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ORIGINAL ARTICLE

The period variation of the double mode high amplitude δ Scuti variable VZ Cnc

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Abstract VZ Cnc is a population I double mode high amplitude δ Scuti variable. We observed the star and collected the data from January 2007 to January 2009 to determine 14 times of maximum light. We also searched its times of maximum light from other papers and from IBVS and got 57 values. We collected a total of 194 times of maximum light and used them to perform an (O-C) analysis and concluded that there may be no tendency of binary orbital light time effect. But by parabola tendency, it shows a continuous period increasing at the rate of 1.4×10^{-8} per year; this is compatible with the stellar evolution model calculation both in direction and size.

Keywords Variable stars · δ Scuti · HADS · Period changes · Stellar evolution

1 Introduction

VZ Cancri (R.A. 2000 = 08:40:52.1; Dec. 2000 = +09:49:27; V = 7.73; A9III) was discovered by Whitney (1950) as a variable star. It was classified as a RR Lyrae (Joy and Wilson 1950), as an ultra short period Cepheid (Berdnikov 1975) and as a dwarf Cepheid (Percy et al. 1980). In 1994 it was identified as a high amplitude δ Scuti star (Arellano Ferro et al. 1994a). Fitch (1955) and Cox et al. (1984) observed and calculated its amplitude in the V band which varied from 0.35 to 0.69 magnitudes and got 2 periods of 0.17836376 days and 0.1428041 days; the period ratio is about 0.801; so they are the radial first overtone and second overtone, respectively. The beat period of the overtone is 0.716292 day. The period variations of VZ Cnc were analyzed first by Todoran (1976), then by Percy et al. (1980), by Jiang and Yang (1982), by Cao and Jiang (1991), by Arellano Ferro et al. (1994a), and by Fu and Jiang (1999). From the beginning until now no one had achieved a reliable solution for the star. Arellano Ferro et al. (1994a) suggested that it may be a binary which has an unseen companion with an orbital period of 53 years. Fu and Jiang (1999) analyzed the collected data. From the large scatter in the (O-C) distribution of the times of maximum light, they did not believe that it was a binary or had any reliable period variation. The times of maximum light of VZ Cnc were collected from 1949 by many observers and the most recent collection belongs to Fu and Jiang (1999); they collected 138 times of maximum light and showed them in their paper. The (O-C) distribution of the times of maximum light showed a complicated scatter. It really needs more observations to make clear the real solution. In this paper we present a discussion on the nature of the (O-C) diagram. Because VZ Cnc is rather bright and has high amplitude with a rather short period, it is a good candidate for small telescopes with CCD cameras. We observed the star from January 2007 to January 2009 at Naresuan University, Phitsanulok, Thailand and Yunnan Observatory, Kunming, China and intend to publish the complete photometry in a separate paper. In the present work we only report the times of maximum light.

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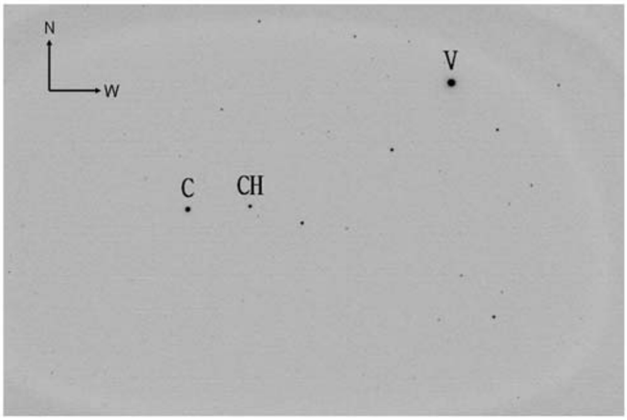

Fig. 1 The typical field of VZ Cnc was taken by a 16 inch Meade Schmidt Cassegrain telescope and ST-8 CCD camera at Naresuan University, Phitsanulok, Thailand; V = VZ Cnc, C = Comparison star, CH = Check star

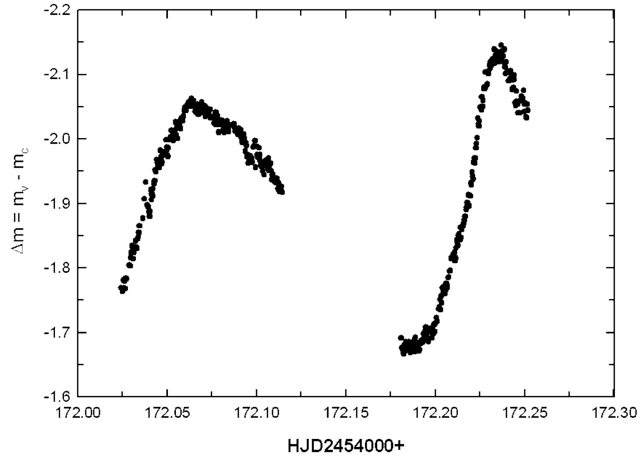

Fig. 2 The magnitude differences $m_v - m_c$ variations as observed on March 12, 2007

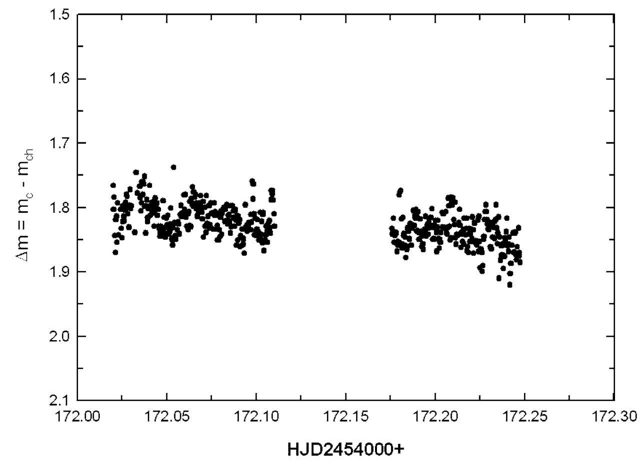

Fig. 3 The magnitude differences $m_c - m_{ch}$ variations as observed on March 12, 2007

2 New observations and data reduction

The new observations were mainly obtained at Naresuan University between 2007 and 2009. The data were collected during 6 nights in January, 3 nights in March, 1 night in April in the year of 2007; 2 nights in April 2008 and 1 night in January 2009. The equipment was a 16 inch Meade Schmidt Cassegrain telescope with a $F/6.3$ focal reducer and a ST-8 CCD camera with a red sensitive chip. The chip has 1530 pixels by 1020 pixels with 9 microns square per pixel and the plate scale is 0.73 arc second per pixel. The field of view is 1,114 arc seconds in R.A. and 743 arc seconds in Dec. The integration time was 30 seconds, and the readout and download time was about 20 seconds, so the resolution time was about 1 minute per measurement. Each night of observation we took 5 bias frames, 5 dark frames, and 5 sky flat field frames without a filter before the sky became too dark. A typical frame of the VZ Cnc field was taken with a 16 inch Meade Schmidt Cassegrain telescope and a ST-8 CCD camera at Naresuan University as shown in Fig. 1. The comparison star (C) has a magnitude of 9.8 with R.A. = 08:41:19.61 and Dec. = +09:45:34.7 and the check star (CH) has a magnitude of 11.3 with R.A. = 08:41:12.91 and Dec. = +09:45:46.7 for the 2000.0 epoch coordinates. We used the aperture photometry of MaxIm DL software to do data reduction. Figure 2 shows an example of the variations of the magnitude differences $m_v - m_c$ during one night of observation. Likewise Fig. 3 displays the magnitude differences $m_c - m_{ch}$ and indicates the short-time constancy of the two comparison stars. The RMS of individual observations was between ±0.01 and ±0.02 depending on weather conditions. Finally, we used high order fitting software to get times of maximum light; the RMS of each time of maximum light was better than ±0.0005 days. From the observations at Naresuan University, we got 10 times of maximum light in 2007, 2 times of maximum light in 2008, and 1 time of maximum light in 2009. We got another time of maximum light on February 11, 2007 by using an 1 m telescope which has a focal length of 13.3 meters at Yunnan Observatory in Kunming, China. The CCD camera was a Princeton Instruments with a chip of 1024 ×1024 square pixels with a pixel size of 24 microns square. The plate scale is 0.37 arc second per pixel which makes the field of view of the frame 6.35 arc minutes square. A typical frame of VZ Cnc is shown in Fig. 4, the light curve of VZ Cnc is shown in Fig. 5, and the light curve of the different magnitudes of the comparison star and the check star is shown in Fig. 6 which were taken from the 1 m telescope at Yunnan Observatory; VZ Cnc is marked by V; the comparison star (C) has a magnitude of 11.7 with R.A. = 08:40:58.04 and Dec. = +09:47:33.1; the check star (CH) has a magnitude of 12.6 with R.A. = 08:40:46.75 and Dec. = +09:48:17.3 for 2000.0 epoch coordinates. The comparison star (C) and

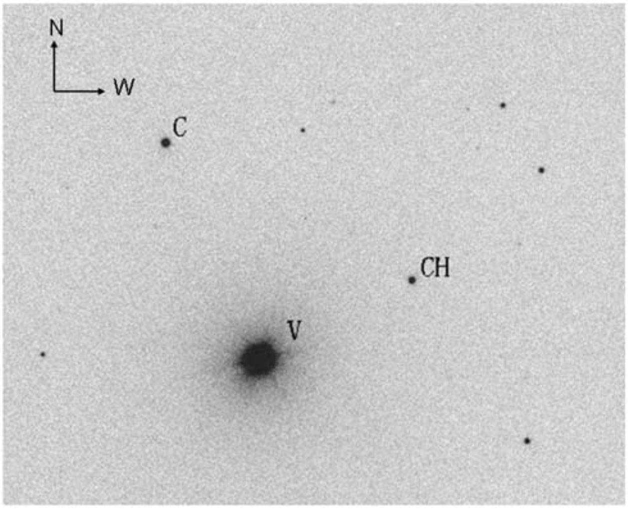

Fig. 4 The typical field of VZ Cnc was taken by an 1 m telescope at the Yunnan Observatory, Kunming, China; V = VZ Cnc, C = Comparison star, CH = Check star

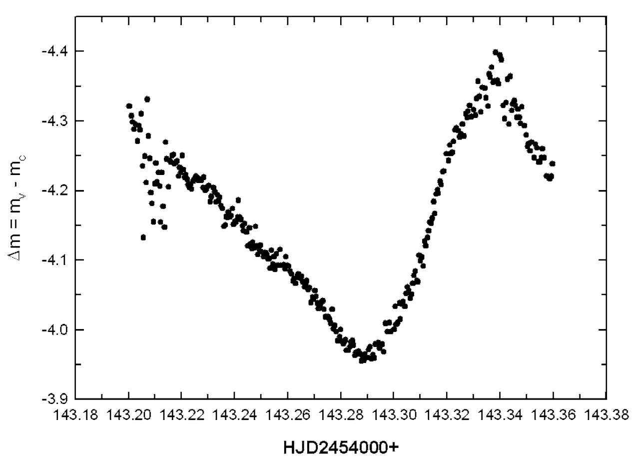

Fig. 5 The magnitude differences $m_v - m_c$ variations as observed on February 11, 2007

the check star (CH) are faint when compared with VZ Cnc. The RMS which was calculated from C–CH was not good; each measurement of the RMS is about ±0.02 for the second part. Due to the bad weather, the first part of the night can't be used. We used the second part of the night to determine one time of maximum light. We calculated the times of maximum light by high order curve fitting. The resolving time was one minute and the RMS was about ±0.0002 days.

3 Collection of the times of maximum light

Percy et al. (1980) collected 121 times of maximum light of VZ Cnc. Jiang and Yang (1982) added 9 times of maximum light from their observations, 3 times of maximum light from He (1961), and 3 times of maximum light from

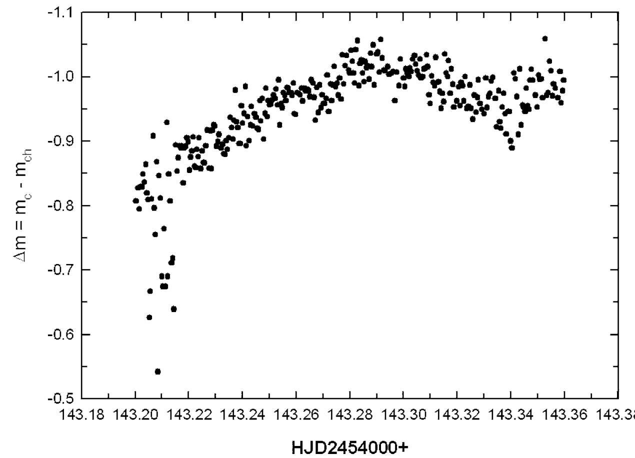

Fig. 6 The magnitude differences $m_c - m_{ch}$ variations as observed on February 11, 2007. Due to the bad weather, the first part can't be used. We used the second part to determine one time of maximum light

Spinrad (1960); in total they had 136 times of maximum light. Cao and Jiang (1991) added 9 times of maximum light from their observations to obtain a total of 145 times of maximum light. Arellano Ferro et al. (1994a) collected 137 times of maximum light including 10 times of maximum light from their observations. The newest literature, which listed VZ Cnc's times of maximum light, was given by Fu and Jiang (1999); the number of the times of maximum light in their paper was 138 which had only 1 number more than the number of Arellano Ferro et al. (1994a). In this paper we collected 138 times of maximum light from Fu and Jiang (1999) and also added the 57 times of maximum light including 14 times of maximum light from our observations which are listed in Table 1. From Table 5 of Jiang and Yang (1982), we found the (O-C) distribution of $E = 14087$ was too large so we did not use it; in total we had 194 times of maximum light.

4 The (O-C) analysis and period variation

We used OMC01 software compiled by Fu et al. (1998) to do linear and quadratic fittings on all the times of maximum light and got the following solutions:

CL = TL + PL × E
TL = 2431550.7171 ± 0.0030 epoch in HJD
PL = 0.17836372 ± 0.00000003 days

CQ = TQ + PQ × E + 0.5 × Beta × E^2
TQ = 2431550.7208 ± 0.003 epoch in HJD
PQ = 0.17836352 ± 0.00000003 days
Beta = (1.7 ± 0.4) × 10^{-8} per year

Table 1 The 57 new times of maximum light

E	HJD(max)	W	Source
14106.0	2434066.7200	1.0	Fi
26422.0	2436263.4410	1.0	Ga
28308.0	2436599.8383	0.5	Sp
28309.0	2436600.0086	0.5	Sp
28313.0	2436600.7212	0.5	Sp
28325.0	2436602.8655	0.5	Sp
28330.0	2436603.7600	0.5	Sp
28353.0	2436607.8583	0.5	Sp
28358.0	2436608.7525	0.5	Sp
28380.0	2436612.6835	0.5	Sp
28442.0	2436623.7315	0.5	Sp
28448.0	2436624.8165	0.5	Sp
28453.0	2436625.6973	0.5	Sp
28487.0	2436631.7645	0.5	Sp
28492.0	2436632.6615	0.5	Sp
30390.0	2436971.1880	1.0	He
30490.0	2436989.0220	1.0	He
30491.0	2436989.2050	1.0	He
36149.0	2437998.3845	0.5	JY
36316.0	2438028.1737	1.0	JY
36322.0	2438029.2430	1.0	JY
36641.0	2438086.1476	0.5	JY
36646.0	2438087.0235	0.5	JY
38307.0	2438383.3015	1.0	JY
38917.0	2438492.1055	0.5	JY
53299.0	2441057.3290	0.5	Bo
55179.0	2441392.6490	0.5	Bo
57294.0	2441769.8910	0.5	Bo
67432.0	2443578.1328	1.0	JY
73117.0	2444592.1330	1.0	JY
100172.0	2449417.7670	0.5	AF
100177.0	2449418.6510	0.5	AF
100183.0	2449419.7330	0.5	AF
100188.0	2449420.6150	0.5	AF
100189.0	2449420.7900	0.5	AF
100233.0	2449428.6380	0.5	AF
100261.0	2449433.6370	0.5	AF
100300.0	2449440.6000	0.5	AF
100306.0	2449441.6610	0.5	AF
120572.0	2453056.3838	0.5	Hua
120617.0	2453064.4091	0.3	Hua
122535.0	2453406.5210	0.5	Hub
124475.0	2453752.5462	0.1	Huc
126447.0	2454104.2762	1.0	pp
126453.0	2454105.3484	1.0	pp
126486.0	2454111.2390	0.5	pp
126508.0	2454115.1483	0.5	pp

Table 1 (*Continued*)

E	HJD(max)	W	Source
126525.0	2454118.1863	1.0	pp
126598.0	2454131.2205	1.0	pp
126666.0	2454143.3392	1.0	pp
126827.0	2454172.0627	1.0	pp
126828.0	2454172.2373	1.0	pp
126900.0	2454185.0798	1.0	pp
126956.0	2454195.0769	1.0	pp
129025.0	2454564.0977	1.0	pp
129036.0	2454566.0710	1.0	pp
130680.0	2454859.2878	1.0	pp

HJD(max) = helio-centric times of maximum light; E = cycle number; W = weight; Source = reference sources; Fi = Fitch (1955); Ga = Gayer (1961); Sp = Spinrad (1960); He = He (1961); JY = Jiang and Yang (1982); Bo = Bogdanov (1972); AF = Arellano Ferro et al. (1994b); Hua = Hubscher (2005); Hub = Hubscher et al. (2005); Huc = Hubscher et al. (2006); pp = this paper. W = 1.0 for Photoelectric or CCD Photometry; W = 0.5 for the times of maximum light taken from IBVS with error larger than 0.0005 days; W < 0.5 for error larger than 0.001 days

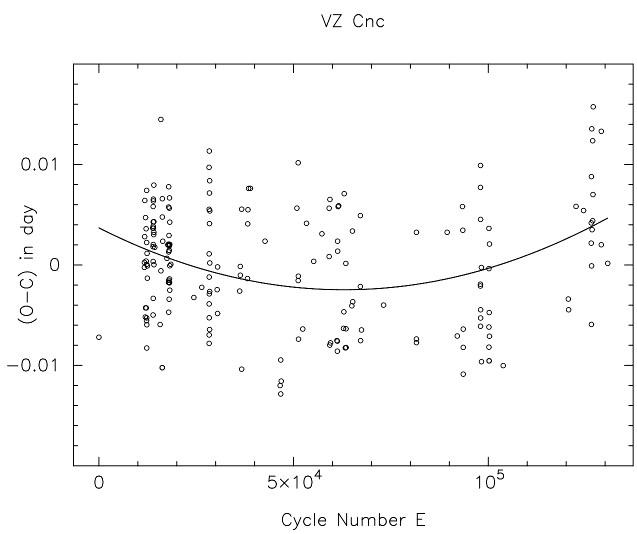

Fig. 7 The (O-C) distribution of VZ Cnc from 1949 to 2009 without correcting for the beat period influence

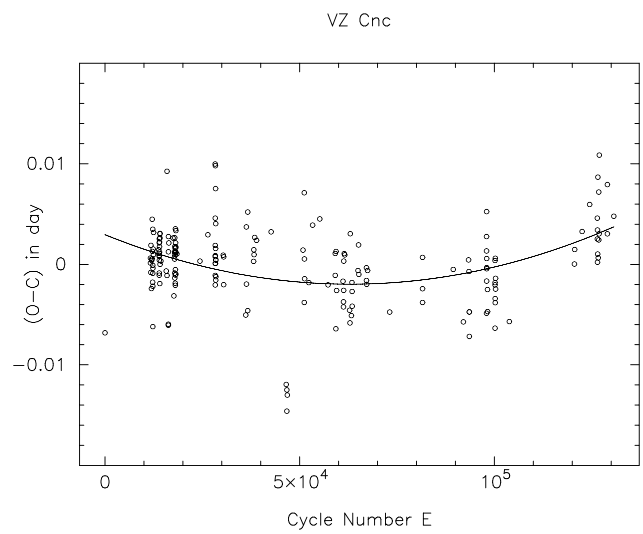

Fig. 8 The (O-C) distribution of VZ Cnc from 1949 to 2009 after correcting for the beat period influence

The RMS of linear and quadratic calculations are 0.005961 and 0.005706, respectively. The parabolic fit to the (O-C) distribution is shown in Fig. 7.

After correcting for the beat period influence, the solutions change to:

$\mathrm{CL} = \mathrm{TL} + \mathrm{PL} \times \mathrm{E}$
$\mathrm{TL} = 2431550.7167 \pm 0.0020$ epoch in HJD
$\mathrm{PL} = 0.17836372 \pm 0.00000002$ days

$\mathrm{CQ} = \mathrm{TQ} + \mathrm{PQ} \times \mathrm{E} + 0.5 \times \mathrm{Beta} \times \mathrm{E}^2$
$\mathrm{TQ} = 2431550.7197 \pm 0.002$ epoch in HJD
$\mathrm{PQ} = 0.17836356 \pm 0.00000002$ days
$\mathrm{Beta} = (1.4 \pm 0.3) \times 10^{-8}$ per year

The RMS of linear and quadratic calculations are 0.003757 and 0.003483, respectively. The parabolic fit to the (O-C) distribution is shown in Fig. 8.

CL = Linear calculation of times of maximum light
CQ = Quadratic calculation of times of maximum light
TL = The first time of maximum light for linear calculation
TQ = The first time of maximum light for quadratic calculation
PL = Pulsating period of linear calculation

PQ = Pulsating period of quadratic calculation
E = Cycle number
Beta = Period variation rate

The scatter and error after correcting for the beat period influence are much smaller than the scatter and error before the corrections as shown in Fig. 7 and Fig. 8. The period variation rates both in direction and size are compatible with the stellar evolution model calculation as mentioned by Breger and Pamyatnykh (1998).

To avoid the influence of the beat period, we subtracted $0.0056 \sin 360°(\psi - 0.05)$ for all those times of maximum light before E = 73117. Here ψ is the decimal part of $(0.716292)^{-1}$ (HJDmax − HJD2433631.8630). As in Cao and Jiang (1991), the new beat period was quite different from the old one so for all those after E = 81538 we subtracted $0.0058 \sin 360°(\psi - 0.1)$. Here ψ is the decimal part of $(0.716278)^{-1}$ (HJDmax − HJD2433631.8630).

5 Discussion and conclusion

Although Whitney (1950) found VZ Cnc to be a variable star in 1949, VZ Cnc has continuously been observed by many astronomers for more than 58 years. It is classified as a population I high amplitude δ Scuti variable. It has two radial pulsating modes with a period ratio of about 0.8, so they are the first overtone and the second overtone. The main period P1 = 0.17836376 days or 4.28 hours with an amplitude varying from 0.35 to 0.69 magnitudes in V as shown in Table 5 of Fitch (1955) is caused by the second overtone pulsation P2 = 0.1428041 days. So the (O-C) distribution of maximum light, determined along with P1, must be influenced by P2. Different times of maximum light have different amplitudes, with different phase shifts compared with each other. From Fitch (1955), the phase shift can be as large as ±0.03 or ±0.0054 days. As we can see from Fig. 7, this influence is really as large a scatter as ±0.06 days in each observation session. In some sessions, if there are only one or few times of maximum light being observed, the bias effect will make the (O-C) distribution show some strange shapes, such as several straight lines with different slopes or sine wave variations.

There are 3 types of period variations suggested by different astronomers. The first type is steadily increasing or decreasing. It looks like an upward or downward parabola in the (O-C) distribution. For a δ Scuti variable type, in most situations, the period variation caused by stellar evolution will be steadily increasing with a rate between 10^{-10} to 10^{-7} per year. In only a few conditions will the period be steadily decreasing. The second type of period variation is light time effect of binary orbital modulation. It looks like a sine-wave shape in an (O-C) distribution. If the orbital period is very long, as in several tens to hundreds of years, so that the observed (O-C) only covers one part of the sine wave so that it looks like an upward or downward parabola, but the rate related to this parabola is too large compared with the stellar evolution rate. The third type is called abrupt variation in period. It looks like several straight lines in an (O-C) distribution. Because the (O-C) distribution within one observation season always has a quite large scatter, this abrupt variation cannot be distinguished from sine wave variation. Here for VZ Cnc, Arellano Ferro et al. (1994a) used their collection of times of maximum light until 1993 and made corrections on the beat period modulation. They then suggested a binary light time effect solution. From our Fig. 8, we tend to explain it as an upward parabola rather than the other 2 types. The reason is that there are 4 points which have a very small (O-C) distribution so that any sine wave or straight lines can't fit them even on a very large scatter bar.

In this paper we used as much data as possible from all sources. Although the scatter within any observation session after the influence of the corrected beat period is still quite large as shown in Fig. 8, about ±0.004 days, the whole tendency can be fitted by an up parabola clearly. As we find more times of maximum light, the periodical variation caused by the light time effect of binary orbital movement becomes not so clear, especially considering the 4 points with (O-C) distribution smaller than −0.01 days before $E = 5 \times 10^4$. It is very difficult to fit these 4 points by any sine wave or several straight lines. So we tend to believe that in any condition the general tendency of (O-C) distribution clearly shows that the main pulsating period PL = 0.17836372 days is continuously increasing at the rate of 1.4×10^{-8} per year which is compatible with the stellar evolution model calculation of Breger and Pamyatnykh (1998). From Fig. 5 of that paper, we can find for population I post main sequence radial pulsator δ Scuti star VZ Cnc with the period of 0.17836372 days should have a period variation rate caused by stellar evolution of less than 5×10^{-8} per year but increasing continuously. So our measured period variation rate which equals 1.4×10^{-8} per year is compatible with it. VZ Cnc is rather bright with quite a high light variation amplitude so it is easy to observe for those people who have small telescopes with CCD cameras to observe in places near urban areas. After 60 years we can find only 194 times of maximum light so the average times of maximum light observed per year is only 3. Some years there were no observations at all. To decrease the influence of the large scatter, it would be better to obtain about 10 times of maximum light per year. We would like more people to observe this interesting bright high amplitude δ Scuti variable with small telescopes and CCD cameras.

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