Clusters of Galaxies in the 2dF Galaxy Redshift Survey*

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Abstract. The 2dF Galaxy Redshift Survey has obtained 135,000 redshifts for galaxies in two broad strips. Here we present the first results of a 3-dimensional search for galaxy clusters based on known 2-dimensional compilations. We derive new redshifts and velocity dispersions for clusters, assess the level of contamination in the sample, analyze the accuracy of photometric redshift estimates and study the space distribution of clusters.

1 Introduction

It has long been known that the distribution of galaxies is not homogeneous over scales of at least 200 h^{-1} Mpc; the first redshift surveys revealed an intricate pattern of filaments, voids and walls (e.g., Da Costa 1999) and showed that samples of the order of 10^5 galaxies were needed to reach the scale of homogeneity and derive cosmologically useful quantities from analysis of the 3-dimensional distribution of galaxies. The 2dF Galaxy Redshift Survey (e.g., Colless 1999) is the first of the new generation of surveys to be able to obtain such samples with reasonable efficiency. Among papers being published by the 2dFGRS Team it is worth mentioning: the b band type-selected luminosity function (Folkes et al. 1999), the K-band luminosity function from 2MASS photometry (Cole et al. 2000), the bivariate brightness distribution (Cross et al. 2000), an accurate estimate of the β parameter (Peacock et al. 2000) and Principal Component Analysis of galaxy populations (Madgwick et al., this volume and 2000).

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Clusters of galaxies are the largest bound structures in the observable universe and the only ones that can be observed and identified to cosmologically significant redshifts. The mass distribution of clusters yields limits to the cosmological density parameter; for instance, the standard Cold Dark Matter (CDM) model, normalized to the COBE data, yields cluster densities in excess of observations by an order of magnitude and this provided the first hint of an open universe model.

However, most studies of clusters are still based on photographic catalogs, such as those of Abell and collaborators (1958; 1989), or the APM (Dalton et al. 1992) or Edinburgh-Durham (Collins et al. 1995). Once the 2dF survey is complete, it will be possible to determine a catalog of groups of galaxies on scales extending from compact groups to giant clusters, using 3-dimensional selection algorithms. While this is not easily done at this stage, it is possible to consider clusters selected from 2-dimensional catalogs in 3-dimensional space and assess their reality and level of contamination, derive their space density and study the properties of their members. In turn, this will allow us to 'define' a cluster for later 3-dimensional searches, matching the properties of known template objects.

2 Selection of Clusters

We have used known cluster catalogs and matched the cluster centroid and search radii to the 2dF redshift catalogs. The procedure we followed is described in detail in De Propris et al. (2000) and is a modified form of the 'gapping' algorithm used by Zabludoff et al. (1993). In summary, we identify isolated peaks in redshift space and compute redshifts and velocity dispersions using an iterative process. We also carry out the same analysis for all significant peaks found in the cluster line-of-sight, as defined by its associated search radius. Figure 1 shows cone plots and redshift histograms for three representative objects.

A summary of cluster identifications is presented in Table 1: we also cross-identify objects present in more than one catalog. The total number of unique objects in our study is 233, of which 123 are present on only the Abell catalogues, 24 in the APM and 86 in the EDCC.

About 1/3 of all clusters are not yet identified in 2dFGRS; in most cases this appears to be due to the fact that clusters are either poor (richness class 0) or very distant (with m_{10} – where this is the magnitude of the 10^{th} brightest galaxy, used as a redshift indicator – values indicating $z > 0.12$). In some instances the clusters lie in a low completeness region and redshifts may become available at a later stage.

Important to any quantitative analysis based on the clusters found here is the need to identify volume-limited subsamples and correct for incompleteness due to our window function and selection efficiency. Two routes have generally been adopted: selection of candidates based on 'cuts' in m_{10}, which

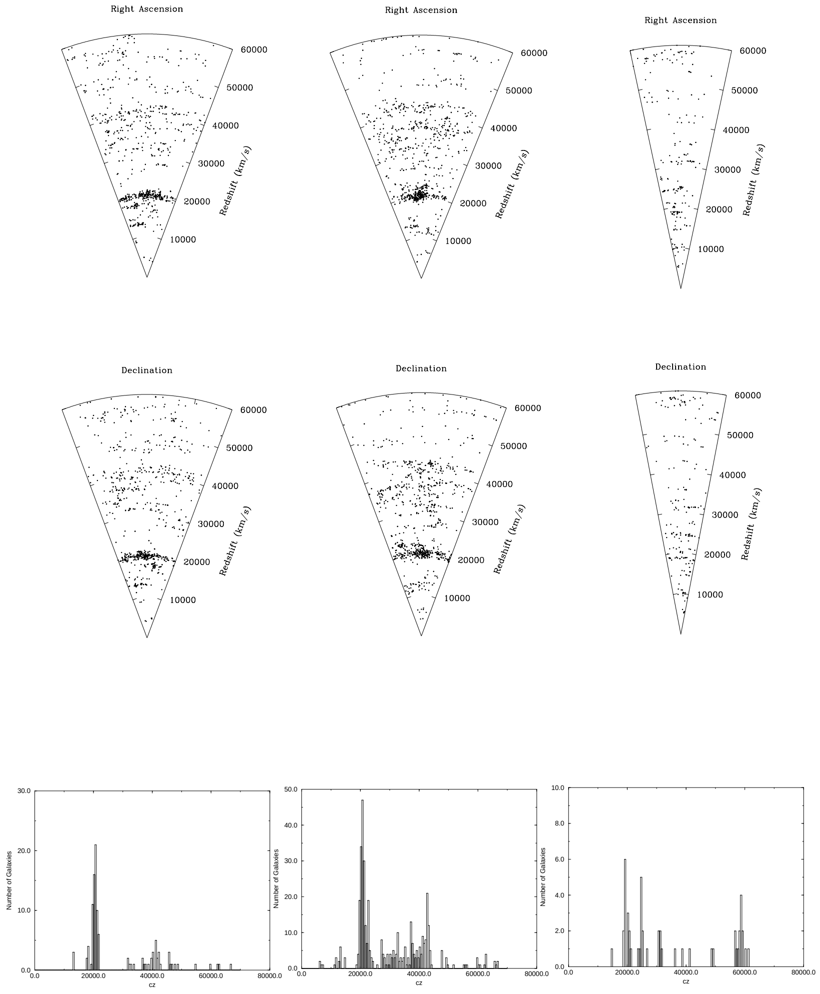

Fig. 1. Cone diagrams (6 Mpc opening angle) and redshift histograms (over the Abell radius) for S0333 (first from left), Abell 3094 (middle) and Abell 3824 (right) as examples of (a) a well-defined isolated object (S0333); (b) a cluster with significant structure in its line of sight (A3094) and (c) a cluster resolved in numerous groups (A3824)

Table 1. Summary of Cluster Identifications

Catalog	N[Clusters(Abell,APM,EDCC)]	N(Redshifts)	N(σ)
Abell N	51(–,7,13)	30	17
Abell S	159(–,22,63)	107	53
APM	54(29,–25)	43	22
EDCC	169(76,25,–)	115	67
Total	433	294	159

defines a roughly volume limited sample and with a richness limits that makes the sample reasonably complete, and a pure redshift selection, now possible from 2dF data. The former technique has been the one most generally used and it is therefore appropriate to consider its accuracy and limitations.

Figure 2 plots estimated vs. 2dF redshifts for all three catalogs being considered (we separate the Abell and Abell et al. catalogs as they are selected differently). We see that, whereas there is a broad relation between real and estimated redshift, there are numerous objects where the estimators fail and all catalogs saturate at some level, where m_{10} approaches the plate limit.

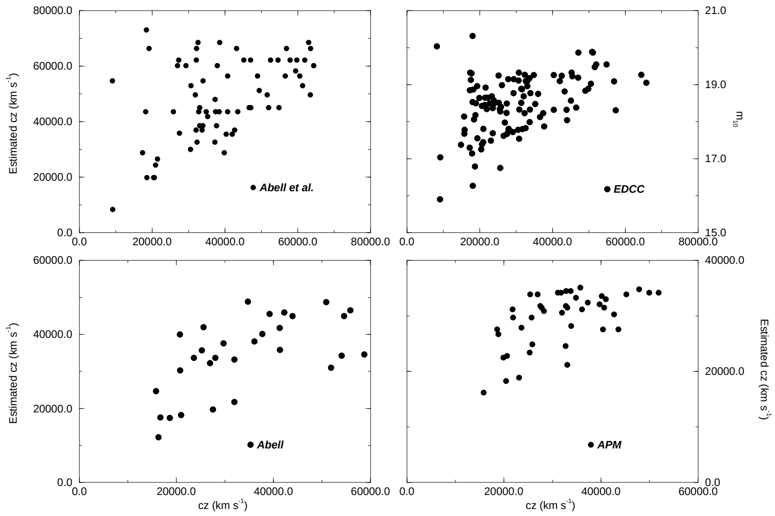

Fig. 2. Comparison of estimated and real redshifts

The broad relation apparent in Figure 2 can be used to define an estimated cz such that, given the spread in the relation, one can select an approximately volume limited sample which is also reasonably complete. We can use this to choose cuts in estimated redshift space and define samples for studies of contamination, where we define contamination as the presence of significant foreground and/or background structure in the line of sight. We define this structure to be significant if our 'gapping' procedure described above yields a redshift or velocity dispersion for any of the secondary peaks.

By this definition we find that the Abell and EDCC samples are contaminated at approximately the 15% level; the APM catalog suffers at only the 5% level, but this is likely a factor of the larger richness cut and smaller search radius used.

Figure 3 plots the space density of clusters in all three catalogs as a function of the cluster redshift; we can use these plots to define a real redshift where the samples are complete; since the space density of clusters is believed to be constant, at least over the volume sampled, any apparent decline in density may be attributed to the onset of incompleteness. We plot the X-ray selected sample of RASS1 (De Grandi et al. 1999) for comparison and to show the apparently constant density of clusters. Our data appear to be complete to about $z = 0.11$ (not coincidentally, the peak in the redshift distribution for the whole survey); this is then chosen as the redshift limit for our estimated redshift cut (and for our pure cz sample). Note that in both the EDCC and Abell survey there is a relative lack of clusters at $z = 0.05$ that may be related to the 'hole' claimed by Zucca et al. (1997), although it is most likely an artefact of the small volume sampled so far.

3 The Space Density of Abell Clusters and the Distribution of σ

We select an estimated 'cut' such that objects with real $cz < 33000$ km/s are included. However, Figure 2 shows that many such objects are actually excluded from the sample. We correct for this by using clusters whose real $cz < 33000$ km/s and calculating how many of these have estimated $cz > 33000$ km/s. We obtain a total space density for all Abell clusters of $26.1 \pm 3.5 \pm 7.6$ (where the second error is the error due to our 0.47 completeness correction and the units are 10^{-6} h^3 Mpc-3) and $4.9 \pm 1.5 \pm 1.8$ for $R > 1$ clusters.

We also choose a sample of clusters with $cz < 33000$ km/s using only those objects with measured redshifts. While this is certainly incomplete it provides a reliable lower limit to the space density of clusters. We obtain, for all Abell clusters, 19.4 ± 2.7 and, for $R > 1$ objects, 7.8 ± 1.8. This latter result is similar to the values determined by Zabludoff et al. and Mazure et al. (1996).

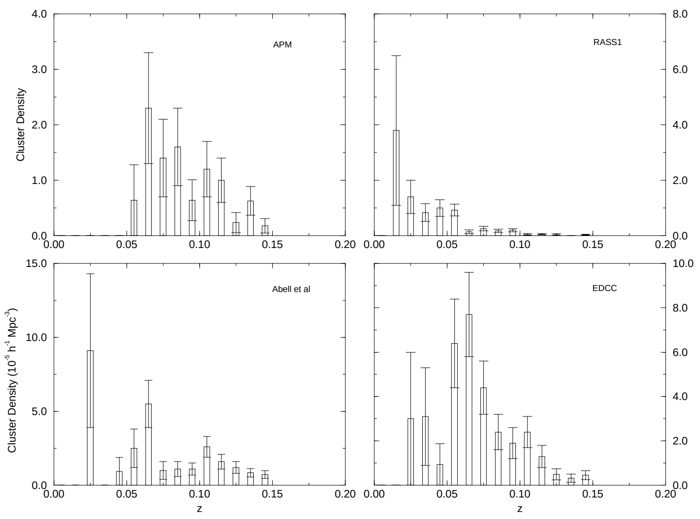

Fig. 3. Space Density of clusters in all catalogs

The distribution of velocity dispersions provides some constraint on models of structure formation, via the shape of the power spectrum of fluctuations. Cluster masses, in particular, provide limits in small scales and help in normalizing Cosmic Microwave Background results. Whereas estimating cluster masses is extremely difficult, the distribution of velocity dispersions may be used as a substitute, especially at the high end, which is most sensitive to cosmology.

We plot our data in Figure 4 together with previous compilations. Although these comparisons should be taken with some caution, especially at the low end, where our sample includes low richness objects, they should be fair at the high end, where we observe reasonable agreement.

The most robust result we can derive is the relative lack of clusters of high velocity dispersion; indeed, since contamination will increase the derived velocity dispersion, we feel that we can determine a significant upper limit to the space density of N($\sigma > 1000$) clusters of < 2.5 (in the same units as above). Our cz sample also allows us to derive a weak lower limit of 0.85. These can be compared with theoretical models by Borgani et al. (1998): we find that our data suffice to rule out Standard CDM models, ΛCDM models with high Ω_M and τCDM cosmologies, while allowing Cold and Hot dark matter models, open CDM and low Ω_M ΛCDM. Our data are therefore in favor of low values of Ω_M, which would indeed bring cluster data in better agreement with the COBE and CMB results.

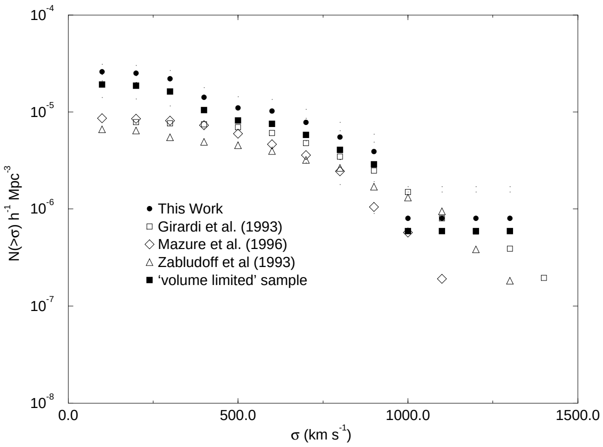

Fig. 4. Distribution of cluster velocity dispersions for our data (filled symbols) and previous work as indicated in legend

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