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ICL light in a z∼0.5 cluster: the MUSE perspective

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Abstract. Intracluster light is contributed by both stars and gas and it is an important tracer of the interaction history of galaxies within a cluster. We present here the results obtained from MUSE observations of an intermediate redshift (z∼ 0.5) cluster taken from the XXL survey and we conclude that the most plausible process responsible for the observed amount of ICL is ram pressure stripping.

Keywords. galaxies, clusters, intracluster light, 3D spectroscopy

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1. Introduction

Many clusters of galaxies show a diffuse, low luminosity light emission commonly known as Intra Cluster Light (ICL). It is normally assumed that the ICL is dominated by stars stripped from their parent galaxies; however hydrodynamical effects can also strip gas and dust from galaxies, adding a contribution to the ICL. It is still unclear how the ICL builds up during the cluster evolution and what is its relation, if any, to the brightest cluster galaxy (BCG), which sits at the bottom of the cluster potential well. Potentially important processes which drive the evolution of galaxies in dense environments are galaxy-galaxy interactions and mergers, in particular in infalling groups and subclusters (the so-called pre-processing), interactions with the cluster potential, galaxy harassment and ram pressure stripping. The study of both components of the ICL, gas and stars, can offer an unique window on the history of the cluster evolution and of its environment.

The majority of published studies of ICL rely on imaging data, sometimes with a limited field of view, which makes difficult to disentangle between the emission coming from the galaxies and the true ICL. Only in the last decades spectroscopic studies have been published, revealing that intracluster stars have subsolar metallicities and ages between 2-13 Gyr, and these have been limited to nearby clusters (Coccato *et al.* 2011; Durrel *et al.* 2002). Only a few more recent studies have extended the redshift range up to z∼ 0.6 (see de Maio *et al.* 2015, Melnick *et al.* 2012) with contrasting results for the ICL stellar metallicity, subsolar in the first work and solar and above in the second one. The clusters studied in the cited works are quite different morphologically, which gives further strength to the connection between the ICL and the cluster evolutionary history.

We present here the results from an imaging and spectroscopic study of a very ICL-rich, X-ray detected cluster found in the XXL survey (Pierre *et al.* 2015†), XLSSC 116, at redshift z=0.534. The cluster exhibits a very large amount of ICL, equivalent to almost two BCGs; its X-ray emission is well fitted by a double-component APEC model with

† http://irfu.cea.fr/xxl

Table 1. Characteristics of the ICL and of the dominant cluster galaxy. For the dominant galaxy, we give first the SED-estimated SFR, and then the spectroscopically-estimated SFR.

	Galaxy type	Age 10^9 Gyrs	r'(AB)	log(M_*) $M_\odot$	log (SFR) $M_\odot$ / yr	log (M/L_{K_s}) $M_\odot/L_\odot$
ICL	Ell1	2.3 [1.1; 5.9]	20.03±0.09	10.7 [10.5; 10.9]	0.7 [-1.2; 1.3] /0.11 [0.04;0.18]	0.69 [0.52; 1.10]
BCG	Sd	9.3 [7.9; 9.8]	21.025±0.006	10.9 [10.4; 11.2]	1.9 [1.5; 2.7] / 1.03 [0.96;1.08]	0.71 [0.25; 0.99]

T_1=0.3 and T_2 ∼ 2.1 keV, and its peak is offset from the BCG by 11" (70 kpc at the cluster redshift), see Adami *et al.* (2016) for more details. In what follows, we use the standard concordance cosmological model (H_0=71.9 km s^{-1} Mpc^{-1}, $\Omega_\Lambda = 0.742$, $\Omega_M = 0.258$).

2. Observations and data analysis

XLSSC 116 is located in the CFHTLS W1 field (Coupon *et al.* 2009), providing u*, g', r', i' and z' data, and it was also observed with CFHT/WIRCAM in K_s, for a total exposure time of 1050s, corresponding to a depth close to $K_{sAB} = 22$ at 5σ level in a Kron-type aperture. Furthermore it was observed in 2014 with MUSE for 4h of Science Verification Time (60.A-9302), covering 1'x1' field, from 480 to 930nm, with a final spectral resolution of 1.25Å/pixel. The images were reduced using the standard TERAPIX pipeline and a wavelet-based method, OV_WAV, (see Da Rocha *et al.* 2005), was used to detect the diffuse light component. The MUSE data were reduced using the instrument pipeline (0.18.2) following the prescriptions in the pipeline cookbook. The spectra were extracted by summing all the pixels within several elliptical regions using ds9; narrow or broad-band images were obtained by collapsing the final cube in the selected wavelength range. Spectroscopic redshifts were obtained with the code EZ (Garilli *et al.* 2010) for all galaxies within the MUSE FOV.

A complex source of ICL in which several galaxies are embedded was detected, extending out to 180 kpc, and with a total integrated magnitude larger than the BCG. A SED fitting of the ICL returns an early type galaxy profile with an estimated age between 2.3 and 6 Gyr. This is completely different from the best SED fit obtained for the BCG, which is well modeled by a late type (Sd) galaxy, with high SFR. These findings are confirmed by MUSE spectra, which return a spectrum dominated by absorption lines for the ICL and a Sd galaxy spectrum for the BCG. The total stellar mass of the ICL and of the BCG are $10^{10.7}M_\odot$ and $10^{10.9}M_\odot$ respectively, see also Table 1.

In addition to this, an emission line diffuse light (ELDL hereafter) region was detected at 5σ level to the SW of the BCG, shining mainly in [OII] and [OIII] redshifted to z=0.534. Its size is approximately 13x6 kpc, and we estimated from MUSE data an upper magnitude in I $\geqslant$ 26.5 , i.e. $M_I \geqslant -16$ at z=0.534. This corresponds approximately to B band rest frame magnitude, so adopting $B_\odot$=5.48, we have a maximum of 4 x 10^8 stars of solar type, i.e. a maximum stellar density of 0.0002 pc^{-3}, 500-1000 times lower than the solar vicinity. The R23 parameter, computed following Moustakas *et al.* (2010), returns a value of almost 10. Using the models of Oey *et al.* (2000), the only possibility to obtain such high R23 is a gas with ∼ 0.3-0.5 solar metallicity, and a low excitation parameter, U ∼ 0.01. The SFR in the ICL, computed using the [OII] line, is of the order of $2.2M_\odot$/year.

3. Results and conclusions

The spectroscopic redshifts of all galaxies were used to investigate the presence of substructure in the cluster: using the Serna-Gerbal method (Serna *et al.* 1996). we detected two of them. The first has an estimated mass of $4.6 \times 10^{13} M_\odot$ and a velocity dispersion of 570 km/s; the second has an estimated mass and velocity dispersion of $4\times 10^{12} M_\odot$ and 170km/s respectively, and it has a velocity shift of 2000 km/s with respect to the mean redshift of the cluster. Galaxies from both structures are well mixed in the cluster red sequence. We have also observed a significant amount of ICL, some of which is dominated by emission lines but not significantly forming stars and a BCG with an old age and an high star formation rate. This may be explained by assuming a relatively recent episode of star formation in the BCG: taking into account the current SFR, at least 2 Gyr are needed to generate enough young stars to account for a significant contribution to the BCG stellar mass. This is close to the age of the ICL, so it is likely that the last episode of SF in the BCG and the ICL are linked together. The brightness of the ICL is also higher than the BCG, but its mass is lower, which likely means that gas in the ICL dominates over the stellar contribution in the optical, something not usually associated with ICL. From the X-ray data, we deduced that XLSSC-116 is not currently undergoing a major merger, because of the lack of a strong temperature jump, therefore any infalling structure must be already in an advanced merging stage and does not show as a dynamical independent structure any longer. According to the models by Poole *et al.* (2007), a merging structure must have passed the second pericenter approach to be undetectable; this time will depend on the cluster-infalling structure mass ratio and on the impact parameter. Assuming 2 Gyr as the time elapsed between the infalling structure first virial crossing and the second pericentric approach, i.e. the beginning of the last episode of SF in the BCG, we would need an impact parameter of 0.15 or lower and a mass ratio close to 1 between the cluster and the infalling structure. This merger might have caused the shift between the location of the BCG and the peak of the X-ray emission, and it likely caused a rapid motion of the galaxies within the cluster gas, generating a ram pressure stripping process. A mass ratio of ~ 1 is ideal for maximing the energy and matter exchange process between the structures, therefore generating a large amount of ICL. The gas, being less strongly bound that the stars, has been stripped in large quantities, and it dominates the light emission, but no significant star formation is produced, due to its low density.

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