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Kinematic parameters and membership lists of open clusters in the Bordeaux Carte du Ciel zone

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Abstract. In the study of open clusters, the distinction between cluster and field members and the assignment of membership probabilities for each individual star in the relevant region are central issues. Here, we present an analysis based on the use of a fully automated method that relies on a hybrid heuristics, based on genetic algorithms and hill-climbing optimisation, as well as different probability distribution functions for the observables. We analysed the use of some variations for the parameterisation of those distribution functions. Finally, a catalogue comprising kinematic parameters and associated membership probability lists for all the open clusters in the Bordeaux PM2000 region was derived.

Keywords. open clusters and associations: general, methods: statistical, methods: data analysis

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1. Introduction

Open clusters are known to be a most valuable tool for studies of our Galaxy and also of stellar astrophysics once the problem of selecting their physical members is solved. In the astronomical literature, open clusters have been used for many purposes, from determination of the spiral structure to investigations of star-formation mechanisms. Particularly, they play an important role as tracers of the dynamics (e.g., Frinchaboy & Majewski 2008) and chemical evolution of our Galaxy's disk (e.g., Friel 1995). Also, at the dawn of precise astronomical surveys such as delivered by *Gaia* (Perryman *et al.* 2001), their contribution to astrophysical studies tends to be of increasing importance.

The problem of membership selection is traditionally solved using kinematic information alone, but in principle membership determination could be done in multidimensional space, using (for example) spatial and kinematic information, as in Zhao *et al.* (1998), or even colour–magnitude diagram (CMD) isochrone information, as in Kharchenko *et al.* (2005). Nonetheless, we argue that when analysing these objects one should rely more on kinematics and as little as possible on a single-age, CMD-based analysis. This is so because it has been reported in the literature that star formation in some open clusters could be noncoeval: see, e.g., Eisenhauer *et al.* (1998) for NGC 3603 and Strobel (1992) for 14 other open clusters.

Keeping this scenario in mind, we set out to obtain open-cluster membership-probability lists and kinematic parameters using a fully automated method, a set of modified parameterisations for the probability distribution functions of Zhao *et al.* (1990, 2006) and high-quality proper-motion data from the Bordeaux PM2000 catalogue.

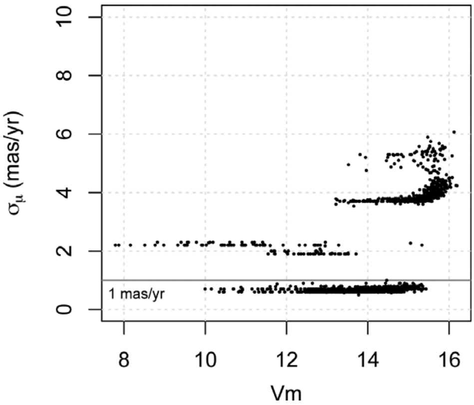

Figure 1. Example of the error distribution for the total proper motion as a function of the meridian V_M magnitude. The data was extracted from the PM2000 catalogue around the NGC 2682 cluster.

2. Data

The source for the proper-motion data is the PM2000 catalogue of Ducourant *et al.* (2006). It comprises $\sim$ 2.6 million stars in the declination range $+11° \leqslant \delta_{\rm J2000} \leqslant +18°$, up to $V_M \sim 16.2$ mag. It contains positions and proper motions on the ICRS, as well as CCD meridian-circle V_M magnitudes. The PM2000 catalogue was derived from a compilation of systematic drift-scan observations in the Bordeaux Carte du Ciel zone with an automated meridian circle, the reduction of 512 Carte du Ciel plates (epoch $t \approx$ 1900) of the Bordeaux zone, scanned with the APM in Cambridge, and three catalogues: AC2000.2 ($t \approx 1907$), USNO-A2.0 ($t \approx 1950$) and the unpublished USNO Yellow Sky catalogue ($t \approx 1978$). The positional precision ranges from 50 to 70 mas, while the proper-motion precisions vary from 1.5 to 6 mas yr^{-1}, depending on magnitude. All data were analysed using a global iterative astrometric reduction process, as described in Teixeira *et al.* (1992) and Benevides–Soares & Teixeira (1992). An example of the errors on the total proper motion can be seen in Figure 1. Open cluster selection was based on the Dias *et al.* (2002) list: for all objects listed therein that were also found in the PM2000 declination range, we extracted PM2000 data.

3. Method

We adopted variations of the general form of the probability distribution function (PDF) for the proper motion of the stars in the region of the clusters. These were basically modified versions of the PDFs proposed by Zhao & He (1990), consisting of bivariate Gaussian mixtures. We considered circular and elliptical cluster PDFs and also took into account that the observational errors could be much greater than the internal dispersion, setting the latter to zero.

We also adopted another PDF that takes the (α, δ) positions of the individual stars into account, as was done by Zhao *et al.* (1998). However, here we directly used the stellar coordinates, leaving the cluster centre as a free parameter. For all parameterisations we constructed the logarithmic likelihood function to be optimised.

To find better global optima for this function, we chose to use heuristics based on evolutionary computing, genetic algorithm (GA). Nonetheless, to find the solution with

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pure GAs is a very expensive task from a computational point of view, as they are generally slow to converge. On the other hand, they are very good at finding the region where the optimum point lies. Therefore, we decided to adopt the code described in Mebane & Sekhon (2007) for the optimisation task. This code is based on a mixture between a GA and a derivative-based hill-climbing algorithm: while the former finds the region of the optimum, the latter finds the optimal point.

All adopted algorithms, parameterisations and data were validated through a comparison with the literature and Monte Carlo simulations.

4. Results

We applied the GA and all parameterisations described above to the selected PM2000 data. The kinematic parameters and membership probability lists for all known open cluster regions in our cluster input catalogue were obtained.

Next, we visually inspected the results using the proper-motion distributions (VPD), probability histograms and member/nonmember star charts. An example of the results for a poorly populated object can be seen in Figure 2.†

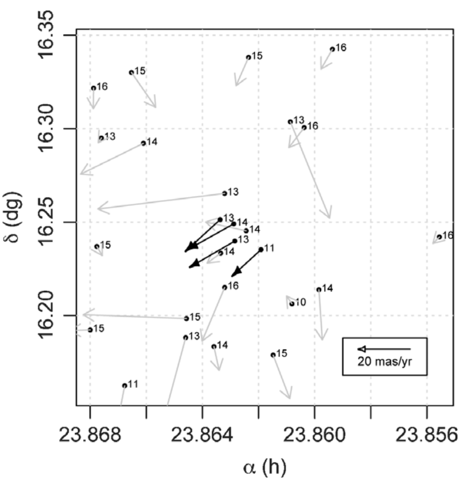

Figure 2. NGC 7772 star chart. The stars with dark arrows are considered members. The numbers indicate the meridian V_M magnitudes.

We realised that, in most cases, the parameterisation that considers the observed internal dispersion of the cluster as zero, allowed us to obtain the best diagrams, even if in several cases the solution obtained using other parameterisations had higher log-likelihood values. This probably means that for most objects we still do not have enough precision for the proper-motion data to disentangle the intrinsic internal dispersion from the observational errors, and that taking into account this parameter could lead one to possibly misleading interpretations of the observations.

We also note that using hybrid optimisation heuristics, besides making the analysis completely automated, allowed us to obtain kinematic parameters even for some very poorly populated objects, such as the open cluster remnant NGC 7772 (see Figure 2).

† We note that only the three stars sharing almost the same proper-motion vector have high-probability membership values using the adopted parameterisation.

5. Conclusions and perspectives

We obtained kinematic parameters and probability membership lists for all open clusters in the PM2000 catalogue. For some clusters, this was the first measurement of their kinematic parameters and membership lists in the literature.

Also, a fully automated system for determining the parameters and membership lists was developed. Although we only used kinematic and spatial data, the tools we have developed could be easily adapted to successfully use CMD, radial velocity or any other data. We note, however, that great care should be taken when choosing which observables to add to the analysis, because for any observable there must be an accompanying model. The latter could bias the analysis results.

More details, as well as the resulting kinematic parameters, membership lists and comments on some interesting objects will be published in a forthcoming journal article.

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