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MOTIONS OF HALO STARS IN THE SOLAR NEIGHBOURHOOD

S. NINKOVIĆ, Z. CVETKOVIĆ and M. STOJANOVIĆ

Astronomical Observatory, Volgina 7, 11060 Belgrade 38, Serbia
E–mail: sninkovic@aob.rs

Abstract. The kinematics of the halo stars from the solar neighbourhood is modelled following a particular Gaussian distribution of their random velocities. Artificial samples are examined containing between 200 and 2000 "stars". Our paper is aimed at establishing fractions of halo stars within given volumes in the velocity subspace centred on the Local Standard of Rest (LSR). Within small volumes in the velocity subspace (within radii of 80 - 120 km s^{-1}) one usually finds not more than 5-10% of all halo stars from the solar neighbourhood. The sphere centred on LSR which contains 50% of all halo stars should have a radius of about 260 km s^{-1}, but this value is strongly affected by the values assumed for the distribution parameters, especially by the difference between the speeds of LSR and halo rotation.

1. INTRODUCTION

It is almost generally accepted that from the point of view of stellar kinematics in the solar neighbourhood there are three main types of stars: those of the thin disc, those of the thick disc and those belonging to the Milky Way halo. Therefore, any kinematical analysis dealing with a sample of stars from the solar neighbourhood is aimed at classifying sample stars as members of either of the two discs or of the halo. More precisely, the procedure is to indicate every sample star as a member of one of the three star groups (the usual term is subsystem, but it is still controversial whether the two discs are separate subsystems of the Milky Way, or they are just components of a single subsystem known as the Milky Way disc). Such a procedure is characterised by the fact that as halo members are identified usually those stars for which, due to their heliocentric velocity, the probability to belong to the disc in general is very low (see e.g. Pauli 2005, Vidojević & Ninković 2009, Cubarsí et al. 2010). As a consequence, halo stars identified in such a way will be the so-called high-velocity stars. From the point of view of stellar dynamics given values of the velocity components at a given position determine the initial conditions which in a given potential results in a galactocentric orbit. Bearing in mind what we know about the motions in the Milky Way disc this would mean to have halo stars in true spatial orbits (see e.g. Vidojević & Ninković 2009) or in orbits close to the galactic plane (even nearly circular), but in the latter case always orbiting the Milky Way centre in the sense opposite to that of the Galactic rotation! So we have a little bit absurd situation that a typical halo star may move around the centre of the Milky Way in

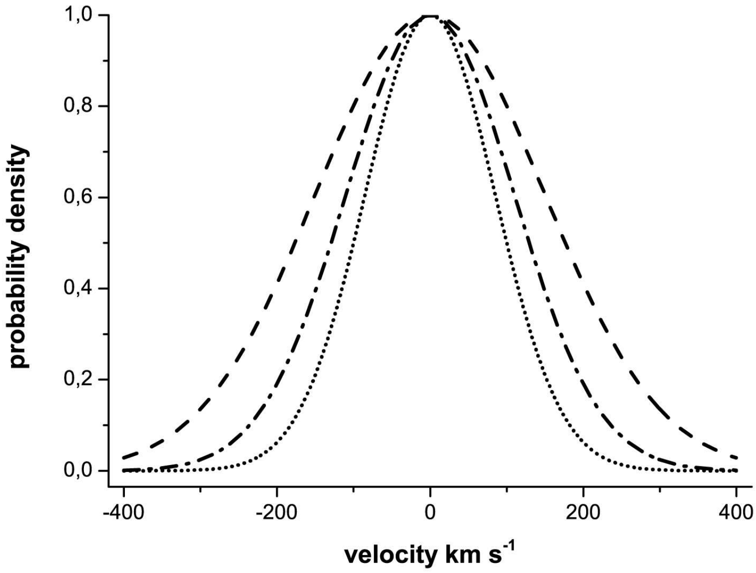

Figure 1: Gaussian distributions in velocity components: dashed curve towards the galactic centre, dashed-dotted curve along the galactic rotation and dotted curve towards the north galactic pole. Dispersions are 150 km s^{-1}, 110 km s^{-1} and 85 km s^{-1}, respectively.

an almost circular orbit, but only in the countersense (with respect to the Milky Way rotation). Therefore, the present authors define as their goal to establish some boundaries in the velocity subspace within which given fractions of the local halo stars can be.

2. METHOD OF ANALYSIS

As the centre of the velocity subspace for the solar neighbourhood we define the Local Standard of Rest (LSR). The local halo kinematics is defined with parameters up to the second order. In general we assume the steady state and axial symmetry so that the centroid motion is rotation. As for the random velocities, a particular Gaussian distribution is assumed (Fig. 1). In this way we have five parameters: the LSR speed, the velocity of halo rotation and the three velocity dispersions along the coordinate axes in the Galactic coordinate system.

The sample we study is artificial. As its optimal size we find 500, but this value is varied within limits 200 and 2000. Since each sample "star" is determined with three random-velocity components, a randomisation becomes necessary. In the computing procedure this is done with three different randomisers. Once the parameter values are specified, it is possible to obtain the motion of every "star" with respect to LSR. In principle, in a kinematical analysis where the subjects are real stars, one uses the heliocentric velocities. The difference between the heliocentric velocity of a star and its velocity with respect to LSR is determined by the velocity with respect to LSR of the Sun, usually referred to as the solar motion. As well known, compared to

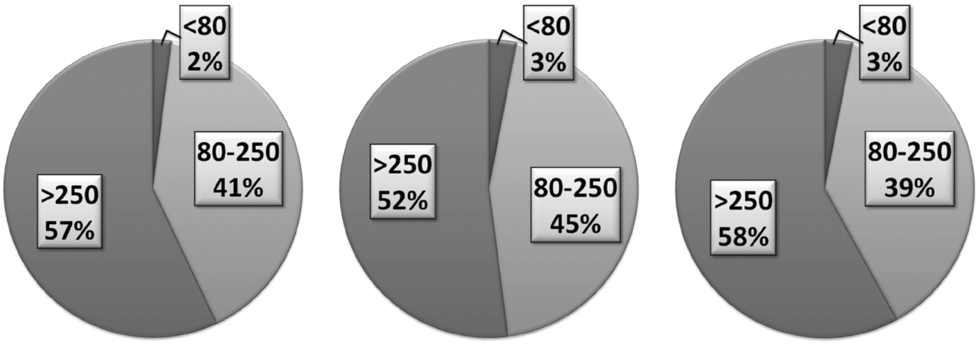

Figure 2: Fractions of stars in the parts of velocity subspace depending on velocity dispersions: 150 km s^{-1}, 110 km s^{-1}, 85 km s^{-1} (left); 140 km s^{-1}, 105 km s^{-1}, 80 km s^{-1} (middle); 170 km s^{-1}, 130 km s^{-1}, 70 km s^{-1} (right). The galactocentric velocity of LSR and halo rotation are always the same - 220 km s^{-1} and 0 km s^{-1}, respectively. The numbers in the figure indicate the boundaries in velocity subspace.

the galactocentric speed of LSR the components of the solar motion have very small values (see e.g. Dehnen & Binney 1998), also the value for one of them, that along the Milky Way rotation, is a matter of some controversy (see e.g. Schönrich et al. 2010). Therefore, in the present paper the velocities with respect to LSR are used; LSR is certainly a better choice than the Sun because it appears as a natural local centre.

Following the well-known IAU recommendation we assume for the LSR speed with respect to the Milky Way centre the value of 220 km s^{-1}. However, bearing in mind the uncertainty we admit this value to be varied by ± 30 km s^{-1}.

As for the local speed of halo rotation we assume, in fact, zero, but this is also varied by ± 30 km s^{-1}. In other words we admit both senses for the halo rotation.

According to the evidence the local halo kinematics is characterised by a triaxial ellipsoid whith the longest axis along $l = 0°$, $b = 0°$ and the shortest one towards $b = 90°$. However, for the particular values of the corresponding velocity dispersions one can find various values (see e.g. Binney & Merrifield 1998 - p. 673, Bensby et al. 2003, Cubarsí et al. 2010). Therefore, we start with the following values: 150 km s^{-1}, 110 km s^{-1} and 85 km s^{-1}. These values are subject to variations with a typical interval of about 15-25 km s^{-1}.

3. RESULTS

To make our results more illustrative we calculate the fractions of stars within given concentric spheres in the velocity subspace centred on LSR. We introduce two radii: that of a basic sphere, the outer radius of an inner shell, to add an outer shell for which the outer radius is infinite.

According to our experience (see e.g. Vidojević & Ninković 2009) wiithin some 80 - 120 km s^{-1} from LSR almost all local thin-disc stars are contained. For this reason these two values are used for the radius of our "basic" sphere. The result is that, practically, for all possible combinations of values for the five parameters we have for

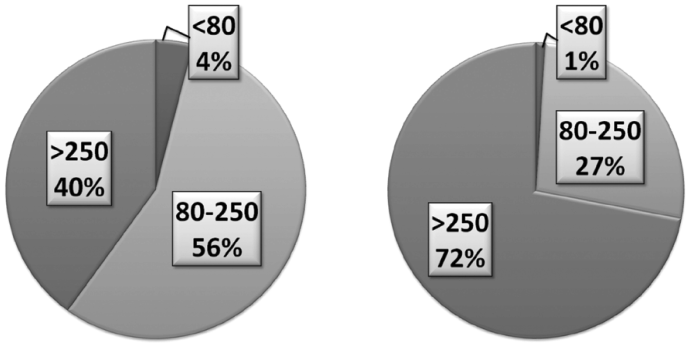

Figure 3: Fractions of stars in the parts of velocity subspace depending on velocities of LSR and halo rotation: 190 km s^{-1} and 30 km s^{-1}, respectively (left); 250 km s^{-1}, -30 km s^{-1}, respectively (right). The velocity dispersions are always the same - 150 km s^{-1}, 110 km s^{-1} and 85 km s^{-1}. The numbers in the figure indicate the boundaries in velocity subspace.

the percentage of halo stars to be $\leq 5\%$ (within 80 km s^{-1}), i.e. $\leq 10\%$ (within 120 km s^{-1}) – Figs. 2 and 3.

The outer radius of the inner shell is assumed to be equal to 250 km s^{-1}. So we determine the fractions of halo stars within 80 km s^{-1}, between 80 km s^{-1} and 250 km s^{-1} and in the outer shell, respectively, but varying the parameter values.

As already said, the percentage within the basic sphere is very low. In other words a vast majority of halo stars is situated beyond 80 km s^{-1} from LSR, but the fractions of the two shells can be significantly different, depending on the values assumed for the parameters. The most influential are the value of LSR speed and that of halo rotation, more precisely their difference is of importance. For instance, our extremal case: LSR speed equal to 190 km s^{-1} and halo rotation of 30 km s^{-1} in the same sense yields about 40% (36-43) of halo stars in the outer shell; on the contrary if LSR speed attains 250 km s^{-1} and the halo is in counterrotation of also 30 km s^{-1} the fraction in the outer shell increases towards 70% (Fig. 3). In the middle case (LSR speed 220 km s^{-1} and zero rotation) the fraction in the outer shell slightly exceeds 50%. On account of this we determine the radius of the sphere containing half halo stars. This is 260 km s^{-1}; within and beyond it the number of halo stars is approximately equal. This result is, clearly, very sensitive to the values of the parameters; by changing them this radius can be pushed inwards or outwards by a few tens of km s^{-1}. Again, the values of the LSR speed and halo rotation have the strongest influence.

4. DISCUSSION AND CONCLUSIONS

First of all, it is found here that within small values for speeds with respect to LSR, such as 80 - 120 km s^{-1} the percentage of halo stars is rather low. Therefore, if the presence of halo stars among such low-velocity stars is ignored, as done usually, the error is not large. However, among stars usually referred to as high-velocity ones (over 100 km s^{-1}) halo stars seem to be almost equally distributed: between 100 and 250 km s^{-1} and over 250 km s^{-1}. The sphere in the velocity subspace centred on LSR containing one half of the halo stars has a radius of about 260 km s^{-1}. All of these values are dependent on those assumed for the parameters, out of which the decisive role belongs to the LSR speed with respect to the centre of the Milky Way and that of halo rotation. More precisely, their difference is of importance. Why the values of the velocity dispersions have a weaker influence can be understood if it is borne in mind that axial ratios in the local halo velocity ellipsoid seem to be rather certain and the values of the dispersions cannot be subject of significant changes because halo stars must exceed significantly in the velocity dispersion in general the two discs; for the thin disc the velocity ellipsoid is rather well known (see e.g. Binney & Merrifield 1998 - p. 656).

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