Diffuse light in $z \sim 0.25$ galaxy clusters: constraining tidal damage and the faint end of the Luminosity Function

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Abstract. The starlight coming from the intergalactic space in galaxy clusters and groups witnesses the violent tidal interactions that galaxies experience in these dense environments. Such interactions may be (at least partly) responsible for the transformation of normal star-forming galaxies into passive dwarf ellipticals (dEs).
In this contribution we present the first systematic study of the IntraCluster Light (ICL) for a statistically representative sample (Zibetti et al. 2005), which comprises 683 clusters selected between z=0.2 and 0.3 from $\sim 1500\,\deg^2$ in the SDSS. Their ICL is studied by stacking the images in the *g*-, *r*-, and *i*-band after masking out all galaxies and polluting sources. In this way a very uniform background illumination is obtained, that allows us to measure surface brightnesses as faint as 31 mag arcsec^{-2} and to trace the ICL out to 700 kpc from the central galaxy. We find that the local fraction of light contributed by intracluster stars rapidly decreases as a function of the clustercentric distance, from ∼40% at 100 kpc to ∼5% at 500 kpc. By comparing the distribution and colours of the ICL and of the clusters galaxies, we find indication that the main source of ICL are the stars stripped from galaxies that plunge deeply into the cluster potential well along radial orbits. Thus, if dEs are the remnants of these stripped progenitors we should expect similar radial orbital anisotropies and correlations between the dE luminosity function and the amount of ICL in different clusters.
The diffuse emission we measure is contaminated by faint unresolved galaxies: this makes our flux estimate depend to some extent on the assumed luminosity function, but, on the other hand, allows us to constrain the number of faint galaxies. Our present results disfavour steep ($\alpha < -1.35$) faint-end powerlaw slopes.

Keywords. galaxies: interactions, clusters: general, intergalactic medium, dwarf, elliptical and lenticular, cD, evolution, formation

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1. Introduction

The diffuse intracluster light (ICL) is produced by stars which are not bound to any individual galaxy in a cluster, but orbit freely in the global gravitational potential of the cluster. The ICL has now been detected in a number of nearby groups and clusters both by means of deep surface photometry (e.g. Bernstein et al. 1995; Feldmeier et al. 2002; Gonzalez, Zabludoff & Zaritsky 2005) and by resolving red giant stars (Durrell et al. 2002) and planetary nebulae (e.g. Arnaboldi et al. 1996). As for the origin of this stellar component, the presence of tidal features and dynamical substructure, that has emerged from a number of studies, strongly supports the hypothesis that intergalactic stars are created via tidal stripping from galaxies and during merger events, rather than *in situ* from isolated extragalactic star forming regions.
Tidal stripping and repeated tidal perturbations in a dense environment (harassment)

may be also invoked as the main mechanism responsible for transforming low mass star-forming discs into dwarf elliptical galaxies (dEs) and compact dwarves. The investigation of the systematic properties of the ICL puts quantitative constraints on the tidal damage that galaxies suffer in clusters and, therefore, can provide invaluable clues to understand the formation of dEs.

Zibetti et al. (2005) have recently analysed the systematic properties of the diffuse stellar emission in a sample of 683 clusters by stacking their images from the Sloan Digital Sky Survey (SDSS, York et al. 2000). In this contribution we will review their results, focusing on the implications for the stripping scenario for the formation of dEs.

2. Sample and photometric technique

The stacking technique aims at obtaining high photometric sensitivity, while strongly reducing the systematic defects that arise in individual observations from flat field inhomogeneities and scattered light from “polluting” (fore- and background) sources. This is achieved by averaging a large number of images of different targets, where the unwanted sources are efficiently masked. Typical required number of images is several hundreds, hence the need for a large imaging database as the SDSS. The results obtained from the stacking of a large number of clusters grant a high statistical significance, but have the disadvantage of lacking information about substructure and cluster-to-cluster variations, that must be derived from the analysis of different subsamples.

For the present study a sample of 683 clusters of galaxies has been drawn from ∼1,500 deg^2 of the first data release of the SDSS (Abazajian et al. 2003). We have used the maxBCG cluster finder algorithm developed by J. Annis to select clusters in the same richness range as the Abell catalogue, between $z = 0.2$ and 0.3. The redshift constraint has been introduced to limit the size of the stacked images to a single SDSS frame, thus avoiding to mosaic images with different background properties for a given cluster. Moreover, at the median z of the sample the $g - r$ colour conveniently maps the 4000Å break, providing valuable information about the intracluster stellar population.

Lacking any kinematic characterisation, we *define* as ICL all the flux beyond the isophote 25 mag arcsec^{-2} (observed r-band) of any galaxy. All galaxies, except the central brightest cluster galaxy (BCG), are masked to this extent. Bright stars are masked out to 3 times the isophotal radius, to prevent their bright haloes being included in the stacking. Images are then centred on the BCG, size-rescaled to the same metric radius, and intensity-rescaled to the same photometric calibration, corrected for Galactic extinction and cosmological SB dimming. A simple average of the masked images is then computed (stacked image). A stacking of images where only the brightest stars were masked has been performed as well, to obtain a map of the total luminosity of the cluster to be compared to the ICL.

We have tested the efficiency of our masking algorithm and quantified the fraction of galaxy light which fails to be masked. Realistic SB distribution have been used to simulate galaxies in the same observed conditions as for real clusters, with different luminosity functions (LFs) parametrised á la Schechter. Depending on the adopted parameters (and particularly on the powerlaw slope of the faint end α) we find that 5 to 20-25% of the light in galaxies can be missed. As we will show below, this effect can be used along with other observational constraints to put limits to the faint end slope of the LF.

The following *results* are derived assuming that the fraction of unmasked galaxy light is 15%, as obtained for the parameters of the Coma cluster LF ($M_r^* = -21.37$, $\alpha = -1.18$, Mobasher et al. 1998), passively evolved to $z = 0.25$.

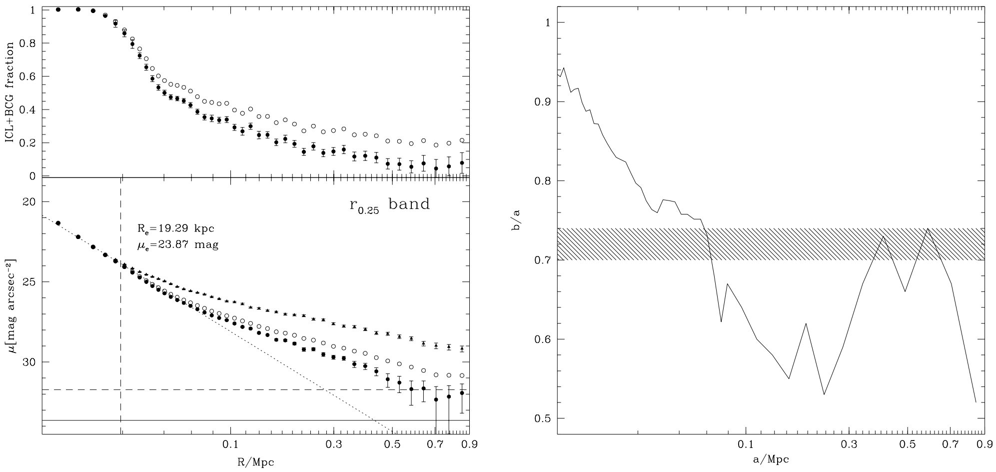

Figure 1. Panel a): r-band surface photometry. The lower section shows the surface brightness profiles for all components (triangles with error bars), for the diffuse light as measured (open circles) and for the corrected ICL (filled circles with error bars). The dotted line represents the best fitting de Vaucouleurs profile to the BCG core, with the vertical dashed line marking R_e. The two horizontal lines show 1σ background uncertainty for the total (dashed) and for the diffuse light. The upper section displays the local relative amount of diffuse light (open circles) and of the corrected ICL+BCG component (filled circles with error bars). Panel b): Isophotal shapes for clusters with a flattened BCG ($b/a < 0.7$ from 2-D de Vaucouleurs fit). The solid line displays the axial ratio of the (uncorrected) diffuse light + BCG, with typical errors of 0.05 in the central regions to 0.1 at 500 kpc. The shaded area is the 1σ interval for the distribution of the total light.

3. Results

By extracting azimuthally averaged SB profiles we can trace the diffuse light out to ~700 kpc from the central galaxy at levels of 31 mag arcsec^{-2}. In the lower panel of fig. 1a) the combined contribution of the BCG and of the ICL is shown by filled circles with error bars. Starting from 80 kpc, the ICL clearly appears as an excess with respect to the inner de Vaucouleurs profile that characterises the BCG. Compared to the total light of all stellar components (triangles), the ICL is remarkably more centrally concentrated, providing a local relative contribution that decreases from 40% of the total SB at 100 kpc, to less than 5% at 600 kpc and beyond. This clearly indicates that the creation/accumulation of intracluster stars is much more efficient in the centre of the cluster. The colour profiles of the ICL ($g-r$ and $r-i$, obtained from the g-, r- and i-band stacked images) are consistent with ($g-r$) or just marginally redder than ($r-i$) the average colours of galaxies, thus suggesting that the intracluster stellar population is not dissimilar from that in galaxies. On a subsample of clusters with BCG having a significant flattening ($b/a < 0.7$ from 2D de Vaucouleurs SB fitting), the stacking has been performed after aligning the images along the major axis of the BCG. The isophotal analysis (fig. 1b) shows that the ICL is strongly aligned with the BCG and displays even a higher degree of flattening. In fact, there is a monotonic decrease of b/a from the BCG core out to 300 kpc, where $b/a \sim 0.5$. It is remarkable that the distribution of galaxies is less aligned with the BCG and/or less flattened than the ICL. This may indicate that the intracluster stars are stripped more efficiently from galaxies that move along radial orbits aligned with the main axis of the BCG.

We have studied the dependence of the ICL SB and luminosity on cluster richness and

BCG luminosity. The SB of the ICL is enhanced in rich clusters and in those having a luminous BCG, and *vice versa*. The clusters with the faintest BCGs appear particularly deficient in ICL. However, the relative contribution of ICL to the total luminosity within 500 kpc is roughly constant 11% for all clusters.

4. dEs as stripped galaxies?

N-body hydrodynamical simulations (also Mastropietro in this Colloquium) have demonstrated that dynamical harassment, tidal and ram-pressure stripping can transform small star-forming disc galaxies into passive dEs (see also Merritt 1984, Moore et al. 1996). It is therefore conceivable that dEs and the ICL share the same origin. The broadband colours are consistent with this scenario, and the fact that the total luminosity of dEs is similar to that of the ICL is very intriguing too. On the other hand, if dEs are the remnants of the galaxies from which a large number of stars have been stripped into the intergalactic space, we should expect (i) that in anisotropic clusters dEs display a similar flat and aligned distribution as the ICL, in addition to some degree of radial orbital anisotropy; and (ii) that the luminosity function of dEs correlates with the amount of ICL. The study of these correlations between ICL and dEs may therefore provide invaluable clues on the origins of these two components and on the violent history of galaxy clusters.

5. Constraints to the faint end of the LF

In all the analysis conducted above, the measured diffuse light is converted into "real" ICL assuming that the fraction of galaxy light that is left unmasked is 15%, according to our simulations for a LF as in Coma. As already mentioned, by varying the parameters of the LF values between 5 and 20-25% are found. However we have a number of constraints that limit the range of variation to <5% around the assumed 15%. M^* is constrained within a few hundredths of mag by directly observed number counts. On the other hand, if a too steep LF is chosen, then the predicted unmasked flux becomes larger than the actual flux in the diffuse component. In particular, if we assume that the LF is independent of radius, then the minimum value of the local fraction of diffuse light represents the maximum fraction of light that might be missed by our masks. Since this fraction is 20% at $R \sim 600$ kpc (see fig. 1a), we calculate that the faint-end powerlaw of a simple Schechter LF cannot be steeper than $\alpha = -1.35$.

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