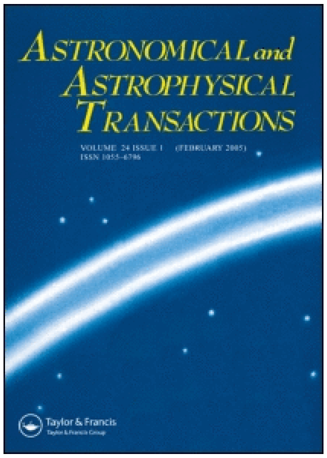

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THE DENSITY PROFILES OF 18 GALAXY CLUSTERS

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The surface number density profiles were determined for 18 galaxy clusters, counting galaxies in circular and elliptical rings. The King formula was fitted to the profiles. The χ^2-test shows that better fits are given for the elliptical than circular rings. Moreover, some secondary maxima observed for circular profiles disappeared in elliptical counts. The secondary maxima on density profiles are mainly due to subclustering inside clusters.

KEY WORDS Galaxy clusters, density profiles

1 INTRODUCTION

The study of the number density profiles in galaxy clusters has a long history. From the pioneering time of Zwicky (1937, 1957) various functions were fitted to the observed surface galaxy distribution in rich clusters. The majority of these functions well-describe the projected distribution of a bound isothermal gas sphere.

The previous investigations concerned the shape of the fitting function and discussion of the invariability of structural parameters obtained from fits (see e.g. Bahcall, 1977; Beers and Tonry, 1986; Quintana, 1979; Sarazin, 1988; Semeniuk, 1983). Presently, the number of clusters with known radial velocities of member galaxies is growing rapidly. Nevertheless, the study of projected distributions, without the knowledge of radial velocities, can lead to some interesting results. It is possible that some memory of the cosmological initial conditions survived in clusters, the subsequent evolution partially wiping out memory. Therefore analysis of large numbers of clusters should reveal some information on the origin and evolution of large-scale structures. West, Dekel and Oemler (1987) and West, Oemler and Dekel (1989) compared observed profiles of galaxy clusters with those coming from numerical simulations for testing scenarios of large-scale origin.

Due to the importance of the properties of density profiles for the determination of various parameters, which serve for making constraints for important questions

Table 1. Observational data

Name	*Type*	*z*	*N*
A14	C	0.0640	629
A85	cD	0.0518	643
A119	C	0.0440	200
A133	cD	0.0604	470
A151	cD	0.0526	226
A194	L	0.0178	159
A261	cD	0.0467	519
A279	cD	0.0797	515
A358	C	0.0576	224
A496	cD	0.0320	604
A644	cD	0.0704	1376
A754	cD	0.0528	329
A978	F	0.0527	518
A1139	I	0.0383	239
A1650	cD	0.0845	738
A1651	cD	0.0825	1140
A1837	cD	0.0376	734
A2670	cD	0.0745	836

such as scenarios of large-scale structure origin, structure evolution and the problem of the existence of non-baryonic dark matter, all factors influencing the shape of density profiles should be carefully checked.

It is well known that in the brightness profile of a galaxy cluster the secondary maximum can be observed (e.g. Sharov, 1960; Oemler, 1974). Its occurrence can be attributed to evolutionary processes in galaxy clusters (see e.g. Trevese and Vignato, 1982) or regarded as remnants of the primordial density perturbations (Occhionero, Vignato and Vittorio, 1978). Gerbal and Salvador-Sole (1980) concluded that this is a temporary phenomenon resulting from condensation of a spherical, with pressure, perturbation, embedded in supercluster. Oemler (1974) and Hickson (1977) linked the existence of this phenomenon with the general properties of the galaxy cluster. On the other hand, the observed non-monotonic decrease of number density with increasing radius can be due to the departure of assumed spherical symmetry of the clusters, as well as the existence of substructures in galaxy clusters (Flin, 1984).

The conclusion of Flin's paper, based on Dressler's data (1980) coming from visual inspection of photographic plates, should be confirmed using modern data from automatically and objectively made data reduction. This motivated the present study.

2 OBSERVATIONAL DATA

Automatic scans of 48-inch Schmidt photographic plates using the COSMOS machine were performed by one of us (HTM) at the Royal Observatory, Edinburgh.

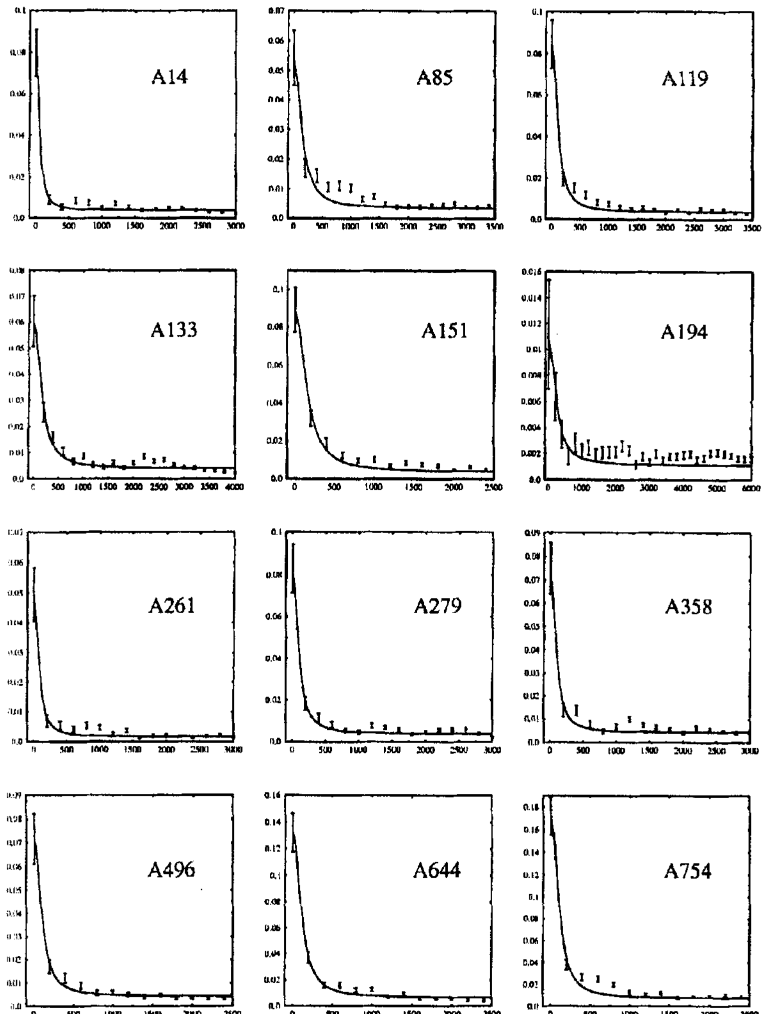

Figure 1 Density profiles based on counts in circular rings; error bars correspond to three standard deviations.

This procedure gives catalogues of galaxies in square regions containing 18 rich galaxy clusters (Abell, Corwin, Olowin, 1989). The catalogue is complete to almost $20^{\mathrm{m}}.0$. In order to extract galaxy cluster from the general field, we considered galaxies within the magnitude range m_3, $m_3 + 3^m$, where m_3 is the magnitude of the third brightest galaxy in the cluster region. The value of the Abell diameter is equal to 3 Mpc. The resulting catalogue was compared with the images obtained from the Digitized Sky Survey, which introduced some small corrections to the final catalogue used for further studies. Table 1 presents data of investigated clusters taken from Strubble and Rood (1982, 1987). The columns in Table 1 are: cluster number, morphological type, redshift and total number of galaxies in the field N in

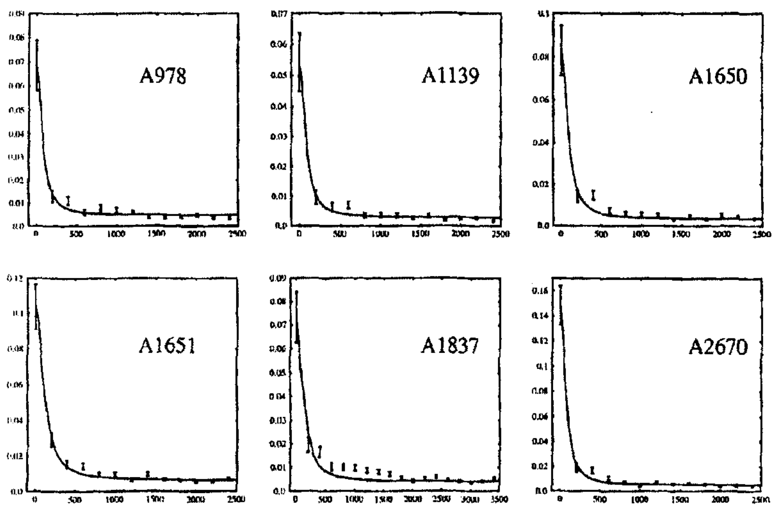

Figure 1 Continued.

the considered magnitude range, respectively.

3 DETERMINATION OF RADIAL PROFILES

The coordinates (in arcsec) of galaxies in the investigated field permitted us to construct a density map. This was done using the methods of Trevese *et al.* (1992). The local surface density $\sigma(x,y)$ at each point is calculated as:

$$\sigma(x,y) = C/R_n^2. \tag{1}$$

The constant C is determined from the condition:

$$\int \sigma(x,y)\,dx\,dy = N$$

where integration is taken over the considered area and R_n is the distance from the given point (x,y) to the nth neighbouring galaxy. We use $n = 10$ throughout this paper.

The maximum of the surface galaxy density on the isodensity map was accepted as the cluster centre. From the centre the counts in circular rings were made and the surface density as a function of the radius r from the cluster centre was calculated (Figure 1). The King formula:

$$\sigma(r) = \sigma_0(1 + r^2/R_C^2)^{-1} + b \tag{2}$$

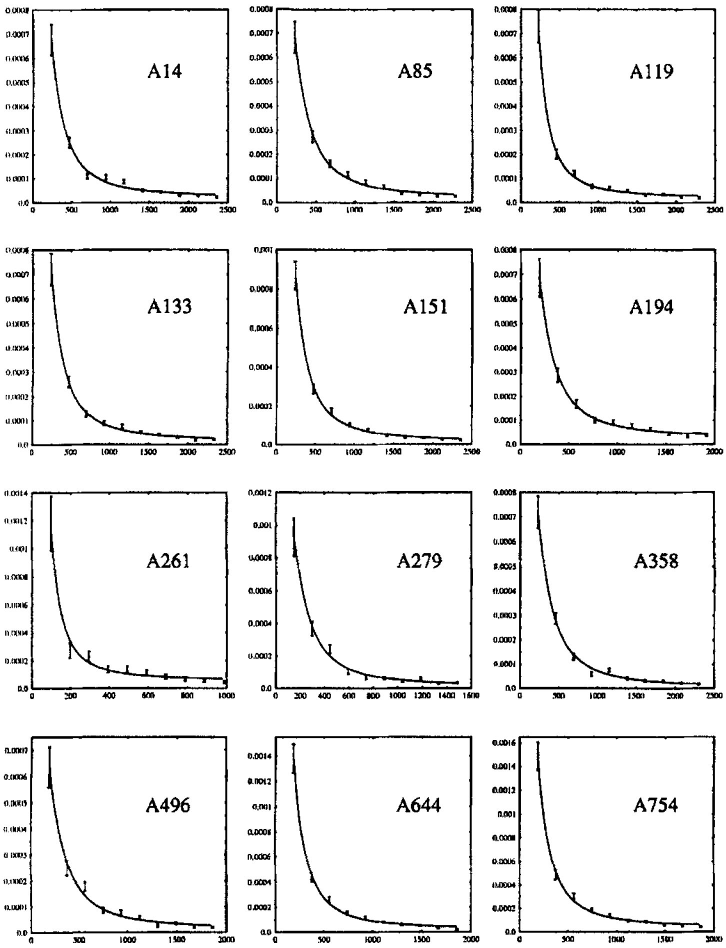

Figure 2 Density profiles based on counts in elliptical rings, error bars correspond to 3 standard deviations.

was fitted to the profile. The goodness of fit was checked using the χ^2-test, similarly to Semeniuk (1983).

This procedure allows one to determine the structural parameters: σ_0 – the central surface density, the core radius R_C and the density of the background b. Moreover, we obtain the values estimating goodness of fit.

In the second step of the present investigation, accepting the previously determined cluster centre and drawing a circle having 3 Mpc diameter, the covariance ellipse was also calculated and the counts in elliptical rings were carried out (Figure 2). The King formula (2) was fitted to the new surface density profile too. The

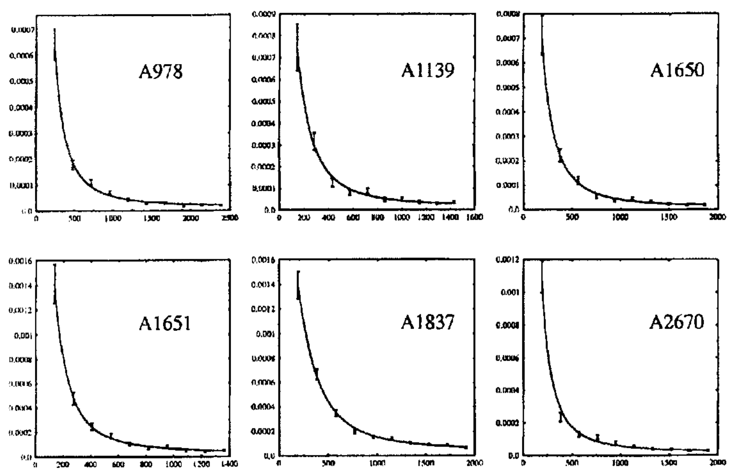

Figure 2 Continued.

χ^2-test, as previously, served as a test of the goodness of fit. In all cases the King formula (2) described better counts in elliptical rings than counts in circular ones. Moreover, often the secondary minimum on the brightness profiles disappeared, as can be seen in, e.g., A85 and A133.

Afterwards the distance between the cluster centre and the secondary maximum was calculated. The search of substructures with distance was made on density maps. Density enhancement at an adequate distance from the cluster centre was considered as a reason for the secondary peak as, e.g., A358 (Figure 3).

In all but one cases it was possible to find the density enhancement on the isopleth map responsible for the existence of the secondary maximum. Figure 3 also presents the case A978 when it was impossible to ascribed the secondary peak to the density enhancement inside the cluster. It should be stressed that some of these substructures are small. This conclusion came from the study of the existence of substructures in these clusters.

It is well known that there are different methods of determination of the parameter called the cluster centre (see e.g. Trevese *et al.*, 1992). We investigated the influence of the width of the circular ring, in which the counts are made, on the result as well as the number of considered galaxies, to the structural parameters (Baier *et al.*, 1994). The resulting structural parameters σ_0, R_c, b strongly depend on these factor.

4 SUBSTRUCTURES IN THE INVESTIGATED CLUSTERS

In order to study the existence of substructures in the investigated clusters two methods proposed by West, Oemler and Dekel (1988) were applied (Krywult, 1997).

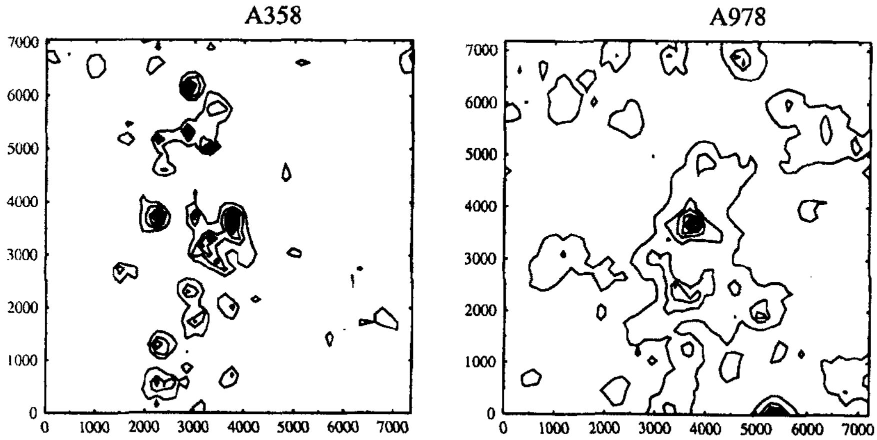

Figure 3 Surface density maps.

The main result from these studies is that various statistical tests give different results. This means that according to one test there is a substructure in a cluster, whilst according to another there is none. For the present studies the most important fact is that small, undetected galaxy groups cause the secondary maxima. But it is not true that each cluster with even strong subclustering has a density profile with a secondary maximum; e.g. cluster A754 shows several substructures, while the profile based on counts in ellipses is quite smooth, as noted previously (Baier *et al.*, 1994).

5 CONCLUSIONS

We have shown that the density profile strongly depends on the assumed shape of the counting rings. The structural parameters derived from the fit are sensitive both to the adopted cluster centre and width of the counting ring. Moreover, the number of galaxies considered as cluster members also influence the result.

The existence of the secondary maxima can be explained by the assumed spherical symmetry of the galactic distribution. Departure from this assumption dissolved the majority of the secondary maxima. But the profiles derived from counts in elliptical rings sometime also exhibit secondary peaks. This is usually due to small aggregations of galaxies inside clusters. These substructures are too small to be detected through the application of these statistical tests. On the other hand there are examples of density profiles, when the secondary maximum is due to neither substructure nor the assumed cluster shape. However, it should be remembered that the description of the cluster shape as spherical or elliptical is approximate (Peach, 1984; Flin, 1984). The true cluster shape is more complicated. The more frequent occurrence of secondary peaks claimed in a particular cluster morphological type can be due to the more frequent appearance of subclustering in these types.

Galaxy clusters, even in projection on the celestial sphere, as shown by numerical simulations, are good tools for studying the origin and evolution of large-scale structures.

The further investigation of the projected number density profiles should be made on a much larger sample of galaxy clusters, a sample not so strongly biased toward BM type I as in the present study. The density profiles should be constructed using unbinned data, as proposed by Hickson (1977) and Sarazin (1980). Also methods appropriate for detection of small concentrations of galaxies should be applied. It looks like when the region of an investigated cluster is determined which is our case, the wavelet analysis (Escalera *et al.*, 1994) allowing one to detect the small density enhancements could be a useful tool.

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