SESSION A

REFERENCE SYSTEMS

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REPORT ON IAU COLLOQUIUM No. 20, 'MERIDIAN ASTRONOMY'

(Invited Paper)

G. VAN HERK
Leiden Observatory, The Netherlands

At the invitation of the Copenhagen University Observatory, 32 workers in the field of meridian astronomy participated in the sessions.

The procedures followed the same scheme as is used in the reports of Commission 8 of the IAU. The subjects discussed were, first, instrumentation; second, reference systems; third, international reference star programmes and special programmes; fourth, investigations.

Invited speakers were respectively B. Strömgren, W. Fricke, J. L. Schombert (the other invited speaker on international reference star programmes, M. S. Zverev, could not participate), and H. Yasuda. None of the invited Soviet Union astrometrists attended the colloquium, so the meeting lacked much valuable advice.

Basically, the topics fell into three time-correlated groups, one dealing with future work, one with the present-day situation, and one with past work.

1. Instrumentation

The future in instrumentation was discussed mainly by Strömgren, Klock and Høg.

STRØMGREN pointed out that astrometry is still important for many astrophysical questions, and hence improvement of astrometrical techniques will help the rest of astronomy. With respect to impersonal methods, he recalled Trumpler's photographic registration of transits, already known in the 20's. Soon photo-electric methods were tried, with intrinsic difficulties, such as the variation in apparent brightness of the star due to scintillation effects and the short time available to do the registrations. These difficulties were greatly overcome by the introduction of the 'flipping technique' in 1933: while the star is passing over a grid in the focal plane, the incoming light is transferred or 'flipped' at regular, registered time-intervals from one photocell to another, enabling the integration to last close to one minute of time. However, when in 1945 a choice had to be made between different techniques for the newly conceived instrument for the Copenhagen Observatory, the photographic method was still chosen, because the modern equipments of the present day were not available then. Modern counting techniques of photon events combined with computerized evaluation of the data is, today, the best possible choice. He recalled the work of Pavlov and Requième in the 60's, and the recent work by Høg. The photographic meridian circle, as it stands today – the work of Laustsen is recalled – compares favourably with the ordinary m.c.: the limiting magnitude to be reached

Gliese, Murray, and Tucker, 'New Problems in Astrometry', 7–21. All Rights Reserved.

is certainly two magnitudes fainter, and the accuracy is the same in α as in δ, and is as good or better than that obtained with the classical instrument. Moreover, no magnitude term seems to be present. It was recalled what high accuracy is needed for galactic research: freedom of systematic errors in proper motions of 0".02 per century is looked for. (Oort's talk of 1952 was mentioned several times in this connection.) The radio astrometric techniques which have come into use lately can give absolute determination of declinations down to the 17th mag., and we need to look for possible ties between the reference system based today on the bright stars and the results obtained on faint objects. The meridian circles should be able to give positions without systematic errors down to the 11th mag. With the use of photo-electric methods we should come to the 13th or 14th mag. Making full use of the photon-events, with a band width of 400 Å, a photo-multiplier with 10% quantum efficiency, a star with $13 < m < 14$ mag. will register 40 primary photon-events per second, and with an observation time of some 30 s, we would have to evaluate an information based on 1000 or more photon-events (an opening of 20 cm is considered). If we reduce with a computer the information stored in time intervals of the order of 0.s01, and choose a width of 6" for the occulting bars in the focal-plane grid to allow for a seeing effect of 3", the required accuracy can be reached, and we can have good positions down to 14th mag. Some 2000 quasars will be available with optical counterparts to the 17th mag. It should not be difficult to pick the meridian circle reference stars of $m \simeq 13$ close to these quasars, and now the magnitude gap is small enough to make the connection successfully. Though there is a gap of avoidance for the quasars, their number is deemed sufficient to evaluate systematic errors of the present reference system in fields 1 h wide and 10–15 deg in δ. The observation of asteroids, pursued to fainter magnitudes, will be done with higher accuracy than today, and much further away from opposition.

Visual observations are still very good when the data are offered to the eye in the correct way as Danjon's astrolabe proves.

In conclusion, absolute observations are very important, and the ultimate goal of meridian astronomy is to tie the results of these absolute observations on the bright stars at the one end to the positions of the fainter stars at the other end.

In the discussion, Tucker suggested the use of one photocell in the flipping technique, but the feared difficulties are not considered of deciding importance, and Høg tells that this flipping technique has inspired him to build his multislit micrometer. Fricke points at the gain in accuracy since 1930: then of the order of ±0".4, now in Brorfelde: ±0".2. Radio-astrometrists obtain today an accuracy of ±0".6 (Wade, 1970), and it will be a big step to come down to 0".02. The risk that the positions from optical methods and radio methods might not be the same was not considered to be serious by Strömgren as long as the radio source had a diameter less than 1". Gliese wanted to know whether the introduction of new, heavy instrumentation to the telescope will not change the results in a systematic way. Klock was of the opinion that this will not be the case if one is careful.

KLOCK described the newly designed meridian circle of the U.S. Naval Observatory, which was at the time of the colloquium still in the hands of the manufacturers, Farrand Optical Co. Inc. The instrument was built with the most modern technical equipment and from the latest type of material, thus ensuring great stability against thermal influences. It is a 10-in. catadioptric instrument, installed on urethane-covered concrete piers. The reading of the angular position of the instrument will be done by two inductosyn-systems, a check for which is provided by a gold inlay circle read by the new automatic circle scanning system. This scanner scans in six places simultaneously. It produces digital data to 1/5000 part of a division interval (0°05). The repeatability is about three times as good as found for the automatic film measuring engines of the USNO, and this confirms the findings at the Copenhagen and Hamburg observatories. The scanning micrometers consist of a geared synchronous motor turning a precision screw which moves a small photodiode-slit assembly. The circle is illuminated by a pulsed Xenon-arc lamp, synchronous with the micrometer screw rotation. The electrical output corresponding to each light pulse is amplified to a level suitable for cable transmission to the control rack. The data points corresponding to the intensity levels are read into a computer each 10 ms. About 600 intensity values define a profile of three division lines on the circle and of the two reference lines attached to each scanner.

The inductosyn-system (electronic angular position transducer) yields angular information through measurement of changing induction between two plates, and is capable of a repeatability of about 0″.04. This system has been used so far as a test on the telescope movement during observing. A temperature instability is still under investigation.

In the new instrument a self-check-system is built in to test the changes in the direction of the optical axis; the flexure can thus be determined in all directions of the telescope.

Høg asks whether this system provides a real check on the connection between optical axis and circle. Klock answers this is not necessary for the purpose if the flexure is small.

HØG describes a suggested new type of horizontal meridian circle made of glass with a zero-expansion temperature coefficient. His underlying idea is to create an instrument with a residual flexure 10 times smaller than is found in the conventional meridian circle. A consequence of this attempt will be that another type of error, namely the determination of the refraction, will be improved upon. The optical parts are mirrors (a model was exhibited). The rotating mirror, covering the meridian is cemented to another flat to check the tilt of the first mentioned one and to the glass declination circle. The image forming mirror whose tilt is checked through a fourth mirror cemented to it, is held in position through rods of non-expanding metal. A minimum number of degrees of freedom is realized in the mechanical parts. The observations are carried out photo-electrically, together with the automatic auto-collimation tests. These tests should allow a sufficient accuracy even when only a short time interval is available. Studies for the best possible ways of shielding the instrument and preventing stratification of the air, are under way.

Anguita refers to the instabilities experienced in zero-expansion glass due to the slow crystallization and he wonders how well one can trust an instrument made of this material. Høg points out that the mirror in his instrument is much smaller than the large Chilean telescope Anguita is referring to, and the coefficent of flexure is 10 times smaller than for the tube, so he believes there will be a good chance the difficulties will not be too serious. Høg expects the reproducibility of the position of the micrometer to be as good as 0″.2, or 0″.02. The tilt of the mirror which covers the meridian should be reproducible to 2″ and therefore this quantity must be measured after every observation of a star to an accuracy of $\pm 0''.05$ in as little as 5 seconds of time. Van Herk remarked that in an ordinary meridian circle the designer also hopes to have zero flexure; it is the practice which shows the deviation from this conception. What will happen here? Høg believed there will be only one Fourier term in the flexure, with no greater coefficient than 0″.02 – which has to be determined in the conventional way. Klock pointed out that there are new methods available for determining the instrumental constants, giving as example Metič's work at Belgrade with a new enclosed tube mark system. Van Herk recalled in this connection the laboratory work done in 1953 by him and De Munck with a tube of 23 m length kept at an inside pressure of 1 mm.

An argument for the need to improve upon instruments was given by VAN HERK who tried to explain Oort's empirical result of 1943, in which he found the technique of observing members of the solar system to improve the equator point in the average to be of the same value as the average from a sufficient number of catalogues where no such observations of solar system members were performed. The systematic errors made in the observations hamper the outcome for the equator point and the equinox. In particular the terms $\Delta\delta_\alpha$ and $\Delta\alpha_\alpha$ will turn up in the computed 'corrections'. Tucker suggested it is not so much a better type of instrument we need, but a better type of observable object, one which will not show such large seasonal correlations which are inseparable from Sun observations. Stoy was of the opinion that systematically we have practically reached the limits of our instruments, and saw the cure as having more instruments to average the errors out. Klock wanted to know whether there is a limitation of declination errors ($\Delta\delta_\delta$) with respect to refraction. Nobody offered an answer. Reiz was of the opinion that, with the high accuracy with which division errors can be determined today ($\pm 0''.02$–$0''.03$) it should now be possible to reduce the systematic terms $\Delta\delta_\delta$ considerably, perhaps even to eliminate it completely. Høg disagreed here: most of the $\Delta\delta_\delta$-term comes from flexure in the tube, the objective, and the micrometer and from the uncertainty in the refraction constant, which in turn is again insufficiently known through the error in the flexure. Gliese reminded us of his *Astron. J.* 1965 paper in which he showed the existence of fluctuations of instrumental systems which cannot be explained.

Of more future plans, LEVY gives an exposé of the efforts made in France where, after a comparison of 6 possible sites for a new astrometric station, the Plateau de Calern, north of Grasse (AM) has been singled out. The site (6 km × 2 km, altitude 1200 m) will be the future location of CERGA (Centre d'Études et de Recherches

Géodynamique et Astronomiques). Since 1971, a time service and a Danjon astrolabe have been installed. There will ultimately be a meridian circle, a wide field astrograph, a long-focus astrograph, equipment for observations of satellites, equipment for distance measurements, a long base line interferometer, gravimeters, and clinometers to study the inclination of the lithosphere. Instruments and workers from foreign countries will be welcome.

REQUIEME described the Bordeaux photo-electric micrometer. A rotating edge-sensor performs the centering on the star image, as in some self-guiding telescopes. The following standard errors are computed for one observation: $\varepsilon_\alpha = \pm 0\overset{s}{.}0069$ (reduced to the equator) and $\varepsilon_\delta = \pm 0\overset{''}{.}20$, with $m < 9.2$. For PZT stars in the declination zone $+40$ to $+60°$, these results are still better ($\pm 0\overset{s}{.}0059$ and $\pm 0\overset{''}{.}168$). A good mounting of the machinery is absolutely essential. The difference in accuracy between α and δ is related to the influence of the divided circle needed in the determination of the δ. Høg was worried over two things: (1) the atmospheric dispersion is a serious problem and with no filter being used to limit the observations to a sufficiently narrow band, the results will show systematic differences on the colour of the star (at $z = 60°$, a B and M type star will show a systematic difference of $0\overset{''}{.}2$, an error very dangerous for astrophysical applications. A visual colour filter should be used, which will cut off at least 1 mag.; (2) the limiting magnitude at dark sky is quoted as 9.5 – with colour filter 8.5, which is 2 mag. less than the Hamburg-Perth instrument has performed. Strömgren had mentioned the possibility of reaching 13.5 mag. Where lies the reason for this discrepancy? The answer is to be sought mainly in the use of too large a diaphragm ($1\overset{'}{.}5$) so that too much sky background and faint stars increase the noise level. Strömgren remarked that we have learned from photometry that dark current is no longer a problem. With a good photo-multiplier and pulse counting technique, even at ambient temperature, the dark current should be 100 times smaller than quoted here. The mechanical qualities of the set-up were so good that it would be worthwhile to try a much smaller diaphragm. Requième pointed out that the size of the latter is imposed by the difficulties of setting the telescope correctly, but Strömgren expressed the opinion that a telescope can certainly be set to a few seconds of arc, and a diaphragm of 15″, as in photometry, should be sufficient. At the request of Benevides-Soares, the time constant for the servoloop and the time interval between contacts at $\delta = 0°$ ($0\overset{s}{.}7$) were given. Klock asked if stars close to the pole could be tracked, and this was confirmed.

LACROUTE proposed the combination of results from two different types of instrument, the meridian circle and the Schmidt camera, in order to connect the system of bright stars, usually observed with meridian circles, with the fainter stars used in connection with the galaxies. The positions from the Schmidt camera come from the over-lapping field techniques. He set out from adopted values for the accuracy with which a meridian observation is carried out (taking Høg's values) and for a Schmidt camera position, using the values given by Andersen. He suggested that each star should be observed with the meridian circle three times to eliminate discordant results. The Schmidt camera positions, though apparently suffering from important systematic errors in some locations on the plates (larger than the purely accidental errors) are in the average of fair accuracy. The Schmidt camera will carry a picture of a reseau to check the relationship between the curved plate and the plane field. The fundamental system (FK4 or a revised improved version) has to be tied by the meridian circle to faint stars (down to $m = 11$), and these faint stars have to be tied to the photographic catalogue of faint stars. What can be achieved in this respect depends on the size of the field in the sky over which the systematic error can be considered to be constant, depending on the average star density in the field, and on the accuracy of the positions. His methods explained in *Ann. Strasbourg* **VI**, 1964, are used. With estimated values for the parameters mentioned, two schemes are considered – a minimal and an optimistic – and the numbers are now given for the stars for which the positions have to be determined in order to reach a required accuracy. In the discussions Høg reported that Dieckvoss has come to the conclusion that the big fields from Schmidt cameras cannot be used for astrometric purposes. Perhaps a field flattener could help. Fricke and Van Herk stated that the Schmidt will give good results as long as the portions of the plate used are small. Strand pointed out that this is different from the problem Lacroute has discussed, and he feels strong doubts about the feasibility of the Schmidt for astrometry over an extended field. Reiz referred to Dixon and Andersen's work and believed that, with the precaution taken to use a circular ring as diaphragm as a mask plate pressed against the photographic plate, the proposal of Lacroute would be possible. Lacroute added that the errors arising from the use of different parts of the mirror could be improved upon by using new non-dilating glass for the mirror.

LOPEZ reported on the Felix Aguilar observatory situated 10 km west of the city San Juan. It is run through an agreement between the Universities of Cordoba and Cuyo. A Repsold meridian circle, with a motor-driven micrometer, and a Danjon astrolabe have been in operation since 1968. Up to August 1972 some 40000 observations on 7190 stars have been made with the meridian circle (the reductions following closely) and 35000 observations on over 300 stars with the astrolabe. Differences in positions with respect to the FK4 have already been given in Brighton.

BENEVIDES-SOARES gave an exposé of the Brasilian meridian circle at Sao Paolo. The instrument is of the Askania type, built by Zeiss (Oberkochen). Great care has been exercised to ensure high mechanical and thermal stability. The pillars are cast from a very homogeneous mixture, anchored solidly to the granite base. The building is protected against solar radiation and has a low heat capacity. Ventilation during the day is applied. The instrumental errors have already been checked regularly; the inclination shows some instability. The impersonal micrometer is motor-driven, the δ-micrometer readings are printed. The 40 cm glass circle will be read by an automatic digital read-out system. A fundamental program of FK4 and FK4 Sup stars is planned.

DEBARBAT recalled various favourable opinions on the merit of observing positions of major and minor planets, and mentioned their importance for theoretical investigations. The Danjon astrolabe is very well suited to participate in this type of work alongside the meridian circles, and in fact the observations over the years 1965–67, made by the two types of instruments do not show any substantial systematic difference, which is very gratifying. It is for this reason that an opinion is asked about a proposal to be made to Commission 8 to recommend the use of Danjon astrolabes for future observations of planets. In the discussion, the unfamiliarity of the practical side of the problem gave rise to doubts whether the connection between the astrolabe observation of the planet and the fundamental stars will be as good as is believed to be the case with the meridian circle observations. In the latter case, from 8 to 30 fundamental stars are observed together with a planet. Now, the astrolabe observers use, in a $1\frac{1}{2}$ h tour, 28 fundamental stars, which are then tied to a planet.

2. Reference Systems

The problem of the fundamental system was broached by FRICKE. He referred to his latest papers: 'Prospects of an Extension of the Fundamental Reference System to Faint Objects and Radio Sources', in press in *Mem. Soc. Astron. Italiana*, and 'Fundamental Systems of Positions and Proper Motions', in *Ann. Rev. Astron. Astrophys.* **10**. The principles underlying the construction of a fundamental system were shortly described. If all the difficulties connected with the motion of the Earth and motions of the stars were overcome, we should have a non-rotating reference system, and the question of the differential galactic rotation would pose no difficulties. All this is not the case in practice. Radio observations can determine today the position of the equator with a systematic accuracy reached in optical astronomy in 1820. There is, however, good reason to believe that the accuracy in absolute declinations will soon be the same as with modern meridian circle work. It is worthwhile to look for the optical counterparts of the radio sources. The α's of these optical counterparts have to supply the zero point in α for the radio system. Proper motions could be improved by connecting them with galaxies. The p.m. obtained via galaxies are free from inaccurate definitions of the equator and equinox, and from uncertainties in the precession. Though the Pulkovo and Lick observatories have already worked in this direction, the goal has not yet been reached. The proper motions with respect to the galaxies agree well in declination between the two observatories, but in α there exists an unexplained difference of $1\overset{''}{.}2$ per century. In the Lick motions a magnitude effect appears to be clearly indicated, and some investigators want this difference to be explained as a real rotation of the brighter stars with respect to the fainter ones around the axis of rotation of the Earth.

Good proper motions alone would not be of much help for a fundamental system, as no ephemerides can be provided in that case. What about a possible improvement and extension of the FK4? There is no doubt the FK4 should be extended to objects as faint as 9^{m}. However, these objects can only be picked out after careful consideration of their suitability: that is, a good proper motion must be found as otherwise the star is of no use in a fundamental system. This depends on the observational history of the star. Perhaps the star list prepared in Leiden on the basis of observational

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history could be of use here. The stars may not be chosen in a narrow range of spectral type – they have to represent all types equally well. In the discussions on this matter, Fricke pointed out he is not in the position to say at this moment which stars, or how many stars will be included in the selection. This has to be considered carefully. The steps to be taken can be arranged under the headings:

(1) Documentation of the observational data;
(2) Problem of extension to fainter limit;
(3) Systematic improvement of the FK4;
(4) Individual correction to data;
(5) The question as to the fundamental constants to be used in defining the new system.

It is emphasized that communication with the observers is very necessary, as past experience has shown that much valuable information cannot be obtained in any other way. The systematic relation between the catalogues and the FK4 has to be investigated. Sometimes incorrect relations are given, so this has to be checked. Therefore it is urged that the results of observations on FK4 stars are given and published by the observers. With respect to the extension to the 9th mag., it was once suggested to use the General Catalogue by Boss, and revise this as soon as enough observations on faint stars would be available. But the Boss system shows a large magnitude error, and the idea had to be abandoned. Fricke wants to use the AGK3R and the SRS as a basis instead, to pick out the fainter stars to be included in the FK4. In building the new system, observations from prior to 1900 will probably no longer be used. For the documentation Gliese will give a report.

As to matters of a general nature, the equator is more easily determined than the position of the equinox. The equator for the FK4 was derived from observations of the Sun and planets from 1857 to 1949. The corrections to the FK3 equator were small quantities within the range of the formal accuracy. Leaving out catalogues from before 1900, the same result was obtained. It is doubted whether 20 more years of observing will improve the situation materially. With the equinox the situation is different. The corrections found to Newcomb's N_1 gave values between $-0^{s}.028$ and $-0^{s}.073$, but no secular change could be detected. The fundamental p.m. in α are affected by an erroneous motion of Newcomb's equinox; the correction, according to Fricke, to be applied to the FK4 p.m. is $1''.23 \pm 0''.15$ per century. The inconsistency in the FK4 (present in all catalogues after 1900) is that no attempt has been made to eliminate this effect in the p.m. – only regional corrections were applied. The same is the case with the obliquity of the ecliptic. A complete rediscussion will be made to investigate the ΔE and $\Delta\varepsilon$ plus new data on the precessional constant. The compiler is not free to use the constants he deems best, but has to stick to the ones which have been internationally agreed upon. It is pointed out that the difference found in the precessional constant is caused by the difference between the declination system of the first fundamental catalogue and the declination system of the FK4. Newcomb took the Auwers-Bradley catalogue of p.m., improved this a little, and the difference between this system and the modern catalogue system is a rotational component of the declination p.m. system around an axis directed to 6^h. Personally, Fricke believed it is time to change the precessional constant, but it is necessary to consider all consequences. A change is likely to be made with the adoption of new masses of the planets which play an important role in constructing ephemerides. Perhaps a decision can be taken in 1976.

Tucker asked whether the criteria of observational history cannot be relaxed so that a more restricted range of magnitude and colour may be represented in the faint stars added to FK4, but Fricke was against this restriction. Schombert reported that within 6 months the USNO will have available five or six thousand proper motions of AGK3R stars with the best observational history. Klock announced that the 6-in. transit circle at Washington has added Flora and Metis to its minor planet list. The major planets are now observed over a much wider range of arc. Van Herk remarked that with the change in p.m. system from FC to FK4, a change in the precessional constant was to be expected. But it remains necessary to explain why this big change did take place, there is something to worry about. Fricke stated that the NFK contains results of many more observatories than FC did, and the position of the equator was, for the first time, determined from solar observations in the northern and the southern sky.

GLIESE reported about the documentation of catalogues made available in the last 20 years, and which were not yet incorporated in the FK4. A preliminary inspection dealt with the instrument, the program, the epoch, region of δ, number of stars, the magnitude range, the observational errors, and whether the catalogue was observed fundamentally or not. From 38 observatories a total of 143 catalogues is available; of these, 102 include bright stars ($m<6.5$), and 89 include faint stars ($m>6.5$); 107 give α-observations, 81, δ-observations (the time services are responsible for this unbalance). In an optimistic mood, Gliese guesses the number of absolute catalogues to be 25. In all some 140000 positions of stars are given. The PZT, the Latitude and the Astrolabe lists will be investigated. Some catalogues are published in combinations, and it will be necessary to investigate how these will be dealt with. References to observations which will be finished in the next years will be very much welcomed. Often Gliese finds in literature comparisons given of observations with a fundamental system, but the conditions of observing are often not given. To judge the catalogue, these details should be published. Stoy wanted to know whether planets should be observed every night. Fricke, referring to the work of Jackson at the USNO, said it does not help to observe the planets every night, as long as the observed arcs remain short. Strömgren was of the opinion that all minor planets should be observed.

Stoy advocated the use of the results from photographic catalogues as well in constructing the fundamental system. Fricke was very doubtful in this respect as he fears the magnitude errors in the photographic catalogues above all. Van Herk ventured to remark that meridian circle catalogues show magnitude errors as well. He had, however, an example of a large discrepancy in photographically determined p.m. similar to that mentioned by Fricke: in the work done on more than a thousand common stars at Hamburg (Osvalds) and at Leiden (Pels), the p.m. in δ agree reasonably well, but the p.m. in α show systematic differences of the order of 1″ per century, totally unexplained.

The state of the internationally executed reference star programmes was described by SCHOMBERT for the epoch July 1, 1972. His report culminated in a table in which, for each participating observatory is given, amongst other items, the declination zone to which each instrument was committed, the number of stars to be observed, and the number of observations to be performed. This table will appear in the IAU report of Commission 8 and is, therefore, suppressed here. The number of observations carried out is very near to 100%. Of the reductions necessary (it may be recalled that the USNO carries out the apparent place reductions for all participants who wish it, and a great deal of the refraction computations as well), an average percentage of something near 78 has been finished.

The question how the final catalogue of the SRS stars will be compiled, drew some debate. Anguita asked whether the final reductions of the SRS stars should be done in the original FK4 system or, knowing that there are strong systematic and accidental errors in the FK4 in the southern hemisphere, should the reductions be done in an improved FK4 system? Gliese remarks here that various published observations show serious errors in the southern α-system in the FK4. More observations are forthcoming. The question arises whether an intermediate α-system should be compiled or, whether we should wait for the results of the observations now under way? Anguita mentioned more recent results than Gliese did. Fricke was of the opinion that the SRS stars should be reduced in the FK4 system. Høg pointed out that this is not an unambiguous statement. Every observatory has its own tradition for distributing the FK4 stars during the night and along the meridian. This is one reason why each observatory ends up with its own system. Every observatory should use its own improved FK4 positions if they wish, provided the observed positions of the fundamental stars are published. This is an essential requirement which has not always been fulfilled. Anguita framed his question in a slightly different way: Will the final SRS catalogue be given in the FK4 system or in some improved system? He further raised the question who was in charge of this program at the beginning. There had been a division of the work at the $-30°$ boundary, one zone under the responsibility of the USNO, the other under the Pulkovo observatory. Strand recalled the past history of the program, the selection of the stars, the chairmanship of the subcommittee of Commission 8, and what part the USNO has done in the reductions. Schombert reported that an agreement had been made between Pulkovo and Washington: all observations will be reported to the USNO and to Pulkovo, the first undertaking to compile the final catalogue. The proposed resolution was amended at the request of Tucker, so that other institutions would be entitled to receive the data.

YASUDA dealt with the special programmes. He pointed out the importance of programmes like the PZT star programme, as it is only possible to connect the different zones of PZT stars with a meridian circle.

It is hoped that, in doing so, systematic errors in the different zones which are, at present still there, will be attenuated. This would result in a better control over the polar position, as the latter is connected with errors of the type $\Delta\alpha_\alpha$ and $\Delta\delta_\alpha$. The secular variation of the polar motion is affected also as the p.m. of the PZT stars are uncertain. The observational part of the northern PZT star programme is shared by 12 meridian circles and one vertical circle, with 4–6 observations per star for each instrument. The results from the observations performed between 1950 to 1970 will be compiled into a preliminary catalogue, and each time a new complete set of observations becomes available, this set will be incorporated in the existing catalogue.

The special programmes on O–B stars are observed at Tokyo. It was stressed that these stars, as well as Cepheids should be observed in the south. Tucker expressed disagreement with Yasuda's phrasing of the recommendation to limit the observations to narrow zones. The main object, to link the different zones, will be endangered. Requième remarked that, for good differential observations, narrow zones would be best, but to link the zones one should go to at least 40° width. Lacroute agreed with this suggestion, as it all depended on what purpose one has in mind. Gliese asked how the stars would be chosen to make the connection between the different zones. Høg pointed out the importance of having all division errors determined in work on narrow zones. Dejaiffe recalled the possibility of linking the PZT stars to the FK4 through the intermediary of the ILS catalogue, which has been tied to the FK4 by the Melchior-Dejaiffe catalogue. It would be profitable to include more ILS stars in the PZT programmes to improve the interconnection.

3. Various Investigations

ISOBE had analyzed the results of the observations of FK4 stars obtained during the AGK3 campaign of 10 meridian circles, and of those stars observed with the Tokyo m.c. during the SRS program. He separated the influence of the systematic error from that of the random ones by analyzing the $(O-C)$'s according to the number of observations on each star. The equation of condition is the well-known relation between the variances for the total error, the systematic error and the nth fraction of that for the random errors, with n the number of observations on the star. He concludes that, in general, with a number of 10 observations per star, the influence from the random errors is of the same order of magnitude as from the systematic errors. Notable favourable exceptions are the Nikolajev and Washington 7-in. instruments.

SCHOMBERT presented the analysis of the differences of the AGK3R stars as found in the AGK3 with those given in the meridian work. There is a discrepancy between the two catalogues in α. These differences exist for a number of consecutive hours, and then vanish. For different zones of δ, these peaks shift to slightly different hours. These differences show a small scatter, and have, for nearly all 5° zones the same value of approximately $+0\overset{''}{.}09$ (sense AGK3R–AGK3). These differences were noticed when the proper motions of the AGK3R stars were derived (the mean errors of these p.m. are of the order of $\pm 0\overset{''}{.}35$ per century) and these p.m. showed fairly systematic differences from the AGK3 p.m., being large near the equator and in the late hours. It was remarked by various people that the differences just described could, perhaps, be due to magnitude errors, and Schombert will look into this matter further. (At the time of the colloquium this investigation was not yet complete. Further investigation has revealed that the differences mentioned are no longer significant: application of the influence of the proper motions due to the differences in epoch between the meridian and the photographic observations made the differences in position disappear. The findings are now in good agreement with the results found by Dr Dieckvoss earlier).

MARCUS discussed the 3000 differences in positions of the Bucharest KSZ stars with those given in the AGK3R. In the equatorial zone of 2° width, the greatest value for $\Delta\alpha$ is $+0\overset{s}{.}010$ for $10\text{ h} < \alpha < 12\text{ h}$. This is similar to the findings given in Schombert's work. – In the discussion: Høg was of the opinion that the similarity with Schombert's work is spurious, and Schombert was afraid the AGK3R could be wrong. – The majority of the $\Delta\alpha$ differences are positive, that of the $\Delta\delta$ negative. A magnitude relation seems hardly to exist. Graphs, representing a three-dimensional representation of the differences show the $\Delta\alpha_\alpha$, $\Delta\alpha_\delta$, $\Delta\delta_\alpha$, $\Delta\delta_\delta$ relations. Küstner series of FK4 stars served to correct the Bucharest observations to the FK4 system; for the declinations, no such correction was found necessary. The differences have been represented by trigonometrical expressions, with coefficients determined from the maxima and minima of the surfaces, using the second derivatives to determine the signs. In the discussion, Marcus points out that temperature differences have been measured at Bucharest, where the meridian circle is poorly situated with respect to the surrounding buildings. Lacroute advocated the method of 'Synthesis' used at Strasbourg to get the best possible connection with a fundamental system. This method reduces the random errors at the same time.

TELEKI sees great need for a more detailed study of the astronomical refraction. The study group, established by the IAU Commission 8 has made a number of studies in this field. Variations in the air density around an observational site depend on the time of the day, the amount of water vapour, and the refractive index cannot be calculated, at present, with sufficient accuracy, neither with respect to accidental, nor to systematic errors. This is a consequence of insufficient knowledge of the meteorological elements, and of the lack of dynamical parameters in the formulae. The vicious circle formed by the dependence of the refraction determination upon the instrumental flexure should be disrupted. The atmospheric dispersion as well as the inclination of the lower layers of the atmosphere should be taken into account. Studies on an extension of the theory to an asymmetrical distribution of the air-density are under way. The almost universally used Pulkovo tables should be revised for every observatory to meet its local circumstances. Plans were outlined to connect the refraction tables to aerological data, to study the non-homogeneous refraction, depending on the size of the scattering particles, the influence of the absorption lines. A full report will be given at Perth.

Høg's request to specify what an individual observer has to do, could not be specifically answered, but contacts with the nearest meteorological station would help. Tucker thought it preferable to determine corrections to the standard tables as is done at Greenwich, rather than introduce a greater number of standard tables. Teleki emphasized again that refraction is a local effect. The determination of the correction for refraction directly from the observational data is not correct. Strand recalled the work he had done on determining refraction near the horizon with the aid of lunar photographs (Dearborn), and he found great changes from day to day with systematic differences of up to 5%. Fricke suggested that, as radio astronomers have difficulties in determining the refraction, a radio astronomer should be contacted for the study group. Both Fricke and Van Herk stressed that the colour differences amongst the stars had a non-negligible effect on the refraction.

VAN HERK described some results of catalogue comparisons. A magnitude term is still demonstrable, and it would be better if meridian circle observers published the value of this parameter, the true apparent magnitude while observing. He defended on physical grounds the process of determining the $\Delta\delta$ according to α directly: stars at 5 h right ascension are observed in entirely different conditions from those at 17 h. This can be shown to be the case in practice. A two-dimensional plot of the differences show areas of equidifference provided the average star density is not too high. In regions where this density is much higher, this gentle picture is disrupted. It seems obvious that, with many more stars, many more nights are involved, with the consequence that entirely different systematic errors traverse each other. The influence of the differences found between the first Grw 1950 and all other catalogues was mentioned; here it is seen that within a small zone, of only 6 to 8 deg width, large differences can occur. Tucker stated that at Herstmonceux, no differences are found in results for stars observed with and without grating. Reiz asked whether the Brorfelde meridian circle, assuming that this is working without magnitude errors, could be of help in checking this type of error in other catalogues, as there will soon be available a catalogue with some 3000 stars in it. Van Herk hoped that the results on the observed FK4 stars will be published as well, as otherwise the comparison would be much more difficult. Gliese asked for an explanation for the fairly large magnitude equation observed between the photo-electric positions in the Russian Time Service Catalogues and the fundamental catalogues N30, FK4. Høg replied that the reductions for his multislit micrometer are entirely symmetric, but in the Russian method one has to rely on a time constant of a d.c. amplifier, and thus a magnitude term could become possible.

YASUDA described the comparison of the 8 PZT catalogues now in use with the AGK3R; the positional differences are analyzed according to $\Delta\alpha_\alpha$ and $\Delta\delta_\alpha$, and the periodic coefficients computed. A large dispersion exists amongst these coefficients. The observations made differentially to the FK4 system have revealed already differences with the FK4 of the type $\Delta\alpha_\alpha$ and $\Delta\delta_\alpha$.

HØG recalled that we are now fairly sure to be able to observe very faint stars with meridian circles in the near future and saw the problem arising of the choice of a reference catalogue of faint stars, to which Fricke emphatically agreed.

MARCUS mentioned that the Prague Observatory would like to see their list of PZT stars embodied in the general programme of PZT stars observed by meridian circles. FRICKE pointed out again what is needed: assume an O star to be at 1 kpc distance. The cosmic scatter in the radial velocity is of the order of 10 km s^{-1}. To reach this limit in the proper motions, these should be known far better than what is achieved today. The idea that the AGK3 would help in this respect was unfounded optimism – we need p.m. with a standard error at least 3 times smaller. Therefore, many more meridian circle observations on O and B stars will be necessary to achieve this goal.

VAN HERK read a letter by Dr J. DOMMANGET, President of Commission 26 (Double Stars), in which the participants are reminded of the urgent need for meridian observations of visual binaries, resolved or unresolved (IAU Colloquium No. 18). If any meridian circle observer is interested in the subject, members of Commission 26 offer their help in establishing suitable programmes.

MARCUS mentioned the observation of double stars at Bucharest; Van Herk recalled the programme started at the USNO in the sixties. Strand mentioned a number of 700 double stars which have visible motion. Reiz was of the opinion that it was not worthwhile observing too narrow double stars with an instrument with a focal length of 250 cm.

4. Resolutions

The following resolutions were brought forward to be recommended to Commission 8 of the IAU.

(1) The recommendation made by Commission 8 at the XIV General Assembly concerning the development of new instrumentation and techniques is re-affirmed. In particular, the provision of a modern transit circle for the Tokyo Astronomical Observatory is strongly recommended. It is further recommended that a Study Group be established for horizontal meridian circles.

(2) It is recommended that an improvement of the FK4 and its extension to a fainter magnitude limit, resulting in a new fundamental catalogue, the FK5, be carried out at the Astronomisches Rechen-Institut, Heidelberg; that observatories throughout the world contribute to this project by providing basic observations, on punched cards if possible; and that all information pertinent to the formation of the FK5 be transmitted to the Astronomisches Rechen-Institut with the observations.

(3) It is recommended that meridian catalogues should include, in addition to the tabular magnitude on a recognised system, an indication of the screens used for each star, so that the approximate magnitude at which the star appeared to the observer can be deduced.

(4) It is recommended that programmes of observations of fundamental stars, with meridian circles and astrolabes, should include members of the solar system.

(5) It is recommended that the SRS catalogue should be compiled by the U.S. Naval Observatory, Washington; and that this observatory should send the basic data to the Pulkovo Observatory and, on request, to other institutions.

(6) The recommendation made by Commission 8 at the XIV General Assembly concerning the inclusion of FKSZ stars in fundamental observational programmes is re-affirmed, with particular reference to observatories in the southern hemisphere.

(7) It is recommended that the work of the Study Group on Astronomical Refraction that has been formed by Commission 8, should continue to be supported.

DISCUSSION

Fricke: I should like to make an addition to Dr van Herk's report. The resolutions adopted at Copenhagen have been submitted to be considered and endorsed by Commission 8 at Sydney. As I have found out in correspondence with members of the Commission, these resolutions will require some changes and additions in order to obtain the approval of the Commission. The most important change concerns the compilation of the SRS catalogue. The compilation is to be carried out for the whole southern sky at the Pulkovo Observatory and at the U.S. Naval Observatory. Consultations on the best possible system for the SRS catalogue shall take place between the Astronomisches Rechen-Institut at Heidelberg, the Pulkovo Observatory and the U.S. Naval Observatory.