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HD 54272, a classical λ Bootis star and γ Doradus pulsator

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ABSTRACT

We detect the second known λ Bootis star (HD 54272) which exhibits γ Doradus-type pulsations. The star was formerly misidentified as a RR Lyrae variable. The λ Bootis stars are a small group (only 2 per cent) of late B to early F-type, Population I stars which show moderate to extreme (up to a factor 100) surface underabundances of most Fe-peak elements and solar abundances of lighter elements (C, N, O, and S). The photometric data from the Wide Angle Search for Planets (WASP) and All Sky Automated Survey (ASAS) projects were analysed. They have an overlapping time base of 1566 d and 2545 d, respectively. Six statistically significant peaks were identified ($f_1 = 1.410\,116\,\mathrm{d}^{-1}$, $f_2 = 1.283\,986\,\mathrm{d}^{-1}$, $f_3 = 1.293\,210\,\mathrm{d}^{-1}$, $f_4 = 1.536\,662\,\mathrm{d}^{-1}$, $f_5 = 1.157\,22\,\mathrm{d}^{-1}$ and $f_6 = 0.226\,57\,\mathrm{d}^{-1}$). The spacing between f_1 and f_2, f_1 and f_4, f_5 and f_2 is almost identical. Since the daily aliasing is very strong, the interpretation of frequency spectra is somewhat ambiguous. From spectroscopic data, we deduce a high rotational velocity ($250 \pm 25\,\mathrm{km\,s^{-1}}$) and a metal deficiency of about −0.8 to −1.1 dex compared to the Sun. A comparison with the similar star, HR 8799, results in analogous pulsational characteristics but widely different astrophysical parameters. Since both are λ Bootis-type stars, the main mechanism of this phenomenon, selective accretion, may severely influence γ Doradus-type pulsations.

Key words: techniques: photometric – stars: chemically peculiar – stars: individual: HD 54272 – stars: variables: δ Scuti – stars: variables: RR Lyrae.

1 INTRODUCTION

The group of classical λ Bootis stars comprises late B to early F-type, Population I stars, with moderate to extreme (up to a factor of 100) surface underabundances of most Fe-peak elements and solar abundances of lighter elements (C, N, O and S). They are rare, with a maximum of about 2 per cent of all objects in the relevant spectral domain, between the zero- and terminal-age main-sequence (ZAMS and TAMS), found to be such objects (Paunzen et al. 2002b).

Michaud & Charland (1986) suggested that the peculiar chemical abundances on the stellar surfaces are due to selective accretion of circumstellar (CS) material. Due to gravitational settling and radiative acceleration, it is then mixed in the shallow convection zone of the star. This explains why the anomalous abundance pattern is similar to that found in the gas phase of the interstellar medium (ISM) in which refractory elements like iron and silicon have condensed into dust grains.

Later on, Kamp & Paunzen (2002) and Martinez-Galarza et al. (2009) developed a model which describes the interaction of the star with its local ISM and/or CS environment. As a result, different levels of underabundance are produced by different amounts of accreted material relative to the photospheric mass. The small fraction of this star group on the main-sequence (MS) is explained by the low probability of a star–cloud interaction and by the effects of meridional circulation, which dissolves any accretion pattern a few million years after the accretion has stopped. The hot end of this model is due to significant stellar winds for stars with $T_{\mathrm{eff}} > 12\,000$ K whereas the cool end, at about 6500 K, is defined by convection which prevents the accreted material manifesting at the stellar surface.

Strong support for the selective accretion scenario has been given by Folsom et al. (2012) who found that half of their sample of Herbig Ae/Be stars exhibit the characteristic λ Bootis-type abundance pattern. We know that the density of CS material around Herbig Ae/Be stars is very high, perfectly suited as the source for accretion.

Almost all λ Bootis stars are located within the classical δ Scuti/γ Doradus instability strip. Paunzen et al. (2002a) presented a detailed analysis of their pulsational behaviour. They concluded that at least 70 per cent of the group members inside the classical instability strip pulsate, and they do so with high overtone p modes ($Q < 0.020$ d).

In this paper, we present the newly detected γ Doradus pulsational characteristics of the classical λ Bootis star, HD 54272. Interesting enough, it was misidentified as a RR Lyrae-type star by Szczygieł & Fabrycky (2007). We performed a detailed time series analysis of the Wide Angle Search for Planets (WASP) and

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All Sky Automated Survey (ASAS) photometric data. Four statistically significant frequencies and their combinations were detected. Our findings are discussed in comparison with the first hybrid λ Bootis/γ Doradus star, HR 8799. The latter is a very interesting young object hosting at least four planets and a massive dusty debris disc (Esposito et al. 2013). HD 54272, on the other hand, is a fast rotating star almost at the TAMS with no detected IR excess. From spectroscopy, we deduce a metallicity of −0.8 to −1.1 dex compared to the Sun. This fact together with the high projected rotational velocities makes this object an interesting and important test case for models dealing not only with γ Doradus pulsation, but also with selective accretion in the presence of meridional circulation.

2 THE CHARACTERISTICS OF HD 54272 AND HR 8799

HD 54272 (BD+19 1620, $V = 8.80$ mag) was first classified as a member of the λ Bootis group by Paunzen (2001). For this star, neither a *Hipparcos* parallax nor a radial velocity is available. Paunzen et al. (2002a) searched for δ Scuti-type pulsations and found a null result with an upper limit of 1.4 mmag within a time series of 2.6 h. It has to be emphasized that long-term trends, such as the here reported γ Doradus pulsation, were not investigated. The only detailed follow-up analysis of the astrophysical parameters (Table 1) for HD 54272 was presented by Paunzen et al. (2002b). The mass, effective temperature and surface gravity are typical for an early F-type MS star. From isochrone fitting, they deduce that it has already spent 83 per cent of its MS lifetime.

In this work we use the refined Yerkes classification (often denoted as 'MK system') scheme introduced by Gray & Garrison (1987). It uses the notation 'k', 'h', and 'm' for the classification of the Ca II K, hydrogen, and metal lines according to standard stars. It allows for a more detailed stellar classification than the classical Yerkes system.

The spectrum of HD 54272 was observed at the Osservatorio Astronomico di Padova-Asiago with the 182 cm telescope using the Boller & Chivens spectrograph (600 lines mm^{-1} grating) which gave a nominal resolution of 2.0 Å $pixel^{-1}$ (dispersion of 85 Å mm^{-1}) and a spectral coverage of about 1200 Å.

In Fig. 1 the observed spectrum is shown together with two standards (HD 23194 and HD 113139). The latter were taken from Gray et al. (2003) and have a resolution of 1.8 Å $pixel^{-1}$. Clearly, the high rotational velocity and the low metallicity of HD 54272 are visible. It is classified as 'kA5hF2mA5V λ Boo'.

Table 1. The astrophysical parameters of HD 54272 (Paunzen et al. 2002b, this work) and HR 8799 (Gray & Kaye 1999; Baines et al. 2012). The errors in the final digits of the corresponding quantity are given in parentheses.

Quantity	HD 54272 values	HR 8799
T_{eff}[K]	7010(217)	7430(75)
[M/H]	−0.8 to −1.1	−0.47(10)
$\log g$	3.83(10)	4.35(5)
M_V [mag]	2.33(30)	2.98(8)
M [$M_\odot$]	1.69(19)	1.47(30)
R [$R_\odot$]	2.2(3)	1.34(5)
L [$L_\odot$]	1.01(12)	0.69(5)
$\log t$	9.12	<8.00
$\upsilon \sin i$ [km s^{-1}]	250(25)	38(2)

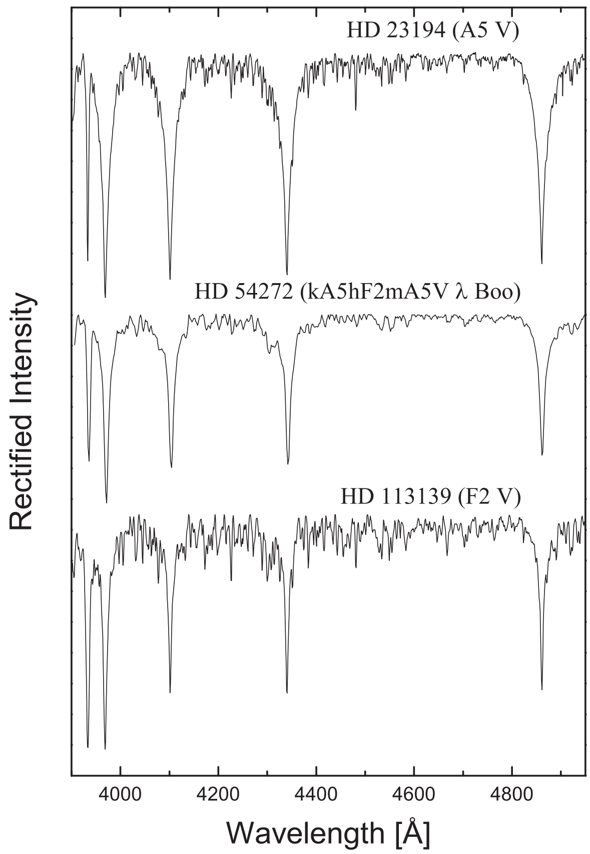

Figure 1. The classification resolution spectrum of HD 54272 together with the two standard stars HD 23194 (A5 V) and HD 113139 (F2 V). The latter were taken from Gray et al. (2003) and have the same resolution as our spectrum.

In order to check the astrophysical parameters of HD 54272 and to search for an IR excess, we made use of the spectral energy distribution (SED) fitting tool by Robitaille et al. (2007). As input data we used the available *UBV*, 2MASS and WISE photometry. The effective temperature and surface gravity are well reproduced with the best-fitting model. Furthermore, no IR excess was detected up to 22.1 μm.

We next investigated the metallicity of HD 54272 in more detail. For this, a synthesized spectrum was computed using the program SPECTRUM[1] (Gray & Corbally 1994) and modified versions of the ATLAS9 code taken from the Vienna New Model Grid of Stellar Atmospheres, NEMO[2] (Heiter et al. 2002). We used a stellar atmosphere with the following parameters (Table 1): $T_{eff} = 7000$ K, $\log g = 3.8$, and $\upsilon_{mic} = 2$ km s^{-1}. The synthetic spectrum was first folded with the instrumental profile and then with different rotational profiles yielding a best fit for 250 km s^{-1} with an uncertainty of about 25 km s^{-1}. To test these parameters, a grid of atmospheres with effective temperatures and surface gravities around the input values were applied. The hydrogen lines are best fitted with the original values with the constraint that they are not sensitive to $\log g$. To estimate the [M/H] value, we used different models from +0 to −2 dex. Fig. 2 shows the result for [M/H] = −0.5 and −1.0 dex, respectively. The median of the difference between the observed and synthetic spectrum with [M/H] = −1.0 dex is only

[1] http://www.appstate.edu/~grayro/spectrum/spectrum.html
[2] http://www.univie.ac.at/nemo

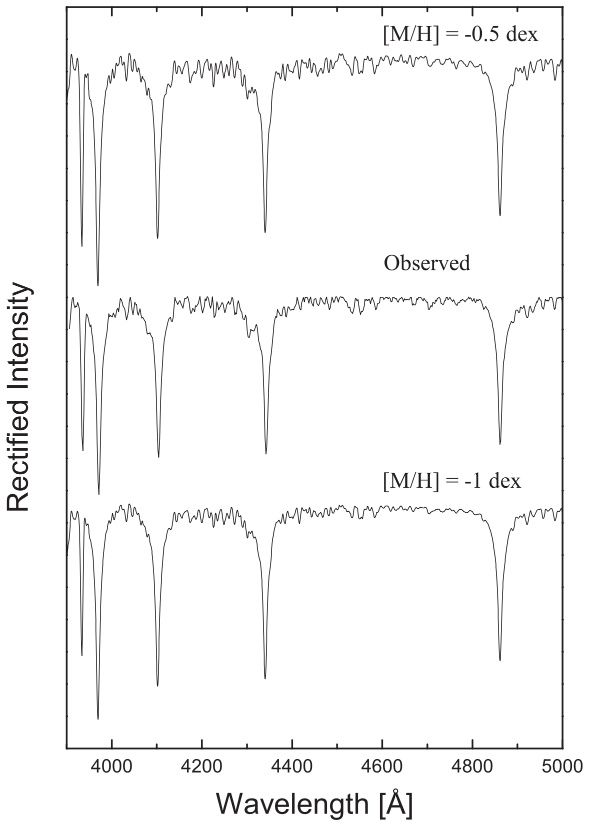

Figure 2. The observed and synthetic ($T_{\rm eff}$ = 7000 K and log g = 3.8) spectra for HD 54272.

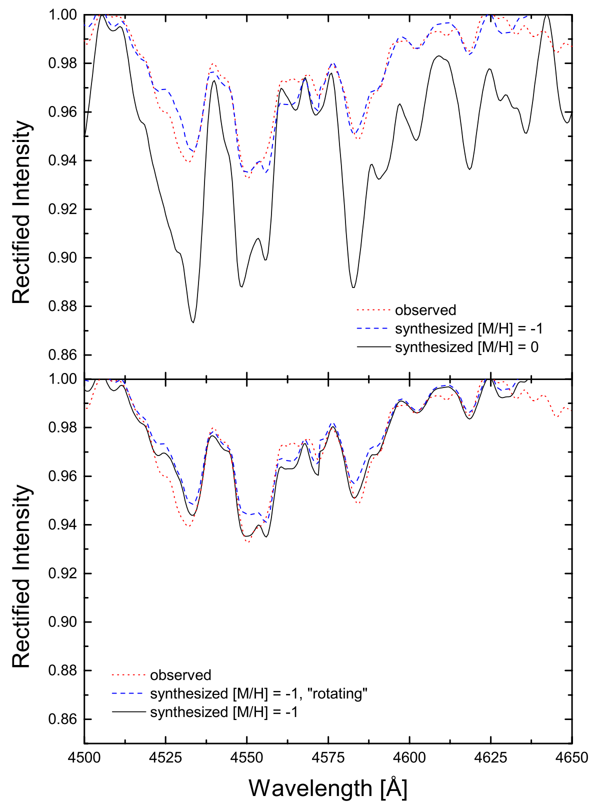

Figure 3. The observed and two synthetic spectra showing the effect of metallicity (upper panel). The generated 'rotating' model (see text) is not very different from the non-rotating one (lower panel).

0.2 per cent. Therefore, we adopted these values for HD 54272. For the estimation of its error, we used models with −0.5 and −1.5 dex and calculated, again, the differences of the synthetic and observed spectra. We notice that the difference with the more abundant model is smaller than the one with the more underabundant one. From this, we conclude that the metallicity range is between −0.8 and −1.1 dex. Fig. 3 shows the effect of the underabundant model for a typical metallic-line region around 4600 Å.

We checked if the high rotational velocity is affecting the derived metallicity. Because no reliable stellar atmospheres, taking into account the rotation, are available, coplanar ones are used. Assuming that the line-of-sight is almost equator-on, the models of Slettebak, Kuzma & Collins (1980) are used to find the $T_{\rm eff}$ and log g values at the poles. From their table 1, the model for a spectral type of A5 and a ratio of the angular velocity to the critical angular velocity of 0.9 almost perfectly fit the parameters of HD 54272. It implies $T_{\rm eff}$ = 9130 K and log g = 4.25 at the poles. Again, we applied the above mentioned method to generate synthetic spectra using a different set of astrophysical parameters each 15° along the disc and assuming rigid body rotation. For the final spectrum, we integrated all individual spectra over the stellar disc. Fig. 3 shows the effect of the rotation using stellar atmospheres with [M/H] = −1.0 dex. Due to the high rotation velocity and the low abundance, the effect is only small and still in the range of the derived uncertainty. This is in line with the results of Takeda et al. (2008), who investigated the effect of stellar rotation on the elemental abundance for A-type stars. They found no trends for $\upsilon \sin i$ values up to 250 km s^{-1} (see fig. 10 therein). As a conclusion, we are confident that the derived metal-weakness is indeed intrinsic and not due to the inadequate treatment of stellar rotation.

According to the formula that the rotation becomes imperceptible when $\upsilon \sin i \leq D$ = 85 Å mm^{-1}, we deduce a lower limit of 85 km s^{-1} for our spectrum. From our spectral synthesis, we derive a $\upsilon \sin i$ of about 250 ± 25 km s^{-1}. Using the mass and radius as listed in Table 1, we calculate a break-up velocity for HD 54272 of 313 km s^{-1}. Adopting an equatorial line-of-sight, this implies that HD 54272 rotates at least with 80 per cent of its break-up velocity. Such a high velocity is exceptional not only for γ Doradus pulsators (Bruntt, De Cat & Aerts 2008), but also for MS stars close to the TAMS, in general (Zorec & Royer 2012). The astrophysical characteristics of HD 54272 fit within the λ Bootis group. In addition, we investigated the $\upsilon \sin i$ distribution of the λ Bootis stars, taken from Paunzen et al. (2002a), and apparent 'normal' type stars. The latter are from the list of Royer, Zorec & Gómez (2007) which covers the corresponding spectral range, excluding the late B-type stars and objects marked as 'CB' (binaries) and 'CP' (peculiar stars). The samples consist of 42 λ Bootis and 953 'normal' stars, respectively. Fig. 4 shows the distributions of both groups. We performed a pair-sample t-test (Rees 1987) which results that both distributions are on a 0.05 level, identical. Therefore, $\upsilon \sin i$ seems not to be an intrinsically 'critical' astrophysical parameter for the formation and stability of the λ Bootis phenomenon. However, the fast rotation of HD 54272 is not the common characteristics for λ Bootis stars (Fig. 4). But there is at least one similar member, HD 193256 (HIP 100286), with a $\upsilon \sin i$ of about 250 km s^{-1}. It is also close to the TAMS but hotter (7700 K).

HR 8799 (HD 218396, V = 5.95 mag) is an exceptional, close-by (about 40 pc), star classified as 'kA5hF0mA5V λ Boo' by Gray & Kaye (1999). They derived the astrophysical parameters as listed in Table 1. The typical λ Bootis-type abundance pattern was later

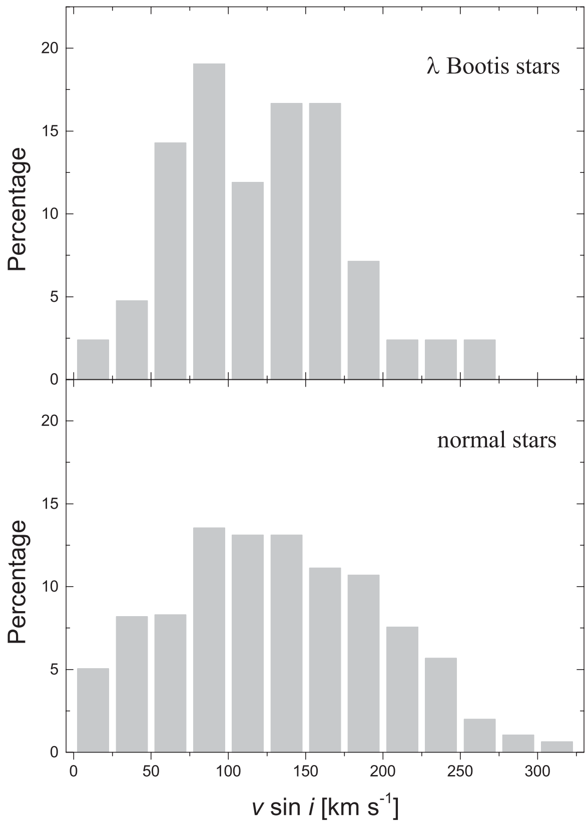

Figure 4. The $v \sin i$ distributions of λ Bootis (upper panel) and apparent 'normal' type (lower panel) stars. According to a pair-sample *t*-test, both distributions are on a 0.05 level, identical.

confirmed by Sadakane (2006). The membership of this star to the Columba Association which has an age of about 30 Myr is still a matter of debate (Zuckerman et al. 2011). Moreover, Baines et al. (2012) summarize the age determinations for this star (see table 1 therein) which range from 30 Myr to 1.6 Gyr. The latter has been deduced from an asteroseismic study by Moya et al. (2010a). We adopted the most probable one, < 100 Myr, as argued and analysed by Baines et al. (2012). HR 8799 is hosting at least four planets and a massive dusty debris disc (Esposito et al. 2013). The γ Doradus-type pulsation of HR 8799 was studied by Zerbi et al. (1999). They found four significant frequencies (1.9791, 1.7268, 1.6498, and 0.2479 d^{-1}) with corresponding amplitudes in Johnson V between 15.98 and 5.66 mmag. Moya et al. (2010b) concluded from a detailed asteroseismic study that HR 8799 is intrinsically metal-weak which is in contrary to the common accepted theory that the λ Bootis phenomenon is restricted to the photosphere alone. However, one has to keep in mind that there are at least two important free parameters (the inclination angle and the correct mode identification) which are vital for the asteroseismic analysis. Such an intrinsic metal-weakness, compared to the Sun, is still in the range which is found in the solar neighbourhood (Luck & Heiter 2005). If we accept this fact, then also a non-solar isochrone has to be used to derive the age of HR 8799. For a given temperature and luminosity, a lower metal isochrone would result in an older age. For the listed metallicity, it would naturally explain the often quoted discrepancy between the age of the Columba Association (30 Myr) and some other determinations indicating an older age (100 Myr). Furthermore, we have to ask (i) if all 'classical' λ Bootis stars are intrinsic metal-weak or not, and (ii) if HR 8799 is a true member of the group.

Table 2. Data characteristics and frequencies detected in the WASP and ASAS data with their identification. The uncertainties in the final digits are given in parentheses.

ID	Frequency [d^{-1}]	Amplitude [mag]	S/N
	WASP		
Points available/used		Time base (used)	
	19704/9949	HJD 2454057−2455623	
f_1	1.410117(2)	0.02128(7)	16.0
f_2	1.283986(5)	0.0138(1)	6.3
f_3	1.293210(4)	0.01454(7)	6.8
f_4	1.536662(9)	0.00664(7)	5.5
f_5	1.15722(1)	0.00546(8)	5.9
f_6	0.22658(1)	0.00523(8)	6.4
	ASAS		
Points available/used		Time base (used)	
	615/541	HJD 2452621−2455166	
f_1	1.41011(1)	0.0232(1)	7.8
f_2	1.28399(2)	0.0147(1)	6.7
f_3	1.293(6)	0.009(3)	4.8
	1.89(3)	0.007(2)	4.4
	5.01(2)	0.007(2)	4.0

3 THE PULSATIONAL BEHAVIOUR OF HD 54272

We analysed the photometric data from WASP (Pollacco et al. 2006) and the ASAS[3] (e.g. Pojmański 1997, 2001) surveys. The WASP data, with the time base of 1566 d, are strongly affected by instrumental artefacts. Therefore, a Fourier model with six harmonics was fitted to the data and measurements deviating more than 2σ were removed. This procedure was applied three times. For the ASAS data (time base of 2545 d), no such procedure was necessary, but the best quality data with flag 'A' and 'B' were used and few outliers were removed manually. Since ASAS gives information about the brightness in five different apertures, a weighted mean value was used. A frequency analysis was performed using PERIOD04 (Lenz & Breger 2004) software, which was also used for the determination of the uncertainties via Monte Carlo simulations.

ASAS data showed only five peaks: f_1, f_2, f_3 and two peaks with no clear interpretation. The latter are probably due to the intrinsic characteristics of the data set and the accuracy of the individual measurements. In the WASP data, six significant peaks were identified (see Table 2). To estimate the reliability of these frequencies, the data were prewhitened with their various combinations. Frequencies, which were left out, were always detected again. In addition, we performed the complete time series analysis for two sub data sets. The overall data set is divided by the time of observations to HJD 2450000+ [5137:5186] and [5500:5624], respectively. This procedure should avoid the influence of seasonal effects on the Fourier analysis and the detection of possible spurious frequencies. Within the errors, all frequencies listed in Table 2 were found in both data sets.

From Fig. 5 it is apparent that frequency spectra are strongly affected by daily aliases, which can be expected when analysing data

[3] http://www.astrouw.edu.pl/asas/

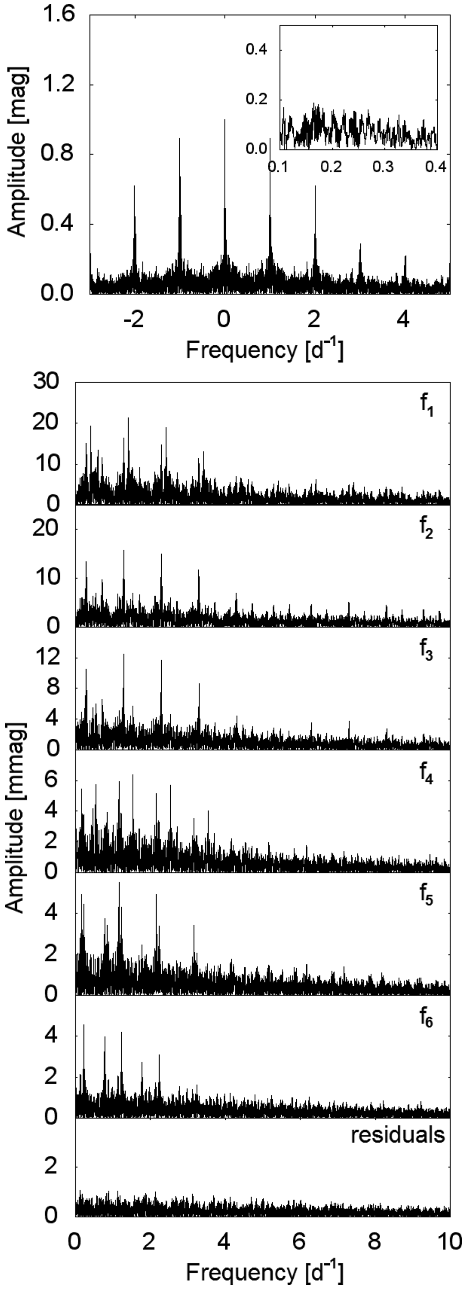

Figure 5. The different steps of the frequency spectrum analysis for the WASP data. Top panel shows the spectral window dominated by daily aliases. The bottom part shows the highest peaks (identified in top left corner of each plot) during prewhitening. The lowest panel shows the residuals after prewhitening with frequencies f_1 to f_6.

from single-side observations. This makes the frequency identification somewhat ambiguous and also $f_i \pm 1\,\mathrm{d}^{-1}$ should be considered as possible frequencies. Without any additional observations peaks can be hardly interpreted and it is only possible to guess potential scenarios. Nevertheless, peaks with the highest amplitudes correspond to the same frequencies in ASAS and WASP data. Therefore peaks that were identified (Table 2) should be of higher reliability than their 1-d aliases.

Considering the frequencies in Table 2, some interesting features appear. The peaks f_2, f_4 and f_5 are almost equally spaced with $f_m \approx 0.12647\,\mathrm{d}^{-1}$ (calculated as average of spacings between frequencies) with respect to f_1: $f_4 - f_1 = 0.12655 \approx f_m$, $f_1 - f_2 = 0.12613 \approx f_m$ and $f_1 - f_5 = 0.25290 \approx 2f_m$. Since the spectral window of the data set (Fig. 5 detail in top panel) does not show any suspicious peak near $0.1265\,\mathrm{d}^{-1}$, we consider this spacing as intrinsic to the pulsation of the star.

This symmetrical pattern is similar to those of modulated RR Lyrae stars (Benkő, Szabó & Paparó 2011), where the side-peaks are products of amplitude and/or phase modulation of the basic pulsation frequency with modulation period corresponding to the spacing between these peaks (in our case, $1/f_m = 7.91$ d). Such an interpretation of the frequency spectra probably led to the misclassification of HD 54272 as a modulated RR Lyrae-type star with a pulsation period of 0.7789192 d ($1/f_2$ in our identification; Szczygieł & Fabrycky 2007). As Fig. 6 shows, the mean amplitude of light changes is only about 0.06 mag, which is too small for RR Lyraes (Smith 2003). However, omitting small amplitude and two other frequencies, which were found, the light-curve shape could easily be interpreted as a modulated RR Lyrae star (Skarka 2013).

We investigated if the found frequencies could be caused by rotation. From the observational point of view, such rotational induced variability was never found for members of the λ Bootis group before (Paunzen et al. 2002a). In general, as further ingredients, a local stellar magnetic field which produces spots on the surface (as well as elemental overabundaces) and slow rotation in order to guarantee stability are needed (Mestel & Moss 2005). This so-called Oblique Rotator model (Stibbs 1950) explains the variations as a geometrical effect as the star rotates, using a simple dipolar geometry. Because HD 54272 is a very fast rotator and magnetic fields were never detected for λ Bootis stars (Bohlender & Landstreet 1990) it is very unlikely that the Oblique Rotator model could be applied. Based on the projected rotational velocity, radius (Table 1), and $i = 0°$ as well as the formula by Preston (1971), we derive a rotational period of 0.45 d for HD 54272. Larger values of the inclination would result in even shorter periods. The fastest rotating objects with periods close to 0.5 d are very hot and high mass He-strong stars (Mikulášek et al. 2010). The $f_i + 1\,\mathrm{d}^{-1}$ aliases of the first five frequencies match the expected rotational period. Also the regular spacing between frequencies could possibly be the consequence of rotation. However, if we assume that the variability is due to rotation then we need a new model to explain this phenomenon because the Oblique Rotator is, with our current knowledge, not applicable for HD 54272. Recently, Balona (2011) investigated the light curves of several thousands of A-type stars observed by the Kepler space mission. He found that almost 10 per cent of A-type stars exhibit variations resembling those usually attributed to starspots in cool stars, including a few exhibiting travelling waves usually interpreted as differentially rotating starspots. Most of these variations can also not be explained by the above mentioned Oblique Rotator model. So, if we interpret the found variability of HD 54272 due to rotation, it would be the first λ Bootis star with starspots on its surface which would be a challenging example for models.

Explanation of peaks corresponding to $f_4 = 2f_1 - f_2$ and $f_5 = 2f_2 - f_1$ as coupling terms, which are often reported in γ Doradus stars (Balona et al. 2011) and which implies non-linearity in the oscillation (similar behaviour was reported in HR 8799, Zerbi et al. 1999), fails, because $2f_1$ and $2f_2$ are not present in frequency spectra and none of daily aliases matches the values needed for such consideration.

Furthermore, we checked the location of our target within the $(b - y)$ versus c_1 diagram which is sensitive to surface gravity (Crawford 1979). For this purpose, we used data for 'normal' (Gray & Garrison 1987, 1989a,b; Garrison & Gray 1994), λ Bootis (Paunzen et al.

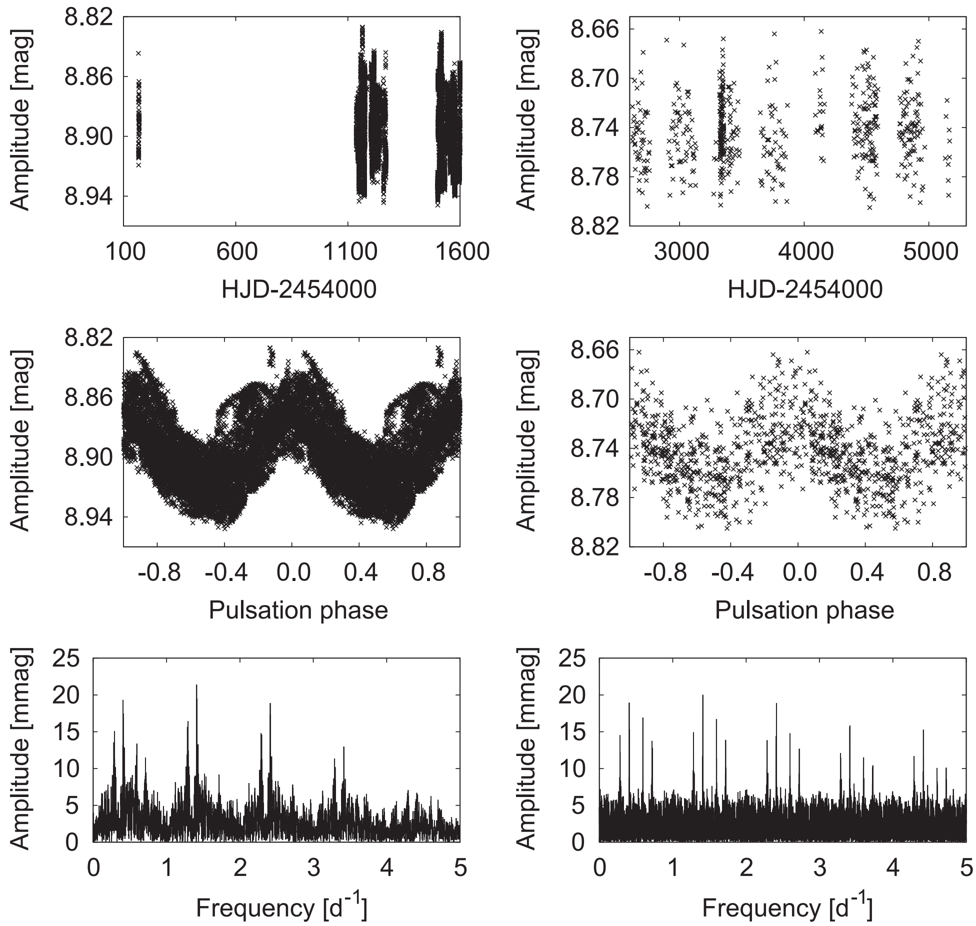

Figure 6. The data distribution and phase plots of WASP (left panels) and ASAS data (right panels) folded with f_1 according to epoch HJD 2455164.116. The bottom panels show the frequency spectra of unprewhitened data.

2002b), and RR Lyrae stars (Fernley et al. 1998) together with the standard relation from Philip & Egret (1980). The photometric indices were either taken from the listed references or from the catalogue by Hauck & Mermilliod (1998). The result is shown in Fig. 7. HD 54272 and HR 8799 are located where the other λ Bootis stars are situated. HR 8799 lies a little bit below the standard line which could be due to its young age and the surrounding dense CS material. The λ Bootis stars are clearly separated from the RR Lyrae stars with two exceptions: HD 148638 and HD 193281. Both stars are rather close visual binary systems with almost equally bright companions. Therefore, the available photometry could be influenced by the binarity.

As a conclusion, the presented analysis clearly shows that HD 54272 is not a RR Lyrae but a γ Doradus pulsator without a hint of δ Scuti variability (Paunzen et al. 2002a).

4 CONCLUSIONS

We analysed the time series of the WASP and ASAS projects in order to shed more light on the pulsational behaviour of HD 54272. This object was classified as λ Bootis star and RR Lyrae variable. A combination which, a priori, excludes each other. Our detailed analysis established this object as a γ Doradus pulsator with six detected frequencies, which could be possibly biased by one day aliases. The amplitudes of detected peaks are between 5 and 21 mmag. The three frequencies with the highest amplitudes were detected in both data sets, independently. This example is also important for other γ Doradus stars which might be misidentified as RR Lyrae variables.

From spectroscopic data, we deduce a classification of ‘kA5hF2mA5V λ Boo’ for HD 54272. A comparison with synthetic spectra yields a high rotational velocity ($250 \pm 25\,\mathrm{km\,s^{-1}}$) and a metal deficiency of [M/H] of about -0.8 to -1.1 dex compared to the Sun. It is located very close to the TAMS. These facts make HD 54272 an important test case for several different models including pulsation, rotation, diffusion, and selective accretion.

Our results are compared with those from the first detected star which shows λ Bootis and γ Doradus characteristics: HR 8799. Although the pulsational behaviours are very similar, the evolutionary statuses are quite different. HR 8799 is a very young object hosting at least four planets and a massive dusty debris disc. If we accept that selective accretion plays a key role for the λ Bootis phenomenon, it seems to have a significant effect on γ Doradus-type pulsation. This could be concluded from the fact that these two stars have widely different evolutionary statuses and astrophysical parameters, but strikingly similar pulsational characteristics.

The detection of further members of the λ Bootis group showing γ Doradus-type pulsation would put further constraints on models explaining and describing these phenomena.

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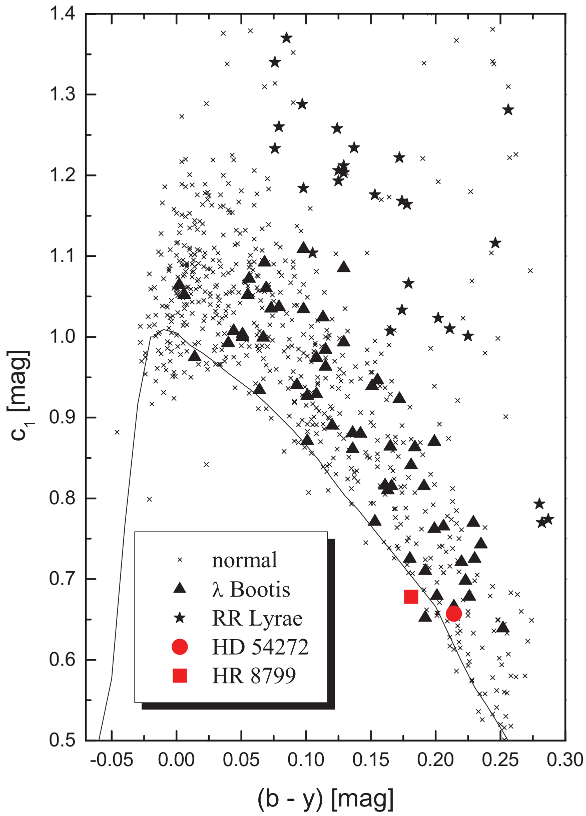

Figure 7. The $(b-y)$ versus c_1 diagram for HD 54272, HR 8799, 'normal' (crosses, Gray & Garrison 1987, 1989a,b; Garrison & Gray 1994), λ Bootis (filled triangles, Paunzen et al. 2002b), and RR Lyrae stars (open circles, Fernley et al. 1998). The solid line is the standard relation from Philip & Egret (1980). The RR Lyrae stars are clearly separated from the λ Bootis stars and our target.

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REFERENCES

Baines E. K. et al., 2012, ApJ, 761, 57
Balona L. A., 2011, MNRAS, 415, 1691
Balona L. A., Guzik J. A., Uytterhoeven K., Smith J. C., Tenenbaum P., Twicken J. D., 2011, MNRAS, 415, 3531
Benkő J. M., Szabó R., Paparó M., 2011, MNRAS, 417, 974
Bohlender D. A., Landstreet J. D., 1990, MNRAS, 247, 606
Bruntt H., De Cat P., Aerts C., 2008, A&A, 478, 487
Crawford D. L., 1979, AJ, 84, 1858
Esposito S. et al., 2013, A&A, 549, A52
Fernley J., Barnes T. G., Skillen I., Hawley S. L., Hanley C. J., Evans D. W., Solano E., Garrido R., 1998, A&A, 330, 515
Folsom C. P., Bagnulo S., Wade G. A., Alecian E., Landstreet J. D., Marsden S. C., Waite I. A., 2012, MNRAS, 422, 2072
Garrison R. F., Gray R.O., 1994, AJ, 107, 1556
Gray R. O., Corbally C. J., 1994, AJ, 107, 742
Gray R. O., Garrison R. F., 1987, ApJS, 65, 581
Gray R. O., Garrison R. F., 1989a, ApJS, 69, 301
Gray R. O., Garrison R. F., 1989b, ApJS, 70, 623
Gray R. O., Kaye A. B., 1999, AJ, 118, 2993
Gray R. O., Corbally C. J., Garrison R. F., McFadden M. T., Robinson P. E., 2003, AJ, 126, 2048
Hauck B., Mermilliod M., 1998, A&AS, 129, 431
Heiter U. et al., 2002, A&A, 392, 619
Kamp I., Paunzen E., 2002, MNRAS, 335, L45
Lenz P., Breger M., 2004, Comm. Astron., 146, 53
Luck R. E., Heiter U., 2005, AJ, 129, 1063
Martinez-Galarza J. R., Kamp I., Su K. Y. L., Gáspár A., Rieke G., Mamajek E. E., 2009, AJ, 694, 165
Mestel L., Moss D., 2005, MNRAS, 361, 595
Michaud G., Charland Y., 1986, ApJ, 311, 326
Mikulášek Z., Krtička J., Henry G. W., de Villiers S. N., Paunzen E., Zejda M., 2010, A&A, 511, L7
Moya A., Amado P. J., Barrado D., García Hernández A. G., Aberasturi M., Montesinos B., Aceituno F., 2010a, MNRAS, 405, L81
Moya A., Amado P. J., Barrado D., García Hernández A. G., Aberasturi M., Montesinos B., Aceituno F., 2010b, MNRAS, 406, 566
Paunzen E., 2001, A&A, 373, 633
Paunzen E. et al., 2002a, A&A, 392, 515
Paunzen E., Iliev I. Kh., Kamp I., Barzova I. S., 2002b, MNRAS, 336, 1030
Philip A. G., Egret D., 1980, A&AS, 40, 199
Pojmański G., 1997, Acta Astron., 47, 467
Pojmański G., 2001, IAU Colloq. 183: Small Telescope Astronomy on Global Scales, 246, 53
Pollacco D. L. et al., 2006, PASP, 118, 1407
Preston G. W., 1971, PASP, 83, 571
Rees D. G., 1987, Foundations of Statistics. Chapman & Hall, London
Robitaille T. P., Whitney B. A., Indebetouw R., Wood K., 2007, ApJS, 169, 328
Royer F., Zorec J., Gómez A. E., 2007, A&A, 463, 671
Sadakane K., 2006, PASJ, 58, 1023
Skarka M., 2013, A&A, 549, A101
Slettebak A., Kuzma T. J., Collins G. W., II, 1980, ApJ, 224, 171
Smith H. A., 2003, RR Lyrae Stars. Cambridge Univ. Press, Cambridge
Stibbs D. W. N., 1950, MNRAS, 110, 395
Szczygieł D. M., Fabrycky D. C., 2007, MNRAS, 377, 1263
Takeda Y., Han I., Kang D.-I., Lee B.-C., Kim K.-M., 2008, J. Korean Astron. Soc., 41, 83
Zerbi F. M. et al., 1999, MNRAS, 303, 275
Zorec J., Royer F., 2012, A&A, 537, A120
Zuckerman B., Rhee J. H., Song I., Bessell M. S., 2011, ApJ, 732, 61

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