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3D–Kinematics of White Dwarfs from the SPY-Project

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Abstract. We present a progress report on the kinematical analysis of the entire SPY (ESO SN Ia Progenitor surveY; see Napiwotzki et al. 2001) sample of about one thousand white dwarfs and hot subdwarfs. In a previous study (Pauli et al. 2003, 2006) 398 DA white dwarfs have been analysed already. Here we extend the study to 634 DA white dwarfs. We discuss kinematic criteria for a distinction of thin disk, thick disk and halo populations. This is the largest homogeneous sample of white dwarfs for which accurate 3D space motions have been determined. They have been derived from radial velocities, spectroscopic distances and proper motions from catalogues. Galactic orbits and further kinematic parameters were computed. Our kinematic criteria for assigning population membership are deduced from a sample of F and G stars taken from the literature for which chemical criteria can be used to distinguish between thin disk, thick disk and halo members. The kinematic population classification scheme is based on the position in the VU-velocity diagram, the position in the eccentricity-J_Z diagram and the Galactic orbit. We combine this with age estimates and find 12 halo and 37 thick disk members amongst our DA white dwarfs. We were unable to determine the population membership of only nine of them. The remaining members of the sample of 632 stars belong to the thin disk population.

Motivation

White dwarfs are the evolutionary end-products of most stars. Therefore, a large number of white dwarfs should be present in the Galaxy. Determining the contribution of white dwarfs to the total mass of the Galaxy could help to solve one of the fundamental questions in modern astronomy: what is the nature of dark matter? The fact that the rotation curves of many galaxies are not Keplerian (Rubin, Thonnard, & Ford 1978) invokes the existence of additional dark matter distributed heavy-halo. It is estimated that for the Milky Way only 10% of the total mass are present in the form of stars, gas and dust in the Galactic disk and halo (Alcock 2000). The role of white dwarfs in the dark matter problem is still uncertain. An open issue is the fraction of white dwarfs in the thick-disk and halo populations, as well as their fraction of the total mass of the Galaxy. In this context, kinematic studies have proved a useful tool in deciding on population membership of white dwarfs. The common problem of kinematic studies of white dwarfs is the lack of radial velocity measurements. Especially deviating conclusions derived from the white dwarfs of the Oppenheimer et al.

(2001) sample demonstrate that different assumptions on the values of the radial velocity $v_{\rm rad}$ can produce different fractions of halo and thick disk stars and thus have a strong impact on the determination of the white dwarf halo density (Reid, Sahu, & Hawley 2001). Therefore a sample of white dwarfs with known radial velocity measurements is needed in order to obtain the full 3D kinematic information. Pauli et al. (2006) presented a complete 3D kinematical study of 398 DA white dwarfs. Here we present a progress report on the analysis of the entire SPY sample of more than one thousand white dwarfs and hot subdwarfs. We present the results of a kinematic analysis of another 237 DA white dwarfs.

3D Kinematics and Population Classification

The ESO Supernova Ia Progenitor surveY (SPY, see Napiwotzki et al. 2003) provided us with high resolution spectra of about 1000 degenerate stars. The sharp absorption core of the hydrogen lines allowed accurate radial velocities to be measured. Typical errors are not greater than $\pm$2km/s. We added radial velocity variable stars, for which the radial velocity curves had been solved and the systemic velocity had been derived (Napiwotzki et al. 2002; Karl et al. 2004; Morales-Rueda et al. 2005). We also included resolved wide binaries with no measured radial velocity variability in two or more spectra ($\Delta v_R < 2$km/s). A spectroscopic analysis, done by Voss & Koester (private communications), yielded atmospheric parameters, which were used to derive masses and gravitational redshifts. Proper motions were extracted from catalogues through the VizieR Service (e.g. USNO–B, UCAC2, etc.). We calculate individual errors of kinematic parameters by means of Monte Carlo error propagation.

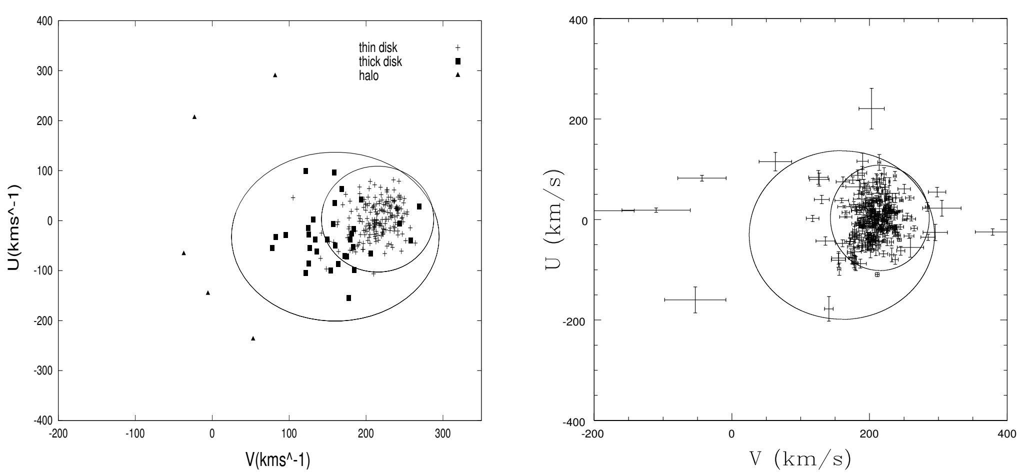

Figure 1. U-V-velocity diagram for the main-sequence calibrators of Pauli et al.(2006, left) and of this paper (right); ellipses: $3\sigma_{\rm thin}$-, $3\sigma_{\rm thick}$-contours.

Pauli et al. (2003, 2006) presented a new population classification scheme based on the VU-velocity diagram (U and V being the velocity components in the Galactic plane), the eccentricity–angular momentum ($e - J_Z$) diagram and the Galactic orbit. For the computation of orbits and kinematic parameters we used the code by Odenkirchen & Brosche (1992) based on the Galactic potential of Allen & Santillán (1991).

Unlike for main-sequence stars the population membership of white dwarfs can not be determined from spectroscopically measured metallicities. Therefore we have to rely on kinematic criteria, which have to be calibrated using a suitable calibration sample of main-sequence stars. In our case this sample consists of 291 F and G main-sequence stars from Edvardsson et al. (1993) and Fuhrmann (2004 and references cited therein).

Halo and thick disk stars can be separated by means of their [Fe/H] abundances, they possess a higher [Mg/Fe] ratio than thin disk stars (see Pauli et al. 2003, 2006 for details). In Figure 1 (left panel) U is plotted versus V for the main-sequence stars. For the thin disk and the thick disk stars the mean values and standard deviations (3σ) of the two velocity components have been calculated. The values for the thin disk are: $\langle U_{\rm ms}\rangle = 3 \pm 35$ km/s^{-1}, $\langle V_{\rm ms}\rangle = 215 \pm 24$ km/s^{-1}, The corresponding values for the thick disk are: $\langle U_{\rm ms}\rangle = -32 \pm 56$ km/s^{-1}, $\langle V_{\rm ms}\rangle = 160 \pm 45$ km/s^{-1}, The values for the standard deviations are: $\sigma_{U_{\rm ms}} = 35$ km/s^{-1}, $\sigma_{V_{\rm ms}} = 24$ km/s^{-1}. The corresponding values for the thick disk are: $\sigma_{U_{\rm ms}} = 56$ km/s^{-1} and $\sigma_{V_{\rm ms}} = 45$ km/s^{-1}. Indeed, nearly all thin disk stars stay inside the $3\sigma_{\rm thin}$-limit and all halo stars lie outside the $3\sigma_{\rm thick}$-limit, as can be seen from Figure 1.

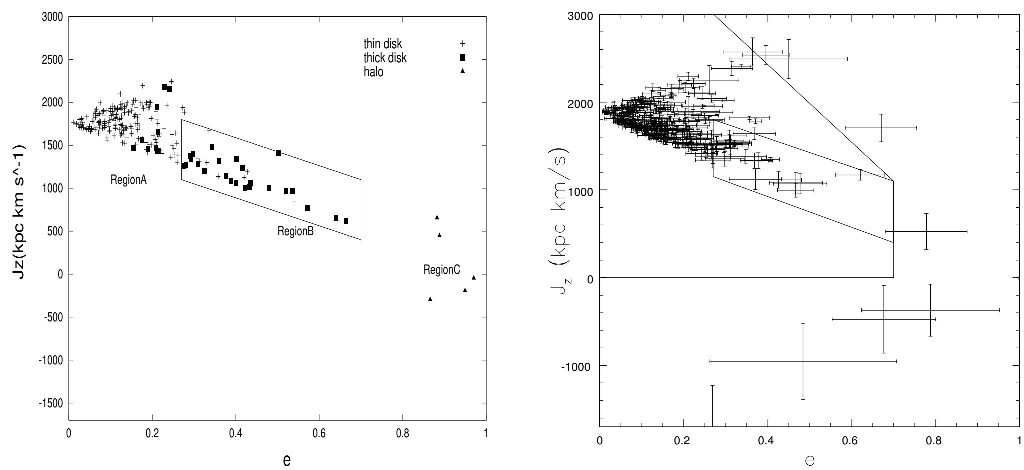

Figure 2. $e - J_{\rm z}$-diagram for the main-sequence calibrators of Pauli et al. (2006, left), Region A refers to the thin disk area, Region B to the thick disk and Region C to the halo area on the graph; the new data of this paper (right) shows also stars above Region B of the calibration sample, which belong either to the thick disk (to the left of the line) or to the halo (to the right of the line). We also found white dwarfs with retrograde orbits (below the horizontal line).

In the $e - J_Z$-diagram three regions (A, B or C) can be defined (see Figure 2, left panel) which host thin disk, thick disk and halo stars, respectively. The Galactic orbits of thin disk, thick disk stars and halo stars differ in a characteristic way allowing another classification criterion to be defined (see Figure 3).

When plotted in a $\rho - Z$ diagram ($\rho = \sqrt{(X^2 + Y^2)}$ with X, Y, Z being the rectangular Galactic coordinates), the populations can be distinguished by their orbits' shape. Thin disk stars reach only small altitudes above the galactic plane ($<$ 600pc, Figure 3, left hand panel). Thick disk stars can climb up to 2.5kpc (Figure 3, middle panel) and finally halo stars reach even higher altitudes above the plane or have a highly chaotic orbit (Figure 3, right hand panel).

Halo candidates are all white dwarfs that are either situated outside the 3σ-limit of the thick disk in the VU-velocity diagram or that lie in Region C in the $e - J_Z$ diagram and have halo type orbits. For the DA white dwarfs the VU-velocity diagram and the $e - J_Z$ are shown in the right hand panels of Figures 1 and 2 respectively. In total 12 white dwarfs fulfil the classification criteria for halo stars and are therefore assigned to the halo. Including some white dwarfs on retrograde orbits characterised by a negative value of V and J_Z.

Thick disk white dwarfs lie either outside the 3σ-limit of the thin disk in the VU-velocity diagram or lie in Region B in the $e - J_Z$ diagram and have thick disk type Galactic orbits. Thirty-seven of them are classified as thick disk members. All, but nine, of the remaining are assumed to belong to the thin disk. Those nine white dwarfs could not clearly be classified as a member of a certain population, thus leaving us with 12 halo, 37 thick disk out of the 632 SPY DA white dwarfs.

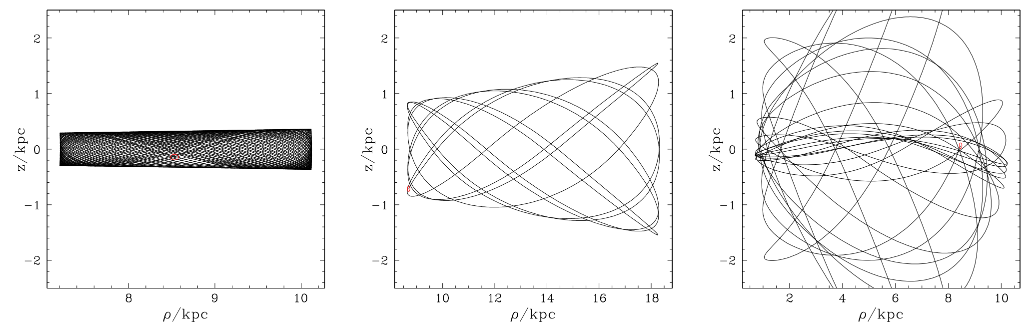

Figure 3. Typical orbits shown in a $\rho - Z$ diagram (with $\rho = \sqrt{(X^2 + Y^2)}$). Plotted are a thin disk (WD0017+061), a thick disk (WD0158-227) and a halo star (WD1314-153) (from left to right; please note the growing scale of the ρ-axis). All orbits were calculated numerically with 500,000 year steps for 2Gyr into the future.

The Age Test

Ages are another criterion for population membership. Halo and thick disk white dwarfs should be old stars. Since the cooling ages of the of most white dwarfs in the SPY sample are small ($< 10^9$yr) they have evolved from long-lived, i.e. low mass stars and hence must themselves be of low mass.

We used the cooling tracks form Wood (1995) and Driebe et al. (1998) (see Figure 4, left hand side) to determine the masses and the cooling times of our white dwarfs and the initial-to-final-mass relation of Weidemann (2000) to get the mass of our progenitor stars.

All but one halo star and 31 of the 39 thick disk white dwarfs have sufficiently low masses and are therefore old. However, our age estimates could be misleading if the stars had evolved through close binary interaction phases or may even result from a merger event. On the other hand the kinematics of a

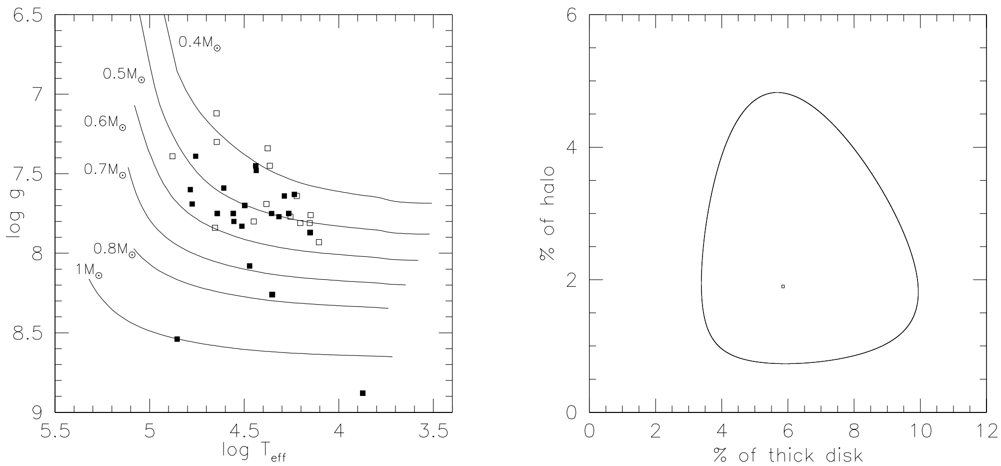

Figure 4. left hand side: cooling sequences (Wood, 1995) and the values of the thick disk (filled squares) and halo (open squares) white dwarfs of this work. And on the right hand side: statistical results, with 3σ-contour.

thick disk or halo white dwarf could be mimicked by a thin disk star ejected from the galactic plane (runaway star). The halo star WD 0239+109 is most likely such a runaway star from the thin disk, as it is only 2.2 Gyr old and is not massive enough ($0.6M_{\odot}$) to be of a merger origin. Only one of the thick disk stars has a high enough mass to be a merger ($1.0M_{\odot}$), two live within a binary system. Hence we issue a birth certificate of the thick disk population only to these 31 white dwarfs. The others could be runaway stars from the thin disk or mergers, as their kinematic classification is quite assured. This leaves us with a fraction of 2.3% halo and 6.2% thick disk white dwarfs. Figure 4 (right hand side) shows our final result within the statistical 3σ-border.

Discussion

The classification scheme developed in Pauli et al. (2003) has been used to kinematically analyse a sample of more than 600 DA white dwarfs from the SPY project. Combining the three kinematic criteria, position in the VU-diagram, position in the $e - J_Z$ diagram and Galactic orbit, with age estimates we have found twelve halo and 37 thick disk members.

When we do the statistics for our local, white dwarf, population memberships we find a 3σ-area as shown in Figure 4 (right hand side). There's still room for 3.5% to 10.5% of the local, hot white dwarfs to to belong to the thick disk. And between 1.0% and 5.3% can belong to the halo population and contributes a big amount to the baryonic dark matter of the milky way.

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