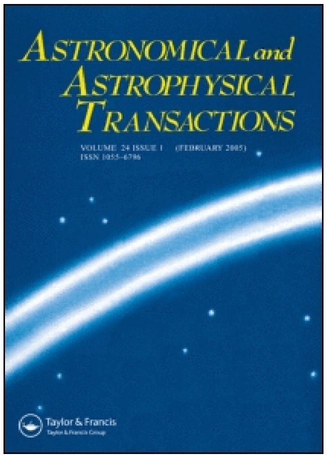

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The population of open clusters of the Galactic disc

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We summarize the results of our recent study of the Galactic disc population of open clusters. This study makes use of a sample of 650 open clusters drawn from the analysis of the high-precision all-sky compiled catalogue ASCC-2.5. On the basis of the combined spatial–proper motion–photometric membership we established uniform scales of spatial (angular dimensions), kinematic (proper motions and radial velocities) and evolutionary (ages) cluster parameters. The sample is complete within 850 pc, which provides unbiased parameters of the local cluster population and its evolution.

Keywords: Open clusters; Structure; Kinematics; Evolution

1. Introduction

We describe here the basic results achieved in the framework of a large project of studying the population of Galactic open clusters from the data of high-precision all-sky catalogues. The project is being performed by a team consisting of the present authors, together with S. Röser and E. Schilbach of the Astronomisches Rechen-Institut, Heidelberg, Germany, and R.-D. Scholz of the Astrophysikalisches Institut Potsdam, Germany. For details we refer the reader to the original papers [1–4]. Some of the results have not yet been published.

The major aims of the project are as follows: to benefit from the Hipparcos and other all-sky surveys in a systematic study of the stellar population in open clusters; to identify in the compiled ASCC-2.5 catalogue, which is based on the Hipparcos and Tycho-2 catalogues, all the known open clusters and associations and to find new clusters; to derive a uniform set of parameters of these clusters (membership, coordinates, radii, proper motions, radial velocities, ages, reddenings and distances); and to determine the parameters of the Galactic disc population of open clusters.

The project is intended to eliminate the major disadvantages in our knowledge on the open cluster population in the pre-Hipparcos era, namely the incompleteness and heterogeneity of the data.

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A convincing example illustrating this statement is presented by the most complete pre-Hipparcos Lund *Catalogue of Open Cluster Data* [5], which, for about 1200 objects, contains only about 400 distances, reddening and ages. The kinematic data of open clusters are even more scarce in the Lund catalogue. This catalogue, however, was the basis of the most recent population studies of galactic open clusters [6, 7]. It is worth mentioning other relevant studies, which are dedicated to more restricted tasks and/or to using limited or specific samples (generally non-uniform and with an unknown degree of completeness): the construction of a cluster age scale of 500 objects [8], the investigation of the structures of 100 northern clusters [9] and the statistics of clusters observed using a charge-coupled device [10].

Nowadays, there are 1700 Galactic open clusters and candidates identified in the optical region and collected in the list published by Dias *et al.* [11], which can be regarded as a continuation of the Lund catalogue.

2. The tool, technique and sample

Our study is based on a homogeneous all-sky compiled catalogue of 2.5×10^6 stars (ASCC-2.5 [12]), which is compiled from the Hipparcos and Tycho catalogue family and selected ground-based catalogues. The third version of the ASCC-2.5 catalogue contains the proper motions in the Hipparcos system, the B and V magnitudes in the Johnson photometric system for 2.5×10^6 stars, the spectral classes for 5×10^5 stars (about 1.6×10^5 stars are supplied with luminosity classes) and the radial velocities for about 5×10^4 stars.

The basic principle that we have used is simultaneous determination of cluster parameters and combined (spatial–kinematic–photometric) cluster membership. Dedicated software for the derivation of cluster parameters was created and a flow chart of the cluster parameter–membership determination was drawn (figure 1).

We construct a combined probability P_c which takes into account all aspects of the member selection procedure, i.e. kinematic (proper motions), photometric and spatial selection criteria, and define it as

$$P_c = P_s \min\{P_\mu, P_{ph}\}.$$

The flow chart was used to process all clusters from the list given by Dias *et al.* [11]. To the list of identified clusters were added new candidate clusters found in the special all-sky search in the ASCC-2.5. Screening the ASCC-2.5 resulted in the identification of 520 known clusters and the detection of 130 new clusters. A uniform combined kinematic–photometric cluster membership was established for these objects and new uniform scales of cluster structure (angular sizes), kinematics (average proper motions and radial velocities), photometry (reddening and distance) and evolution (age) were established. The cluster parameter statistics are given in table 1.

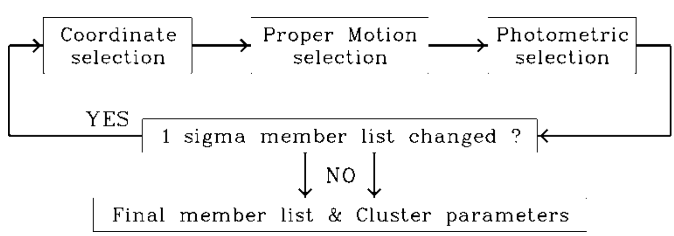

Figure 1. The flow chart of cluster parameter–membership determination.

Table 1. Cluster parameter statistics.

Parameter	Previous known out of 1700	Revised or confirmed out of 520	New determinations out of 650
Combined probability	–	–	38 463
Size	1700	515	135
Distance and reddening	760	320	330
Proper motion	458	219	431
Radial velocity	258	159	163
Age	637	325	325

The constructed sample can be regarded as complete in a wide solar neighbourhood. With the exception of a considerable excess at $d_{xy} = 0.35 - 0.55$ kpc (d_{xy} is the cluster heliocentric distance projected on to the Galactic plane), the cluster surface density distribution is almost flat up to $d_{xy} = 0.85$ kpc. At larger distances, the surface density of clusters is steadily decreasing. We consider this as evidence of cluster incompleteness beyond $d_{xy} = 0.85$ kpc and adopt this value as the completeness limit of our sample.

3. Structure parameters of open clusters

For all clusters of our sample, we determined and/or redetermined the angular sizes with the radial density profiles of the selected cluster members. We considered two structural components: the core and the corona. The core radius r_1 was defined as the distance from the cluster centre where the decrease in stellar surface density becomes flatter. The corona radius r_2 or, simply, the cluster radius corresponds to a distance where the surface density of stars merges with the surrounding field. The advantage of our approach with respect to other methods is that our estimations of cluster sizes are based on complete information on cluster membership which includes photometric as well as astrometric criteria. For about 500 open clusters of our sample, the sizes are also given in the Lund catalogue [5]. As expected, the cluster radii from [5] are, on average, lower by a factor of 2, and they fit the core rather than the corona.

The formalized spatial parameters r_c and r_t were determined from fitting of the observed density profiles with King's [13] empirical formula. We were able to determine with a reasonable accuracy of 30% the King parameters for about 250 clusters. Comparison of these values with visual estimates has shown that, on average, $\langle r_t/r_2\rangle \approx 1.7$. This factor was used to calibrate r_t values for all clusters and to determine their masses via the formula

$$M_{cl} = \frac{4A(A-B)r_t^3}{G},$$

Table 2. Structure parameters of open clusters (modes are shown in parentheses).

Value	New: Core	New: Cluster	Previous
Empirical radii (pc)	0.5–6.5 (0.8)	1–20 (2.5)	0.5 (0.3)
King radii (pc)	0.5–12 (1.0)	2–35 (4.0)	
Mass $m_\odot$		10–15 000 (100)	

where A and B are the Oort constants [4] and G is the heliocentric gravitational constant [13]. The general properties of the structure parameter distribution are given in table 2.

4. Spatial distribution of open clusters

On the basis of the colour excesses of individual clusters we constructed a distribution of interstellar reddening in the wide solar neighbourhood. We found that the absorption in the Galactic disc is lowered in direction of Orion, which produces transparency corridors in this direction and produces an apparent spiral arm (usually referred to as the Local or Orion Arm). In contrast, the small number of clusters seen in the directions of Galactic longitudes $l \approx 40°$ and $l \approx 150°$ can be accounted for by the presence of strong absorption in these directions. These peculiarities of the apparent distribution of clusters in the Galactic plane projection are shown in figure 2. Taking them into account, the distribution of young clusters in the Perseus and Carina–Sagittarius regions is in agreement with a flat (a pitch angle of the order of $-6°$) grand design spiral pattern.

Revealing the completeness area allows us to derive unbiased parameters of the open cluster population such as the local density, the distribution perpendicular to the Galactic plane, and the total number of clusters currently existing in the Galaxy. To determine the distribution parameters we used 259 clusters located within the completeness radius. We found that the open cluster symmetry plane resides at $Z_0 = -22 \pm 4$ pc, and the cluster height scale is equal to $h_Z = 56 \pm 3$ pc. The total density of clusters in their plane of symmetry is equal to $D(Z_0) = 1015\,\mathrm{kpc}^{-3}$; the total surface density $\Sigma = 114\,\mathrm{kpc}^{-2}$. The latter value exceeds by a factor of about 5 the surface density of open clusters inferred from the data of a previous open cluster population survey by Janes *et al.* [7], giving $\Sigma = 24.9\,\mathrm{kpc}^{-2}$. Using the derived parameters, we can estimate the total number of open clusters observed currently in the Galactic disc to be about 10^5.

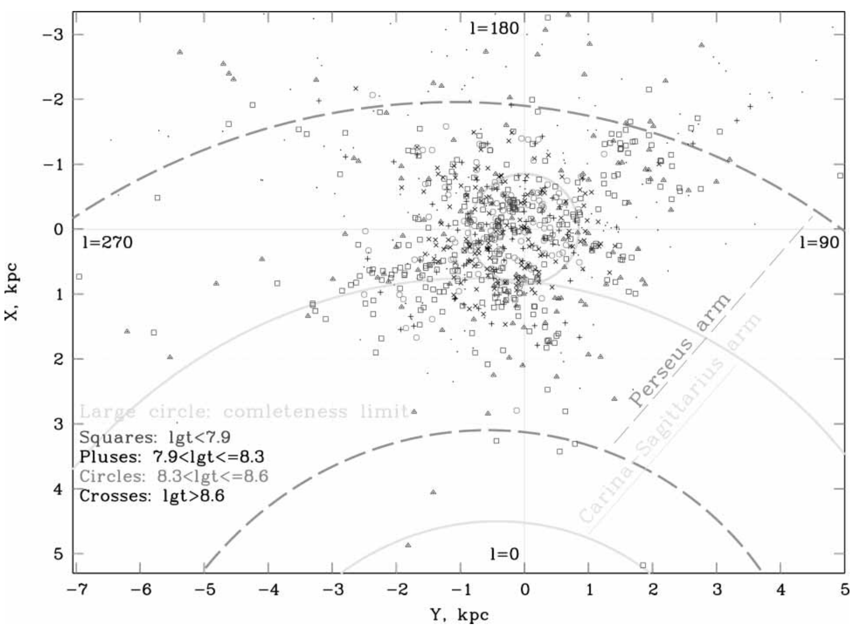

Figure 2. Peculiarities of the apparent distribution of clusters in the Galactic plane projection.

Table 3. Kinematic and orbital parameters of the subsystem of open clusters in the Galaxy.

Parameter	Value	Rms error	Parameter	Value	Rms error
$U_\odot$ (km s^{-1})	+9.44	1.14	$\overline{R_a}$ (kpc)	8.631	0.034
$V_\odot$ (km s^{-1})	+11.90	0.72	σ_{R_a} (kpc)	0.427	0.024
$W_\odot$ (km s^{-1})	+7.20	0.42	$\overline{R_p}$ (kpc)	6.706	0.056
σ_U (km s^{-1})	13.86	0.81	σ_{R_p} (kpc)	0.682	0.040
σ_V (km s^{-1})	8.75	0.51	$\overline{Z_{max}}$ (kpc)	0.260	0.016
σ_W (km s^{-1})	5.05	0.30	$\sigma_{Z_{max}}$ (kpc)	0.189	0.011
$\sigma_U : \sigma_V : \sigma_W$	1:0.63:0.36		$\bar{e}$	0.127	0.003
A (km s^{-1} kpc^{-1})	+14.5	0.8	σ_e	0.037	0.002
B (km s^{-1} kpc^{-1})	−13.0	1.1			

5. Kinematics of open clusters

We determined the kinematic parameters of the open cluster subsystem with the complete kinematic data (tangential and radial velocities) of 148 clusters located within the completeness area. These parameters are the solar motion components ($U_\odot$, $V_\odot$, $W_\odot$) and semiaxes (σ_U, σ_V, σ_W) of the velocity ellipsoid. Assuming the form of the Galactic potential proposed by Saio and Yoshii [14], we also derived elements of their Galactic box orbits. This includes the apocentre distance R_a, the pericentre distance R_p, the eccentricity e and the maximum vertical distance Z_{max} that a cluster can reach in its orbital motion. The Oort constants A and B of the Galactic rotation were determined from the proper motions of 581 clusters with distances $d_{xy} \leq 2500$ pc. The results are given in table 3.

Assuming the galactocentric distance of the Sun to be $R_{G,0} = 8.5$ kpc, we obtain the angular velocity of the Galactic rotation as $\Omega_0 = A - B = 27.5 \pm 1.3$ km s^{-1} kpc^{-1} and the corresponding rotation velocity of the system of open clusters as 233.8 km s^{-1}.

Since the age for each open cluster of our sample was determined by the same method, we can determine the real dependence of the cosmic (or true) velocity dispersion on the cluster age. We used the dispersion of the tangential velocities $\tilde{\sigma}_T$ along the galactic coordinates (l, b) corrected for the rms error of observations. The resulting relation is well approximated by the following equations:

$$\tilde{\sigma}_{T_l} = (1.44 \pm 0.45) \log t_6 + (3.93 \pm 0.84),$$
$$\tilde{\sigma}_{T_b} = (1.33 \pm 0.17) \log t_6 + (1.65 \pm 0.33),$$

where t_6 is the cluster age in megayears. Using the ratio ($\sigma_U : \sigma_V : \sigma_W$) in table 3, we derive the ellipsoid of the cosmic dispersion as (7.2 : 4.1 : 2.6) km s^{-1} for young open clusters with $\log t = 6.7$, and (17.5 : 10.0 : 6.3) km s^{-1} for old clusters with $\log t = 9.5$.

6. Cluster complexes

We consider local cluster grouping that has been found to be a violation of the regular distribution of the clusters in the space of coordinates and velocities. As we find from a detailed spatial–kinematic analysis, the above fluctuations can be attributed to the existence of four open cluster complexes (OCCs) of different ages containing up to a few tens of clusters. Without exception each complex turned out to be as large as 1 kpc; its members show the same kinematic behaviours and a narrow (within the observed errors) age spread. We found that the youngest cluster complex OCC 1 ($\log t < 7.9$) is inclined to the Galactic plane by 19°. It is

Table 4. Comparative parameters of the cluster complexes.

Complex	N	$\log t$ (years)	size (kpc)	(U, V, W) ($\mathrm{km\,s^{-1}}$)
OCC 1	23	6.7–7.9	0.8 × 1.0	(−4.0, −0.2, +0.3)
OCC 2	27	8.5	0.6 × 1.3	(+1.9, +3.3, +2.5)
Perseus–Auriga	8	8.5	0.5	(+4.6, +21.1, +4.3)
Hyades	9	>8.7	1.4	(−34.4, −0.8, +2.0)

apparently a signature of Gould's Belt, which is known so far, in general, as an aggregation of field stars, gas and associations. The most populous OCC 2 complex has a moderate age ($\log t \approx 8.45$). The clusters of OCC 3, which have the same age but different kinematics, are seen in breaks between Perseus–Auriga clouds. The oldest and the loosest group OCC 4 ($\log t \approx 8.85$) shows a large motion in the Galactic anticentre direction of about $40\,\mathrm{km\,s^{-1}}$, which agrees with those of the Hyades and Praesepe clusters (included by us in this complex also). The cluster complex parameters are given in table 4.

7. Evolution of the cluster population

The cluster formation rate and lifetime obtained from the age distribution of field clusters within the completeness area are found to be equal to $0.23 \pm 0.03\,\mathrm{kpc^{-2}}$ and 322 ± 31 Myears, respectively. Because of the incompleteness of his sample for older clusters, Wielen [15] obtained these data as $0.10\,\mathrm{kpc^{-2}}$ and 231 Myears.

The derived lifetime value implies that the total number of cluster generations that have been ever born in the Galactic disc is of the order of 30–40. If a typical open cluster of the Pleiades type is assumed, then the total surface density of disc stars passing through the open cluster member phase is about $4 \times 10^6\,\mathrm{kpc^{-2}}$ which, if compared with the local star density in the disc of about $7 \times 10^7\,\mathrm{kpc^{-2}}$, gives for the open cluster input about 6% of the total Galactic disc stellar population. Our estimates are even lower than the 'pessimistic' estimate of 10% obtained by Miller and Scalo [16] from much poorer statistics.

8. Further steps

We plan to extend our study on the basis of new data sources (such as the near-infrared catalogue 2MASS, or the radial velocity survey RAVE), coupled with the extension of the set of considered stellar parameters, the extension of the star list and an improvement in the accuracy of stellar data (especially for faint stars). We expect that with this new tool we shall be able to solve the following tasks: to increase (by at least 50%) the number of clusters with accurate parameters, to extend the cluster completeness area radius to about 1.5 kpc, including in this area the nearest spiral arms, and to carry out a comparative study of spiral arm and inter-arm cluster populations.

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