COMPLETION OF THE STERNBERG ASTRONOMICAL INSTITUTE ASTROGRAPHIC CATALOGUE PROJECT

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1. Introduction

The first astronomical photographic survey, the *Carte du Ciél* was initiated in 1887 by a group of French astronomers. The observational campaign was started in 1891, while the last of more than 22,000 total plates were photographed in 1950; most of observations (more than 90%) were performed prior to 1920. Detailed description of the *Carte du Ciél* development can be found elsewhere (Kolchinsky 1989, Eichhorn 1974, Debarbat *et al.* 1987).

The main outcome of the project was the *Astrographic Catalogue*(AC) (or, more correctly, *Carte du Ciél* Astrographic Catalogues to emphasize zonal arrangement). It comprises close to 8.5 million measurements of rectangular coordinates and brightness estimates. The majority of stars were photographed on two plates; therefore, the total number of catalogue stars is circa 4.5 million.

Due to the early epoch (around 1905) and high positional accuracy (0.25″ may be expected after performing global block adjustment and tying AC to *HIPPARCOS* reference frame), the AC constitutes an excellent first epoch for massive derivation of proper motions. Given a modern epoch with at least the same level accuracy of positions, resulting proper motions will have unprecedented quality of 3–4 mas/year.

In 1987, within the framework of the preparation of the input catalogue for the *LOMONOSOV* space astrometry mission, the Sternberg Astronomical Institute (SAI) AC project was initiated. The main stages of the project are described in the following sections.

B.J. McLean et al. (eds.), New Horizons from Multi-Wavelength Sky Surveys, 409–414.

2. The Astrographic Catalogue: Machine-readable Version

AC data are published in 254 volumes, nearly 90% of which were present in SAI library. Other volumes were kindly supplied by colleagues from Pulkovo and Kazan Observatories (Russia), Golosiivo and Odessa Observatories (Ukrain), Tartu University Observatory (Estonia) and Astronomisches Rechen-Institut (Heidelberg, Germany).

Keypunching of AC data was started in 1987 and took nearly 4 years. Total amount of work may be estimated as 50 manyears. The first preliminary machine-readable version subject to processing appeared in 1990 and the final version for both hemispheres was completed January 1994.

Verification of the keypunched AC data set included both manual and automated procedures, which assured that data comply to formats and records sequencing used in published volumes, all the fields are present and all the exceptions (field incomplete or uncertain) are marked with special flags. All the misprints reported in published erratum lists were accounted for.

Machine-readable version of the AC includes all the published measurements of 19 completed zones of Astrographic Catalogue plus 406 published plates of the original unfinished Potsdam section. Total number of plates is 22,652; total number of measurements is 8,633,975. Number of plates, measurements and observation epochs statistics are given in Table 1.

3. Astrometric Calibration of the AC Plates Material

Astrometric calibration of AC plates should provide reliable and consistent transformation of the measured Cartesian coordinates into positions referred to a modern reference system (*e.g*, the present standard—ICRS). This could in principle be achieved by either standard procedure of individual plates reduction (conventional plate adjustment, CPA) or by rigorous block-adjustment ("plate-overlap technique" (Eichhorn 1960).

Conventional plate adjustment requires a reference catalogue of sufficient density and accuracy (both systematic and random) to derive accurate estimates of the parameters of plate-to-sphere transformation (or, in astrometric terminology, plate constants). Prerequisites are defined by:

- size of AC plate: $2.1 \times 2.1°$,
- number of expected plate parameters: observatory specific systematic errors may lead to as many as 18 unknowns per plate and
- standard error of measurement: 100 to 300 mas per coordinate.

Modern reference catalogues that could be used for the AC CPA purposes are: Astrographic Catalogue Reference Stars (ACRS, Corbin and Urban 1991), Positions and Proper Motions (PPM, Röser and Bastian 1991,

TABLE 1. AC zones: Final assignment

Zone	Declination limits	Plates taken	Measurements	Epoch: Earliest, Latest and Median
Melbourne	−90° to −65°	1149	392,615	1892 1940 1897.4
Sydney	−64° to −52°	1400	744,034	1891 1948 1907.3
Cape	−51° to −41°	1512	901,244	1897 1911 1902.2
Perth	−40° to −32°	1376	604,365	1902 1924 1911.0
Cordoba	−31° to −24°	1360	467,404	1903 1915 1911.9
Hyderabad South	−23° to −17°	1260	521,867	1901 1928 1918.5
Tacubaya	−16° to −10°	1260	516,646	1900 1938 1904.0
San-Fernando	−09° to −03°	1260	346,142	1891 1917 1896.7
Algiers	−02° to +04°	1260	330,459	1891 1911 1903.7
Toulouse	+05° to +11°	1260	433,087	1893 1935 1909.5
Bordeaux	+11° to +17°	1260	355,071	1893 1925 1904.9
Paris	+18° to +24°	1261	436,494	1891 1927 1895.2
Oxford	+25° to +33°	1500	631,816	1892 1936 1907.6
Uccles	+34° to +35°	320	158,660	1939 1950 1944.6
Hyderabad North	+36° to +39°	592	242,550	1928 1937 1930.6
Helsingfors	+40° to +46°	1008	284,661	1892 1909 1894.6
Catania	+47° to +54°	1009	320,631	1894 1931 1902.8
Vatican	+55° to +64°	1046	479,976	1891 1926 1908.3
Greenwich	+65° to +90°	1153	322,238	1892 1905 1896.5
Potsdam	+32° to +39°	460	144,015	1893 1900 1895.6
Totals	−90° to +90°	22,652	8,633,975	1891 1950 1904.4

Bastian *et al.* 1992) and the final *HIPPARCOS* catalogue (upon completion, Kovalevsky *et al.* 1995).

Analysis of the properties of these catalogues under the constraints listed above immediately shows that *NONE* of three catalogues can serve as a reference catalogue for AC CPA purposes, mainly due to their low accuracy at AC epoch and insufficient density. Therefore, conventional plate adjustment could not be used as an approach to high-precision astrometric calibration of the *Astrographic Catalogue*.

Rigorous block-adjustment (also called global block adjustment, GBA) does not in principle require a reference catalogue at the time of solving equations of observations for unknowns (plates constants and/or stars positions)—it can proceed in any arbitrary coordinate system, while comparatively small (but highly accurate) reference catalogue could be introduced at final stage to define necessary rotation of an arbitrarily chosen system to any desired one.

Global block adjustment starts with a preliminary step—definition of plate models which describe telescope and measuring machine specific systematic errors. Parameters of such a model later become unknowns in a global system of equations to be solved.

Being unable to define plate models for AC zones by common means, we should go back to conventional plate adjustment, though this time with a completely different purpose: to define zone-specific reduction models on the basis of available reference catalogues. Obviously, this approach is limited to plate-scale systematics which will in turn be statistically significant with respect to the chosen reference catalogue.

Summing up, we use conventional plate adjustment of AC plates material with ACRS as a reference catalogue in order to define observatory specific plate-scale systematic errors. By means of CPA we also construct a *Provisional AC Catalogue*, to be used as a list of initial positions of stars within global block adjustment procedure. Meanwhile, we believe the provisional positions to be of quite good quality—accuracy of catalog positions is between 0.25″ and 0.45″ depending on the section—and therefore valuable on its own.

The original approach to the global block-adjustment of the photographic sky survey as developed by Eichhorn and was based on the assumption of the absence of epoch difference between overlapping plates. This is obviously not true in the AC case—internal (within section) overlaps expose significant epoch variations, and the situation is much worse with the cross-section overlaps.

The best approach would be to introduce high-quality modern-epoch positions of the substantial number of AC stars into global block-adjustment. Modern-epoch positions will facilitate elimination of proper motions from GBA equations and, on the other hand, will provide the direct link of the AC positions to modern reference frame. Application of this approach may be expected within the Tycho Reference Catalogue project (TRC), *cf.* (Röser and Høg 1993), which is aimed at derivation of the high-quality proper motions for about 1,000,000 Tycho stars using the AC as early epoch.

4. Photometric Calibration of the Astrographic Catalogue

The Astrographic Catalogues also provide brightness estimates along with measured coordinates of stars. These estimates, while being extremely non-uniform in quality and reduction schemes applied, are still highly important. Photometric data reduced into a modern system will be of interest in general and specifically within the framework of construction of the astrometric catalogue based on Astrographic Catalogues. Moreover, in order

to retain consistency, coma and magnitude effects, if present, should be studied in terms of magnitudes derived from original AC brightness estimates.

Unfortunately, available photometric standards, *e.g.*, (Hauck *et al.* 1990) do not allow to access individual variations of photometric systems of AC plates and therefore are poorly suited for the AC photometry calibration task. The only reasonable approach may be realized with the forthcoming TYCHO catalogue which will cover nearly 25% of AC stars. It will provide high-precision photometry necessary for individual AC brightness estimates calibration.

5. Applications of the AC: Present and Prospect

The Astrographic Catalogue is first and foremost a reservoir of proper motions, and therefore most of its applications deal with proper motions. We will note few projects of the kind:

- Positions and Proper Motions Catalogue (completed), where Astrographic Catalogue observations were used to obtain proper motions 2–3 times more precise than that of preceding reference catalogues,
- Tycho Reference Catalogue (proceeding) aimed at even more precise proper motions of more than 1 million stars.

On the other hand, AC should not be overlooked as a deep enough photographic survey of high reliability. For instance, due to manual objects selection and measuring the AC is nearly free of artifacts. This consideration enabled a number of projects aimed at identification of different types of objects that present special interest on the basis of AC positions and proper motions. Examples of applications of the latter type are:

- Accurate astrometry for HD/HDE/HDEC stars (Nesterov *et al.* 1995),
- Catalog of positions and proper motions of variable stars (Gulyaev and Ashimbaeva 1996).

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