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The Luminosity Function of EDisCS Cluster Galaxies

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Abstract

We briefly outline the **ESO Dis**tant **C**luster **S**urvey (EDisCS), which has extensive photometric and spectroscopic coverage of 15 clusters at $0.5 < z < 0.8$ spanning a range of richness. Using the full photometric redshift probability distribution, calibrated from the ~ 500 spectroscopic redshifts, we remove foreground and background galaxies, rejecting 60% of all the galaxies to the spectroscopic limit while retaining 90% of all spectroscopically confirmed members. Additional statistical subtraction removes a remaining 15% from the original total. We construct stacked rest-frame b_J-band luminosity functions for our clusters which lie above and below $z = 0.6$ and use them to derive the brightening compared to the local mean cluster luminosity function. Assuming the local value of $\alpha = -1.28$ from De Propris, we infer a brightening of $\Delta M_{b_J} = -0.35 \pm 0.16$ for the low redshift sample ($\langle z \rangle = 0.5$) and $\Delta M_{b_J} = -1.05 \pm 0.17$ for the high redshift sample ($\langle z \rangle = 0.75$), in reasonable agreement with the predictions of fundamental plane studies.

1.1 Where We Are

Much progress has been made in studying the properties of local galaxy clusters and the effects of environment on galaxy properties. At high redshift, unfortunately, the study of clusters is not as advanced as at low redshift. At $z \sim 0.5$, the samples are moderate in size (Dressler et. al. 1999) and have poorly understood selection criteria, complicating the relation of these findings to the cluster population as a whole and making it difficult to compare these studies to the predictions of theoretical models. At even higher redshifts, i.e. $z \sim 0.8$, there are only a few well studied clusters, selected predominantly by detection in the x-ray and therefore limited to the most massive at their respective redshifts.

We are currently entering a new era of cluster studies. With the availability of large catalogs of clusters at $z \sim 0.5-0.8$, the advent of large ground-based telescopes with efficient multi-object spectrographs, the exquisite resolution provided by the Hubble Space Telescope, and the possibility of comparing detailed cluster observations with state-of-the-art numerical simulations, the time is ripe for a new, comprehensive study of cluster evolution over a large range in redshift.

1.2 A Comprehensive Study of Galaxy Cluster Evolution

The **ESO Dis**tant **C**luster **S**urvey (EDisCS) is a European Southern Observatory (ESO) Large Program designed to study cluster and cluster galaxy evolution over the range $z \sim 0.5-0.8$. The science goals of the photometric part of the survey are in part: to characterize the absolute rest-frame ultraviolet (UV) to near infrared (NIR) spectral energy distributions (SEDs) of the galaxies down to the faintest limits, to quantitatively study the galaxy morphologies, to study the mean cluster luminosity functions as a function redshift and cluster properties, and to measure the gravitational weak lensing shear. In practice, this involves deep optical to NIR imaging of a large enough number of clusters to represent the mean cluster properties in the respective redshift intervals, the use of bulge-disk decomposition software (GIM2D; Marleau & Simard 1998) to quantify the galaxy morphologies, and the use of photometric redshift to reject non cluster members using only the photometry. A second set of science goals are to study the kinematics, chemical abundances, SFRs, and SFHs of the cluster galaxies. This involves the collection of ~ 50 confirmed spectroscopic members per cluster, with high signal-to-noise, medium resolution spectra. Finally, all of these observations are to be compared directly to a set of high resolution N-body simulations with semi-analytic prescriptions for gas cooling, star formation, dust obscuration, and chemical enrichment which are being run by team members at MPA (Springel, et al. 2001; De Lucia et al. 2004).

1.2.1 Survey Description and Progress

To insure the most efficient use of telescope time possible, successive refinement steps were taken to arrive at a robust cluster sample. The original sample of 30 EDisCS cluster candidates, 15 at $z \sim 0.5$ and 15 at $z \sim 0.8$ was drawn from the Las Campanas Distant Cluster Survey (LCDCS; Gonzalez et. al. 2001 ApJS, 536, 561) which identifies cluster candidates on the basis of overdensities in shallow optical images smoothed to the expected spatial scales of cluster cores. To confirm the presence of a galaxy overdensity at the expected cluster position and to confirm the presence of the expected red sequence of cluster galaxies, four nights were used to obtain short optical images at the Very Large Telescope (VLT) using the FORS2 optical imager. After this initial imaging, the original sample of 30 cluster candidates was paired down to the 10 most likely candidates in each of the two redshift bins. These 20 clusters were then deeply imaged over 10 nights at the VLT in three optical bands, BVI for the $z \sim 0.5$ candidates and VRI for the $z \sim 0.8$ candidates. In addition, 20 nights of NIR observations were to be obtained at the New Technology Telescope (NTT) using the SOFI NIR camera, K_s band for the $z \sim 0.5$ candidates and and JK_s for the $z \sim 0.8$ candidates. At the present time, all of the optical imaging is complete and the NIR data is $2/3$ complete, with the remaining data coming this spring. Most of the data was taken under excellent conditions with almost all combined images having $< 1.0''$ FWHM seeing. Using the full set of optical and NIR images, I-band selected catalogs with multi-band photometry were constructed using the SExtractor software (Bertin & Arnouts 1996). The optical and NIR observations including the construction of the catalogs will be described in upcoming papers (White et al. 2004; Aragón-Salamanca et al. 2004).

The spectroscopic phase of the project has the dual goals of confirming the reality of each cluster candidate by looking for a physical spike in redshift space and obtaining high quality spectra for ~ 50 members in each cluster. After completing eight nights out of our total allocated time of 22 nights as of March 2002, we have confirmed that 75% of our cluster candidates were real clusters, with 6 clusters at $0.6 \leq z \leq 0.8$, and are on track to obtaining ~ 50 members per cluster with high quality spectra. Most of the remaining spectroscopic time is scheduled for completion in Spring 2003 with the remaining few nights planned for Spring 2004. The spectroscopic data will be presented in Halliday et al. (2004).

1.3 Weeding Out The Interlopers

At the present time we have an impressive data set, with extensive photometry over a long wavelength baseline, a set of 15 confirmed clusters with a range in cluster richness, and spectroscopy of ~ 500 galaxies, of which ~ 50 per cluster are confirmed cluster members. We now use our data in hand to address the problem of how to efficiently reject non-cluster members among those galaxies without spectroscopy. Because our spectroscopic time, although quite generous, was spread over many clusters, there is no chance to build up a complete list of confirmed members, even at the brightest magnitudes. We remove likely non-members in two steps, first removing them using the photometric redshifts and then statistically subtracting off the remaining field galaxies. The photometric redshifts were calculated independently using the code of Rudnick et. al. (2001) and the *Hyperz* code (Bolzonella, Miralles, & Pelló 2000) to control systematics in the identification of likely non-members. The photometric redshifts of the galaxies in our sample are also quite accurate, with $\langle |z_{spec} - z_{phot}| \rangle = 0.06-0.08$ for both the $z \sim 0.5$ and $z \sim 0.8$ clusters. We first discriminate between cluster members and non-members using a method similar to that proposed by Brunner & Lubin (2000), namely using P_{clust}, the normalized $P(z)$ integrated in a $\Delta z = 0.2$ slice around the spectroscopic cluster redshift z_{clust}. Our method differs from that of Brunner & Lubin (2000) first in that we use realistic $P(z)$ distributions instead of assuming them to be Gaussian, a very poor assumption, especially at the faint end. Second, we use our two different photometric redshift techniques to jointly reject non-members if they are rejected by either of the two codes. This results in a more robust rejection which is less dependent on systematic errors in the photometric redshifts than rejection by a single technique. We use the spectroscopic sample to calibrate a P_{clust} threshold such that we can reject $\sim 60\%$ of all the galaxies to the spectroscopic limit, while retaining $\sim 90\%$ of all confirmed cluster members, independent of rest-frame color. As is seen in Figure 1.1, this cut typically increases the cluster contrast by a factor of ~ 3 after rejection.

The previous technique removes 75-80% of all galaxies in a sample limited to $I < 25$. The remaining galaxies, which presumably lie within ± 0.1 of z_{clust}, come in two flavors: non-members, which are presumably spread uniformly across the field, and members, whose surface density decreases away from the cluster center. To isolate the galaxies within a physical projected cluster radius $r_{clust} = 0.75 h_{70}^{-1}$ physical Mpc, we statistically subtracted off galaxies which lie at a projected radius $r_{proj} > r_{clust}$ after binning in rest-frame $B-V$ color and absolute magnitude. This method not only subtracts off the contribution from true non-members, but also from members which have $r_{proj} > r_{clust}$, which means that we may be slightly oversubtracting the background. Even so, the statistical subtraction typically removes only 15% of the original sample, or 50% of the galaxies not rejected on the basis of their P_{clust} values. Our photometric redshift preselection allows us to statistically subtract off far fewer galaxies from the original sample when compared to methods which only use statistical subtraction, hence decreasing the uncertainties in the number of galaxies in each final luminosity and color bin.

1.4 The b_J Luminosity Function and Evolution

Using the observed SED of each galaxy and the spectroscopic redshift of the cluster in which it resides, we derive the rest-frame b_J luminosity normalized to the total flux in the *I*-band as measured using the AUTO aperture from SExtractor (Bertin & Arnouts 1996). We then use our cleaned cluster galaxy samples to construct the luminosity function (LF)

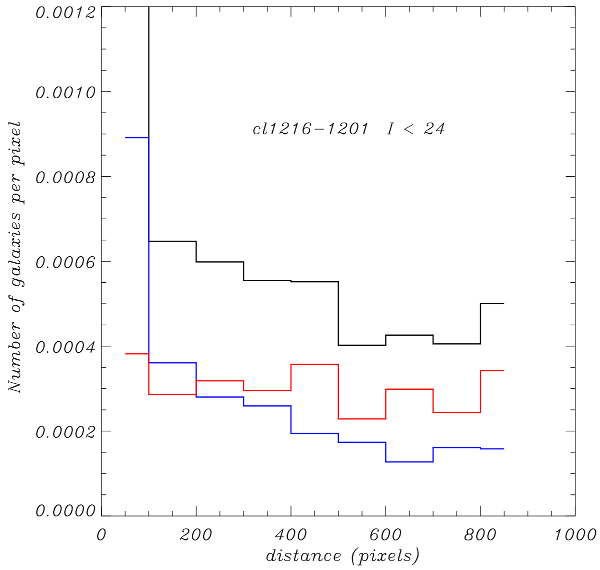

Fig. 1.1. The effect of our P_{clust} threshold on the radial surface density profile of the cluster cl1216-1201 at $z = 0.7955$. The black line indicates the raw cluster profile, the red line indicates the profile of those galaxies rejected by our technique, and the blue line shows the profile for the remaining objects. The rejected objects have a flat profile, as expected for non-members. The contrast in the retained population is typically improved by a factor of ~ 3 after the P_{clust} cut.

for each cluster. We do not include a completeness correction, but our conclusions should be insensitive to such corrections since they are based on the bright end of the LF where the corrections should be very small. At the same time, the signal to noise for individual clusters is low at the bright end, and we stacked all of our cluster together to obtain a mean cluster LF in each redshift bin. We split our sample up at $z = 0.6$ and plot the mean high and low redshift LFs in Figure 1.2. We determine the brightening of our LFs with respect to the local mean cluster LF from 2dF (De Propris et al. 2003) by fitting our LFs a Shechter function (1976), keeping α fixed at the 2dF value of -1.28 and marginalizing over the normalization. Doing this results in a derived brightening of $\Delta M_{b_J} = -0.35 \pm 0.16$ for the low redshift sample ($\langle z \rangle = 0.5$) and $\Delta M_{b_J} = -1.05 \pm 0.17$ for the high redshift sample ($\langle z \rangle = 0.75$), where the mean redshifts were computed by weighting the individual cluster redshifts by their weak lensing σ (Clowe et al. 2004). We compare this to the brightening predicted by fundamental plane evolution out to $z = 1.27$ (van Dokkum & Stanford, 2003 ApJ, 585, 78), which predicts $\Delta M_{b_J} = -0.57 \pm 0.05$ at $z = 0.5$ and $\Delta M_{b_J} = -0.86 \pm 0.08$ at $z = 0.75$.* Given that the fundamental plane evolution is valid only for ellipticals, while our luminosity function includes galaxies at all colors, it is expected that the brightening should be somewhat different. Still, it is encouraging that our values agree at the $\sim 2\sigma$ level.

* For this comparison we neglect the difference in evolution between the B-band and the b_J bands. For a single burst with $z_f = 2.5$, the expected $b_J - B$ color changes by 0.03 between $0 < z < 0.75$.

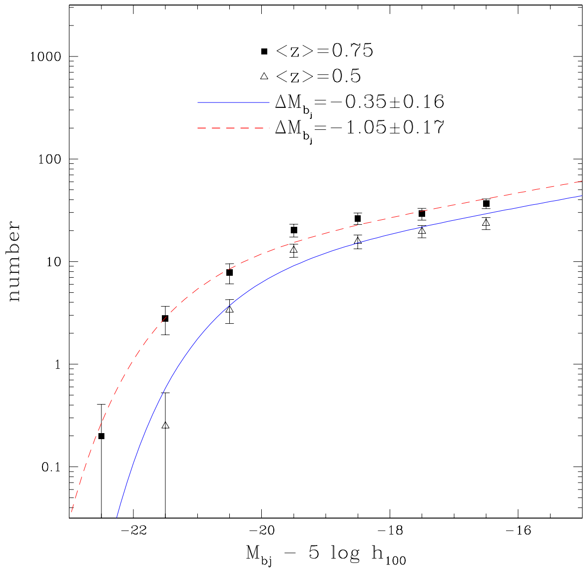

Fig. 1.2. The mean rest-frame b_J-band galaxy luminosity function for all of the $z > 0.6$ clusters (solid points) and that for all of the $z < 0.6$ clusters (open points). The blue solid line is the best fit Schechter function to the low redshift sample with α fixed at the local value of -1.28. The red dotted line is the best fit to the high redshift sample, also with $\alpha = -1.28$. The quoted brightening is with respect to the local luminosity function.

These luminosity functions now serve as a constraint for models of galaxy formation which predict the properties of the cluster galaxy population. In addition, we have enough clusters in our sample to explore how the luminosity functions depend on cluster properties, such as the early type fraction and the cluster velocity dispersion.

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