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# GALACTIC SUBSYSTEMS FROM ARIHIP CATALOGUE

S. VIDOJEVIĆ
*Department of Astronomy, Faculty of Mathematics, University of Belgrade,*
*Studentski trg 16, 11000 Belgrade, Serbia*
*E–mail: sonja@matf.bg.ac.yu*

**Abstract.** A sample containing 4614 stars with available space velocities and qualitative kinematical data from the ARIHIP Catalogue is formed. The components of the solar motion ($U_{\odot}, V_{\odot}, W_{\odot}$) with respect to the dynamical local standard of rest, the elements of the velocity ellipsoid (the intensity and spatial distribution) and the value of the asymmetric drift are obtained in two different ways: according to space velocity and color index. The results agree very well with the values found in the literature. For the purpose of detaching galactic subsystems the cumulative distribution of space velocities is studied. The fractions of stars, belonging to the assumed three subsystems, are found to be: thin disc 92%, thick disc 6% and halo 2%. These results are verified by analyzing the shape and size of the galactocentric orbits of the sample stars, i.e. by analyzing the planar and vertical eccentricities of the orbits.

## 1. INTRODUCTION AND DATA SOURCE

Our Galaxy, the Milky Way, is known to have a composite structure. In other words, it consists of several components or subsystems. Regarding that any study limited to the solar neighbourhood, i. e. to a very small volume surrounding the Sun, cannot take into account the spatial distribution, the emphasis is put to the kinematics because the volume of the velocity subspace is large enough. The intention is to find out a new criterion of separation among the subsystems and, consequently, to establish their fractions in the solar neighbourhood. For the given purpose we use the moduli of the heliocentric velocities, usually referred to as space velocities. The data source used here is astrometrical catalogue named Arihip, constructed by Wielen et al. (2001) from several catalogues: FK6 , GC+HIP, TYC2+HIP and original Hipparcos (HIP) Catalogue (ESA 1997). Among all stars given in Arihip (total of 90,842) there are 73,023 designated as "astrometrically excellent". Line-of-sight velocity is the main limiting factor in selecting the sample because they are available for only 17.5% of Arihip stars. Among these stars there are those suspected to be multiple or variable. For clear reasons both are not taken into account. Finally, in order to have parallaxes as reliable as possible, only stars closer than 200 pc (parallax $\leq$ 5 mas) are taken into account. In this way we obtain a sample containing only 4614 stars, mostly stars belonging to the Main Sequence.

## 2. ANALYSIS OF SPACE VELOCITY AND COLOR INDEX

The kinematics of stars near the Sun has long been known to provide crucial information regarding both the structure and the evolution of the Milky Way. In the early 1950s Parenago (1950) and others pointed out that stellar kinematics is correlated with astrophysical parameters of stars and varies systematically with stellar type. The sense of these variations is that groups of stars that are on average younger have smaller velocity dispersions and larger mean Galactic rotation velocities than older stellar groups. Among the most important astrophysical parameters is certainly the color index. Since in Hipparcos Catalogue (ESA 1997) one finds the apparent magnitudes for two colors visual and blue, it is possible to obtain color index $(B - V)$.

The sample is divided into 8 groups with color index intervals not less than 0.05 magnitudes. In addition, one more group is formed, Parenago's group, with color index greater than 0.61 (Fig. 1). For each group the components of solar motion in the galactic cartesian system are obtained as well as velocity dispersions and vertex deviation (velocity ellipsoid). Projection of the velocity ellipsoids onto $UV$ plain gives a good view to their elements (Fig. 2). Mean solar motion in $U$ and $W$ velocity components with respect to the local standard of rest is calculated by averaging: $U_\odot = 12.1 \pm 0.1$ km s$^{-1}$ and $W_\odot = 7.7 \pm 0.1$ km s$^{-1}$. To obtain the velocity component $V_\odot$ we used the theory which predicts its linear dependance on $S^2 = \sigma_U^2 + \sigma_V^2 + \sigma_W^2$. Linear fitting gives $V_\odot$ with respect to the local standard of rest for hypothetical class of stars for which $S^2$ is equal to zero (Fig. 3). In this way we obtain $V_\odot = 5.7 \pm 0.1$ km s$^{-1}$. It is known, that this theoretical dependance is valid only for galactic disc stars, not for halo stars. For that reason we remove the stars with space velocity greater than 100 km s$^{-1}$ (8.4%) which typically belong to the halo or thick disc. The whole procedure is repeated on reduced sample, by dividing sample stars into new groups, calculating solar motion and velocity ellipsoids for each group and new values of velocity components of solar motion: $(U_\odot, V_\odot, W_\odot) = (9.6 \pm 0.1, 6.8 \pm 0.1, 7.4 \pm 0.1)$ km s$^{-1}$ (result 1).

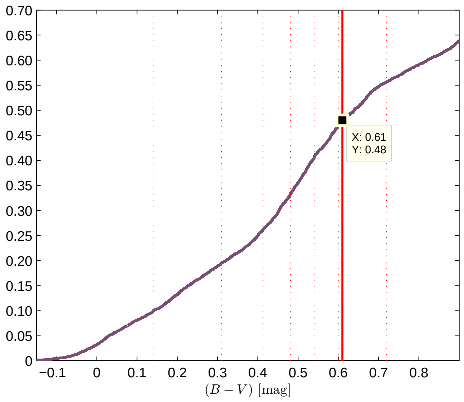

Figure 1: Cumulative distribution of color index. Signed point at $(B - V) = 0.61$ is Parenago's discontinuity.

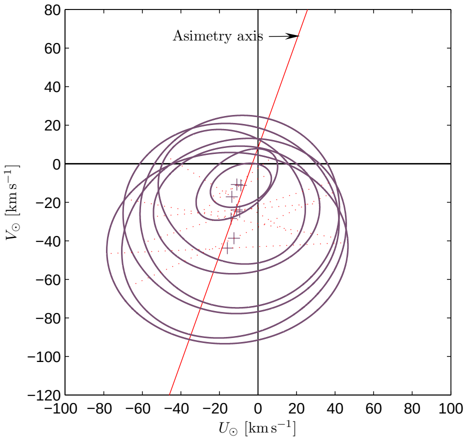

Figure 2: Projections of velocity ellipsoids onto $UV$ plain.

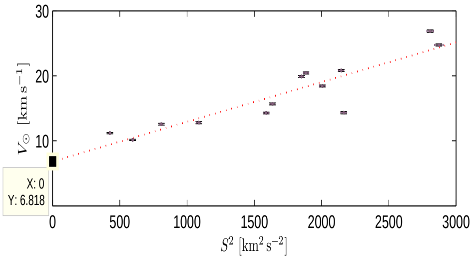

Figure 3: Dependance of velocity component $V_\odot$ on $S^2$ after removing the fastest stars.

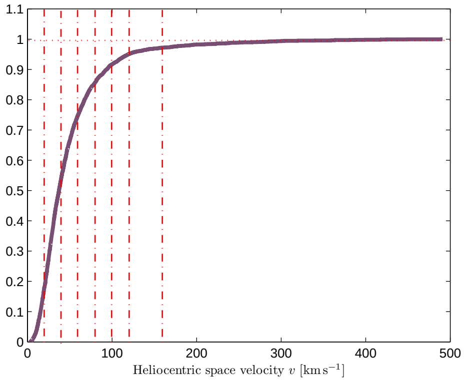

Figure 4: Cumulative fraction number versus heliocentric space velocity.

## 3. CUMULATIVE SPACE VELOCITY DISTRIBUTION

The space velocity cumulative distribution of sample stars is analyzed. The shape of cumulative distribution suggests to divide sample stars into several intervals. The corresponding values are presented in Table 1. The dependence of the cumulative number on the corresponding value of space velocity is presented in Fig. 4. It is easily seen that up to the space velocity of about 80 to 100 km s$^{-1}$ the cumulative number increases rather strongly. At higher velocities this increase is weakened to become practically negligible after 180 km s$^{-1}$. This behaviour of the cumulative number will be thoroughly examined.

The inclination of the curve, being almost equal to 90° at very low velocities, is decreased to less than 10° at the value of 100 km s$^{-1}$ where it has an abrupt change to become very low at higher velocities. The fraction of stars with the heliocentric space velocities less than 100 km s$^{-1}$ is 91.6%. These stars could belong to the thin disc. The lowest value of the curvature radius, i. e. the highest value of the curvature coefficient, occurs at the space velocity of about 180 km s$^{-1}$. At velocity values higher than this one the increment of the cumulative number is very low. Such behavior is expected for stars from the galactic halo. The sample contains 103 (2.2%) stars with space velocity exceeding the value of 180 km s$^{-1}$.

Table 1: Grouping of sample stars according to the space velocity.

| Group | $v$ [km s$^{-1}$] | Cum. $n$ | $n$ |
|---|---|---|---|
| 1 | $0 \leq v < 20$ | 831 | 831 |
| 2 | $0 \leq v < 40$ | 2 504 | 1 673 |
| 3 | $0 \leq v < 60$ | 3 463 | 959 |
| 4 | $0 \leq v < 80$ | 3 935 | 472 |
| 5 | $0 \leq v < 100$ | 4 227 | 292 |
| 6 | $0 \leq v < 120$ | 4 388 | 161 |
| 7 | $0 \leq v < 160$ | 4 485 | 97 |
| 8 | $0 \leq v \leq v_{\mathrm{max}}$ | 4 614 | 129 |

If these two fractions (91.6% and 2.2%) are accepted for the thin disc and halo, then the remaining stars should belong to the thick disc. Their fraction is 6.2%.

The next step is to calculate the mean solar motion, velocity dispersions and vertex deviation (velocity ellipsoid) for each group from Table 1. In the groups containing stars with higher heliocentric velocities, stars belonging to the thick disc and halo will be more numerous than in those containing stars with lower velocities. This fact will be reflected in the values of the velocity dispersions. This is the reason why the elements of the velocity ellipsoid are calculated. For each group the components of solar motion in the galactic cartesian system are also obtained. Mean solar motion with respect to the local standard of rest is calculated by averaging: $(U_\odot, V_\odot, W_\odot) = (8.2 \pm 0.1, 5.7 \pm 0.1, 6.6 \pm 0.1)$ km s$^{-1}$ (result 2).

## 4. GALACTOCENTRIC ORBITS

Finally, the question of belonging to any of the three subsystems in our sample is examined by studying the galactocentric orbits of the sample stars. The numerical solutions of the differential equations represent the projection of the spatial cylindrical coordinates onto the meridional plane $(R, Z)$. According to their shapes and sizes they can roughly comprise three cases which correspond to the thin disc, thick disc and halo.

The orbits of halo stars are not concentrated to the galactic plane, they occupy a large volume of the configuration subspace of the phase space, in other words they behave chaotic (Fig. 5a).

The orbits of stars belonging to the thin and thick discs are similar in their shapes (not in sizes). They have well defined minimum and maximum distances to the axis of the galactic rotation ($R_\mathrm{p}$ and $R_\mathrm{a}$, respectively) and also the corresponding distances to the galactic plane ($|Z_\mathrm{p}|$ at $R_\mathrm{p}$ and $|Z_\mathrm{a}|$ at $R_\mathrm{a}$), unlike the case of the halo. Therefore, it is suitable to define the following dimensionless quantities:

$$e_\mathrm{p} = \frac{R_\mathrm{a} - R_\mathrm{p}}{R_\mathrm{a} + R_\mathrm{p}}, \qquad e_\mathrm{v} = \frac{\frac{1}{2}\left(|Z_\mathrm{a}| + |Z_\mathrm{p}|\right)}{R_\mathrm{m}}, \tag{1}$$

where $R_\mathrm{m} = \frac{1}{2}(R_\mathrm{a} + R_\mathrm{p})$ is the mean distance to the axis of galactic rotation, whereas $e_\mathrm{p}$ is the planar and $e_\mathrm{v}$ vertical eccentricity.

For the stars belonging to the thin disc (Fig. 5c) we establish the following upper limits: $(e_\mathrm{p} < 0,5)$ and $(e_\mathrm{v} < 0,08)$. Within these eccentricity limits the shape and size of the projection of a galactocentric orbit onto the meridional plane correspond to a small trapezium with well defined sides. These stars have nearly circular orbits and therefore they cannot go far from the initial galactocentric position in both $R$ and $|Z|$. We find 4258 sample stars (92.3%) corresponding to these eccentricity limits.

A similar analysis is carried out for stars of the thick disc (Fig. 5b). The eccentricity limits are: $(0,5 < e_\mathrm{p} < 0,8) \wedge (0,08 < e_\mathrm{v} < 0,3)$. The projections of their orbits still have the trapezium shape, but partly curvilinear. These stars in their motion remain close to the galactic plane, but the planar eccentricity can be very high. Due to this they can reach a distance to the galactic rotation axis very different from the present one. We find 270 (5.9%) such sample stars.

The remaining 86 stars (1.9%) have very chaotic orbits, thus they belong to the halo.

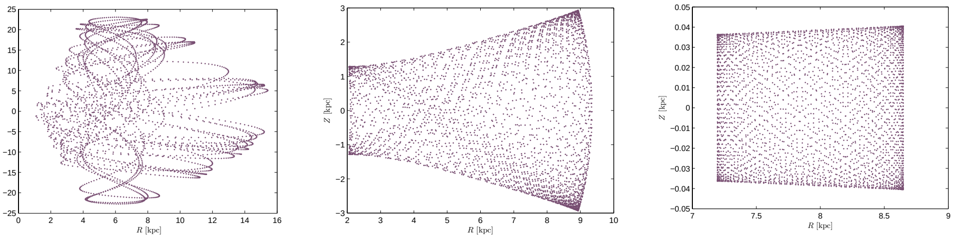

Figure 5: Typical orbits of stars. From left to right: a) halo star, b) thick disc star, c) thin disc star.

## 5. CONCLUSION

(i) Intensity of solar motion components with respect to the local standard of rest, agrees very well with the literature. Our two results and results obtained from Hipparcos data by other authors are presented in Table 2.

Table 2: Comparison of results.

| Author | $U_\odot$ | $V_\odot$ | $W_\odot$ |
|---|---|---|---|
| Dehnen & Binney, 1998 | $10.0 \pm 0.4$ | $5.2 \pm 0.6$ | $7.2 \pm 0.4$ |
| Hogg et al., 2005 | $10.7 \pm 0.5$ | $4.0 \pm 0.8$ | $6.7 \pm 0.2$ |
| result 1 | $9.6 \pm 0.1$ | $6.8 \pm 0.1$ | $7.4 \pm 0.1$ |
| result 2 | $8.2 \pm 0.1$ | $5.7 \pm 0.1$ | $6.6 \pm 0.1$ |

(ii) By analyzing the cumulative distribution of space velocities we establish that up to a heliocentric space velocity of about $100\,\mathrm{km\,s^{-1}}$ stars belong to the thin disc, between 100 and $180\,\mathrm{km\,s^{-1}}$ stars belong to the thick disc and stars above $180\,\mathrm{km\,s^{-1}}$ belong to the halo.

These results are verified by analyzing the velocity ellipsoids and galactocentric orbits of the sample stars. Based on this, the method using the cumulative distribution might be applied for the separation of the galactic subsystems. However, any method based on kinematics only is not sufficient for the difficult task of subsystem separation since the physical properties of stars should also be taken into account.

(iii) The fractions found here are: 92% – thin disc, 6% – thick disc and 2% – halo.

These values seem reasonable, but the fraction of the halo might be too high. The number of halo stars in the solar neighbourhood is generally very small so the true halo fraction is still very uncertain. This may be a task for future studies.

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