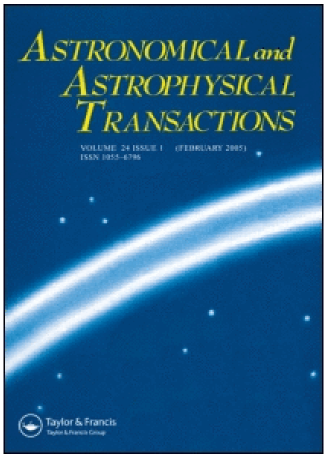

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The rotational vector of the Local Stellar System

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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 Local Stellar System 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

1. Introduction

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

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

2. Rotational vector of nearby stars

The Hipparcos catalogue provides a nice opportunity to find the direction of the rotational vector $\mathbf{\Omega}$ for a group of stars in different distance ranges. If the system used by a catalogue is the International Celestial Reference Frame (which is the case in the Hipparcos catalogue), 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.

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Table 1. Values of the solar motion and the components of the rigid rotational vector for stars at different distances: Ω_x, Ω_y, Ω_z, components of the rotational vector; $|\mathbf{\Omega}|$, modulus of the angular velocity; L_Ω, B_Ω, coordinates of the rotational pole.

Distance (pc)	Ω_x (km s^{-1} kpc^{-1})	Ω_y (km s^{-1} kpc^{-1})	Ω_z (km s^{-1} kpc^{-1})	$\lvert\mathbf{\Omega}\rvert$ (km s^{-1} kpc^{-1})	L_Ω (deg)	B_Ω (deg)
0–50	-16.2 ± 8.7	16.1 ± 8.3	-8.2 ± 8.4	24 ± 23	135 ± 21	-20 ± 20
50–100	-0.87 ± 2.3	-5.8 ± 2.3	-5.5 ± 2.3	8.0 ± 1.8	261 ± 23	-43 ± 16
100–150	2.1 ± 1.4	-8.5 ± 1.4	-7.3 ± 1.4	1.3 ± 1.1	284 ± 9	-40 ± 7
150–200	1.56 ± 1.2	-4.0 ± 1.3	-13.2 ± 1.2	13.9 ± 1.0	291 ± 17	-72 ± 5
200–250	-1.41 ± 1.3	-1.61 ± 1.5	-17.1 ± 1.3	17.3 ± 1.3	229 ± 38	-83 ± 5
250–300	0.93 ± 1.6	2.89 ± 2.3	-20.0 ± 1.6	20.7 ± 1.6	72 ± 32	-82 ± 6
300–400	-0.75 ± 1.7	-1.15 ± 3.5	-21.9 ± 2.0	21.9 ± 2.0	237 ± 100	-86 ± 8

Consider now the behaviour 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 the rotational vector.

Brief results are presented in table 1. Figure 1 illustrates the dependences of $|\mathbf{\Omega}|$ and the latitude $b_{\mathbf{\Omega}}$ of the rotational pole on the distance. The analysis of these results shows the following.

(i) The rotational vector is determined by substantial errors in the Sun neighbourhood from 0 to 50 pc. The large non-rotational motions dominate any rotational components in the proper motions within this region.
(ii) 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°.
(iii) 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.

The full rotational vector may be considered as the superposition of the Galactic rotation $\boldsymbol{S}$ and the rotation $\boldsymbol{Q}$ of the LSS:

$$\mathbf{\Omega} = \boldsymbol{S} + \boldsymbol{Q}. \qquad (1)$$

The rotational vector is known to become perpendicular to the Galactic plane if distant stars are used. This means that the components Ω_x and Ω_y are insignificant whereas the component Ω_z assumes a value of about 20 km s^{-1} kpc^{-1}. This result can be interpreted as the dilution of the 'normal' Galactic kinematics by the stars of the LSS at distances up to 150 pc. On the other hand, the 'normal' Galactic kinematics dominate other phenomena above 250 pc. This consideration allows us to assume that the 'true' Galactic rotation is the rotation that derives

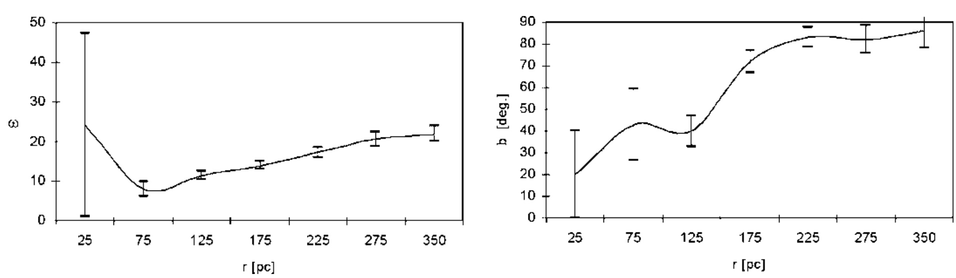

Figure 1. Dependences of $|\mathbf{\Omega}|$ (km s^{-1} kpc^{-1}) and b_Ω on the distance to stars.

from stars more distant than 250 pc. For those stars, we assume that $\boldsymbol{Q} \equiv \mathbf{0}$ and $\boldsymbol{\Omega} \equiv \boldsymbol{S}$. For instance, for stars of spectral type F at distances of 300–400 pc, we obtain

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

This yields

$$|\boldsymbol{S}| = 21.9 \pm 2.0\,\mathrm{km\,s^{-1}\,kpc^{-1}}, \tag{3}$$

$$B_s = -86 \pm 8^\circ. \tag{4}$$

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

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

From the simple equation

$$\boldsymbol{Q} = \boldsymbol{\Omega} - \boldsymbol{S}, \tag{6}$$

we obtain

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

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

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

Finally, we may conclude the following.

(i) The positive value of q_z tells us that the rotation of the LSS is opposite to the rotation of the Galaxy ($q_z\Omega_z < 0$).
(ii) The value $|\boldsymbol{Q}| = 20\,\mathrm{km\,s^{-1}\,kpc^{-1}} = 0.5''\,\mathrm{century^{-1}}$ is very close to that derived from other work devoted to the LSS (about $1''$ century^{-1}).
(iii) The coordinates of the rotational pole are close to those adopted for Gould's Belt.

3. Refined parameters of the Local Stellar System

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

The 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. OB stars and also red giants do not satisfy the hypothesis of the LSS rotation. This means that stars of intermediate ages form the LSS. On the other hand, the KM stars of the 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 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 and F stars from the main sequence of the Hertzsprung–Russell diagram that are closer than 200 pc.

The coordinates of the rotational pole are as follows:

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

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

$$l_0 = 253 \pm 9^\circ, \tag{10}$$

$$b_0 = -13 \pm 8^\circ, \tag{11}$$

$$r_0 = 180 \pm 70 \text{ pc}. \tag{12}$$

The angular velocity and its derivatives assume the following values:

$$\omega_0 = +0.92 \pm 0.19 \text{ century}^{-1}, \tag{13}$$

$$\omega_0'' = -0.95 \pm 0.27 \text{ century}^{-1}, \tag{14}$$

$$\omega_0'' r^2 = +2.12 \pm 0.83 \text{ century}^{-1}. \tag{15}$$

The LSS performs 1 rev during 1.4×10^8 years in the counterclockwise 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 the twentieth century. The existence of the LSS was linked with Gould's Belt in particular.

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 allow us to conclude that the stellar population of the LSS is extended to 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 dynamic basis, as this would exceed the bounds of the present research.

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

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

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

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