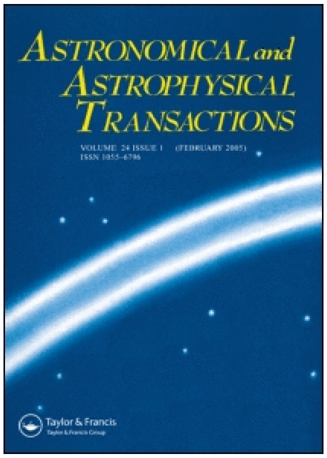

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CONTRIBUTION OF HIPPARCOS TO THE DETERMINATION OF PRECESSION

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The IAU (1976) luni-solar precession constant was derived by Fricke from intensive study of the catalog of 512 FK4–FK4/Sup distant stars. At present, when the data from the catalog HIPPARCOS is available, it is helpful to reconsider Fricke's analysis. This paper presents a redetermination of precession based on the following new factors: (a) the accurate parallaxes of stars have been taken into account; (b) galactic rotation and other kinematics have been eliminated from the proper motions of 512 stars; (c) the systems of the FK5 and improved GC catalog were used in combination with the HIPPARCOS catalog; (d) a new method (the MOTOR) of studying stellar kinematics was used. This method is based on the decomposition of proper motions on a set of orthogonal functions. The MOTOR, in contrast to the commonly used Least Squares Procedure, provides a test for whether or not the model is compatible with the data.

Derived corrections to the IAU (1976) luni-solar precession constant are consistent with the results from VLBI observations and kinematic study of modern catalogues of proper motions.

Keywords: Luni-solar precession; HIPPARCOS; MOTOR method

1 INTRODUCTION

Newcomb's value of the luni-solar precession constant

$$p = 5024.64''/cy, \quad 1900.0$$

was revised by W. Fricke (1977). From the kinematic analysis of the 512 FK4/FK4 Sup stars (combined solution $\mu\cos\delta$ and μ' in the system of the FK4) he found:

$$\Delta n = 0.44 \pm 0.06''/cy;$$
$$\Delta k = -0.19 \pm 0.09''/cy,$$

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where Δn and Δk are corrections of the precessional constant in DEC, and R.A. respectively. These values yield:

$$\Delta p = 1.10 \pm 0.15''/cy;$$
$$\Delta E = 1.20 \pm 0.16''/cy,$$

where Δp is the correction to the luni-solar precession in longitude and $\Delta E = \Delta\lambda + \Delta e$; $\Delta\lambda$ is the correction to the planetary precession and Δe is the rate of the fictitious equinox motion.

The IAU (1976) value of general luni-solar precession in longitude

$$p = 5029.0966''/cy, \quad J2000.0$$

is based on Fricke's analysis.

Working with the VLBI technique is expected to improve precession further. The first provisional results (McCarthy *et al.*, 1983) say that Fricke over-corrected Newcomb's precession and the IAU (1976) precession must be reduced by the value $0.3''/cy$.

This paper gives evidence that the same result also follows from the catalog of 512 stars (henceforth F512) provided that the data from the HIPPARCOS catalog is added to the ground based proper motions.

2 STATISTICS OF THE CATALOG F512

This catalog contains positions and proper motions $\mu\cos\delta$ and μ' in the systems of catalog GC, N30, FK3, and FK4. In addition, the catalog lists the visual magnitudes, spectral types, color indexes B–V, radial velocities and estimates of distances based on spectral classification and photometric data. This distribution of 512 stars over the celestial sphere is shown in Figure 1. From Figure 2 we see that the majority of stars belong to B and A spectral types, and that almost all stars are located in the interval $100 < r < 300$ pc.

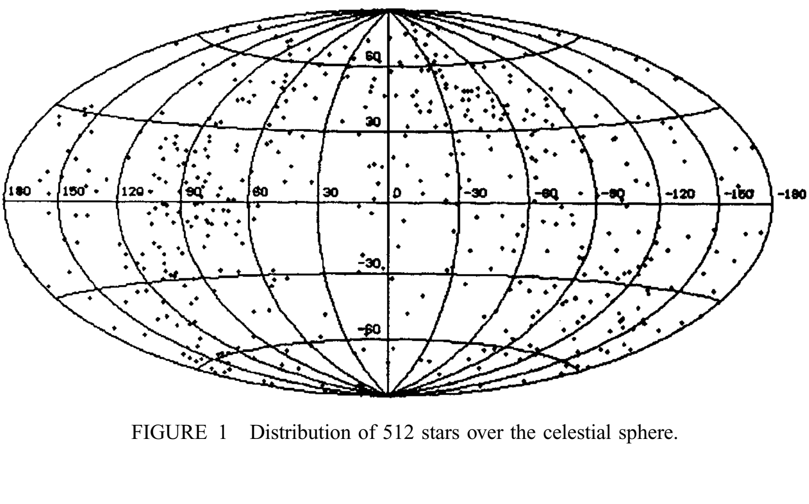

FIGURE 1 Distribution of 512 stars over the celestial sphere.

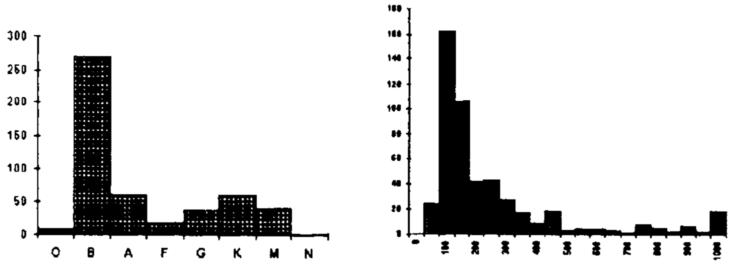

FIGURE 2 Distribution of 512 stars on spectral type (left) and on distances (right).

3 FROM PARALLAX FACTORS TO PARALLAXES

The equations of condition used by Fricke are based on the Oort–Lindblad model of galactic rotation:

$$\begin{aligned}\mu\cos\delta &= f(X\sin\alpha - Y\cos\alpha) - \omega_1\sin\delta\cos\alpha - \omega_2\sin\alpha\sin\delta\\ &\quad + \omega_3\cos\delta + P(\cos 2l\cos b\cos\varphi + 0.5\sin 2l\sin 2b\sin\varphi); \qquad (1)\\ \mu' &= f(X\sin\delta\cos\alpha + Y\sin\delta\sin\alpha - Z\cos\delta) + \omega_1\sin\alpha - \omega_2\cos\alpha\\ &\quad + P(\cos 2l\cos b\sin\varphi - 0.5\sin 2l\sin 2b\cos\varphi). \qquad (2)\end{aligned}$$

Here X, Y and Z are the equatorial Solar motion components; f is the parallax factor; $\omega_1, \omega_2, \omega_3$ are the components of an angular velocity vector of the stars under consideration; l, b are the galactic coordinates of stars; φ is the parallactic angle at l, b; $P = A/47.4$ and $Q = B/47.4$, where A and B are the Oort's constants.

The separate or combined solutions of Eqs. (1) and (2) yield the values X, Y, Z, ω_1, ω_2, ω_3, P, from which the coordinates of the apex of Solar motion, the Oort's constant B and precessional corrections are derived according to equations

$$\omega_1 = -0.868Q, \qquad (3)$$
$$\omega_2 = -0.198Q - \Delta n, \qquad (4)$$
$$\omega_3 = 0.456Q + \Delta k. \qquad (5)$$

In his analysis Fricke used the parallax factors instead of the estimates of distances from the catalog F512. At present, we are able to take the distances of 512 stars from the HIPPARCOS catalog. As a by-product, we can compare both sets of distances. This comparison is shown in Figure 3, from which we see that up to 200 pc both systems of distance agree rather well. Naturally, for distant stars ($r > 200$ pc) this agreement is worse. Still, with the exception of three stars (NN 487, 490, 496) the correlation between the two sets of distances is equal to 0.596.

Transition from parallax factors to distances from the HIPPARCOS catalog yields the following results.

SOLAR MOTION

- With parallax factors:

$$A = 266.0 \pm 2.3^\circ; \qquad D = 26.7 \pm 2.1^\circ.$$

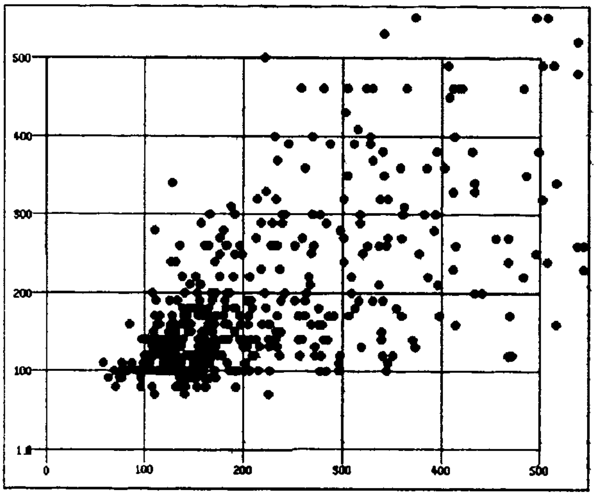

FIGURE 3 Comparison of distances for 512 stars. Horizontal axis – data from HIPPARCOS. Vertical axis – data from F512. Unit – pc.

- With distances from HIPPARCOS:

$$V = 14.5 \pm 0.5\,\mathrm{km\,s^{-1}}; \quad A = 263.9 \pm 2.2^\circ; \quad D = 28.2 \pm 2.1^\circ.$$

GALACTIC ROTATION

- With parallax factors:

$$Q = -0.34 \pm 0.07''/cy; \qquad P = 0.34 \pm 0.08''/cy.$$

- With distances from HIPPARCOS:

$$Q = -0.30 \pm 0.07''/cy; \qquad P = 0.29 \pm 0.08''/cy.$$

PRECESSION

- With parallax factors:

$$\Delta p = 1.08 \pm 0.20''/cy; \qquad \Delta E = 1.15 \pm 0.20''/cy.$$

- With distances from HIPPARCOS:

$$\Delta p = 0.98 \pm 0.17''/cy; \qquad \Delta E = 0.97 \pm 0.18''/cy.$$

We see that no drastic changes occurred when we placed the stars where they should be instead of forcing them to be equidistant from the Sun.

4 THE MOTOR

Following an approach based on the Oort–Lindblad model of galactic rotation, we made a kinematic analysis of 512 stars using a model of a three-dimensional differential centroid velocity field (Ogorodnikov, 1930; Milne, 1932; du Mont, 1977). To solve the equations of condition we used a new method, based on orthogonal representation of proper motions – the MOTOR method (Vityazev, 1999). This method is a further development of the initial method ROTOR (Vityazev, 1994, 1997) which was created to determine the mutual rotation between two reference frames. Below, we give a short outline of the method.

The equations of condition for proper motions in the galactic system of coordinates are:

$$\mu_l \cos(b) = \sum_{i=1}^{7} L_i f_i(l, b), \tag{6}$$

$$\mu_b = \sum_{i=1}^{10} L'_i f'_i(l, b), \tag{7}$$

where

$$L_i = \{U, V, \omega_1 - M_{22}^+, \omega_2 + M_{13}^+, \omega_3, M_{11}^*, M_{12}^+\}, \tag{8}$$

$$L'_i = \{U, V, W, \omega_1, \omega_2, M_{11}^*, M_{23}^+, M_{12}^+, M_{13}^+, M_{23}^+\}. \tag{9}$$

Here, the following notations are used:

- U, V, W are the components of solar motion in the direction of the principal galactic coordinate axes x, y, z;
- $\omega_1, \omega_2, \omega_3$ are the components of the angular velocity vector of rotation in the proper motions of the stars about the axes x, y, z;
- $M_{12}^+, M_{13}^+, M_{23}^+$, are the shears in the galactic planes $(x, y), (x, z), (y, z)$;
- $M_{11}^+, M_{22}^+, M_{33}^+$ are the components of a dilation in the direction of axes x, y, z. Since proper motions do not discriminate between expansion or contraction, in what follows we set $M_{22}^+ = 0$. In this case the unknowns M_{11}^+ and M_{33}^+ become equivalent to $M_{11}^* = M_{11}^+ - M_{22}^+$ and $M_{33}^* = M_{33}^+ - M_{22}^+$ respectively;
- $f(l, b)$ and $f'(l, b)$ are the known functions of galactic coordinates l and b.

Usually, the Least Squares Technique is used to derive these parameters from the proper motions of stars. The LS approach is the best way to do this provided that the data consists of *nothing else but modeled terms and noise*. In practice, we do not know what is beyond the model. If it is not only noise then the LS method may give an unrealistic solution marred by some systematic terms. To overcome this difficulty, we propose a new method based on representing the proper motions by means of orthogonal functions. For the sake of brevity we shall call this method the MOTOR method (MOTions by Orthogonal Representation). A short description of the method is given below.

Decompose each of the functions $f_i(l, b)$ on a set of orthogonal functions which are the products of Legendre polynomials $L_n(b)$ and Fourier terms F_{kl} (Bien *et al.*, 1978). Substituting the results into Eq. (6) we get:

$$\mu_l \cos b = \sum_{nkl} C_{nkl} L_n(b) F_{kl}(l). \tag{10}$$

It is not difficult to show that the coefficients C_{n01} are proportional to the parameter ω_3 while the coefficients C_{n2-1} and C_{n21} are proportional to M^*_{11} and M^+_{12} respectively for $n = 0, 1, \ldots$. This means that, at least theoretically, rotation and deformation of the stellar system may be derived not only from the lowest order harmonics but from the high order functions as well. This is the basic idea of the MOTOR method, since the ability to derive several estimates of one and the same parameter and to compare them tests whether the model is compatible with the data. Note that the parameters ω_3, M^*_{11} and M^+_{12} define the velocity of rotation and deformation of the stellar system in the principal galactic plane (x, y). To derive the analogous characteristics with respect to the planes (x, z) and (y, z) one must calculate the spherical coordinates and the proper motions of stars in two new systems of coordinates with the main plane perpendicular to the galactic plane.

In order to realize the MOTOR method one should have an appropriate procedure to derive the coefficients C_{nkl}, C'_{nkl} from the proper motions. It is likely that the method proposed by Broshe (1966) is the best for MOTOR. We will call this technique the ORM (Orthogonal Representation Method). For a given set of proper motions $\mu_l \cos b$ and μ_b and for a chosen significance level the ORM derives the coefficients that yield the systematic part in Eqs. (6) and (7) together with their r.m.s.e. σ, σ'. Now we are in a position to describe the practical algorithm of MOTOR method.

Given are: the catalog of N stars with known galactic coordinates l, b, parallaxes π, and proper motions $\mu_l \cos b, \mu_b$ measured in arcsec per century. The algorithm consists of the following steps.

1. Deriving and eliminating the motion of the Sun
   Using the LS technique solve the equations

$$47.4(\mu_l \cos b) = \pi U \sin l - \pi V \cos l, \tag{11}$$
$$47.4(\mu_b) = \pi U \cos l \sin b + \pi V \sin l \sin b - \pi W \cos b, \tag{12}$$

   for U, V, W and subtract the reflex of the solar motion from the proper motions. In the next steps the proper motions of stars released from the solar motion are used.
2. Artificial proper motions
   Set $L_i = 1, L'_i = 1$ and calculate the artificial proper motions (APM) according to Eqs. (6) and (7). The artificial proper motions are used to calibrate the MOTOR method for each specific distribution of stars over the celestial sphere.
3. Orthogonal representation of the APM
   Using the ORM, calculate the coefficients C_{nkl} to represent the APM by Legendre–Fourier harmonics.
4. Orthogonal representation of the proper motions
   Using the ORM, calculate the coefficients $S_{nkl} \pm \sigma_{nkl}$ to represent the real proper motions by Legendre–Fourier harmonics.
5. Deriving estimates of the parameters in the coordinate system (X, Y, Z)

$$\omega_3^{(0)} = \frac{S_{001}}{C_{001}} \pm \frac{\sigma_{001}}{C_{001}}; \quad \omega_3^{(2)} = \frac{S_{201}}{C_{201}} \pm \frac{\sigma_{201}}{C_{201}};$$
$$M_{11}^{*(0)} = \frac{S_{02-1}}{C_{02-1}} \pm \frac{\sigma_{02-1}}{C_{02-1}}; \quad M_{11}^{*(2)} = \frac{S_{22-1}}{C_{22-1}} \pm \frac{\sigma_{22-1}}{C_{22-1}};$$
$$M_{12}^{+(0)} = \frac{S_{021}}{C_{021}} \pm \frac{\sigma_{021}}{C_{021}}; \quad M_{12}^{+(2)} = \frac{S_{221}}{C_{221}} \pm \frac{\sigma_{221}}{C_{221}}.$$

If the values of one and the same parameter designated by upper index 0 or 2 are not contradictory then put

$$\omega_3 = \omega_3^{(0)}; \quad M_{11}^{*} = M_{11}^{*(0)}; \quad M_{12}^{+} = M_{12}^{+(0)}.$$

6. Analysis in the (x, z) plane
   Rotate the galactic coordinate system at 90° around the y-axis and calculate new spherical coordinates b', l' and proper motions $\mu_{b'} \cos b'$, $\mu_{l'} \cos b'$ according to equations

$$\sin b' = \cos b \cos l, \qquad \tan l' = \frac{\sin l}{\tan b}. \tag{13}$$

$$\mu_{b'} \cos b' = -\mu_b \sin b \cos l - \mu_l \sin l \cos b, \tag{14}$$

$$\mu_{l'} \cos b' = \mu_b [\cos b \sin l' - \sin b \sin l \cos l'] + \mu_l \cos b \cos l \cos l'. \tag{15}$$

   Apply the procedures described in steps 3, 4, and 5 to obtain ω_2 and M_{13}^{+}.
7. Analysis in the (y, z) plane
   Rotate the galactic coordinate system at 90° around the x-axis and calculate new spherical coordinates b'', l'' and proper motions $\mu_{b''} \cos b''$, $\mu_{l''} \cos b''$ according to equations

$$\sin b'' = -\cos b \sin l, \qquad \tan l'' = \frac{\tan b}{\cos l}. \tag{16}$$

$$\mu_{b''} \cos b'' = -\mu_b \sin b \sin l - \mu_l \cos b \cos l, \tag{17}$$

$$\mu_{l''} \cos b'' = \mu_b [\sin b \cos l \sin l'' + \cos b \cos l''] + \mu_l \cos b \sin l \sin l''. \tag{18}$$

   Apply the procedures described in steps 3, 4 and 5 to obtain ω_1, M_{33}^{*}, and M_{23}^{+}.
8. End of the algorithm.

To compare the MOTOR method with the Least Squares technique, consider the following situations.

1. Let $\omega_3 = 2''/cy$, *i.e.* let the proper motions reflect the rigid body rotation of a frame about the x-axis. In addition, let the proper motions contain Gaussian noise with the r.m.s.e $= 1''/cy$:

$$\mu_l \cos b = \omega_3 \cos b + \text{noise}. \tag{19}$$

   The results of evaluation the parameter ω_3 by our methods are:

$$\text{LS}: \quad \omega_3 = 2.03 \pm 0.09''/cy,$$

$$\text{MOTOR}: \quad \omega_3^{(0)} = 1.97 \pm 0.09, \quad \omega_3^{(2)} = 2.00 \pm 0.33''/cy.$$

   We see that in the case of the Signal + Noise model both methods are equally reliable.
2. Replace the Gaussian noise with a systematic component

$$\mu_l \cos b = \omega_3 \cos b + \sin b. \tag{20}$$

The corresponding results are:

$$\text{LS}: \quad \omega_3 = 2.03 \pm 0.34''/cy,$$
$$\text{MOTOR}: \ \omega_3^{(0)} = 2.00 \pm 0.02, \quad \omega_3^{(2)} = 2.00 \pm 0.09''/cy.$$

Here we see that the LS gives too large value of the r.m.s.e. since it does not discriminate between the stochastic noise and the 'systematic noise'. On the contrary, the MOTOR method yields a realistic value of the r.m.s.e, since it takes the information that comes from rotation.

3. Now we take the data that does not contain rotation

$$\mu_l \cos b = \omega_3 \cos^8 b + \text{noise}. \tag{21}$$

The LS and the MOTOR solutions look as follows:

$$\text{LS}: \quad \omega_3 = 1.16 \pm 0.30''/cy,$$
$$\text{MOTOR}: \ \omega_3^{(0)} = 1.34 \pm 0.10, \quad \omega_3^{(2)} = 3.00 \pm 0.36''/cy.$$

The LS solution is rather good, and nobody would hesitate to adopt it as a reliable characteristic of rotation, though we know that there is no rotation in the data. On the other hand, the MOTOR method yields two contradictory estimates and this tells us that our model is wrong.

In other words, the MOTOR method is preferable to the Least Squares technique since it:

- takes into account only the harmonics which correspond to effects of 3D kinematics of stars,
- tests the data for compatibility with the model,
- discovers the existence of systematic terms which may affect the kinematics of the model.

Due to these properties the MOTOR method yields realistic results even when the observational data contain not only noise but other systematic terms that have nothing to do with the kinematics of the Ogorodnikov–Milne model.

5 KINEMATICS OF THE 512 STARS IN THE ICRF

If the proper motions from ground-based catalog are used, then the general vector of the rigid body rotation of the stellar system must be represented in the form

$$\bar{\omega} = M_{32}^{-}\bar{v}_1 + M_{13}^{-}\bar{v}_2 + M_{21}^{-}\bar{v}_3 + \Delta\bar{P} + \Delta\bar{E}, \tag{22}$$

$M_{32}^{-}, M_{13}^{-}, M_{21}^{-}$ are the angular velocity components of the rotation of the stellar system about the principal galactic axes; $\Delta\bar{P}$ is the angular velocity due to error in the precession constant; $\Delta\bar{E}$ is the component due to so-called fictitious motion of the equinox.

The values $\Delta p = |\Delta\bar{P}|$ and $\Delta E = |\Delta\bar{E}|$ define the corrections Δn and Δk according to

$$\Delta n = \Delta p \sin \varepsilon, \tag{23}$$
$$\Delta k = \Delta p \cos \varepsilon - \Delta E \tag{24}$$

with ε standing for the obliquty of the ecliptic.

TABLE I Analysis of the 512 Residual Proper Motions in the System HIPPARCOS Catalog. Unit$''$/cy.

	μ_l	μ'_l	μ''_l	*LSM*
M^-_{32} $(j = 0)$	–	–	-0.04 ± 0.06	-0.03 ± 0.06
M^-_{32} $(j = 4)$	–	–	0.03 ± 0.22	
M^-_{31} $(j = 0)$	–	0.06 ± 0.07	–	0.07 ± 0.07
M^-_{31} $(j = 4)$	–	0.68 ± 0.23	–	
M^-_{21} $(j = 0)$	-0.39 ± 0.08	–	–	-0.33 ± 0.07
M^-_{21} $(j = 4)$	0.07 ± 0.38	–	–	
M^*_{11} $(j = 7)$	-0.34 ± 0.23	–	–	-0.30 ± 0.19
M^*_{11} $(j = 19)$	0.47 ± 1.07	–	–	
M^*_{33} $(j = 7)$	–	–	-0.46 ± 0.18	-0.45 ± 0.17
M^*_{33} $(j = 19)$	–	–	0.36 ± 0.57	
M^+_{21} $(j = 8)$	0.48 ± 0.13	–	–	0.36 ± 0.09
M^+_{21} $(j = 20)$	0.11 ± 0.52	–	–	
M^+_{31} $(j = 8)$	–	0.19 ± 0.09	–	0.17 ± 0.09
M^+_{31} $(j = 20)$	–	0.69 ± 0.28	–	
M^+_{23} $(j = 8)$	–	–	0.06 ± 0.09	0.07 ± 0.08
M^+_{23} $(j = 20)$	–	–	0.13 ± 0.27	

Solving Eq. (6) yields only three parameters $\omega_1, \omega_2, \omega_3$, so it is impossible to evaluate all five parameters of Eq. (22). Usually, Eq. (22) is solved for $\Delta p, \Delta E$ and $M^-_{21} = Q$ under supposition that $M^-_{32} = 0, M^-_{13} = 0$ (see Eqs. (3)–(5)). This means that determining precession from proper motions can be justified only for a sample of stars which have no other rotation except the rotation around the axis perpendicular to the plane of the Galaxy.

Being tied to the ICRF, the proper motions of the HIPPARCOS catalog are free of precessional effects. This gives us a unique possibility to check whether or not the rotation of the 512 stars is flat. We applied the MOTOR method and the LS techniques to solve 512 Eq. (6) with the proper motions taken from the HIPPARCOS catalog. The results are shown in Table I.

The most important result is that both techniques yield $M^-_{32} = 0$ and $M^-_{31} = 0$. This means that the rotation of the system of 512 stars is really flat. Nevertheless, the contradictary determinations of all other parameters testify the fact that the kinematics of 512 stars is hardly compatible with the Ogorodnikov–Milne model. Fortunately, the HIPPARCOS catalog saves the situation. As we have said, the proper motions of this catalog are free of precessional effects. For this reason the differences *Cat. – HIPPARCOS* are free of any kinematics and depend only on precessional corrections. This saves us having to undertake kinematic modeling and gives the possibility to have in hand data containing only the precessional information.

6 PRECESSION DERIVED FROM THE FK5 AND HIPPARCOS

Guided by this idea we derived from 512 differences *FK*4–*HIPPARCOS* the components of the angular velocity:

$$\omega_1 = 0.39 \pm 0.03''/cy,$$
$$\omega_2 = 0.07 \pm 0.03''/cy.$$

Now from equations

$$\omega_1 = -0.0965\Delta p + 0.4838\Delta E,$$
$$\omega_2 = 0.8623\Delta p - 0.7470\Delta E$$

we find the correction to Newcomb's precession

$$\Delta p = 0.94 \pm 0.08''/cy,$$
$$\Delta E = 0.99 \pm 0.08''/cy.$$

This result is valid in the system of the FK4. Reducing our differences to the system of the FK5

$$\Delta\mu_{\mathrm{FK5}} = (\mathrm{FK4} - \mathrm{HIPPARCOS}) + S,$$

where S stands for systematical differences FK5 – FK4 (Fricke *et al.*, 1988) yields

$$\omega_1 = 0.38 \pm 0.03''/cy,$$
$$\omega_2 = 0.04 \pm 0.03''/cy.$$

With these values for correction to Newcomb's precession one has

$$\Delta p = 0.82 \pm 0.08''/cy,$$
$$\Delta E = 0.95 \pm 0.08''/cy.$$

Now, for the correction to the IAU 1976 value of the luni-precession constant and for the term ΔE we have

$$\Delta p = -0.28 \pm 0.08''/cy,$$
$$\Delta E = -0.25 \pm 0.08''/cy$$

7 PRECESSION DERIVED FROM IMPROVED GC AND HIPPARCOS

The PGC, GC and N30 form a sequence of American catalogs which were created to provide researchers with absolute positions and proper motions of stars for investigating stellar kinematics and the motions of the planets. The success of such works depends on the level of systematic errors in a catalog. Unfortunately, the positions of the GC are overburdened with large periodic errors since the authors of this catalog, guided by the mistaken idea that such errors are generated by the uneven speed of the Earth's rotation, refused to make the corresponding corrections to PGC position. This fault reduced the accuracy of the GC itself and spoiled the quality of the catalog N30 for compilation of which the data from the GC has been used.

An improved R.A. system of the GC (henceforth CGC, C-corrected) was created by Vityazev and Vityazeva (1985). They derived the periodical corrections ΔGC to RA of the GC on material from 20 catalogs with observations made between 1845 and 1925 and found that the faults in the GC compiling (not observations!) prevented the GC from being as accurate more than 50 years ago (with respect to systematic errors) as the FK4 and the FK5 are nowadays.

Now, using the correction ΔGC we calculated 512 differences

$$\mathrm{CGC} - \mathrm{HIPPARCOS} = (\mathrm{GC} + \Delta\mathrm{GC}) - \mathrm{HIPPARCOS}$$

to obtain

$$\begin{aligned} \omega_1 &= 0.35 \pm 0.04''/cy, \\ \omega_2 &= 0.08 \pm 0.04''/cy, \\ \omega_3 &= 0.06 \pm 0.04''/cy. \end{aligned}$$

Setting $\omega_2 = \omega_3 = 0$, we have found

$$\begin{aligned} \Delta p &= 0.76 \pm 0.10''/cy, \\ \Delta E &= 0.88 \pm 0.10''/cy. \end{aligned}$$

Hence, the correction to the IAU (1976) value of the luni-precession constant and the term ΔE are:

$$\begin{aligned} \Delta p &= -0.34 \pm 0.10''/cy, \\ \Delta E &= -0.33 \pm 0.10''/cy. \end{aligned}$$

8 CONCLUSIONS

Here we gather our determinations of the correction to the IAU (1976) luni-solar precession constant:

$$\begin{aligned} \text{FK5, HIPPARCOS (this paper)}: &\ \Delta p = -0.28 \pm 0.8''/cy, \\ \text{CGC, HIPPARCOS (this paper)}: &\ \Delta p = -0.34 \pm 0.10''/cy, \\ \text{PPM (Vityazev, 1996)}: &\ \Delta p = -0.35 \pm 0.05''/cy. \end{aligned}$$

To this we must add that our corrections are consistent with results obtained by Miyamoto *et al.* (1993) from the kinematic investigation of 30 000 K–M giants (the catalog ACRS):

$$\Delta p = -0.27 \pm 0.03''/cy.$$

Our corrections are in good agreement with the corrections which were derived from the PPM and the Pulkovo proper motions, tied to galaxies (Bobylev, 1997):

$$\Delta p = -0.28 \pm 0.08''/cy.$$

Still more valuable is a comparison of all corrections derived from the proper motions with the results obtained independently with the VLBI technique (Walter, Ma, 1994):

$$\Delta p = -0.36 \pm 0.11''/cy.$$

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