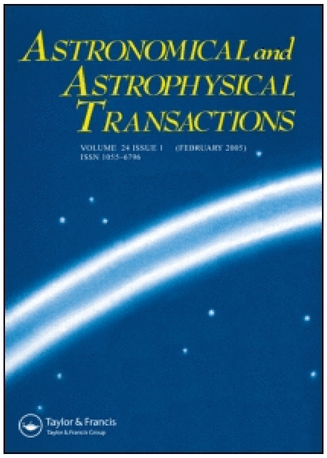

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THE LOCAL STAR SYSTEM: KINEMATICS DERIVED FROM RADIAL VELOCITIES

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The rotational parameters of the Local star system have been derived from radial velocities of 2537 stars of FK5. The most likely geometrical description of the Local system is presented. The results obtained from the radial velocities do not contradict those derived from proper motions and may be considered as evidence for the existence of the Local Star system.

KEY WORDS Radial velocities, local star system

1 INTRODUCTION

In the previous paper (Tsvetkov, 1994) results based on an investigation of proper motions of stars were obtained evidencing for the existence of the Local star system (henceforth LSS). As known, the rotation of the LSS influences not only proper motions but radial velocities, too. For complete knowledge of the LSS kinematics, a study of radial velocities is desirable.

2 THE EQUATION OF THE LOCAL STAR SYSTEM ROTATION

Shatsova (1950) derived equation that describe the contribution of the Local Star system to proper motions and radial velocities. In this paper, for convenience, we give a short description of the basic equation, which outlines the influence of the LSS rotation on radial velocities.

Let us fix a coordinate system with its origin placed at the center of the Sun and its Z-axis directed to the North Galactic pole (Figure 1). We arrange the X-axis in such a way that the LSS rotation vector ω be parallel to XZ-plane and Y-axis be normal to both others. The longitude of the X-axis coincides with the longitude of the rotational pole L_0; we denote its polar distance as P_0. Draw the perpendicular from the point S to ω; the point of their intersection M_0 we call the center of

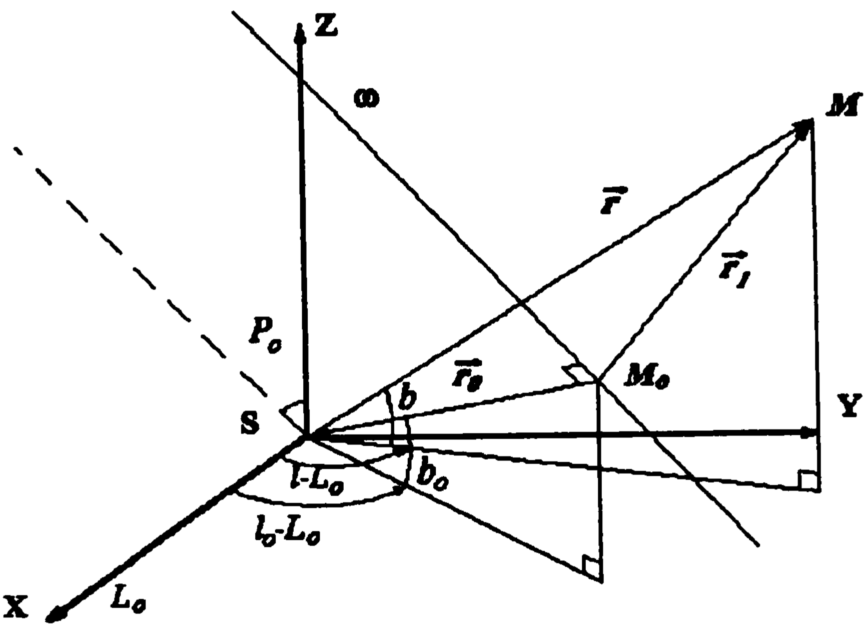

Figure 1 To the theory of the LSS rotation.

rotation of the LSS. Extend the vector $\vec{r_1}$ from point M (an arbitrary star) and $\vec{r}_1$ from M_0 to M. The longitudes of these points are $l - L_0$ and $l_0 - L_0$; the latitudes are b and b_0.

For the velocity of point M one can write

$$\vec{v} = \vec{\Omega} \times + \vec{\omega} \times \mathbf{r}_1 \tag{2.1}$$

where $\vec{\Omega}$ is the angular velocity of the Galaxy, $\vec{\mathbf{R}}$ is the distance from the Galactic center.

From observational data we can determine only differential effect, if we suppose that the Sun takes part in the rotation of the LSS:

$$\Delta\vec{v} = \vec{v} - \vec{v}_0. \tag{2.2}$$

Using the relations

$$\vec{r}_1 = \vec{r}_0 + \vec{r} \text{ and } \vec{\mathbf{R}} = \vec{\mathbf{R}}_0 + \mathbf{r} \tag{2.3}$$

from Eqs. (2.1–2.2) we acquire:

$$\Delta\vec{v} = (\vec{\Omega} - \vec{\Omega}_0) \times \vec{\mathbf{R}}_0 + \vec{\Omega} \times \vec{r} + (\vec{\omega} - \vec{\omega}_0) \times \vec{r}_0 + \vec{\omega} \times \mathbf{r}, \tag{2.4}$$

i.e., the Galactic motion and the LSS rotation are separated (in Eqs. (1.2–1.4) the subscript "0" refers to the Sun). Suppose now that the formulae of the Galactic rotation are known and we project only $(\vec{\omega} - \vec{\omega}_0) \times \vec{r}_0 + \vec{\omega} \times \vec{r}$ onto the axes. This yields the following expressions for the contribution of the LSS rotation to the radial velocities of stars:

$$\begin{aligned}\Delta\nu_r &= (\omega-\omega_0)r_0[\sin P_0 \sin b_0 \cos b_0 \sin(l-L_0)\\ &- \cos P_0 \cos b_0 \cos b \sin(l-l_0) - \sin P_0 \cos b_0 \sin(l_0-L_0)\sin b].\end{aligned} \quad (2.5)$$

Now we suppose that the angular velocity ω depends only on the distance from the rotation axis ρ:

$$\omega = \omega(\rho(\vec{\mathbf{r}}_1)) \quad (2.6)$$

and does not depend upon the distance from the symmetry plane. This is supported by theoretical investigations (Ogorodnikov, 1944), which tell us that the angular velocity of a stationary stellar system is independent of Z.

Since we do not know the function $\omega = \omega(\vec{\mathbf{r}}_1)$, we may expand it in the Tailor's series by powers of r. The existence of the third harmonics in the representation of observational proper motions points that the rotational center is very close and we can not ignore the second terms:

$$\omega(\vec{\mathbf{r}}) = \omega_0 + \left(\frac{d\omega}{dr}\right)_0 + \frac{1}{2}\left(\frac{d^2\omega}{dr^2}\right)_0 r^2; \quad (2.7)$$

here $\frac{d\omega}{dr}_0$ and $\left(\frac{d^2\omega}{dr^2}\right)_0$ are the first and the second derivatives of ω along the $\vec{\mathbf{r}}$ direction in the Sun's vicinity.

After evaluating the derivatives it turns out that Eq. (1.7) can be rewritten as

$$\omega - \omega_0 = \Omega' + \Omega'' \sin b; \quad (2.8)$$

where Ω' and Ω'' are functions symmetrical about the Galactic plane:

$$\begin{aligned}\Omega' &= (\omega_0' r)\Big\{-\cos b_0 \cos(l-l_0)\\ &+ \frac{1}{2n_0}\Big[1-\sin^2 b(\sin^2 b_0 + \cos^2 P_0)\\ &- \cos^2 b\left(\cos^2 b_0 \cos^2(l-l_0) + \sin^2 P_0 \cos^2(l-L_0)\right)\Big]\Big\}\\ &+ (\omega_0'' r^2)\frac{1}{2}\left\{\cos^2 b_0 \cos^2 b \cos^2(l-l_0) + \sin^2 b_0 \sin^2 b\right\}\end{aligned} \quad (2.9)$$

$$\begin{aligned}\Omega' &= (\omega_0' r)\Big\{-\sin b_0 - \frac{1}{n_0}\cos b[\sin b_0 \cos b_0 \cos(l-l_0) + \sin P_0\\ &\times \cos P_0 \cos(l-L_0)]\Big\} + (\omega'' r^2)\{\cos b \sin b_0 \cos b_0 \cos(l-l_0)\}.\end{aligned} \quad (2.10)$$

In these equations and further $n_0 = \frac{r_0}{r}$; ω_0 is the angular velocity of the LSS rotation in the Sun's vicinity; $\omega_0' = \left(\frac{d\omega}{d\rho}\right)_)$, $\omega_0'' = \left(\frac{d^2\omega}{d\rho^2}\right)_0$ are the first and the second derivatives in the Sun neighbourhood along the normal direction to the rotation axis.

The direct use of Eqs. (1.5) leads to inconvenience, because of other kinematic phenomena, which interfere with the LSS rotation. It is difficult to separate the motions of various kinds due to considerable correlations.

Since the influences of the Galactic rotation and the Solar motion are both symmetrical with respect to the Galactic equator, we can exclude them if we introduce the differences of radial velocities "North-South":

$$\delta\nu_r = (\Delta\nu_r)_N - (\Delta\nu_r)_S, \tag{2.11}$$

taken in symmetrical points of the sky. These values will not contain previous effects even if we do not know the exact law of the Galactic rotation. Still, the Solar motion component $Z_\odot$ penetrates into them and we need to exclude it. Really, from Eq. (1.5) we find

$$\begin{aligned} \delta\nu_r = & -2r_0 \sin b \cos b_0 \\ & \Big\{ -\Omega' \sin P_0 \sin(l_0 - L_0) \\ & +\Omega''[\sin P_0 \sin b_0 \sin(l - L_0) - \cos P_0 \cos b \sin(l - l_0)] \Big\} \\ & -2Z_\odot \sin b. \end{aligned} \tag{2.12}$$

Theoretically, Eq. (1.12) allows us to find the next seven LSS parameters from proper motions:

L_0, P_0	– the latitude and the polar distance of the rotational pole;
l_0, b_0, r_0	– the coordinates of the rotational center;
ω'_0, ω''_0	– the angular velocity derivatives in the solar neighbourhood.

However, because of strong correlation between some parameters, we refrained from acquiring L_0 and P_0 from radial velocities. In the previous work the values of L_0, P_0 were adopted to be equal to the coordinates of the Gould's Belt pole:

$$L_0 = 343^\circ, \ P_0 = 17^\circ. \tag{2.13}$$

In the present paper we shall make the same suggestion intentionally so that the results can be compared with those derived from proper motions. The common problem in the stellar kinematics is poor knowledge of stellar parallaxes. Therefore, following conventional way, instead of $r_0, \omega'_0, \omega''_0$ we will determine the following parameters:

$$n_0 = \frac{r_0}{\langle r \rangle}, \quad \omega'_0\langle r \rangle, \quad \omega''_0\langle r^2 \rangle, \tag{2.14}$$

where angle brackets denote averaging of the corresponding values. In these designations the multiplier r_0 in the equation (1.12) can be expressed as

$$r_0 = n_0\langle r \rangle. \tag{2.15}$$

Unfortunately, we are forced to find the average distance to star listed in a catalogue before solving equation (1.12). This obstacle makes troubles in getting the LSS parameters from the radial velocities as compared with the proper motions case. Also, we are not able to find such an important parameter as the angular velocity because it does not enter the equation (1.12). In order to improve the comparison of the results and to set the initial approximation for solving the system of equations (1.12) we measure $\omega_0'\langle r\rangle$, $\omega_0''\langle r^2\rangle$ in arcseconds per century. For this we multiply these values by $k = 0.0474$ to measure them in km s^{-1} pc^{-1}. After this the equation (1.12) may be represented as

$$\begin{aligned} \delta\nu_r &= -2kn_0 \sin b \cos b_0 \\ &\quad \Big\{ -\Omega' \sin P_0 \sin(l_0 - L_0) \\ &\quad +\Omega''[\sin P_0 \sin b_0 \sin(l - L_0) - \cos P_0 \cos b \sin(l - l_0)]\Big\} \\ &\quad -2Z_\odot \sin b. \end{aligned} \tag{2.16}$$

So, we have the next six parameters to be determined from analysis of radial velocities:

$$l_0, \quad b_0, \quad n_0, \quad \omega_0, \quad \omega_0'\langle r\rangle, \quad \omega_0''\langle r^2\rangle.$$

3 PREPARATION OF DATA

We used a subset of 2537 stars of $FK5/FK5$Sup for which the radial velocities are available. Following our method, we do not need radial velocities but their differences "North–South" $-\delta\nu_r$. It is difficult to find the couple for each star in the opposite hemisphere. The way out is to use radial velocities averaged over trapezia in zones symmetrical with respect to the Galactic equator. The coordinates of the centers of such trapezia are determined by the following expressions:

$$l_i = \frac{180^\circ}{n} + \frac{360^\circ}{n}(i-1), \quad i = 1, 2, \ldots, n \tag{3.1}$$

$$b_i = 90^\circ - \frac{90^\circ}{m} - \frac{180^\circ}{m}(j-1), \quad 1, 2, \ldots, m \tag{3.2}$$

where m is the number of latitude zones ($m/2$ is the number of zones in one hemisphere), n is the number of trapezia in every zone. The indices of a trapezium for a star can be found as

$$i = \left[\frac{l}{360^\circ}n\right] + 1, \quad j = \left[\frac{90^\circ - b}{180^\circ}m\right] + 1, \tag{3.3}$$

where brackets denote an integer part. This procedure yields a grid $m \times n$ of points (2.1), (2.2) a table, which contains averaged values of the $\delta\nu_r$, for all the trapezia,

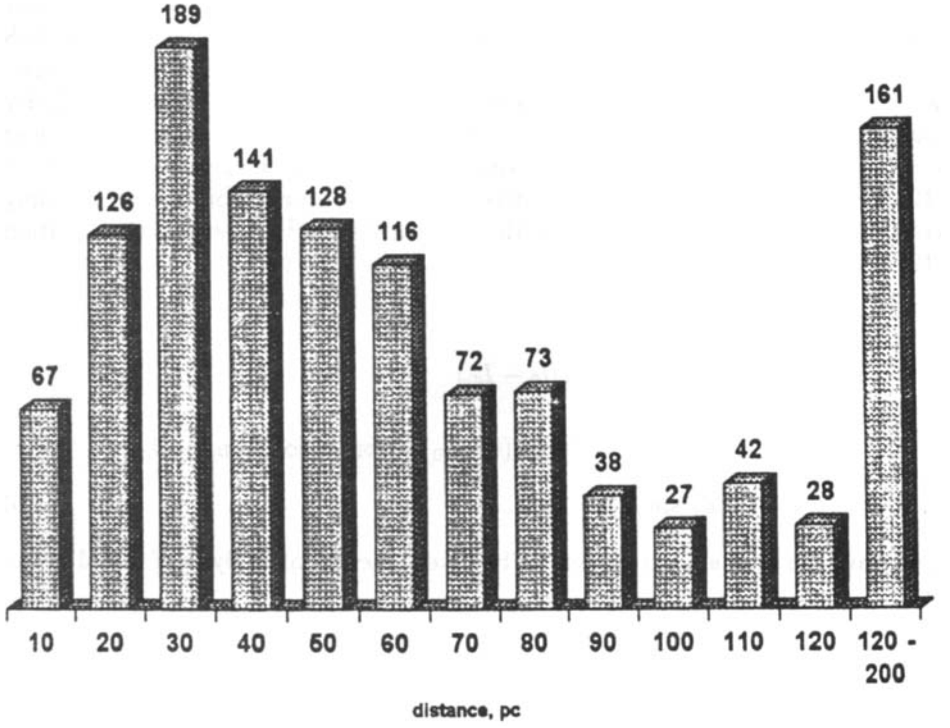

Figure 2 Distribution of the stars by distance.

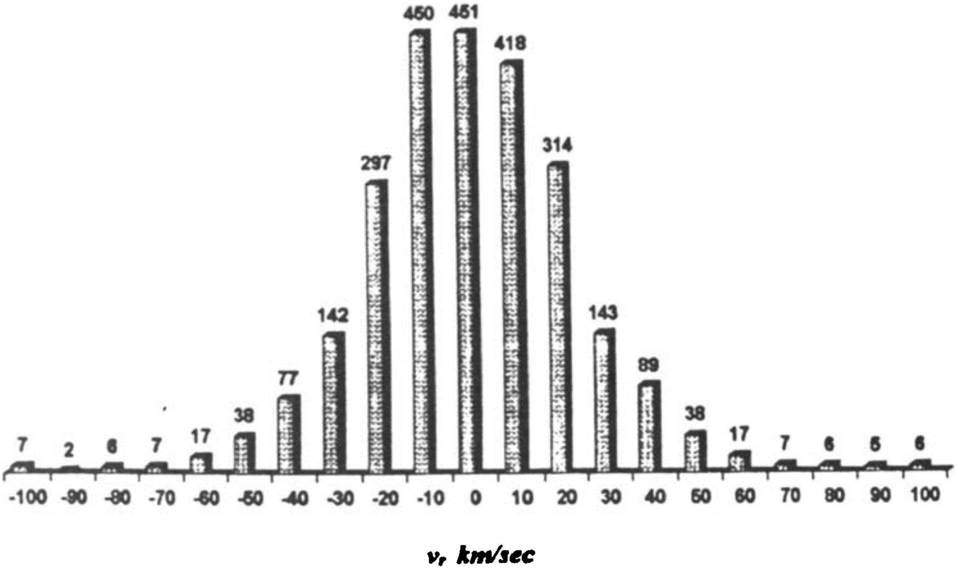

Figure 3 Distribution of the stars by radial velocity.

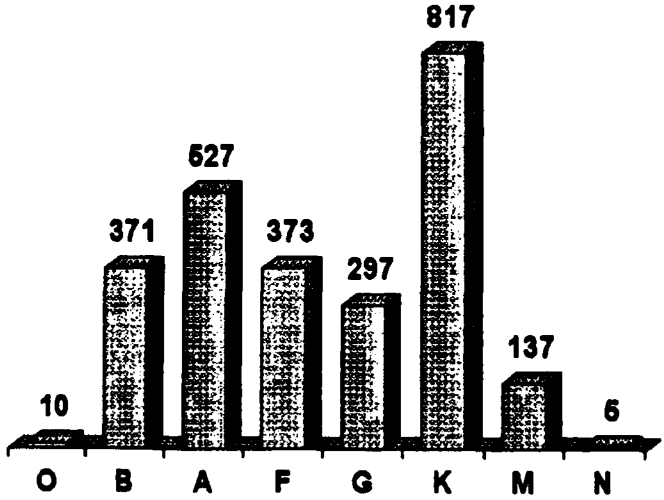

Figure 4 Distribution of the stars by spectral types.

as well as a table of numbers of employed stars. To each trapezium a weight may be assigned that is a sum of stars corresponding to North–South couples of areas. We get the final numerical material for our investigation after subtracting the South values from the North ones. For more detailed studies, we can construct such tables for star groups marked with some specific features, for instance, the spectral type.

Besides the differences of radial velocities we must know the component $Z_\odot$ of the Solar motion and the average distance of stars of the catalogues. The $Z_\odot$-component follows from the solution of the Airy–Kovalsky equation for radial velocities:

$$-X_\odot \cos b \cos l - Y_\odot \cos b \sin l - Z_\odot \sin b = \nu_r. \tag{3.4}$$

The 2537 stars of the FK5 give

$$Z_\odot = 8.08 \pm 0.77\ \text{km/sec}. \tag{3.5}$$

The determination of the average distance of the FK5 stars $\langle r \rangle$ is a more difficult problem. Luckily, 1170 stars of set used have trigonometric parallaxes. Figure 2 illustrates the distribution of the stars over distances. This permits us to estimate $\langle r \rangle$ to be

$$\langle r \rangle = 36\ \text{pc}. \tag{3.6}$$

A few stars have large velocities and it is reasonable to exclude them from examining. Taking into account the distribution of the stars over radial velocities we rejected stars for which $|\nu_r| > 40$ km/sec. The number of such stars was found to be equal to 109.

The majority of FK5 stars having data about radial velocity, belong to spectral type **K** though there is a large group of stars of intermediate and early spectral

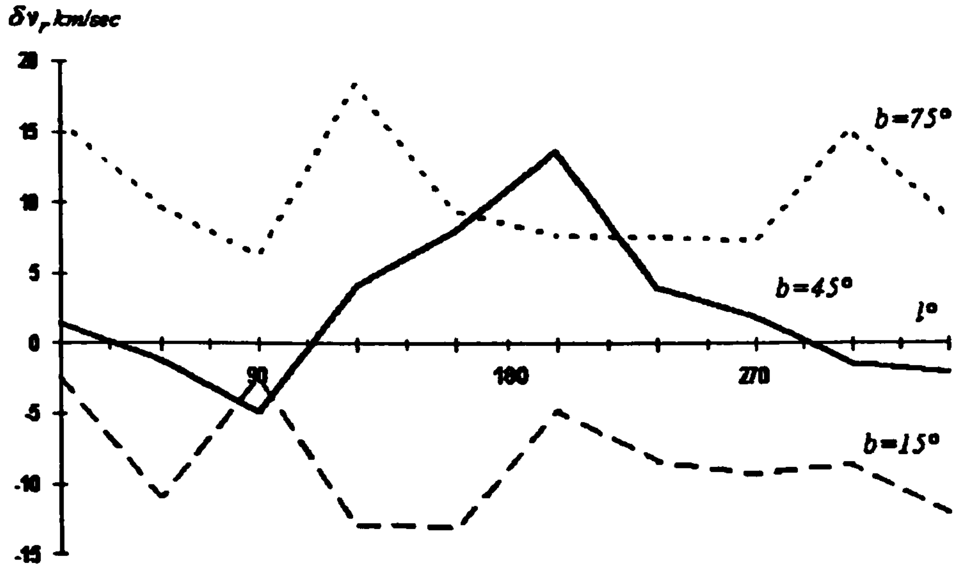

Figure 5 The observational asymmetry of radial velocities (for all stars).

types. Our previous paper shows that O–F stars satisfy the equations of the LSS rotation better than others. In the present work we will try to find the dependence of the rotational parameters on spectral types of stars, too.

The differences of the radial velocities "North–South" show a significant asymmetry, in which one can notice a systematic part due to the 1st and 2nd harmonics by l. This circumstance confirms the LSS rotation. Figure 5 shows the $\delta\nu_r$ after subtracting the solar motion component $Z_\odot$ from $(\nu_r)_N - (\nu_r)_S$.

4 THE METHOD TO SOLVE THE LSS EQUATIONS

We use the linearization method to solve the equation (1.16), which can be represented here as

$$y = f(\vec{x}, \vec{t}), \tag{4.1}$$

where y is $\delta\nu_r$;

$\vec{x}$ is the vector of unknown variables l_0, b_0, n_0, $\omega_0'\langle r\rangle$, $\omega_0''\langle r^2\rangle$;

$\vec{t}$ is the vector of coordinates of a North trapezium center,

f is a non-linear function of $\vec{x}$ and $\vec{t}$.

To apply the conventional LSM technique for solving Eq. (3.1), the latter is to be linearized.

Let us assume that we know an initial approximation $\vec{x}_0$ of $\vec{x}$ from preliminary considerations. Then one can calculate

$$y_0 = f(\vec{x}_0, \vec{t}) \tag{4.2}$$

for every point $\vec{t}$ and write, using the Tailor's series representation with the accuracy to the first power term:

$$\Delta y = y - y_0 \approx \sum_j \Delta x_j \frac{\partial f}{\partial x_j}\Big|_{\vec{x}_0} \tag{4.3}$$

The system generated by Eq. (3.3) is linear concerning unknown corrections Δx_j, to components of $\vec{x}$. Now, one can solve this system

$$\hat{\mathbf{A}}\Delta\vec{x} = \bar{\mathbf{Y}} \tag{4.4}$$

by the conventional least squares technique. The elements of the matrix A are

$$A_{ij} = \frac{\partial f(\vec{x}, \vec{t}_i)}{\partial x_j}\Big|_{\vec{x}_0} \quad \begin{matrix} i=1,2,\ldots m \\ j=1,2,\ldots 5 \end{matrix} \tag{4.5}$$

where $\vec{t}_j = (l_i, b_i)$ are the coordinates of the center of the ith North trapezium. The partial derivatives may be evaluated by a symmetrical formula:

$$\frac{\partial f}{\partial x_j} = \frac{f(x_1, x_2, \ldots, x_j + \Delta_j, \ldots, x_n, \vec{t}_i) - f(x_1, x_2, \ldots, x_j - \Delta_j, \ldots, x_n, \vec{t}_i)}{2\Delta_j} \tag{4.6}$$

The elements of the column $\mathbf{Y}$ are written as

$$Y_i = y_i - f(\vec{x}_0, \vec{t}_i), \tag{4.7}$$

where y_i are the average values of $\delta\nu_r$ in the ith trapezium. Weights may be assigned to all the equations.

Adding the corrections Δx_j obtained from the solution of Eq. (1.16) to the components $\vec{x}_0$ produces the next approximation $\vec{x}_1$:

$$\vec{x}_1 = \vec{x}_0 + \Delta\vec{x}. \tag{4.8}$$

We repeat this process until the condition

$$|\Delta x_j| < \varepsilon_j \tag{4.9}$$

is fulfilled. Here ε_j is the required accuracy of computation of the jth component of $\vec{x}$. After the first numerical experiment had been made, we adopted ε_j as an average root square error of Δx_j. As for Δ_j, they were appointed to be

$$\Delta_j = \frac{1}{2}\varepsilon_j. \tag{4.10}$$

This was done to make the length of the interval $[x_j - \Delta_j, x_j + \Delta_j]$ exceed the mean square error of Δx_j.

Table 1. The results of testing the method

σ, km/s	l_0	b_0	n_0	$\omega_0' r$	$\omega_0'' r^2$
0	286 ± 0.4	-5.0 ± 0.1	1.50 ± 0.01	-1.00 ± 0.01	2.49 ± 0.01
0.1	277 ± 6.2	-8.6 ± 2.5	1.56 ± 0.24	-0.84 ± 0.15	2.12 ± 0.55
0.2	272 ± 9.7	-11.4 ± 4.4	1.65 ± 0.56	-0.74 ± 0.27	1.87 ± 0.91
0.5	268 ± 16	-14.7 ± 7.6	1.21 ± 0.36	–	–
1	255 ± 26	-25 ± 16	1.08 ± 0.55	–	–

Note. Units: l_0, b_0, degrees; n_0, dimensionless; ω_0, $\omega_0' r$, $\omega_0'' r^2$, arcsec/cy.

5 TESTING THE METHOD

Before applying the method was applied to the radial velocities of the FK5, it was tested on artificial data. We adopted the values of the LSS parameters (close to those obtained from proper motions):

$$l_0 = 286^\circ,\ b_0 = -5^\circ,\ n_0 = 1.5,\ \omega_0' r = -1'',\ \omega_0'' r^2 = -2''.5,$$

and computed model catalogues of radial velocities using Eq. (1.12).

If the random component is small and initial approximations are not far from reality, the method works irreproachably and allows to get all the parameters after 2–3 iterations. It is known that the noise level in the determination of a radial velocity is less than 1 km/sec. For testing the method on stability we created several model catalogues constructed as a combination of the equation (1.16) and random parts with different dispersions (from 0 to 1 km/sec). We found the values of all the parameters if the level of noise was $0.1 \div 0.2$ km/sec. However, when the dispersion reached 0.5 km/sec, we were able to obtain only the geometric parameters l_0, b_0 and n_0 because strong correlations disturbed the results based on scarce observational data.

Table 2. The values of the LSS parameters derived from ν_r with adopted $\omega_0' r = -1''$ arcsec/cy and $\omega_0'' r^2 = 2.5''$ arcsec/cy.

$M \times N$	ν_r	Sp	l_0	b_0	n_0
6 x 10	All	All	227 ± 34	29 ± 45	2.6 ± 1.8
6 x 12	All	All	221 ± 31	17 ± 22	4.3 ± 3.8
8 x 18	All	All	221 ± 34	17 ± 25	4.4 ± 4.3
6 x 10	< 40	All	241 ± 22	37 ± 26	4.0 ± 1.6
8 x 18	< 40	All	223 ± 27	16 ± 18	5.5 ± 3.8

Note. Units: l_0, b_0, degrees; n_0, dimensionless.

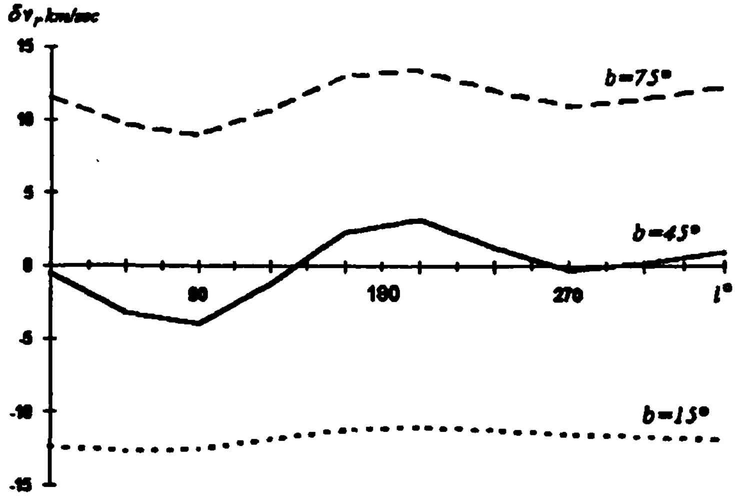

Figure 6 The asymmetry of radial velocities derived from Eq. (1.16) with adopted values of parameters from the first line of Table 2.

6 THE RESULTS OF FK5 PROCESSING

The determination of the LSS parameters was done by a two step procedure. The first step was the preliminary preparation of data by averaging the FK5 stars over trapezia and selecting them by spectral type. The second one is just the solution of the system of the LSS rotation equations by the successive approximation method. The initial approximation for the solution had been taken from our previous investigation of proper motions.

First we found the parameters of the Local Star system rotation from all 2537 stars over the grid 6×10. We could determine three geometrical parameters: the coordinates of the direction to the center of rotation and the relative distance to it. The derivatives of the angular velocity had been fixed on the values derived from proper motions. When we changed the size of the grids, we got the same values but the numbers of stars in one cell became so small that accidental deviations caused by the stars with large $\delta\nu_r$, which are not included in the LSS, increased the mean square errors of the parameters. In spite of that, the convergence of approximations was good and the values themselves were close to ones that proper motions gave.

We tried to reject fast stars. This provided the same values of the parameters but the mean square errors were less than for all stars together.

An attempt to investigate the influence of spectral type on the LSS parameters failed because of too small numbers of stars of selected spectral type per one cell.

Figure 6 shows the contribution of the rotation of the LSS to the asymmetry of radial velocities for three values of galactic attitude. One can see that the curves fit the observational data in Figure 5 rather well. although systematic part of high order is present which our model does not describe.

7 CONCLUSIONS

The small number of used stars and the distance problem makes the determination of the LSS rotation parameter from radial velocities less sure than in the case of proper motions. Therefore, we prefer the results of our first work. Nevertheless, the results obtained from radial velocities do not contradict the LSS rotation and we may consider them as evidence for the existence of the Local Star system. What is needed to improve our knowledge of the structure and the kinematics of the LSS? Certainly, it is a comprehensive catalogue of proper motion and of radial velocities. The more stars in a catalogue will have the parallaxes and astrophysical data the better it will be suitable. It is hoped that HIPPARCOS would be a catalogue of this type. It is interesting to compare astrometrical results with astrophysical observations of gas cloud, etc. Thorough investigation can rectify the understanding of the nearest space in the solar neighbourhood.

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References

Fricke, W., Schwan, H., and Lederle, T. (1988) *Fifth Fundamental Catalogue (FK5)*, Veröff. Astron. Rechen. Inst., Heidelberg No. 32.

Ogorodnikov, K. F. (1958) *The Dynamics of Stellar Systems*, Moscow.

Shatsova, R. B. (1950) Assymetry of Proper Motions of Boss' GC, *Nauchnye zapisky LGU* No. 136.

Shatsova, R. B. (1952) Assymetry of Radial Velocities of Stars, *Nauchnye zapisky LGU* No. 153.

Tsvetkov, A. S. (1994) The Local Star System: Kinematics Derived from Proper Motions, *Astronom. & Astrophys. Transactions* (in press).