COMPLETION OF THE “CARTE DU CIEL” ASTROGRAPHIC CATALOGUE PROJECT OF THE STERNBERG ASTRONOMICAL INSTITUTE

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Abstract. Observations performed within the framework of the “Carte du Ciel” international project more than 70 years ago provide an excellent first epoch for the extensive determination of proper motions. Combination of the Astrographic Catalogues (AC) with modern photographic surveys will yield high precision proper motions for 4 million stars.

The aim of the astrometric reduction is to obtain the positions of the AC stars with respect to the FK5 reference frame. Systematic errors for the telescope were carefully investigated and accounted for, whenever possible. Final random errors of positions vary by zone; 0.2"– 0.5" appears to be a realistic estimate. Proper motions to be derived from AC and modern survey of matching quality are expected to have an accuracy of 4–6 mas/year.

Key words: catalogs – astrometry – stars: proper motions

1. INTRODUCTION

The first astronomical “Carte du Ciel” photographic sky survey was initiated in 1887 by a group of French astronomers. The observational campaign started in 1891. The last photograph of more than 22,000 plates was taken in 1950. Most of observations (90%) were made before 1920. A detailed description of the “Carte du Ciel” development can be found elsewhere (e.g., Kolchinskii 1989, Eichhorn 1974).
The main result of the project is the Astrographic Catalogue (AC, or, in full, “Carte du Ciel” Astrographic Catalogues, to emphasize the zonal arrangement of the catalogs). It contains the measured Cartesian coordinates and brightness estimates of about 9 million stars. Most of the stars have been photographed on two plates, so the total number of the catalog stars is about 5 million.

Its prime objective, the computation of the equatorial coordinates, could not be achieved within the “Carte du Ciel” project for such a large number of stars. Even the published data could not be used in modern computerized analysis until a complete machine-readable version of the AC had been prepared (Nesterov et al. 1991, Gulyaev & Nesterov 1992). Today the Astrographic Catalogue presents a unique first epoch for the extensive derivation of proper motions. It can also be used in many applications such as a highly reliable deep sky survey.

A detailed report about the machine-readable AC development can be found in Gulyaev & Nesterov (1992). In this paper we discuss conventional plate adjustment (CPA) of the AC plates.

2. REFERENCE CATALOG PROBLEM

Given the size of the AC plates ($2^\circ \times 2^\circ$) and the number of stars necessary to study systematic patterns (typically at least 40 per plate), only two modern reference catalogs appear to be suitable for the purpose of the AC plate adjustment. These are the Astrographic Catalogue Reference Stars (ACRS, Corbin & Urban 1991) and Positions and Proper Motions (PPM, Röser & Bastian 1991, Bastian et al. 1993). We must point out that, in fact, both are unsuitable in terms of standard error of the catalog star position at the AC epoch versus AC measurement error, the former being typically 0.3”–0.4”, whereas the latter is 0.1”–0.15” per coordinate. Unfortunately, this fact is to be ignored due to lack of more accurate reference catalogs.

AC positions were used as an early epoch in the compilation of the PPM catalog; therefore, PPM is dependent on AC and cannot in this case be used for setting up an independent reference frame. Moreover, results of the AC CPA performed with PPM as a reference catalog may prove difficult to interpret. Based on these considerations, we used ACRS as a reference catalog throughout the CPA of all AC sections.
3. REDUCTION MODELS

Transformation of the measured Cartesian star coordinates to the equatorial coordinates is specified by an adopted reduction model that takes into account astrographic aberrations. Refraction and annual aberration effects were removed prior to reduction, “on a sphere”, and therefore are not included in the reduction process. Let us consider the standard 6-constants (Turner) scheme:

\[ \xi = a_1 \cdot x + b_1 \cdot y + c_1, \quad \eta = a_2 \cdot x + b_2 \cdot y + c_2, \quad (1) \]

where \( \xi, \eta \) are the standard (ideal) Cartesian coordinates derived from the equatorial coordinates, \( x, y \) are the measured coordinates on a plate and \( a_1, \ldots, c_2 \) are unknowns (plate parameters, or “constants”). Each reference star provides a pair of equations of type (1). Resulting equations are in practice solved for the unknowns \( a_1, \ldots, c_2 \) by least-squares adjustment (LSA).

LSA residuals represent an accumulated effect of the random measurement errors and incompleteness of reduction model (1). The distribution of residuals over the astrograph field of view (the so-called residual map) provides essential information on incompleteness and, in fact, could be used to infer what terms should be added to the reduction model.

As an example, in Fig. 1 we provide the residual maps for four AC telescopes (Perth, Hyderabad, Algiers and Vatican observatories). Each vector \( (\varepsilon_x, \varepsilon_y) \) represents the averaged residuals at a given point (bin) on all plates of a section. A bin size of \( 5' \times 5' \) was used for these maps.

The maps appear to be quite different, what means that the AC normal astrographs could not be treated as similar instruments. We must point out that the objectives of the AC astrographs were in fact constructed by four different manufacturers – Henry Brothers (France), Grubb and Cook (Great Britain) and Steinchel (Germany).

The refined reduction model given below was able to account for almost all of the present aberrations. The model is as follows (we use non-standard notation):

\[
x = \frac{c_1 \cdot \xi + c_2 \cdot \eta + c_3}{1 + c_7 \cdot \xi + c_8 \cdot \eta} + c_9 \cdot (x - x_c) \cdot r^2 + c_{10} \cdot b \cdot (x - x_c) \]
\[+ c_{11} \cdot \cos(\frac{2\pi x}{5}) + c_{12} \cdot \sin(\frac{2\pi x}{5}) + c_{13} \cdot \cos(\frac{\pi x}{5}) + c_{14} \cdot \sin(\frac{\pi x}{5}), \]
The notation is as follows: \( x, y \) are the measured coordinates, \( \xi, \eta \) are the standard coordinates, \( x_c, y_c \) is the point of intersection of the optical axis and the plate ("origin of distortion"), \( b \) is the brightness estimate, \( r^2 = (x - x_c)^2 + (y - y_c)^2 \) is the distance from the origin and \( c_1, \ldots, c_8 \) are unknowns, or plate parameters. The parameters \( c_7 \) and \( c_8 \) describe a possible plate inclination, \( c_9 \) stands for cubic distortion, \( c_{10} \) is for coma-type magnitude equation, \( c_{11}, \ldots, c_{14} \) are the periodic errors in \( x \) with the 5 mm and 10 mm periods, respectively, and \( c_{15}, \ldots, c_{18} \) are the same errors in \( y \).

4. SIMPLIFIED PLATE-OVERLAP APPROACH

Unfortunately, both the density of available reference stars and their respective standard errors of position at the AC epoch are insufficient for the determination, independently for each plate, of all the parameters described above, i.e. to perform CPA with a reference model of type (2). Statistical estimation shows that the systematic errors introduced by reduction are minimized by using a 6- (or even 4-) parametric model. Therefore, additional parameters \( c_7, \ldots, c_{18} \) of equations (2) have to be determined for some subset of plates under assumption that for all plates of a subset these parameters are the same.

There arise two obvious problems: how to separate plates into subsets and how to determine parameters within a given subset.

The former problem can be solved by studying observing conditions. For example, the parameter describing plate inclination for some of the telescopes varies significantly over a period of several decades. Another example is given by the Hyderabad telescope. Its distortion term was found to be dependent on the season.

The second problem may be dealt with by solving the system of equations given by all stars on all plates of a subset for \( c_7, \ldots, c_{18} \) simultaneously (a variation of the plate-overlap method). We have chosen another, somewhat simpler, approach:

- parameters \( c_1, \ldots, c_{18} \) are first derived separately for each plate;
Fig. 1. Averaged residual maps for four observatories: Perth and Hyderabad (top row), Algiers and Vatican (bottom row).
values of $c_7, \ldots c_{18}$ are subsequently averaged over a chosen subset of plates;

averaged values are then used in (2) as the fixed values rather than the unknowns to derive $c_1, \ldots c_6$ for every plate.

The applicability of a specific reduction model for every section was checked using the mean standard deviation of positions of the same star on overlapping plates.

5. FINAL ACCURACY ESTIMATES

The accuracy of reduced positions can be estimated as $0.25'' - 0.50''$, depending on observatory. The expected accuracy of proper motions (provided modern epoch positions are of the same quality) can be estimated as $4-6$ mas/year.

REFERENCES


Gulyaev A. P., Nesterov V. V. (eds.) 1992, Four Million Stars Catalogue, Moscow University Press

