CdC-SF Catalogue.II: Application of its Proper Motions to Open Clusters

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Abstract W

e present an astrometric catalogue of positions and proper motions derived from the *Carte du Ciel* plates of the San Fernando zone, photographic material with a mean epoch 1901.4 with 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 on the ICRS system defined by Tycho-2. Comparison with the reference catalog indicates external errors of $0\farcs2$. The UCAC2 Catalogue was used as second-epoch positions to derive proper motions with a mean accuracy of 1.2 mas/year for the proper motions for well-measure stars.

The usefulness of the resulting catalogue of proper motions 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.

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1 Introduction

Open clusters represent a powerful laboratory in which one can address many astrophysical questions. The young open clusters are especially interesting for the study of the process of star formation and are key to answering questions related to Galactic structure. The reason is that clusters consist of groups of stars sharing approximately the same age, the same chemical composition and the same distance from the Earth.

Results obtained from the study of stellar clusters have improved our knowledge of the structure, dynamics and evolution of the Galaxy, especially in the solar vicinity. Spectroscopic observations of cluster members allow the determination of cluster metalicities and radial velocities. In turn, by studying numerous open clusters with a range in age and position in the Galaxy allows for a determination of the radial gradient in abundance, a fundamental parameter in the study of the Galaxy. Together with other young objects, such as HII regions, the open clusters are also tracers of the Galactic spiral arms (Russeil 2003). Their spatial coordinates, ages and motions have allowed the direct determination of the motion of the spiral structure as well as the location of the corotation radius, (Dias & Lépine 2005).

For the majority of these studies, the correct discrimination between cluster stars and field stars is crucial for the precise determination of the parameters of the cluster, both kinematical and astrophysical.

Although the open clusters are useful representatives of the population of the disk of the Galaxy, any systematic research as to their physical nature - size, number of members and age - encounters a limitation. The available information on open clusters is not homogeneous. Granted, there are general catalogues that are compilations of the existing bibliography, for example Ruprecht et al. (1981), Lyngå (1987), Dias et al. (2006) and the WEBDA database of Mermilliod (1995). These collections with generic parameters of the clusters are essential sources for any future work in this field. However, their parameters can not be used as a whole for systematics studies, or for comparisons between clusters, because these consist of a compilation of data published in different studies, obtained with different methods.

Open clusters typically exhibit internal velocity dispersions on the order of 1 Km s^{-1} or less. The velocity dispersion of the field disk-population stars is in general more than 10–20 times greater. Thus, by measuring the relative proper motions of the stars in the field of an open cluster, it is possible to separate cluster members from nonmembers.

The work of Dias et al. (2006), *New Catalogue of Optically Visible Open Cluster and Candidates*, updates the WEBDA database, but only 22% of the clusters have a proper-motion estimation. In that work, the determination of the mean proper motion of the clusters and the astrometric membership selection are based on UCAC2 proper motions, with a mean error of 8 mas/yr (Zacharias et al. 2004).

For this reason, our CdC-SF Catalogue with precise and accurate proper motions, is a potentially powerful tool to assist in member discrimination and to provide mean absolute cluster space velocities, due to a smaller error in the catalogue's absolute proper-motion system compared to that of the UCAC2 for instance.

2 CdC-SF: An Astrometric Catalogue of proper motions

The CdC-SF Catalogue is an astrometric catalogue with precise positions and proper motions derived from the photographic plates of the *Carte du Ciel*, San Fernando Zone. Although the Catalogue's construction has been explained in detail in the last meeting of the SEA (Vicente & Abad, 2006), we summarize here the main processes involved and the properties of the Catalogue.

2.1 Reduction of the plate material

The Real Instituto y Observatorio de la Armada in San Fernando (Spain) was assigned the area between -2° and -10° declination, but this 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. Digitization has been done with an innovative method: a flatbed commercial scanner (Agfa DuoScan f40), that allows us to use the original plates instead of copies for transport to a conventional, nonportable plate-scanning machine.

Special techniques have been developed to handle the combination of plate material and flatbed scanner. A variety of post-scan corrections are shown to be necessary. In particular, the large distortion introduced by the non-uniform action of the scanner is modeled using multiple scans of each plate. We also tackle the specific problems associated with the triple-exposure images, the superposed *réseau* grid lines present on all plates, the false detections due to spurious dust, degradations that have accumulated during storage, and typical effects in photographic material caused by optical aberrations. The final estimated single-measurement internal error per exposure we obtain is 3 μm for single-exposures plates, and 5 μm for triple-exposures ones.

The corrected measures are reduced to celestial coordinates using the Tycho-2 Catalogue as reference and a plate-overlap formulation (Stock 1981). 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 for stars

brighter than 14 are $(\sigma_{\alpha cos\delta}, \sigma_\delta) = (0\farcs12, 0\farcs11)$. The precision we attain is comparable to that realized with similar plate material using slower, less affordable and less widely available conventional measuring machines, such as a PDS microdensitometer. A comparison of our catalogue with Tycho-2 positions at the CdC plates' epoch gives a dispersion of these differences of $(\sigma_{\alpha cos\delta}, \sigma_\delta) = (0\farcs22, 0\farcs24)$. Details of the reduction procedures are given in Vicente et al. (2007).

2.2 Determination of the proper motions

These early-epoch Carte du Ciel positions are combined with modern-epoch positions from the UCAC2 catalogue to derive proper motions for the stars in the CdC-SF Catalogue. The proper motions are placed on the ICRS system via a direct comparison to Hipparcos proper motions for those stars in common with our catalogue. A handful of open clusters allow us to estimate the the proper-motion errors and confirm that magnitude equation is not present. Internal error is about 1.2 mas/yr for stars with V≤14 (Vicente et al. 2008) as is shown in Fig. 1a.

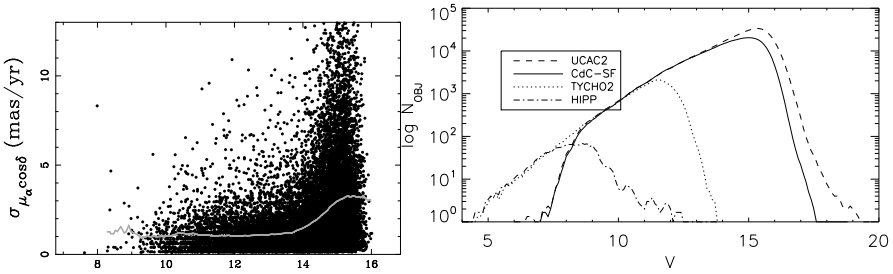

Fig. 1 a) Proper-motion uncertainties as a function of magnitude. Each point represents 25 stars and the grey line indicates a moving mean. **b)** Magnitude distribution of the CdC-SF Catalogue compared to other astrometric catalogues.

2.3 The CdC-SF Catalogue

The final catalogue contains positions and proper motions for approximately 560,000 stars. The partial catalogue obtained, comprising 420 plates, which is one third of the full CdC-SF collection, covers the right ascension range $\alpha = (06^h, 14^h)$, cooresponding to a range of -10 to +60° galactic latitude. We compare in Fig. 1b the magnitude distribution of the CdC-SF Catalogue with other astrometric catalogues, for the same areal sky coverage. The turnover

of the CdC-SF distribution is at V=15.1. A summary of the main properties of the CdC-SF Catalogue is given in Table 1.

Table 1 CdC-SF Catalogue

mean epoch	1901.4
system	ICRS
area covered	$\sim$1080 degrees^2
range in α	$06^h \leq \alpha \leq 14^h$
range in δ	$-10.5^\circ \leq \delta \leq -2.5^\circ$
magnitude range	$6 \leq V \leq 16.3$
completeness limit	$V \simeq 15.1$
number of stars	503769
measuring error	3 $\mu m \sim 0\farcs18$
positional error	$(0\farcs21, 0\farcs19)$
(V<14)	$(0\farcs12, 0\farcs11)$
μ error (mas/yr)	(2.0,1.9)
(V<14)	(1.2,1.1)

While all plates of the San Fernando zone have been scanned and digitized, currently, the algorithms have been applied only to one third of the zone; that with right ascension between 6 and 14 hours. The processing of the remaining plates in the future will be straightforward, using the procedures developed and presented here.

3 Membership probabilities in Open clusters

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

In Fig. 2 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 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.

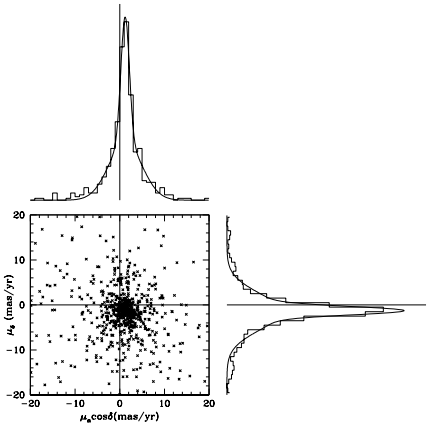

Fig. 2 Vector-point diagram of NGC 2323 based on CdC-SF proper motions. The marginal distribution histograms are also shown along with their functional fits, comprised by the sum of two Gaussians.

Table 2 Cluster and field star distribution parameters

Cluster	Cluster					Field				
	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)					(mas/yr)		
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

3.1 Color-Magnitude Diagram of NGC 2323

One of the main purposes of astrometric cluster membership studies is to provide a color-magnitude diagram (CMD) with reduced field-star contamination. Fig. 3 shows the CMD for NGC 2323 for all stars and just for the probable members. The theoretical isochrones (Girardi et at. 2000) can be fitted better in the cleaned diagram.

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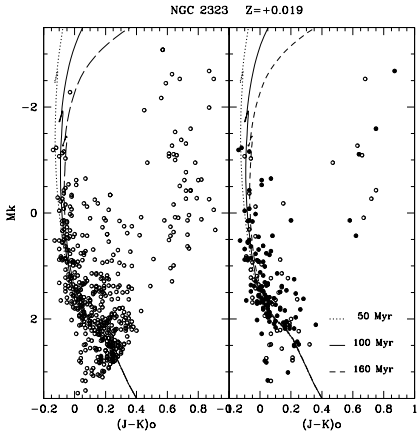

Fig. 3 Color-magnitude diagram (CMD) for NGC 2323 and theoretical isochrones; **a)** CMD of the whole sample. **b)** CMD of probable members (P≥51%, open symbols) and highly probable members (P≥81%, filled symbols).

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