The rotational vector of the Local stellar system

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It is shown that the rotational vector of nearby stars derived from the proper motions of the Hipparcos catalogue is not perpendicular to the Galactic plane. We found that the rotation of stars nearer than 150 pc can be considered as the superposition of the Galactic rotation and the **L**ocal **S**tellar **S**ystem (henceforth the LSS) rotation. The kinematics of stars which are more distant than 200 pc are very close to the standard model of the Galactic rotation.

Keywords: Milky Way; structure; kinematics

Introduction

The anomalies of local galactic kinematics have been studied by many authors using the Hipparcos data [1-5]. All of these investigations use a more or less standard approach to evaluate the Oorth's constants, the parameters parameters of Solar motion, etc.

It is not well known that the complicated methods to study the kinematics of the LSS were invented in the middle of XX century by R.Shatsova [6]. The detailed derivation of equations of the LSS rotation is described in [7]. The application of this method to new observational material was made in [8].

Rotational vector of nearby stars

The Hipparcos catalogue provides a nice opportunity to find the direction of rotational vector $\mathbf{\Omega}$ for a group of stars at different distance ranges. If the system of a catalogue is ICRF (which the Hipparcos catalogue is the case), there are no precessional components in the proper motions by definition. This means that the rotational vector of a large group of stars must be perpendicular to the Galactic plane.

Consider now the behavior of the rotational vector for groups of stars which are placed at different distances from us. We use the the Ogorodnikov-Milne model to obtain the components of rotational vector.

The brief results are presented in Table 1. Figure 1 illustrates the dependence of $|\Omega|$ and the latitude of rotational pole b_Ω on the distance. The analysis of these results shows that

- The rotational vector is determined by substantial errors in the Sun neighborhood from 0 to 50 pc. The large non-rotational motions dominate any rotational components in the proper motions within this region.

- The rotational vector can be determined very reliably for the distance ranges from 50 to 150 pc, but its direction differs drastically from the normal to the Galactic plane, the deviation reaching 50^o.

- The rotational vector approaches the normal position at the distance 150 pc smoothly, and its direction becomes normal at the distance 250 pc. The angular velocity assumes the usual value in this region, too.

One may consider the full rotational vector as the superposition of the Galactic rotation $\mathbf{S}$ and the rotation of the LSS $\mathbf{Q}$:

$$\mathbf{\Omega} = \mathbf{S} + \mathbf{Q} \tag{1}$$

The rotational vector is known to get perpendicular to the Galactic plane if the distant stars are used. This means that the components Ω_x and Ω_y are insignificant whereas the component Ω_z assumes the value of about $20\,km \cdot s^{-1} \cdot kpc^{-1}$. One can interpret this result as the dilution of the "normal" Galactic kinematics by the stars of the LSS in the distances till 150 pc. On the other hand, the "normal" Galactic kinematics dominates other phenomena since 250 pc. This consideration allows us to assume that the "true" Galactic rotation is the one that derives from stars more distant than 250 pc. For those stars, we assume $\mathbf{Q} \equiv 0$ and $\mathbf{\Omega} \equiv \mathbf{S}$. For instance, for the stars of the spectral type F at the distances 300-400 pc, we obtain

$$\begin{aligned} \Omega_x &= -0.75 \pm 1.75 \quad \mathrm{km \cdot s^{-1} \cdot kpc^{-1}}, \\ \Omega_y &= -1.15 \pm 3.48 \quad \mathrm{km \cdot s^{-1} \cdot kpc^{-1}}, \\ \Omega_z &= -21.88 \pm 2.03 \quad \mathrm{km \cdot s^{-1} \cdot kpc^{-1}}. \end{aligned} \tag{2}$$

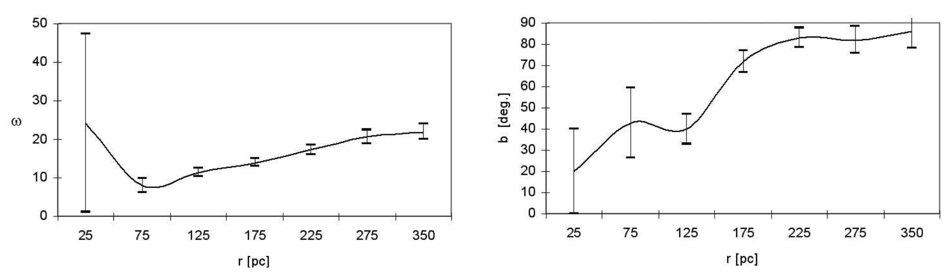

Figure 1: *Dependence of* Ω $(km \cdot s^{-1} \cdot kpc^{-1})$ *and* b_Ω *on the distance to stars.*

Table 1: Values of the solar motion and the components of rigid rotational vector for stars at different distances.

$\Omega_x, \Omega_y, \Omega_z$	–	components of the rotational vector $[\mathrm{km} \cdot \mathrm{s}^{-1} \cdot \mathrm{kpc}^{-1}]$;
$\lvert\Omega\rvert$	–	modulus of the angular velocity $[\mathrm{km} \cdot \mathrm{s}^{-1} \cdot \mathrm{kpc}^{-1}]$;
L_Ω, B_Ω	–	coordinates of the rotational pole [degrees].

	0-50 pc	50-100	100-150	150-200
Ω_x	-16.2 ± 8.7	-0.87 ± 2.3	2.1 ± 1.4	1.56 ± 1.2
Ω_y	16.1 ± 8.3	-5.8 ± 2.3	-8.5 ± 1.4	-4.0 ± 1.3
Ω_z	-8.2 ± 8.4	-5.5 ± 2.3	-7.3 ± 1.4	-13.2 ± 1.2
Ω	$24. \pm 23.$	8.0 ± 1.8	11.3 ± 1.1	13.9 ± 1.0
L_Ω	135 ± 21	261 ± 23	284 ± 9	291 ± 17
B_Ω	-20 ± 20	-43 ± 16	-40 ± 7	-72 ± 5

	200-250 pc	250-300	300-400
Ω_x	-1.41 ± 1.3	0.93 ± 1.6	-0.75 ± 1.7
Ω_y	-1.61 ± 1.5	2.89 ± 2.3	-1.15 ± 3.5
Ω_z	-17.1 ± 1.3	-20.0 ± 1.6	-21.9 ± 2.0
Ω	17.3 ± 1.2	20.7 ± 1.8	21.9 ± 2.0
L_Ω	229 ± 38	72 ± 32	237 ± 100
B_Ω	-83 ± 5	-82 ± 6	-86 ± 8

This yields

$$\begin{aligned} \mathbf{S} &= 21.9 \pm 2.0 \quad \mathrm{km} \cdot \mathrm{s}^{-1} \cdot \mathrm{kpc}^{-1}, & (3) \\ B_s &= -86^\circ \pm 8^\circ. & (4) \end{aligned}$$

We are now able to evaluate the vector $\mathbf{\Omega}$ and then the vector $\mathbf{Q}$ for stars having the same spectrum but placed from 100 to 200 pc:

$$\begin{aligned} \Omega_x &= +5.53 \pm 1.45 \quad \mathrm{km} \cdot \mathrm{s}^{-1} \cdot \mathrm{kpc}^{-1}, \\ \Omega_y &= -7.84 \pm 1.44 \quad \mathrm{km} \cdot \mathrm{s}^{-1} \cdot \mathrm{kpc}^{-1}, \\ \Omega_z &= -6.20 \pm 1.49 \quad \mathrm{km} \cdot \mathrm{s}^{-1} \cdot \mathrm{kpc}^{-1}. \end{aligned} \qquad (5)$$

From the simple equation

$$\mathbf{Q} = \mathbf{\Omega} - \mathbf{S} \qquad (6)$$

we obtain

$$
\begin{aligned}
q_x &= +6.3 \pm 2.3 \quad \mathrm{km} \cdot \mathrm{s}^{-1} \cdot \mathrm{kpc}^{-1}, \\
q_y &= -6.7 \pm 3.7 \quad \mathrm{km} \cdot \mathrm{s}^{-1} \cdot \mathrm{kpc}^{-1}, \\
q_z &= +15.7 \pm 2.5 \quad \mathrm{km} \cdot \mathrm{s}^{-1} \cdot \mathrm{kpc}^{-1}.
\end{aligned}
\tag{7}
$$

This gives following parameters of the rotational vector of the LSS:

$$
\begin{aligned}
Q &= 18.2 \pm 2.7 \quad \mathrm{km} \cdot \mathrm{s}^{-1} \cdot \mathrm{kpc}^{-1}, \\
L_q &= 313^\circ \pm 19^\circ, \\
B_q &= +60^\circ \pm 9^\circ.
\end{aligned}
\tag{8}
$$

Finally, we may conclude that:

- The positive value of q_z tells that the rotation of the LSS is reverse to the rotation of the Galaxy ($q_z \cdot \Omega_z < 0$);
- The value: $Q = 20\,\mathrm{km} \cdot \mathrm{s}^{-1} \cdot \mathrm{kpc}^{-1} = 0.5''/\mathrm{cy}$ is very close to the one derived from other works devoted to the LSS (about $1''/\mathrm{cy}$);
- The coordinates of the rotational pole are close to the ones adopted for Gould's belt.

Refined parameters of the Local stellar system

We calculated the parameters of the LSS by solving the equations (2.15), (2.16) from paper [7] using the new coordinates of the rotational pole.

Theory of the LSS rotation describes the singular kinematics of the nearby stars satisfactorily. Nevertheless, not all the stars of the Hipparcos catalogue are suitable for the rotational equation. The most appropriate stars prove to be A and F stars from the main sequence. The OB-stars and as well as the red giants do not satisfy the hypothesis of the LSS rotation. This means that the stars of middle age form the LSS. On the other hand, the KM-stars of main sequence were observed by the Hipparcos satellite only in the closest vicinity of the Sun, namely, closer than 50 pc. It was shown that the peculiar motions are predominant at such small distances. If it were possible to measure the proper motions of red dwarf at distances up to 200 pc, we would discover the LSS rotation for these stars, too.

Summarizing, we present the most probable values of the LSS parameters for A-, F-stars from the main sequence of HR-diagram that are closer than 200 pc.

The coordinates of the rotational pole are as follows:

$$L_0 = 313^\circ \pm 19^\circ, \qquad B_0 = +60^\circ \pm 9^\circ. \tag{9}$$

The coordinates of the direction and the distance to the rotational axis are:

$$l_0 = 253^\circ \pm 9^\circ, \tag{10}$$
$$b_0 = -13^\circ \pm 8^\circ, \tag{11}$$
$$r_0 = 180 \pm 70 \quad \text{pc}. \tag{12}$$

The angular velocity and its derivatives assume the following values:

$$\omega_0 = +0.92 \pm 0.19 \quad ''/\text{cy}, \tag{13}$$
$$\omega_0' r = -0.95 \pm 0.27 \quad ''/\text{cy}, \tag{14}$$
$$\omega_0'' r^2 = +2.12 \pm 0.83 \quad ''/\text{cy}. \tag{15}$$

The LSS makes one revolution during 140 millions years in the counter-clockwise direction, if one looks from the North Galactic pole. In other words, it rotates against the Galactic rotation.

It has to be stressed that the LSS was associated with the system of young OB-stars at the beginning of XX century. The existence of the LSS was linked with Gould's Belt exceptionally.

The kinematic analysis of the OB-stars does not reveal any rotation of these stars as a part of the LSS. However, this does not mean that the OB-system does not belong to the LSS, especially as the determined coordinates of the rotational pole are the same as for Gould's Belt. The distribution of young stars over the sky leads to greater correlations between the parameters in the equations of the LSS rotation. This might be a reason why the kinematic analysis has failed.

All these effects make us conclude that the stellar population of the LSS is extended to the stars of A and F spectral types. Nevertheless, it is too early to presume that the LSS and Gould's Belt are conceptually equal.

In our study of the LSS we consider the kinematic question only. We are not concerned with the nature of the LSS nor with its dynamical basis, as this would exceed the bounds of the present research.

However, we believe it would be useful to quote some facts from modern stellar dynamic and astrophysics. New approaches to this question have appeared in the late XX century, and they enabled a different way of looking at this problem. In [9] it is shown that the vortexes are situated between the spiral arms near co-rotation radius which rotate in the direction opposite to the general Galactic rotation. Their origins are explained by the hydrodynamical theory. It is conceivable that the LSS is such a vortex between the spiral arms.

The existence of the LSS is confirmed by the studies of the 21 cm line profiles [10]. This paper is a convincing example that the vortex with opposite direction is located in the Sun vicinity.

Thus, the existence of the LSS is a hypothesis verifiable by theoretical demonstration, the analysis of the proper motions as well as radio observations.

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