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1. Introduction

This group of metal poor stars were introduced with the identification of an 'abnormal' spectrum for λ Boötis in the famous classification survey of Morgan, Keenan & Kellman (1943) based on a blue sensitive photographic emulsion. More stars were discovered with comparable spectra and with other peculiarities, 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 nature and evolution of this group of stars, on the other hand it resulted also in obscuring the group of λ Boötis stars by objects which definitely have not much in common with the prototype. Confusion peaked in the 80ieth, when the group of λ Boötis stars degenerated to a sort of trash can for stars which could not be classified otherwise. This development is nicely described in a review on λ Boötis stars by Gray (1997).

2. Defining the group of λ Boötis stars

Two main directions in modelling the phenomenon have developed, both being based on gravitational settling of chemical elements in a radiation field. Diffusion was successful in explaining the surface characteristics of AmFm stars, HgMn and of other chemically peculiar stars (see reviews by Alecian 1993, Babel 1993, Michaud & Proffitt 1993). For λ Boötis stars in contrary, a *depletion* of the heavy elements is needed, which requires to invoke at least one addition mechanism. Mass loss was assumed by Michaud & Charland (1986) to be this mechanism and they determined that $\dot{M} \geq 10^{-13} M_{\odot} yr^{-1}$ results in underabundances of most heavy elements by a factor of up to three after about 10^{8}yr. However, when rotation was included to the models (Charbonneau 1993) development of the characteristic underabundance pattern of λ Boötis stars was prevented by meridional circulation at any epoch of the main-sequence evolution. Furthermore, Gray & Corbally (1993) identified one very young λ Boötis star in the Orion OB1 association ($t \approx 5 \cdot 10^{6}$yr) which, for the first time, clearly contradicts the evolutionary scale predicted by the diffusion/mass-loss model.

Noting the similarity between the λ Boötis abundance pattern and that of the interstellar gas, Venn & Lambert (1990) proposed accretion of metal depleted gas from a circumstellar shell as alternative mechanism responsible for the λ Boötis phenomenon. This model was put on more firm grounds by Charbonneau (1991) and Turcotte & Charbonneau (1993) who demonstrated for a (Pop. I) dwarf star with $T_{\rm eff} = 8000$ K and $\dot{M} \geq 10^{-13} M_{\odot}$ yr that the photospheric abundances reflect that of the accreted matter as long as this process is ongoing or at least has not ceased earlier than $\approx 10^{6}$yr ago.

The virtue of a theory is the possibility for a comparison of observations with predictions which are, e.g., that for $v_{equat} \geq 270\, km\, s^{-1}$ circulation destroys the accreted abundance pattern, that the cool border of the λ Boötis phenomenon depends on the *total* amount of accreted mass and neither on $\dot{M}$ nor on the element. The hot border is caused by diffusion being stronger than accretion, and hence is expected to be element dependent. One also would expect to find indications for a circumstellar shell (CS), and the existence of old λ Boötis stars would be very difficult to reconcile with the accretion/diffusion model.

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Membership criterion: It is evident that a homogeneous and statistically sufficiently large catalogue of λ Boötis stars is required for the needed tests, which cover a wide parameter range in the H-R diagramme. The generation of such a catalogue (Paunzen et al. 1997a,d) therefore was our first goal and a λ Boötis classification criterion had to be extracted from what appears to be consensus:

λ BOÖTIS STARS ARE POP. I, A- TO F-TYPE, METAL POOR STARS,
BUT WHICH HAVE SOLAR ABUNDANT C, N, O AND S.

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

The abundance pattern is well defined and resembles largely to that of the interstellar gas, but one should keep in mind that a similar pattern can also be produced by a non- or slowly rotating star with mass loss. There could be are other scenarios - however not yet considered - which produce a similar abundance pattern. This part of the definition can be tested to a high precision with spectroscopic means, however, with an enormous amount of efforts (e.g., Venn & Lambert 1990, Stürenburg 1993, Paunzen et al. 1997b, Heiter et al. 1997).

More of a problem poses the Pop. I criterion. 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 for Pop. I. We were able to confirm that λ Boötis stars have a similar $v \sin i$ distribution (Paunzen et al. 1997d) as is typical for luminosity class IV and V stars in our solar neighbourhood (Woolf & Simon 1997). Periods of pulsating λ Boötis stars are similar to (Pop. I) δ Scuti stars (Paunzen et al. 1997g), which indicates that the spectral peculiarity is restricted only to the atmosphere. Some authors prefer to substitute the 'Pop. I' criterion by 'dwarf', but that might introduce bias when testing λ Boötis theories by excluding evolved stars systematically. The same argument applies to 'core hydrogen burning stars'. We have chosen to retain the Pop. I criterion which is also used in the astronomy and astrophysics reference handbook: Landolt-Börnstein (Seiter & Dürbeck 1982). Bascially, 'Pop. I' means in the context of our definition of λ Boötis stars that the observed low metallicity is only a surface phenomenon of otherwise solar abundant stars.

Secondary λ Boötis indicators: Several additional peculiarities were found (review by Gerbaldi & Faraggiana 1993) for subsets of λ Boötis 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 Hydorgen. Detectability in λ Boötis 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 Boötis stars in our membership lists. A photometric program presently is carried out by ISO is dedicated to a detection of an IR excess (Weiss et al. 1996). An example for the last type of criterion are the 'very large $v \sin i$ values' attributed to λ Boötis stars which are not corroborated by investigations of Abt & Morrell (1993) and Paunzen et al. (1997d).

Spectral features typical for circumstellar shells have been identified in 5 out of 11 observed λ Boötis stars by Holweger & Rentsch-Holm (1995). In at least one case (HD 111786) evidence are controversial and may be actually caused by a SB2 system (Farragiana et al. 1997).

Possible confusion: If only a limited spectral resolution and/or spectral region are available, confusion of λ Boötis stars with field horizontal-branch stars (FHB) is possible (Corbally et al. 1997). Although the origin of abundances of λ Boötis and FHB stars are different (FHB (Sweigart 1985): primordial abundances were mixed during the preceeding red giant phase into the atmosphere) both groups show a similar pattern of metal deficiency, except for C, N, O and S, which are also underabundant in FHB stars. As was shown by Solano & Paunzen (1997) with IUE low resolution spectra, it is simple to discriminate between λ Boötis and FHB stars if also the latter elements are included in the classification procedure.

Further sources of confusion with λ Boötis stars are post-AGB stars, He-weak, high $v \sin i$ stars, etc. However, higher spectral resolution and in extreme cases a full abundance analysis including C, N, O, and/or S allows for a clear discrimination.

3. Steps towards a better understanding

The need for a large *and* homogeneous catalogue of λ Boötis stars which covers a wide parameter range in the H-R diagram is evident. We therefore started a spectroscopic survey (with R. Gray) and obtained supplementary photometry (with P. North) of λ Boötis star candidates in the field and in clusters of different age (Paunzen et al. 1997a,d). From 44896 entries in the Hauck-Mermillod catalogue, 3100 candiate stars were extracted, of which 1907 candidates remained after a SIMBAD supported cross check with the literature. Including standard stars, classification spectra were obtained for 850 stars till fall 1997, of which 550 are fully reduced and ready for classification. Presently 121 stars were classified independently by R. Gray and EP, of which only 12 stars turned out to be of λ Boötis type which corresponds to about 10% success rate for a preselected sample.

Parallel to this survey high resolution (mostly echelle) spectra were obtained by U. Heiter and EP to investigate, among others, a possible trend of the abundance spectrum with the position of a target star within the H-R diagram - as is predicted for the hot border by the accretion/diffusion theory -, to determine $T_{\rm eff}$ and $\log g$ spectroscopically in order to identify the hot and cool borders of the λ Boötis group, to investigate the incidence of binarity and to extend significantly the range of elements with determined abundances. For this purpose convenient tools were developed in Vienna, as are the Vienna Atomic Line Data Base (VALD: Piskunov et al. 1995), an automatic procedure for determining abundances (AAP: Gelbmann 1997, Gelbmann et al. 1997), and a software package to compute opacity distribution function tables for an atmosphere which does not need to be solar-scaled, but can be that of any given λ Boötis star. So far, two new SB2 systems with λ Boötis components have been discovered and the individual abundances were determined (Paunzen et al. 1997b), for other λ Boötis stars the abundance spectra were extended to more elements and the effect of scaled ODF's on the atmospheric structure was investigated (Heiter et al. 1997).

In our paper on the pulsation of HD 142994 (Weiss et al. 1994) we discussed the diagnostic potential of asteroseismology for λ Boötis stars. A survey to determine the photometric stability was initiated and close to 50% of the λ Boötis stars were found to be pulsating, compared to about 35% which are published for A-type stars for a comparable detection limit. Results on *non*-pulsating (Paunzen et al. 1997c) and on pulsating members (Paunzen et al. 1997e, g) further support the Pop. I classification criterion for λ Boötis stars, because all pulsation properties are in agreement with $Z = 0.02$ models. For HD 111786 and HD 142994 we organized an international observing campaign and the analysis (Paunzen et al. 1997f) again lends credibility to the Pop. I criterion. Most, if not all, pulsating λ Boötis stars seem to be multi-mode pulsators, a result which is supported by Bohlender et al. (1996 and priv. comm.) who find periodic spectral line profile variations. The largest contemporaneous photometric and spectroscopic campaing presently is organized by D. Mkrtichian for 29 Cygni.

Important boundary conditions for the evolutionary status of λ Boötis stars can be drawn from spectroscopic surveys in clusters and associations (Gray & Corbally 1989, Paunzen & Gray 1997, Gray & Paunzen priv. comm.). In the Orion OB1 association ($\leq 5 \cdot 10^6$ yr) the authors found 4 λ Boötis stars, in NGC 2264 ($\leq 10^7$ yr) 2 λ Boötis stars and in Blanco 1 ($\leq 10^7$ yr) only 1 λ Boötis star. No λ Boötis stars were found among the A-type stars classified in 10 intermediate age or old clusters like αPersei ($\approx 1.4 \cdot 10^7$ yr), Pleiades ($\approx 7 \cdot 10^7$ yr), Praesepe ($\approx 4 \cdot 10^8$ yr), and the Hyades ($\approx 9 \cdot 10^8$ yr). With the availability of HIPPARCOS parallaxes of unprecedented quality, we could determine the luminosity of field λ Boötis stars with impressive accuracy and put speculations on the age of λ Boötis stars on better grounds (Paunzen 1997). An independent mass determination of at least one λ Boötis SB2 system from orbital parameters would drastically reduce the errors for an estimate of the evolutionary status, and in particular would help to decide whether λ Boötis stars are pre-main-sequence or main-sequence objects. Consequently, we initiated an observing program on this issue in collaboration with S. Yang (DAO).

In conclusion, the authors favour the accretion/diffusion theory since most of the exciting results obtained in the last years indicate a rather young age for λ Boötis stars. However, several open question remain (why is the circumstellar shell barely, if at all detectable, what happens with the dust, how to explain the few presumably more evolved λ Boötis stars, etc. ?) and inconsistencies of observed facts with either of the theories, which, unfortunately cannot be discussed in this necessarily incomplete review in detail. If it can be proven that the accretion/diffusion mechanism indeed is responsible for the phenomenon, λ Boötis stars could serve as excellent probes of the abundance pattern of the insterstellar gas for a wide range of elements and spatial distribution - which, however, presently is limited to the solar neighborhood. This motivation clearly goes beyond the primary goal of our research devoted to a particular group of chemically peculiar stars and potentially adds to the significance of λ Boötis stars.

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