Galaxy groups in the 2dF galaxy redshift survey: Luminosity and Mass Statistics

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26 August 2002

ABSTRACT
Several statistics are applied to groups and galaxies in groups in the Two degree Field Galaxy Redshift Survey. Firstly we estimate the luminosity functions for different subsets of galaxies in groups. The results are well fitted by a Schechter function with parameters $M^* - 5\log(h) = -19.90 \pm 0.03$ and $\alpha = -1.13 \pm 0.02$ for all galaxies in groups, which is quite consistent with the results by Norberg et al. for field galaxies. When considering the four different spectral types defined by Madgwick et al. we find that the characteristic magnitude is typically brighter than in the field. We also observe a steeper value, $\alpha = -0.76 \pm 0.03$, of the faint end slope for low star-forming galaxies when compared with the corresponding field value. This steepening is more conspicuous, $\alpha = -1.10 \pm 0.06$, for those galaxies in more massive groups ($M \geq 10^{14} h^{-1} M_\odot$) than the obtained in the lower mass subset, $\alpha = -0.71 \pm 0.04$ ($M < 10^{14} h^{-1} M_\odot$).

Secondly, we compute group total luminosities using Moore, Frenk & White prescriptions. We define a flux-limited group sample using a new statistical tool developed by Rauzy. The resulting group sample is used to determine the group luminosity function finding a good agreement with previous determinations and semianalytical models.

Finally, the group mass function for the flux-limited sample is derived. An excellent agreement is obtained when comparing our determination with analytical predictions over two orders of magnitude in mass.

Key words: galaxies: clusters: general - galaxies: luminosity function, mass function - galaxies: statistics.

1 INTRODUCTION

Groups of galaxies constitute one of the most suitable laboratories for the study of properties of intermediate galaxy density environments and their consequences on the process of galaxy formation and evolution. Furthermore, several hints about the large scale structure of the universe and how structures evolve in the universe can be drawn from the statistical studies of groups and their properties. Some of them, for instance the luminosities and morphological types of their member galaxies, are sensitive to the processes of mergers and interactions between individual galaxies inside a potential well. Meanwhile, other properties as group abundance as a function of total luminosity or mass, can provide constraints to hierarchical clustering scenarios and cosmological models. In this paper, we provide a robust statistical study about the luminosities of group galaxy members, and also on global group properties such as total luminosities and masses, using one of the largest group catalogues at the present. The accuracy of these determinations allow us a fair comparison with analytical and semianalytical predictions.

Most studies on the environmental dependence of the galaxy luminosity function have been carried out either in the field or in rich clusters using the largest two dimensional catalogues and small redshift surveys. Regarding field galaxy luminosity functions, several works have been devoted to its determination in the last decade (Loveday et al. 1992, Marzke, Huchra & Geller 1994, Lin et al. 1996, Zucca et al. 1997, Ratcliffe et al. 1998). With the advent of large redshift surveys such as the Two degree Field Galaxy Redshift Survey (2dFGRS) and the Sloan Digital Sky Survey (SDSS), more reliable statistical results have been obtained. The field luminosity functions determined by Blanton et al. (2001) (SDSS) and Norberg et al. (2002) (2dFGRS) show an excellent agreement, finding a luminosity function accurately described by a Schechter function with parameters $M^* - 5\log(h) \simeq -19.66$ and $\alpha \simeq -1.21$. In particular, the 2dFGRS allowed the determination of the field luminosity function...
function for galaxies of different spectral types (Madgwick et al 2002) finding a systematic steepening of the faint end slope moving from passive ($\alpha = -0.54$) to active ($\alpha = -1.5$) star forming galaxies, and also a corresponding faintening of $M^*$. A controversial issue about the luminosity function of galaxies in clusters is the steepening at the faint end, compared with field galaxy luminosity function (Valotto et al 1997, Trentham 1997, López-Cruz et al 1997). Recently Goto et al. (2002) computed a composed luminosity function using 204 clusters taken from SDSS (York et al. 2000). They found that the slopes of the LF’s become flatter toward redder color band and that have brighter characteristic magnitude and flatter slopes than the field LF.

The lack of statistical results on smaller overdensities such as groups of galaxies is mainly due to the fact that two dimensional identification privileges the largest overdensities. Analyzing a sample of 66 groups of galaxies identified in redshift space, Muriel, Valotto & Lambas (1998) find a flat faint end for the galaxy luminosity function in groups ($\alpha \simeq -1.0$) compared with the luminosity function in clusters where a large relative number of faint galaxies is present. It is important to remark that most of the luminosity function estimations in groups and clusters of galaxies are computed subtracting background and foreground contamination due to the lack of spectroscopic information for galaxy members.

One step further, in order to understand the transition between galaxy and galaxy systems luminosities, is the computation of the luminosity function of galaxy groups. Moore, Frenk & White (1993), reanalysing the groups in the Center for Astrophysics (CfA) redshift survey, developed a method for the estimation of the total luminosity of groups identified in magnitude-limited galaxy surveys. This method allowed them the computation of the luminosity function of galaxy systems for a sample of 163 groups with at least tree members. Another attempt to determine the luminosity function of virialized systems was made by Marínoni, Hudson & Giuricin (2002). They used the Nearby Optical Galaxy (NOG) sample, which comprise ~7000 galaxies with $cz \leq$ 6000 km s$^{-1}$ and $B \leq 14$, finding a very good agreement with Moore, Frenk & White (1993) previous determination.

On the other hand, the abundance of haloes as a function of mass constitutes a key point in both, the determination of a cosmological model and the understanding of the structure collapse. At the present, the more popular models for halo abundance are the analytical model of Press & Schechter (1974) for spherical collapse, the Sheth & Tormen (1999) model for ellipsoidal collapse and Jenkins et al. (2001) fit obtained from numerical simulations. Many efforts have been made to determine the mass function of galaxy systems from observations (Bahcall & Cen 1993, Biviano et al. 1993, Girardi et al. 1998). Recently, Girardi & Giuricin (2000) have computed the mass function for a sample of nearby loose groups by García (1993). They found the group mass function to be a smooth extrapolation of the cluster mass function and a reasonable agreement with the Press & Schechter (1974) predictions.

Currently, one of the largest group catalogue was constructed by Merchán & Zandivarez (2002). They have identified groups on the 2dF public 100K data release using a modified Huchra & Geller (1982) group finding algorithm that takes into account 2dF magnitude limit and redshift completeness masks. This catalogue constitutes a large and suitable sample for both, the study of processes in group environment and the properties of the group population itself. 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 $M \geq 10^{13} M_{\odot}$ the relative fraction of star forming galaxies is significantly suppressed, indicating that even intermediate mass environments affect star formation. Domínguez et al. (2002) presented hints toward understanding local environment effects affecting the spectral types of galaxies in groups by studying the relative fractions of different spectral types as a function of the projected local galaxy density and the group-centric distance. A similar analysis were performed in known galaxy clusters and their environments in the 2dFGRS by Lewis et al (2002).

The aim of this work is to use the Merchán & Zandivarez (2002) group catalogue to obtain reliable determinations of internal and global properties of groups: luminosity functions of galaxies in groups, group luminosity and mass functions. The outline of this paper is as follows. In section 2, we present a revised version of the 2dF Galaxy Group Catalogue (2dFGGC) used throughout this work. Section 3 describes the methods and results of the luminosity function of galaxies in groups while in section 4 description corresponds to the luminosity function of galaxy groups. The computation of group mass function and a comparison with analytical models are presented in section 5. Finally, in section 6 we summarize our conclusions.

### 2 THE 2DFGGC

Samples of galaxies and groups used in this work are a new sample constructed using a revised version of the masks and mask software of the 2dFGRS 100k data release, which includes the $\mu$-masks described in Colless et al. (2001) (see http://msowww.anu.edu.au/2dFGRS/Public/Release/Masks/index.html). The group catalogue is obtained following the same procedure as described by Merchán & Zandivarez (2002). In the previous work, the finder algorithm used for group identification is similar to that developed by Huchra & Geller (1982) but modified in order to take into account redshift completeness and magnitude limit mask present on the current release of galaxies. Here we include the effect introduced by the magnitude completeness mask ($\mu$-mask). 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. The revised group catalogue comprises a total number of 2198 galaxy groups with at least 4 members and mean radial velocities in the range $900$ km s$^{-1} \leq V \leq 7500$ km s$^{-1}$. These groups have a mean velocity dispersion of 265 km s$^{-1}$, a mean virial mass of $9.1 \times 10^{13} h^{-1} M_{\odot}$ and a mean virial radius of 1.15 $h^{-1}$Mpc. These results show that the new identification keeps the mean properties of the group catalogue obtained by Merchán & Zandivarez (2002), as expected from the fact that the introduction of the magnitude completeness mask is a second order correction.
3 LUMINOSITY FUNCTION OF GALAXIES IN GROUPS

In this section we estimate the luminosity functions (LF) of galaxies in groups. The following analysis comprises the study of the whole sample of galaxies in groups and different subsets defined by galaxy spectral types as defined by Madgwick et al. (2002). This classification is based on the \( \eta \) parameter which is very tightly correlated with the equivalent width of \( H_\alpha \) emission line, correlates well with morphology for emission line galaxies and can be interpreted as a measure of the relative current star-formation present in each galaxy. The four spectral types are defined as:

- 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 characterised by 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 starburst.

### 3.1 Luminosity function estimators

In a comparative study of different LF estimators using Monte Carlo simulations, Willmer (1997) shows that the \( C^- \) method of Lynden-Bell (1971) and the STY method derived by Sandage, Tammann & Yahil (1979) are the best estimators to measure the shape of the LF. Moreover, Willmer’s analysis states that the \( C^- \) is the most robust estimator, being less affected by different values of the faint end slope of the Schechter parametrisation and sample size. In this work we use both, the \( C^- \) method to make a non parametric determination of the LF and the STY method to calculate the maximum likelihood Schechter fit to the LF.

The \( C^- \) method was simplified and developed by Choloniewski (1987) in order to compute simultaneously the shape and normalisation of the luminosity function. The LF is obtained by differentiating the cumulative LF, \( \Psi(M) \). The function \( X(M) \) defined as the observed density of galaxies with absolute magnitude brighter than \( M \), represents only an undersampling of the \( \Psi(M) \),

\[
\frac{dX}{X} = \frac{d\Psi}{\Psi} \quad (1)
\]

the key point of the method is to construct a quantity \( C(M) \), subsample of \( X(M) \), such that

\[
\frac{dX}{C} = \frac{d\Psi}{\Psi} \quad (2)
\]

Linden-Bell (1971) defined that quantity as the number of galaxies brighter than \( M \) which could have been observed if their magnitude were \( M \). Following Choloniewski (1987), and taking into account the sky coverage of the 2dF present release, the differential LF can be written as

\[
(\Phi(M)) = \frac{\Gamma}{\Delta M} \sum_{i=1}^{N} \frac{\psi_i}{R(\alpha_i, \delta_i)^{-1}} \quad (3)
\]

where

\[
\Gamma = \prod_{k=2}^{N} \frac{C_k + 1}{C_k} \left( V \sum_{i=1}^{N} \frac{\psi_i}{R(\alpha_i, \delta_i)} \right)^{-1} \quad (4)
\]

\[
\psi_k = \frac{1}{k} \sum_{i=1}^{k} \frac{C_i + 1}{C_{i+1}} \quad (5)
\]

and \( R(\alpha, \delta) \) is the redshift completeness of the parent catalogue. \( C_k \equiv C^- (M_k) \) is defined as \( C(M) \) but excluding the object \( k \) itself and weighting each object by the inverse of the magnitude-dependent redshift completeness defined as \( c_k(b_j, \mu) = 0.99(1 - \exp(-b_j - \mu)) \) where \( \mu = \mu(\alpha, \delta) \) (see Norberg et al. 2002).

In addition to the non-parametric method described above we also apply the STY method which uses a maximum likelihood technique to find the most probable parameters of an analytical \( \Phi(M) \), in general assumed to be a Schechter function:

\[
\Phi(M) \propto 10^{-0.4(M-M^*)}\exp[-10^{-0.4(M-M^*)}] \quad (6)
\]

The probability \( p_i \) of having an object with absolute magnitude \( M_i \) is

\[
p_i = \frac{\Phi(M_i)}{\int_{M_{\text{bright}}}^{M_{\text{faint}}} \Phi(M) dM} \quad (7)
\]

where \( M_{\text{bright}} \) and \( M_{\text{faint}} \) are the brightest and faintest absolute magnitudes observable in the sample at the redshift of the considered galaxy with the corresponding \( k + e \) correction. Consequently, the method seeks for the parameters \( M^* \) and \( \alpha \) maximizing the likelihood function.
\[ L = \prod_{i=1}^{N} p_i. \]  

As we did before, we use the \( \mu \)-mask to weight each galaxy by \( 1/c_i(b_j, \mu) \) to compensate for the magnitude-dependent incompleteness. The errors can be estimated from the error ellipsoid defined as

\[ \ln L = \ln L_{\text{max}} - \frac{1}{2} \chi^2(N), \]

where \( \chi^2(N) \) is the \( \beta \) point of the \( \chi^2 \) distribution with \( N \) degrees of freedom.

The comoving volumes involved in previous equations are estimated with the general formula

\[ V = \frac{\omega c}{H_0} \int_{z_1}^{z_2} \frac{d_L(z)^2}{\Omega_0(1+z)^3 + (1 - \Omega_0 - \Omega_{\Lambda})(1+z)^2 + \Omega_{\Lambda}} \]

where \( \omega \) is the solid angle, \( c \) is the speed of light, \( H_0 = 100 \ h \ \text{km s}^{-1} \ \text{Mpc}^{-1} \) and the \( d_L(z) \) is the luminosity distance. Hereafter we adopt the cosmological model \( \Omega_0 = 0.3 \) and \( \Omega_{\Lambda} = 0.7 \).

### 3.2 Luminosity function results

In Figure 1 we show the luminosity function for all galaxies in groups in arbitrary units. It should be taken into account that the normalisation procedure is only necessary for the group LF. Absolute magnitudes are computed using the \( k + e \) mean correction for galaxies in the 2dFGRS as derived by Norberg et al. (2002). Error bars are estimated using 10 mock catalogues constructed from numerical simulations of a cold dark matter universe according to the cosmological model adopted in this work with a Hubble constant \( h = 0.7 \) and a relative mass fluctuation \( \sigma_8 = 0.9 \). These simulations were performed using 128^3 particles in cubic comoving volume of 180h^{-1}Mpc per side. The solid line shows the STY best fit which corresponds to the Schechter parameters \( M^* = -19.90 \pm 0.03 \) and \( \alpha = -1.13 \pm 0.02 \). Quoted errors are the projections of 1\( \sigma \) joint error ellipse (inset plot) onto each axis. The inset plot of Figure 1 also shows the error ellipsoids defined by 2 and 3\( \sigma \) error dispersion.

As pointed out by Martínez et al. (2002), the relative fraction of the spectral types in groups and field are different, being Type 1 galaxies the dominant population in groups. We are interested in deepening this result by studying the LF for the four spectral types in groups. The luminosity functions for different galaxy spectral types are shown in Figure 2. In these computations we applied a redshift cut-off \( z < 0.15 \) since \( \eta \) determinations are available only for galaxies in this redshift range. In this case, error bars were estimated using the bootstrap resampling technique. The corresponding STY best fit parameters are quoted in Table 1, and were computed using only those galaxies brighter than \( M_{b_j} - 5 \log h = -17 \) avoiding points with larger error bars.

At this point, a straightforward comparison between our results and those obtained for field galaxies in the 2dFGRS by Madgwick et al. (2002) can be made. The comparison between the LF Schechter parameters is shown in Figure 3. Overall, a brightening of the characteristic magnitude is observed for galaxies in groups with a statistical significance \( \sim 2\sigma \). This is particularly significant for Type 1 galaxies that are the main contributors to the general LF of galaxies in groups (3\( \sigma \)). The denser environment of groups could be thought as the natural responsible of this brightening. In this particular environment, galaxy mergers seems to be the most probable cause since tidal interactions are more effective when the galaxy encounter is slow. The later situation, is more frequently observed in groups where smaller velocity dispersions contrast with the high velocity dispersions observed in rich clusters. Other processes, as ram-pressure (Abadi, Moore & Bower 1999) or galaxy harassment (Moore et al. 1996) should not be as effective as in rich clusters where the intra-cluster gas is much denser and the interaction rate is higher.

Nevertheless, the processes mentioned above may be important in the generation of red low mass galaxies, that are possibly the remnants of dynamical stripped galaxies in high mass systems and can be the responsible for the steepening of the luminosity function in clusters. The observed difference in the \( \alpha \) parameter for Type 1 galaxies (lower panel of Figure 3) may be explained in this framework. In order to test this scenario, we reanalyze the LF for non star-forming galaxies (Type 1) splitting the sample in high \( (M \geq 10^{14} M_{\odot}) \) and low \( (M < 10^{14} M_{\odot}) \) group mass subsets. A significant difference is observed at the faint end slope of the LF from this comparison, resulting Schechter \( \alpha \) parameters of \(( -1.10 \pm 0.06 ) \) and \(( -0.71 \pm 0.04 ) \) for high and low mass subsamples respectively (Figure 4). These results may support our hypothesis that in groups, mergers are probably responsible for the \( M^* \) brightening, meanwhile process as the ram-pressure and galaxy harassment could generate the increase at the LF faint end slope as observed for non-star forming galaxies in high mass systems. Besides the steepening of the faint end slope of Type 1 galaxies LF in higher mass systems, the galaxy LF for high and low mass groups do not differ appreciatively between them showing roughly the same behaviour as the overall LF of galaxies in groups (Figure 1).

Despite the differences between the resulting luminosity functions per spectral type, the general LF of galaxies in groups is quite similar to that of 2dF field galaxies obtained by Norberg et al. (2002) and Madgwick et al. (2002). This behaviour could be possibly due to the different relative abundances of Type 1 galaxies in the field and groups. In groups Type 1 galaxies are by far the dominant population, consequently, these galaxies almost determine by themselves \( M^* \). Meanwhile, in the field, Types 2, 3 and 4 contribute more strongly to the LF, generating a \( M^* \) brighter than the corresponding to Type 1 galaxies alone. Regarding the faint end slope of the overall LF, the main contributors are late type galaxies (except for high mass groups, as stated above) in both, field and groups. Since there are no significant differences between the \( \alpha \) parameters for late types in the field and groups, then the overall faint end slopes are similar.

### 4 LUMINOSITY FUNCTION OF GROUPS

The next step in this work is to analyse the luminosity distribution of groups independently of the detailed arrangement of luminous material within each object. In this section we determine individual group luminosities that allow us the
Figure 2. $b_J$ band luminosity function per spectral type for galaxies in groups from the 2dFGGC (arbitrary units) computed using the $C^{-}$ method. Error bars are bootstrap resampling technique estimates. Solid lines show the STY Schechter fits to the data. Inset panels display 1σ, 2σ and 3σ confidence ellipses enclosing the best fit Schechter function parameters, see Table 1.

Table 1. STY estimates of the Schechter parameters for the luminosity functions of galaxies in groups

<table>
<thead>
<tr>
<th>Sample</th>
<th>Redshift range</th>
<th>Number of galaxies</th>
<th>$M^* - 5 \log(h)$</th>
<th>$\alpha$</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>0.003 − 0.25</td>
<td>14620</td>
<td>−19.90 ± 0.03</td>
<td>−1.13 ± 0.02</td>
</tr>
<tr>
<td>Type 1</td>
<td>0.003 − 0.15</td>
<td>6202</td>
<td>−19.85 ± 0.04</td>
<td>−0.76 ± 0.03</td>
</tr>
<tr>
<td>Type 2</td>
<td>0.003 − 0.15</td>
<td>3445</td>
<td>−19.54 ± 0.05</td>
<td>−0.94 ± 0.04</td>
</tr>
<tr>
<td>Type 3</td>
<td>0.003 − 0.15</td>
<td>1871</td>
<td>−19.37 ± 0.08</td>
<td>−1.25 ± 0.05</td>
</tr>
<tr>
<td>Type 4</td>
<td>0.003 − 0.15</td>
<td>952</td>
<td>−19.40 ± 0.10</td>
<td>−1.40 ± 0.07</td>
</tr>
</tbody>
</table>
computation of the group luminosity function and the subsequent comparison with previous determinations and predictions from semianalytical models of galaxy formation.

4.1 Group luminosities

We compute group luminosities following the prescription by Moore, Frenk & White (1993). For each group the total luminosity, \( L_{\text{tot}} \), is the sum of the luminosity of the galaxy members (\( L_{\text{obs}} \)) plus the integrated luminosity of galaxies below the magnitude limit of the survey (\( L_{\text{cor}} \))

\[
L_{\text{tot}} = L_{\text{obs}} + L_{\text{cor}}.
\] (11)

In the computation of \( L_{\text{cor}} \) we assume that group members are independently drawn from the previously computed Schechter fit to the luminosity function of galaxies in groups. Consequently, the expected luminosity of faint group members is

\[
L_{\text{cor}} = N_{\text{obs}} \int_{L_{\text{lim}}}^{\infty} L \Phi(L)dL, \quad \Phi(L)dL,
\] (12)

where \( L_{\text{lim}} = 10^{0.4(M_{\odot} - M_{\text{lim}})} \), \( M_{\text{lim}} = m_{\text{lim}} - 25 - 5 \log(d_L(z)) \) and \( M_{\odot} = 5.30 \) (\( b_j \) band). The reliability of this scheme for computing luminosities of virialized systems was widely tested by Moore, Frenk & White (1993) using groups from the CfA catalogue and flux and volume limited mock catalogues. In order to apply this procedure to our group catalogue we introduce some changes that take into account the particular sky coverage of the parent catalogue: \( m_{\text{lim}} \) is a function of the angular position of the group and \( N_{\text{obs}} = \sum_{i=1}^{N} w_i \), where the sum extends over the group members and each member is weighted with the inverse of the redshift completeness, \( w_i = 1/R(\alpha_i, \delta_i) \), at its angular position.

4.2 Group luminosity function

As a first step in computing the group luminosity function using the \( C^- \) method, it is necessary to find out the completeness limit in group apparent magnitude of our catalogue. Rauzy (2001) proposed a new tool in order to define this completeness limit for a magnitude-redshift sample. This method does not presuppose that the galaxy population does not evolve with time and is homogeneously distributed in space as the \( V/V_{\text{max}} \) test of Schmidt (1968). Rauzy’s method assumes that the sample is complete in apparent magnitude up to a given magnitude limit \( m_{\text{lim}} \).

The limiting magnitude determines a correlation between the absolute magnitude \( M \) and the \( k + e \) corrected distance modulus \( Z \). This method is based on the definition of a random variable

\[
\zeta \equiv \frac{\Psi(M)}{\Psi[M_{\text{lim}}(Z)]}
\] (13)

where \( M_{\text{lim}}(Z) = m_{\text{lim}} - Z \). \( \zeta \) should be uniformly distributed between 0 and 1 and should be statistically independent of \( Z \) and the angular selection function. For each object, an unbiased estimate of \( \zeta \) is provided by

\[
\hat{\zeta} = \frac{r_i}{n_i + 1},
\] (14)

where \( r_i \) is the number of objects in the sample with \( M \leq M_i \) and \( Z \leq Z_i \), and \( n_i \) is the number of objects such that \( M \leq M_{\text{lim}}(Z_i) \) and \( Z \leq Z_i \). The expectation \( E_{\zeta} \) and variance \( V_{\zeta} \) of the \( \zeta_i \) are \( 1/2 \) and \( (n_i - 1)/(12(n_i + 1)) \) respectively. Then, the statistic \( T_C \), defined as

\[
T_C = \frac{\sum_{i=1}^{N_{\text{gal}}} \left( \hat{\zeta}_i - \frac{1}{2} \right)^2}{\left( \sum_{i=1}^{N_{\text{gal}}} V_{\zeta_i} \right)^{1/2}}
\] (15)

has mean zero and variance unity. The test consists in computing the quantity \( T_C \) on truncated subsamples according to an increasing apparent magnitude limit \( m_* \). While \( m_* \) remains below \( m_{\text{lim}} \), the subsample is complete and \( T_C \) statistics is distributed with a mean close to zero and unity fluctuations. When \( m_* \) becomes greater than \( m_{\text{lim}} \), the incompleteness introduces a lack of objects with \( M \) fainter than \( M_{\text{lim}}(Z) \), therefore \( T_C \) is expected to fall down systematically to negative values. The behaviour of \( T_C \) for our group catalogue is shown in the upper panel of Figure 5, where it can be seen that \( T_C \) decreases monotonously for limiting apparent magnitudes greater than \( m_{\text{lim}} \sim 15.6 \) (vertical solid line), taking values under \(-2(1 - 2\sigma_{T_C})\) (horizontal long dashed lines). The lower panel of the same figure shows the \( k + e \) corrected distance modulus \( Z \) as a function of the absolute magnitude for all groups, the vertical solid line corresponds to the 15.6 limiting apparent magnitude cutoff as determined with the \( T_C \) analysis. Dashed horizontal line in the lower panel of Figure 5 represents a low redshift cut-off (\( z_{\text{cut}} = 0.04 \)) that we impose in order to avoid small volume undersampling effects.
Finally, our flux-limited group sample comprises 922 groups with the constraints $0.04 \leq z \leq 0.25$ and $m_{bJ} \leq 15.6$. We compute for this sample the group LF with the $C^{-}$ method in a similar way as we did for galaxies in groups in Section 3, but in this case no weight is needed in the $C_k \equiv C^{-}(M_k)$ computation since the choice of the magnitude cut-off ensures the completeness of the final sample. The resulting group LF is shown in Figure 6. Error bars were computed by applying the same LF estimator to the mock catalogues in a similar way as explained in Section 3. In the same figure we show the results from groups in the CfA redshift survey by Moore, Frenk & White (1993) and from semianalytical models by Benson et al. (2000) for a Λ cold dark matter model. A general good agreement with previous results is observed except for $M_{bJ} - 5 \log h > -21.5$. Since the 2dFGGCC has only groups with at least 4 members, there is a lack of low luminosity systems that could explain the differences in the low luminosity tail in Figure 6 when comparing with previous works. As shown by Moore, Frenk & White (1993), the faint end of the group luminosity function is made up almost entirely of single galaxies; binaries and groups with three members link this to the steep bright tail of richer groups and clusters. We have checked whether the 4-member criterion is affecting the faint-end of the group luminosity function by re-computing it including groups with 3 and 2 members. The resulting group LF is in agreement with the results of Moore, Frenk & White (1993) in the whole absolute magnitude range. Nevertheless, it should be recalled that the 4 member cut-off is necessary in order to avoid spurious detections. As stated by Merchán & Zandivarez (2002), this false detections can reach approximately $\sim 40\%$ when considering groups with only three members.

5 MASS FUNCTION OF GROUPS

The statistical strength of our group sample allows us an accurate measurement of the group mass function. In this section we explore the mass function of intermediate mass systems, using the flux-limited sample defined in the previous section. For this purpose we use the $1/V_{\text{max}}$ procedure, that is a non-parametric method consisting in weight each object with the inverse of the maximum comoving volume of the survey, $V_{\text{max}}$,

$$V_{\text{max}}(M_i) = \int_{\text{min}(z_2,z_{\max})}^{\text{max}(z_1,z_{\min})} \frac{dV}{dz} dz$$

in which it remains observable given all the observational selection limits. The extremes of the volume integral are found by solving the equations

$$M_i = \begin{cases} m_2 - 5 \log d_L(z_{\max}) - 25 - k(z_{\max}) \\ m_1 - 5 \log d_L(z_{\min}) - 25 - k(z_{\min}) \end{cases}$$

that are the redshifts of objects with the same absolute magnitude, $M_i$, of the considered object, but with apparent magnitude at the bright and faint limits of the survey. Consequently, the differential mass function can be computed as
Figure 6. Group luminosity function (solid circles) for our flux-limited group sample compared with the CfA redshifts survey groups (open triangles) Moore, Frenk & White (1993) and the semianalytical models of Benson et al (2000) (dashed lines).

\[ dN/dM(M) = \sum_{|M_i - M| \leq dM/2} \frac{1}{V_{\text{max}}(M_i) R(\alpha_i, \delta_i)} \]  

where \( M_i \) are the group masses and \( R(\alpha_i, \delta_i) \) are the mean group redshift completeness.

For a meaningful comparison between the resulting group mass function and analytical mass function predictions (Press & Schechter 1974, Sheth & Tormen 1999 and Jenkins et al. 2001), it is necessary to relate the group virial masses with the mass definition in the models. Group virial masses were computed inside a galaxy density contrast \( (\delta \rho/\rho) = 80 \) (Merchán & Zandivarez 2002), which corresponds to a mass density contrast \( (\delta \rho/\rho)_m = (\delta \rho/\rho)/b \), where \( b \) is the linear bias factor. If we estimate \( b = 1/\sigma_8 \), assuming \( \sigma_8 = 0.9 \), the resulting density contrast is \( (\delta \rho/\rho)_m = 72 \). In order to make a comparison with the analytical predictions, the masses should be computed for a particular density contrast depending on the cosmological model. Taken into account the relation between the virial density of collapsed objects in units of the critical density and the dimensionless density parameter \( \Omega_0 \), as quoted by Eke, Cole & Frenk (1996), we must have \( (\delta \rho/\rho)_m \sim 330 \) for our cosmological model, assuming spherical collapse approximation. To find the relation between the group virial masses and that corresponding to the matter overdensity 330, we assume a simple mean overdensity profile for groups that scales as \( r^{-2} \), where \( r \) is the group-centric distance. Given that in this case \( M \propto r \) then the resulting scaling relation is \( M_{330} \approx M_{72} \sqrt{72/330} \).

Figure 7 shows the comparison between the group mass function, with masses scaled using the previous relation, and the analytical prediction for Press & Schechter (1974), Sheth & Tormen (1999) and Jenkins et al. (2001). Overall, analytical predictions are in excellent agreement with our results spanning two orders of magnitude in mass \( (10^{13} h^{-1} M_\odot \lesssim M \lesssim 10^{15} h^{-1} M_\odot) \). The differences for masses smaller than \( \sim 10^{13} h^{-1} M_\odot \) arise as consequence of the lack of low mass groups, mainly due to the member number cut-off imposed to the 2dFGGC.

6 CONCLUSIONS

Here, we have applied several statistical analysis to groups and galaxies in groups taken from an updated version of the Merchán & Zandivarez (2002) group catalogue (2dFGGC). We have focused on an accurate determination of the luminosity functions of galaxies in groups, and the luminosity and mass functions of groups taking advantage of the statistical power of the 2dFGGC.

In the LF computations, we have used a version of the Choloniewski (1987) approach to the \( C^- \) method by Lynden-Bell (1971), adapted to the particular sky coverage of the 2dFGRS. The choice of this particular estimator of the luminosity function is inspired in the conclusions of the comparative analysis of LF estimators by Willmer (1997), who states that the \( C^- \) method is less affected by inhomogeneities in the sample. The resulting luminosity function for galaxies in groups (Figure 1) is well fitted by a Schechter function with shape parameters \( M^* - 5 \log(h) = -19.90 \pm 0.03 \) and \( \alpha = -1.13 \pm 0.02 \) as determined by a STY fitting procedure. These values are quite consistent
with those obtained by Norberg et al. (2002) for field galaxies in the 2dFGRS.

We have performed a similar analysis in subsamples of galaxies (Figure 2 and Table 1) defined by the spectral types of Madgwick et al. (2002). In general, the characteristic mag-
galaxies (Figure 2 and Table 1) defined by the spectral types in the 2dFGRS.

The faint end slopes of the luminosity functions, $\alpha$, are consistent with those corresponding to field galaxies except for low star forming. Type 1, galaxies, that show a steeper value in groups (Figure 3). We deepen our analysis for Type 1 galaxies exploring the behaviour of $\alpha$ for two subsets of groups: low ($M \leq 10^{14} h^{-1} M_\odot$) and high ($M > 10^{14} h^{-1} M_\odot$), virial masses. We observe an increase in the faint end slope of the Type 1 LF ($\alpha = -1.10 \pm 0.06$) for galaxies in high mass systems meanwhile for galaxies in low mass systems it remains closer to the global value ($\alpha = -0.71 \pm 0.04$) (Figure 4). This effect could be the result of internal processes in higher mass system environments such as ram-pressure and galaxy harassment, that are not expected to be significantly important in smaller over-
densities.

We have defined group luminosities following Moore, Frenk & White (1993), as the sum of its observed luminosity plus a normalised integral of the galaxy luminosity function below the flux limit of the survey. This definition has proved to be reliable in the computation of group total luminosity using observations and artificial flux and volume-
limited catalogues. The main aim of this computation is the determination of the luminosity function for our group cata-
ologue. Since the $C^-$ method for luminosity function esti-
mation requires a fair selection criterion, we have used the Ranzy (2001) $T_c$ statistics to determine an apparent magnitude cut-off for the 2dFGGC that ensures the highest level of completeness. Our final flux-limited group sample comprises 922 groups with apparent magnitudes brighter than $b_J = 15.6$ (Figure 5). The resulting group luminosity function for this sample (Figure 6) is consistent with Moore, Frenk & White (1993) determination for groups in the CfA redshift survey and with the semianalytical model prediction of a $\Lambda$ cold dark matter cosmology performed by Benson et al. (2000). This agreement is acceptable in the luminosity range $M_{b_J} \leq -21.5$. The differences observed at fainter lu-
minalities are mainly due to the lack of groups with less than 4 members in the 2dFGGC. The intrinsic characteristics of the group finding algorithm used in the construction of the 2dFGGC by Merchán & Zandivarez (2002), determine that below this limit any resulting sample has an unacceptable level of contamination by spurious detections.

The flux-limited group sample adopted in the luminos-
ity function computation is also fair enough for the determi-
nation of the group mass function. This determination was achieved by using an adapted version of the $1/V_{\text{max}}$ that considers the sky coverage of the group sample. Finally, a comparison with analytical predictions of halo abundances is made using a simple scheme to relate group virial masses and that corresponding to the adequate overdensity in our cosmological model. The results are displayed in Figure 7, where it can be seen a notorious agreement with the Press & Schechter (1974), Sheth & Tormen (1999) and Jenkins et al. (2001) mass functions for masses $M \geq 10^{13} h^{-1} M_\odot$. Again, the disagreement for low masses can be attributed to absence of poor groups.

The statistical significance of the group catalogue used in this work allowed us to obtain very important clues about internal properties of intermediate mass systems and also to observe the level of agreement obtained from both analytical and semianalytical predictions in the framework of a $\Lambda$ cold dark matter model.

Acknowledgments

We are indebted with Diego G. Lambas and Hernán Muriel for interesting comments and discussions. We thank to Peder Norberg and Shaun Cole for kindly providing the software describing the mask of the 2dFGRS and to the 2dFGRS Team for having made available the current data sets of the sample. We would like to thank J. Coltrane. HJM, AZ and MEM are supported by fellowships from CONICET, Argentina. MJLD is supported by a fellowship from SE-
CyT, Universidad Nacional de Córdoba, Argentina. This work has been partially supported by grants from Consejo de Investigaciones Científicas y Técnicas de la República Ar-
gentina (CONICET), the Secretaría de Ciencia y Técnica de la Universidad Nacional de Córdoba (SeCyT), Agencia Na-
cional de Promoción Científica de la República Argentina and Agencia Córdoba Ciencia.

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