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Time-dependent Behaviour of the Low Amplitude δ Scuti Star HD 52788 *

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Abstract Wavelet transform is applied to reanalyze the low amplitude δ Scuti star HD 52788, which exhibits complex light variations with uncertain frequency solutions. We gain an insight into the strong instability of pulsation present in the star. Based on an estimate of the star's physical parameters, its evolutionary status is determined. An attempt of asteroseismic modelling failed to predict the observed dense frequencies. Because of its varying pulsation spectrum, HD 52788 is a distinctive and very interesting object among δ Sct stars for testing current models of stellar evolution and pulsation.

Key words: methods: data analysis — stars: oscillations — δ Scuti — stars: individual (HD 52788)

1 INTRODUCTION

HD 52788 (=V383 Carinae =SAO 234839=HIP 33616, V=8.37 mag) was announced to be a δ Scuti star by Kurtz (1979). He obtained a total of 104 hours of differential photometric observations during 1978, 1979 and 1980 (Kurtz 1979, 1981), but he did not find a consistent frequency solution for the pulsation of the star. Kurtz stressed that these data are still inadequate for deriving a unique set of frequencies that represents the light variations. Two possible explanations were proposed: one is the frequency spectrum in HD 52788 changes with time so that there are no stable frequencies to be found; the other is that there are many closely spaced frequencies of similar amplitude present in HD 52788, and the complexity of the amplitude spectrum of all these frequencies and their aliases is too great to be sorted out with the data set available. Kurtz also added that further observations of HD 52788 would not be as fruitful as for other δ Sct stars.

What interests us is the unstable pulsation spectrum of HD 52788. It is impossible, however, to observe this star (α_{2000} = $06^{\rm h}59^{\rm m}04^{\rm s}$, $\delta_{2000} = -58^\circ30'54''$) for observers in the northern hemisphere. So we tried reanalyzing Kurtz's data with the aid of wavelet transform and modern Fourier transform. Furthermore, a tentative asteroseismic modelling was made for a comparison

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with the observed parameters. Based on these analyses and computations we gained an insight into the star's pulsational instability. We shall point out the importance of further studies on the star.

2 FOURIER ANALYSIS

We shall denote by K78[1] , K79 and K80 the data sets acquired respectively in 1978, 1979 and 1980 by Kurtz (1979, 1981), and by KC, the three put together. We have discarded the few data points on the two nights 1978 March 14/15 and 1980 March 21/22, which were most probably collected in bad weather conditions. The observations obtained on 1978 January 17/18 were also excluded because they had the largest standard deviation of 3.5 mag. In addition, a total of 36 points from HJD 2444230.3825 to 2444230.5279 were deleted from K79.

Fourier analysis was carried out for each data set by using PERIOD98 (Sperl 1998). We found significant peaks in the power spectra mainly located around $10\,\mathrm{d}^{-1}$. The results are summarized in Table 1. Because the separate frequency solutions for the three individual data sets are mutually inconsistent, attempts to resolve KC led to poor fitting results. Using one data set's solution to the others also produced bad results.

Table 1 Fourier Solutions for the Data Sets K78, K79, K80 and KC

Term	K78		K79		K80		KC	
	Freq. (d^{-1})	Ampl. (mag)	Freq. (d^{-1})	Ampl. (mag)	Freq. (d^{-1})	Ampl. (mag)	Freq. (d^{-1})	Ampl. (mag)
f_1	7.978	0.0073	8.059	0.0081	8.885	0.0165	9.719	0.0068
f_2	9.688	0.0093	10.765	0.0066	7.352	0.0097	8.881	0.0070
f_3	7.842	0.0050	7.517	0.0061	5.179	0.0058	8.035	0.0060
f_4	8.517	0.0052	6.884	0.0031	9.793	0.0062	8.349	0.0048
f_5	7.384	0.0031	11.698	0.0037	—	—	9.932	0.0046
f_6	4.720	0.0029	3.444	0.0020	—	—	—	—
f_7	11.213	0.0027	—	—	—	—	—	—
f_8	12.827	0.0018	—	—	—	—	—	—
σ (mag)		0.0029		0.0026		0.0039		0.0064

As Kurtz stated, the frequency solutions are clearly complex. Not one frequency detected in a given data set was found again in another. The frequencies $8.517\,\mathrm{d}^{-1}$ in K78 and $7.517\,\mathrm{d}^{-1}$ in K79 should be one frequency if the daily alias was taken into consideration. However, this frequency was not present in K80. The inconsistent frequencies suggest significant pulsation instability on an annual or shorter time-scale. To gain an insight into the time-dependence of the pulsation, we made a wavelet analysis of the data.

3 WAVELET ANALYSIS

In the analysis of time-series data of pulsating stars, beyond the detection and identification of pulsation frequencies, one needs to investigate the stability of the pulsation modes and possible mode couplings as the oscillations can be involved in non-linear processes, such as the transfer of energy from one mode to another or when chaotic dynamics obtains. The detection of a varying period is very important as it gives information on the evolutionary status or on binary nature of the pulsating star. However, it is difficult to determine the period variability

[1] For the first part data of 1978 (Kurtz 1979), HJD values have been corrected according to the author's note (Kurtz 1981).

in the case of limited data base. The conventional Fourier analysis is unable to give any information on period variation because it localizes only the frequency information and not the time information. Unlike Fourier analysis, in which we analyze signals using sines and cosines, wavelet analysis uses wavelet basis to decompose and reconstruct a periodic signal or oscillation. The wavelet basis localizes in both the time and frequency domain, so it is well suited to the mission of detecting the time dependence of any signals or oscillations. In fact, it has been proved as a versatile tool to disclose the behaviour of the time evolution of the signal.

There is quite a number of examples of using wavelet analysis to study various oscillating phenomena. First, Goupil et al. (1990, 1991) gave a wavelet view on the pulsating white dwarfs. They found the amplitude modulation in the DB variable white dwarf PG 1351+489 resulted from two close frequencies, which cannot be resolved by the Fourier spectrum only. They interpreted the two frequencies as two 1:2 resonant modes and chaos arising through period doubling bifurcations. Next, by applying wavelet transform to the light curves of the semiregular variable Y Lyncis, Szatmáry & Vinkó (1992) showed two short periods of the four periods resolved from the Fourier transform to be unstable. Lastly, Scargle et al. (1993) investigated the quasi-periodic oscillations and very low frequency noises in the X-ray accretion source Sco X-1 and explained them as transient chaos. Other papers such as Coupinot et al. (1992), Starck et al. (1997) and so on, also used the wavelet technique. The applicability of wavelet analysis to the study of periodicity in the light curves of variable stars has been explored by some authors including Szatmáry et al. (1994, 1996). Wavelet transform, as these authors have demonstrated, is well-suited to the detection of the local behaviour of the light curve of variable stars, and the investigation of time-dependent phenomena including amplitude/frequency modulation and changes of period and phase. Foster (1996) developed the weighted wavelet Z-transform (WWZ) for analysing unevenly spaced data.

However, in the case of multiple pulsation modes, the wavelet transform seems hard to represent the light variations. Before applying the WWZ to practical data we would like to check the performance of wavelet transform for unevenly spaced multiperiodic artificial data. Our test data include four frequencies with zero phases but different amplitudes: $f_1 = 8.885\,\mathrm{d}^{-1}$, $A_1 = 0.0165\,\mathrm{mag}$; $f_2 = 7.352\,\mathrm{d}^{-1}$, $A_2 = 0.0097\,\mathrm{mag}$; $f_3 = 5.179\,\mathrm{d}^{-1}$, $A_3 = 0.0058\,\mathrm{mag}$; $f_4 = 9.793\,\mathrm{d}^{-1}$, $A_4 = 0.0062\,\mathrm{mag}$, which are the same as the four frequencies detected in the data set K80. The data were sampled exactly following K80. There are 335 data points with a zero point of 0.0005 mag. Figure 1 shows the periodicity and pulsation amplitude of the artificial light variations as a function of time. The amplitude variations given in the figure represent the whole energy variations of all the oscillating components. As the figure shows, it is hard to resolve individual frequency terms. Roughly, we can see oscillations around three frequencies 9.0, 8.0 and $7.3\,\mathrm{d}^{-1}$. Indeed, wavelet analysis is not good at resolving frequencies accurately, but it is good at revealing the time-dependence of an oscillation signal. From the top panel of Fig. 1 we can see the time dependence of frequency, or multiperiodicity. We also can easily see the resolved multiple frequencies and their stabilities — that a given frequency of them is only stable at a some instant of time. In the case of monoperiodic pulsation, this figure would imply a changing period.

Then we applied the wavelet analysis to HD 52788. Figure 2 shows the wavelet solution of the data set K80, there are four distinct pulsation frequencies. Results for all three data sets are presented in Fig. 3, which shows the pulsation of HD 52788 to be dramatic. The pulsation varies with time and no fixed frequencies can fully represent the light variations.

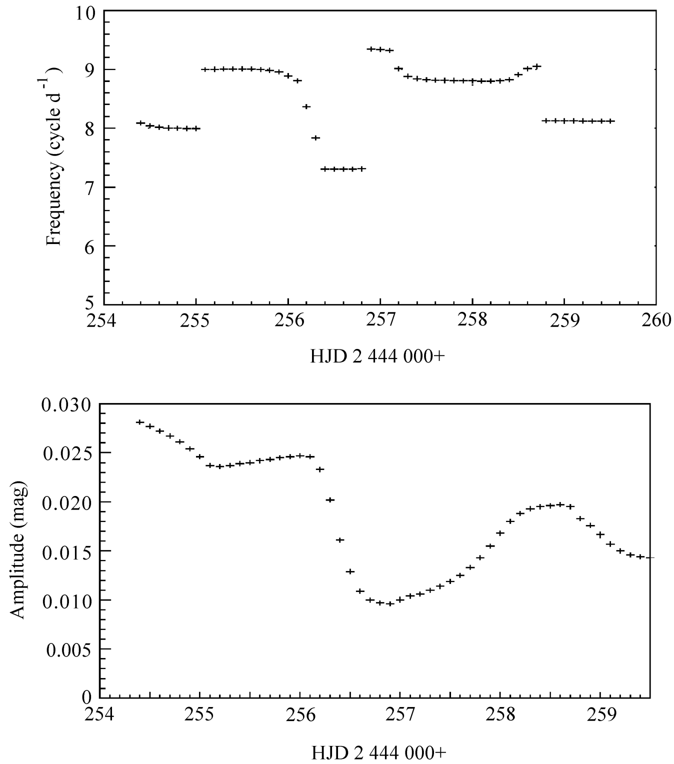

Fig. 1 Time dependence of frequency and amplitude of test data sampled at uneven intervals. Top panel shows a clear multiperiodic feature.

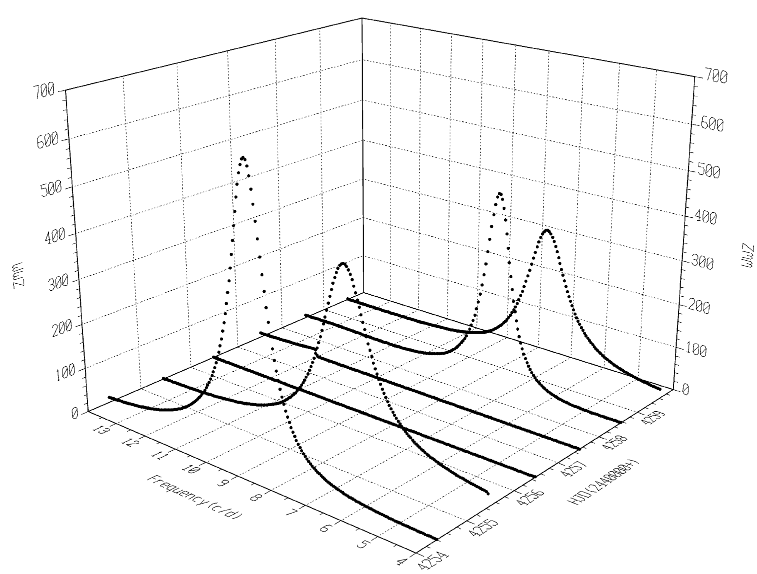

Fig. 2 Wavelet solution of the 1980 data.

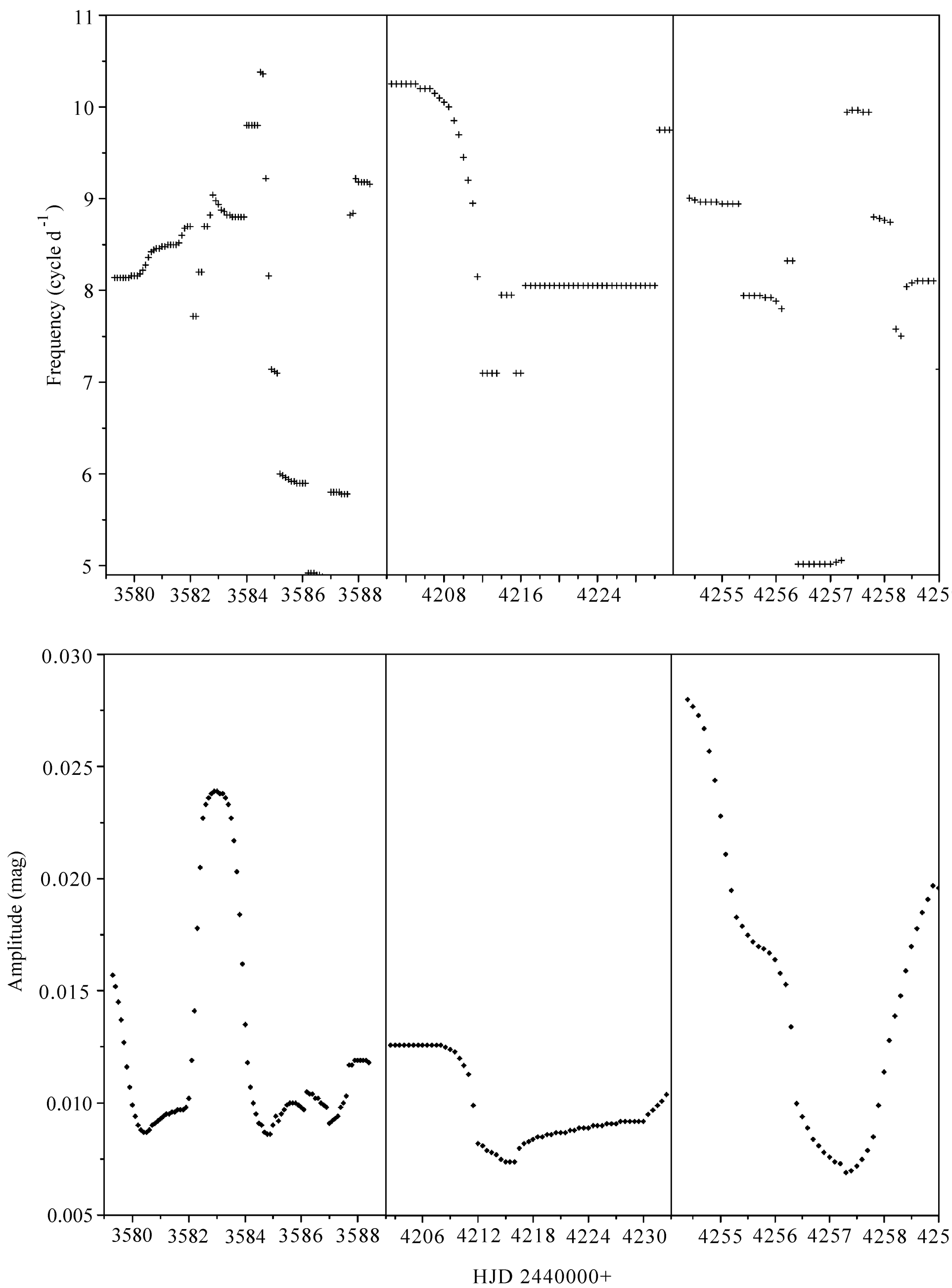

Fig. 3 Time-dependence of the pulsation frequencies (*crosses*) and amplitudes (*diamonds*) of HD 52788. Panels from left to right refer to the data collected in 1978, 1979 and 1980, respectively. Different time scales are used in the graphs.

4 ASTEROSEISMIC MODELLING

Asteroseismology is commonly understood to mean the study of normal-mode pulsation in stars which, as in the Sun, displays a large number of simultaneously excited modes. Delta Scuti stars are one type of stars, that have such pulsation characteristics. Asteroseismic modelling attempts to identify the star's evolutionary phase and pulsation modes. Prior to modelling the pulsation frequencies must be well determined from the observations. Then the frequencies need to be identified with specific pulsation modes in order to enable a comparison with specific models of stellar structure and evolution. Unfortunately, a stable frequency solution of HD 52788 is unavailable much less mode identifications. Nevertheless, to work out the theoretical implications, we ran the standard code of structure and evolution developed by Luo (1991, 1997) and a classical adiabatic/nonadiabatic oscillation program of models of pulsation (Li & Stix 1994). An example of these two programs is given in Liu et al. (1999).

A rough estimate of the physical parameters of the star was obtained from the $uvby\beta$ narrowband photometric results, $V = 8.839$, $(b - y) = 0.249$, $m_1 = 0.193$, $c_1 = 0.805$ and $\beta = 2.733$ mag (Kurtz 1979). We derived the effective temperature, luminosity and gravity to be: $T_{\rm eff} = 7240 \pm 170$ K, $M_{\rm bol} \approx M_v = 1.60$ mag, and $\log g = 3.53 \pm 0.04$. A spectral type of F0Ib was assumed for the star. M_v was found at essentially zero interstellar reddening, and normal metal abundance by using the calibrations of Crawford (1979). The effective temperature and gravity were determined from model-atmosphere calibrations of $uvby\beta$ photometry (Moon & Dworetsky 1985), in which the grids are sufficiently insensitive to metal abundance to be used. The $T_{\rm eff}$ and M_v values are in good agreement with Kurtz's results (see fig. 2 of Kurtz 1979). Then a pulsation mass of $0.9\,M_\odot$ was estimated from the relation: $\log M/M_\odot = 12.502 + \log g - 0.4M_{\rm bol} - 4\log T_{\rm eff}$. In addition, we derived the mean metal abundance [Me/H]=0.25 (Z=0.03556) from $\delta m_1 = -0.016$ mag. This value is slightly higher than for normal main-sequence stars.

There are three steps involved in the model calculation. First, the evolution program establishes a zero age main-sequence model for the star. Then an evolution track divided into 300 phases between ages 5.0×10^5 and 1.0×10^{10} years is built assuming normal initial chemical abundances $X = 0.70$ and $Z = 0.03$. Figure 4 shows the evolutionary stage of HD 52788 determined by its two observed quantities $\log L/L_\odot = 1.26$ and $\log T_{\rm eff} = 3.860$. The $1.8\,M_\odot$ track would place HD 52788 at a later evolutionary phase, while the $1.85\,M_\odot$ and $1.90\,M_\odot$ tracks, an earlier phase. The calculations indicate preference for a $1.85\,M_\odot$ star at the age of about 3.7 Gyr. Lastly, we compute the pulsation frequencies for the phases where the luminosity and effective temperature of the calculated tracks of different masses match with those observed.

We choose the four phases listed in Table 2 to calculate the pulsation frequencies under both adiabatic and nonadiabatic conditions. The phases are expressed as counts from 1 to 300 throughout a whole track in Fig. 4 and $(O - C)$ is the difference between the observed and calculated values. Figure 5 displays the computed frequencies compared with the observed ones. It is shown that there is no difference between the adiabatic and nonadiabatic models.

Table 2 Four Evolutionary Phases Selected for Pulsation Modelling of HD 52788

Mass/Phase	$\log L/L_\odot$	$(O-C)$	$\log T_{\rm eff}$	$(O-C)$
1.80/126	1.2574	+0.0026	3.8692	−0.0092
1.85/110	1.2632	−0.0032	3.8555	+0.0045
1.85/111	1.2683	−0.0083	3.8579	+0.0021
1.90/099	1.2606	−0.0006	3.9083	−0.0483

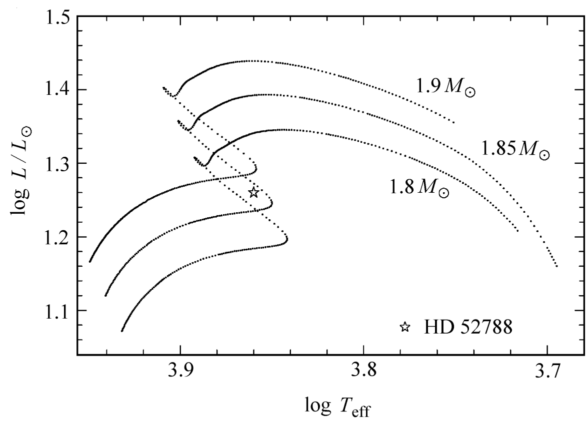

Fig. 4 Evolutionary stage of HD 52788.

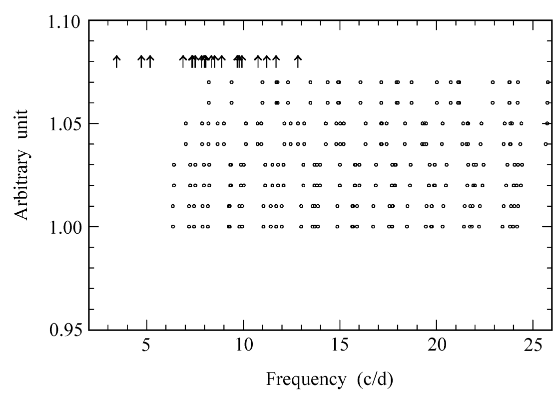

Fig. 5 Calculated sets of pulsation frequencies (*circles*) at different evolutionary phases compared with the observed set (*arrows*). From the bottom line of *circles*, every two lines are a pair corresponding to the adiabatic and nonadiabatic models at phases 1.85/110; 1.85/111; 1.80/126 and 1.90/099 (Table 2), and the top line of *arrows* is the observed set.

5 CONCLUDING REMARKS

Inconsistent Fourier solutions of the low amplitude δ Sct star HD 52788 among the three sets of data obtained in 1978, 1979 and 1980 indicate the star's complicated pulsational behavior. The pulsation is highly unstable. We attempted to unveil the pulsation instability in detail with the aid of wavelet analysis and oscillation modelling. The wavelet analysis clearly revealed the star's changing frequency spectrum. The changing pattern is on a time scale of days. Current computed modes do not match with the observed ones yet.

The observed frequencies are spaced in a narrow band (Fig. 5). They can be divided into four groups: below 6 d^{-1}, around 8 d^{-1}, around 10 d^{-1} and from 12 to 15 d^{-1}. All the oscillation models give a wide range of pulsation frequencies above 6 d^{-1}, and predict no frequencies below 6 d^{-1}. The models also predict fewer frequencies in the 6–10 d^{-1} range than is observed.

It is known that all variables in the classic Cepheid instability strip and its extensions are pulsating with unstable modes. However, the unstable modes generally have a 'relative stability' on time scales longer than a couple of observing seasons. This is the case observed in most δ Sct stars. The varying pulsation frequency spectrum of HD 52788 is noticeable and unique among the δ Sct stars, and further observations will be very helpful to solve the puzzle of strong pulsation instability in the star. It may be of importance in checking the current models of stellar structure, evolution and pulsation. At present time, we do not understand the mechanism underlying such a dramatic pulsation instability in HD 52788. Therefore, we hope to see a more detailed pattern of pulsation dependence on time on a longer time and data base. We need to probe into the underlying causes, and further studies would be fruitful. We propose to make extensive time-series CCD photometry and spectrometry of HD 52788. We hope observers in the southern hemisphere will join in.

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