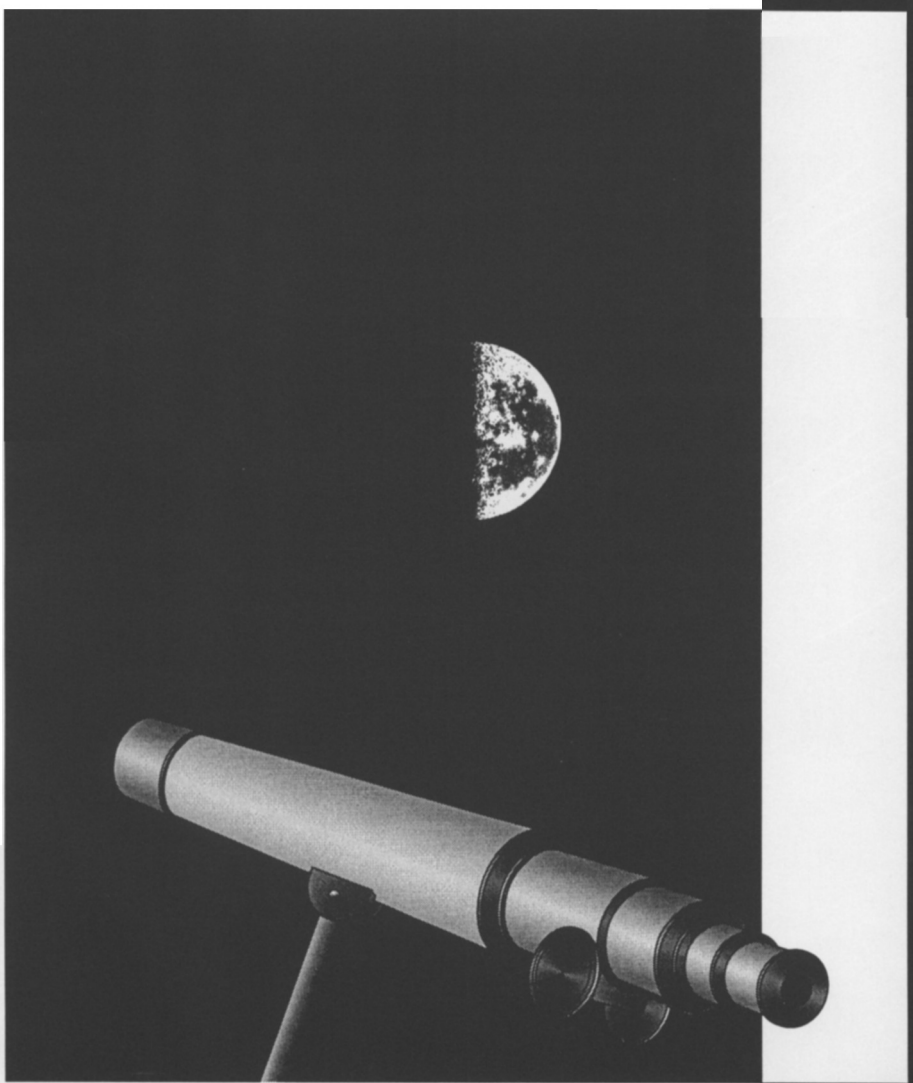

OBSERVATIONAL TECHNIQUES and CATALOGUES

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NEW REDUCTIONS OF THE ASTROGRAPHIC CATALOGUE

High Accuracy, Early Epoch Positions for Proper Motion Studies

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Abstract. The Astrographic Catalogue (AC) measures are being reduced at the U.S. Naval Observatory to provide early epoch positions for approximately 5 million stars. The data, when combined with recent observations, provide a baseline of about 100 years with which to compute proper motions. Due to the inhomogeneity of telescopes and measuring techniques used in the AC program, each of the 22 zones is being reduced independently with the Astrographic Catalog Reference Stars (ACRS). The data are analyzed and corrected for radial distortions, tilt, magnitude-dependent terms, coma, and distortions based on reseaux and measuring apparatus. To date, eleven zones have been reduced and are available on the WWW (http://aries.usno.navy.mil/ad/ac.html) or the international data centers. Mean errors of the positional data vary from zone to zone, but are generally in the 190-320 mas range per each image.

The newly reduced AC data are being combined with the USNO's Twin Astrograph Catalog (TAC) in support of the Sloan Digital Sky Survey. This catalog should be available by the end of 1996. When the Tycho data are released, the AC positions will be used to improve the proper motions of the Tycho stars. In order to aid this work, the AC zones released by USNO have Tycho identifications, where applicable.

1. The Carte du Ciel

The Carte du Ciel was an international effort begun more than a century ago to determine accurate positions for all stars brighter than 11^{th} magnitude using photographic plates and, using another set of plates, to publish charts representing the relative positions of all stars of 14^{th} magnitude and brighter. The charts proved to be very expensive to photograph and reproduce, so many institutions did not complete this part of the work. However, the program to measure all stars to 11^{th} magnitude was completed.

I. M. Wytrzyszczak, J. H. Lieske and R. A. Feldman (eds.),
Dynamics and Astrometry of Natural and Artificial Celestial Bodies, 493, 1997.

Actually, the original goal of 11^{th} magnitude was generally surpassed. The plate measures, as well as the formulae used to transform them to equatorial coordinates, have been published in what is known as the Astrographic Catalogue (AC).

2. Current Status of the Astrographic Catalogue

The Astrographic Catalogue, as originally published, can not be easily used by astronomers; one major reason is that the plate measures, called x, y were not in machine-readable form. The USNO, Strasbourg data center, and a few other institutions have now transferred all x, y and image diameter measures (or magnitudes) to magnetic media. New reductions of the data are required and several projects in the past have done this for many of the zones (Eichhorn and Gatewood, 1967; Günther and Kox, 1970; Lacroute and Valbousquet, 1974). One problem, however, with these reductions is that, other than the zone from $-2°$ to $+31°$, only the new plate constants are given; right ascensions and declinations for the stars are not. Another problem is that the reference catalog, the AGK2/3, which was the best available at the time, is no longer desirable for this work (Corbin and Urban, 1989; Corbin, 1978). In order to be useful, new reductions need to be made and equatorial coordinates need to be provided for all stars.

The U.S. Naval Observatory is in the process of making reductions to all the AC measures, using the Astrographic Catalog Reference Stars (ACRS) as the reference catalog (Corbin and Urban, 1988; Corbin and Urban, 1990). Since each observatory used different telescopes, measuring machines and measurers, each zone is being reduced independently. Currently, eleven zones have their reductions completed and available to the astronomical community at the CDS and ADC, as well as on the World Wide Web at http://aries.usno.navy.mil/ad/ac.html. Characteristics of the zones reduced to date are found in Table 1.

3. Usefulness of the AC Data

Positional information contained in the Astrographic Catalogue data is extremely valuable to astrometry because the epoch, accuracy, and limiting magnitude of the observations make them ideal for first epoch positions used in the determination of proper motions. The importance of the AC data is demonstrated in the following example. It is easily shown that, given two observations of a star separated by t years, the error in proper motion, σ_μ, is inversely proportional to t. The error in a computed coordinate, σ_x, some Δt years after being observed at position x_0, is

$$\sigma_x = \sqrt{\Delta t^2 \sigma_\mu^2 + \sigma_{x_0}^2} \tag{1}$$

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TABLE 1. Characteristics of AC zones currently available.

Zone	Pl. center from (Eq. 1900)	to	Epochs	Number of objects	Measuring method	$\overline{\sigma_\alpha}$ $\overline{\sigma_\delta}$ of single image [arcsecs]	
Vatican	+64	+55	1895–1922	256 000	grid	0.41	0.43
Hyder. North	+39	+36	1928–1938	149 000	scale	0.32	0.29
Uccle	+35	+34	1939–1950	117 000	screw	0.32	0.37
Oxford 2	+33	+32	1930–1936	117 000	scale	0.32	0.31
Oxford 1	+31	+25	1892–1910	277 000	scale	0.32	0.31
Paris	+24	+18	1891–1927	253 000	screw	0.22	0.21
Bordeaux	+17	+11	1893–1925	224 000	screw	0.22	0.21
Toulouse	+11	+5	1893–1935	270 000	screw	0.29	0.28
Algiers	+4	−2	1891–1911	200 000	screw	0.19	0.19
San Fernando	−3	−9	1891–1917	225 000	screw	0.33	0.34
Cape	−41	−51	1897–1912	540 000	screw	0.31	0.28

Using only Tycho data, with position and proper motion errors of 30 mas and 30 mas/year respectively, a positional error of 270 mas at epoch 2000.0 will result. When combined with the AC data (using a position error of 250 mas and an average epoch difference of 85 years), the standard deviation of the proper motion will be less than 3 mas/year. For the epoch 2000.0, $\sigma_x \approx 40$ mas with the combined Tycho/AC, which is a vast improvement over 270 mas using Tycho alone.

4. Current and Future Plans

The U.S. Naval Observatory is responsible for the astrometric pipeline of the Sloan Digital Sky Survey (SDSS; Gunn, 1995). One aspect of this is to provide the SDSS team a reference catalog, which will be a combination of the AC data and the USNO Twin Astrograph catalog (TAC; Zacharias and Douglass; 1995). This combined catalog will provide positions and proper motions, good to 100 mas and 3.5 mas/year respectively, for over 700 000 stars north of −18°. Parts of this catalog have been delivered to the Sloan team for testing purposes; the entire catalog will be delivered in the fall of 1996 and will be made available to the astronomical community then. See the TAC homepage at http://aries.usno.navy.mil/ad/tac.html.

Although the Sloan reference star catalog will be a valuable tool for the astronomical community, it does not adequately cover the entire celestial

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sphere. The Tycho data will provide global coverage of about 1 million stars down to magnitude 11.0. As shown above, the improvement in the Tycho proper motions will be dramatic. To facilitate such work, the AC stars have been matched with the Tycho Input Catalogue (TIC; Halbwachs *et al.*, 1994). Even Tycho's 1 million stars only account for only one-quarter of the stars in the AC. To realize the full potential of the AC data, a new observational program covering the entire sky and all stars down to 13^{th} magnitude should be made. One such program being considered is the USNO's 8-inch CCD Astrograph project, utilizing the 8 inch twin astrograph fitted with new optics and a CCD detector (Zacharias and Rafferty, 1995).

5. Investigation of Plate Models

As stated earlier, each AC zone is reduced independently. The core of the plate reduction software is the same as that used in the reductions of the Cape Photographic Catalogue 2 data (Zacharias *et al.*, 1992). An eight-constant plate model, consisting of four orthogonal terms (a, b, c, and d), two non-orthogonal terms (e and f) and two tilt terms (p and q) is initially used, as shown in Eqs. 2 and 3.

$$\xi = ax + by + c + ex + fy + x^2p + xyq \tag{2}$$

$$\eta = ay - bx + d - ey + fx + xyp + y^2q \tag{3}$$

Investigations of radial distortions, tangential distortions, magnitude equation, coma, periodic measuring errors and réseau dependent systematic errors are investigated following the procedures outlined elsewhere (Urban and Corbin, 1996; Urban *et al.*, 1996). Using the information from these investigations, a plate model is developed for each of the AC zones. Equations (4) and (5) show the corrected x, y values used in the final plate adjustments.

$$x' = x + \mathrm{RD} + \mathrm{TD} + \mathrm{ME}_x + \mathrm{MC}_x + \mathrm{S}_x mx + \mathrm{MA}_x + \mathrm{FDP}_x \tag{4}$$

$$y' = y + \mathrm{RD} + \mathrm{TD} + \mathrm{ME}_y + \mathrm{MC}_y + \mathrm{S}_y my + \mathrm{MA}_y + \mathrm{FDP}_y \tag{5}$$

In Eqs. (4) and (5), RD is the correction applied to compensate for radial distortion; TD is the correction to compensate for tangential distortion; ME and MC are corrections to compensate for magnitude equation and x, y-dependent magnitude equation; S is the correction for coma; MA corrects for measuring apparatus errors, and FDP compensates for any remaining field distortion pattern. The variable m is the computed magnitude. By substituting x', y' for x, y in Eqs. 2 and 3, the 8 constants for each plate are computed.

6. Investigation of Discordant Data

Although modeling the plates for each zone in extremely important, it becomes almost trivial if methods to discover and correct systematic errors have been well thought out and implemented. A more time-consuming task is the correction of discordant data, such as mismatched images, blended images of multiple stars and typographical errors.

Images from different plates separated slightly further than the expected precision may be a result of a double star, poor measurements of the same star or good measurements of a star that has moved due to proper motion. Catalogs such as the Preliminary Version of the Third Catalogue of Nearby Stars (CNS3; Gliese and Jahreiss, 1991) and the Washington Double Star catalog (WDS; Worley and Dougalss, 1995) aid in the decision making.

Images of double stars that are blended on one plate but discrete on another require special treatment and need to be discovered and discarded. Generally, the blend falls near the photocenter of the two discrete images. If the blended image is identified as coming from the same star as one of the discrete images, then the *computed* separation will be smaller than it is in actuality. If the blended image is not identified as coming from either stars making the discrete images, then coordinates of three stars will be computed when only two stars exist. Multiple star systems with at least one member with a large σ_α or σ_δ, indicating a possible photocenter image identified with a discrete image, are investigated. Any system apparently containing more than two members in close proximity, indicating a photocenter image not identified with either discrete images, is also investigated.

As a result of the the two-fold overlap pattern used in taking the AC plates, all bright stars should appear on at least two plates unless a combination of large proper motions and plate epoch differences combine to move the star several arcseconds. This possibility is minimized by searching a wide area around each bright star with only one image. If a high proper motion candidate is found, data from the Twin Astrograph Catalog and the CNS3 are used to verify its existence.

A bright star may only appear to have one image if one of its records contains a typographical error. To find and correct this, all single image stars with magnitude 10.5 or brighter are investigated. The process involves generating positions for these images if one alters one of the digits of the printed x or y value, then performing a search around these pseudo-positions. If another image is found at one of the locations, a typographical error may be present. The TAC data are used to determine which of the two, if either, should be changed. Possible printing errors in the magnitude data are discovered by range checks and the investigation of unusual σ_{mag}.

Once images are matched together appropriately and blends and typographical errors are fixed, the plate model validity is re-examined. Following

any needed revisions, weights can be assigned and the final weighted catalog positions and epochs are computed.

7. Catalog Descriptions

The catalogs contain the mean position for each star as computed from its weighted images, referred to the system of FK5 (via the ACRS), equinox J2000.0 at the weighted mean epoch of observation. Magnitudes are provided and, in general, have been computed from the published diameters and formulae found in the printed volumes. Mean epochs for each star as computed by its weighted images are provided, as are the number of images used in the reductions. Standard deviations of the weighted mean, $\sigma_{\overline{\alpha}}$ and $\sigma_{\overline{\delta}}$, are computed for every star with more than one image (Germain, 1996). The ACRS numbers (Corbin *et al.*, 1991) and Tycho Input Catalogue numbers are provided, where applicable. In cases of potential misidentifications with the TIC list, notes are provided to users.

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