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γ Doradus variable stars in the Pleiades cluster: results from a photometric multiste campaign

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Abstract. The variability of the two γ Doradus star belong to Pleiades cluster, HD 22702 and HD 23585, have been confirmed by using new photometric measurements collected during a multisite campaign in 1998. Respect to previous observing runs, the frequency analysis shows new peaks close the 3 cd^{-1} for both stars. With the aim of performing a modal identification, the method based on amplitudes ratios and phase shifts with non-adiabatic time dependent convection (TDC) has been applied. The physical parameters obtained from the photometry put the star HD 23585 out the blue observational edge of the γ Dor region in the HR diagram. This behaviour together with the high value of $v \sin i$ have not allowed us to perform an identification of the excited modes. Respect to the the star HD 22702, a preliminary study of stability provides results consistent with a $l = 2$ identification for the found oscillation frequencies except for f_3 , where a $l = 1$ mode is also probable. Also for this star, the TDC treatment has not been able to discriminate the found modes. Therefore, in addition to new $v \sin i$ measurements, it is fundamental to carry out an exhaustive modelling by considering the pertinent corrections in the rotation.

1. Introduction

The γ Doradus variables are long-period pulsating stars situated on the intersection of the main-sequence with the red edge of the δ Scuti region. In spite of the number of bona-fide members is still reduced comparing with other types of pulsating stars, these stars present common characteristics: luminosity class IV or V, early F spectral type, period ranging from 0.3 to 3 days and small amplitudes around few hundredths of magnitude. Their pulsational behaviour is

produced by excited non-radial gravity (g) modes of high-radial (n) and low angular (l) orders (see [9]; [6]; [13]; [8]).

Systematic observations in open clusters have been carried out with the aim of increasing the number of this type of pulsating stars. Distinguished works are those performed by [10], [24] or [11] who found some long period variable stars in Hyades, NGC 2516 and M 34 clusters respectively. An exhaustive study on the search for γ Dor stars in ten bright open cluster between 35 and 800 Myr was carried out by [14] (see [16]) using two statical tests. One of the selected cluster was Pleiades. In ([15], hereafter Paper I), we presented the outcomes obtained from photometric measurements of 28 AF type stars performed during four years. Two of the eight detected variables, HD 22702 and HD 23585, presented a behaviour of γ Doradus-type with the shortest known periods. With the purpose of confirming the nature of these eight stars, specially the variability of the γ Dor candidate stars, this multisite campaign was carried out. In this report, we present the main results obtained for both stars as well as a first attempt to characterize them using seismic models.

2. Observations and reductions

Our photometric campaign was carried out at seven observatories situated on different geographical longitudes during the autumn-winter of 1998-1999 (see Table 1). Single-channel photoelectric photometer and CCD camera were used in the most of cases except the four-channel fast photometer at Xinglong Station of the Beijing Astronomical Observatory and two identical simultaneous Strömrgren spectrograph attached to both telescopes at the Sierra Nevada and San Pedro Mártir observatories.

Eight stars were observed in this campaign but here we will focus the study on HD 22702 (V1) and HD 23585 (V2). We chose the star cluster HD 23733 ($V = 8.^m3$, A9V) as main comparison (C1) for both stars. HD 23733 did not show any sign of variability in previous observing run reported in Paper I. Those measurements collected by using CCD, the check stars were chosen depending on the field of view of each camera. In addition to the observatories and telescopes implied in this project, filters, observed stars, number of nights and observers are shown in Table 1.

Table 1. Log of the photometric campaign.

Observatory	Telescope	Filter(s)	Stars	Nights	Observer(s)
Sierra Nevada Observatory	0.9m	<i>uvbyβ</i>	C1, V1, V2	52	SM, ER, AR, VC
Orson Pratt Observatory	0.4m	<i>V</i>	V1, V2	15	EGH
Beijing Astronomical Observatory	0.85m	<i>vy</i>	V1	11	AYZ
San Pedro Mártir Observatory	1.5m	<i>uvby</i>	C1, V1, V2	6	AAF, JPS
	0.84m	<i>V</i>	C1, V1, V2	8	JP, RP
Tien-Shan Astronomical Observatory	1m	<i>V</i>	C1, V1, V2	6	AVK
Seoul National University Observatory	0.6m	<i>V</i>	V1	6	SO
Bohyunsan Optical Astron. Observatory	1.8m	<i>V</i>	V1, V2	5	SLK

During the data reduction process, in order to obtain precise values of the oscillation frequencies, those points with high standard deviations were subtracted from each data set. The timings for the differential magnitudes were corrected and the single-colour measurements were converted into intervals similar to that corresponding to the multi-colour data to avoid weighting effects. In total, around 3500 and 2500 useful data corresponding to V1 and V2 respectively were taken over a time-span of 135 d from 1998 September to 1999 February. The

data in each filter for the different sites were normalised to zero-point. Considering that the SNO data set contains the major number of points and that the Strömngren v -filter present larger S/N , we add other contributions to the v -SNO measurements using the corresponding alignments. By this, the Johnson V data sets were transformed to v amplitudes. For each contribution, the transformation factor was determined with weighting according to the amplitude of the main frequency obtained previously with the SNO measurements. A range of factors between 1 and 1.3 was found for the different data set and new values of the differential magnitudes were calculated. The different steps in the reduction process, were carried out for both stars V1 and V2.

3. Frequency analysis

The resulting combined ' $v + V$ ' filters were subjected to exhaustive frequency analysis. Fourier analysis was performed using three different algorithms: the code described in [18], the package PERIOD04 ([12]) and *Multifre* code (see [16]), providing similar results for both stars. Frequencies, amplitudes and S/N ratios are reported in Table 2 for V1 and V2. In both cases, the programs were stopped when the new peaks obtained in the periodogram are not significant. An independent peak is considered as significant if the amplitude signal-to-noise exceeds 4.0 assuming the criterion given by [1] and [2].

Table 2. Frequencies, amplitudes and S/N ratios obtained for V1 and V2 by using the combined $v + V$ filter.

V1=HD 22702			V2=HD 23585		
Frequency (c/d)	Amplitude (mmag)	S/N	Frequency (c/d)	Amplitude (mmag)	S/N
$f_1 = 2.57468$	17.39	18.9	$f_1 = 2.95073$	6.43	14.4
$f_2 = 2.39477$	16.42	17.2	$f_2 = 3.07008$	4.45	10.2
$f_3 = 1.53512$	5.64	5.3	$f_3 = 3.22079$	2.66	6.3
$f_4 = 2.88603$	5.42	6.1	$f_4 = 3.13630$	2.43	5.6
$f_5 = 2.75424$	5.36	6.0			
$f_6 = 2.35958$	4.16	4.3			
$f_7 = 3.07014$	3.87	4.5			

The two frequency solutions were considered as definitive and the fitting of amplitudes and phases were obtained for the Strömngren filters. Table 3 and 4 report the results from the Fourier analysis applied to the *uvby* data set for V1 and V2 variables respectively.

In Paper I, only two frequencies 2.5668 and 1.3950 cd^{-1} were detected for HD 22702 and a value of 2.9507 cd^{-1} for the star HD 23585. The quality of the data as well as the number of measurements collected from different observatories are the main causes in the increase of number of significant frequencies. In the case of V1, the peaks corresponding to the frequencies with largest amplitude, f_1 and f_2 , were detected in previous observing runs. If we compare both values of f_2 , the frequency 1.3950 cd^{-1} is clearly an $f_2 - 1 \text{ cd}^{-1}$ alias. In Paper I, for the second star only the peaks of f_1 was found by the periodogram and, therefore, it was suspected of being an ellipsoidal variable. Due to the fact that the amplitude in the four filters have different values and the amplitude ratios were similar to γ Dor stars, we suggested HD 23585 belong to this type of variables. Now, with the additional frequencies detected from the new data it is possible to confirm its variability.

Table 3. Solution for the *uvby* photometry of V1

Frequency (c/d)	<i>u</i>		<i>v</i>		<i>b</i>		<i>y</i>	
	A (mmag)	ϕ (rad)	A (mmag)	ϕ (rad)	A (mmag)	ϕ (rad)	A (mmag)	ϕ (rad)
$f_1 = 2.57468$	12.38	0.7042 370	18.02	0.8095 143	15.65	0.8002 152	12.39	0.7917 225
$f_2 = 2.39477$	10.89	0.6374 431	17.32	0.6615 151	14.95	0.6475 162	11.13	0.5708 255
$f_3 = 1.53512$	3.29	3.6320 1395	5.12	4.1088 508	4.55	4.0584 528	4.75	3.9575 590
$f_4 = 2.88603$	3.51	2.7673 1289	5.65	3.0645 446	5.26	3.0752 442	4.37	3.0161 624
$f_5 = 2.75424$	4.13	3.6329 1095	6.08	3.8484 420	5.72	3.8726 413	4.30	3.9195 644
$f_6 = 2.35958$	2.92	2.9842 1592	4.29	3.3190 605	3.63	3.3802 661	3.49	3.3679 807
$f_7 = 3.07014$	2.20	1.6198 2089	3.69	1.6820 695	3.29	1.6069 721	3.44	1.6274 808
mean value (mmag)	0.11		0.17		0.15		0.12	
residuals (mmag)	1.46		0.82		0.75		0.88	

Table 4. Solution for the *uvby* photometry of V2

Frequency (c/d)	<i>u</i>		<i>v</i>		<i>b</i>		<i>y</i>	
	A (mmag)	ϕ (rad)	A (mmag)	ϕ (rad)	A (mmag)	ϕ (rad)	A (mmag)	ϕ (rad)
$f_1 = 2.95073$	5.00	2.4933 721	6.81	2.6046 226	6.63	2.6142 213	5.09	2.6721 311
$f_2 = 3.07008$	2.78	1.4080 1321	4.84	1.7314 323	4.28	1.7241 320	3.58	1.7224 450
$f_3 = 3.22079$	2.43	4.9821 1497	3.01	5.1831 517	2.73	5.1862 499	2.04	5.1808 784
$f_4 = 3.13630$	1.29	4.3666 2873	2.63	4.2900 599	2.41	4.3460 575	2.18	4.3140 742
mean value (mmag)	0.00		-0.03		-0.03		-0.02	
residuals (mmag)	1.04		0.44		0.39		0.45	

4. Photometry and modal identification

One of the advantages of having available multi-colour photometry is the possibility of identifying the spherical degree l of the pulsation modes by means of the passband amplitudes obtained from our light curves. These observed amplitudes are compared with those predicted by the theory, that in the case of γ Doradus stars, by the non-adiabatic time dependent convection

(TDC) models ([5]; [3]). Using the TDC treatment it is possible to determinate which modes are predicted to be unstable and their corresponding theoretical values of the frequencies and photometric amplitudes.

The physical parameters used for the modelling were determined from the Strömgren photometry reported in Paper I. The values for both stars are listed in Table 5. The photometric indices have been dereddened by using the method described in Paper I. The calibrations given by [22] provide T_{eff} and $\log g$ values while the metal contents have been calculated using [21] relation for metal abundances. The results obtained for both stars are in very agreement with the metallicity value of the Pleiades cluster, -0.03 , found in bibliography ([4]). Figure 1 shows the location of the V1 and V2 stars in the HR diagram. V1 is well situated in the γ Dor region while V2 is located under the ZAMS on the left of the blue observational edge.

Table 5. Stömgren indices and derived physical parameters for V1 and V2 variables

V1=HD 22702		V2=HD 23585	
$V=8.^m81$	$M_v=2.^m88$	$V=8.^m37$	$M_v=3.^m01$
$b-y=0.^m238$	$T_{\text{eff}}=7160$ K	$b-y=0.^m190$	$T_{\text{eff}}=7420$ K
$m_1=0.^m159$	$\log g=4.24$	$m_1=0.^m178$	$\log g=4.35$
$c_1=0.^m681$	$\log(L/L_{\odot})=0.78$	$c_1=0.^m717$	$\log(L/L_{\odot})=0.73$
$\beta=2.^m747$	$[\text{Me}/\text{H}]=-0.035$	$\beta=2.^m780$	$[\text{Me}/\text{H}]=-0.025$
	$v\sin i=?$		$v\sin i=100$ kms^{-1}

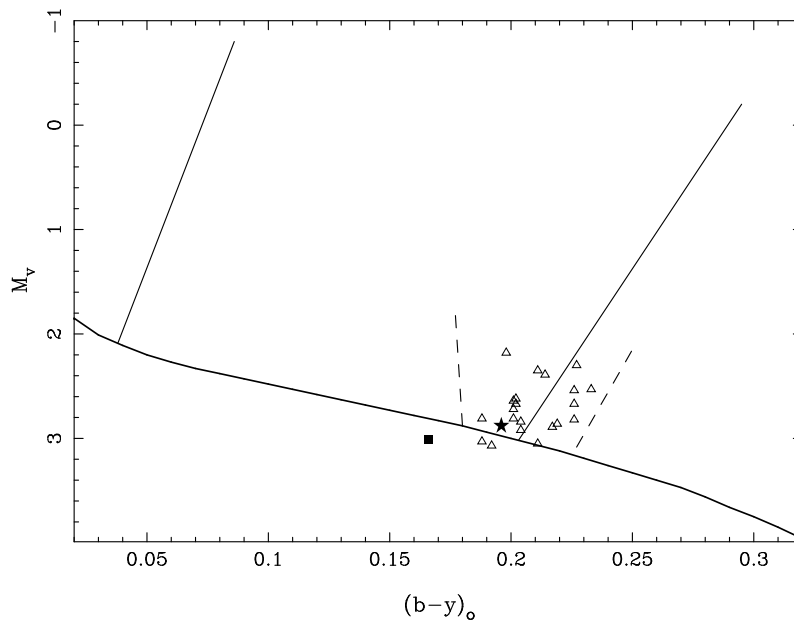


Figure 1.

Location of V1=HD 22702 (star) and V2=HD 23585 (square) in the HR diagram, beside the sample of bona-fide γ Doradus and the observational edges by [7]. The borders of the δ Scuti region are taken from [19]

In both stars, for all the TDC models considered, the theoretical predictions for the phase differences fall outside the observed error bars for all modes, independently of the mode degree l . It is notable, the low amplitude observed in the u passband for the several modes in both stars. This behaviour which was also found by [20] analyzing the γ Doradus star HD 218427, is not common in the type of variability and it is not possible to explain by using our models. In order to estimate a probable range of unstable modes, a stability analysis was performed using a mixing-length parameter of $\alpha = 1.80$, mass $M = 1.55M_{\odot}$ and ratio $R = 1.5619R_{\odot}$ in the models. Due to the ambiguous location of the HD 23585 on the HR diagram, this preliminary study was only carried out to the V1 object. In this case, the physical parameters considered were $\log(L/L_{\odot}) = 0.76$, $T_{\text{eff}} = 7161.8$, $\log g = 4.2414$ and $Z = 0.016$. As result, all the modes can be identified as $l = 2$ except for f_3 , which a $l = 1$ cannot be discard. A possible explication could be the rotation. [3] demonstrated that TDC models reproduced the observed amplitudes and phases for slowly rotating γ stars.

In addition, we tried to apply the frequency ratio method (FRM) ([17]) to our stars in order to obtain information on the radial order n and degree l of the modes. For the V1 star, the FRM yielded no results. This may be explained by the presence of rotation (see [23]) however its $v \sin i$ is unknown. The second star, V2, has a value of $v \sin i$ too large and, as discussed by [23], the FRM cannot be applied.

In conclusion, an exhaustive and refined modelling is required (in progress) with a particular attention to the effect of rotation.

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