Groups and clusters detection on DPOSS catalogs

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Abstract. We discuss the implementation and validation of a procedure aimed to detect groups and clusters of galaxies in DPOSS catalogs.

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 $g$) and the availability of three colours (J, F and N).

In this poster we discuss a first application, on a small part of the whole data set, of a newly implemented procedure to search for candidate galaxy clusters and groups. Final goal of this project is a 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 $\rho_M$, then the function of the mass distribution doesn’t depend on the cosmic density parameter $\Omega$ but only on the spectrum index $n$ (Gott & Turner 1977). 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 cata-
logue of groups of galaxies identified for a given $k$, gives a measure of the initial spectrum index $n$.

2. Detection of candidate groups

Even though on rather arbitrary ground, we define as a group all galaxy ensembles having less than 15 members having total magnitude within 3 magnitudes from that of the brightest members. The implemented procedure is described in detail in De Filippis (1999).

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 (Soares D.S.L. 1989). This algorithm makes use of apparent magnitudes and projected positions 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 $\Theta$ 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 $x$ allows to combine the angular separation of different pairs to a single distribution removing the effects of clustering in the background.

3. Detection of candidate clusters

Starting points 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 then matched (assuming a maximum matching distance of 7″, for details see Puddu et al. 1999).

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″ to produce a density map. Then, S-Extractor (Bertin & Arnouts 1996) is run in order to identify and extract all the overdensities having number density $2\sigma$ above the mean background and covering a minimum detecting area of 4 pixels ($4.8^\prime\prime$ sq.). In this way, as in the Schectman (1985) approach, we are not assuming any a priori cluster model. An application to the DPOSS field 610 is shown in Figure 1.

All the previously known Abell and Zwicky clusters are recovered and many new candidates 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.
Figure 1. Results for DPOSS field n. 610 (1°, +15°). Circles mark the position of detected candidate clusters while squares mark already known Abell and Zwicky 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 et al. 1995; then we added groups of galaxies according to the multiplicity function by Turner E.L. & Gott J.R. 1976, with redshift computed according to:

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

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

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

where $M^* = -20.85$ and $a = -0.83 - +0.17$. Other parameters varied in the course of the simulations were: i) the diameter of the group inside a gaussian distribution centered 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 at $p = 0.6$. 
In Figure 2 we show the multiplicity function obtained from 12 DPOSS plates (covering a total solid angle of 483\,deg$^2$) compared to six other MFs taken from the literature: MF derived from magnitude limited surveys making use of redshift information, the CfA survey (Geller & Huchra 1983; Garcia et al. 1993; Ramella & Pisani 1997; Ramella et al. 1998), MF derived from diameter limited survey (Maia & Da Costa 1989) and MF derived from limited magnitude survey without redshift informations (Turner & Gott 1976). As it can be clearly seen, the MF derived by applying our method to DPOSS material is at 98\% confidence level undistinguishable from literature MF obtained from redshift surveys.

4.2. Cluster algorithm validation

We took two different approaches: through simulation and through magnitude - color diagrams. In order to produce realistic simulations we followed a rather lengthy procedure. First of all, we needed a fairly 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 (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 centers and 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 centers randomly selecting a radius in the range $[2 - 3]$ Mpc and weighting the number of members accordingly to the above derived
MF. Absolute magnitudes for galaxies are then extracted from 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 \([0.15, 0.2]\).

### 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 largely overlap with our candidate clusters sample. These data were used to derive color-magnitude diagrams.

To calibrate the CCD frames taken in the \( g, r \) and \( i \) Gunn–Thuan system, we use S-Extractor to identify galaxies and derive the colour-magnitude diagram \((r \text{ vs. } g - r)\) for the candidate cluster region and for a test field (background) well selected. Then we statistically subtract the field contamination and identify the excess of galaxies as 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 allows also to derive a rough photometric redshift (which, due to the broad band, 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%.

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

### References

- Bertin, E., Arnouts, S. 1996, A&AS, 117, 393
- De Filippis, E., Longo, G., Andreon, S., et al. 1999, MmSAI, in press [astro-ph/9909368](http://arxiv.org/abs/astro-ph/9909368)
- Garcia, A.M. 1993, A&AS, 100, 47
- Geller, M.J., Huchra, J.P. 1983, ApJS, 52, 61
- Gott J.R., Turner E.L. 1977, ApJ216, 357
- Maia, M.A.G., Da Costa, L.N. 1989, ApJS, 69, 809
- Maia, M.A.G., Da Costa, L.N. 1990, ApJ, 352, 457
- Metcalfe, N., Shanks, T., Fong, R., Roche, N. 1995, MNRAS, 273, 257
- Puddu, E., et al. 1999, MmSAI, in press [astro-ph/9909367](http://arxiv.org/abs/astro-ph/9909367)
- Schectman, S.A. 1985, ApJS, 57, 77
Figure 3. Color - magnitude diagram for the candidate cluster obtained accordingly to the procedure described in the text. Right (high S/N candidate): the cluster turns out to be of richness class I and to be at $z = 0.10 - 0.12$. Left (low S/N candidate): the cluster turns out to be of richness class I and to be at $z = 0.26 - 0.3$.

Soares, D.S.L. 1989, PhD Thesis
Turner E.L., Gott J.R. 1976, ApJS, 32, 409
Weir, N., Fayyad, U.M., Djorgovski, S.G., Roden J. 1995, PASP, 107, 1243