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The population membership of sdB stars: a kinematic analysis

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Abstract. We analysed the kinematics of a sample of 110 sdB stars, presenting new data for about 2/3 of the sample. The vast majority of the stars shows a kinematic behaviour similar to that of thick disk stars. About 15 objects have orbital velocities differing substantially from those of the rest. Some have solar (i.e. thin disk) velocities. The dispersion of the orbital velocities of the full sample is somewhat larger than expected for a thick disk alone. Therefore the sdB stars belong to both the thin and thick disk, as well as to a halo component. In addition to a study of the kinematics, we calculated the orbits using a galactic potential model. While most stars have disk type orbits, a few venture far above the galactic plane. Most orbits have eccentricities of less than 0.5, a few of more than 0.7, with the region in between somewhat underpopulated. This indicates that the (thick) disk and the halo are kinematically disjunct. The statistics of the z-distance at given time intervals in the orbits of the stars leads to the z-probability distribution of the sample. For the disk component we so find a scale height of $\sim$ 1 kpc, which is consistent with the result of an earlier study and also similar to other results for the scale height of the thick disk. The other component has a much larger scale height. Evidently, most sdB stars of our sample belong to the disk, but a halo minority exists. Therefore in general, the kinematic history of the sdBs is different from that of the cooler HBA stars, which are mainly or even exclusively halo objects.

Key words: astrometry – stars: kinematics – stars: horizontal branch – stars: Population II – Galaxy: halo – Galaxy: structure

1. Introduction

Studies of the structure, kinematics and populations of our Galaxy are essential for the understanding of structure and evolution of galaxies in general. Especially the older stars conserve valuable information about the early stages of our Galaxy.

There are several ways to gain access to information about galactic structure. One possibility is to analyse their distribution perpendicular to or along the galactic plane. This is mainly done using star counts, either counting all stars in a certain field and studying the distribution using stellar population models etc. (see e.g. Reid & Majewski 1993), or by deriving the distribution of a certain easy to classify type of star, such as Red Giants, White Dwarfs or Horizontal Branch stars (especially RR-Lyraes). The advantage of the latter method is, that its depends less on models, thus eliminating an important source of uncertainty.

Another possibility is to study the kinematic behaviour of stars. Here we perform such a study using sdB stars. We analyse their velocities and orbits (Sect. 3) and the orbits to derive a scale height (de Boer et al. 1997). sdB stars are relatively bright (when compared to other old stars) and because of their blue colour and their relatively unique spectra they are easily identified. This makes them very good tracers of older populations. One problem is present for studies of the kinematics: many sdBs are close binaries, which means that some objects have variable radial velocities with quite large amplitudes. Most earlier studies dealing with sdB stars and their population membership, come to the result that they are entirely members of the (Thick) Disk; see e.g. de Boer et al. (1997), Villeneuve et al. (1995). One aim of this study is to find a possible halo component.

A positive identification of such a halo component might also help in finding answers for another important question, namely how are sdB stars formed? Obviously, their progenitors must have lost a large amount of mass, to end as a star consisting only of a 0.5 $M_\odot$ Helium burning core with an extremely thin H-shell. The process leading to such a mass loss is still not understood, in spite of theories trying to explain this phenomenon. Knowing whether sdB stars are a part of all of the local populations or not, can give evidence for the role that parameters such as age (and hence initial mass) and metallicity play.

Before starting the discussion we must first define the populations in our context. The *(old) Thin Disk* is considered to have a scale height of about 300 pc and a mean orbital velocity (Θ) of 210 km s^{-1}, and moderate velocity dispersions

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(~30 km s^{-1}). The *Thick Disk* (also called intermediate population II (IPII)) rotates slower ($\bar{\Theta} \simeq 175\,\mathrm{km\,s^{-1}}$), has larger dispersions of about 50 km s^{-1} and a scale height of about 1 kpc. The third component, the *Halo*, hardly rotates at all ($\bar{\Theta} \simeq 20\,\mathrm{km\,s^{-1}}$), has large velocity dispersions of more than 100 km s^{-1} and a very flat z-distribution. The fourth component, the *bulge* does not reach to the local regime and is thus not discussed further.

2. The Data

2.1. Composition of the sample

The sample is composed of 110 sdB stars coming from different sources. For 57 stars taken from the Hamburg-ESO-Survey (HE) new imaging and spectroscopic data have been obtained. The data of 41 stars have been taken from de Boer et al. (1997) which mostly belong to the Palomar-Green-Survey (PG, Green et al. 1986), further nearby stars with Hipparcos data have been included in the sample. Distances and radial velocities for the latter are partially new, partially published in Altmann & de Boer (2000) and references therein. One star's kinematics has been analysed by Geffert (1998).

As the sample consists of all sdB stars for which we have the complete data, we do not expect any selection effects due to object selection, apart from the point that the sources of our objects do not cover low galactic latitudes. For this reason stars at small distances from the galactic plane are underrepresented. These are most likely those which have Thin Disk kinematics.

2.2. Data and data reduction

The new data for the HE-stars were all obtained at the ESO LA Silla observatory, mainly using the 1.54m Danish telescopes and its DFOSC focal reducer and the 1.52m ESO telescope equipped with the FEROS and B&C spectrographs. The imaging data were used for photometry and to determine proper motions. For the first epoch data DSS scans were used, the epoch difference being between 18 and 28 years. The photometry has been corrected for interstellar extinction using the maps of Schlegel et al. (1998). In a few cases, for which the data were observed in non photometrical conditions, we took the values from literature or adapted the B-magnitudes of the HE-survey to V-band by adding 0.28 magnitudes[1]. The spectroscopy was reduced using standard methods. From the spectra, the physical parameters, such as $\log g$ and T_{eff}, and the radial velocities were derived.

Using $\log g$ and T_{eff} and the V magnitudes we calculated distances of our stars assuming the canonical mass for a sdB star of 0.5 $M_{\odot}$ (Saffer et al. 1994a). From these quantities and model atmospheric fluxes, radii and angular diameters of the stars were derived. From radii and angular diameters, the distances for our stars from the earth follow immediately. The reddening of all observed sdB stars is negligible ($E(B-V) < 0.03$).

The error for the distance is ~20%, that of the radial velocities are in the order of 30 km s^{-1}. As many sdB stars are close binaries, some of them may have variable radial velocities. For a few objects the amplitudes could be larger than our measuring error. The error of the proper motions can only be estimated, because we only have one set of first epoch data. We assume it to be in the order of 5-6 mas/yr.

3. Kinematics and orbits

The observational quantities are then transformed into the $XYZ, UVW, \Phi\Theta$ system and orbits calculated using the galactic gravitational potential model of Allen & Santillan (1991) (for details, see Altmann & de Boer (2000) or de Boer et al. (1997)). From the orbit morphologies the eccentricities, given by

$$ecc = \frac{R_{\mathrm{a}} - R_{\mathrm{p}}}{R_{\mathrm{a}} + R_{\mathrm{p}}} \tag{1}$$

and the normalized z-extent, given by

$$nze = \frac{z_{\max}}{\varpi(z_{\max})}, \tag{2}$$

which accounts for the gravitational potential diminishing at larger galactocentric distances (ϖ), have been derived.

The distribution of orbital velocities (Θ) of our sample is shown in Fig. 1. Most of the values cluster around 200 km s^{-1}, which is typical for disk stars. There are, however, a few data points far from this main distribution. For the whole sample the mean Θ is 199 km s^{-1} and its dispersion is 75 km s^{-1}. If one removes all stars with eccentricities larger than 0.6 (excluding more or less the outliers of Fig. 1), the values are 201 km s^{-1} and 52 km s^{-1}. The dispersion is rather similar to those of other studies (e.g. Ojha et al. 1994) for the Thick Disk; the mean value of Θ, which is a little higher than expected for the Thick Disk, may be caused by some of the stars belonging to the Thin Disk. Excluding those stars being currently located less than 0.9 kpc from the galactic disk (thus minimizing any Thin Disk "contamination") leads to a much lower $\bar{\Theta}$ of 178 km s^{-1}. The other velocity components are also similar to Thick Disk values.

Most of the orbits are box type orbits with small to moderate vertical extent (Some exemplary orbits are shown in Fig. 2). The nze and ecc values are also in general quite moderate. Some stars have near solar orbits, a few have high eccentricities and also large values for nze. The distribution of ecc shown in the left panel of Fig. 3 shows a broad peak at values below $\sim$ 0.5 and indication of another group at higher values giving the impression of a somewhat bimodal distribution. The distribution of nze on the other hand has a sharp peak at low values which has a wing at moderate values and a few data points over a large range. The distributions in ecc and nze lead us to conclude that our sample consists of two groups, which was also seen in the analysis of the velocities. One, the Disk or Thick Disk population rotates with moderate velocity dispersions on orbits with rather low eccentricies and stays relatively close to the galactic plane. This group

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[1] which is a good value for $B - V$ of a single sdB star.

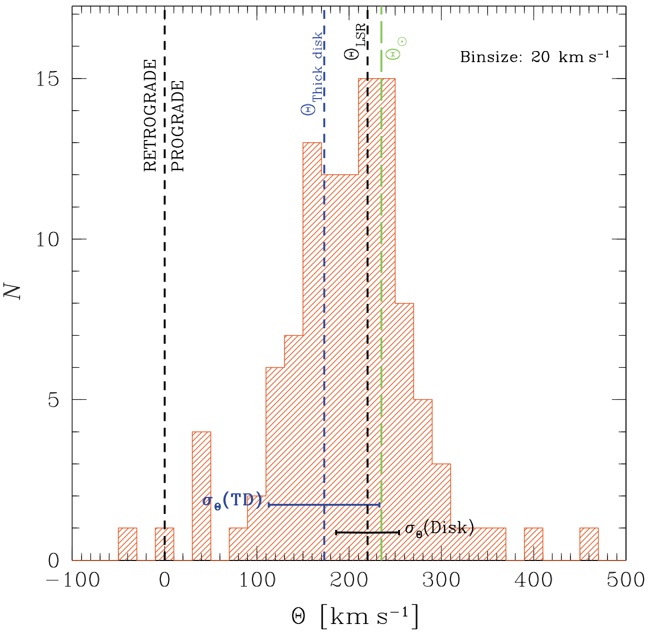

Fig. 1. Histogram of the orbital velocities for all 110 stars of the sample. The values for $\Theta_{\rm Thick\ disk}$ and $\sigma_\Theta({\rm TD, Disk})$ have been taken from Ojha et al. (1994).

comprises about 85 - 90% of our sample. The second contains stars which have far hotter kinematics and high eccentricities, some stars venturing very close to the galactic centre, other very far out. Their orbital velocities deviate much from the Θ of disk stars. Presumably these stars belong to the galactic halo. As there are stars having a far larger Θ than the *local standard of rest* (LSR) and others which orbit much slower - some even retrograde - they seem to form two subgroups, a high- and a low velocity Halo. However, looking at the range in Θ during the whole orbit there is actually no significant difference between these two groups. They represent actually different phases of similar orbits, with the high velocity objects being near their perigalacticon, and the low velocity stars near their apogalacticon. Although there might possibly be a different origin for the two subgroups this does not become clear from their kinematic behaviour.

4. Determining a scale height of the stars using their orbits

Calculating the orbits using fixed time steps, one can derive the probability distribution versus e.g. the distance z from the plane[2]. Doing this for the orbits of all stars, leads to the z-probability distribution of the whole sample. If one now fits an exponential to the distribution one may derive the scale height(s). This method was first used to derive scale heights of sdB stars in de Boer et al. (1997) and is described there in detail.

The z-distribution of our sample as shown in Fig. 4 can be used to find the scale height of the sdB population. A first inspection shows that there are probably two groups, one having a scale height of $\sim$ 1 kpc and a second one extending further out.

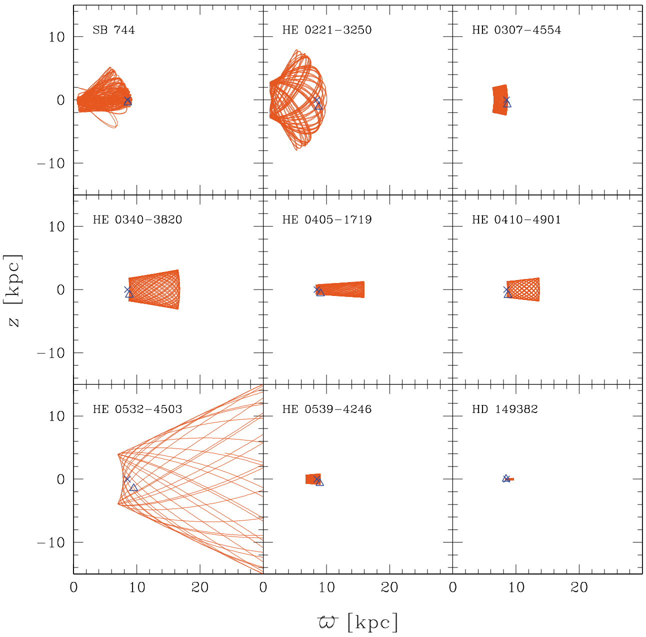

Fig. 2. Examples of the orbits of the sdB stars. The orbits are depicted as meridional plots and calculated over a timespan of 10 Gyr. Please note that the most common types of orbits, the disk orbits, are grossly underrepresented in this figure. The cross denotes the current position of the Sun and the triangle the current position of the star

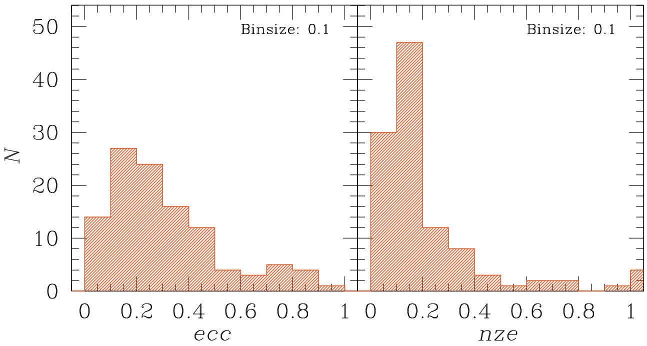

Fig. 3. Histograms showing the distributions of *ecc* (left panel) and nze (right panel) for the stars of the sample. Note the peaks at low values in in *ecc* and nze and the local minimum in the distribution of the eccentricities near *ecc*=0.6

The density ratio in the disk (N_0) at $z = 0$ kpc of the two components is about 2%. This is similar to the results of other studies analysing contributions by Thick Disk and Halo stars to the stellar population at the galactic plane, however significant scatter can be found for both quantities in literature. There is some degeneracy between scale height and density ratio, with larger z_0 corresponding with smaller N_0. The values of z_0 for the Thick Disk range between 0.6 kpc (Chen et al. 2001) and 1.4 kpc (Reid & Majewski 1993, CADIS), most of them clustering around 0.8 - 1.0 kpc.

Clearly, our sample contains sdB stars of the Thick Disk population and of the Halo population. Our results of the

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[2] z is the (positive) distance between the galactic plane and an object, while Z means the Z-coordinate in the XYZ, UVW system.

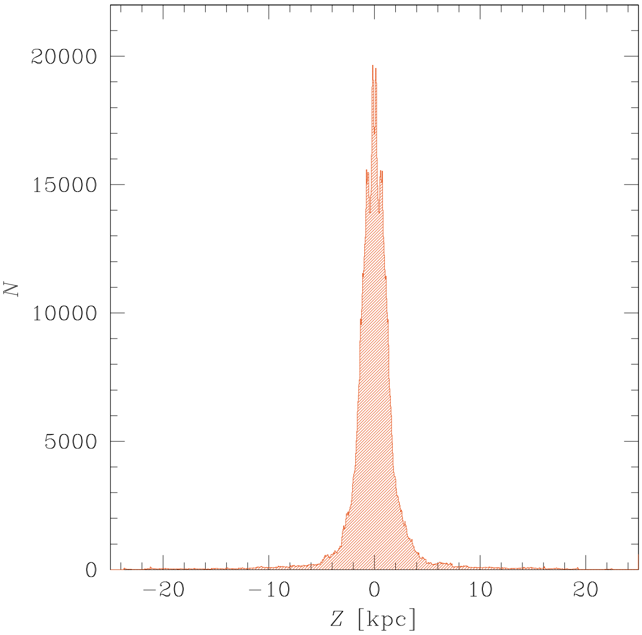

Fig. 4. Histogram of the z distance-statistics of all the stars of the sample. An exponential distribution can be fitted leading to a scale height (see text). The binsize is 50 pc

analysis of the kinematics and the orbital morphologies (see Sect. 2) are also confirmed in the analysis of the probability distribution of the sample perpendicular to the galactic plane. 15 stars are found to belong to the Halo, which is somewhat more than 10% of our sample.

5. Discussion and conclusions

As shown in Sections 3 and 4, the sdB stars forming our sample, belong to at least two of the galactical populations, namely the Thick Disk and the Halo. There is some evidence, that some of the Disk sdBs belong to the Thin rather than the Thick Disk; however we cannot prove this with the current sample.

Our results for the Disk component lie fairly in the middle of the range of other results relying on star counts. Therefore we conclude that our result for the scale height of the Thick Disk of $\sim$ 1 kpc is probably not too far from the true value. To analyse any substructure in the Disk component, especially to find out whether sdB stars also belong to the (old) Thin Disk, a sample of candidates located at low galactic latitudes or only nearby stars must be analysed.

The Halo component has a scale height of several kpc. Now it is hard to imagine an exponential disklike distribution with such a thickness, considering the extent of the Galaxy. Therefore the halo would form an ellipsoidal, possibly spherical distribution, for which an exponential fit is not exactly appropriate.

In earlier work (Altmann & de Boer 2000) we analysed the trend in kinematics along the blue horizontal branch, with all HBA stars being members of the Halo, and the sdB stars members of the Disk. Now we have found a Halo sdB population. This means that the spreading of the sdB stars among the galactic populations is similar to that of other low mass stars which exist in both Disk and Halo. Therefore the evolution of stars into sdBs does probably not depend strongly on parameters like metallicity. One possibility is that sdB stars are the result of close binary evolution, with strong mass transfer from the star which is now the sdB star to its companion. There is strong evidence that a large fraction of the sdB stars are in fact binaries (see e.g. Maxted et al. 2001). These close binaries should exist in all stellar populations, which means that sdB stars should exist in all populations.

Another scenario is extreme mass loss during and prior to departure from the RGB phase, the *peel off* model by D'Cruz et al. (1996). Their HB models show a depletion of the HB in the middle temperature range with increasing metallicities, while the edges, i.e. the RHB and the HBB and sdB stars, are strongly populated at all metallicities. This is actually exactly what we see: No HBA stars in the Disk and sdB stars in both Disk and Halo.

To conclude, both the binary evolution and the peel off model are not in contradiction with our results. The sdB stars are at least distributed among Thick Disk and Halo like stars in general, which means that stars from all of these galactic components equally evolve into sdB stars. Furthermore sdB stars are a valuable tracer for studies of the galactic structure and kinematics. Our results will soon be published in greater detail (Altmann et al., in prep.).

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