

A Catalogue of Galaxy Clusters and Groups Based on the Muenster Red Sky Survey

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Abstract

We present a catalogue of galaxy structures (groups and clusters) found in an area of 5,000 square degrees in the southern hemisphere. The catalogue, which we call the PF CATALOGUE, was created by making use of galaxy positions and magnitudes given in the Muenster Red Sky Survey (MRSS). We applied an automated procedure for structure finding, involving the Voronoi tessellation. The completeness limit for galaxies in the MRSS is $r_F = 18^m3$. Therefore, the present version of the PF CATALOGUE is based on galaxies brighter than this limit. In order to be included in the PF CATALOGUE, a structure must have at least 10 members in a magnitude range $m_3, m_3 + 3^m$. We found 6188 structures which are listed in the present catalogue.

The PF CATALOGUE contains positions, radii, areas, number of galaxies within the magnitude limit $m_3, m_3 + 3^m$, a number estimation of background galaxies; ellipticity and position angle for each structure, as well as the magnitudes of the first, the third and the tenth galaxies in a structure, taken from the MRSS.

Keywords: galaxy clusters, catalogues

1 Introduction

Our scientific goal consists in the study of properties of a large sample of galaxy structures. In order to perform such a study, we need a sample of galaxy clusters

extracted in a uniform manner from a homogeneous set of data. Present-day astronomy requires (and also provides) large numbers of data. The rapid development of observational techniques permits to study high redshift objects. The properties of these high-redshift objects can be compared with medium and low-redshift structures. Such a comparison might allow us to distinguish between primordial and evolutionary effects in structures, thereby shedding more light on the origin and evolution of structure.

It was our aim to study the properties of *nearby* structures obtained from homogeneous data in uniform manner. The Muenster Red Sky Survey (MRSS hereafter) is such a homogeneous galaxy sample, since the application of an automated procedure gives a statistically uniform sample. This sample constitutes the observational basis for our study of structure properties. We would like to point out that the MRSS covers a larger sky region than the APM, and that it is made in red light. A comparison with APM constructed in totally independent manner can give some additional information, too.

The present paper is organized in the following manner: In section 2, we shortly describe the properties of the MRSS and the method of structure search. Section 3 contains the description of the PF CATALOGUE of structures. In section 4, some results are discussed.

2 Observational data and method of catalogue creation

The MRSS galaxy catalogue is the result of a large-scale galaxy survey in the red spectral region, covering an area of 5,000 square degrees. Together with the APM catalogue (4,300 square degrees) in the blue spectral region, the MRSS catalogue forms at present one of the largest coherent data base for cosmological investigations in the southern hemisphere (Unguru et al. 2003).

217 ESO Southern Sky Atlas R Schmidt plates with galactic latitudes $b < -45^\circ$ were digitized with the two PDS microdensitometers of the Astronomisches Institut at Muenster. The classification of objects into stars, galaxies and perturbed objects was done with an automatic procedure with a posterior visual check of the automatic classification. The external calibration of the photographic magnitudes was carried out by means of CCD sequences obtained with three telescopes in Chile and South Africa. The MRSS contains positions, red magnitudes, radii, ellipticities and position angles of about 5.5 million galaxies and it is complete down to $r_F = 18^m.3$.

We selected the Voronoi tessellation technique (VTT hereafter: Voronoi 1908) for cluster detection (Panko & Flin, 2004). Icke and van de Weygaert (1987), Ebeling & Wiedenmann (1993), Ramella et al. (1999, 2001), Marinoni et al. (2002), Neyrinck et al. (2005) discussed the application of VTT for cluster search. The more formally defined Delaunay–Voronoi tessellation was presented by Schaap & van de Weygaert (2000). This technique is completely non-parametric, and therefore sensitive to both symmetric and elongated clusters, allowing correct studies of non-spherically symmetric structures. Moreover it is a correct cluster finding algo-

rithm when galaxy background is nonuniform (Kim et al. 2002). For a distribution of seeds, the VTT creates polygonal cells containing one seed each and enclosing the whole area closest to the seed. This is the definition of a Voronoi cell in 2D. This natural partitioning of space by the VTT has been used to model the large-scale distribution of galaxies. Galaxy positions are input as the seeds for the 2D Voronoi tessellation, and the Voronoi cell around each galaxy is interpreted as the effective area that each galaxy occupies in the projection plane. The inverse values of these areas yield local densities for each galaxy position. This information is then used to define the threshold and to select galaxies that live in highly overdense regions, which we identify as clusters. This search was made using the procedure **kiang**, the corn of the VGCF (Voronoi Galaxy Cluster Finder), an automatic package for the identification of galaxy clusters in two-dimensional galaxy catalogues (Ramella et al. 1999)

As input information, we used fragments of the MRSS. Each fragment had a size of 4° in Dec. and from 0^h35 to 1^h0 in R.A. (depending on declination), with a 0.5° overlap between fragments. As a result, we obtained the coordinates of the centre of the each overdense region, the number of galaxies in the region, the estimated number of background galaxies (both before and after fitting), and the area of the structure. At the first step of investigation we checked the validity of the application of the VTT on a small portion of the MRSS (Panko and Flin, 2004). We also determined the optimal input parameters for cluster searches in MRSS (Panko & Flin, in press). They are the “confidence level for the overdensity selection” and “confidence level for fluctuations rejection”. Our values of these parameters (0.8 and 0.95) agree completely with default values as given by Ramella et al. (2001).

The VTT permits to extract structures with different numbers of galaxies and various shapes within the same statistical approach. In order to establish the reliability of our Catalogue of Galaxy Clusters, we compared the position of our objects with those of ACO clusters (Abell, Corwin & Olowin, 1989), and find good agreement for rich structures (Panko & Flin, 2006a,b).

For each structure in our catalogue, further analysis was carried out individually. The structures with at least 10 galaxies in the considered area were included to our catalogue. For galaxies in brightness lying inside the magnitude limits m_3 , $m_3 + 3^m$, calculations were carried out. For each structure, the covariance ellipse was inscribed, considering only galaxies above the mentioned magnitude limit. This allows us to determine the ellipticity and the position angle of the structure.

This was done in a standard way. We calculated the tangential coordinates x , y (in arcsec) for galaxies located in each field containing structure in standard manner. Using the above-mentioned magnitude limit m_3 , $m_3 + 3^m$ and these rectangular coordinates, we determined the coordinates of the structure barycenter $\bar{x}$, $\bar{y}$, as

$$\bar{x} = \frac{\sum x}{N_m} \quad (1)$$

$$\bar{y} = \frac{\sum y}{N_m} \quad (2)$$

where N_m is the number of considered galaxies.
 $\overline{x^2}$, $\overline{y^2}$ and $\overline{xy}$ were calculated as:

$$\overline{x^2} = \frac{\sum (x - \bar{x})^2}{N_m} \quad (3)$$

$$\overline{y^2} = \frac{\sum (y - \bar{y})^2}{N_m} \quad (4)$$

$$\overline{xy} = \frac{\sum (x - \bar{x})(y - \bar{y})}{N_m} \quad (5)$$

The semiaxes in arcsec for the best-fitting ellipse were calculated from:

$$a^2 = \frac{\overline{x^2} + \overline{y^2}}{2} + \sqrt{\left(\frac{\overline{x^2} - \overline{y^2}}{2}\right)^2 + (\overline{xy})^2} \quad (6)$$

$$b^2 = \frac{\overline{x^2} + \overline{y^2}}{2} - \sqrt{\left(\frac{\overline{x^2} - \overline{y^2}}{2}\right)^2 + (\overline{xy})^2} \quad (7)$$

The ellipticity parameter which directly derived from a and b :

$$E = 1 - \frac{b}{a} \quad (8)$$

The position angle θ of the object was calculated as:

$$\tan 2\theta = 2 \frac{\overline{xy}}{\overline{x^2} - \overline{y^2}}. \quad (9)$$

Some additional parameters were calculated using the galaxy parameters from MRSS.

The PF CATALOGUE presented here (ASCII file `pfcatal.dat`) is based on the statistically complete basic galaxy catalogue MRSS, having a magnitude limit of $r_F = 18^m.3$. We prepared also two other versions of the catalogue. In both cases all procedures of structure finding was done independently. In the first one, all MRSS galaxies were considered. In this case, we find more than 15,000 structures. However, in this case the differences between limiting magnitudes of ESO neighbouring plates is clearly seen. Restricting the limiting magnitude of the considered galaxies to $r_F = 19^m.3$, these differences vanish; the application of the whole procedure gives almost 12,000 structures. We hope that these two versions can be useful for some studies too.

3 Description of the catalogue

We found 6188 structures. As an example, the first page of the PF Catalogue is given below as Table 1. The consecutive columns of the Table contain the following information:

Ident	structure identification, based on the first digits of R.A. and Dec.
R.A., Dec.	Right Ascension and Declination for 2000.0
R	equivalent radius in arcseconds for full area of structure
S	the area of structure in square arcseconds
N	the number of all galaxies in the field of structure
N_m	the number of galaxies in the field of structure within the magnitude limit m_3 , $m_3 + 3^m$
n_{bg}	estimated number of background galaxies
a, b	major and minor semiaxes of the fitted ellipse
E	ellipticity of the structure
PA	the position angle of the major semimajor axis of structure. The angle is counted clockwise from direction to the North Pole, same as the PA for galaxies in the MRSS catalogue
m_1, m_3, m_{10}	magnitudes of the brightest, the third-brightest and the tenth-brightest galaxy as given in MRSS
PA1	the position angle of the brightest galaxy major axis (from MRSS)
E_m	average mean ellipticity for galaxies (calculated from MRSS data)
PA $_m$	mean position angle of galaxies in structure (calculated from MRSS data)

4 Discussion

The radii of detected structures range from 102 to 2493 arc seconds. The density of galaxies in fields with detected structures varies from 163 to 5153 galaxies per square arc minute.

The richest cluster has 837 members in the considered magnitude range $m_3 - m_3 + 3^m$. 410 have ≥ 100 members; they are rich clusters. 1655 structures have ≥ 50 members in a similar magnitude range; we can designate them as clusters.

It is interesting to note that the distribution of all clusters and rich clusters exhibits a similar behavior. In the projection on the celestial sphere, they follow the same pattern, long filaments and empty regions. This can be very well seen in the distribution of rich structures (Fig. 1, lower panel)

About 100 structures need a more detailed analysis, because the number of galaxies within the considered magnitude limit and the number of background galaxies are similar. The histogram presenting the number of structures with a given number of galaxies in the structure is shown in Fig. 2, and the distribution of structure ellipticities is presented in Fig. 3.

Table 1: Structure of the PF CATALOGUE.

Ident	R.A.	Dec.	R	S PA	N m_1	N_m m_3	n_{bg} m_{10}	a PA1	b E_m	E PA_m
0000-3612	0.0003655	-36.119448	248	84382 45.8	14 15.39	14 17.09	4 17.88	241 97.1	176 0.37	0.27 56.3
0000-3045	0.0015391	-30.447226	776	739940 42.4	63 15.35	63 16.38	35 17.13	841 53.5	655 0.33	0.22 78.4
0000-6650	0.0022222	-66.499423	744	1294000 71.1	50 14.14	50 15.88	25 16.63	747 81.8	568 0.34	0.24 100.9
0000-7209	0.0022401	-72.080531	622	516900 179.8	28 15.95	28 16.87	15 17.43	646 6.8	402 0.31	0.38 72.6
0000-2521	0.0039350	-25.201199	749	1112300 28.6	80 15.17	80 15.94	34 16.27	676 0.0	548 0.29	0.19 95.2
0000-5700	0.0044515	-56.995964	416	191060 61.6	22 16.50	22 16.81	9 17.38	438 153.4	27 0.27	0.38 97.0
0000-3746	0.0046668	-37.456856	396	341670 151.2	25 15.87	25 16.33	11 17.14	394 90.9	271 0.33	0.31 75.1
0000-3946	0.0062652	-39.451021	881	2191400 18.2	89 14.74	89 15.75	43 16.45	912 56.2	705 0.30	0.23 92.3
0000-4738	0.0077480	-47.370013	797	1190100 32.6	88 13.88	56 14.81	38 16.26	706 23.7	630 0.33	0.11 73.3

5 Conclusions

The PF CATALOGUE of galaxy structures covering an area of 5,000 square degrees on the southern sky was constructed using MRSS as an observational basis. Input data were restricted to the statistical uniformity and completeness of the MRSS, this is to the magnitude limit $r_F = 18^m3$. So, the presented version of the PF CATALOGUE is statistically complete sample of structures, which allows one to perform reliable statistical investigations. Even from the data in the PF CATALOGUE is clear that structure ellipticities and alignment will be first target of our investigation. The second one will be luminosity function.

We applied the Voronoi tessellation for structure finding. This is a powerful and convenient manner of structure finding. Therefore, we agree with Icke's (2006) claim on the correctness of this technique. Our experience allows us to conclude that at the present stage of software development it is impossible to construct structure catalogue in a totally complete automatic manner. In software there are parameters, whose values have to be established experimentally by the observer. Moreover, the lower limit of the member objects included into structure is also decided by the observer. Some other points must also be solved by the human, not by the machine. Such very important points in catalogue preparation as reliability, speed and repeatability are the main advantages of the applied techniques.

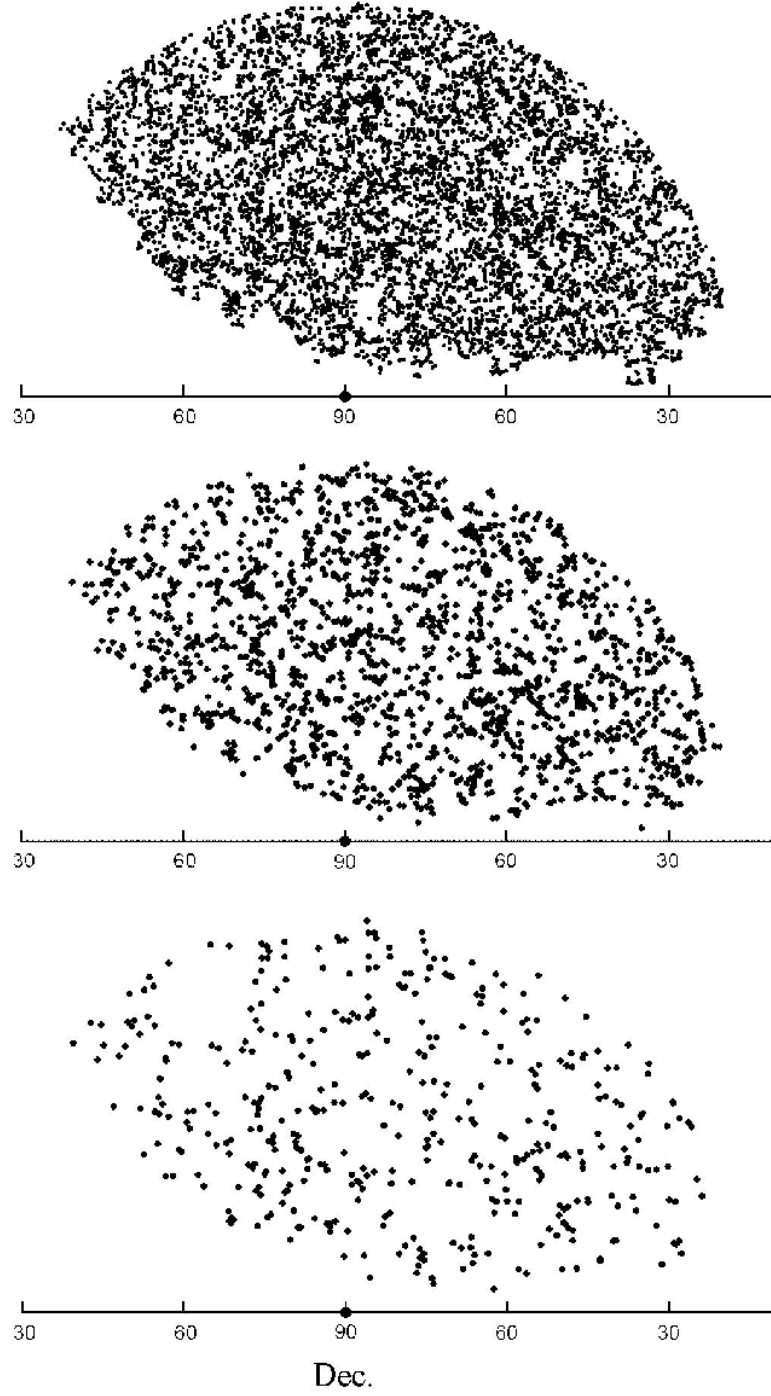


Figure 1: Location of all structures (top), structures with ≥ 50 members (middle), and galaxy clusters with at least 100 members (bottom) on the celestial sphere.

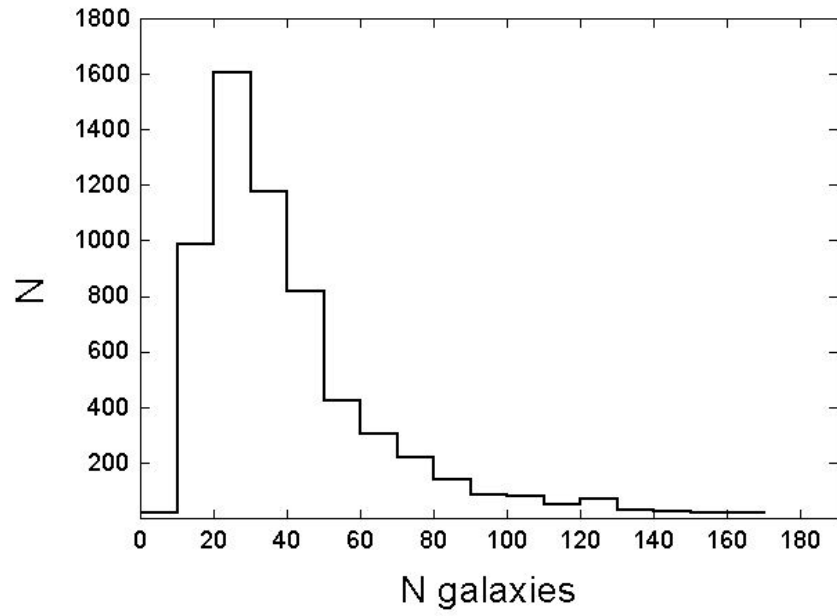


Figure 2: Histogram of number of structures with given number of member galaxies.

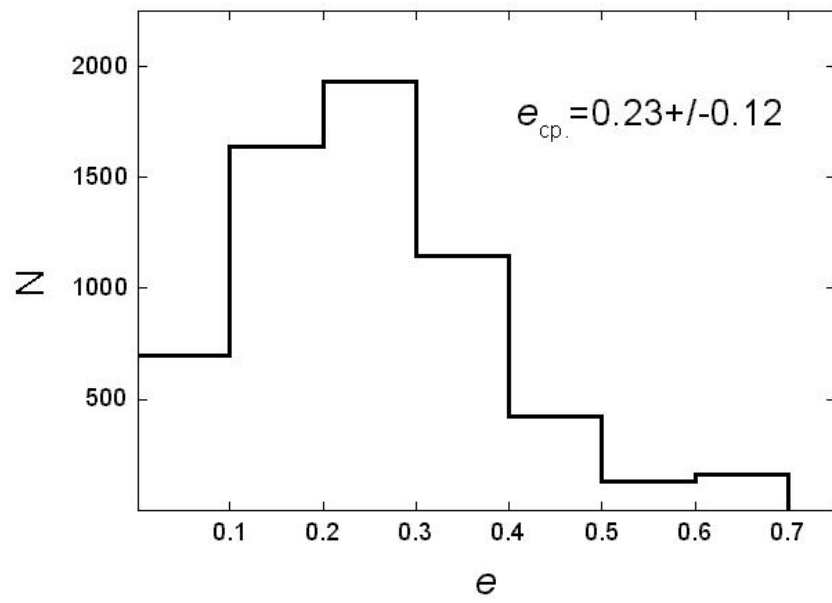


Figure 3: The distribution of structure ellipticities.

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