NEW IMPETUS TO ASTROMETRY

(Inaugural Address)

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In 1964 a conference was held at Flagstaff, Arizona, in honour of Ejnar Hertzsprung. At this conference Martin Schwarzschild presented the inaugural address. The title was 'New Impetus to Astrometry'. I was so much impressed by everything what he, as an astrophysicist, had to say that I have always remembered his analysis of important astrometric problems with admiration. Nine years after the Flagstaff Conference, I find it appropriate to open this Symposium in referring to Schwarzschild's lecture and in presenting my views on recent developments and on progress which I expect in the future.

Major achievements in astrometry during the past decade resulted mainly from the introduction and development of new instrumental techniques, the application of astrometric methods in new areas of astronomy, and from the vigorous and successful work in large international undertakings. An important part of the recent progress was unforeseen, namely, the progress made in the absolute measurement of positions of objects by means of radio techniques.

Let us first consider the classical areas of astrometry. I will follow here Schwarzschild in first citing the determination of the local inertial frame of rest, which in practice, is given by a system of positions and proper motions of fundamental stars and the knowledge of accurate values of the so-called constants of precession, nutation and aberration. While in 1963 the Fourth Fundamental Catalogue (FK4) was completed on the basis of observations before about 1950, an enormous effort began with the aim of improving the system and the individual data of the FK4. The observations have been carried out with the transit circle, the vertical circle, and with Danjon's astrolabe. By means of improved techniques the errors of observations have been decreased by a factor of about two compared with the observations on which the FK4 was based, and it has become possible to push the magnitude limit of meridian circles to stars fainter than visual magnitude nine. Furthermore, considerable contributions have been made to the improvement of the system in the southern sky, which in the FK4 was based almost entirely on observations made at the Cape Observatory alone. The number of absolute and differential observations made since 1950 is already sufficiently large to justify an extensive analysis with the aim of an improvement of the FK4 and its extension from magnitude 7.5 to 9.0. Progress has also been made in determining precession. It has become clear that Newcomb's planetary precession requires a small correction due to recent improvements of the values of the planetary masses. The point has been reached where further correc-

Gliese, Murray, and Tucker, 'New Problems in Astrometry', 1–4.

tions to the planetary masses cannot yield a significant change in planetary precession for all possible purposes within the next few decades. The situation is different for the lunisolar precession where we know that Newcomb's determination is affected by large errors. Two methods of determination have recently been applied, the traditional one based on fundamental proper motions which are affected by erroneous precession. and a new one based on the comparison of fundamental proper motions with those measured with respect to galaxies. Moreover, it has become evident that recently derived values of lunisolar precession differ from Newcomb's value mainly due to the differences between the declination system of the FK4 and that used by Newcomb which was essentially the declination system of the 'FK1' compiled in 1879 (*Fundamental Catalog für die Zonenbeobachtungen am Nördlichen Himmel*, abbreviated FC). From all findings, which shall not be reviewed here, I would consider it desirable that the next fundamental catalogue, the FK5, should be based on revised values of precession.

The second area of astrometry I am now going to consider is the determination of proper motions of a large number of stars for purposes of stellar kinematics. The classical approach consisting in the repetition of plates taken with astrographs has resulted in the AGK3 giving positions for the epochs 1930 and 1958 and proper motions of about 180000 stars in the northern sky. Here is an example of work which would have hardly been possible without international cooperation, that has proved to be a strong source of impetus to major achievements. Many observatories distributed over the whole world have shared in the task of determining the positions of reference stars in the system of the FK4 by means of transit circle observations. As a result the positions of the 20000 reference stars forming the AGK3R catalogue belong to the most accurately known at an epoch around 1960. In the AGK3, which is in print now, the average mean error of a proper motion is $\pm 0''.80$ per century. For the improvement of the individual proper motions in the system of the FK4 older catalogues may be used which have not had the support of a strong system of reference stars. Among such older sources are the AGK1, Astrographic, and Yale Zone catalogues whose full exploitation is a task for the near future. I am of the opinion that, in addition, a full coverage of the northern sky by overlapping plates down to photographic magnitude twelve should be made as soon as possible. If this would be done soon, the AGK3R stars can be used again as reference stars. The repeated use of the AGK3R stars requires the knowledge of their proper motions, and the larger the epoch interval counted from 1960 will become, the more accurate the proper motions of the reference stars must be. Proper motions may be derived for many of them, by using positions known from older meridian observations that were carried out in a well defined system and can be expected to be free of serious errors depending on the magnitude.

The improvement of the AGK3 proper motions by both methods, the exploitation of old catalogues and the repetition of the plates, is a necessity for stellar kinematics. The present errors of $\pm 0''.80$ in each coordinate which are about four times the errors in FK4, yield satisfactory tangential velocities only for stars nearer than 300 pc

($\varepsilon_{v_t} = \pm 11.4$ km s^{-1} at $r = 300$ pc). In practice, one can expect to shift this limit to about 600 pc by the methods just mentioned.

In the southern sky, the situation with respect to a photographic reference system of positions and proper motions is not as favorable as north of the equator. The Southern Reference Star program will supply the reference star positions for plates that are being taken at the Cape and Sydney observatories. In order to provide a useful reference system in the south, the SRS program can be considered as one step only; the observations of the program stars must be continued in future with transit circles. They are not only required for providing the reference frame for photographic plates but also for the improvement of the fundamental system.

In view of the great effort required for measuring proper motions of stars with respect to the fundamental system, all attempts must be welcomed that use galaxies as representatives of an inertial frame of reference. The first results presented during the past few years from plate pairs taken at the Lick Observatory and at Pulkovo are very encouraging for the following reasons: they have allowed a comparison with the fundamental reference system via the AGK3; they contain stars much fainter than AGK3 stars in large areas over the sky accessible to these observatories; and last not least, the independent approach made at these two observatories will certainly help to get a better judgement of the reliability of the measurements. The comparison of the results obtained independently at Lick and Pulkovo indicates that the proper motions in declination are in fair agreement with each other and with the fundamental system. The proper motions in right ascension measured at Lick and at Pulkovo, however, differ from each other by more than one second of arc per century, and the mean of both is very near to the fundamental μ_α. This discrepancy is not yet explained. Furthermore, the high expectations set in the measurements with respect to galaxies call for a continuous effort in the improvement of the individual accuracy by further observations, since, at present, peculiar motions of stars with respect to galaxies are satisfactory only, if the stars are not farther away than about 300 pc.

I wish to proceed now to a third area which has been introduced into astrometry only recently, but with most exciting success. This is the area of radio astrometry, and within this area I want to draw particular attention to the new possibilities of establishing a fundamental system of positions by absolute determinations of declinations and right ascensions of compact radio sources by means of radio interferometers. Nothing else than the zero point in right ascensions has to be adopted from other sources, if one wants to adopt the vernal equinox as the zero point. Progress in radio astrometry appears to be so rapid that any statement made by a non-expert in the field, like myself, can hardly be up-to-date. In my article on 'Fundamental Systems of Positions and Proper Motions' published last year in *Ann. Rev. Astron Astrophys.* I wrote that the methods of determining absolute radio positions are near the point where they can compete with the methods of traditional fundamental astrometry. From recent information by radio astrometrists 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. We all are certainly very much looking forward to the reports of our colleagues from the field of radio astrometry in this Symposium. To my knowledge it is the first time that optical and radio astrometrists are meeting in an IAU Symposium for a discussion of joint problems, and here is a challenging opportunity of making benefit for future developments.

The new impetus offered by radio astrometry to optical measurements has widely opened the use of large telescopes for the purpose of determining accurate positions of optical counterparts of compact radio sources. Here is the opportunity of linking the astrometric system based on radio observations with the fundamental system with the aim of establishing an extragalactic inertial system represented by bright stars and optically faint objects. All what I have said about the desirability of an improvement of the FK4 and the establishment of accurate photographic reference systems over the whole sky are necessary steps in this direction. The possibility that the compact radio sources may not all be extragalactic, that their positions in the sky may not be strictly identical with those of the optical counterparts, and that some of them may have large transverse motions should not discourage us from vigorously pursuing the aim just mentioned.

There are other areas in astrometry in which the use of large telescopes has given vital impetus. These are the determination of parallaxes of faint stars, the observation of double stars, and the search for high proper motion stars. In these fields are most fascinating contributions to astrophysics by finding absolute faint stars thus providing us with data on very faint red dwarfs, on the end of the white dwarf sequence, and on very small stellar masses. I am sure that it is no overstatement, if I remind our younger colleagues that the astrometrists have one of the keys in their hands for progress in astrophysics. This holds for observers as well as for all those who are engaged in improving the techniques of observation, of measuring, and of analysis.

I am coming to the end in addressing in particular our younger colleagues. There are before us many fascinating tasks whose accomplishment is fascilitated by new and automized observing instruments, measuring machines and fast computers. You are encouraged in many ways to get in contact with colleagues from all over the world and to take part in international cooperation. There are challenging opportunities of making a major contribution to astronomical research. I would, however, be seriously misunderstood, if one would assume that these magnificent opportunities are accessible in an easy walk. The qualification for successful research can only be reached by hard work. The requirements for qualification have not diminished, in the contrary, they have grown considerably. The astrometrist is not an operator at an instrument, a measuring machine or a computer who is expecting that new impetus will come from outside. He has to govern large areas of astronomy such that he himself can give impetus to new achievements. It is my sincere hope that this Symposium will contribute to raise some enthusiasm for great accomplishments in astrometry in the future.