

A search for new γ Doradus stars in the Geneva photometric database

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Abstract. We present a study of selected potential γ Doradus stars observed in the Geneva photometric system. Eleven stars were monitored at least during the last year of functioning of the 70 cm Swiss telescope at La Silla, leading to about one thousand photometric measurements and permitting a detailed analysis of these stars. After the analysis, five stars are thought to be constant stars. We report three new γ Dor stars. A spectroscopic campaign has been started at La Silla with the new 1m20 Swiss telescope, equipped with the spectrograph CORALIE, of which we show the results for the selected stars.

Key words: stars: fundamental parameters – stars: oscillations – stars: variables: general – techniques: photometric

1. Introduction

The γ Dor stars constitute a new class of pulsating variables that was discovered only recently. Krisciunas (1998) and Zerbi (2000) review the history of the discovery and the current observational status of this group of variables. We refer to these papers for a general introduction on γ Dor stars, but we mention here that these objects are thought to exhibit multiperiodic high-order g-mode pulsations with periods in the range of 0.5–3 days.

Much effort is currently made to find new members of this group, in order to constrain their pulsational characteristics and their position in the HR diagram. This is especially relevant since the subject of the precise excitation mechanism is not yet settled. Promising theoretical models are currently being worked out. No direct confrontation between the new theoretical ideas about the driving and the observational status has been performed yet, one of the reason being that the number of *bona fide* members is still low and that these stars have quite a large variety in their observational behaviour.

We already performed a systematic detection and classification of γ Dor stars from the Hipparcos Periodic Annex using the Geneva photometric system. The method used was a multivariate discriminant analysis and it led to the discovery of 14 new

γ Dor candidates (Aerts et al. 1998). Moreover, Handler (1999), searching for new γ Dor stars in the Hipparcos catalogues of the periodic and unsolved variables, found respectively 13 and 18 new “prime” γ Dor candidates which are non-redundant with other studies.

The paper is organised as follows. In Sect. 2, we present the obtained data from the Geneva photometry, and compare it to the Hipparcos photometry. In Sect. 3, we search for periodic behaviour in the data. In Sect. 4, we present the spectra of the stars. Finally, we end with some conclusions in Sect. 5.

2. Geneva photometric data

The content of the Geneva catalogue is the union of more than 200 scientific programmes, including all stars in the Bright Star Catalogue south of $\delta = +20^\circ$. The Geneva photometric database now contains 344 500 measurements of 47 600 stars. There are seven filters, namely U, B, V, B1, B2, V1, G. During the reduction scheme, a weight is assigned to each measurement and the noise level of single measurements with the weights 3 or 4 for the V band is about 4 to 5 milli-magnitudes. For the article, we take the intermediate value of 4.5 milli-magnitudes.

We started a search in the Geneva photometric database for γ Dor candidates. We selected in the Geneva catalogue F0-F9 stars which fitted the observational window and with a high dispersion, σ_{m_V} . The eleven chosen candidates were monitored with the P7 photometer attached to the 70 cm Swiss telescope at La Silla observatory. We here report our analyses of the new photometric data.

Generally, we disregarded the very few measurements that already existed of the programmed stars in the Geneva database and used only the data taken during the dedicated campaigns. These consist from 2 to 7 runs of each 3 weeks, during which each star was observed typically twice per night. The total time span of the data varies between 1 to 5 years with a mean of 2 years.

The Geneva photometry permits an accurate determination of temperature T_{eff} , gravity $\log(g)$, and metallicity [M/H]. In Table 1 we list the physical properties of our 11 stars derived from the Künzli et al. (1997) calibrations. The errors given are the ones resulting from the interpolation in the tables of standard stars. They are only valid assuming that the average colours are free from errors. The standard errors should therefore not be

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Table 1. Basic statistical photometric information and basic physical properties derived from the Geneva photometry

HD	Sp. Type	n_G	$\overline{m_V}$	$\sigma_{\overline{m_V}}$	p_{val}	T_{eff}	$\log(g)$	[M/H]
5590	F2V	102	9.1918	0.0004	0.958	6640 ± 40	4.32 ± 0.14	-0.11 ± 0.09
7455	F5V	43	8.4212	0.0006	0.779	6380 ± 40	3.93 ± 0.13	-0.15 ± 0.09
8393	F7w...	104	9.4761	0.0004	0.548	5980 ± 30	3.89 ± 0.13	-0.40 ± 0.10
10167	F0V	119	6.6575	0.0008	0.000	6950 ± 60	4.44 ± 0.12	-0.29 ± 0.10
12901	F0	122	6.7238	0.0015	0.000	7010 ± 60	4.47 ± 0.09	-0.40 ± 0.11
22001	F5IV-V	34	4.7008	0.0007	0.789	6640 ± 40	4.34 ± 0.14	-0.19 ± 0.09
26298	F0/F2V	107	8.1451	0.0005	0.000	6720 ± 50	4.36 ± 0.16	-0.33 ± 0.10
27604	A8V+...	111	6.0663	0.0004	0.629	6310 ± 30	3.60 ± 0.13	0.02 ± 0.08
33262	F7V	94	4.6974	0.0007	0.000	6160 ± 30	4.58 ± 0.13	-0.22 ± 0.09
35416	F3V	96	7.5216	0.0006	0.001	6600 ± 40	4.39 ± 0.14	-0.46 ± 0.11
48501	F2V	140	6.2381	0.0014	0.000	7020 ± 60	4.49 ± 0.10	-0.10 ± 0.10

considered as physical error estimates. Our targets are in general slightly metal weak and some are just slightly hotter than the sun.

2.1. Variability detection

A χ^2 test was used to evaluate the variability status of the photometric time series. Table 1 lists also the main characteristics of these photometric time series. Because there is usually a huge time gap between the first data ever taken in the Geneva system and the newer dedicated photometric sequences, the measurements taken before the Julian date 2 448 000 were removed. All more recent data points were kept, such that we have a higher resolution in the frequency domain as will become evident from the subsequent period searches. In Table 1, n_G is the number of measurements with weight strictly greater than 2, $\overline{m_V}$ is the mean V magnitude, $\sigma_{\overline{m_V}}$ is the dispersion of the mean V magnitude, p_{val} is the p-value associated with the χ^2 .

In the sample of the 11 stars studied, fixing the size of the test at 1%, we found that five stars are constant stars (HD 5590, HD 7455, HD 8393, HD 22001, HD 27604). In these stars the high initial σ_{m_V} was due to off measurements at the beginning of the time series. We note that the time series of the star HD 8393 seems to show a slight drift and that the time series of the star HD 27604 has a few data points with a high magnitude.

2.2. Cross verification with Hipparcos data

The 11 stars were also measured by the Hipparcos satellite. In Table 2 we have the correspondence between HD and HIP (Hipparcos identifier), the V magnitude, the absolute magnitude M_V , its error σ_{M_V} , the colour $B - V$ and its associated error σ_{B-V} , the number of observations n_H , the median magnitude H_p , the standard error of the H_p median magnitude σ_{H_p} , the p-value associated with the χ^2 test p_{val} and the result of the analysis by the Hipparcos teams RH, which indicates that the star was classified as: constant C, microvariable M, double star D, member of the atlas of the unsolved variable U (cf. ESA 1997 and Eyer 1998). The HR diagram is represented in Fig. 1 with the location of the eleven stars. Note that there is a probable identification problem in the Hipparcos catalogue. The star

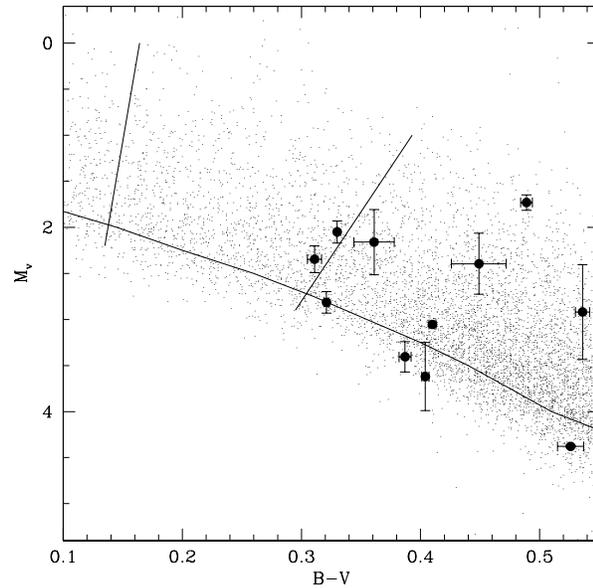


Fig. 1. HR diagram for the eleven stars based on the Hipparcos parallax and the $B - V$ index from the Hipparcos catalogue. The solid lines indicate the main sequence and the borders of the instability strip. The small points are the Hipparcos stars with very accurate parallaxes and $B - V$ colours.

HD 7455 is referred to HIP 5745. According to its absolute magnitude and to its TYCHO colours, we conclude that the correct identification of this star is HIP 5735 and not HIP 5745.

We remark that out of the eleven stars, one has only flagged measurements (double star), five stars can be declared to be constant, five can be declared variable. The classification from Hipparcos is nearly consistent with the classification obtained from the Geneva photometry. However, there are two discrepant cases: HD 8393 (HIP 6387) and HD 26298 (HIP 19383). The latter case is explained by the fact that the precision of Hipparcos is not as good as the Geneva photometry at these magnitudes; the former case is more puzzling.

3. Period search

For the 6 remaining stars left from the analysis of the Geneva photometry, we searched for periodic behaviour with differ-

Table 2. Magnitude V, absolute M_V magnitude deduced from Hipparcos parallax and result of the Hipparcos main mission photometric analysis

HIP	HD	V	M_V	σ_{M_V}	$B - V$	σ_{B-V}	n_H	H_p	σ_{H_p}	p_{val}	RH
4481	5590	9.21	3.62	0.37	0.404	0.003	116	9.2992	0.0013	0.420	
5735	7455	8.44	2.39	0.33	0.449	0.023	131	8.5365	0.0017	0.096	C
6387	8393	9.49	2.92	0.51	0.536	0.006	122	9.6049	0.0020	0.001	
7649	10167	6.67	2.05	0.12	0.330	0.000	174	6.7527	0.0008	0.000	
9807	12901	6.74	2.35	0.15	0.311	0.006	134	6.8180	0.0014	0.000	U
16245	22001	4.71	3.05	0.02	0.410	0.003	130	4.8043	0.0004	0.946	C
19383	26298	8.16	2.16	0.35	0.361	0.017	86	8.2464	0.0015	0.678	C
20109	27604	6.08	1.73	0.08	0.489	0.005	117	6.1838	0.0005	0.834	D
23693	33262	4.71	4.38	0.01	0.526	0.011	100	4.8191	0.0008	0.000	
25183	35416	7.53	3.40	0.17	0.387	0.005	133	7.6039	0.0015	0.000	M
32144	48501	6.26	2.81	0.12	0.321	0.002	283	6.3324	0.0066	–	D

Table 3. Results using different period search algorithms for the V band. The frequencies are given in cycle/day

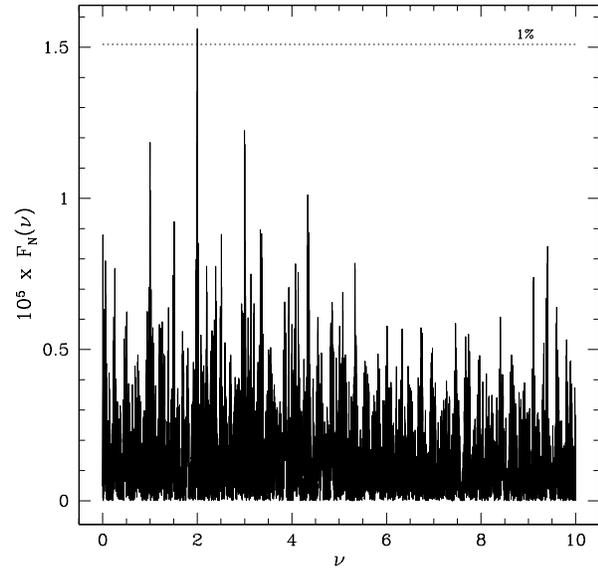
HD	Deeming	Ferraz-Mello	Scargle	PDM
10167	0.48760	1.00256	0.51258	0.51258
12901	1.21552	1.21552	1.21551	1.21551
26298	2.00061	1.00014	1.00199	2.00179
33262	0.00952	0.00281	0.00952	0.00967
35416	0.00467	0.00016	1.00464	1.97870
48501	0.09122	0.09122	0.09126	0.09110

ent methods, namely Fourier (Deeming 1975 and Ferraz-Mello 1981, Scargle 1982) and PDM (Jurkevich 1971, Stellingwerf 1978). The results are listed in Table 3. The frequency resolution is taken as $1/(8(t_{n_G} - t_1))$, where t_1 and t_{n_G} are the times for the first and last data points. The interval in frequency is chosen between 0 and 30 [1/days]. The reason for searching short periods is a possible contamination of the sample by δ Scuti stars.

For two stars (HD 12901, HD 48501) there is an agreement between all methods. For two other stars (HD 10167, HD 26298), the resulting frequencies are close to a sampling frequency. For the star HD 33262, the period is about 100 days. For the star HD 35416, each method gives a different result. It seems that the time series of this star shows a long term trend explaining the long periods found. With a model with trend and noise the behaviour of the star is explained (within a 1% test size).

For the time series, we performed extensive Monte-Carlo simulations to determine the false alarm probability. The H_0 hypothesis is constructed as follows. We take a gaussian signal sampled at the same times with the same variance, and perform a Fourier transform over a frequency interval from 0 to 10 [1/days] with a time step of $1/(8(t_{n_G} - t_1))$. In the delicate case of the time series of HD 26298, we see that the maximum of the power spectrum is higher than the 1% level derived from simulations (cf. Fig. 2), which clarifies that this star is variable.

We present in Fig. 3 the folded curves with the period obtained from the PDM method.

**Fig. 2.** Power spectrum of HD 26298, the horizontal line is the 1% false alarm probability obtained from Monte-Carlo simulations.

For the 6 stars for which a period search was performed, three stars are in the compatible range for γ Dor stars behaviour. However, two stars have periods related to the sampling period of one day, leaving gaps in the phase diagram (cf. Fig. 3).

The stars with a sufficiently dense covering over all phases have clearly high residuals after prewhitening with the main period, pointing to possible multiperiodic behaviour or a non-regular behaviour. For the star HD 12901, the fraction of the variance explained by a sinusoidal model with one period (0.8227 day, amplitude: 16.3 milli-mag) is 49%, and with two periods (0.8227 and 0.8430 day, amplitudes: 15.1 and 9.7 milli-mag) is 67%. For the star HD 48501, the fraction of the variance explained by a sinusoidal model with one period (10.959 days, amplitude: 15.7 milli-mag) is 44%, and with two periods (10.959 and 0.7750 day, amplitudes: 14.4 and 12.8 milli-mag) is 70%. Since there is a period close to 1 day, we can include this star in our list of candidates. We conclude that both HD 12901 and HD 48501 are clearly multiperiodic.

3.1. Pulsation, eclipses?

The sample might be contaminated by EW eclipsing binaries, the period of which can be of the same order than that of the intrinsic periods of γ Dor stars.

A test that discriminates between these possibilities (besides spectroscopic observations) is a study of the periodic signal in the colour. The bona-fide γ Dor stars are known to have colour changes. These changes have the same periods than those found in the light variability.

If the system is eclipsing and if the two stars are identical, then no colour variations will be observed. If, however, the two stars have different colours, then the signal will have a double periodic behaviour.

For HD 12901, we find the same period in the colour $B - V$ as in V . For HD 48501, the period found is not near 10 days but is 0.91 day. This points out that the period around 10 days might be an alias period of the one near one day. For the stars HD 10167 and HD 26298, it seems that the period is half of the period found in the V magnitude. HD 35416 has no significant colour variations.

3.2. Amplitudes in different filters

We performed the period search in different filters (U, B, B1) to check if the main period mentioned above appears in all these filters. The frequency spectra in the different filters behave as follows:

- for HD 12901 and HD 48501, the spectra in the different bands are similar. The highest amplitude for both occurs in the B1 filter.
- for HD 10167, there is a different spectrum in the U band but all the other bands have the same structure (B1 having the highest amplitude).
- HD 33262, HD 35416 have similarities in certain different bands.
- HD 26298 has a different behaviour in different bands.

3.3. Conclusion on the photometric variability analysis

Out of the eleven stars five are constant, one has no significant periodic behaviour (HD 35416), one has a long term behaviour (HD 33262), one could be a γ Dor star but there is an aliasing problem (HD 48501), and three stars have periods compatible with γ Dor behaviour. Two of these have an incomplete phase coverage (HD 10167, HD 26298) and one has a good phase coverage (HD 12901). The check for colour variations does not permit to rule out any cases.

4. CORALIE measurements

4.1. Data description

We have started a campaign with the CORALIE spectrograph for detecting possible line-profile variations in the γ Dor candidates. CORALIE is an echelle spectrograph attached to the

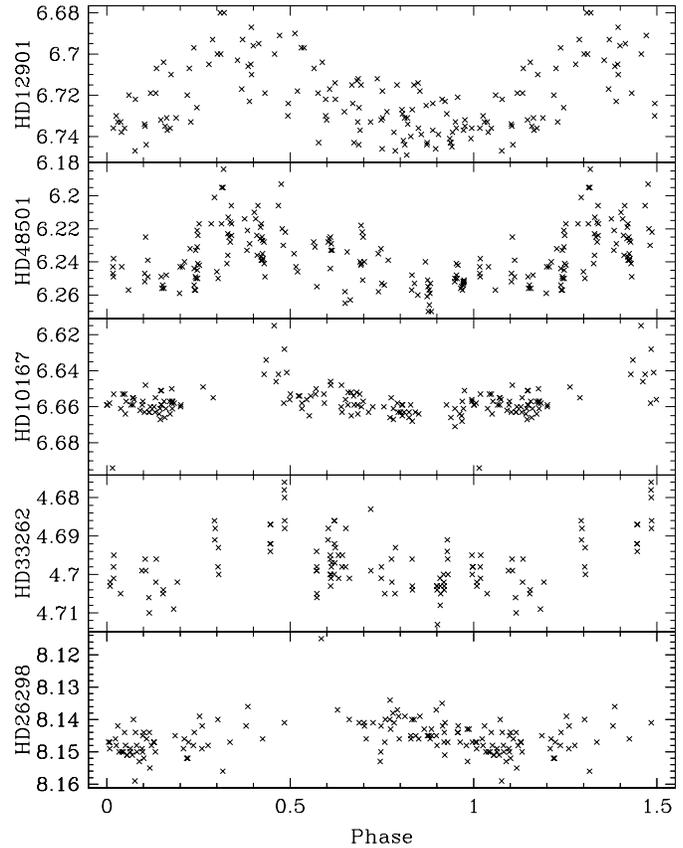


Fig. 3. Phase diagrams of the V magnitude for the stars HD 12901, HD 48501, HD 10167, HD 33262, HD 26298, with periods taken from the results of the PDM method given in Table 3.

new 1m20 Swiss telescope at La Silla, which was primarily built to search for extraterrestrial planets. The software gives online radial velocities of the observed object by doing a cross correlation with a template. The correlation profile is directly accessible, and so can be used to derive immediately possible duplicity and to determine the rotational velocity of the star. The correlation profile reflects also the double star character by presenting a double peak. The star HD 10167 is clearly a double star (cf. Fig. 4). The photometric variability of this object is probably due to the duplicity and not to a γ Dor phenomenon. We find that the star HD 27604 is also a double star.

Besides the correlation profile, the spectrum itself can be obtained from 388 nm to 681 nm with a resolution of about 50 000 at 500 nm. We present here the spectra of nine stars. Two stars were too faint to be measured.

We searched for a spectral line which is not blended and which could show clear profile variations. For each star a set of five spectra was taken and for the promising candidates larger sets of spectra have been taken and will be presented in the near future. The question of chromospheric activity will also be addressed. We will elaborate much more extensively on our line-profile variation study of many candidate γ Dor stars in a forthcoming paper.

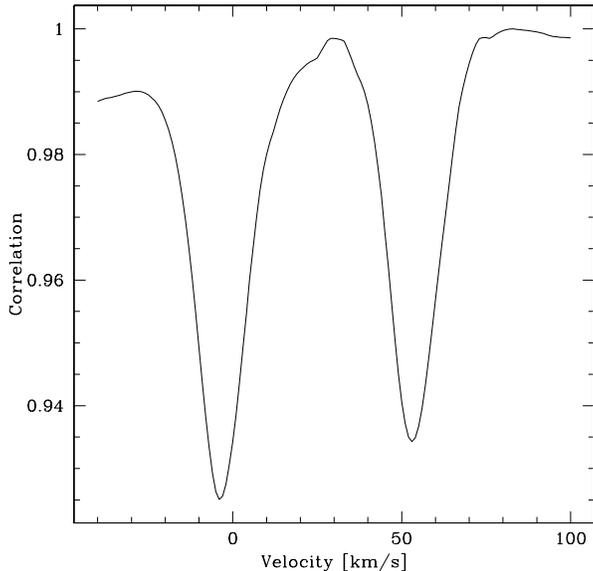


Fig. 4. Correlation for the star HD 10167. It is clearly a double star.

Table 4. Rotation velocities $v \sin(i)$, radii, masses and rotation periods of the sample

HD	$v \sin i$ [km s^{-1}]	R/R_{\odot}	M/M_{\odot}	Period [days]
12901	64	1.2	1.5	0.9
22001	10	1.3	1.4	6.4
26298	50	1.2	1.4	1.2
33262	8	0.9	1.2	5.7
35416	< 4	1.1	1.3	–
48501	40	1.1	1.5	1.4

In order to select a suitable spectral line, we use the spectrum of a standard star, with a high resolution. In this way, we are then able to distinguish which lines are not blended. Our choice was to concentrate on the calcium line at 6122 \AA . Other spectral lines can be taken as the FeII at 4508 \AA and also TiII at 4501 \AA . Many stars show a rapid rotation which broadens the lines and makes an analysis difficult.

We superposed the spectra of the 9 stars around the unblended Ca line in Fig. 5.

4.2. Rotation speed and rotation period

We determined the $v \sin(i)$ by the following method: we used the star HD 7455 which has a small $v \sin(i)$ as a template and applied an artificial rotation broadening to its spectrum with different $v \sin(i)$. We computed then its correlation profile. We compared the correlation profile of the star for which we want to know the $v \sin(i)$ with the different computed correlation templates. The solution which minimised the residuals between the solution and the template is taken as the best $v \sin(i)$. They are listed in Table 4. The underlying hypothesis is that all the broadening is due to rotation. The radii and the masses were determined by doing an interpolation using the tables of Schaller et al. (1992), and Schaerer et al. (1993) and by taking the physical

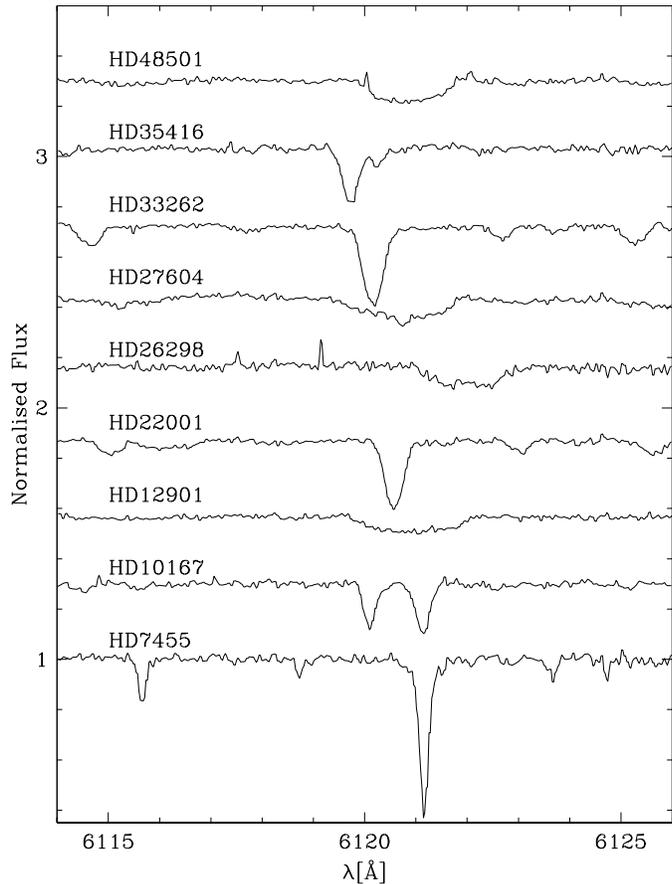


Fig. 5. CORALIE spectra for the 9 stars observed around the unblended CaI line at 6122 \AA . Two stars in our list are too faint to be observed.

parameters from the Geneva photometry. We then determined the maximal rotation periods of the stars by assuming $i = \pi/2$. We note that the estimates of the rotation period are of the same order of magnitude as the periods found in the photometry. It is therefore important to find multiperiodicity and/or additional evidence of the γ Dor nature to be able to exclude rotational modulation as a cause of the observed variability.

5. Conclusion

The more thoroughly the candidates were studied the more they were rejected. We end therefore with a shorter list of γ Dor stars. Establishing such a list needs strong efforts, but it is important for describing precisely the physical properties of this pulsating star group.

We have found three new γ Doradus stars (HD 12901, HD 48501, HD 26298). One of them (HD 12901) was indicated by Handler (1999) to have a possible δ Scuti behaviour on the basis of Hipparcos data. Our Geneva photometry, however, clearly points towards multiple periods longer than those of δ Scuti stars and in the region expected for γ Doradus stars. HD 48501 is also a multiperiodic variable. The line-profile variability of these three new γ Dor stars will be discussed in a separate paper.

It is presently important to find as many confirmed γ Doradus stars as possible, in order to constrain the suggested

theoretical excitation models. In particular, the question remains whether or not the γ Doradus phenomenon only occurs for F0 – F2 type stars or also for much cooler objects as suggested by Aerts et al. (1998). If the latter is true, then it is tempting to assume that the γ Doradus stars may exhibit simultaneously opacity-driven g-modes and stochastically excited solar-like p-modes. The occurrence of both such types of pulsations would broaden the interest for the stars because they would become unique objects for seismology. In this respect, the search for solar-like oscillations in bright selected γ Doradus stars by future seismology space missions, such as MOST, MONS and COROT, would be extremely valuable.

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