The λ Bootis stars

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Abstract. In this article the current knowledge of the group of λ Bootis stars is reviewed. These metal poor objects are quite outstanding compared to other chemically peculiar stars of the upper main sequence. Up to now no theory has been developed which is able to explain the majority of observational results. This article is mainly focused on the work which needs to be done in the future in order to clarify the λ Bootis phenomenon.

Key words: Stars: λ Bootis – Stars: chemically peculiar – Stars: early type

1. Introduction

This group of metal poor stars was introduced with the identification of an 'abnormal' spectrum for λ Bootis (Figure 1) in the classification survey of Morgan et al. (1943). Meanwhile, more stars with the same peculiarities were discovered, in particular when the available spectral region was extended to the red and beyond the optical region towards the IR and to the UV.

This flood of additional information is helpful on the one hand in providing more physical evidence needed to understand the nature and evolution of this group of stars, on the other hand it resulted also in obscuring the group of λ Bootis stars by objects which definitely have not much in common with the prototype. Confusion peaked in the eighties, when the group of λ Bootis stars degenerated to a sort of trash can for stars which could not be classified otherwise. This development is described in reviews on λ Bootis stars by Gerbaldi & Faraggiana (1993) and Gray (1997).

This was also the reason for a general discussion about the definition of λ Bootis stars at this workshop. In the following I will give my personal point of view summarizing the observational facts and proposed theories.

2. Working definition

It is evident that a homogeneous and statistically sufficiently large catalogue of λ Bootis stars is required before applying any statistically sound analysis. Therefore, the compilation of such a catalogue (Paunzen & Gray 1997; Paunzen et al. 1997) was the first goal and a λ Bootis classification criterion had to be extracted from what appears to be a consensus:

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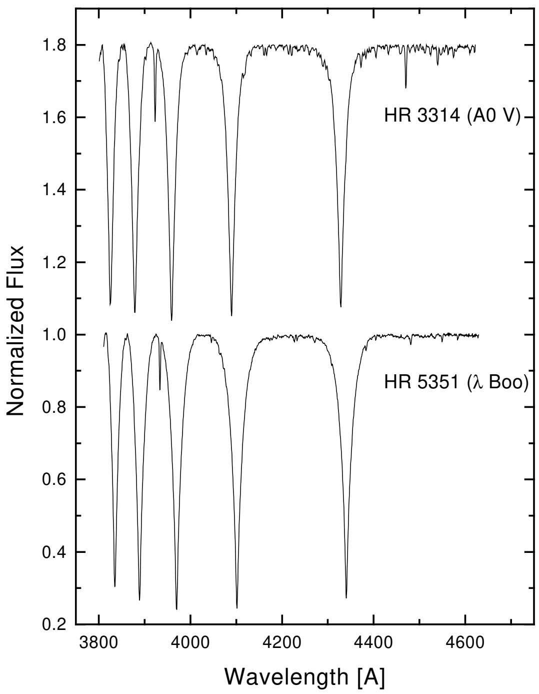

Figure 1. Intermediate resolution spectrum of λ Bootis and of a corresponding MK standard star.

λ Bootis stars are Pop. I, A- to F-type, metal poor stars,
with solar abundances of C, N, O and S.

The spectral types are easily translated into $T_{\rm eff}$ and $\log g$ values which can be estimated fairly accurately with photometric indices or on spectroscopic grounds. No restriction is chosen for the luminosity class, because it remains to be determined in a survey, to what extent the λ Bootis phenomenon is limited to the main-sequence or includes also evolved stars.

Pop. I criterion is more problematic. Evidence have been compiled by Michaud & Charland (1986) for this property, however, for a rather small sample. The arguments were low radial velocities and U, V and W velocities which are typical of Pop. I. We were able to confirm that λ Bootis stars have a similar $v \sin i$ distribution (Paunzen et al. 1997) as is typical of luminosity class IV and V stars in our solar neighbourhood. Periods of pulsating λ Bootis stars are similar to (Pop. I) δ Scuti stars (Paunzen et al. 1998), which indicates that the spectral peculiarities are restricted only to the stellar atmosphere and not to the stellar interior. Some authors prefer to substitute the 'Pop. I' criterion by 'dwarf', but that might introduce bias when testing λ Bootis theories by excluding evolved stars systematically. The same argument applies to 'core hydrogen burning stars'. I have chosen to retain the Pop. I criterion which is also used in the astronomy and astrophysics reference handbook: Landolt-Börnstein (Seitter & Dürbeck 1982). Basically, 'Pop. I' means in the context of the definition of λ Bootis stars that the observed low metallicity is only a surface phenomenon of otherwise solar abundant stars.

Several additional peculiarities were found (reviewed by Gerbaldi & Faraggiana 1993) for subsets of λ Bootis stars which, however, should not be considered as primary classification indicators, as they are either a consequence of the chosen definition, or detectable only for extreme cases, or are incorrect. An example for the first is the 160 nm spectral feature which is caused by a quasimolecular absorption leading to a satellite in the Lyα profile due to perturbation by neutral Hydrogen. Detectability in λ Bootis stars is possible due to reduced line blending caused by the low metallicity (Holweger et al. 1994). For the second type of criterion one can refer to an IR excess observed above a 2σ level with IRAS (King 1994) for only 2 out of the 20 λ Bootis stars in the membership lists. An example for the last type of criterion are the 'very large $v \sin i$ values' attributed to λ Bootis stars which are not corroborated by investigations of Abt & Morrell (1995) and Paunzen et al. (1997).

Spectral features typical for circumstellar shells have been identified in five out of eleven observed λ Bootis stars by Holweger & Rentzsch-Holm (1995). In at least one case (HD 111786) evidence is controversial and may be actually caused by an SB2 system (Faraggiana et al. 1997).

3. Photometric properties

Narrow band photometry has often been used to distinguish chemically peculiar from normal stars. The Strömgren (Fig. 2, 3) as well as the Geneva photometric systems provide estimates of temperature, surface gravity and chemical composition of stars. However, these calibrations were derived for *normal* stars with *solar abundances*. Nevertheless, the conclusions from the Figures mentioned are:

- *Metallicity:* All members have a low metallicity which decreases with temperature. A photometric parameter space which includes all candidate stars is well determined.

- *Temperature:* The temperature ranges from early A V to early F V stars.

- *Surface gravity:* λ Bootis stars cannot be distinguished from normal dwarf stars.

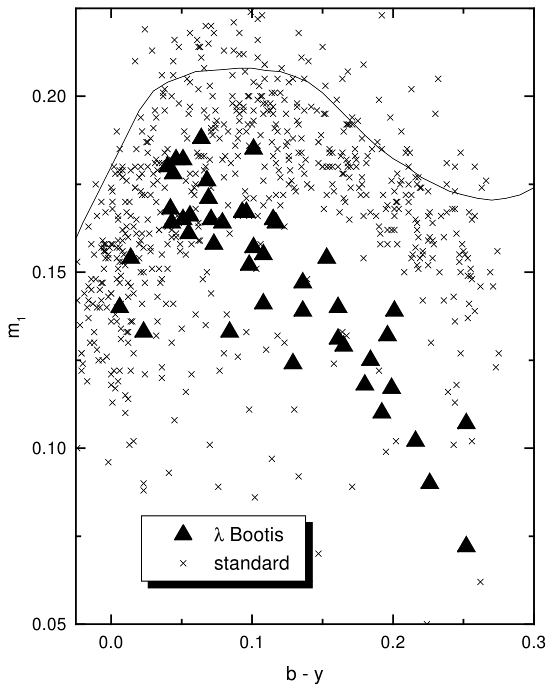

Figure 2. m_1 versus $b-y$. Crosses are normal stars from Gray & Garrison (1987, 1989a,b), filled triangles are λ Bootis stars from Paunzen et al. (1997) and Paunzen & Gray (1997). The standard line is taken from Philip & Egret (1980)

– *Confusion with non-λ Bootis stars:* As is also obvious from the Figures, other stars populate the same parameter space. An unambiguous detection of λ Bootis stars with standard photometry alone is impossible, although to some extend a discrimination with metallicity sensitive indices is useful (e.g. the Δa index was found to be negative for all λ Bootis stars by Maitzen & Pavlovski 1989a,b). But such attempts have led in the past to many spurious entries in various catalogues and to confusion in the subject.

In parallel to the photometric observations needed for the colour indices, the photometric stability of the catalogue stars was also investigated. Altogether, 52 programme stars have been used to analyze the pulsation properties of λ Bootis stars (Paunzen et al. 1998). Using observational (M_V vs. $b-y$) and calibrated

($\log(L/L_\odot)$ vs. $\log T_{\rm eff}$) diagrams, a ratio of variable to nonvariable members of at least 50 % was derived inside the classical instability strip.

The location of all known pulsating programme stars in a $\log(\rho/\rho_\odot)$ vs. $\log P$ diagram is consistent with those of (solar abundant) δ Scuti stars which supports the hypothesis that the λ Bootis abundance pattern (see the article by U. Heiter in this proceedings) is restricted to the stellar surface. The possibly excited modes range from the fundamental mode up to high overtones. Otherwise no outstanding behaviour compared to δ Scuti stars seems to be present.

These results encourage us to apply the tools of asteroseismology in order to secure information about the evolutionary status and the *overall* chemical composition of λ Bootis stars.

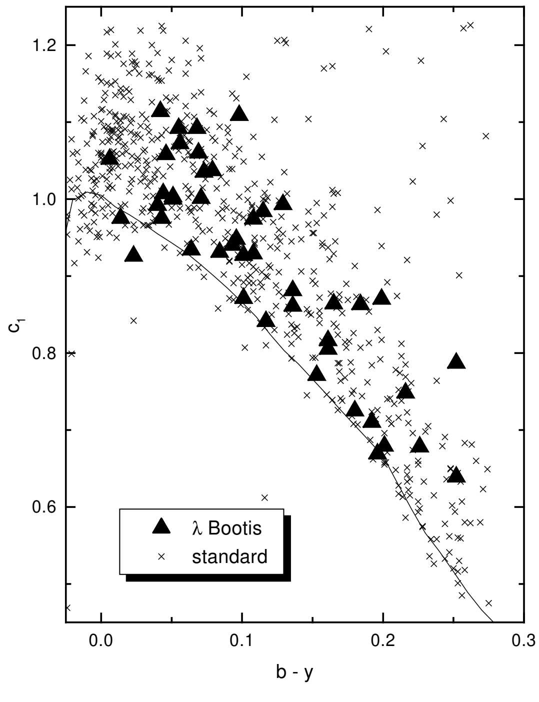

Figure 3. c_1 versus $b-y$. Symbols are the same as in Fig. 2

4. Other observational results

In this section I would like to give a summary of observational results found for λ Bootis stars. Most of these properties are *not* shared by all members. Please note that the number of members is still small (less than 50), making the conclusions preliminary.

- *Ultraviolet region:* Strong absorption features for some members (Faraggiana et al. 1990) at 160 and 304 nm were found. These features are not unique for this group. IUE low resolution spectra help to distinguish λ Bootis from FHB stars (Solano & Paunzen 1998).
- *Optical domain:* No magnetic field was found so far (Bohlender & Landstreet 1990). Indications of a gas shell for five out of eleven members were detected. Pulsation is a common fact for λ Bootis stars inside the classical instability strip. Three SB systems with λ Bootis type components are known.
- *Infrared region:* There are only two λ Bootis stars with a prominent IR excess known. Recent ISO results indicate more candidates.

For more details refer to the reviews by Gerbaldi & Faraggiana (1993) and Gray (1997).

5. Theories about the λ Bootis phenomenon

Two competing theories were developed in order to understand the origin of the λ Bootis phenomenon.

The original diffusion/mass loss theory advanced by Michaud & Charland (1986) produced λ Bootis stars only at the *end* of their main sequence lifetimes. They showed that a mass loss rate of about 10^{-13} solar masses per year together with diffusion in the stellar atmosphere can actually lead to the observed underabundances of elements after 10^9 years. According to their theory, λ Bootis stars have to be old and evolved stars.

Alternatively, Venn & Lambert (1990) suggested that the λ Bootis phenomenon is associated with the accretion of metal-depleted gas from the interstellar medium. Charbonneau (1991) has shown that this theory can also produce λ Bootis stars, but contrary to the theory of Michaud & Charland, these stars would be *unevolved* λ Bootis stars at the ZAMS. It is of considerable significance that Gray & Corbally (1993) discovered the first clear example of a λ Bootis star on the ZAMS of the Orion OB1 association. Recently, further members of this group were detected in young open clusters such as Blanco 1 and NGC 2264 (Paunzen & Gray 1997). These discoveries strengthen the hypothesis that the λ Bootis phenomenon is related to an evolutionary phase associated with the arrival of a star on the ZAMS, and in particular this seems to rule out the diffusion/mass loss theory. This is in accordance with the suggestion by King & Patten (1992) that λ Bootis stars may be connected to β Pictoris and/or Vega-type stars. On the other hand, the range of stellar ages in which the λ Bootis phenomenon occurs is *not* well established.

Very recently, Andrievsky (1997) suggested that λ Bootis stars might be 'products' of W UMa binary systems. According to this theory, λ Bootis stars are remnants of close (interacting) binary systems resulting in *evolved* stars.

With the new Hipparcos data it was possible to establish that at least six stars are *very close to the Zero Age Main Sequence*. Details can be found in the articles of E. Paunzen and A.E. Gómez in these proceedings.

6. What needs to be done?

There are some points which are important in order to solve the still open questions about the λ Bootis phenomenon. In the following I will review some of them:

– *Homogenity of the group:* Further members have to be established (on the grounds of as many criteria as possible) in order to improve any statistics. This has to be done as an iterative process, keeping the criteria as "free parameters".

– *Common properties:* After one has established a homogenous group of stars as large as possible, their common properties have to be studied. An analysis of some parameters (e.g.: $v \sin i$ distribution, behaviour in the infrared, abundance pattern) might help to clarify the physical processes responsible for this phenomenon.

– *Evolutionary state:* In order to test any proposed theory it is essential to know the evolutionary state of this group. Finding λ Bootis stars in open clusters seems the best way to do so. Calibrations of ages using (theoretical) models always suffer from approximations (e.g. rotation, overshooting).

– *Theories:* Using these new boundary conditions, theories might be improved taking all observational results into account.

This workshop has demonstrated an increasing interest in this group. I hope that many members of our working group are able to contribute in this field.

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