CCD MERIDIAN CIRCLE REDUCTIONS USING TYCHO POSITIONS AS REFERENCE

Y. Réquième[1], J.F. Le Campion[1], G. Montignac[1], G. Daigne[1], J.M. Mazurier[1], M. Rapaport[1], B. Viateau[1], P. Benevides-Soares[2], R. Teixeira[2], E. Høg[3], V.V. Makarov[4]

[1]Observatoire de Bordeaux, URA 352 CNRS, BP 89, 33270 Floirac, France
[2]IAG-USP, Departamento de Astronomia, CP 9638, 01065 Sao Paulo, Brazil
[3]CUO, Juliane Maries Vej 30, 2100 Copenhagen OE, Denmark
[4]CUO, Oestervoldgade 3, 1350 Copenhagen, Denmark

ABSTRACT

A first CCD 512×512 camera working in scan mode (declination field 14 arcmin) has been tested during 9 months on the Bordeaux automatic meridian circle, then mounted on the Sao Paulo meridian instrument. A second improved camera, with a larger field (28 arcmin), was installed at Bordeaux in June 1996.

Using as reference final positions of the Tycho stars provided by the Tycho Consortium for 16 test fields, and the corresponding Starnet proper motions obtained by S. Röser (ARI, Heidelberg), the accuracy of the positions obtained with both Bordeaux and Sao Paulo cameras was found to be about 0.05 arcsec for a star measured at least four times in the range 9–15 mag.

The Bordeaux and Sao Paulo instruments are currently used for observations of selected fields (around quasars, open clusters, Solar System objects). As a long-term programme, Bordeaux is starting CCD observations of the Bordeaux Astrographic Catalogue zone (+11° to +17°) and the measurement of the old Bordeaux Carte du Ciel plates in order to derive accurate proper motions in this zone up to $V = 15$ mag.

Key words: optical reference frames; CCD astrometry; Tycho.

1. INTRODUCTION

The success of the European space mission Hipparcos has brought into question the future of the meridian circles. The availability of the Hipparcos optical reference frame with accuracy at the milliarcsec level makes the classical visual meridian instruments definitively obsolete. Even several automatic meridian circles are now closed: their limiting magnitude was too small and their observing speed too slow to participate efficiently in the extension of the new reference frame.

However from 1988 onwards, it was clearly demonstrated at Flagstaff (Stone 1993, Stone et al. 1996) that a CCD detector mounted at the focus of a meridian circle and working in drift-scan mode could give a positional internal error less than 50 milliarcsec up to $V = 15 - 16$ mag. The Bordeaux and Sao Paulo observatories decided a few years later to explore this new way with differential reductions using the Tycho Catalogue as reference when it is released.

2. THE BORDEAUX AND SAO PAULO CCD DRIFT-SCAN CAMERAS

The first Bordeaux CCD drift-scan camera was tested during 9 months on the Bordeaux automatic meridian circle and then moved on the Sao Paulo meridian instrument in May 1995. A second improved camera has been mounted on the Bordeaux meridian circle in June 1996.

The main features of the Sao Paulo camera are:

* Thomson 7895M CCD 512*512 pixels
* Pixel size 19 microns= 1.51 arcsec
* Declination field: 13 arcmin
* Equivalent exposure time: $51/\cos\delta$ seconds
* Magnitude range: $8.5 < V < 15$

The corresponding characteristics of the Bordeaux camera are :

* Thomson 7896M CCD 1024*1024 pixels
* Pixel size 19 microns= 1.65 arcsec
* Declination field: 28 arcmin
* Equivalent exposure time: $112/\cos\delta$ seconds
* Magnitude range: $8.5 < V < 16$

Both cameras are cooled at $-40°$C by thermoelectric Peltier elements and water circulation. The dark current is negligible in comparison with the Sao Paulo and Bordeaux sky background. The transfer of charges at the sidereal rate is controlled by a rubidium clock. The spectral bandpass is 520–680 nm by using filter GG495 + BG38. The observed star field is continuously displayed in real-time.

3. CENTERING OF THE IMAGES

The background is extracted from the image matrix by a polynomial adjustment, or with a median filter when the Moon is relevant or for satellites of planets.

The star images are fitted by a bi-dimensional Gaussian, with a correlation coefficient if significant. If several maxima appear in the selected pixel square around the main image, several Gaussians are adjusted for measuring the components of multiple stars when the separation is greater than 4 arcsec.

Due to the small value of the ratio of the FWHM of the images (2.5 arcsec on average) to the pixel size (1.51 or 1.65 arcsec), it is necessary to apply a correction for the Gaussian bias resulting from this undersampling.

4. GLOBAL REDUCTION OF THE OVERLAPPING SCANNED STRIPS

The field to be measured is covered by coincident or overlapping strips scanned during different nights. The differential reduction is carried out in two steps.

4.1. Preliminary Reduction of the Strips of each Night

For each strip corresponding to the considered field the raw (X,Y)'s of the reference stars are processed by least-squares adjustment of a polynomial model in X and Y:

$$\alpha_{\rm REF} = a + bX + cY$$
$$\delta_{\rm REF} = a' + b'Y + c'X + [d'X^2 + e'X^3 + f'X^4]$$

where $\alpha_{\rm REF}$ and $\delta_{\rm REF}$ are the reference catalogue positions reduced at the observing epoch with the associated proper motions and converted to apparent coordinates. Higher terms are added only for very long strips or when motion of the instrument is detected during the scanning.

Stars with residuals larger than 3-sigmas are rejected and the solution is repeated. Using the (3,3) or the (3,6) parameters so determined for each strip, the mean J2000 positions are computed for all the stars with mean error less than 3-sigmas. The whole set of these positions is taken as the new reference catalogue (orientated in the reference catalogue system) for the second step of the reduction.

4.2. Final Reduction

We have adopted an iterative procedure modelling the residuals of each nightly strip by spline functions. Use of spline corrections is proposed for a modelization of the instrumental drifts and of the long-period fluctuations of the refraction (mainly between 4 and 30 minutes).

At the end of each iteration a new mean catalogue of all the stars is computed which will be used as reference for the following iteration. The final catalogue for the selected field is obtained with a satisfactory convergence after 4 or 5 iterations.

5. THE REFERENCE CATALOGUE

For the choice of the catalogue of reference stars three parameters have to be taken into account:

– the declination field of our cameras is limited respectively to 13 and 28 arcmin. Since the length of our scanned strips is generally fixed to 1 hour, the corresponding fields of view are 3.5 and 7 square degrees. Therefore we need a reference catalogue with at least 3 stars per square degree.

– the saturation effect appears for stars brighter than 8.5 and results in a variable systematic error in declination. The Hipparcos Catalogue has just the required star density but a large part of the stars has to be rejected because of the saturation effect.

– the error of the CCD meridian observations is expected to be about 50 mas or below. The accuracy of the reference stars should be of the same order or better. The PPM catalogue was used for our first tests but it was clearly shown that the accuracy of this catalogue did not match the quality of the CCD measurements.

Tycho positions and proper motions have been kindly made available in advance to us by the TDAC Consortium for 16 test fields between $-20°$ and $+62°$. The difference of epoch between the Tycho catalogue and Bordeaux and Sao Paulo observations was 3.5 to 6 years. The quality of the Tycho proper motions is rapidly deteriorating beyond $V = 9$ mag and their use resulted in a significant increase of the dispersion. Finally thanks to a collaboration with S. Röser (ARI, Heidelberg),we have used the proper motions of the preliminary STARNET catalogue computed from the Astrographic Catalogue and the Guide Star Catalogue.

6. PRELIMINARY RESULTS

6.1. Internal Positional Error

After global reduction of a field the mean standard error of a star position is about ± 0.06 arcsec up to $V = 14$ mag and ± 0.18 arcsec at $V = 15.5$ mag. Figure 1 illustrates the variation of the standard error with the magnitude for a typical field. The increase of the positional error for the faintest stars is mainly governed by Poisson statistics. 4 to 6 observations per star at least are planned for all the fields to be measured.

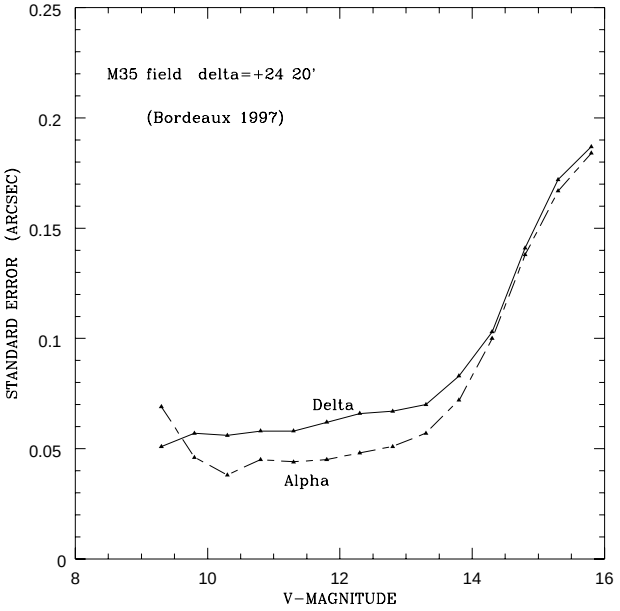

Figure 1. Standard error as a function of magnitude for a field around M35 observed at Bordeaux.

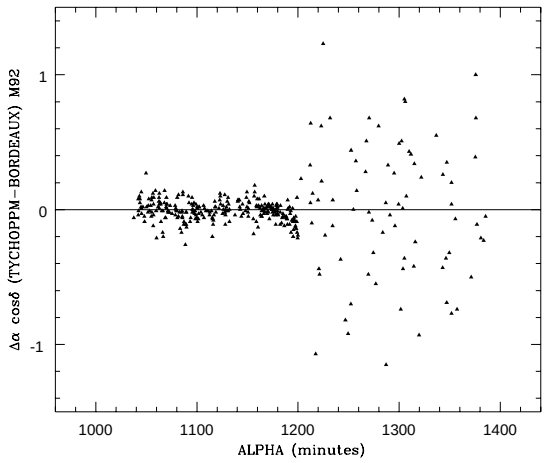

Figure 2. For the first Bordeaux observations of this field around M92, the Tycho positions were available only for 3 hours and PPM data were used for the second part of the scans: reference star right ascension residuals plotted against right ascension (unit arcsec).

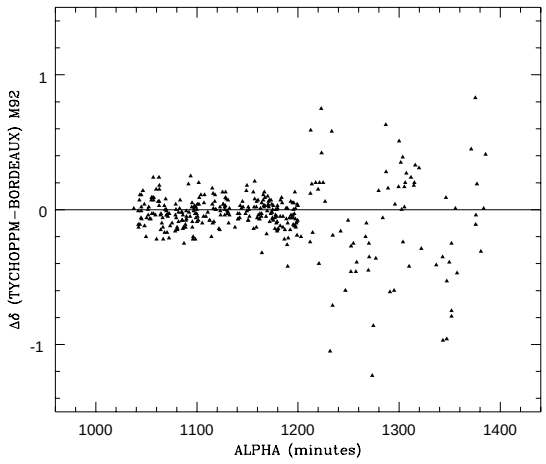

Figure 3. Same as Figure 2, but here reference star declination residuals.

6.2. Tycho–Bordeaux Residuals

Let us call TYCHOST the catalogue made up of Tycho positions and STARNET proper motions. When the catalogue TYCHOST is used as reference, the standard deviation of the (TYCHOST-Bordeaux) residuals at Bordeaux and Sao Paulo is on average in both coordinates:

$$\pm 0.06 \text{ arcsec for } -16^\circ < \delta < +62^\circ$$

The increase of the standard deviation is significant only for zenith distances greater than 60°.

When the PPM was taken as reference, the standard deviation of the residuals was found to be 0.25–0.35 arcsec. In Figures 2 and 3 are plotted the reference star residuals in a field for which the Tycho data were available only during 3 hours in right ascension. The PPM catalogue was used for the 3 additional hours of observations. The plots of the residuals against right ascension illustrate the remarkable improvement obtained using the Tycho positions associated with the STARNET proper motions. However, these results were obtained during the early tests of the 512×512 camera: the increase of the residuals in declination is due to an unsatisfactory clamp of the Bordeaux instrument at this epoch, resulting in an irregular drift during the observing scans.

The Hipparcos Catalogue was used only on a test field around M35. After rejection of the Hipparcos stars brighter than 8.0 mag, the standard deviation of the (Hipparcos–Bordeaux) residuals was:

$$\pm 0.04 \text{ arcsec at declination } +24^\circ\ 15'.$$

That means that the precision of our CCD observations is at present limited by the Tycho positions for V >10.5 and by the STARNET proper motions.

6.3. Comparisons Sao Paulo–Bordeaux

A common equatorial field was well observed with our first 512×512 camera at Bordeaux, then at Sao Paulo, with a difference of epoch less than 4 months. The limiting magnitude was found to be practically the same in both sites (about 15.5 mag).

For this field, using the same TYCHOST reference catalogue and the same reduction procedure, the standard deviation of the differences (Sao Paulo–Bordeaux) was:

$$\pm 0.07 \text{ arcsec for V} < 14$$

$$\pm 0.08 \text{ arcsec for } 14 < \text{V} < 15$$

6.4. Comparisons Flagstaff–Bordeaux

Equatorial fields have been observed by the USNO Flagstaff CCD meridian circle for the calibration of the Sloan project. One of those overlapped partially a field observed at Bordeaux at the same epoch. The Flagstaff field was 7.°5 in R.A. and 51 arcmin in Dec., the Bordeaux one was correspondingly 20° and 35 arcmin. The Flagstaff positions were computed by R.C. Stone, from the same TYCHOST catalogue and with a polynomial model similar to the Bordeaux one but without spline corrections.

In these conditions the standard deviation of the differences (Flagstaff–Bordeaux) for all common stars observed at least 3 times in both obervatories up to $V = 15.5$ mag (660 stars) was:

± 0.065 arcsec in R.A. and ± 0.070 in Dec.

6.5. Observations of Pluto

Thirteen positions of Pluto were measured at Bordeaux in the TYCHOST reference system and compared to the ephemerides DE403. The mean offset (Bordeaux–DE403) at the epoch 1995.25 was:

$+0.05 \pm 0.03$ arcsec in R.A.

$+0.13 \pm 0.03$ arcsec in Dec.

Six positions of Pluto obtained at the epoch 1996.55 give a mean offset of:

$+0.11 \pm 0.03$ arcsec in R.A.

$+0.17 \pm 0.03$ arcsec in Dec.

7. ONGOING PROGRAMMES AND FUTURE WORK

This includes:

– extension of the Hipparcos and Tycho reference frames. The Bordeaux project MERIDIAN 2000 was started in January 1997. It includes CCD meridian observations of the whole Bordeaux Astrographic Catalogue zone (+11° to +17°) and measurements of the old Bordeaux Carte du Ciel plates in order to obtain accurate proper motions in this zone up to $V = 15$ mag;

– link to the extragalactic reference frame via bright quasars and radio stars;

– calibration fields for wide-field CCD mosaics;

– calibration fields in the zodiacal zone for small field astrometry;

– Pluto and selected asteroids for mass determinations;

– open clusters.

Other programmes are in discussion and all proposals are welcomed.

ACKNOWLEDGEMENTS

It is a pleasure to thank the TDAC Consortium for providing in advance the Tycho data of 16 test fields observed at Bordeaux and Sao Paulo, and also S. Röser who kindly made available the preliminary STARNET proper motions. We would like also thank R.C. Stone for his friendly cooperation. This work was supported by the French CNRS (URA 352 and the Aquitaine Region, and also by CNPq (Brazil) and CNRS through travel grants.

REFERENCES

Høg, E., 1997, The Tycho Catalogue: Astrometry and Photometry, ESA SP–402, this volume

Stone, R.C., 1993, in Developments in Astrometry and Astrophysics and their impact on Astrophysics and Geodynamics, IAU Symposium 156, eds I.I. Mueller and B. Kolaczek (Kluwer, Dordrecht), 65

Stone, R.C., Monet, D.G., Monet, A.K., Walker, R.L. et al., 1996, AJ, 111, 1721

Yoshizawa, M., Suzuki, S., Kuwabara, T., Ishizaki, H., 1993, IAU Symposium 156, (Kluwer, Dordrecht), 71