THE FK5: PRESENT STATUS AND SOME DERIVED RESULTS

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ABSTRACT

Work on all parts of the FK5 is near to completion. The Basic FK5 has been published in the course of 1989 so that this catalogue is now officially released; the data have been made available to the various data centres. Work on the bright part of the FK5 Extension is finished since the end of 1988 and a tape version was sent to various institutions on request. Work on the Faint Extension is also nearly finished and the complete FK5 Extension will presumably be available on magnetic tape in a few months.

Some results obtained from new observations of FK5 stars are presented. Comparisons of the FK5 with FC, NFK, FK3, FK4, GC, N30 were performed and are discussed with respect to systematic and individual accuracy. The parameters of galactic rotation and precession, and the distance to the Hyades cluster have been derived using proper motions which were obtained within the work on the FK5.

1. INTRODUCTION

One of the main purposes of a fundamental catalogue is to represent the conventional celestial reference frame to which the positions of other objects in the sky can be referred. In this sence the Fifth Fundamental Catalogue, FK5 (Fricke et al., 1988) represents the practical materialization of the conventional celestial reference system as defined by the Earth's equator and the ecliptic including also the theories of their motion and involved parameters. For a deeper discussion reference is made to the textbook by Kovalevsky, Mueller and Kolaczek (1989).

The proper motions in a fundamental catalogue are of particular importance since they allow not only the transformation of the reference frame from one epoch to another epoch, but they can also be directly used for investigating the kinematics of the Galaxy or for determining the distances to nearby star clusters.

In order to fulfill these requirements a fundamental catalogue has to be improved from time to time by including new observations and

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using new theories and constants. In the following we want to report on the construction and the present status of the work on the FK5. By comparing the FK5 with all its four predecessors the progress shall be demonstrated which has been made with respect to internal precision and systematic accuracy since the first fundamental catalogue, the FC by Auwers (1879). New observations have recently become available providing information on the accuracy of the FK5; some of these results are presented.

Finally some results for the parameters of precession and galactic rotation and for the distance to the Hyades cluster are given. These results were derived from new proper motions obtained within the work on the FK5.

2. PRESENT STATUS OF THE WORK ON THE FK5

The FK5 will consist of two parts: first the Basic FK5 which is represented by the improved positions and motions of the classical fundamental stars given already in the FK4 (Fricke, Kopff, 1963), and second the FK5 Extension represented by about 3,000 new fundamental stars extending the fundamental system to apparent magnitude 9.5. In recent years Prof. Fricke and myself have continuously reported on the progress of this work. An extensive list of references for these reports can be found in the paper by Schwan(1988a).

2.1. The "Basic FK5"

The "Basic FK5" is the direct result of a revision of the FK4. This revision has been described by Schwan (1987) and, in some more detail, also in the introductory part to the FK5. It is therefore sufficient to give here only a very brief summary of that work. The major parts in the revision of the FK4 were the elimination of the regional errors in the FK4 system, the elimination of the error in the FK4 equinox and of its fictitious motion, the improvement of the individual accuracy of each star, and the transition to the IAU (1976) System of Astronomical Constants.

We have based the FK5 system on about 85 catalogues giving absolute or quasi-absolute observations made after 1900. The improvement of the internal precision of the FK4 could be performed by including new observations given in about 90 catalogues into the FK4 positions and proper motions without re-discussing the old observations already used in the FK4. It seems to be important to mention that this procedure was only possible because the FK4 gives the mean errors for the central epoch of each star. Mean errors of position and proper motion in compiled catalogues should always be given in this way since these quantities are uncorrelated.

In addition the FK4 positions and proper motions were rotated to the dynamical equinox by applying Fricke's (1982) correction to the FK4 equinox (including also the elimination of its fictitious motion), and by introducing the new expressions for general precession (Lieske et al., 1977) which are based on Fricke's (1977) determination of the con-

stant of luni-solar precession and on improved values for the planetary masses.

The FK5 represents therefore, as far as possible, an inertial reference frame related to the dynamical equinox as the origin.

A magnetic tape version of the Basic FK5 has been made available by the Astronomisches Rechen-Institut to various institutes since the end of 1986. With the publication of the printed version of the catalogue (Fricke et al., 1988) the Basic FK5 is officially released and the data have been made available to the various data centres.

2.2. The "FK5 Extension"

The FK5 Extension will consist first of about 1,000 stars in the magnitude range five to seven selected from the FK4 Supplement (Fricke, 1963), and second of about 2,000 stars selected from the list of International Reference Stars in the magnitude range 6.5 to 9.5. This part of the work is being performed in collaboration with US Naval Observatory, where Dr. Corbin is working on the faint part of the FK5 Extension. The mean positions and proper motions are being derived from relevant catalogues of stellar positions observed in the present century. All reductions are made in the FK4 system and still adopting Newcomb's values for the precessional quantities. The final mean positions and proper motions will be transformed to the IAU standards.

The basic material for deriving the Bright Extension consists of more than 100 catalogues with a sufficiently large number of fundamental stars allowing the determination of the systematic relation to the FK4, and with also a non-negligible number of FK4 Sup stars. About 1,000 FK4 Sup stars were selected as new fundamental stars on the basis of the precision of their positions and motions and also in trying to achieve an even distribution on the sky as well as with respect to apparent magnitude. Work on the Bright Extension was completed in 1988 and a magnetic tape version was sent by the Astronomisches Rechen-Institut to various institutes.

Table 1. Average mean epochs and mean errors of positions and proper motions in right ascension (My-A) and declination (My-D) for the Basic FK5, the Bright and Faint Extension of the FK5, and the FK4. Right ascensions are multiplied with cos δ. The proper motions are per century.

Catalogue	Average mean epoch		Average mean errors			
	RA	Dec	RA	Dec	My-A	My-D
Basic FK5	1955	1944	$0^{s}.001$	$0''.02$	$0^{s}.005$	$0''.07$
Bright Extension	56	49	.002	.04	.010	.18
Faint Extension	42	39	.004	.07	.019	.30
FK4	1917	1915	0.002	0.04	0.011	0.17

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The Bright and Faint Extension will be published in one volume. The combining of the two subsets may still cause a few changes in the final star list. Work on the Faint Extension will be presumably be finished within this year, so that a tape version of the complete FK5 Extension (Bright and Faint) may be expected early in 1990.

The errors of mean positions and proper motions of the Basic FK5, of the Bright and Faint Extension and, for comparison, also of the FK4 are given in Table 1. The numbers are averages over the whole sky. An inspection of these numbers shows that the average proper motion errors of the Bright Extension are about twice as large as the errors of the Basic FK5, and the proper motion errors of the Faint Extension are about twice the errors of the Bright Extension. This is a consequence of the poor history of observation of the fainter stars. The precision of the Bright Extension of the FK5 is comparable to that of the FK4.

3. COMPARISON OF THE FK5 WITH NEW OBSERVATIONS

Comparisons of the FK5 catalogue with new observations were first presented by L. Morrison (1987). The Carlsberg Meridian Circle observations made at La Palma and observations made at Bordeaux near 1986 showed similar systematic differences Cat-FK5 in declination in the region near to $\delta = 55$ degrees of the order of 0.1 arc sec. These differences were confirmed by observations made with the new Tokyo Photoelectric Meridian Circle in 1986 (Yoshizawa, Suzuki, 1988). This deviation must therefore be regarded as a systematic error in the FK5. The mean epoch of the FK5 declination system in that region is 1935, half a century from the epoch of the new observations; proper motion errors in the FK5 system give therefore a significant contribution. The early mean epoch in that region of the sky indicates also the considerable contribution of old observations which are likely responsible for this systematic error. It may also be worth mentioning that systematic differences between the FK5 and modern observations can now be detected and determined with much more confidence because of the significant smaller random errors in the FK5 (with respect to the FK4) as well as in the more precise modern observations.

New astrolabe observations made at Santiago de Chile in the zone -5 to -60 degrees in 1976 will be discussed by Noël and Débarbat (1989). The differences $\Delta\alpha_\delta \cos\delta$ between these observations and the FK5 are considerably smaller than those with respect to the FK4 demonstrating the higher systematic accuracy of the FK5 in that region. The mean standard deviations of the systematic differences in right ascension are $0^s.0035$ and $0^s.0016$ for the FK4 and FK5, respectively, demonstrating the increase of internal precision in the FK5 by a factor of about two. The systematic differences in declination are very similar for the FK4 and FK5. This could be expected since the corresponding changes in the transition from the FK4 to the FK5 were small. The mean errors of the systematic differences $\Delta\delta_\delta$ are reduced from $0''.048$ for the FK4 to $0''.026$ for the FK5 demonstrating again the considerable increase of internal precision in the FK5.

4. COMPARISON OF THE FK5 WITH FC, NFK, FK3, FK4, GC, N30

4.1. The catalogue comparisons

The Basic FK5 was compared with all its predecessors: the FC (Auwers, 1879), the NFK (Peters, 1907), the FK3 (Kopff, 1937) and the FK4 (Fricke, Kopff, 1963), and in addition with the N30 (Morgan, 1952) and the GC (Boss, 1937). The purpose of these comparisons is first to provide means for transforming observations from one of these catalogue systems to the FK5 system, and second to get information on the systematic and internal accuracy of the various catalogues.

Table 2. Mean epoch and equinox of the catalogues, the precession used and the differences to the IAU(1976) values at the catalogue epoch, the treatment of elliptic aberration in the respective catalogue and the number of stars; Δm, Δn are per century.

Catalogue	Equinox and Epoch	Precession	Prec. difference IAU(1976)-Cat Δm	Δn	Elliptic Aberr.	Number of stars
Basic FK5	J2000	IAU(1976)	-	-	elim.	1535
FK4	B1950	Newcomb	+1".0376	+0".4360	incl.	1535
FK3	B1950	Newcomb	+1.0376	+0.4360	incl.	1535
NFK	B1900	Newcomb	+1.0444	+0.4412	incl.	925(+662)
FC	B1875	Struve	+0.4790	-0.0886	incl.	539(+83)
N30	B1950	Newcomb	+1.0376	+0.4360	incl.	5268
GC	B1950	Newcomb	+1.0376	+0.4360	incl.	33342

Some data of general interest or of importance for the catalogue comparisons are presented in Table 2. Given are the epoch and equinox of the comparison, the precession used in the catalogue, the differences Δm and Δn between the catalogue and IAU values at the epoch of the catalogue comparison (in the sence IAU(1976) minus Cat), the treatment of elliptic aberration in the catalogue positions, and the number of stars. The two numbers for FK3 indicate the addition of the 662 "Zusatzsterne" and for FC its southern extension from -10 to -32 degrees (Auwers, 1883).

The comparisons were made at the mean epoch and equinox given in Table 2 and by eliminating the effects of different treatment of elliptic aberration and of different precessional values. In principle these terms could have been included in the comparison, but they are more rigourously taken into account by using the conventional analytical expressions. In the transformation of observations from the catalogue system to the FK5 system one has therefore to consider these effects separately in addition to the systematic differences obtained from the catalogue comparisons.

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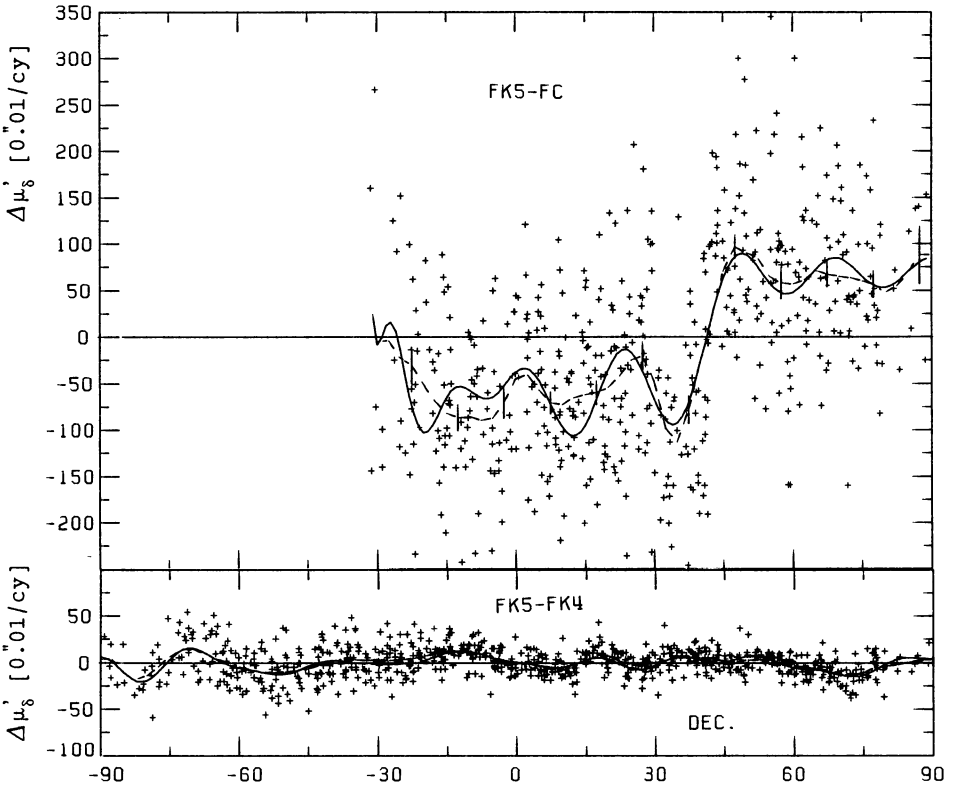

Fig. 1. Systematic differences $\Delta\mu_\delta'$ between the FK5 and FC (upper part) and FK4 (lower part); units are 0".01/cy.

As an example we present in the upper part of Fig. 1 the systematic differences $\Delta\mu_\delta'$ (according to the method by Bien et al., 1978) for FK5-FC and in the lower part for FK5-FK4 (Auwers stars were used only, i.e. star numbers 1-925). Each cross is the difference $\Delta\mu'$ for one common star. The figure illustrates impressively the large improvement made with respect to systematic and individual accuracy from FC to FK4. The FK5 proper motion errors are once more about half the dispersion of the residuals Cat-FK4.

Before discussing the catalogue comparisons in detail we want to give a few general remarks. Comparisons of the FK5 with its predecessors were performed by using only the Auwers stars because these are the only stars in FC and NFK. In addition comparisons with the whole set of FK5 stars were performed. Since the FC and NFK give no mean epochs all comparisons were made at the respective standard epochs (cf. Table 3). The positions at that epoch contain part of the proper motions and these differences are not directly comparable. We restrict the following discussion therefore on the proper motions.

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4.2. Catalogue equator and equinox

A significant part of the differences arises from different zero points (equinox and equator) in the various catalogues. The systematic differences are more easily compared by first reducing all catalogues to the same zero point. With the mean equatorial deviations FK5-Cat (third to sixth column in Table 3) all catalogues were rotated to the FK5 equinox, and the declinations were adjusted according to

$$\Delta_{red} = \Delta_{orig} - \langle\Delta\rangle \, (1 - |\delta|/90)$$

where Δ stand for $\Delta\delta$ or $\Delta\mu'$, respectively. This reduction brings the catalogue equator to the FK5 equator and leaves the pole unchanged.

Table 3. Mean equatorial differences in position (at the catalogue epoch) and centennial proper motion between the FK5 and the various catalogues, the dispersions $\sigma_\mu \cos\delta$, σ_μ, of the residuals FK5-Cat resulting from the catalogue comparisons and the corresponding average quadratic deviation $s_\mu \cos\delta$, s_μ, of the systematic differences (for the region north of -40 degrees).

FK5 - Cat		Mean equat. deviation at the Cat-epoch				Disp. of residuals		Mean quadr. syst. dev.	
Catalogue	Epoch	RA	Dec	My-A	My-D	$\sigma_\mu\cos\delta$	σ_μ,	$s_\mu\cos\delta$	s_μ,
FC	1875	$-^s.071$	$+''.42$	$+^s.179$	$-''.64$	$^s.077$	$''.86$	$^s.035$	$''.56$
NFK	1900	-.055	+.13	+.079	+.19	.034	.47	.021	.23
FK3(Auwers)	1950	+.035	-.03	+.083	-.05	.017	.22	.008	.08
FK3(Zusatz)	1950	+.039	.00	+.090	+.01	.027	.37	.009	.09
FK4(Auwers)	1950	+.035	-.02	+.085	+.03	.010	13	.007	.05
FK4(Zusatz)	1950	+.036	-.01	+.086	+.05	.031	.17	.008	.08
GC	1950	+.028	+.13	+.084	+.17	.023	.29	.008	.15
N30	1950	+.026	+.02	+.081	+.05	.020	.27	.006	.11
FK3(all **)	1950	+.037	-.01	+.086	-.02	.022	.29	.007	.08
FK4(all **)	1950	+.036	-.01	+.085	+.04	.011	.15	.007	.06

An inspection of the mean equatorial deviations in Table 3 shows that the equators of FK3, FK4 and N30 agree practically with FK5, the NFK and GC equators agree approximately with each other but differ from the FK5, and the FC deviates extremely. The mean differences of the right ascension proper motions are also very similar (with the exception of FC) and arise from the equinox correction E = $0^s.085$/cy as determined by Fricke (1982). The proper motion systems in right ascension of all catalogues (FC excluded) show therefore the same rotation with respect to the FK5. For 1950 one derives the deviation E = $0^s.035$ between the FK5 equinox and those of FK3 and FK4, respectively; this difference is the correction applied in the FK5. At 1950 we have

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E = -0^{s}.016 for NFK corresponding to a difference of 0^{s}.053 with respect to the FK3 and in accordance with the correction to the NFK equinox (Kopff, 1937, p. 106). The equinoxes of GC and N30 are identical (Morgan, 1952, p. X) and deviate from FK3 and FK4 by 0^{s}.010 (Kopff, 1937); this is numerically confirmed by the corresponding mean differences in Table 3.

4.3. Systematic deviations Cat-FK5

The systematic proper motion differences as a function of the declination and reduced to the FK5 zero point are presented in Fig. 2. The

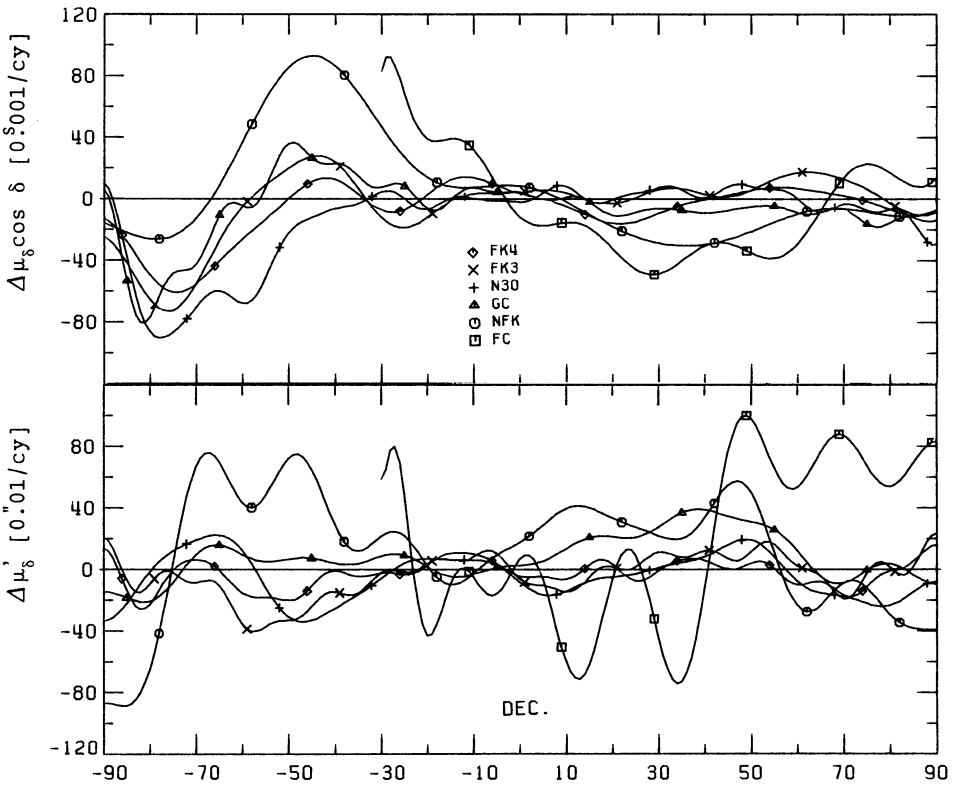

Fig. 2. Systematic differences of the proper motions in right ascension (upper part) and declination (lower part) between the FK5 and the catalogues FC, NFK, FK3, FK4, N30, GC. The differences are reduced to the FK5 equinox and equator. Units are 0^{s}.001/cy and 0".01/cy, respectively.

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FC deviates extremely from all other catalogues and the NFK shows also large deviations in the southern sky. The large errors in the FC reflect directly the systematic errors in Bradley's observations made at about 1755 and re-reduced by Auwers (1888); these are the only old observation used for deriving the FC proper motions. A comparison (not given) of the FK5 with Bradley's observations has reproduced the systematic differences FK5-FC in great detail. All catalogues show for $\Delta\mu_\delta \cos\delta$ a similar trend in the very southern sky. Excluding the old systems of FC and NFK one finds in general only moderate differences between the various systems, and the deviations from the FK5 take only in the southern sky considerable values. For $\Delta\mu_\delta \cos\delta$ there is some similarity between the systematic differences for GC, N30, FK3 and FK4. The mean quadratic deviations between the various catalogue systems and the FK5 are given in the last two columns of Table 3. We have restricted the averaging to the zone north of -40° since the large differences $\Delta\mu_\delta \cos\delta$ in the very southern sky would have dominated the mean. From these numbers one must conclude that the right ascension systems of GC, N30, FK3 and FK4 have, on the average, the same deviation from the FK5, whereas in declination there is a decrease in the series GC, N30, FK3, and FK4.

4.4. Internal catalogue precision

Information on the internal catalogue precision can be found in columns seven and eight of Table 3 where the dispersion of the residuals is given as resulting from the catalogue comparison. The contribution of the FK5 errors are in practice negligible. A comparison of the dispersions for the Auwers stars in the series FC, NFK, FK3(Auwers), FK4(Auwers) reveals that with each new fundamental catalogue their average precision in proper motion was increased by a factor of about two. This holds also for the transition from FK4 to FK5; the estimated precision for the Auwers stars in the FK5 is $0^{s}.004$/cy and $0''.07$/cy for the proper motions in right ascension and declination, respectively.

5. PRECESSION, GALACTIC ROTATION AND THE HYADES DISTANCE IN THE SYSTEM OF THE FK5

Fundamental proper motions are the basic source for the derivation of the parameters for general precession and galactic rotation. In an extensive work Fricke (1977) has determined these quantities in the system of the FK4 and partly including results obtained in the N30 system. The transition from FK4 to FK5 system involves regional systematic corrections to the FK4 proper motions as a function of the right ascension and declination. In a recent paper Schwan (1988b) has shown that these corrections do no significantly change Fricke's values for precession and galactic rotation.

The Hyades distance is one of the corner stones for establishing the extragalactic distance scale. Although van Bueren's (1952) distance modulus m-M = $3^{m}.03$ can now definitely be ruled out there still exists a considerable discrepancy between various recent determinations. The

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mean value for the Hyades distance modulus resulting from investigations using new proper motions is m-M = $3^{m}.31$ (Hanson, 1980).

From work on the FK5 we have obtained improved proper motions for all FK4, FK4 Sup and N30 stars. Among these stars there were 44 Hyades stars which could be used for determining their distances by applying the convergence point method (Schwan, 1989). The distance modulus for the centre of these 44 Hyades stars is m-M = $3^{m}.37 \pm 0^{m}.07$.

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Discussion

MORRISON: Yesterday we heard the result from radio astronomy of a correction of –0.2 arcsec/century to Fricke's value of luni-solar precession. In your recent analysis of the FK5 proper motions, you find no change to Fricke's value. Can you comment on the discrepancy between the optical and radio results?

SCHWAN: It is difficult to say how the optical proper motions can produce effects of the quoted size. But there is a considerable correlation between the precession and the motion of the equinox. It may be that these two effects cannot be well enough separated in the FK5.

MURRAY: How does the precession derived *only* from FK5 declinations compare with the new VLBI values?

SCHWAN: There are differences between the values determined from proper motions in right ascension and from declination-only, but unfortunately I cannot remember the exact numbers obtained from the individual solutions. The precessional correction from μ_δ was indeed in the direction of the VLBI results with a value of about –0.1 arcsec/century and a mean error of comparable size.

NEMIRO: The system of GC has the errors of the type $\Delta\alpha_\alpha$, $\Delta\mu_\alpha$, $\Delta\delta_\delta$, $\Delta\mu'_\delta$. Those errors must be carefully investigated and then the comparision of FK5–GC becomes much more valuable.

SCHWAN: The comparison was made with the aid of the analytical method as published in *Veröffentlichungen des Astronomischen Rechen-Instituts*, No. 29. This method determines the systematic effects depending on the right ascension, declination and the apparent magnitude simultaneously. In the viewgraph I have presented only the delta-dependent systematic differences which describe the most prominent deviations between the catalogue systems.

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