The optical and near-infrared properties of nearby groups of galaxies

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Summary. We present a study of the optical (BRI) and near-infrared (JHK) luminosity functions (LFs) of the GEMS sample of 60 nearby groups of galaxies between $0.01 < z < 0.04$, with our optical CCD photometry and near-IR photometry from the 2MASS survey. The LFs in all filters show a depletion of galaxies of intermediate luminosity, two magnitudes fainter than $L_*$, within $0.3 R_{500}$ from the centres of X-ray faint groups. This feature is not as pronounced in X-ray bright groups, and vanishes when LFs are found out to $R_{500}$, even in the X-ray dim groups. We argue that this feature arises due to the enhanced merging of intermediate-mass galaxies in the dynamically sluggish environment of low velocity-dispersion groups, indicating that merging is important in galaxy evolution even at $z \sim 0$.

1 Introduction

Observational studies of the environmental dependence of galaxy evolution mostly concentrate on galaxies in rich clusters, even though $< 5\%$ of galaxies are found in such environments. Most galaxies are found in groups, and arguably the group environment plays an important role in their evolution. In groups, galaxies could be transformed by their interaction with the intra-group medium, or with other galaxies by means of a variety of processes (e.g. stripping, tidal interaction) or through merging with other galaxies. Here we seek to study the optical and near-IR properties of galaxies in groups to find whether they support the relative importance of any of these processes.

2 Luminosity functions of GEMS groups

We explore the optical properties of galaxies in a sample of 60 nearby groups, known as the Group Evolution Multi-wavelength Study (GEMS, detailed descriptions in [1, 2]). This sample represents a variety of groups over a large range of evolutionary stages, and are all in the fields of $> 10$ ks of ROSAT
Fig. 1. Cumulative $B$-band Luminosity Function of 25 GEMS galaxy groups, divided into two categories: X-ray bright groups ($L_X > 10^{41.7}$ erg s$^{-1}$), plotted as triangles and X-ray dim groups ($L_X < 10^{41.7}$ erg s$^{-1}$), plotted as circles. Only the LF of X-ray bright groups can be fit with a single Schechter function.

PSPC observations (some of them are not detected). As a description of the Group environment, we use their bolometric X-ray luminosity $L_X$, and divide the sample into two subsamples: X-ray bright if $L_X > 10^{41.7}$ erg s$^{-1}$, and X-ray dim if less (including the undetected ones). This X-ray luminosity refers to that of the group plus any central galaxy that might exist (for more details, see [3]).

2.1 B(VR)IJK photometry

The optical subsample consists of 25 GEMS groups: 17 of them were observed at the 2.5m INT, La Palma, with the WFC, imaging an area of $4 \times 22.5 \times 11.3$ arcmin of sky with BVI filters. Another 8 groups were observed with the 2.2m ESO/MPI telescope at La Silla, Chile, using the WFI, with a field of $34 \times 33$ arcmin, with broadband BRI filters. For each group, we went out to a radius of $0.3 R_{500}$ from their centres.

Furthermore, we extracted JHK magnitudes of all 60 GEMS groups from the 2MASS All-Sky Extended Source Catalog (2MASX), going out to a radius $R_{500}$ of its centre for each group, down to a limiting magnitude of $M_K = 13.75$. The adopted group centres, values of $R_{500}$ and distances to these groups can be found in [1], and details of member selection and data reduction in [3, 4].

2.2 Stacked luminosity functions

In Fig. 1, we show the cumulative $B$-band luminosity function (LF) for our optical subsample (25 GEMS groups), evaluated by co-adding galaxies of several groups in equally spaced bins of absolute luminosity, with galaxies chosen from within $0.3 R_{500}$ from the centre of each group. This reveals that the LF of the X-ray dim groups ($L_X < 10^{41.7}$ erg s$^{-1}$) is significantly different from that of the X-ray brighter groups. Fig. 2 shows the differential LFs, (left) for
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Fig. 2. The mean differential Luminosity functions of GEMS Groups, within 0.3R$_{500}$ from their respective centres, *(Left:)* in the B-band, for a subsample of 25 groups, and *(Right:)* K-band (2MASS), for all 60 GEMS groups. They are divided into X-ray bright groups (L$_X > 10^{41.7}$ erg s$^{-1}$, triangles) and X-ray dim groups (circles), stacked together to form composite LFs for the respective sub-classes. The LFs of the dim groups show “dips” between $-19 < M_B < -17$ and $-24 < M_K < -23$

the B-band, within 0.3 R$_{500}$ (same data as Fig. 1), and (right) for the K-band, within R$_{500}$. The differential LFs reveal the nature of the difference, in the form of a prominent dip, at around $M_B = -18$ and $M_B = -23.5$ (more details of observational data in [3, 4, 5]).

We interpret this deficiency of intermediate luminosity galaxies as evidence of rapid evolution through merging. In the low velocity dispersion environment, as in X-ray dim groups, dynamical friction would facilitate more rapid merging, thus depleting intermediate luminosity galaxies to form more giant central galaxies. Since the collision cross-section depends on the size of a galaxy, the dwarf galaxies at the faint end of the LF are more likely to merge with a giant galaxy, than merge with each other. This ensures galaxies in a range of intermediate luminosities are preferentially depleted, thus enhancing the bright end of the LF.

We suggest that X-ray dim (or low velocity dispersion) groups are the present sites of rapid dynamical evolution rather than their X-ray bright counterparts, and may be the modern precursors of fossil groups. Such LF features are seen in some clusters as well, such as Coma (e.g. [6]), which we would argue has resulted from recent merger with groups.

The optical LFs are determined only out to 0.3 R$_{500}$ of each group, but we can investigate the nature of the LF in their outer parts from the near-IR LFs from the 2MASS survey. We consider three ranges of radial distance in finding the mean K-band LF in Fig. 3. The dip between $-24 < M_K < -23$ seen in the LF in the central regions of the groups gradually disappears as the LF is averaged out to larger radii, approaching R$_{500}$, where the LFs of both X-ray bright and dim groups are of a similar shape.
Fig. 3. Differential $K$-band luminosity functions of (Left:) all X-ray dim GEMS groups ($L_X < 10^{41.7}$ erg s$^{-1}$), out to a fraction of the projected group radius. (Right:) The same for all X-ray bright groups ($L_X > 10^{41.7}$ erg s$^{-1}$). The three plots in each case go out to 0.3, 0.6 and 1.0 times $R_{500}$ respectively. The intermediate luminosity dip feature is more prominent in the inner regions of the X-ray dim groups. The LF of the X-ray bright groups remains similar in shape at all radii.

2.3 Brightest group galaxies

One of the consequences of this scenario is that the brightest group galaxies in the X-ray dim groups are expected to be more massive and brighter than those in X-ray bright groups. Fig. 4 shows the colour of galaxies as a function of radial distance, stacked in radial bins scales by $R_{500}$, to reveal that X-ray dim groups have redder central galaxies. It also shows that in X-ray bright groups, the difference in $B$-magnitude between their brightest and second brightest galaxies is in general smaller than in X-ray faint groups. The X-ray bright groups have several galaxies of comparable luminosity (and mass) at the bright end, possibly being the end-products of earlier mergers on smaller scales in sub-groups that were incorporated in the virialised systems we observe today.

3 Conclusions

We argue that the missing intermediate-luminosity galaxies in the optical and near-infrared luminosity functions of X-ray dim groups indicate that, in the dynamically sluggish environment of such groups (which have low velocity dispersion), dynamical friction would facilitate more rapid merging, thus depleting intermediate-luminosity galaxies to form a few giant central galaxies. We also show that this effect is seen only in the interior regions of the groups ($R < 0.3 R_{500}$), and vanishes as one approaches $R_{500}$, rather than a bright-end enhancement caused by excess star formation. In [4], we show that this feature cannot arise due to enhanced star formation in the brightest galaxies, or due to a varying morphological mix of galaxies in various groups.

It is often suggested (e.g. [7]) that mergers are not an important ingredient of galaxy evolution in the recent Universe ($z < 1$). Here we have shown that
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Fig. 4. Left: The average $B-K$ colour of galaxies as function of distance (scaled by $R_{500}$) from the centre of the parent group. X-ray dim groups have redder central galaxies. Right: The X-ray luminosity of our GEMS groups, as a function of the difference in magnitude between the brightest and second brightest galaxies in each group. The biggest values for $\Delta M_{12}$ are in the X-ray dim groups.

in nearby poor groups, merging is still an important process. This picture of galaxy evolution leads to a definite prediction. If X-ray dim groups are indeed systems undergoing rapid dynamical evolution, the stellar populations in their galaxies would be significantly younger than those in X-ray bright groups in case of dissipative merging. This can be observationally verified.

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