THE SEARCH FOR UNWANTED SIGNALS: SYSTEMATIC TRENDS IN PROPER MOTIONS OF FUNDAMENTAL STARS

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SUMMARY

An investigation of the N30 along the same lines as that of the FK4 (Brosche and Schwan 1981) reveals quite similar non-standard systematic motions. Some consequences are indicated for the determination of cluster parallaxes, of secular parallaxes and of the galactic rotation. In general, we stress the necessity of always searching for *every* signal in the data - including those ones which are not understood and hence not 'wanted'.

1. INTRODUCTION

In general, any non-random behaviour of empirical data can be considered to be a signal. With regard to their meanings, signals may be divided into (1) the ones carrying information on the subject under scientific investigation (the 'wanted' signals) and (2) other ones, mainly systematic errors of any origin (the 'unwanted' signals). Again, both types can be differentiated (a) into a class within which the model to describe the data is known - and (b) the remaining class. While in the first class (a) at most an a priori limited number of parameters is to be determined, any 'model' for the second class (b) involves an arbitrary choice of a complete system of functions and a statistical criterion for the selection of the admitted functions. A widely used alternative in the second class (b) consists in the application of numerical filters to the data. The problems connected with the choice of an appropriate filter are nothing other than transformations of the problems of a functional representation.

From the view-point of the data analysis, the problems related to (1a) and (2a) are at least recognized if not solved. Examples are: for (1a) the representation of systematic

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stellar motions by a certain number of physical constituents (Fricke 1977), for (2a) the treatment of the errors of a meridian circle by the formula of Tobias Mayer. The problems related to (1b) are also recognized, simply because the signal is 'wanted'. A surface photometry of a chaotic object may serve as an example of this situation. The problems with the (2b)-cases have been investigated later since they concern 'unwanted' signals. Today, one is generally aware of them, at least, if the effects are expected or if any visible effects *must consist* in systematic errors. The systematic differences between various astrometric catalogues are a classical paradigm. A statistically quantifiable method has been developed (Brosche 1966 and 1970) and extended (Schwan 1977, Bien et al. 1978) at the Astronomisches Rechen-Institut Heidelberg. Here we want to draw attention to the fact that many cases are combinations of (1a) and (2b) or that we should suspect this unless the contrary is proven.

The application to stellar proper motions means: although the use of the above mentioned methods should have minimized the remaining systematic errors in a resulting fundamental system, one cannot expect that there is no unmodelled signal left in the system - be it an error or an unknown physical effect. While a simultaneous treatment for the (1a) and (2b)-parts of the signal is desirable, a consecutive procedure for the two parts should be acceptable in most cases. In the language of a functional representation: those very terms which are already used - and hence 'absorbed' - by the physical model (1a) cannot be expected to appear in a second search for effects à la (2b). For this reason, (2b) may be incomplete; vice versa, the parameters determined with (1a) may be contaminated with (2b)-parts, which is the more probable, the more significant such a part appears.

2. PROPER MOTIONS OF FUNDAMENTAL STARS

Let us now pass over from the somewhat abstract terminology of the introduction to the special situation of the fundamental proper motion system. From space motions of 512 FK4- and FK4-Sup-stars, Fricke (1977) derived the fundamental parameters of the secular spinning motion of the Earth, of the solar motion and of the galactic rotation. We investigated the residuals after subtraction of those modelled motions (Brosche and Schwan 1981, henceforth quoted as paper I) and found an unexpected variety of further systematic parts to exist in the motions.

First of all, the radial velocities show non-consistent "K-terms" and some high-order terms. To our knowledge, radial velocity catalogues have never been compared at the same sophisticated level as astrometric catalogues. So, until this virtue is more highly esteemed in the realm of spectroscopy, we don't wish to promote explanations of the effects in radial velocity.

Restricting ourselves to the proper motions, the main question is the same: do we see systematic errors of the system or real physical effects? For this purpose, one would like to analyse another independent fundamental system of proper motions. To some extent, the N30-catalogue (Morgan, 1952; Eichhorn, 1974) is independent; it has often been confronted with FK4 results. Therefore we also use the N30 (before the advent of the FK5) as a certain check on whether our results with the FK4 system are associated only with this very system or not.

As in paper I, we give here the data for the two distance groups (378 nearby stars "n" and 128 distant stars "d") and for the two galactic components of the proper motions $\mu_l \cos b$ and μ_b (in units of 0".01/100^a). The significance level for the acceptance of functions was again $\zeta_o = 5^o/o$, but we also note the individual ζ of the accepted functions. The results for the N30 proper motions are exhibited in Table 1 in the same manner as in Table 2 of paper I, except that we suppress the correlation matrix here (for equal combinations of significant functions, the correlation is the same as in paper I). We have added a column for the appearance of the same terms in paper I. This column already shows that a considerable part of the non-standard systematic motions is of the same functional nature both in the FK4 and in the N30. As a rule, the common appearance is more frequent for the more significant terms. Seemingly the only exception is the function (n, m, l) = (2, 1, 1) in the case of μ_b (nearby stars): it appears in the FK4 only. Moreover, in the case of a common appearance, the sign and the values of the coefficients b_j are also quite similar (see Fig. 1). The total values of the systematic parts found here are shown in Fig. 2. By comparison with Fig. 2 of paper I one gets an impression of the overall similarity of the two cases. It is strong for the ($\mu_l \cos b$)-component of the nearby stars and weak for the distant stars. For this reason, but not only for this reason we attribute a greater value to the comparison of *specific* terms of the series development.

A detailed discussion of the physical nature of the motions found here seems premature, especially since we shall soon have the FK5. We were curious, however, as to whether the most obvious defects of the FK4, e.g. its $\Delta\alpha \cos \delta$ wave at extreme southern declinations (Anguita, 1974), are able to produce some of our significant contributions.

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TABLE 1

a) $\mu_l \cdot \cos b$

Nearby stars (N = 378)
g = 5 σ = 147 s = 16.9

j	n	m	l	b_j 0".01/100^a	±	$\sigma(b_j)$	ζ %	FK4	FK4'
1	5	0	1	−17.1	±	8.7	4.8		
2	10	0	1	−17.3		8.2	3.1		
3	3	1	0	−19.7		7.8	1.1	**	**
4	3	1	1	19.6		8.5	1.9	**	**
5	4	1	0	−25.3		8.3	0.30	**	*

Distant stars (N = 128)
g = 3 σ = 64 s = 9.8

j	n	m	l	b_j	±	$\sigma(b_j)$	ζ	FK4	FK4'
1	8	0	1	13.6	±	6.9	1.5	*	*
2	9	0	1	−22.5		7.4	3.3	*	*
3	4	2	0	19.5		6.3	0.38		

b) μ_b

Nearby stars (N = 378)
g = 7 σ = 112 s = 15.2

j	n	m	l	b_j	±	$\sigma(b_j)$	ζ	FK4	FK4'
1	0	0	1	26.0	±	5.8	0.008	***	***
2	3	0	1	22.0		6.7	1.4	**	**
3	5	0	1	19.9		6.8	0.35	*	*
4	3	1	0	−11.4		5.9	3.2		
5	5	1	1	−15.4		6.1	1.9	*	*
6	8	1	0	−11.8		6.4	4.8		
7	2	2	1	−11.0		5.1	3.0		

Distant stars (N = 128)
g = 3 σ = 63 s = 9.6

j	n	m	l	b_j	±	$\sigma(b_j)$	ζ	FK4	FK4'
1	1	0	1	36.8	±	9.6	0.24	***	*
2	1	1	0	−9.7		4.7	2.2		*
3	2	1	1	19.4		8.2	2.0		*

The last rows indicate the appearance in the FK4 (paper I) and in the preliminary improved version FK4':
* with ζ < 5%, ** ζ < 1%, *** ζ < 0.1%.
The total number of stars is 506, because we omitted 6 stars with distances > 1300 pc from the original set of 512 stars.

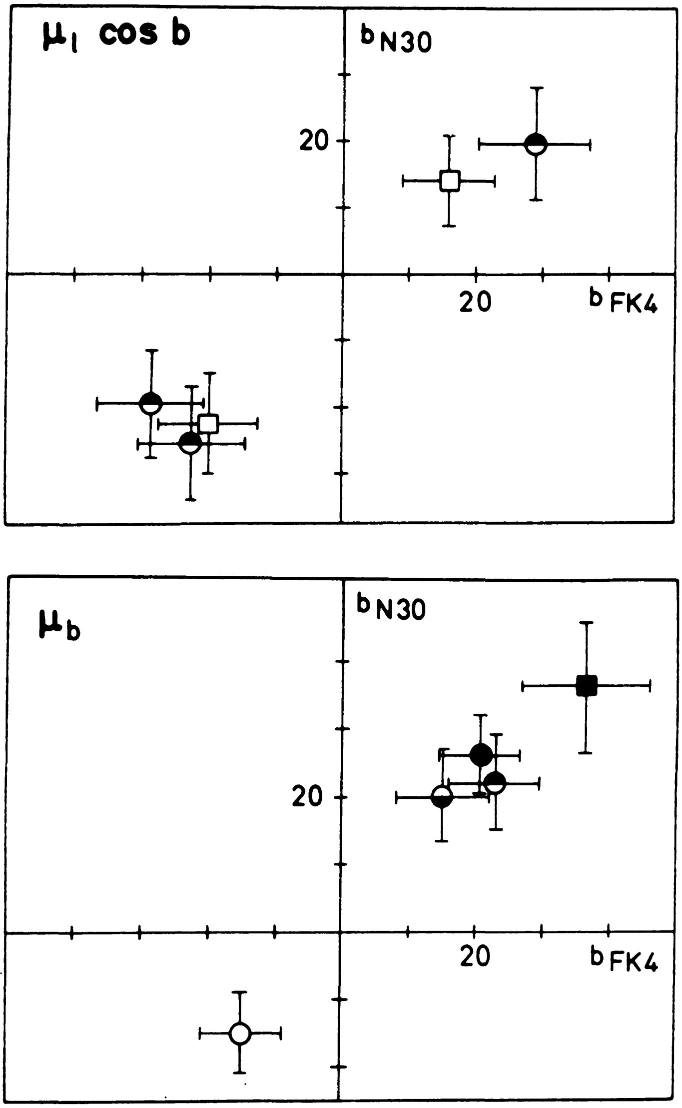

Fig. 1

Comparison of the coefficiens of significant common terms in the spherical harmonics development for the N30 and the FK4.
Circles = nearby stars, squares = distant stars

Filled symbols: the coefficient is significant with ζ < 1% in both catalogues
Semifilled symbols: ζ < 1% in FK4 (upper half) or N30 (lower half)
Empty symbols: ζ > 1% in both cases

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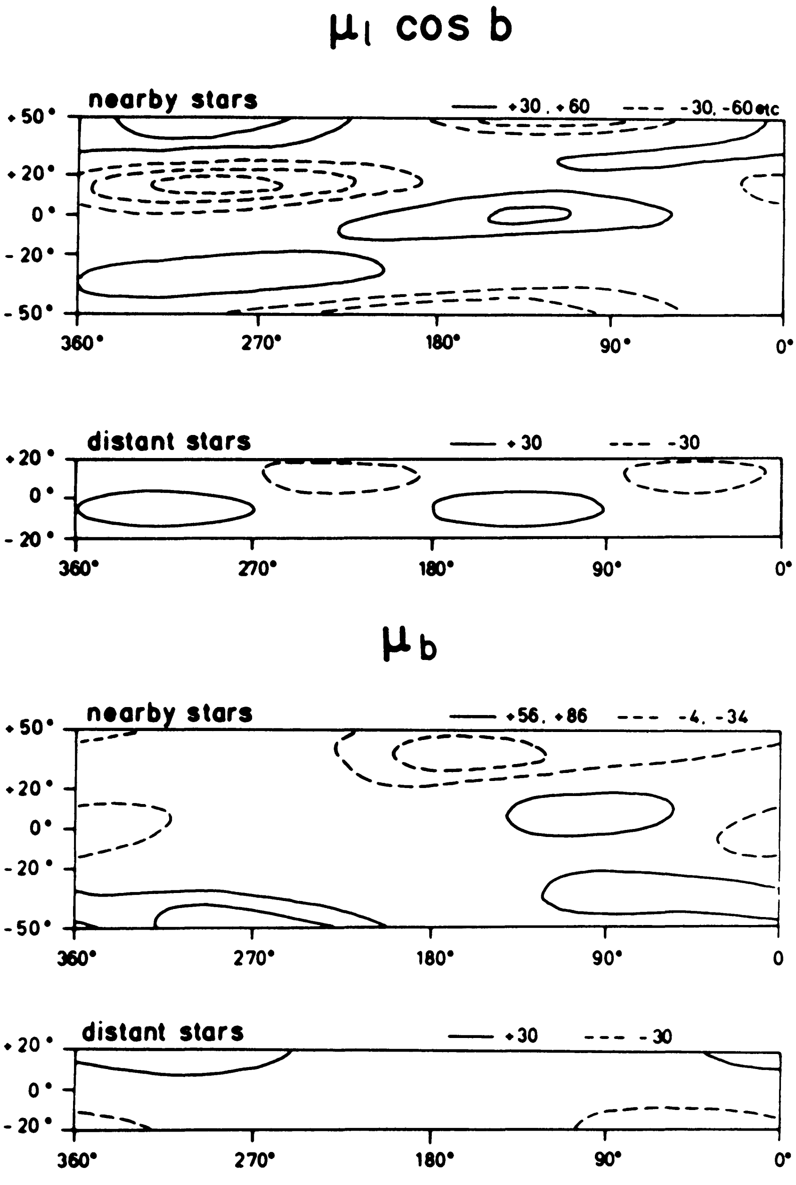

Fig. 2

The systematic non-standard motions of the N30 for the two galactic components of motion and the two distance groups. To exaggerate the important values, isolines are drawn only from about three times the r.m.s. error of the functional values onwards (counted from the constant term in case of μ_b of the distant stars)

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For this purpose the system of the FK4 was corrected in a preliminary way and the resulting (FK4') proper motions of our 506 stars were treated as the FK4 motions in paper I and the N30 motions here. If some of the significant terms are a consequence of that strongest system defects only, they should diminish or vanish after such a correction. Yet the results obtained in such a way are very similar to the ones for the FK4 (paper I).

3. CONSEQUENCES

The most remarkable effects found in paper I were summarized in its Table 4. Examination of the N30-results leads to the following resumé: effects No 1,4,5 are the same for the N30 (within the error limits). Effects 2 and 3 can be interpreted as latitude-dependent group velocities; No. 2 is the same for the nearby stars, while distant stars do not have an (m=1)-function. With regard to No. 3: nearby stars have a certain (m=1)-component, but the values do not coincide with that of the FK4; distant stars also have (m=1)-terms in contrast to the results for the FK4.

Although a firm statement on the consequences of our findings can only be made when the nature of those non-standard motions has been understood, we wish to mention some examples which may need revision in the future. *Cluster motion parallaxes*, e.g. that of the Hyades, are based on the identity of the velocity vectors of the member stars, both in direction and in magnitude. A shift of the zero point of those vectors, that is adding a constant velocity to all vectors, does not affect the results. Hanson (1975) estimated the maximum allowable velocity deviations to be smaller than 1% of the cluster's motion. On the other hand, this condition might be relaxed because (a) a large moving group around the central cluster is able to supply new temporary members to the cluster (b) the possible focussing effect of the spiral density waves counteracts the diffusion (Bubeniček and Palouš, 1983). Hence one should not completely exclude a *real* violation of the identity condition. A part of it could appear in our non-standard motions and cause inconsistent solutions. Likewise, if our effects are errors (and the Hyades most likely are subject to these errors), they will influence the determination of the parallax. Just for illustration and for an estimation of the order of magnitude, let us assume that the average absolute proper motion of the Hyades is in error by the amount of the FK4 effects. Hence the corrected value would be obtained by subtracting our effects. This would make the true proper motion a few % smaller and the distance correspondingly larger. Perhaps we have here a possibility of reconciling the meridian circle cluster parallax with Hanson's value, based on an extragalactic reference. As a second practical issue, let us refer to *secular parallaxes*. Since they are based on the reflex of the solar motion with respect to specific stars, it is of vital importance that this solar motion is constant - and known. Especially our effects Nr. 2 and 3 - whether they are real or not - must drastically influence secular parallaxes. In case our effects are system errors, *any* statistical parallax based on the FK4 and N30 systems is influenced. If the effects are real motions, *only* star classes belonging to our sample are concerned. The latter include classical cepheids. Instead of calibrating them by the requirement that the solar motion from their proper motions fits with that from their radial velocities, we could ask that the first agrees with the solar motion of early type stars from proper motions, which, of course, represents the distance scale of this wider class. If we use Wielen's (1974) solar motion for the nearby classical cepheids and compare it with our solar motion of the distant stars in the FK4 (paper I, Figure 3), we obtain an extension of the cepheid distances by a factor $\lambda \simeq 1.2$ or an increase in their absolute luminosities $\Delta M = -0\overset{m}{.}2$, which agrees better with the new Hyades scale (but this should only serve as an example!).

Perhaps the most perplexing effect is No. 1, which manifests itself by zonal functions in the μ_l of the distant stars. It cannot be represented by a linear velocity field and hence it might have been overlooked so far. The corresponding coefficients are not very significant, but the results for the FK4, the N30 and the modification of the FK4 mentioned above are very consistent with each other. The determination of the absolute rotation of the Milky Way is perhaps the most ambitious task of the whole of classical astrometry. It is based on the fundamental motions of the distant stars. The usual value of Q is just the average over our curves in Fig. 3. If our curves are error curves, the determination of Q depends critically on the galactic latitudes of the contributing stars. In case the curves represent real motions, it would literally mean that a piece of a layer at $b = -5^{\circ}$ does not rotate with respect to the inertial system while other sheets at $b = +10^{\circ}$ and -20° rotate twice as fast as the average; the distance from the intermediate one to the outer ones is about 130 pc perpendicular to the galactic plane. But the other alternative is equally difficult to contemplate. If the appearance of this effect is due to errors, who can be sure that the average is not strongly in error as well? Is it just a stroke of luck that our values for the absolute rotation of the Milky Way are in the right order of magnitude? Or rather not of luck, that is, if their possible deviation from the real value is hidden by such an

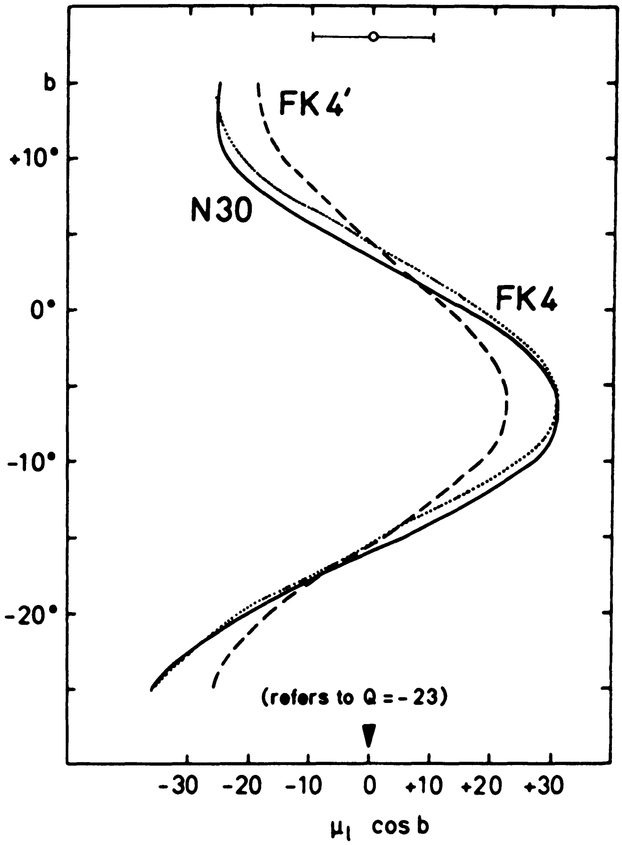

Fig. 3

The zonal part of μ_l cos b of the distant stars for the N30 (———), the FK4 (·····) and the FK4' (----). Note that the zero of the abscissa refers to Q = -23 (0".01/100^a) or B = -10.9 km s^{-1} kpc^{-1}.

apparent consistency? In paper I we expressed the conjecture that a part if not all of the effects found are caused by the 'shingle' structure of the spiral arms. This view has been supported qualitatively by Schlosser and Feitzinger (1983) and Schlosser and Görnandt (1983). It remains to be seen how this picture is able to explain quantitatively the observed facts. The velocity gradients $\frac{dW}{dz}$ perpendicular to the plane of the Milky Way are -18 (km/s)/kpc and +29(km/s)/kpc for the nearby and distant stars respectively (as derived from the μ_b of the FK4 system). This is of the same order of magnitude as the gradients of the HI derived from 21cm surveys (Feitzinger and Spicker, 1983).

4. CONCLUSIONS

Seemingly we have to live with the fact that there are more motions in the heaven or due to the Earth than our scholarly wisdom has dreamt of. For this problem, we expect a much sounder basis for further considerations from the FK5 and from the results of the astrometry satellite HIPPARCOS.

Since this is a methodological meeting, we want to emphasize a more general moral which can be learnt from our special case: we should not trust in the a priori completeness of a theoretical model and we should perform - a posteriori or simultaneously - all possible tests to check its justification. We should search for *every* signal in the data, however unwanted it may be.

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