Outskirts of Galaxy Clusters: Intense Life in the Suburbs
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Wide-field spectroscopy of a galaxy cluster pair at z=0.4

David G. Gilbank[1], F. J. Castander[2], M. L. Balogh[3] and R. G. Bower[3]

[1]Department of Astronomy and Astrophysics, University of Toronto, 60 St George Street, Toronto, Ontario, Canada, M5S 3HE email: gilbank@astro.utoronto.ca

[2]Institut d'Estudis Espacials de Catalunya/CSIC Gran Capità 2-4, 08034, Barcelona, Spain.

[3]Institute for Computational Cosmology, University of Durham, South Road, Durham, DH1 3LE, UK

Abstract. We present preliminary results from a wide-field spectroscopic survey of two galaxy clusters at $z = 0.4$, separated by <10 h^{-1}Mpc on the sky. Both clusters are similarly optically rich, have velocity dispersions $\sim$ 700 km s^{-1}, but differ in X-ray luminosity by a factor of $\sim$20.

1. Introduction

While galaxy clusters are dominated by passively evolving galaxies, field galaxies at $z \sim 0.4$ generally have very high star formation rates. In the hierarchical merging model of galaxy formation (e.g. Cole et al. 2000 and references therein) clusters grow through the accretion of galaxies from surrounding filamentary structures, which implies that galaxy properties are altered as they drain into overdense regions. However, the contrast between the cluster and the field at large clustercentric radii, is extremely low and thus identifying cluster members in these outer regions is observationally expensive. To increase efficiency, we targeted the inter-cluster region between a pair of clusters at $z = 0.4$ separated by $\lesssim 10h^{-1}$ Mpc on the sky, identified via the selection of the colour-magnitude relation of early type galaxies (see method of Gladders & Yee 2000) from the X-ray Dark Cluster Survey (XDCS; Gilbank 2001, Gilbank et al. 2004). Furthermore, these systems have similar optical luminosities in early-type galaxies, L_{E}, but very different (more than an order of magnitude) X-ray luminosities. Thus, this field provides the ideal sample for not only studying the evolution of galaxies in clusters out to large radii, but also the *differential* evolution of clusters with differing X-ray properties, observed at the same epoch. We present results from a wide-field spectroscopic survey tracing from one cluster core to the other across the lower density inter-cluster region, using LDSS2 on the 6.5-m Magellan telescope and FORS2 on the VLT.

2. Spectroscopic observations

The clusters were discovered in V- and I-band imaging taken with the 2.5-m INT. The field was re-imaged for spectroscopy in the R-band using FORS2 on the VLT, and galaxies brighter than $R < 20.5$ were selected for spectroscopy, adding fainter galaxies where space allowed. In total 626 galaxies were observed, resulting in 432 secure, 33 probable, 24 single-line and 36 lower confidence redshifts. 101 galaxies failed to yield a redshift. The mean redshifts of the two systems were measured to be $z_{\mathrm{A}} = 0.4127$ and $z_{\mathrm{B}} = 0.4203$, yielding a velocity difference of ≈ 1700 km s^{-1} in the mean rest frame, with velocity dispersions of $\sigma_{\mathrm{A,rest}} = 670 \pm 60$ km s^{-1} and $\sigma_{\mathrm{B,rest}} = 700 \pm 100$ km s^{-1} respectively. These implies virial radii of approximately $1.5h^{-1}$ Mpc (Girardi et al. 1998),

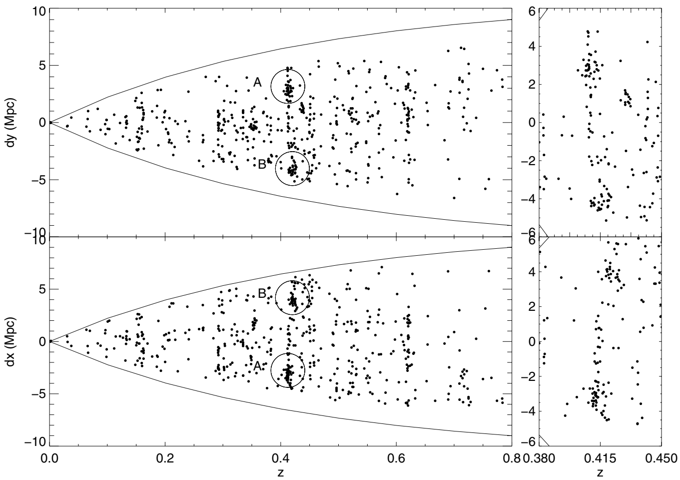

Figure 1. Declination (upper panels) and Right Ascension (lower panels) slices vs redshift for the field surveyed. The clusters A and B are circled and labelled in both wide field slices (left panels). A zoomed region around the cluster pair is shown to the right.

or ≈4.6 arcmins on the sky. The redshift distribution (shown as 'cone diagrams' in Fig. 1) shows evidence of filamentary structure connecting the clusters. We are unable to say if this connecting structure is due to a filament just linking the two clusters, or to an extended sheet of galaxies at the systems' redshift, because of our survey geometry: a line of masks from cluster core to cluster core.

In Fig. 2 we show the spectroscopically-selected colour-magnitude diagrams as a function of environment for each cluster in turn, and for the inter-cluster region. Both clusters show strong red-sequences of member galaxies (which is unsurprising, as this was the technique with which they were selected), and relatively low fractions of blue galaxies: 0.38 ± 0.11 and 0.25 ± 0.11 (although these fractions are possibly biased high, due to the greater ease of securing redshifts for blue, emission line galaxies over red, absorption line galaxies, at the faint end). The inter-cluster region also shows galaxies as red as those on the cluster red-sequences, but none as bright, and the fraction of blue galaxies is much higher (0.59 ± 0.13).

We attempt to characterise the environmental dependence of star-formation by examining the distribution of [OII] equivalent widths (EWs). Firstly we compare the distributions of each cluster with those of the X-ray luminous CNOC1 clusters (Balogh et al. 1999) and find that they are statistically indistinguishable. Secondly we compare the distribution in the inter-cluster region to that of a preliminary subsample of the CNOC2 field survey (R. Whitaker, priv. comm.). The distributions differ only at around the 1-σ level. Kodama et al. (2001) found that the transformation of galaxy properties occurs on a more local level, in groups in the cluster outskirts. This suggests that the lack of difference we see is due to the bulk of the galaxies in this large inter-cluster region being 'pristine' field galaxies, and that any signal of the truncation of star-formation is diluted over the large area we sample. Our next step is to examine the line-strengths of galaxies in more localised regions, in order to search for signatures of changes in star-formation properties.

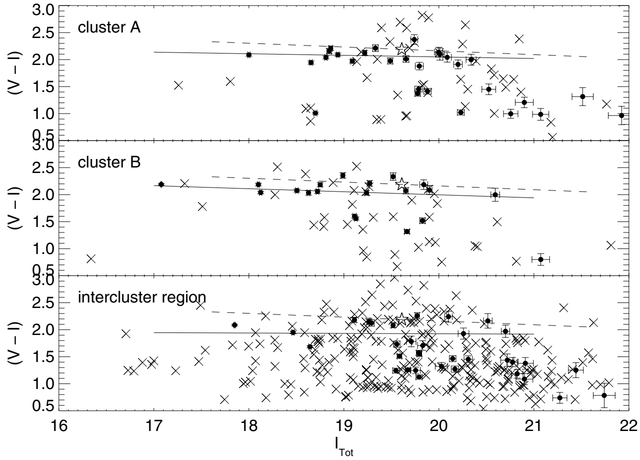

Figure 2. Colour-magnitude diagrams for the supercluster field, split by environment: top panel - cluster A; central panel - cluster B; lower panel - inter-cluster region. Filled points with error bars show spectroscopically confirmed members within the virial radius ($\sim$4.6 arcmin) projected distance (or outside these radii for the inter-cluster area). Crosses are spectroscopically confirmed non-members. Overplotted are the biweight fit to the CMR (solid line) and the model CMR (broken line) for the clusters' redshift.

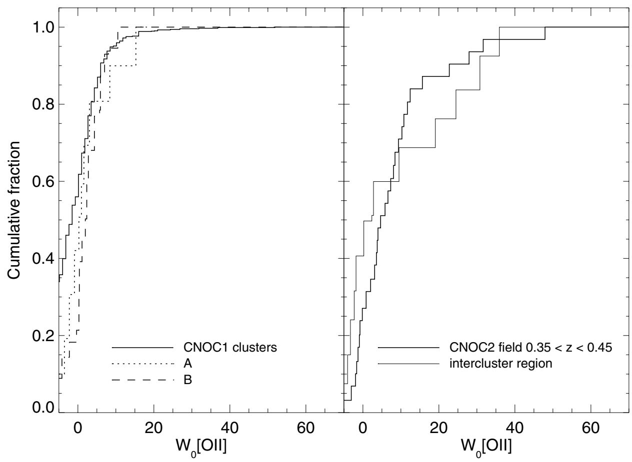

Figure 3. [OII] equivalent width distributions for our two $z = 0.4$ clusters and the CNOC1 X-ray luminous clusters (left panel) and for the inter-cluster region compared with a subsample of the CNOC2 field survey at comparable redshifts.

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