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On the multiperiodicity of the δ Scuti star BDS 1269A (VW Arietis).

The fifth campaign of STEPHI network in 1993

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Abstract. — This paper reports on the fifth STEPHI multi-site photometric campaign in 1993 devoted to the δ Scuti star BDS 1269A (VW Ari). The observation yielded a data set of 150.7 hours. Our analysis has resulted in 7 identified frequencies. These frequencies exhibit three couple-frequency character, and also fit the previous investigations quite well. An attempt to identify the pulsation modes is made, but no equidistant evidence can be detected, and a second-order effect for rotational splitting has to be considered to explain the complicated nature of BDS 1269A.

Key words: star: δ Scuti star: variable — star: oscillations — star: BDS 1269A, HD 15165

1. Introduction

The STEllar PHotometry International (STEPHI) seismology is a multi-national collaborative effort which aims at searching for a significant number of modes in large amplitude pulsating δ Scuti stars, in order to infer information on the internal structure of the objects according to their observed eigenfrequencies. Three continent sites are involved in this network, and 3 four-channel Chevreton photometers are used coincident with the rapid photometric technique (Michel et al. 1992). STEPHI campaign runs every one year, striding over an average 3 weeks. Five campaigns have been undertaken since 1987. The STEPHI multi-channel, multi-site observation enjoys priority in the following aspects: its simultaneous observation leads to a higher density of measurements on four objects (variable, comparison star, check or supplementary star, sky background); it lowers to a minimum the short time-scale variation caused by atmospheric transparency.

The δ Scuti variables are stars located in the lower region of instability strip and show evidences of variability involving several modes. The presence of their many radial and non-radial pulsating modes makes them very interesting STEPHI candidates in terms of asteroseismology investigation.

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2. Observation

BDS 1269 is a visual binary system with a δ Scuti star as the primary (Mechler 1974) and a normal early F main sequence secondary BDS 1269B (HD 15164). The brighter primary in this system BDS 1269A (HD 15165, VW Ari) is our program star. Relevant parameters on this system from Runciński (1978) are in Table 1. Careful observations have been undertaken since its first finding by Mechler in 1974. Besides the published data, we also include an unpublished 8 night observation. The 8 night observation was carried out on a 60cm reflector with a Johnson V filter at Xinglong observatory by Y.Y. Liu and M. Cao in November 1990. The comparison and check stars are the same as the ones chosen by STEPHI observation in 1993. In total, it contains 475 measurements. We divided these collected different observations according to their time into four data sets (data 1, data 2, data 3 and data 4). The observing log is presented in Table 2. However, different periods have been rendered by some of the observers and even adopting quite the same data, discrepant results were reported. Table 2 may give readers an idea

Table 1. Relevant parameters on 4 objects of STEPHI93

star	HD	V	B	$b-y$	m_1	c_1	S_p
variable	HD 15165	6.7	6.7	0.185	0.102	0.858	A3
companion	HD 15164	8.3	8.5	0.190	0.162	0.687	F0
comparison	HD 15095	7.5	7.7	0.353	0.177	0.324	G0
check	HD 15042	7.7	7.6	0.185	0.102	0.858	B9

Table 2. Scheme of observations on BDS 1269A

	HJD 2440000. +	reported frequencies c/d	notes
data 1	2300.8767-2396.8250	11.4, 10.0	McMillan et al. 1976
data 2	3085.6809-3087.9070	6.71, 11.1	Percy 1980
		6.35, 10.72	Runciński 1978
		6.35, 10.74, 6.07, 6.56	Kurtd 1980
		6.23, 6.51, 11.77, 9.71, 11.34	Li et al. 1993
data 3	7087.0922-7092.3526	6.21, 6.52, 11.83, 9.71, 11.38	Li et al. 1993
data 4	8205.0061-8222.1711		unpublished data

about all the observational data and their main results concerning this star. Moreover, one characteristic of this system is that the primary BDS 1269A is metal deficient and the secondary has normal metal abundance (Mechler 1974). It was just because of so many intriguing reports dealing with this star that urged us to choose it as the target in the fifth campaign of STEPHI network in November 1993 (hereafter STEPHI93). HD 15095 and HD 15042 were chosen as comparison and check stars respectively. A few photometric features of them are also listed in Table 1.

The newly collected data on BDS 1269A in STEPHI93 were obtained using two identical 4-channel Chevreton photometers (Belmonte et al. 1991) with narrow blue filter (λ=4215 Å, $\Delta\lambda$=193 Å) at Observatorio del Teide in Spain (OT) and Xinglong observatory in China (XL). At Xinglong, each observation consists of a large amount of four 6 s integrations on the variable, sky background, comparison star, and check star simultaneously (on 2 or 3 nights the check star channel had instrumental problem). At OT, only the first three targets were monitored in the same way during the STEPHI93 campaign since the check star channel had some problems. Finally, we got a data set of 150.7 hours spanning 18 days. The journal of observations is presented in Table 3.

The bi-site STEPHI93 monitoring provides a large number of simultaneously recording high-speed photometry on BDS 1269A, HD 15095, sky and HD 15042 (this only at Xinglong). The pulsation instrumental amplitude versus time series can be obtained directly from the ratio between continuous counts on BDS 1269A and HD 15095 after the extinction correction. This yields the pulsating light curves of variable star, which exhibit the pulsation variation along not straight line but parabola due to the systematic drift. In consideration of this, for every night observation, a parabola calculated from the least square fit to the instrumental magnitudes was adopted to remove the nightly shift. In Fig. 1, two such instrumental amplitude versus time for BDS 1269A and comparison HD 15095 at Xinglong observatory are illustrated. The observed light curves of STEPHI93 are shown in

Table 3. The observing log

Date	XL (hour)	OT (hour)
Oct.06	6.23	
Oct.07	6.75	
Oct.09	7.42	
Oct.13		1.05
Oct.14		8.32
Oct.15	5.87	2.27
Oct.16	7.87	3.65
Oct.17	8.22	8.50
Oct.18	7.00	8.08
Oct.19	7.78	8.28
Oct.20	8.00	
Oct.21	7.07	8.67
Oct.22	7.95	4.92
Oct.23		8.47
Oct.24		8.33
Total	80.15	70.54

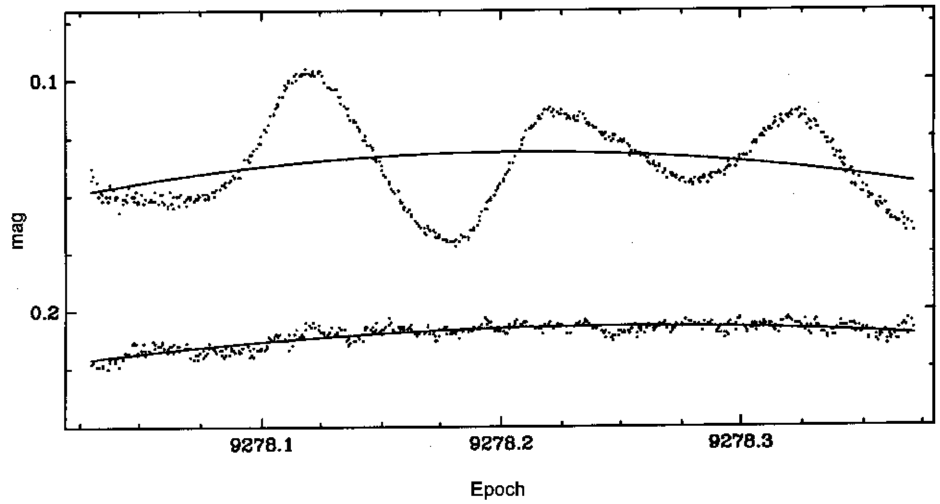

Fig. 1. Typical instrumental magnitude light curves of BDS 1269A (upper one) and HD 15095 (lower one) obtained at XL on October 17, 1993. The thin continuous parabola express the atmospheric extinction curves. The epoch is HJD.2440000.+

Fig. 2. The same procedures were sequentially repeated on comparison and check stars for Xinglong data in order to confirm the stability of comparison star. But no significant periodicity was detected and an observational standard deviation of comparison star $\sigma = 0.0096$ mag was determined.

3. Multiple frequency detection

The frequency finding on BDS 1269A was carried out using program MFA (see Hao 1991). In order to check the consistency of frequency, Breger's (1990) program PERIOD was independently used. These two programs produced same results within noise level. In principle, two analyses basically are the same. Any of them uses the iterative technique employing both Fourier transforms and least squares fitting.

The resulting spectral window and amplitude power spectrum utilizing MFA for STEPHI93 are sketched in Fig. 3. Figure 2 gives the fitting plots to all the light curves on star BDS 1269A. The collected measurements solved the light curves by seven frequencies schemed in Table 4 leaving the rms residual being 0.0104 mag, the level of the observational error. Meanwhile, the analysis from Hernández of Belmonte's group resulted in an eight frequency solution with 99% confidence level. They are listed in the right part of Table 4. The method they adopted is ISWF plus pre-whitening technique described in Belmonte et al. (1991). The relevant amplitude spectra are shown in Fig. 3. The first seven frequencies are the same as that of MFA. However, the eighth pulsation component 13.55 c/d cannot be seen in MFA's power spectra. The eighth frequency found in MFA's power spectra is quite different from 13.55 c/d, and it cannot give an obviously improved fitting residual. Adding 13.55 c/d, we used the eight solution to fit the data STEPHI93 to detect its existence. But, we still could not find an improved fitting to the light curves, and the fitting standard derivation is even worse than that of seven frequency solution. Since we cannot confirm the authenticity of frequency 13.55 c/d, we regard the seven frequencies as our final solution and 13.55 c/d as a possible constituent.

As mentioned above, between years 1974 and 1990, many observations have been performed, while intriguing explanations were suggested. In an effort to confirm our frequencies, the seven frequency solution yielded by both MFA and ISWF was applied to the 4 previous data sets. Plots of the data with their fitted curves using these seven frequencies are shown in Fig. 4. The seven frequency solutions with their changing amplitudes and phases in 4 different data sets are outlined in Table 5. We have noticed that these amplitudes and phases are different from those found in Table 4.

In the literature, different observers proposed their own frequency solutions about BDS 1269A as listed in Table 2. For instance, Percy (1980) suggested 6.71 and 11.11 c/d frequencies after he dealt with the data from McMillan et al. (1974), Ruciński (1976), and his own observation in 1976 using maximum entropy method. However Kurtz (1980) identified another two frequencies 6.35, and 10.74 c/d when he re-analyzed Ruciński's 3 consecutive night observation. Nevertheless, Li et al. (1993) obtained 5 components from monitors of Percy (1980) and Ruciński (1978). Even the solutions vary, some characteristics can still be seen. First, frequency 6.34 (or 6.35) c/d was commonly reported several times. It, perhaps, was incorrectly detected as a beat of f_1 and f_2 of STEPHI93. Second, because the previous observations suffer from the 1 c/d alias problem, the 11.77 c/d and 9.71 c/d frequencies reported by Li et al. (1993) are probable the f_6 of

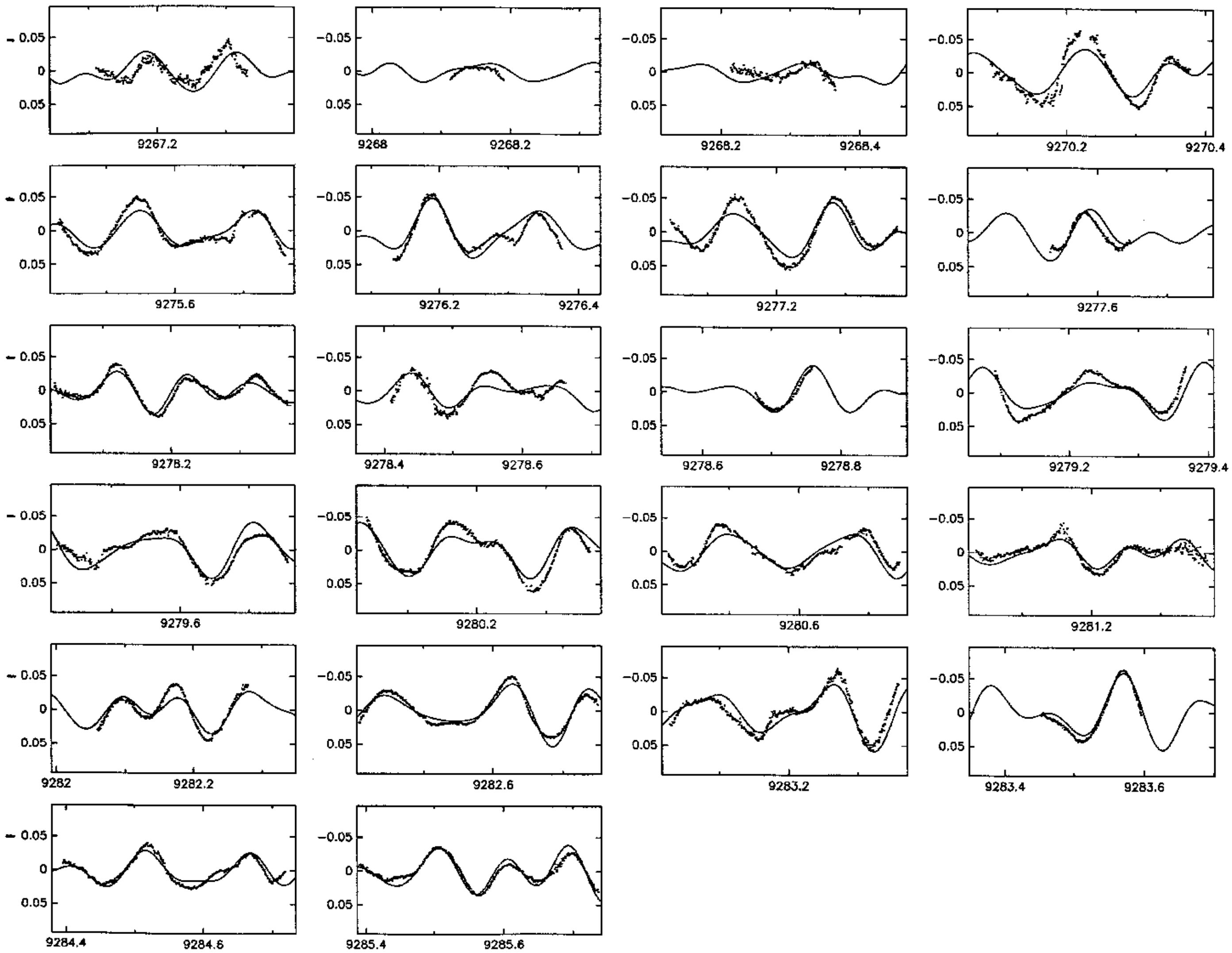

Fig. 2. BDS 1269A light curves and their fitting with the seven frequency solution resulted from STEPHI93 observation. The epoch is HJD.2440000.+, amplitude in mag

Table 4. Identified frequencies of BDS 1269A

	MFA solution					ISWF + pre-whitening solution		
	Frequency		Amplitude	Phase	Q value	Frequency		Amplitude
	μHz	c/d	mmag	2πrad	day	μHz	c/d	mmag
f_1	72.07	6.2273±0.0003	20.08±0.17	0.2826±0.0036	0.0287	72.1	6.22	22.0
f_2	75.44	6.5186±0.0005	11.02±0.17	0.5478±0.0068	0.0274	75.5	6.52	11.0
f_3	108.21	9.3496±0.0006	10.57±0.17	0.8235±0.0071	0.0191	108.1	9.34	11.3
f_4	125.19	10.8162±0.0007	9.34±0.19	0.7269±0.0095	0.0165	125.3	10.82	7.8
f_5	110.10	9.5130±0.0008	7.33±0.17	0.047±0.010	0.0188	110.3	9.53	5.9
f_6	124.17	10.7327±0.0010	6.08±0.18	0.204±0.014	0.0167	124.1	10.71	5.3
f_7	148.68	12.8456±0.0013	4.70±0.18	0.079±0.016	0.0139	148.8	12.85	5.2
f_8						156.8	13.55	3.0
	rms residual $\sigma = 0.0104$					confidence level 99%		

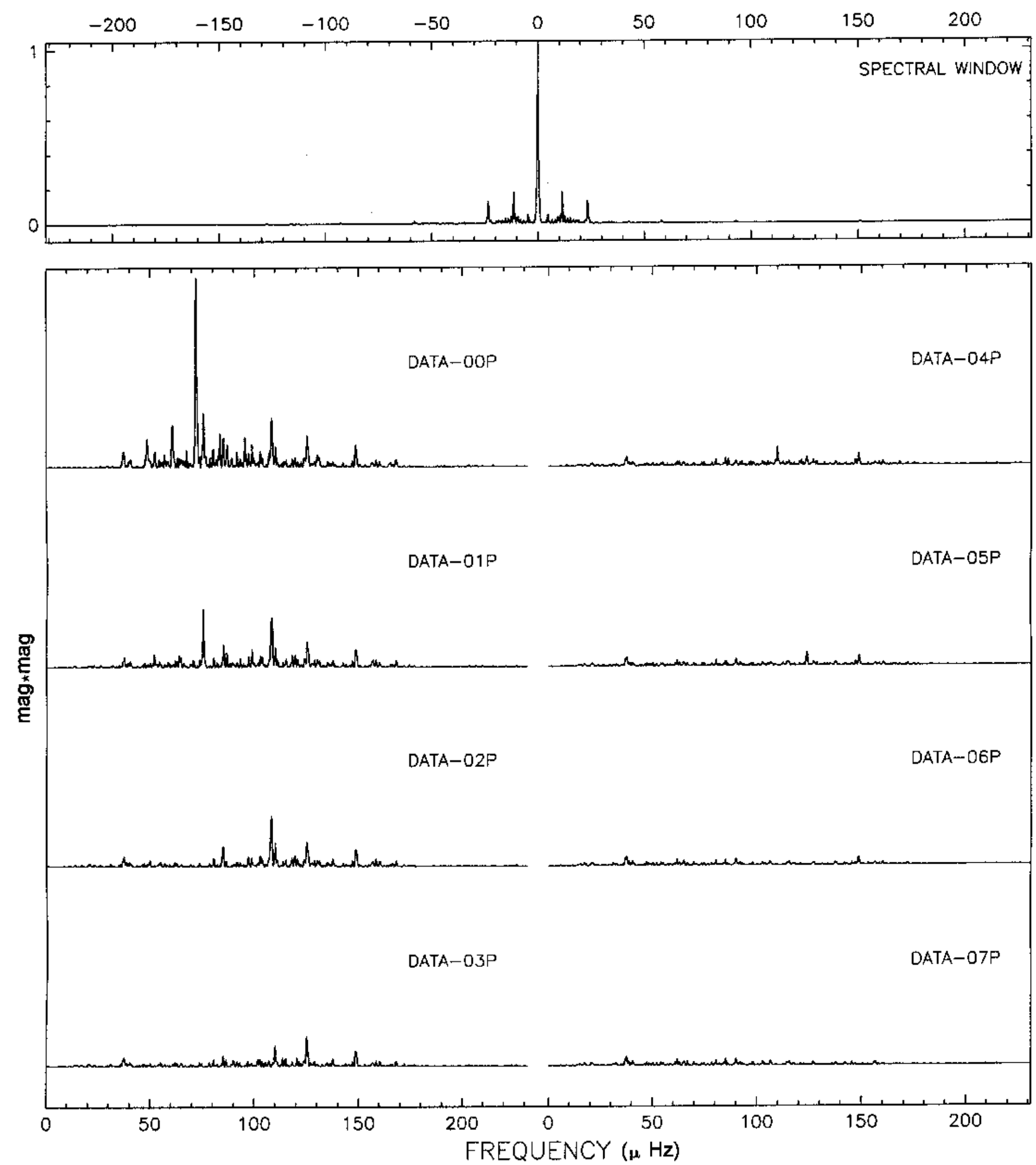

Fig. 3. a) A spectral window and power spectra of BDS 1269A determined by MFA from STEPHI93 observation. Seven frequencies are unambiguously detected (see left panel of Table 4)

STEPHI93, and similarly, the reported 11.83 c/d is perhaps the f_4 or f_7 of STEPHI93. Lastly, although the newly determined $f_3 = 9.349$ c/d (108.21 μHz) and $f_5 = 9.513$ c/d (110.10 μ Hz) of STEPHI93 were not clearly found in the previous observation, they are absolutely obvious from the long STEPHI93 run. The discrepant results between STEPHI93 and previous (Table 2) are not only caused by various analytic methods, but also lie in the fact that earlier single site observations, with different filters, were largely separated and covered relatively short time span. Hence the insufficient lengths of observing run led to poor resolution and terrible windowing. For a complex multi-period δ Scuti star, this can especially result in serious ambiguous determinations like, for example the reported 11.83 and 11.77 c/d (see Table 2) which are probably spurious components. We noticed that the first six current frequencies in Table 4 can be regarded as three couple-frequencies and dispersed in three domains. f_1 and f_2 distribute closely, f_3 and f_5 are close to each other, moreover, f_4, f_6 are only $1\mu Hz$ different. f_7 might be regarded as coupling with f_8 of Hernández's eighth frequency solution. This kind of phenomenon has appeared in several δ Scuti type stars such as δ Scuti itself and 1 Mon. Their power spectra display the same behavior (Brown & Gilliland

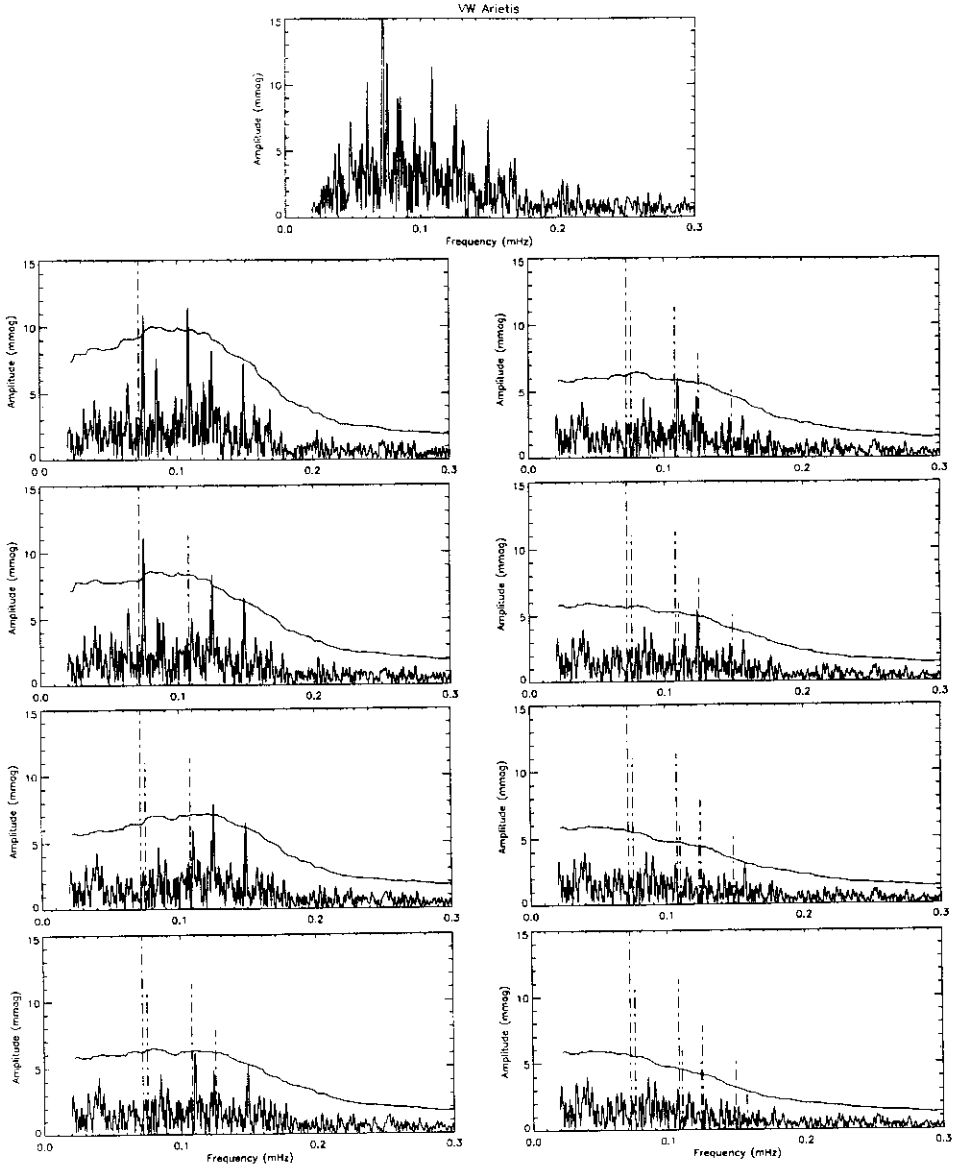

Fig. 3. b) Successive amplitude spectra resulted from ISWF plus pre-whitening process. Dash-dot lines represent the successive frequencies while the continuous line stands for the respective 99% confidence level. Four frequencies are obviously detected, another four are highly probable (see right panel of Table 4)

1994) as BDS 1269A, however the reason is not known clearly yet.

4. Discussion

The basic physical parameters of the BDS 1269 system are here determined from its photometric character through calibration described by Figueras et al. (1991). The resultant values are: $M_v = 1.24 \pm 0.20$, $T_{\rm eff} = 7070$ K $\pm$ 200 K, $\log g = 3.49 \pm 0.06$, $R = 3.12\ R_\odot$ for the primary, for the secondary, $M_v = 2.95 \pm 0.20$, $T_{\rm eff} = 7340$ K $\pm$ 200 K, $\log g = 4.24 \pm 0.06$, $R = 1.44\ R_\odot$. By interpolating Schmidt-Kaler's bolometric correction, we obtained a $B.C$ value -0.10 for BDS 1269A, hence its bolometric magnitude is $M_{\rm bol} = 1.14$. With these quantities, an estimate of mass on BDS 1269A and BDS 1269B from Breger (1974):

$$g/g_\odot = \frac{M}{M_\odot} \times (\frac{T_{\rm eff}}{T_{\rm eff\odot}})^4 / \frac{L}{L_\odot} \quad (1)$$

$$M_{\rm bol} = M_{\rm bol\odot} - 2.5\log\frac{L}{L_\odot} \quad (2)$$

can be obtained $M = 1.28\ M_\odot$ and $M = 1.26\ M_\odot$, respectively. Then, a very tentative model for the pulsating behavior on BDS 1269A can be made. We first calculated

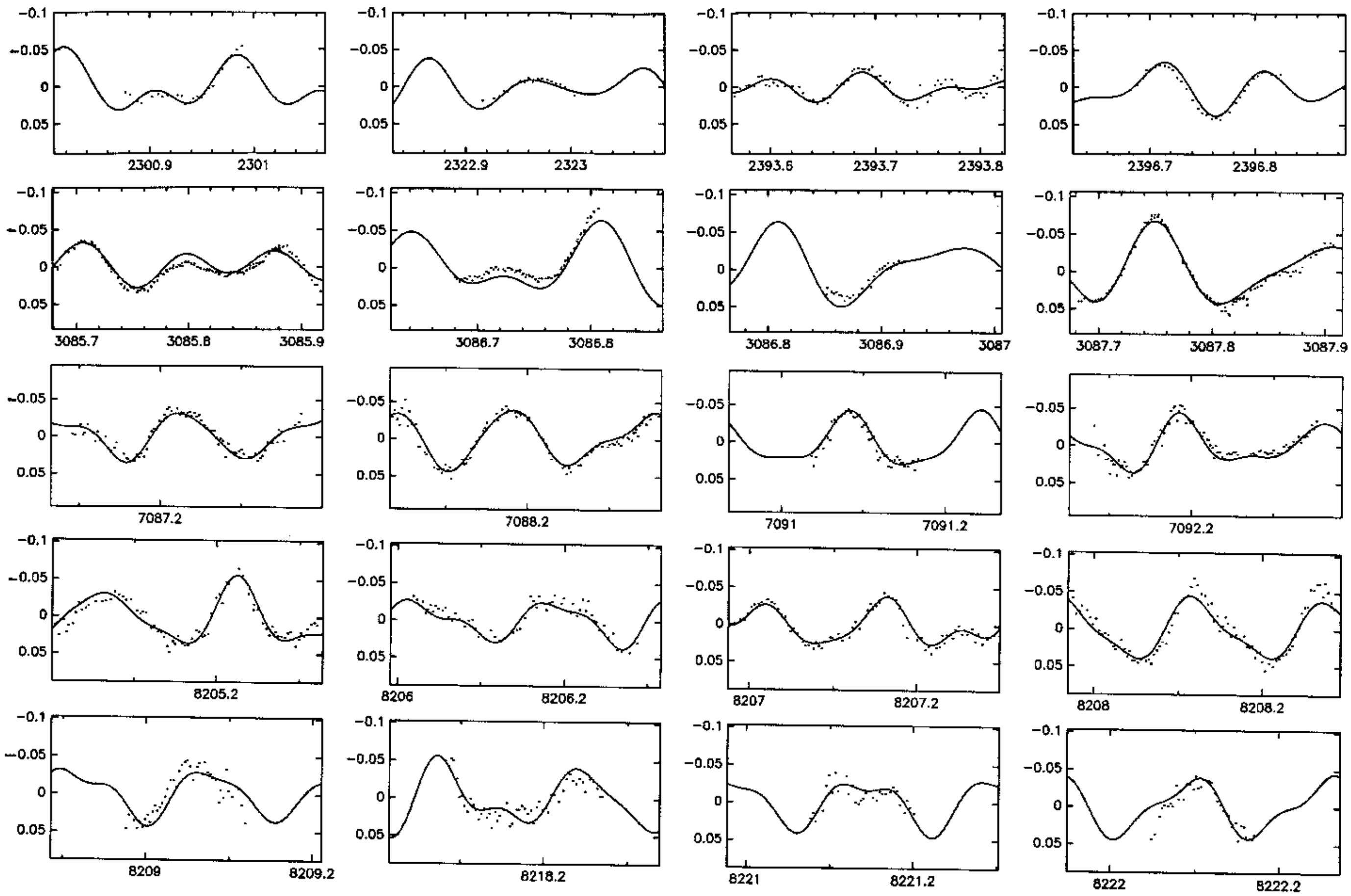

Fig. 4. Fitting light curves of the resultant seven frequencies from MFA to previous four data sets. Fitting residuals are listed in Table 5. The abscissa is HJD.2440000.+, Y axis is in mag

Table 5. Identified results of BDS 1269A when applied to earlier data

	Frequency c/d	data 1 Amplitude mmag	data 1 Phase 2πrad	data 2 Amplitude mmag	data 2 Phase 2πrad	data 3 Amplitude mmag	data 3 Phase 2πrad	data 4 Amplitude mmag	data 4 Phase 2πrad
f_1	6.2273	1.17	0.0228	26.5	0.5106	25.6	0.9410	28.4	0.3565
f_2	6.5186	4.6	0.3113	16.6	0.1370	9.0	0.6641	9.7	0.3885
f_3	9.3496	13.0	0.0042	5.6	0.2348	2.2	0.8457	4.8	0.5960
f_4	10.8162	22.9	0.1592	9.5	0.3187	5.2	0.5373	8.2	0.7156
f_5	9.5130	19.7	0.6520	8.9	0.8076	7.4	0.4936	5.0	0.5124
f_6	10.7327	9.9	0.6261	12.9	0.2714	6.4	0.0967	7.7	0.4821
f_7	12.8456	11.6	0.4353	6.8	0.1544	5.4	0.4109	10.2	0.8972
		σ= 0.0089		σ= 0.0121		σ= 0.0071		σ= 0.0105	

σ is the rms residual

the pulsation Q values according to Breger (1990),

$$\log Q_i = -6.456 + \log P_i + 0.5 \log g + 0.1\ M_{\rm bol} + \log T_{\rm eff} \quad (3)$$

these values are listed in the last column of MFA solution of Table 4. If adopting Fitch's (1981) model, we could be led to the following assignment, either f_1 or f_2 could be associated with the p_1 mode for $l = 1$; f_4 or f_6 may correspond to p_3 mode for $l = 3$; as for f_3, or f_5, it might be mode p_3 of $l = 1$; f_7 perhaps relates to mode p_5 of $l = 1$. However, as we have demonstrated in several recent works (see e.g. Pérez Hernández et al. 1995), several extra factors (like rotation, overshooting et al.) must be taken into account to get a reasonable interpretation. A detailed theoretical analysis of the data is in progress and will be presented in a future work.

5. Conclusion

A complete frequency analysis from the fifth STEPHI observational net in 1993 has yielded an unambiguous seven-frequency solution on the δ Scuti star BDS 1269A (VW Ari). Another possible frequency (yielded only by one analysis with 99% confidence level) is also reported. This solution gives a satisfactory fitting to both the current and earlier measurements. BDS 1269A is again proved to be a multiperiodic pulsator with slow rotation. Its detected frequencies are grouped in three or four (in eight frequency solution) couples, which cannot be explained clearly. At present stage, we can only say that non-radial rotationally split modes would be very likely necessary to give a reliable theoretical interpretation of the frequency spectrum. It should be stressed that multi-site campaigns exhibit their promising advantage over differential photometry by providing good quality data that could not be easily reached by single site observation.

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