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Guide Star Catalog Revisited - The Determination of Proper Motions

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Abstract. We are compiling a catalogue of positions and proper motions of 4 million stars, based on the Guide Star Catalogue (GSC) and the Astrographic Catalogue (AC). The GSC is re-reduced by a method described in this paper. The AC has been newly reduced recently by us for the determination of positions and proper motions of the PPM catalogue.

The expected accuracy of the proper motions of the GSC-AC catalogue ranges between 5 and 6 mas/year. Having an average star density of 100 per square degree, this catalogue will be a useful tool for the reduction of CCD frames.

1. Introduction

Being the largest catalogue containing astrometric data, the Guide Star Catalog is the first one based entirely on Schmidt plates. It has been known from the beginning (Russell et al., 1989) that the astrometric reduction of the GSC Schmidt plates was far from perfect, particularly for the southern hemisphere, because no suitable reference star catalogue was available. With the completion of PPM-South this situation has changed. It is now possible to study systematic distortions on the plates in more detail, and to remove them.

The Astrographic Catalogue has been brought into machine-readable form at Sternberg Institute, Moscow (Nesterov et al., 1990). More than 100 years after the beginning of this huge project of international astronomical cooperation, its scientific value can now for the first time be fully exploited.

At present, good (5 milli-arcsec and better) proper motions are available for some 400 000 stars, only. The catalogue we describe in this paper will increase this number by a *factor of ten*. Work on a new reduction of the GSC by a method described below is in progress, and completion of the whole catalogue is foreseen for the middle of 1995.

2. The method of plate reduction

We present a method of plate reduction which is easy to program and yields numerically stable results. In this paper we describe the application of our method to the re-reduction of GSC, but it can be used for the reduction of any photographic plate provided that enough reference stars are available and measured.

For the following we assume that a classical first-order plate adjustment has already been performed that determines orientation and scale. This is the first step of the reduction. As a second step, our approach proposes a "fixed number of reference stars" numerical filter acting in the tangential plane. This will be explained in the following. For each star measured on the plate, we first search for the N nearest neighbouring reference stars. Then the following correction is made to the *measured* coordinates x_S,y_S of the star (*measured* means after the first-order plate adjustment *in the tangential plane*):

$$x_{S,Fil} = x_S - \frac{1}{N}\sum_{n=1}^{N}(x_R(n) - \xi_R(n))$$

where $x_R(n)$ are the *measured* coordinates of the reference stars and $\xi_R(n)$ their standard coordinates. The sum extends over all N neighbouring reference stars. The y_S are corrected correspondingly.

The number N of reference stars in the filter is the only free parameter of the method. The problem with filtering (generally with any plate adjustment method) is the introduction of local correlations between the field star and the surrounding reference stars. The smaller the number of reference stars and the higher the order of the fit, the larger the local correlation gets. The method proposed here is 0th order and uses 30 reference stars.

Taff et al. (1990) recommended the subplate overlap method for a new reduction of GSC. However, fixing the size of a subplate creates the danger of having too few reference stars on those subplates where the reference catalogue has a low spatial star density. This is avoided in our method, it automatically adjusts to the inhomogeneities of the reference catalogue. The higher the spatial density of the reference catalogue is, the smaller the diameter of the filter gets and the better the fit.

Modifications of the method are conceivable. After the selection of the N-stars neighbourhood for a field star, one could perform a higher-order least-squares fit with these N stars, which is only applied for the reduction of this field star.

Summarizing, we can describe our method as follows: each star on the plate defines its own subplate of N reference stars with itself at the centre (except for the edges); the fit that is made on this subplate is only applied to this particular star. With present-day high-speed computers, there is no drawback to the method because of computing time.

3. Application to GSC

As a starting point we used the GSC Version 1.0, and selected the zone with plate centres close to -30 degrees. As *measured* coordinates we took the gnomonically

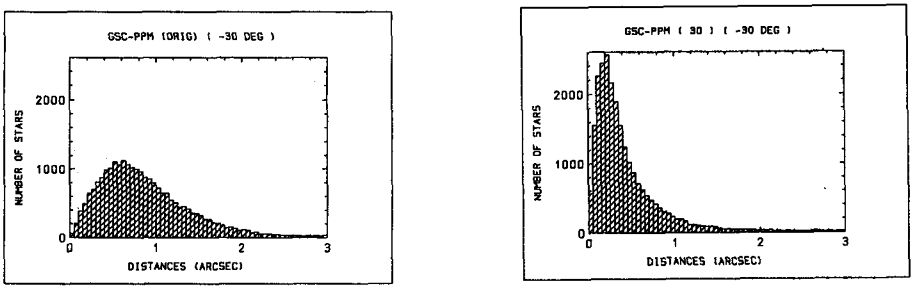

Figure 1. Distribution of the angular distances d between GSC and PPM for all plates with centres near -30 degress declination. The left part of the figure gives the distances between GSC 1.0 and PPM, the right part the distances after re-reduction of GSC using a 30-stars filter. The size of the bins is 50 milli-arcsecs.

projected α, δ of GSC 1.0. A zone on the southern sky was selected, because there we can use the high precision (0.1 arcsec) and the large density (10 stars per square degree) of PPM, leading to more than 300 reference stars per plate, on the average. Only stars fainter than V=8.0 mag are used for the reduction. The brighter stars show systematic errors (see below). Figure 1 (left) shows the distribution of the angular distance $d = \sqrt{(\ \Delta\alpha\cos\delta\ )^2 + (\ \Delta\delta\ )^2}$ between GSC 1.0 and PPM for all stars in the -30 degrees zone. The position of the maximum in this distribution is equal to the rms-errors of the underlying coordinates (i.e. $\Delta\alpha\cos\delta$ or $\Delta\delta$). We infer from Figure 1 (left) 0.6 arcsec as rms-errors for the GSC 1.0 coordinates. Figure 1 (right) shows the same distribution after the re-reduction. Now the maximum is at 0.22 arcsec, which comes close to the measuring accuracy of the GSC. Strictly speaking we measure by these maxima the cores of the underlying distributions of the coordinates. If we fit Gaussians to the coordinate distributions, the tails become more important and we derive 0.7 and 0.35 arcsec as rms errors of the coordinates before and after re-reduction.

As a real test for the performance of the method one has to compare with an independent set of stars, not with the reference stars used. Such a set is given by the 90000 Stars Supplement to PPM (Röser et al., 1994). Figure 2 shows the distributions of the angular distances corresponding to Fig. 1 for the stars in the 90000-Supplement. The same improvement factor as for the reference stars holds. This proves the good quality of our plate reduction method. Note that at the epoch of GSC, the positional accuracy of the 90000-Supplement is almost equal to that of PPM itself.

Next we plot the mean residuals of the reference stars as a function of the position on the plate for the mean of all 63 plates in the -30 degrees zone. This is given in Figure 3. The method yields excellent results in the inner parts of the plates with some deterioration at the plate edges. This is quite

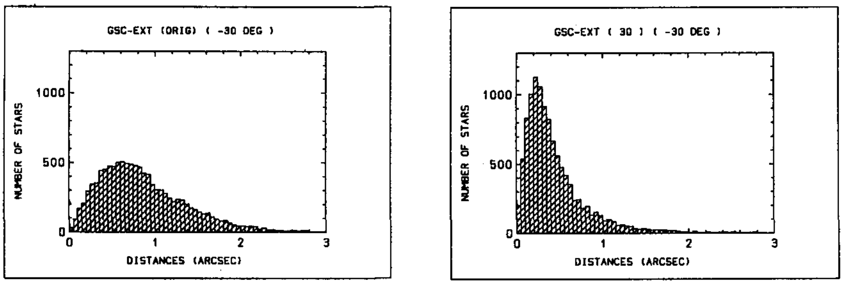

Figure 2. Same as Figure 1, but the distances between GSC and the 90000-Stars Supplement of PPM are plotted. The stars in the Supplement were not used for the reduction.

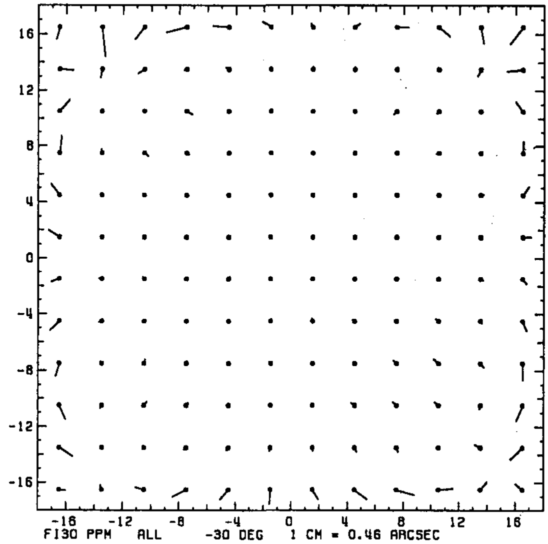

Figure 3. Mean residuals after filtering as a function of the position on the plate. The average of 63 plates is plotted. Each dot or arrow represents the mean of about 200 stars in a 3 by 3 cm subarea of the plate. Units on the axes are cm on the plate. 1 cm corresponds to 11 arcmin on the Palomar and SERC Schmidt plates. It also corresponds to a length of an arrow of 0.46 arcsec.

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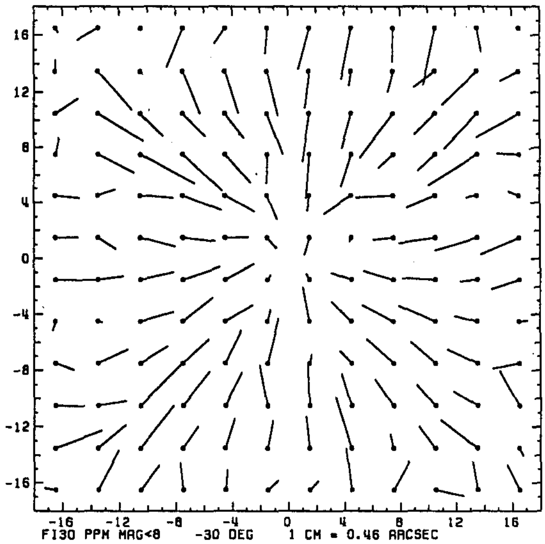

Figure 4. Same plot as in Figure 3, but for the stars brighter than V=8.0 mag. Each arrow represents the mean of about 15 stars.

understandable from the design of the method. One could think of modifications of the method near the edges, either by reducing the number of stars in the filter, or, as mentioned above, using first-order plate fits instead of zeroth-order. Both modifications increase the local correlations, so in all applications a careful choice between close adjustment and higher correlation is necessary.

Although for our purpose (i.e. the derivation of proper motions between GSC and AC) we need to consider only the faint stars (fainter than V = 9 mag) it is quite interesting to study the astrometric quality of the bright stars after re-reduction. In Figure 4. we plot the average residuals of the stars brighter than V=8.0 mag for all the 63 plates of this zone as a function of the position on the plate. Quite surprisingly for a coma-free instrument like a Schmidt we note a coma-like distribution of the residuals. Note also the size of the effect: more than 1 arcsec. The effect suddenly vanishes for stars fainter than V=8.2 mag. Correcting this effect will result in a drastic improvement of GSC positions for bright stars.

4. The Astrographic Catalogue - Proper Motions

The Astrographic Catalogue (AC) contains positions and rough magnitudes for about 4.0 million stars. The mean epoch of observation is near 1900. AC provides a complete sky survey to about 12th photographic magnitude with a

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positional accuracy of 0.35 arcsec or better (rms-error per coordinate). In an earlier paper (Volchkov et al., 1993) the project of deriving proper motions for AC stars is described, and early results for the San Fernando and Cordoba zones of AC are presented. However, GSC 1.0 was used as second-epoch observations.

Using GSC 1.2 or GSC re-reduced as described above, considerably better proper motions can be expected. From the results of section 3, we may assume an rms-error per coordinate of 0.35 arcsec as a pessimistic estimate for re-reduced GSC. During the compilation of PPM, the complete AC was reduced to the J2000/FK5-system, and information about the individual rms-errors of the positions in the different AC zones was obtained. A table giving these data is published by Röser and Høg (1994). Using these values, we may expect a catalogue of positions and proper motions of about 4 million stars with average rms-errors of the proper motions of 5.2 mas/year on the northern, and 5.8 mas/year on the southern sky. These proper motions are almost as precise as those from the northern part of PPM, but the number of stars is ten times higher than the total number in PPM.

Acknowledgments

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Discussion

Hawkins: Are you using the original visual measures of the A.C., and if so would it be worth re-measuring them by machine?

Röser: The original measures as printed in the AC volumes are used. They were keypunched at the Sternberg Institute, Moscow. However, in a few zones, re-measuring was worthwhile to improve the quality of the proper motions.