Galaxy groups in the 2dF redshift survey: Galaxy Spectral Type Segregation in Groups

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ABSTRACT

The behaviour of the relative fraction of galaxies with different spectral types in groups is analysed as a function of projected local galaxy density and the group-centric distance. The group sample was taken from the 2dF Group Galaxy Catalogue constructed by Merchán & Zandivarez. Our group sample was constrained to have a homogeneous virial mass distribution with redshift. Galaxies belonging to this group sample were selected in order to minimize possible biases such as preferential selection of high luminosity objects. We find a clear distinction between high virial mass groups ($M_V > 10^{13.5} M_\odot$) and the less massive ones. While the massive groups show a significant dependence of the relative fraction of low star formation galaxies on local galaxy density and group-centric radius, groups with lower masses show no significant trends. We also cross-correlate our group subsample with the previously identified clusters finding that this sample shows a very similar behaviour as observed in the high virial mass group subsample.

Key words: galaxies: groups - star formation - spatial distribution - segregation

1 INTRODUCTION

There is a strong evidence that high density environments can significantly affect many galaxy properties. This evidence is both theoretical (e.g. Gunn & Gott 1972, Torman 1998) and observational (e.g. Zabludoff & Franx 1993, Henriksen & Jones 1996). In particular
star formation rates (Dressler et al. 1985, Balogh et al. 1998, Allam et al. 1999, Hashimoto et al. 1999, Moss & Whittle 2000, Carter et al. 2001), gas content (Giovanelli & Haynes 1985, Vollmer et al. 2001, Solanes et al. 2001) and morphology change. Dressler (1980) find a clear correlation between galaxy morphology with the projected local galaxy density (hereafter \( \Sigma_{gal} \)) defined with the ten nearest galaxies on the sky. Dressler et al. (1997) also found that, for distant clusters the fraction of S0 galaxies is 2-3 times smaller than in lower redshift clusters suggesting that S0’s are generated in large numbers only after cluster virialization. Whitmore et al. (1993) reexamine Dressler’s sample of galaxies in clusters and suggest that the morphology-cluster centric distance relation is more fundamental than the morphology-local galaxy density relation. Whitmore & Gilmore (1991) found that the fraction of ellipticals is roughly 15% at the edge of a cluster all the way to about 0.5 Mpc from the center, at which point it begins to rise dramatically, reaching values of 60 – 70% at the very center.

Various physical process have been proposed to explain these and other systematic differences between the field and cluster galaxy populations. Among them we can mention gas evaporation (Cowie & Songaila 1977), ram pressure stripping (Gunn and Gott 1972, Abadi et al. 1999, Quilis et al. 2000), truncated star formation (Larson et al. 1980, Balogh, Navarro & Morris 2000), galaxy harassment (Moore et al. 1996), merging (Barnes 1992, Lavery & Henry 1998, Steinmetz & Navarro 2002), tidal striping and shaking (Bird & Valtonen 1990, Miller 1988), etc. Although the above processes are all plausible, the effects provided by initial conditions on galaxy formation could also be a very important part in the segregation scenario within current hierarchical models of structure formation as the Cold Dark Matter model.

Recently, Domínguez, Muriel & Lambas (2001) analysed the relative fraction of morphological galaxy types in clusters as a function of the projected local galaxy density, and different cluster global parameters: projected gas density, projected total mass density and reduced clustercentric distance. The authors conclude that there are different mechanisms controlling the morphological segregation depending on the galaxy environment. They found that mechanisms of global nature dominate in high density environments, namely the virialized regions of clusters, while local galaxy density is the relevant parameter in the outskirts where the influence of cluster as a whole is relatively small compared to local effects.

In the field, galaxies form stars at rates several times higher than systems of similar luminosities at the cores of clusters. This is partly a result of the well-known morphology-
density relation, since ellipticals and S0 galaxies are more abundant in clusters (Dressler 1980), but there is evidence that even later type galaxies in clusters and groups form stars at lower rates than in the field (Zabludoff & Mulchaey 1998, Balogh et al. 1999, Allam et al. 1999) suggesting that the cluster environment somehow curbs the star formation rates of all galaxies, regardless of morphology.

Postman & Geller (1984) gave evidence for the existence of a morphology-density relation in loose groups obtained from the CfA Redshift Survey. The authors found an absence of morphology-density relation at very low densities. However high density groups show a small change in the morphological fractions for the densest bins. Whitmore (1995) suggests that a possible problem with their study was the inclusion of clusters of galaxies in their sample. Many of the galaxies in the densest groups are cluster members. By removing these cluster galaxies the author reexamined the morphology-density relation finding that it is very weak or non existent in groups. Hashimoto et al (1999) using a very large and homogeneous dataset from the Las Campanas Redshift Survey showed that the star formation rates of galaxies are sensitive to the local galaxy density, in such way that galaxies show higher levels of star formation in low density than in high density environments.

Most of the galaxies in the universe belong to groups of galaxies, but, due to the difficulty of discerning them from the field, groups of galaxies are, as a whole, not as well studied as larger systems. These favorable environments for galaxy interactions, where the influence of the intergalactic medium and the tidal influences of the global potential are weaker, provide useful insights to understand the effects of the medium on morphology and star formation. A useful parameter that contains information on both morphology and current star formation in galaxies is that defined in Madwick et al (2002) where low values of this parameter, $\eta < -1.4$, correspond mainly to early-types dominated by an old stellar population while positive large values of $\eta$ correlate with late morphological types and increasing star formation rates.

Merchán & Zandivarez (2002) have identified galaxy groups in the 2dF public 100K data release using a modified Huchra & Geller (1982) group finding algorithm taking into account the 2dF magnitude limit and redshift completeness masks. The global effects of group environment on star formation was analysed by Martínez et al (2002) using this catalogue. They have found a strong correlation between the relative fraction of different galaxy types and the parent group virial mass. For groups with $M \gtrsim 10^{13} M_\odot$ the relative fraction of star forming galaxies is significantly suppressed indicating that the low mass group environment is affecting star formation.
Figure 1. Fraction of the different spectral types as a function of the projected local galaxy density for galaxies in low mass groups ($M_V < 10^{13.5} M_\odot$). Type 1 correspond are plotted with filled circles connected with dotted lines, Type 2 with filled squares connected with short dashed lines, Type 3 with open circles connected with long dashed lines and Type 4 with filled triangles connected with dotted dashed lines. Error bars were estimated using the bootstrap resampling technique. The horizontal lines are the mean fraction of galaxies for each spectral type in the whole 2dFGRS with same selection criteria as galaxies in groups. In the small box in the upper left corner are displayed the fraction of spectral Type 1 (dotted line) and Type 2 plus Type 3 (continuous line).

In this paper, we present hints toward understanding local environment effects affecting the spectral types of galaxies in groups, taking advantage of a very large and homogeneous available dataset. In analogy with the dependence of morphology on environment we introduce the spectral type-density relation and spectral type fraction as a function of the group center distance for a subsample of galaxies in groups taken from the catalogue of Merchán & Zandivarez (2002). The outline of this paper is as follows. Section 2 describes the selection of the samples, whereas in section 3 the correlation between the fraction of galaxies of different star forming characteristics with local galaxy density and group center distance are analysed. Finally, a summary is presented in section 4.

2 SAMPLE SELECTION

Samples of galaxies and groups used in this work were selected from the Merchán & Zandivarez (2002) group catalogue (hereafter 2dFGGC). This catalogue was constructed from the 2dF public 100K data release of galaxies with the best redshift estimates within the northern (NGP, $-37^\circ.5 < \delta < -22^\circ.5$, $21^h 40^m < \alpha < 3^h 30^m$) and southern ($-7^\circ.5 < \delta < 2^\circ.5$, $9^h 50^m < \alpha < 14^h 50^m$) strips of the catalogue. The finder algorithm used for group identifica-
Table 1. Comparison of Groups Catalogues Mean parameters. UZC+SSRS2 values consider only groups with more than five members

| Catalogue   | N  | $\sigma$(km/s) | $\bar{M}(h^{-1}M_\odot)$ | $R_V(h^{-1}Mpc)$ |
|-------------|----|----------------|--------------------------|-----------------|
| 2dFGGC      | 2209 | 261            | $8.5 \times 10^{13}$     | 1.12            |
| LCRSGC      | 1495 | 164            | $1.9 \times 10^{13}$     | 1.16            |
| UZC+SSRS2   | 441  | 264            | $4.6 \times 10^{13}$     | 1.06            |

The group properties are similar to that developed by Huchra & Geller (1982) but modified taking into account redshift completeness and magnitude limit mask present on the current release of galaxies (see Figure 13 and 15 of Colless et al. 2001). In the construction of the 2dFGGC values of $\delta \rho/\rho = 80$ and $V_0 = 200$ km s$^{-1}$ were used to maximize the group accuracy. These optimal parameters are the result of several tests using mock catalogues that take into account the current radial and angular selection functions of the 2dFGRS. The linking parameters were scaled to a fiducial redshift $cz = 1000$ km s$^{-1}$. The resulting group catalogue comprises a total number of 2209 galaxy groups with at least 4 members and mean radial velocities in the range $900$ km s$^{-1} \leq V \leq 75000$ km s$^{-1}$. Virial group masses were estimated using the virial radius and the velocity dispersion ($M_{vir} = \sigma^2 R_V/G$, Limber & Mathews 1960) where the former is computed with the projected virial radius and the later with their radial counterpart. In Table 1 we show the comparison between the mean properties of the 2dFGGC with the most recent results for groups in Las Campanas Redshift Survey (LCRS, Tucker et al 2000) and the combination of the groups in the Updated Zwicky Catalogue and Southern Sky Redshift Survey 2 (UZC+SSRS2, Ramella et al 2002)

Our sample of galaxies in groups is similar to the first sample used in Martínez et al. (2002), selected in order to achieve the highest level of completeness. The groups are limited to the redshift range $0.02 \leq z \leq 0.056$ due to the highly homogeneous distribution of group virial masses with redshift. Therefore, we minimize the possibility of a preferential bias to high mass groups in the sample. To prevent a sample biased to high luminosity galaxies, we also introduce an absolute magnitude cut-off on the galaxies ($M_{bJ} \leq -17.2$) defined by the volume sampled. Thus any preferred galaxy type is avoided.

Madgwick et al (2002) have shown that for emission line galaxies, the equivalent width of $H_\alpha$ emission-line, $EW(H_\alpha)$, is very tightly correlated to the $\eta$ parameter defined in that work. The $\eta$ parametrization of a galaxy spectral properties is based upon a Principal Component Analysis of the galaxy spectra that takes into account the relative emission/absorption line strength present in a galaxy’s optical spectrum. This classification correlates well with
morphology and can be interpreted as a measure of the relative current star-formation present in each galaxy.

Since we are interested in the study of the properties of galaxies on systems of galaxies, we consider the 4 types of Madgwick et al (2002):

- Type 1: $\eta < -1.4$,
- Type 2: $-1.4 \leq \eta < 1.1$,
- Type 3: $1.1 \leq \eta < 3.5$,
- Type 4: $\eta \geq 3.5$.

The Type 1 class is characterized with an old stellar population and strong absorption features, the Types 2 and 3 comprise spiral galaxies with increasing star formation, finally the Type 4 class is dominated by particularly active galaxies such as starbursts. With this distinction we are able to analyse the environmental dependence of galaxy spectral types in groups.

3 GALAXY SEGREGATION ANALYSIS IN GROUPS

In this section, the fraction of each galaxy type is studied as a function of local galaxy environment, namely, the projected local galaxy density and the normalized group-centric distance.
3.1 Projected local galaxy density

We follow the suggestion of Domínguez, Muriel & Lambas (2001) that at low density environments the local galaxy density is a primary parameter in determining galaxy morphology. Therefore, we analyse how different types correlate with projected local galaxy density. This density was computed in a way similar to that in Dressler (1980) but using the area defined by the circle that encloses the fifth nearest neighbor to each galaxy. It is worth emphasizing the fact that since each galaxy in 2dFGGC has redshift measurements so our statistical analysis is free of projection effects. We have restricted ourselves to those groups in our sample which have at least 8 members within the constraints described in the previous section in order to improve the reliability of the statistical analysis. The stability of $\Sigma_{gal}$ was tested changing the number of neighbors used in its computation. We have found no significant discrepancies in $\Sigma_{gal}$ using the fifth, sixth and seventh nearest neighbor. The choice of the fifth member is due to the possibility of defining a more reliable estimation of local density for the poorest groups that dominate in number. Another test which gives additional support to our choice of the fifth member was performed in groups with more than 15 members computing $\Sigma_{gal}$ with the fifth and the tenth nearest neighbor as analysed by Dressler (1980). As in the previous test, we find that both computations of $\Sigma_{gal}$ are indistinguishable within the uncertainties.

We split the sample into two subsamples of low ($M_V < 10^{13.5} M_\odot$) and high ($M_V \geq$
Table 2. Previously identified clusters in the subsample of the 2dFGGC

| Name         | R.A.(degrees) | DEC (degrees) | z   | $M_V$ ($h^{-1}M_\odot$) | $R_V$ ($h^{-1}Mpc$) |
|--------------|---------------|---------------|-----|--------------------------|---------------------|
| APMCC 375    | 48.950        | -28.607       | 0.044 | 0.14E+14                | 0.47                |
| ABELL 4049   | 357.133       | -28.460       | 0.029 | 0.71E+14                | 1.24                |
| ABELL S1155  | 356.940       | -29.357       | 0.050 | 0.55E+14                | 0.77                |
| ABELL S1171  | 359.728       | -27.723       | 0.028 | 0.58E+14                | 1.08                |
| EDCC 155     | 337.220       | -25.629       | 0.034 | 0.16E+15                | 0.96                |
| EDCC 129     | 334.070       | -24.640       | 0.038 | 0.16E+14                | 1.05                |
| EDCC 121     | 333.441       | -25.430       | 0.031 | 0.22E+14                | 0.33                |
| PCC N45-300  | 152.605       | -2.410        | 0.043 | 0.34E+14                | 0.78                |
| WBL 248      | 149.461       | -2.736        | 0.020 | 0.36E+14                | 0.60                |
| ABELL 0993   | 154.866       | -4.691        | 0.055 | 0.24E+15                | 1.47                |
| ABELL 0978   | 154.445       | -6.133        | 0.055 | 0.26E+15                | 1.16                |
| ABELL 1214   | 168.565       | -5.253        | 0.039 | 0.24E+14                | 0.79                |
| ABELL 1334   | 174.084       | -3.993        | 0.056 | 0.20E+15                | 1.11                |
| MKW 05       | 209.336       | -2.760        | 0.025 | 0.44E+14                | 0.81                |
| ABELL 0957   | 152.796       | -0.688        | 0.045 | 0.36E+15                | 1.13                |
| PCC N56-369  | 161.872       | 0.710         | 0.039 | 0.10E+15                | 1.13                |
| ABELL 4053   | 357.983       | -27.840       | 0.050 | 0.26E+14                | 0.58                |
| ABELL S0006  | 0.492         | -30.752       | 0.026 | 0.65E+13                | 0.48                |
| ABELL S0001  | 359.973       | -30.853       | 0.030 | 0.54E+14                | 0.91                |
| EDCC 694     | 41.476        | -27.991       | 0.023 | 0.19E+14                | 0.91                |

10$^{13.5}M_\odot$) virial mass. There are 18 and 32 groups in each subsample with a total of 161 and 417 galaxies respectively. In Figures 1 and 2 are shown the relative fraction of each galaxy type as a function of $\Sigma_{gal}$ for low and high mass groups respectively. Error bars in the figures were estimated using the bootstrap resampling technique. Horizontal lines in the figures are the mean fraction of galaxies for different types within the 2dF Galaxy Redshift Survey within the same sampled volume and luminosity cut-off.

By comparison of Figures 1 and 2 it can be appreciated that there is an important difference between the two group subsamples. For the low-mass subsample there is no significant trend with $\Sigma_{gal}$. On the other hand, the high-mass subsample exhibits a large increase in the fraction of non star forming galaxies (Type 1) with increasing $\Sigma_{gal}$. These behaviours can be better appreciated in the upper left panels in the Figures that correspond to the fractions of Types 1 (dotted line), and combined Types 2 and 3 (continuous line). Type 4 galaxies, which correspond to the tail of the $\eta$ distribution were omitted since they include particularly active galaxies and AGNs. These results are consistent with Whitmore (1995) and Maia & da Costa (1990) who also find a lack of a trend of morphology-density relation in groups when excluding clusters.

We have also studied a sample consisting of groups which correspond to clusters identified in previous surveys. By cross-correlating group positions with clusters in the NASA/IPAC Extragalactic Database (NED), we have found 20 groups in this subsample of the 2dFGGC...
Figure 4. Fraction of the different spectral types as a function of the groupcentric distance normalized to the projected virial radius. The galaxies belong to low mass groups ($M_V < 10^{13.5} M_\odot$). The symbols and lines are the same as in Figure 1.

Figure 5. Same as in Figure 4 but computed with galaxies in high mass groups ($M_V \sim 10^{13.5} M_\odot$).

with a cluster identification in NED (see Table 2). When the same analysis is applied to this sample of groups (Figure 3) we find a great similarity in the results to those found in the high mass group subsample shown in Figure 2. This is a totally consistent result since this sample is expected to correspond to the most massive groups.
Another way to analyse the dependence of galaxy types within the group environments is through galaxy group-centric distances normalized to the group virial radius. In the analysis of Whitmore, Gilmore & Jones (1993) and Whitmore (1995) the cluster-centric radial distance is found to be a primary driver in contrast to the local galaxy density, a secondary parameter in the morphology segregation. In this subsection we perform a similar analysis to that in subsection 3.1 using the group-centric distance instead of $\Sigma_{\text{gal}}$. Since the computation of group-centric distances is less sensitive to the number of galaxies than $\Sigma_{\text{gal}}$ we construct our sample with all groups with at least 6 members. This choice allow us to improve the statistics.

We also split the sample into two subsamples of low ($M_V < 10^{13.5}M_\odot$) and high ($M_V \geq 10^{13.5}M_\odot$) virial mass as in subsection 3.1. There are 41 and 42 groups in each subsample with a total of 308 and 494 galaxies, respectively.

In Figure 4 and 5 are shown the relative fraction of each galaxy type as a function of the group-centric distance for low and high mass groups respectively. Horizontal lines in the figures are the mean fraction of galaxies for the 2dF Galaxy Redshift Survey as in Figures 1 and 2.

By comparison of Figures 4 and 5 it can be appreciated that there is a difference between
the two group subsamples. For the low-mass subsample there is no significant trend with $R/R_{\text{vir}}$. On the other hand, the high-mass subsample exhibits a continuous decrease of the fraction of non star forming galaxies (Type 1) with increasing $R/R_{\text{vir}}$. These results are consistent with the results of Figures 1 and 2. A possible explanation can be found in Balogh & Navarro (2000) where it is found that star formation declines gradually after galaxies enter in the system, as a result of the removal of the gaseous envelopes that supply the fuel needed for star formation. This could explain the strong correlation found by Martínez et al (2002).

An important analysis could be performed if X-ray information were available for an important sample of the groups. Effects associated with the intragroup medium might be responsible of the removal of the gas supply of the galaxies, in such X-ray group sample could provide stronger gradient on galaxy fractions. The similarity of the gradients between the high mass subsample and the previously identified clusters (showed in Figure 6) indicate the importance of a separate analysis for group and cluster environments.

4 CONCLUSIONS

We have performed a correlation analysis between the relative fraction of spectral types and the projected local galaxy density, $\Sigma_{\text{gal}}$, in a sample of groups taken from the 2dFGGC constructed by Merchán & Zandivarez (2002). Several possible sources of biases have been considered: Firstly a reliable sample of groups has been selected with a redshift independent virial mass distribution and a volume complete selection of their galaxy members. Secondly, to test the stability of the results on $\Sigma_{\text{gal}}$ estimates, we have computed $\Sigma_{\text{gal}}$ with different number of galaxy neighbours finding that using the five nearest members gives accurate results. It should be remarked that our analysis was made on spectral types of group member galaxies, so that this study in contrast to many previous works lacks projection effects. We find a clear distinction between high virial mass groups ($M_V \gtrsim 10^{13.5} M_\odot$) and the less massive ones. While the massive groups show a significant dependence of the relative fraction of low star formation galaxies on $\Sigma_{\text{gal}}$, groups with lower masses show no significant trends.

In a similar fashion, we have analysed the spectral type fractions as a function of group-centric distance. There is a significant difference between the behaviours of the two subsamples. While for the low-mass subsample there is no significant trend with $R/R_{\text{vir}}$, the high-mass subsample shows a continuous decrease of the fraction of non star forming galaxies (Type 1) with increasing $R/R_{\text{vir}}$. 

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In support of our analysis, we have considered a subsample of our groups that were previously identified as clusters. It is worth noticing that these objects are poor clusters since they do not have strong X-ray emission. We find that this subsample is mainly composed of the tail of high group masses and shows a very similar behaviour to our high virial mass samples.

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