Groups and clusters detection on DPOSS catalogues: a first attempt to compute a global Multiplicity Function

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We discuss the implementation and validation of a procedure aimed to detect groups and clusters of galaxies in DPOSS catalogues, and we also present the results of a first attempt to get a multiplicity function ranging from small groups to rich clusters of galaxies.

1 Introduction

The Digitised Palomar Sky Survey (hereafter DPOSS) offers an unique data set to explore the large scale structure of the nearby ($z < 0.2$) universe due to its virtually unlimited sky coverage, to its deepness (21.5 in J) and the availability of three colours (J, F and N).
The absolute photometric calibration is performed in the g, r and i Gunn-Thuan system using at least two sets of CCD frames taken at $1 - 2m$ class telescopes. Calibration is made on faint galaxies in order to minimize saturation effects and colour terms.
In this poster we discuss a first application of a small part of the data set to the search for candidate galaxy clusters and groups. Final goals are the construction of an objective catalogue of candidate groups and clusters at low redshift ($z < 0.2$) and a statistically robust measurement of the multiplicity function (hereafter MF) of galaxies.
The MF is a powerful tool to test the various cosmological scenarios. For instance, if the protostructures form from a hierarchical gravitational instability caused by primordial density fluctuations:

$$\frac{d\rho}{\rho_m} \propto A \cdot M^{(-1/2+n/6)}$$

where n is the initial spectrum index at era of baryonic recombination, and if one identifies groups of galaxies with mean density $r_g > k$ times the average cosmological density ρ_M, then the function of the mass distribution does not depend on the cosmic density parameter Ω but only on the spectrum index n. The groups, which are seen now at a density enhancement k, would therefore correspond to density fluctuations of amplitude A at recombination. Therefore, a measurement of the MF at the present epoch derived from a catalogue of groups of galaxies identified for a given k, gives a measure of the initial spectrum index n.

This poster is structured as follows: in Sect. 2 and 3 we discuss the algorithms implemented for the detection of candidate groups ($N < 15$) and clusters ($N > 15$). In Sect. 4.1 and 4.2 we discuss the reliability of the results obtained by applying the same algorithms to a small set of plates and in Sect. 5 we present the first results for the MF.

2 Detection of candidate groups

Even though on rather arbitrary ground, we define as a group all galaxy ensembles having less then 15 members having total magnitude within 3 magnitudes from that of the brightest members. The implemented procedure is described in detail by De Filippis et al.[2].
In order to compile a catalogue of candidate groups of galaxies, in absence of redshift information, we implemented a modified version of the van Albada algorithm[13]. This algorithm makes use of apparent magnitude and projected position on the sky only, and gives for each pair of adjacent galaxies their probability of being physically bound.
Assuming a Poisson statistic, the probability that the distance of a fixed galaxy to its nearest non-physical companion lies between Θ and $\Theta + d\Theta$, is given by:

$$P_I(\Theta)d\Theta = exp[-\pi\Theta^2 n]2\pi\Theta n d\Theta$$

The introduction of an adimensional distance x (defined as the ratio of the observed to the expected mean distance to nearest neighbour (Figure 1)) allows to combine the angular separation of different pairs to a single distribution removing the effects of clustering in the background.

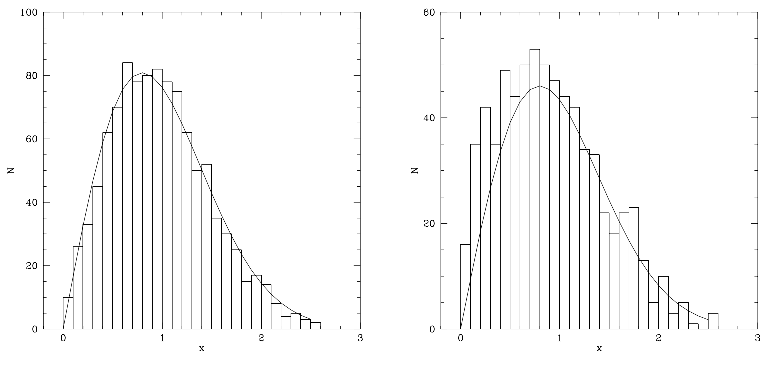

Figure 1: If all nearest neighbours in a given magnitude range are not physical, the observed distribution of x must agree with the expected one (left). In general, however, there will be an excess of neighbours with small values of x: they represent physical companions (right).

3 Detection of candidate clusters

Starting point are the individual J, F and N catalogues produced by SKICAT for a given DPOSS field after conversion to the g, r and i Gunn-Thuan system. The three catalogues are

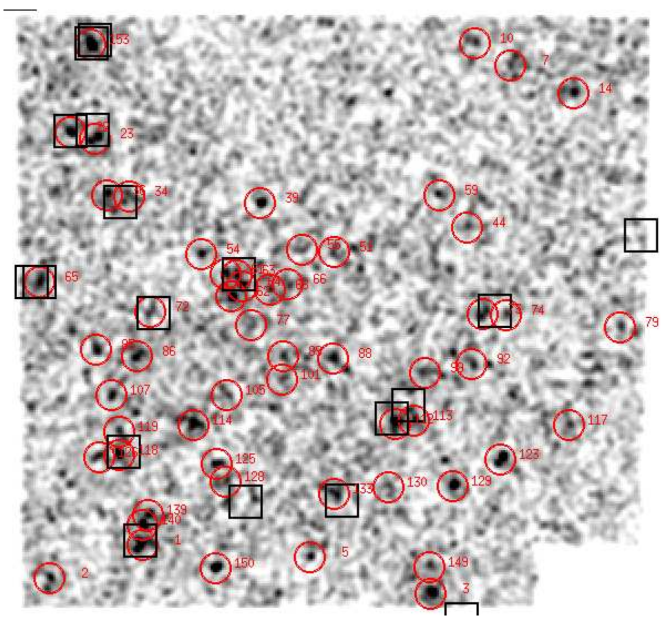

Figure 2: Results for DPOSS field n. 610 (1^h, +15 deg). Circles mark the position of detected candidate clusters while squares mark already known Abell and Zwicky clusters.

then matched (assuming a maximum matching distance of 7 arcsec [9]).
After matching, all objects having $r > 19.5$ are filtered out and the resulting matched catalogue is binned into equal area square bins of 1.2 arcmin to produce a density map. Then S-Extractor [1] is run on this map in order to identify and extract all the overdensities having number density of 2σ above the mean background and covering a minimum detecting area of 4 pixels ($4.8 arcmin^2$). In this way, as in Schectman [12] approach, we are not assuming any a priori cluster model.
An application to the DPOSS field 610 is shown in Figure 2.
All the previously known Abell and Zwicky clusters are recovered and many new candidates are detected. For each candidate cluster we then measure the S/N detection ratio and the Abell richness class.

4 Validation of the algorithms

In absence of a suitably complete samples of galaxies with known redshift we were forced to validate the algorithms shortly summarised above using either simulations or photometric techniques. In what follows we shall discuss first the groups and then the clusters.

4.1 Group algorithm validation

In order to test the accuracy (lost groups) and reliability (spurious groups) of the algorithm we tested it on 70 realistically simulated fields. We first produced the galaxy background by assuming uniform distribution and the field luminosity function given by Metcalfe [8]; then we added simulated groups of galaxies according to the multiplicity function by Turner & Gott [14], with redshift computed according to:

$$N(z) = \frac{32\pi\rho_0 c^3}{3H_0}\left[\frac{1}{z+1}\left(1-\frac{1}{\sqrt{(1+z)}}\right)\right]^3$$

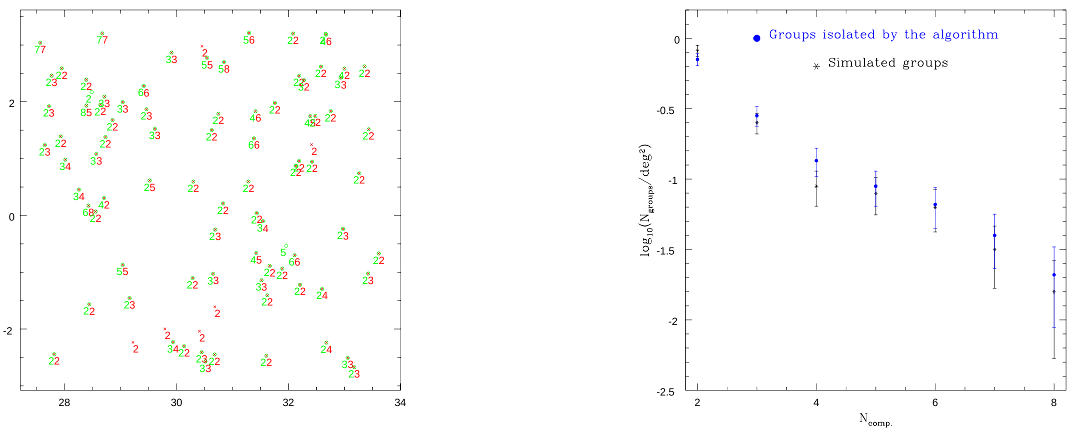

Figure 3: Left panel: comparison between simulated groups (red) and detected ones (green). Figures give the corresponding number of members. Right panel: comparison between the multiplicity function used for the simulation (from literature data) and the multiplicity function recovered by the algorithm.

and absolute magnitude of the brightest galaxy in the group taken from the cumulative LF for groups of galaxies:

$$\Phi(M)dM = \Phi^*[10^{0.4}(M^* - M)]^{(\alpha+1)} \cdot exp[-10^{[0.4(M^*-M)]}]dM$$

where $M^* = -20.85$ and $\alpha = -0.83 \pm 0.17$. Other parameters varied in the course of the simulations were: I) the diameter of the group inside a Gaussian distribution centred at $D_0 = 0.26 Mpc$; II) the maximum possible redshift for a group (chosen in the range $0.2 < z < 0.7$). Different simulations have been performed changing the lower limit of the probability for which two galaxies are considered physical companions by the algorithm. The best compromise between accuracy and reliability is found for $p = 0.6$.
With this choice, our algorithm succeeds in retrieving, from the simulated catalogues, more than 90% of the groups having more than three components (Figure 3).

4.2 Cluster algorithm validation

We took two different approaches: through simulation and through magnitude - colour diagrams. In order to produce realistic simulation we are following a rather long procedure. First of all, we needed a fairy accurate multiplicity function to be used as input parameter for the simulation. Since there is no good MF available in literature we used a set of 20 DPOSS triplets to identify clusters and derive a preliminary MF (Figure5) (we used only very high S/N clusters for which there is no doubt about their physical nature).
In order to simulate the fields we first distribute randomly the cluster centres then we set the absolute magnitude of the brightest cluster galaxy accordingly to the Schecter LF. Then we assume the cluster distribution to be uniform in the volume element and randomly assign to each cluster a redshift in the range $[0.02, 0.2]$. Then we grow the clusters around their centres randomly selecting a radius in the range $[2-3]Mpc$ and weighting the number of members accordingly to the above derived MF. Absolute magnitude for secondary galaxies are then weighted with a Schechter function ($M^* = -21.41, \alpha = -1.24$) and scaled to apparent magnitudes taking into account the K-correction term. We finally add field galaxies using the Metcalfe field counts and LF. Even though simulations are still in progress, preliminary results show that our algorithm can recover 95% of the clusters at $z < 0.15$ and 70% of the clusters in the range $[0.15, 0.2]$.

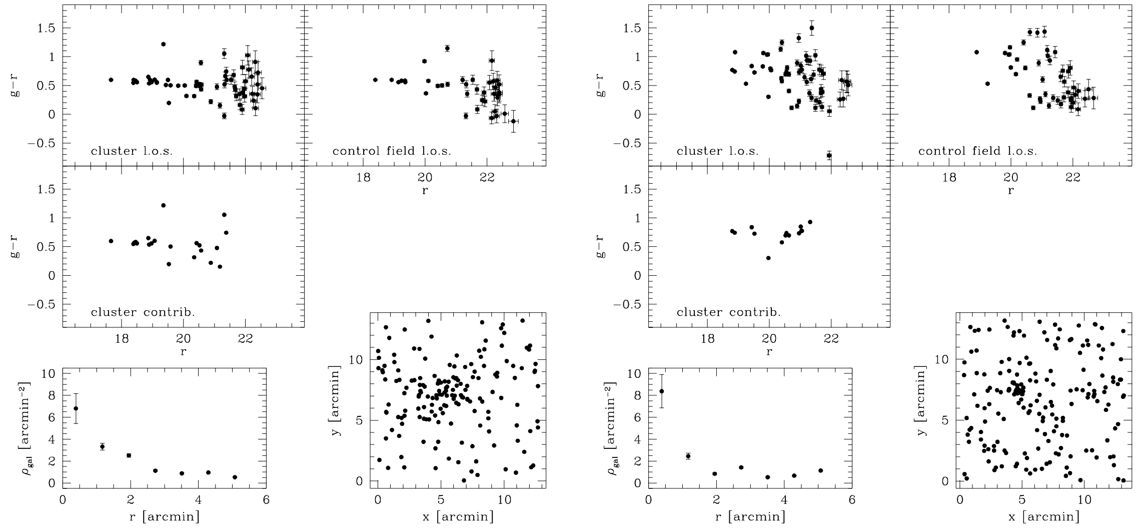

Figure 4: Colour - magnitude diagram for the candidate cluster obtained accordingly to the procedure described in the text. Right (good candidate): the cluster turns out to be of richness class I and to be at $z = 0.10 - 0.12$. Left (bad candidate): the cluste r turns out to be of richness class I and to be at $z = 0.26 - 0.3$.

4.3 Photometric validation

As stressed above, DPOSS data are calibrated via independent CCD frames taken at various telescopes in the $1 - 2m$ range. This means that we have at our disposal a large number of deep fields, where galaxy photometric properties can be measured with high photometric accuracy. In the last two years we selected calibration fields in order to obtain a wide overlap with our sample of candidate clusters. These data were used to derive colour - magnitude diagrams.
For calibrating CCD frames taken in the g, r and i Gunn-Thuan system, we use S-Extractor with which we can identify galaxies and derive the colour-magnitude diagram (r vs. g-r) either for the candidate cluster region and for a well selected test field (background). Then we statistically subtract the field contamination and identify cluster members.
The existence of an excess of galaxies in the putative cluster line of sight and the fact that they obey to the usual colour-magnitude relation is taken as confirmation of the existence of the putative cluster.
These galaxies are then used to build the cluster radial profile. The colour-magnitude diagram also allows to derive a rough photometric redshift (which, due to the band broadness, has however a rather large error).
Preliminary results confirm that for $z << 0.15$ the candidate clusters found by our algorithm are 95% "true" clusters. At higher redshift ($0.15 < z < 0.2$) this fraction drops to 70%(Figure 4).

5 The multiplicity function

In Figure 5 we show the multiplicity function obtained from 13 DPOSS plates (subtending a total solid angle of $483deg^2$) compared to six other MFs taken from the literature:

1. **MF derived from magnitude limited surveys making use of redshift information:** Garcia [3], CfA [4], NorthCfA [10], ESP [11];
2. **MF derived from diameter limited survey:** Maia [6];
3. **MF derived from limited magnitude survey without redshift information:** Turner [14].

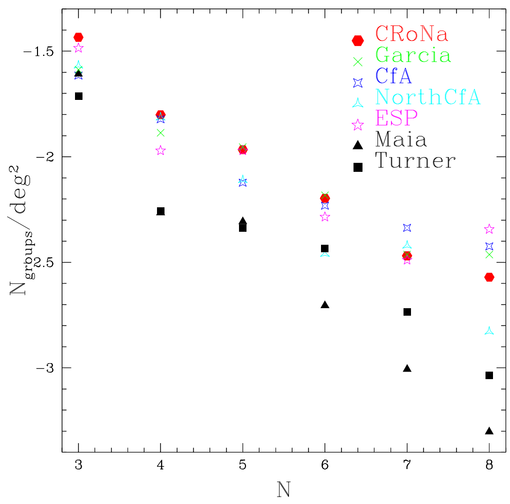

Figure 5: Comparison of our MF against those derived by other authors

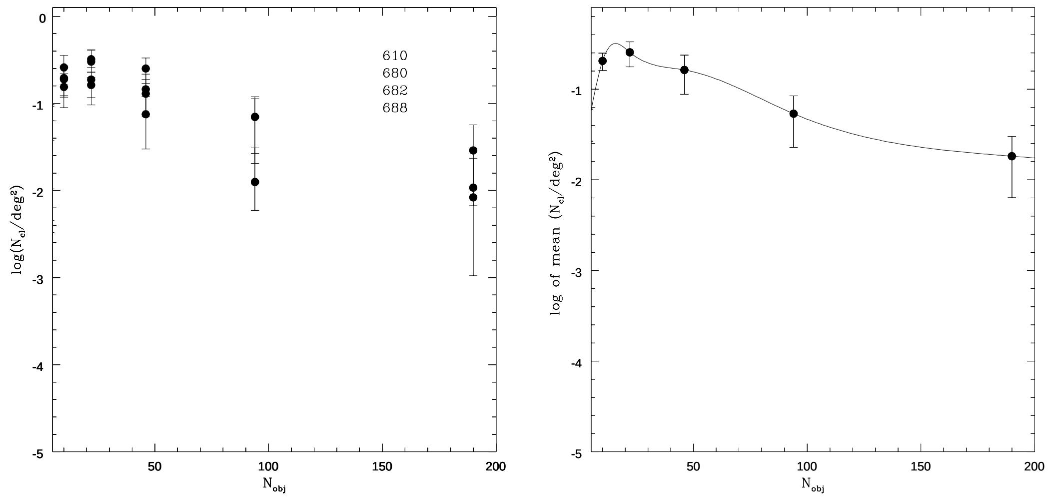

Figure 6: *Left panel*: example of four MFs derived for some of the DPOSS fields. *Right panel*: average MF derived from 20 fields and used for the simulation.

As it can be clearly seen, the MF derived by applying our method to DPOSS material is at 98% confidence level indistinguishable from the MF in literature obtained from redshift surveys. Therefore, with our algorithm, even in absence of redshift information, it is possible to explore wide areas of the sky and to retrieve grou ps ($N > 2$) with an efficiency comparable to that of 3-D surveys.

In Figure 5 we show a preliminary plot of the multiplicity function ranging from small groups to rich clusters obtained for 20 DPOSS fields.

6 Future work

We plan to improve the simulation by adding non-circular symmetry for the simulated clusters, to study the dependence on the zero-order correlation functions and to apply the colour-magnitude diagram test to all clusters available in our calibration data set.

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