AC 2000: The Astrographic Catalogue on The Hipparcos System

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Catalog of Positions Derived from the Astrographic Catalogue Measures. Positions are on the Hipparcos System (J2000.0) at the Epochs of Observations.

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The CD-ROM cover is an illustration of the Henry brothers using the Paris Astrograph, originally appearing in E. Mouchez's "La Photographie Astronomique" (Paris 1887). The picture was reproduced from General History of Astronomy, Volume 4 A (Gingerich 1984).

1 Introduction

The AC 2000 is a catalog of 4,621,836 stars covering the entire sky. The data are from the images measured and published as part of the Astrographic Catalogue (AC). The positions are on the Hipparcos reference frame (ESA 1997), having originally been reduced plate-by-plate using the Astrographic Catalog Reference Stars (ACRS; Corbin & Urban 1988, Corbin & Urban 1990). Each of the 22 zones of the AC has been reduced independently, since telescopes, observing techniques and measurement methods varied. This document describes the history behind the Astrographic Catalogue, the methodology employed in the plate reductions, the technique used to bring the data to the system defined by Hipparcos, the resulting catalog and information about each of the participating observatories.

2 The Carte du Ciel

The Carte du Ciel was an international effort begun more than a century ago to determine positions better than 0.5 arcsec for all stars brighter than 11th magnitude using photographic plates and, using another set of plates, to publish charts representing the relative positions of all stars of 14th 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 astrographic program designed to measure all stars to 11th magnitude was completed. Actually, the original goal of 11th magnitude was generally surpassed. In fact, some observatories routinely measured stars as faint as 13th magnitude. These 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).

In total, 20 observatories from around the world participated in exposing and measuring the plates. Each was assigned a specific zone, between two parallels of declination, to photograph. In order to compensate for any plate defects, each area of the sky was to be photographed twice, using a two-fold, corner-to-center overlap pattern. This pattern was continued even at the zone boundaries; each observatory's plates would overlap with those of the observatories responsible for the adjacent zones. The participating observatories agreed to standardize the type of telescope, so each plate photographed had a similar scale of approximately 60 arcsec/mm. The measurable areas of the plates were 2×2 degrees, so the overlap pattern consisted of plates that were centered on every degree band in declination, but offset in right ascension by two degrees. The first plates in the even degree bands were centered at right ascension 0 hours 0 minutes; the first plates in the odd degree bands were centered with right ascension several minutes higher (corresponding to approximately one degree).

In addition to the overlap pattern and type of telescope to use, the observatories also agreed to expose a grid, called a *réseau*, on each plate. It was originally used to monitor emulsion shifts. After the shifts were demonstrated to be quite small, the practice of exposing a réseau on each plate was continued because it aided in the measuring of the star positions by letting the measurer refer each image position to the grid lines. Each réseau unit was approximately 5 mm. The réseau orientation defined the plate's x, y coordinate system.

All participating observatories (with the exception of Vatican) used one of two measuring methods, *short-screw* or *eyepiece scale*. In both methods, a set of spider wires was centered over an image, then the distance traveled by the slides carrying the spider wires was read. With the short-screw method, this distance was read off of the screws used to move the slides. With the eyepiece scale method, this distance was inferred by a scale in the focal plane of the microscope. In general, the eyepiece scale method was faster, but less precise.

Although telescope type, plate size, and use of a réseau were standardized, many other factors, such as reference catalog used, reduction technique and printing formats were left up to the individual institutions.

3 Published Data

Most observatories published their results in several volumes; each consisting of measures from plates centered on the same degree of declination. Generally, each line in the printed volumes consists of data from one star, including its measured x, y value, a measure of brightness (magnitude or diameter), the plate number and a running number on the plate. Other data concerning epoch of exposure, hour angle at mid-exposure, air temperature, barometric pressure, réseau used, observer, measurer and measuring machine are usually provided in separate tables. Additionally, provisional plate constants used to transform the x, y measures to standard coordinates are supplied.

The published data have been transferred to machine-readable form via double-keypunching (that is, typing each record twice to remove most key-punching mistakes) including errata found in the published volumes. An additional literature search has been conducted on all zones to increase the probability that all published errata not found with the original volumes have been corrected. Each page of each volume was searched for pertinent notes. If important notes were found, they were keypunched and the measures to which they refer were flagged. A summary of the keypunching information can be found in Table 3.

4 Preparing the Data for the Reduction Software

It was necessary to prepare the data to put it in a standard format required by the plate adjustment software. The preparation process was broken down into three discrete tasks: matching the images with reference stars; matching images with those of the same star on another plate; and converting the data to a standard format.

Matching images with the reference stars

The reference catalog used throughout the individual plate reductions of the Astrographic Catalogue was the Astrographic Catalog Reference Stars (ACRS; Corbin & Urban 1988, Corbin & Urban 1990). This was compiled with the distinct purpose of reducing the AC measures. The ACRS is a dense set of reference stars, about eight per square degree, containing data from over 150 different catalogs specifically included to strengthen the positions and proper motions at early epochs and thus providing accurate positions for the AC plates. The ACRS is on the system of FK5. A typical ACRS at the epoch of an AC plate will have a positional error of about 200 to 250 mas per coordinate.

Equatorial coordinates for all AC images were computed from the rectangular coordinates via the published plate constants. The ACRS data were then brought to the average epoch of the zone and transformed to the AC equinox, B1900.0. A positional match was then made between the AC and ACRS. Checks were made to ensure that *illegitimate* matches have not taken place. An example of an illegitimate match is an ACRS star that matches with two separate AC images that are on the same plate. Also at this stage, all plates were checked to ensure that each contains an adequate number of identified reference stars. Fewer than expected matched reference stars on a plate may indicate problems with the published constants or plate centers. These plates were investigated and the problems were corrected.

Matching images with those on other plates

The same equatorial coordinates computed in the previous step were used to identify images of the same stars that lie on different plates. Images within 2.0 arcsec were generally identified as the same star at this stage. Illegitimate matches were investigated and treated appropriately. Each image was then assigned an *internal star number* that is unique for each star in the zone, regardless of the number of plates on which it appears. The data were verified to ensure that all images marked with an ACRS number have the same internal star number, and visa versa. No two images on one plate were allowed to have the same internal star number.

Converting data to a standard format

The data were combined in one, standard format file. This file contained all pertinent information about each plate and image. Plate information such as plate centers, sidereal time of exposure, metrology data, measuring machine and measurer, réseau used, emulsion type, and epoch of exposure were included, if they were published. Data pertaining to each star, that is the x, y values, image diameter or magnitude, internal star number, and ACRS identifier, were included. A conversion from the published x, y units to units of millimeters, along with a translation of the coordinates so the origin is in the approximate plate center, was performed when necessary. The persons responsible for the zone preparations can be found in Table 4.

5 Preliminary Reductions and Investigation of Plate Models

The core of the plate reduction software was the same as that used in the reductions of the Cape Photographic Catalogue 2 data (Zacharias et al. 1992). For all but the Potsdam, Perth and Sydney zones, 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) was initially used, as shown in Eqs. 1 and 2 . For the Potsdam, Perth and Sydney data, the same plate model was used except the corrections corresponding to the two tilt terms (p and q) were pre-applied to the data and were not solved for on individual plates.

$$\xi = ax + by + c + ex + fy + x^2p + xyq \tag{1}$$

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

At this step, no corrections to the published x, y values were applied. Investigations of radial distortions, tangential distortions, magnitude equation, coma, periodic measuring errors and réseau dependent systematic errors were investigated following the procedures outlined previously (Urban & Corbin 1996; Urban et al. 1996). Since an uncompensated systematic error may cause a star to be an outlier, only reference stars with residuals over five times the standard deviation of unit weight of the solution were removed while various plate models were investigated.

Corrections to the x, y values

Results of investigations of systematic errors may lead to applying a correction to the published star measures prior to final plate constant determinations.

To investigate if radial distortion exists in the data, the reference star radial residuals were plotted against distance from the plate center. If a radial distortion was present, the data points were described by a non-zero function. Additionally, the radial residuals were examined for magnitude, measurer and measuring machine dependence. A similar investigation was conducted looking for the existence of a tangential distortion, however none was found in any of the zones.

The presence of a magnitude equation, which is a systematic offset of stars based solely on their brightness, was investigated by plotting the reference stars' residuals with respect to magnitude. This was performed separately for both the x and y coordinates. Also, the existence of a magnitude equation that is dependent on the x, y measures was also investigated. Additionally, magnitude equation varying with measurer and plate epoch was considered. Note that a magnitude equation outside the range of the reference stars is extremely difficult to find (Eichhorn 1974). It is possible to compensate for a magnitude equation in the magnitude range of the reference stars, but it is unwise to extrapolate those corrections to field stars that may be two or three magnitudes fainter.

The presence of coma, a change in scale based on magnitude, is uncovered in two ways. First, investigating the x, y-dependent magnitude equation will reveal coma if it exists within the range of the reference stars. Second, using fainter stars, a plot of the difference between the mean position (computed from overlapping plates) and an individual image position vs. plate coordinates of the individual position will, using data from hundreds of stars and different magnitude ranges, reveal the presence of coma. If coma was found, it was examined for variations with respect to plate epoch.

Errors caused by the measuring mechanism were investigated by analyzing the residuals of reference stars as a function of location on the x and y measuring apparatus (usually a screw or an eyepiece scale). The presence of an error with a period corresponding to the length of the measuring screw or eyepiece scale is quite likely caused by the machining of that part, but may also be a function of the measurer. In either event, these errors can be corrected.

Additionally, the presence of a remaining field distortion pattern can be examined by using plots similar to those produced while investigating coma. These patterns were investigated for dependence on magnitude, réseau, measuring machine and measurer.

Using the information from these investigations, a plate model was developed for each of the AC zones. Equations (3) and (4) show the corrected x, y values used in the final plate adjustments.

$$x' = x + \mathrm{RD} + \mathrm{TD} + \mathrm{ME}_x + \mathrm{MC}_x + \mathrm{S}_x mx + \mathrm{MA}_x + \mathrm{FDP}_x \tag{3}$$

$$y' = y + \mathrm{RD} + \mathrm{TD} + \mathrm{ME}_y + \mathrm{MC}_y + \mathrm{S}_y my + \mathrm{MA}_y + \mathrm{FDP}_y \tag{4}$$

In Eqs. (3) and (4), 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. 1 and 2, the 8 constants for each plate were computed. The significant systematic errors found and corrected in each zone are listed in Table 5.

6 Investigation of Discordant Data

Once a suitable plate model was determined, the computed positions were used to investigate problems such as mismatched images, blended images of multiple stars and typographical errors.

Incorrectly matched images from overlapping plates

Images may be incorrectly matched in a variety of ways. Images are originally matched in the way described in the subsection "Matching images with those on other plates." Positions computed from the provisional plate constants can change significantly due to the new reductions. So, images earlier believed to be from two stars because their positions were dissimilar may now be recognized as coming only from one if their new positions are closer. To investigate this possibility, images closer together than a certain distance were investigated. The distance chosen depended on the range in plate epochs (since proper motion will then be a factor) as well as accuracy of the x, y measures. Images that fall outside 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. Deciding which was the case was often difficult because no comparable catalog with the epoch of the AC plates exists with which to check the stars in question. The Preliminary Version of the Third Catalogue of Nearby Stars (Gliese & Jahreiss 1991) aided in detecting high proper motion stars, but this catalogue, as its name states, contains only nearby stars. The Luyten's Two-Tenths Catalogue and its supplement (Luyten 1979, 1980; Luyten & Hughes 1980) has also been used in aiding in the identification of high proper motion stars. The Washington Double Star catalog (WDS; Worley & Douglass 1996), the internationally recognized source of visual double star data, was also used but is limited because of its incompleteness over the AC magnitude range and its occasional use of AC data. However, certain criteria were followed in deciding if two images were from the same or different stars. These criteria were zone specific, but for most zones images were identified as coming from the same star if an image was within 3.5 arcsec of a mean position and there was no indication of duplicity. Images from different stars, but incorrectly identified as coming from the same star, will result in a high standard deviation in right ascension or declination, σ_α or σ_δ. Stars with the largest σ_α and σ_δ were investigated for this possibility.

Duplicate entries

Virtually every zone has mistakenly printed some of its measures more than once. These were easily found since the data in question was either exactly the same as another record (in cases of true duplication) or the resulting star positions of two records were ridiculously close for the telescope scale and typical seeing. In general, images closer than 1.0 arcsec that appear on the same plate were suspected of being duplicate entries. In cases of this type, generally only one of the measures was kept.

Blended images

Images of double stars that are blended on one plate but discrete on another require special treatment. Two possible problems exist under these circumstances. First, if the blend is identified as one of the separate images, then the computed separation of the double star will be smaller than it is in actuality (since the blend will fall near the photocenter). Second, if the blend is not identified with either discrete image, then three sets of coordinates will be computed where only two stars exist.

Under the first scenario (a blend is matched with a discrete image), the data will consist of a multiple star system with at least one star having a large standard deviation of position, σ_α or σ_δ. To investigate this possibility, the area around each star was searched for the presence of another star. If a nearby star was found, then the data were examined for a blend if σ_α

or σ_δ of either star exceeded a certain amount (usually 1.0 or 0.9 arcsec). Additionally, any two stars closer than about 3.0 arcsec, or any triple or quadruple systems, were examined.

Under the second scenario, (a blend is not identified with either of the discrete images), then a star system will appear to have one more member than it really has. To minimize this occurrence, an area with radius of about 10 arcsec around each star was searched for the presence of two other stars. Additionally, an area with radius of about 15.0 arcsec was searched for three other stars. If multiples were found, they were examined to ensure that images were identified correctly. In the situation described above, blends are discarded.

Large proper motion candidates

Due to the span of plate epochs, images from large proper motion stars may be displaced from one another by several arcsec and hence not be matched as coming from the same star. To minimize this occurrence, a search in the Luyten's Two-Tenths Catalogue and its supplement was made to identify high proper motion stars. An additional search for large proper stars in the Third Catalogue of Nearby Stars was also made. Stars in the final catalog having large standard deviations of position are known high proper motion stars.

Typographical errors

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 bright, single image stars were investigated. (The exact magnitude limit depends on the zone. Typically all stars down to 11.5 are investigated.)

The process involved generating positions for these images if one altered one of the digits of the printed x or y value, then performing a search around these pseudo-positions. If another image was found at one of the locations, a typographical error may be present. The Twin Astrograph Catalog (TAC; Zacharias et al. 1996), was used to determine which of the two, if either, should be changed for all zones north of, and including, Tacubaya. For the more southerly zones which are not covered by TAC, the Tycho Input Catalogue (Halbwachs et al. 1994) has been used. If a corresponding star was not found in the TAC or TIC, then a search in the the Digitized Sky Survey using the Skyview interface was made to determine which, if either, contains a typographical error.

To minimize the possibility of a printing error in the magnitude data, a standard deviation of the magnitude, σ_{mag}, was generated from the computed magnitudes for every star appearing on more than one plate. The stars with the largest σ_{mag} were investigated. Additionally, range checks were made on the original data as well as the final computed magnitudes to ensure that all values were reasonable.

Investigation of other potential problems

To investigate the possibility of a few plates being adjusted incorrectly, the positions of the 500 stars with the largest σ_α and σ_δ were plotted for each zone. Additionally, the percentage of stars on each plate whose σ_α and σ_δ are in the highest 1% of that zone were computed. Plates that have more of these than expected were investigated.

Positions of all stars were plotted to ensure that the data contain no missing areas, such as a block of data having not been typed or accidentally discarded. Positions of stars having only one image, and positions of stars having multiple images, were plotted separately to investigate the possibility of missing plates.

To avoid the presence of non-stellar objects in the final catalogue, a search in the New General Catalogue of Nebulae and Clusters of Stars (NGC), the Index Catalogue (IC), and the Second Index Catalogue (Sinnot 1988) was made. The Digitized Sky Survey, using the Skyview interface, was used to graphically show potential NGC and IC objects present in the data. Those records found to be non-stellar NGC or IC objects have been discarded.

7 Final Plate Model and Weights

It was necessary to ensure that the plate model was still valid because it was originally developed on the data that included erroneous identifications and typographical errors. Once any needed revisions are made, plate weights can be assigned. For most of the AC zones, a plate's weight is the inverse of the variance of the positions of the stars which it contains, after removing the stars with the highest 1% σ_α and σ_δ. The removal of these stars prior to computing the plate weights reduced the possibility that a few, high proper motion stars adversely affected the weighting of an entire plate.

No grating was used in the AC program, so bright stars are over-exposed on the plates and should not be used in the final adjustment nor be included in the final catalog. All stars with mean computed magnitudes brighter than 4.0 have been removed prior to final plate adjustments. Reference stars with a residual larger than 3.0 times the standard deviation of unit weight of the plate solution were removed from determining the plate parameters and the plate adjustment is performed again. These stars are included in the final catalog, but are treated as field stars.

8 Linking of Individual Zones

The Astrographic Catalogue was observed in discrete zones in the sky, and the reductions, by necessity, were made on individual zones. However it is desirable to link these together to make one, cohesive catalog. To do this, stars in common to adjacent zones were identified. Blended images, high proper motion stars, and typographical errors were investigated as described above. Each star was assigned a new internal star number. All images were combined to yield weighted mean right ascension and declinations in the FK5 system at the weighted mean epoch of observation for the equinox J2000.0.

9 Conversion of the AC Magnitudes

The Astrographic Catalogue contains non-uniform magnitude measures, in part because of different techniques used by participating observatories. Many of the published magnitudes are unreliable, especially for the faintest and brightest stars. Thus, it is desirable to transform the magnitudes to some kind of well-known (or often used) system. The plates used were most sensitive in the blue spectral region, so a logical choice of systems was the Tycho B, since the Tycho catalog (ESA 1997) contains about one million stars covering much of the AC magnitude range.

Each zone was treated independently. Only stars identified in Tycho as being single and with negligible variability were used for the calibration.

Differences between AC and Tycho B magnitudes as a function of AC magnitude were computed. Polynomial expressions describing the results were computed via least-squares fitting. Some extrapolation of these polynomials was required because, in general, the Tycho catalog is not as faint as the AC. (Usually an extrapolation of less than 0.5 magnitudes was used. Beyond that the corrections were held constant). Corrections based on these functions were applied to each observation within the zone. Thus the magnitudes contained in AC 2000 should, in a broad sense, be close to that of Tycho B.

10 Conversion to the Hipparcos System

The conversion of the FK5 based Astrographic Catalogue to the system of Hipparcos was necessary because Hipparcos is now recognized as the standard reference frame in the optical wavelength, following the recommendation of the IAU Working Group on Reference Frames. The conversion was made in three steps.

1. Stars in common between the AC and Hipparcos were identified. Systematic differences between the two catalogs were found and applied by the following method. For each AC position, all AC observations of Hipparcos stars within a 2 degree radius were identified. A weighted mean residual was computed using the differences between the observations and the Hipparcos catalog positions at the epochs of the AC observations. The weighting function used was parabolic; those closest to the central AC star were given the most weight while those near 2 degrees away were given the least. At this stage, no residuals exceeding 1500 mas were used. The weighted mean residual was then applied to the central AC observation.

2. After step 1, it is possible that a magnitude equation remains in the AC positions due to the presence of one in the ACRS or a remaining one in the original AC measures. Thus, each of the 22 zones was analyzed and corrected independently. For each zone, mean residuals (AC-Hipparcos) as a function of magnitude were computed and described by a least-squares fit to a polynomial function. Since individual observations of any star may contain different measured AC magnitudes,

each observation was corrected based on the value of the polynomial function.

3. A repetition of step 1 was necessary for convergence. During this step, no residuals exceeding 750 mas were used.

11 Cross-Referencing Information

In order to aid users and to facilitate future work on the Astrographic Catalogue, most stars from the ACRS, Hipparcos, and Tycho Catalogs have been identified. This cross-reference is not intended to be 100% complete, however the vast majority of stars from these catalogs are identified.

Identification of the ACRS stars was a natural result of the original plate reductions. Even ACRS stars not used in the plate reductions due to large residuals are identified.

Identification of the Hipparcos stars was necessary for the conversion to the Hipparcos system. To make the identification, only stars in the Hipparcos catalog identified as being single or whose solutions for the components are given were matched (No stars with '*' or '+' in the AstroRef field were used; only multiples with 'C' in MultFlag were used). Using these, the Hipparcos positions were moved to the epoch of the AC stars. A search area with a radius of six arcsec around the AC star was used. If there was a one-to-one match, that is one AC star and one Hipparcos star in the search area, then the Hipparcos number is added to the AC record. If there was not a one-to-one match, for example one Hipparcos star and two AC stars, then a ratio of the distances between the Hipparcos and the closest AC star and the Hipparcos and the farther AC star was computed. If the value of the ratio is 0.2 or less and the magnitude difference between the close AC and Hipparcos star was less than 1.5 magnitudes, then the Hipparcos number was added to the closer AC record. Otherwise, the matching was considered ambiguous and no cross identification was made.

To match the Tycho catalog, no Tycho stars where duplicity is indicated nor extremely low astrometric quality entries were matched (No stars with 'D','R' or 'S' in the MultFlag field or stars with '9' in the Q field were used). Using a similar procedure as the Hipparcos matching, the Tycho stars were brought to the the AC star's epoch by the application of the Tycho proper motions. An area with a radius of 15 arcsec around each AC star was searched. If more than one Tycho star was found in the search area, a ratio test (using .2 as the cutoff) of the differences was utilized. For the Tycho stars not matched at this point, another search was made but without application of any proper motions. A search area with a radius of 20 arcsec was used. Again, a ratio test of .2 was applied for all non-singular matches. For the Tycho stars still not matched, a search in the New Luyten's Two Tenths catalog was made. The Luyten's proper motion was then applied to the Tycho stars to bring them to the epoch of the AC positions. A search area with a radius of 15 arcsec around each AC star was used. Once again, if more than one star fell within the search area, a ratio test was used to determine which observations were really the same star.

12 Description of AC 2000

Right ascension

The mean right ascension for each star as computed from its weighted images, in units of hours, minutes and seconds of time, referred to the Hipparcos system (J2000.0) at the weighted mean epoch of observation.

Declination

The mean declination for each star as computed from its weighted images, in units of degrees, minutes and seconds of arc, referred to the Hipparcos system (J2000.0) at the weighted mean epoch of observation.

Magnitude

Each magnitude listed here is the average of all the images for that star. They should roughly correspond to the Tycho B system. See section "Conversion of the AC Magnitudes" for details.

Epoch

The mean epoch for each star as computed by its weighted images, in years.

Number of images used

The number of individual images used to compute position, magnitude, epoch and standard deviation of position.

Standard deviation of weighted mean

The standard deviations of weighted means, $\sigma_{\overline{\alpha}}$ and $\sigma_{\overline{\delta}}$ are computed for every star with more than one image. The formula used is:

$$\sigma^2_{\overline{x}} = \frac{\overline{x^2} - \overline{x}^2}{N' - 1} \tag{5}$$

where

$$x = \alpha_i, \delta_i \tag{6}$$

and

$$N' \equiv N \left[\frac{\langle w \rangle^2}{\langle w^2 \rangle} \right] \tag{7}$$

where w is the weight of an individual observation. A description of the derivation of this formula can be found elsewhere (Germain 1997).

AC 2000 number

This number is used in the reduction process to identify all images of the same star that may appear on different plates. This is generated at the U.S. Naval Observatory and added on to the original x, y data. When the x, y data are released, these numbers can be used to link the data to the final catalog.

ACRS number

If a star has been identified as being in the Astrographic Catalog Reference Stars (Corbin et al. 1991), then the ACRS identifier is given in this field. If the star has not been identified as such, this field is blank.

Hipparcos number

If a star has been identified as being in the Hipparcos Catalogue then the Hipparcos number is provided. See section "Cross-Referencing Information" for details.

Tycho number

If a star has been identified as being in the Tycho Catalogue, then the Tycho identifier is provided. See section "Cross-Referencing Information" for details.

Verification Flag

A '1' in this field indicates the star has a single image and is not found in Hipparcos, Tycho, ACRS or the Hubble Guide Star Catalogue 1.2. These "stars" may not exist but instead may be the result of typographical errors, plate defects or other such blunders.

13 Participating Observatories

Work from the observatories that participated in the photographing and measuring of the Astrographic Catalogue data are summarized below. Some important characteristics of each zone can be found in Table 2 and in Appendix A. The telescope characteristics agreed upon was a normal astrograph with an aperture of roughly 33 cm and a focal length of 3.43 m. This created a scale close to 60 arcsec/mm on the plates. All observatories, with the exception of Nizamiah, used this type of instrument.

The Royal Observatory at Greenwich

The Royal Observatory at Greenwich was an original participating institution in the Astrographic Catalogue project, sending representatives to the International Congress on Astronomical Photography held in Paris in 1887. This meeting outlined the plans for the Carte du Ciel project. Funding was provided shortly following this meeting. A telescope built by Sir Howard Grubb following the design agreed upon in Paris was delivered in May 1890. Greenwich centered its plates between +65 and +90 degrees, with five plates taken on the pole in different orientations. In total, 1153 plates were exposed and measured in this zone. Three exposures were made on each plate lasting six minutes, three minutes and 20 seconds. The telescope was moved 20 arcsec between the exposures, so the six and three minute exposures are offset from each other in declination, the six minute and 20 second exposure are offset in right ascension. The plate epochs span from 1892 to 1905.

After initially measuring some plates using micrometer screws, Professor H.H. Turner realized that a different measuring technique was required if the job were to be completed in a timely fashion. At his request, an eyepiece scale type measuring machine was built and greatly reduced the time to measure a plate. Many other observatories adopted this measuring procedure. Systematic measuring of the plates began in October 1894. A duplex micrometer, which is a measuring machine capable of measuring two plate simultaneously, was put into use in February 1895. This aided the identification of images of the same star but on different plates since it was possible to arrange the plates in the machine so that the same field of sky was coincident under the measuring apparatus. (Remember that each plate overlapped surrounding plates so that each area of sky appears on at least two plates.) All plates were measured in two orientations, with the plates being rotated 180 degrees between measurements. In all degree bands except the +65, +66, and +67 degree bands, the same measurer was used for both orientations. Both the six minute and three minute exposures were measured for all stars that appeared on the 20 second exposure. Details can be found in the introductions to the published volumes (Christy & Dyson 1904-1932).

The Vatican Observatory

The Vatican Observatory, located in Vatican City, was founded in 1888 while the Carte du Ciel program was in its infancy. Vatican staff members realized that participation in this program would immediately give their young observatory international recognition. Pope Leo XIII commissioned Father Francesco Denza and Father Giuseppe Lais to attend the Astrographic Congress and enroll the Vatican as one of the participating institutions.

After being accepted as a participant, the Vatican commissioned the Henry brothers of France to build the telescope and P. Gautier to build a machine to measure the stars on the plates. Father Denza describes the finished telescope: "The instrument consists of two parallel telescopes: The photographic telescope with an aperture of 33 cm and a focal length of 3.43 m; and the finding telescope or collimator with 20 cm aperture and a focal length of 3.6 m. Both are housed in a metal tube with a rectangular cross section of 37 by 68 cm. Both objectives are fixed on the same block of bronze at one end of the tube and at the other end is the photographic plate holder and the eyepiece of the collimator. A thin metallic diaphragm separates the two telescopes. ...The photographic objective is a doublet of flint and crown and it is both achromatic and aplanic for the most intense chemical rays of the spectrum." (Denza 1891).

The telescope was installed in the Leonine Tower in 1891. This tower, located on the highest point of Vatican Hill, was originally constructed in 840 AD under Pope Leo IV as a defense against the Saracen invasions. It is about 20 meters above ground (about 100 meters above sea level) with walls about 4.5 meters in thickness.

The Vatican was assigned the strip of sky between +55 and +64 degrees on which to center the plates. In order to achieve the two-fold sky coverage 1040 plates would be needed. (Actually, 1046 plates were exposed and measured.) The job of photographing and developing the plates was carried out primarily by one person, Father Lais, who worked on this for over 25 years until the time of his death in 1921. Lais's aid, Carlo Diadori, completed the photographing in 1922. For the first several years that Father Lais was working at the telescope, no plates were being measured.

Father Johann Hagen, appointed director of the Observatory in 1906, was committed to seeing the project completed. He soon realized that the machine built by Gautier to measure the stars was too slow. After investigating different measuring techniques employed by other institutions, he decided on the use of an eyepiece grid. In the method used by Vatican, a 10×10 mm area of a plate, corresponding to 2×2 réseau intervals, was magnified in a microscope along with a grid which is segmented into 0.05 mm steps. The edge of the grid was aligned with the edge of the 2×2 réseau interval area. The location of a star within the magnified area was read from its apparent position on the grid. This method was indeed efficient, allowing the Vatican to be one of the first observatories to complete its assigned zone despite utilizing minimal manpower. However, the accuracy was not as high as can be obtained with the measuring techniques used at other participating institutions. Vatican was the only observatory in the Astrographic Catalogue program to use the eyepiece grid technique. Also during his trips to other observatories, Father Hagen saw extensive use of women in measuring the plates, freeing the full-time, male astronomers from this time-consuming, repetitive task. He brought in three nuns from the Instituto di Maria Bambina to measure the plates. These nuns worked from 1910 to 1921 and measured the vast majority of the Vatican data. The Oxford University Observatory agreed to compute the plate constants used to convert the rectangular measures to equatorial coordinates.

For additional information concerning the history of the Vatican Observatory and its personnel, see the book In the Service of Nine Popes (Maffeo 1991). Additional details regarding the Vatican's participation in the Astrographic Catalogue project can be found in the introductions to the data (Vatican 1914-1928), written in Italian.

The Catania Observatory

The Catania University Observatory, located in Catania, Sicily, centered its plates between +47 and +54 degrees. In total, 1010 plates were exposed and measured in this zone. The epochs span from 1894 to 1932, but over 95%

were exposed prior to 1906. All the plates were measured using the short-screw method. Additional details can be found in the introductions to the published data (Catania 1907-1963).

The Helsingfors Observatory

The Helsingfors Observatory, located in Helsinki, Finland, centered its plates between +40 and +46 degrees. In total, 1008 plates were exposed and measured in this zone. The epochs span from 1892 to 1909, but over 94% were exposed prior to 1897. All the plates were measured using the short-screw method. One screw was used; the plates were rotated 90 degrees to measure both x and y coordinates. The plates measured early in the work had images from both the longest and middle exposures measured in one orientation. Later (after 1896), only the images from the longest exposure were measured, but the plates were rotated 180 degrees between measurement so these images were measured twice (this also helped remove any bias a measurer may have). Various aspects of the work are detailed in the introduction to Volume 1 (Helsingfors 1903-1937).

The Potsdam Observatory

In 1887, at the meeting of the International Congress which established the Astrographic Catalogue, the zone with plate centers from +39 to +32 degrees was assigned to the Potsdam Observatory. Potsdam began photographing the plates by 1893 and 1226 plates were exposed by the end of 1900. Each plate had two exposures of 5 minutes duration. Unfortunately, the measurements of the plates lagged behind the exposures. By the start of World War I only 406 plates were measured. Following the war, Potsdam announced it could no longer continue with the project, and a re-photographing of its zone was made by Oxford, Uccle, and Hyderabad. The remaining plates were never measured. An allied bomb during World War II destroyed virtually the entire set of plates (Dick 1988, 1990).

In total, 406 plates were measured and published as the Potsdam zone. These plate are scattered throughout the zone, so many are not overlapped by others. All were measured using one of two short-screw type measuring machines. The plates were measured in one direction only; the plates were not rotated. Various aspects of the work are detailed in the introductions of the printed volumes (Potsdam 1889-1915).

The Nizamiah Observatory, Hyderabad

In 1887, at the meeting of the International Congress which established the Astrographic Catalogue, the zone from -17 to -23 degrees was assigned to the Observatory of Santiago. By 1900, the work was still not progressing, so a proposal to establish an observatory in Montevideo was made. This, too, did not progress so Santiago asked to re-undertake the project. At the same time, the Nizamiah Observatory, located in Hyderabad, India, offered to work on this zone as well. So, in 1909 there were two observatories offering to work on the -17 to -23 zone. A resolution passed by the Congress in 1909 assigned the -17 to -20 zone to Hyderabad. After completing the photographing and measuring of these four bands in 1920, the International Astronomical Union recommended that Hyderabad continue photographing down to -23 degrees declination. This work was completed in 1928. This zone between -17 and -23 degrees is known as the Hyderabad South zone. Hyderabad also observed a section of the sky in the Northern hemisphere that Potsdam was originally assigned. This zone, between +36 and +39 degrees, is known as the Hyderabad North zone.

In total, 1260 plates were exposed and measured in the Hyderabad South zone. The epochs span from 1914 to 1928, with only a handful taken after 1923. For the Hyderabad North zone, 592 plates were exposed and measured The epochs span from 1928 to 1937, with just a very few taken after 1934. The telescope used was not one of the Henrys' design, as all the other AC participation observatories used. Instead of a 13 inch, the Hyderabad instrument, built by Cooke and Sons of York, had an aperture of only 8 inches. Its objective was described as a "patent photo-visual lens". The smaller aperture meant longer exposures were required to achieve the desired magnitude limit set for the AC. The telescope's focal length was 133 inches. All the plates were measured using one of four eyepiece scale type measuring machines, all built by Cooke and Sons. Various aspects of the work are detailed in the introductions of the printed volumes (Edinburgh 1918-1930, London 1934-1946).

The Uccle Observatory

The Royal Observatory of Belgium, located in Uccle, was assigned the zone with plate centers running from +34 to +35 degrees. Although Uccle was not an original participating observatory in the AC project, it became one because the Potsdam Observatory, originally assigned to cover this area, was unable to fulfill its commitment. The telescope used was of similar design as the Henry brothers, but built by Gautier. In total, 320 plates were exposed between 1939 and 1950. The epochs of the plates are spread fairly uniformly, except for a lack of plates exposed between mid-1943 and mid-1945. The measurements took place at the Paris Observatory with the use of three short-screw measuring machines. The réseau used was one from the Toulouse Observatory. An introduction can be found in Volume 1 of the printed catalog (Paris 1960,1962).

The Oxford Observatory

The University Observatory at Oxford was originally assigned the zone +25 to +31 degrees on which to center the plates. This is known as the Oxford I zone. An additional zone with plates centered on +32 and +33 degrees declination was photographed at Oxford after Potsdam announced they would not be able to complete their assigned area (+32 to +39). This two degree band is referred to as the Oxford II zone.

The telescope used was the same design as the Henry brothers' instrument located in Paris. The Oxford lens was made by Sir Howard Grubb and attached to an existing Grubb $12\frac{1}{4}$ inch, which was utilized as a guiding instrument. All plates of the Oxford 1 zone were taken between mid-1892 and 1910, with over 80% exposed by the end of 1903. These plates were measured mostly by boys from the New College Choir School, and Mr. T. J. Moore, a gardener who was interested in astronomy. The measuring apparatus was designed with an eyepiece scale, similar to that employed by the Greenwich Observatory in their AC work, with the exception that only one plate was measured at a time whereas Greenwich measured two.

Mr. F.A. Bellamy of University Observatory at Oxford supervised much of the work in photographing the 320 plates required to complete the Oxford 2 zone. He employed the same techniques used in the Oxford 1 zone and used the same Grubb refractor operated 30 years earlier. Mr. Bellamy would have photographed the entire zone himself, however he died with 32 fields left unobserved. These 32 fields were exposed at the Royal Observatory at Greenwich by Mr. H.G.S. Barrett with the telescope used for the Greenwich Zone (+65 to +90). These last 32 plates were the only plates in the Astrographic Catalogue that did not have a réseau exposed on them, however they were measured with one clamped on the glass. All plates of the Oxford 2 zone were exposed between 1930 and 1936. (Actually there are two plates that appear to have typographical errors in their epochs. One is date in 1918; the other in 1930, but 8 months prior to any other plate.) Mr. Barrett also supervised the measurement and reduction of these plates at Oxford, using the eyepiece scale technique. However World War II intervened preventing the determination of the plate constants for 92 of the fields. After the war, the constants for these remaining plates were determined under Dr. H. Kox at the Hamburg Observatory at Bergedorf. A detailed introduction covering the participation of the University Observatory at Oxford in the Astrographic Catalogue project can be found in Volume 1 of the Oxford I zone catalog (Turner 1906-1911), as well as in the book The Great Star Map also by Turner. An introduction to the Oxford II zones can be found in Volume 1 of the Oxford II zone catalog (Paris 1953-1954).

The Paris Observatory

The Paris Observatory agreed to photograph the zone with plate centers between declinations +18 and +24 degrees. The telescope used was the original Henry brothers' instrument, after which all other AC telescopes were supposed to be patterned. In total, 1261 plates were photographed and measured. The measuring technique employed at Paris was the short-screw method, which was the most accurate utilized with the AC plates. The epoch range of the plates are from October 1891 through November 1927, however only 7 plates were exposed after 1907 and all but 100 were exposed prior to 1900. An introduction to the Paris Observatory's participation in the Astrographic Catalogue can be found in the introductions to the individual volumes (Paris 1902-1932).

The Bordeaux Observatory

The Bordeaux University Observatory, located in Floirac, France, was assigned the zone between +11 and +17 degrees declination on which to center its plates. The telescope used was a similar design to the Paris instrument and was built by the Henry brothers. In total, 1260 plates were exposed between 1893 and 1925, all but five being taken before 1913. The plates were measured at Bordeaux using the short-screw method. An introduction to the Bordeaux Observatory's participation in the Astrographic Catalogue project can be found in Volume 1 of the published data (Paris 1905-1934).

The Toulouse Observatory

The Toulouse University Observatory agreed to participate in the Astrographic Catalogue project by taking plates centered between +5 and +11 degrees declination. In total, 1260 were exposed and measured. The epochs vary from 1893 to 1935, and were taken in three fairly distinct groupings. Most were exposed before the end of 1910. Another set is taken between 1918 and 1922. The last few plates are scattered between 1930 and 1935. All the plates were measured with using a short-screw type measuring machine, however not all plates were measured at Toulouse. Ninety plates were measured at the Bordeaux University Observatory and 36 were measured at the Paris Observatory. Various aspects of the work are detailed in the introductions of the printed volumes (Paris 1903-1948).

The Algiers Observatory

The Algiers Observatory was assigned the zone between -2 and +4 degrees on which to center its plates. All 1260 plates were exposed between 1891 and 1911. The plates were measured using the short-screw method. Details about the Algiers Observatory's participation in the Astrographic Catalogue project can be found in the introduction to the catalogs (Trépied 1903,Paris 1903-1924).

The San Fernando Observatory

The Naval Observatory of San Fernando (Spain) was assigned the area between -3 and -9 degrees declination on which to center its plates. The telescope used was built by Gautier, with the objective made by the Henry brothers. All of the 1260 plates were exposed between 1891 and 1917. Over 1000 were taken before 1899, then only a few per year until 1917. The plates were measured using a short screw micrometer. An introduction to San Fernando's participation in the Astrographic Catalogue project can be found in Volume 1 of the published data (San Fernando 1921-1929).

The Tacubaya Observatory

At the meeting of the International Congress which established the Astrographic Catalogue, the zone from -10 to -16 degrees was assigned to the National Astronomical Observatory of Tacubaya, located near Mexico City, Mexico. In total, 1260 plates were exposed and measured in the Tacubaya zone. (Actually, one of the plates had an incorrect and unknown plate center and has been discarded from the reductions, leaving a total of 1259 plates). All but five plates were exposed between 1900 and 1912. The five later plates were exposed between 1926 and 1938. All the plates were measured using the eyepiece scale method. An introduction of the history of the work can be found in Volume 1 part 1 of the -15 degree zone (Tacubaya, 1913-1962).

The Cordoba Observatory

At the 1887 Paris meeting, the zone from -24 to -31 degrees was assigned to the La Plata Astronomical Observatory. In 1900, the zone was re-assigned to Cordoba. The telescope was installed at the end of 1901. In 1908, Dr. Thome, the Director of Cordoba, died and Dr. Perrine was named new director. After some investigations, Perrine decided to re-observe all areas. He discovered that the telescope was out of focus and many of the plates were impaired, and that the plates were centered on apparent place coordinates, not at those defined at equinox 1900. Plates of this series were exposed starting in 1909 and finished by the end of 1913. These plates were measured between 1909 and 1920. In total, 1360 plates were exposed as part of the Astrographic Catalog.

The telescope used was one of the Henrys' design and build, following the standard with a 33 cm aperture and 3.47 m focal length. In the introduction written by Perrine, he states that the guiding is difficult because the guide scope has only a 19 cm aperture, as opposed to the more conventional 25 cm in use by most of the participating observatories. The mount was built by Gautier. Some plates showed a "triangular distortion" that was traced to a warp in the ring which held the lens in place. This ring was replaced in 1911. The lens, from August 9, 1910 until the end of the program, was stopped down to 11 inches. This, according to Perrine, greatly improved the image quality.

Virtually all plates were taken and developed by R. Winter or F.P. Symonds. Four exposures on each plate were made; two long exposures of the same duration (both of 5 or 6 minutes) one medium exposure (of 60 to 90 seconds) and one short exposure (of 5 to 8 seconds). The telescope was moved in declination between exposures. In order to expedite the work, two measuring machines of the short-screw type were retro-fitted with eyepiece scales. As a result, 140 plates were measured using the short-screw method, the remaining 1220 plates were measured using the eyepiece scale method. In total, five different measuring machines were used, allowing each measurer to have his or her own machine. The réseaux used were supplied by Gautier and Prin; four were used throughout the work. Investigations of two of the réseaux were made in Paris and the deviations were found to be negligible; no corrections for the réseaux were applied to the measures. Only stars within one degree in right ascension and declination of the plate center were measured. All stars having three images were measured unless images ran together, which was the case of the brightest stars. Four measures were made on each star; a measure was made on both of the long exposures in both orientations of the plate. (Following an initial measurement of all stars, the plate was reversed 180 degrees and all stars re-measured.) In general, measures in the direct and reverse orientations of the plate were made on the same day by the same measurer. In total, 37 man-years went into measuring the plates. Various aspects of the work are detailed in the introduction of Volume 26 of the Observatory Results (Cordoba 1925-1934).

The Perth Observatory

At the International Congress which established the Astrographic Catalogue, the Observatory of Rio de Janeiro was assigned to photograph the area between -32 and -40 degrees declination. In 1900, the work at Rio had not progressed and so the Perth Observatory undertook the task. The telescope used was from Sir Howard Grubb, and was of similar design to other telescopes used for the AC work. Although observing was progressing, no resources were available to measure the plates. At this time, the Perth Observatory was primarily a meteorological station, and the meteorological work took precedence. This changed in 1908 when the Australian Federal Government established the Australian Weather Bureau. About this time, four women were hired as plate measurers. Professor Dyson of the Edinburgh Observatory offered assistance in the measuring. Perth accepted this offer and started sending those plates of the -40 degree zone. By 1915, the Edinburgh Observatory completed its commitment by measuring all of the plates centered on the -40, -39 and -38 degree band. This area is known as the Perth-Edinburgh AC zone. Observing continued at Perth until 1919, at which time all areas had been photographed. Personnel at Perth measured all plates between -37 and -32 degrees; this is known as the Perth zone. In total, 432 and 944 plates make up the Perth-Edinburgh and Perth zones, respectively.

All plates had three exposures taken, one of 4 minutes, 2 minutes and 13 seconds, or that of 6 minutes, 3 minutes or 20 seconds. The change in exposure times took place following a 1909 meeting of key personnel from different observatories participating in the AC. At that meeting, many people expressed concern about the uniformity of limiting magnitudes on different plates. Many of the Perth plates were re-examined and found to be unsatisfactory. The areas affected were re-observed and a method of ensuring more uniformity was developed.

In general, no guiding of the instrument other than the sidereal drive was made, as it was found unnecessary. All plates were the brand Ilford "special rapid". All were measured using an eyepiece scale machine, similar to the Oxford Observatory's. For all but 5 plates, the measurements done at Perth were made in two orientations of the plate by the same person; the plate being rotated 180 degrees between measurements. In total, 10 measurers were used at Perth. For the plates measured at Edinburgh, images were measured in two orientations of the plate, with the plate being rotated 180 degrees between measurements. For the direct orientation, the second exposure (either 2 or 3 minutes) was measured; the longest exposure was measured with the plate in reverse orientation. Quite often more than one measurer was used on each plate. Various aspects of the work can be found in the introduction to Volume 23 of the Perth-Edinburgh data (Perth 1922, Paris 1949-1952) and in Volumes 1 and 17 of the Perth data (Perth 1911-1921).

The Royal Observatory at the Cape of Good Hope

The Royal Observatory at the Cape of Good Hope, South Africa, took the zone between -41 and -51 on which to center its plates. In all, 1512 plates were exposed and measured. The epochs range from 1897 to 1912, with 97% of them being exposed prior to 1906. The telescope used was built by Sir Howard Grubb. Two machines were used to measure the plates, both were designed by David Gill and built by Repsold of Hamburg (Gill 1898). Both machines employed the short-screw measuring method and were of similar design. An introduction to the participation of the Royal Observatory at the Cape of Good Hope in the Astrographic Catalogue project can be found in Volume 1 of the published data (London 1913-1926) .

The Sydney Observatory

H.C. Russell, the Government Astronomer at Sydney, was in attendance at the 1887 meeting of the International Congress. He committed the Sydney observatory to photograph the sky between declinations -52 and -64 degrees. The lens used for the project was built by Howard Grubb of Dublin, and it followed the general design established by the International Congress. The lens was delivered in December of 1890. Most of the telescope was built in Sydney. The observing program began in earnest in 1892. The telescope was moved twice in the course of the AC work; first from inside Sydney to Redhill (located about 12 miles from Sydney) in 1899, and then back to its original location in 1931. The observing was left unchanged until 1912, when W.E. Cooke took over the project. He was unsatisfied with the quality of many plates and eventually rejected and rephotographed many of the areas. Until this time, plates were being sent to Melbourne for measurement, but under Cooke the Sydney observatory began to measure their own photographs. Prior to Cooke's arrival, plates were positioned so the center of the plate was in the sharpest focus (The astrograph used in photographing the plates did not have a flat field of focus, so some areas of the plate are in focus while others are not. This is true for all the telescopes used in the Astrographic Catalogue work). Cooke altered this and made the ring about 50 arcsec from the center the place with the sharpest focus. In 1926, Cooke retired and James Nagle took over. He altered the place of best focus in a ring about 40 arcsec from plate center. Nagle died in 1941, and H.W. Woods took over. Some plates were found unsatisfactory or missing. The remaining areas were photographed between 1944 and 1948. In total, 1400 plates were taken as part of the Astrographic Catalogue. All plates exposed between 1890 and 1930 were taken by James Short.

Plate measuring did not start for about six years after the first plates were taken. Evidently there was a suggestion about having all plates from all participating observatories sent to Paris for measurement. This plan was not ever put in place, but the Australians liked this idea so they decided that Melbourne would be used to measure both the Sydney and Melbourne plates. As mentioned above, this changed with Cooke's arrival and Sydney started measuring their own plates. There were four short-screw measuring machines used in Melbourne, and two eyepiece scale machines used at Sydney. From this point on, all stars were measured twice with the plates being rotated 180 degrees between measurements. Various aspects of the work are detailed in the introduction of Volume 53 of the data (Sydney 1925-1971).

The Melbourne Observatory

In 1887, following the meeting which established the Astrographic Catalogue, the Victorian government agreed to have the Melbourne Observatory participate in the project. Melbourne was assigned the zone from -65 to -90 degrees. The telescope used was built by Howard Grubb of Dublin, and it followed the general design established by the International Congress. The telescope was delivered in December of 1890. The observing program started about one year later in January 1892 and continued until 1927 (Actually, one plate was exposed in 1940). Over 80% of the plates were exposed prior to 1898. In total, 1149 plates were taken as part of the Astrographic Catalogue. All plates had three exposures on them of 5 minutes, 2.5 minutes and 20 seconds duration, with the exception of the plates taken prior to February 26, 1892, whose exposures were slightly longer. The réseau was exposed on the plates shortly after the plates were removed from the telescope. In total, six different réseaux were used during the program; three were supplied by Gautier and three were made at Melbourne.

Plate measuring did not commence in earnest until November 1898, when six women were hired at Melbourne. Two measurers were used for each plate, one taking the northern half and one the southern. The plates were rotated 180 degrees and the stars were remeasured by the same person. All reference stars on each plate were measured by both measurers. Four measuring machines were used throughout most of the work; all used short-screws for the star measurements. The Melbourne staff tried using an eyepiece scale measuring machine for the plates but found the measuring error too high.

Periodic and progressive screw errors were investigated. None were applied, as they were found to be negligible. (Further reductions performed at the U.S. Naval Observatory as part of the new reductions show this not to be true.) Investigations into errors of the réseaux were made and these corrections were applied to the data prior to publishing. Various aspects of the work are detailed in the introduction of Volume 1 of the data (Melbourne 1926-1929; Paris 1955-1958; Sydney 1963).

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A Notes on Participating Observatories Data Characteristics

- Greenwich notes:
  - Five plates are centered on the pole.
  - A duplex micrometer was used; two plates were measured simultaneously. Formats of the published volumes reflect this.
- Vatican notes:
  - One plate has a published epoch of 1891.
  - A measuring grid was used instead of eyepiece scale or screw.
  - Most plates were measured by one of three women. Measurer "E", who measured about 50% of the plates, was significantly worse than the other two.
  - Plate weights, computed at USNO, are based on measurer.
- Catania notes:
  - Over 95% of the plates were exposed prior to 1906.
  - Errata are found throughout volumes, mostly at the end of each plate's x, y data.
  - Measures of large images (bright stars) are often listed many times (with slightly different values).
  - Multiple stars are often measured both as center of light AND individual images.
  - One plate has been taken with the same plate center as another, but only faint stars measured on the second. Hence only reference stars near the edges were available on that plate.
  - Many typographical errors in the printed volumes were found by USNO. These have been corrected.
- Helsinki notes:
  - Over 95% of the plates were exposed before 1897.

  - Helsinki was under Russian rule during the time of exposures and measurements of the plates.

- Potsdam notes:

  - The number of plates exposed was 1226, of which only 406 were measured and published. No funds after World War I were available to continue the work.
  - All but 34 plates were destroyed during World War II.
  - In cases where stars were measured and published twice, USNO used the mean of the measures in the reductions.
  - Personal equation tables (describing observer dependent magnitude equation) are published. USNO developed its own corrections by observer that supersedes the Potsdam tables.
  - Generally, only stars brighter than 11.0 were measured
  - Plate weights, computed at USNO, are based on measurer.

- Hyderabad North notes:

  - Nizamiah Observatory had the only instrument not of standard design. Objective diameter was 20 cm (not 33 cm) so longer exposures were required to achieve the desired limiting magnitude. The plate scale approximately 61 arcsec/mm.
  - This zone was photographed in response to the incompletion of the Potsdam region.
  - India was under British rule during the time of exposures and measurement of the plates.

- Uccle notes:

  - This zone was photographed in response to the incompletion of the Potsdam region.
  - One plate was broken prior to diameter measurements.
  - Measurements were made at Paris.
  - No hour angle of exposure is given.

- Oxford II notes:
  - This zone was photographed in response to the incompletion of the Potsdam region.
  - Thirty two plates in this zone were exposed and measured at Greenwich. These are the only plates of the AC without a reseau printed on them.
  - One plate has a published epoch of 1918.
  - Kox (Hamburg Observatory) determined plate constants for 92 of the plates. All others were computed at Oxford.
- Oxford I notes:
  - Some reseaux had rulings of 5.04 mm (5.00 mm was standard). Introductions indicate which ones, but the introduction appears to be wrong for 3 plates.
- Paris notes:
  - Only 7 plates were exposed after 1907.
  - Corrections indicated in the ARI version (1991) of the keypunched data have been applied.
  - Additional typographic errors found in Bull. of CDS 12 (p32-40) by Dunham and Herget were applied, where needed.
  - One plate was printed with the x, y measures of two plates (see end of Volume 2).
  - Nine plates were measured using *Baillaud method*, not utilizing the reseau. These plates did not have field distortion pattern corrections applied during the reductions at USNO.
  - Notes indicate that several stars were not measured to their full precision (0.1 microns). Images were not kept if the x, y values were not given to 1.0 micron or better.
- Bordeaux notes:
  - Both Toulouse and Bordeaux have plates centered on +11 degrees.

  - Only five plates were taken after 1913.
  - Corrections indicated in the ARI version (1991) of the keypunched data have been applied.
  - Many typographical errors in the printed volumes were found by USNO. These have been corrected.

- Toulouse notes:
  - Both Toulouse and Bordeaux have plates centered on +11 degrees.
  - Ninety plates were measured at Bordeaux and 36 plates were measured at Paris.
  - Corrections indicated in the ARI version (1991) of the keypunched data have been applied.
  - Notes indicate that several stars were not measured to their full precision (0.1 microns). Images were not kept if the x, y values were not given to 1.0 micron or better.
  - The odd zones(+5,7,9 and 11) are split. The first part (usually 0 to about 6h) do not have reseaux corrections applied, but do give information on which measuring machine (1 or 2) and which reseaux was used. After the split, there is no information regarding micrometer or reseaux. For the even zones, there is information regarding where the plates were measured and often what type of plate emulsions were used. However, there is no data regarding which reseau was used.

- Algiers notes:
  - Algeria was under French rule during the AC data acquisition.

- San Fernando notes:
  - Y-coordinate increases to South
  - 80% of the plates were taken before mid-1898.
  - One plate was exposed with Saturn and 3 of its satellites.
  - Four records have footnotes saying "body moved during exposure of the plate".

- Tacubaya notes:
  - All but five plates were taken before 1913.
  - One of the plates was not used by USNO because it has an unknown plate center.
  - Many typographical errors in the printed volumes were found by USNO. These have been corrected.
  - The type is very poor in some of the volumes.
- Hyderabad South notes:
  - The Nizamiah Observatory had the only instrument not of standard design. The objective's diameter was 20 cm (not 33 cm) so longer exposures were required to achieve the desired limiting magnitude. The plate scale is approximately 61 arcsec/mm.
  - India was under British rule during this .
  - Five reseaux were used, some with non-standard rulings. Rulings of 5.00, 5.04 and 4.985 mm used.
  - Y increases to South.
- Cordoba notes:
  - 1220 plates were measured using an eyepiece scale, 140 were measured with a short-screw.
  - Errata were found in Information Bulletin of CDS 22 79-86 (1982).
  - Lens was stopped down to 28 cm in August 1910 to give better images.
  - Reseaux with rulings of 5.00 mm were used for all plates except those numbered 2001 through 2290. These have 5.05 mm between rulings. Note that this is slightly different than what is given on page xviii of Volume 26.
  - Many typographical errors in the printed volumes were found at USNO. These have been corrected.
- Perth notes:

  - This zone covers only those plates photographed and measured at Perth.
  - A change of scale for plate 2063 through 2209 is present. This was the result of someone altering the telescope focus.
  - A Scale value, usually given as a letter, is used as an estimate of magnitude for all but the brightest stars.
  - Very few typographical errors were found at USNO.

- Perth-Edinburgh notes:
  - This zone covers plates taken at Perth, but measured at Edinburgh, Scotland.
  - Very few typographical errors were found at USNO.
  - Y increases to South.

- Cape notes:
  - Images were measured with micrometer one have significantly lower mean errors than those measured with micrometer two.
  - Actual diameters were measured for many stars, but the faintest stars were given a "density" measurement, dependent on how dark each image appears.
  - South Africa was under British control during the AC work.

- Sydney notes:
  - The telescope was relocated twice during the AC work.
  - The plate location of sharpest focus altered during the work, depending on observatory director.
  - Early plates were sent to Melbourne for measurement, using screw method. Later, the plates were measured at Sydney with an eyepiece scale.
  - The plates were exposed in three discrete epoch spans, 1892 to 1901, 1918 to 1929, and 1944 to 1948.
  - Many typographical errors in the printed volumes were found at USNO. These have been corrected.

  - Authors suspect a magnitude equation by measurer, but no identification of the measurers of individual plates are given.
  - Scale value as estimate of magnitude is given for the majority of images.
  - X increases to the West

- Melbourne notes:
  - Over 80% of the plates were taken before 1898.
  - One plate has an epoch of 1940.
  - Additional Melbourne errata were found in Sydney Volume 53, pg 64.

Table 1: Byte-by-byte description of AC 2000 using format requested by the CDS.

Bytes	Format	Units	Label	Explanations
1- 2	I2	h	RAh	Right Ascension (hours)
4- 5	I2	min	RAm	Right Ascension (minutes)
7-12	F6.3	s	RAs	Right Ascension (seconds)
14	A1	—	DE-	Declination (sign)
15-16	I2	deg	DEd	Declination (degrees)
18-19	I2	arcmin	DEm	Declination (minutes)
21-25	F5.2	arcsec	DEs	Declination (seconds)
27-31	F5.2	mag	B(mag)	Magnitude from image diameters
33-40	F8.3	yr	Ep	Mean epoch of position
42-43	I2	—	Num	Number of images used
44-49	F6.3	arcsec	e_RAs	?Standard deviation of mean, RA
50-55	F6.3	arcsec	e_DEs	?Standard deviation of mean, Dec
57-64	I8	—	AC2000	AC 2000 Number
66-71	I6	—	HIPP	?Hipparcos Number
73-84	A13	—	TYCHO	?Tycho ID
86-92	I7	—	ACRS	?ACRS number
93-93	I1	—	VER	?Verification Flag

Table 2: Characteristics of each observatory's plates

Zone	Country or region	declination of centers	techn	num of plates	epoch
Greenwich	England	+90 +65	scale	1153	1892 1905
Vatican	Italy	+64 +55	grid	1046	1895 1922
Catania	Sicily	+54 +47	screw	1010	1894 1932
Helsinki	Finland	+46 +40	screw	1008	1892 1910
Potsdam	Germany	+39 +32	screw	406	1893 1900
Hyderabad N	India	+39 +36	scale	592	1928 1938
Uccle	Belgium	+35 +34	screw	320	1939 1950
Oxford II	England	+33 +32	scale	320	1930 1936
Oxford I	England	+31 +25	scale	1188	1892 1910
Paris	France	+24 +18	screw	1261	1891 1927
Bordeaux	France	+17 +11	screw	1260	1893 1925
Toulouse	France	+11 +5	screw	1260	1893 1936
Algiers	Algeria	+4 -2	screw	1260	1891 1912
San Fernando	Spain	-3 -9	screw	1260	1891 1918
Tacubaya	Mexico	-10 -16	scale	1259	1900 1938
Hyderabad S	India	-17 -23	scale	1260	1914 1929
Cordoba	Argentina	-24 -31	both	1360	1909 1913
Perth	Australia	-32 -37	scale	944	1902 1919
Perth-Edinb.	Australia	-38 -40	scale	432	1903 1914
Cape	S. Africa	-41 -51	screw	1512	1897 1912
Sydney	Australia	-52 -64	both	1400	1892 1948
Melbourne	Australia	-65 -90	screw	1149	1892 1928

Table 3: Numbers of images in each zone and institutions aiding in key-punching the data, by zone

Zone	stars (thousand)	images (thousand)	keyed and verified
Greenwich	179	322	USNO
Vatican	256	480	CIDA, Venezuela (verified USNO)
Catania	163	320	USNO
Helsinki	159	284	USNO
Potsdam	108	143	CIDA, Venezuela (verified USNO)
Hyderabad N	149	242	USNO
Uccle	117	159	USNO
Oxford II	118	161	USNO
Oxford I	277	471	Strasbourg
Paris	254	436	Strasbourg
Bordeaux	224	355	Strasbourg
Toulouse	270	433	Strasbourg
Algiers	200	330	Strasbourg
San Fernando	226	346	USNO
Tacubaya	312	518	USNO
Hyderabad S	293	521	USNO
Cordoba	309	467	Sternberg, Russia
Perth	228	402	USNO
Perth-Edinb.	139	202	USNO
Cape	545	901	USNO
Sydney	431	743	USNO
Melbourne	218	392	Univ of Fla., USNO

Table 4: Personnel involved in plate reductions

Zone	prepared	reduced
Greenwich	Gary Wycoff, John Martin	Sean Urban
Vatican	John Martin	Sean Urban
Catania	John Martin, Gary Wycoff	Sean Urban
Helsinki	Harry Crull, Edward Jackson, David Hall	Sean Urban
Potsdam	Marion Zacharias	Marion Zacharias
Hyderabad N	Edward Jackson	Sean Urban
Uccle	Edward Jackson	Sean Urban
Oxford II	John Martin	Sean Urban
Oxford I	John Martin	Sean Urban
Paris	Edward Jackson	Sean Urban
Bordeaux	Edward Jackson	Sean Urban
Toulouse	David Hall	Sean Urban
Algiers	Edward Jackson	Sean Urban
San Fernando	Gary Wycoff	Sean Urban
Tacubaya	John Martin, Gary Wycoff	Sean Urban
Hyderabad S	Edward Jackson, Sean Urban	Sean Urban
Cordoba	Gary Wycoff	Sean Urban
Perth	David Hall, Gary Wycoff, John Martin	Marion Zacharias
Perth-Edinb.	David Hall, Gary Wycoff	Sean Urban
Cape	Sean Urban	Sean Urban
Sydney	David Hall, Gary Wycoff	Sean Urban
Melbourne	Gary Wycoff	Sean Urban

Table 5: Corrections applied to x,y data prior to final least squares adjustment. Also includes single image precisions by zone.

In the table, a "Y" indicates a correction was applied, an "n" indicates it was not. Values in parentheses indicates an additional dependence on those characteristics.

mg=magnitude, mr=measurer, mp=microscope, rs=reseau, ep=epoch, x=x-coordinate, and y=y-coordinate.

Note that Ox II/Grn "zone" refers to the 32 plates observed at Greenwich for the Oxford II zone.

Zone	con	radial dist	Mag Eq.	Coma	Screw	FDP	$\overline{\sigma}$ ra	$\overline{\sigma}$ dec
Greenwich	8	Y(mg)	Y	Y	n	Y	.29	.30
Vatican	8	Y(mg)	n	n	Y(mr)	Y(mp)	.41	.43
Catania	8	Y(mg)	Y(x,y)	n	n	Y(mg)	.33	.31
Helsinki	8	Y(mg)	Y(x,y)	Y	Y(mr)	Y	.24	.22
Potsdam	6	n	Y(mr)	Y	n	Y	.26	.25
Hyder. N	8	Y	Y(x,y)	Y	n	Y(mg)	.32	.29
Uccle	8	Y(mg,x,y)	Y	Y	Y	Y(mg)	.32	.37
Oxford II	8	n	Y(x,y)	n	n	Y	.32	.31
Ox II/Grn	8	Y	n	n	n	n		
Oxford I	8	n	Y(x)	n	n	Y	.32	.31
Paris	8	Y(mg)	Y	n	Y(mp)	Y(rs)	.22	.21
Bordeaux	8	n	Y(ep)	n	Y	Y(rs)	.22	.21
Toulouse	8	Y(mg,mp)	Y(x,y)	n	Y(mp)	Y(rs)	.30	.28
Algiers	8	Y(mg)	Y	n	n	n	.19	.19
San Fer.	8	Y(mg)	Y	Y	n	Y(mg)	.33	.34
Tacubaya	8	n	Y	n	n	Y(mg)	.27	.26
Hyder. S	8	Y(mg)	Y(x,y)	Y	n	Y(mg,rs)	.33	.34
Cordoba	8	Y(mg)	Y(x,y)	n	Y(mp)	Y(mg)	.35	.30
Perth	6	Y	Y	Y	n	Y	.33	.30
Per-Edin.	8	Y(mg)	Y(x,y)	n	Y	Y(mg)	.31	.30
Cape	8	n	Y(x,y)	Y(ep)	Y(mp)	Y(mg,rs)	.31	.29
Sydney	6	Y(mg)	Y(mp,rs,x,y)	n	Y(mp)	Y(mg,rs)	.48	.43
Melbourne	8	Y	Y	n	Y(mp)	Y(mg)	.37	.35