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Superclusters of galaxies in the 2dF redshift survey

III. The properties of galaxies in superclusters

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ABSTRACT

Context. Superclusters are the largest systems in the Universe to give us information about the very early Universe. Our present series of papers is devoted to the study of the properties of superclusters of galaxies from the 2dF Galaxy Redshift survey.
Aims. We use catalogues of superclusters of galaxies from the 2dF Galaxy Redshift Survey to compare the properties of rich and poor superclusters. In particular, we study the properties of galaxies (spectral types, colours, and luminosities) in superclusters.
Methods. We compare the distribution of densities in rich and poor superclusters, and the properties of galaxies in high and low-density regions of rich superclusters, in poor superclusters, and in the field. In superclusters and in the field, we also compare the properties of galaxies in groups, and the properties of those galaxies which do not belong to any group.
Results. We show that in rich superclusters the values of the luminosity density smoothed on a scale of 8 h^{-1} Mpc are higher than in poor superclusters: the median density in rich superclusters is $\delta \approx 7.5$ and in poor superclusters $\delta \approx 6.0$. Rich superclusters contain high-density cores with densities $\delta > 10$, while in poor superclusters such high-density cores are absent. The properties of galaxies in rich and poor superclusters and in the field are different: the fraction of early type, passive galaxies in rich superclusters is slightly higher than in poor superclusters, and is the lowest among the field galaxies. Most importantly, in high-density cores of rich superclusters ($\delta > 10$), there is an excess of early type, passive galaxies in groups and clusters, as well as among those which do not belong to any group. The main galaxies of superclusters have a rather limited range of absolute magnitudes. The main galaxies of rich superclusters have higher luminosities than those of poor superclusters and of groups in the field.
Conclusions. Our results show that both the local (group/cluster) environments and global (supercluster) environments influence galaxy morphologies and their star formation activity.

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

1. Introduction

It is presently well-established that galaxies belong to various systems from groups and clusters to superclusters, forming the supercluster-void network. Early studies of the superclusters of galaxies were reviewed by Oort (1983). These studies were based on observational data about galaxies, as well as on data about nearby groups and clusters of galaxies. Classical cluster catalogues were constructed by Abell (1958) and Abell et al. (1989) by visual inspection of Palomar plates. The first relatively deep all-sky catalogues of superclusters of galaxies were compiled by Zucca et al. (1993) and Einasto et al. (1994, 1997b, 2001) using data about Abell clusters.

The modern era of the study of various systems of galaxies began when new deep-redshift surveys of galaxies were published. These surveys cover large regions of the sky and with these data it is possible to investigate the distribution of galaxies up to fairly large distances from us. These surveys formed the basis for new catalogues of groups, clusters, and superclusters of galaxies. The first was the Las Campanas catalogue of groups by Tucker et al. (2000). The Las Campanas Galaxy Redshift Survey and the Sloan Digital Sky Survey were also used to compile catalogues of groups, clusters, and superclusters by Einasto et al. (2003a,b, hereafter E03a and E03b) and Basilakos (2003). Group and supercluster catalogues based on the 2-degree Field Galaxy Redshift Survey (2dFGRS) were published by Eke et al. (2004), Yang et al. (2004), and Tago et al. (2006, hereafter T06), and by Erdogdu et al. (2004) and Porter & Raychaudhury (2005).

The pioneering studies of the properties of galaxies in clusters by Davis & Geller (1976) and Dressler (1980) showed that a correlation exists between the spatial density of galaxies and their morphology – early type galaxies tend to be located in the central regions of clusters, where the local densities are high, while late type galaxies are located mostly in the outer regions of clusters, having lower local densities around them. Einasto (1991) showed that clustering of galaxies depends on both their luminosity and morphology. Already, early studies of the morphological segregation of galaxies on supercluster scales have demonstrated that this segregation extends to scales of 10−15 h^{-1} Mpc (Giovanelli et al. 1986; Einasto & Einasto 1987; Mo et al. 1992).

Early studies also showed the presence of luminosity segregation of galaxies (Hamilton 1988; Einasto 1991).

Phillipps et al. (1998) determined a dwarf population – density relation, which showed that the dwarf-to-giant ratio (*DGR*) in low-density regions is higher than in high-density regions.

The data about galaxies in the Las Campanas Galaxy Redshift Survey, the Sloan Digital Sky Survey, and the 2-degree Field Galaxy Redshift Survey (2dFGRS) enable us to study the properties and the spatial distribution of galaxies in detail. Numerous papers have demonstrated a segregation of galaxies by their spectral type, luminosity, and colour index (Norberg et al. 2001, 2002a; Zehavi et al. 2002; Goto et al. 2003; Hogg et al. 2003, 2004; Balogh et al. 2004a; De Propris et al. 2003; Madgwick et al. 2003b; Croton et al. 2005; Blanton et al. 2004, 2006 among others). De Propris et al. (2004) and Blanton et al. (2006) show that the blue galaxy fraction and the recent star formation history in general depend mostly on the local environment of galaxies. In the Blanton et al. (2006) study, the local environment was defined as the spatial density on the $0.5{-}1\ h^{-1}$ Mpc scale, and the global environment as density on the $5{-}10\ h^{-1}$ Mpc scale. Croton et al. (2005) show that galaxy populations depend also on the large-scale environment. Balogh et al. (2004a) compared the populations of star-forming and quiescent galaxies in groups from the 2dFGRS and SDSS surveys and in small ($1.1\ h^{-1}$ Mpc) and large-scales ($5.5\ h^{-1}$ Mpc) and showed that the relative numbers of these galaxies depend on both the local and global environments. Even low-density environments contain a large fraction of non-star-forming galaxies.

Recently several studies have addressed the question whether a critical density exists so that star formation is supressed in all groups/clusters where the density exceeds this critical value (typically within 1−2 cluster virial radii, Gray et al. 2004; Haines et al. 2006). This assumption is supported by the results of Lewis et al. (2002), who used the data about star-forming galaxies in the 2dFGRS to found a correlation between the star formation activity and the local galaxy density that holds for galaxies at distances at least two virial radii from the cluster/group centre.

On the basis of the 2dFGRS, we recently compiled a new catalogue of superclusters of the 2dF galaxies (Einasto et al. 2007a, hereafter Paper I). In Einasto et al. (2007b, hereafter Paper II) we studied various properties of these superclusters: their multiplicity, geometry, luminosity functions, and other properties. We also compared the properties of real superclusters with simulated superclusters from the millennium simulations (Springel et al. 2005) and from the semianalytical mock catalogue by Croton et al. (2006).

The purpose of the work is to compare the properties of rich and poor superclusters (density distributions in superclusters) and to compare the properties of galaxies (spectral types, colours, and luminosities) in rich and poor superclusters and in the field. The use of a large catalogue of superclusters enables us for the first time to study the properties of galaxies in a large number of rich and poor superclusters. These data enabled us to analyse populations of galaxies of different luminosities, morphologies, and star formation rates in various environments: in rich and poor superclusters, as well as in groups located in superclusters and in the field. One aim of this study is to clarify whether the properties of galaxies depend mostly on the local (group/cluster) environment or whether they also depend on their global (supercluster) environment. We also compare the luminosities of the main galaxies of rich and poor superclusters.

The paper is composed as follows. In the next section we describe the supercluster data. Then we study the properties of galaxies in superclusters, the density distribution in superclusters of different richness, and the properties of galaxies in groups located in regions of different large-scale densities in superclusters. Then we compare the luminosities of main galaxies in superclusters and in groups located in the field. In the last section we discuss the results and list our conclusions.

2. Data

2.1. Catalogues of superclusters and groups

We have used the 2dFGRS final release (Colless et al. 2001, 2003) that contains 245 591 galaxies. This survey has allowed the 2dFGRS team and many others to estimate fundamental cosmological parameters and to study the intrinsic properties of galaxies in various cosmological environments; see Lahav (2004, 2005) for recent reviews.

We used the data about galaxies and groups of galaxies to compile a catalogue of superclusters of galaxies from the 2dF survey (Paper I). The 2dF sample becomes very diluted at large distances, thus we restrict our sample by a redshift limit $z = 0.2$ and apply a lower limit $z \geq 0.009$ to avoid confusion with unclassified objects and stars. When calculating (comoving) distances, we used a flat cosmological model with the parameters: matter density $\Omega_m = 0.3$, dark energy density $\Omega_\Lambda = 0.7$ (both in units of the critical cosmological density). Here and elsewhere h is the present-day dimensionless Hubble constant in units of 100 km s^{-1} Mpc^{-1}.

Galaxies were included in the 2dF GRS, if their corrected apparent magnitude $\mathrm{b_j}$ lay in the interval from $m_1 = 13.5$ to $m_2 = 19.45$. The faint limit actually fluctuated from field to field, these fluctuations have been taken into account in the calculation of weights assigned to galaxies. These weights were used to correct the luminosities of galaxies. In the calculation of weights we used for every galaxy the individual values of the faint end magnitudes of the observational window, m_2, which fluctuate from field to field. Also we used a correction for the incompleteness factor $c = \gamma(1 - \exp{(m - \mu)})$, where $\gamma = 0.99$, m is the observed magnitude of the galaxy, and the parameter μ varies from field to field (see Eq. (5) of Colless et al. 2001). The weight of the galaxy is proportional to the inverse of the incompleteness factor. To calculate weights, we assumed that galaxy luminosities are distributed according to the Schechter (1976) luminosity function:

$$\phi(L)\mathrm{d}L \propto (L/L^*)^\alpha \exp{(-L/L^*)}\mathrm{d}(L/L^*), \tag{1}$$

where α and L^* (or the corresponding absolute magnitude $M^* - 5\log_{10} h$) are parameters.

Following Eke et al. (2004), we accepted $M_\odot = 5.33$ in the $\mathrm{b_j}$ photometric system. Further we adopted the $k + e$-correction according to Norberg et al. (2002b) (for details see Paper I). We used the following Schechter parameters to calculate the luminosity weights: $\alpha = -1.21$, $M^* - 5\log_{10} h = -19.66$ (N02). The weights were used to calculate the estimated total luminosity of groups (T06) and superclusters (Paper I) as follows (Einasto et al. 2003b),

$$L_{\mathrm{tot}} = L_{\mathrm{obs}} W_L, \tag{2}$$

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

$$W_L = \frac{\int_0^\infty L\phi(L)\mathrm{d}L}{\int_{L_1}^{L_2} L\phi(L)\mathrm{d}L} \tag{3}$$

is the luminous-density weight (the ratio of the expected total luminosity to the expected luminosity in the visibility window).

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.

We used these luminosities to calculate the luminosity density field with a cell size of 1 h^{-1} Mpc smoothed with an Epanechnikov kernel of radius 8 h^{-1} Mpc; this density field was used to find superclusters of galaxies. We defined superclusters as connected, non-percolating systems with densities above a certain threshold density; the actual threshold density used was 4.6 in units of the mean luminosity density. A detailed description of the supercluster finding algorithm can be found in Paper I.

In our analysis we also used the data about groups of galaxies from the 2dF GRS (T06). Groups in this catalogue were determined using the Friend-of- Friend (FoF) algorithm in which galaxies are linked together into a system if they have at least one neighbour at a distance less than the linking length. The linking length increases slowly with increasing distance from the observer due to sample dilution; for details about the group finding algorithm and the analysis of the selection effects see T06.

Here we want to stress that groups of galaxies were determined using identical FoF parameters independently of the global environment. Thus these parameters fix a certain local number density threshold that is identical both in superclusters and in the field. At lower local number densities, all galaxies are isolated and at higher number densities galaxies belong to groups with at least two member galaxies. Later we will use this division as a local density indicator, to compare the properties of galaxies in various local and global environments.

The catalogues of groups and isolated galaxies can be found at `http://www.aai.ee/~maret/2dfgr.html`, the catalogues of superclusters – at `http://www.aai.ee/~maret/2dfscl.html`.

2.2. Properties of galaxies used in the present analysis

To study various properties of galaxies in superclusters, we used the data about luminosities, spectral types and colours of galaxies as given in the 2dF redshift survey. We divide galaxies into populations of bright/faint galaxies, early/late type galaxies, non-star-forming, and star-forming galaxies and passive/actively star formating galaxies by their luminosity, spectral parameter η, and by the colour index *col* (Madgwick et al. 2002, 2003a; Wild et al. 2005).

In order to divide galaxies into populations of bright and faint galaxies, we wanted to use an absolute magnitude limit close to the break luminosity M^* in the Schechter luminosity function. According to the calculations of the luminosity function, the value of $M^\star$ varies for different galaxy populations (Madgwick et al. 2003a; de Propris et al. 2003; Croton et al. 2005); having values from −19.0 to −20.9. Therefore we used a bright/faint galaxy limit $M_{\rm bj} = -20.0$ as a compromise between different values.

The spectral parameter of galaxies, η, correlates with the morphological type of galaxies (e.g. Madgwick et al. 2002; de Propris et al. 2003); E/S0 galaxies (morphological T-type $T < 0$, Kennicutt 1992) have $\eta \le -1.4$. Thus we divided galaxies into populations of early and late type galaxies using this limit of the spectral parameter η. Moreover, the spectral parameter η is correlated with the equivalent width of the H_α emission line, which makes them an indicator of the star formation rate in galaxies (Madgwick et al. 2002, 2003a). We used the value $\eta < 0.0$ to define the population of quiescent galaxies and $\eta \ge 0.0$ for star-forming galaxies.

We also used information about the colours of galaxies (the rest-frame colour index, $col = (B - R)_0$, Cole et al. 2005) to divide galaxies into populations of passive galaxies and actively star-forming galaxies. For passive (red) galaxies $col \ge 1.07$. We used this limit to separate the populations of passive and actively star-forming galaxies.

2.3. Selection effects and sample of supercluster for the present study

Due to the selection of galaxies within fixed apparent magnitude limits, the observational window in absolute magnitudes shifts toward higher luminosities when the distance of galaxies increases. We analysed the selection effects in our supercluster catalogue in detail in Papers I and II. This analysis showed, in particular, that selections due to the use of a flux-limited sample of galaxies have been properly taken into account when estimating total luminosities of superclusters. For the details we refer the reader to Papers I and II.

One selection effect in flux-limited samples is the decrease of the number of galaxies in superclusters with increasing distance (Fig. 2). Therefore for the analysis we used only systems with at least 10 member galaxies from the main supercluster catalogue of Paper I (which includes all systems up to a comoving distance $D = 520\ h^{-1}$ Mpc) and left out the poorest systems in the supercluster catalogue.

For further analysis of selection effects, we divided our sample of superclusters into the nearby and distant samples, using the limiting distance $D = 300\ h^{-1}$ Mpc. In order to compare the properties of galaxies in individual superclusters, we used volume-limited samples as follows: for the nearby sample we selected galaxies of $M_{\rm bj} \le -18.4$ (in the $b_{\rm j}$ filter used in the 2dFGRS), and galaxies of $M_{\rm bj} \le -19.7$ for the distant sample.

In Fig. 3 we plot the ratio of the numbers of bright and faint galaxies B/F, the ratio of the numbers of early and late type galaxies E/S, and the ratio of the numbers of passive and actively star-forming galaxies P/A in superclusters with respect to the distance and to the number of galaxies. We see that the scatter of the ratio B/F with distance and with the number of galaxies in superclusters (the number of galaxies in superclusters in volume-limited samples, not in full samples) is very small for the nearby sample. In the distant sample the scatter of this ratio is larger, and it increases with distance. This scatter is smaller for richer superclusters. Due to a higher luminosity cut-off in distant superclusters, individual differences between poor distant superclusters affect this ratio more stongly than in nearby superclusters.

Figure 3 shows that the ratios of the numbers of early and late type galaxies E/S and the ratios of passive and actively star-forming galaxies P/A with respect to the distance of superclusters and to the number of galaxies in superclusters increase with distance (in Fig. 1 we show the location of superclusters with the ratio $E/S \ge 3$). Also, this ratio is higher in poor superclusters; in some poor superclusters the ratio E/S is more than ten times higher than in superclusters on average. In some poor superclusters, the number of passive galaxies is 15–20 times larger than the number of actively star-forming galaxies.

This analysis demonstrates that the properties of nearby superclusters show only a small scatter. Additionally, the properties of rich superclusters with at least 200 member galaxies are rather homogeneous. A larger scatter of the properties of distant superclusters may be due to selection effects. This is also

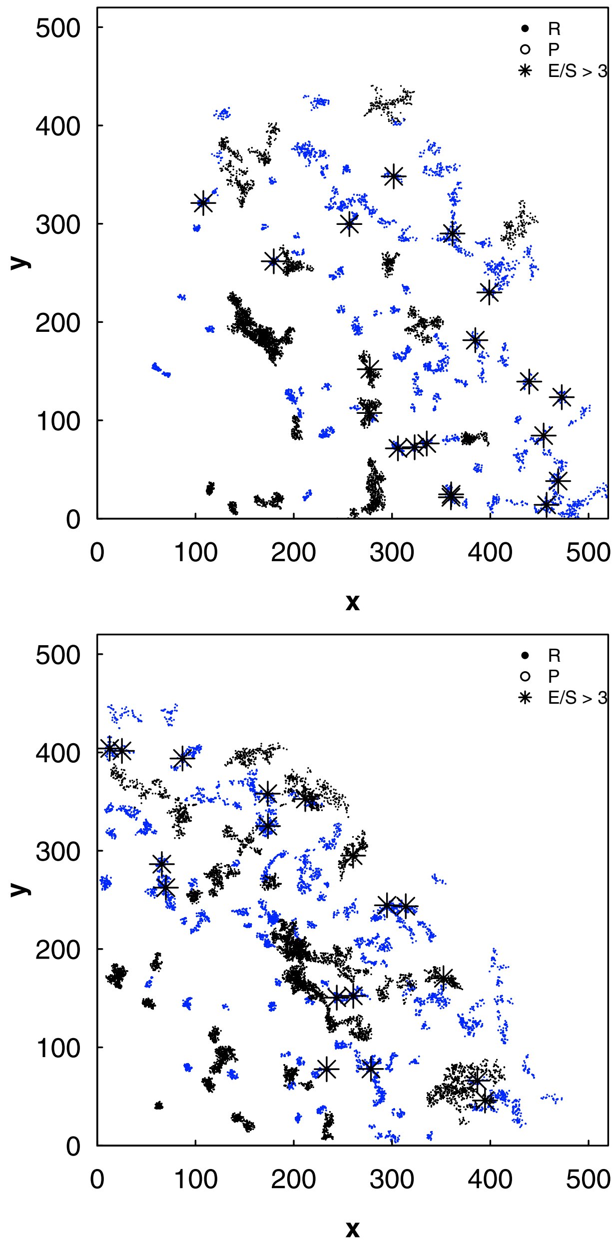

Fig. 1. Galaxies in superclusters with at least 20 member galaxies. *Upper panel*: Northern sky; *lower panel*: Southern sky. Darker dots represent galaxies in rich superclusters with at least 200 member galaxies; lighter dots – galaxies in poor superclusters. Stars indicate poor superclusters, which have the ratio $E/S \geq 3$ (see Sect. 2.3).

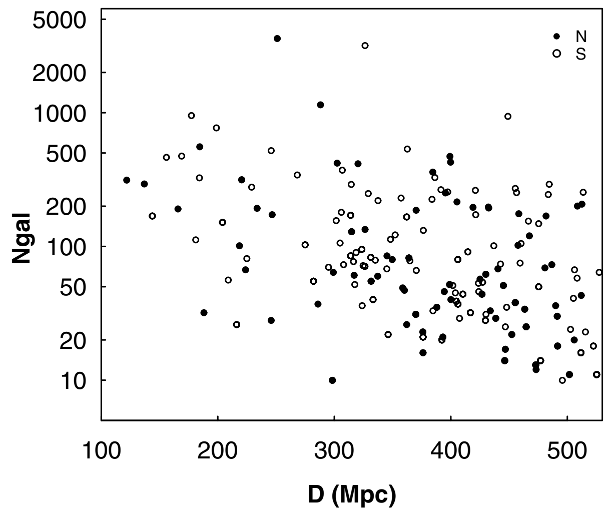

Fig. 2. The distribution of the number of galaxies in superclusters at various distance. N – Northern sky, S – Southern sky.

in accordance with our results in Paper II where we also saw a large scatter of the properties of distant superclusters. These are probably affected by selection effects and poor statistics at large distances (see Fig. 2).

In order to avoid strong selection effects, we chose for the further analysis the volume-limited sample of nearby superclusters with the parameters given above, in total 49 superclusters. We also divided superclusters by their richness: rich superclusters with at least 200 member galaxies (we denote this sample as R), and poor superclusters with less than 200 member galaxies (P). We also used the data about field galaxies, i.e. the galaxies that do not belong to superclusters (approximately 2/3 of all galaxies), as a comparison sample (FG).

3. Properties of galaxies in superclusters

3.1. Luminosities, types, and colours of galaxies in superclusters of different richnesses

Table 1 shows the galaxy content of rich and poor superclusters and field galaxies. Here we also divide galaxies by their luminosity: bright galaxies with $M_{\rm bj} \leq -20.0$ and faint galaxies with $M_{\rm bj} > -20.0$. In Table 2 we give the statistical significance that the distributions of luminosities, spectral parameter η, and colour index *col* are drawn from the same parent sample according to the Kolmogorov-Smirnov test.

We plot in Fig. 4 the differential luminosity functions for galaxies in rich and poor superclusters and in the field (right panel), as well as the distribution of luminosities of galaxies in rich and poor superclusters and in the field (left panel). As we see, the Poisson errors in the probability density histograms are very small, due to a large number of galaxies in our sample. Thus we usually do not show these errors to avoid overcrowding of the figures. Figure 5 shows the distributions of the colour indices *col* of galaxies. We calculated these distributions using the probability density function in R (a language for data analysis and graphics, Ihaka & Gentleman 1996).

Figure 4 shows that there is a weak excess of faint galaxies among field galaxies in comparison with galaxies in superclusters and a much bigger excess of bright galaxies in rich and poor superclusters. Therefore the ratio of the numbers of bright and faint galaxies in the field is lower than this ratio for galaxies in superclusters (Table 1). The Kolmogorov-Smirnov (KS) test shows (Table 2) that the differences between the luminosity distributions of galaxies in rich and poor superclusters are statistically significant at least at a 97% confidence level, and the differences between luminosity distributions of galaxies in superclusters and in the field even at a much higher level (Table 1).

The ratio of the numbers of early and late type galaxies, E/S (characterised by their spectral parameter η) in rich and poor superclusters and in the field (Table 1) shows differences between these populations: this ratio is slightly higher for galaxies in rich superclusters than for galaxies in poor superclusters. Note that this ratio is also higher for bright galaxies in rich superclusters than for bright galaxies in poor superclusters because in rich superclusters the fraction of early type galaxies among bright galaxies is larger than in poor superclusters. In the field,

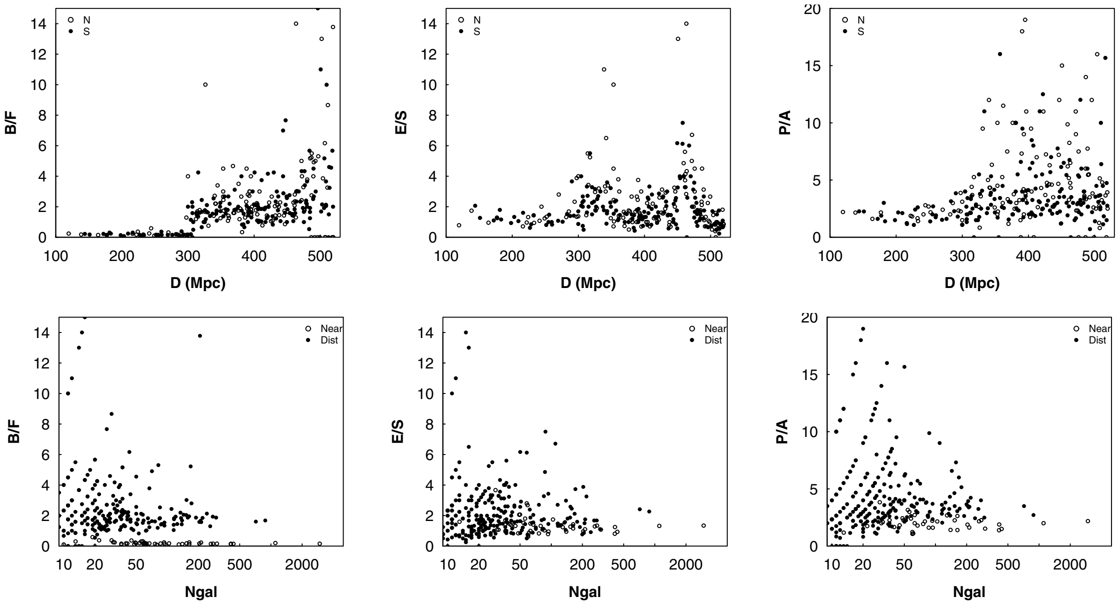

Fig. 3. The properties of galaxies in superclusters versus distances of superclusters (*upper panels*, N – Northern sky, S – Southern sky) and versus the number of galaxies in superclusters (*lower panels*, N – nearby superclusters, D – distant superclusters). *Left*: the ratio of the numbers of bright and faint galaxies; *middle*: the ratio of the numbers of early and late type galaxies; *right*: the ratio of the numbers of passive and actively star-forming galaxies. divided by colour index *col*.

Table 1. The galaxy content in superclusters.

ID	Supercluster rich	poor	populations Field Gal.
$N_{\rm gal}$			
All	7461	1652	36 949
B/F	0.17	0.18	0.14
E/S			
All	1.23	1.21	0.66
B	2.66	2.36	1.60
F	1.09	1.08	0.58
q/SF			
All	2.42	2.29	1.41
B	7.31	6.78	4.34
F	2.11	1.98	1.24
P/A			
All	1.99	1.98	1.03
B	3.11	2.52	1.59
F	1.84	1.89	0.97
$F_{\rm gr}$			
Gr_{10}	0.34	0.30	0.05
Gr_2	0.41	0.47	0.43
I	0.25	0.23	0.52

Sample identification (all – all galaxies, *B* – bright galaxies, *F* – faint galaxies. B/F – the ratio of the numbers of bright ($M_{\rm bj} \leq -20.0$) and faint ($M_{\rm bj} > -20.0$) galaxies, E/S – the ratio of the number of early and late type galaxies, q/SF – the ratio of the numbers of quiescent and actively star-forming galaxies (according to the spectral parameter η), P/A – the ratio of the number of passive and actively star-forming galaxies (according to the colour index *col*). $F_{\rm gr}$ – the fraction of galaxies in groups; Gr_{10} – rich groups with at least ten member galaxies, Gr_2 – poor groups with less than ten galaxies, and *I* – isolated galaxies, i.e. not in any group.
2–4: Supercluster populations: rich superclusters, poor superclusters, field galaxies.

Table 2. The galaxy content in superclusters.

Sample	ID	Kolmogorov-Smirnov test results. *D*	*P*
Bmag			
R	P	0.040	0.02635
R	FG	0.036	1.076e−07
P	FG	0.069	4.117e−07
col			
R	P	0.061	8.495e−05
R	FG	0.162	<2.2e−16
P	FG	0.173	<2.2e−16
η			
R	P	0.027	0.2564
R	FG	0.158	<2.2e−16
P	FG	0.156	<2.2e−16

Note: maximum difference (*D*) and the probability (*P*) that the distributions of population parameters are taken from the same parent distribution.

the fraction of early type galaxies is smaller than in superclusters. This is well known from previous analyses of the density dependence of the galaxy luminosity function (e.g. Blanton et al. 2006), but this dependence is demonstrated here for superclusters as coherent overdensity regions.

The ratio of the numbers of quiescent and actively star-forming galaxies, q/SF (as defined by their spectral parameter η) in rich and poor superclusters and in the field (Table 1) shows even larger differences between bright and faint galaxies both in superclusters and in the field. For bright galaxies this fraction is about three times higher than for faint galaxies. This agrees with the conclusion of Kauffmann et al. (2004) that the star formation rate depends strongly on the environmental density, but here it is shown for supercluster environments.

We note another difference between the galaxy populations of rich superclusters and in the field. In rich superclusters there is an excess of early type (and passive) galaxies among faint galaxies while in the field late type (and star-forming) galaxies dominate among faint galaxies.

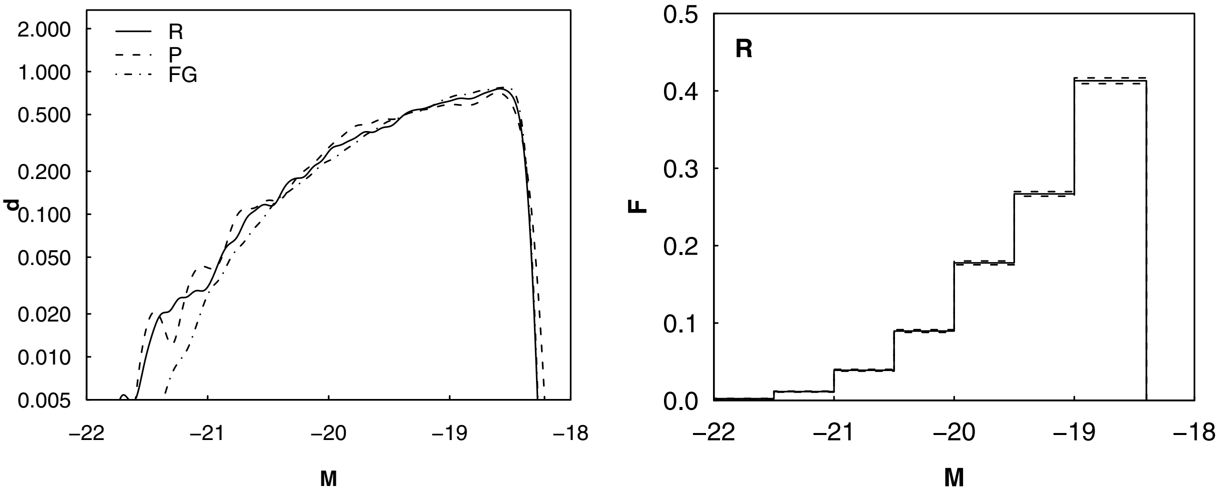

Fig. 4. *Left panel*: the differential luminosity functions for galaxies of the 2dFGRS in rich (R) and poor (P) superclusters and in field (FG) for nearby (N) and distant (D) samples. *Right panel*: differential luminosity function $F = \mathrm{d}N/\mathrm{d}M$, where M is the absolute magnitude of a galaxy, for galaxies in rich (R) superclusters; here the solid line shows luminosity function and dashed lines indicate Poisson errors.

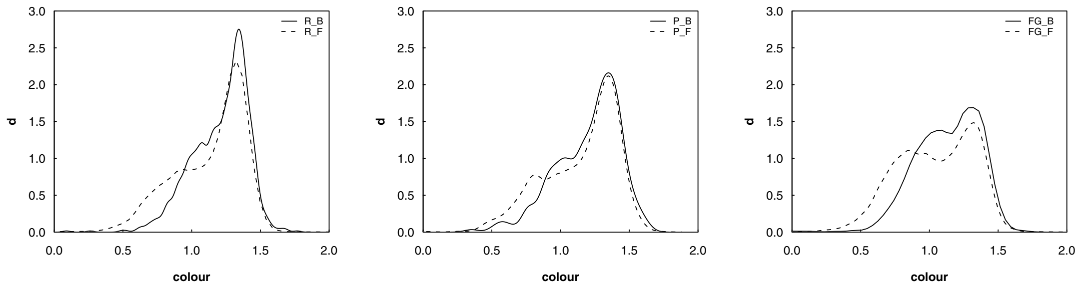

Fig. 5. The distribution of the colour index *col* for galaxies in rich (R, *left panels*) and poor (P, *middle panels*) superclusters and in the field (FG, *right panels*), volume-limited samples, galaxies divided by luminosity: bright galaxies with $M_{\mathrm{bj}} \leq -20.0$ and faint galaxies with $M_{\mathrm{bj}} > -20.0$.

The ratio of passive and active galaxies P/A according to their colour index *col* is given in Table 1 for galaxies in rich and poor superclusters and in the field. In Fig. 5 we show the distributions of the colour index for bright and faint galaxies in these systems. This figure shows a continous change in the distributions of the colours of galaxies from rich to poor superclusters and to field galaxies. The number of red galaxies in rich superclusters is larger than in poor superclusters among both bright and faint galaxies. These distributions are comparable with the environmental study of the galaxy colour distribution of Balogh et al. (2004b). Table 1 shows that there is an excess of quiescent galaxies in rich superclusters even among faint galaxies, while in the field the fraction of actively star-forming galaxies is relatively large. The fraction of actively star-forming galaxies in the field is larger than the fraction of these galaxies in superclusters.

The KS test shows that the differences between the distributions of colour indices of galaxies in rich and poor superclusters, as well as the differences between colour indices of galaxies in superclusters and in the field are statistically significant at least at the 99% confidence level.

The differences between the distributions of the spectral parameters and colour indices of bright and faint galaxies are expected due to the morphology-luminosity-density relation. However, our results show that galaxy populations in rich and poor superclusters are somewhat different; in rich supercluster there are relatively more early type, passive, red galaxies than in poor superclusters.

3.2. Density distribution in rich and poor superclusters

Next we study how the properties of galaxies – their luminosities, types and activity – depend on the large-scale environment, defined as the value of the density field at the location of galaxies (environmental density). We compare the distribution of densities at the location of galaxies of each subsample and for all populations.

The results of this analysis are presented in Table 3 and in Fig. 6. In Table 3 we give the lower quantile, median, and upper quantile values of densities, as well as the results of the KS tests – the maximal differences between the density distributions D, and probabilities p, which show whether sample pairs may belong to the same parent sample.

Let us at first analyse the general distribution of densities in superclusters of various levels of richness (Fig. 6). One remarkable feature seen in this figure is the different distribution of densities in rich and poor superclusters. Densities that correspond to rich superclusters have a median value of $\delta \approx 7.5$, and the maximum densities are about $\delta \approx 17{-}20$ (see also Paper II, where we showed that both mean and maximal densities in rich superclusters are higher than in poor superclusters). These high densities show that rich superclusters contain high-density cores. Densities in poor superclusters show a completely different distribution: they have a median value of $\delta \approx 5.3{-}6.3$, and the maximum value densities are less than $\delta \approx 10$.

We recall that superclusters were defined as connected nonpercolating systems with densities above a threshold density 4.6 in units of the mean luminosity density. We used an identical

Table 3. Environmental densities and KS test results for galaxies of various populations in rich and poor superclusters and for field galaxies.

ID	N	1Q	Med	3Q	KS D	KS p
1	2	3	4	5	6	7
R	7461	5.85	7.35	9.72		
P	1652	4.94	5.38	6.10		
FG	36949	0.99	1.96	2.80		
R_B	1062	5.84	7.32	9.43		
R_F	6399	5.85	7.34	9.73	0.023	0.7
P_B	250	4.90	5.37	6.08		
P_F	1402	4.94	5.38	6.10	0.035	0.95
FG_B	4423	1.27	2.05	3.09		
FG_F	32526	0.95	1.73	2.75	0.015	0.000162
R_E	4044	6.00	7.57	10.22		
R_S	2143	5.73	7.19	9.30	0.080	1.6e−10
P_E	888	4.97	5.44	6.15		
P_S	493	4.88	5.32	5.98	0.099	0.7e−4
FG_E	14262	1.18	1.99	3.04		
FG_S	14882	0.91	1.64	2.64	0.078	2.2e−16
R_q	5192	5.94	7.47	9.98		
R_{SF}	2143	5.73	7.08	9.18	0.067	2.8e−6
P_q	1129	4.95	5.41	6.14		
P_{SF}	493	4.87	5.30	5.96	0.087	0.011
FG_q	21003	1.09	1.91	2.94		
FG_{SF}	14882	0.87	1.59	2.60	0.10	2.2e−16
R_P	4948	5.94	7.49	10.01		
R_A	2513	5.71	7.08	9.12	0.077	5.1e−9
P_P	1097	4.96	5.43	6.14		
P_A	555	4.87	5.31	5.98	0.086	0.009
FG_P	18764	1.12	1.94	3.00		
FG_A	18185	0.87	1.58	2.57	0.11	2.2e−16

The columns in the table are as follows:
1: Population ID. R – rich superclusters, P – poor superclusters, FG – field galaxies; B – bright galaxies ($M_{\rm bj} \leq -20.0$), F – faint galaxies ($M_{\rm bj} > -20.0$), E and S – early and late type galaxies, P and A – passive and actively star-forming galaxies (according to the spectral parameter η), q and SF – quiescent and actively star-forming galaxies (according to the colour index *col*).
2: the number of galaxies in each population.
3–5: the lower quartile, median, and upper quartile values of supercluster parameters.
6 and 7: the Kolmogorov-Smirnov test results: the maximum difference and the probability that the distributions of population parameters are taken from the same parent distribution.

threshold density limit for superclusters of all richnesses. Then we divided superclusters by richness according to the number of galaxies in them, without using any additional condition about the values of the density field in supercluster regions. Thus these differences in density distributions reflect intrinsic properties of rich and poor superclusters, and are not due to some parameters in the supercluster construction.

Next we analysed the distribution of densities at the location of galaxies from different populations. Table 3 shows the distribution of densities around bright and faint galaxies. In poor superclusters the differences between the density distributions are not statistically significant (according to the KS test); in rich superclusters the probability that the density distribution around bright and faint galaxies are taken from the same parent distribution is 0.7. In the field the differences between densities at the location of bright and faint galaxies are statistically significant at a very high level.

Now we compare the density distributions at the location of galaxies of different types. Table 3 shows that, in all systems at the location of early type galaxies, the values of the density field are higher than at the location of late type galaxies. A closer look at Fig. 6 shows several interesting details. In both rich and poor superclusters at densities less than $\delta \approx 7$ there is an excess of late type galaxies. In rich superclusters at densities $\delta \geq 10$ there is an excess of early type galaxies.

The density distributions at the location of quiescent and star-forming galaxies, characterized by their spectral parameter η are given in Table 3. We see that the overall distributions of densities is rather similar to those for early and late type galaxies. Passive galaxies are located at higher environmental densities than actively star-forming galaxies.

The middle panel of Fig. 6 shows the density limits for regions where galaxies of different star formation rates dominate. At densities lower than $\delta \approx 7$, there is an excess of star-forming galaxies in both rich and poor superclusters. Passive galaxies dominate in regions with densities $\delta \geq 10$. These are the same density limits as for early and late type galaxies.

Now let us study the distribution of the environmental densities for galaxies divided into populations of passive (red) and active (blue) galaxies using colour information (Table 3). As found before, passive galaxies have higher environmental densities than actively star-forming galaxies. We see in Fig. 6 that also in this case the density limits for lower density regions where star-forming galaxies dominate and for higher density regions where passive galaxies dominate are the same as in the previous case.

The KS test confirms that the differences between environmental density distributions for galaxies of different properties are statistically significant at very high levels (Table 3). The differences between the densities extend to the lowest amplitudes of the density field (for field galaxies).

To conclude, this figure shows a correlation between the properties of galaxies and environmental density. There are also certain differences between rich and poor superclusters: in rich superclusters there are higher density cores with $\delta > 10$, while in poor superclusters those high-density regions are absent. This is another important difference between rich and poor superclusters. In high-density cores of rich superclusters, early type, red, passive galaxies dominate; in lower density regions ($\delta < 7$), there is an excess of late type, blue, and actively star-forming galaxies. In poor superclusters the galaxy content is similar to that of the low-density regions of rich superclusters (see also Table 4). Among the field galaxies we also see that at lower densities, $\delta < 2.5$ late type, star-forming galaxies dominate, while there is an excess of early type, passive galaxies at higher densities, $\delta > 2.5$.

3.3. Properties of galaxies in groups of different richness in superclusters

About 75% of galaxies in superclusters and about 50% of galaxies in the field belong to groups of galaxies of different richness. We use the group richness as a local density indicator, and study properties of galaxies in different global environments – in high and low-density regions of rich superclusters, in poor superclusters, and in the field. In this analysis we divide groups by their richness as follows: rich groups and clusters, $N_{\rm gal} \geq 10$ (we denote this sample as Gr_{10}); poor groups, $2 \leq N_{\rm gal} < 10$ (Gr_2); and isolated galaxies, $N_{\rm gal} = 1$ (I).

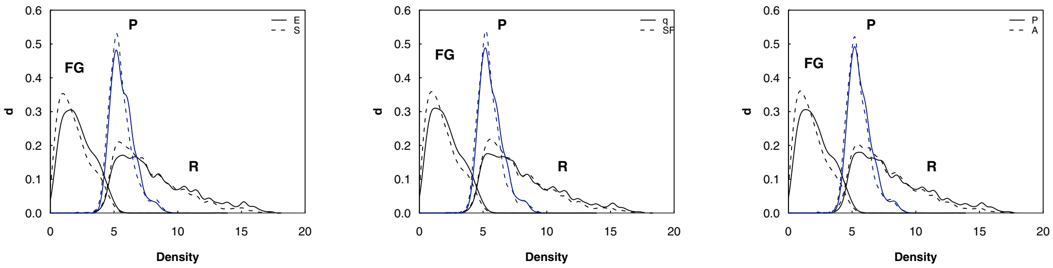

Fig. 6. Environmental density distributions for different populations of galaxies n rich (R) and poor (P) superclusters and in the field (FG). *Left panel*: early and late type galaxies; *middle panel*: quiescent and actively star-forming galaxies (as determined by the spectral parameter η); *right panel*: passive and actively star-forming galaxies (as determined by the colour index *col*).

We note that, in principle, it is the local number density that determines the extent of groups of galaxies (see Sect. 2.1). This number density is identical for all global environments at a given distance from the observer, thus comparing the properties of galaxies in groups and those of isolated galaxies gives us information about properties of galaxies up and below a certain local number-density level. Therefore, we analyse how both the small (group) scale and large (supercluster) scale environments influence the properties of galaxies. The results of this analysis are presented in Table 4 and in Fig. 7. In Table 5 we give the results of the Kolmogorov-Smirnov test showing the probability that the distributions of the spectral parameters η and the colour index *col* are drawn from the same parent sample.

Figure 7 and Table 4 show additional interesting features. First we analyse the colour distribution of galaxies in groups if different richness class, hosted by superclusters and located in the field. The fraction of passive (red) galaxies is largest in rich groups in the high-density cores of rich superclusters. Even in poor groups in these high-density regions the fraction of passive galaxies is larger than this fraction in poor groups in poor superclusters and in the field. And finally, the fraction of passive galaxies among galaxies that do not belong to groups, but are located in superclusters, is 1.5 times higher than among isolated galaxies in the field. Therefore star formation in galaxies in high-density cores of superclusters is suppressed even for isolated galaxies and not only in rich groups and clusters in these regions. This demonstrates the strong influence of the supercluster environment on galaxy properties.

The fraction of star-forming galaxies in low-density regions of rich superclusters and in poor superclusters is similar as already found by Blanton et al. (2006). In the field, star-forming galaxies are as abundant as isolated supercluster galaxies, while passive galaxies dominate in groups.

Figure 7 also shows a shift to blue colours when we compare the distribution of the colour index *col* for isolated galaxies in superclusters and in the field. Therefore the differences between colour distributions berween these populations are even larger than the ratio P/A shows.

We see similar trends when we study the fractions of quiescent and actively star-forming galaxies, according to spectral information, in rich and poor groups in superclusters and in the field. In high-density regions of rich superclusters, the fraction of passive galaxies is the largest. Even among isolated galaxies in these regions, the ratio of the numbers of quiescent and actively star-forming galaxies is comparable to in poor groups in less dense environments, in low-density regions of rich superclusters and in poor superclusters.

The ratio of the numbers of early and late type galaxies shows a strong dependence on the large-scale environment: in high-density cores early type galaxies dominate both in rich and in poor groups; even among isolated galaxies in these regions late and early type galaxies are almost equally present, while in poor superclusters and in low-density regions of rich superclusters late type galaxies dominate among isolated galaxies.

The KS test shows (Table 5) that the probability that the galaxy content in rich and poor clusters and that of isolated galaxies in high-density regions of rich supercluster, and in

Table 4. Properties of galaxies in groups of different richness in superclusters.

ID 1	R_H 2	R_L 3	P 4	FG 5
N_{gal}				
Gr_{10}	878	1664	501	1788
Gr_2	536	2528	769	15981
I	285	1570	382	19180
E/S				
All	1.72	1.12	1.21	0.66
Gr_{10}	2.52	2.00	2.46	1.67
Gr_2	1.35	1.03	1.04	0.82
I	0.93	0.70	0.69	0.49
q/SF				
All	3.24	2.24	2.29	1.41
Gr_{10}	4.87	4.04	4.69	3.47
Gr_2	2.44	2.01	2.09	1.61
I	1.99	1.59	1.30	1.17
P/A				
All	2.69	1.81	1.98	1.03
Gr_{10}	4.23	3.37	3.91	2.89
Gr_2	2.21	1.72	1.73	1.29
I	1.28	1.12	1.23	0.78
B/F				
All	0.16	0.17	0.19	0.14
Gr_{10}	0.16	0.19	0.20	0.20
Gr_2	0.18	0.18	0.19	0.16
I	0.10	0.13	0.11	0.11

The columns in the table are as follows:
1: group membership: Gr_{10} – galaxies in rich ($N_{gal} \geq 10$) groups, Gr_2 – galaxies in poor ($N_{gal} < 10$) groups, I – isolated galaxies (i.e. galaxies that do not belong to groups);
2–5: populations: R_H – high-density regions ($\delta \geq 10$) of rich superclusters, R_L – low-density regions ($\delta < 10$) of rich superclusters, P – poor superclusters, FG – field galaxies;
E/S – the ratio of the numbers of early and late type galaxies, q/SF – the ratio of the numbers of quiescent and actively star-forming galaxies (according to the spectral parameter η), P/A – the ratio of the numbers of passive and actively star-forming galaxies (according to the colour index *col*), B/F – the ratio of the numbers of the bright ($M_{bj} \leq -20.0$) and faint ($M_{bj} > -20.0$) galaxies.

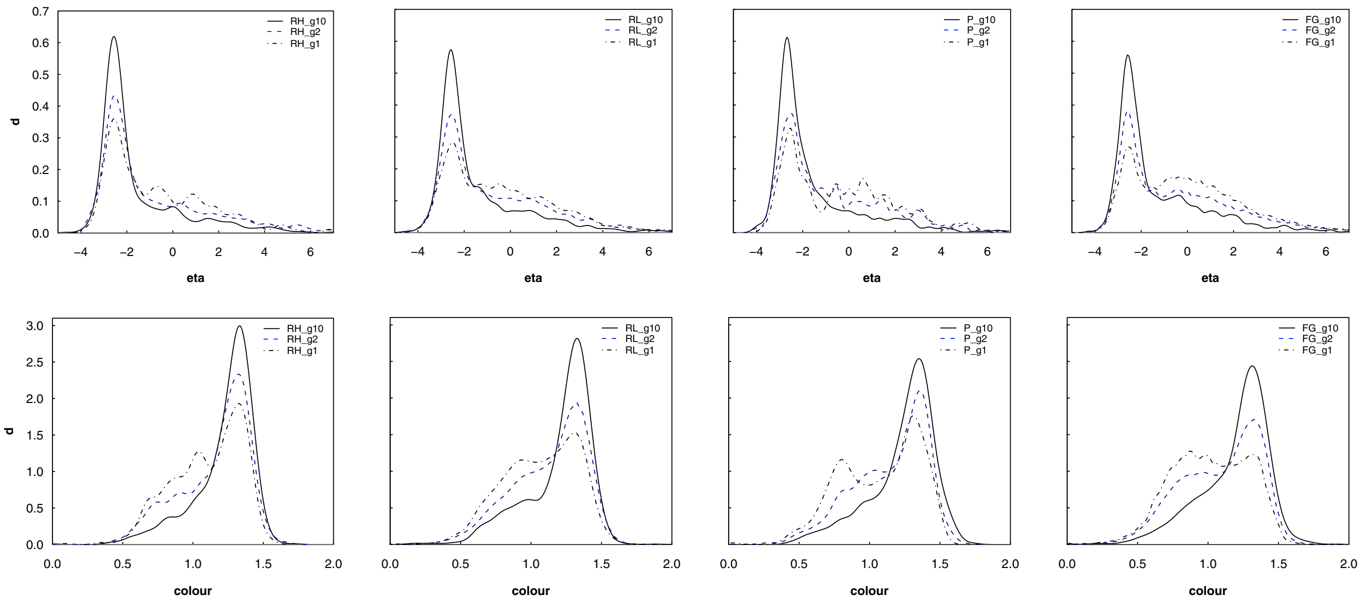

Fig. 7. Distributions of the spectral parameter η (*upper panels*) and the colour index *col* (*lower panels*) for galaxies in rich ($N_{\rm gal} \geq 10$) and poor ($N_{\rm gal} < 10$) groups, and for isolated galaxies. *From left to right*: $R_{\rm HD}$ – high density ($\delta \geq 10$) regions of rich superclusters, $R_{\rm LD}$ – low density ($\delta < 10$) regions of rich superclusters, *P* – poor superclusters, *FG* – field galaxies.

low-density regions of rich superclusters, and in poor superclusters are taken from the same parent distribution is typically less than 0.1, the probability that the galaxy content in superclusters and in the field are taken from the same parent distribution is much lower.

These results show that both local (group/cluster) environments and global (supercluster) environments are important in forming galaxy morphologies and star formation activity. In particular, we provide a strong dependence of the galaxy colours on the supercluster environment besides the dependence on the local density, while the actual star formation rate depends more on the local environment. Similar conclusions were derived from Blanton et al. (2006), but there only the large-scale density field was considered and not superclusters as physical entities. In particular, we showed characteristic differences between rich and poor superclusters.

A weak dependence of the ratio of the numbers of bright and faint galaxies on the environment, found in the present analysis, is caused by the fact that we only used the data about relatively bright galaxies. Among isolated galaxies, the fraction of bright galaxies is smaller, thus the differences between the properties of galaxies in groups and isolated galaxies at least come partly from the luminosity difference. However, in superclusters of different richness the ratio B/F for galaxies in groups and for isolated galaxies is similar, thus the differences between the properties of galaxies in rich and poor superclusters are not due to the different luminosities of galaxies.

3.4. Luminosities of supercluster main galaxies

We determined the main group for each supercluster and its main galaxy as described in Paper I. The most luminous cluster in the vicinity of the highest density peak in a supercluster is considered as the main cluster and its brightest galaxy – the main galaxy of the supercluster. When determining main galaxies, we used an automated search routine, without using supplementary information on the morphological type, colour, etc.

Figure 8 (left panel) shows the luminosities of main galaxies of superclusters at various distances from the observer. Since almost all main galaxies have a higher luminosity than the 2dF survey limit the trend with distance is weak. Note the narrow range of luminosities of main galaxies.

Figure 8 (right panel) shows the distributions of luminosities of supercluster main galaxies. This figure shows that main galaxies of rich superclusters have higher luminosities than those of poor superclusters. The median luminosities of main galaxies of rich and poor superclusters and of groups in the field are, correspondingly, $M_{\rm bj} = -21.2$, $M_{\rm bj} = -20.8$ and $M_{\rm bj} = -19.3$ mag. The Kolmogorov-Smirnov test shows that the probability that the luminosities of main galaxies of rich and poor superclusters are taken from the same parent distribution is less than 0.05, the probability that the luminosities of main galaxies of superclusters and of groups in the field are taken from the same parent distribution is less than 10^{-16}.

4. Discussion and conclusions

A detailed study of luminosity functions of galaxies from the 2dF survey in regions of different density of the large-scale environment was made by Croton et al. (2005) and in clusters by De Propris et al. (2003). De Propris et al. (2003) found that the luminosity functions of early type galaxies in clusters are brighter and steeper than those in the field and that clustering of passive galaxies is stronger than clustering of actively star-forming galaxies (Madgwick et al. 2003b). Using densities smoothed on a scale of 8 h^{-1} Mpc Croton et al. (2005) divided the volume under study into 7 regions of various environmental densities from extreme voids to cluster populations and found that the brightest galaxies in voids are approximately 5 times fainter than those in clusters. Even larger differences between luminosities of galaxies in high and low-density regions were found in Einasto et al. (2005b). In the present paper we show, in accordance to these results, that the luminosity-density dependence is important for galaxies of all types, both in superclusters and among field galaxies at all densities.

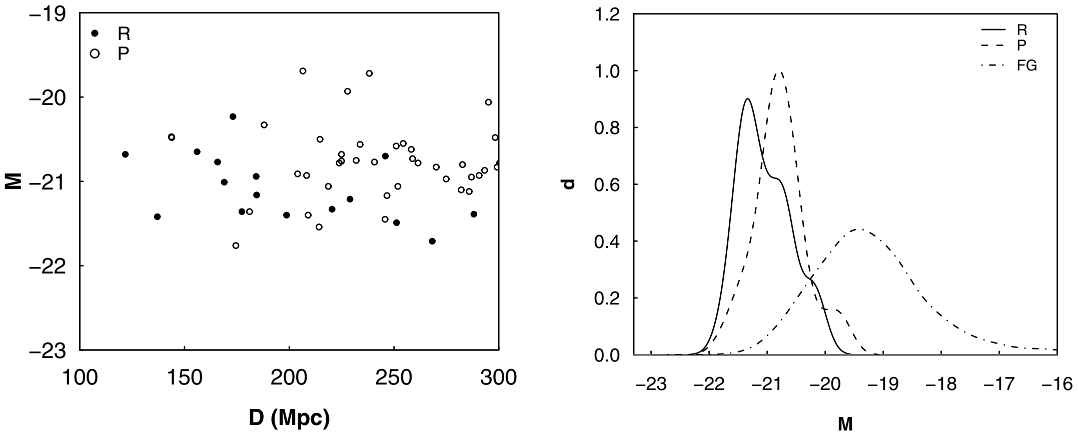

Fig. 8. *Left panel*: the luminosity of the main galaxy of rich (R) and poor (P) superclusters vs. the distance of the supercluster. *Right panel*: the distributions of the luminosities of main galaxies of rich (R) and poor (P) superclusters and of groups in the field (FG).

Table 5. Properties of galaxies in groups of different richness in superclusters. The Kolmogorov-Smirnov test results.

ID1	ID2	D	P
1	2	3	4
col			
RH$_{Gr10}$	RH$_{Gr2}$	0.14	1.90e-06
RH$_{Gr2}$	RH$_{I}$	0.13	0.005
RH$_{Gr10}$	RL$_{Gr10}$	0.05	0.070
RH$_{Gr2}$	RL$_{Gr2}$	0.08	0.007
RH$_{I}$	RL$_{I}$	0.08	0.071
RL$_{Gr10}$	P$_{Gr10}$	0.10	0.001
RL$_{Gr2}$	P$_{Gr2}$	0.07	0.008
RL$_{I}$	P$_{I}$	0.07	0.080
P$_{Gr10}$	FG$_{Gr10}$	0.11	1.00e−4
P$_{Gr2}$	FG$_{Gr2}$	0.11	1.20e−07
P$_{I}$	FG$_{I}$	0.14	1.30e−06
η			
RH$_{Gr10}$	RH$_{Gr2}$	0.17	2.8e−08
RH$_{Gr2}$	RH$_{I}$	0.11	0.021
RH$_{Gr10}$	RL$_{Gr10}$	0.07	0.009
RH$_{Gr2}$	RL$_{Gr2}$	0.08	0.008
RH$_{I}$	RL$_{I}$	0.09	0.052
RL$_{Gr10}$	P$_{Gr10}$	0.08	0.015
RL$_{Gr2}$	P$_{Gr2}$	0.03	0.594
RL$_{I}$	P$_{I}$	0.07	0.108
P$_{Gr10}$	FG$_{Gr10}$	0.11	1.1e−4
P$_{Gr2}$	FG$_{Gr2}$	0.09	4.1e−5
P$_{I}$	FG$_{I}$	0.09	4.8e−3

The columns of Table 5 are as follows:
1–2: sample ID. Gr_{10} – galaxies in rich ($N_{\rm gal} \geq 10$) groups, Gr_2 – galaxies in poor ($N_{\rm gal} < 10$) groups, I – isolated galaxies (i.e. galaxies that do not belong to groups); RH – high-density cores of rich superclusters, RL – low-density regions of rich superclusters, P – poor superclusters, FG – field galaxies.
3–4: the Kolmogorov-Smirnov test results: the maximum difference and the probability that the distributions of population parameters are taken from the same parent distribution.

Phillipps et al. (1998) determined the dwarf-to-giant ratio *DGR* in rich clusters and in the field and find that there is relatively more dwarf galaxies in the field (a low-density environment) than in clusters (a high-density environment). Our Fig. 4 also shows that galaxies in the field have lower luminosities than galaxies in superclusters. Comparison of the ratios of the numbers of bright and faint galaxies B/F in groups of different richness and for isolated galaxies (Table 4) shows as well that there are relatively more bright galaxies in groups and more faint galaxies among isolated galaxies (in a low density environment), in accordance with the results by Phillipps et al. (1998).

Several recent studies address the problem whether the properties of galaxies, and their star formation activity in particular, correlates with the local and/or global environment of galaxies, defined, for example, as the clustercentric distance. The well-known morphology-density relation is an example of such a correlation (Dressler 1980). One question asked in these studies is whether a critical density exists so that star formation is suppressed in all groups/clusters where the density exceeds this critical value. Lewis et al. (2002) use the data about star-forming galaxies in the 2dFGRS to show that a correlation exists between the star formation activity and the local galaxy density that holds for galaxies at distances at least two virial radii from the cluster/group centre.

Balogh et al. (2004a) compare the populations of star-forming and quiescent galaxies on small (1.1 h^{-1} Mpc) and large scales (5.5 h^{-1} Mpc) and show that the relative numbers of these galaxies depend both on the local and global environments. Even low-density environments contain a large fraction of non-star-forming galaxies. They conclude that the galaxy population must be only indirectly related to their present-day environment. Possible physical mechanisms must have been more effective in the past and perhaps affected the star formation rate on very short (less than 1 Gyr) timescales, like starbursts induced by galaxy interactions in close pairs of galaxies (see Balogh et al. 2004a, and references therein).

Gray et al. (2004) use data about the supercluster A901/902 and find strong evidence that the highest-density regions in clusters are mostly populated with quiescent galaxies, while star-forming galaxies dominate in outer/lower-density regions of clusters. Similarly, Haines et al. (2006) demonstrate that the colours of galaxies in the core region of the Shapley supercluster depend on the environment, redder galaxies being located in cluster cores. They also find large concentrations of faint blue galaxies between clusters.

Our results are in accordance with those; in addition we have shown that even on supercluster scales, the properties of galaxies and their environmental densities are correlated. In high-density cores of rich superclusters, the fraction of quiescent (red) galaxies is higher than this fraction in lower density regions even for those galaxies not belonging to groups or clusters.

Porter & Raychaudhury (2005) investigated the star formation rate in groups of galaxies from the Pisces-Cetus supercluster, according to their spectral index η. They concluded that galaxies in rich clusters have lower star formation rates than galaxies in poor groups. This agrees with our results, showing that galaxies from a higher density environment have lower star formation rates than galaxies from a lower density environment.

Our previous analysis in Paper II demonstrated that geometrical properties of rich and poor superclusters are different, that rich superclusters have larger sizes, and that their shapes and compactness differ from those of poor superclusters. The mean density of superclusters increases gradually with increasing total luminosity or richness of superclusters. This demonstrates that rich superclusters are physical systems with different properties from those of poor systems, and they do not just represent percolations of several loose systems.

Our present study reveals additional differences between rich and poor superclusters. Rich superclusters contain high-density cores that are absent in poor superclusters. Using the group richness as a local density indicator, we have shown that the fraction of early type and passive galaxies in groups and clusters and among isolated galaxies in high-density cores of rich superclusters is higher than in groups in poor superclusters and in the field.

Hilton et al. (2005) find that the fraction of early spectral type galaxies is significantly higher in clusters with a high X-ray flux. Many of these clusters belong to rich superclusters (Einasto et al. 2001; Belsole et al. 2004), so this result is in accordance with the present paper.

Our analysis shows that the main galaxies of superclusters form a specific class of galaxies with a very limited range of luminosities. Main galaxies of rich superclusters are more luminous than main galaxies of poor superclusters. A similar conclusion was reached by Einasto & Einasto (1987) using data on nearby superclusters. This agrees with the result of De Propris et al. (2003) that there is an excess of very bright galaxies in the cores of clusters. The main galaxies of superclusters are formed by multiple merger processes, as indicated by direct observations and numerical simulations (see Laine et al. 2003; Gao et al. 2005a).

It has been known for a long time that first-ranked cluster galaxies have a small dispersion of absolute magnitudes (Hubble & Humason 1931; Hubble 1936; Sandage 1976). More recent studies by Postman & Lauer (1995) and Laine et al. (2003) have shown that absolute magnitudes of brightest cluster galaxies have a scatter of about 0.24−0.33 mag. The scatter of luminosities of supercluster main galaxies is larger than the scatter of brightest cluster galaxies. There may be several reasons for this. One possibility is that we found the main group and its main galaxy by an automated search routine, and supplementary information on the morphological type, colour, etc. has not been used. For this reason our sample of main galaxies is probably not as homogeneous as samples of the first-ranked cluster galaxies investigated by Hubble, Sandage, Postman and others.

Numerical simulations show that the dynamical evolution in high-density regions is determined by a high overall mean density that speeds up the clustering of particles (Einasto et al. 2005b, and references therein; Gao et al. 2005b). In high-density regions clustering starts early and continues until the present. The haloes that populate high-density regions are themselves also richer, more massive, and have higher velocities than the haloes in low-density regions. In low-density filaments that cross voids, as well as in the outer low-density regions of high-density systems, the mean density is low and thus the evolution is slow; and in these regions, haloes themselves are also poor, less massive, and they have low velocities. These differences affect the evolution and properties of galaxies in various environments.

In this paper we have used a catalogue of superclusters of galaxies from the 2dF galaxy redshift survey to study the properties of galaxies in superclusters and the properties of the richest superclusters. Our main conclusions are the following.

- The density distributions in rich and poor superclusters are different. The densities in rich superclusters are higher than in poor superclusters, and rich superclusters contain high-density cores that are absent in poor superclusters.
- Rich superclusters contain a higher fraction of early type, passive, red galaxies than poor superclusters.
- The properties of galaxies are correlated with the values of the luminosity density field smoothed on a scale of 8 Mpc/h: early type, passive, non-starforming galaxies have higher environmental densities, while late type, active, star-forming galaxies have lower environmental densities. This trend extends to field galaxies and to the lowest densities in our sample.
- The fraction of early type, passive galaxies is the highest in rich groups/clusters in high-density regions of rich superclusters. In these high-density regions, even among isolated galaxies, the fraction of star-forming galaxies is smaller than the fraction of star-forming galaxies among isolated galaxies in poor superclusters and in the field.
- The main galaxies of rich superclusters have higher luminosities than the main galaxies of poor superclusters and the main galaxies of groups in the field (the median values of luminosities are, correspondingly, $M_{\rm bj} = -21.2$, $M_{\rm bj} = -20.8$, and $M_{\rm bj} = -19.3$ for rich and poor superclusters and for groups in the field).

Our results show that both the local (group/cluster) environment and the global (supercluster) environment are important in influencing galaxy morphologies and their star formation activity. This indicates the importance of the role of superclusters, and especially rich superclusters as a high-density environment, which affects the properties of their member galaxies and groups/clusters of galaxies.

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