THE ESTABLISHMENT OF AN ASTROMETRIC STANDARD REGION -- A DESCRIPTION OF THE METHOD WITH REFERENCE TO THE ASTROMETRIC STANDARD REGION IN PRAESEPE (M44)

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ABSTRACT. An astrometric standard catalog has been derived for the region centered on the Praesepe open star cluster. This catalog includes positions and proper motions of 408 objects on the system of the FK4 reduced from 9 catalogs and 145 plates from 15 different telescopes and spanning 110 years. The accuracy of the positions ranges from 0.01 to 0.15 arcsec and for the proper motions from 0.0002 to 0.004 arcsec/yr, depending on the number and quality of the observations. The method of catalog construction is an application of the central overlap technique.

1. INTRODUCTION

An astrometric standard region is a catalog of star positions and proper motions which are as free as possible from systematic errors and on a fundamental system. Such a catalog can then be used to test the imaging characteristics of telescopes, to look for systematic errors in other catalogs and to provide a reference for absolute measurements. The need for standard fields in astrometry has been discussed for some time. The IAU Commission 24 working group on parallax standards approved a list of three regions to be photographed routinely by parallax observatories. These three regions included Praesepe, discussed in detail here, as well as the Pleiades and IC4756. When catalogs for the other regions are also complete, astrometrists will have a set of standards for comparison of the imaging characteristic of astrometric instruments. In this paper we will discuss the method to establish a standard region, with particular reference to the standard catalog derived for the region around the Praesepe star cluster, M44 (Gatewood and Fredrick, 1971; Russell, 1976; Russell and Gatewood, 1985), and give an example of its application.

2. PREPARATION FOR THE DERIVATION OF A STANDARD REGION

The bulk of the work in the derivation of a standard catalog is in the preparation -- choosing an area of the sky, choosing the list of

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objects to be included, researching published catalogs, finding all of the observations in the area, borrowing old and new photographic plates and measuring them.

2.1. Choice of Region -- Area of Praesepe Star Cluster

The choice of the area of the sky which will be used for the catalog is most dominated by finding an area with a long observing history, with some consideration for accessibility to observers. Other things to consider are features which would allow an independent check of the positions and proper motions and a good distribution of stars.

The region of the Praesepe open star cluster was first photographed in 1867 (Gould, 1870), the second area of the sky after the Pleiades to be photographed and measured for positions. It is centered at 20 degrees declination, so is accessible to most observers. The star cluster provides a concentration of stars which can be included in the catalog for the benefit of small field instruments. An additional advantage of the Praesepe area is that it is on the ecliptic, so that solar system objects which pass through the area may have their positions determined more accurately than with respect to astrographic catalogs. Finally there is a background small cluster of galaxies, which may be included as "stars" in the standard catalog as a check for systematic errors in the proper motions.

2.2. Research for Available Catalogs and Plates

The available resources will determine the size of a possible region, what magnitude range it will have and its ultimate accuracy. The catalogs are the easier part of the exercise here; the more difficult task is finding what plates are available, their limiting magnitude, their condition and whether their measurements can be obtained. For the Praesepe region, there were a number of catalogs available, dominated by the AGK3 and the Yale zones. Fortunately, most of the astrometric observatories had photographs of at least the Praesepe star cluster and it had been covered by a number of large field astrographs. Since the standard region was being established mostly for the calibration of long focus astrographs, the size of the field covered by the Lick double astrograph, roughly 3 by 4 degrees, was used since it was considered sufficient for most applications. Also available were Bruce plates, epoch about 1895; both of these wide angle plates went faint enough that the catalog could be extended to 16th magnitude, which also should be sufficient for most long focus telescopes.

2.3. Choice of Stars for the Standard Catalog

This part of the planning for the region is critical. It must be preceded by the research of published catalogs so that all stars in the catalogs to be used will be included. This is followed by the choice of the other field stars. The Praesepe catalog is centered on the cluster so that the central square degree of the region includes over 30% of the stars. This concentration is for small field instruments. Over the entire 3 by 4 deg region 408 stars were chosen with a visual magnitude range of 5.7 to 16.4 and B-V of -0.29 to 1.60. The list of stars includes 10 galaxies, though the catalog will be referred to as a list of stars. Less than half of the stars are cluster members, so that the presence of the cluster should not affect the calculated proper motions. Of more concern because of the presence of the cluster is that its members' magnitude-color correlation not dominate the catalog. The final star list includes enough field stars that the correlation between magnitude and color of the stars is reduced to about 0.5; thus magnitude and color related characteristics of telescopes can be separated.

2.4. Assembling the Observations

Collecting the observations, in most cases measurements of photographic plates, is the most labor intensive part of deriving a standard region. The Praesepe region included over 10,000 individual measurements of star positions, not including objective grating images, from 145 plates spanning the epochs 1867 through 1976. These were from 15 telescopes, including most of the long focus telescopes currently in use and a few historical instruments, e.g. the Rutherfurd refractors, whose plate measurements were published. All but a few of the plates were measured by hand.

3.0. DATA REDUCTION FOR THE ASTROMETRIC STANDARD REGION

The data assembled must be reduced by a method which is able to incorporate several plates with different plate models and different plate centers. Traditional plate-to-plate relative astrometry cannot be used under these circumstances. The plates must be tied to a catalog system and reduced as nearly as possible into the absolute coordinate system, into the "real sky" so to speak. A comparison of several methods of data reduction is given by Russell (1978) in a previous meeting of this IAU commission. The one chosen for the reduction of the Praesepe region is the central overlap technique. A rigorous non-iterative overlap also could be used, but the simplicity of the central overlap technique is preferred. The only limitation of the latter is that in the case of a large set of plates with little overlap it is slow to converge.

The central overlap technique is an iterative method which begins with a reference catalog and the plate measurements and assumes that the plate constant models for the instruments are known. The plate constant reduction for each plate is performed to produce a list of positions, i.e. right ascensions and declinations, including one for each star on each plate. These are sorted by star. Then the data, i.e. positions and epochs, for each star are solved for its position and proper motion. This is done for all stars, those used as reference stars in the plate constant reduction and the field stars as well. When all of the star constant reductions have been completed, the reference catalog is updated, i.e. replaced, with the information from the star constant solutions. This completes the first iteration. Then the plate constant solutions are repeated using the updated catalog; the star constants solutions are repeated using the data from the second plate constant solutions and another updated catalog is created. This continues until the catalog converges.

In the central overlap technique the information from all plates goes into the updated catalog and affects the solution of any individual plate on the next iteration, therefore the implicit overlap. The technique is called the central overlap because it works best, i.e. converges most rapidly, when the plates are nearly concentric.

In the derivation of the astrometric standard region in Praesepe the central overlap technique was applied in a two level approach to speed convergence. The first pass, called the reference plate reduction, included only a few wide field plates from early and late epochs. These were reduced to convergence first to enrich the catalog as much as possible, then all of the data, including the reference plates, were included in the final set of iterations.

3.1. Primary Reference Catalog

In its normal application in parallax and proper motion studies (e.g. Gatewood and Eichhorn, 1973), the central overlap technique is used with an initial reference catalog from one source, e.g. the AGK3. In the reduction of an astrometric standard region it was hoped to include as many catalog observations as possible, so the observations from all the catalogs were combined into one. The positional data from nine catalogs was collected and, if necessary, corrected to the system of the FK4. Note that proper motion data were not explicitly included, only the original observations from which the catalog motions were calculated. Then these catalog positions were sorted by star and the star constants, position and proper motion, calculated from all observations. The result was called the primary reference catalog and it was this catalog which was used as the reference catalog for the reference plate reduction.

The primary reference catalog included 122 of the 408 stars. It was dominated by the AGK3 and the Yale zone catalogs. The positional accuracy was $\pm$ 0.02 to 0.2 arcsec and the proper motion accuracy was $\pm$0.0008 to 0.01 arcsec/yr; the latter values are per coordinate and are the same in right ascension and declination.

3.2. Reference Plate Reduction

The plates chosen for this were the large area plates, which represented a wide range of epochs, and all of the plates which had been taken with objective gratings. Since the wide angle astrograph plates included most of the stars in the final list of 408, reducing them first would give an intermediate catalog which included most of the stars. Thus the smaller field plates would have a larger number of reference stars available in the catalog when they were included in the second set of iterations.

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It is worthy of note that if any error were found in the plate modeling, the data reductions would have to be rerun from the time those plates were introduced into the solutions. Thus an error in modeling any of the reference plates would result in starting over again from the very beginning.

The measurements from the grating plates were pre-reduced for magnitude and coma effects. Since the measurements from these plates were already corrected for any magnitude related effects caused by their instruments, any systematic error with magnitude in their reduction would be a sign of a magnitude error in the catalog, probably introduced from some of the other plates. Unfortunately the grating plates were all of relatively recent epoch.

The results of the second iteration of the reference plate reduction showed systematic errors with magnitude in the proper motions of the stars. This was traced to the following circumstances: the Bruce plates were early epoch, they were known to have a magnitude term in their positions, the primary reference catalog included stars with only a limited range of magnitudes, the magnitude term in the Bruce telescope was not well-determined, thus the magnitude-related systematic error in the proper motions came from the early epoch observations.

To correct the problem with the early epoch positions of the faint stars would require having grating plates at an early epoch or including a few faint stars in the reference catalog. Since there were not early epoch grating plates available, the problem became one of trying to find positions of faint stars at an early epoch to include in the catalog. This was accomplished in the following way. Experimentation showed that the Allegheny Observatory long-focus refractor, the Thaw telescope, showed no magnitude terms in its late epoch plates, and is known to have a long history of stability. It was assumed that the early plates from it would also not show a magnitude term. A few early and late epoch Allegheny plates were reduced into the primary reference catalog, and data from 4 faint stars were chosen and included in the catalog. The rerun of the reference plate solution showed no systematic trend of the proper motions with magnitude. The iterative solution of the reference plates was continued with no further problems.

3.3. All Data Reduction

The reduction of all of the data was very intensive in computer time. If only one set of iterations had been required, it would have been time consuming. But as the catalog improved with addition of new plate material, errors in the models of various telescopes were discovered and the iterations from the introduction of those plates had to be rerun. However, when the final runs were completed and the solutions had converged on a catalog, the results were two-fold: a standard catalog for use in modeling the imaging of any set of observations taken of this region of the sky, and the plate models for the telescopes at the epochs included in this study.

The astrometric standard catalog in Praesepe has positional error of ± 0.01 to 0.15 arcsec and proper motions errors of ± 0.0002 to 0.004 arcsec per yr. These error are per coordinate and are the same in right ascension and declination. The wide range of accuracies is due to the various number and quality of observations for each star. There are 64 stars which were observed at essentially one epoch and thus still need proper motion determinations. Since this is intended as a "living" catalog which will be updated with new plates and new instruments, these likely will be calculated in the near future.

The magnitude and colors for the catalog were determined from image diameter measurements calibrated using photoelectric photometry by Johnson (1952). The internal precision of the magnitudes is slightly better than 0.1 mag.

4. EXAMPLE OF THE APPLICATION OF AN ASTROMETRIC STANDARD REGION

An example of the usefulness of astrometric standard regions, specifically the Praesepe catalog described here, is included elsewhere in this volume (see Russell and Williams).

5. SUMMARY

The version of the Praesepe astrometric standard catalog used above will be published shortly (Russell and Gatewood, 1985). This version will be followed with updates which will include new plates to better determine the proper motions of the faint stars, include additional telescopes, and hopefully someday will enlarge the region. Other possible improvements would be to remeasure the plates with automatic measuring machines whenever possible, include some measurements from electronic detectors, and to include several stars which were observed with transit instruments specifically for this project. In any case it is planned that this be a catalog which is continually updated. It is also hoped that additional standard regions be constructed so that most astrometric observers may have the advantage of a standard field visible at all times of the year.

6. REFERENCES

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Discussion:

THORNBURG: How accurate will the positions be?
RUSSELL: 0".01 for the brighter cluster stars; a few 0".1 for the fainter stars.
THORNBURG: What about the accuracy of relative positions?
RUSSELL: Should be better, but how much isn't known yet. I have no good estimate yet for the true internal error of the catalog.