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The heterogeneous class of λ Bootis stars⋆,⋆⋆

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Abstract. We demonstrate that it is arduous to define the λ Boo stars as a class of objects exhibiting uniform abundance peculiarities which would be generated by a mechanism altering the structure of their atmospheric layers. We collected the stars classified as λ Boo up to now and discuss their properties, in particular the important percentage of confirmed binaries producing composite spectra (including our adaptive optics observations) and of misclassified objects. The unexplained *RV* variables (and thus suspected binaries), the known SB for which we lack information on the companion, the stars with an UV flux inconsistent with their classification, and the fast rotating stars for which no accurate abundance analysis can be performed, are also reviewed.

Key words. stars: atmospheres – stars: chemically peculiar – stars: binaries: spectroscopic

1. Introduction

The peculiarity of the λ Boo star was detected by Morgan et al. (1943); these authors gave the first implicit definition of the class in describing the λ Boo spectrum. Weak metal lines characterize the spectrum of this star and of the other members of the class. In fact, the common characteristic that distinguishes the λ Boo stars is the underabundance of elements which are usually overabundant in stars belonging to other CP groups.

A handful of papers on λ Boo and a few other similar stars appeared in the following years; abundance analyses, made with the curve of growth method, were performed by Burbidge & Burbidge (1956) and by Baschek & Searle (1969).

The λ Boo group was almost forgotten in the following years; a sign of this is the fact that while included in the first Bertaud (1959) catalogue of peculiar A stars, they were later excluded in the revised and updated edition by Bertaud & Floquet (1974).

The state of the art at the beginning of the 80's is well summarized by Wolff (1983) in her Monograph on A-type stars: she got rid of this class at page 3 by writing that so little is known on a very small number of objects, not homogeneous in their composition, that the class is no further discussed in the book.

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⋆ Partly based on observations collected at the CFH Telescope (Hawaii) and at TBL of the Pic du Midi Observatory (France).
⋆⋆ Table 5 is only available in electronic form at
http://www.edpsciences.org

Only 12 stars were classified as λ Boo in the Catalog of Stellar Groups (Jaschek & Egret 1982) and 2 of them (HD 79 469 (θ Hya) and HD 21 2061 (γ Aqr)) proposed by Sargent (1965) had been rejected by Baschek & Searle's (1969) abundance analysis, as well as by later studies.

It was at that time that a sudden revival of interest took place, at least partly related to the fact that:

- highly performant echelle spectrographs,
- high S/N CCD detectors,
- large catalogues of intermediate band photometric colour indices (*uvbyβ*, Geneva)

became available.

The first objective was to enlarge the number of the members of this class by selecting new candidates with homogeneous properties. These properties are author-dependent since they rely on a λ Boo definition varying with time and authors. Several lists proposed by different authors and based on different selection criteria became available and have been used to construct our list of λ Boo candidates.

The search for λ Boo stars through the classical method of classification of blue low dispersion spectra has been made in a systematic way by Gray (1988); he compiled a list of λ Boo stars which has been regularly updated with newly discovered members; this is the most systematic and homogeneous study of these stars. Larger samples have been constructed for statistical studies of the λ Boo properties by other authors, in particular by the Vienna group.

The present selection of all the stars classified as λ Boo is made to achieve the purpose of our ongoing study: the selection of a statistically significant sample of *non-binary* stars, if they really exist, showing the spectral properties given by Morgan et al. (1943) for the star λ Boo. In fact, since 1999 (Faraggiana & Bonifacio) we have realized that a non-negligible percentage of stars classified as λ Boo are in fact unresolved binaries with the spectrum contaminated by that of the companion.

In the present paper we present, in Sect. 2, the criteria used to select the candidates on the basis of classification papers and the resulting list of λ Boo stars. In Sect. 3 we discuss the binaries with a companion so bright to produce a composite spectrum, as indicated by the Hipparcos experiment observations, by the interferometric measures and by the Washington Double Star Catalog data.

In Sect. 4 the results of our observations with the adaptive optics system mounted at the CFH telescope are presented. The measure of the magnitude difference of the HD 141 851 companion has been obtained for the first time, showing that its contribution cannot be neglected in the spectral analysis of this object.

Section 5 describes the duplicity indications from the values of radial velocity and $v \sin i$ measurements extracted from the literature and from the notes in the Hipparcos (ESA 1997) catalogue. Some of the λ Boo candidates appear to be misclassified stars, as explained in Sect. 6, and for others the existence of a companion has been demonstrated by the study of high resolution spectra (Sect. 7).

The $T_{\rm eff}$ and $\log g$ values derived from the visual photometric colour indices are discussed in Sect. 8, the derived absolute magnitudes are compared with those obtained from the parallax measured by Hipparcos in Sect. 9. The inconsistencies between the magnitudes measured in the visual and in the UV bands observed by the S2/68 experiment on board the TD1 satellite indicate an abnormal behaviour for several stars classified as λ Boo; these peculiarities are discussed in detail in Sect. 10.

2. The λ Boo candidates: Differences between λ Boo selections

We constructed a list, given in Table 1, of λ Boo candidates which comprises all stars which have been classified as members of this class either by spectroscopic or by photometric criteria.

The sources used to assemble this table are labelled as follows:

- Column 1 (HD): HD number.
- Column 2 (G): stars classified as "confirmed λ Boo stars" by Gray on the list available on his website (`www1.appstate.edu/dept/physics/spectrum/lamboo.txt`) and the four stars classified as λ Boo by him and collaborators in other papers: HD 290 492 (Paunzen & Gray 1997), HD 87 271 (Handler et al. 2000), HD 174 005 (Gray et al. 2001) and HD 218 396 (Gray & Kaye 1999).
- Column 3 (P1): the "consolidated catalogue of λ Boo stars" by Paunzen et al. (1997) (P1).
- Column 4 (AM): stars classified as λ Boo by Abt & Morrell (1995) (AM) in their paper on $v \sin i$ of A-type stars.
- Column 5 (H): λ Boo stars selected by Hauck & Slettebak (1983) and Hauck (1986).
- Column 6 (A): λ Boo stars classified by Abt (1984a,b, 1985); this author notes that it is very difficult to separate weak-line A-type from λ Boo stars.
- Column 7 (L): three λ Boo stars in the Orion cluster classified by Levato et al. (1994).
- Column 8 (AJ): λ Boo stars classified by Andrillat et al. (1995) from near IR range spectra.
- Column 9 (V): λ Boo stars classified by Vogt et al. (1998).
- Column 10 (P2): λ Boo stars classified by Paunzen (2001) (P2).
- Column 11: spectral classification by Gray and collaborators, taken from his extensive series of papers on stellar classification.
- Column 12: remarks obtained in this papers, their meaning is given in Sect. 11.

The criteria adopted for these classifications are mostly based on spectra. In some cases, photometric selections have been made: that based on the characteristics of the Geneva photometric colour indices (H column) and that based on the Δa index (V column) which measures the metallicity of the star.

In 2002, Paunzen et al. (2002) after "a critical assessment of the literature" published a list of "57 well-established λ Boo stars". This list differs from the previous ones by the same author, which have been qualified as the "consolidated catalogue" (P1) or the "new and confirmed" (P2) and we decided to limit our selection to the list published in 2001, ignoring any further rapid evolution of the λ Boo star selection by these authors.

The resulting list of 136 λ Boo candidates in Table 1 represents the sample of objects we shall discuss in this paper.

We note immediately that some of these stars are well-known objects which have been assigned either to the λ Boo class or to other classes of peculiar stars; as a matter of fact, they are misclassified binaries and will be discussed in Sect. 6.

The inspection of Table 1 shows that the classification of the λ Boo stars is not easy. This can be interpreted as a consequence of the spectral characteristics of these stars: i) the low blanketing, so that very few and weak metal lines are present in the spectra and ii) the very high $v \sin i$ of several candidates, which washes out the lines.

As a result different authors selected different objects and even the same author can produce different lists at different dates. For example, several differences are present in the lists by P1 and P2. Seven λ Boo stars in the 1997 edition have been classified as normal in 2001, and are referenced as P* (Paunzen et al. 2001) in Table 1 Col. 10. The latter classification is: HD 38 545: A2Va (shell),

HD 39 421: A1Va(wk4481),

HD 98 772: A1Va,

HD 141 851: A2Van,

HD 149 303: A3 IV-V(wk4481),

HD 160 928: A2IV weak met,

HD 177 120: A0.5 IV shell.

Table 1. The list of λ Boo stars.

HD	G	P1	AM	H	A	L	AJ	V	P2	Spectral classification	Remarks
3			AM								inconsistent UV flux (bin.?)
319	G	P1		H	A			V	P2	A1mA2 Vb λBoo PHL	
2904			AM								inconsistent UV flux (bin.?)
4158		P1		H					P2?		
5789			AM								
6173					A						
6870		P1							P2		misclassified:
7908									P2		
11 413	G	P1	AM	H	A			V	P2	A1 Va λBoo PHL	
11 503			AM							B9.5 IV$^+$n	
13 755									P2		
15 165									P2		
16 955				H	A						
21 335				H	A		AJ			A3 IVn	
22 470			AM								composite, Hipparcos
23 258			AM								
23 392	G								P2	A0 Va$^-$ (λBoo) NHL	inconsistent UV flux (bin.?)
24 472									P2		inconsistent UV flux (bin.?)
26 801					A						
30 422	G	P1						V	P2	A3 Vb λBoo PHL	
30 739			AM							A0.5 IVn	inconsistent UV flux (solar ab.)
31 295	G	P1	AM	H			AJ	V	P2	A0 Va λBoo NHL	
34 787			AM								misclassified
35 242								V	P2		
36 496							AJ				composite, Hipparcos
36 726	G								P2	kA0hA5mA0 λBooNHL	
37 411	G									kA0hA3mA0Va(e)/shell λBoo	
37 886						L					misclassified
38 545	G	P1					AJ		P*	A2 Va$^+$ λBoo PHL	composite, Hipparcos
39 283							AJ			A1 Va	inconsistent UV flux (solar ab.)
39 421		P1		H	A			V	P*	A1 Van	
41 580					A						
47 152			AM								composite, Hipparcos
54 272									P2		inconsistent UV flux (bin.?)
56 405					A			V		A2 Va	inconsistent UV flux (bin.?)
64 491	G		AM						P2	kA3hF0mA3 V λBoo (PHL)	composite, spectrum
66 684			AM							B9 Va	discordant $v \sin i$ values
74 873	G								P2	kA0.5hA5mA0.5 V λBoo NHL	inconsistent UV flux (solar ab.)
75 654		P1						V	P2		
79 108			AM					V			*RV* variable
81 104					A						composite, spectrum
81 290		P1							P2		
83 041		P1							P2	FHB F2VkA3mA2 λ Boo PHL	misclassified
83 277									P2		inconsistent UV flux (bin?)
84 123		P1							P2		misclassified:
84 948		P1					AJ		P2		SB2, metal ab. to be reviewed
87 271	G									A9kA0mA0 V λBoo	
87 696			AM							A7 V	inconsistent UV flux (solar ab.)
89 239			AM								inconsistent UV flux (solar ab.)
89 353					A						misclassified
90 821	G									kA2hA7mA2 Vn λBoo	
91 130	G		AM							A0 Va$^-$ λBoo (PHL)	
97 773							AJ?				composite, Hipparcos
97 937					A						
98 353				H	A		AJ			A1 Va (composite spectrum ?)	composite, spectrum
98 772		P1	AM						P*		
101 108		P1		H			AJ		P*		

Table 1. continued.

HD	G	P1	AM	H	A	L	AJ	V	P2	Spectral classification	Remarks
102 541									P2		inconsistent UV flux (bin.?)
105 058	G	P1		H			AJ		P2	kA1hA7mA1 V λBoo (PHL)	
105 759	G									kA2hF0mA2 V (λBoo)	
106 223		P1		H			AJ		P2	F3 V m-3	misclassified
107 233	G	P1							P2	kA1hF0mA1 Va λBoo PHL	
108 283			AM							A9 IVnp SrII	misclassified
109 738		P1							P2		
109 980			AM								
110 377			AM						P2		
110 411	G	P1					AJ		P2	A0 Va (λBoo) NHL	
111 005									P2		D, Hipparcos
111 604			AM						P2		*RV* variable
111 786	G	P1	AM	H					P2	A1.5 Va$^-$ λBoo PHL	composite, spectrum
112 097			AM								
118 623			AM							A7 Vn	composite, Hipparcos
120 500	G								P2	kA1.5hA5mA1.5 V (λBoo) NHL	
120 896									P2		
125 162	G	P1	AM	H			AJ		P2	A0 Va λBoo NHL	
125 489			AM							A7 Vn	inconsistent UV flux (bin.?)
125 889									P2		
130 158			AM								
130 767									P2		
138 527			AM								D, Hipparcos
141 851		P1		H	A				P*		composite, AO
142 703	G	P1	AM						P2	kA1hF0mA1 Va λBoo PHL	
142 994	G	P1							P2	A3 Va λBoo PHL	
144 708			AM								
148 638									P2		D, Hipparcos
149 130									P2		
149 303		P1			A				P*		
153 747									P2		
153 808			AM							A0 IV$^+$	composite, spectrum
154 153									P2	F1 V m-2.5	misclassified
156 954		P1							P2		inconsistent UV flux (bin.?)
159 082			AM								inconsistent UV flux (bin.?)
160 928		P1							P*		composite, interferometry
168 740		P1							P2		
168 947									P2		inconsistent UV flux (bin.?)
169 009			AM								*RV* variable
169 022				H						A0II$^-$(n)shell	misclassified
170 000			AM							kB9hB9HeA0V(Si)	composite, Hipparcos
170 680	G	P1	AM						P2	A0 Van (λBoo) NHL	inconsistent UV flux (solar ab.)
171 948	G	P1			A				P2	A0 Vb λBoo NHL	SB2, twin stars?
174 005	G									A7V kA2mA2 λBoo	composite, spectrum
175 445									P2		inconsistent UV flux (bin.?)
177 120		P1			A				P*		inconsistent UV flux (bin.?)
177 756			AM							kB8HeA0IV wk4481	*RV* variable
179 791				H	A						inconsistent UV flux (solar ab.)
183 324	G	P1	AM	H	A		AJ		P2	A0 Vb λBoo NHL	*RV* variable
184 190		P1									
184 779		P1							P2		
191 850									P2		
192 424		P1			A						
192 640	G	P1	AM	H					P2	A0.5 Va$^-$ λBoo PHL	discordant $v \sin i$ values
193 063					A						

Table 1. continued.

HD	G	P1	AM	H	A	L	AJ	V	P2	Spectral classification	Remarks
193 256	G	P1							P2	A2 Va λBoo PHL	D, Hipparcos
193 281	G	P1							P2	A3mA2 Vb λBoo PHL	
196 821			AM								inconsistent UV flux (bin.)
198 160	G	P1							P2	A2 Vann λBoo PHL:	metal ab. to be reviewed
198 161	G									A2	metal ab. to be reviewed
200 841					A						inconsistent UV flux (bin.?)
204 041	G	P1	AM						P2	A1 Vb λBoo PHL	inconsistent UV flux (bin.?)
204 965					A						
210 111	G	P1							P2	kA2hA7mA2 Vas λBoo PHL	
210 418				H	A					A2mA1 IV-V (SB2)	composite, spectrum
212 150			AM								inconsistent UV flux (bin.?)
214 454			AM							A9 V kA7mA6	
216 847									P2		inconsistent UV flux (bin.?)
217 782							AJ				composite, Hipparcos
218 396	G									kA5hF0mA5 v λ Boo	
220 061			AM	H	A					A8 V kA5mA5 λ4481weak	*RV* variable
220 278				H	A					A5 Vn	composite, Hipparcos
221 756	G	P1			A		AJ		P2	A1 Va$^+$ (λBoo) P/NHL	inconsistent UV flux (solar ab.)
223 352			AM							A0Va$^+$n	
225 218			AM								inconsistent UV flux (bin.)
261 904									P2		
290 492	G								P2	A0.5 Vb (λBoo) NHL	composite, interferometry
290 799	G	P1				L			P2	A2 Vb λBoo PHL	
294 253	G	P1				L			P2	B9.5 Va (λBoo) NHL	

The spectral classification is taken from Gray and co-authored papers.
Symbols of the columns:
G: Gray (his website) and stars added in published papers (see text).
P1: Paunzen et al. (1997).
AM: Abt & Morrell (1995).
H: Hauck & Sletteback (1983), Hauck (1986).
A: Abt (1984a, 1984b, 1985).
L: Levato et al. (1994).
AJ: Andrillat et al. (1995).
V: Vogt et al. (1998).
P2: Paunzen (2001).
P*: classified as non-λ Boo in Paunzen et al. (2001), see text.

Three λ Boo stars in the 1997 edition are not considered so any more in the 2001 edition (HD 184 190, HD 192 424 and HD 290 492). HD 4158, a λ Boo star in the 1997 list, is only a doubtful member of the class in the 2001 list. On the other hand, HD 154 153, included in Paunzen's (2001) list, was among the rejected stars in Paunzen et al.'s (1997) catalogue because it was defined as an "evolved star".

The Paunzen et al. (1997) catalogue comprises 45 consolidated members; more than 25% of them changed their classification 4 years later.

In general, the agreement between the different lists is quite poor: for example, Table 1 shows that only 9 stars are in common between G, P1 and AM. The excellent agreement claimed by Paunzen (2001) between his (P2) and the (AM) classification is not evident from our Table 1.

We conclude that it is very difficult to produce a list of unambiguous members of the λ Boo class and that a careful inspection of the candidates must be made before discussing the abundance pattern of this class.

3. Hipparcos and speckle interferometry

Duplicity indications have been found by the Hipparcos experiment and by interferometry.

In Table 2 the measures of the angular separation and magnitude difference and the variability notes of the *H* magnitude in the Hipparcos catalogue (ESA 1997) are given in Cols. 2, 3 and 4. The angular separation and the magnitude difference, collected in the Washington Visual Double Star Catalog (WDS) (Worley & Douglass 1997) are in Cols. 5 and 6. Column 7 reports the interferometric measurements of the separation from the binary search results obtained by the interferometric technique (Hartkopf et al. 2003); the smallest value has been chosen when several measures are given in this catalogue. The values

Table 2. Duplicity detection and measures.

HD	Hip. ρ arcsec	Hip. dHp Δm	Hip. Hvar	WDS ρ arcsec	WDS Δm	Interf. ρ arcsec
3			D			<0.030
319				2.1	5.1	
2904			C			
4158			–			
5789	7.856	0.87	R	7.8	0.8	
6173			–			
6870						
7908						
11 413			U			
11 503	7.606	0.05	D	8.6	0.0	7.267
13 755			U			
15 165			P			
16 955	2.992	3.93				
21 335						0.075
22 470	0.152	1.36	P			<0.054
23 258						
23 392			C			<0.155
24 472						
26 801						
30 422						
30 739						
31 295			C			
34 787			C			
35 242						
36 496	0.180	0.98	D			0.107
36 726			–			
37 411			–			
37 886			–			
38 545	0.155	0.64	D	0.1	–	0.071
39 283			C			<0.038
39 421						<0.038
41 580			D			
47 152	0.212	0.77	D	0.1	–	0.057
54 272			–			
56 405						<0.038
64 491						<0.124
66 684	3.527	0.73	D	3.5	0.9	<0.038
74 873						<0.038
75 654						
79 108			C			<0.038
81 104	5.731	1.08	D	5.8	1.0	
81 290			C			
83 041			C			
83 277			D			
84 123						<0.155
84 948			C			<0.155
87 271			U			
87 696			C			<0.038
89 239			C			<0.030
89 353			U			
90 821			–			<0.155
91 130			M			<0.030
97 773	0.138	0.04	D			0.080
97 937						<0.030
101 108	7.087	2.90	D	6.7	3.2	
102 541						

Table 2. continued.

HD	Hip. ρ arcsec	Hip. dHp Δm	Hip. Hvar	WDS ρ arcsec	WDS Δm	Interf. ρ arcsec
105 058			U			<0.155
105 759			U			
106 223			C			
107 233			U			
108 283						<0.073
109 738						
109 980			M			<0.038
110 377						<0.038
110 411						<0.038
111 005			D			
111 604			U			<0.038
111 786						
112 097						
118 623	1.800	2.04	D	1.1	1.9	
120 500						
120 896			C			
125 162						<0.030
125 489			C			<0.038
125 889						
130 158			U			
130 767			C			
138 527			D			<0.038
141 851			C	0.1	–	0.069
142 703			C			
142 994			–			
144 708	3.350	3.99	D			<0.038
148 638			D			
149 130			C			
149 303	16.356	3.08	D			<0.038
153 747			U			
153 808				0.2	–	<0.038
154 153						
156 954			C			
159 082			C	0.2	–	<0.05
160 928			C	0.1	0.0	0.086
168 740			M			
168 947			–			
169 009			U			<0.038
169 022						2.392
170 000	0.382	1.45	P	0.6	1.5	0.125
170 680			C			<0.038
171 948						
174 005			C			
175 445						
177 120	7.985	2.19	U	8.0	1.5	
177 756						<0.030
179 791			C			<0.030
183 324						
184 190			–			
184 779			–			
191 850			–			
192 424	6.183	0.04	D	6.2	0.0	
192 640			U			<0.124
193 063	5.396	0.57	D	5.3	0.5	
193 256			D			
193 281	3.841	3.41	D	4.7	3.0	

Table 2. continued.

HD	Hip. ρ arcsec	Hip. dHp Δm	Hip. Hvar	WDS ρ arcsec	WDS Δm	Interf. ρ arcsec
196 821						
198 160	2.447	0.30	D	2.7	0.31	2.446
198 161	2.447	0.30				
200 841			C			
204 041			C			<0.155
204 965			C			
210 111						
210 418						<0.054
212 150			C			
214 454						
216 847						
217 782	0.387	2.17	D			0.338
218 396			P			
220 061			P			<0.030
220 278	0.139	1.13	D			0.111
221 756						
223 352				3.3	7.04	
225 218	5.342	3.66	D	0.1*		
261 904			–			
290 492			–	0.6	1.4	0.42
290 799			–			
294 253			–			

HD 225 218: the primary is the A component of a wide visual binary; the given separation is that of the Aa components.
Remarks from ESA Hipparcos Catalogue (1997).
Notes on Hipparcos-defined type of variability, the Hvar Type (52):
C: no variability detected (“constant”).
D: duplicity-induced variability.
M: possibly micro-variable (amplitude <0.03 mag).
P: periodic variable.
R: $V - I$ colour index was revised due to variability analysis.
U: unsolved variable which does not fall in the other categories.

for the angular separation are given only for binaries with separation lower than 10 arcsec.

For 9 stars (HD 22 470, HD 36 496, HD 38 545, HD 47 152, HD 97 773, HD 118 623, HD 170 000, HD 217 782, HD 220 278) the separation and the magnitude difference measured by Hipparcos are such that the observed spectrum is composite. For two of them (HD 118 623 and HD 217 782) the Tycho Space Experiment Data made it possible to add the colour indices difference (Fabricius et al. 2002).

The separation and magnitude of the HD 160 928 companion given in the WDS catalogue show its weight on the brightness of the observed object.

HD 290 492 produces also a composite spectrum according to WDS data which have been confirmed by Marchetti et al. (2001). For this star the Tycho Space Experiment Data (Fabricius et al. 2002) show that the two components have different magnitudes (VT = 9.77 and 10.33; BT = 9.98 and 10.31) and unequal colour indices. Paunzen & Gray (1997) claimed to have observed the spectrum of this close binary system without any contamination by the companion separated, according to them, by 2 arcsec. The difference in the separation between their measure and that of Marchetti et al. (2001) is 1.3 arcsec. A rough estimate of the period of orbital motion can be computed from masses and absolute magnitude corresponding to normal stars for the two components, giving a value for the period of some thousands of years. The period fraction covered between the two observation epochs is negligible. Therefore, it is impossible that the stars have moved so much between these two observations if the same star has been observed. The classification as λ Boo given by Paunzen & Gray (1997) is clearly based on the composite spectrum. This example demonstrates, once more, our point of view that the combination of two similar, but unequal spectra can easily produce a weak line spectrum.

For the two spectroscopic binaries HD 153 808 and HD 159 082 we note the discrepancy between the negative binary detection by interferometry in Hartkopf et al. (2003) and the separation of 0.2 arcsec given in the WDS Catalogue; for both stars the latter value refers to Miura et al.'s (1995) paper, which calls for confirmation.

4. Adaptive optics

Another method of detecting binary systems, with small separation, is adaptive optics, which gives access not only to the measure of the angular separation, as in the case of speckle interferometry, but also to the magnitude difference between the components.

We have applied this method to a sample of λ Boo stars with the adaptive optics system PUEO at the CFH telescope for a search of stars near to our targets, which are separated by less than 2 arcsec, because we are interested only in companions which can contaminate spectral observations. The near-infrared camera KIR, designed to be used at the focus of PUEO, was used in a run in May 2001 and the images were taken with two filters: Hcont and Jcont.

On each target 50 exposures of approximately 0.1 seconds were combined (the actual integration time of each object was adjusted for optimal signal-to-noise without saturation). A 5-point dither pattern was used to obtain the infrared sky by taking the median of the dithered images. Standard infrared data reduction techniques were then applied (sky subtraction, flat fielding and dead pixel correction). The images were also deconvolved using a PSF provided by the wave front sensor (Véran et al. 1997). The deconvolution was a simple linear division by the MTF and filtering in the Fourier plane; the net effect of this deconvolution is mostly to reduce the halo produced by uncorrected seeing. Examples of adaptive optics images are provided in Fig. 1 which shows unambiguous detection of companions on both raw and deconvolved images. Each image was visually inspected for binarity; it is estimated that the minimum separation that can be detected is 0.09″. The maximum contrast depends on the distance to the primary but, as a rough estimate, contrasts on the order of tens are easily detectable within the central arcseconds and hundreds (if not thousands) outside of the central arcsecond.

Table 3 gives the list of the observed stars and the results we have obtained.

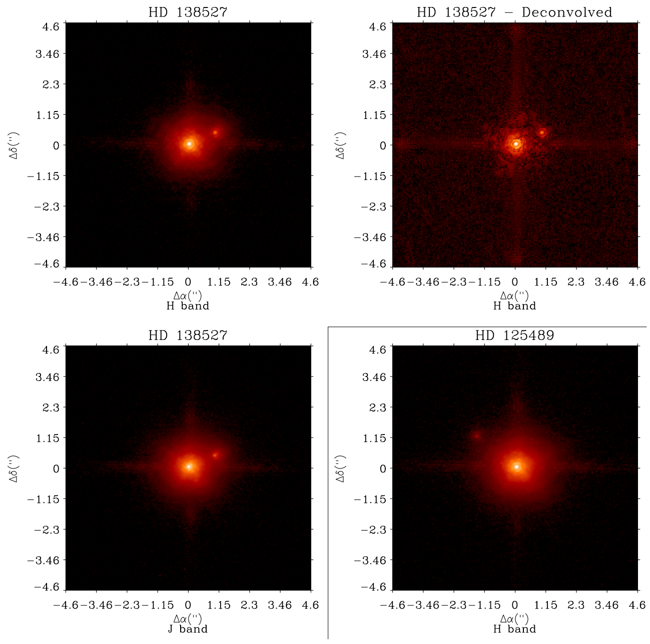

Fig. 1. Raw adaptive optics images in J and H bands for HD 125 489 and HD 138 527, and deconvolved image in H band for HD 138 527. The scale on both axes is given in arcsec.

For HD 105 058 and HD 125 489 (Fig. 1) the detected companion is too faint to affect spectroscopic observations.

For the HD 141 851 binary system the existence of a secondary separated by less than 0.1 arcsec has been known since 1987 (McAlister et al. 1987); however, the companion has been considered too faint to affect the observed spectrum, which has always been interpreted as that of a single object (North et al. 1994; Paunzen et al. 1999; Kamp et al. 2002; Andrievsky et al. 2002). The AO observations confirm the presence of a companion star that cannot be separated at a spectrograph entrance. The magnitude difference is measured for the first time by our observations to be 1.2 in the H filter and allows us to affirm that the average atmospheric parameters and the abundances derived from them in the quoted papers are far from being reliable values, especially if derived from lines of neutral species, which are more heavily affected by the cooler companion.

The presence of a faint companion near HD 138 527 (Fig. 1) makes this object an interesting binary system to explore before assigning it to the λ Boo class.

We note that no close companion to the spectroscopic binary, HD 153 808, was detected.

5. Duplicity indication from radial velocity, *v* sin *i* and Hipparcos Catalogue notes

The values of the radial velocity (*RV*) and of the projected rotational velocity ($v \sin i$) are presented in Table 4.

The *RV* and associated notes are taken from the Bright Star Catalogue (Hoffleit & Warren 1994) (*BSC*) and are given Cols. 3 and 4.

The inspection of the values of the *RV* and more precisely of its variability gives important information on the presence of a companion which may affect the spectrum. The values are

Table 3. λ Boo stars observed with the PUEO adaptive optics. The note "nothing detected" means that there is no companion at less than 2 arcsec.

HD	Dates observ.	Filter	Results
64 491	4 May 2001	H2	nothing detected
	5 May 2001	Jcont	nothing detected
	6 May 2001	Hcont	nothing detected
83 041	4 May 2001	Hcont	nothing detected
	6 May 2001	Hcont	nothing detected
84 948	5 May 2001	Hcont	nothing detected
90 821	4 May 2001	Hcont	nothing detected
101 108	5 May 2001	Hcont	nothing detected
105 058	5 May 2001	Hcont	detection of a star 250 times fainter 1.5 arsec (northwest)
105 759	6 May 2001	Hcont	nothing detected
106 223	4 May 2001	Hcont	nothing detected
111 786	4 May 2001	Hcont	nothing detected
	5 May 2001	Jcont	nothing detected
112 097	6 May 2001	Hcont	nothing detected
118 623	4 May 2001	Hcont	no other companion (see Table 1)
120 500	6 May 2001	Hcont	nothing detected
125 489	6 May 2001	Hcont	detection of a star 100 times fainter 1.8 arcsec (northeast)
130 158	4 May 2001	Hcont	nothing detected
138 527	5 May 2001	Jcont	detection of a star 20 times fainter 0.6 arcsec(northwest)
	6 May 2001	Hcont	detection of a star 20 times fainter 1 arcsec (west)
141 851	4 May 2001	Hcont	detection of a star 3 times fainter 0.15 arcsec (east)
	6 May 2001	Hcont	detection of a star 3 times fainter 0.2 arcsec
142 703	4 May 2001	Hcont	nothing detected
153 808	4 May 2001	Hcont	nothing detected
	6 May 2001	Hcont	nothing detected
156 954	4 May 2001	Hcont	nothing detected
171 948	5 May 2001	Hcont	nothing detected
177 120	6 May 2001	Hcont	nothing detected
183 324	6 May 2001	Hcont	nothing detected
192 640	6 May 2001	Hcont	nothing detected

Table 4. Radial velocity and notes given in the *BSC* and $v \sin i$ from various sources.

HR	HD	*RV*	notes	*R*	*AM*	*UF*	*BSC/CDS*
1	3	–18		–	210:	275	195
12	319	–13	V	61	45		
129	2904	–10		–	225:	210	154
	4158	–		–	–		
283	5789	1	SB	–	230:	305	298
	6173	–		–	–		
	6870	–		–	–		
	7908	–		–	–		
541	11 413	7		139	–		
545*	11 503	4	V	–	185	185*	152
	13 755	–		–	–		
	15 165	–		129	–		
803	16 955	–11		–	160	130	
1036	21 335	31		–	200:	255	214
1100	22 470	14		–	65	80	98
1137	23 258	15	SB	–	110	100	87
	23 392	–		–	–		
	24 472	–		–	–		
	26 801	–		–	–	–	
1525	30 422	19		134	100	200	157
1544	30 739	24	SB	–	195	235	212
1570	31 295	13	V	121	105	110	104
1751	34 787	12	SB	–	200:	290	268
1777	35 242	9		–	75	105	
1853	36 496	–15	V?	–	180	225	209
	36 726	–		–	–		
	37 411	–		–	–		
	37 886	–		–	–		
1989	38 545	21	V	–	175		
2029	39 283	–12	V?	70	55	70	72
2039	39 421	39		225	215:		
	41 580			–		–	–
2425	47 152	18	V?	–	25		29
	54 272	–		–	–		
2758	56 405	10	V?	160	145		152
3083	64 491	22	V	–	15	75	70
3164	66 684	–17	V?	–	65		103
3481	74 873	23	V	–	10	85	74
3517	75 654	9		45	–		
3651	79 108	20	V	172	160	160	150
	81 104	–		–	–	–	–
	81 290	–		–	–		
	83 041	–		–	–		
	83 277	–		–	–		
	84 123	–		–	–		
	84 948	–		–	–		
	87 271	–		–	–		
3974	87 696	–18	V	–	150	160	148
4041	89 239	7		–	135	100	83
4049	89 353	–33		–	–		
	90 821	–		–	–		
4124	91 130	–15	V	–	190	130	125
	97 773	–		–	–		
4366	97 937	–20	SB	–	120		109
4380	98 353	–3	SB2O	–	–	50	47
4391	98 772	1		–	230:	170	160
	101 108	–		–	–	100	
	102 541	–		–	–		
	105 058	–		–	–	130	
	105 759	–		–	–		
	106 223	–	–	–	–	100	
	107 233	–		–			
4733	108 283	–4	SB	–	185		227

Table 4. continued.

HR	HD	*RV*	notes	*R*	*AM*	*UF*	*BSC/CDS*
	109 738	–		–	–		
4811	109 980	–15		–	255:	235	220
4824	110 377	9	SB	–	160		153
4828	110 411	2	SB	–	–		173
	111 005			–	–		
4875	111 604	–14	V	–	180	185	183
4881	111 786	–18		45:	135		
4900	112 097	–10	SB	–	61		67
5127	118 623	–6	V	–	190	235	204
	120 500	–	–	–	–		
	120 896	–		–	–		
5351	125 162	–8		–	110		110
5368	125 489	–22	V	–	145		157
	125 889	–		–	–		
5514	130 158	–18		–	55		0
	130 767	–		–	–		
5770	138 527	–18	V	–			75
5895	141 851	–8	V	249	185		
5930	142 703	12		112	95		
	142 994	–		–	–		
6002	144 708	–25	SB	–	255:		239
	148 638	–		–	–		
	149 130	–		–	–		
6162	149 303	–16	V	–	–		
	153 747	–		–	–		
6324	153 808	–25	SBO	–	50	85	78
6338	154 153	–33		125	–		
	156 954	–		–	–		
6532	159 082	–12	SBO	21	30		32
6597	160 928	–9		–	–		
6871	168 740	–21		–	–	150	123
	168 947	–		–	–		
6878	169 009	–24	V?	–	35	≤30	≤ 41
6879	169 022	–15		236	–	175	140:
6920	170 000	–16	SB1O	–	65	85	88
6944	170 680	–37	V	224	200:	305	213
	171 948	–		–	–		
	174 005	–		87:	–		
	175 445	–		–	–		
	177 120	–		–	–		
7236	177 756	–12	V	–	–	160	176
7288	179 791	9	V?	–	180	185	175
7400	183 324	12	V	109	105		73
	184 190	–		–	–		
	184 779	–		–	–		
	191 850	–		–	–		
	192 424	–		–	–		
7736	192 640	–17	V	86	35	75	37
	193 063	–		–		–	–
	193 256	–		–	–	65	53
7764	193 281	4	V	99	75	90	82
7903	196 821	–37	SB?	24	10	30	20
7959	198 160	–16		–	–		
7960	198 161	–10		–	–		
	200 841	–		–	–		
8203	204 041	–9		68	55		68
8237	204 965	–17	SB	–	85	70	65
8437	210 111	–4		54	–		
8450	210 418	–6	SB2	–	130	120	117
8525	212 150	–18		–	180	230	165:
8613	214 454	12	SB	–	93		87
	216 847	–		209	–		
8766	217 782	2	SB	–	195	205	190
8799	218 396	–12		–	40	55	45

Table 4. continued.

HR	HD	*RV*	notes	*R*	*AM*	*UF*	*BSC/CDS*
8880	220 061	16	V	–	135	150	143
8890	220 278	–12		–	160	140	141
8947	221 756	13	V	–	75	100	109
9016	223 352	14	V?	299	280:		
9105	225 218	–8	SB	–	20		
	261 904	–		–	–		
	290 492	–		–	–		
	290 799	–		–	–		
	294 253	–		–	–		

HD 11 503 has a wrong HR number in *BSC*: HR 545 = HD 11 502 and HR 546 = HD 11 503.
UF gives this value for HD 11 502.
HD 193 256: $v \sin i$ = 240 km s^{-1}, according to Holweger & Rentzsch-Holm (1995).

available for 79 stars; for 50 of them an indication of radial velocity variability (*V*) or suspected variability (*V*?) or the indication of spectroscopic binary (*SB*) is given in this catalogue.

For each of the 30 objects having the *V* or *V*? indication, we searched for information to explain this *RV* variability. A number of these stars belong to known visual binary systems and the *RV* variation is easily ascribed to the presence of the widely separated companion which is spatially resolved by the entrance of a spectrograph and therefore cannot produce a composite spectrum.

The inspection of the speckle interferometry data base (Hartpkopf et al. 2003) has not revealed the presence of a companion for 13 stars of the remaining 14 *RV* variables: HD 39 283, HD 56 405, HD 74 873, HD 79 108, HD 87 696, HD 111 604, HD 125 489, HD 138 527, HD 169 009, HD 177 756, HD 179 791, HD 183 324 (the star not observed by speckle), HD 220 061 and HD 221 756.

The adaptive optics observations described in the previous section have detected a companion of HD 138 527 and gave a negative result for HD 183 324.

Among the 20 SB stars, there are two SB2 stars (HD 98 353 and HD 210 418, see Sect. 7) which must be considered misclassified λ Boo stars, as already noticed by Gray (see last column Table 1). For two stars (HD 170 000, HD 217 782) the separation and the brightness of the companion measured by the Hipparcos experiment (see Table 1) show that the observed spectrum is composite. The composite spectrum of the triple system HD 153 808 is discussed by Faraggiana et al. (2001a); HD 225 218 is a complex system (see Table 2).

The unexplained *RV* variables and the *SB* with a companion of unknown magnitude remain doubtful λ Boo candidates.

Values of $v \sin i$ are given in Col. 5 to 8 of Table 4. Those in Col. 5 are taken from Royer et al. (2002a,b). The AM values (Col. 6) are based on the fit of the observed profiles of 2 lines, Fe II 4476 and Mg II 4481, with a gaussian curve for which AM measured the half width. Royer et al. made a more refined work: the $v \sin i$ is derived from the frequency of the first zero of the Fourier transform of several line profiles. Other sources of rotational velocity values are the Uesugi & Fukuda (1982) (*UF*) and the *BSC* catalogues, Cols. 7 and 8 respectively. These last two catalogues, being critical compilations of heterogeneous values taken from the literature, are not directly comparable with the values of Cols. 5 and 6; we will discuss only the stars for which very discrepant values are found. For these stars, we extended the search to all previous measures found in the literature to extract information on very different $v \sin i$ values, considered as a possible sign of a spectroscopic binary observed at different phases.

The stars emerging from this comparison are some of the objects already known as misclassified λ Boo stars. For example, for HD 64 491 (Faraggiana & Gerbaldi 2003), the $v \sin i$ are 15, 70 and 75 km s^{-1} according to AM, *BSC* and UF respectively. For HD 111 786 (Faraggiana et al. 2001a), Royer et al. (2001a) measured 45 km s^{-1} while AM and Stürenburg (1993) measured 135 km s^{-1}.

For other stars the origin of the discrepant $v \sin i$ values remains unexplained, in particular for three stars: HD 66 684, HD 74 873 and HD 192 640. For HD 66 684 the following $v \sin i$ values are reported: 65 km s^{-1} (AM), 103 km s^{-1} (*BSC*), 107 km s^{-1} (Wolff & Simon 1997), 145 km s^{-1} (Dworetsky 1974). For HD 74 873 AM measured 10 km s^{-1}, the *BSC* gives 74 km s^{-1} and Dworetsky (1974) measured 95 km s^{-1}.

For the very classical and widely studied λ Boo star HD 192 640 AM measured 35 km s^{-1} in agreement with the measure by Meisel (1968), who gives 30 ± 20 km s^{-1}, but very different from Slettebak (1954) 85 km s^{-1}, Stürenburg (1993) 80 km s^{-1}, Adelman (1999) 80 km s^{-1} and Royer et al. (2002b) 86 km s^{-1}. If we recall that this star has variable *RV* and an *U* (unsolved variable: Col. 4 of Table 2) comment in the Hipparcos catalogue, the two low $v \sin i$ values may be not simple misprints.

These stars deserve further study to exclude the hypothesis that they are undetected spectroscopic binaries producing composite spectra.

To conclude, we may add that for more than 40 stars no radial velocity and no $v \sin i$ values have been measured so, at this stage, it cannot be decided whether these stars are good λ Boo candidates.

The Hipparcos space experiment data Catalogue (ESA 1997) contains also information on the constancy of the measured magnitude; this note is reported in Col. 4 of Table 2. Duplicity-induced variability "D" is quoted for most of the stars for which duplicity has been measured by Hipparcos, but also for some other targets; these are: HD 3, HD 83 277, HD 111 005, HD 138 527 (which is also a *RV* variable and for which the adaptive optics observations detected the presence of a faint companion, Sect. 4), HD 148 638 and HD 193 256. The nature of this variability remains to be determined. Five stars in Table 2 have a variable Hip magnitude for which a period has been determined: HD 15 165, HD 22 470, HD 170 000, HD 218 396 and HD 220 061. For two stars, HD 22 470 and HD 170 000, it may be interpreted as the rotational period of one of the components belonging to the CP class; for the 3 remaining stars it corresponds to a δ Scuti variability.

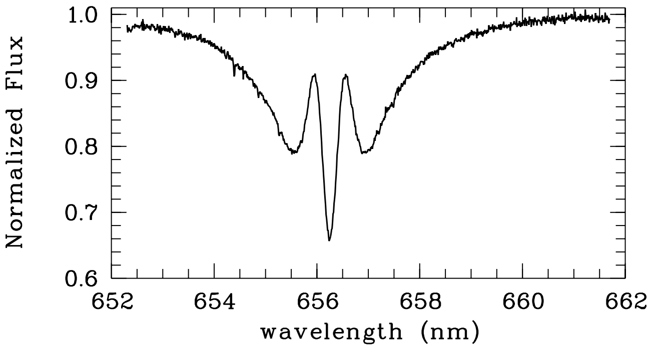

Fig. 2. The H_α profile of the hydrogen emission line star HD 34 787, misclassified as λ Boo. The spectrum has been taken at the Observatoire du Pic du Midi with the MUSICOS spectrograph on Oct. 7, 2002.

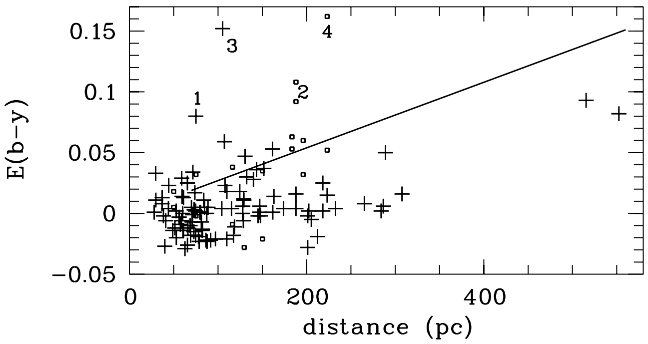

Fig. 3. Extinction $E(b-y)$ compared to the distance given in Col. 11 of Table 5. The stars having two derived $T_{\rm eff}$ and log g and consequently two values for $E(b-y)$ are represented by dots. The solid line is the Vergely et al. (1988) mean extinction law of 0.27 mag per kpc. The labels are: 1 = HD 91 130, 2 = HD 153 747, 3 = HD 169 009 and 4 = HD 177 120.

6. Misclassified candidates

Objects belonging to other classes of peculiar stars can be confused with λ Boo stars in the absence of a complete and accurate analysis. Such already detected objects are:

HD 6870 and HD 84 123 have kinematics slightly deviating from that of Pop. I stars and peculiar spectroscopic characteristics for λ Boo stars; they are more likely members of the thick disc population (Faraggiana & Bonifacio 1999).

HD 34 787 is classified as λ Boo by AM and has been investigated by Hauck et al. (1998) who measured CS components in the Ca II K line and Na I doublet. It is included in the P2 list. This star had been rejected by P1 because, according to these authors, it did not show the λ Boo characteristics selected by Baschek et al. (1984) and by Faraggiana et al. (1990) in their study of IUE spectra; however, HD 34 787 was not mentioned in these two papers and has never been observed by IUE.

This star is one of the new hydrogen emission line star found by Irvine (1990) in his survey of rapidly rotating early-type stars. The H_α profile observed by this author on 1986 Dec. 1 (Fig. 3 of his paper) is very similar to those we have observed on Oct. 7, 2002 (Fig. 2) and on Feb. 15, 2003.

The TD1 data show that the UV flux is lower than that computed from a model with solar abundances, contrary to what is predicted by the low blanketing of λ Boo stars. A more correct classification of HD 34 787 is A0 V ne.

HD 37 886 is a hot star classified as B8 III in CDS and Hg-Mn by Woolf & Lambert (1999), who measured [Mn/H] = 2.25 (with the convention N(H) = 12.0). This star has not been observed by Hipparcos nor by interferometry.

HD 83 041 has been classified as an FHB candidate by MacConnell et al. (1971); it is considered one of the 10 FHB with λ Boo characteristics by Corbally & Gray (1996) or more probably a blue straggler (Gray et al. 1996).

HD 89 353 is the extremely iron-deficient post-AGB binary star, better known as HR 4049, so it cannot be considered a λ Boo candidate.

HD 106 223 and HD 154 153 have been classified as "intermediate Pop II F-type stars" by Gray (1989) and the author notes that these stars form a very homogeneous population. For the first of them a summary of its classification history is also given in this paper. According to Gray, HD 106 223 and HD 154 153 belong to the group of intermediate population II stars with a metallicity class of −3 and −2.5 respectively.

HD 108 283 is a well-known shell star (see for example Sletteback 1951; Jaschek & Andrillat 1998; Gray et al. 2001).

HD 169 022 "listed as probable λ Boo star by Hauck & Slettebak (1983), but see the description of the spectrum in Slettebak (1975, ApJ 197, 137)" says Gray (1988).

7. Binaries with composite spectra

The discussion of the previous sections has demonstrated that for a number of objects the classification as λ Boo is inappropriate because it is based on a spectrum heavily contaminated by a companion. These stars, when considered as single objects, show a peculiar spectrum and controversial classifications may be found in the literature. For example, some stars are λ Boo according to some authors, but well-known Ap stars according to others. For these unresolved binaries no classification of their composite spectrum can be considered reliable. This is the case for:

20 Eri = HD 22 470 sep = 0.152 arcsec Δm = 1.36

53 Aur = HD 47 152 sep = 0.212 arcsec Δm = 0.77

ϕ Dra = HD 170 000 sep = 0.382 arcsec Δm = 1.45.

The Hipparcos experiment has clarified the origin of the peculiarities of the 9 stars cited in Sect. 3.

The contamination of the HD 160 928 and HD 290 492 spectra are demonstrated by WDS data and that of the HD 141 851 spectrum by our adaptive optics observations.

Another example of a wrong λ Boo classification is that of the already quoted SB2 HD 98 353 (55 UMa), which is in reality a triple system; it has often been assigned to the λ Boo class in spite of the fact that it has been known to be a double-line spectroscopic binary since 1908 (Lee 1908); details on the history of this star and on the discovery of a third companion are given by Horn et al. (1996), who detected the spectral lines of the tertiary component and gave the orbital solution of this triple system. The high variability of the line profiles with phase is apparent from Figs. 1 and 2 of this paper. More detailed analysis of the three components is given in Liu et al. (1997). The magnitude difference between the two brightest components has been estimated to be 0.33 mag from the new orbital solution computed by Söderhjelm (1999).

HD 81 104 duplicity has been detected by Bidelman et al. (1988); they classified this star as A3Vn SB2.

Another SB2 star is HD 210 418; we only report the Gray & Garrison (1987) note: "SB2 and therefore the spectrum may be composite and not actually metal poor".

HD 198 160 and HD 198 161 have similar visual magnitudes ($V = 6.28$ and 6.59), and form a binary system so close that only the combined colours have been measured. The only abundance analysis is that made by Stürenburg (1993) and is based on the hypothesis that the two stars are twin, i.e. have the same $T_{\rm eff}$ and $\log g$ derived from the combined colour indices. However, Tycho Space experiment data (Fabricius et al. 2002) detected a slight difference in the colours $\Delta V = 0.35$ and $\Delta B = 0.39$. In conclusion, for none of them can reliable metal abundances be derived from photometricaly derived atmospheric parameters.

Two stars have been classified as λ Boo and SB2 by Paunzen et al. (1998): HD 84 948 and HD 171 948. We (Faraggiana et al. 2001a) observed HD 84 948 and demonstrated that the atmospheric parameters chosen by Paunzen et al. for the abundance analysis of this star are not correct for at least one component.

Some of the most useful criteria for detecting a composite spectrum are described in Faraggiana et al. (2001a) and have already been applied to several stars. The objects whose spectrum is tangled by that of one or more companions, according to our high resolution spectral inspection, are: HD 64 491 (Faraggiana & Gerbaldi 2003), HD 111 786 (Faraggiana et al. 1997, 2001a), HD 153 808 (Faraggiana et al. 2001a), HD 174 005 (Faraggiana et al. 2001b). This programme is going on; other stars have been recently found to be spectroscopic binaries, producing a composite spectrum that simulates that of a single λ Boo star; they will be discussed in a paper in preparation, together with the series of criteria selected for the duplicity detection.

Further observations are required for the other stars classified as SB or radial velocity variables (see previous section) to verify that the companion is too faint to affect the spectrum, before assigning them to the λ Boo class.

All the above-mentioned stars cannot be considered λ Boo stars until the correct analysis of the composite spectrum is made, and this is not the subject of our investigation, which is based on one or a few spectra for each target. In fact, the aim of our research is restricted to the selection of a statistically significant sample of stars without any sign of duplicity, among the proposed candidates; only these can be considered reliable λ Boo candidates, according to the classical definition of the class and only for them can a metal abundance analysis based on $T_{\rm eff}$ and $\log g$ derived from photometric colours be made. We cannot exclude a priori that the composite spectrum of a binary is formed by the combination of those of two λ Boo stars; however, this must be proved by a correct analysis and cannot be derived by analysing the object as a single star.

8. Atmospheric parameters

A further source of information about possible duplicity is the consistency of the spectral characteristics in different wavelength ranges. Inconsistencies have also been found, for some stars, between their visual photometric indices and their spectral classification. In fact, it is well known and repeatedly stressed in the non-recent literature (see for example Olsen 1980) that the most probable cause of unusual photometric indices is duplicity.

One way to compare the visual and the UV flux behaviours is to compute the atmospheric parameters from the visual photometric colour indices and to compare the observed UV fluxes with those computed by adopting the parameters derived from the visual.

The following two sections, on the visual absolute magnitude and on the UV flux measured by the TD1 satellite, have been developed with this in mind.

To derive the atmospheric parameters, we adopted the classical method, i.e. deriving them from photometric data. We recall that photometrically derived values are obtained on the hypothesis that the stars are single objects; they have no physical meaning if the colour indices are contaminated by the flux of a companion. In spite of this, they have been computed for all the stars of the sample to look for inconsistencies, the only exception being HD 89 353, better known as the post-AGB HR 4049, for which the photometric calibrations valid for normal stars cannot be employed.

Seven stars have no Strömgren photometry, 30 stars no Geneva values.

We used the photometric colour indices of $uvby\beta$ photometry with the Moon & Dworetsky (1985) (MD) calibration and those of Geneva photometry with the Künzli et al. (1997) calibration.

The photometric data were retrieved from the Hauck & Mermilliod Catalogue (1998) for $uvby\beta$ photometry, complemented for some stars by values extracted from the General Catalogue of Photometric Data by Mermilliod et al. of the Geneva Observatory (`http//www.unige.ch/sciences/astro/`).

The values of the Geneva photometry are taken from the General Catalogue of Photometric Data by Mermilliod et al. of the Geneva Observatory.

The values of the atmospheric parameters are given in Table 5: Cols. 2 to 6 refer to $uvby\beta$ photometry, Cols. 7 to 10 to the Geneva photometry. The Table 5 is only available in electronic form.

Column 2 gives the remarks taken from the Hauck & Mermilliod Catalogue (1998): variability (V) and indication of the component(s) observed for binaries (A or AB). In Col. 10, the remarks are similar to that of Col. 2, but related to the Geneva photometry.

We computed the reddening $E(b-y)$, given in Col. 3, using the programme by Moon (1985). $T_{\rm eff}$ and log g, in Cols. 4 and 5, are computed with the MD programme according to the value of the group given in Col. 6. Columns 7 and 8 give $T_{\rm eff}$ and log g computed with the Künzli et al. (1997) programme, using as reddenning $E(B2-V1) = 1.146\,E(b-y)$; Col. 9 shows the metallicity, [M/H] computed only for stars having a $T_{\rm eff}$ lower than 8000 K.

In the application of Moon's (1985) programme we realized that for several stars the observed colours are inconsistent with each other and with the spectral classification; these stars are: HD 3, HD 4158, HD 35 242, HD 38 545, HD 39 421, HD 153 747, HD 153 808, HD 175 445, HD 177 120, HD 179 791 and HD 290 799. For these 11 stars $T_{\rm eff}$ and log g have been derived by using two algorithms of the MD routine, and these two values of $T_{\rm eff}$ and log g are given in Table 5 for comparison. The most striking example is that of HD 4158.

For the 98 stars, excluding those mentioned above, having atmospheric parameters computed with MD and Künzli et al. algorithms, the mean value of the differences in $T_{\rm eff}$ is 29 K, with a standard deviation of 161 K, and for log g the mean value of the differences, (MD minus Künzli et al.) is −0.22, with a standard deviation of 0.24.

The stars with a difference in $T_{\rm eff}$ larger than 350 K are HD 2904, HD 22 470, HD 106 223, HD 130 158, HD 144 708, HD 149 303, HD 193 256, HD 204 965. As concerns the log g, the differences are such that this will not affect the choice of the template flux distribution to be compared with the UV flux observed by the S22/68 space experiment on board TD-1.

The stars with a negative value of the colour excess $E(b-y)$ larger than the expected observational error (0.02 mag) are good candidates for having a distorted visual energy flux distribution. The inconsistency of the colour indices produces an uncertainty on the reddening computation and therefore on the derived $T_{\rm eff}$, log g. No star has a negative $E(b-y)$ value lower than −0.030, which is a mild value, not considered peculiar for this study.

The values of $E(b-y)$ as a function of the distance (given in Col. 11 of Table 5), as computed from the Hipparcos parallax, have been compared (Fig. 3) to the extinction in the solar neighbourhood determined by Vergely et al. (1998). From this comparison it follows that only 4 stars have a slightly larger extinction than the normal one: HD 91 130, HD 153 747, HD 169 009 and HD 177 120; two of them HD 153 747 and HD 177 120 have been previously noted as having incoherent observed colours with their spectral classification.

These comparisons show that the behaviour of the stars of this sample is similar in the two photometric systems.

9. Visual absolute magnitude

The absolute magnitude M_V can be derived from two independent methods and the comparison of the values so obtained is another way to detect peculiar objects. These methods are:

- the direct determination using Hipparcos parallax and the previously computed reddening;
- the calibrations of the *uvbyβ* photometry adopted in the Moon (1985) programme.

Before comparing the values obtained by these two approaches, we checked the reliability of this M_V photometric calibration by comparing it to the one recently defined by Domingo & Figueras (1999) for main-sequence stars in the range of spectral type A3−A9. We used the relation given by these authors (relation 7), not taking into account the influence of $v \sin i$ which is not available for all the stars of the sample. The mean value of the differences between the absolute visual magnitude computed from the Moon (1985) calibration and that using the Domingo & Figueras (1999) relation is 0.006 mag with a standard deviation of 0.15 mag.

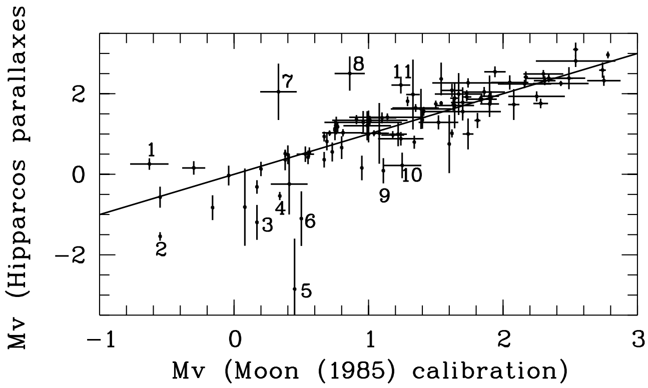

Fig. 4. The absolute visual magnitude M_V derived with the Moon (1985) calibration versus the one computed from the V mag using Hipparcos parallaxes; the dereddening is applied according to the relation $A_V = 3.2(1.35E(b-y))$. The stars with inconsistent observed colours in the Strömgren and the Geneva photometric systems are not plotted. The solid line is the bisector. The labels are for the stars for which the difference between the two computed absolute magnitudes exceed 0.5 mag. 1 = HD 108 283, 2 = HD 169 022, 3 = HD 196 821, 4 = HD 170 000, 5 = HD 225 218, 6 = HD 66 684, 7 = HD 148 638, 8 = HD 105 058, 9 = HD 5789, 10 = HD 174 005 and 11 = HD 106 223.

Figure 4 shows that there are no systematic differences between the absolute magnitudes computed from the parallaxes and the V mag and the one determined through a calibration of the Strömgren photometric system.

The error bar on M_V derived from Hipparcos data is due from the uncertainties in the parallaxes measurements. It has been computed according to the relation:

$$\sigma(M_V) = ((\sigma(V))^2 + (2.17\sigma(\pi)/\pi)^2 + (\sigma(A_V)^2)^{0.5}.$$

A constant value of 0.01 has been taken for $\sigma(V)$, and we adopted 0.05 as the error on A_V. For the photometrically derived M_V we have plotted an horizontal bar which is equal to the difference between the values given by the Moon (1985) calibration and those by Domingo & Figueras (1999); this is not an error bar.

In Fig. 4 the stars with the largest discrepant values have been noted and some of them correspond to questionable λ Boo candidates, according to the discussion given in previous sections or to stars for which the Hipparcos magnitude variability is ascribed by duplicity or remains unexplained (D or U respectively in Col. 4 of Table 2).

10. TD1 UV fluxes

The revised edition of the Thompson et al. (1978) catalogue of Stellar Ultraviolet Fluxes, available at CDS, has been chosen for computing the ultraviolet magnitudes (UV mag), and their errors, corresponding to the flux measured in the four spectral domains centered at 156.5 nm, 196.5 nm, 236.5 nm and 274 nm. The magnitudes are normalised to the V magnitude.

These fluxes are available for 96 out of the 136 stars of Table 1, but for 4 of them (HD 7908, HD 109 980, HD 111 005 and HD 112 097) the error bars are too high for any information to be derived from these fluxes.

The computed fluxes to be used as templates have been obtained from the grid of Kurucz fluxes (1993). The theoretical UV magnitudes have been calculated by integrating these fluxes over the response profile of the four passbands of the S2/68 experiment, using for each channel, the absolute efficiency curve given in the printed version of the Thompson et al. (1978) catalogue.

In making this comparison we have to take into account that the main possible sources of discrepancy are:

i) the TD1 errors on the observed fluxes;

ii) the uncertainties on the adopted values of the reddening and of $T_{\rm eff}$, $\log g$;

iii) the fact that the Kurucz fluxes are computed from models having scaled abundances with respect to the solar ones. These fluxes cannot reproduce accurately the λ Boo spectra which are characterized by abundance deficiencies of the Fe-peak elements, but not of the light elements CNOS. Moreover, the λ1600 A absorption feature characteristic of many λ Boo stars and due to the Lyα satellite (Holweger et al. 1994) is not introduced in these computations.

The observed UV magnitudes have been normalized to the V value and dereddened according to the UV extinction $A(\lambda)/E(B-V)$ given by Thompson et al. (1978), where $E(B-V) = 1.35E(b-y)$, $E(b-y)$ being the value in Table 5. The computed magnitudes are obtained from the Kurucz fluxes, $T_{\rm eff}$ and log g are taken from Table 5, and various values of metallicity are tested. The comparison of these two sets of values shows that the λ Boo in the UV display astonishing differences, because the stars already known to produce composite spectra are not those with the most abnormal UV patterns.

HD 98 353 represents a striking example: this object is an SB3 system (see Sect. 7) composed of non-twin stars. The UV spectrum is fitted by computations based on $T_{\rm eff}$, log g derived from visual photometry (Table 5) if [M/H] = -1.0 is adopted. The UV data of HD 98 353 may be reproduced by the computations based on $T_{\rm eff}$ = 8500, $\log g$ = 4.0 and [M/H] = -1.0 as displayed Fig. 5.

A detailed inspection allows us to group the stars into 5 groups given in Col. 12 of Table 5.

- Group 1 (8 stars, 9% of the sample): stars for which the observed flux is lower than the one predicted for solar abundances, indicating a blocking similar to that of the Ap stars if the object is considered single. An example is given in Fig. 6. Three of these stars are unsolved binaries (see Table 2) HD 22 470, HD 47 152, HD 170 000. HD 159 082 is a questionable binary (see Sect. 3).

A preliminary inspection of the high resolution observations, made at the Observatoire du Pic du Midi with the MUSICOS spectrograph, which will be discussed in a forthcoming paper, shows that HD 196 821 is one of the newly detected stars with a composite spectrum.

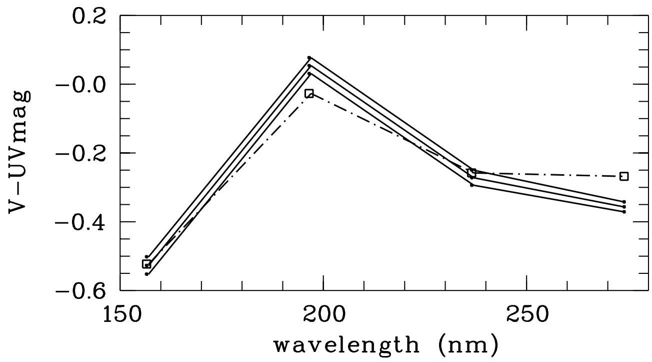

Fig. 5. HD 98 353 UV magnitudes in each spectral band are plotted; a line joins these measures. The upper and lower lines represent the errors on these measurements. No de-reddening is applied (see Table 5). The computed UV mag for $T_{\rm eff}$ = 8500 K, $\log g$ = 4.0 and [M/H] = -1.0 are plotted and joined with a dash-dot line.

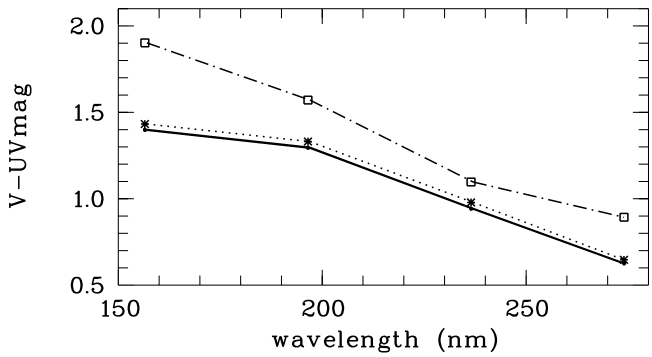

Fig. 6. HD 170 000 UV magnitudes in each spectral band are plotted; a line joins these measures. The upper and lower lines represent the errors on these measurements. The dotted line joins the dereddened magnitudes according to the extinction value given Table 5. The computed UV mag for $T_{\rm eff}$ = 12 500 K, $\log g$ = 4.5 and solar abundances are plotted and connected with a dash-dot line.

- Group 2 (10 stars, 12% of the sample): stars for which the observed flux is fitted by that computed with the solar abundance or close to it; also these cannot be considered as classical λ Boo stars. An example is given in Fig. 7.

The observations of the visual spectrum of HD 34 787 (see Sect. 6) have confirmed that this is not a λ Boo star. The spectrum of HD 36 496 is a composite one according to the duplicity detection (Table 2). The behaviour of the UV flux of HD 179 791 does not allow us to discriminate between the two sets of atmospheric parameters given Table 5.

- Group 3 (19 stars, 23% of the sample): stars for which the observed flux cannot be fitted by any model either because the UV flux is too high (Fig. 8) (6 stars, group 3a) or because the flux is distorted compared to the theoretical one (Fig. 9) (13 stars, group 3b).

Three of them are known to be binaries for which the companion affects the spectrum: HD 38 545, HD 64 491 and HD 97 773; for one, HD 225 218, a companion at 0.01 arcsec has been detected by interferometry; two stars, HD 3 and

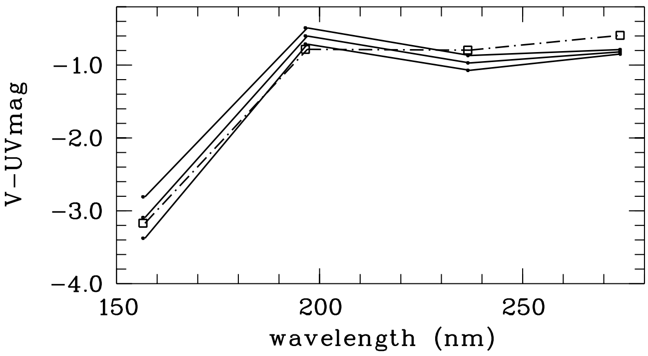

Fig. 7. HD 36 496 UV magnitudes in each spectral band are plotted; a line joins these measures. The upper and lower lines represent the errors on these measurements. No de-reddening is applied (see Table 5). The computed UV mag for $T_{\rm eff}$ = 7500 K, log g = 4.0 and [M/H] = −0.5 are plotted and linked with a dash-dot line. The UV spectrum agrees with [M/H] = −0.27 derived from the Geneva photometry. This star is a binary detected by speckle interferometry and the Hipparcos experiment (see Table 2).

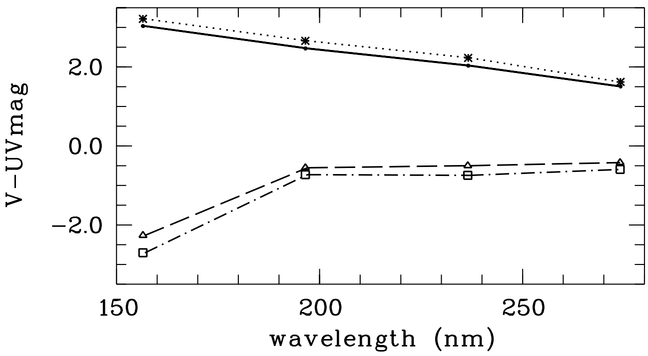

Fig. 8. HD 168 947 UV magnitudes in each spectral band are plotted; a line joins these measures. The upper and lower lines represent the errors on these measurements. The dotted line connects the dereddened magnitudes according to the extinction value given Table 5. The computed UV mag for $T_{\rm eff}$ = 7500 K, log g = 3.5, [M/H] = −1.0 and −2.0 are plotted and linked respectively with a dash-dot line and a long dash line; the metallicity derived with the Geneva photometry is −0.87.

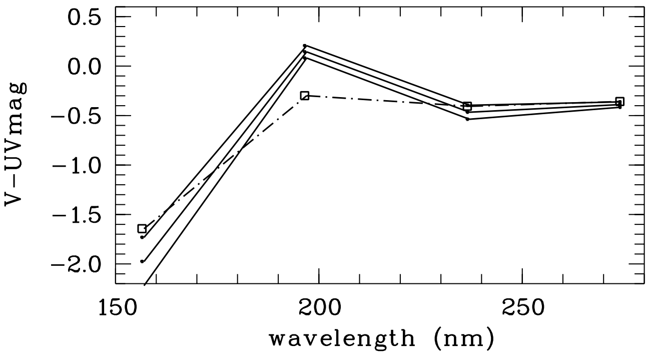

Fig. 9. HD 204 041 UV magnitudes in each spectral band are plotted; a line joins these measures. The upper line and lower lines represent the errors on these measurements. No de-reddening is required for this star. The computed UV mag for $T_{\rm eff}$ = 8000 K, log g = 4.0 and [M/H] = −1.0 are plotted and linked with a dash-dot line; according to the Geneva photometry the metallicity is −0.83.

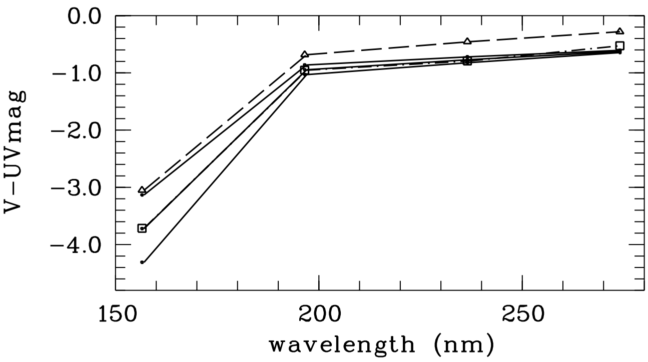

Fig. 10. HD 218 396 UV magnitudes in each spectral band are plotted; a line joins these measures. The upper and lower lines represent the errors on these measurements. HD 218 396 is compared to $T_{\rm eff}$ = 7000 K, log g = 4.0, [M/H] = −1.0 (dash-dot line); $T_{\rm eff}$ and log g are close to the values derived from Strömgren photometry which indicates a slightly negative reddening $E(b-y) = -0.027$. The comparison with $T_{\rm eff}$ = 7250 K, log g = 4.5, [M/H] = −0.5 (long dash line) is less satisfactory; these values correspond to those given by the Geneva photometry: $T_{\rm eff}$ = 7347 K, log g = 4.55 and [M/H] = −0.68.

HD 83 277, have a "D" note in the Hipparcos catalogue (Hvar type (52)).

We note that the fit for HD 3, HD 38 545, HD 175 445 and HD 177 120 is distorted, whatever $T_{\rm eff}$ is chosen. The TD1 observations do not permit us to discriminate between the two $T_{\rm eff}$ computed.

- Group 4 (41 stars, 48% of the sample): stars with an observed flux fitted by the computed one with metal underabundance, in most cases ten times lower than that of the Sun (Fig. 10); this is the largest group.

For HD 35 242 two sets of parameters have been computed (Table 5). The fit is similar for each set of parameters with [M/H] = −1.0. Nevertheless, for $T_{\rm eff}$ = 8900 K, the flux measured at 1565 λ is slightly too low.

For HD 39 421 two sets of parameters have been computed (Table 5). The fit with the metallicity [M/H] = −1.0 corresponds to a $T_{\rm eff}$ of 8500 K and no reddening. But for the set of parameters ($T_{\rm eff}$ = 9000 K, log g = 4.0) and the moderate reddening of $E(b-y) = 0.038$, the fit is obtained with [M/H] = 0.0, not allowing us to discriminate between the two sets of parameters.

HD 153 808 has two sets of parameters (Table 5) and the quality of the fit is slightly better with the set derived in the case of no-reddening.

However, even this group includes 5 already known binaries, demonstrating that the UV fit with underabundant fluxes is not a sufficient condition to safely select λ Boo stars.

- Group 5 (7 stars, 8% of the sample): the spectra of these stars are fitted by spectra based on [M/H] = −1.0 except for the observed magnitude at 1565 A which is too low; this can be interpreted as due to the presence of a strong λ1600 absorption feature characteristic of many λ Boo stars. However Figs. 11 and 12 demonstrate ambiguous information embodied in an observed spectrum. In fact, the same effect is observed in a star, HD 120 500, classified as λ Boo by Paunzen & Gray (1997), and in HD 210 418, classified as a normal SB2 by

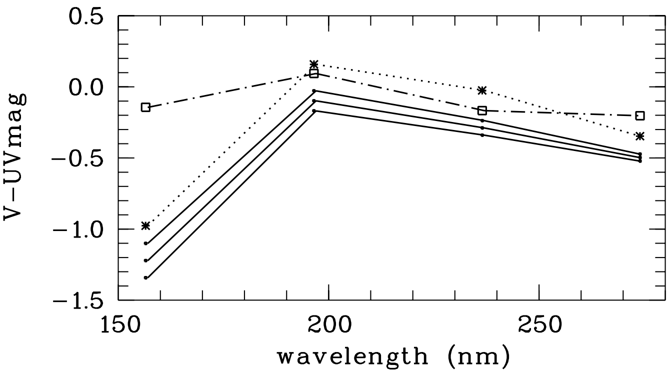

Fig. 11. HD 120 500 UV magnitudes in each spectral band are plotted; a line joins these measures. The upper and lower lines represent the errors on these measurements. The dotted line connects represent the dereddened magnitudes according to the extinction value given in Table 5. The computed UV mag for $T_{\rm eff}$ = 8750 K, log g = 4.0 and [M/H] = −1.0 are plotted and linked with a dash-dot line.

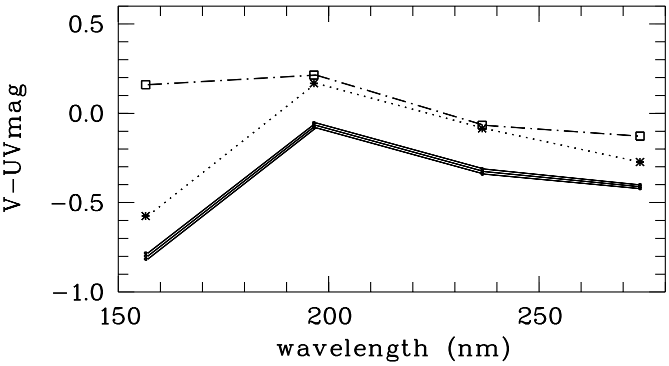

Fig. 12. HD 210 418 UV magnitudes in each spectral band are plotted; a line joins these measures. The upper and lower lines represent the errors on these measurements. The dotted line connects the dereddened magnitudes according to the extinction value given in Table 5. The computed UV mag for $T_{\rm eff}$ = 9000 K, log g = 4.0 and [M/H] = −1.0 are plotted and linked with a dash-dot line.

Gray & Garrison (1987). In both cases only an unrealistically strong λ1600 feature would explain the low value of the magnitude at 1565 A. HD 210 418 and HD 217 782 are binaries with a companion bright enough to affect the spectrum.

For 6 stars the TD1 observations are available but no photometric observations have been made in Strömgren and Geneva systems.

On the hypothesis that the stars are unreddened, the best fit with computations is obtained with the following parameters: HD 105 779 $T_{\rm eff}$ = 8000 K, log g = 4.0 and [M/H] = −0.5; HD 171 948 $T_{\rm eff}$ = 9250 K, log g = 4.0 and [M/H] = −1.0; HD 192 424 $T_{\rm eff}$ = 10 500 K, log g = 4.0 and [M/H] = 0.0.

Martinez et al. (1998) have derived for HD 105 779 $T_{\rm eff}$ = 8000 K, log g = 4.0 and [M/H] = −1.0 from spectroscopic data and $T_{\rm eff}$ = 7500 K, log g = 3.8 from photometric data. For HD 192 424 the estimated parameters suggest that it is not a λ Boo star.

For 3 others HD 26 801, HD 81 104, HD 193 063, the V magnitude and the shape of the UV flux suggest reddening, so that no estimation of $T_{\rm eff}$ and log g have been attempted.

This study of the UV properties of the known λ Boo stars includes about 70% of the objects of our survey. An analysis based on the behaviour of the UV flux, using the atmospheric parameters derived from visual photometry, shows that a large number of these stars cannot be classified as stars with a lower than solar atmospheric metallicity.

The 8 stars of group 1 and the 10 of group 2 have a spectral energy distribution similar to that of peculiar or normal A-type stars and they include a number of recently discovered binaries. The highly distorted flux of the 19 objects of group 3 is not coherent with that of any known star. The most likely explanation for this unexpected behaviour is that it is the combined flux from two sources with different $T_{\rm eff}$; in fact, the flux of 1/3 of the 3b objects is already known to be due to a composite flux from the two components of a binary system.

In conclusion the present analysis of the large TD1 data base allows us to reject 27% of the sample stars of Table 1; some of these rejected objects are excluded from the λ Boo class also on the basis of the presence of a near bright companion.

11. Conclusions

A careful inspection of the information available in the literature and retrieved from data bases has allowed us to demonstrate that the λ Boo class includes stars with very different physical properties. A not negligible percentage is represented by binaries producing composite spectra. The detection of duplicity can be achieved by a careful inspection of high resolution spectra for stars with low or moderate $v \sin i$; spectra characterized by broad and shallow features, mostly due to blends of different species, do not make it possible to derive information on duplicity and are also not suitable for an accurate abundance analysis (see for example Hill 1995) or even for useful radial velocities (Nordström et al. 1997), especially for hot stars as those classified as λ Boo.

The Hipparcos and the interferometric measures have allowed us to discover that 11 stars are binaries with low values of angular separation and magnitude difference.

Our adaptive optics observations allowed us to reject one more star, HD 141 851, for which only the companion separation was known before.

Spectral analysis has allowed us to reject the triple system HD 98 353, the two SB2 stars HD 81 104, HD 210 418 and the four stars analysed in our previous papers (HD 64 491, HD 111 786, HD 153 808, HD 174 005).

Therefore, 19 stars (14%) cannot be assigned to the λ Boo class on account of established duplicity; for these stars, the fluxes collected by photometric and spectroscopic devices are average values of two components and cannot be analysed as originating from a single source.

A group of misclassified stars is that discussed in Sect. 6 and includes 10 stars.

For 3 further objects, the metal abundance analyses made up to now which should prove the λ Boo character, are based on incorrect values of $T_{\rm eff}$ and log g parameters (HD 84 948, HD 198 160, HD 198 161). For the SB2 HD 171 948 the abundances are based on the hypothesis that the two components are twin stars.

The UV fluxes discussed in Sect. 10, even if based on low-resolution observational data, have allowed us to reject 28 more stars.

Altogether 58 stars out of 136 (43%) objects cannot be safely considered as single objects belonging to a class of A-type stars defined as λ Boo.

For the remaining stars, very little is known for those not belonging to the *BSC*. The discussion of the brightest objects, i.e. those present in this catalogue, is restricted to 41 stars: 10 of them are classified SB and 16 have a variable *RV*. For most of them, this variability is explained by a visual companion too far away or too faint to affect the spectrum, but this is not the case for HD 79 108, HD 111 604, HD 169 009, HD 183 324, HD 220 061. These 5 stars and the 10 SB require further study before being safely classified as λ Boo.

The conclusion obtained on individual stars of the λ Boo class is summarized in the last column of Table 1. Only one comment concerning the questionable λ Boo classification is given for each star.

When several criteria have been found, the given one is the "strongest". Their meaning is:

- "misclassified:" and "misclassified" refers to stars discussed in Sect. 6.
- "composite, Hipparcos", "composite, interferometry" and "composite, AO" means that the spectrum is affected by, at least, one bright enough component, this one being detected by Hipparcos space experiment, by interferometric observations or by adaptive optics (see Sects. 3, 4).
- "composite, spectrum", "SB2, metal ab. to be revised", "SB2, twin stars?" and "metal ab. to be revised" when spectral analysis of the composite spectrum has been made (Sect. 7).
- "inconsistent UV flux" is quoted when the TD1 magnitudes have been found not in agreement with the hypothesis that the star is λ Boo (groups 1, 2 and 3 defined in Sect. 10). Between parenthesis is the description of the fit when it can be expressed shortly: "solar ab.", "bin?" if the binarity of the star is suspected and "bin" if the star is a binary.
- "*RV* variable", "discordant $v \sin i$ values" or "D, Hipparcos" when observations suggest a binarity without knowledge on the contamination by the companion (Sect. 5).
- A blank means that no definite information are available.

In conclusion we have demonstrated that the λ Boo class, if exists, comprises very, very few stars and that it is very easy to classify a binary as λ Boo.

Acknowledgements. Large use has been made of the SIMBAD database operated at the CDS, Strasbourg, of the General Catalogue of Photometric Data by Mermilliod et al. (1997, A&AS, 124, 349), available on line at the Geneva Observatory site and of the IUE Final Archive data processed with the INES system. We warmly thank the Referee, H. Hensberge, for the careful examination of the paper and for its precious suggestions to shorten and clarify it.

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Table 5. Reddening, atmospheric parameters and distance in parsec computed from the Hipparcos parallaxes. The TD1 groups described in Sect. 10 are given in the last column; " * " indicates that the star has not been observed by this satellite "–" is given when no visual photometry is available and " : " when the TD1 values have a too large error to be used. We recall that HD 89 353 (HR 4049) is not considered here (see Sect. 6).

HD	Rem 1	$E(b-y)$	$T_{\rm eff}$ MD	log g MD	Gr	$T_{\rm eff}$ Gen	log g Gen	[M/H]	Rem 2	dist (pc)	UV flux category
3		–0.021	8640	3.63	6	8644	3.69	–		150	3b
3		0.035	9260	3.65	5	9231	3.98	–		”	”
319	AB	0.001	8150	3.80	6	8139	3.66	–	AB	80	4
2904		0.001	9970	3.75	1	9607	3.84	–		162	3b
4158		–0.030	6500	3.03	7	6763	3.52	–1.59		–	*
4158		0.250	12 260	2.90	1	11 798	4.47	–		”	”
5789	AB	0.012	10 040	4.12	1	–	–	–		129	*
6173		0.001	7820	3.40	6	–	–	–		–	*
6870	V	–0.021	7240	3.77	6	7362	4.29	–1.08	V	97	*
7908		–0.023	7070	4.07	6	7187	4.48	–0.67		88	:
11 413	V	0.002	7950	3.84	6	7813	4.08	–2.03	V	75	4
11 503	V	–0.029	10 970	4.25	1	–	–	–		63	*
13 755		–0.019	6960	3.30	6	–	–	–		212	*
15 165	AV	–0.018	6870	3.27	6	–	–	–		118	4
16 955	AB	0.023	9060	3.92	5	8971	4.08	–	AB	108	5
21 335		–0.006	7850	3.74	6	7780	4.09	-0.86		129	4
22 470	V	–0.002	14 510	4.12	1	14 097	4.16	–	V	145	1
23 258		–0.018	9500	4.42	5	9555	4.35	–		75	4
23 392		0.016	9840	4.47	5	9740	4.21	–		308	3a
24 472		–0.022	6760	3.68	6	6924	4.30	–0.71		92	3a
26 801		–	–	–	–	–	–	–		–	–
30 422	V	–0.009	7990	4.16	6	7886	4.37	–0.52	V	57	4
30 739		0.014	9560	3.56	1	9464	3.81	–		59	2
31 295		0.013	8970	4.26	5	8981	4.28	–		37	*
34 787		0.004	9890	3.49	1	9843	3.59	–		104	2
35 242		0.032	8900	4.03	5	8747	4.06	–		75	4
35 242		–0.002	8280	3.97	6	8294	3.84	–		”	”
36 496	AB	0.001	7660	4.04	6	7581	4.36	–0.27	A	79	2
36 726		0.027	9380	4.49	5	9274	4.30	–		–	*
37 411		0.068	8970	4.10	5	8982	4.19	–		–	*
37 886		0.050	12 550	4.18	1	12 497	4.35	–		–	*
38 545		–0.028	8600	3.59	6	8495	3.58	–		130	3b
38 545		0.042	9340	3.61	1	9156	3.92	–		”	”
39 283		0.017	9150	3.85	5	9183	4.12	–		74	2
39 421		–0.009	8450	3.71	6	8380	3.56	–		116	4
39 421		0.038	9090	3.73	5	8951	3.86	–		”	”
41 580		–	–	–	–	11 287	4.10	–	A	–	*
47 152		0.011	10 190	4.22	1	10 312	4.32	–	ABV	129	1
54 272		–0.015	6860	3.84	6	–	–	–		–	3b
56 405		0.005	9010	4.20	5	8964	4.20	–		85	1
64 491		–0.014	7120	4.08	6	7304	4.56	–0.67		60	3b
66 684	AB	0.006	10 040	4.02	5	10 010	4.13	–	AB	287	4
74 873		0.013	8720	4.38	5	8714	4.19	–		61	2
75 654	V	–0.019	7260	3.70	6	7325	4.19	–0.95	V	78	4
79 108		0.004	9830	4.07	5	9852	4.17	–		115	4
81 104		–	–	–	–	–	–	–		–	–
81 290		0.008	6560	3.49	7	6821	4.14	–0.76		265	*
83 041	V	0.015	6850	3.53	6	6998	4.16	–1.14	V	223	*
83 277		–0.002	6780	3.52	6	6765	3.77	–1.16		201	3b
84 123		0.018	6890	3.56	6	7113	4.29	–0.84		110	4
84 948		–0.028	6780	3.39	6	–	–	–		201	*
87 271		0.001	7450	3.52	6	–	–	–		147	4
87 696		0.001	8050	4.20	6	7853	4.41	–0.07		28	2
89 239		0.000	10 390	4.25	1	10 595	4.46	–		128	2
89 353	V	–	–	–	–	–	–	–	V	–	–

Table 5. continued.

HD	Rem 1	$E(b-y)$	$T_{\rm eff}$ MD	log g MD	Gr	$T_{\rm eff}$ Gen	log g Gen	[M/H]	Rem 2	dist (pc)	UV flux category
90 821		0.006	8270	3.73	6	–	–	–		–	*
91 130		0.080	9690	3.84	1	9718	4.34	–		75	5
97 773	AB	0.002	7420	3.77	6	–	–	–		202	3b
97 937		–0.007	7180	3.84	6	7152	4.26	–0.18		71	4
98 353		–0.003	8620	4.24	5	8599	4.12	–		56	4
98 772		–0.022	8590	3.80	6	8536	3.85	–		86	4
101 108	AB	0.004	7880	3.81	6	7750	4.15	–0.62	AB	233	*
102 541		0.018	7690	4.13	6	7744	4.46	–0.47		125	3a
105 058	V	0.004	7670	3.57	6	7745	4.05	–2.02	V	188	*
105 759		–	–	–	–	–	–	–		–	–
106 223		–0.021	6490	3.29	7	6864	4.08	–1.44		110	4
107 233		–0.007	7190	4.00	6	7267	4.41	–1.14		81	*
108 283		0.011	7120	2.87	6	6945	3.32	–0.40		84	4
109 738		0.017	7610	3.87	6	7599	4.15	–0.92		–	*
109 980		–0.026	7660	3.85	6	7699	4.21	–0.28		65	:
110 377	V	–0.010	7750	3.92	6	7661	4.18	–0.59	V	68	4
110 411	V	0.008	8970	4.36	5	8865	4.13	–	V	37	4
111 005		0.004	6910	3.74	6	–	–	–		174	:
111 604		–0.011	7660	3.47	6	7622	3.88	–1.61		119	4
111 786	V	0.000	7490	3.95	6	7397	4.29	–1.13	V	60	4
112 097		-0.014	7250	3.93	6	7248	4.29	–0.11		61	:
118 623	AB	–0.006	7400	3.57	6	7384	4.02	–0.34	AB	59	4
120 500		0.036	8840	3.89	5	–	–	–		143	5
120 896		–0.005	7370	3.81	6	–	–	–		205	*
125 162		0.011	8800	4.24	5	8751	4.13	–		30	4
125 489		0.005	8040	4.14	6	–	–	–		70	1
125 889		0.026	7330	3.96	6	7257	4.27	–0.79		–	*
130 158		0.016	10 940	3.60	1	11 336	3.72	–		188	*
130 767		0.006	9510	4.26	1	9189	4.16	–		128	4
138 527		0.030	11 220	3.99	1	11 250	4.06	–		132	4
141 851		–0.014	8080	3.86	6	8258	3.69	–		49	4
142 703	V	–0.020	7120	3.88	6	7295	4.38	–1.53	V	53	4
142 994	V	0.002	6950	3.23	6	6892	3.68	–0.88	V	–	*
144 708	AB	0.047	10 650	3.58	1	10 241	3.75	–	AB	131	4
148 638		0.028	7840	3.47	6	–	–	–		140	*
149 130		0.014	6850	3.47	6	6830	3.82	–0.48		163	*
149 303	A	–0.018	8120	3.80	6	8483	3.78	–	A	69	*
153 747	V	0.108	9850	3.91	1	9745	4.26	–	V	188	*
153 747	V	0.092	9530	3.90	5	9413	4.14	–	V	”	”
153 808		0.018	10 420	4.21	1	10 449	4.33	–		50	4
153 808		0.005	10 130	4.20	5	10 113	4.24	–		”	”
154 153		–0.012	6940	3.54	6	7001	4.08	–0.88		66	4
156 954		–0.014	7040	3.97	6	7083	4.37	–0.56		82	3a
159 082		0.037	11 230	3.99	1	–	–	–		152	1
160 928	AB	–0.013	7910	3.87	6	7866	4.18	–1.21	AB	83	4
168 740	V	–0.001	7680	3.89	6	7532	4.20	–1.54	V	71	4
168 947	V	0.027	7540	3.66	6	7481	4.00	–0.87	V	–	3a
169 009		0.152	10 480	3.94	1	10 180	3.81	–		105	4
169 022		0.023	9830	3.04	1	9524	2.99	–		44	*
170 000	ABV	0.005	12 450	4.36	1	12 392	4.35	–	ABV	89	1
170 680		0.025	10 090	4.11	5	9998	4.19	–		65	2
171 948		–	–	–	–	–	–	–		131	–
174 005	A	0.053	7910	3.79	6	7709	4.00	–0.79	A	162	4
175 445		0.032	9050	4.01	5	–	–	–		196	3b
175 445		0.060	9570	4.10	1	–	–	–		”	”
177 120		0.162	9630	3.50	1	9733	3.65	–	AB	223	3b
177 120		0.052	7800	3.44	6	8038	2.72	–	AB	”	”

Table 5. continued.

HD	Rem 1	$E(b-y)$	$T_{\rm eff}$ MD	log g MD	Gr	$T_{\rm eff}$ Gen	log g Gen	[M/H]	Rem 2	dist (pc)	UV flux category
177 756		–0.002	11 560	4.09	1	11 613	4.04	–		38	4
179 791		0.053	9100	3.51	5	9042	3.80	–		183	2
179 791		0.063	9290	3.52	1	9200	3.88	–		”	”
183 324	V	0.029	9190	4.22	5	9137	4.28	–	V	59	5
184 190		0.029	7170	4.07	6	7092	4.41	–0.84		–	*
184 779		–0.004	7090	3.45	6	7190	4.10	–0.76		–	*
191 850		0.002	7380	3.67	6	7275	4.11	–0.62		–	*
192 424		–	–	–	–	–	–	–		–	–
192 640	V	–0.006	7980	3.98	6	7752	4.06	–2.24	V	41	4
193 063		–	–	–	–	–	–	–		–	–
193 256		0.002	7810	3.68	6	7455	3.83	–1.18		218	*
193 281	AB	0.025	8110	3.60	6	8096	3.35	–	AB	218	*
196 821		0.002	10 390	3.55	1	10 260	3.63	–		284	1
198 160	AB	0.003	7970	3.98	6	7975	4.33	–0.63	AB	73	*
198 161	AB	0.003	7970	3.98	6	7836	4.19	–1.13		73	*
200 841		0.082	10 250	3.52	1	–	–	–		552	3b
204 041		0.000	8110	4.03	6	7938	4.26	–0.83		87	3b
204 965		0.006	9000	3.53	6	8471	3.51	–		147	*
210 111		–0.023	7450	3.75	6	7545	4.26	–1.18		79	5
210 418		0.033	9150	3.92	5	9097	4.08	–		30	5
212 150		0.050	10 310	3.24	1	–	–	–		289	1
214 454		0.002	7510	3.57	6	7282	3.89	–0.21		53	4
216 847		–0.002	7360	3.41	6	7258	3.88	–0.52		148	3a
217 782	AB	0.059	9140	3.68	5	9213	3.81	–	AB	107	5
218 396		–0.027	7170	4.10	6	7347	4.55	–0.68	V	40	4
220 061	V	–0.012	7750	3.59	6	7656	3.98	–0.57	V	51	4
220 278	AB	–0.015	7620	3.67	6	7617	4.10	–0.50	AB	73	3b
221 756	V	0.034	9020	3.91	5	9151	4.25	–	V	72	2
223 352	AB	0.004	9880	4.19	5	9790	4.17	–	AB	44	4
225 218	AB	0.093	9230	3.48	1	–	–	–		515	3b
261 904		0.029	9560	4.33	5	9456	4.18	–		–	*
290 492	AB	0.103	10 390	4.16	1	–	–	–		–	*
290 799		0.074	9160	4.24	5	–	–	–		–	*
290 799		0.004	8000	4.26	6	–	–	–		”	”
294 253		0.038	10 370	4.50	5	10 383	4.38	–		–	*