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Nonvariability among λ Bootis stars[⋆]

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Abstract. With asteroseismic techniques it is possible to investigate the interior and the evolutionary status of stars via their frequency spectrum. Both information would be very much needed for λ Bootis stars, a group of metal-poor Population I, A-type stars, since no conclusive theory exists explaining the observed abundance anomalies. Geneva and Strömgren photometry place these stars inside the classical instability strip or at least very close to it. We therefore have started an extensive photometric survey for pulsation in λ Bootis stars and have discovered so far 13 new variables.

In this paper we present results for stars which presumably are constant, because we are able to establish only an upper level for possible variability. A typical noise level of 3 mmag for Strömgren b was achieved in the relevant frequency domain up to 100 d^{-1}.

Considering the given noise level of our survey, we conclude that at least 50% of all investigated λ Bootis stars inside the instability strip are pulsating, making this group remarkable compared to stars with similar spectral types. This may suggest that a low (surface) metallicity has an influence on the pulsation behavior of stars. New models, as well as further observations are needed to clarify the λ Bootis phenomenon using asteroseismic techniques.

Key words: astronomical data bases — surveys; stars — λ Bootis; stars — chemically peculiar; stars — early type

1. Introduction

The prototype of λ Bootis stars was found by Morgan et al. (1943) and the group can be described as metal-poor Population I, A-type stars with no magnetic field larger than 300 G. In a recent paper (Paunzen et al. 1997) we have reviewed the various classification criteria and have established a homogeneous group of λ Bootis stars. Although λ Bootis stars occupy the same parameter space in a Hertzsprung-Russell-diagramme as do "normal" A-type and some peculiar (CP1, cool CP2) stars, they are distinguished e.g. by results of high resolution spectroscopy and UV observations.

The evolutionary status of λ Bootis stars is still controversial. The two theories discussed in the literature involve diffusion, either in combination with accretion of interstellar matter as in post-AGB stars (Turcotte & Charbonneau 1993), or with mass loss (Michaud & Charland 1986).

With the tools of asteroseismology it is in principle possible to investigate the evolutionary status and internal structure of a star from its pulsation frequency spectrum. We therefore have started a photometric survey for pulsation among λ Bootis stars in 1993. Eight observing runs were at least partly dedicated to this survey so far (Table 2). Up to now we have found 13 new pulsating members of this group (Weiss et al. 1994; Paunzen & Handler 1996 and references therein). Frequencies (6 to 45 d^{-1}) and amplitudes suggest a close connection to δ Scuti stars.

The main theoretical framework to describe δ Scuti pulsation is well developed, although the effects of diffusion and low metallicity on pulsation are not conclusively investigated yet. A comparison of the CP1 and λ Bootis stars is especially interesting. For both groups, diffusion seems to be the main mechanism responsible for the overabundance (CP1) as well as for the underabundance of metals (λ Bootis stars). However, the first group consists of typically nonvariable stars (Alecian 1996), which is not the case for the second group.

Some preliminary null results of our survey have been published in a series of IBVS-notes (Kuschnig et al. 1996; Paunzen et al. 1996a,b). In this paper we present all data on "constant" stars, in the sense that we are able to give an upper limit for a possible variability. For each set of differential data we have computed a Fourier spectrum (Figs. 4a to 4c).

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[⋆] Based on observations obtained at ESO-La Silla, CTIO, SAAO, McDonald Observatory, Instituto Astrofisica Andalucia Observatory.

Table 1. Observation log and results for the observed stars

Star	JD	hours	num$_{\rm Obs}$	m_V	M_V	β	$b-y$	Spec.	Fig	f[d^{-1}]	UL[mmag]	ref
HD 319	2449166	1.4	53	5.93	1.1	2.851	0.079	λ Boo		82.5	4.2 [b]	1
HD 203				6.18				F2IV	*			
HD 31295	2449741	2.2	462	4.64	1.5	2.898	0.044	λ Boo		12.7	7.4 [v]	5
HD 30913				6.79				F2				
HD 31283				5.19				A3V	*			
HD 38545	2449692	3.3	204	5.76	0.4	2.852	0.042	λ Boo		11.7	4.2 [v]	4
	2449693	5.0	248									
	2449697	3.0	120									
HD 39317				5.56				B9p	*			
HD 66920	2449741	1.2	247	6.33	1.0	2.866	0.073	λ Boo(?)		36.1	3.6 [v]	5
HD 64142				7.72				F3V	*			
HD 66168				6.61				F8V				
HD 74873	2450095	2.4	22	5.87	2.0	2.890	0.064	λ Boo		61.3	9.4 [v]	8
HD 74228				5.62				A3V	*			
HD 79025	2449695	3.6	132	6.65	0.3	2.829	0.094	λ Boo(?)		21.3	2.2 [v]	4
HD 78326				7.90				A0IV	*			
HD 79622				8.13				K5III				
HD 81290	2449842	3.3	29	8.88	1.8	2.672	0.252	λ Boo		75.8	2.4 [b]	6
HD 82517				7.73				A2V	*			
HD 82573	2449468	2.4	459	5.74	0.6	2.863	0.068	λ Boo(?)		91.7	1.6 [v]	3
HD 81712				6.80				A7V	*			
HD 82724				6.80				A0V				
HD 83277	2449476	3.6	656	8.31	2.0	2.707	0.238	λ Boo(?)		6.1	4.2 [v]	3
HD 82709				7.70				A9V				
HD 83547				8.30				A0V	*			
HD 91130	2450097	3.0	44	5.93	1.1	2.854	0.073	λ Boo		19.7	7.6 [v]	8
HD 90840				5.77				A4V				
HD 91365				5.58				A2V	*			
HD 125162	2449936	2.5	90	4.18	1.5	2.894	0.051	λ Boo		52.6	6.6 [b]	7
	2449940	1.8	68									
HD 124675				4.53				A8IV	*			
HD 141851	2449168	3.4	113	5.10	1.4	2.846	0.071	λ Boo		84.7	4.2 [b]	1
	2449175	4.7	182									
HD 140873				5.39				B8III				
HD 141378				5.52				A5IV	*			
HD 143148	2449560	4.0	244	7.39	1.7	2.738	0.194	λ Boo(?)		49.2	4.4 [b]	2
HD 142542				6.29				F5V	*			
HD 142851				7.13				A0V				
HD 145782	2449166	3.9	116	5.71	0.2	2.870	0.080	λ Boo(?)		77.3	6.4 [b]	1
HD 144480				5.57				B9.5V	*			
HD 149303	2449939	3.2	118	5.64	1.1	2.848	0.064	λ Boo		5.8	2.4 [b]	7
HD 149081				6.45				A1V	*			
HD 149630				4.17				B9V				
HD 154153	2449175	2.7	104	6.18	1.6	2.719	0.199	λ Boo(?)		96.4	3.2 [b]	1
HD 153234				6.51				F3V				
HD 154025				6.28				A2V	*			
HD 156954	2449839	3.4	23	7.68	2.5	2.726	0.201	λ Boo		5.7	2.6 [b]	6
HD 156392				8.26				F2V	*			
HD 171948	2450008	3.2	23	6.71				λ Boo		30.9	2.6 [b]	7
HD 171569				7.15				A0	*			
HD 171799				7.57				A0				
HD 179791	2449475	3.6	192	6.49	0.1	2.846	0.064	λ Boo(?)		11.5	3.6 [v]	3
HD 178596				5.22				F0III				
HD 180482				5.59				A3IV	*			

Table 1. continued

Star	JD	hours	$\mathrm{num_{Obs}}$	m_V	M_V	β	$b-y$	Spec.	Fig	$f[\mathrm{d}^{-1}]$	UL[mmag]	ref
HD 188164	2449173	3.3	133	6.35	1.9	2.851	0.098	λ Boo(?)		4.1	3.4 [b]	1
	2449174	5.0	192									
HD 188097				5.75				Am	*			
HD 192424	2449939	4.2	160	7.08				λ Boo		46.2	4.6 [b]	7
HD 193668				7.02				B9	*			
HD 193256	2449560	4.1	184	7.70	0.9	2.819	0.115	λ Boo		15.1	2.6 [b]	2
	2449563	2.3	31									
	2449564	4.5	89									
HD 194170				8.27				A4V	*			
HD 193281	2449563	2.3	32	6.61	0.4	2.844	0.098	λ Boo		18.1	3.4 [b]	2
	2449564	4.6	88									
HD 194170				8.27				A4V	*			
HD 204041	2449568	4.2	270	6.45	1.9	2.845	0.093	λ Boo		80.0	1.8 [b]	2
HD 203405				6.78				F2				
HD 204121				6.13				F5V	*			

JD	Julian date of observation
hours	Duration of observation
$\mathrm{num_{Obs}}$ ...	Number of data points
m_V	mag(V) from Mermilliod & Mermilliod (1994)
M_V	Calibrated absolute magnitude (see Sect. 5.2.)
β, $b-y$ ...	Strömgren colours from Hauck & Mermilliod (1990) and Handler (1995)
Spec	Data on spectral classification from Paunzen et al. (1997) and Simbad
Fig	Flag on comparison star used for Fig. 4a to 4c
f	Frequency of the highest peak in amplitude spectrum
UL	Upper level of nonvariability for the indicated Strömgren filter
ref	Reference in Table 2.

2. Selection of candidate and comparison stars

Candidates for our photometric survey were primarily taken from Renson et al. (1990) and Gray & Corbally (1993). We performed a critical search in the literature to reject candidates which probably are not λ Bootis stars. Finally, we have compared the list (Table 1) with our new catalogue (Paunzen et al. 1997). For some of the observed stars, classification spectra are still missing (indicated with a question mark in the row of the spectral classification in Table 1). Nevertheless the level of confidence is very high that all presented programme stars are true λ Bootis stars, except HD 154153. This star could belong to the intermediate Population II group (Gray 1989) and was also quoted as probable misclassified in Renson et al. (1990). But further observations have to clarify its evolutionary status.

We have tried to use at least two comparison stars in the same magnitude and spectral range as the candidate star. The selected comparison stars were checked via Simbad for already known variability.

3. Observations

The observations were performed at different sites as listed in Table 2. All telescopes were equipped with a photomultiplier, and photometer apertures larger than $20''$ were used. The integration time (> 10 s) was chosen such that each data point is only limited by scintillation and not by photon noise (Young 1967). For most programme stars we have used two comparison stars (observed typically every 5 min) to correct for atmospheric and instrumental effects. The sky background was measured at least once each hour. Most, but not all of the stars were measured in Strömgren v and b. The date and duration of the observations, and the number of data points for each programme star are listed in Table 1.

4. Reductions

All data were corrected for dead time, atmospheric extinction and sky background. In case of observations during more than one night, we merged the data prior to a Fourier analysis. Neither smoothing nor averaging was applied. The differential data were calculated by subtracting one data set from the other. If necessary, we interpolated linearly between two data points of the comparison star

Table 2. Sites, observers and used telescopes for our survey

Site	Year	Observer	Telescope	stars	ref
ESO	1993	E. Paunzen	50 cm	5	1
ESO	1994	E. Paunzen	50 cm	4	2
SAAO	1994	R. Kuschnig	50 cm	3	3
CTIO	1994	M. Gelbmann	60 cm	2	4
SAAO	1995	R. Kuschnig	50 cm	2	5
CTIO	1995	E. Paunzen	60 cm	2	6
McDonald	1995	G. Handler	90 cm	4	7
IAA	1996	R. Kuschnig	90 cm	2	8

for a given time.

The differential data were used to calculate amplitude spectra with a standard Fourier technique (Deeming 1975; Breger 1990) up to the Nyquist frequency as shown in Figs. 4a to 4c. We have also checked the differential data of both comparison stars for variations.

5. Results

5.1. Noise level of our survey

The detection threshold is depending on the quality of the night, the star's brightness, the telescope size and the duration of the observations. Consequently, for a faint star and/or a poor night this threshold can be as high as 10 mmag whereas for the best cases we find a few mmags (Fig. 1). There can be several reasons why a candidate star yields a null result, e.g. the internal stellar structure, or atmospheric and instrumental effects. Also beating of several independent pulsation modes together with a small time base could simulate constancy. Nevertheless we consider a star to be constant, if the Fourier spectrum of the differential light curve does not contain a statistically significant peak in the frequency range up to the Nyquist frequency. Of course, we cannot exclude variability on a lower amplitude level.

For 5 stars (HD 31295, HD 74873, HD 91130, HD 125162 and HD 179791) of the presumably constant stars one might be tempted to assume low amplitude variability. But based on the noise level in the amplitude spectra of the respective stars, the highest peak is *not* statistically significant. Figure 1 shows the distribution of upper limits for nonvariability, merging the results of Strömgren v and b photometry (Table 1). Models and observations (Matthews et al. 1996) indicate an amplitude scaling for A-type stars of Amplitude[v] $= 1.1 \cdot$ Amplitude[b], justifying our merging procedure. A typical noise level of 3 mmag was achieved for the relevant frequency domain up to $100\,\mathrm{d}^{-1}$ (Fig. 1). The distribution of the frequencies with the highest (but statistically insignificant) amplitudes shows a maximum at $10\,\mathrm{d}^{-1}$ (Fig. 2), perhaps caused by insufficiently corrected sky transparency variations, with no other significant trends.

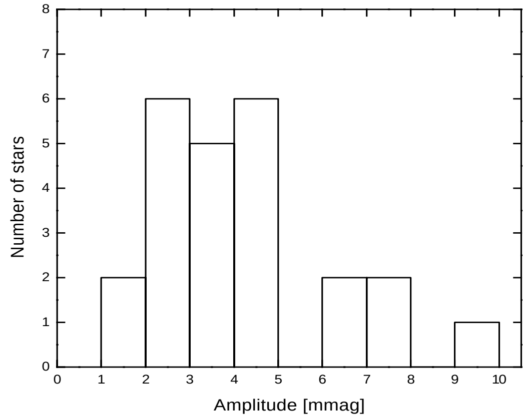

Fig. 1. Distribution of the upper levels for nonvariability for all observed stars

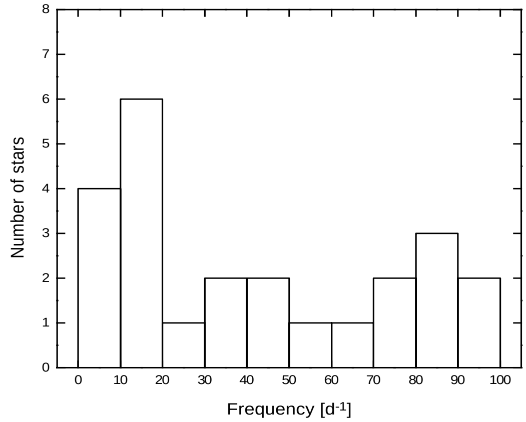

Fig. 2. Distribution of the frequencies for the highest derived amplitudes

5.2. Location in the Hertzsprung-Russell-diagramme

After establishing nonvariability among the observed candidate stars within a given limit, we have investigated their location in a $(b-y)$ vs. M_V diagramme. Strömgren colours were taken from Hauck & Mermilliod (1990) and Handler (1995). No photometric indices are available for HD 171948 and HD 192424. The dereddening procedure and calibration in the Strömgren system uses the results given by Crawford (1979) and comprises the iteration procedure described by Hilditch et al. (1983). The reddening for all stars is small ($E(b-y) < 0.015$), except for the two cases HD 145782 ($E(b-y) = 0.03$) and HD 193281 ($E(b-y) = 0.025$) indicating that all stars are within the solar neighbourhood. Gray (1988) showed that peculiar hydrogen line profiles and very high v sin i values, as found in some λ Bootis stars, influence β and hence M_V. We have to stress again that all calibrations are derived for "normal" type stars. Since the intrinsic error in M_V is about ±0.3 mag (Crawford 1979), we completely neglect those effects.

Figure 3 shows the location of all observed λ Bootis stars with the typical error bars for both parameters indicated. The variable stars were taken from Paunzen et al. (1997) and calibrated as just described.

Taking into account the given errors, only 11 "constant" stars lie within the instability strip (although its hot border is not unambiguously defined), namely:

HD 319, HD 74873, HD 79025, HD 141851,
HD 143148, HD 154153, HD 156954, HD 188164,
HD 193256, HD 193281, HD 204041.

On the other hand 12 variable λ Bootis stars are placed there, suggesting that at least 50% of all investigated members inside the instability strip are pulsating. If we exclude HD 79025, HD 154153 and HD 188164, since they are not yet definitely established members of the λ Bootis group, the ratio increases to 2/3.

This is a remarkable result compared to "normal" type stars in the same region of the Hertzsprung-Russell-diagramme. Previous surveys for pulsating stars in clusters indicate that the incidence of δ Scuti variables is not larger than 35 percent of all stars within the instability strip (Breger 1975; Slovak 1978). These results were achieved with limits for nonvariability comparable to this paper. On the other hand, we have investigated a biased sample of stars, based on metallicity. Nevertheless, since variable and constant members of open clusters generally have also the same metallicity, there is strong evidence that our result is significant compared to "normal" type stars. The metallicity measured spectroscopically for chemically peculiar stars very probably is restricted to the surface only, but the average metallicity for the entire star is "normal".

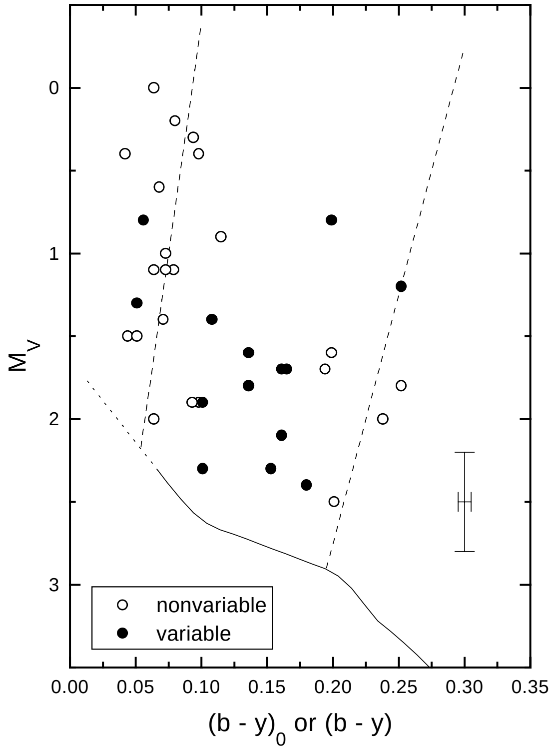

Fig. 3. The location of λ Bootis stars in a $(b-y)$ vs. M_V diagramme. The standard line is taken from Crawford (1979), the borders of the instability strip are from Breger (1979)

6. Conclusion

We have established nonvariability for 24 λ Bootis candidate stars with an upper limit of typically 3 mmag, of which 11 stars are placed within the instability strip, based on the calibration in the Strömgren system. If this evidence can be confirmed it would mean that at least 50% of all λ Bootis stars inside the instability strip are pulsating. Frequencies and amplitudes connect them with δ Scuti stars. For nearly solar abundant stars the percentage of variability is significantly less, suggesting that a low metallicity influences the instability behavior of stars. Models have to be developed taking into account the abundance pattern of λ Bootis stars. Asteroseismic tools should make it possible to investigate the stellar interior and evolutionary status of λ Bootis stars. This would significantly improve the knowledge of astrophysical parameters and help to establish theories explaining the λ Bootis phenomenon. Further observations are needed to improve the statistics on the pulsation behavior of this group. Photometric time series (ground based or from space) of well established members could help to confirm the ratio of pulsating and constant stars as well as decrease the level for nonvariability.

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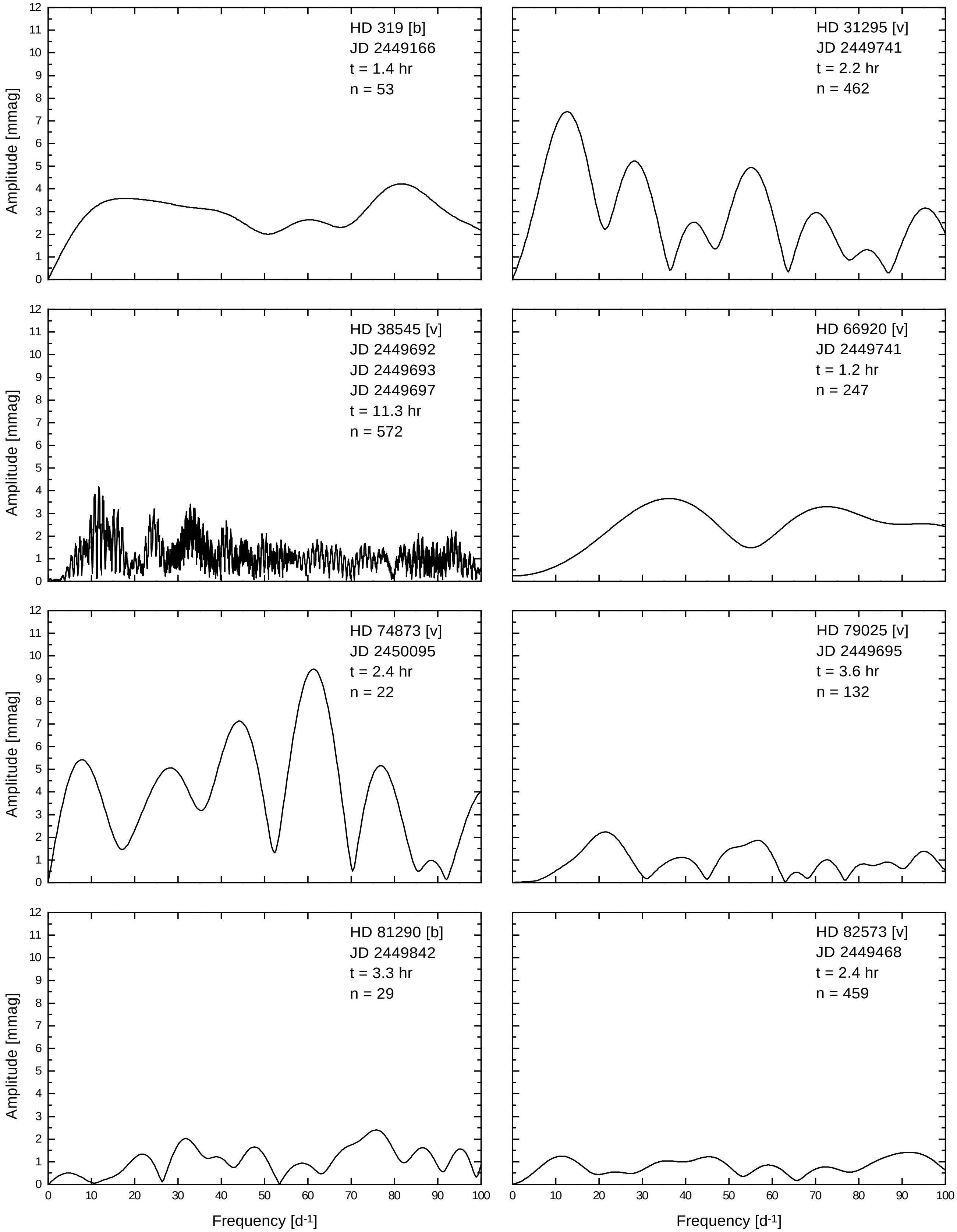

Fig. 4. a) Amplitude spectra for candidate stars. Listed are the HD number, used filter, Julian date, duration and number of observations as given in Table 1

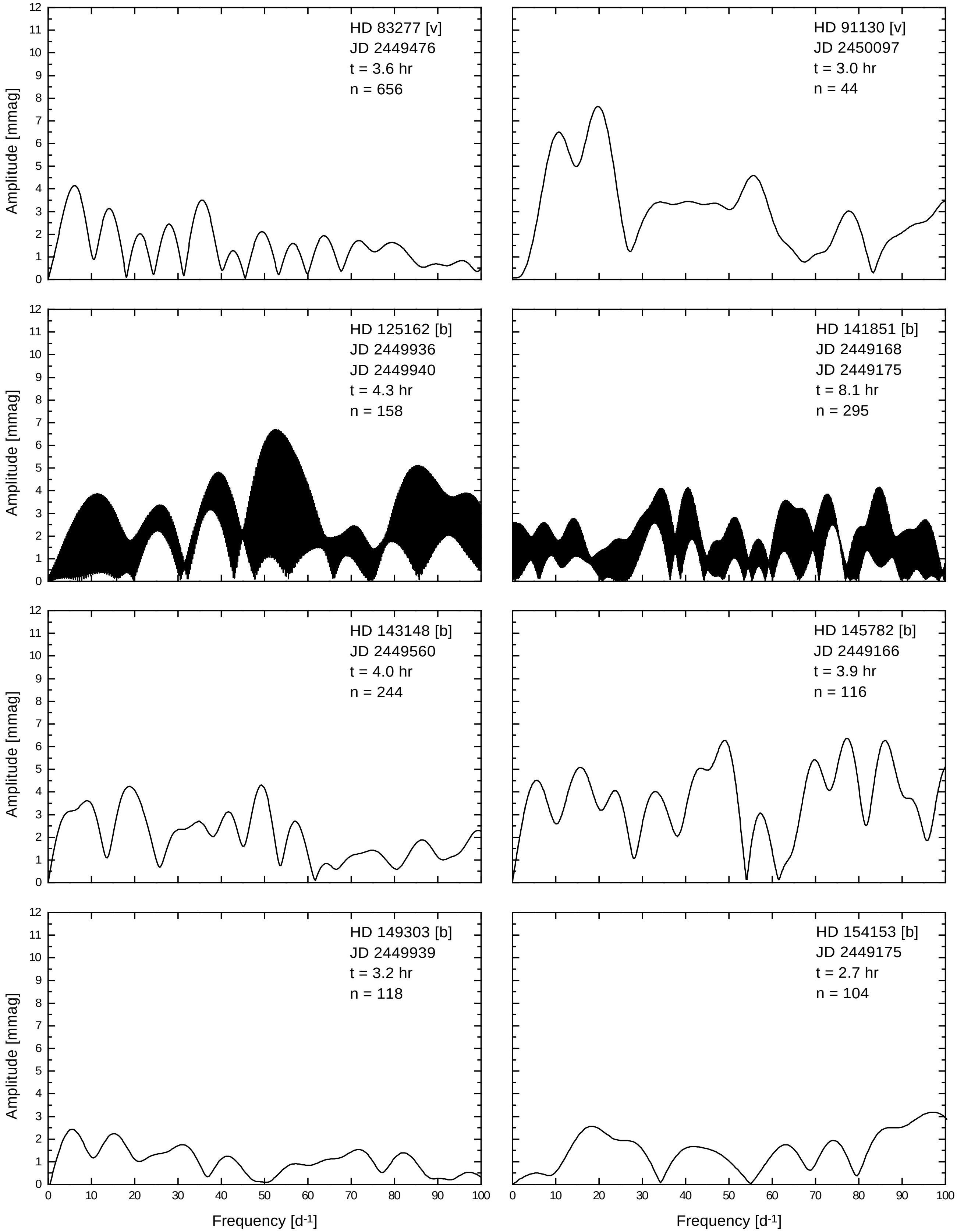

Fig. 4. b) Amplitude spectra for candidate stars. Listed are the HD number, used filter, Julian date, duration and number of observations as given in Table 1

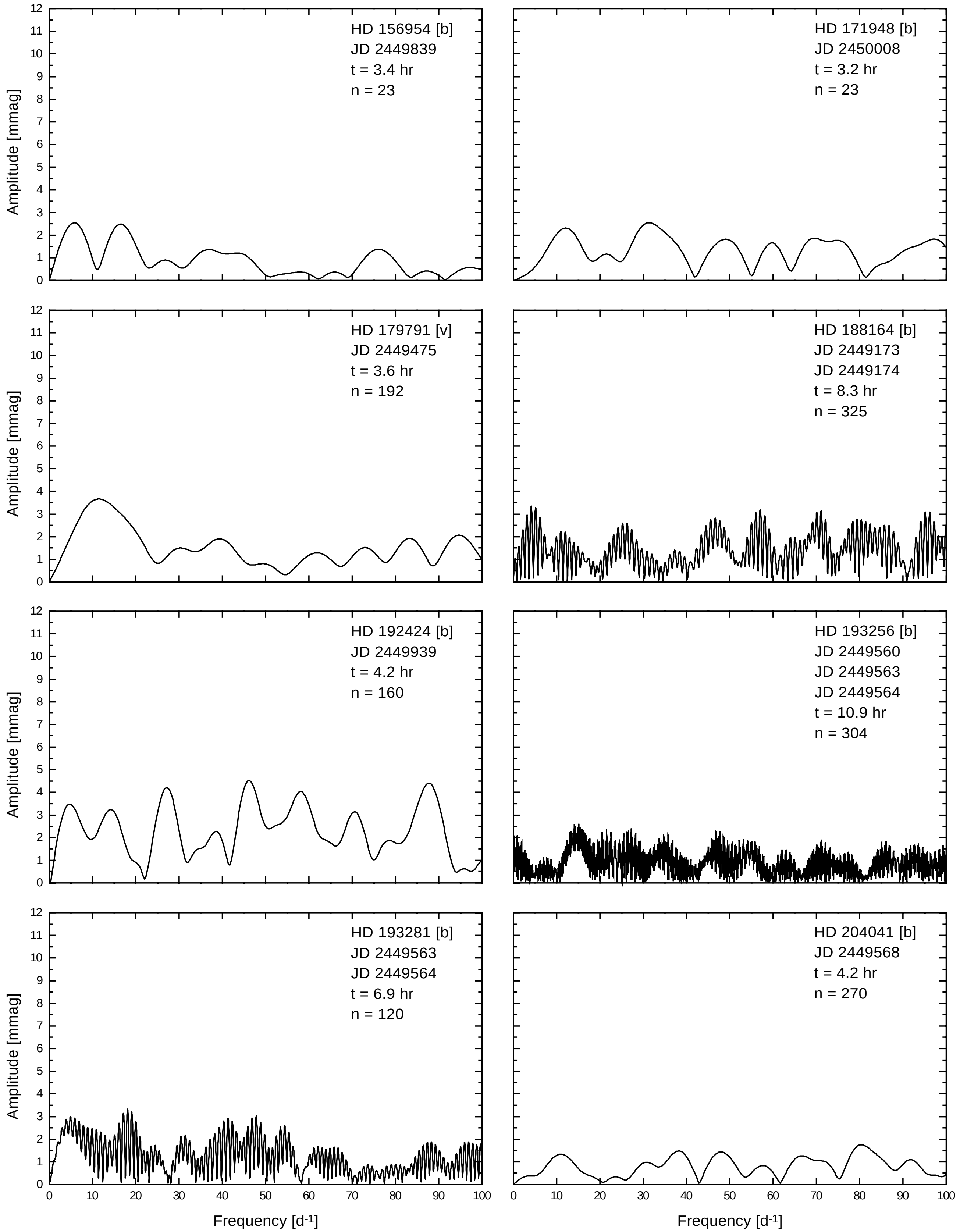

Fig. 4. c) Amplitude spectra for candidate stars. Listed are the HD number, used filter, Julian date, duration and number of observations as given in Table 1

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