Astron. Astrophys. 331, 633–638 (1998)

ASTRONOMY AND ASTROPHYSICS

Identification of λ Bootis stars using IUE spectra

I. Low resolution data*

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Received 10 April 1997 / Accepted 28 October 1997

Abstract. An analysis of the stars included in the catalogue of λ Bootis stars by Paunzen et al. (1997) and which also have IUE observations is presented here. Population I A-F type stars as well as field horizontal branch stars were also included in the analysis. Using line-ratios of carbon to heavier elements (Al and Ni) allows us to establish unambiguous membership criteria for the λ Bootis group.

Key words: stars: chemically peculiar – stars: early type – ultraviolet: stars

1. Introduction

Historically there has been a confusion about the definition of the λ Bootis stars mainly due to the lack of features in the optical spectra of these stars suitable to be used as discriminating criteria (rotational velocities, line intensities, photometric properties, etc.). So, for instance, λ Bootis and FHB stars show a similar abundance pattern except for the light elements (C, N, O and S) which present solar abundances in λ Bootis stars and underabundances in FHB stars (e.g. Stürenburg 1993; Adelman & Philip 1992). However, the origins of these patterns are different (the photospheric abundances of FHB stars reflect both the primordial abundances and the effects of mixing during the preceding red giant phase (Sweigart 1985), whereas the mechanism responsible for the abundances in λ Bootis stars is not well understood yet (Paunzen et al. 1997, hereafter Paper I). Moreover, these abundance patterns cannot be immediately determined on the basis of spectroscopical classification in the optical domain mainly due to the intrinsic line weakness for the light elements as well as due to line blending. Only a detailed abundance analysis (and, with some considerations, photometric indices; see Paper I) is able to distinguish between these two groups. In an attempt to solve this situation, a new definition of λ Bootis stars is proposed: λ Bootis stars are defined as *Population I, metal-poor (except of C, N, O and S) A to F-type stars*. Based on this definition a catalogue of λ Bootis stars whose properties have been firmly established has been built up.

Some authors have pointed out that the lack of discriminating criteria in the optical domain can be alleviated if the ultraviolet range is used (Cucchiaro et al. 1980; Baschek et al. 1984; Faraggiana et al. 1990). The main goal of this work is to select those λ Bootis stars from Paper I with ultraviolet observations and identify features that could be used as indicators of the λ Bootis phenomenon.

There are two main reasons to perform this analysis: First, the number of λ Bootis stars with accessible ultraviolet observations has significantly increased since the last compilation by Faraggiana et al. (1990). Moreover, the Archive of the International Ultraviolet Explorer satellite (IUE, hereafter) has been improved with the creation of the IUE Final Archive: all IUE images are now uniformly processed and calibrated making possible a homogeneous analysis.

2. Analysis

λ Bootis stars included in Paper I with available ultraviolet observations are listed in Tab. 1. The spectra of these stars have been compared to corresponding spectra of Population I A-F type stars with solar abundances (called 'standards' hereafter) selected from the list given by Faraggiana et al. (1990) plus those late B to early F-type, luminosity classes IV and V stars from the Bright Star Catalogue with IUE observations (Tab. 3). Furthermore, spectra of FHB stars from the list by Jaschek et al. (1985) were also analyzed (Tab.2). From this list, we have discarded Feige 86, BD +32 2188 and BD +36 2242 because their effective temperatures ($T_{eff} > 10000$ K) place them outside the λ Bootis temperature domain. The Low resolution ($\approx$ 6Å) images of two cameras, SWP (1150 to 1980 Å) and LWP

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* Tables 1-3 are only available in electronic form at CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/Abstract.html

(1850 to 3350 Å) have been used in this work. At the time of this work, the reprocessing of the High resolution images is not finished yet and its analysis will be part of a subsequent paper. The effective temperatures for the λ Bootis and standard stars have been derived using the calibration by Moon & Dworetsky (1985). The Strömgren colours for the λ Bootis stars are from Paper I and Hauck & Mermilliod (1990) for the FHB and the standard stars. The effective temperatures of the FHB stars have been taken from the most recent references in the literature and an average value was adopted. These averages were compared with the values obtained using the calibration given by Hayes & Philip (1988) resulting in a good agreement. The calibration by Moon & Dworetsky (1985) was not applied because of the invalidity of the calibration for Population II stars. The values of surface gravities for the λ Bootis and the standard stars were also calculated using the Moon & Dworetsky (1985) calibration. Surface gravities for the FHB stars were taken from the literature. The adopted physical parameters for the samples of stars are given in Tabs. 1-3.

The ultraviolet spectra were normalized to unity using a global pseudo-continuum through the highest points. Equivalent widths of the features described in Sect. 3 were measured performing a numeric integration after fitting a second degree polynomial between pixels. The intrinsic error of this method is negligible compared to other errors associated with the equivalent width determination (e.g. the location of the continuum).

3. Results

Because of the low spectral resolution (FWHM $\approx$ 6 Å) we cannot separate individual lines but only blended features named according to the main contributor as identified from the computation of the synthetic spectrum generated using ATLAS9 (Kurucz 1993). Therefore, the equivalent widths of these features will be useful only for an empirical classification but cannot be used to derive abundances. The following absorption features are easily identifiable in the ultraviolet spectra of A to F-type stars:

- Carbon: C I 1657 Å; C I 1931 Å
- Magnesium: Mg II 2800 Å (blend of Mg II 2795 Å; Mg II 2798 Å; Mg II 2802 Å; Mg II 2805 Å;)
- Aluminium: Al II 1670 Å
- Nickel: Ni II 1741 Å (blend of Ni II 1741 Å; Ni II 1748 Å; Ni II 1751 Å; Ni II 1754 Å)

These features have been selected according to the definition of the λ Bootis class (metal-poor stars except for C,N,O and S). Weak features which cannot be accurately measured (e.g. C II 1335 Å, Fe II 2598 Å) were discarded. Strongly blended features (Al II 1721 Å, Al I 1765 Å, Fe II 2765 Å) were also discarded. Although the variation of a blended line with T_{eff} and log g is the result of the intrinsic variations of the blend components, the intensity of the main contributor of the features quoted above is so high that the variations of the other contributors can be neglected (except for Ni II 1741 Å, Fig. 1). From this figure it can be deduced that the dependency of the wavelength edges of the features with T_{eff} or log g is negligible. However, a careful wavelength selection must be made for C I 1657 Å to avoid the Fe I 1648 Å feature.

In Fig. 2 we have plotted the equivalent widths of these features as a function of the effective temperature for the λ Bootis, FHB and the standard stars. Equivalent widths were measured only for those lines not affected by any external error sources (saturation, cosmic rays, bright spots, reseau marks). If more than one spectrum is available for a given star, the average equivalent width has been calculated. As reported by Baschek & Slettebak (1988), a correlation between the equivalent width and effective temperature is shown. Two errors sources have been considered here: the intrinsic measurement error given by the standard deviation if there is more than one spectrum for a star and the error due to the uncertainty in gravity. However, synthetic computations demonstrated that, in the range 6500 - 9000 K, the variation in EW of the blended features obtained when the synthetic spectrum is degraded at the IUE Low resolution due to varying log g between 3.0 and 4.5 is always less than 5% and does not affect the overall distribution of T_{eff} versus EW. Furthermore, small abundance variations from star to star may produce some uncertainty in the values of EW. Nevertheless, these errors are also negligible when compared with the intrinsic measurement error. According to the definition of the λ Bootis stars, we would expect that the metallic lines appear weaker than in standard stars. This is also immediately evident from Fig. 2 although the small number of determined equivalent widths for Mg II 2800 prevents a statistically significant conclusion for this feature. Moreover, the criterion based on the feature at λ 1741 Å is less reliable than that based on AlII 1670 because this latter feature is less contaminated by other contributors (Fig.1). The two measured carbon features (C I 1657 and C I 1931) indicate that the equivalent widths (and therefore, under some considerations, the abundance) for the λ Bootis stars are similar to those of the standard stars confirming the results by Venn & Lambert (1990) and Stürenburg (1993) in the optical domain.

3.1. Ratio between absorption lines

According to the definition of the λ Bootis class, the differences between λ Bootis and standard as well as FHB stars can be enhanced by using line-ratios of elements with solar abundance (e.g. carbon) to the heavier elements (e.g. aluminium) instead of using equivalent widths of single lines. Using these ratios, we are also able to minimize systematic errors introduced by the continuum. Fig. 3 shows the derived line-ratios for all stars. We see how λ Bootis stars can be clearly distinguished from FHB and standard stars. Using either C I 1657 or C I 1931 for the ratios with heavier elements yield similar results. Since the intrinsic equivalent widths for C I 1657 are stronger than those of C I 1931 (Fig. 3), we have only used the C I 1657 line to establish limits for the membership to the λ Bootis group. The adopted limits are rather conservative in order to minimize spurious detections. We consider, therefore, a star to be a member of the λ Bootis group if:

- C I 1657/Al II 1670 $>$2

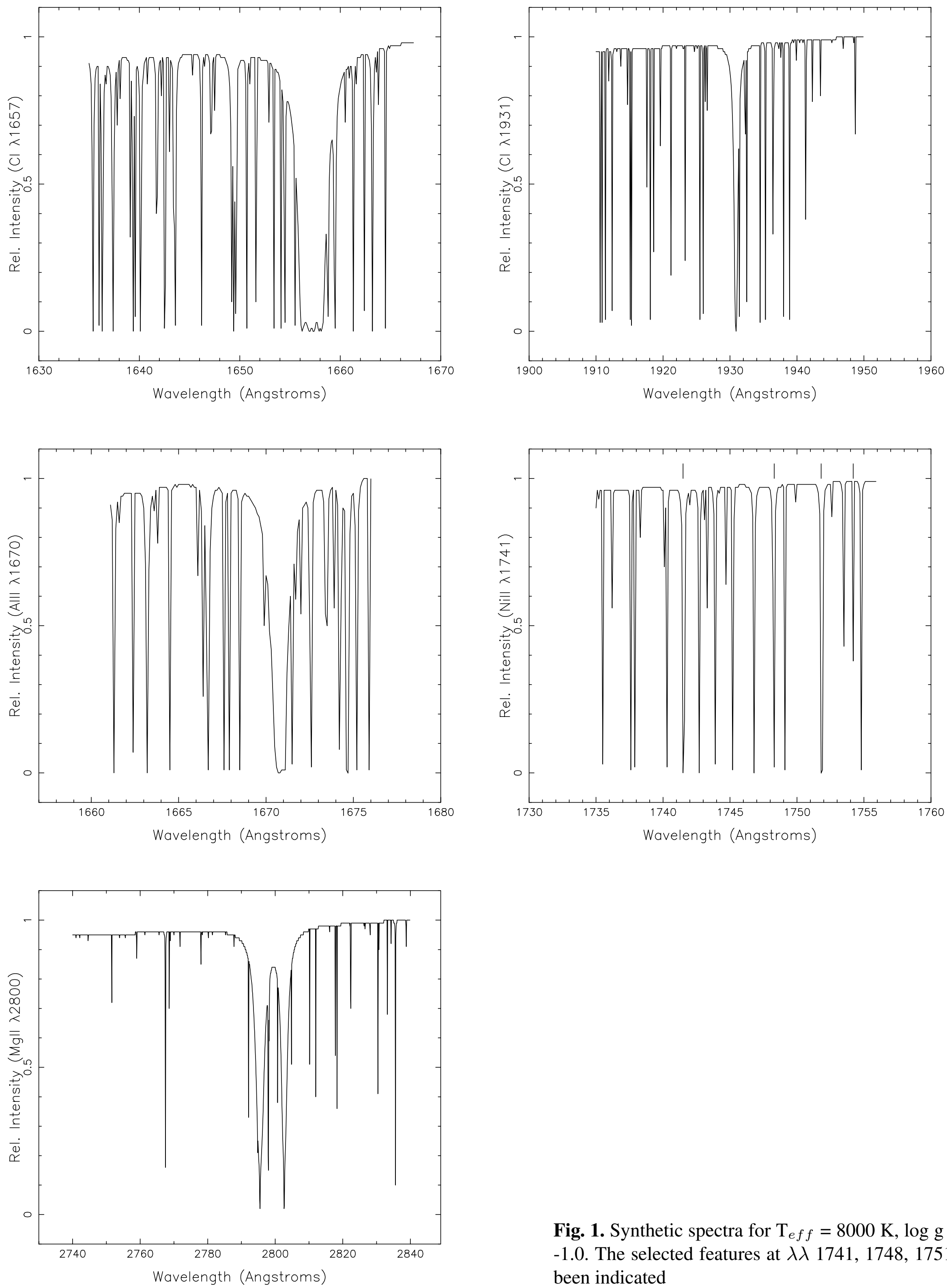

Fig. 1. Synthetic spectra for T_{eff} = 8000 K, log g = 4.0 and [M/H] = -1.0. The selected features at λλ 1741, 1748, 1751 and 1754 Å have been indicated

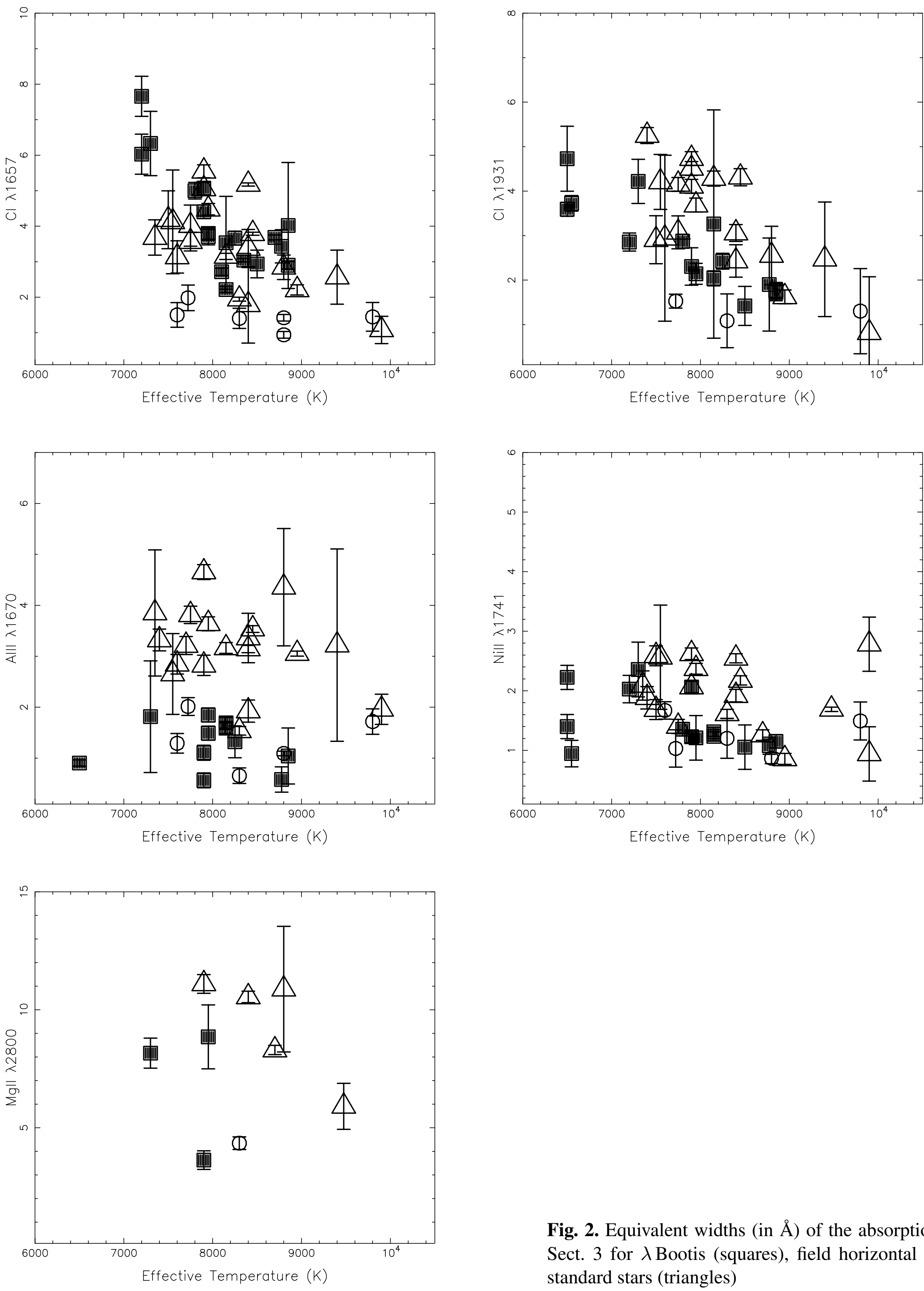

Fig. 2. Equivalent widths (in Å) of the absorption lines described in Sect. 3 for λ Bootis (squares), field horizontal branch (circles) and standard stars (triangles)

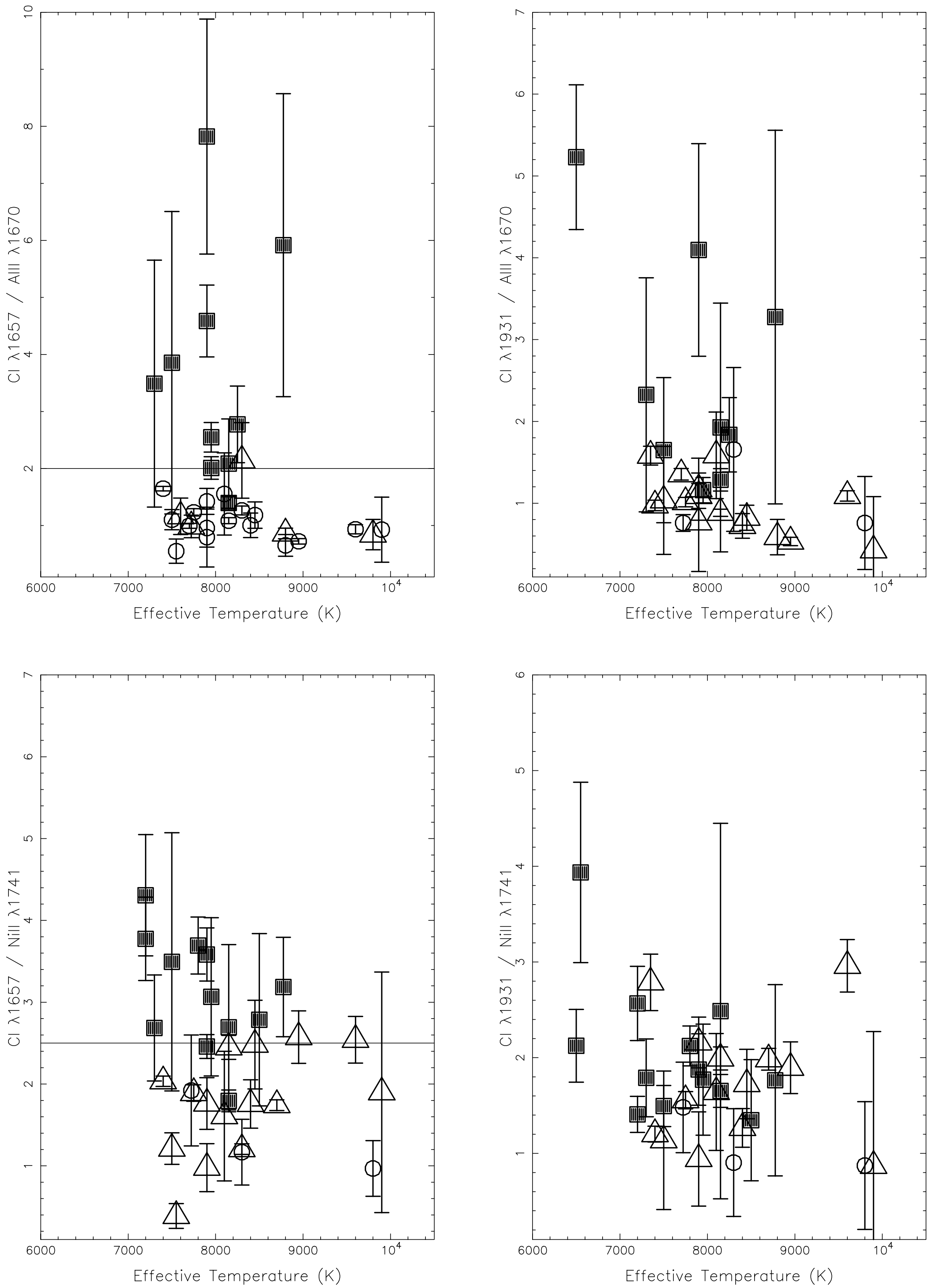

Fig. 3. Same as Fig. 2 but for the line-ratios

– C I 1657/Ni II 1741 >2.5

The limits have been set in such a way that they are valid for the entire effective temperature range. Small uncertainties due to variations in log g and [M/H] have been also taken into account making, therefore, these limits independent of physical parameters (T_{eff}, log g, [M/H]). Moreover, they are also independent of evolutionary status since a clear distinction between λ Bootis and FHB stars can be made.

3.2. Continuum depressions centered at 1600 Å and 3040 Å

These two very strong, originally unidentified, absorption features in the spectra of λ Bootis stars were reported by Baschek et al. (1984) and Faraggiana et al. (1990) and have been used in the past as the main criteria to identify λ Bootis stars. However, the 1600 Å depression is also very strong in FHB (Population II) stars and was found in cool DA white dwarfs whereas the 3040 Å depression is seen in a few solar abundant, standard stars as well as in FHB stars thus making these features not unique for λ Bootis stars.

Holweger et al. (1994) have identified the 1600 Å feature as caused by quasimolecular absorption leading to a satellite in the Lyman α profile due to perturbations by neutral hydrogen. The satellite is not observable in Population I A-F type stars because of the extremely strong distortion of the UV flux by metal lines (especially Si and Fe). This feature disappears at spectral types later than A5 ($T_{eff} < 8000$ K) due to the steep decrease of the flux shortward of about 1400 to 1600 Å (depending on the effective temperature and metallicity). Only few λ Bootis stars listed in Tab. 1 have appropriate effective temperatures to show up this feature.

The 3040 Å depression still remains unidentified. Since it is only loosely correlated with the 1600 Å depression (Baschek et al. 1984), a consideration as criterion for the λ Bootis phenomenon seems not appropriate. Moreover, the intrinsic weakness of the 3040 Å feature makes its detection very difficult.

Taking all these facts into account, we decided not to include both features in our analysis.

4. Conclusions

We have analyzed the IUE Low resolution spectra of λ Bootis stars from Paper I as well as FHB and standard stars. This should provide easily identifiable and unambiguous indicators of the λ Bootis phenomenon in the ultraviolet which makes the IUE Final Archive a powerful tool to find new λ Bootis stars as well as to preselect candidates for a spectroscopic survey in order to increase the number of known λ Bootis stars. We have determined equivalent widths for C, Mg, Al and Ni of λ Bootis, FHB and standard stars. Using different line-ratios, we consider a star to be member of the λ Bootis group if:

– C I 1657/Al II 1670 >2
– C I 1657/Ni II 1741 >2.5

This definition is independent of the effective temperature and evolutionary status. With these criteria, a clear distinction between λ Bootis and other stars (especially FHB stars) can be achieved. A similar analysis based on IUE High resolution data will be part of a subsequent paper.

Acknowledgements. This research was partly carried out within the working group *Asteroseismology-AMS* with funding from the Fonds zur Förderung der wissenschaftlichen Forschung (project *S7303-AST*). We are indebted to our referee, Dr. Faraggiana, for helpful and valuable comments. We also thank Dr. Fernley for his careful read.

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