Astron. Astrophys. 326, L29–L32 (1997)

ASTRONOMY
AND
ASTROPHYSICS

Letter to the Editor

On the evolutionary status of λ Bootis stars using Hipparcos data*

Ernst Paunzen

Institut für Astronomie der Universität Wien, Türkenschanzstr. 17, A-1180 Wien, Austria (paunzen@galileo.ast.univie.ac.at)

Received 24 June 1997 / Accepted 5 August 1997

Abstract. We have used the Hipparcos data to derive absolute magnitudes and thus the evolutionary status for the group of λ Bootis stars. The origin for this small group of nonmagnetic, chemically peculiar stars, still remains a matter of debate. Using new evolutionary tracks, we are able to provide an age determination to distinguish between the two proposed theories - the diffusion/mass-loss and the accretion theory.

Our results establish the member of this group as objects which are *very close to the Main Sequence*. This is also supported by Pre-Main Sequence evolutionary tracks as well as by observational results. We therefore contradict prior conclusions that most of these stars are in the middle of their Main Sequence lifetime. The new results strongly support the predictions of the accretion theory.

Key words: stars – λ Bootis ; stars – chemically peculiar; stars – early type; stars – fundamental parameters; stars – pre-main sequence

1. Introduction

Using the Hipparcos parallaxes, we have determined absolute magnitudes for members of the λ Bootis group. We have examined possible correlations for the observed parallaxes with other astrophysical quantities (e.g. distance, effective temperature, metallicity, etc.). No systematic trend between the (old) photometrically calibrated and (new) absolute magnitudes has been detected. Although there are some individual differences, the overall validity of the "standard" calibration for the (chemically peculiar) λ Bootis stars is proven. The origin of these nonmagnetic, A to F-type metal-deficient dwarfs still remains controversial. The two main competing theories involve diffusion, either in combination with mass-loss (Michaud & Charland 1986), or accretion of interstellar matter as in post-AGB stars (Turcotte & Charbonneau 1993). The latter model requires that λ Bootis stars are very close to the Zero-Age Main Sequence. The recent discovery of λ Bootis stars in the young Orion OB1 association and NGC 2264 (Paunzen & Gray 1997) seems to support the predictions of the accretion theory. But an age determination of galactic field stars by Iliev & Barzova (1995), on the other hand, resulted in evolved members. We have recalibrated these stars using the accurate new absolute magnitudes as well as new stellar evolutionary tracks (CESAM; Morel 1997). Furthermore, we have used Pre-Main Sequence models (Palla & Stahler 1993) to confirm our results.

2. The new Hipparcos data

Candidates as well as members of the λ Bootis group were taken from Paunzen et al. (1997) and Paunzen & Gray (1997). The Hipparcos data for the program stars were extracted with the help of Simbad. We have used the observed visual magnitudes (a comparison between the Hipparcos photometry and the values from Mermilliod & Mermilliod (1994) resulted in a good agreement) to calculate the absolute magnitudes M_V(H). Table 1 lists the found parallaxes with the determined absolute magnitudes as well as the given errors.

In order to compare these results with the photometrically calibrated ones, the Strömgren system (colours taken from Hauck & Mermilliod 1990) was used. The dereddening procedure and calibration use the results given by Crawford (1979) and comprise the iteration procedure described by Hilditch et al. (1983). Gray (1988) showed that peculiar hydrogen line profiles and very high $v \sin i$ values, as found in some λ Bootis stars, influence β and hence M_V(p). We have to stress again that all calibrations are derived for "normal" type stars. The intrinsic error in M_V(p) is therefore about ± 0.3 mag (Crawford 1979).

Figure 1 shows M_V(H) versus M_V(p) for our program stars from Table 1. There seems to be a trend for stars with $0 < M_V(\mathrm{p}) < 1.5$ mag, but this is, however, not statistically significant. There is no evident correlation with the apparent distance.

Send offprint requests to: E. Paunzen

* Based on observations obtained with the Hipparcos satellite

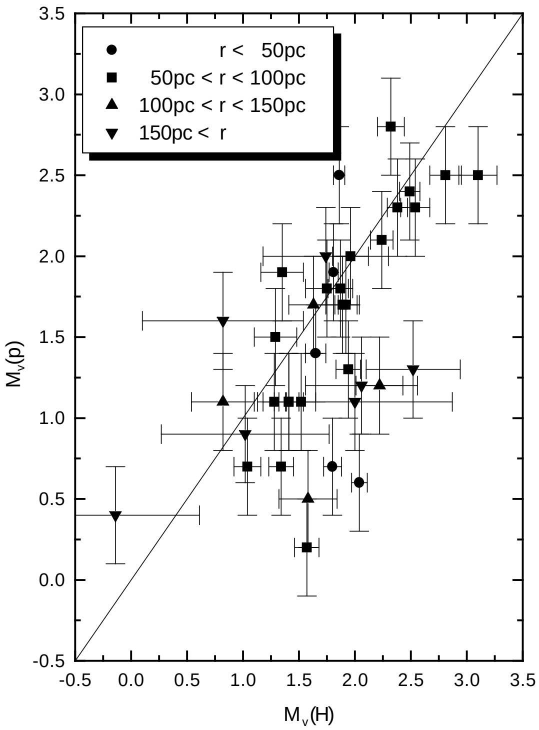

Fig. 1. Comparison between the Hipparcos and photometrically calibrated absolute magnitudes. Although the scatter is quite high, there seems to be a systematic trend, but which is, nevertheless, *not* statistically significant.

The parameter $\Delta M_V = M_V$(H) $- M_V$(p) was derived (Table 1) to search for correlations with other astrophysical quantities. A histogram of ΔM_V (bin-size of 0.2 mag) resulted in a mean of 0.3 mag (which was found to be statistically significant) and a distribution which is unsymmetric and therefore not gaussian. This means that M_V(H) tends to be fainter than M_V(p). Speaking in terms of the evolutionary status, λ Bootis stars are younger and have lower masses than previously thought (see Sect. 3). To check for other possible correlations, we have applied a linear regression technique (Rees 1987). This method uses the estimated errors (both for x and y) as reciprocal weights (a larger error corresponds to a lower weight).

Since it is well known that the calibration in the Strömgren system often fails for certain spectral types (e.g. between A0 and A2) and it is valid only for ”normal“ (solar abundant) stars, we have used the effective temperature and [Fe/H] to look for such effects. The effective temperatures for all program stars were derived as described in Sect. 3. The [Fe/H] values were taken from Stürenburg (1993) for only 14 program stars (no additional data were found in the literature). Both parameters show no correlation with ΔM_V. We, therefore, conclude that there is no influence of the effective temperature and metallicity on the absolute magnitude calibration for the (chemically peculiar) λ Bootis stars. In order to check the influence of the rotational velocity on the photometric calibration, we have taken the $v \sin i$ values from Paunzen et al. (1997) and Paunzen & Gray (1997) for the program stars marked with an asterisk in Table 1 (no data are available for the remaining stars). The $v \sin i$ values range from 10 to 250 kms^{-1}. Again, no correlation with ΔM_V was found.

Table 1. Hipparcos data of our program stars, M_V(p) is the photometrically calibrated absolute magnitude with $\sigma M_V(\mathrm{p}) = 0.3$ mag; $\Delta M_V = M_V$(H) $- M_V$(p), an asterisk denotes the stars with known $v \sin i$ values

HD	r [pc]	M_V(H)	M_V(p)	ΔM_V
319*	80.3±4.8	1.41±0.13	1.1	0.31
6870	97.1±5.7	2.54±0.13	2.3	0.24
11413*	74.8±3.6	1.57±0.11	0.2	1.37
23392	307.7±102.2	0.82±0.72	1.6	−0.78
30422*	57.5±2.2	2.38±0.09	2.3	0.08
31295*	37.0±1.3	1.80±0.08	0.7	1.10
38545*	129.5±15.6	1.58±0.26	0.5	1.08
64491*	60.4±3.4	2.32±0.12	2.8	−0.48
74873*	61.1±4.3	1.96±0.16	2.0	−0.04
75654	78.0±3.5	1.92±0.10	1.7	0.22
81290	265.3±69.0	1.74±0.56	2.0	−0.26
83041	223.2±53.3	2.06±0.50	1.2	0.86
84123	110.0±10.1	1.63±0.22	1.7	−0.07
91130*	75.0±4.3	1.52±0.13	1.1	0.42
98772*	86.4±4.2	1.34±0.11	0.7	0.64
101108	232.6±93.0	2.00±0.87	1.1	0.90
105058*	188.0±36.7	2.52±0.42	1.3	1.22
106223*	109.9±10.4	2.22±0.21	1.2	1.02
107233	81.2±5.3	2.81±0.14	2.5	0.31
110411*	36.9±1.1	2.04±0.07	0.6	1.44
111786*	60.2±2.6	2.24±0.10	2.1	0.14
120500	143.5±18.5	0.82±0.28	1.1	−0.28
125162*	29.8±0.5	1.81±0.04	1.9	−0.09
141851*	48.9±2.0	1.65±0.09	1.4	0.25
142703*	52.9±2.2	2.49±0.09	2.4	0.09
149303	69.1±2.8	1.41±0.09	1.1	0.31
156954	82.1±6.3	3.10±0.17	2.5	0.60
160928	82.5±6.5	1.29±0.19	1.5	−0.21
168740*	71.3±3.5	1.87±0.11	1.8	0.07
170680*	65.4±3.5	1.04±0.12	0.7	0.34
183324*	59.0±3.0	1.94±0.11	1.3	0.64
192640*	41.0±0.9	1.86±0.05	2.5	−0.64
193256*	218.7±75.8	1.02±0.75	0.9	0.12
193281*	218.7±75.8	−0.14±0.75	0.4	−0.54
198160*	73.2±6.2	1.35±0.19	1.9	−0.55
204041*	87.3±7.5	1.75±0.19	1.8	−0.05
210111*	78.7±5.5	1.89±0.15	1.7	0.19
221756*	71.6±3.2	1.28±0.10	1.1	0.18

3. Evolutionary status of λ Bootis stars

Iliev & Barzova (1995) presented an age and mass determination of 20 well established λ Bootis stars (and Vega). They concluded that most of the investigated stars are in the middle of their Main sequence evolution which is believed to be inconsistent with the much favoured accretion theory. Only one star of their sample (HD 290799, a member of the young Orion OB1 association) seems to fulfill the predictions of the accretion theory. We have therefore used the Hipparcos data (available for 18 stars from

Table 2. Age and mass determination derived from the CESAM code (column "MS"; Morel 1997) and Pre-Main Sequence tracks (column "PMS"; Palla & Stalla 1993) in comparison with the values given by Iliev & Barzova (1995), column "IL95"

			MS		PMS		IL95			
HD	$\log T_{eff}$ [±0.02]	$\log L/L_\odot$	$M/M_\odot$ [±0.1]	$\log t$ [±0.05]	$M/M_\odot$ [±0.1]	$\log t$ [±0.05]	$\log T_{eff}$ [±0.02]	$\log L/L_\odot$ [±0.10]	$M/M_\odot$ [±0.2]	$\log t$ [±0.05]
319	3.91	1.34±0.05	2.0	8.76	2.0	6.70	3.92	1.53	2.2	8.81
11413	3.90	1.28±0.04	1.9	8.82	1.9	6.70	3.91	1.41	2.1	8.87
30422	3.90	0.96±0.03	1.8	7.00	1.8	7.00	3.91	1.03	1.8	8.58
31295	3.95	1.20±0.03	2.0	7.00	2.0	7.00	3.96	1.40	2.2	8.54
38545	3.95	1.29±0.09	2.1	7.30	2.1	6.90	3.96	1.98	2.7	8.66
107233	3.87	0.80±0.05	1.6	7.00	1.5	7.00	3.86	0.94	1.6	9.04
110411	3.94	1.09±0.03	1.9	7.00	1.9	7.00	3.96	1.30	2.1	8.30
111786	3.89	1.02±0.04	1.8	8.34	1.8	6.90	3.88	1.11	1.8	8.99
125162	3.94	1.20±0.01	2.0	7.20	2.0	7.00	3.95	1.38	2.1	8.58
142703	3.86	0.93±0.03	1.7	8.50	1.7	6.80	3.87	1.00	1.7	9.02
183324	3.96	1.20±0.04	2.1	7.00	2.1	7.00	3.97	1.51	2.3	8.52
192640	3.90	1.16±0.02	1.9	8.65	1.9	6.90	3.91	1.23	1.9	8.85
193256	3.90	1.50±0.27	2.2	8.79	2.3	6.60	3.92	1.48	2.1	8.86
193281	3.91	1.96±0.27	2.5	8.84	2.8	6.30	3.92	1.81	2.5	8.72
198160	3.90	1.37±0.07	2.0	8.77	2.0	6.70	3.90	1.24	1.9	8.86
204041	3.91	1.20±0.07	1.9	8.57	1.9	6.70	3.91	1.21	1.9	8.81
210111	3.88	1.16±0.05	1.8	8.84	1.8	6.50	3.89	1.30	2.0	8.94
221756	3.96	1.41±0.04	2.2	8.10	2.1	6.90	3.96	1.67	2.4	8.65

Iliev & Barzova 1995) to test their conclusions. Furthermore, we have used Pre-Main Sequence evolutionary tracks from Palla & Stahler (1993) to calibrate the group of λ Bootis stars in terms of the accretion theory.

First, the program stars have to be located in a $\log T_{eff}$ versus $\log L/L_\odot$ diagram within the stellar evolutionary tracks. The effective temperature was derived using the calibrations given by Napiwotzki et al. (1993) in the Strömgren system (calibrations in the Geneva system from Künzli et al. 1997 were found to be consistent). The determined effective temperatures (Table 2) are in good agreement with the one from Iliev & Barzova (1995). Using the absolute magnitudes M_V(H) from Table 1, the bolometric corrections taken from Balona (1994) were added. With $M_{Bol}(\odot) = 4.75$ given by Cayrel de Strobel (1996), we have calculated $\log L/L_\odot$.

To determine the ages and masses of our program stars, the new CESAM models (for a description see Morel 1997) were used. The initial parameters were X = 0.7 and Z = 0.02 (solar abundance), these values were found to be valid for the study of (chemically peculiar) λ Bootis stars by Iliev & Barzova (1995). This seems to be appropriate because the main contribution to the overall metallicity is due to C, N and O (solar abundant in λ Bootis stars). Furthermore, there are strong indications that the λ Bootis phenomenon is restricted to the stellar surface (Holweger & Rentzsch-Holm 1995).

The results of our study are presented in Table 2. It is immediately evident that due to the individual corrections for the absolute magnitude, all program stars (beside HD 193256 and HD 193281, a distant close binary system) are (within the errors, $\sigma(\log t) = 0.05$ and $\sigma(M/M_\odot) = 0.1$) significant *younger* and *less massive*. In order to test the possible Pre-Main Sequence hypothesis and thus the consistency with the accretion theory, we have applied the evolutionary tracks from Palla & Stahler (1993).

We are able to conclude from Table 2 that six stars (HD 30422, HD 31295, HD 107233, HD 110411, HD 125162 (λ Bootis itself) and HD 183324) are indeed *very close to the Main Sequence*. This is proven by the individual results derived from the Pre- and Main Sequence tracks (Fig. 2). For additional three stars (HD 38545, HD 111786 and HD 221756) both models are very close resulting in a high confidence for the same conclusion. These findings contradict the results from Iliev & Barzova (1995) and strongly support the accretion theory. The remaining nine program stars are on the Main Sequence (using the appropriate models) but still significant less evolved than reported by Iliev & Barzova (1995; see Fig. 2 therein).

As a new approach, we suggest to use the ages and masses derived from Pre-Main Sequence models. This results in consistent values compared to other low-mass "dusty" Pre-Main Sequence objects such as Herbig Ae/Be stars (Miroshnichenko et al. 1997) or β Pictoris (Crifo et al. 1997). The explanation for λ Bootis stars as true Pre-Main Sequence object could also lead to a solution for the apparent small number of members. A star with $2M_\odot$ needs only a few 10^6 years to reach the Main Sequence. The probability to find such objects is therefore very small compared to the lifetime on the Main Sequence (there is also only a comparable small number of Herbig Ae stars known). This conclusion is further strengthened by the lack of λ Bootis stars in open cluster older than 10^7 years (Paunzen & Gray 1997).

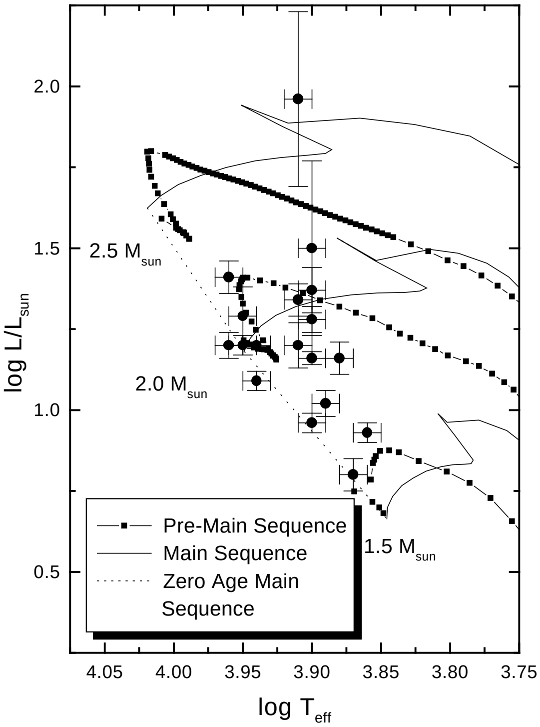

Fig. 2. The location of λ Bootis stars recalibrated with the new absolute magnitudes using Pre- and Main Sequence evolutionary tracks (Palla & Stahler 1993; Morel 1997)

4. Conclusions

We have used the Hipparcos data to calibrate absolute magnitudes and estimate the evolutionary status (mass and age) for the group of λ Bootis stars. No systematical influence of the apparent distance, effective temperature, metallicity and rotational velocity on the difference between the photometrically calibrated and "new" absolute magnitudes were found, thus proving the validity of the "standard" photometric calibration (e.g. in the Strömgren system) for these (chemically peculiar) stars.

Using new Main Sequence evolutionary tracks, we have recalibrated the sample of λ Bootis stars listed in Iliev & Barzova (1995) resulting in significant younger ages and smaller masses. We are able to conclude that six stars (e.g. λ Bootis itself) are definitely *very close to the Main Sequence*, this is, with a high probability, also true for additional three program stars. These results contradict the conclusions of Iliev & Barzova (1995) and support the proposed accretion theory. Furthermore, we suggest that the remaining program stars are also Pre-Main Sequence objects. We therefore present a calibration using Pre-Main Sequence evolutionary tracks yielding consistent ages and masses as found for other young low-mass objects (e.g. Herbig Ae/Be stars and β Pictoris). The small number (statistical effect due to the short "lifetime" on the Pre-Main Sequence) and the lack of λ Bootis stars in open cluster older than 10^7 years further strengthens our hypothesis.

Acknowledgements. This research was carried out within the working group *Asteroseismology-AMS* with funding from the Fonds zur Förderung der wissenschaftlichen Forschung (project *S7303-AST*). I would like to thank Dr. Audard and Dr. Palla for providing the relevant models. Use was made of the Simbad database, operated at CDS, Strasbourg, France.

References

Balona L.A., 1994, MNRAS 268, 119
Cayrel de Strobel G., 1996, A&AR 7, 243
Crawford D.L., 1979, AJ 84, 1858
Crifo F., Vidal-Madjar A., Lallement R., et al., 1997, A&A 320, L29
Gray R.O., 1988, AJ 95, 220
Hauck B., Mermilliod M., 1990, A&AS 86, 107
Hilditch R.W., Hill G., Barnes J.V., 1983, MNRAS 204, 241
Holweger H., Rentzsch-Holm I., 1995, A&A 303, 819
Iliev I.K., Barzova I.S., 1995, A&A 302, 735
Künzli M., North P., Kuruzc R.L., Nicolet B., 1997, A&AS 122, 51
Mermilliod J.C.,Mermilliod M., 1994, Catalogue of Mean UBV Data on Stars, Springer-Verlag, New York
Michaud G., Charland Y., 1986, ApJ 311, 326
Miroshnichenko A., Ivezić Z., Elitzur M., 1997, ApJ 475, L41
Morel P., 1997, A&AS (in press)
Napiwotzki R., Schönberner D., Wenske V., 1993, A&A 268, 653
Palla F., Stahler S.W., 1993, ApJ 418, 414
Paunzen E., Gray R.O., 1997, A&AS (in press)
Paunzen E., Weiss W.W., Heiter U., North P., 1997, A&AS 123, 93
Rees D.G., 1987, Foundations of Statistics, Chapman & Hall, p. 399
Stürenburg S., 1993, A&A 277, 139
Turcotte S., Charbonneau P., 1993, ApJ 413, 376

This article was processed by the author using Springer-Verlag LaTeX A&A style file *L-AA* version 3.