COMMISSION 8 : POSITIONAL ASTRONOMY (ASTRONOMIE DE POSITION)

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I. INTRODUCTION

According to the recommendations of the Paris IAU Secretariat, the present triennial commission report is intended to put special emphasis on outstanding achievements around the main objectives of the commission rather than on abstracting all the literatures relevant to the commission. The highlights of the commission during the triennium under review have been the establishment of the conventional stellar reference frame FK5, an intensive effort in extension of the stellar reference frame to a celestial network of higher star densities and fainter magnitudes, and the launch of the astrometric satellite HIPPARCOS, as are described in this report. IAU conferences of interest to the commission and its membership held during the past triennium include the following:

IAU Colloquium No.100, "Fundamentals of Astrometry" was held at Belgrade in September 1987. H. K. Eichhorn, C. A. Murray, and A. R. Upgren are editing the proceedings.

IAU Symposium No.133, "Mapping the Sky—past heritage and future directions" was held at Paris in June 1987. The editors of the proceedings are S. Débarbat, J. A. Eddy, H. K. Eichhorn, and A. R. Upgren (46.012.073).

IAU Symposium No.141, "Inertial Coordinate System on the Sky" was held at Leningrad in October 1989. The editors of the proceedings are J. H. Lieske and V. K. Abalakin.

II. GROUND-BASED OBSERVATIONS

1. Meridian Circles

The **Carlsberg Automatic Meridian Circle (CAMC)** continued in regular use at the international observatory of the Roque de los Muchachos on the island of La Palma in the Canaries. It is operated jointly by the **Copenhagen University Observatory**, the **Royal Greenwich Observatory**, and the **Real Instituto y Observatorio de la Armada en San Fernando**.

A new and more accurate micrometer designed by Helmer was fitted to the CAMC and came into regular use in 1988. The first results were presented at the XXth IAU General Assembly in August 1988. The accuracy in the zenith of a single observation with the new micrometer was 0.14 arcsec, compared with 0.19 arcsec on the old micrometer which was used up to February 1988. The limiting magnitude was increased to $14^{m}.8$, enabling Pluto to be observed for the first time by a meridian circle. These observations were reported by Fabricius *et al.* (1989, IAU Symp. No.141).

The **Carlsberg Meridian Catalogue – La Palma – No.3** was published (45.002.036). It contains positions, proper motions, and magnitudes of 19156 stars north of declination −45°. The limiting magnitude is $m_v = 13.3$. With the availability of the FK5 Basic in 1987, the CAMC observations made in the years 1984 to 1986 were re-reduced using the FK5 positions. The revised positions of the program stars were combined with the observations made in 1987 to form one homogeneous catalogue. The catalogue was issued in June 1990 as **Carlsberg Meridian Catalogue – La Palma – No.4**. It comprises 50929

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mean places and magnitudes of stars, based on nearly 300000 observations. The catalogue also contains nearly 8000 positions and magnitudes of 68 solar system objects. The contribution made by this catalogue to the optical reference frame was discussed by Morrison *et al.* (1989, IAU Symp. No.141). The Catalogue has an average density of 1 star per square degree in the declination range $-45°$ to $+90°$, and an average accuracy of 0.12 arcsec in position and 0.3 arcsec in centennial proper motions for stars with $m_v<9$. A joint discussion of the CAMC observations of FK5 stars with those made at the Bordeaux Observatory provided evidence of systematic errors in the FK5 Basic reaching 0.1 arcsec in some parts of the sky.

As a start to extending the reference frame to fainter magnitudes, stars (FRS) in the range $11 < m_v < 12$ and at a density of 1 star per square degree were selected at the Copenhagen University Observatory from the northern zones of the Astrographic Catalogue. Observation of these stars was started in 1989 at La Palma. The selection of stars in the southern hemisphere continues at San Fernando (Morrison).

The **U. S. Naval Observatory** continues with its effort to make absolute observations of the FK5, IRS and Radio Stars and differential observations of the IRS. This is the Pole-to-Pole Fundamental Program involving the **6-inch Transit Circle** in Washington and the **7-inch Transit Circle** in Black Birch, New Zealand.

In April 1989 the first circle of the northern portion of the 6-inch program was completed with a total of 122054 observations for the AGK3R, FK4, FK4 Sup, Faint Fundamental and Radio Stars in addition to solar system objects. After the completion of the first circle the photoelectric circle scanning system was replaced by a system using CCD cameras. A similar system will be installed in New Zealand in the near future. The second circle observations commenced in February 1990.

The 7-inch Transit Circle in Black Birch began its program in June 1987. In the past triennium each year of the program has shown an increase in the number of observations, and 53637 observations were carried out in 1989. The 7-inch has been particularly successful in its daytime observation in that substantial numbers of clock and azimuth stars are observed in conjunction with the Sun, Mercury and Venus during most day tours. This should permit reduction of these tours free from the difficulty to determine day-minus-night correction. Comparisons of solar system observations made by the 6- and 7-inch transit circles show excellent agreement between the visual observations and those obtained by the image dissector (Corbin, Gauss).

Since 1987, the **Pulkovo Horizontal Meridian Circle (Pulkovo HMC)** has obtained about 10000 observations of the FK5 and IRS stars (Kirian). The Kislovodsk Mountain Station (h = 2100m) of the **Pulkovo Observatory** has made, with the Struve-Erthel Vertical Circle and Struve-Erthel Large Transit Instrument, about 2500 observations of remarkable accuracy of the Sun, Mercury, Mars, and day-time stars (Devyatkin and Gnevysheva: 1989, IAU Symp. No.141). The **Nikolaev Observatory** has continued observations for the Sun and inner planets.

The **Bordeaux Automatic Meridian Circle** has been used for the determination of positions of 6000 northern Non-Astrometric stars which were included in the HIPPARCOS input catalogue in due time. A catalogue of 220 Radio Stars observed at least 20 times is in preparation. Since 1989 the FRS program proposed by the CAMC group (1 star per square degree with $11 < m_v < 12.5$) has been observed at Bordeaux for the zones $+10°$ to $+25°$ and $+50°$ to $+76°$. Evidence of systematic errors of the FK5 as a function of the declination was confirmed by both CAMC and Bordeaux. A global reduction method developed at Sao-Paulo by Benevides-Soares and Teixeira was successfully applied to two years of Bordeaux Automatic Meridian Circle observations in a single least squares adjustment (Requième).

At the **Cerro Calan National Astronomical Observatory, Santiago** (Chile), the Repsold Meridian Circle has been modernized. In the past triennium, more than 10000 individual observations have been carried out for stars, including 42 radio stars, and 5 major and 4 minor planets. Second epoch observations are in progress for 7610 IRS program stars included in the Santiago 67 Catalogue (Carrasco and Loyola: 1989, IAU Symp. No.141), and they are going to be used for determining the proper motions of these stars. Observations of 651 FKSZ program stars were completed, where 40 FKSZ and 82 FK4 stars were observed in both culminations. Using Zverev's quasi-absolute method, reductions of these stars are in progress. Based on observations in the period of 1963–1968, the **Santiago Declination Catalogue** of 412 FK4 stars was published (43.002.001).

In 1987, Li Dong-ming and Luo Ding-jiang have organized three photoelectric transit instruments and four photoelectric astrolabes in China to observe bright stars (600 FK5 stars and 1400 GC stars). At the Beijing Astronomical Observatory, a photoelectric micrometer was mounted on the **Beijing Transit Instrument**, with which stars of 9th magnitude can be observed. Based on observations during the period 1980–1984, the Third Preliminary Catalogue of Stars' Right Ascension with the **Photoelectric Transit Instrument (PPCP3)** at Beijing was compiled (Luo Ding-jiang, Lu Lizhi).

At the Belgrade Astronomical Observatory, astrometric work with the **Belgrade Meridian Circle** has been continued, and since 1975 the meridian circle has made regular observations of the Sun and inner planets (Sadžakov and Dačić: 1987, IAU Colloq. No.100, see also 46.041.035 and .036).

Since 1985, the **Tokyo Photoelectric Meridian Circle (Tokyo PMC)** of the **National Astronomical Observatory**, Japan has been in regular operation. The first observation program comprises about 33000 stars and solar system objects (the Sun, six major and nine minor planets) for determining the dynamical reference frame. During the past triennium, the Tokyo PMC has carried out more than 93000 effective observations of program stars and more than a thousand observations for the solar system objects.

A global adjustment method developed by Yoshizawa and Suzuki has been adopted in compiling the annual catalogue series. The first annual Catalogue (**Tokyo PMC 85**) was published in 1987 (Yoshizawa and Suzuki: 44.002.066). It contains 1007 positions of stars observed in 1985 and reduced to the FK4 system. The second annual catalogue (**Tokyo PMC 86**) of 3974 positions of stars observed in 1986 and referred to the FK5 system was published in 1989 (Yoshizawa and Suzuki: 49.002.067 and 50.002.106). The Tokyo PMC 86 confirmed local systematic errors of the level of 0.1 arcsec in the FK5 system, which are similar to those found by the CAMC and the Bordeaux Meridian Circle. It may be worth mentioning that systematic differences between the FK5 and photoelectric observations can now be detected and determined in a shorter period and with much more confidence than before, because of the smaller random errors in the FK5 as well as the modern observation. Work on the Tokyo PMC 87-89 is in progress. Development of a new CCD micrometer for the Tokyo PMC is in progress (Suzuki *et al.*: 49.041.024). The so-called drift scanning method is the basic electrical architecture for detecting and accumulating the photons. The new micrometer will enable astrometric observations of faint celestial objects down to 15th magnitude (Yoshizawa).

M. Candy reviews the past activities of the **Perth Observatory**, which are relevant to the commission report: After the compilation of the well known **Perth 70** Catalogue, Perth Observatory staff continued observations with the **Hamburg Meridian Circle** equipped with a photoelectric micrometer, and produced the **Perth 75** and **Perth 83** Catalogues. In 1987, while automation of the instrument was being further planned, the Western Australian Government withdrew financial support, as an economy measure. In 1989, the meridian circle was dismantled and returned to Germany. The vacant dome is still available if another country wishes to send a team and instrument to Perth.

2. Modernization of Meridian Instruments

The U. S. Naval Observatory at Flagstaff is converting the **8-inch Transit Circle** into a CCD scanning telescope. The refurbishment will enable the accurate measurement of positions of more than 50 stars per field relative to extragalactic objects down to the limiting magnitude of about 17. The azimuth and level of the instrument can be monitored by a laser interferometric system in real time (Stone and Monet: 1989, IAU Symp. No.141).

The **Reversible Cooke Transit Circle** at Herstmonceux, which was taken out of service in 1981, was moved to the Copenhagen University Observatory at Brorfelde, where it is being used for testing new equipment destined for the CAMC. A start was made to developing a CCD system for reading the graduated circle.

The **San Fernando Meridian Circle** in Spain is being modified to convert it to an automatic instrument similar to the CAMC operating at La Palma. A photoelectric micrometer as well as an automatic setting system have been installed. A new circle reading system with CCD technique is being investigated. It is expected that the observation with the modified equipment will be started in 1991 (Quijano, Sánchez, Muiños).

3. Photoelectric Astrolabes

In the past, the astrolabes were used to determine Earth Rotation Parameters; meanwhile, it was already known that these instruments were able to determine positions of stars as well as planets and the Sun, especially with a remarkable precision in right ascension. Several astrolabes catalogues have been already incorporated in the FK5. In this context it is now clear that the astrolabe observations in addition to the meridian observations on the ground are of great importance for investigating and improving the fundamental reference frame. After the end of astrolabe observations for Earth rotation parameters, the major objective of the astrolabe observations in Argentina, Brazil, Chile, China, France, and Spain was shifted to research for the stellar and dynamical reference frames. The **Working Group on Astrolabes** of Commission 8 under the leadership of Chollet has been coordinating the worldwide astrolabe stations in this new objective.

In France, the modification of the astrolabe at the **Paris Observatory** has completed, and particular attention has been paid to observations of radio stars (β Persei and α Scorpii) in the FK5 catalogue and Jupiter (Chollet, Débarbat). The **CERGA** solar astrolabe has been devoted to catalogue observations, the solar diameter and position observations with high precision (49.041.001). At **San Fernando** (Spain), the modification of the astrolabe to convert it into a multi-purpose instrument, permitting the observation of Sun, planets and stars, is now in its last stage (Quijano).

Modifications for automation of four photoelectric astrolabes at **Shanxi, Beijing**, and **Yunnan Observatories** in China are near to completion. These modifications include also a goal to reach the limiting magnitudes 9.5 to 10.0 for stars and planets. At Shanxi, the refitted astrolabe will work on two different zenith distances to determine the absolute declination of stars. At Beijing, the Third Preliminary Catalogue of Stars Observed with the Photoelectric Astrolabes (PACP3) has been compiled (Hu Ning-sheng, Li Dong-ming).

In the southern hemisphere, the particular importance of astrolabe observations has been acknowledged for improving the southern counterpart of the fundamental reference frame. At **Santiago** (Chile) the modification of its astrolabe was completed in 1990, enabling observations at two zenith distances (30° and 60°). With the modified astrolabe permitting observations in a wider declination range, observation programs for fundamental stars, planets, and radio stars were started in 1989. The right ascension of α Scorpii was also determined at Santiago (43.041.016). The regular observation of the Sun at $z = 60°$ commenced also in May 1990 and the whole apparent orbit of the Sun can be observed at Santiago (Noël). The modification of the astrolabe is also in progress at **Sao Paulo** (Brazil) and the solar diameter was observed.

4. New Astrometric Instruments on the Ground

Recent advances and possible future directions in optical astrometry are reviewed by Monet (46.041.017). The review concentrates on detectors and technology.

The U. S. Naval Observatory is developing an **Astrometric Interferometer** which will be in operation in late 1994. The interferometer will be built upon the experience gained from the Mark III stellar interferometer at Mt.Wilson (Shao *et al.*: 45.034.066, Mozurkewich: 45.041.012, Kaplan *et al.*: 46.032.061, Kaplan: 1989, IAU Symp. No.141), which has been a joint project involving the Smithsonian Astrophysical Observatory, the Naval Research Laboratory, MIT, and USNO. The USNO astrometric interferometer will achieve unprecedented precision in the optical regime, with statistical and systematic errors below 5 and 1 milli-arcsec for wide and narrow angle measurements, respectively (Hughes).

The **Glass Meridian Circle** with 24cm aperture is a type of the horizontal meridian circle being developed as the cooperative project, **Danish-Chinese Meridian Telescope (DCMT)**. The mechanism and electronics of the instrument have been constructed mainly at the **Nanjing Astronomical Instruments Factory** (Hu Ning-sheng) in close cooperation with the **Copenhagen University Observatory** (E. Høg) at Brorfelde and the **Shaanxi Astronomical Observatory** (Li Zhigang). The complete instrument is now being tested at Shaanxi, at first with visual micrometers.

At the Pulkovo Observatory, based on the experience gained from the **Pulkovo Horizontal Meridian Circle** (Gumerov *et al.*: 45.032.053 and Pinigin: 49.032.006), a new automatic meridian circle called **Sukharev Meridian Automatic Horizontal Instrument (MAHIS)** is being constructed in cooperation with observatories in Pulkovo, Nikolaev, and Kazan. The expected systematic errors of the MAHIS are within ±0.05 arcsec (Gumerov *et al.*: 1989, IAU Symp. No.141). At the **Nikolaev Observatory**, the second version of the **Nikolaev Axial Meridian Circle (AMC)** is also under construction. At the Golosejovo Astronomical Observatory, Kiev a new **Horizontal Meridian Axial Circle (MAC)** is being further automized (Pinigin).

At the Yunnan Observatory (China), the **Low Latitude Meridian Circle (LLMC)** is being developed and will be installed in 1992. The LLMC aims at participating in the absolute observation of positions of stars down to 13th magnitude and linking observations in the northern and southern hemispheres (Mao Wei).

III. SPACE ASTROMETRY

1. HIPPARCOS–TYCHO Space Mission

The primary goal of the **European Space Agency**'s space astrometry mission, **HIPPARCOS** is to acquire the astrometric parameters (positions, trigonometric parallaxes, and annual proper motions) of about 120000 stars to an accuracy of about 2 milli-arcsec. The HIPPARCOS system of positions and proper motions will be linked to the extragalactic (radio) reference frame by means of the Hubble Space Telescope as well as ground-based observations, resulting in a highly accurate optical inertial reference frame. The **TYCHO** experiment will in addition provide two color photometry (B and V) and positions, to a lower precision than those attained by the main HIPPARCOS observation, of about 500000 stars to a limiting magnitude of about 11.

During the past triennium, the construction, testing and laboratory calibration of the flight model of HIPPARCOS satellite have progressed without major problems and the satellite was finally launched on 8 August, 1989 by an Ariane IV on an elliptic transfer orbit. However, due to the non-operation of the apogee boost motor the satellite could not be placed on its planned geostationary orbit. It was only possible to raise the perigee to almost 600km. With an apogee of about 36000km, the orbital period is about 10.6 hours, and four or five times a day the satellite crosses the Earth's radiation belts.

As a result of this unexpected situation, the present (elliptic) orbit created serious problems from the point of view of ground station coverage, frequent radiation belt passages, perturbing torques, and longer Earth occultations and eclipses encountered over February–March 1990 period. At the initial phase, there prevailed a pessimistic view of the prospects for the HIPPARCOS mission, and there arose from the astronomical community a proposal that an early HIPPARCOS II mission be considered by ESA.

The months after launch involved considerable modifications to the satellite operations. Fortunately, contrary to what was feared after launch, most of the difficulties have been overcome. Some of the early concerns about the short expected mission lifetime have proved to be not found. Measurements of the solar array degradation due to the passages through the radiation belts suggest a possible lifetime of more than 3 years. The ground station coverage has been greatly improved by adding to the nominal Odenwald (Germany) station, telemetry stations in Perth (Australia), Goldstone (U.S.A.), and Kourou (French Guiana). The fraction of useful observing time (after allowing for coverage losses, occultations, attitude initializations, etc.) is now around 60–70%. During the long eclipse periods over Feb.–Mar. 1990, the satellite survived successfully and it was not necessary to stop operation.

On-board, the payload and spacecraft subsystems have proved to be within the specifications and, in some respects is more efficient, and they are working extremely well. After two months of commissioning and calibration of the instrument, routine operations commenced on 26 November 1989. Between then and the end of May 1990, some 300 Gbits of data covering some 2 million stellar observations have been acquired, including minor planets and natural satellites. The HIPPARCOS data is now passing routinely through the critical elements of the data analysis chain, up to the great circle reduction level to derive star abscissae on a great circle with a precision of 5–10 milli-arcsec.

With the clarification of the lifetime predictions, the inclusion of the additional ground stations, and the confirmation of the data quality, it has been possible now to retain the intended observing program essentially without modification. Although usable data can be obtained for only about 60% (essentially because of the difficulties with the attitude determination due to the excess background flux in the star-mapper detector when the satellite passes through the radiation belts, and to the Earth's occultations), the results obtained hitherto show a better precision than expected. If the mission survives for more than 3 years at the current performance levels, the original astrometric goals should be achievable and may be better. Thus, the **HIPPARCOS Science Team** has, on 11 May 1990, withdrawn an earlier proposal to consider the HIPPARCOS II (see also Perryman: 1989, IAU Symp. No.141).

Much of the international scientific involvement in the HIPPARCOS mission has been concentrated to the four consortia of institutes and individual scientists: the **INCA** (Input Catalogue) Consortium under the leadership of Turon, which was entrusted with the task of defining the unique observing program for the main mission and gathering the ground-based observations; the **FAST** (Fundamental Astronomy by Space Techniques) Consortium and **NDAC** (Northern Data Analysis Consortium) under the leadership of Kovalevsky and Høg, respectively, which are in charge of the independent reduction of data from the main mission; and the **TDAC** (TYCHO Data Analysis Consortium) under the leadership of Høg, which is devoted to analyzing the star mapper data stream.

INCA Consortium Report: The HIPPARCOS Input Catalogue, including 118000 stars to be observed by the satellite, was delivered to ESA and to the Data Reduction Consortia by mid-1989. Ephemerides of the minor planets and two satellites of Jupiter and Saturn (Europa and Titan) for observation with the HIPPARCOS were also delivered. These ephemerides and predicted ephemerides for large amplitude variable stars are regularly updated every 6 and 2 months, respectively. All the data collected in the framework of the INCA Consortium (positions, proper motions, magnitudes, multiplicity, colours, variability) were introduced in the INCA Data Base in the Centre de Données Stellaires of Strasbourg.

The final version of the Input Catalogue is the outcome of the collective seven year work of the Consortium. Contents of the Catalogue were selected from about 220000 proposed stars by means of nine successive iterations permitting progressive improvements of its contents from the scientific point of view as well as from the data collection point of view.

In line with the expectations before launch of the satellite, publication of a printed version of the Input Catalogue is now being planned for early 1991. This catalogue will contain the currently best available ground-based astrometric and photometric data on the HIPPARCOS program stars, including information on multiplicity, variability, and catalogue cross-references, as well as finding charts for the fainter objects. For Scientific Aspects of the Input Catalogue Preparation, see also 46.012.040 (Turon).

FAST Consortium Report: The finalization of the software designed to reduce the data collected by the HIPPARCOS was the main objective of the cooperative effort of this consortium. At the time of the launch, most of the software was integrated in the CNES computer in Toulouse and was subsequently qualified and accepted.

As a consequence of the revised orbital conditions of the satellite, serious modifications to the software had to be designed and checked with real data. Although the satellite was operating continuously since 26 November 1989, the FAST consortium was checking and finalizing its softwares till end of July 1990. However, the consortium has now reduced the equivalent of 20 days of data acquired by the satellite. It appears from the examination of the results that the instrument is performing very well, apparently even better than expected. The precisions estimated by simulations and accuracy assessments have been fully confirmed. As an example, the abscissae of stars on a reference great circle after 6 to 7 hours of continuous observations give a formal r.m.s. error between 4 and 5 milli-arcsecs. For bright stars ($m_v < 8$), the r.m.s. errors of the grid coordinates obtained from the modulation parameters are of the order of 7 milli-arcsec. In parallel, most of the instrumental parameters have been calibrated to a very satisfactory precision. For instance, the basic angle is determined to better than 0.2 milli-arcsec for each hour periods. During the first months of operation, the basic angle decreased by 2 milli-arcsec per month. A decision to commence the full-scale processing of all data since Nov. 1989, once adequate agreement has been achieved, is expected by the autumn of 1990 (Kovalevsky).

NDAC Report: The software for the complete reduction of the HIPPARCOS observations has been developed and was ready for the first observation from HIPPARCOS received in November 1989. It has been adapted to handle the unexpected problems in the data and the results have been used to improve satellite operations. Extensive comparisons of the results obtained by the NDAC and FAST data reduction teams have been carried out with simulated data and now with real data. This has proved to be very efficient for locating and eliminating errors in the reduction software. Continued comparisons at several levels of the reductions should ensure that two teams in the end can agree on a unique HIPPARCOS Catalogue, with a confidence that would otherwise be difficult to obtain in view of the very large and complex data reduction. The comparisons performed up to the level of the great circle reduction show that the results are essentially in agreement at the level of a few milli-arcsec. That is, the NDAC reductions of the first few weeks of mission data show that the abscissae of 1500 stars on a reference great circle are determined with a formal standard deviation about 5 milli-arcsec from 7 hours of observation. Sixteen instrument parameters up to second order are solved for and are very constant, the day-to-day variation being generally less than 1 milli-arcsec at the edge of the field (Høg).

TDAC Report: The main data reduction chain of the TDAC involves the Astronomisches Rechen-Institut (Heidelberg), Astronomisches Institut (Tübingen), Observatoire Astronomique (Strasbourg), and Copenhagen University Observatory. Working from a TYCHO Input Catalogue containing about 2 million brightest stars on the sky, the star mapper signals are extracted and analyzed in order to derive B and V magnitudes and positions for stars brighter than $B = 11$ (about 500000 stars). The first weeks of observations from the TYCHO experiment on board HIPPARCOS had been analyzed by May 1990 and confirm that the original expectations can be fulfilled even with the revised mission, if the mission survives for 3 years as currently expected (Høg).

The extensive descriptions of the satellite and payload, the construction of the Input Catalogue, and the data processing methods were published in the form of the following three documents: **The Hipparcos Mission, pre-launch status** (ESA SP-1111, June 1989), Vol. I The Hipparcos Satellite (M. A. C. Perryman, H. Hassan, and others), Vol. II The Input Catalogue (M. A. C. Perryman, C. Turon, and others), and Vol. III The Data Reductions (M. A. C. Perryman, L. Lindegren, C. A. Murray, E. Høg, J. Kovalevsky, and others).

2. New Astrometric Missions in Space

The HIPPARCOS mission has opened new perspectives of astrometry in space. The increasing demand for higher accuracy in astrometry is now compelling further the astrometrists to challenge the post HIPPARCOS mission.

In U.S.A., Reasenberg *et al.* (46.035.032, 50.036.18, and 1989, IAU Symp. No.141) are proposing a space-based optical astrometric interferometer, capable of measuring the angular separation of two stars about 90° apart and down to the limiting magnitude of 17th with 5-microarcsec nominal accuracy. The proposed mission is called **POINTS** (Precision Optical INTenferometer in Space).

In U.S.S.R., two astrometric missions are under investigation. A group of the Pulkovo Observatory at Leningrad is proposing a mission called **AIST** (Astrometric Artificial Satellite Telescope), which would determine high-precision positions of stars down to magnitude 14th and of laser sources on the Earth (Chubey *et al.*, 1989, IAU Symp. No.141). Another group in the Sternberg State Astronomical Institute at Moscow is proposing another mission project called **LOMONOSOV**, which is aimed at developing a high-accuracy coordinate system of the entire sky (Nesterov *et al.*: 1989, IAU Symp. No.141).

IV. STELLAR REFERENCE FRAMES AND CATALOGUES

1. The FK5

One of the main purposes of a Fundamental Catalogue is to represent the Conventional Celestial Reference Frame to which the positions of other celestial objects can be referred at any instance. The **Fifth Fundamental Catalogue (FK5)**, on which work has been continued at the **Astronomisches Rechen-Institut**, Heidelberg, 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 (see also the textbook,"Reference Frames in Astronomy and Geophysics" edited by Kovalevsky *et al.*: 50.003.006). The FK5 will consist of two parts, the Basic FK5 and the FK5 Extension.

The Basic FK5: The Basic FK5 is a direct revision of the FK4 containing the classical 1535 fundamental stars. Work on the Basic FK5 has been completed with the publication of the printed version of the catalogue (Fricke *et al.*: 49.002.078). The major parts of the revision of the FK4 are 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.**

In order to provide means for transforming positional data referred to one of the fundamental catalogues to those on the Basic FK5, the systematic relations between the Basic FK5 and the FC, NFK, FK3, FK4, GC, and N30 have been determined by Schwan (1989, IAU Symp. No.141), and are available from the Astronomisches Rechen-Institut.

The FK5 Extension: The FK5 Extension will consist first of about 1000 stars (Bright Extension) in the magnitude range 5 to 7 selected from the FK4 Supplement, and second of about 2000 stars (Faint Extension) selected from the **International Reference Stars (IRS)** in the magnitude range 6.5 to 9.5. The selection of the new fundamental stars and the determination of mean positions and proper motions for these stars have been made jointly by the Astronomisches Rechen-Institut, Heidelberg (Schwan) and the U. S. Naval Observatory (Corbin). Work on the Bright Extension has been completed and the informations on these have been available on magnetic tape since the end of 1988. Work on the Faint Extension has also been finished and its final version contains 2125 stars. The combining of the two extension lists has been completed and the compilation of some auxiliary data on a uniform basis is in progress.

The overall precision of the FK5 Extension is 0.055 arcsec for the positions at the mean epoch 1944, and 0.255 arcsec for the centennial proper motions. The errors averaged over the whole sky of mean positions and mean centennial proper motions of the Basic FK5, of the Bright and Faint Extensions, and, for comparison, also of the FK4 are given in Table 1 (Schwan: 1989, IAU Symp. No.141).

Table 1

Catalogue	Average Mean Epoch		Average Mean Errors			
			Positions		Centennial Proper Motions	
	α	δ	α	δ	μ_α	μ_δ
Basic FK5	1955	1944	$0.^{s}001$	$0.''02$	$0.^{s}005$	$0.''07$
Bright Extension	1956	1949	$0.^{s}002$	$0.''04$	$0.^{s}010$	$0.''18$
Faint Extension	1942	1939	$0.^{s}004$	$0.''07$	$0.^{s}019$	$0.''30$
FK4	1917	1915	$0.^{s}002$	$0.''04$	$0.^{s}011$	$0.''17$

The transition from the FK4 to the FK5 implies considerable corrections to be applied to the FK4 proper motions. These corrections are of importance for results in the galactic kinematics which have been previously obtained from studies of stellar proper motions. A rediscussion of such results should therefore be performed. Based on the proper motion system of the Basic FK5, Schwan (1990, Astron. Astrophys., **228**, 69) has revised the Hyades Distance modulus determined by Hanson (1980), and confirmed the parameters for general precession and galactic rotation (45.043.006), which have been determined by Fricke (1977). On the other hand, Miyamoto *et al.* (1987, IAU Colloq. No.100, 45.043.005, and .155.031) discussed an implication of the transition of the proper motion system from the FK4 to FK5 in the warping motion of the galactic disk.

2. The SRS and SIRS Catalogues

The joint work by the U. S. Naval Observatory and the Pulkovo Observatory on the compilation of the

Southern Reference Stars (SRS) was completed in April 1988. Positions of 20488 stars are given in the SRS catalogue with an average mean error of 0.10 arcsec at the mean epoch of observation of 1968. The positions are based on an average of 16 observations per one SRS and are referred observationally to the FK4 system. The SRS catalogue is given in the FK4/B1950 system and has also been transformed to the FK5/J2000 system. Magnetic tape copies of the SRS catalogue have been distributed to the astronomical data centers and to Hamburg Observatory for use in the reduction of the plate measurements for the 2nd Cape Photographic Catalogue (CPC2) (see also, Smith *et al.*: 1989, IAU Symp. No.141). With the completion of the SRS catalogue, it became possible to begin work on the proper motions of these stars. Corbin completed the compilation of proper motions of the **Southern International Reference Stars (SIRS)**, corresponding to the **NIRS** (or AGK3RN). The final version of the SIRS contains 19126 stars. The substantial part of these stars has the better observational histories. The average mean errors of the centennial proper motions in this part are ±0.43 arcsec in R.A. and ±0.44 arcsec in Decl. The SIRS is available on both FK4/B1950.0 and FK5/J2000.0.

3. Faint Fundamental Stars

A discussion concerning the need to define fundamental stars fainter than the Faint Extension of FK5 took place at the XIXth IAU General Assembly, and the **Working Group on Star Lists** was formed jointly by Commissions 8 and 24. Corbin, the chairman of the WG, reports that the WG met during the IAU Symposium No. 141 at Leningrad and agreed that a list of fundamental stars in the 9th to 13th magnitude range should be selected from the stars in the HIPPARCOS Input Catalogue and those included in current observing programs such as the one at La Palma. Corbin and Morrison are collaborating in preparing a proposed list about 2000 stars in that magnitude range. It is hoped that the WG will have agreed on a final list by the time of the Buenos Aires General Assembly.

4. High Density Reference Star Catalogues of SAO Type

Demand for an accurate and modern representation of the FK5 at higher star densities and fainter magnitudes has increased. In order to replace the AGK3 catalogue and the northern part of the SAO catalogue by such a representation, Röser and Bastian at the Astronomisches Rechen-Institut compiled a new catalogue of **Positions and Proper Motions** of reference stars on the northern sky (**PPM**-North). It contains 181731 stars north of $-2.5°$ for equinox and epoch J2000.0 on the FK5 system. The average mean errors in positions at epoch 1990 and in centennial proper motions are 0.27 arcsec and 0.42 arcsec, respectively. The high-precision subset (31841 stars) of the PPM-North is defined as the set of either the AGK3R or the Carlsberg Automatic Meridian Circle catalogues. The PPM-North has been available on magnetic tape from the astronomical data centers since 1988.

The preliminary version of the southern part of the PPM catalogue has been also available on magnetic tape from the astronomical data centers since May 1990. The preliminary PPM-South catalogue contains 144787 stars chosen from the **FOKAT-YU** catalogue (Bystrov *et al.*: 49.002.017). Work on the PPM-South is a joint effort of Bastian, Röser, Wielen at the Astronomisches Rechen-Institut, Polozhentsev, Potter, Yagudin at the Pulkovo Observatory, Yatskiv at the Kiev Observatory, and Nesterov at the Sternberg Institute. Compared with the SAO catalogue, the PPM catalogue (PPM-North + PPM-South) of about 326000 reference stars is an improvement by about a factor 3 both in positional accuracy at epoch 1990 and in the accuracy of proper motions.

For many years the U. S. Naval Observatory has also participated in the effort to convert the published volumes of the Astrographic Catalogue to a usable catalogue. Work on a high density reference catalogue, the **Astrographic Catalogue Reference Stars (ACRS)**, derived from the large photographic catalogues and the modern meridian circle catalogues, is being completed. The ACRS comprises 325416 stars to the 10th magnitude and covering the whole sky. The mean errors of centennial proper motions are expected to be 0.4 arcsec or less (Corbin and Urban: 46.036.220, 49.111.014, and 1989, IAU Symp. No.141).

5. The Astrometric Data Base ARIGFH

The Astronomisches Rechen-Institut has started to collect "all" relevant astrometric data on positions and proper motions of stars in a comprehensive astrometric data bank, called **ARIGFH**. Presently, the results from ground-based observations are included, but in future the ARIGFH should also contain observations obtained from space. The best mean position and proper motion for each observed star will be derived from the ARIGFH, providing a comprehensive and most accurate **General Catalogue** of stellar positions and proper motions (**ARIGC**). A combination of the HIPPARCOS catalogue with fundamental catalogues, such as the FK5 Basic, will provide, for the common stars, positions and proper motions, which are significantly more accurate than those in the original catalogues (Wielen: 1989, IAU Symp. No.141).

6. Other Observation Catalogues

The Perth Observatory has published, in 1990, the **Perth 83** — A Catalogue of Positions of 12263 Stars, derived from observations during the years 1980 through 1987 at the Perth Observatory. The final list was developed in consultation with Nikoloff and Høg and compiled for the Perth Observatory at the Copenhagen University Observatory, Brorfelde. The Perth 83 is in the same system as the two previously published catalogues (Perth 70 and Perth 75) and can therefore be used as a supplement to both catalogues and extends the basis of a reference frame for the southern hemisphere. The Perth 83 is now available on magnetic tape.

The compilation of the **Washington Fundamental Catalogue (WFC)** from absolute observations made since 1900 is in progress. Equator and equinox corrections have been determined from observations of the Sun in all of the Washington and Cape catalogues observed since 1900, based on the **DE200** ephemeris. The work is now being extended to include observations of Venus and Mercury. It is expected that the system of the WFC will also be defined by the series of absolute observations currently being made with the 6-inch Transit Circle in Washington and the 7-inch Transit Circle in New Zealand. Differential catalogues observed since 1900 are also being considered to improve the individual positions and proper motions. The WFC will contain about 40000 stars (Smith).

Scott (45.002.093) published a catalogue of 10010 AGK3R stars during the 6-inch Transit Circle W4/50 1956–62 program. The results of observations have been referred rigorously to the absolutely determined W4/50 system.

Based on Pulkovo meridian observations, the final version of the **AGK3R Pulkovo Catalogue** of 11506 Stars north of declination +25° has been compiled (Baturina *et al.*: 50.002.069). The mean errors in coordinate are $\Delta\alpha\cos\delta = \pm0\overset{s}{.}010$ and $\Delta\delta = \pm0\overset{''}{.}32$. The general **FKSZ** catalogue of positions and proper motions of 931 faint stars was compiled by Zverev *et al.* (44.002.021).

Based on observations with the Belgrade meridian circle, Sadžakov et al. have compiled and published a catalogue of positions of 1576 stars of **Belgrade Catalogue** of Double Stars and 490 FK4 stars (1990, Publ. Obs. Astron. Belgrade, **38**), a catalogue of positions 578 FK4 stars observed during 1981–1987 (49.002.014), and a catalogue of positions of 290 bright stars around radio sources observed during 1982–1987 (1990, Astron. J., in press).

The Real Instituto y Observatorio de la Armada at San Fernando published **Catálogo SRS de San Fernando** of 3678 stars of the SRS Program ($-10° > \delta > -30°$) carried out with the visual meridian circle of the **Instituto y Observatorio de Marina** (44.002.082).

7. Catalogue Comparisons and Reduction Methods

Schwan has established a computer program for evaluating the analytical representation of the systematic differences between the FK4 and FK5 or other catalogues of star positions or proper motions (45.041.021). Benevides-Soares has established a method of global reduction of fundamental astrometric observations and applied it to astrolabe data (45.041.002). These two methods are used as standard ones for comparisons and reduction of global astrometric data. Fan Yu *et al.* (49.036.148) proposed all-stars adjustment method for the reduction of meridian and astrolabe catalogues, thereby increasing the homogeneity of the catalogue system with respect to accidental and systematic errors. Concerning the improvement of the fundamental catalogue, Bien (44.041.019) proposed an application of the maxmum likelihood method to the problem of weighting the positions of meridian circle catalogues.

8. Theoretical Investigations

Discussion of the transformation procedure from FK4 to FK5 was continued by Smith *et al.* (49.041.002) and Yallop *et al.* (49.041.003) based on the formulation by Aoki *et al.* (34.041.033). Murray (50.043.002) claimed that the Aoki *et al.* formulation was erroneous, whereas the formulation proposed by Standish (32.043.003) was essentially correct. However, Sôma and Aoki (1989, IAU Symp. No.141; *Astron. Astrophys.*, in press) have shown that Murray did not take into account the indirect effect of the equinox correction on proper motions, and have concluded that the Aoki *et al.* formulation is correct.

The relation between the celestial reference system and the terrestrial reference system has been established theoretically, and the merits and drawbacks of adopting the so-called Non-Rotating Origin in the celestial reference frame are in a controversy (Aoki: 46.043.002, Capitaine: *Celes. Mech.*, in press).

A set of algorithms has been presented by Kaplan *et al.* (49.041.022) for computing the apparent positions of planets and stars. Analytical expressions for the Earth's position and velocity needed for calculation of stars' apparent positions have been obtained (Sôma *et al.*: 45.081.046).

V. LINKAGE OF THE STELLAR REFERENCE FRAME TO THE IDEAL REFERENCE SYSTEM

The stellar reference frame materialized by positions and proper motions of stars in the Galaxy includes the galactic internal motions (galactic rotation, warping motion, local systematic motions of stars, etc.). Thus, it is necessary to link the stellar reference frame to other reference frames deemed to be inertial or practically non-rotating.

1. Towards the Establishment of a Unified Optical / Radio Reference Frame

In order to establish a unified conventional Optical / Radio Reference Frame, programs for linking the stellar (optical) reference frame to the extragalactic (radio) reference frame have been intensively carried out in a worldwide astrometric cooperation.

The celestial reference frame based upon radio observation of extragalactic sources is deemed to be almost inertial. A progress report on a campaign, started from 1987, to establish an extragalactic radio reference frame with a minimum density of one source per hundred square degrees was given by Russel *et al.* (1989, IAU Symp. No.141). The sources chosen all over the sky are compact and display flat radio spectrum as well as optical emission.

The optical positions of the faint optical counterparts ($18 < m_v < 22$) of the radio sources are usually obtained with a two-step procedure, using wide field astrographs for linking the faint secondary reference stars around the sources to IRS stars, and large 4-m class prime focus photographs for determining the positions of the optical counterparts referred to the secondary reference stars. The accuracy of the Optical / Radio linking is aimed at better than 0.05 arcsec globally.

At the **Hamburg Observatory** work has concentrated mainly on the establishment of an extragalactic Optical / Radio reference frame in a joint long-term program with the U. S. Naval Research Laboratory, U. S. Naval Observatory, Goddard Space Flight Center, and Australia Telescope National Facility (CSIRO). Positions of about 50 radio stars have been obtained with the VLA, and the corresponding optical observations are now underway using the Hamburg and Black Birch USNO-Twin astrographs. Optical positions of extragalactic radio sources have been derived for about 100 candidates using large telescopes (Calar Alto 2.2m, KPNO 4m, AAT 3.9m) for direct photography. The necessary faint secondary reference stars have been obtained with the Hamburg, Lick and Black Birch USNO Astrographs. Positions of selected radio stars and IRS stars around selected extragalactic radio sources have been obtained with the 7-inch (Black Birch) and 8-inch (Flagstaff) Transit Circles of USNO (de Vegt).

In a joint project by the Observatorium Hoher List, Astronomisches Institut der Universität Münster, Astronomisches Rechen-Institut, Instituto de Astronomia UNAM (México), and Department of Astronomy of Bulgarian Academy of Science, the optical positions of 21 extragalactic radio sources were determined in the system provided by the Brorfelde catalogue with an internal precision of 0.12 arcsec (Geffert *et al.*, 50.041.012).

At the Zô-Sé branch of the **Shanghai Observatory**, based on observations with the 40cm Astrograph, positions of 85 radio stars and 3 extragalactic radio sources were compiled (see also 49.041.013). In 1989, the 1.56m astrometric telescope of the Shanghai Observatory was put into operation in collaboration with the 40cm twin astrograph of the **Purple Mountain Observatory** to determine the optical positions of 40 radio sources (Xu Tong-qi).

In the southern hemisphere, another joint project to link the Optical / Radio reference frames has started, and optical and radio positions of six extragalactic sources were determined. On the average, the optical (Perth 70) and radio reference frames appear to be consistent at the tenth of an arcsecond level (Jauncy *et al.*: 50.041.013).

Programs of the Optical / Radio link carried out with several telescopes in U.S.S.R. and the Tautenberg Schmidt Telescope were summarized by Dick and Kumkova (50.043.003). Duma and Ivashchenko suggested a method of determining the relative orientation between Optical / Radio reference frames on the basis of non-synchronous optical and VLBI observations with artificial satellites.

At the **Torino Astronomical Observatory**, measurements of precise optical positions of 75 extragalactic radio sources with the photoelectric transit instrument at Torino and astrolabe at Cagliari are in progress (45.041.039). The positions will be reduced to the CAMC catalogues.

Walter has continued work on a realization of the radio reference frame and compiled a catalogue of 210 extragalactic radio sources (49.002.007 and 50.041.003). Based on the compilation catalogue, he derived a provisional correction to the conventional luni-solar precession value. The result shows a reduction of the conventional value of about 2 mas per year (1989, IAU Symp. No.141). In order to improve the accuracy of the linkage between the stellar and radio reference frames, Sôma *et al.* (1989, IAU Symp. No.141) have stressed the importance of observations of future lunar and planetary occultations of radio sources in addition to 3C273B. Concerning the Radio / HIPPARCOS link, see the report of Comm. 24.

2. Link to the Planetary (Dynamical) Reference Frame

Observations of solar system objects, including the Sun, referred to the stellar reference frame are necessary for linking the stellar reference frame to the Newtonian inertial system.

New possibilities of accurate link were proposed: Whipple *et al.* (45.043.012 and 46.041.043) have been proposing observations of minor planets at their crossing points. Miyamoto and Sôma (49.043.027) have shown that combined observations with the modern meridian circle and astrograph for three faint minor planets with orbital period shorter than 2 years enable us to determine the equinox correction with accuracy better than 0.05 arcsec within an observational period of a few years. On the other hand, Fedij (49.041.007) has studied the influence of the mutual perturbation of Ceres, Pallas, Juno, and Vesta on the estimates of systematic corrections to star catalogues, and shown that the perturbation should be taken into account in the procedure of systematic improvement of catalogues.

In order to determine an accurate relation of the orientation of the fundamental reference frame defined by the FK4 catalogue to that of the dynamical reference frame adopted in Bretagnon's planetary theory **VSOP82**, Niimi (1990, Publ. National Astron. Obs., Japan, **1**) analyzed the meridian observations of the Sun and the major planets except Pluto made in the period 1934–1980. The corrections to the equinox, the equator, and the obliquity were determined by inspecting carefully the phase effect appearing in observations of planets and the systematic error in declination observations of the Sun.

Using observations of the Sun made with the USNO 6-inch transit circle from 1911 to 1971, Yao and Smith (46.041.055) obtained equator and equinox corrections based on Newcomb's, **DE102**, and **DE200** ephemerides for each six catalogues.

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