SUMMARY AND CONCLUSIONS

BART J. BOK
Steward Observatory, Tucson, Ariz., U.S.A.

This has been a good Symposium. There obviously is a need to review now the problems of the accepted fundamental reference system of star positions and proper motions. The basic Fourth Fundamental Catalog (FK4) has been *the* reference catalog for the past 10 years. It needs updating and especially it should be made more directly usable for discussions of positions and motions referred to faint galaxies. In the preparation of the next catalog we should make use of radio galaxies as basic reference points for fixing precision stellar positions. The Symposium came at the right time! Radio Astrometry has burst upon the scene and it is essential that the optical and radio astrometrists should get to know each other and exchange views about the manner in which together we may work towards the establishment of a fundamental system of positions and proper motions more reliable than we have had in the past. There has also been much activity in the area of measuring proper motions of faint stars relative to galaxies and we obviously have to consider the best manner in which these valuable new contributions can be applied most usefully to basic astrometry. Our Symposium was held in the right place! It is high time that we should draw attention to the accomplishments and the future needs of basic southern hemisphere astrometry; Perth, Western Australia, is obviously a good place to discuss such matters. Finally we should discuss questions relating to instrumentation. Over the past decade there has been what could be called a 'breakthrough' in instrumentation, not only in the radio area, but also in the more traditional optical area of measurement by transit circles. There have been many new developments in the field of automatic measurement of photographic plates. This was clearly the time to take stock and plan for the future.

The Scientific Organizing Committee had sensibly picked seven areas for special discussion. I shall report briefly on each of these in order of the Perth presentations.

A. REFERENCE SYSTEMS

Ten years ago the Rechen-Institut in Heidelberg, of which the Chairman of the Scientific Organizing Committee, Walter Fricke, is the Director, published the Catalog FK4 with precision positions and proper motions for 1535 fundamental stars. FK4 needs updating and we must have, in addition, data of comparable quality, firmly tied into our basic fundamental system, for many additional stars and for some faint galaxies. Our present requirements are twofold. First, we need urgently a Supplement to FK4 that will include precision data on the FK4 Reference System for a few thousand faint stars. This Supplement should include precision positions

Gliese, Murray, and Tucker, 'New Problems in Astrometry', 325–333.

on the FK4 System for a number of star-like galaxies as well. Second, we must get in shape for FK5, which will require that we obtain precision positions for the epoch of 1975, more or less, for most of the stars in FK4. Furthermore, we must obviously check and improve as well the quality of the proper motions for the stars in FK4.

We had much useful discussion during our Symposium about the need to determine afresh the basic values for the precessional corrections in use today. The adopted values for the precessional constants that we use today are still those derived by Simon Newcomb early in this century. I am sure that Newcomb would be pleased to learn, if he could be so informed, that his constants have continued to be the basic ones for about three-quarters of a century. But I think, too, that Newcomb would be the first one to suggest that the time has come for slightly different values to be adopted for use in compiling FK5! It seems from our discussion that the planetary precession is probably fixed with sufficient accuracy already, but that the luni-solar precession needs careful overhauling. Along with this, we must look into new determinations of the Oort constants of galactic rotation, A and B.

W. Fricke and W. Gliese indicated that 1980 is the present target date for the publication of FK5. They reported that 150 dependable new catalogs of position have been published since 1950, and these must obviously be incorporated in FK5. The present plan is to include in FK5 all observations that will become available before the end of 1975. The work on a Supplement to FK5 should proceed in parallel with the work on the basic Catalog. Our Symposium suggested that there is a need for a Supplement containing 3000 to 5000 stars. The new requirements presented by radio astrometry, and also those for positions and motions of faint galaxies, should receive special attention. Present systematic uncertainties in proper motions of reference stars are considerable. Errors of the order of 0".005 to 0".007 per year may well be present. However, with continuing effort and insistence on precision positions and proper motions, such errors may well be reduced to $\frac{1}{3}$ their present values for FK5. Proper motions of precision with small systematic and accidental uncertainties are absolutely essential for the calibration of the distance scale of our Milky Way System, for the basic calibration of the HR diagram and for all sorts of problems relating to the calibration of absolute magnitudes of the stars. The astrophysicist, the student of galactic structure and the astronomers involved in the study of distances of faint galaxies all require as a basis for their work a good fundamental system of reference positions and proper motions.

B. SOUTHERN HEMISPHERE REFERENCE SYSTEMS

Problems relating to positions and proper motions of stars south of declination $-35°$ received special attention at our Symposium. When FK4 was prepared, the situation with regard to positions and proper motions of southern stars was in a sad condition. The only observatory south of the equator that contributed effectively to FK4 was the Cape Observatory in South Africa. The principal reason why our Symposium is being held in Perth is that, by doing so, special attention would be drawn to southern hemisphere needs. Moreover, the astronomers gathered at remote Perth wish to ex-

press their thanks and congratulations to their colleagues who have worked so hard during the last decade to remedy the existing deficiencies in the south.

New southern observations figured prominently in our discussions at Perth. B. J. Harris, the Director of Bickley Observatory in Western Australia, and his colleagues, notably I. Nikoloff, have worked on the problem in close association with a group of astronomers from Hamburg, Germany. In the later 1960's our German colleagues brought a precision transit circle to Western Australia for work on the southern heavens. We learned that 110000 observations have been obtained with this instrument and that all of these have been reduced and analyzed. In addition, we now possess basic data from 45000 absolute positions determined by the Chilean and Soviet astronomers jointly working at Cerro Calán Observatory near Santiago. The results of this magnificent work were reported for the two groups by the Santiago Director, C. A. Anguita. And, third, the U.S. Naval Observatory has completed the making of 115000 observations of southern stars with a transit circle at the El Leoncito Station in Argentina. The various groups working from the southern hemisphere are agreed that large corrections $\Delta\alpha_\delta$ must be made to FK4 positions in the South Polar Cap.

We cannot expect to rest on our laurels. We now possess a good set of basic positions for southern reference stars for the epoch 1970, but, to obtain good proper motions for these stars, a continuing major effort is obviously called for. If we diminish our southern hemisphere efforts at this time, then we are asking for trouble by the year 2000, for we must obviously have for all of our reference stars good proper motions along with high quality positions. We must continue observational positional work from several southern hemisphere observatories. We were delighted to learn of the excellent progress being made in the preparation of an extensive catalog of Southern Reference Stars.

C. RADIO ASTROMETRY

Our Symposium will be remembered principally as having been the occasion for the first meeting of radio and optical astrometrists. One of our principal tasks has been to consider how the results of radio astrometry can be incorporated in our researches on fundamental systems of reference for positions and proper motion. Among our colleagues attending the Perth Symposium were about a dozen radio astronomers. Three of them presented major review papers: C. M. Wade of the National Radio Astronomy Observatory of Charlottesville, Virginia, and Greenbank, West Virginia, B. Elsmore of the Mullard Radio Astronomy Observatory of Cambridge, England, and C. C. Counselman of Massachusetts Institute of Technology. The three took the time to explain in detail to the optical astronomers the techniques of observation used by radio astrometrists, a gesture that was both effective and much appreciated by all present.

In his Introductory Remarks, Chairman Fricke noted that a year ago the methods of determining absolute radio positions were near the point where they could compete with the methods of traditional fundamental astrometry. He said further "I find that

this point has already been reached and that the radio methods have been developed to such a perfection that an even higher accuracy can be reached than in optical absolute measurements." At the conclusion of our Symposium I feel free to report that all of us present at Perth wholeheartedly agree with Fricke's evaluation.

The most impressive results to date have been obtained with the aid of connected element radio interferometers involving moderate baselines of a few kilometers. Absolute values for the declinations of the radio sources can be found from the measurements of the rates at which these sources move through the interferometer patterns. What the radio astronomer does basically when he fixes a declination, is to determine a very precise radius for the daily circle described by the radio source under investigation. He requires no optical measurements of position for reference purposes. Absolute declinations come automatically from his observational data. Precise time measurement is fundamental to success in radio astrometry. The radio astronomer can measure large arcs in the heavens with the same precision as small arcs, and differences in right ascension can therefore be very precisely observed. The radio astronomer cannot observe the Sun and planets with the same precision as that obtainable for radio stars and galaxies, and asteroids are not suitable (at least not yet!) as basic reference points. The radio astronomer is therefore not capable yet of fixing directly the zero point of his system of right ascensions, the vernal equinox, and he must turn to his optical colleagues for zero point determinations. This requires that special emphasis must be given to the determination of precision optical positions for radio sources that have been identified optically. Such sources are (1) all radio stars, (2) radio galaxies and (3) quasars.

Highly dependable positions for radio sources have been obtained. Presently determined radio positions have uncertainties in right ascension and in declination which are in the range of $\pm 0''.1$ to $\pm 0''.01$. Data of such precision are now available for close to 100 radio sources, spread evenly over the sky from the North Pole to about 40° southern declination. Three good radio stars, Algol, Beta Lyrae, and P Cygni are already known and more are promised; their fundamental optical positions in the reference system of FK4 (and soon of FK5) must obviously be measured with high precision. We must not overlook the pulsar in the Crab Nebula as an optically identified radio source! The optical astrometrist has as one of his major future assignments to determine with minimum delay a good fundamental position for any star that is identified as emitting radio radiation. Many optically identified compact galaxies emit radio radiation, and the optical positions for these objects must of course become available also with minimum delay. The same applies to the quasars which are shown on our photographs and which often emit strong radio radiation.

While the work in radio astrometry for moderate baselines is already yielding first-class results, even greater precision is ultimately promised from observation using the techniques of Very Long Baseline Interferometers, some of them intercontinental. At Perth, Counselman indicated that he is of the opinion that ultimately precisions of the order of $\pm 0''.005$, or better, may be obtainable. But this is still in the future. It became clear during the discussion at Perth that, for the effective use

of radio positions already measured or about to become available, optical astrometrists must provide through the Supplements to FK4 and FK5 high caliber positions not only for *all* radio stars and for most optically identified radio galaxies, but that there is furthermore a need of a good many good standards between 16th and 19th apparent magnitude for stars near radio galaxies.

Much interest was expressed at the Perth Symposium in the results of the University of Texas radio astrometry survey, reported by J. N. Douglas. With the aid of the Texas 120-channel radio interferometer, source positions have already been determined to within one second of arc for 2000 radio sources and 50000 more such sources are within reach of this equipment with comparable precision.

Once again the southern hemisphere is being discriminated against. The radio interferometers that have been most effective to date have all been in the northern hemisphere. The Perth Symposium passed unanimously a resolution urging the extension of the application of radio astrometric techniques to southern hemisphere observations. If this is not done soon, then we shall have to live for the next twenty years or so with a lopsided fundamental system of reference for positions and proper motions. The northern hemisphere will be in good shape and the south will be lagging behind. All astronomy and astrophysics will suffer as a consequence.

One of the great things that developed from the meeting at Perth was that it brought together optical and radio astrometrists – who realize that one cannot succeed without the other.

D. ASTROMETRY WITH LARGE TELESCOPES

E. PROPER MOTIONS AND GALACTIC PROBLEMS

During our Symposium, many important papers were presented in the sessions under the above headings. We devoted a full day of our Symposium to the problems of astrometry with large telescopes, especially the measurement of proper motions and trigonometric parallaxes of faint stars, and the use of this material in Milky Way research.

In a way, the most significant presentations related to the measurement of positions and proper motions with reference to galaxies. The vast complex of researches initiated by W. H. Wright at Lick Observatory in California, and by A. N. Deutsch of Pulkovo Observatory in the U.S.S.R. have produced already some very important and impressive results. A. R. Klemola and Deutsch reported on the Lick and Pulkovo programs. The Lick Observatory Program is well on the way toward completion. Most first and second epoch photographs have been made with the twin 20-in. photographic and photovisual refractors at Lick Observatory. The separation between first and second epoch plates is mostly of the order of 20 years. The Lick method consists of measuring relative positions of a considerable number of stars faint galaxies on a pair of plates, and from these positions the proper motions of the stars can then be obtained with reference to the galaxies. Close to 60000 stars and faint galaxies are being measured at Lick, 30000 of them stars of "special interest" (including 2400 RR Lyrae stars) and 29000 stars that possess good reference

positions in the system of FK4, mostly from AGK3. These will ultimately be related directly to the positions in the system of FK5. At Pulkovo Observatory, Deutsch and his associates have completed measurements of positions of stars relative to star-like knots in 85 spiral and other external galaxies.

The first result of intercomparisons between Lick proper motions and the Pulkovo proper motions were reported at our Symposium. These results are not cheerful. There seem to be considerable systematic differences between the annual proper motions determined by the two rather different methods, with occasional systematic differences in R.A. being found as great as $0''.010\ yr^{-1}$. This is a matter that clearly requires prompt further examination, and we are assured that such examination will be forthcoming soon. The techniques developed and applied at Lick and at Pulkovo Observatories obviously have terrific importance, for the results obtained by these methods should lead to a firm tying-in between positions and proper motions for the brighter stars and for faint stars and galaxies. In the preparation of the Supplements to FK4 and FK5 careful attention will have to be given to the inclusion of a good number of Lick and Pulkovo stars (and galaxies) on these lists.

During the session on proper motions and galactic problems, S. V. M. Clube of Edinburgh presented a paper that shows that very new and unexpected results may come from analyses of proper motions of faint stars observed in the Lick survey. He seems to have detected unexpected local streaming tendencies within 300 pc of the Sun on the basis of his analysis of the first list of 8000 Lick proper motions.

We heard during our Symposium a good deal about three related projects. Anguita announced that a survey in principle not unlike the one at Lick Observatory is being undertaken at the U.S.S.R. Station at Cerro El Roble in Chile (with a Maksutov Telescope) and a second northern survey is planned with the telescope of Tautenburg Observatory in the German Democratic Republic. All of this was very welcome news, but not so welcome was the information that the Yale-Columbia Project at the El Leoncito Station in Argentina is in danger of being prematurely stopped by lack of funds. The Yale-Columbia effort, which to date has been supported by the National Science Foundation, may not even have the funds for the completion of its whole first epoch program of photographic and photovisual plates. In a general outline, the Yale-Columbia program follows closely the precepts of the Lick Program and ultimately we may expect from it for the southern hemisphere results of a scope and precision comparable to those now becoming available from the Lick Program. But to do the job right, we need now to see to it that the first epoch plates are completed without delay and that these plates should be of the required high quality. The initiation of the program for the taking of second epoch plates can be postponed for a while, for at least 15 years should elapse between the taking of first and second epoch plates for proper motion work. However, it would be a disaster if the first epoch program would not be fully completed now. The Symposium at Perth passed a resolution showing its deep concern regarding the possibility that another southern hemisphere project may be neglected. A resolution in support of the completion of the Yale-Columbia Program was also passed by IAU Commission 24 during the

General Assembly in Sydney, which was held during the two weeks after the Perth Symposium.

W. J. Luyten received an ovation for the magnificient work that he has done on locating and studying faint stars of large proper motion with his new fully automatized and computerized plate scanner and measuring engine. He offered a list of 11000 stars with proper motion in excess of $0''.18\ yr^{-1}$, and another list of 800 new stars with proper motions in excess of $0''.5\ yr^{-1}$. He noted that his latest maximum of the General Luminosity Function is at photographic magnitude +15.4 which is a little brighter than his earlier result, which placed the maximum at +15.7.

During our discussions frequent reference was made to the astrometric needs for access to large reflectors and Schmidt telescopes. Astrometrists need this access because it is only through the use of these instruments that such projects as the determination of faint membership of open and globular star clusters can be resolved. Unless such access is provided now, the first epoch plates for proper motion work will not be available 20 years hence when questions will be asked about such faint membership. In a way the most satisfactory solution is that achieved by the U.S. Naval Observatory. At its Flagstaff Station it operates the 61-in. astrometric reflector, a truly magnificent instrument for work of this nature. Harley Wood, the Government Astronomer for New South Wales in Australia, pointed out that a similar instrument is very much needed for astrometric work in the southern hemisphere. The 98-in. Isaac Newton Telescope at Herstmonceux is already being used 3 or 4 nights per month for astrometric research. C. A. Murray reported first results for parallax and positional work based on photographs made with this telescope. Very encouraging results were also reported by W. F. van Altena with the good old Yerkes 40-in. refractor.

We listened to various reports about the current status of research on trigonometric parallaxes. K. Aa. Strand reported that good progress is being made with the program of trigonometric parallaxes under way at the U.S. Naval Observatory's Flagstaff Station. 209 trigonometric parallaxes obtained from photographs made with the 61-in. astrometric reflector have already been published. The selection of future stars to be placed on the Flagstaff and other programs was discussed at length. Work on trigonometric parallaxes with large reflectors is so time-consuming that great care must be taken in advance in the selection of candidates for the measurement of trigonometric parallaxes. Large proper motion is a fine first criterion for selection, but every star chosen tentatively for such work should be examined carefully. If the star is bright enough, Schmidt reflector objective prism photographs should be examined or higher dispersion spectra should be obtained with image tube spectrographs. The Hoag-Schroeder technique, in which a transmission grating is placed close to the Cassegrain focus of a large reflector, promises to be very useful as well. Furthermore, every candidate should be subjected in advance to careful photo-electric photometry, which, for the redder stars, had best be done in visual and near infrared light.

During our discussions much attention was paid to the cutting down of the ac-

cidental errors in measured trigonometric parallaxes. In spite of much effort, most finished trigonometric parallaxes are uncertain by $\pm 0''.004$. Some further reduction in the mean errors obtainable from observatories on Earth may be achieved, but not much. However, I should report that space research holds great promise in this area. The Large Space Telescope should yield trigonometric parallaxes with errors on the order of $\frac{1}{3}$ of those now obtainable from Earth. Truly spectacular results may be expected when space missions with astrometric equipment extend the baseline through observations from the vicinity of Jupiter and simultaneously by observation from a distance of 5 AU in the opposite direction! The sample of our Milky Way system for which trigonometric parallaxes figure importantly at the present time lies entirely within 25 pc distance from the Sun. With much effort and proper care it now seems within attainable limits that our precision might go up sufficiently to double the radius of the sample, which would yield reliable data to distances of 50 pc from the Sun. With another doubling of precision through observation from space vehicles near the Earth, we should be able to move out to radius of 100 pc from the Sun, which would increase the volume of our space sample by a factor of 64 over that within reach to 25 pc distance. By extending our baseline to 5 AU, this volume could be increased by another factor 125, and our sample would be able to give us reliable trigonometric parallaxes for stars to 500 pc from the Sun.

F. ASTRONOMICAL REFRACTION PROBLEMS

G. ASTROMETRIC TECHNIQUES

During the final days of our Symposium, we had much discussion about improvements in techniques of observation for astrometric purposes, and we listened to several descriptions of new and ingenious measuring engines for obtaining photographic positions. The basic instrument for the measurement of stellar positions is still the meridian or transit circle. Its future was examined with care a year ago at an International Colloquium held at Copenhagen. G. van Herk reported about the discussions at Copenhagen, and it is helpful that his report will become part of our Proceedings. Whereas, early observers were proud to measure with transit circles stars of 10th apparent magnitude by simple visual techniques and recordings, it will soon become possible to obtain comparable accuracy to 12th mag. with the same instruments that have been used in the past. All of this is achieved through the application of photoelectric techniques and of automization of the recordings, a field of research and development to which the President of the IAU, Bengt Strömgren, has made some important and fundamental contributions. Modifications of the traditional transit instruments are being considered and have been developed by several astrometric groups. The horizontal mirror transits especially deserve attention. Our French colleagues spoke again very warmly about future uses of the Danjon astrolabe. Not only will this instrument be one of the basic pieces of equipment for use at the new astrometric observatory in the south of France (near Grasse), the 'Centre d'Etudes et de Recherches Géodynamique et Astronomiques' (CERGA), but we learned during our discussion that such astrolabes are being groomed especially for research

in the neglected southern hemisphere. The instrumental development undertaken at the U.S. Naval Observatory, and at the astrometric observatories in Copenhagen, Hamburg, Ottawa and Pulkovo, deserve special attention for the future.

We have already referred above to Luyten's equipment for measuring and analyzing photographic plates. We listened to reports about several high speed automatic measuring instruments. The GALAXY Machine at Edinburgh, and other similar machines in Great Britain, promise to be exceedingly useful instruments for positional work. The automatic measuring machine, which has been in operation at the U.S. Naval Observatory for the past seven years, has proved its worth and a new version, incorporating laser interferometry techniques, is expected to go into operation soon. Lick Observatory has obtained a completely new version of its automatic measuring engine, which will soon be the instrument to measure the galaxy reference plates for the Lick Program.

H. CONCLUSION

It behoves a reporter of an IAU Symposium to end his remarks by presenting the principal conclusions that resulted from the discussions. On the last day of our meetings we took the time to discuss, occasionally rather vehemently, three major resolutions that we wished to bring to the attention to the whole of the astronomical world. These Resolutions represent the essence of our recommendations, and they show more clearly than anything that I can say or write, how effective and constructive a Symposium all of us have attended!