The dynamical state of galaxy groups and their luminosity content

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ABSTRACT
We analyse the dependence of the luminosity function of galaxies in groups (LF) on group dynamical state. We use the Gaussianity of the velocity distribution of galaxy members as a measurement of the dynamical equilibrium of groups identified in the SDSS Data Release 7 by Zandivarez & Martínez 2011. We apply the Anderson-Darling goodness-of-fit test to distinguish between groups according to whether they have Gaussian or Non-Gaussian velocity distributions, i.e., whether they are relaxed or not. For these two subsamples, we compute the 0.1r-band LF as a function of group virial mass and group total luminosity. For massive groups, $M > 5 \times 10^{13} M_\odot h^{-1}$, we find statistically significant differences between the LF of the two subsamples: the LF of groups that have Gaussian velocity distributions have a brighter characteristic absolute magnitude ($\sim 0.3$ mag) and a steeper faint end slope ($\sim 0.25$). We detect a similar effect when comparing the LF of bright ($M^*_{\text{group}} - 5 \log(h) < -23.5$) Gaussian and Non-Gaussian groups. Our results indicate that, for massive/luminous groups, the dynamical state of the system is directly related with the luminosity of its galaxy members.

Key words: galaxies: fundamental parameters – galaxies: clusters: general – galaxies: evolution

1 INTRODUCTION
Group environment plays a key role in the evolution of the overall galaxy population in the Universe. Many works in the literature have studied galaxies in groups to understand how this particular environment affects galaxies and their properties (e.g. Martínez et al. 2002; Eke et al. 2004b; Balogh et al. 2004; Zandivarez et al. 2006; Weinmann et al. 2006; Yang et al. 2009; Robotham et al. 2010). The understanding of how the different processes act upon galaxies requires not only a characterisation of how galaxy properties are related to the environment but also to their motion therein. The action of the different physical mechanisms depend on the dynamics of galaxies within systems (e.g. Yepes et al. 1991; Fusco-Femiano & Menci 1998; Abadi et al. 1999). There is evidence that some properties of galaxy systems are closely related to galaxy dynamics (e.g. Withmore et al. 1993; Adami et al. 1998; Biviano et al. 2002; Lares et al. 2004; Ribeiro et al. 2010).

A possible way to characterise the dynamical state of a galaxy group is analysing its velocity distribution. It is known that a Gaussian velocity distribution is indicative of a group in dynamical equilibrium, while departures from Gaussianity may indicate that perturbative processes are working (Menci & Fusco-Femiano 1996; Hou et al. 2009). However, there is a difficulty in determining whether a given velocity distribution differs significantly from Gaussian, mainly when studying smaller systems as galaxy groups with only a few galaxy members. In a recent work, Hou et al. (2009) have demonstrated that a reliable distinction can be made between Gaussian and non-Gaussian groups even for those with low group membership. They conclude that the Anderson-Darling (A-D) goodness-of-fit test is the most reliable statistics to distinguish between relaxed and dynamically disturbed systems even for those with at least 5 galaxy members. Therefore, this statistical method is a very suitable tool to analyse the internal dynamics of a system.

Recently, Zandivarez & Martínez (2011) (hereafter ZM11) used the Seventh Data Release of the Sloan Digital Sky Survey (hereafter SDSS DR7; Abazajian et al. 2009) to identify groups of galaxies and study several dependencies of the LF. They found that the characteristic magnitude brightens and the faint end slope becomes steeper as a function of mass. This change in the luminosity function is mainly due to the red spheroids and the varying number contributions of the different galaxy types. They also found evidence of luminosity segregation for massive groups. Moreover, the mass trend of the LF is much more pronounced for groups located in low density regions. However, the effects of the internal dynamics of groups on the galaxy LF is an issue that has not been fully addressed. Therefore, in this paper we extend the work by ZM11 by studying the link between the LF and the dynamical state of groups by means of their galaxy member velocity distributions using the A-D test. The layout of this paper is as follows. In section 2 we describe the group sample. The analysis of the LFs is in section 3. Finally, in section 4 we discuss the results.

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2 THE SAMPLE

For this work, we use the sample of groups constructed by ZM11. This sample has been identified in the Main Galaxy Sample (MGS; Strauss et al. 2002) of SDSS DR7 which comprises galaxies down to an apparent magnitude limit of 17.77 in the r band. In ZM11, the group identification was performed following Méchan & Zandivarez (2005): firstly, a standard Friends-of-Friends (fof) algorithm links MGS galaxies into groups; and secondly, an improvement of the rich group identification is performed by means of a second identification on galaxy groups which have at least ten members using a higher density contrast. The latter is done in order to split merged systems or to eliminate spurious member candidates, an improvement of the rich group identification is performed by means of a second identification on galaxy groups which have at least ten members using a higher density contrast. The latter is done in order to split merged systems or to eliminate spurious member candidates. The final group sample comprises 15,961 groups which have at least 5 members. The thick solid line is the least square linear fit between $M_{\text{group}}$ and $\log(M_{\text{vir}})$. Vertical line, $M_{\text{vir}} = 5 \times 10^{13} M_{\odot} h^{-1}$, is the high mass cut-off, while horizontal line, $M_{\text{group}} - 5 \log(h) = -23.5$, is the corresponding high luminosity cut-off obtained from the estimated linear relation and the high mass cut-off value.

$H_0 = 100 \, h \, \text{km s}^{-1} \, \text{Mpc}^{-1}$ and $K$-corrected using the method of Blanton et al. (2003b) (KCORRECT version 4.1). We have also included evolution corrections to this magnitude following Blanton et al. (2003b). We have adopted a band shift to a redshift 0.1 for the r band (hereafter $0.1 r$), i.e. to approximately the mean redshift of the main galaxy sample of SDSS.

To distinguish between relaxed groups with Gaussian velocity distributions and groups with non-Gaussian dynamics we adopted the A-D goodness-of-fit test. In a recent study, Hou et al. (2009) have demonstrated that the A-D is one of the most reliable and powerful tests to measure departures from an underlying Gaussian distribution. This test does not require binning or graphical analysis of the data. From the outcome of the A-D test, we classify groups into two subsamples: the non-Gaussian (NG) groups are those which have a confidence level above 90% of not having a Gaussian velocity distribution, while Gaussian (G) groups are those whose confidence level of not having a Gaussian velocity distribution is below 50%. Since the A-D test is reliable when data sets have at least 5 points (Hou et al. 2009), for the purposes of this work we restrict the ZM11 sample to groups with at least 5 members. From the total of 9,387 groups with at least 5 galaxy members, 479 are classified as NG while 5,250 as G groups. In Fig. 1 we show, for our samples of G and NG groups, the stacked distribution of the radial velocity of the galaxies (V) relative to their parent group radial velocity ($V_{CM}$) normalised to the group velocity dispersion ($\sigma_v$). We perform a fitting procedure to clearly describe the velocity distribution behaviours. It can be seen (solid lines, Fig. [I]) that the stacked velocity distribution of G groups is well represented by a Gaussian function (upper panel), while the NG groups show clear departures from a single Gaussian function, being well fit by the sum of two Gaussian functions (lower panel). The small asymmetry in the velocity profile of NG groups is due to the only 4 groups which have more than 90 members. Among them, 3 have left-skewed radial velocity distribution, and 1 group has a right-skewed one. By excluding these large groups, the stacked radial velocity distribution of Galaxy magnitudes used throughout this paper are Petrosian, are in the AB system and have been corrected for Galactic extinction using the maps by Schlegel et al. (1998). Absolute magnitudes have been computed assuming a flat cosmological model with parameters $\Omega_0 = 0.3$, $\Omega_{\Lambda} = 0.7$ and $H_0 = 100 \, h \, \text{km s}^{-1} \, \text{Mpc}^{-1}$ and $K$-corrected using the method of Blanton et al. (2003b) (KCORRECT version 4.1). We have also included evolution corrections to this magnitude following Blanton et al. (2003b). We have adopted a band shift to a redshift 0.1 for the r band (hereafter $0.1 r$), i.e. to approximately the mean redshift of the main galaxy sample of SDSS.

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NG groups becomes very close to symmetrical, still non-Gaussian and well fit by the sum of two Gaussian functions displaced from each other.

### 3 THE LF OF GALAXIES IN GROUPS

This study is based on the analysis of the luminosity function of galaxies in groups as a function of a given physical property, using the group subsamples defined in the previous section. As in ZM11, the system physical property adopted is the group virial mass. For groups that are not in dynamical equilibrium, i.e. those classified as NG, the virial mass might not be a suitable measure of the system mass. Thus, comparing the LF of G and NG groups as a function of mass can be thought as inappropriate. Thus, to complement the analysis of the LF we use also another group property which is known to be correlated with mass, the virial mass. For groups that are not in dynamical equilibrium, i.e. those classified as NG, the virial mass might not be a suitable measure of the system mass.

In order to explore in detail these possible differences at the high mass/luminosity tails and to assess their reliability, we re-compute the LF for massive/luminous groups by using single bins high mass/luminosity tails and to assess their reliability, we re-compute the LF for massive/luminous groups by using single bins high mass/luminosity tails. Comparing the LF parameters for G and NG groups, we observe that, within errors, there are no significant differences in the Schechter parameters, with the exception of the high mass/luminosity tails, where there is an indication that galaxies in G groups may have brighter $M^*$ and steeper $\alpha$ values.

In agreement with previous results (e.g. Zandivarez et al. 2008, Robotham et al. 2011, ZM11) there is a clear brightening of the characteristic magnitude and a decreasing faint end slope as a function of group total absolute magnitude (left panels). Comparing the LF parameters for G and NG groups, we observe that, within errors, there are no significant differences in the Schechter parameters, with the exception of the high mass/luminosity tails, where there is an indication that galaxies in G groups may have brighter $M^*$ and steeper $\alpha$ values.

In order to explore in detail these possible differences at the high mass/luminosity tails and to access their reliability, we re-compute the LF for massive/luminous groups by using single bins in mass and luminosity in the single high mass/luminosity bins.

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1 The binned LF were computed using the $C^-$ method (Lynden-Bell 1971, Choloniewski 1987).
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Figure 5. STY best fitting Schechter parameters of the $^{0.1}r$ band LFs of G (solid line) and NG (dotted line) groups in the single high mass (left panel) and the single high luminosity (right panel) bins. We also show their 1, 2 and 3σ confidence ellipses.

Figure 5 shows that the LF of galaxies in massive G and NG groups differ at 3σ level. The right panel of Fig. 5 shows the LF parameters corresponding to G and NG high luminosity groups. Again, we observe a clear difference in the LF of galaxies in G and NG groups, in this case at a 2σ significance level.

4 DISCUSSION

ZM11 showed that the LF depends not only on local environment (group mass, group-centric distance) but also on the large scale environment surrounding the groups. Using the same sample of groups, in this work we present evidence that the dynamical state of the system is another important ingredient in the evolution of the luminosity of galaxies. Our results indicate that, for high mass/luminosity groups, the LF of galaxies in G groups have brighter $M^*$ and steeper $\alpha$, than the LF of galaxies in NG groups. Therefore, the different internal dynamical state of a system is a clear indicator of a different history in the galaxy luminosity evolution.

Systems of galaxies have Gaussian velocity distributions only if they are in dynamical equilibrium. Galaxies in these systems have had enough time to suffer the long term action of several physical processes during their evolution. Galaxy mergers play a central role in galaxy evolution in systems. Some other processes such as strangulation (Larson et al. 1981), ram pressure (Gunn & Gott 1972) and galaxy harassment (Farouki & Shapiro 1981), are more efficient in high mass systems, where the effect observed for different dynamical state of the systems it has been shown to be more important. The action of all these processes over the group lifetime can produce both, bright and faint galaxies thus providing a plausible explanation for our results.

On the other hand, since the stacked velocity distributions for NG groups is well described by two Gaussian functions, it is likely that the non Gaussianity is caused by the presence of a multimodal galaxy population. This behaviour opens the possibility for the non Gaussian velocity distributions to be the consequence of an undergoing merging process (e.g. Menci & Fusco-Femiano).
or even multiple merging events (e.g. Girardi et al. 2005). The different merging populations inhabiting these systems could still be experiencing the influence of their own parent halo, and hence preserving the galaxy properties corresponding to the individual (smaller) halos that are infalling to form the (larger) non-Gaussian group. Therefore, these smaller entities should supply the non-Gaussian system with less bright galaxy luminosities that correspond to less massive/luminous systems. This scenario supports the observed fainter characteristic absolute magnitude and the shallower faint end slope for non-Gaussian systems. Galaxies inhabiting these non relaxed systems are unlikely to feel the influence of the environmental physical mechanisms described in the previous paragraph, thus preventing the formation of very bright galaxies as well as a large number of faint ones. In agreement with this scenario, Ribeiro et al. (2010) using the A-D test over a sample of groups from the 2PIGG catalogue demonstrated that galaxies in Gaussian groups are significantly more evolved than galaxies in non-Gaussian systems. Also, using a subsample of the 2PIGG groups, Ribeiro et al. (2011) have shown that non-Gaussian systems are composed of multiple velocity modes, in accordance with the scenario of secondary infall of clumps at a stage before virialisation. Both previous studies were performed analysing the surroundings of groups out to 4 times the corresponding radius (4R200). In our work we show that a similar behaviour can be observed from the analysis of the internal dynamics of groups (only galaxy members, mostly inside the virial radius) and these different dynamical environments can be evidenced in the galaxy luminosities of high mass/luminous systems. Our results suggest another way to test models of galaxy evolution, since the connection between galaxy luminosities (i.e. astrophysics) and the dynamics of the systems should be present.

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