Chapter 35
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 for the CLASH-VLT cluster MACS J1206.2-0847 at $z = 0.439$, based on HST and SUBARU data, including ∼600 spectroscopically confirmed member galaxies. The LFs on the wide SUBARU FoV are well described by a single Schechter function down to M∼M*+3, whereas this fit is poor for HST data, due to a faint-end upturn visible down M∼M*+7, suggesting a bimodal behaviour. We also investigate the effect of local environment by deriving the LFs in four different regions, according to the distance from the centre, finding an increase in the faint-end slope going from the core to the outer rings. Our results confirm and extend our previous findings

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on the analysis of mass functions, which showed that the galaxies with stellar mass below $10^{10.5}\,M_\odot$ have been significantly affected by tidal interaction effects, thus contributing to the intra cluster light (ICL).

35.1 Introduction

The galaxy LF, which describes the number of galaxies per unit volume as function of luminosity, is a powerful tool to study the properties of galaxy populations and to constrain their evolution through comparisons with the dark matter halo mass function. The dependence of the observed galaxy LF on the environment provides a powerful discriminator among the environmental-related mechanisms that have been suggested to drive 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. [1] 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 and Hodgkin [12]). The LFs can vary from cluster to cluster or/and also in different cluster regions, depending on 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 $z = 0.439$, by examining the effect of local environment through the comparison of the LFs in four cluster regions. This study has an unprecendeted combination of depth and area, taking advantage of both multiband HST data and Subaru panoramic imaging, as well as extensive spectroscopic coverage.

35.2 Data and Catalogues

Ground-based photometric observations were carried out with the SuprimeCam at Subaru, covering $30' \times 30'$, with total exposure times of 2,400, 2,160, 2,880, 3,600 and 1,620 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 [3] in conjunction with PSFEx [4], 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 [11]).

The final photometric catalogue contains ~34,000 objects down to $R_c = 24$ mag. The CLASH-VLT campaign provided 2,749 reliable spectroscopic redshifts. To complete the spectroscopic sample, we have used photometric redshifts, calibrated on the large redshift catalog, as described in Biviano et al. [5]. Thus, our final sample includes 2,468 cluster members (590 of which are spectroscopically confirmed). In order to derive the LFs, we also applied the completeness corrections to the observed galaxy counts reported in Annunziatella et al. [2].

MACS J1206.2-0847 was observed with HST in 16 broadband filters, from the UV to the near-IR as part of the CLASH multi-cycle treasury program (see Postman et al. [9]). As described in Grillo et al. [8], in the HST/WFC3 FoV we selected cluster members by measuring the probability for a 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), based on the color distribution of the 233 galaxies in the spectroscopic sample. With this method, we obtained a total sample of 1,177 spectroscopic or photometric members, down to F814W = 26.5 mag.

This dataset has allowed us to investigate the cluster galaxy population down to M$\sim$M*+7 (corresponding to stellar masses of $\mathscr{M} \sim 10^{8.2}\,M_{\odot}$) in the central region (R<0.4 r_{200}) and M$\sim$M*+3 ($\mathscr{M} \sim 10^{9.5}\,M_{\odot}$) out to 3.5 r_{200} ($r_{200} = 1.96$ Mpc; [5]).

In order to match the photometry of the HST data in the F814W band, and of the SUBARU data in the Rc band, we derived a linear relation between the magnitudes measured in these two bands

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35.3 Results

We show in Fig. 35.1 (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. [2], this is equivalent to referring to the local galaxy number density in this dynamically relaxed cluster (but see also Girardi et al. [7]). The LFs are well described by a single Schechter function. Environmental effects are apparent in the slope of LFs, which is found to be steeper in the outskirts compared to the central region, by more than 1σ. We assess the statistical significance of the difference between LFs non parametrically, via a Kolmogorov-Smirnov test, which gives a very low probability (<0.04 % in the better case) to the hypothesis that the distribution of galaxies are drawn from the same population in the first region respect to the three adiacent areas. This steepening is also in agreement with the stellar mass function (MF) presented by Annunziatella et al. [2]. As shown in Fig. 35.1 (right panel), we find 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. Interestingly, this stellar mass matches the ICL stellar mass estimated by Presotto et al. [10]. Thus, the deficit of these galaxies

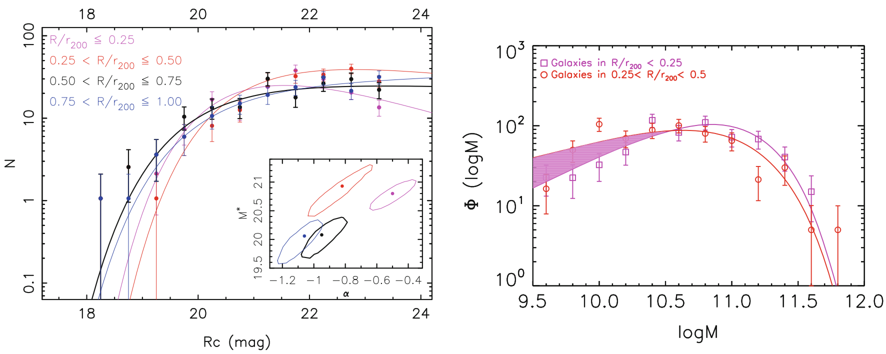

Fig. 35.1 *Left panel*: LFs of galaxies in MACS J1206.2-0847, covering regions with increasing distance from the centre. *Continuous lines* are the fits with the Schechter function. The best–fit Schechter parameters for α and M^* with their 1σ contours for the corresponding LFs are also reported in the *small panel*. *Right panel*: MFs of galaxies in the core of MACS J1206.2-0847 and the outer adjacent ring. The *shaded area* highlights the deficit of low mass galaxies in the core, which adds up to $\sim 6 \times 10^{11} M_\odot$ (see Annunziatella et al. [2] for details)

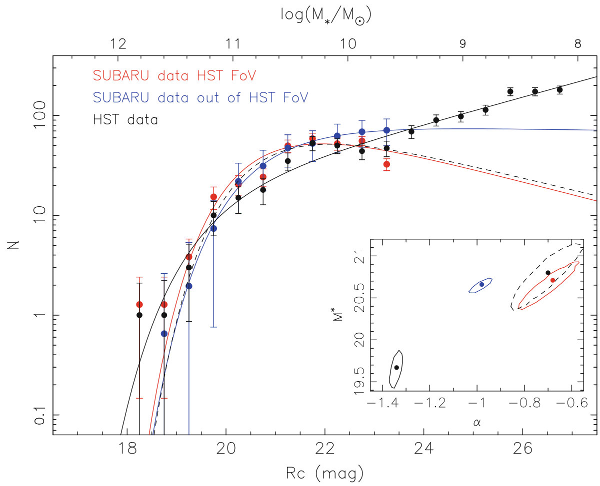

Fig. 35.2 LFs of galaxies in MACS J1206.2-0847, from HST data (*black*) and from SUBARU data in the same region covered by HST (*red*) and in the external region (*blue*). *Continuous lines* are the fits with the Schechter function. *Dashed line* is the fit to HST data down to $M = M^* + 3$. The best–fit Schechter parameters for α and M^* with their 1σ contours for the corresponding LFs are also reported in the *small panel*

in the core can be interpreted as stripped stellar mass which went to populate the ICL component during the cluster assembly process. The deficit of faint galaxies could be also related to galaxy merging processes, however, we don't observe an excess of massive galaxies in cluster cores compared to more external regions (see Annunziatella et al. [2]). In Fig. 35.2, 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. Instead, as for the central $\sim$0.4 r/r_{200} region mapped by HST, the fit with a single Schechter function is poor. The residuals show that the fit systematically under- and over-predicts the observed counts in the range $21 < R_c < 23.5$ ($10^{10.5} < \mathscr{M} < 10^{9.5}\,M_\odot$), and there is an upturn at $R_c > 23.5$, suggesting that a bimodal behaviour of the LF is more suitable to describe the LF down to $M = M^{*}+7$. 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 (DeMaio et al. [6]). We are now extending the analysis of the LF and MF to other clusters from the CLASH-VLT dataset, three of which include $\sim$1,000 spectroscopic members. This high-number statistics will allow us to also take into account structural and stellar population properties of the cluster members, to elucidate the impact of tidal effects in the mass assembly history of massive clusters.

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