Pulsation Analysis of the High Amplitude {\delta} Scuti Star CW Serpentis

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Pulsation Analysis of the High Amplitude δ Scuti Star CW Serpentis

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ABSTRACT

Time-series photometric observations were made for the High Amplitude δ Scuti star CW Ser between 2011 and 2012 at the Xinglong Station of National Astronomical Observatories of China. After the frequency analysis of the light curves, we confirmed the fundamental frequency of $f = 5.28677\ cd^{-1}$, together with 8 harmonics of the fundamental frequency, 7 of which are newly detected. No additional frequencies were detected. The $O - C$ diagram, produced with the 21 newly determined times of maximum light combined with those provided in the literature, helps to obtain a new ephemeris formula of the times of maximum light with the pulsation period of $0.189150355 \pm 0.000000003\ days$.

Subject headings: stars:variables: δ Scuti — stars: individual: CW Ser — techniques: photometric

1. Introduction

δ Scuti stars are a class of pulsating variable stars that lies in the classical instability strip cross the main sequence on the Hertzsprung-Russell diagram, whose pulsations are driven by the $\kappa-$mechanism which drives the pulsations of both Cepheids and the RR Lyrae stars as well. With masses between 1.5 and $2.5M_{\odot}$, periods between 0.03 and 0.3 days, luminosities between 10 and 50 $L_{\odot}$, δ Scuti stars pulsate with amplitudes from mmag up to tenths of a magnitude (Breger 2000).

The high-amplitude δ Scuti stars (hereafter HADS) are a subgroup of δ Scuti stars as slow rotators with one or two dominant radial modes whose amplitudes are larger than 0.1 mag, although some of them may have low-amplitude, non-radial modes in addition to the main pulsation modes (Poretti 2003). It is interesting to probe whether the non-radial mode is an overall property of the pulsations of all HADS.

Pulsations of the HADS CW Serpentis (hereafter CW Ser (= HIP 077798, $\alpha_{2000} = 15^h52^m10^s$, $\delta_{2000} = 06°05'26''$, $< V >= 11^m.83$, $P_0 = 0^d.1892$, $\Delta V = 0^m.47$, A-F) were discovered by Hoffmeister (1935). Gieren et al. (1975) made time-series photometry for CW Ser, derived two times of maximum light and the period value of $P = 0^d.18915054 \pm 0.00000001$. CW Ser has been observed only by a few runs since its pulsation period is rather long. The spectral type of CW Ser was classified as F by Halprin & Moon (1983) and Lopez de Coca et al. (1990) by using the $uvby\beta$ photometry. Xu et al. (2002) calibrated it's spectral type as A-F. There were also several runs of photometric observations carried out in Konkoly observatory from 1975 to 2005 (Gieren et al. 1975; Agerer & Hubscher 1996; Agerer & Huebscher 1998; Agerer et al. 1999, 2001; Hubscher et al. 2005).

In the following sections, we present a detailed study of the pulsations and period changes of

CW Ser, mainly based on extended time-series photometric observations from 2011 to 2012 at the Xinglong Station of National Astronomical Observatories of China (NAOC). The organization of the paper is: Section 2 describes the data collection and reduction; Section 3 introduces the pulsation analysis of the new data; Section 4 discusses the calculated changes of the peirod with the $O-C$ method; Section 5 gives our conclusions.

2. Observations and Data Reduction

Time-series photometric observations for CW Ser were made with the 85-cm telescope located at the Xinglong Station of NAOC between March 2011 and June 2012. The 85-cm telescope was equipped with a standard Johnson-Cousin-Bessel multicolour filter system and a PI1024 BFT CCD camera mounted on the primary focus (Zhou et al. 2009). The CCD camera has 1024×1024 pixels, corresponding to a field of view of $16.5' \times 16.5'$, Since March 2012, this CCD camera was replaced by a PI512 BFT, which has 512×512 pixels corresponding to a field of view of $15' \times 15'$. The observations were carried out through a standard Johnson V filter with exposure time ranging from 20 to 150 seconds, depending on the atmospheric conditions. A journal of the new observations is listed in Table 1.

Table 1: Journal of the new observations in V with the 85-cm telescope between 2011 and 2012.

CCD	Year	Month	Nights	Frames
PI BFT1024	2011	March	4	1,249
		May	7	2,247
PI BFT512	2012	March	5	830
		April	2	245

In total, 4,571 CCD frames of data were collected for CW Ser within 18 nights. Figure 1 shows an image of CW Ser taken with the 85-cm telescope, where the comparison star and the check star are marked (see Table 2). After bias, dark and flat-field corrections, aperture photometry was performed by using the DAOPHOT program of IRAF. The light curves were then produced by computing the magnitude differences between CW Ser and the comparison star. The standard deviations of the magnitude differences between the check star and the comparison star yielded an estimation of photometry precisions, with the typical value of $0^{\rm m}.003$ in good observation conditions and $0^{\rm m}.011$ in poor cases. Although there were slight zero-point shifts, we adjusted it with the fit light curves of the data for every month (assuming the frequencies are stable in one month).

Table 2: Information of the comparison and the check star.

ID	Star-Name	α(2000)	δ(2000)	V(mag)
Comparison	USNOA2 0900-08292504	$15^h53^m17^s.32$	$+05°59'13''.6$	11.15
Check	USNOA2 0900-08293690	$15^h53^m24^s.81$	$+05°59'15''.5$	13.50

Figure 2 shows the light curves of CW Ser in Johnson *V* band observed with the 85-cm telescope in 2011 and 2012, which were used to make frequency analysis.

3. PULSATION ANALYSIS

Frequency analysis was performed with the light curves of CW Ser in 2011-2012 with the software PERIOD04 (Lenz & Breger 2005), which makes Fourier transformations of the light curves to search for significant peaks in the amplitude spectra. The light curves are fitted with the following formula,

$$m = m_0 + \sum_i A_i \sin(2\pi(f_i t + \phi_i)). \quad (1)$$

The solutions with frequencies whose signal-to-noise ratios (S/N) are larger than 4.0 (Breger et al. 1993) were listed in Table 3. The solid curves in Figure 2 show the fits with the frequency solution in 2011-2012. From Table 3, one notes that the 8 frequencies are composed of the fundamental

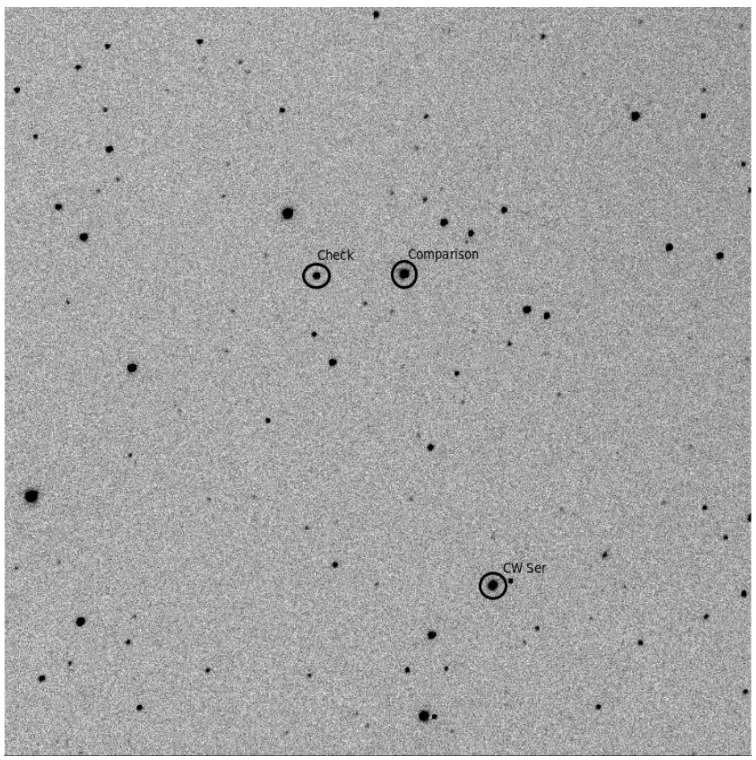

Fig. 1.— CW Ser, the comparison star and the check star, marked in an image taken with the 85-cm telescope. The field of view is $16.5' \times 16.5'$. North is down and East is to the right.

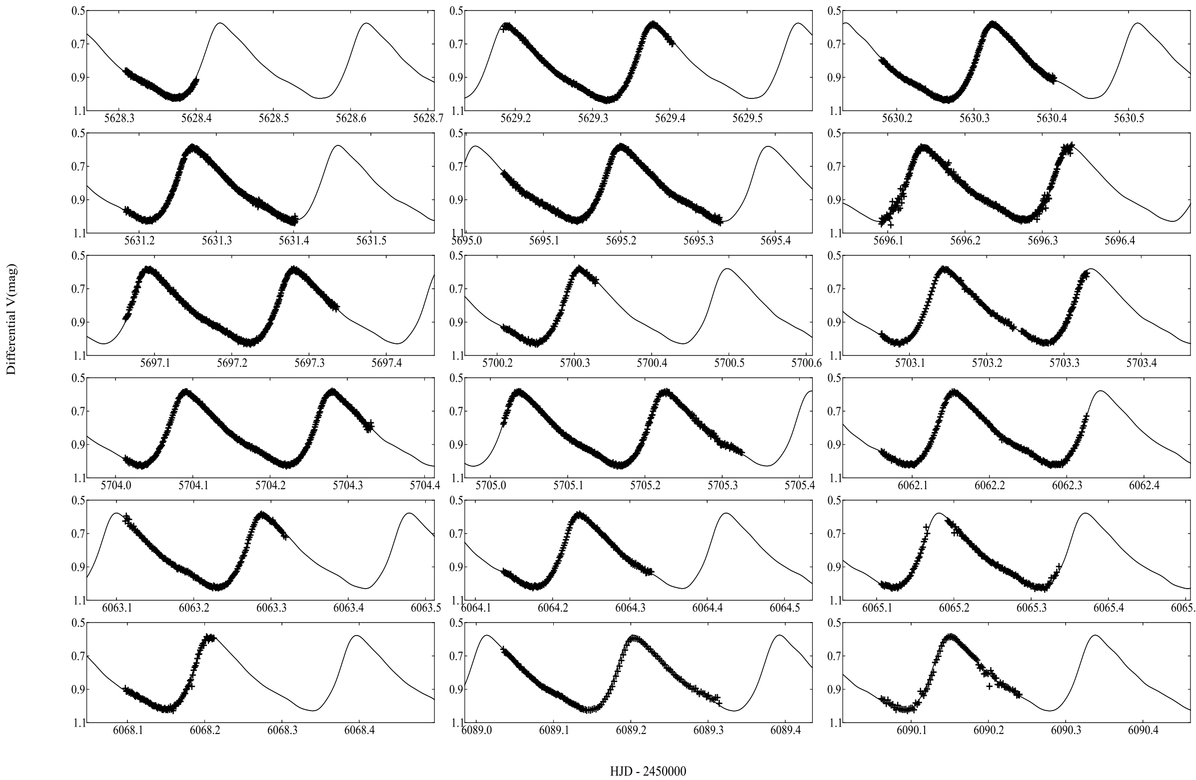

Fig. 2.— Light curves of CW Ser in the *V* band from 2011 to 2012. The solid curves represent the fitting with the 8-frequency solution listed in Table 3.

frequency and its 7 harmonics while no other frequencies in addition to the fundamental frequency and the harmonics are detected.

As can be seen from Figure 2, the constructed curves fit well the observed light curves, which shows that the fundamental frequency and its harmonics can explain the pulsation behavior of CW Ser.

Figure 3 shows the window function of the light curves in V of CW Ser from 2011 to 2012. Figure 4 shows the amplitude spectra of the frequency pre-whitening process. Note that the peaks located in the low-frequency domain ($0 - 3\ c\ d^{-1}$) are not considered as significant signals of the variable star due to the instrument sensitivity instability and variations of sky transparency in the low frequency domain.

Table 3: Multiple frequencies of CW Ser in 2011-2012.

	Frequency ($c\ d^{-1}$)	Amp (mmg)	S/N
f_0	5.28677	187.34	47.1
$2f_0$	10.57354	66.37	39.4
$3f_0$	15.86032	19.86	27.2
$4f_0$	21.14712	10.11	17.9
$5f_0$	26.43660	5.02	15.6
$6f_0$	31.72064	2.83	7.8
$7f_0$	37.00211	1.81	6.0
$8f_0$	43.29979	1.04	4.9

4. The $O - C$ Diagram

With the new observations from 2011 to 2012, the light curves around the maximum light were fitted with third polynomials, which are sufficient to derive times of maximum light. 21 new times of maximum light in V band are determined with the date in 2011-2012.

In order to make the $O-C$ analysis for the period change of CW Ser, the maximum times newly determined were combined with those provided by Gieren et al. (1975), Agerer & Hubscher (1996), Agerer & Huebscher (1998), Agerer et al. (1999), Agerer et al. (2001) and Hubscher et al. (2005). In total, 30 times of maximum light are collected and listed in Table 4, where the first time of maximum light is not included since we do not know the used detector and the data precision. In addition, there exists a large time gap between the first time of maximum light and the other data points.

The $O-C$ values are calculated and listed in Table 4 as well. The $O-C$ diagram is shown in Figure 5. A straight-line fit to the 30 times of light maxima yields the ephemeris formula,

$$HJD_{max} = 2431212.3095(8) + 0.189150355(3)E \tag{2}$$

, with a standard deviation of $\sigma = 0.0091(7)\ days$.

Since there are too free data points in the $O-C$ diagram, we do not try to make a second-order polynomial fit to estimate the period change rate.

5. Conclusions and Discussion

On the basis of the time-series photometric data from 2011 to 2012, we determined the fundamental frequency of pulsation as $5.28677 \pm 0.00001\ c\ d^{-1}$. No additional frequencies were resolved in the residual spectrum after prewhitening the fundamental frequency and its 7 harmonics. The light variations of CW Ser can be well reproduced with the fundamental radial mode and its 7 harmonics.

Analysis of the light curves of CW Ser suggests that no nonradial mode pulsations with amplitudes larger than $1.04\ mmag$ are detected, which shows that nonradial mode is not an overall property of the pulsations of all HADS at this amplitude level.

The 7 harmonics resolved in the pulsaitons of CW Ser indicate the distortion of the light curves from the standard sinusoidal function, which does not help the asteroseismological analysis for CW Ser since no new independent modes are presented. However, the existence of multiple harmonics shed lights on the nonlinear behaviour of the pulsation-excitation zone in the star.

According the $O - C$ method, we provide a new ephemeris formula of the times of maximum light with the pulsation period of $0.189150355 \pm 0.000000003\ days$

More observations, includeing high duty-cycle time-series photometry and high quality spectroscopic observations, are extremely needed to caluculate the period change rate of CW Ser and deduce the properties of this HADS.

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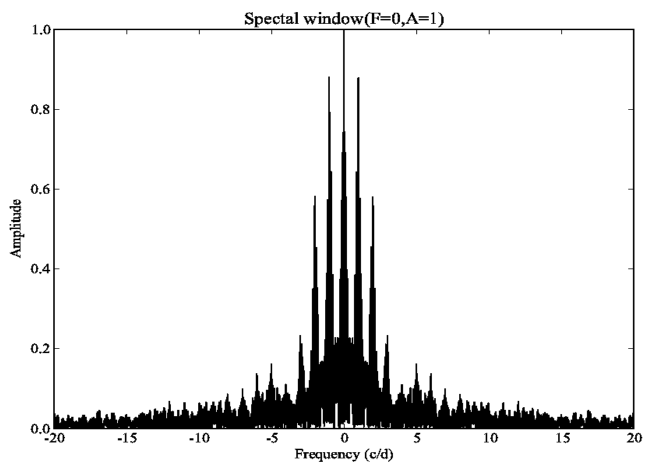

Fig. 3.— Spectral window of the light curves in V for CW Ser from 2011 to 2012.

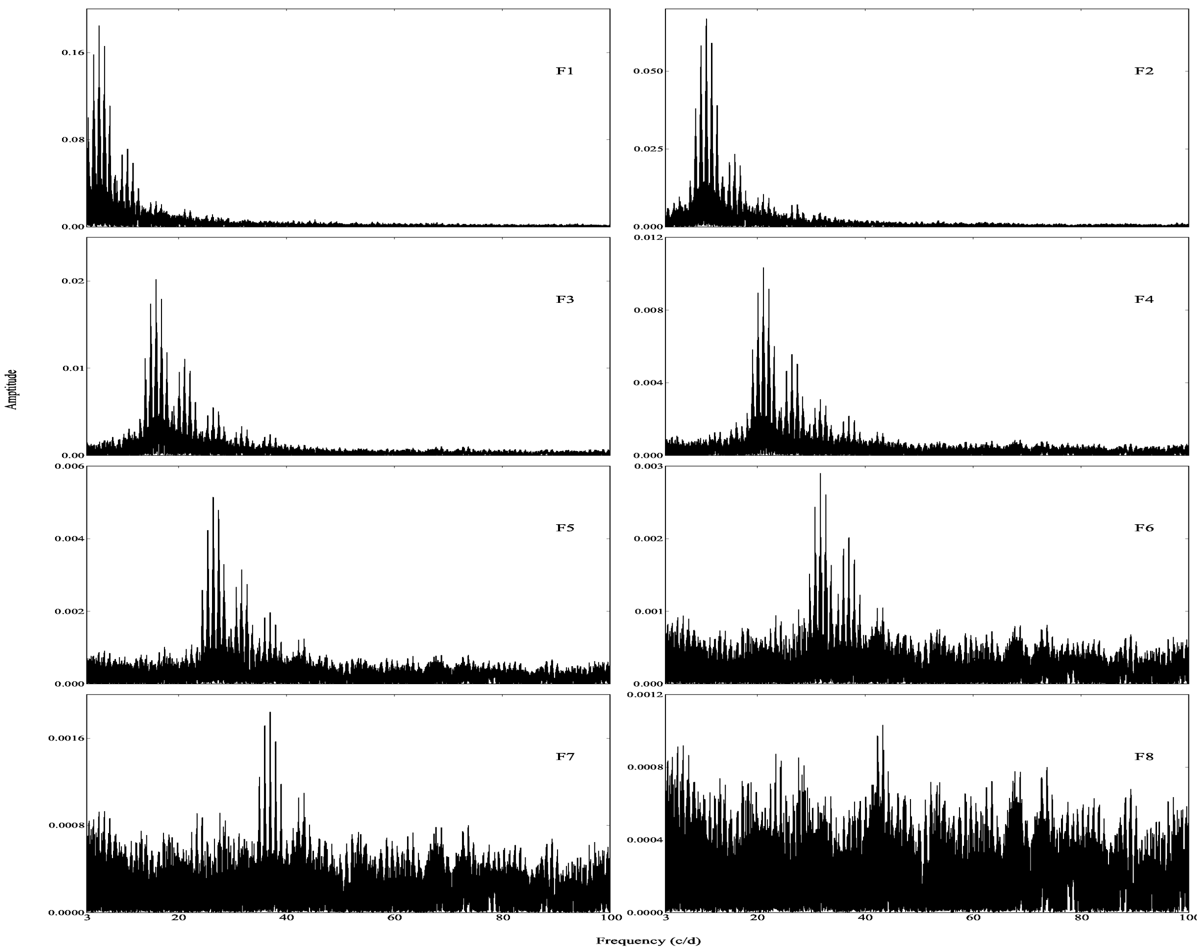

Fig. 4.— Fourier amplitude spectra of the frequency pre-whitening process for the light curves in V observed with the 85 cm telescope of NAOC in 2011-2012.

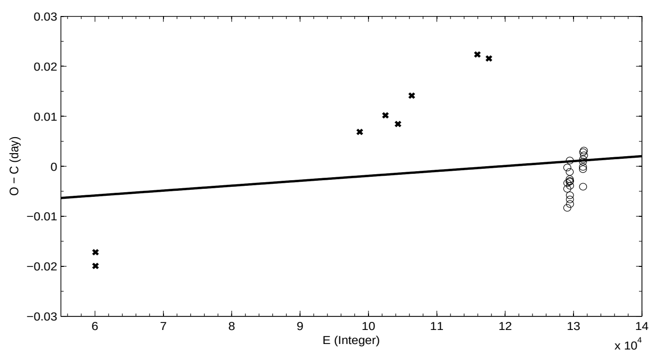

Fig. 5.— $O - C$ diagram constructed with the data from the literature (cross) and the new data (open circle). The $O - C$ values are in days. E: cycle number.

Table 4. Times (T_{max} in HJD 2400000+ days) of maximum light of CW Ser. E: cycle number. O-C: in days. Det: Detector. pe: photoelectric photometer. Points not used in the O-C analysis are marked with an asterisk. S: Source.

NO.	T_{max}	E	$O-C$	Det.	Weight	S
0	31212.2800	0	—	?	—	(1)*
1	42575.5000	60075	-0.0171	pe	1.0	(2)
2	42576.4430	60080	-0.0199	pe	1.0	(2)
3	49888.4551	98737	0.0068	CCD	2.0	(3)
4	50599.4746	102496	0.0102	CCD	2.0	(4)
5	50944.4831	104320	0.0084	CCD	2.0	(5)
6	51325.4376	106334	0.0141	CCD	2.0	(6)
7	53143.3699	115945	0.0223	pe	1.0	(7)
8	53462.6549	117633	0.0215	pe	1.0	(7)
9	55628.3966	129083	-0.0082	CCD	2.0	(8)
10	55629.3504	129088	-0.0002	CCD	2.0	(8)
11	55630.2919	129093	-0.0045	CCD	2.0	(8)
12	55631.2388	129098	-0.0033	CCD	2.0	(8)
13	55695.1719	129436	-0.0030	CCD	2.0	(8)
14	55696.3073	129442	-0.0025	CCD	2.0	(8)
15	55697.2545	129447	-0.0011	CCD	2.0	(8)
16	55700.2832	129463	0.0011	CCD	2.0	(8)
17	55703.1135	129478	-0.0057	CCD	2.0	(8)
18	55703.3018	129479	-0.0066	CCD	2.0	(8)
19	55704.0575	129483	-0.0075	CCD	2.0	(8)
20	55704.2503	129484	-0.0038	CCD	2.0	(8)
21	55705.1970	129489	-0.0029	CCD	2.0	(8)
22	56062.1276	131376	0.0009	CCD	2.0	(8)
23	56063.2610	131382	-0.0005	CCD	2.0	(8)
24	56064.2072	131387	-0.0001	CCD	2.0	(8)

Table 4—Continued

NO.	T_{max}	E	$O-C$	Det.	Weight	S
25	56065.1490	131392	-0.0040	CCD	2.0	(8)
26	56065.3436	131393	0.0013	CCD	2.0	(8)
27	56068.1823	131408	0.0028	CCD	2.0	(8)
28	56089.1783	131519	0.0031	CCD	2.0	(8)
29	56090.1231	131524	0.0021	CCD	2.0	(8)

Note. — Sources: (1) Hoffmeister (1935); (2) Gieren et al. (1975); (3) Agerer & Hubscher (1996); (4) Agerer & Huebscher (1998); (5) Agerer et al. (1999); (6) Agerer et al. (2001); (7) Hubscher et al. (2005); (8) this work.

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