Astron. Astrophys. 353, 135–146 (2000)

ASTRONOMY AND ASTROPHYSICS

Kinematical trends among the field horizontal branch stars*

Martin Altmann and Klaas S. de Boer

Sternwarte, Universität Bonn, Auf dem Hügel 71, 53121 Bonn, Germany

Received 30 August 1999 / Accepted 27 October 1999

Abstract. Horizontal branch (HB) stars in the field of the Milky Way can be used as tracers for the study of early stages of the evolution of our galaxy. Since the age of individual HB stars is not known a priori, we have studied the kinematics of a sample of field HB stars measured with Hipparcos to look for signs of age and population nature. Our sample comprises 14 HBA, 2 HBB and 5 sdB/O stars. We found that the kinematics of the HBA stars is very different from that of the sdB/O stars (including those from an earlier study). The HBA stars have low orbital velocities, some are even on retrograde orbits. Their orbits have large eccentricities and in many cases reach large distances above the galactic plane. In contrast, the sdB/O stars show disk-like orbital characteristics. The few HBB stars (with $T_{\rm eff} > 10,000$ K) in our sample seem to have kinematics similar to that of the sdB/O stars.

In order to see if there is a trend among the HB stars in their kinematics, we investigated also RR Lyrae stars measured with Hipparcos. Here we found a mixed kinematical behaviour, which was already known from previous studies. Some RR Lyrae stars have disk-like orbits (most of these being metal rich) but the majority has halo-like orbits, very similar to those of our HBA stars.

Since the atmospheres of most types of HB stars do not reflect original metallicities any more the kinematics is the only aspect left to study the origin and population membership of these stars. Thus, the clear trend found in kinematics of stars along the HB, which is also a sequence in stellar mass, shows that the different kinds of field HB stars arose from stars having different origins in age and, e.g., metallicity or mass loss rate.

Key words: stars: horizontal-branch – stars: kinematics – stars: Population II – Galaxy: halo – Galaxy: kinematics and dynamics – Galaxy: structure

1. Introduction: HB-stars, their population membership and the galactic structure

Stars of horizontal-branch nature are important objects in studies of the older stellar populations and in studies of galactic structure in relation with formation theories for the Milky Way. Their virtue lies in three properties. First, they have rather well defined absolute magnitudes and their distances are therefore easy to determine. Second, their nature is such that they are easy to discover, in particular at higher galactic latitudes. Third, the stellar evolution leading to such stars is in principle relatively well understood.

The horizontal branch (HB) stellar phase is the core helium burning late stage of evolution of originally low to medium mass stars. During the red giant phase the stars have lost mass such that a helium core of $\simeq 0.5$ M$_\odot$, surrounded by an outer shell of hydrogen gas, remains. For very thin shells, $M_{\rm shell} < 0.02$ M$_\odot$, the stars are rather blue and of spectral class sdB (subdwarf B), for ever thicker shells their atmospheres are cooler, leading to spectral types such as horizontal branch B and A (HBB and HBA) and to the red HB (RHB) stars with $M_{\rm shell} \simeq 0.5$ M$_\odot$. Between the HBA and RHB stars lies the pulsational instability strip with the RR Lyrae stars. (For the systematics of the spectral classification see de Boer et al. 1997c.) HBA and HBB stars are often called blue HB (BHB) stars, the even hotter sdB and sdO stars are also known as extended or extreme HB (EHB) stars.

BHB and EHB stars can be easily found based on their blueness, the RR Lyr stars due to their variability. Of the BHB stars, the HBAs are easily identified, as their physical parameters differ from main sequence A stars, while HBBs may be confused with main sequence B stars. However, at higher galactical latitudes A or B main sequence stars are very rare. RHB stars can easily be confused with subgiants and giants because they lie in the same region of the HRD.

To trace the structure of the (local part of the) Milky Way one employs several techniques (see also the review by Majewski 1993). The classical method is to perform star counts (see, e.g., Bahcall & Soneira 1984). Selecting stars based on their proper motion allows, if their radial velocities and distances are also determined, to study the true kinematics of the stars (see, e.g., Carney et al.1996 and papers cited there). Basing oneself on proper motions one naturally studies the general group of more nearby stars extended by true high-velocity stars. Another method is to sample distances and radial velocities of a specific set of stars, such as BHB or RR Lyr stars, to investigate these parameters in a statistical manner (see, e.g., Kinman et al.1994, 1996). A more specific method is to observe statistically complete samples of stars of a special type in several directions to derive scale heights (for sdB stars see e.g., Heber 1986, Moehler

Send offprint requests to: M. Altmann (maltmann@astro.uni-bonn.de)

* Based in part on HIPPARCOS data

et al.1990, Theissen et al.1993), or scale lengths in the Milky Way. A further possibility is to go beyond the present kinematic parameters by calculating orbits based on distances, radial velocities, and proper motions. This method has been used for high proper motion stars (Carney et al. 1996), other dwarf stars (Schuster & Allen 1997), and for globular clusters (Dauphole et al. 1996). Also the orbits of sdB stars have been investigated (Colin et al. 1994, de Boer et al. 1997a). The latter study showed that most of the sdB stars have orbits staying fairly well inside the Milky Way disk, indicating that the sdB stars are not generally part of the halo population.

In the present study we have attempted to perform a similar analysis for HBA and HBB stars (for short: HBA/B stars). Our sample consists of the local HB stars which were observed by the Hipparcos satellite. These are the HB-like stars with the most accurate spatial and kinematic data available to date.

However, only for a few HBA/B stars are the parallaxes accurate enough to calculate reliable distances (de Boer et al. 1997b). For the other stars the distance still must be derived from photometry. Here one needs to know the absolute magnitude of field horizontal branch stars. Especially since the publication of the Hipparcos catalogue a lot of effort has gone into fixing this value. However, this has not yet led to total agreement. For a review of various approaches to solving this problem we refer to de Boer (1999) and Popowski & Gould (1999).

An important parameter in these studies is the metallicity of the stars, as it is generally thought to be correlated with age. For dwarf stars metallicities can be estimated using photometric indices or spectroscopy (see the summary by Majewski 1993). For HB stars this is, unfortunately, not a trustworthy method. The atmospheres of many HB stars have most probably been altered chemically with respect to the original composition. Gravitational settling of heavy elements in the sdB/O star and possibly HBB star atmospheres leads to a present lower content of elements like He, while levitation of heavy elements leads to atmospheres with enhanced abundances of certain elements like Fe or Au as found in several field horizontal branch stars, e.g. Feige 86 (Bonifacio et al. 1995). Levitation must also be the explanation for the high metal abundances in blue HB stars in M 13 (Behr et al. 1999) and NGC 6752 (Moehler et al. 1999) finally uncovered to explain deviant flux distributions near the Balmer jump of globular cluster blue HB stars (Grundahl et al. 1999). Therefore, original metallicities (as well as the original masses) are no longer accessible quantities. Determining the kinematic properties can help deciding which of the HB stars are intrinsically more metal poor and which are more metal rich, and hence of somewhat younger origin.

The main subjects of our study are the HBA/B stars which are located in the colour magnitude diagram on the horizontal branch between the RR-Lyrae stars and the hot subdwarfs. Unfortunately the main sequence crosses the HB at the HBB region, so that HBB stars can be confused with normal B stars. Therefore we have only few HBB stars in our sample. We mainly focus on HB stars with temperatures lower than 10000 K which lie above the main sequence.

Sect. 2 deals with the data neccessary for our study. In Sect. 2.3 we determine the absolute magnitudes and distances of the HBA/B and sdB/O stars with the method of *auto-calibration* using the shape of the HB defined by the stars with the best Hipparcos parallaxes. In Sect. 3 we discuss the kinematical behaviour of the HBA/B and sdB/O stars and make comparisons with the results of de Boer et al. (1997a). To further explore a possible trend in kinematics of stars along the HB we investigate (Sect. 4) the orbits of a sample of RR-Lyrae stars.

2. The data

2.1. Composition of the sample

Our sample consists of the Hipparcos (ESA 1997) measured HB stars. In order to identify them we searched through lists of bright HB-candidates in publications concerning horizontal branch stars, such as Corbally & Gray (1996), Huenemoerder et al.(1984), and de Boer et al.(1997b) for the HBA/B stars and Kilkenny et al.(1987) for sdB/O stars. However, for a few stars in these lists indications exist that they are probably not horizontal branch stars. Among these are HD 64488 (Gray et al. 1996), HD 4772 (Abt & Morell 1995, Philip et al. 1990), HD 24000 (Rydgren 1971), HD 52057 (Waelkens et al. 1998, Stetson 1991) and HD 85504 (Martinet 1970). This sample, although being of limited size, represents the HB stars with by far the best kinematical data currently available.

Two further stars are HB-like but were excluded from the study nevertheless. BD +32 2188 has a rather low value for $\log g$ so that it lies considerably above the ZAHB in the $\log g - T_{\rm eff}$ diagram. Being metal deficient (Corbally & Gray 1996) it can be considered a horizontal branch star evolving away from the ZAHB. Because the evolutionary state is not fully HB the star cannot be part of our sample. HD 49798 is a subluminous O-star. However, its $\log g$ is relatively low and its trigonometrical parallax implies a star with absolute brightness of about -2 mag, far too bright for a normal sdO star. It is probably on its way from the horizontal branch to become a white dwarf or it is a former pAGB star. Because of these aspects we excluded this star.

A large fraction of the known horizontal branch stars has no published radial velocity and could therefore not be used for our study. A few stars had radial velocities but no Hipparcos data.

There is no constraint on the position, so that the sample stars are located in all parts of the sky. However, as many studies were made in fields near the galactic poles we have relatively more stars at very high galactic latitudes. Although our sample of stars is certainly not statistically complete in any way, we do not expect noticeable selection effects due to position in the sky (see Sect. 5.2.).

2.2. Physical properties of the stars, extinction

While many of the stars are classical template HB stars, like HD 2857, HD 109995, HD 130095 or HD 161817, others are not as well studied.

Table 1. Physical properties of the sample of horizontal branch stars.

Name	HIP	V^{a} [mag]	$B-V^{a}$ [mag]	E_{B-V} [b] [mag]	δM_V [b] [mag]	Type[c]	$T_{\rm eff}$ [K]	log g	Source[d]
HD 2857	2515	9.967	0.219	0.050	−0.001	HBA	7700	3.1	GCP, HBC
HD 14829	11124	10.228	0.023	0.020	−0.580	HBA	8700	3.3	GCP
HD 60778	36989	9.131	0.135	0.020	−0.040	HBA	8600	3.3	GCP, S91, HBC
HD 74721	43018	8.717	0.042	0.000	−0.330	HBA	8600	3.3	GCP, S91, HBC
HD 78913	44734	9.291	0.094	0.030	−0.215	HBA	8700	2.5	IUE-fit, S91
HD 86986	49198	8.000	0.119	0.035	−0.130	HBA	7900	3.1	B97b, S91
BD +36 2242	59252	9.904	−0.065	0.010	−1.188	HBB	11400	4.4	HBC
HD 106304	59644	9.077	0.027	0.040	−0.696	HBA	9500	3.0	IUE-fit, S91
BD +42 2309	60854	10.820	0.043	0.000	−0.324	HBA	8400	3.3	GCP
HD 109995	61696	7.603	0.047	0.001	−0.307	HBA	8300	3.15	B97b, S91
BD +25 2602	64196	10.148	0.057	0.065	−0.659	HBA			S91
HD 117880	66141	9.059	0.082	0.015	−0.201	HBA	9200	3.4	GCP, S91, HBC
Feige 86	66541	10.006	−0.140	0.050	−2.193	HBB	15300	4.1	HBC
HD 130095	72278	8.155	0.032	0.064	−0.840	HBA	8800	3.15	B97b, S91
HD 139961	76961	8.857	0.098	0.107	−0.666	HBA	8750	3.3	B97b, S91
HD 161817	87001	7.002	0.166	0.020	−0.001	HBA	7500	2.95	B97b, S91
CD −38 222	3381	10.400	−0.224	0.013	−2.639	sdB	28200	5.5	B97b, B97a
Feige 66	61602	10.602	−0.286	0.040	−3.556	sdB	28000	4.9	KHD, S94
HD 127493	71096	10.040	−0.251	0.095	−3.756	sdO	40000	5.8	KHD
HD 149382	81145	8.872	−0.280	0.050	−3.598	sdOB	40000	5.8	KHD, S94
HD 205805	106917	10.158	−0.241	0.025	−2.929	sdB	25000	5.0	B97b, B97a

[a] V, $B-V$ from the Hipparcos Catalogue
[b] E_{B-V}, δM, see Sect. 2.2 and 2.3
[c] Type: HBA stars: $T_{\rm eff} < 10500$ K; HBB stars: 20000 K $> T_{\rm eff} \geq 10500$ K; sdB/O stars: from literature (see under $source$)
[d] The values for log g and $T_{\rm eff}$ have been taken from the first work cited. HBC: Huenemoerder et al. (1984), GCP: Gray et al. (1996), B97a: de Boer et al. (1997a), B97b: de Boer et al. (1997b), KHD: Kilkenny et al. (1987) and references therein, S91: Stetson (1991), S94: Saffer et al. (1994), IUE-fit: see Sect. 2.2

For most of our stars values for $\log g$ and $T_{\rm eff}$ are available in the literature from a variety of methods. Sources are given in Table 1. For HD 78913 and HD 106304 $\log g$ and $T_{\rm eff}$ were derived from a fit of Kurucz models to spectrophotometric IUE data and photometry. For BD +25 2602 no data are available to determine $\log g$ and $T_{\rm eff}$. We keep it as part of our sample, as it was identified as a horizontal branch star by Stetson (1991).

Wherever possible we took the values for E_{B-V} from de Boer et al. (1997b), supplemented by values listed in Gratton (1998). For the other stars we derived the E_{B-V}, with $(B-V)$- and $(U-B)$-values taken from the SIMBAD archive and a two-colour-diagram. Note that with this method there may well be metallicity dependent effects having an influence on the reddening derived. For the star CD -38 222 no $(U-B)$ data are available; the reddening is very small as follows from the IRAS maps of Schlegel et al. (1998). We adopted the value from that study.

2.3. Absolute magnitudes and distances

We obtained the distances of the HB stars using the absolute magnitude of the relevant portion of the HB rather than directly using the Hipparcos parallaxes. The reason for this is that most of the parallaxes are smaller than 3 mas which means that their error of on average 1 mas is too large to calculate accurate distances. The absolute magnitudes M_V, which are a function of the temperature and thus of $(B-V)_0$, have been derived through self calibration as follows.

We started with the determination of the shape of the field horizontal branch. For this we calculated the absolute magnitudes of those HB and sdB/O stars which have reasonably good parallaxes. For the determination of the mean absolute magnitude of the HB sample we excluded HD 74721 and BD +42 2309 because their absolute magnitudes, calculated from their parallaxes, are too bright by more than 3.5 magnitudes. Also excluded at this point are HD 14829 and HD 117880, whose parallaxes lead to absolute magnitudes far too faint. With this medianization (leaving out the extremes to both sides) we ensure that our result is not affected by stars with extreme values. Furthermore the stars having parallaxes with $\Delta\pi/\pi > 1$ were excluded for the determination of the shape of the HB.

We then fitted by eye a curve to our sample in the colour magnitude diagram. In order to smooth this curve, it was approximated by a polynomial. Note that we aim to fit the observed parameters of the field horizontal branch and that we do not rely on a shape taken from globular clusters or theoretical models (see Fig. 1).

From this we determined the value δM_V giving the difference of M_V for each $(B-V)_0$ with respect to M_V at $(B-V)_0$=0.2 mag. Although the available metallicity mea-

Table 2. Spatial and kinematical data for the stars[a] of our sample

Name	RA (Eq. 2000.0) hr, min, sec	DEC ° ′ ″	$\mu_\alpha\cos\delta$ mas/yr	μ_δ mas/yr	$\Delta\mu_\alpha\cos\delta$ mas/yr	$\Delta\mu_\delta$ mas/yr	π mas	$\Delta\pi$ mas	d pc	$v_{\rm rad}$ km s^{-1}	ref.[b] $v_{\rm rad}$
HD 2857	00 31 53.80	−05 15 42.3	−6.85	−66.05	1.58	0.85	1.79	1.67	687	−149	CG
HD 14829	02 23 09.23	−10 40 38.9	+31.31	−46.85	1.89	1.58	4.40	1.96	619	−176	P69
HD 60778	07 36 11.79	−00 08 14.9	−20.92	−84.04	1.21	0.73	2.35	1.23	479	+39	eE
HD 74721	08 45 59.29	+13 15 49.6	−41.83	−112.42	1.31	0.93	0.34	1.46	356	+9	eE
HD 78913	09 06 54.78	−68 29 22.1	+36.48	+22.87	0.95	0.80	2.69	0.88	469	+313	cE
HD 86986	10 02 29.48	+14 33 27.0	+144.06	−208.27	1.05	0.53	3.78	0.95	267	+9	bE
BD +36 2242	12 09 15.84	+35 42 42.9	−5.57	−1.83	1.20	0.88	1.83	1.25	409	−4	dE
HD 106304	12 13 53.63	−40 52 23.7	−90.36	−117.00	0.99	0.71	2.83	1.12	336	+95	cE
BD +42 2309	12 28 22.18	+41 38 52.7	−21.30	−33.61	1.19	1.39	0.47	1.76	942	−152	dE
HD 109995	12 38 47.69	+39 18 32.9	−114.81	−144.19	0.83	0.68	4.92	0.89	215	−132	BB
BD +25 2602	13 09 25.64	+24 19 25.3	−84.51	−18.73	1.83	1.44	1.40	1.54	540	−74	eE
HD 117880	13 33 29.86	−18 30 53.1	−85.65	−140.33	1.18	0.75	4.80	1.10	433	−45	cE
Feige 86	13 38 24.77	+29 21 57.0	−15.34	−109.79	1.49	0.92	4.61	1.65	255	−22	cE
HD 130095	14 46 51.35	−27 14 53.3	−213.89	−79.77	1.29	0.75	5.91	1.08	199	+58	BB
HD 139961	15 42 52.97	−44 56 40.0	−187.04	−92.41	1.28	1.19	4.50	1.19	280	+145	dE
HD 161817	17 46 40.65	+25 44 57.3	−37.05	−43.23	0.50	0.57	5.81	0.65	183	−363	bW
CD −38 222	00 42 58.28	−38 07 37.2	+43.85	−7.00	1.88	1.23	3.07	1.73	262	−52	GS
Feige 66	12 37 23.52	+25 04 00.1	−2.72	−26.71	1.80	1.36	5.11	1.74	182	+1	cE
HD 127493	14 32 21.51	−22 39 25.5	−32.80	−17.22	1.45	1.37	5.21	1.49	118	+13	bW
HD 149382	16 34 23.34	−04 00 52.0	−5.95	−3.92	1.83	1.73	13.07	1.29	79	+3	cW
HD 205805	21 39 10.55	−46 05 51.4	+76.39	−9.93	1.20	0.90	3.77	1.70	201	−57	B97a

[a] Positions, proper motions and parallaxes (with errors) listed in this table are from the Hipparcos Catalogue, the distances, as derived in Sect. 2.3.
[b] References for radial velocities: E: The Revision of the General Catalogue of Radial Velocities (Evans 1967), W: The General Catalogue of Radial Velocities (Wilson 1953); here the small case letters indicate the quality of the radial velocity:
a: $\Delta v_{\rm rad} < 0.9$ km s^{-1}, b:$\Delta v_{\rm rad} < 2.0$ km s^{-1}, c: $\Delta v_{\rm rad} < 5.0$ km s^{-1}, d: $\Delta v_{\rm rad} < 10.0$ km s^{-1}, e: $\Delta v_{\rm rad} > 10.0$ km s^{-1}.
B97a: de Boer et al. (1997a), BB: Barbier-Brossat (1989), CG: Corbally & Gray (1996), GS: Graham & Slettebak (1973), P69: Philip (1969)

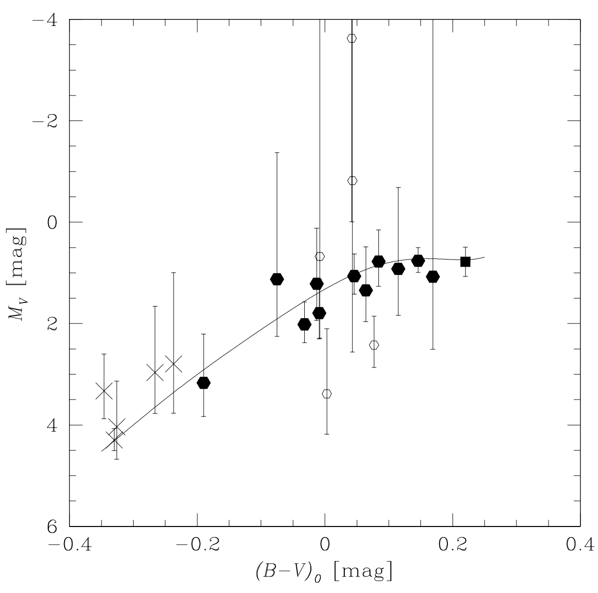

Fig. 1. Colour magnitude diagram showing the stars of our sample and the curve which was used as the shape of the FHB. Hexagons: HBA/B stars (open symbols mean stars not used for the fit), crosses mean sdB/O stars, the square depicts RR Lyrae.

surements show a large spread for individual stars (see Table II of Philip 1987), the averages for each lie around [Fe/H] ~ -1.5 dex. Since the effect of metallicity on M_V is small for RR Lyr stars (about 0.1 mag per 0.5 dex, see de Boer 1999) we will neglect the metallicity effects for the HBA stars.

Distances and absolute magnitudes of a sample of stars obtained through trigonometric parallaxes have to be corrected for the Lutz-Kelker bias (Lutz & Kelker 1973). This statistical effect, depending on the relative error of the parallaxes, leads to an over-estimation of the parallax on average, leading to too faint absolute magnitudes and too short distances of the sample.

The correction we applied is based on the averaging of parallaxes. For that we have to correct the parallaxes of individual stars, acknowledging that such a correction is only valid in a statistical sense. The expected parallax π^* given by

$$\pi^* = 10^{0.2[M_V - V - \delta M_V] - 1 + 0.62 E_{B-V}} \quad (1)$$

with M_V being the absolute magnitude, V the apparent magnitude, E_{B-V} the reddening. δM_V is a term which accounts for the temperature and/or $B-V$ dependence of the absolute magnitude of BHB stars in the same way as done by Gratton (1998). Now M_V is varied and $\chi^2(M_V)$=$\sum_i(\pi_i^*(M_V) - \pi_i)^2/(\Delta\pi_i)^2$ is calculated (formula as revised by Popowski & Gould 1999). At the correct M_V the average of χ^2 should be minimized.

M_V is now found using all stars, regardless of their $\Delta\pi/\pi$, except the four excluded above. We arrived at an absolute magnitude of $M_V = 0.63 \pm 0.08$ mag for the horizontal part ($(B-V)_0 \sim 0.2$ mag) of the horizontal branch. As stated before this value should be valid for [Fe/H]~ -1.5 dex. However, as the curve defining the shape of the HB is subjective to a certain extent the real error of the HB's absolute magnitude is somewhat larger. The absolute magnitudes and thus the distances of the individual stars including those omitted earlier are obtained by adding their δM_V to the mean absolute magnitude of the HB.

2.4. Proper motions and positions

Positions and proper motions used in this work were taken from the Hipparcos catalogue (ESA 1997). The mean error of the proper motions is below 1.5 mas/yr (see Table 2) which means an error in the tangential velocity of 3.5 km s^{-1} for a star at a distance of 500 pc. As most of our stars have smaller distances the error caused by the proper motion uncertainty is even smaller.

No star of the sample of HBA/B or sdB/O stars has an astrometric flag in the Hipparcos catalogue, indicating there were no problems in the data reduction. The Hipparcos goodness-of-fit statistic is below +3 in all cases, meaning that the astrometric data derived from the Hipparcos catalogue should be reliable and there are no indications that our sample contains double stars.

2.5. Radial velocities

The radial velocities were taken from original sources (see Table 2), in part found from the Hipparcos Input Catalogue (Turon et al. 1987). The typical uncertainties are about 10 km s^{-1}, so that they should not have a large effect on our results. The size of our sample was limited to a large extent by the lack of radial velocities; for only about 30% of the HB-candidates radial velocities could be found.

Radial velocities can be affected by binarity of the star. We cannot absolutely exclude this possibility for some of the stars, but as noted in Sect. 2.4 there are no indications for binary nature for any of our stars.

For some stars, Corbally & Gray (1996) found drastically different values for the radial velocity. They note however that in many of these cases their values may be affected for some reason (see their Sect. 4) as they show strong deviations with respect to values from the literature. We therefore used radial velocities from Corbally & Gray only for HD 2857 for which no other value is available.

3. Kinematics and orbits

In order to gain information about the nature and population membership of the stars we analyse their kinematic behaviour and calculate their orbits.

3.1. Calculating orbits and velocities

Before calculating the orbits the observational data have to be transformed into the coordinates of the galactic system $(X, Y, Z; U, V, W)$. In this coordinate system X points from the Sun in direction of the galactic centre with its origin in the galactic centre, Y points into the direction of the galactic rotation at the position of the sun, and Z toward the north galactic pole. The same applies to the corresponding velocities U, V, W.

The orbits are calculated using the model for the gravitational potential of our Milky Way by Allen & Santillan (1991) which was developed to be used in an orbit calculating program (Odenkirchen & Brosche 1992). This model has been extensively used in the studies of de Boer et al. (1997a), Geffert (1998) and Scholz et al. (1996). There are several other models available which yield similar results as long as the orbits do not extend to extreme distances from the galactic centre (Dauphole et al. 1996). The model of Allen & Santillan (1991) is based on $\Theta_{\rm LSR} = 220$ km s^{-1} and $R_{\rm LSR} = 8.5$ kpc. The values for the peculiar velocity of the Sun used in the calculations in this paper are $U_{\rm pec,\odot} = 10$ km s^{-1}, $V_{\rm pec,\odot} = 15$ km s^{-1}, $W_{\rm pec,\odot} = 8$ km s^{-1}.

To determine the parameters $z_{\rm max}$, the maximum height reached above the galactic plane and R_a and R_p, the apo- and perigalactic distances, we calculated the orbits over 10 Gyr. This for certain does not give true orbits as the orbits are probably altered in time by heating processes. However this long timespan allows to better show the area the orbit can occupy in the meridional plane (see Fig. 2).

As in de Boer et al. (1997a), we also calculated the eccentricity ecc of the orbit, given by

$$ecc = \frac{R_{\rm a} - R_{\rm p}}{R_{\rm a} + R_{\rm p}} \qquad (2)$$

and the normalised z-extent, nze, given by

$$nze = \frac{z_{\rm max}}{\varpi(z_{\rm max})}. \qquad (3)$$

The parameter nze is more relevant than $z_{\rm max}$, since it accounts for the effect of diminished gravitational potential at larger galactocentric distance ϖ.

To assign a star to a population often the U, V, W-velocities and their dispersions are used, as well as the orbital velocity Θ. For stars near the Sun (small Y), the V velocity is nearly the same as Θ. However, for stars further away from the Sun's azimuth, Θ becomes a linear combination of U and V. Therefore Θ should be preferred. In order to make comparisons with results from other studies, we use both U, V, W and Θ.

We calculated the errors of the velocity components and the orbital velocity using Monte Carlo simulations of Gaussian distributions to vary the input parameters within their errors as described by Odenkirchen (1991). This is neccesary rather than just calculating errors using Gauss error propagation laws because the parameters are significantly correlated. For the error calculation we used the software of Odenkirchen (priv. comm.). The proper motion errors were taken from the Hipparcos catalogue. The errors of the distances were calculated from the error in absolute magnitude as derived in Sect. 2.3. We took the errors of the radial velocities as published in the respective articles. For those radial velocities of Wilson (1953) and Evans

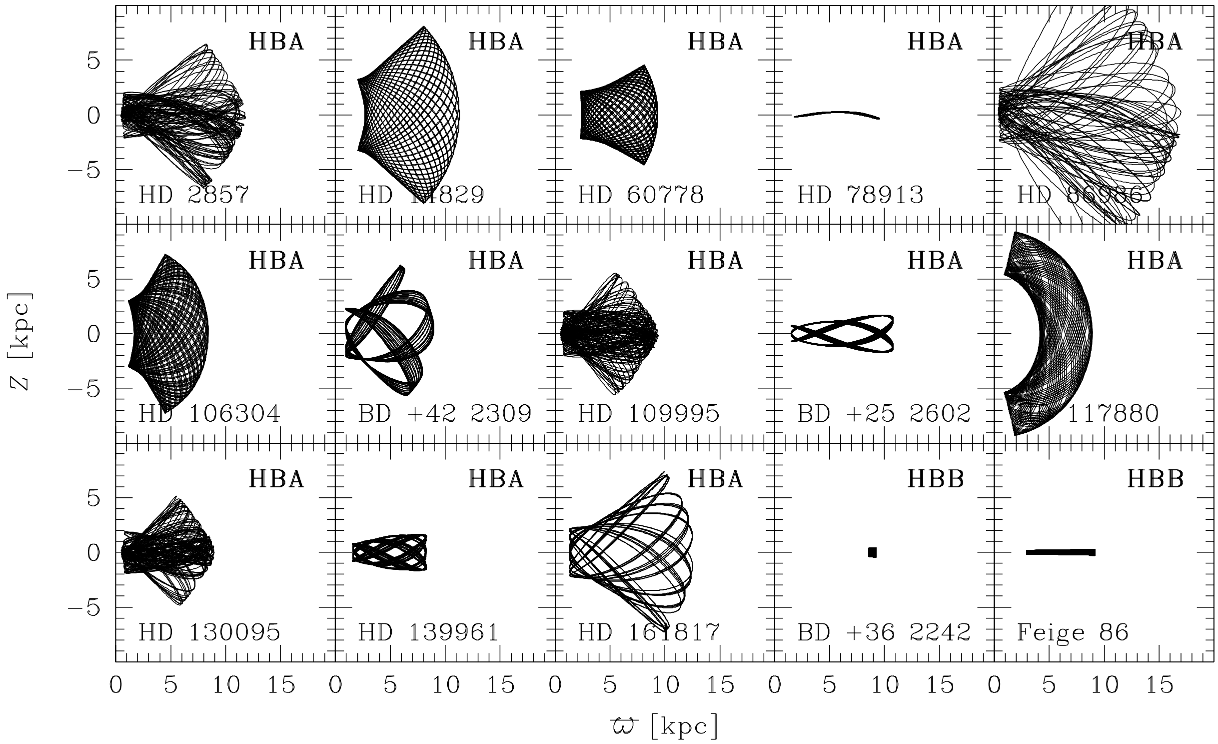

Fig. 2. Orbits of the HBA/HBB stars displayed in meridional cuts. The orbits shown here have been calculated for 10 Gyr, in order to make the shape of the orbit better visible (The orbit of HD 74721 (similar to HD 60778) is not shown). For orbits of sdB stars see de Boer et al. (1997a).

(1967) having quality mark "e", meaning the error is larger than 10 km s^{-1}, we used 15 km s^{-1} as error. This is justified as can be seen by comparison of these values with those of other studies. Generally the error in the velocity components is less than 10 km s^{-1}. Only a few stars have somewhat larger errors, the largest error in Θ being 12 km s^{-1}. For the HBA/B stars the typical value of $\Delta\Theta$ is about 7 km s^{-1}, for the on average closer sdB/O stars $\Delta\Theta$ is 1 to 2 km s^{-1}.

We have not estimated errors for nze, ecc, $R_{\rm a}$ and $R_{\rm p}$ because they have not been used individually in the interpretation. Moreover the larger values of nze are very sensitive to small variations in the shape of the orbit. This especially applies to stars having chaotic orbits. Variations in the input distance modulus showed that the resulting variations in all of these quantities except nze are relatively small in most cases. For a discussion of overall effects on a sample see de Boer et al. (1997a).

3.2. Morphology of the orbits

The orbits of the HBA/B stars show a large variety of shapes. Nearly all of the cooler HBA stars have a small perigalactic distance ($R_{\rm p} \leq 3$ kpc) and the most extreme case, HD 86986, reaches a perigalactic distance of only 0.4 kpc. The single exception is HD 117880, which has a $R_{\rm p}$ of nearly 4 kpc.

Four stars have truly chaotic orbits, the rest has boxy type orbits, but some of these show signs of chaotic behaviour as well. HD 79813 has an orbit staying very close to the disc, while HD 117880 orbits nearly perpendicular to the galactic plane. On the whole about half of our stars have orbits which are chaotic or show signs of that. This agrees quite well with the results of Schuster & Allen (1997) who analysed a sample of local halo subdwarfs.

Most of the stars have apogalactic distances of $\simeq$ 8 to 11 kpc, just one star (HD 86986) goes well beyond. The reason for this clumping in $R_{\rm a}$ is not physical but due to selection effects. Stars with $R_{\rm a} \leq 7.5$ kpc never venture into the observable zone (at least observable by Hipparcos). On the other hand the probability of finding the stars is greatest when they are near their major turning point, $R_{\rm a}$. So it is clear that the mean $R_{\rm a}$, as well as to a lesser extent the eccentricity, are affected by selection effects.

Stars belonging to the thin disk would have orbits with very small eccentricities and nze values (solar values: ecc= 0.09, nze= 0.001, see de Boer et al. 1997a), while thick disk stars would have larger values on average. Halo stars have generally orbits with large eccentricities while their nze show a large range.

The eccentricities of the HBA star orbits are very large, ranging from 0.5 to nearly 1.0, the values for nze vary by a huge amount, from 0.04 (HD 78913) to 5 (HD 117880). The stars BD +36 2242 and Feige 86 are exceptions, their values for both parameters are more appropriate for disk objects. We note that these two stars are the hottest of the HBA/B sample. The kinematics of the four HBB stars from Schmidt (1996) show overall behaviour similar to that of BD +36 2242 and Feige 86 (Fig. 2). All of these are hotter than 11000 K, the $T_{\rm eff}$ of BD +36 2242.

Table 3. Orbital and kinematical characteristics

Name	R_a [kpc]	R_p [kpc]	z_{max} [kpc]	ecc	nze	U [km s^{-1}]	V [km s^{-1}]	W [km s^{-1}]	Θ [km s^{-1}]	I_z [kpc km s^{-1}]	Type
HD 2857	11.81	0.44	6.47	0.93	1.04	+156	+25	+67	+29	+251	HBA
HD 14829	11.29	2.69	8.11	0.62	1.01	+108	+71	+156	+71	+622	HBA
HD 60778	9.35	2.41	4.56	0.59	0.56	+53	+82	−115	+80	+714	HBA
HD 74721	8.65	1.95	4.42	0.63	0.59	+22	+70	−109	+69	+606	HBA
HD 78913	9.52	1.79	0.38	0.68	0.05	+107	−77	+24	−83	−695	HBA
HD 86986	16.96	0.33	13.26	0.96	1.63	+248	+24	+50	+20	+217	HBA
BD +36 2242	9.96	8.58	0.42	0.04	0.05	+3	+227	+3	+227	+1945	HBB
HD 106304	8.42	1.65	7.27	0.67	1.62	−22	+38	−150	+39	+327	HBA
BD +42 2309	9.96	0.91	5.26	0.83	0.89	+29	+34	−110	+35	+300	HBA
HD 109995	9.41	0.48	5.52	0.90	1.00	+4	+30	−96	+30	+258	HBA
BD +25 2602	10.80	1.51	1.71	0.75	0.18	−146	+72	−53	+72	+607	HBA
HD 117880	8.91	4.17	9.29	0.36	4.89	−55	−28	−199	−26	−217	HBA
Feige 86	9.18	2.95	0.27	0.51	0.03	+76	+117	−7	+118	+995	HBB
HD 130095	8.94	0.49	5.13	0.90	0.93	−58	+30	+65	+31	+258	HBA
HD 139961	8.26	1.57	1.68	0.68	0.22	+3	−69	+81	−69	−568	HBA
HD 161817	12.51	1.30	7.36	0.81	0.74	−169	−54	−129	−56	−473	HBA
CD -38 222	9.31	7.29	1.23	0.12	0.13	−38	+206	+59	+207	+1749	sdB
Feige 66	9.10	7.76	0.22	0.08	0.02	+24	+217	+8	+217	+1841	sdB
HD 127493	8.53	7.71	0.20	0.05	0.02	+10	+212	+15	+212	+1780	sdO
HD 149382	9.64	8.33	0.13	0.07	0.01	+13	+233	+10	+233	+1966	sdB
HD 205805	11.48	6.72	0.19	0.26	0.02	−82	+225	−3	+225	+1880	sdB

Note: Due to a change in the convention (see Geffert 1998), the values of I_z have changed their sign (positive Θ have now positive I_z) in contrast to previous work (e.g. de Boer et al. 1997a)

Table 4. Mean orbital parameters Θ, ecc and nze for various subsamples of HB stars

Types	subsample	number of stars	nze	σ_{nze}	Θ [km s^{-1}]	σ_Θ [km s^{-1}]	ecc	σ_{ecc}
HBA	this paper	14	1.10	1.15	+17	52	0.74	0.16
HBB	this paper & Schmidt (1996)	6	0.24	0.15	+151	55	0.41	0.27
sdB/O	this paper	5	0.04	0.05	+218	10	0.12	0.08
sdB	this paper & de Boer (1997b)	44	0.25	0.17	+198	50	0.15	0.11
RR Lyr	all	32	0.86	1.50	+80	114	0.59	0.33
RR Lyr	[Fe/H] > -0.9	7	0.08	0.05	+218	37	0.19	0.13
RR Lyr	$-0.9 >$[Fe/H]> -1.3	7	0.88	0.57	+43	109	0.64	0.38
RR Lyr	$-1.3 >$[Fe/H]> -1.6	10	1.54	2.43	+32	74	0.68	0.40
RR Lyr	$-1.6 <$[Fe/H]	8	0.68	0.47	+51	107	0.65	0.30

The star HD 117880 features an orbit somewhat dissimilar from the others. While its nze is very high, its eccentricity is by far the lowest of the sample of HBA stars.

3.3. Velocity components and dispersions

The HBA stars ($T_{\rm eff} \leq$ 10,000 K) have a mean orbital velocity of Θ = 17 km s^{-1}, lagging about 200 km s^{-1} behind the local standard of rest. However, the velocity dispersions are large: 102, 53 and 95 km s^{-1} in U, V, W respectively. This shows that there are many stars with a non disk-like kinematical behaviour in the sample of HBA/B stars. They therefore belong to the galactic halo population rather than to the disk.

The orbital velocities of the HBA stars in the sample do not have a Gaussian distribution, as one might have expected. Instead, they seem to have a somewhat flatter distribution (see Fig. 4). About 75% of our stars have prograde velocities, four stars have retrograde orbits. However the exact distribution cannot be studied reliably due to the limited number of stars at disposal.

Both the analysis of the kinematic properties and the shapes of the orbits imply that the HBA/B stars mostly are members of the galactic halo population. However, there seems to be a difference in kinematics and hence population membership between the cooler and the hotter stars. Stars cooler than about 10,000 K have low orbital velocities and a large spread in nze. In contrast to this are the hotter stars whose kinematics and orbits are consistent with those of disk objects. The HBB stars of Schmidt (1996) which are all hotter than 10,000 K behave like sdB stars, too.

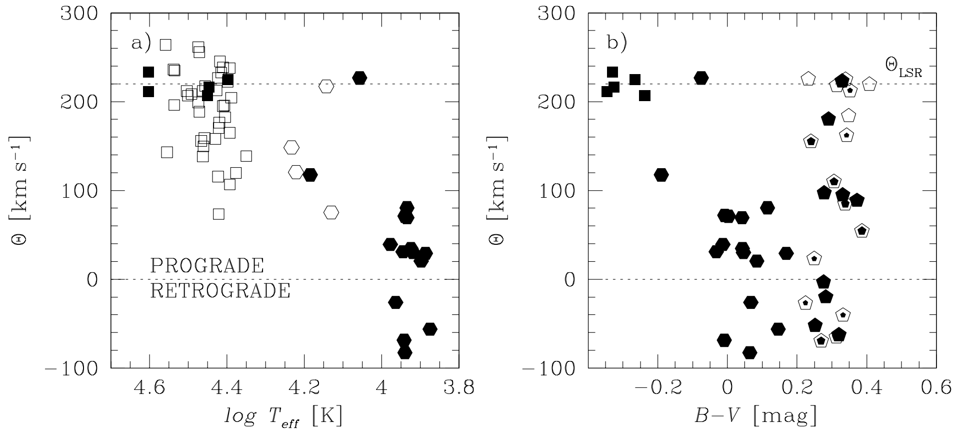

Fig. 3a and b. Kinematical trend of stars along the field horizontal branch characterized by the orbital velocity (Θ) as plotted against effective temperature $T_{\rm eff}$ and $B-V$. Panel **a:** Θ versus $T_{\rm eff}$. Filled symbols show the stars with Hipparcos data (Table 3), open symbols are sdB stars of de Boer et al. (1997a) and HBB stars of Schmidt (1996). The symbol shapes represent: hexagons HBA/B stars; squares sdB/O stars. Panel **b:** Θ versus $B-V$, highlighting the cooler part of the HB and including RR Lyrae stars (see Sect. 4). The RR-Lyrae stars are plotted with pentagons subdivided according to [Fe/H]< -1.6 dex (full), -1.6 dex $\leq$[Fe/H]$<$ -1.3 dex, -1.3 dex $\leq$[Fe/H]$<$ -0.9 dex and [Fe/H]$\geq$ -0.9 dex (open symbols)

3.4. Kinematics of sdB/O stars

The sample of sdB/O stars show classical disk behaviour: Their mean orbital velocity is $\Theta = 219$ km s^{-1}, meaning a negligible asymmetric drift. The V velocity dispersion (which is also the dispersion in Θ, because the stars are in the solar vicinity) is relatively small, similar to that of old thin disk orbits, while the dispersion in U is much larger, fitting to thick disk values. The dispersion σ_W is somewhere in between. These values are quite similar to those of the sdB star sample of de Boer et al. (1997a). Until now no population of *field* sdB stars with halo kinematics has been found. Yet, hot subdwarfs of the horizontal branches of halo globular clusters are, of course, well known (see e.g. Moehler et al. 1997).

3.5. Trend of kinematics along the HB?

Given the results above there seems to be a trend in the kinematics of star types along the blue part of the horizontal branch (see Fig. 3). The sdB/O stars have disklike orbits. The same probably applies to the HBB stars hotter than about 10,000 K, though the statistics are rather poor for this part of the HB. In contrast to that stand the cooler HBA stars which have much smaller orbital velocities, large orbital eccentricities and large ranges of nze, thus showing a behaviour fitting more to halo than to disk objects.

This result suggests to analyse the kinematics of the adjoining cooler stars of the HB, the RR Lyraes.

4. RR Lyrae stars

4.1. A sample of RR Lyrae stars from the literature

Recently, Martin & Morrison (1998) carried out an investigation of the kinematics of RR Lyrae stars which is mainly based on the study of Layden (1994). For our analysis we will use only those stars having Hipparcos data. Six Hipparcos stars were excluded because they have a proper motion error larger than 5 mas/yr.

The RR Lyrae stars present the observational difficulty in that they are variables with both V and $B-V$ changing continously. For most of the sample we were able to take the mean magnitudes from Layden (1994). For the remaining stars we derived the intensity-mean magnitudes with help of the formula given by Fitch et al. (1966) and revised by Barnes & Hawley (1986) which is the same method as used by Layden (1994), using the photometric data of Bookmeyer et al. (1977). The Layden photometry was dereddened using the Burstein & Heiles (1982) reddening maps.

For later steps in this study it is necessary to know the mean $B-V$ of the RR Lyrae stars. As the colour curves of the stars are quite similar to the brightness curves, with the star being bluest when it is near maximum brightness, we took the same formula as we used to calculate the mean magnitude. This is not entirely correct but gives $B-V$ close to the actual one. For six stars we did not have the appropiate light curve data, so we could not determine the mean $B-V$ for them. Therefore only 26 RR Lyraes are shown in Fig. 3.

As the RR-Lyrae stars are in most cases fainter and therefore farther away than our HBA/B stars they have a rather large $\Delta\pi/\pi$. For this reason we used the absolute magnitude derived in Sect. 2.3 to calculate the distances for these stars. We thus have ignored the effects of metallicity on M_V for individual stars. Also possible evolutionary effects on M_V (see Clement & Shelton 1999) have been ignored, an aspect Groenewegen & Salaris (1999) did not consider in their determination of the RR Lyrae M_V either. Since we study the orbits of the RR Lyrae as a sample these limitations will not affect our conclusions.

For most RR Lyrae stars we took the radial velocities from the sources mentioned in Sect. 2.5, supplemented by radial velocities from Layden (1994).

The metallicities of the RR-Lyrae stars were taken from Layden (1994) as far as possible. A few values come from Layden et al. (1996) and Preston (1959).

4.2. RR-Lyrae kinematics

We calculated the orbits for the RR Lyrae stars in the same manner as for the HBA/B and sdB stars. The RR-Lyrae stars show a spread in kinematical behaviour wider than that of the HBA/B stars. Many stars have orbits similar to those of the HBA stars, others show disklike orbits with orbital velocities in the vicinity of 200 km s^{-1}. Of the halo RR-Lyrae stars many have perigalactic distances smaller than 1 kpc, as we also found for the HBA stars. The RR-Lyrae stars have orbital velocities typically spanning the entire range found for disk and halo stars (see Fig. 3). Three members of our sample of RR Lyr stars have orbits shaped somewhat different from those of the rest of halo orbits, looking similar to that of HD 117880.

In Fig. 3 we have sorted the RR Lyr stars according to their metallicity using different plot symbols. The stars with an [Fe/H]> -0.9 dex have high Θ like disk stars. The stars with lower metallicities are more evenly distributed in Θ. There are several stars with disk-like kinematics with a very low metallicity as low as [Fe/H]< -2.0 dex (see Table 4).

5. Selection effects

The study of the spatial distribution of HB stars involves, unfortunately, several selection effects. The general aspects have been reviewed by Majewski (1993) and will not be repeated in detail here. Yet, for each stellar type discussed in this paper a few comments are in place.

HBA stars have in most cases been identified from photometry, notably because of a larger than normal Balmer jump. This larger jump is mostly due to lower metallicity of the stellar atmosphere. If the atmospheric metallicity is identical to the original one, then the criterion favours intrinsically metal poor stars, which are presumably the older ones. However, also stars starting with a little more mass than the Sun and thus of solar composition will become HB stars and, when as old as the Sun, by now are solar metallicity HB stars. If they were of HBA type, they would not have been recognized in photometry of the Balmer jump. Such stars would be underrepresented in our sample. The HBA stars considered here come from all galactic latitudes, so that selection effects due to galactic latitude are not to be expected. However stars which have orbits going far away from the disk are always underrepresented, as their fraction of time near the disk (and hence being observable) is much smaller than for those which do not go far from the disk.

RR Lyraes, being variables, are not prone to such selection effects. Most of them are identified solely by their variability. Metallicity or high velocity are generally not used as criteria for the identification for RR Lyrae stars. For a discussion of selection effects due to galactic latitude we refer to Martin & Morrison (1998), as our sample is a subsample of theirs.

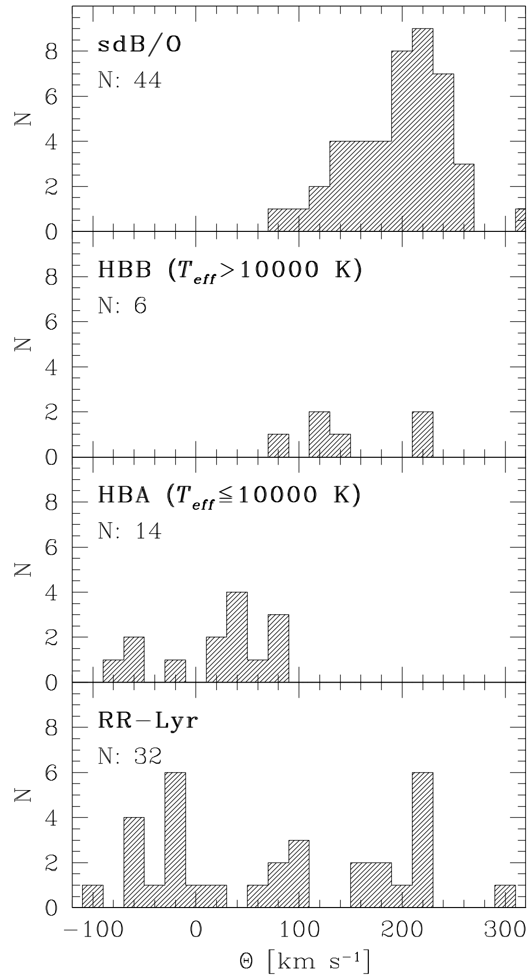

Fig. 4. Histogram showing the distribution of orbital velocities of the investigated stars. The binsize is 20 km s^{-1}.

The sdB/O stars were identified in surveys for quasars, e.g. the PG catalogue (Green et al. 1986) or Hamburger Quasar Survey (Hagen et al.1995). This means their blue colour is the criterion, rather than proper motion, radial velocity or metallicity. Therefore we do not expect a selection bias towards metal poor halo stars. Moreover, de Boer et al. (1997a) showed that the sdB/O stars observed now near the Sun come from widely differing locations in the Milky Way. As these catalogues only map objects which are somewhat away from the galactic plane, they miss the majority of stars with solar type orbits. sdO stars may be confused with pAGB stars descending down the HRD towards the white dwarf regime.

The HBB stars of Schmidt (1996) are also taken from the PG catalogue, so that there should not be noticeable selection effects, either. However HBB stars and main sequence stars have similar physical properties such as $\log g$, so that there may be confusion with the latter. Apart from this the selection effects mentioned for the sdB/O stars apply to the HBB stars, too.

Finally, some words concerning the distribution of distances of the different samples are in place. Generally, if one deals with stars having different absolute magnitudes, as in our case when the sdBs are several magnitudes fainter than the HBAs, one gets samples with different mean distances. The intrinsically fainter stars are on average much nearer than the brighter stars, if the two groups have similar apparent magnitudes. This means that the spatial regions sampled differ depending on the absolute magnitude of the stars. This would imply that the sdB sample is biased towards disk stars as we do not sample them far enough from the galactic plane where there may be a higher concentration of halo stars than further in. This is however not the case. As we include some of the results of de Boer et al. (1997a) which come from a completely different source, namely mostly from the PG-catalogue (Green et al. 1986) dealing with significantly fainter stars, the PG stars actually have on average larger distances than any of our HBA stars. For this reason we do not expect that the difference in kinematics arises from the distribution of the distances in the samples.

6. Discussion: trends and population membership

6.1. Overall trends

As shown in Figs. 3 and 4 the kinematics of the stars of horizontal branch type appears to have a trend along the HB indeed.

The *sdB stars* have in general rather disk-like orbits and kinematical properties. The ones analysed here (Table 4) show the same behaviour as those from the large sample of sdB stars investigated previously (de Boer et al.1997a).

The *HB stars*, the prime goal of our investigation, span a wide range in orbit parameters but when this group is split in HBB and HBA stars a cut is present.

The (hotter) *HBB stars* behave rather like the sdBs with orbits of disk-like characteristics. However, such stars are difficult to recognize and our sample is small. A much larger sample may show a larger variation in kinematics.

The *HBA stars* have mostly halo orbits (mean $\Theta \simeq 17$ km s^{-1}). This is very similar to the value at which most other studies concerning metal poor stars in the solar neighbourhood arrive (see Table 2 of Kinman 1995). However, the known sample may be observationally skewed toward stars with low atmospheric metallicity (large Balmer jump).

The *RR-Lyrae stars* have orbits spanning a large range in orbital parameters, too. However, a trend seems to be present with metallicity. The metal poor stars have halo orbits similar to those of the HBA stars with rather low orbital velocities of less than 100 km s^{-1}, and large ecc and nze. The metal rich stars on the other hand have rather disk-like kinematical characteristics. A similar distribution of metallicities and orbital velocities was also found in the studies of Chen (1999) and Martin & Morrison (1998).

Although there are a few RR Lyraes having high orbital velocities ($\Theta \geq 160$ km s^{-1}) and clearly disk-like orbits (some of which are very metal poor), HBA stars with such characteristics are not found in our sample. On the other hand no RR Lyraes with [Fe/H]> -0.9 dex with halo-like orbits or kinematics are present. This means that a high metallicity for a RR Lyr star is a good indicator that it is a disk star. However, a low metallicity does not mean that a star neccessarily belongs to the halo.

For an overview of literature data on values for Θ (or asymmetric drift) for various star groups we refer to Fig. 3 in the review of Gilmore et al. (1989).

6.2. Discussion

Since the sdB stars (and possibly the HBB stars) have disk-like orbits, these stars must be part of a relatively younger, more metal rich group among the HB stars. Majewski (1993) uses the expression ‘intermediate Population II’, other authors use the words ‘thick’ or ‘extended disk’. In addition to the disk-nature of their orbits, the vertical distribution is consistent with a scale height of the order of 1 kpc (Villeneuve et al. 1995, de Boer et al. 1997a). Since the amount of metals in their atmospheres may have been altered by diffusion it is not possible to estimate the true age from the metallicity.

The HBA stars have really halo orbits. This must mean they belong to a very old population. Their atmospheric metal content is low indeed, the determinations showing a large scatter per star and from star to star ranging between -1 and -2 dex. However, metal rich HBA stars which are known to exist in star clusters (see Peterson & Green 1998), would likely be underrepresented in the sample.

If the halo contains mostly old stars, like globular cluster stars, then the resulting halo HB stars should occupy the HB in ranges related with metallicity as with the globular clusters (see Renzini 1983). The very metal poor ones ($[M/H] \simeq -2$ dex) would be HB stars of HBB and HBA nature as well as RR Lyrae, the ones of intermediate metallicity ($[M/H] \simeq -1.5$ dex) would be very blue down to sdB like, and the metal rich ones ($[M/H] \simeq -1$ dex) would be RHB stars, perhaps including some RR Lyrae. This behaviour may also explain the existence of the two Oosterhof groups (see van Albada & Baker 1973 or Lee et al. 1990) of RR Lyrae, since only the very metal poor and the relatively metal rich globular clusters contain RR Lyrae. Evolutionary changes of the HB stars may also affect the location on the HB (Sweigart 1987, Clement & Shelton 1999).

However, sdB stars with halo kinematics have not been found (de Boer et al. 1997a). Instead, they have only disk orbits. This must mean that the stars which originally formed in the halo had an initial mass, a metallicity and a red giant mass loss such that RR Lyrae and HBA stars were the end product, and not sdB stars.

As for the RR Lyrae stars, they show a wide range in kinematic behaviour, more or less in line with the atmospheric metal content. The actual metallicity did not bias the identification of these stars, since they are selected based on variability. One tends to divide the RR Lyrae sample into metal poor and metal rich RR Lyrae (see Layden 1994). Here we recall that in the HB stars the contents of heavier elements in their atmospheres may be altered (see Sect. 1). The RR Lyrae stars with the continuous upheaval of the pulsation may stimulate mixing so that their atmospheres probably show the true metallicity. Thus, for RR Lyraes the metallicity may be used as a general population tracer. The observed range of metallicities would mean that there are old as well as younger RR Lyraes.

Old RR Lyrae must be very metal poor and should have halo orbits. The majority of the RR Lyrae included in our analysis fit these parameters. There are, however, a substantial number of RR Lyr stars in our sample with disk-like kinematics but low metallicities, in several cases as low as -2 dex. The origin of this group of stars, dubbed the 'metal weak thick disk', is still unknown (see Martin & Morrison 1998 for a discussion).

Young (or younger) RR Lyrae should be relatively metal rich and have disk orbits. The investigated sample contains such stars. These objects should have an age, main-sequence mass, metallicity and RGB mass loss such that RR Lyrae emerge, i.e. HB stars with a thicker hydrogen shell. They are, being relatively metal rich, also of slightly different M_V than the metal poor and old ones. In fact, they are fainter and their distances should be based on the appropriate brightness-metallicity relation. The dependence is, however, feeble and amounts to just 0.1 mag for 0.5 dex. We tested how serious ignoring this effect is on the derived orbits by reducing the RR Lyr star distances by 10%. It does not lead to a change of significance in the histogram of Fig. 4.

6.3. Summary

Our orbit studies allow to see a trend in the kinematics of the field HB stars along the horizontal branch. This appears to give us access to the structure of the Milky Way and its halo as well as information about possible formation scenarios. The trends related with age and history could only be found using the kinematics, since it has become clear that the atmospheric metallicity in HB-like stars has no relation to the one of the main sequence progenitor. The location of the stars on the HB must be a complicated function of age, main-sequence mass, initial metallicity, and mass loss on the RGB. For the HB-like stars of today indications for the age can be determined from the present kinematic parameters. Only detailed models for metallicity dependent stellar evolution from main sequence through the RG phase with mass loss should, in comparison with the observables of horizontal branch stars, eventually be able to retrieve the true origin of the HB stars.

Acknowledgements. We thank Oliver Cordes for supplying the values of $\log g$ and $T_{\rm eff}$ for two stars. We are very grateful to Michael Odenkirchen who supplied us the orbit calculating software. Furthermore we thank Michael Geffert for enlightening discussions, Wilhelm Seggewiss and Jörg Sanner for carefully and critically reading the manuscript. This research project was supported in part by the Deutsche Forschungs Gemeinschaft (DFG) under grant Bo 779/21. For our research we made with pleasure use of the SIMBAD in Strasbourg.

References

Abt H.A., Morell N.I., 1995, ApJS 99, 135
Allen C., Santillan A., 1991, Rev. Mex. Astron. Astrofis. 22, 255
Bahcall J.N., Soneira R.M., 1984, ApJS 55, 67
Barbier-Brossat M., 1989, A&AS 80, 67
Barnes III T.G., Hawley S.L., 1986, ApJ 307, L9
Behr B.B., Cohen J.G., McCarthy J.K., Djorgovski S.G., 1999, ApJ 517, L135
Bonifacio P., Castelli F., Hack M., 1995, A&AS 110, 441
Bookmeyer B.B., Fitch W.S., Lee T.A., Wisniewski W.Z., Johnson H.L., 1977, Rev. Mex. Astron. Astrofis. 2, 235
Burstein D., Heiles C., 1982, AJ 87, 1165
Carney B.W., Laird J.B., Latham D.W., Aguilar L.A., 1996, AJ 112, 668
Chen B., 1999, A&A 344, 494
Clement C.M., Shelton I., 1999, ApJ 515, L85
Colin J., de Boer K.S., Dauphole B., et al., 1994, A&A 287, 38
Corbally C.J., Gray R.O., 1996, AJ 112, 2286
Dauphole B., Geffert M., Colin J., et al., 1996, A&A 313, 119
de Boer K.S., 1999, In: Egret D., Heck A. (eds.) Harmonizing the cosmic distance scale in a post Hipparcos era. ASP Conf. Ser. 167, 129
de Boer K.S., Aguilar-Sánchez Y., Altmann M., et al., 1997a, A&A 327, 577
de Boer K.S., Tucholke H.-J., Schmidt J.H.K., 1997b, A&A 317, L23
de Boer K.S., Drilling J., Jeffery C.S., Sion E.M., 1997c, In: Philip A.G.D., Liebert J.W., Saffer R.A. (eds.) Third Conf. on Faint Blue Stars. Davis Press, Schenectady, p. 513
ESA, 1997, The Tycho and Hipparcos catalogues. ESA SP-1200
Evans D.S., 1967, In: Batten A.H., Heard J.F. (eds.) IAU Symp. 30, Determination of Radial Velocities and their Applications. Reidel, Dordrecht, p. 57
Fitch W.S., Wisniewski W.Z., Johnson H.L., 1966, Comm. Lunar Plan. Lab. 5, 71
Geffert M., 1998, A&A 340, 305
Gilmore G., Wyse R.F.G., Kuijken K., 1989, ARA&A 27, 555
Graham J.A., Slettebak A., 1973, AJ 78, 295
Gratton R.G., 1998, MNRAS 296, 739
Gray R.O., Corbally C.J., Philip A.G.D, 1996, AJ 112, 2291
Green R.F., Schmidt M., Liebert J.W., 1986, ApJS 61, 305
Groenewegen M.A.T., Salaris M., 1999, A&A 348, L33
Grundahl F., Catelan M., Landsman W.B., Stetson P.B., 1999, ApJ, submitted
Hagen H.-J., Groote D., Engels D., Reimers D., 1995, A&AS 111, 195
Heber U., 1986, A&A 155, 33
Huenemoerder D.P., de Boer K.S., Code A.D., 1984, AJ 89, 851
Kilkenny D., Heber U., Drilling J.S., 1987, IAU Coll. 95, In: Philip A.G.D., Hayes D.S., Liebert J.W. (eds.) The Second Conference on Faint Blue Stars. Davis Press, Schenectady, p. 731
Kinman T.D., 1995, In: van der Kruit P.C., Gilmore G. (eds.) IAU Symp 164, Stellar Populations. Kluwer, Dordrecht, p. 75
Kinman T.D., Suntzeff N.B., Kraft R.P., 1994, AJ 108, 1722
Kinman T.D., Pier J.R., Suntzeff N.B., et al., 1996, AJ 111, 1164
Layden A.C., 1994, AJ 108,1016
Layden A.C., Hanson R.B., Hawley S.L., Klemola A.R., Hanley C.J., 1996, AJ 112, 2110
Lee Y.-W., Demarque P., Zinn R., 1990, ApJ 350, 155
Lutz T., Kelker D.H., 1973, PASP 85, 573
Majewski S.R., 1993, ARA&A 31, 575
Martin J.C., Morrison H.L., 1998, AJ 116, 1724
Martinet L., 1970, A&A 4, 331
Moehler S., Heber U., de Boer K.S., 1990, A&A 239, 265
Moehler S., Heber U., Durell P.R., 1997, A&A 317, L83
Moehler S., Sweigart A.V., Landsman W.B., Heber U., Catelan M., 1999, A&A 346, L1
Odenkirchen M., 1991, Diploma Thesis, Universität Bonn
Odenkirchen M., Brosche P., 1992, Astron. Nachr. 313, 69
Peterson R.C., Green E.M., 1998, ApJ 502, L43
Philip A.G.D., 1969, ApJ 158, L113

Philip A.G.D., 1987, In: Philip A.G.D., Hayes D.S., Liebert J.W. (eds.) IAU Coll. 95, The Second Conference on Faint Blue Stars. Davis Press, Schenectady, p. 67
Philip A.G.D., Hayes D.S., Adelman S.J., 1990, PASP 102, 649
Popowski P., Gould A., 1999, In: Heck A., Caputo F. (eds.) Post-Hipparcos Cosmic Candles. Kluwer, Dordrecht, p. 53
Preston G.W., 1959, ApJ 130, 507
Renzini A., 1983, Mem. Soc. Astron. Ital. 54, 335
Rydgren A., 1971, PASP 83, 656
Saffer R.A., Bergeron P., Koester D., Liebert J., 1994, ApJ 432, 351
Schlegel D.J., Finkbeiner D.P., Davis M., 1998, ApJ 500, 525
Schmidt J.H.K., 1996, Ph.D. Thesis, Universität Bonn
Scholz R.D., Odenkirchen M., Hirte S., et al., 1996, MNRAS 278, 251
Schuster W.J., Allen C., 1997, A&A 319, 796
Stetson P.B., 1991, AJ 102, 589
Sweigart A.V., 1987, ApJS 65, 95
Theissen A., Moehler S., Heber U., de Boer K.S., 1993, A&A 273, 524
Turon C., Crézé M., Egret D., et al., 1987, Hipparcos Input Catalogue. ESA SP-1136
van Albada T.S., Baker N.H., 1973, ApJ 185, 477
Villeneuve B., Wesemael F., Fontaine G., Carigan C., Green R.F., 1995, ApJ 446, 646
Waelkens C., Aerts C., Kestens E., Grenon M., Eyer L., 1998, A&A 330, 215
Wilson R., 1953, General Catalogue of Radial Velocities. Carnegie Institution of Washington, Washington D.C.