Is the proposed spectroscopic binary model able to explain the observed abundance pattern and photometric metallicity indices for the group members? What is the percentage of undetected spectroscopic binary systems?

We have 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 for single stellar atmospheres, Vega and two typical Λ Bootis stars, HD 107233 and HD 204041, were generated. 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. A carefully preselection of Λ Bootis stars results in a homogeneous group of objects which can be used to investigate the group characteristics.

**Key words.** Stars: chemically peculiar – stars: early-type – techniques: photometric
On the $\lambda$ Bootis spectroscopic binary hypothesis

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Received 07 August 2006 / Accepted 29 August 2006

Abstract. It is still a matter of debate if the group of $\lambda$ Bootis stars is homogeneously defined. A widely discussed working hypothesis formulates that two apparent solar abundant stars of an undetected spectroscopic binary system mimic a single metal-weak spectrum preventing any reliable analysis of the group characteristics.

1. Introduction

More than 60 years after the first notification of the peculiar nature of $\lambda$ Bootis (HR 5351) itself was addressed in the spectral classification survey by Morgan et al. (1943) the origin and even the existence of a homogeneous group of $\lambda$ Bootis stars is still a matter of debate.

Several theories were developed to explain the main characteristic of this group which comprise of 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, $\lambda$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 $\lambda$ Bootis stars and the spectroscopic binary hypothesis

The group of $\lambda$ Bootis stars is quite outstanding on the upper main sequence. It comprises only 2% or less of all objects in the relevant spectral domain and the only difference to normal type stars is the abundance pattern. These stars have moderate to extreme (up to a factor 100) surface underabundances of 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 total. However, the known spectroscopic binary systems were already excluded (see Section 2 therein). We have to emphasize that this list is not an “ultimate list” but was compiled on the basis of observational evidence, e.g. results from spectral classification (Paunzen 2001), starting from the first catalogues by Renson, Faraggiana & Böhm (1990) and Paunzen et al. (1994).

The origin of the peculiar elemental abundances for the $\lambda$ Bootis group can be explained by selective accretion of circumstellar or interstellar material (Venn & Lambert 1990, Waters, Trams & Waelkens 1992, Kamp & Paunzen 2002, Andrievsky 2006). This scenario is widely accepted to date. However, the issue still remains whether the group itself is homogeneously defined as addressed 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 $\lambda$ 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 rather 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 $\lambda$Booits star.

To investigate the chances of $\lambda$Bootis stars being disguised binary systems, we modelled a set of stars spanning the range in fundamental parameters (Table I) populated by $\lambda$Bootis stars (Paunzen et al. 2002). The turbulent velocity was fixed at a value of 2 km s$^{-1}$, convection was modelled according to Canuto & Mazzitelli (1991 hereafter CM) since we are situated in the re-
Fig. 1. A comparison of the synthetic Strömgren-Crawford $uvby\beta$, Maitzen $\Delta a$ (left panels) and the Geneva 7 color system (right panels) with the observations for the group of $\lambda$ 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 as asterisk, the two synthetic “standard” $\lambda$ Bootis stars are open triangles. The standard lines are from the literature.
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, Cooper & Smith 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 where obtained form the Vienna Atomic Line Database (VALD, Kupka et al. 1999). All lines for which $\nu/\alpha \geq 1$ ($\ell_{\nu}$ and $\alpha_{\nu}$ are line and continuum absorption coefficient) was realized for the given model structure were selected. 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 $\Delta a$ (Paunzen, Stütz & Maitzen 2005) and the Geneva 7-color system. As it is common practice, Vega was our reference point for the synthetic photometry. We modelled this stars atmosphere according to the parameters of Hill & Landstreet (1993), the observed photometric indices were 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).

We would only consider the stars of group (5) as being good candidates for undetected spectroscopic binary systems. No conclusion can be drawn for group (6), the abbreviations are P assed or F ailed. The last row contains the number of objects as part of the total sample.

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

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

### Table 2. Location of the stars according to Figure 1. A plus sign means that the objects are located within the area of the spectroscopic binary models. The results for the individual stars is listed in Table 3.

### Table 3. The results for $\lambda$ Bootis stars taken from Paunzen et al. 2002 according to Figure 1 and Table 2. We would only consider the stars of group (5) as being good candidates for undetected spectroscopic binary systems. No conclusion can be drawn for group (6), the abbreviations are P assed or F ailed. The last row contains the number of objects as part of the total sample.

4. Results and Conclusions

Figure 1 shows the results of the relevant photometric diagrams. The observational data for the $\lambda$ 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 $\lambda$ Bootis stars are

Very interesting are the other three diagrams which include directly metallicity depend indices (Paunzen et al. 2005). The most important index is $\Delta a$, for which, unfortunately, the least measurements are available whereas $\Delta (V1-G)$ seems less sensitive with a larger scatter. We notice that Vega as metal-deficient object (Hill & Landstreet...
According to Figure 1, we have divided our sample in six different groups numbered from (1) to (6) depending if the placement is compatible with the spectroscopic binary models 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 which are not located in the spectroscopic binary area (SBA hereafter) in any diagram. The third and fourth group include stars which are situated in the SBA either in the (V1 - G) or Z diagram, but not in the classical metallicity and the Δa diagram or do not have an available Δa measurement (fourth group). The fifth group comprise 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 close visual binary whereas inconsistent $\sin i$ measurements were reported by Heiter et al. (2002) for HD 170680. The four binary star whereas inconsistent 455 mmag into account.

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 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 a further investigation which is below 10% of the complete sample.

A carefully preselection of λ Bootis stars results in a homogeneous group of intrinsic λ Bootis stars which can be used to investigate the group properties in more detail.

References

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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, the NASA’s Astrophysics Data System and the General Catalogue of Photometric Data (GCPD).