A&A 458, L17–L20 (2006)
DOI: 10.1051/0004-6361:20066195

Astronomy
&
Astrophysics

LETTER TO THE EDITOR

On the λ Bootis spectroscopic binary hypothesis

Ch. Stütz and E. Paunzen

Institut für Astronomie der Universität Wien, Türkenschanzstr. 17, 1180 Wien, Austria
e-mail: `Ernst.Paunzen@univie.ac.at`

Received 6 August 2006 / Accepted 29 August 2006

ABSTRACT

Context. It is still a matter of debate whether the group of λ Bootis stars have been homogeneously defined. A widely discussed working hypothesis postulates that two apparent, solar-abundant stars of an undetected spectroscopic binary system mimic a single metal-weak spectrum thus preventing any reliable analysis of the group characteristics.

Aims. We investigate whether the proposed spectroscopic binary model can explain the observed abundance pattern as well photometric metallicity indices and what the percentage of undetected spectroscopic binary systems is.

Methods. We used the newest available stellar atmospheres to synthesize 105 hypothetical binary systems in the relevant astrophysical parameter range. These models were used to derive photometric indices. As a test, values were generated for single stellar atmospheres, Vega and two typical λ Bootis stars, HD 107233 and HD 204041.

Results. The synthesized indices fit the standard lines and the observations of the three stars excellently. For about 90% of the group members, the spectroscopic binary hypothesis cannot explain the observations.

Conclusions. A careful preselection of λ Bootis stars results in a homogeneous group of objects that can be used to investigate the group characteristics.

Key words. stars: chemically peculiar – stars: early-type – techniques: photometric – stars: atmospheres – stars: binaries: general

1. Introduction

More than 60 years after the peculiar nature of λ Bootis (HR 5351) itself was made clear in the spectral classification survey by Morgan et al. (1943), the origin and even the existence of a homogeneous group of λ Bootis stars is still a matter of debate. Several theories were developed to explain the main characteristic of this group which comprises main sequence late B to early F type stars: the lighter elements (C, N, O, and S) are solar abundant, whereas the heavier elements are significantly underabundant (Paunzen 2004).

In this letter we quantify the hypothesis formulated by Faraggiana & Bonifacio (1999) and Gerbaldi et al. (2003) that some, if not all, λ Bootis stars are in fact undetected spectroscopic binary systems with two solar-abundant components simulating a combined single-lined metal-weak spectrum.

2. The group of λ Bootis stars and the spectroscopic binary hypothesis

The λ Bootis stars are a very extraordinary group on the upper main sequence. It comprises only 2% or less of all objects in the relevant spectral domain and the only difference from normal type stars is the abundance pattern. These stars have moderate to extreme (up to a factor 100) surface underabundances for most Fe-peak elements (with the exception of Na) and solar abundances of lighter elements (C, N, O, and S).

Our working group has tried to establish unambiguous membership criteria and to sort out misclassified objects cumulating in the list published by Paunzen et al. (2002). At this time, we believe it includes the most probable members on the basis of various membership criteria, 57 in all. However, the known spectroscopic binary systems have already been excluded (see Sect. 2 therein). We have to emphasize that this list is not an "ultimate one" but it was compiled on the basis of observational evidence, e.g. results from spectral classification (Paunzen 2001), starting from the first catalogues by Renson et al. (1990) and Paunzen et al. (1997).

The origin of the peculiar elemental abundances for the λ Bootis group can be explained by the selective accretion of circumstellar or interstellar material (Venn & Lambert 1990; Waters et al. 1992; Kamp & Paunzen 2002; Andrievsky 2006). This scenario is widely accepted to date. However, the issue still remains as to whether the group itself is homogeneously defined as originally questioned by Gerbaldi et al. (2003). Their working group has formulated the hypothesis that the tendency to detect lower abundances for numerous elements in high-resolution spectroscopy abundance analysis might be explained by assuming an unidentified (or unidentifiable) binary system of two "normal" (solar abundant) stars with similar spectral type. As a consequence, they conclude that the group of λ Bootis stars consists of single type objects and an unknown, but probable high percentage of undetected spectroscopic binary systems.

In the following we investigate this hypothesis by comparing synthetic photometric indices of binary systems to those of apparent group members.

3. Modelling the spectroscopic binary systems

The working hypothesis is fairly simple: a spectroscopic binary system with two solar abundant components has to simulate the total energy flux distributions and thus the photometric colors of an apparent single λ Bootis star.

Table 1. Parameter space used for the models and the astrophysical parameters of the standard star Vega and the λ Bootis stars HD 107233 and HD 204041.

	Models	Vega	107233	204041
T_{eff} [K]	7000–9000	9560	6900	8100
$\log g$ [cgs]	3.50–4.50	4.05	3.80	4.10
υ_{turb} [km s^{-1}]	2	2	3	2
Convection	Canuto & Mazzitelli (1991)			

Table 2. Location of the stars according to Fig. 1. The results for the individual stars are listed in Table 3.

Diagram	(1)	(2)	(3)	(4)	(5)	(6)
Δa	−	−	−			
$\Delta(V1-G)/Z$	−	−	+/−	+/−	+	
m_1/m_2	−		−	−	+	
m_1						+/−

A plus sign means that the objects are located within the area of the spectroscopic binary models.

Table 3. The results for λ Bootis stars taken from Paunzen et al. (2002) according to Fig. 1 and Table 2. We would only consider the stars of group (5) as good candidates for undetected spectroscopic binary systems, and no conclusion can be drawn for group (6).

(1)	(2)	(3)	(4)	(5)	(6) a.
6870	319	31295	111604	23392	13755 **P**
11413	7908	35242	156954	110377	15165 **P**
24472	30422	101108	193256	170680	54272 **P**
75654	74873		193281	198160	87271 **P**
81290	91130				90821 **F**
83041	110411				105759 **P**
83277	125162				111005 **P**
84123	130767				120500 **F**
102541	183324				120896 **P**
105058	204041				175445 **F**
106223	221756				
107233					
109738					
125889					
142703					
142994					
149130					
153747					
154153					
168740					
168947					
184779					
192640					
210111					
216847					
44%	19%	5%	7%	7%	18%

a. **P**assed (intrinsic λ Bootis) or **F**ailed (undetected binary system); The last row contains the percentage of objects as part of the total sample.

To investigate the chances of λ Bootis stars being disguised binary systems, we modelled a set of stars spanning the range in fundamental parameters (Table 1) populated by λ Bootis stars (Paunzen et al. 2002). The turbulent velocity was fixed at a value of 2 km s^{-1} and convection was modelled according to Canuto & Mazzitelli (1991, hereafter CM) since we are situated in the region of weak to no convection. To model the atmospheres, as well as the energy flux distribution of these stars and of our photometric anchor Vega, we used the code LLmodels v.SE/8.0 (Shulyak et al. 2004). This model atmosphere code supports individual chemical composition, VCS theory (Vidal et al. 1973; Lemke 1997) for the treatment of Hydrogen lines, and the CM convection treatment. To represent the atomic line opacities, we created a separate linelist for each model. The line parameters were obtained from the Vienna Atomic Line Database (VALD, Kupka et al. 1999). All lines were selected for which $l_\nu/\alpha_\nu \geq 1\%$ (l_ν and α_ν are line and continuum absorption coefficient) was realized for the given model structure. The step size in wavelength of our synthetic spectra was set to 0.1 Å.

We built energy flux distributions of 105 hypothetical binary stars by preparing all possible combinations of always two spectra. On these, we performed synthetic photometry for the Strömgren-Crawford $uvby\beta$, Maitzen Δa (Paunzen et al. 2005), and the Geneva 7-color system. As is common practice, Vega was our reference point for the synthetic photometry. We modelled this star's atmosphere according to the parameters of Hill & Landstreet (1993), and the observed photometric indices were acquired from the SIMBAD and GCPD astronomical databases.

To also show a comparison to synthesized intrinsic λ Bootis stars we modelled the stars HD 107233 and HD 204041 with the parameters and abundances listed in Heiter et al. (2002).

For our statistical analysis we did not take the reddening into account. Gerbaldi et al. (2003) have discussed the problems extensively using the standard Strömgren-Crawford $uvby\beta$ dereddening procedures for the group of λ Bootis stars. We compared their values with those of Paunzen et al. (2002) and found a good agreement. However, the reddening for most objects is negligible because they are all located in the solar neighborhood.

4. Results and conclusions

Figure 1 shows the results of the relevant photometric diagrams. The observational data for the λ Bootis stars were taken from Paunzen et al. 2002. The classical metallicity sensitive diagrams m_1 versus $(b-y)$ and m_2 versus $(B2-V1)$ show that for cooler objects, the λ Bootis stars are nicely separated from the models on the main sequence (see c_1 versus $(b-y)$). These observational facts were also described in Paunzen et al. (1997).

Very interesting are the other three diagrams that include directly metallicity depend indices (Paunzen et al. 2005). The most important index is Δa, for which, unfortunately, the least measurements are available whereas $\Delta(V1-G)$ seems less sensitive with a larger scatter. We notice that Vega – as a metal-deficient object (Hill & Landstreet 1993; García-Gil et al. 2005) – shows, as expected, a reduced Δa value. Otherwise, the standard lines and observations of Vega fit the synthetic values very closely. The differences between the synthetic and observed values for the two λ Bootis stars are only 1 to 2 mmag for Δa, Z, and $\Delta(V1-G)$.

According to Fig. 1 we divided our sample into six different groups numbered from (1) to (6) depending on whether the placement is compatible with the spectroscopic binary models when taking an error of ±5 mmag into account. The final division is listed in Table 2 whereas Table 3 shows the results for the individual stars. The first two groups include objects that are not located in the spectroscopic binary area (SBA hereafter) in any diagram. The third and fourth groups include stars that are situated in the SBA either in the $\Delta(V1-G)$ or in the Z diagram, but not in the classical metallicity and the Δa diagram or else they do not have an available Δa measurement

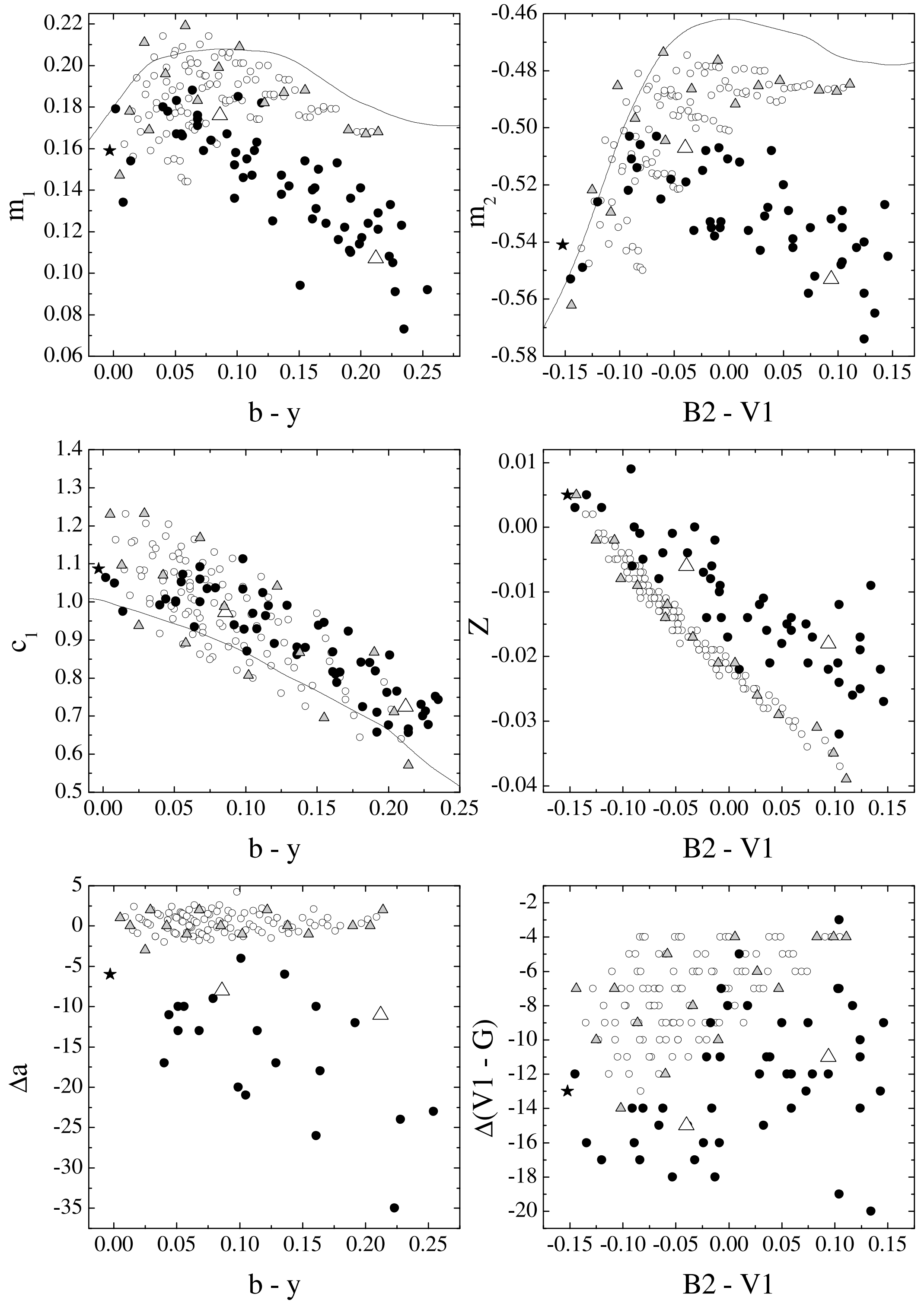

Fig. 1. A comparison of the synthetic Strömgren-Crawford *uvbyβ*, Maitzen Δa (*left panels*) and the Geneva 7 color system (*right panels*) with the observations for the group of λ Bootis stars (full circles). The open circles are the binary models, whereas the grey shaded triangles are the single-star models used to construct them. Vega is marked with an asterisk, the two synthetic "standard" λ Bootis stars are open triangles. The standard lines are from the literature.

(fourth group). The fifth group comprises good candidates for undetected spectroscopic binaries among the λ Bootis group because these stars compare well to the synthetic photometry of the binary models. HD 198160 is already known as a close visual binary star, whereas inconsistent $v \sin i$ measurements were reported by Heiter et al. (2002) for HD 170680. The four objects in this group certainly deserve more attention in the future. The last group includes those stars that could only be tested within the m_1 versus $(b-y)$ diagram, which prevents any clear conclusion.

If we compare the list of Table 3 with the results of Faraggiana et al. (2004), only two stars, HD 11413 and HD 210111, were reported as spectroscopic binary systems on the basis of radial velocity shifts of two and three spectra, respectively. Both are well-investigated δ Scuti pulsators (Koen et al. 2003; Breger et al. 2006), which makes them especially interesting for further investigations. We conclude that, if these stars are indeed binary systems, at least one component is of a λ Bootis type similar to the systems investigated by Iliev et al. (2002).

The percentage of undetected spectroscopic binary systems mimicking a single, metal-weak object seems very low. From 47 well-investigated stars, groups (1) to (5), only four objects seem good candidates for further investigation, which is lower than 10% of the complete sample. A careful preselection of λ Bootis stars results in a homogeneous group of intrinsic λ Bootis stars that can be used to investigate the group properties in more detail.

Acknowledgements. This research was performed within the projects *P17580*, *P17890* and *P17920* of the Austrian Fonds zur Förderung der wissenschaftlichen Forschung (FwF). Use was made of the SIMBAD database, operated at the CDS, Strasbourg, France, of NASA's Astrophysics Data System, and of the General Catalogue of Photometric Data (GCPD).

References

Andrievsky, S. M. 2006, A&A, 449, 345
Breger, M., Beck, P., Lenz, P., et al. 2006, A&A, 455, 673
Canuto, V. M., & Mazzitelli, I. 1991, ApJ, 370, 295
Faraggiana, R., & Bonifacio, P. 1999, A&A, 349, 521
Faraggiana, R., Bonifacio, P., Caffau, E., Gerbaldi, M., & Nonino, M. 2004, A&A, 425, 615
García-Gil, A., García, L., Ramón, J., Allende Prieto, C., & Hubeny, I. 2005, ApJ, 623, 460
Gerbaldi, M., Faraggiana, R., & Lai, O. 2003, A&A, 412, 447
Grevesse, N., & Sauval, A. J. 1998, Space Sci. Rev., 85, 161
Heiter, U. 2002, A&A, 381, 959
Heiter, U., Weiss, W. W., & Paunzen, E. 2002, A&A, 381, 971
Hill, G. M., & Landstreet, J. D. 1993, A&A, 276, 142
Iliev, I. K., Paunzen, E., Barzova, I. S., et al. 2002, A&A, 381, 914
Kamp, I., & Paunzen, E. 2002, MNRAS, 335, L45
Koen, C., Paunzen, E., van Wyk, F., Marang, F., Chernyshova, I. V., & Andrievsky, S. M. 2003, MNRAS, 338, 931
Kupka, F., Piskunov, N., Ryabchikova, T. A., Stempels, C., & Weiss, W. W. 1999, A&AS, 138, 119
Lemke, M. 1997, A&AS, 122, 285
Morgan, W. W., Keenan, P. C., & Kellman, E. 1943, An Atlas of Stellar Spectra (Chicago: University of Chicago Press)
Paunzen, E. 2001, A&A, 373, 633
Paunzen, E., Weiss, W. W., Heiter, U., & North, P. 1997, A&AS, 123, 93
Paunzen, E., Iliev, I. Kh., Kamp, I., & Barzova, I. S. 2002, MNRAS, 336, 1030
Paunzen, E. 2004, in Proc. IAU Symp. 224, ed. J. Zverko, J. Ziznovsky, S. J. Adelman, & W. W. Weiss, 443
Paunzen, E., Stütz, Ch., & Maitzen, H. M. 2005, A&A, 441, 631
Renson, P., & Faraggiana, R., & Böhm, C. 1990, Bull. Inform. CDS 38, 137
Shulyak, D., Tsymbal, V., Ryabchikova, T., Stütz, Ch., & Weiss, W. W. 2004, A&A, 428, 993
Venn, K. A., & Lambert, D. L. 1990, ApJ, 363, 234
Vidal, C. R., & Cooper, J., & Smith, E. W. 1973, ApJS, 25, 37
Waters, L. B. F. M., & Trams, N. R., & Waelkens, C. 1992, A&A, 262, L37