A&A 479, 927–937 (2008)
DOI: 10.1051/0004-6361:20078036

Astronomy & Astrophysics

Groups of galaxies in the SDSS Data Release 5

A group-finder and a catalogue*

E. Tago[1], J. Einasto[1], E. Saar[1], E. Tempel[1], M. Einasto[1], J. Vennik[1], and V. Müller[2]

[1] Tartu Observatory, 61602 Tõravere, Estonia
e-mail: erik@aai.ee
[2] Astrophysical Institute Potsdam, An der Sternwarte 16, 14482 Potsdam, Germany

Received 8 June 2007 / Accepted 16 November 2007

ABSTRACT

Aims. We extract groups of galaxies from the SDSS Data Release 5 to study the supercluster-void network and environmental properties of groups therein. Groups of galaxies as density enhancements can be used to determine the luminosity density field of the supercluster-void network.

Methods. We use a modified friends-of-friends (FoF) method with slightly variable linking lengths in transverse and radial directions to eliminate selection effects and to reliably find as many groups as possible. To determine the scaling of the linking length we calibrated group sizes and mean galaxy number densities within groups by shifting nearby groups to larger distances.

Results. Our final sample contains 17 143 groups in the equatorial, and 33 219 groups in the northern part of the DR5 survey. The group catalogue is available at the CDS.

Conclusions. The mean sizes and velocity dispersions of our groups practically do not change with their distance. This means that the selection effects have been properly taken into account when generating the group catalogue.

Key words. cosmology: observations – cosmology: large-scale structure of Universe – galaxies: clusters: general

1. Introduction

Groups and clusters of galaxies are important ingredients of the Universe, useful, e.g., for studying its large-scale structure or the underlying cosmological model. The cluster catalogues by Abell (1958) and Abell et al. (1989) were constructed by visual inspection of the Palomar plates. The new generation of galaxy group catalogues includes the Las Campanas catalogue of groups by Tucker et al. (2000), the catalogues based on the SDSS (Sloan Digital Sky Survey) data releases (EDR, DR1, DR2, DR3, DR4, DR5) and the 2dFGRS (2 degree Field Galaxy Redshift Survey) data releases (100 K, final, Colless et al. 2001, 2003). This inspired numerous research teams to investigate more refined cluster finding algorithms and to compile catalogues of galaxy systems (de Propris et al. 2002a; Merchán & Zandivarez 2002, 2005; Bahcall et al. 2003; Lee et al. 2004; Eke et al. 2004a; Yang et al. 2005; Einasto et al. 2005; Goto 2002; Weinmann et al. 2006; Tago et al. 2006; Berlind et al. 2006).

In our previous paper (Tago et al. 2006, hereafter Paper I) we extracted 2dFGRS groups, and we gave an extensive review of papers dedicated to group search methods, and of the published group catalogues. In this introduction we present a short review of studies of galaxy groups.

In recent years a number of new group-finding algorithms and modified well-known methods have been applied (Goto et al. 2002; Kim et al. 2002; Bahcall et al. 2003; review by Nichol 2004; Koester et al. 2007). However, the friends-of-friends method (FoF, sometimes called the percolation method) remains the most frequently applied for redshift surveys.

Several authors have compiled group catalogues using the 2dF Galaxy Redshift Survey. One of the largest sample of groups has been compiled by Eke et al. (2004a), who compared the real group samples with samples found for simulated 2dF redshift survey galaxies. Yang et al. (2005) applied more strict criteria in group selection, and as a result obtained a 2dF group catalogue that contains mainly compact groups and a larger fraction of single galaxies. In Paper I we applied criteria yielding groups of galaxies with statistical properties between these two catalogues.

Using earlier releases of the SDSS Lee et al. (2004, EDR), Einasto et al. (2003b), Merchán and Zandivarez (2005, DR3), Goto (2005, DR2), Weinmann et al. (2006, DR2; see for details Yang et al. 2005), Zandivarez et al. (2006, DR4), Berlind et al. (2006, DR3) have obtained catalogues of groups (and clusters) of galaxies with rather different properties. Several authors have presented catalogues of rich clusters of galaxies (Aguerri et al. 2007; Popesso et al. 2007; Miller et al. 2005) using the SDSS data. All these group catalogues are constructed on the basis of spectroscopic data, using certain selection criteria. These group catalogues are listed in Table 1 (we did not include rich cluster catalogues in this table and shall discuss these catalogues separately).

In contrast to other authors, Berlind et al. (2006) have used volume-limited samples of the SDSS. This resulted in one of the most detailed search methods, and reliable group catalogues. Recently Paz et al. (2006) and Plionis et al.(2006) studied shapes and virial properties of the 2dFGRS groups (2PIGG), the Sloan Survey Data Release 3 groups and groups in numerical simulations, and found a strong dependence on richness.

* Full Table 3 is only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/479/927

Table 1. A list of group catalogues based on the SDSS.

Authors 1	Release, Sample 2	$N_{\rm gal}$ 3	$N_{\rm gr}(n \geq 2)$ 4	$N_{\rm gr}(n \geq 4)$ 5	$z_{\rm lim}$ 6	$LL_{\rm r0}$ 7	$LL_{\rm p0}$ 8	% (≥2) 9	% (≥4) 10
Merchán (2005)	DR3 Main	300 000		10 864	0–0.3	200			22
Goto (2005)	DR2 SQL	259 497	335		0.03–	1000	1.5		6 ($n \geq 20$)
Weinmann (2006)	DR2 Main VAGC	184 425	16 012	3720	0.01–0.2	0.3^1	0.05^1	30	15
Berlind (2006)	DR3 sam14 VAGC	298 729							
	vol.lim. Mr20	57 332		4119^3	0.015–0.1	0.75	0.14	56.3	37.2^3
	vol.lim. Mr19	37 938		2696^3	0.015–0.068	0.75	0.14	58.9	40.7^3
	vol.lim. Mr18	18 959		1362^3	0.015–0.045	0.75	0.14	60.0	42.2^3
This paper	DR5 Main DAS	387 063	50 362	9454	0.009–0.2	250	0.25	41.1	17.8

Columns: 1: Authors of the group catalog, 2: SDSS sample and release number, 3: number of galaxies, 4: number of groups ($n \geq 2$), 5: number of groups ($n \geq 4$), 6: redshift limits for sample galaxies, 7: FoF linking length in radial velocity, for $z = 0$, 8: FoF linking length in the projected distance in the sky, for $z = 0$, 9: fraction of galaxies in groups ($n \geq 2$), 10 fraction of galaxies in groups ($n \geq 4$).
Notes: [1] For Weinmann et al. groups the linking lengths are in the units of the mean galaxy separation; [3] for Berlind et al. groups the richness $n \geq 3$. * For Berlind et al. the apparent magnitude limit was $r \leq 17.5$, for the rest $r \leq 17.77$.
Group-finders:
Merchán: FoF + mock catalog + iterative group re-centering + Schechter LF for LL scaling.
Goto: FoF + group re-centering.
Weinmann: FoF + DM halo mock catalog + group re-centering.
Berlind: FoF + DM halo mock catalog.
This paper: FoF + density/luminosity relation in groups for LL scaling + Minimal Spanning Tree.

The papers dedicated to group and cluster searches use a wide range of both sample selection methods as well as cluster search methods and parameters. The choice of methods and parameters depends on the goal of the catalogue. In Paper I we drew a conclusion that in previous group catalogues the luminosity/density relation in groups had not been taken into account.

In the present paper our goal is to generate a catalogue of groups using the recent public release (DR5) of the SDSS. We have applied the well-known friends-of-friends (FoF) group search method to search for groups. To create a group catalogue we take into account the luminosity-density relation of galaxies in groups.

Selection effects in data are important factors in choosing the galaxy selection methods and in understanding group properties. In the present paper we investigate various selection effects in SDSS (described in detail in Paper I) that influence the compilation of group catalogues. In order to take the selection effects into properly account we applied several procedures discussed below.

The data used are described in Sect. 2. Section 3 discusses the group-finding algorithm. Selection effects that influence the choice of parameters for the FoF procedure are discussed in Sect. 4. To select an appropriate cluster-finding algorithm we analyse in Sect. 5 how the properties of groups change, if they are observed at various distances. Section 6 describes the final procedure used to select the groups, and the group catalogue. We also estimate luminosities of groups; this is described in Sect. 7. In the last section we compare our groups with groups found by other investigators, and present our conclusions. As in Paper I we use for simplicity the term "group" for all objects in our catalogue including clusters of galaxies.

2. The data

In this paper we have used the data release 5 (DR5) of the SDSS (Adelman-McCarthy et al. 2007, see also 2006, DR4) that contains 674 749 galaxies with observed spectra. The spectroscopic survey is complete from $r = 14.5$ to $r = 17.77$ mag. Stars were excluded by spectroscopic data (redshifts), except for those rare cases where the spectra might have been wrongly interpreted.

We have restricted our study to the main galaxy sample obtained from the SDSS Data Archive Server (DAS), with 488 725 galaxies. This sample was selected as the standard main galaxy sample described by Adelman-McCarthy et al. (2007) and the SDSS web site. The survey currently consists of two main contiguous areas (northern and equatorial, hereafter N and E samples, respectively), three narrow strips in the Southern sky, and a short strip at high declination. We have excluded these smaller areas from our group search. For the two areas we used the coordinate ranges given in Table 2.

We apply a lower redshift limit $z = 0.009$ to our sample to exclude galaxies of the Local Supercluster. As the SDSS sample becomes very diluted at large distances, we restrict our sample by a upper redshift limit $z = 0.2$. Later we will see that for our purposes this SDSS main sample is largely homogeneous up to $z = 0.12$.

We have found duplicate galaxies due to repeated spectroscopy for a number of galaxies in the DAS Main galaxy sample. We have excluded from our sample those duplicate entries that have spectra of lower accuracy. There were two types of duplicate galaxies. In one case duplicates had exactly identical ID numbers, coordinates and magnitudes; they were simple to find and to exclude. Another kind of duplicates had slightly different values of coordinates and magnitudes. This kind of duplicates cannot be seen in the sky distribution of galaxies but were discovered as an enhanced number density of galaxy pairs after the FoF procedure. The majority of the second kind of duplicates have been found at the common boundary of the data releases DR1 and DR2 (at Dec −1.25° and +1.25°). We have excluded them as duplicate galaxies (see Figs. 1 and 2). In total we have excluded from both samples 6439 identical galaxies and 1480 galaxies with slightly different data.

The total number of galaxies was thus reduced to 129 985 in the equatorial sample and to 257 078 in the northern sample. The data on the final samples are presented in Table 2. In the present paper we have used only the SDSS DR5 release. The redshifts were corrected for the motion relative to the CMB. For linear dimensions we use co-moving distances (see, e.g., Martínez & Saar 2003), computed using the standard cosmological parameters: the Hubble parameter

Table 2. The SDSS DR5 main samples used, and the FoF parameters for the group catalogue (DR4 is for comparison, but not used).

Sample	RA, λ deg	Dec, η deg	$N_{\rm gal}$	$N_{\rm groups}$	$N_{\rm single}$	$LL_{\rm r0}$ km s^{-1}	$LL_{\rm p0}$ Mpc/h	z_*	a
1	2	3	4	5	6	7	8	9	10
SDSS DR4 E	120...255	–1...16	116 471	16 244	65 016	250	0.25	0.138	1.46
SDSS DR4 N	–63...+63	6...39	197481	25 987	115 488	250	0.25	0.138	1.46
SDSS DR5 E	120...255	–1...16	129 985	17 143	75 788	250	0.25	0.055	0.83
SDSS DR5 N	–63...+63	6...39	257 078	33 219	152 234	250	0.25	0.055	0.83

Columns: 1: Subsample of the SDSS redshift catalogue, 2: right ascension limits for the equatorial (E) sample, λ coordinate limits for the northern (N) sample (degrees), 3: declination limits for the E sample, η coordinate limits for the N sample (degrees), 4: number of galaxies in a subsample, 5: number of groups in a subsample, 6: number of single galaxies, 7: FoF linking length in radial velocity, for $z = 0$, 8: FoF linking length in the projected distance in the sky, for $z = 0$, 9: characteristic scaling distance for the linking length, see Eq. (1), Sect. 5, 10: scaling amplitude for the linking length, see Eq. (1), Sect. 5.

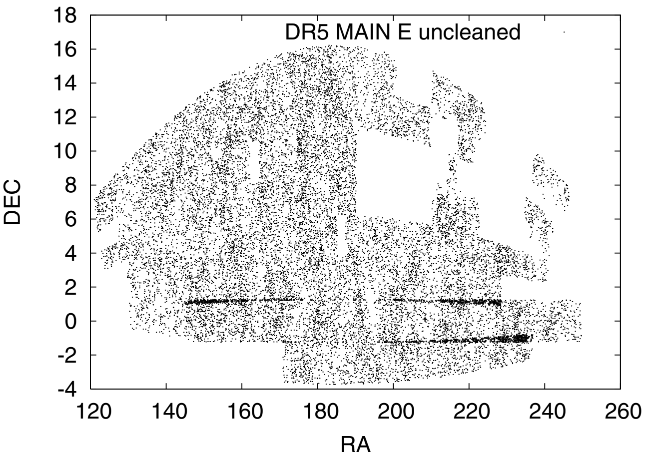

Fig. 1. Groups of galaxies in the sample E. Duplicate galaxies appear as an increased density of groups at the boundaries of the data releases 1 and 2.

$H_0 = 100\,h$ with $h = 1$, the matter density $\Omega_{\rm m} = 0.3$, and the dark energy density $\Omega_\Lambda = 0.7$.

3. Friends-of-friends algorithm

One of the most conventional methods to search for groups of galaxies is cluster analysis that was introduced in cosmology by Turner & Gott (1976), and successfully nicknamed the "friends-of-friends" algorithm by Press & Davis (1982). This algorithm, along with the percolation method, was widely used after promotion by Zeldovich et al. (1982) and by Huchra & Geller (1982). In this method, galaxies can be linked into systems using a certain linking length. In Paper I we have explained the FoF method and the role of the linking length (or neighbourhood radius) in detail.

Our experience and analysis show that the choice of the FoF parameters depends on the goals of the study. For example Weinmann et al. (2006) searched for compact groups in the SDSS DR2 sample. They applied strict criteria in the FoF method and obtained, as one of the results, a lower fraction of galaxies in groups. Berlind et al. (2006) applied the FoF method to volume-limited samples of the SDSS (see Table 1). Their goal was to measure the group multiplicity function and to constrain dark matter halos. The uniform group selection reduced the incompleteness of the sample, but it also led to a lower number density of groups.

In this paper our goal is to obtain DR5 groups for further determination of the luminosity density field and to derive the properties of the galaxy network. Groups are mostly density enhancements within filaments, and rich clusters are high-density peaks of the galaxy distribution in superclusters (Einasto et al. 2003c,d; 2007a,b). Hence, our goal is to find as many groups as possible to trace the supercluster-void network.

The virialisation condition, or a certain density contrast level an alternative criterion do not work universally well for all density ranges of the galaxy distribution. However, a similar problem arises in the case of the FoF method. As shown by Einasto et al. (1984), it is not easy to find a suitable linking length even for a volume-limited sample of galaxies. The same conclusion has been reached by Berlind et al. (2006), based on a much larger sample and a more detailed analysis. The problem arises due to the variable mean density of galaxies in different regions of space. Additional difficulties arise in the case of flux-limited samples of galaxies where the linking length depends also on the distance from the observer. In the original analysis by Huchra & Geller the linking length l was chosen to scale as $l \sim f^{-1/3}$, where f is the selection function of galaxies. This scaling corresponds to the hypothesis that with increasing distance the galaxy field, and the groups, are randomly diluted. A recent summary of various methods to find clusters in galaxy samples is given by Eke et al. (2004a).

As shown in Paper I, it is actually the density of galaxies in groups, not in the general field, that determines the choice of group selection parameters. There exists a close correlation between luminosities of galaxies in groups and their positions within groups: bright galaxies are concentrated close to the center, and less bright companions lie in the outskirts (for an early analysis of this luminosity-density correlation see Einasto et al. 1974, for a recent discussion see Paper I). In Paper I we found that while constructing group catalogues in the 2dFGRS, a slightly increasing linking length with distance has to be used.

A similar problem arises in the SDSS. As selection effects were analyzed in detail in Paper I, we shall discuss only briefly the selection effects in the SDSS survey. We perform tests to find an optimal set of parameters for the FoF method in this study.

4. Selection effects

The main selection effects in group catalogues are caused by a fixed interval of apparent magnitudes in galaxy surveys (see for details Paper I). This effect is illustrated for the SDSS DR5 groups in Fig. 3.

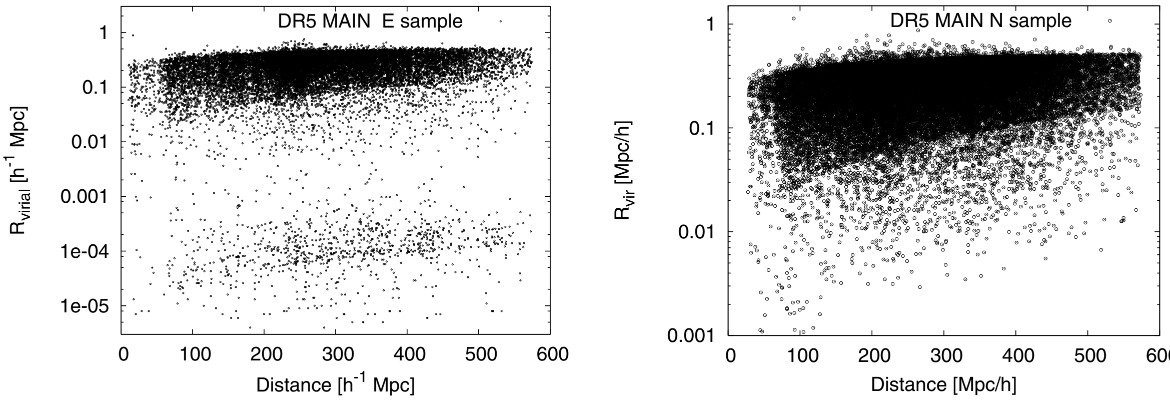

Fig. 2. The virial radius – distance relation for the E and N samples (*left and right panels*, respectively). Duplicate galaxies appear in the sample E as a separate population due to false pairs at very low values of the virial radius (see the band at $R_{\rm vir} \approx 10^{-4}$ Mpc h^{-1}).

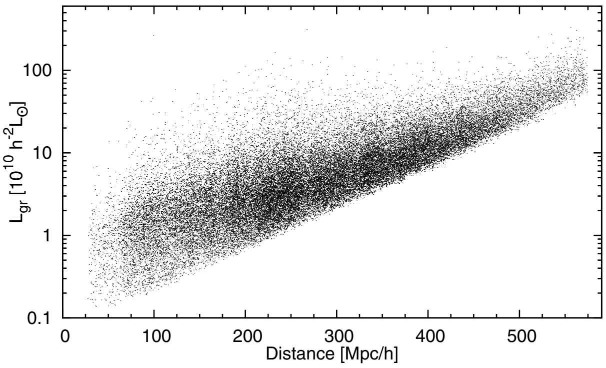

Fig. 3. The total estimated luminosities of groups as a function of distance from the observer (see Sect. 7 for details).

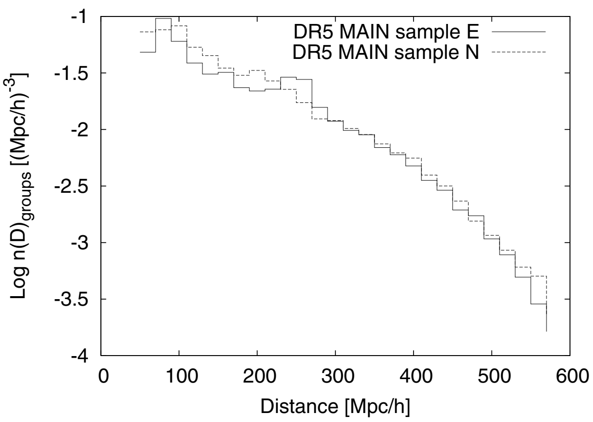

Fig. 4. The number density of groups in the SDSS DR5 MAIN E and N samples (logarithmic scale) as a function of distance from the observer.

The main consequence of this selection effect is the inhomogeneous spatial distribution of groups: the volume density of groups decreases with increasing distance. We show this effect in Fig. 4, where we plot the mean number density of groups as a function of distance, separately for the northern and the equatorial areas. Note that the local maximum of the number density of groups in the E sample at distances ≈250 h^{-1} Mpc is due to a very rich supercluster SCL126 (Einasto et al. 1997).

5. Scaling of the linking length

Sizes of groups depend directly on the choice of the linking length, or more generally on its scaling law. Strong selection effects can be observed here. As an example, the median sizes of the distant 2PIGG groups (Eke et al. 2004a) are 7 times larger than those for the nearby groups.

In the majority of papers dedicated to group searches, the group finders are tuned using mock *N*-body catalogues (e.g. Eke et al. 2004a; Yang et al. 2005). The mock group catalogues are homogeneous and all parameters of the mock groups can be easily found and applied to searches for real groups. Still, mock groups are only an approximation of the real groups, using model galaxies in dark matter haloes. As we have noted, it is difficult to properly model the luminosity-density correlation found in real groups.

At large distances from the observer, only the brightest cluster members are visible, and these brightest members form compact cores of clusters, with sizes much less than the true size of the clusters.

Because of this, we have used observed groups to study the scaling of group properties with distance. This procedure is described in detail in Paper I. As this is an important part of our search method, we present here the method briefly and give the results for the SDSS DR5 groups.

We created the test group catalogues from the samples SDSS DR5 E and N, selecting in the nearby volume $d <$ 100 h^{-1} Mpc all rich groups (with multiplicity $N_{\rm gal} \geq 20$), in total 222 groups. We used both constant and variable linking lengths to create the test groups; the final results did not depend on this choice. The values of these parameters are given in Sect. 6.1. Assuming that the group members are all at the mean distance of the group we determined their absolute magnitudes and peculiar radial velocities. Then we shifted these nearby groups, calculating the parameters of groups (new *k*-corrections and apparent magnitudes for the group members), as if the groups were located at larger distances. We increased the distances step by step (using a z = 0.001 step in redshift). As with increasing distance more and more fainter members of groups fall outside the observational window of apparent magnitudes, the group membership changes. We then determined new properties of the groups – their multiplicities, characteristic sizes, velocity dispersions and densities. We also calculated the minimum FoF linking length necessary to keep the group together at this distance. To determine that, we built the minimal spanning tree (MST) for the group (see, e.g., Martínez & Saar 2003), and found the maximum length of the MST links.

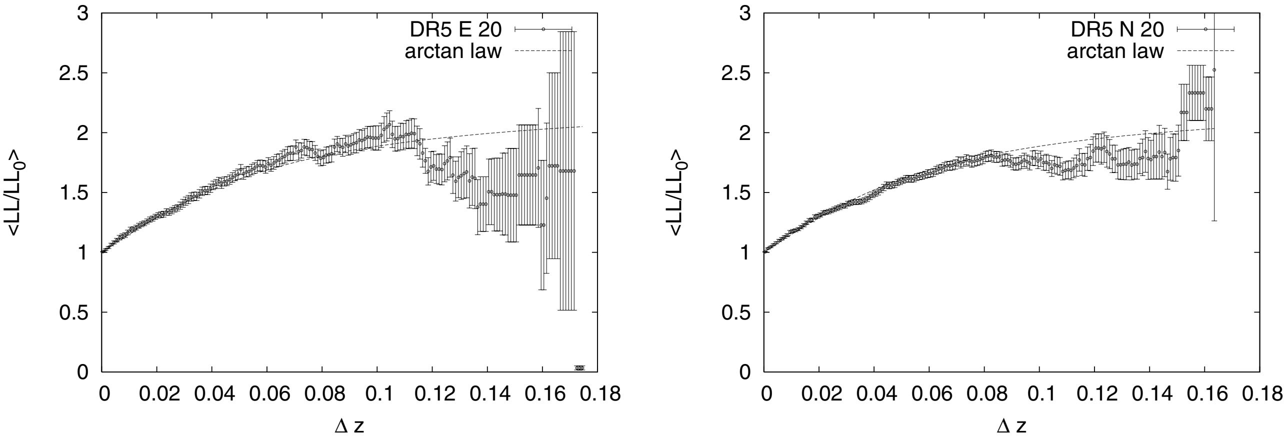

Fig. 5. Scaling of the group FoF linking length with redshift for the samples DR5 E (*left panel*) and DR5 N (*right panel*). The ordinate is the ratio of the minimal linking length LL at a redshift z necessary to keep the group together to the original linking length LL_0 that defined the group at its initial redshift z_0; the abscissa is the redshift difference $\Delta z = z - z_0$.

As the original groups had different sizes and initial redshifts, we found the relative changes of their properties with respect to the redshift change. The individual linking lengths have a substantial scatter. In Fig. 5 we show the variation of the mean linking length and its rms error with the redshift change.

We determine the mean values of the linking lengths in $\Delta z = 0.001$ redshift bins (the step we used for shifting the groups). We have found that the scaling is not sensitive to the richness of the test group; in order to extend the scaling to larger redshifts we use nearby groups with richness $n \geq 20$ as test groups. The scaling law for the SDSS is moderately different from the scaling law found for the 2dFGRS groups in Paper I, but it still can be approximated by a slowly increasing arctan function. Due to the narrow magnitude window of the SDSS, at higher values of z only compact cores of groups (or binary galaxies) are found. This causes deviation from the scaling law, starting at the redshifts above which most groups retain only their compact cores where the brightest group galaxies reside. Therefore, the behaviour of the scaling law is also a test for the redshift of the homogeneity limit of the group catalogue ($z \approx 0.12$ in our case). A good parameterization of the scaling law is

$$LL/LL_0 = 1 + a \arctan(z/z_\star), \tag{1}$$

where $a = 0.83$ and $z_\star = 0.055$. (As the test groups all lie at small redshifts, we can replace the redshift change Δz by the redshift itself.)

The main difference between the scaling laws of the DR5 and 2dF groups lies in the validity range. This is due to different magnitude limits in these flux limited samples. We consider this difference in more detail below. The selection of initial groups does not influence much the scaling of their properties with distance. We tested this using three different initial scaling laws to select the test groups: two with a constant linking length and one with a variable linking length. The final scaling relation practically did not depend on the initial group selection (i.e. on the initial scaling law).

6. Group catalogue

6.1. The group finder

We adopt the scaling of the linking length found above, but we have to select the initial values for the linking length.

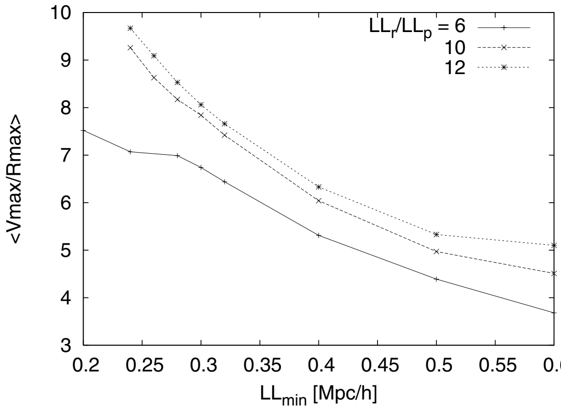

Fig. 6. The mean ratio of radial and perpendicular sizes of groups in the sample E as a function of the initial value of the linking length for three values of the linking length ratios.

In order to find the best initial linking lengths, we tried a number of different parameter values – for the radial linking length $LL_{\rm r0} = 100$–700 km s^{-1} and for the transversal linking length (in the plane of the sky) $LL_{\rm p0} = 0.16$–$0.70\ h^{-1}$ Mpc, and we finally chose the values $LL_{\rm r0} = 250$ km s^{-1} and $LL_{\rm p0} = 0.25\ h^{-1}$ Mpc. Higher values for $LL_{\rm p}$ lead to inclusion of galaxies from neighbouring groups and filaments. Lower values for $LL_{\rm r}$ exclude the fastest members in intermediate richness groups.

Usually the ratio of the radial to the transversal linking lengths $LL_{\rm r}/LL_{\rm p}$ is a constant in the FoF group search. We try to find the ratio $LL_{\rm r}/LL_{\rm p}$ that best reproduces the size ratio of groups, found in detailed studies of individual groups. Figure 6 demonstrates how the mean group size ratio depends on the initial linking length LL for three different $LL_{\rm r}/LL_{\rm p}$ ratios: 6, 10, and 12. If we accept the initial $LL_{\rm p0} = 0.25\ h^{-1}$ Mpc, then we find the best ratio $LL_{\rm r0}/LL_{\rm p0}$ to be 10. If we accept the size ratio 10 (for example from detailed studies of cluster shapes in redshift space) we find that the best $LL_{\rm p0}$ is $0.25\ h^{-1}$ Mpc where the curve $\langle LL_{\rm r}/LL_{\rm p}\rangle(LL_{\rm p0})$ reaches the size ratio $LL_{\rm r}/LL_{\rm p} = 10$ in Fig. 6.

The selected parameters lead to reasonable group properties. However, a closer inspection shows that one of our rich groups has a richness much larger ($N = 569$) than the rest. This is the well-known nearby ($d = 27\ h^{-1}$ Mpc) binary Abell cluster A2197/2199. We consider this cluster as an exception, and

Table 3. The first rows of the SDSS DR5 group catalogue described here.

ID_{gr}	N_g	RA [deg]	Dec [deg]	Dist [Mpc h^{-1}]	$Size_{sky}$ [Mpc h^{-1}]	σ_V [km s^{-1}]	R_{vir} [Mpc h^{-1}]	L_{main} [10^{10} h^{-2} $L_\odot$]	L_{obs} [10^{10} h^{-2} $L_\odot$]	L_{est} [10^{10} h^{-2} $L_\odot$]
1	2	3	4	5	6	7	8	9	10	11
1	4	146.57633972	–0.83209175	195.056	0.6823	53.7783	0.33341	0.17353E+01	0.40818E+01	0.52815E+01
2	2	146.91120911	–0.31007549	385.390	0.1291	25.2219	0.12908	0.21835E+01	0.41985E+01	0.10160E+02
3	3	146.88099670	–0.49802899	249.334	0.1522	101.6915	0.09505	0.27161E+01	0.36896E+01	0.53377E+01
4	2	146.78494263	0.02115750	368.779	0.3185	173.4426	0.31840	0.37278E+01	0.56619E+01	0.13310E+02
5	4	146.74797058	–0.25555125	383.818	0.3404	191.9961	0.15149	0.37084E+01	0.99677E+01	0.24499E+02

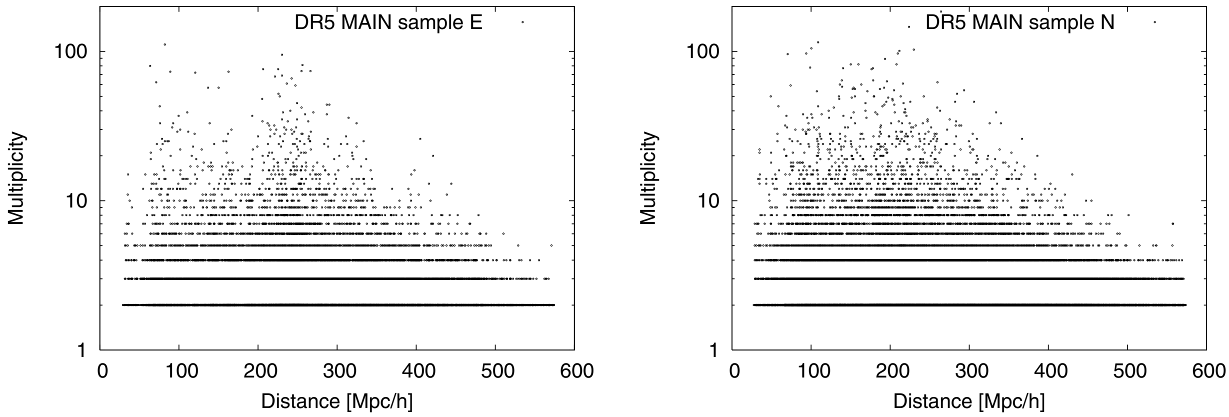

Fig. 7. The multiplicity of groups in the samples E and N as a function of distance from the observer (*left and right panels*, respectively).

do not use lower linking lengths. At slightly lower values of the linking lengths this cluster falls apart, and becomes a cluster pair with usual properties.

6.2. The final catalogue

Our final catalogue (Table 2) includes 17143 groups in the equatorial area and 33 219 groups in the high declination area with richness ≥2. As an example we present here the first lines of our group table (Table 3) that includes the following columns for each group:

1. Group identification number;
2. group richness (the number of member galaxies);
3. RA (J2000.0) in degrees (the mean of member galaxies);
4. Dec (J2000.0) in degrees (the mean of member galaxies);
5. group distance in h^{-1} Mpc (the mean comoving distance for member galaxies, corrected for the movement with respect to CMB);
6. maximum projected size (in h^{-1} Mpc);
7. rms radial velocity (σ_V, in km s^{-1});
8. virial radius in h^{-1} Mpc (the projected harmonic mean);
9. luminosity of the cluster main galaxy (in units of 10^{10} h^{-2} $L_\odot$);
10. total observed luminosity of visible galaxies (10^{10} h^{-2} $L_\odot$);
11. estimated total luminosity of the group (10^{10} h^{-2} $L_\odot$).

An identification number is attached to groups by the group finder in the order that the groups are found. The calculation of luminosities is described in the next section.

We also give (in electronic form) a catalogue of all individual galaxies along with their group identification number and the group richness, ordered by the group identification number, to facilitate search. The tables of galaxies end with a list of isolated galaxies (small groups with only one bright galaxy within the observational window of magnitudes); their group identification number is 0 and group richness is 1. All tables can be found at `http://www.aai.ee/~erik/sdss`. Colour figures of some groups can be found in our web page `http://www.aai.ee/~maret/dr5gr.html`.

7. Properties of groups

7.1. Multiplicities, sizes and velocity dispersions of groups

Next we present shortly the main properties of our groups.

In Fig. 7 we show the multiplicity of groups (the number of member galaxies) as a function of distance from the observer for the E and N samples. Due to the use of an apparent magnitude limited sample the richness (multiplicity) of groups depends on the distance.

We see that rich groups with at least 30 member galaxies are seen only up to a distance of about 300 h^{-1} Mpc, thereafter the mean multiplicity decreases considerably with distance. This selection effect must be accounted for in the multiplicity analysis.

In Fig. 8 we show the cumulative richness distribution and the multiplicity function (left and right panels, respectively). The cumulative function of group richness characterises the fraction of poor and rich groups. It is a robust characteristic: functions for the E and N samples are almost identical.

The right panel of Fig. 8 shows the fraction of galaxies in groups of different richnesses. As a differential probability distribution, it is sensitive to high richness values.

In Figs. 9 and 10 (left panels) we show the sizes of groups from the final catalogue. We define the size of the group as its maximum projected diameter, the largest projected galaxy pair distance within the group. We see that the sizes of the largest groups slightly increase with distance up to d = 250 h^{-1} Mpc, and thereafter slowly decrease. This decrease is expected since in more distant groups only bright galaxies are seen, and they form the compact cores of groups. We also plot the median, and the 25% and 75% quartiles of the distribution of the sizes of

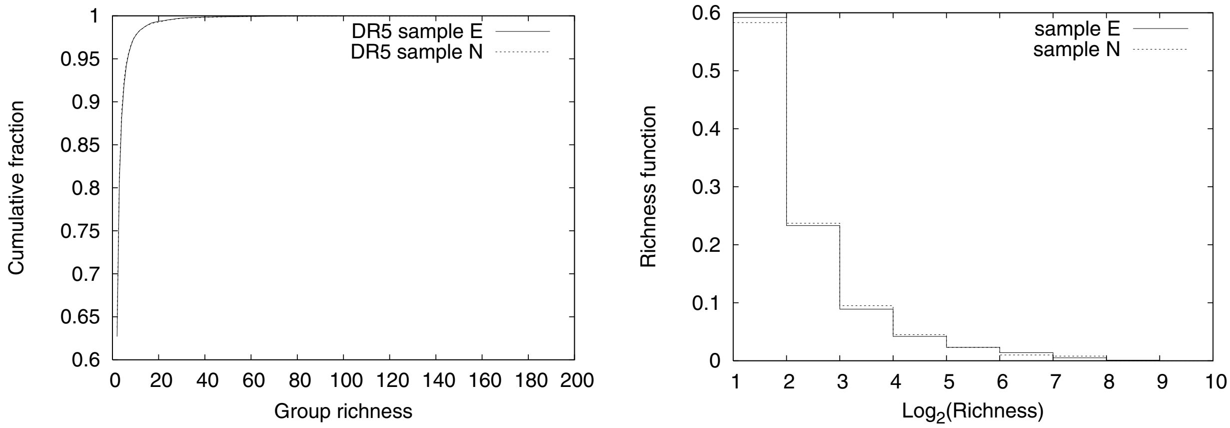

Fig. 8. The cumulative richness distribution (*left panel*) and the multiplicity function (*right panel*) for the E and N samples.

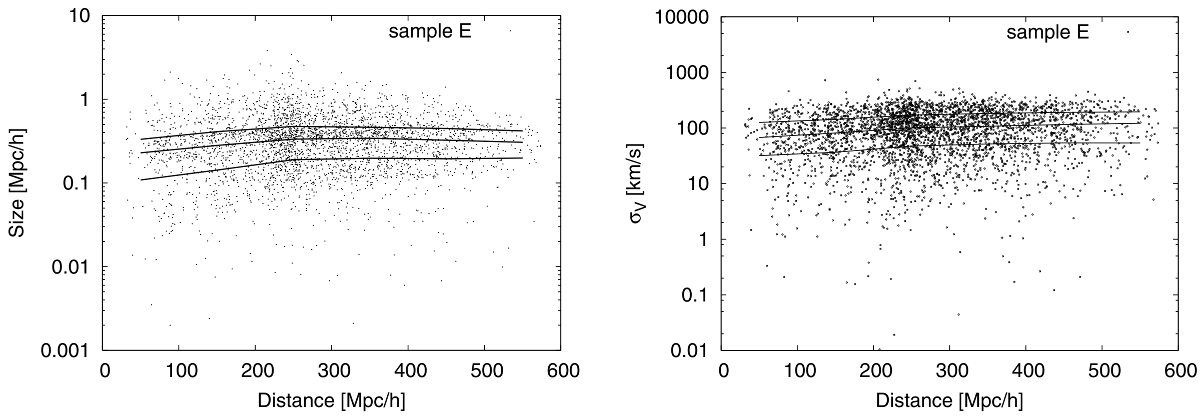

Fig. 9. *Left panel*: the (maximum projected) sizes of our SDSS DR5 groups in the E sample as a function of distance. The median, and the 25% and 75% quartiles of the distribution are shown by solid lines. *Right panel*: the same for the rms velocities of the groups.

groups. Figures 9 and 10 (left panels) show that the median and quartile sizes of groups increase slowly up to distances of about 180 h^{-1} Mpc and then remain almost constant. The increase of the sizes of groups at small distances is due to several reasons: nearby our sample is dominated by faint galaxies which form small groups (with one or two bright galaxies). This is partly due to the absence of nearby bright galaxies in the SDSS sample, and partly due to the fact that the underdense region behind the Local Supercluster is populated by less rich, smaller groups (see Einasto et al. 2003c, about environmental enhancement of groups). The largest groups from the E sample are located in the region of the rich supercluster SCL126. A remarkable feature in these figures is that the median and quartiles of the group size distributions remain nearly constant at distances $d \geq 300\, h^{-1}$ Mpc. This shows that the selection effects have been properly taken into account by our scaling procedure.

The velocity dispersions σ_V^2 for our groups were calculated using the standard formula

$$\sigma_V^2 = \frac{1}{(1+z_{\rm m})^2} \sum_{i=1}^{n} (V_i - V_{\rm mean})^2 / (n-1) \tag{2}$$

where $V_{\rm mean}$ and $z_{\rm m}$ are the mean group velocity and redshift, respectively, V_i is the velocity of an individual group member, and n is the number of galaxies with observed velocities in a group. The rms velocities are plotted in Figs. 9 and 10 (right panels), where we show again the median, and the 25% and 75% quartiles of the distribution. As in the case of sizes, we see also here that the values of median and quartiles of group's velocity dispersions increase very slowly with distance. The reasons for this are the same as described in the previous paragraph. At very large distances, where our groups consist mainly of very bright galaxies and correspond to cores of rich groups, the velocity dispersions are larger than in the case of poor, faint groups at small distances.

Together these figures show that the selection effects have been properly taken into account when generating group catalogues.

7.2. Luminosities of groups

The limiting apparent magnitudes of the complete sample of the SDSS catalogue in r band are 14.5 and 17.77. The faint limit actually fluctuates slightly from field to field, but in the present context we shall ignore that. We regard every galaxy as a visible member of a group or cluster within the visible range of absolute magnitudes, M_1 and M_2, corresponding to the observational window of apparent magnitudes at the distance of the galaxy. To calculate the total luminosities of groups we have to take into account possible members outside the visibility window. This estimated total luminosity is calculated as follows:

$$L_{\rm tot} = W_L \sum_{i=1}^{n} L_{{\rm obs},i}, \tag{3}$$

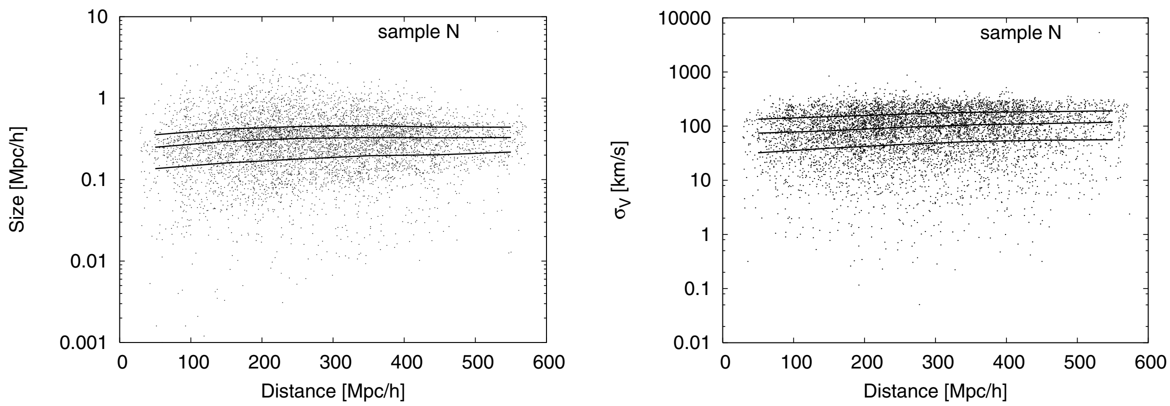

Fig. 10. *Left panel*: the (maximum projected) sizes of our SDSS DR5 groups in the N sample as a function of distance. The median, and the 25% and 75% quartiles of the distribution are shown by solid lines. *Right panel*: the same for the rms velocities of the groups.

where $L_{\mathrm{obs},i} = L_{\odot}10^{0.4\times(M_{\odot}-M)}$ is the luminosity of a galaxy of an absolute magnitude M, and

$$W_L = \frac{\int_0^{\infty} L\phi(L)\mathrm{d}L}{\int_{L_1}^{L_2} L\phi(L)\mathrm{d}L} \tag{4}$$

is the luminosity weight (the ratio of the expected total luminosity to the expected luminosity in the visibility window). The sum in (3) includes all group members, and n is the group richness. In the last equation $L_i = L_{\odot}10^{0.4\times(M_{\odot}-M_i)}$ are the luminosity limits of the observational window, corresponding to the absolute magnitude limits of the window M_i, and $M_{\odot}$ is the absolute magnitude of the Sun. In the calculation of weights we assumed that galaxy luminosities are distributed according to a double power-law function that was popular in the past (see, e.g., Christensen 1975; Kiang 1976; Abell 1977; Mottmann & Abell 1977):

$$\phi(L)\mathrm{d}L \propto (L/L^*)^{\alpha}(1 + (L/L^*)^{\gamma})^{(\delta/\gamma)}\mathrm{d}(L/L^*), \tag{5}$$

where α, γ, δ and L^* are parameters. We use the double power-law rather than the Schechter function, as it gives a better fit for the observed galaxy luminosity function, especially at its high-luminosity end.

We use the double power-law function with the parameters: $\alpha = -1.123$, $\gamma = 1.062$, $\delta = -17.37$, $L^* = 19.61$. We used all the SDSS main galaxies (galaxies in groups and isolated galaxies) to find the luminosity function. A more detailed explanation of the double power-law function and how we derive the parameters is given in our paper on the 2dFGRS luminosity function (Einasto et al. 2007c).

The k-correction for the SDSS galaxies was calculated using the KCORRECT algorithm (Blanton & Roweis 2006). We also accepted $M_{\odot} = 4.52$ in the r photometric system.

We give for each group the total observed and corrected luminosities, and the luminosity weight.

The luminosity weights for the groups of the SDSS DR5 are plotted as a function of the distance d from the observer in Fig. 11. We see that the mean weight is slightly higher than unity at a distance $d \sim 175\ h^{-1}$ Mpc, and increases both toward smaller and larger distances. The increase at small distances is due to missing very bright members of groups, which lie outside the observational window, and at large distances the increase is caused by the absence of faint galaxies. The weights grow fast for nearby groups and for groups farther away than about $400\ h^{-1}$ Mpc. At these distances the correction factors start to dominate and the luminosities of the groups become uncertain.

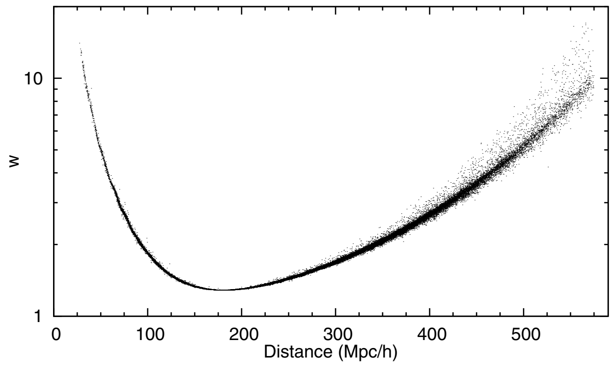

Fig. 11. The luminosity weights of groups of the SDSS DR5 versus the distance from the observer.

8. Discussion and conclusions

8.1. Some issues related to the poor de-blending

Various potential caveats related to the automatic pipeline data reduction in the SDSS have been discussed and flagged in the NYU-VAGC, which is based on the SDSS DR2 (Blanton et al. 2005). Most of these issues are related to poor de-blending of large and/or of LSB galaxies with complicated morphology (e.g. star-forming regions, dust features etc.). At low redshifts a number of SDSS galaxies have been found shredded, i.e. a nearby large galaxy image is split by the target selection algorithm into several sub-images (e.g. Panter et al. 2007). Therefore, the treatment of nearby galaxies requires special care. This potential bias is largely reduced in our new catalogue by setting reasonably high magnitude ($r > 14.5$) and redshift ($z > 0.009$) limits, which exclude most of the luminous and/or nearby galaxies of the Local Supercluster. However, missing the brightest galaxies ($M_r \leq -20$) may affect group luminosity and richness up to the redshift 0.06 (Fig. 11). Our detailed inspection of about 100 nearby groups has shown that not more than 10% of these nearby groups have missing spectroscopic (redshift) data for their bright member galaxies. We conclude that this has a small effect on our full catalogue and the linking length scaling. The total group luminosities have been corrected statistically for the luminosity window used in the SDSS.

We performed estimated quality checks of a number of groups in the new catalogue using the SDSS Sky Server Visual Tools. We inspected a) the members of the 139 nearest ($z < 0.012$) groups – 42 groups in the equatorial (E) sample and 97 groups in the northern (N) sample; b) conspicuously dense

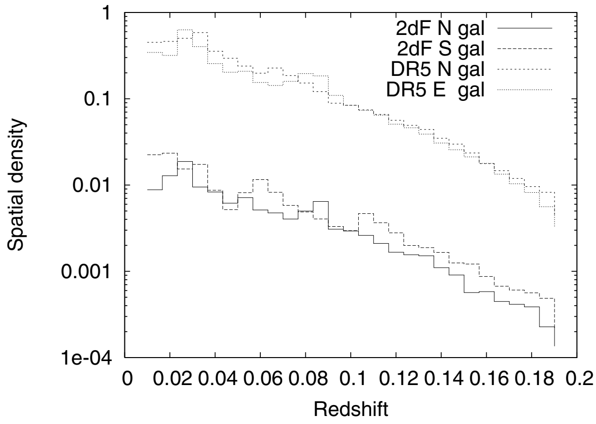

Fig. 12. The number density of galaxies in the 2dF N and S samples, and in the SDSS DR5 E and N samples as a function of distance from the observer. The histograms for the 2dF are arbitrarily shifted along the ordinate for clarity.

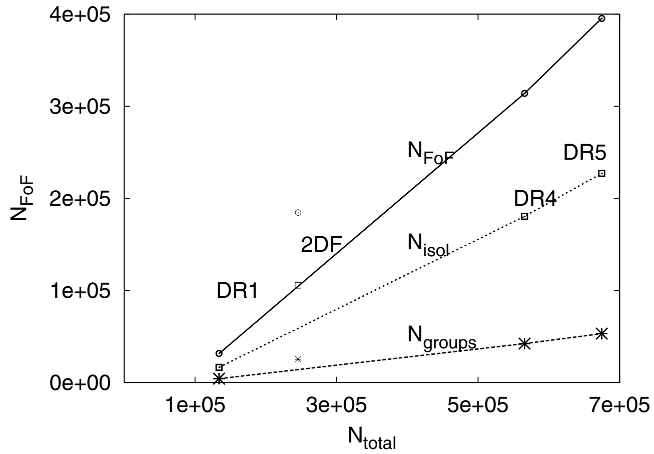

Fig. 13. The number of sample galaxies, groups and isolated galaxies involved in the FoF procedure versus the total number of galaxies in the releases of the SDSS and 2dF surveys. Note a well-defined proportional growth with the releases for the SDSS and a higher "yield" for the 2dF. These relations suggest that the FoF method has been applied homogeneously to the different releases.

groups as evident in the bottom section of Fig. 2, and in the Figs. 9 and 10. The results of these checks can be summarized as follows.

1) *De-blending errors.* In the nearest 139 groups with initially 525 member galaxies poor de-blending has been noted for 21 (4%) galaxies distributed in 9 (6.5%) groups. Poor de-blending means either that the bright galaxy is represented in the DR5 spectroscopic sample with a single off-center source of typically reduced brightness, or that the primary galaxy is shredded into multiple (faint) H II regions.

As an example of poor de-blending we refer to the group number 30 644. Its luminous member NGC 3995 (B_T = 12.7) with knotty morphology is represented in the DR5 with 3 entries, i.e. with 3 distinct spectra of its H II knots of magnitudes r = 12.6, 15.13, and 17.64, respectively. The other three luminous group members, NGC 3966 (m_B = 13.60), NGC 3994 (B_T = 13.30), and NGC 3991 (m_B = 13.50) are each represented in the DR5 by two knots with magnitudes r = 12.49, 16.88, and r = 12.63, 16.60, and r = 14.81, 17.89, respectively. After excluding the knots with $r < 14.5$ those intrinsically luminous galaxies will be represented in our catalogue by their faint(er) knots and their true total magnitudes are underestimated by 1.5−3.5 mag. It appears to be one of the most severely biased nearby groups.

2) All the 25 very dense E groups with $R_{\rm vir} < 1\ h^{-1}$ kpc, shown in the bottom section of Fig. 2, are caused by duplicates. Among them there are 14 "pairs" (i.e. actually a single galaxy with two records in the DR5 spectroscopic sample), 7 "triplets" and 4 "quartets". Among the N groups there are only two duplicates in the given $R_{\rm vir}$ range.

3) Considering the group size distribution (Figs. 2, 9, and 10 (left panels))

- all 13 groups with size <1 h^{-1} kpc are among those with $R_{\rm vir} < 1\ h^{-1}$ kpc in the Fig. 2, i.e. they are duplicates;
- the conspicuous lower boundary of the tightly populated region (which varies nearly proportionally to distance) is probably determined by the fiber collision distance ∼55″ of the survey. The groups distributed in the range between this lower boundary and that of size 10 h^{-1} kpc are in the majority real pairs, i.e. no duplicates. Pairs with size <10 h^{-1} kpc are likely mergers, or advanced mergers (with 1 h^{-1} < size < 5 h^{-1} kpc).
- The upper boundary of the tightly populated region likely results from the linking-length scaling relation (1), since there is no single pair above this boundary. That means, that our sample could be biased against wide (i.e. in the majority optical) pairs.

As a result of our cursory checks we have found relatively few bad de-blends, either in form of mismatches between spectral targets and optical centers, or more severe shreddings of large and/or LSB galaxies. Although the redshifts are good, photometric and structural measurements are often erroneous in such cases. The fraction of groups checked so far is small, however it comprises the nearest, i.e. potentially most affected part of the full sample. We estimate that de-blending errors will have a minor effect, when working with large (sub)samples of groups.

8.2. Comparison with other catalogues

In Table 1 we show some characteristics of several extensive catalogues of groups of galaxies obtained on the basis of the SDSS data releases DR2, DR3, and DR5.

All these catalogues except those by Berlind et al. have been generated using apparent magnitude limited samples. The three group catalogues by Berlind et al. have been obtained using volume limited samples. At the price of a smaller galaxy sample they have the advantage that the selection effects in these catalogues are small.

Several studies have shown (see, e.g., Kim et al. 2002) that different methods give rather different groups for the SDSS sample. The same is true for the 2dFGRS groups (Paper I).

In Fig. 14 we give an example of how the group-finder algorithm works. Comparison with the Merchán et al. (2005) groups and Berlind et al. (2006) groups shows that all three slightly different FoF algorithms identify quite similar groups. The criteria used in Merchán et al. (2005) tend to split the groups along the line-of-sight and/or easily exclude the galaxies in the outskirts of groups.

In Fig. 15 we compare the groups in the volume limited Mr18 sample of Berlind et al. (2006) to our groups in a similar redshift range. We see that we can detect more groups (121 our groups versus 88 groups in the Mr18) and slightly richer groups (6.1 galaxies per one our group versus 5.5 galaxies in one Mr18 group), mainly due to inclusion of fainter ($M_r > -18$) galaxies.

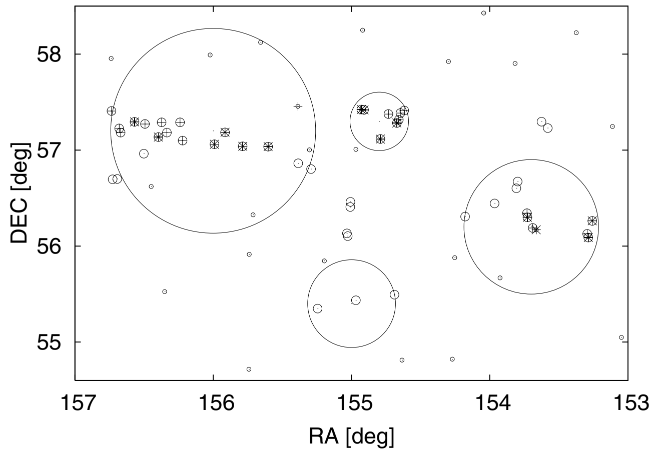

Fig. 14. Eight nearby ($z < 0.04$) groups ($n \geq 2$) as identified in this work in a relatively sparce filament. The group members are shown with circles and four individual groups are encompassed by large circles. The field galaxies in the same redshift range are marked with small circles. For comparison, the members of the corresponding Merchán et al. (2005) groups ($n \geq 4$) are marked with tilted crosses (×), and those of the Berlind et al. (2006) groups (the Mr18 sample, $n \geq 3$) are shown with crosses. Note that in Merchán et al. (2005) the rich, elongated group at left is divided into two (NE and SW) subgroups, which are nearly projected on each other along the line-of-sight.

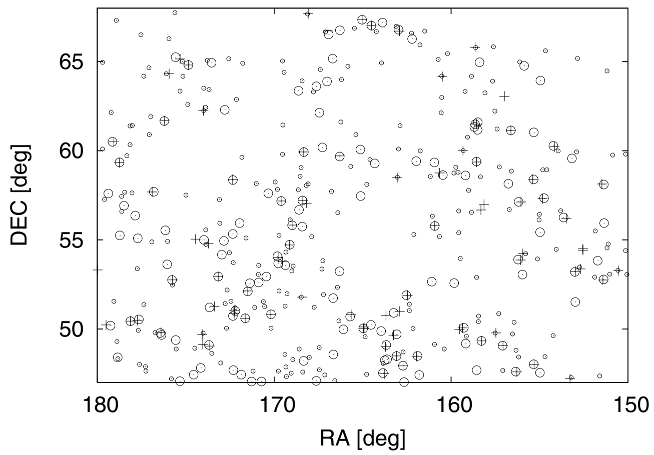

Fig. 15. Groups of the Berlind et al. (2006) Mr18 sample (crosses) compared to our groups in the same redshift ($0.015 < z < 0.045$) and richness ($N_{\rm gal} \geq 3$) range (large circles). The pairs of galaxies ($N_{\rm gal} = 2$) in our catalogue are shown with small circles.

Therefore, we face the problem of how to compare these catalogues in which the authors have used different data releases and applied different group-finder criteria: richness and size of groups, linking lengths, the ratio of the radial to perpendicular linking lengths, etc. These criteria depend on the goals of a particular study.

For example, Weinmann et al. (2006) applied rather strict criteria for group selection, based on the idea that galaxies in a common dark matter halo belong to one group. As a result, they obtained a group catalogue that contains mainly compact groups and a large fraction of single galaxies.

Goto et al. (2005) have created a cluster catalogue applying very strong criteria for the system search to study cluster galaxy evolution. Their catalogue contains only very rich groups ($N_{\rm gal} \geq 20$).

An important characteristic, useful when comparing catalogues, is the fraction of single (isolated) galaxies or, equivalently, the fraction of galaxies in groups. Single galaxies can be considered as belonging to small groups or to haloes represented only by one observed galaxy in the visibility window.

The last two columns in Table 1 give the fraction of galaxies in groups of richness $n \geq 2$ and $n \geq 4$. These are 30 and 42% for the groups by Weinmann et al., and for our groups of richness ≥2, and 22 and 17.8% for the groups by Merchán et al., and for our groups of richness ≥4, respectively. In fact, these values represent the low richness end of the multiplicity function.

We note that the fraction of galaxies in our 2dF GRS groups with multiplicity >=2 is very similar – 43 % (Paper I). This suggests that the multiplicity distribution is a robust characteristic, similar for these two surveys and independent of small differences in the FoF parameters.

On the other hand, we see that Weinmann's groups, which are intended to be compact, have a remarkably lower fraction of galaxies in groups (30%) than our groups. Comparing these fractions for Merchán's and our groups, the results are much closer (for richness $n \geq 4$).

The most reliable group catalogue(s) have been obtained by Berlind et al. (2006; SDSS collaboration). Their purpose was to construct groups of galaxies to test the dark matter halo occupation distribution. In order to obtain highly reliable groups they chose a different method, using volume-limited samples of the SDSS. This way has an unwanted result – a much smaller sample, but also (Table 1) an advantage – less incompleteness problems and a higher fraction of galaxies in groups than in other catalogues. Berlind et al. (2006) demonstrated that there exists no combination of radial and perpendicular linking length reproducing all three important properties of groups (in a mock catalogue): the multiplicity function, the projected size and the velocity dispersion.

There exist also several catalogues of rich clusters that have been compiled using the SDSS data: catalogues by Aguerri et al. (2007), Popesso et al. (2007), and Miller et al. (2005).

The properties of rich clusters in these catalogues are rather different from those of our groups. In particular, in these studies large values of velocity dispersions have been obtained for several reasons.

Aguerri et al. (2007) searched for rich clusters (in DR4) and found 88 clusters up to the redshift limit 0.1. We have found more than 50 000 groups up to the redshift 0.2. This difference is caused largely by different search parameters. Aguerri et al. (2007) used two methods for determining the velocity dispersion of the clusters. The first one was the ZHG method with a linking length of $LL_{\rm r} = 500$ km s^{-1}. This gave them a first approximation of the velocity dispersion, and as they mentioned, this method can overestimate the velocity dispersion of the clusters. However, they also used the KMM method in order to remove group aggregates, and to obtain final more accurate velocity dispersions of the clusters.

Popesso et al. (2007) studied 137 rich Abell clusters, of which 40% are underluminous in X-rays. Miller et al. (2005) have identified 748 clusters with a richness of more than 10 in the SDSS DR2 using the C4 algorithm. In the case of these rich clusters the highest velocity dispersions are much larger than in our sample of groups due to the different selection criteria.

In addition, we present the radial rms velocities, but the comparison is difficult since it is not clear whether other catalogues give the radial or spatial rms velocities.

It is obvious that for the groups of low richness, velocity dispersion has not much meaning. In particular, for galaxy pairs the rms velocity is proportional to the velocity difference of the pair of galaxies.

8.3. Conclusions

We have used the Sloan Digital Sky Survey Data Release 5 to create a new catalogue of groups of galaxies. Our main results are the following.

1) We have taken into account selection effects caused by magnitude-limited galaxy samples. The two most important effects are the decrease of the group density and the decrease of the group richness with increasing distance from the observer. We show that at large distances from the observer the population of more massive, luminous and greater groups/clusters dominates. This increase of the mean size of groups is almost compensated for the absence of faint galaxies in the observed groups at large distances. The remaining bright galaxies form a compact core of the group. This compensates for the increase of group sizes caused by domination of the population of more massive groups. This confirms the similar luminosity/density relation found for the 2dFGRS groups earlier.
2) We calibrate the properties of groups to determine empirically the scaling of the group properties and that of the FoF linking length with distance. As the SDSS Main catalogue and the 2dFGRS galaxies have similar redshift distributions and luminosity functions, the linking length scaling laws for these catalogues are very close, growing only slightly (by the arctan law), but only up to the redshift $z = 0.12$. Beyond this redshift the group linking lengths decrease sharply. At higher redshifts we detect mainly compact cores of the groups due to a more narrow magnitude range (visibility window) of the SDSS. This behaviour of the scaling law can be used as a test showing up to which redshift limit a group-finder could be applied.
3) We present a catalogue of groups of galaxies for the SDSS Data Release 5. We applied the FoF method with a slightly increasing linking length; the catalogue is available on the web page (http://www.aai.ee/~erik/sdss).
4) We present the distribution of sizes and velocity dispersions of groups and show that the changes in the median and quartiles of the distribution of sizes and velocity dispersions of groups with distance are small. This means that the selection effects have been properly taken into account when generating our group catalogues.

Acknowledgements. Funding for the Sloan Digital Sky Survey (SDSS) and SDSS-II has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Science Foundation, the US Department of Energy, the National Aeronautics and Space Administration, the Japanese Monbukagakusho, and the Max Planck Society, and the Higher Education Funding Council for England. The SDSS Web site is http://www.sdss.org/.
The SDSS is managed by the Astrophysical Research Consortium (ARC) for the Participating Institutions. The Participating Institutions are the American Museum of Natural History, Astrophysical Institute Potsdam, University of Basel, University of Cambridge, Case Western Reserve University, The University of Chicago, Drexel University, Fermilab, the Institute for Advanced Study, the Japan Participation Group, The Johns Hopkins University, the Joint Institute for Nuclear Astrophysics, the Kavli Institute for Particle Astrophysics and Cosmology, the Korean Scientist Group, the Chinese Academy of Sciences (LAMOST), Los Alamos National Laboratory, the Max-Planck-Institute for Astronomy (MPIA), the Max-Planck-Institute for Astrophysics (MPA), New Mexico State University, Ohio State University, University of Pittsburgh, University of Portsmouth, Princeton University, the United States Naval Observatory, and the University of Washington.
We are pleased to thank the SDSS collaboration for the DAS version of the fifth data release, special thanks to James Annis. We thank the anonymous referee for many useful comments. We acknowledge the Estonian Science Foundation for support under grants Nos. 6104, 6106 and 7146, and the Estonian Ministry for Education and Science support by grant SF0062465s03. This work has also been supported by the University of Valencia through a visiting professorship for Enn Saar and by the Spanish MEC project AYA2006-14056 (including FEDER). J.E. thanks Astrophysikalisches Institut Potsdam (using DFG-grant 436 EST 17/2/06), and the Aspen Center for Physics for hospitality, where part of this study was performed.

References

Abell, G. 1958, ApJS, 3, 211
Abell, G. 1977, ApJ, 213, 327
Abell, G., Corwin, H., & Olowin, R. 1989, ApJS, 70, 1
Adelman-McCarthy, J. K., Agüeros, M. A., Allam, S. S., et al. (The SDSS Collaboration, DR4) 2006, ApJS, 162, 38
Adelman-McCarthy, J. K., Agüeros, M. A., Allam, S. S., et al. (The SDSS Collaboration, DR5) 2007, ApJS, 172, 634
Aguerri, J. A. L., Sánchez-Janssen, R., & Muñoz-Tuñón, C. 2007, A&A, 471, 17
Bahcall, N., McKay, T. A., Annis, J., et al. 2003, ApJS, 148, 243
Berlind, A. A., Frieman, J., Weinberg, D. H., et al. (the SDSS Collaboration) 2006, ApJS, 167, 1
Blanton, M. R., & Roweis, S. 2007, AJ, 133, 734
Blanton, M. R., Schlegel, D. J., Strauss, M. A., et al. 2005, AJ, 129, 2562
Colless, M. M., Dalton, G. B., Maddox, S. J., et al. 2001, MNRAS, 328, 1039
Colless, M. M., Peterson, B. A., Jackson, C. A., et al. 2003 [arXiv:astro-ph/0306581]
Christensen, C. G. 1975, AJ, 80, 282
De Propris, R., Couch, W. J., Colless, M., et al. (2dF GRS Team) 2002a, MNRAS, 329, 87
Einasto, J., Saar, E., Kaasik, A., & Chernin, A. D. 1974, Nature, 252, 111
Einasto, J., Klypin, A. A., Saar, E., & Shandarin, S. F. 1984, MNRAS, 206, 529
Einasto, M., Tago, E., Jaaniste, J., Einasto, J., & Andernach, H. 1997, A&A Suppl., 123, 119 (E97)
Einasto, J., Hütsi, G., Einasto, M., et al. 2003b, A&A, 405, 425
Einasto, M., Einasto, J., Müller, V., Heinämäki, P., & Tucker, D. L. 2003c, A&A, 401, 851
Einasto, M., Jaaniste, J., Einasto, J., et al. 2003d, A&A, 405, 821
Einasto, J., Tago, E., Einasto, M., & Saar, E. 2005, in Nearby Large-Scale Structures and the Zone of Avoidance, ed. A. P. Fairall, & P. Woudt, ASP Conf. Ser., 329, 27
Einasto, J., Einasto, M., Tago, E., et al. 2007a, A&A, 462, 397
Einasto, J., Einasto, M., Tago, E., et al. 2007b, A&A, 462, 811
Einasto, J., Tempel, E., Saar, E., et al. 2007c, in preparation
Eke, V. R., Baugh, C. M., Cole, S., et al. 2004, MNRAS, 348, 866
Goto, T. 2005, MNRAS, 359, 1415
Goto, T., Sekiguchi, M., Nichol, R. C., for the SDSS collaboration 2002, AJ, 123, 1807
Huchra, J. P., & Geller, M. J. 1982, ApJ, 257, 423
Kiang, T. 1976, MNRAS, 174, 425
Kim, R. S. J., Kepner, J. V., Postman, M., et al. 2002, AJ, 123, 20
Koester, B. P., McKay, T. A., Annis, J., et al. 2007, ApJ, 660, 239
Lee, B. C., Allam, S. S., Tucker, D. L., et al. 2004, AJ, 127, 1811
Martínez, V. J., & Saar, E. 2003, Statistics of the Galaxy Distribution, Chapman Hall/CRC, Boca Raton, 432
Merchán, M., & Zandivarez, A. 2002, MNRAS, 335, 216
Merchán, M., & Zandivarez, A. 2005, ApJ, 630, 759
Mottmann, J., & Abell, G. O. 1977, ApJ, 218, 53
Miller, C. J., Nichol, R. C., Reichart, D., et al. 2005, AJ, 130, 968
Nichol, R. 2004, Carnegie Obs. Astroph. Ser., 24 [arXiv:astro-ph/0305041]
Panter, B., Jimenez, R., Heavens, A. F., & Charlot, S. 2007, MNRAS, 378, 1550
Paz, D. J., Lambas, D. G., Padilla, N., & Mercho, M. 2006, MNRAS, 366, 1503
Plionis, M., Basilakos, S., & Ragone-Figueroa, C. 2006, ApJ, 650, 770
Popesso, P., Biviano, A., Böhringer, H., & Romaniello, M. 2007, A&A, 461, 397
Press, W. H., & Davis, M. 1982, ApJ, 259, 449
Tago, E., Einasto, J., Saar, E., et al. 2006, AN, 327, 365 (Paper I)
Tucker, D. L., Oemler, A. Jr., Hashimoto, Y., et al. 2000, ApJS, 130, 237
Turner, E. L., & Gott, J. R. 1976, ApJS, 32, 409
Weinmann, S. M., van den Bosch, F. C., Yang, X., Mo, H. J., & Jing, Y. P. 2006, MNRAS, 366, 2
Yang, X., Mo, H. J., van den Bosch, F. C., & Jing, Y. P. 2005, MNRAS, 356, 1293
Zandivarez, A., Martínez, H. J., & Merchán, M. 2006, ApJ, 650, 137.
Zeldovich, Ya. B., Einasto, J., & Shandarin, S. F. 1982, Nature, 300, 407