FUNDAMENTAL CATALOGUES

W. Gliese
Astronomisches Rechen-Institut
Mönchhofstr.12-14
D-6900 Heidelberg
Fed.Rep. of Germany

The first plates for the great enterprise, the Carte du Ciel or the Astrographic Catalogue, were taken in 1891. At that time no fundamental system existed which was usable as a basis for reference stars over the whole sky and was commonly accepted by the astronomical community. Therefore reference stars were taken from available catalogues, sometimes updated to the epoch of the plates by application of proper motions. Other observatories used their own reference stars specially observed on transit circles. For the last-mentioned method the work at the Cape Observatory is an instructive example which was described by Sir David Gill, an experienced observer, in a catalogue of Astrographic Standard Stars (Gill, 1906). The methods of observation are fully described in the volumes of the Cape Meridian Observations. For the derivation of proper motions southern catalogues dating from 1835 to 1900 were used, applying Newcomb's values for precession. The determination and elimination of serious systematic errors played an important role. "Eye-and-Ear" observers had their personal errors which even changed with the years for the same person, occasionally even during tiresome long watches in a single night. Further sources of errors include: None-reversible instruments, zenith discontinuities, magnitude equations, possible changes of flexure, pivot errors and their variations, and unsufficient knowledge of the polar motion in old catalogues. Many of these questions were investigated and described in extended introductions to observational catalogues but in some cases such problems were only incompletely explained. Reference stars for the Astrographic Catalogues were observed on various "fundamental system" if fundamental at all.

The historical development of the compilation of fundamental catalogues and their introduction in astrometry is described in detail by Eichhorn (1974) and by Fricke (1985). Two different sources have been used: One is the "German Series" from Auwers first Fundamental Catalogue (1879) to the NFK (Peters, 1907), the FK3 (Kopff, 1937), the FK4 (Fricke and Kopff, 1963), and today to the FK5. This series had the purpose to present the best possible primary reference system. The restriction to 925 fundamental positions and proper motions in the NFK, and 1535 stars in FK3 and FK4 necessitated for the reduction of photographic positions,

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the observations of further reference stars with respect to the primary fundamental catalogue. The "American Series" (as it is called by Eichhorn) from Newcomb (1899), Eichelberger (1925) and Lewis Boss (PGC, 1910) to Benjamin Boss (GC, 1937) resulted in a catalogue of 33342 stars. When some weak points in this immense compilation became evident, an improved catalogue of 5268 stars (called N30; Morgan, 1952) closed this series.

In my opinion it seems not necessary to repeat here the excellent presentation by Eichhorn and by Fricke. My own work at the fundamental system acquainted me with some special problems and I should like to add a few comments.

It has been a long way from Auwers first fundamental catalogue FC to FK5. In 1879 a few hundred stars were compiled as reference stars for the AGK1, which was observed in zones at several northern places. The extension to the south pole was done in diverse steps but until today the southern part of the fundamental catalogue of positions (and even more that of proper motions) remained the problematic region of the system.

In some respect the southern hemisphere presents more interesting phenomena than the northern sky - for instance the Galactic Centre, and the Magellanic Clouds. For meridian observers, however, the lack of bright stars in the vicinity of the pole has been a handicap for observing absolute catalogue systems. Furthermore, the southern observatories active in astrometry in the past are 55° or more from the South Pole in latitude. Determination of a correct azimuth by observations of successive transits of the same star in upper and in lower culmination ("Pulkovo Method") are difficult and most observers did not follow these rules. Southern fundamental systems derived after 1900 assigned the highest weight to the great series of Cape catalogues observed with the reversible transit circle.

After 1960, new quasi-absolute observations made at Cerro Calan by colleagues from Pulkovo and from Chile detected significant positive errors up to $0^{s}025 \cos\delta$ in the FK4 right ascension system south of -45° (Anguita, 1974). Stoy (1974) supposed that different observational methods used for the slow-moving polar stars resulted in an apparent twist of the polar cap relative to the rest of the sky and such a twist in the system was perpetuated by the practice of adopting FK3 places for both azimuth and clock stars.

The question is whether such systematic differences between the α_δ systems observed before 1950 and after 1960 can be produced by incorrect proper motion systems. The problem seems to be complicated by a small catalogue of 67 FK3 circumpolar stars observed during five winter months in 1936 with the Cape Reversible Transit Circle. In addition to the clock stars in the equatorial zone, these 67 stars between -69 and the pole were observed in many successive upper and lower culminations. By this procedure the azimuth was determined strictly absolute, not depending on already known star positions. The right ascension system of this small catalogue did not agree with the systems of the large Cape catalogues of that time. But when this "Cape Catalogue of Circumpolar Stars" (Gliese, 1966) was finally reduced, its α_δ system of 1936 did agree essentially with the systems of quasi-absolute and absolute

catalogues with epochs after 1960.

If we accept these results, what conclusions must be drawn ? If the Cape α_δ system did not vary significantly from 1936 to 1965 no remarkable errors in the proper motion μ_δ system would exist in the Cape catalogue series ! However, it is difficult to assign a weight to a catalogue of 67 stars from -69° to -90° observed during a period of only five months. If this surprising agreement with the catalogues after 1960 did not occur the data from 1936 would not have a great bearing on the fundamental system. However, in view of this result we cannot say that this circumpolar star catalogue is meaningless.

Dr. Schwan will inform us about the FK5 in one of the following papers. I feel sure that for the new fundamental catalogue the best possible solutions have been derived from the material at hand. However, as a very sceptical colleague, I have still some doubt whether the southern observations do allow already the compilation of a fundamental system of positions and proper motion south of -40 with an accuracy comparable with the northern system.

When deriving the proper motions system in right ascension of the FK4 and of its predecessor, it has been assumed that an instrumental system would not change essentially with time. Therefore differences occuring between the α_δ systems of catalogues observed with the same instrument should be produced by the proper motion system.

However critical examinations proved this assumption to be incorrect. A derivation of α_δ systems in the instrumental series of the Greenwich and the Pulkovo catalogues, of the Washington Nine-inch and Six-inch catalogues and of the series observed with the Cape Reversible Transit Circle (Gliese, 1965) showed in all these cases, fluctuations of a few milliseconds from one catalogue to the next, which is not removable by varying the instrumental proper motion systems. From instrument to instrument such fluctuations had different amplitudes. The Washington Six-inch transit proved to be the most stable of the transit circles. In southern declinations the FK4 proper motion system in right ascension is based on the observations with an instrument showing large α_δ changes which occur even during the observations for one large catalogue (2nd Cape Catalogue for 1950) when neither the equipment of the instrument nor methods of observations and reductions were changed. An explanation of these fluctuations is not yet known. So it seems to be recommendable for the derivation of a fundamental proper motion system, not to restrict it to observations with one instrument but to use all absolute catalogues which are available.

The occuring instrumental variations in the Cape series is emphasized by the diagram shown in Figure 1 (Gliese, 1965) of the differences $\Delta\alpha_\delta \cos\delta$ in the sense (catalogue system minus the mean instrumental system). The numbers mark the mean epochs from 1908 to 1958; Z is the declination of the zenith. From 1908 to 1940 (1. Cape Catalogue for 1950) there seems to be a nearly continuous trend towards positive deviations from the mean system. The direction is reversed after that period and the new trend continues until 1953 or even 1958 during the observations for the 2nd Cape catalogue for 1950. The positions used for this comparison were separated into data observed before the mean epoch (1955.7) and after that mean epoch. There appears

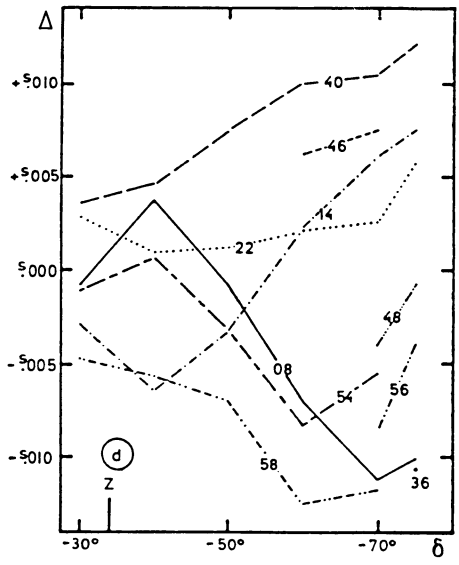

Fig. 1. Observed Differences $\Delta\alpha_\delta \cos\delta$ (Catalogue system - mean instrumental system of the Cape Reversible Transit Circle) from 1908 to 1958. (Gliese, 1965).

a difference of $\Delta\alpha_\delta \cos\delta$ of $-0^s.005$ in about four years. Are these trends really produced by an apparent twist of the polar cap relative to the rest of the sky as supposed by Stoy ? It is noteworthy that the amplitude increases with declination from -30° to -80°. But it is also remarkable that the system of the small circumpolar catalogue observed during the Winter of 1936 does not follow this trend. This catalogue is represented in the diagram by one dot only.

At IAU Symposium No.61 at Perth, Anguita (1974) demonstrated that the southern absolute and quasi-absolute catalogues observed between 1960 and 1970 yielded significant α_δ-corrections to the FK4 system which reached $-0^s.025 \cos\delta$ at -70°/-80°. In the introduction to FK4 (Fricke and Kopff, 1963) the average value of the mean errors $\Delta\alpha_\delta \cos\delta$ at -75° are given as $0^s.009$ for 1935 or about $0^s.016$ for 1965. We conclude that the errors in the FK4 system were significantly undervalued at least in some regions.

And what about the mean errors of the individual right ascensions and declinations ? They are given in the FK4 for each star at its mean epoch. For northern objects these errors are small; the smallest is of the order $0^s.001$ and $0''.02$ in right ascension and declination respectively. The mean epochs of the individual observations are nearly all between 1895 and 1930 whereas those of the system are 1935 (RA) and 1925 (Dec). In a paragraph called "Accuracy of modern observations", Fricke (1985) emphasized that there are some modern catalogues in which the observers have reached an accuracy comparable with or even better than that of the FK4 at the epoch of observation.

As a continuation of the list of star catalogues 1900-1962 (514 entries; Heinemann, 1964) we have compiled 280 catalogues and lists which became available to us from 58 observatories and stations. This

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material contains more than 330000 determinations of right ascensions and declinations by transit circles, transit instruments, vertical circles, zenith telescopes, PZT's and astrolabes. Photographic positional catalogues were not included. Furthermore several very important combined catalogues were published or made available as manuscripts or on tapes: AGK3R (21499 stars), SRS (20490), NPZT 74 and 58 (1719 and 1111), Astrolabe catalogues CGA (1158), GCA-China (606) and GCPA-China (1579), Time Services USSR catalogue KSV (807), and PFKSZ-2 (587). Many of these data have been included in FK5.

With expectation we are all a waiting HIPPARCOS and its results. Many of us are looking forward to using the new accurate positions for deriving a still better fundamental system or for combining these data with ground-based observations. Dr. de Vegt will show in his paper that one hundred years since the beginning of work on the Astrographic Catalogue, it should be enjoyable to recognize its value for modern investigations as well as for earlier ones.

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COMBINED CATALOGUES

AGK3R United States Naval Obs., Washington. On tape. (21499 stars).
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SRS 1986, Southern Reference Stars. Results of the U.S. Naval Observatory compilation. On tape. (20488 stars). Results of Pulkovo compilation. On tape. (20493 stars).

Discussion:

CORBIN Of the catalogues on the diagram, were not most observed without screens, except the latest?
GLIESE Yes, only the ones after 1950 were observed with screens.
CORBIN And was the 1908 not observed with a fixed-wire micrometer?
GLIESE I believe at that time they already had a moving-wire micrometer.
CORBIN Then perhaps I am wrong; I thought the Repsold was installed after 1910 - about 1915. My question then, is: Could the two different sets of slopes in the diagram not be related to a magnitude equation?
GLIESE I don't think so; a magnitude equation is not usually a function of declination.
CORBIN Well, in some catalogues the magnitude equation has been shown to vary with declination to produce an effect coupled with velocity equation.
GLIESE Yes, there have been such effects, perhaps they were a factor here.
MURRAY Was there any formal connection between the AG zone catalogue programme and the Carte du Ciel?
GLIESE Auwers had participated in the meeting of 1887 at Paris. I have just been informed that AGK1 positions were used in some cases as references for AC-plates.
NOEL I would like to point out that the first demonstration of the existence of FK4 $\Delta\alpha\delta$ errors at the Southern Hemisphere was published in 1969 by Anguita and Noel. This was acknowledged by Fricke in a review paper on the fundamental system of positions and proper motions in the Annual Review of Astronomy and Astrophysics in 1972.
GLIESE I was already informed by Zverev in 1964 at the IAU General Assembly at Hamburg; we had a private discussion on these observations at Cerro Calan and the Cape circumpolar observations in 1936.
EICHHORN The diagram which you have shown is a good illustration of what happens if a particular entity - in this case the stellar reference system - is determined on a principle which is different from the one which defines it. The inertial system is defined dynamically, but the stellar catalogue system (at a particular small range of epochs) is realized utilizing only the kinematics of the Earth, specifically the vector of the rotational velocity of that element on the Earth's surface to which the optical axis of the measuring instrument is attached in a supposedly monitored fashion. The fact that these systematic errors occur is an impressive demonstration of

the fact that the model in the total orientation of the optical axis of the measuring instrument is seriously inaccurate. We would have had a better system had we allowed the dynamics of the bodies of the solar system to have their full say in the fixing of the system. This was, of course, impossible without computers, but it would be possible now. With HIPPARCOS introducing yet another measuring principle, completely independent on the vector of rotational velocity of any terrestrial observer, we will have more observational input into the establishment of a self-consistent system. We can only hope that the various group of observers (HIPPARCOS, Earth rotation based) will not insist in preserving their own system, but that an optimum compromise between the various experimental (observational) estimations of the same geometrical entity will be adopted by all those groups who have contributed to its establishment, and be offered to the community of physical scientists.

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