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CDC-SF: PROPER MOTION CATALOGUE FROM *CARTE DU CIEL* PLATES, SAN FERNANDO ZONE

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RESUMEN

Presentamos un catálogo astrométrico de posiciones y movimientos propios, obtenido con las placas *Carte du Ciel* de la zona de San Fernando, material fotográfico de época media 1901.4 y magnitud límite V$\sim$15. Se ha utilizado un escáner comercial de sobremesa para la digitalización de las placas. Ha sido necesario desarrollar técnicas especiales para el tratamiento del material y corregir la amplia distorsión que introduce el escáner. Las coordenadas ecuatoriales están en el sistema ICRS mediante Tycho-2 que se usa como referencia. Los errores externos comparados con Tycho-2 son de $0\farcs2$. Para obtener movimientos propios se ha usado el catálogo UCAC2 como segunda época, obteniendo una incertidumbre de 1.2 mas/año, para las estrellas de V$\leq$14.

Como muestra de la calidad del catálogo desarrollado, se presenta un análisis cinemático de siete cúmulos estelares abiertos ASCC 30, BOCHUM 3, NGC 2215, NGC 2301, NGC 2311, NGC 2323 y NGC 2548, determinando las probabilidades de pertenencia de cada estrella y las propiedades fundamentales de cada cúmulo.

ABSTRACT

We present an astrometric catalogue of positions and proper motions derived from the *Carte du Ciel* plates of the San Fernando zone, which has a mean epoch 1901.4 and a limiting magnitude V$\sim$15. Digitization has been made using a conventional flatbed scanner. Special techniques have been developed to handle the combination of plate material and the large distortion introduced by the scanner. A variety of post-scan corrections are shown to be necessary. The equatorial coordinates are obtained on the ICRS system defined by Tycho-2. Comparison with the reference catalog indicates external errors of $0\farcs2$. The UCAC2 Catalogue was used for second-epoch positions to derive proper motions with a mean accuracy of 1.2 mas yr^{-1} for the the well-measured stars.

The usefulness of the resulting proper motion catalog is demonstrated by means of a proper-motion analysis of seven open clusters, ASCC 30, BOCHUM 3, NGC 2215, NGC 2302, NGC 2311, NGC 2323 and NGC 2548, determining individual membership probabilities and characterizing the gross properties of each cluster.

Key Words: astrometry — catalogs — reference systems — stars: kinematics — techniques: image processing

1. INTRODUCTION

The *Carte du Ciel* project was established at the Astrophysical Congress held in Paris in 1887 and had a twofold objective: the construction of a complete catalogue to V$\sim$11, the *Astrographic Catalog* (AC), and to map the sky to V$\sim$14, the *Carte du Ciel* (CdC). A total of twenty observatories around the world were assigned the task of taking the photographic plates. This plate material constitutes the first observational full-sky record, currently with 100 years of antiquity in most cases. As such, it presents a valuable resource for wide-area proper motion determinations and, thus, kinematic studies of the Galaxy. The AC objective was successfully completed, culminating in the recent AC2000 Catalogue (Urban et al. 1998) on the Hipparcos system. However, only a few observatories completed their assigned declination zones for the CdC project.

2. DIGITIZATION OF THE PLATE MATERIAL

The Real Instituto y Observatorio de la Armada in San Fernando, Spain (ROA) was assigned the area between $-2°$ and $-10°$ declination. The area was fully completed for both surveys producing a total of 2520 plates. In particular, the collection of 1260 *Carte du Ciel* plates has not been exploited up to now. Each plate covers a field of $2° \times 2°$ and observations were planned in a full overlapping strategy. Plates along odd declinations were exposed three times, producing a pattern of images for each star that is roughly an equilateral triangle. All the plates also contain superposed *réseau* grid lines.

The photographic plates of the AC/CdC surveys represent an important legacy of ROA and as such

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cannot be removed from the Institute. As an alternative, the AC/CdC plates were duplicated onto acetate material in 1999 in order to be measured with the PDS microdensitometer of the Centro de Investigaciones de Astronomía (CIDA) in Venezuela and PDS at Yale University. However, after several preliminary tests were performed, the project was stopped because the duplication process and acetate material introduced relatively large systematic errors, up to 15 μm in amplitude.

The possibility of using a flatbed scanner to digitize the plates was then investigated by testing a scanner (Agfa DuoScan f32) of the Universidad de Zaragoza (Spain). The results obtained (Vicente & Abad 2003) are thus summarized: the possibility to transport the scanner to ROA in order to use the original plates; the residual mean errors, after correction for distortion, are low and similar to those of traditional measuring machines; the high speed of digitizing and the low cost of the machine. A similar flatbed commercial scanner (Agfa DuoScan f40) was then purchased by CIDA. ROA has completed the digitization of its collection of 2520 AC/CdC plates.

3. MEASUREMENT OF THE PLATES

The most important characteristics of the plates that complicate the determination of precise astrometry include: (1) the merging of the triple-exposure images on the odd-numbered declination plates, (2) the blending and confusion of stars that fall on the superposed *réseau* grid lines, (3) the false detections due to plate flaws, spurious dust and degradations that have accumulated during storage, and (4) typical effects in photographic material caused by optical aberrations. All of these are succesfully treated.

The centering of the positions is made using a bivariant Gaussian fitting method, developed at Yale for use with their PDS machine (Lee & van Altena 1983), choosing the UCAC2 catalogue (Zacharias et al. 2004) as an input list of approximate positions of star images to be centered. A loss of up to 15% of stars can be expected due to interferences with the grid lines and spurious flaws as well as the blending of the triple exposures.

After the variety of post-scan corrections is made, the final single-measurement internal error estimate per exposure is 3 μm and 5 μm for single- and triple-exposure plates, respectively. Details of the procedures are given in Vicente, Abad, & Garzón (2007).

4. ASTROMETRIC REDUCTION OF THE PLATES

The transformation from (x, y) coordinates into celestial coordinates (α, δ) was performed by the

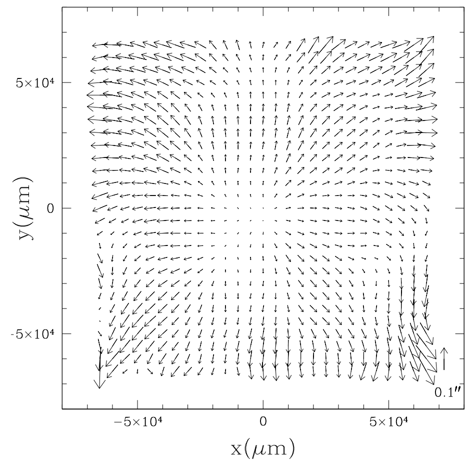

Fig. 1. Position residuals as a function of coordinates after a linear plate model is applied.

block-adjustment technique (Stock 1981) including a determination of the field distortion (Abad 1993). The Tycho-2 Catalogue (Høg et al. 2000) was used as a reference catalogue at the epoch of the plates, due to its proper motions having an accuracy of 2.5 mas yr^{-1}. It also has a sufficient density of stars and a magnitude limit of V$\sim$11.5.

Residuals were obtained as differences between individual positions and their average, if the star is not in the reference catalogue. If the star is identified as a reference, we calculate also the residual difference between the average position and the catalogue position. The pattern in Figure 1 shows the stacked residuals, which are used as a representation of the systematic field distortion remaining in the plates. This function is then applied to the positions and a new iteration of the astrometrical reduction is performed. Different correction masks are derived by binning stars into one-magnitude wide intervals to determine the magnitude dependence of the systematic errors. The distortion is found to be more pronounced at bright magnitudes.

An estimated internal error for each star in the catalogue is derived based on the rms of the positional differences of each image in the overlapping plates to the average position. The mean values of these uncertainties are $(\sigma_{\alpha\cos\delta}, \sigma_\delta) = (0''.21, 0''.19)$ for the entire sample, and for stars brighter than 14, the mean values are $(\sigma_{\alpha\cos\delta}, \sigma_\delta) = (0''.12, 0''.11)$.

A comparison of our catalogue with the Tycho-2 positions at the CdC plates' epoch as a function of magnitude shows no systematic pattern and mean differences remain constant through all magnitudes. Thus our catalogue can be considered to be on the

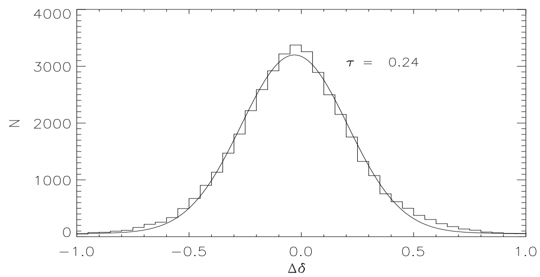

Fig. 2. External errors of CdC-SF Catalogue based on comparison with Tycho-2 positions at the epoch of the plates. The plot for $\Delta\alpha\cos\delta$ is similar. Units for $\Delta\delta$ are arcsec.

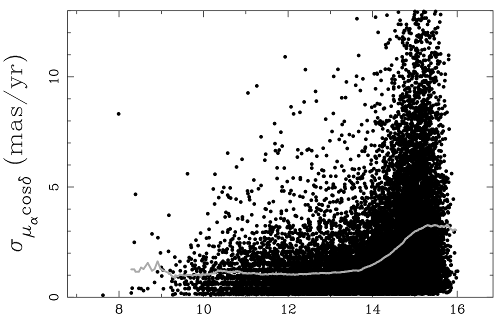

Fig. 3. Proper-motion uncertainties as a function of magnitude. Each point represents 25 stars and the grey line indicates a moving mean. σ_{μ_δ} shows a similar behavior.

ICRS system as defined by Tycho-2. The dispersion of these differences is $(\sigma_{\alpha\cos\delta}, \sigma_\delta) = (0''.22, 0''.24)$, and is well described by a Gaussian distribution as shown in Figure 2.

5. DETERMINATION OF THE PROPER MOTIONS

The early-epoch Carte du Ciel positions are combined with modern positions from the UCAC2 catalogue to derive proper motions. The proper motions are placed on the ICRS system via a direct comparison to Hipparcos proper motions for stars in common with our catalogue, correcting for systematic effects. A handful of open clusters allow us to estimate the proper-motion errors and confirm that the magnitude equation is not present. The internal error is about 1.2 mas yr^{-1} for stars with V≤14 (Vicente, Abad, & Garzón 2008) as is shown in Figure 3.

6. THE CDC-SF CATALOGUE

The final catalogue contains positions and proper motions for over 500,000 stars. The partial catalogue obtained, one third of the full CdC-SF collection, covers the right ascension range $\alpha = (06^h, 14^h)$, comprising 420 plates, and covers −10 to +60° in galactic latitude. We compare in Figure 4 the magnitude

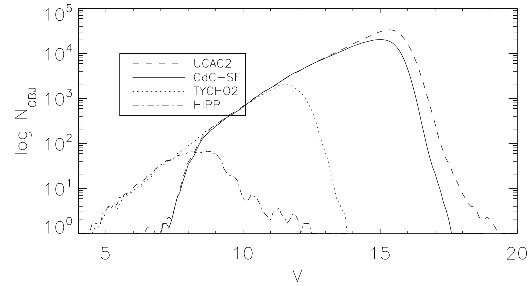

Fig. 4. Magnitude distribution of the CdC-SF Catalogue compared to other astrometric catalogues.

TABLE 1

CDC-SF CATALOGUE

mean epoch	1901.4
system	ICRS
area covered	∼1080 degrees^2
position range in α	$06^h \leq \alpha \leq 14^h$
position range in δ	$-10.5^\circ \leq \delta \leq -2.5^\circ$
magnitude range	$6 \leq V \leq 16.3$
completeness	$V \simeq 15.1$
number of stars	503769
measuring error	$3\ \mu m \sim 0''.18$
positional error	$(0''.21, 0''.19)$
(V<14)	$(0''.12, 0''.11)$
μ error (mas yr^{-1})	(2.0,1.9)
(V<14)	(1.2,1.1)

distribution of the CdC-SF Catalogue with other astrometric catalogues for the same sky coverage. The falloff of the CdC-SF distribution occurs at V=15.1. A summary of the main properties of the CdC-SF Catalogue is given in Table 1.

Future versions of the CdC-SF Catalogue with expanded coverage to the full 24h of right ascension will be derived by applying the techniques presented here to the remainder of the digitized plate material.

7. OPEN CLUSTERS

We determine membership probabilities following the method of Sanders (1971), constructing one-dimensional marginal distributions from the proper-motion distribution (the VPD) and fitting these with the sum of two Gaussians, one representing the cluster and the other the field.

In Figure 5 we show the VPD and cluster+field marginal distributions of NGC 2323, as an example. The fitted sum of two Gaussians (smooth curve) is superimposed onto the corresponding observed distribution (histogram). The complete set of derived

TABLE 2

CLUSTER AND FIELD STAR DISTRIBUTION PARAMETERS

	Cluster					Field				
Cluster	N_c	$\mu_\alpha \cos\delta$	$\sigma_{\mu_\alpha \cos\delta}$	μ_δ	σ_{μ_δ}	N_f	$\mu_\alpha \cos\delta$	$\sigma_{\mu_\alpha \cos\delta}$	μ_δ	σ_{μ_δ}
		(mas yr^{-1})					(mas yr^{-1})			
ASCC 30	79	−1.55	1.50	0.52	1.11	214	−3.16	4.87	1.40	4.46
Bochum 3	14	−2.06	0.61	−1.10	0.97	28	−2.27	3.30	−2.35	5.90
NGC 2215	13	3.18	0.91	−7.25	0.93	48	4.22	3.83	−3.69	3.51
NGC 2302	15	−1.47	1.38	−1.92	1.39	53	−1.36	3.22	−0.58	5.39
NGC 2311	38	−2.60	1.44	2.06	0.89	67	−2.69	3.37	4.33	3.31
NGC 2323	176	1.21	0.95	−1.27	0.90	305	1.25	3.73	−1.51	4.07
NGC 2548	277	−0.65	1.19	3.39	1.37	824	−2.23	4.73	2.51	5.74

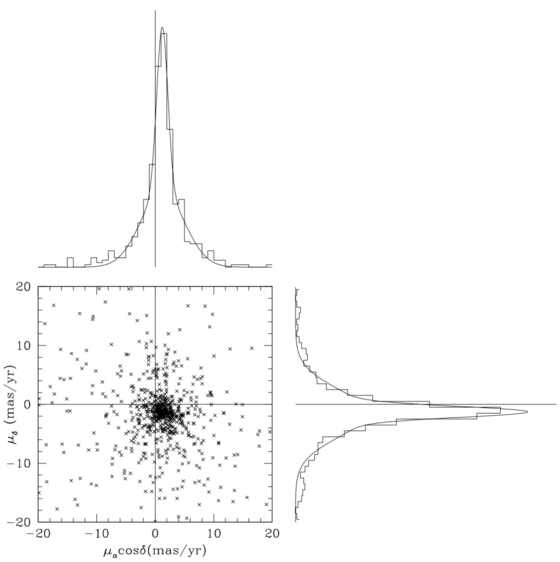

Fig. 5. Vector-point diagram of NGC 2323 based on CdC-SF proper motions. The marginal distribution histograms are also shown along with their functional fits, represented by the sum of two Gaussians.

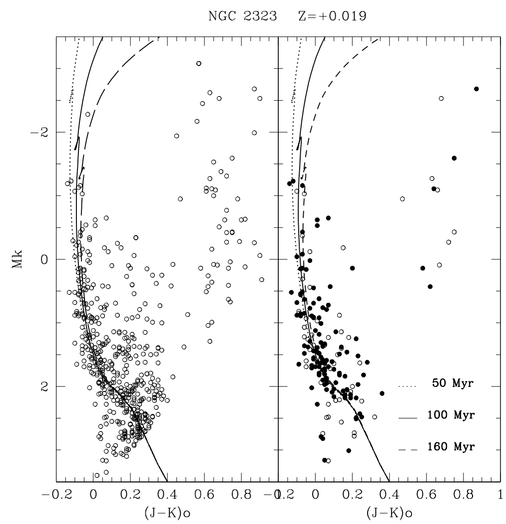

Fig. 6. Color-magnitud diagram (CMD) for NGC 2323 and theoretical isochrones; **(a)** CMD of the whole sample. **(b)** CMD of probable members (P≥51%, open symbols) and highly probable members (P≥81%, filled symbols).

cluster and field parameters of the seven clusters studied is given in Table 2.

The resulting individual probability values, P, may be used as a kinematic criterion for membership segregation, considering as members those stars with P>50%, for example.

One of the main purposes of astrometric cluster membership studies is to provide a color-magnitude diagram (CMD) with reduced field-star contamination. Figure 6 shows the CMD for NGC 2323 for all stars and just for the probable members. The theoretical isochrones (Girardi et al. 2000) fit better in the cleaned diagram.

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