IAU Symposium 109, Gainesville, "Astrometric Techniques"

CONCLUDING REMARKS

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I have been asked to give an overview of what we have learned at this Symposium. In his introduction, Dr. Eichhorn told us what we were going to learn. Then all the speakers taught us, and we were learning. Now I am supposed to tell you what we have learned! Dr. Eichhorn expressed the hope that by doing it three times we might walk away from here with some additional knowledge. The organizing committee told me that this paper would introduce the discussion we just had; since this discussion is over, and we even passed a resolution, that part of my task is finished. It is of course hard to give a summarizing paper when the two papers just before it have introduced some entirely new and highly interesting subjects, and several more papers are to follow. In my opinion this was a very impressive Symposium: some forefront work has been reported, and many improvements have been made in the accuracy of the products of astrometry. But even more, this Symposium has pointed the way to a very exciting decade to come.

We have seen a lot of progress since the meeting in Vienna 5 1/2 years ago. VLBI produces ever greater accuracy. The measuring machine technology has suddenly improved in accuracy, and especially in speed. We have seen exciting contributions from the Chinese astrometrists. CCD and other electronic focal plane devices, including speckle interferometry are coming into their own and promising a wealth of new information. We have come a step closer to Space Telescope and HIPPARCOS; both of these instruments are now under construction. Optical and infrared interferometry for astrometry have been introduced in a serious way. Several catalogs that have been promised for a long time are now published or on the verge of publication: the Washington Double Star Catalog and the Double Star Orbit Catalog, the new Parallax Catalog, the Nearby Star Catalog, and the Yale Bright Star Catalog. All of these new publications are compilations of the information that we have been assembling over the years. The title of this Symposium is "Astrometric Techniques"; this means that we had to classify data reduction and the many theoretical discussions about reference frames, new technology, data handling etc.

H. K. Eichhorn and R. J. Leacock (eds.), Astrometric Techniques, 799–803.

as "techniques." I expected perhaps a little bit more in terms of technological discussions, but the overall result was a sound and well-balanced mixture.

We started out rather extensively discussing the various fundamental catalogs and the well known systematic errors in the FK4, with proper motion errors up to one second of arc per century in the southern hemisphere. We know this because fortunately we have a few new southern hemisphere catalogs, which will be incorporated into the FK5 and will provide considerable improvement to this rather horrible situation. It was reported that some individual positions in the northern hemisphere FK4 are off by as much as 0.8 arcseconds. Those of us who made the statement in this Symposium that "as long as I have one FK4 star and one radio source in the same field I can tie reference frames together" should watch out! It might behoove people in need of individual positions to wait for another two years until the individual corrections to the FK4 stars are available. The alternative is to do the data reductions using FK4 in such a way that we can easily revise them, once the complete FK5 catalog is out. I noted with pleasure that the stellar reference frame is to be made more homogeneous with supplementary stars to be added both to the FK5 and IRS. I noted with some worry that the proper motion surveys are becoming very expensive: including overhead, a pair of Lick-Yale type proper motion plates now cost $200. This high cost comes at a time when one is inclined to contemplate new photographic surveys because the plate measuring machines are becoming superb. The new machines are fast, and they produce a 0.5 micron or better accuracy. They are in fact so fast that it has been suggested that one should consider remeasuring the AGK2 and even those plates of the Carte du Ciel that are still around the various observatories. A formidable task, you say? Is it any more formidable than the undertaking by the Space Telescope Science Institute of measuring a 30 Mega-Star Guide Star Selection System in two years? That GSSS project, when completed, will provide both to the astrometric community and to astronomy at large an invaluable arsenal of positional data, and of input data to search and measuring programs. It could well form the core for a remeasuring program of older plates. The dynamical reference frame is in fantastic shape; new technologies, especially the radar ranging techniques, have brought us a big step further in firming up the fundamental system formed by the planets.

I have tried to list the new telescopes. I noted that the construction of the Chinese 1.56-meter telescope (the one that is one centimeter bigger than the Flagstaff 1.55-meter) is progressing very well and we all look forward to seeing that in operation and contributing new parallaxes. It is unfortunate that we still do not have a similar telescope in the southern hemisphere. The ingenious, intriguing new ideas in the Chinese Astrometry community regarding telescope construction, including porposals for transit circles and the glass transit circle, are to be mentioned. The Tokyo transit circle, the Danish-British Carlsberg transit circle in La Palma and

the U. S. Naval Observatory 7-inch transit circle in New Zealand will all be fully operational in the next six to nine months. CCD and other array technology provides the possibility of doing measurements in the focal plane to better than half a micron. We have seen an enormous jump in speckle interferometry; I noted that 3000 measurements have been made on 500 objects, and many of them still reside unreduced on magnetic tape somewhere because the field has grown so fast that the few practitioners cannot keep up with the data flow. Speckle interferometry for very close-in differential astrometry is a terrific new tool of which I am sure we will see a lot in the very near future.

Two of the big topics at this Symposium are space astrometry and interferometry. We have heard that in the HIPPARCOS project there are possibilities of systematic errors, that the investigators are looking into them and that they can hopefully be overcome. It is very gratifying indeed to find that the last few years have seen a very thorough study of the entire HIPPARCOS system. When it was discussed five years ago I was worried that our European colleagues might be carrying their enthusiasm too far: we were told repeatedly that there would be no systematic errors in HIPPARCOS. I am very pleased that indeed that subject has been studied extensively. This gives more confidence than we already have in the success of the undertaking, particularly since all of these studies have led to the conclusion that we can still expect, in large regions of sky, the same accuracy that was promised from the start. At the same time I hope everybody bears in mind that at most ten thousand stars will have a 10 percent accuracy in their parallaxes, not hundred thousand stars. But even ten thousand stars with 10 percent parallaxes is an enormous increase over what we have at the present. I was rather taken by the prediction of the TYCHO Project that it will lead to annual proper motions with three milli-arc-seconds (mas) accuracy, for five hundred thousand stars, by taking all the older catalogs and combining them with the TYCHO 10-50 mas positions.

I was impressed by the confidence with which the various consortia apparently are tackling the enormous problems of the reduction programs and are confident that in the end they will come out with almost identical results. I will not say anything about the exciting possibilities of tying the HIPPARCOS and the radio reference frame together using the Space Telescope. The whole big field of international cooperation which is opening up in this area is impressive.

In interferometry we see at this time that ground-based optical and infrared astrometric interferometry are now reasonably well funded programs which promise a hundredth of an arc second or better in "absolute" positions; I expect that we will have a good evaluation of those techniques in the coming three years or so. This is undoubtedly a promising technique because, unlike VLBI, it measures stars and not radio sources and thus can tie in directly to the fundamental

coordinate system. This brings us to the (radio) Very Long Baseline Interferometry. There are now VLBI catalogs of fifty to one hundred sources with arc-length errors of 3 mas. We find that the JPL and the Goddard Space Flight Center Systems, basically determined with different techniques, different algorithms, and different telescopes, are aligned to within 1.5 mas. We are 1.5 orders of magnitude up on where we were six years ago. Listening to these marvelous achievements, however, the following thought crossed my mind: We will have fifty to one hundred positions of radio objects, which have optical magnitudes between 13 and 21 and which determine an extragalactic reference frame. But what good are they for galactic kinematics, dynamics, cluster dynamics, and absolute parallaxes? All these fields of endeavor deal with stars, optical objects, often faint, sometimes bright. The valiant attempts to tie an optical reference system into this marvelous radio reference frame have so far yielded frame-wide accuracies of perhaps 0.05 arc-seconds, with deviations of a few tenths of an arc-second for individual objects. At the 0.1 arc-second level one runs into all the systematic errors of the optical system. They will improve as we improve the optical system but the major improvement is expected to come from HIPPARCOS. We may even go further and have a HIPPARCOS II, but can we wait that long? What if the satellite falls into the ocean? What do we do with our students in the meantime? They cannot wait, and the field must not stagnate. Fortunately, as we have learned at this Symposium, ground-based astrometry is very, very much alive.

Satellites are either short-lived or overbooked; surveys and other long-term programs however are an essential part of astrometry. We need higher accuracy for limited areas and have seen at this Symposium that such accuracies are attainable from the ground. We can get them "easily" in space, in a short amount of time, but given time and continued enthusiasm, the ground-based astrometrist can get the same results for a small fraction of the cost of satellite observations. We can reach ground-based accuracies in proper motion below 0.1 mas per year. We heard the fascinating story of how measuring the tangential motions of the Magellanic Clouds would once and for all determine the mass of our Galaxy. It seems to me that with the improvements in plates, measuring machines and electronic position determination in the focal plane, we may well get there in the next ten or twenty years.

Then we heard that outrageous prediction from the VLBI community: Don't worry about tying the radio reference frames to something; in two years we will compare the raw radio reference frames at epoch and without worrying about what the Earth has been doing. After fitting them together at epoch we will then adjust the Earth's motions to fit the reference frame. This brings us to the quasi-ideal natural reference frame, independent of theories and observational constraints. We will have an opportunity for clarifying and simplifying our fundamental notions. There is a revolution in available precision. Not in our wildest dreams thirty years ago did

we ever think in milli-arc-seconds. As Dr. Eichhorn so eloquently said, the result is that many definitions in astrometry are being kept alive by amendments; he called it artificial respiration. He pointed, for example, to that legalistically contorted definition of the ecliptic. In the discussion preceding this summary it was pointed out that as observers we are tied to the Earth and thus to the equatorial system. But in our thought processes and in our concepts we must remove ourselves from the Earth. Turn our definitions around, so that we tie the Earth and its motions to a natural non-rotating reference frame. We should start the discussion. But let us not overdo it, let us not hurriedly adopt new definitions. There is time. We must start with quiet discussions in small groups; we have the mechanism in the IAU Commissions and working groups, initiated or spurred on by the Commission presidents. A session at the next IAU might be highly worthwhile to start the ball rolling. Eventually perhaps even an invited discourse on the fascinating new avenues opened up by Astrometry would be a possibility.

This then is how far we have come even in the 5 1/2 years since the Vienna Symposium. We are seriously discussing a radical change in outlook, based on ground-based achievements and on some promises from space, and to be nurtured by ground-based work augmented by space experimentation. Astrometry is in for a very exciting decade and this Symposium has set the tone.