ALL-SKY CENSUS OF GALACTIC OPEN CLUSTER STARS

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We present the results of a systematic study of the wider neighbourhoods of 520 Galactic open clusters from data of the all-sky high-precision homogeneous catalogue ASCC-2.5. About 30 000 members have been selected on the basis of proper motion, photometric and spatial criteria. Angular and linear sizes of cluster cores and coronas, mean cluster proper motions in the Hipparcos system, distances and ages are derived for all clusters, including some 200 clusters, for which distances and ages have been obtained for the first time. Mean radial velocities are computed for about 300 clusters (for about 100 clusters for the first time). The typical cluster radii are found to be more than two times larger than previously published values. The catalogue of cluster parameters is supplemented by a catalogue of 171 000 stars located in 520 cluster areas and by an atlas of diagrams for each individual cluster.

INTRODUCTION

Open clusters (OCs) are typical representatives of the Galactic disc population. Since each cluster includes up to several hundred stars, its age, spatial coordinates and velocities can be determined much more accurately than for other Population I objects. The principal drawback of using clusters as objects for such studies is the contamination of cluster areas with fore- and background stars as well as inhomogeneity, and incompleteness of stellar data. This makes rather difficult the correct separation of cluster members and field stars. The uncertainty of this procedure influences the estimates of the principal parameters of the cluster: its stellar content, structure, space velocity, colour-magnitude diagram, and age.

So far, about 1700 open clusters have been discovered in the Galaxy. However, only after the Hipparcos mission had been successfully completed it became possible to create catalogues of open-cluster parameters determined in reference systems that are uniform over the entire sky in terms of the observational material and/or methods used.

The study of the nearest clusters was among the primary tasks of the Hipparcos [6] mission. Robichon *et al.* [13], Baumgardt *et al.* [3], and Loktin and Beshenov [11] determined the trigonometric parallaxes of 50, 205, and 45 open clusters based on pre-selected lists of 550, 715, and 638 members, respectively. Robichon *et al.* [13] and Baumgardt *et al.* [3] obtained the mean proper motions of the open clusters in the Hipparcos reference frame. Dias *et al.* [4, 5] determined these parameters for 205 clusters using data for about 5900 Tycho-2 stars selected as cluster members by the statistical method of Sanders [14]. As a common feature, these papers are aiming at the study of kinematics of open clusters. Kharchenko *et al.* [8] determined structural (cluster radii), and kinematic (average proper motions) parameters for 401 open clusters. A more complete set of cluster parameters (proper motions, sizes, distances, and sometimes ages) was determined for a few tens of objects by Platais *et al.* [12] and Alessi *et al.* [1] as a result of searching new clusters in the Hipparcos and Tycho-2 catalogues.

Our study is based on the All Sky Compiled Catalogue of about 2.5 Million Stars [7], called hereafter ASCC-2.5. This catalogue is based on Tycho-2 data, but is supplemented with some specific Hipparcos data sets, as well as with some ground-based catalogues. Thus, the stellar content and data quality is improved in comparison to other Hipparcos-family catalogues. The ultimate goal of the current project is the determination

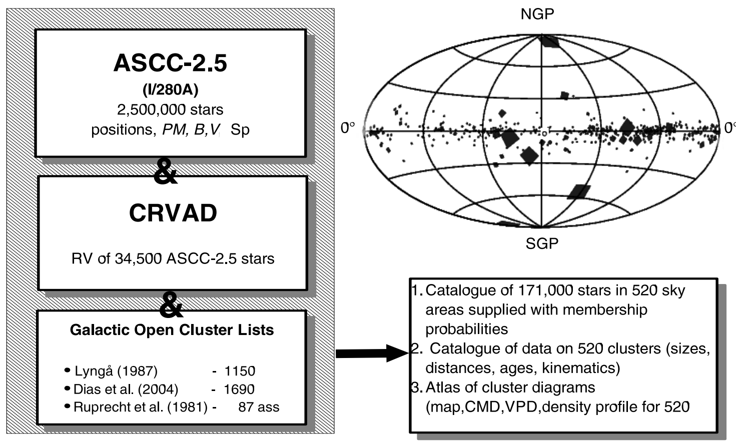

Figure 1. ASCC-2.5 is constructed from catalogues of the Hipparcos family and ground based (PPM, CMC11) catalogues and is complete down to $V \approx 11.5$ ($V_{lim} \approx 14$). All known clusters including stars brighter than V_{lim} are identified

of unbiased spatio-kinematic parameters of open clusters obtained from the spatially unlimited and uniform data extracted from the Hipparcos-based all-sky catalogue ASCC-2.5.

THE ASCC-2.5

The ASCC-2.5 is the result of a cross-identification of stars from large high-precision catalogues from space (Hipparcos and Tycho family: Hipparcos main catalogue with the Multiple System Annex, Tycho-1, Tycho-2, ACT-RC, TRC) and from ground-based (CMC11, PPM-N, PPM-S, PPM-add) observations and their reduction to standard systems of corresponding stellar data (see [7] or the ASCC-2.5 ReadMe file at the CDS for more details on the references and for a detailed description of the ASCC-2.5). The main stellar data presented in the ASCC-2.5 are the equatorial coordinates (taken from the source catalogues in the order given above, reflecting a priority in the accuracy of coordinates), weighted mean proper motions, B and V stellar magnitudes. Additionally, the trigonometric parallaxes, spectral types in the MK or HD system, multiplicity and variability flags as well as the Hipparcos, Tycho-2, HD, and DM designations are given (if available).

All data in the ASCC-2.5 are reduced to the Hipparcos proper motions and Johnson photometric systems. The catalogue provides the most complete list of stars having uniform data down to about $V = 14$, with a completeness limit at about $V = 11.5$. The ASCC-2.5 is a full-sky catalogue which is important for an unbiased determination of the cluster sizes, and contains an extended set of stellar data which allows to carry out the selection of cluster members in a multidimensional space of spatial coordinates, proper motions, and photometric data. Additionally, the ASCC-2.5 was recently cross-identified by Kharchenko *et al.* [9] with the General Catalogue of Radial Velocities [2] and can be used for the calculation of 3D velocities of open clusters.

SELECTION OF OPEN CLUSTER MEMBERS

Unbiased determination of cluster parameters is only possible if the cluster members are correctly separated from field stars. The most objective methods of membership evaluation are based on kinematic parameters, first and foremost on proper motions as the most complete kinematic data sets.

Since the publication of the paper by Sanders [14] describing a statistical method of separation of cluster members, there have been many examples of successful implementations of this technique to various clusters. This method, however, is only efficient if the sample under study is kinematically uniform (with respect to the accuracy of proper motion) and representative enough (enabling to construct and analyze the corresponding distribution functions). Generally, for poor samples, the method of Sanders produces an unstable separation. Due to the bright limiting magnitude, Hipparcos-based catalogues are biased to small samples of open cluster members, and using Sanders' technique, one therefore could meet difficulties. For example, applying this method to the Tycho-2 data, Dias *et al.* [4, 5] only succeeded to determine the membership for less than half of the clusters contained in the Tycho-2 catalogue.

In the current study (see Kharchenko *et al.* [10] for details), we use spatial (location with respect to the cluster centre) and kinematic (proper motions) criteria for the selection of cluster members, and photometric constraints to clear the cluster member sample from co-moving field stars located in the cluster colour-magnitude diagram (CMD) beyond major sequences of the cluster.

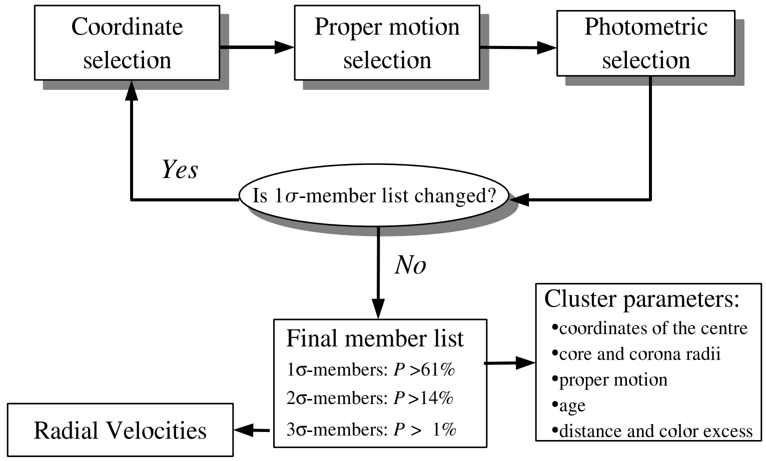

Figure 2. Illustration of the applied iterative member-selection algorithm. Arrows indicate a sequence of basic selection phases shown as rectangles. Iterations are performed until the list of 1σ-members is no more changing

The membership probabilities are determined as:

$$P_\mu = \exp\left\{-\frac{1}{4}\left[\left(\frac{\mu_x-\overline{\mu}_x}{\varepsilon_{\mu_x^i}+\delta\varepsilon}\right)^2+\left(\frac{\mu_y-\overline{\mu}_y}{\varepsilon_{\mu_y}+\delta\varepsilon}\right)^2\right]\right\}, \quad \text{(proper motion probability)}$$

$$P_{ph} = \exp\left\{-\frac{1}{2}\left[\frac{\Delta(B-V)}{\varepsilon_{(B-V)}}\right]^2\right\}, \quad \text{(photometric probability)}$$

$$P_c = \begin{cases} \min\{P_\mu, P_{ph}\}, & r \le r_{cl}\,, \\ 0, & r > r_{cl}\,, \end{cases} \quad \text{(combined probability)}$$

here $\overline{\mu}$ is the average proper motion of the most probable cluster members, $\Delta(B-V)$ is the distance of a star from the main sequence borders (for stars residing within the MS strip $\Delta(B-V)=0$), ε corresponds to the rms error of the respective parameters. Both membership probabilities and corresponding cluster average parameters were determined with the help of an iterative procedure shown in Fig. 2. The same and uniform membership selection procedure has been applied to all clusters. This yields complete set of cluster parameters (core and corona sizes, proper motions, radial velocities, distances, and ages) all over the sky.

SUMMARY OF THE DERIVED RESULTS

Due to its origin from the all-sky space-based experiment Hipparcos, the member sample presented here has two important features: (i) accurate and homogeneous data, which served as the basis for a consistent approach for the identification of open cluster membership regardless of the cluster position at the sky, and (ii) unlimited areas for searching possible cluster members. This allow to determine the cluster parameters free from a spatial bias. The applied cluster member selection criteria considerably clear off the cluster neighbourhoods, and improve the conditions for the determination of cluster sizes, which are strongly affected by contaminating field stars.

In Fig. 3 and in Table 1 we show a few results based on the cluster parameters derived after a new membership determination. Figure 3 confirms, that young clusters avoid the inter-arm regions, whereas the older clusters are distributed more uniformly. Table 1 shows that cluster radii for cleared samples are as a rule 2–3 times larger than published in the literature from the counts contaminated with field stars. Linear cluster radii are also much larger, and at the upper limit approach association sizes.

Table 1. Typical radii (in pc) of clusters (R_{cl}) and associations (R_{ass}). Standard deviations are given in brackets

Value	New		Previous
	Core	Corona	
$\overline{R_{cl}}$ (10 min)	0.5 (0.2)	0.9 (0.2)	0.5 (0.3)
$\overline{R_{cl}}$ (10 max)	6.4 (2.4)	17.2 (2.2)	6.7 (4.5)
$\overline{R_{cl}}$ (all)	2.0 (3.2)	5.0 (1.3)	2.7 (2.7)
$\overline{R_{ass}}$ (all)	6.6 (2.6)	21.9 (11.7)	–

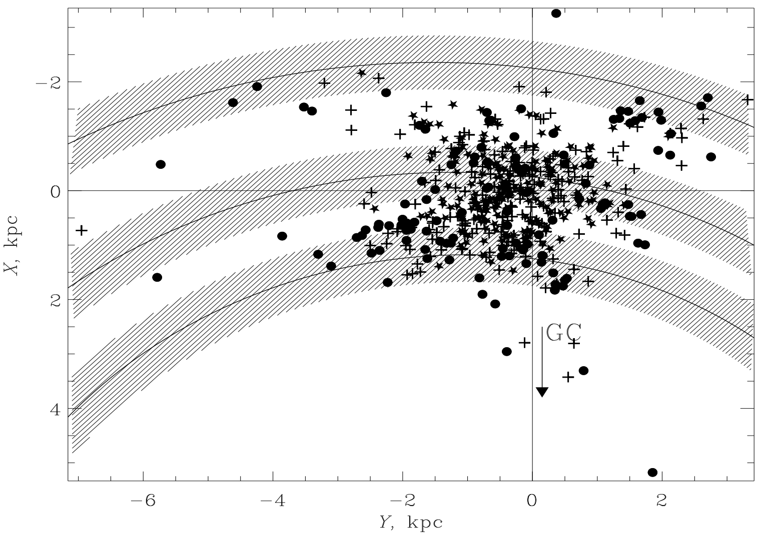

Figure 3. Distribution of open clusters in the Galactic disc plane. Filled dots are clusters younger than $\log t = 7.4$, pluses – those with $\log t = 7.4...8.4$, and stars are clusters with $\log t > 8.4$. The shaded curves are the Perseus, Local, and Carina–Sagittarius spiral arms (from top to bottom)

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