Star clusters: basic galactic building blocks
Proceedings IAU Symposium No. 266, 2009
R. de Grijs & J. R. D. Lépine, eds.

doi:10.1017/S1743921309991359

Membership probability via control-field colour–magnitude decontamination†

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Abstract. The fundamental physical parameters of open clusters are important tools to understand the formation and evolution of the Galactic disk and to test star-formation and evolution models. However, only a small fraction of the known open clusters in the Milky Way have precise determinations of distance, reddening, age, metallicity, radial velocity and proper motion. One of the major problems in determining these parameters lies in the difficulty to separate cluster members from field stars and to assign membership. We propose a decontamination method by employing 2MASS data in the regions around the clusters NGC 1981, NGC 2516, NGC 6494 and M11. We present decontaminated colour–magnitude diagrams of these objects showing the membership probabilities and structural parameters as derived from King-profile fitting.

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

1. Introduction

Despite the large number of known open clusters, many have only been discovered recently and have not been studied in detail or do not have well-determined parameters (Mermilliod 1995; DAML02: Dias *et al.* 2002; Kharchenko *et al.* 2005). Sky surveys like 2MASS (Skrutskie et al. 2006) have produced large amounts of near-infrared data and contributed to the discovery of even more objects.

The determination of the fundamental parameters of open clusters provides important tools for investigations of the Galactic disk and star-formation models. However, contamination by field stars and significant reddening severely hamper the detection and characterization of clusters, especially towards the Galactic plane or the Galactic Center.

We devised a method to remove the field-star contamination on colour–magnitude diagrams (CMDs) by sampling the population from a nearby control field and then removing it from the cluster's CMD. The 2MASS catalog was selected because of its full-sky coverage and our ability to extract data from spatially unlimited regions. Also, near-infrared wavelengths are particularly sensitive to discriminate cluster stars from the contaminating field for young stellar systems (e.g., Santos *et al.* 2005).

2. Data

VIZIER (`http://vizier.u-strasbg.fr/viz-bin/VizieR`) was used to extract near-infrared photometric data from 2MASS in circular fields centered on NGC 1981, NGC 2516, NGC 6494 and M 11, with the clusters' center coordinates taken from DAML02. The data comply with the 2MASS Level 1 requirement (i.e., $J < 15.8$, $H < 15.1$ and $K < 14.3$ mag) and was extracted within 30 arcmin of the clusters' center coordinates.

† The full poster (in pdf format) is available at
`http://www.astro.iag.usp.br/~iaus266/Posters/pCorradi.pdf`.

Comparison fields were selected for the targets with the same area of the cluster data and similar reddening, as deduced from near-infrared (2MASS) and mid-infrared (*IRAS*) images. The NGC 1981 comparison field was extracted 1 deg to the northwest of the cluster due to the southward nebulosity associated with NGC 1977. For the remaining targets, circular annular fields centered on the cluster were used. Figure 1 compares spatial-density profiles for the targets constructed from raw data and the decontaminated subsample, as discussed below.

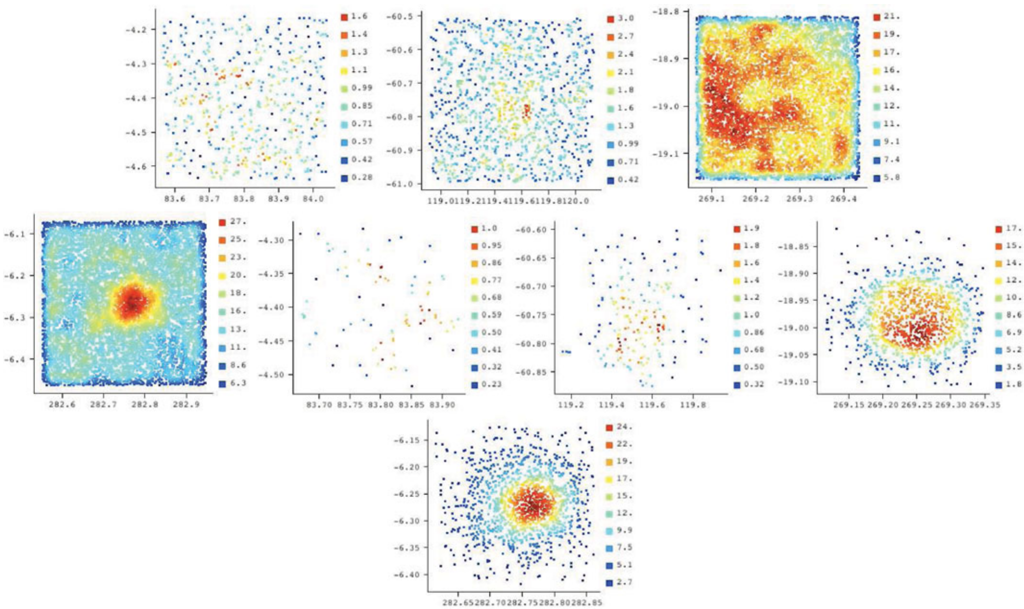

Figure 1. Spatial-density profiles for targets (left to right) NGC 1981, NGC 2516, NGC 6494 and M 11 using raw *(top)* and decontaminated data *(bottom)*. Color bars on the right represent stellar density.

3. New center determination

Precise determination of the clusters' central coordinates is an essential step before a reasonable radial density profile can be obtained. Catalogued center values are mainly intended for identification purposes and generally imprecise. Therefore, we estimated the centers of the targets by first selecting a region around the coordinates given by DAML02. In addition, the selected region was divided into bins of right ascension (RA) and declination (Dec) and star counts were obtained inside each bin. We used these star counts to construct spatial profiles and fit a Gaussian function to the stellar distributions in RA and Dec. The center coordinates were initially taken as the center of the fitted Gaussian.

This procedure was applied to different bin sizes and the corresponding center coordinates were used to create histograms showing the most recurrent RA and Dec. No trends were found between the coordinates and bin size and we adopted these most recurrent values as the new center coordinates of the clusters. Table 1 shows our results.

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Table 1. (*left*) Center determination and their difference to the cluster center in DAML02 catalog. (*right*) Determined King parameters and uncertainties.

	Center determination			King-profile parameters		
Cluster	$\alpha_{\rm new}$	$\delta_{\rm new}$	$\Delta_{\rm lit}$	σ_0	R_c	$\sigma_{\rm bg}$
NGC 1981	$+05^h\ 35^m\ 07.9^s$	$-04^\circ\ 20'\ 34.8''$	$3.57'$	2.61 (0.3)	1.0 (0.2)	0.51 (0.05)
NGC 2516	$+07^h\ 57^m\ 42.0^s$	$-60^\circ\ 43'\ 22.8''$	$3.35'$	14.9 (2.0)	0.5 (0.1)	0.95 (0.07)
NGC 6494	$+17^h\ 56^m\ 37.7^s$	$-19^\circ\ 00'\ 32.4''$	$5.49'$	17.8 (0.8)	2.9 (0.2)	10.7 (0.4)
M11	$+18^h\ 51^m\ 02.2^s$	$-06^\circ\ 15'\ 32.4''$	$0.71'$	42.9 (2.5)	2.1 (0.2)	4.0 (1.3)

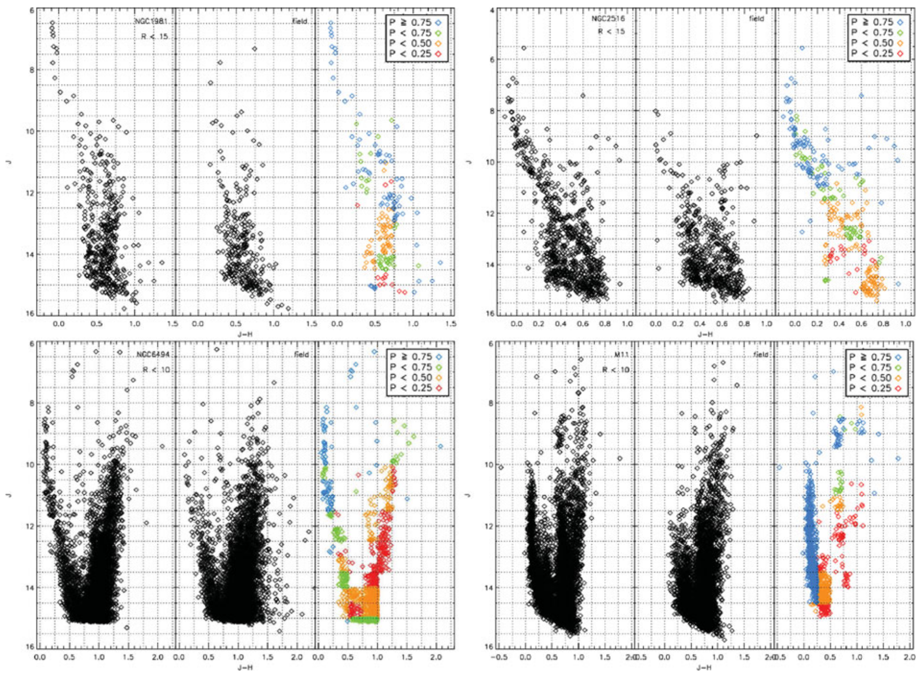

Figure 2. Cluster and control-field CMDs. From top left to bottom right: NGC 1981, NGC 2516, NGC 6494 and M11. Raw cluster data *(left)*, control field *(middle)*, cleaned subsample *(right)*. The color-coded inset shows the assigned membership probability.

4. Membership-probability assignment

For membership assignment we constructed CMDs for both cluster and field stars and divided the diagrams into small cells in J and $J-H$. The cells are small enough to detect local variations of field-star contamination of the various sequences in the CMD, but large enough to accommodate a significant number of stars. Typical cell sizes are $\Delta J = 0.5$ mag and $\Delta(J-H) = 0.25$ mag, with dense (sparse) clusters requiring smaller (larger) cells. Membership probabilities are assigned to stars within each cell based on the overdensity of cluster stars in relation to field stars, according to the relation $P = (N_{\rm clu} - N_{\rm fld})/N_{\rm clu}$. Zero probability was assigned whenever an excess of field stars over cluster stars occurred in a given cell.

For CMD decontamination, a subset of the original cluster sample was created by removing from each cell in the cluster's CMD, the expected number of field stars as measured in the control-field CMD. Stars were removed based on their distance to the center of the cluster, and cells without cluster overdensity had all stars inside their limits removed. We will refer to this final subsample as the 'clean' subsample. Figure 1 shows

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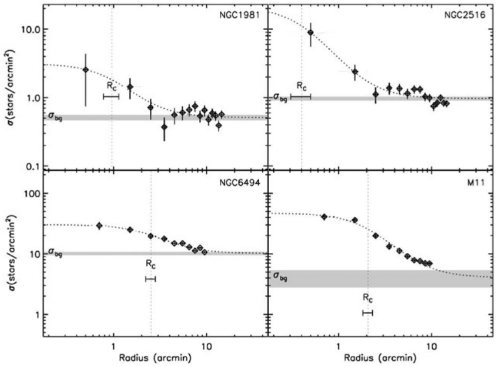

Figure 3. King-profile fits to the target clusters. From top left to bottom right: NGC 1981, NGC 2516, NGC 6494 and M11. Core radii and background densities are indicated.

the spatial-density profiles of the targets using the raw and clean data. Figure 2 shows the cluster, field and clean CMDs for the target clusters.

Radial density profile

To probe the spatial profile and derive structural properties of the targets, radial density profiles (RDPs) were constructed by counting stars inside rings of one arcmin width, centered on the cluster, and then dividing by the area of the ring. King-profile fitting used the modified function $\sigma(R) = \sigma_{\rm bg} + \sigma_0/(1 + (R/R_{\rm c})^2)$, as introduced in King (1962). Figure 3 shows RDPs around the new center coordinates for the target clusters using the clean subsample.

Table 1 shows the central surface density, σ_0, core radius, $R_{\rm c}$ and background surface density, $\sigma_{\rm bg}$, with their respective uncertainties, for the decontaminated samples. The values found for M11 agree, within the uncertainties, with those determined by Santos *et al.* (2005).

5. Conclusion

By removing stars similar to the field population in the cluster region, the method effectively leaves the final subsample of stars less contaminated by the background. Additionally, it provides membership probabilities for all cluster stars, removing stars with zero probability from the sample. This subsample allows for much better defined cluster sequences in the CMD, providing good conditions for subsequent isochrone fitting and more accurate values for the clusters' parameters, as can be seen clearly in Figures 1 and 2.

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