.125	$\nu_0 + \nu_1$
F_6	1.3947	16.142	0.0248	0.676	$\nu_1 - \nu_0$

where t_0 is the beginning time; A_i , the amplitude; and ϕ_i , the phase. The result of the analysis provides the multiple-frequency solution and the residual, as well as various power spectra where the best multiple frequency fits have been prewhitened.

The analysis results on data set VZ1 and VZ3 are listed in Tables 3 and 4. Figures 2 and 3 show the spectral windows and power spectra of VZ1 and VZ3, respectively. In Figs. 4 and 5, the observation points and fit light curves of VZ1 and VZ3 are shown respectively. The residuals of VZ1 and VZ3 after 6 frequency fittings are 0.021 mag and 0.027 mag, respectively.

4.2. Fit to other data sets

As mentioned above, the other data sets are not suitable to do independent multiple-frequency analysis. So the 6 frequencies obtained from the analysis for VZ1

Fig. 2. Spectral window and power spectra of the data set VZ1. Multiple pulsation frequencies are extracted one by one

Fig. 3. Spectral window and power spectra of the data set VZ3. Multiple pulsation frequencies are extracted one by one

Fig. 4. Observation points and fit curves of VZ1. The abscissa is HJD 2449000.0+, while the ordinate is ΔV (mag)

Fig. 5. Observation points and fit curves of VZ3. The abscissa is HJD 2436000.0+, while the ordinate is ΔV (mag)

Fig. 6. Observation points and fit curves of VZ2a. The abscissa is HJD 2430000.0+, while the ordinate is ΔV (mag)

Fig. 7. Observation points and fit curves of VZ4a. The abscissa is HJD 2433600.0+, while the ordinate is ΔV (mag)

Table 5. Fitting results for VZ2a, VZ2b, VZ2c and VZ4a, VZ4b, VZ4c with the 6 frequencies

No.	Frequency	Amplitude (mag)					
	(c/d)	VZ 2a	VZ 2b	VZ 2c	VZ 4a	VZ 4b	VZ 4c
f_1	5.6066	0.1935	0.2777	0.2497	0.2150	0.3129	0.2051
f_2	11.2128	0.0741	0.1002	0.0907	0.0802	0.1839	0.0915
f_3	7.0022	0.0643	0.0807	0.0838	0.0573	0.0857	0.0750
f_4	16.8188	0.0373	0.0466	0.0494	0.0539	0.0970	0.0529
f_5	12.6095	0.0304	0.0422	0.0431	0.0394	0.0547	0.0456
f_6	1.3957	0.0198	0.0466	0.0374	0.0276	0.0135	0.0311
Residual (mag)		0.031	0.038	0.037	0.025	0.018	0.020

(see Table 3) are used to do fitting on data set VZ2a, VZ2b, VZ2c and VZ4a, VZ4b, VZ4c. Table 5 lists the fitting results. Figures 6 and 7 show the observation points and corresponding fitting light curves for VZ2a and VZ4a, respectively. The agreement between the observations and the fitting curves for VZ2b, VZ2c and VZ4b, VZ4c, which are not displayed in this paper, is as good as those for VZ2a and VZ4a, respectively.

5. Discussion and conclusions

Studying carefully the frequency values in Table 3, one may find that f_1, f_3 correspond to the periods of 0.17836376 and 0.1428041 days which were identified by Fitch (1955) and Cox et al. (1984), while f_6 corresponds to the beat period of 0.716292 days. However, more frequencies are proved to be present in the pulsation of VZ Cnc! We may find that $f_2 \approx 2f_1$, $f_4 \approx 3f_1$, and $f_5 \approx f_3 + f_1$, $f_6 \approx f_3 - f_1$. Thus, if we label f_1 as $\nu_0 = 5.6066$ c/d and f_3 as $\nu_1 = 7.0022$ c/d, the other frequencies can be marked in terms of ν_0 and ν_1 . The identification results are listed in the last column of Tables 3 and 4 within small errors. At the same time, it may be found that the frequencies ν_0 and ν_1 are usually associated with the first and second overtones of radial pulsation based on the similarity of their period ratio (0.801) to the theoretically expected value of 0.810. The analysis of the light curves of VZ Cnc also shows that the pulsation frequencies of this star are quite stable while the amplitudes are changing slightly from 1950 to 1993.

The results of multiple frequency analyses show that the star VZ Cnc oscillates simultaneously with two modes of first and second overtones, and some harmonics and cross-frequencies generated by the nonlinear effects. About the large scatter in the O – C diagram under the supposition of two modes, although we do not give firm and definitive explanation, the discovery of more than 2 frequencies in the power spectrum of the light curve of this star might give one possibility.

References

- Ahnert P., 1959, Mitt. über veränderliche Sterne No. 395
Balona L.A., Stobie R.S., 1983, SAAO Circ. No. 7, 19
Berdnikov L.N., 1975, Perem. Zvezdy 2, 199
Cao M., Jiang S.Y., 1991, Acta Astron. Sin. 32, 401
Cester B., Guiricin B., Mardirossian F., Mezzetti M., Pucillo M., 1977, Inf. Bull. Var. Stars, No. 1338
Cox A.N., McNamara B.J., Ryan W., 1984, ApJ 284, 250
Deeming T.J., 1975, Ap&SS 36, 137
Ferro A.A., Nuñez N.S., Avila J.J., 1994, PASP 106, 696
Fitch W.S., 1955, ApJ 121, 690
Fitch W.S., Wisniewski W.Z., Johnson H.L., 1966, Comm. Lunar Planet. Lab. 71, 146
Fu J.N., Jiang S.Y., Zhou A.Y., 1998, Publ. Beijing Astron. Obs. 32, 35
Guman I., 1955, Budapest Mitteilungen 36, 3
Hahn G., Lustig G., Jasicek H., Klement G., 1975, Inf. Bull. Var. Stars, No. 1078
Hao J.X., 1991, Publ. Beijing Astron. Obs. 18, 35
Jiang S.Y., Yang Z.Z., 1982, Acta Astron. Sin. 23, 333
Joy A.H., Wilson R.E., 1950, PASP 62, 58
López de Coca P., Rolland A., Rodríguez E., Garrido R., 1990, A&AS 83, 51
Percy J.R., Matthews J.M., Wade J.D., 1980, A&A 82, 172
Piersimoni A.M., Di Paolantonio A., Burchi R., De Santis R., 1993, A&AS 101, 195
Ponsen J., Oosterhoff P.T., 1966, Bull. Astron. Inst. Netherlands 18, 459
Popovici C., 1971, Inf. Bull. Var. Stars, No. 508
Spinrad H., 1960, ApJ 131, 134
Todoran I., 1976, IBVS, No. 1141
Whitney B.S., 1950, PASP 62, 56