A&A 373, 625–632 (2001)
DOI: 10.1051/0004-6361:20010630
© ESO 2001

Astronomy & Astrophysics

A spectroscopic survey for λ Bootis stars

II. The observational data*

E. Paunzen[1,2], B. Duffee[3], U. Heiter[1], R. Kuschnig[4], and W. W. Weiss[1]

[1] Institut für Astronomie der Universität Wien, Türkenschanzstr. 17, 1180 Wien, Austria
[2] Zentraler Informatikdienst der Universität Wien, Universitätsstr. 7, 1010 Wien, Austria
[3] Department of Computer Science Keele University, Keele, Staffordshire, UK
[4] Department of Physics and Astronomy, University of British Columbia, Vancouver, British Columbia, Canada

Received 3 April 2001 / Accepted 27 April 2001

Abstract. λ Bootis stars comprise only a small number of all A-type stars and are characterized as nonmagnetic, Population I, late B to early F-type dwarfs which show significant underabundances of metals whereas the light elements (C, N, O and S) are almost normal abundant compared to the Sun. In the second paper on a spectroscopic survey for λ Bootis stars, we present the spectral classifications of all program stars observed. These stars were selected on the basis of their Strömgren $uvby\beta$ colors as λ Bootis candidates. In total, 708 objects in six open clusters, the Orion OB1 association and the Galactic field were classified. In addition, 9 serendipity non-candidates in the vicinity of our program stars as well as 15 Guide Star Catalogue stars were observed resulting in a total of 732 classified stars. The 15 objects from the Guide Star Catalogue are part of a program for the classification of apparent variable stars from the Fine Guidance Sensors of the Hubble Space Telescope. A grid of 105 MK standard as well as "pathological" stars guarantees a precise classification. A comparison of our spectral classification with the extensive work of Abt & Morrell (1995) shows no significant differences. The derived types are 0.23 ± 0.09 (rms error per measurement) subclasses later and 0.30 ± 0.08 luminosity classes more luminous than those of Abt & Morrell (1995) based on a sample of 160 objects in common. The estimated errors of the means are $\pm\,0.1$ subclasses. The characteristics of our sample are discussed in respect to the distribution on the sky, apparent visual magnitudes and Strömgren $uvby\beta$ colors.

Key words. astronomical data bases – surveys – stars: chemically peculiar – stars: early type – stars: fundamental parameters

1. Introduction

In a series of papers (e.g. Paunzen et al. 1997; Paunzen & Gray 1997, Paper I hereafter; Paunzen 1999), we have tried to define, homogenize and enlarge the group of λ Bootis stars. Paper I describes the selection of candidates via photometric boxes, the requirements of spectroscopic observations and the positive detections from the OHP 1994 and 1995 data. The discovery of eight new (three in the Orion OB1 association) and eleven good (two in NGC 2264) candidate λ Bootis stars has proved the capability of our selection criteria. In this paper we present the data for all observed stars of this program from nine different observing runs. Candidates were observed in six young and intermediate age open clusters (NGC 2232, NGC 2264, NGC 2301, NGC 3532, NGC 6025 and NGC 6475), the Orion OB1 association as well as the Galactic field. Because of a turnable slit, we have also got spectra of other stars close to our program stars and objects observed with the Fine Guidance Sensors of the Hubble Space Telescope were obtained.

The most recent work on the spectral classification for the relevant temperature range was published by Abt & Morrell (1995). They have classified almost all A-type stars of the Bright Star Catalogue. A detailed investigation of 160 objects in common with this work shows no significant differences to our classification scheme.

Send offprint requests to: E. Paunzen,
e-mail: `Ernst.Paunzen@univie.ac.at`

* Based on observations from the Observatoire de Haute-Provence, Osservatorio Astronomico di Padova-Asiago, Observatório do Pico dos Dias-LNA/CNPq/MCT, Chews Ridge Observatory (MIRA) and University of Toronto Southern Observatory (Las Campanas).

Article published by EDP Sciences and available at http://www.aanda.org or http://dx.doi.org/10.1051/0004-6361:20010630

Table 1. Observing log for all classification resolution observations, in brackets are the identification for each night in Tables 2–4.

OHP (1994): 1.8 Å pixel^{-1}; 3700–4650 Å		
21./22.02. (1A)	22./23.02. (1B)	23./24.02. (1C)
24./25.02. (1D)	25./26.02. (1E)	26./27.02. (1F)
28./01.03. (1G)		
OHP (1995): 1.8 Å pixel^{-1}; 3800–4750 Å		
07./08.02. (2A)	08./09.02. (2B)	09./10.02. (2C)
11./12.02. (2D)		
Asiago (1995): 2.0 Å pixel^{-1}; 3800–5000 Å		
12./13.03. (3A)	13./14.03. (3B)	
Asiago (1997): 2.0 Å pixel^{-1}; 3800–5000 Å		
11./12.02. (4A)		
LNA (1995): 0.9 Å pixel^{-1}; 3800–4800 Å		
13./14.06. (5A)	14./15.06. (5B)	15./16.05. (5C)
MIRA (1994): 1.9 Å pixel^{-1}; 3700–4550 Å		
07./08.10. (6A)	08./09.10. (6B)	10./11.10. (6C)
11./12.10. (6D)	13./14.10. (6E)	17./18.10. (6F)
18./19.10. (6G)	19./20.10. (6H)	
UTSO (1995): 0.7 Å pixel^{-1}; 4190–4550 Å		
10./11.04. (7A)	11./12.04. (7B)	13./14.04. (7C)
14./15.04. (7D)	15./16.04. (7E)	16./17.04. (7F)
17./18.04. (7G)	18./19.04. (7H)	19./20.04. (7I)
20./21.04. (7J)	21./22.04. (7K)	22./23.04. (7L)
23./24.04. (7M)	24./25.04. (7N)	23./24.08. (8A)
24./25.08. (8B)	25./26.08. (8C)	26./27.08. (8D)
27./28.08. (8E)	28./29.08. (8F)	23./24.10. (9A)
25./26.10. (9B)	07./08.11. (9C)	08./09.11. (9D)
09./10.11. (9E)	10./11.11. (9F)	11./12.11. (9G)

A statistical analysis of the observed sample together with the incidence of λ Bootis stars among Galactic field objects and members of open clusters will be published in the third part of this series.

2. Observations, reduction and classification

The observations were performed at five different observatories:

- Observatoire de Haute-Provence (OHP; 1994/1995): the 193 cm telescope with the CARELAC spectrograph, using the 600 lines mm^{-1} grating (centered at 4200 Å) resulted in a nominal resolution of 1.8 Å pixel^{-1} and a spectral coverage of 950 Å; observers: U. Heiter and E. Paunzen.
- Osservatorio Astronomico di Padova-Asiago (Asiago; 1995/1997): the 182 cm telescope with the Boller & Chivens spectrograph (600 lines mm^{-1} grating) gave a nominal resolution of 2.0 Å pixel^{-1} and a spectral coverage of about 1200 Å; observers: U. Heiter and E. Paunzen.

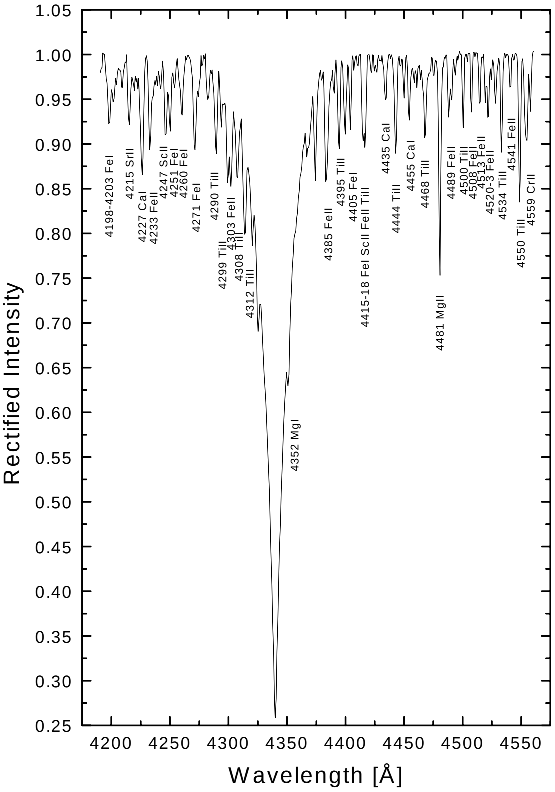

Fig. 1. Spectral lines and blends identified for the A3 V standard star HD 135379 ($v \sin i = 60\,\mathrm{km\,s^{-1}}$) observed at UTSO.

- Observatório do Pico dos Dias-LNA/CNPq/MCT (LNA; 1995): the 160 cm telescope with the Cassegrain spectrograph (1200 lines mm^{-1} grating) gave a nominal resolution of 0.9 Å pixel^{-1} and a spectral coverage of about 1000 Å; observer: E. Paunzen.
- Chews Ridge Observatory (MIRA; 1994): the 91 cm telescope with the MIRA spectrograph (1800 lines mm^{-1} grating) gave a nominal resolution of 1.9 Å pixel^{-1} and a spectral coverage of about 850 Å; observer: R. Kuschnig.
- University of Toronto Southern Observatory, Las Campanas (UTSO; 1995): the Helen-Sawyer-Hogg 61 cm telescope with the Garrison's classification spectrograph gave a nominal resolution of 0.7 Å pixel^{-1} and a spectral coverage of about 350 Å; observers: B. Duffee and E. Paunzen.

A detailed observing log with the different nights is given in Table 1 (quoted also in Tables 2–4).

Besides 708 λ Bootis candidates (in the magnitude range from 0 to 14), 24 other stars (objects in the vicinity of the program stars as well as Guide Star Catalogue stars) were observed and classified (all spectra are available upon request from the first author). Furthermore, 105 standard (taken from Morgan et al. 1978; Gray & Garrison 1987, 1989a,b; Garrison & Gray 1994), "pathological" (e.g. magnetic chemically peculiar, metallic lined, Field-Horizontal-Branch stars; mainly taken from

Renson et al. 1991) and well established λ Bootis stars (taken from Gray & Corbally 1993) were observed to secure a precise and homogeneous spectral classification. In total, 837 stars were observed in nine different observing runs dedicated to this project.

Observations were obtained in six open clusters (NGC 2232, NGC 2264, NGC 2301, NGC 3532, NGC 6025 and NGC 6475), the Orion OB1 association and the Galactic field.

A detailed description of the reduction and classification procedure is given in Paper I (Sects. 4 and 5).

Our project is mainly dedicated to late B, A and early F-type stars (the temperature range of λ Bootis stars). Therefore, the grid of standard stars in that spectral range (B8 to F2) is very dense yielding a well determined classification. On the other hand, some additional standards outside this range were observed in order to classify individual stars. The classification error in this spectral range (B0 to B8 and F2 to K0) is about ± 2 subclasses. We are not able to give a precise classification for stars later than K0 (indicated as "(K0)" in Table 4) due to the lack of standards as well as the strength of molecular bands (e.g. CH and CN; Jaschek & Jaschek 1987).

A very important point is the limited spectral range (4190–4550 Å, thus centered at Hγ) of the observations carried out at UTSO (Table 1). It is obvious that not all classical metal lines used for the classification process lie within this spectral range. More important, the Ca II K line could not be observed. It has therefore to be justified that the derived spectral classifications from this site fit well into the MK standard scheme. Figure 1 shows the identified lines and blends for the A3 V MK standard star HD 135379 ($v \sin i = 60\,\mathrm{km\,s^{-1}}$). Two conclusions can be drawn from this figure:

- Several Ca I lines (4227 Å, 4435 Å and 4455 Å) allow to estimate the overall strength of this element;
- No prominent Si, Cr and Eu lines are within this spectral range implying that no CP2 (for the definition see Preston 1974) stars can be detected.

Although there are three prominent Ca I lines in this spectral range, we have *not* included a k-line type (normally based on the Ca II K line) in the spectral types (Tables 2–4). The main reason is that the apparent abundances derived from Ca II K and other Ca I lines are not necessarily the same (Stürenburg 1993). There might also be different effects of the stellar atmosphere or the stellar rotation on these lines misleading the spectral classification process.

Figure 2 shows the temperature as well as the luminosity sequence for MK standards (in parentheses are the $v \sin i$ values from the literature) observed at UTSO. With the help of Hγ and Ca I 4227Å the spectral type can be easily estimated within less than one subclass. The shape of Hγ is very well correlated with the luminosity class. The spectral types derived from this set of spectra are therefore well in the MK standard scheme. The uncertainties should be the same or even better (because of the higher dispersion) than for the other sets.

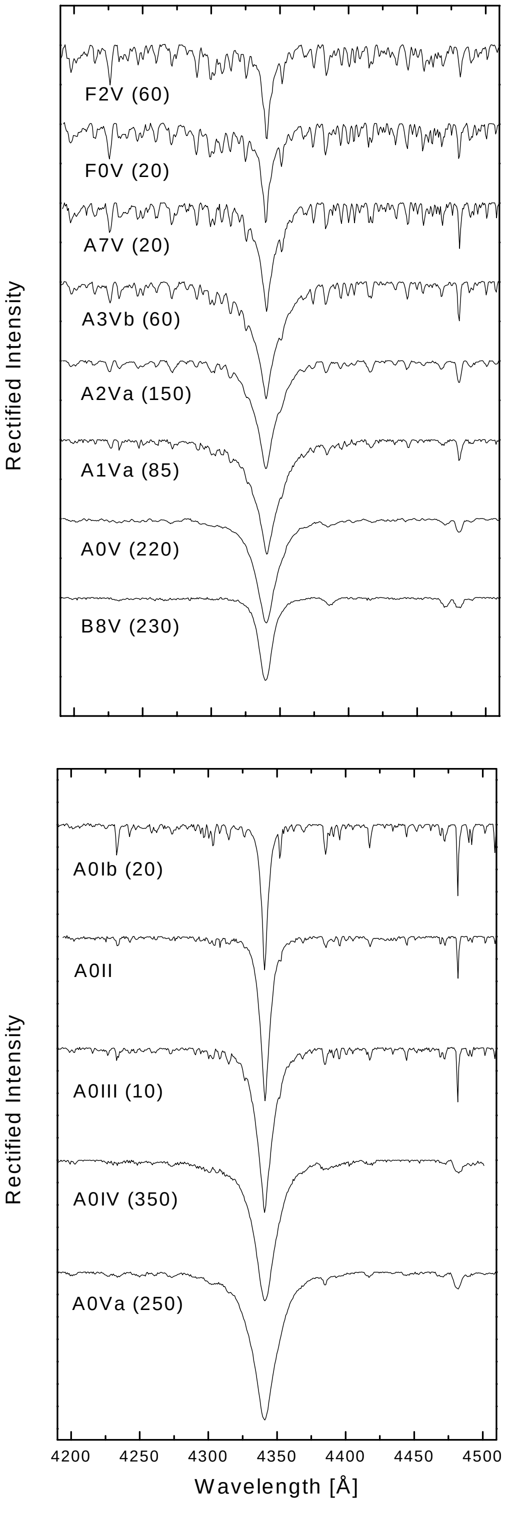

Fig. 2. Temperature (upper panel) as well as luminosity sequence (lower panel) of MK standards observed at UTSO. In parenthesis are the $v \sin i$ values from the literature.

3. Results

In this section the spectral classification of all program stars are presented.

Table 2. Galactic field stars*.

HD	HR	HIP	V	$b-y$	m_1	c_1	β	Spec	$v\sin i$	ID
256	10	602	6.20	+0.074	0.160	1.087	2.822	A3 V (shell)	220:	8C
319	12	636	5.93	+0.079	0.164	1.037	2.851	A1 Vb λ Boo		8C
358	15	677	2.07	−0.046	0.120	0.520	2.743	Bp		6B
565		798	6.34	+0.084	0.168	1.093	2.845	A5 V		8B
2178		2027	7.64	+0.020	0.177	1.110	2.844	A0 V PHL?		8E
2629		2343	7.46	+0.247	0.139	0.536	2.689	F2 V		9D
2842		2510	7.99	+0.228	0.127	0.671	2.729	F0 V		9D
4158			9.53	+0.216	0.102	0.748	2.674	hF3mF0 V (wk met)	85	8C
4321	204	3611	6.51	+0.106	0.164	1.111	2.831	A0 IV SB?	15	7C
4772	232	3858	6.27	+0.066	0.162	1.212	2.836	A2 Vn	150	8E
5524		4442	7.19	+0.058	0.207	1.028	2.890	A3 V (wk met)		8E
5715	278	4709	6.40	+0.056	0.198	1.035	2.880	A3 V	90	7C
6173			8.55	+0.102	0.079	1.103	2.816	A0 IIIn		2A
6521		5094	7.82	+0.095	0.175	1.129	2.816	A5 V		9E
6870		5321	7.48	+0.153	0.154	0.771	2.757	hF0mA1 λ Boo	165	8E
7323		5675	7.83	+0.064	0.165	1.066	2.871	A0 V		8E
7804	378	6061	5.13	+0.034	0.173	1.116	2.891	A3 V (wk met)	100	9D
7908		6108	7.30	+0.192	0.136	0.652	2.728	hF0mA3 V λ Boo		8E
7916	380	5992	6.23	+0.036	0.150	0.967	2.870	A0 V		9E
8003	384	6312	6.33	+0.045	0.195	0.997	2.886	A2 V	285:	7C
8511	401	6539	6.21	+0.133	0.192	0.851	2.797	F0 IVn (wk met)	195	8D, 9D, +
9065	431	6888	6.59	+0.201	0.156	0.769	2.716	F0 V		8E
9100	432	6981	6.01	+0.090	0.166	1.093	2.817	A3 V	110	7B
9414	443	7115	6.17	+0.022	0.183	1.069	2.894	A1 Vn		8E
9673		7323	7.89	+0.142	0.163	0.938	2.803	F0 IV		8E
10062		7231	7.21	+0.065	0.148	1.219	2.878	A1 V		9E
10894		8306	7.05	+0.013	0.142	1.070	2.850	A0 V		9D
10920		8296	6.70	+0.032	0.181	1.053	2.871	A0 V		8E
11088		8454	7.37	+0.144	0.148	0.824	2.799	F4 V G-band? SB?		9D
11413	541	8593	5.94	+0.108	0.141	0.974	2.829	A1 Va λ Boo		8B
11956		8985	6.72	+0.094	0.169	1.123	2.840	kF0hA5mF0 V		9F
12636			8.39					A7 V		6F
12712		9571	7.28	+0.102	0.179	1.094	2.824	A6 V		9F
13467		10242	6.67	+0.113	0.160	1.034		A3 III-IVn		9D
13755		10304	7.84	+0.181	0.153	0.841		hF2mA5 V λ Boo		8B
14213	671	10814	6.21	+0.100	0.156	1.085	2.832	A3 Vp	60	7C
14417	684	10854	6.50	+0.036	0.180	1.074	2.898	A1 V	50	7D, 8C
14940		11192	6.68	+0.212	0.145	0.661		A9 V		8E
15042		11319	7.61	+0.080	0.122	1.180	2.835	A0 III		9D
15415		11302	7.86	+0.098	0.167	1.084	2.862	A5 V		9G
15439		11303	7.64	+0.207	0.141	0.939		F0 V (wk met?)		9E
16432	773	12332	5.45	+0.092	0.182	1.095	2.829	A6 V	120	7B
16701		10993	7.82	+0.235	0.139	0.572		F0 V		9E
16861	797	12647	6.32	+0.035	0.182	1.027	2.915	A1 V	15	7C, 9D
17168	817	12786	6.21	+0.011	0.165	1.019	2.899	A1 V	80	8E
17254	821	12775	6.15	+0.041	0.181	1.075	2.881	A2 V		9C
17864	853	13271	6.36	+0.015	0.169	1.006	2.894	A0 V		8E

*This table in its complete form is only available at the CDS via anonymous ftp to `cdsarc.u-strasbg.fr (130.79.128.5)` or via `http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/373/625`. The first page is printed here for guidance regarding its form and content.

An important part of the spectroscopic survey is dedicated to Galactic field stars. The main reason is the large amount of published photometric and spectroscopic data which allows an efficient preselection of possible candidates.

Tables 2 (this table in its complete form is only available at the SIMBAD database via anonymous ftp or upon request from the first author) and 3 list all observed stars with the V-magnitude (Mermilliod & Mermilliod 1994; Perryman et al. 1997), the available Strömgren $uvby\beta$ colors (Hauck & Mermilliod 1998), the derived spectral classification (column "Spec"), the projected rotational velocities from the literature (Uesugi & Fukuda 1982;

Table 3. Observed members of open clusters and the Orion OB1 association.

HD/NGC	V	$b-y$	m_1	c_1	β	Spec	ID	member
35793	9.78	+0.067	0.164	1.002	2.919	A2 Va	2C	OB1 assoc.
35807	9.21	+0.051	0.132	0.910	2.850	A1 V	2C	OB1 assoc.
36117	7.98	+0.057	0.174	0.976	2.877	A2 V	1F	OB1 assoc.
36139	6.87	+0.032	0.163	1.078	2.872	A2 V	1F, 9F	OB1 assoc.
36352	9.20	+0.015	0.149	0.991	2.924	kA0hA0mA2 IV-V	2B	OB1 assoc.
36726	8.81	+0.043	0.164	0.975	2.922	kA0hA5mA0 V λ Boo	1F	OB1 assoc.
37886	9.00	+0.002	0.110	0.672	2.780	B8 III	2A	OB1 assoc.
38048	9.29	+0.086	0.154	0.891	2.867	A4 V	2C	OB1 assoc.
96212	8.66	+0.031	0.148	1.078		A1 III	5B	NGC 3532
96213	8.28	−0.002	0.141	0.816	2.813	composite?	5B	NGC 3532
96227	8.21	−0.004	0.137	1.114	2.849	A2 V	5B	NGC 3532
96388	8.84	+0.039	0.130	1.169	2.840	A1 IV	5B	NGC 3532
96414	9.05	+0.063	0.160	1.057	2.850	A0 IV	5B	NGC 3532
290492	9.27	+0.084	0.133	0.931	2.851	A0.5 Vb (λ Boo)	2D	OB1 assoc.
293815	10.06	+0.159	0.103	0.935		B9 III	2D	OB1 assoc.
294166	10.31	+0.160	0.140	0.870	2.954	A1 V	2D	OB1 assoc.
294202	10.19	+0.200	0.130	0.930	2.821	B9 V	2D	OB1 assoc.
294253	9.65	+0.023	0.133	0.926	2.904	B9.5 Va (λ Boo)	2A	OB1 assoc.
2232 #18	9.18				2.880	A2 Va	2B	
2232 #28	9.58				2.890	A1 Van	2B	
2232 #30	9.71					A3 Va	2B	
2264 #36	10.99	+0.020	0.170	0.910	2.900	A1 Va	1F	
2264 #43	10.55	+0.130	0.190	0.970	2.840	A5 IV	1F	
2264 #46	9.21	+0.150	0.140	1.100	2.820	A3 IV	1F	
2264 #87	10.77					A1.5 V (wk met)	2C	
2264 #99	10.84					A1 Va	1E	
2264 #100	10.03	+0.080	0.150	1.100	2.830	B8 IV	1F	
2264 #103	10.09					F3 V	1E	
2264 #132	10.22	+0.010	0.100	0.680	2.810	B8 V	1E	
2264 #137	9.93	−0.030	0.120	0.600	2.760	A1 V	1F	
2264 #138	10.20	+0.040	0.160	0.960	2.890	A0.5 V λ Boo	1E	
2264 #145	10.65	+0.050	0.170	0.920	2.900	A0.5 V	1E	
2264 #152	9.12					B8 V	1E	
2264 #157	10.07	−0.020	0.120	0.650	2.770	B8 V	1E	
2264 #158	10.33	+0.240	0.170	0.800	2.780	kA2hA2mA5 V	1F	
2264 #159	10.97					A0 V	1E	
2264 #165	10.98	+0.090	0.190	0.970	2.840	A5 V	1E	
2264 #179	9.94	+0.000	0.150	0.830	2.840	B9 IV	1F	
2264 #181	10.07	−0.020	0.120	0.720	2.790	B8 V	1F	
2264 #187	9.23	−0.040	0.130	0.640	2.780	B9 V	1E	
2264 #193	9.79					A5 III	1E	
2264 #205	10.63	+0.030	0.160	0.770	2.830	F3 V	1E	
2264 #222	9.93	+0.070	0.180	1.100	2.880	A3 V	1F	
2264 #223	10.91					F0 V	1F	
2264 #224	11.52	+0.380	0.220	0.380	2.610	F3 V	1E	
2264 #228	11.12	+0.230	0.170	0.600	2.710	F2 V	1F	
2301 #19	11.81	+0.374	0.181	0.371	2.638	F0 V	2C	
2301 #20	13.47					F0 V	2C	
2301 #24	11.69					A3 Va	2C	
6025 #20	11.25	+0.139	0.165	0.878		A2 Vp	5A	
6475 #18	8.78	+0.093	0.135	1.096	2.890	A1 Van	5A	
6475 #23	8.93	+0.101	0.199	0.972	2.877	A1 Van	5A	
6475 #47	8.92	+0.127	0.179	0.945	2.854	A3 V	5A	
6475 #72	8.20	+0.035	0.147	0.984	2.864	A0 III	5A	
6475 #79	9.01	+0.105	0.161	1.070	2.908	B9 IV	5A	
6475 #89	8.56	+0.119	0.173	1.010	2.857	A2 IV	5B	

Table 4. Observed stars from the FGS project (left panel) and objects in the vicinity of our program stars (right panel).

GSC-number	V	α(2000)	δ(2000)	Spec	ID	NGC	V	Spec	ID
0076702013	9.6	07 21 57	+09 59 04	(K0)	1C	2264 #20V	10.8	F8 V	1F
0188100478	10.4	06 09 45	+24 31 20	G0 V	1B	2264 #50	8.2	B4 V	1F
0188100556	11.7	06 09 50	+24 32 52	G2 V	1B	2264 #67	10.9	B1 V	1F
0188101136	11.4	06 08 57	+24 48 22	A1 V	3A	2264 #74	8.5	B3 V	1F
0188101232	10.5	06 10 03	+24 42 44	(K0)	1B	2264 #88	9.1	B6 IV-V	1F
0188101236	9.5	06 09 32	+24 43 57	G2 V	1B	2264 #109	9.1	B6 V	1F
0188101251	10.3	06 09 56	+24 42 20	F9 V	1B	2264 #121	11.8	G0 V	1F
0188101271	11.0	06 09 36	+24 41 37	G8 III	1B	2301 #23	12.8	F8 V	2C
0188101272	11.8	06 09 45	+24 43 18	(K0)	1B	6475 #48	9.1	F7 V	5A
0188101359	12.3	06 09 50	+24 41 44	A3 V	1B				
0188101542	9.3	06 09 57	+24 37 09	A0 IV	1B				
0199100133	10.1	12 19 12	+29 12 01	F3 V	3B				
0201800783	10.3	14 35 50	+25 08 11	G2 V	3B				
0242201025	11.0	06 28 02	+30 04 04	G8 V	1C				
0291700684	11.1	05 27 47	+42 19 21	F8 V	1C				
0476602124	12.2	05 31 17	−00 29 29	G8 III	1C				
0477000235	10.7	05 31 05	−02 38 31	(K0)	1C				
0534700028	11.7	05 51 31	−07 34 06	F0 IV	2A				

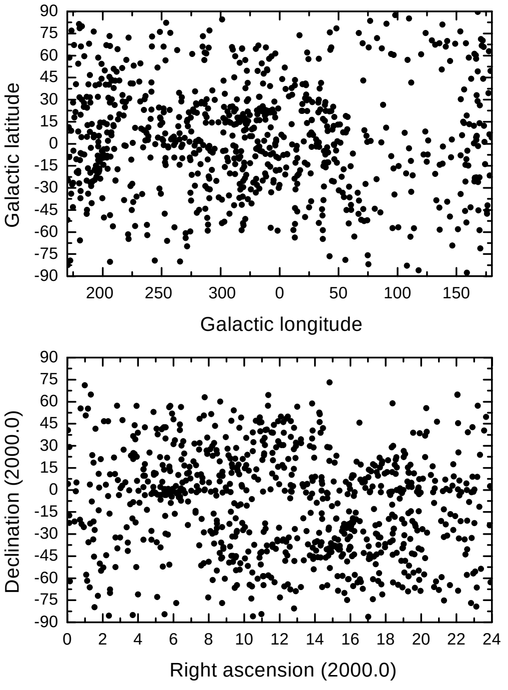

Fig. 3. The distribution on the sky of all observed stars.

Abt & Morrell 1995) and the night in which they were observed according to Table 1 (Col. "ID").

Among this sample several stars showing a weak Mg II 4481Å line were found. Such a peculiarity is ambiguous (Paper I) and not the main criterion for a λ Bootis type. These stars deserve therefore further attention. Additional observations with higher resolution are needed for an unambiguous spectral classification, but mainly due to the otherwise normal metallic-line spectrum, one is definitely able to rule out a membership to the λ Bootis group.

Besides our preselection of candidates via photometric indices, stars were included in our survey which have been addressed as λ Bootis candidates in the literature (Renson et al. 1990; Levato et al. 1994; Abt & Morrell 1995; Andrillat et al. 1995). Eight objects have been described in Paper I as members (HD 105058, HD 170680 and HD 171948) or good candidates (HD 39421, HD 84123, HD 84948, HD 101108 and HD 149303).

Since then, 24 additional stars were observed. Three of them (HD 6870, HD 75654 and HD 106223) are definite members of the λ Bootis group. The other 21 objects are not classical λ Bootis stars although some of them are somewhat metal weak (Table 2): BD+33 2070, BD+33 2171, HD 4158, HD 23258, HD 37886, HD 39421, HD 67262, HD 79108, HD 81104, HD 98772, HD 114879, HD 114930, HD 130158, HD 141851, HD 160928, HD 169009, HD 169022, HD 179791, HD 187949, HD 210418 and HD 220061.

Renson et al. (1990) have classified eleven of them (BD+33 2070, HD 4158, HD 39421, HD 79108, HD 81104, HD 98772, HD 141851, HD 160928, HD 187949, HD 210418 and HD 220061) as good candidates and five (HD 114879, HD 114930, HD 130158, HD 169022 and HD 179791) as probably misclassified. HD 37886 was referenced as a λ Bootis type star by Levato et al. (1994), but our classification (B8 III, Table 3) contradicts that and agrees very well with Guetter (1981), who classified it as B8 V. This star was probably misidentified by Levato et al. (1994).

In order to establish upper and lower limits for a time scale of the λ Bootis phenomenon, members of open clusters for our spectroscopic survey were selected. All given parameters for the open clusters and associations are from Lyngå (1987). Stars were observed in NGC 2232 ($\log t = 7.59$), NGC 2264 ($\log t = 6.99$), NGC 2301 ($\log t = 8.19$), NGC 3532 ($\log t = 8.40$),

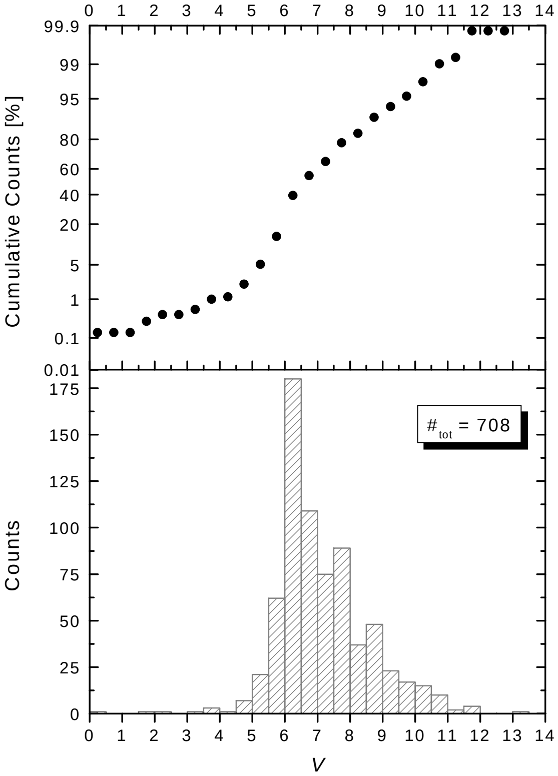

Fig. 4. The distribution of the V-magnitude for all observed program stars (Tables 2 and 3).

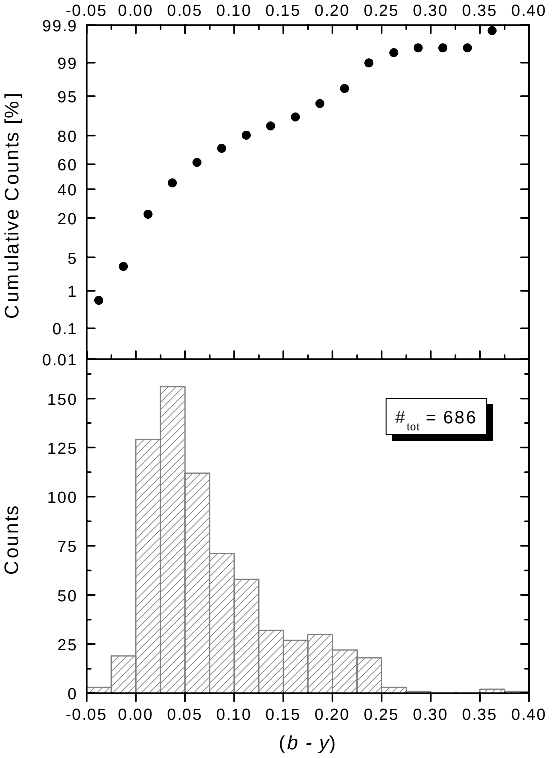

Fig. 5. The distribution of the available $(b-y)$-values for all observed program stars (Tables 2 and 3).

NGC 6025 ($\log t = 7.75$) and NGC 6475 ($\log t = 8.11$). Furthermore, candidates in the Orion OB1 association ($\log t = 7.00$) were investigated. The star numbers given in Tables 3 and 4 are those from Maria (1992; NGC 2232), Walker (1956; NGC 2264), Vasilevskis et al. (1965; only NGC 2264 #20V), Grubissich & Purgathofer (1962; NGC 2301), Kilambi (1975; NGC 6025) and Koelbloed (1959; NGC 6475). Only one new member of the λ Bootis group in NGC 2264 and three new in the Orion OB1 association (already published in Paper I) were detected (Table 3). This rather small number of investigated clusters is due to the limited amount of observing time at large telescopes as well as the lack of available Strömgren $uvby\beta$ photometry.

Let us now investigate the observed sample (Tables 2 and 3) in more detail. Note that the sample is not biased by the V-magnitude or the coordinates. Figure 3 shows the distribution of all program stars on the sky. There is a lack of suitable objects between $+75^{\circ} < b < +90^{\circ}$ and $-75^{\circ} < b < -90^{\circ}$ mainly because no Strömgren photometry is available and/or due to the mechanical limitation of the used telescopes. Otherwise the objects are uniformly distributed over the whole sky. Figure 4 shows the V-magnitude distribution of all observed program stars. Most of the stars lie in the magnitude range $6 < V < 7$ mag. This is mainly caused by the use of rather small telescopes. But more than 20% (or about 140 objects) of all candidates are fainter than 8th magnitude. If one keeps in mind that a signal-to-noise ratio better than 150 and a dispersion higher than 120 Å mm^{-1} were two main characteristics for the observations, this number is very high. Although the available observing time for such a project on large telescopes is very limited, the modern CCD-technique made it possible to reach also the fainter stars. The distribution of the available $(b-y)$-values for the program stars (Fig. 5) coincidences with the fact that there is an overlap with λ Bootis and normal type stars at hotter effective temperatures (Paunzen 1999). This overlap is due to the insensitivity of m_1 to detect metal-weak stars hotter than A2. More than 80% of all program stars lie between $-0.050 < (b-y) < +0.100$ mag. This corresponds to spectral types between B9 and A5.

For a test of the applied spectral classification procedure, the paper of Abt & Morrell (1995) was selected. They used 39 Å mm^{-1} spectra on photographic plates, as well as the classical MK system for the classification. In total, 202 stars have been found common in both lists. Objects were rejected with an ambiguous spectral classification (e.g. HD 83965, kA2hA4mA3 IV) resulting in a sample of 160 stars. Our types are 0.23 ± 0.09 (rms error per measurement) subclasses later and 0.30 ± 0.08 luminosity classes more luminous than those of Abt & Morrell (1995). The systematic differences are not significant because the estimated errors of the means are ± 0.1 subclasses. These results are comparable to, or even better than the error estimations given in Abt & Morrell (1995).

3.1. Data on HST Guide Stars

The stars listed in Table 4 (left panel) have been used for guiding the Hubble Space Telescope (HST) with the Fine Guidance Sensor (FGS) instruments (Kuschnig et al. 1997). A significant amount of FGS measurements are analyzed in order to find variable stars among HST Guide Stars (GS). Since all acquired GS are selected from the Guide Star Catalogue (GSC) and their visual brightness ranges from 9 to 13 mag, usually no spectral type or photometric color information can be found in the literature. Hence, some of the GS, for which the FGS photometry reveals interesting results, have been proposed as targets for classification spectroscopy. A detailed study of these objects will be published elsewhere. Table 4 (left panel) lists these stars with their V-magnitudes, coordinates (both from the GSC) and derived spectral types.

4. Conclusion

We have presented spectral classification for 708 λ Bootis candidate stars in the magnitude range 0 to 14. Candidates were selected on the basis of their Strömgren $uvby\beta$ colors.

Beside these λ Bootis candidates, we have obtained spectra of 15 guide stars for which the FGS photometry reveals interesting results. Furthermore, 9 objects which happen to be located in the vicinity of our program targets were, due to a turnable slit, observed. In total, 732 stars were observed and classified.

Our classification scheme on a refined MK system is very close to the classical MK system used by Abt & Morrell (1995). The derived types are 0.23 ± 0.09 (rms error per measurement) subclasses later and 0.30 ± 0.08 luminosity classes more luminous than those of Abt & Morrell (1995) based on a sample of 160 objects in common. The systematic differences are not significant because the estimated errors of the means are ±0.1 subclasses.

The observed sample is uniformly distributed over the sky with the lack of objects at very high Galactic latitudes caused by missing photometric data. More than 20% of all program stars are fainter than 8th magnitude whereas 80% lie between $-0.050 < (b-y) < +0.100$ mag. The latter is caused by the insensitivity of m_1 to detect metal-weak stars for objects hotter than A2.

A detailed investigation of the observed data will be published in the third paper of this series.

Acknowledgements. We would like to thank all scientific committees which granted observing time for this project. We are indebted to Dr. Gray for his support during the last years and to our referee, Dr. Morrell, for helpful comments. This work benefitted from the Fonds zur Förderung der wissenschaftlichen Forschung, project *S7303-AST, Asteroseismology-AMS*. Use was made of the SIMBAD database, operated at CDS, Strasbourg, France.

References

Abt, H. A., & Morrell, N. I. 1995, ApJS, 99, 135

Andrillat, Y., Jaschek, C., & Jaschek, M. 1995, A&A, 299, 493

Garrison, R. F., & Gray, R. O. 1994, AJ, 107, 1556

Gray, R. O. 1988, AJ, 95, 220

Gray, R. O., & Corbally, C. J. 1993, AJ, 106, 632

Gray, R. O., & Garrison, R. F. 1987, ApJS, 65, 581

Gray, R. O., & Garrison, R. F. 1989a, ApJS, 69, 301

Gray, R. O., & Garrison, R. F. 1989b, ApJS, 70, 623

Grubissich, C., & Purgathofer, A. 1962, Zeitschr. Astrophys., 54, 41

Guetter, H. H. 1981, AJ, 86, 1057

Hauck, B., & Mermilliod, M. 1998, A&AS, 129, 431

Jaschek, C., & Jaschek, M. 1987, The classification of stars (Cambridge University Press, Cambridge)

Kilambi, G. C. 1975, PASP, 87, 975

Koelbloed, D. 1959, Bull. Astr. Inst. Netherl, 14, 265

Kuschnig, R., Weiss, W. W., Gruber, R., Bely, P. Y., & Jenkner, H. 1997, A&A, 328, 544

Levato, H., & Malaroda, S. 1974, AJ, 79, 890

Levato, H., Malaroda, S., Grosso, M., & Morrell, N. I. 1994, PASPC, 60, 93

Lyngå, G. 1987, Catalogue of Open Cluster Data, 5th edition, CDS, Strasbourg

Maria, M. A. 1992, Ap&SS, 198, 121

Mermilliod, J. C., & Mermilliod, M. 1994, Catalogue of Mean UBV Data on Stars (Springer-Verlag, New York)

Morgan, W. W., Abt, H., & Tapscott, J. W. 1978, Revised MK Spectral Atlas for Stars Earlier than the Sun, Yerkes Obs., Univ. Chicago, and Kitt Peak National Obs.

Paunzen, E. 1999, Ap&SS, 266, 379

Paunzen, E., & Gray, R. O. 1997, A&AS, 126, 407 (Paper I)

Paunzen, E., Weiss, W. W., Heiter, U., & North, P. 1997, A&AS, 123, 93

Perryman, M. A. C., Høg, E., Kovalevsky, J., Lindegren, L., & Turon, C. 1997, The Hipparcos and Tycho Catalogues, ESA SP-1200

Preston, G. W. 1974, ARA&A, 12, 257

Renson, P., Faraggiana, R., & Böhm, C. 1990, Bull. Inform. CDS, 38, 137

Renson, P., Kobi, D., & North, P. 1991, A&AS, 89, 61

Stürenburg, S. 1993, A&A, 277, 139

Uesugi, A., & Fukuda, I. 1982, Revised Catalogue of Stellar Rotational Velocities, Department of Astronomy (Kyoto Univ., Kyoto)

Vasilevskis, S., Sanders, W. L., & Balz, A. G. A. 1965, AJ, 70, 797

Walker, M. F. 1956, ApJS, 2, 365