24. PHOTOGRAPHIC ASTROMETRY (ASTROMETRIE PHOTOGRAPHIQUE)

1.0 Highlights

Despite some much publicized disappointments, the highlights of Astrometry during the past three year period are dominated by the successful launches of the ESA Hipparcos astrometric satellite and the NASA Hubble Space Telescope. For the past 15 to 20 years the research activities of many Commission members have been monopolized by the design and development of the associated instrumentation and the preparation of catalogues of objects to be observed. Unfortunately, the successful launch of Hipparcos was followed by a failure of the apogee boost motor to ignite and place the satellite into its proper geostationary orbit. After considerable replanning, the perigee was raised to a safe level and access to additional ground stations was arranged so that observations could still be made from the 10.6 hour period elliptical orbit. Even though Hipparcos passes through the Earth's particle radiation belts twice a day, little degradation in the solar panel output has been observed subsequent to the initial decrease in the output and a lifetime of approximately three years is predicted for the satellite.

As of this writing, validation procedures have been run by both of the data reduction consortia. Internal checks between the two groups show an agreement on the level of a few milli-arcsec (mas) or better. The photometric results indicate that an accuracy of a few thousandths of a magnitude per transit is achieved for the brighter stars, which is close to the predicted value. The Tycho star mapper has so far provided updated positions for about 50000 stars in the accuracy range of 5 to 100 mas depending on the brightness and number of observations, which indicates that the Input Catalogue positions have standard errors of about 0.3", in good agreement with their quoted errors. Based on these initial results and the lifetime projected for the satellite, it is estimated that the original goals for the astrometric programs of Hipparcos will be reached. [M. Perryman (ESTEC), E. Høg (NDAC/TDAC), J. Kovalevsky (FAST), and C. Turon (INCA)].

While the launch and deployment of the Hubble Space Telescope proceeded as planned, it soon became apparent that there were serious optical problems in the HST caused by a manufacturing blunder in the null corrector for the 2.4 meter primary mirror. The process of characterizing the deleterious effects of the spherical aberration on the various instruments and evaluating their performance is currently underway. However, the preliminary results indicate that about 15% of the light is contained in a sharp nearly diffraction limited core, while the balance of the light is in a highly structured halo with a radius of approximately 2 arcsec. As a consequence, it is still possible to obtain extraordinary resolution of fairly low dynamic range scenes, but for a given exposure time the limiting magnitude of the HST is reduced by approximately two magnitudes. The effect of the degraded point spread function on the accuracy of imaging astrometry is currently being evaluated. [D. Monet (U.S. Naval Obs.), T. Girard and W. van Altena (Yale)]

The interferometric Fine Guidance Sensors (FGSs) of the HST were designed to be insensitive to symmetric optical aberrations, however in the presence of very large amounts of spherical aberration it appears that the alignment tolerances of the optical components become extremely critical. At the present time only one of the FGS units is producing acceptable interferometric transfer scans, and in that case with a reduced effective aperture. The smaller effective aperture reduces the limiting magnitude of the FGS by approximately one magnitude. Tests are currently underway to characterize the observed aberrations and determine the usefulness of the FGSs for astrometric work. In spite of these problems, observations have already been made of binary stars that show remarkable resolution and demonstrate that the HST will be able to do significant binary star astrometry at the very least. The impact of the aberration on parallax determinations is not clear at this time. If the optical problems were not enough, the strong thermal gradients in the solar arrays at the day/night terminator crossings, which

D. McNally (ed.), Reports on Astronomy, Vol. XXIA, 229–234.

occur twice in every 100 minute orbit, introduce oscillations into the telescope which disturb the pointing stability and increase the difficulty of making precise astrometric observations. It seems likely that a combination of software fixes during the next several months will be able to minimize the oscillations introduced by the solar arrays. [W. Jefferys, G. Benedict, R. Duncombe, P. Hemenway, and P. Shelus (U. Texas), O. Franz and L. Wasserman (Lowell Obs.), L. Fredrick (U. Virginia) and W. van Altena (Yale)].

The accuracy of ground-based parallax observations made impressive strides, equalling in one case the prelaunch predictions of 0.5 mas for the HST parallaxes! D. Monet and C. Dahn report that observations with a small field CCD camera at the U.S. Naval Obs. have demonstrated that parallaxes of faint stars with an accuracy of one mas can be regularly obtained with a dedicated telescope in a good climate. C. Anguita and M.-T. Ruiz have obtained similar results with CCD cameras at CTIO, but with somewhat lower accuracy due to the problems associated with observing at national facilities. A wide field scanning Ronchi ruling used at the Allegheny Obs. by G. Gatewood and his collaborators is beginning to yield parallaxes with an accuracy of approximately 1.5 mas on 9th magnitude stars.

The relatively new technique of letting the sky drift by a CCD in a fixed transit instrument, while electronically shifting the CCD image in synchronism with the sky, is being used by several investigators. Over the course of a year the whole sky can be scanned and catalogued to faint magnitudes with reasonable precision. J. McGraw (Steward Obs.) and his colleagues and G. Benedict (McDonald Obs.) have obtained a positional accuracy of 40 mas for stars brighter than 17th magnitude and lower accuracy for objects down to nearly 19th magnitude. D. Monet and R. Stone (U. S. Naval Obs.) and A. Buffington (Univ. of Calif, San Diego) are also investigating the use of strip scanning to determine positions, parallaxes and proper motions.

One further technique that may revolutionize the field of wide angle astrometry for bright stars is ground-based stellar interferometry currently under development by M. Shao and his collaborators at the U.S. Naval Obs. and a proposal for a space interferometer by R. Reasonberg.

Finally, it is ironic to note that none of the Highlights in this Report reflect the name of our commission, Photographic Astrometry. Certainly that is not meant to imply that photography has outlived its usefulness, for it is still the technique of choice for many of the activities of our commission. Perhaps at some time in the future we may find a name that properly describes the full range of our activities.

2.0 Trigonometric Parallaxes and Nearby Stars

In addition to the parallax work noted above, several other programs continued to observe a variety of stars ranging from the many low luminosity main sequence stars and white dwarfs that populate the solar neighborhood, to metal-poor stars and the more luminous rare stars. The U. S. Naval Observatory continued its photographic parallax program with plates being taken with the 155-cm reflector in Flagstaff, Arizona. C. Dahn and R. Harrington report that the observation list consists primarily of faint high proper motion stars; however a number of bright stars have recently been added to the program that are observed behind neutral density spot filters. The goal of the latter project is to improve the parallaxes for the bright stars that were observed primarily in the early part of this century. The Van Vleck Observatory continued to work primarily on the Vyssotsky stars, subdwarfs and the Hyades Cluster stars. A. Upgren reports that the current parallax accuracy for Van Vleck plates measured on the Yale PDS is about ±5 mas. Experimentation is also in progress with the use of hypersensitized IIIa-F plates in addition to the normal 103a-D plates. E. Weis also continued his photometric observations in the BVRI system related to the stars currently on the Van Vleck parallax program. The Shanghai Observatory continued with its parallax program on the Zo-Se refractor under the direction of J.-j. Wang. At the McCormick Observatory, P. Ianna continued to observe parallaxes both at McCormick and in Australia with the old Yale refractor; the work has emphasized Hyades Cluster members and stars of special interest. L. Fredrick continues to have the lead responsibility for the "astrophysically interesting stars" in the HST parallax program. The Sproul Observatory continued with its parallax observations under the direction of W. D. Heintz. At the Yerkes Observatory, K. Cudworth and E. U. Vilkki report that the discontinuation of external support for the parallax program has forced the phasing out of the observational program. The observations of the remaining 37 stars are nearly complete and the measuring is progressing slowly.

The analysis of published parallaxes continued in the preparation at Yale of the new edition of the General Catalogue of Trigonometric Parallaxes by W. van Altena, J. T. Lee and D. Hoffleit. Newly computed corrections to absolute parallax have been included which are based on an improved model of the galaxy. R. B. Hanson, T. E. Lutz and van Altena continued their analyses of the metal poor stars in order to determine an improved Pop. II distance scale. W. Gliese and H. Jahreiß report that work is continuing on the Third Catalogue of Nearby Stars, which now contains more that 5000 candidates. Some 30% of the stars have trigonometric parallaxes smaller than the limit of 0.040 arcsec and are therefore only suspected of being "nearby". D. Hoffleit also continued work on the revisions to the tape version of the Bright Star Catalogue with W. Warren of NASA. In addition, she has nearly completed writing her history of astronomy at Yale through the Brouwer period, which involves much of the history of astrometry.

3.0 Proper Motions and Positions

There has been a revival of interest in the preparation of catalogues of positions and proper motions. No doubt a considerable part of this revival is due to the increasing availability of machine readable catalogues, which makes it easier to collate and analyze large amounts of data. However, both Hipparcos and the HST have provided a significant impetus to the efforts in this area due to their needs for accurate positions and proper motions to locate the objects of interest and to point the satellites. Due to the considerable overlap of interests between Commissions 8 and 24, the reader is advised to refer to the Commission 8 Report. In particular, the activities of the Working Group on Star Lists for Commissions 8 and 24 chaired by T. Corbin will be found in the Report of Commission 8. Similarly, in the area of proper motions in clusters, the reader is advised to consult the Commission 37 Report for material that may not be included here.

The two major programs for determining the proper motions of stars with respect to faint galaxies continued to make substantial progress from the previous Report. At the Lick Observatory, A. Klemola, B. Jones and R. Hanson completed the second epoch photography of the Northern Proper Motion program for the fields north of -23° in 1988. They are currently determining the absolute proper motions of 200,000 stars in some 900 fields outside the Milky Way. R. Hanson is using the NPM data to study the solar motion and galactic rotation. The extension of the NPM to the southern hemisphere (SPM) is continuing at the Yale Observatory in collaboration with the Universidad Nacional de San Juan, Argentina. W. van Altena, T. Girard and C. López report that they have started the measurements and reductions of an extended region around the South Galactic Pole and are experimenting with establishing a set of secondary positional standards down to the 18th magnitude with a density of about 10 to 15 stars/deg^2. C. López determined improved positions (±0.7") for the variable and suspected variable stars south of -67° as a part of the SPM project. Work on the determination of absolute proper motions of stars referred to the brighter galaxies in the Pulkovo and Kiev zone continues. To date, N. M. Bronnikova, V. P. Rylkov and N. V. Kharchenko report that 900 plates in 150 areas have been measured and observations in the UBV system are being made at Baldone (near Riga) and at the Abastumani Observatory.

In addition to the global surveys mentioned above, several investigations directed at deeper studies in specific galactic directions are underway, primarily using plates measured on the MAMA measuring machine in Paris, which is directed by J. Guibert. O. Bienaymé and collaborators are determining proper motions (±2 mas/yr) and UBV colors for several thousand stars in 4 galactic directions, to V=18 mag. covering 4 to 20 deg^2 using Schmidt plates from CERGA, Tautenberg, ESO and the POSS copies. E. Schilbach is engaged in a large investigation of the relative proper motions (±2-3 mas/yr) of stars in 17 fields no more that 10° from the main meridian section of the Galaxy using 2 to 3 first epoch plates taken in the 1960s. C. Soubiran is determining the distribution of proper motions (±2.6-3.9 mas/yr) of about 4000 stars in a 7.5 deg^2 area towards the north galactic pole in an investigation of the luminosity function of low mass stars in the solar neighborhood. An extensive search for halo stars and an investigation of the structure of the galaxy is being made by A. Fresneau using proper motions that he has measured on the MAMA machine for one million stars in the declination range +1° to +31° and magnitude range 9.5-12.5. In an analysis of the FK5 proper motions, P. Brosche and H. Schwan have found a strong dependence of Oort's parameter B on the galactic latitude.

The Hipparcos Input Catalogue Consortium (INCA) completed the observation catalogue of 118,000 stars and delivered it to ESA and the data reduction consortia in 1989. C. Turon reports that these stars were selected from the 220,000 stars proposed for observation. During the past decade they have had their positions, proper motions, magnitudes and colors and the knowledge of their variability and duplicity improved in an extensive effort by astronomers throughout the world. There is no doubt that the INCA Data Base will be of great use to the astronomical community in many other areas following its planned publication in 1991. Further information on the INCA Data Base is contained in the Report of Commission 8 and the investigations relating to the duplicity of the stars are reported by J. Dommanget in the Report of Commission 26; the studies of the higher order multiplicity by J. Anosova and V. Orlov are also reported to Commission 26.

The past triennium has seen considerable progress towards the completion of several important catalogues of positions and proper motions. Chr. de Vegt reports that the classical plate reduction of the CPC2 has been completed and both the FK4/B1950 and FK5/J2000 tape versions are in the process of being released, while the final block adjustment solution is being worked on in Hamburg. The new Zodiacal Zone Catalogue of the U. S. Naval Observatory was completed and published. R. Harrington reports that the Catalogue (J2000) of positions of approximately 45,000 stars within 16° of the ecliptic, but North of declination -30° was obtained from plates taken with the twin 20-cm astrograph in Washington, while the proper motions were obtained from a remeasurement of old Yale Zone plates. Following the completion of the Northern Hemisphere observations the twin-astrograph was moved to New Zealand where it is now awaiting a new red sensitive lens before starting the Southern Hemisphere observations.

Several major catalogue projects are reported by N. M. Bronnikova, I. I. Kanaev, D. D. Polojentsev, and H. I. Potter. A new catalogue of 200,000 stars south of the equator down to the 11th magnitude has been compiled at Pulkovo based on 6000 plates taken from 1983-1988 with the expedition astrograph at Ordubad, Nakhichevan ASSR and Tarija, Bolivia. The average accuracy of a position in this catalogue (FOKAT-South) is ±0.15". A somewhat deeper equatorial catalogue called EKAT is being made to the 12th magnitude in the zones +20° to -20° based on plates taken at Tarija and Ordubad. At the Nikolaev Observatory, G. I. Pinigin reports that G. K. Gorel is preparing an equatorial catalogue in the +4° to -4° region. An all sky catalogue of 4949 Bright Star positions (BKAT) based on 8000 plates observed at Ordubad and Tarija with a neutral density spot filter is nearing completion.

3.1 Derived Catalogues of Positions and Proper Motions

In addition to the important task of the observation and construction of new catalogues, it is also necessary to create derived catalogues which combine many different observed catalogues into one system. These derived catalogues provide the users of astrometric data a convenient source for the "best" data available for particular stars. Aside from the INCA Catalogue and Data Base for Hipparcos, which represents a subset of the data, three other major catalogues have been made available or are nearing completion.

The "Catalogue of Astrometric Data" (CAD or CDA) was prepared at Heidelberg to supply accurate coordinates for the Hipparcos Input Catalogue; H. Jahreiß reports that it contains positions for 485,000 stars and proper motions for 332,000 stars. (INCA - ESA SP-1111 1989). Also at Heidelberg, U. Bastian and S. Röser report on the publication of "The Catalogue of Positions and Proper Motions" (PPM), which is intended to be a successor to the SAO Catalogue. It contains 326,518 stars with an average positional accuracy of 0.27" at 1990 and a typical rms proper motion error of ±5 mas/yr. At the U. S. Naval Observatory, T. Corbin is completing a new reference star catalogue for the 20-cm twin-astrograph all sky observations.

3.2 Special Catalogues

A number of special catalogues has been created primarily for the reduction of planetary positions, space craft guidance and the establishment of calibration regions. At the Pulkovo Observatory, fourteen EKAT plates have been measured to provide a reference frame to reduce the 1988 Mars opposition observations. At the Lick Observatory, A. Klemola has constructed a catalogue of 5000 star positions in collaboration with the Jet Propulsion Laboratory in the field of the minor

planet Gaspra for the Galileo spacecraft encounter in 1991. Another standard region around the Praesepe cluster is being established at the Engelhardt Observatory. N. Rizvanov reports that a series of plates taken with three different telescopes in both the visual and photographic passbands covering an 8°x8° region with stars down to the 14th magnitude is being measured and reduced into the PPM system; the reductions show that the accuracy of the PPM in this part of the sky is ±0.24" in both coordinates.

P. Brosche reports that about 400 precise positions of minor planets were obtained from plates taken at Merida, Venezuela, ESO and Hoher List. Work also continued at the Felix Aguilar Observatory in San Juan, Argentina on the determination of the positions of minor planets and comets, while in Mendoza at CRICYT, R. Branham is studying possible errors in the FK5 based on observations of minor planets. At the U. S. Naval Observatory, D. Pascu has continued his program of observations with the 26-inch refractor in Washington and the 61-inch reflector in Flagstaff of the satellites of Jupiter, Saturn and Mars. Many of these observations have been made in support of the U.S and Soviet planetary space probes. N. Rizvanov reports that at the Engelhardt Observatory of the Kazan University they have determined several hundred positions of the major planets and their satellites, while at the Nikolaev Observatory, G. I. Pinigin reports that V. I. Voronenko, G. K. Gorel and L. A. Gudkova have determined more than 1000 positions of the major planets, their satellites, comet Austin and minor planets.

3.3 The Optical-Radio Reference Frame Link

Efforts continued with our programs designed to establish a link between the radio and optical reference frames. At Heidelberg, H. Walter and G. Herring continued with their observations aimed at the determination of positions and proper motions in the vicinity of radio sources, while the U. S. Naval Observatory is involved in a collaborative project with the Hamburg Observatory to take plates with the twin-astrograph in New Zealand. P. Brosche reports that positions around 21 compact radio sources and positions and proper motions around four QSOs have been determined by M. Geffert and his collaborators. In addition, N. Argue, R. Duncombe and P. Hemenway continued to work actively on the link program through their projects with Hipparcos and the HST.

4.0 Proper Motions and Star Clusters

Proper motions in and around star clusters continued to be a subject of vital interest to the astronomical community for the purpose of determining the membership, structure, mass and luminosity function of the cluster and for the study of galactic dynamics. Due to the interests that we have in common with Commission 37, the reader should consult their Report for completeness. In the area of proper motions within clusters, several observatories maintained active programs. I. Platais of the Radioastrophysical Observatory in Riga (now at Yale Observatory) has determined the relative proper motions of several thousand stars in the regions of the open clusters NGC 752 and NGC 7209. He is also nearing completion on an investigation of NGC 7789. At the Lick Observatory, A. R. Klemola and J. Stauffer of the NASA Ames Research Center continued a photometric and astrometric survey of the extended Pleiades field to isolate faint red members. Klemola plans to extend this work to the construction of a catalogue of all known members of the Pleiades cluster. B. F. Jones and M. F. Walker continued their program of the membership determination in young clusters, including the Orion Trapezium Region, NGC 2264, NGC 6530 and several others. Also at Lick, S. Francic completed a study of the membership of the clusters NGC 752, NGC 1342, NGC 1528, NGC 1647, NGC 2281, NGC 6633, and IC 4725. At the Van Vleck Observatory, J. T. Lee has begun a proper motion study in the central part of the Hyades cluster using Van Vleck plates with an 18 year baseline. At the Yerkes Observatory, K. M. Cudworth and his collaborators have continued their proper motions studies of several clusters, including NGC 6712 and M4. The measurements and reduction are nearly completed for M28, M107, 47 Tuc, NGC 6791 and Tr 14/16. A. A. Latypov of the Tashkent Observatory reports that he has determined the membership of the clusters NGC 6882/6885 and is nearing completion of a study of the open cluster NGC 6664. At the Hoher List Observatory, M. Geffert and collaborators are studying the membership of the ultraviolet-bright stars in M12, the open cluster NGC 1647 and determining the position of the x-ray source in M15. Many of the plates have been measured on the MAMA machine in collaboration with J. Guibert. At the Yale Observatory, T. Girard and collaborators determined the membership and internal motions in the open cluster M67, in addition to the membership of the cluster NGC 5617. T.-g. Yang in collaboration with T. Girard has remeasured the plates of

NGC 188 to a fainter limit and is in the process of determining revised membership for more than 1000 stars in the vicinity of the cluster.

B. F. Jones, A. R. Klemola and D. Lin of the Lick Observatory have nearly completed the first phase in the measurement and analysis of the absolute proper motions of the LMC red-giant stars in its remote halo around the globular cluster NGC 2257. K. Cudworth reports that he has determined improved proper motions for several extreme velocity stars and has used these data in a study of the galactic escape velocity. M. Geffert and collaborators at Lick, Belgrade and Münster have determined the absolute proper motion of M12 with respect to faint galaxies on the Lick Observatory system to study the orbits of M12 and three other clusters.

5.0 Instrumentation, Techniques and Reduction Methods

In a major new program, D. Monet of the U. S. Naval Observatory has designed a laser interferometer encoded automatic measuring machine which will accommodate four 14x14-inch Schmidt plates at one time and will measure either in a single channel "PDS mode" or in a fast mode where it uses a large CCD to image successive sections of the plates. On line analysis of the data will produce the positions of all stars on the four plates without the need to store the actual scans. Delivery of the machine is expected in early 1991.

At the Hamburg Observatory, Chr. de Vegt reports that the Hamburg astrograph has now been equipped with an autoguider based on a modification of the Lick Observatory astrograph autoguider. He is also continuing with the design study of a 1.5 m astrometric telescope for the purpose of constructing a high precision faint star catalogue in the magnitude range 18-19 and has begun testing a new granite based measuring machine using a CCD detector as the principal measuring device.

A. A. Kiselev published a monograph entitled "Theoretical Basis of Photographic Astrometry", where he uses vector notation and gives the theory of central projection, tangential coordinates, and the methods and problems of the reduction of photographic astrometric observations.

I. Platais has developed a new image centering routine based on the use of cubic splines. He finds that it has improved accuracy for faint stars over the conventionally used algorithms. He is now testing the new algorithm on galaxies found on plates from the Yale Southern Proper Motion survey and the CTIO 4 m telescope.

At Bonn, P. Brosche and collaborators have developed and tested a plate reduction method using orthogonal basis functions instead of the customary power series. In addition, overlap programs from Bordeaux were transferred to Bonn by C. Ducourant and applied to the Hipparcos link observations and Galas is studying the variation of image centers on simulated CCD frames in differing observing conditions.

At CRICYT in Mendoza, Argentina, R. Branham has derived an algorithm for calculating a total orthogonal least squares solution in compact storage mode. This should be used in the case where the data errors are present in both equations of condition as well as the observations. (*Computers in Physics* **3**, 42, 1989) He has also derived a covariance matrix to handle the situation where the residuals show a systematic variation with time. The standard covariance matrix assumes no variation with time of the residuals. (*Proceedings of the Second Franco-Chilean Conference on Applied Mathematics*, 1990, University of Santiago Press, in Press).

As a part of his work on the HST project, W. H. Jefferys and his collaborators B. McArthur and J. McCartney continued with the development of the Gaussfit and Pickels programs for the analysis of the HST astrometry data and the selection of reference and guide stars for the HST.