

# Shell signs in the hydrogen-line spectrum of some $\lambda$ Bootis-type stars

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**Abstract.** The hydrogen-line spectrum of eight  $\lambda$  Boo type stars is studied. The observed  $H_\delta$  and  $H_\gamma$  profiles are compared with Kurucz's theoretical profiles. The existence of weak emission-like details in the cores of five  $\lambda$  Boo stars is demonstrated. The Inglis-Teller formula is used to calculate the electron densities. It is found that electron densities in the atmospheres of stars with peculiar H-line profiles are twice lower than in stars with normal profiles. The conclusion is made that stars with peculiar profiles exhibit some of the characteristics usually observed in stars with extended atmospheres.

**Key words:** stars: $\lambda$  Bootis – stars: chemically peculiar

## 1. Introduction

According to Gray (1988),  $\lambda$  Boo type stars can be divided into two groups. Stars in the first group have normal hydrogen-line (NHL) profiles, typical of the A dwarfs. The second group contains stars with peculiar hydrogen-line profiles (PHL). They have weak cores and broad, but shallow wings. Stürenburg (1993) has found a significant correlation between Gray's classification and his gas shell index. This index is related to the presence of sharp circumstellar absorption details in the cores of some metallic lines like Ca K and Na D. The PHL stars have strong signs of a gas shell, while the NHL stars show only weak indications. Thus, the observational data clearly point to a connection between the  $\lambda$  Boo phenomenon and circumstellar gas. Here we report on the effective temperatures and gravities obtained from fits to theoretical hydrogen-line profiles, as well as on the gas shell signs found directly in the hydrogen-line spectrum of some PHL  $\lambda$  Boo stars.

## 2. Input data

Co-added photographic spectra obtained in the range  $\lambda\lambda$  3600–4800 ÅÅ with a moderate resolution ( $\Delta\lambda/\lambda \sim 20\,000$ ) are used for studying the hydrogen-line spectrum of eight  $\lambda$  Boo stars. Three of them: HD 31295, HD 125162, and HD 183324 exhibit NHL profiles, while the others: HD 105058, HD 111786, HD 142703, HD 192640 and HD 221756 show PHL profiles.

### 3. Hydrogen-line spectrum

Observed  $H_\delta$  and  $H_\gamma$  profiles were compared with Kurucz' (1993) theoretical profiles computed with realistic (low metal) abundances. The line fitting procedure included a bicubic spline interpolation scheme and a  $\chi^2$ -minimization in the two-dimensional parametric grid limited by  $T_{\text{eff}} = 6\,000\text{ K} - 10\,000\text{ K}$  and  $\log g = 3.0 - 5.0$ . The fitting procedure did not take in the innermost  $\pm 3\text{ \AA}$  from the line center of the observed hydrogen lines.

Effective temperatures and gravities obtained from our 'best-fit' theoretical profiles are listed in the Table 1. The dashes reflect the fact that hydrogen-line profiles are not sensitive to gravity below about  $8\,300\text{ K}$ . Already published data are given for comparison. There are no significant differences between the effective temperatures obtained by different methods.

**Table 1.**  $T_{\text{eff}}$  and  $\log g$  determined from fitting the  $H_\gamma$  and  $H_\delta$  profiles, compared with the data compiled from different sources. The last two columns contain the numbers of the last resolved Balmer line and the corresponding electron densities

HD	C	This study		Other sources			$n_{\text{max}}$	$\log N_e$
		$T_{\text{eff}}$	$\log g$	$T_{\text{eff}}$	$\log g$	S		
31295	NHL	8900	4.2	8900	4.2	1	18.7	13.16
				8550	4.0	2		
				8900	4.2	2 <sup>+</sup>		
				8750	4.0	3		
				9000	4.2	5		
105058	PHL	7900	–	7800	3.6	1 <sup>+</sup>	19.5	13.05
111786	PHL	7700	–	7500	3.9	1	20.1	12.93
				7600	4.0	5		
125162	NHL	8600	4.1	8800	4.2	1	18.2	13.25
				8400	4.0	2		
				8500	4.3	2 <sup>+</sup>		
				8800	4.0	3		
				8900	4.1	5		
142703	PHL	7500	–	7200	4.0	1	19.4	13.04
				7200	3.9	4		
				7400	4.1	5		
				9300	4.2	1		
183324	NHL	9100	4.1	9250	4.1	5	18.3	13.23
				8000	4.0	1		
192640	PHL	8100	–	8000	3.9	2	19.9	12.96
				8000	–	2 <sup>+</sup>		
				8150	4.0	3		
				8000	4.1	5		
				9100	3.9	5		
221756	(PHL)	8900	4.0	9000	4.0	1	19.7	12.99
				9100	3.9	5		

1 - uvby $\beta$  (Moon & Dworetzky (1985)), 1<sup>+</sup> - uvby $\beta$  with 'unknown'  $\beta$

2 - UBV (Baschek & Searle, 1969), 2<sup>+</sup> -  $H_\gamma$  (Baschek & Searle, 1969) + this study

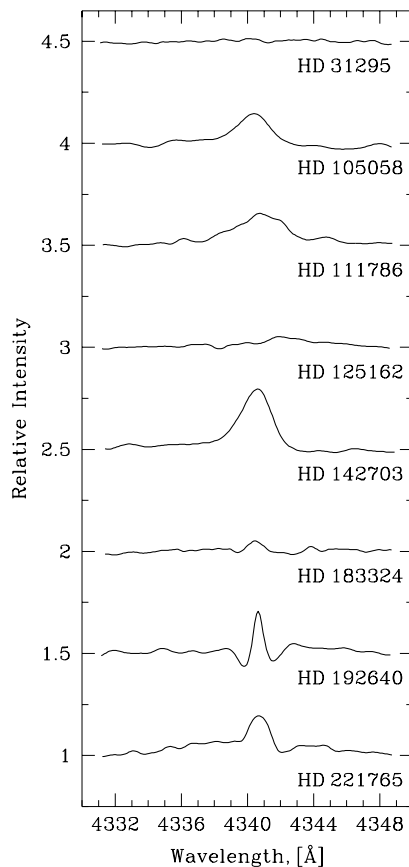
3 - uvby with fixed  $\log g = 4.0$  (Baschek & Slettebak, 1988)

4 - Geneva photometry (Paunzen & Weiss, 1994)

5 - uvby $\beta$  and stellar evolutionary models (Iliev & Barzova, 1995)

### 3.1. The residuals

To pay attention to the hydrogen-line cores which were excluded from the fitting procedure, all observed  $H_\gamma$  profiles were rectified with their theoretical ‘best-fits’. In other words, the theoretical profiles were used as *continua*. Residuals obtained for each star after the normalization are shown in Figure 1. Weak ‘emission-like’ details were found in the bottoms of  $H_\gamma$  lines of five  $\lambda$  Boo stars. Taking into account the central depths of  $H_\gamma$  lines, equivalent widths of the weak emissions in Figure 1 can be found between 80 and 250 mÅ. These values are less than two percent of the equivalent width of  $H_\gamma$  lines. We found similar details with quite smaller amplitudes (down to the limit of detection) in  $H_\delta$  profiles.



**Figure 1.** Isolation of weak emission components in the  $H_\gamma$  lines of five  $\lambda$  Boo type stars. The stars that show no peak details are NHL stars. Note the shell feature seen nearly pole-on in the case of HD 192640

The nature of ‘emission-like’ residuals is not entirely rotational. For example, the details found in the  $H_\gamma$  lines of HD 105058 and HD 142703 have nearly the same FWHM, while their rotational velocities differ by about 50 percent ( $130 \text{ km s}^{-1}$  against  $90 \text{ km s}^{-1}$  respectively). The full width of the ‘emission-like’ details at their base is larger than the value of  $v \sin i$ . Similar structures, but on a much larger scale, are canonical for the Ae/shell stars. This led us to suggest that the ‘emission-like’ details could represent a manifestation of gas shells or envelopes around the  $\lambda$  Boo stars from our list. The most interesting case of a shell seen nearly *pole-on* in HD 192640, which is among the slowest rotating  $\lambda$  Boo stars ( $v \sin i = 35 \text{ km s}^{-1}$ , Abt & Morrell 1995) gives an additional support to this suggestion. Finally, all five stars with ‘emission-like’ details in their  $H_\gamma$  lines are PHL stars.

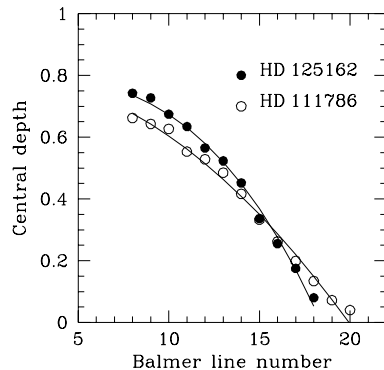
### 3.2. Electron densities

We used the Inglis–Teller formula that connects the electron density  $N_e$  in the atmosphere with the number  $n_{\max}$  of the last resolved Balmer line:

$$\log N_e = 22.7 - 7.5 \log n_{\max} \quad (1)$$

Both coefficients are taken from Allen (1973). As a rule, the  $N_e$  value obtained from the Inglis–Teller formula is related to the uppermost atmospheric layers where optical depth  $\tau \approx 0.1$  and where the Balmer lines with the highest numbers are formed. In practice, the number  $n_{\max}$  is derived from the relation between Balmer line number and central depth  $R_c$  or equivalent width  $W_\lambda$ . An extrapolation of this relation towards the higher numbers gives  $n_{\max}$  as the point where  $R_c$  (or  $W_\lambda$ )  $\approx 0$  (see Fig. 2). It is obvious that in this case  $n_{\max}$  may be a fractional number. The values thus obtained for  $n_{\max}$  have been corrected for the rotation and for the spectral class by using the coefficients proposed by Kopylov (1961). The error in  $n_{\max}$  depends mainly on the number of points used and on the errors in the  $R_c$  determination. With errors in  $R_c$  between one and two percent the number  $n_{\max}$  in our case can be determined with a standard error of 0.2. This value is consistent with the results of Kopylov (1961), who has found the errors in  $n_{\max}$  between 0.07 and 0.15. The error of about 0.2 in  $n_{\max}$  leads to an error in the resulting value of  $\log N_e$  of about 0.05–0.06.

The last visible numbers are listed in Table 1 along with the corresponding electron densities. The numbers  $n_{\max}$  measured by us for all the stars studied are in the range 18.2–20.1. The distributions of  $n_{\max}$  suggest that the last resolved



**Figure 2.** The number  $n_{\max}$  for a given star is determined as the point where the interpolated polynomial crosses the abscissa

Balmer line numbers of PHL stars are generally larger than in NHL stars. Non-parametric Wilcoxon rank sum test shows that the distributions in the Table 1 are different at the 98% confidence level. The Hodges–Lehmann estimate gives that the difference between two medians is 1.1. If this value is interpreted in terms of parametric statistics, it will exceed the standard error of  $n_{\max}$  by about 5 times.

## 4. Discussion

The main result from the last subsection is that  $N_e$  at the level  $\tau \approx 0.1$  in the atmosphere of PHL type stars is nearly twice lower than we derived for  $\lambda$  Boo stars with NHL. This could be interpreted as some evidence that  $\lambda$  Boo stars

with PHL are closer to the end of their evolution *on the MS*, because in the spectral range A0–F0  $n_{\max}$  reaches 17.0 for ZAMS, 18.5 for the middle of the main sequence, and 20.0 for the luminosity classes IV–III (Kopylov 1966). An additional support to this interpretation could be seen even in the fact that the  $\log g$  values of PHL stars determined from photometric data are in general smaller than those of NHL stars. The contradiction with the suggestion of Venn & Lambert (1990) and gas/dust separation scenario developed by Waters et al. (1992) (both of them require  $\lambda$  Boo stars to be young and near the ZAMS) is obvious.

The presence of gas shells or envelopes which surround many  $\lambda$  Boo stars can change the situation upside-down, making PHL stars to bear a resemblance to the well-known Be or Ae/shell stars. For example, Pleione shows a B8V spectrum while in its quiescent mode, while during the shell phases  $n_{\max}$  has reached 40. Thus, the larger  $n_{\max}$  in the spectra of PHL stars can be considered as yet another shell symptom. It is important to note that the influence of gas shells on the hydrogen-line spectrum of Ae/shell stars which show weak or no emissions usually is much more visible in the highest Balmer line numbers. This fact could explain why the  $\beta$  indices and the corresponding effective temperatures of PHL  $\lambda$  Boo stars can be close to those obtained from spectroscopy, while the Balmer discontinuity, and, therefore, luminosity indices like  $c_1$ ,  $d$  or  $\delta$  can be affected by the shell. The conclusion is that  $\log g$  values of PHL stars obtained by photometry seem to need a revision, because stronger evidences for circumstellar shells imply more disturbed  $\log g$  values. Unfortunately, hydrogen-line profiles offer no alternative solution, since the effective temperatures of these stars are mostly below the critical limit of about 8 300 K.

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