Luminosity functions in the CLASH-VLT cluster MACS J1206.2-0847: the importance of tidal interactions

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Abstract We present the optical luminosity functions (LFs) of galaxies in the CLASH-VLT cluster MACS J1206.2-0847 at z=0.349, based on HST and SUBARU data, including $\sim$ 600 spectroscopically confirmed member galaxies. The luminosity functions on the wide SUBARU FoV are well described by a single Schechter function down to M$\sim$M*+3, while this fit is poor for HST data, due to a faint-end upturn visible down M$\sim$M*+7, suggesting a bimodal behaviour. We also investigate the effect of environment by deriving the LFs in four different regions according to the distance from the centre, and we observe an increase in the faint-end slope going from the core to the outer rings. These results confirm those of Annunziatella et al. 2014, according to which the galaxies with stellar mass values smaller than $10^{10.5}$ M$_\odot$ have been significantly affected by tidal interaction effects, thus contributing to the intra cluster light (ICL). This interpretation is further supported by the detailed analysis of the MACS J1206.2-0847 ICL by Presotto et al. 2014.

1 Introduction

The galaxy luminosity function, which describes the number of galaxies per unit volume as function of the luminosity, is a powerful tool to study the properties of galaxy populations and to constrain their evolution through comparisons with the

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halo mass function. The dependence of the observed galaxy LF on the environment provides a powerful discriminator among the proposed mechanisms responsible for galaxy transformations e.g. merging, ram-pressure stripping, tidal interactions. Interestingly, in dense environments, a single Schechter function was found to be a poor fit of the LF, due to the presence of an upturn at fainter magnitudes (e.g. Agulli et al. 2014 and references therein). This feature is present in dynamically evolved regions (i.e. regions with a large fraction of elliptical galaxies, a high galaxy density, and a short crossing time) but absent in unevolved regions, such as the Ursa Major cluster and the Local Group (e.g. Trentham & Hodgkin 2002). The LFs can vary from cluster to cluster or among field, groups, clusters and also in different cluster regions, according to the mixture of different galaxy types induced by cluster-related processes. In order to asses the relative importance of the processes that may be responsible for the galaxy transformations, we have performed a photometric study of the cluster MACS J1206.2-0847 at z=0.349, by examining the effect of the environment through the comparison of the LFs in four cluster regions.

Throughout the paper, we adopted a cosmology with Ω_M=0.3, Ω_Λ= 0.7, and H_0=70 km $s^{-1}Mpc^{-1}$. According to this cosmology, 1 arcmin corresponds to 0.341 Mpc at z=0.439. The r_{200} for this cluster is equal to 1.96 Mpc.

2 Data and catalogues

Ground-based photometric observations were carried out with the SuprimeCam at Subaru, covering $30' \times 30'$, with total exposure times of 2400 s, 2160 s, 2880 s, 3600 s and 1620 s in B, V, R_c, I_c and z band respectively, and seeing values between 0.7 and 1.0 arcsec. The photometric catalogues were extracted using the software SExtractor (Bertìn & Arnouts, 1996) in conjunction with PSFEx (Bertìn, 2011), which performs PSF fitting photometry. Spectroscopic data were acquired with the VIMOS instrument at the ESO VLT, as part of the ESO Large Programme CLASH-VLT *Dark Matter Mass Distributions of Hubble Treasury Clusters and Foundations of ΛCDM Structure Formation Models* (P.I. Piero Rosati; see Rosati et al., 2014).

The final photometric catalogue contains $\sim$ 34000 objects down to R_c = 24 mag, 2749 of which with reliable spectroscopic redshift estimates. Since our spectroscopic sample is not complete, the cluster membership, for the galaxies without spectroscopy, was estimated by means of the photometric redshifts, as described in Biviano et al. 2013. We obtained a final sample of 2468 cluster members of which 590 are spectroscopically confirmed. In order to derive the LFs, we also applied the corrections to the observed galaxy counts reported in Annunziatella et al. 2014.

MACS J1206.2-0847 was also observed with HST in 16 broadband filters, from the UV to the near-IR (see Postman et al. 2012). As described in Grillo et al. 2015, we selected cluster members in the HST/WFC3 FoV by measuring a probability of galaxy to be cluster member according to its multi-dimensional color space distribution from 12 CLASH bands (excluding the F225W, F275W, F336W, and F390W bands, due to the low signal-to-noise), in comparison with the color distribution of the spectroscopic sample. With this method, we obtained 1144 members down to F814W=27 mag.

This dataset has allowed us to investigate the cluster galaxy population down to M$\sim$M*+7 ($\mathscr{M} \sim 10^{8.2}$ M$_\odot$) in the central region (R<0.4r$_{200}$) and M$\sim$M*+3 ($\mathscr{M} \sim 10^{9.5}$ M$_\odot$) out to 3.5r$_{200}$. In order to match the photometry of the data in the F814W and R$_c$ bands, we derived an empirical linear relation between the two bands on the basis of the spectroscopically confirmed members observed both with Subaru and HST.

3 Results

We show in Fig. 1 (left panel) the R$_c$ LFs obtained from SUBARU data in four different cluster environments. We differentiate the environment in the cluster with the clustercentric distance from the brightest cluster galaxy. As reported in Annunziatella et al. 2014, this is equivalent to referring to the local galaxy number density in this dynamically relaxed cluster (but see also Girardi et al. 2015). The LFs are well described by a single Schechter function, and we detected an environmental effect on the LFs. In fact, the slope of the LF in the central region is at more than 1σ different from that of the outer regions. This steepening is in agreement with the results of Annunziatella et al. 2014 on the investigation of the stellar mass function (MF). In fact, as shown in Fig. 1 (right panel), there is a deficit of low mass galaxies in the cluster core, which adds up to $\sim 6{\times}10^{11}$ M$_\odot$, computed by extrapolating the slope of the MF in the external region. This nicely matches with the ICL stellar mass estimated in Presotto et al. 2014. Thus, the deficit of these galaxies in the core can be interpreted as stripped stellar mass which went to populate the ICL.

In Fig. 2, we present the LF of the cluster members in HST data (in black), compared with that obtained from SUBARU data in the same region (in red) and in the outer region (in blue). Ground based photometric data are adequately fitted by a single Schechter function, while the fit with a single Schechter function is poor in the central $\sim$0.4 r/r$_{200}$ region mapped by HST, due to an upturn at magnitudes fainter that R$_c$=23.5, suggesting a bimodal behaviour of the LF down to M$\sim$M*+7. There is an evidency of some structure in the residuals: the fit systematically under- and over-predicts the observed counts in the range 21<R$_c$ <23.5 ($10^{10.5} < \mathscr{M} < 10^{9.5}$ M$_\odot$). This result confirms the scenario reported above for the ICL and supports the idea that the ICL is built-up by the tidal stripping of $\sim$M*+2 mag galaxies (De Maio et al. 2015).

We are now extending such kind of studies to other galaxy clusters in our sample to investigate whether and why tidal effects might have been more effective in some clusters than in others.

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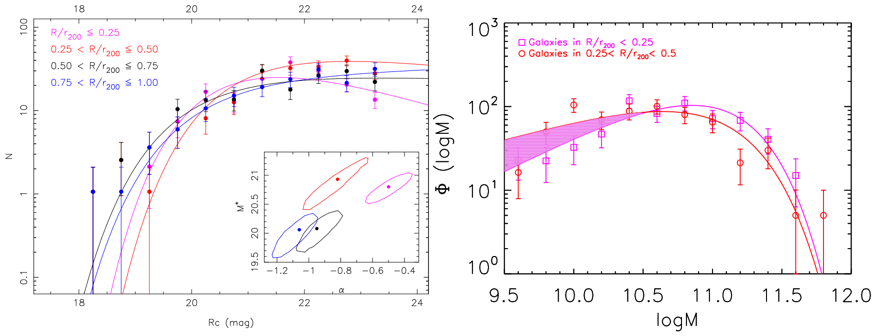

Fig. 1 *Left panel*: Luminosity functions of galaxies in MACS J1206.2-0847, covering regions with increasing distance from the centre. Continuous lines are the fits with the Schechter function. The best–fit Schechter parameters for α and M^* with their 1σ contours for the corresponding LFs are also reported in the small panel. The counts are per half magnitudes. *Right panel*: Mass functions of galaxies in the core of MACS J1206.2-0847 and the outer ring. The shaded area highlights the deficit of low mass galaxies in the core, which adds up to $\sim 6\times10^{11}\mathrm{M}_\odot$ (see Annunziatella et al. 2014 for details).

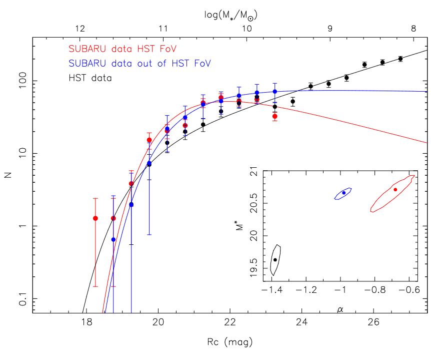

Fig. 2 Luminosity functions of galaxies in MACS J1206.2-0847, from HST data (black) and from SUBARU data in the same regione covered by HST (red) and in the external region (blue). Continuous lines are the fits with the Schechter function. The best–fit Schechter parameters for α and M^* with their 1σ contours for the corresponding LFs are also reported in the small panel. The counts are per half magnitudes.