The Fate of Luminous Compact Blue Galaxies: An Environmental Approach

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Abstract.

Luminous Compact Blue Galaxies (LCBGs) are a heterogeneous class which dominate an intermediate phase of galaxy evolution. These sources account for the majority of the star formation between $0.3 < z < 1$, yet the identity of their present-day counterparts is an open question. An environmental dependence to their evolution may provide the answer. We have undertaken the first census of LCBGs in intermediate-redshift clusters using broad and narrow-band images from the WIYN Long Term Variability Study. Several key clusters are in the southern sky. The Southern African Large Telescope’s (SALT) Prime Focus Imaging Spectrograph (PFIS), with a field of view matching our WIYN data, will allow us to determine several fundamental characteristics of cluster LCBGs, including (1) star formation rates (SFR) and metallicities from low dispersion multi-object spectroscopy (MOS); (2) dynamical masses from line-widths measured via high dispersion MOS; and (3) cluster velocity dispersions of LCBGs relative to other cluster emission-line galaxies via Fabry-Perot imaging or MOS. We tentatively connect these distant galaxies with their local, evolved counterparts, and discuss how PFIS observations will enable us to make the physical distinction between LCBGs in clusters and the field.

1. Introduction

A key prediction of CDM hierarchical formation models (e.g., White & Frenk 1991) is the “down-sizing” of star formation sites, whereby the characteristic galaxy mass dominating the co-moving star-formation rate decreases with redshift (Cowie et al. 1996). At high redshift, Lyman-break galaxies dominate; we believe they are associated with today’s high-mass systems (Lowenthal et al. 1997; Steidel et al. 1996). Today, the most intensely star-forming systems are low-mass HII galaxies. Between $0.1 < z < 1.0$ the situation is less clear.

“Luminous compact blue galaxies” (LCBGs) appear to be the most rapidly evolving class of galaxy at intermediate redshift (Lilly et al. 1998; Mallen-Ornelas et al. 1999). These enigmatic galaxies, initially identified by Koo & Kron (1988), are luminous ($M_B \sim -20$), small ($R_e \sim 2 - 3$ kpc), and massive engines of star formation (up to $\sim 40 M_\odot yr^{-1}$) (Koo et al. 1995, Guzmán et al. 1998, Hammer et al. 2000). They appear to form a link in redshift, size, and
luminosity between Lyman-break galaxies and HII galaxies today (Lowenthal et al. 1997; see our Figure 1). LCBGs are a major contributor to the observed enhancement of the star-formation density of the universe at $z \lesssim 1$, and their mass and number density decline in concert with the rapid drop in the global SFR since $z = 1$ (Guzmán et al. 1998).

However, a debate continues about today’s descendants of LCBGs. Due to their narrow emission line-widths and number density, Koo et al. (1995) proposed LCBGs are the progenitors of today’s lower-mass spheroidal (Sphs) galaxies: If their current burst of star formation terminates, LCBGs fade by 4 mag in a few Gyrs, yielding luminosities, surface-brightnesses, sizes, and colors similar to, e.g., NGC 205 (Guzmán et al. 1998). LCBGs have also been proposed as the period when bulges of spiral galaxies form due to their high gas phase metallicities (Hammer et al. 1999, Kobulnicky & Zaritsky 1999). In this picture, the bright, blue compact regions are embedded within a lower-surface brightness, disk of larger size, (Barton & Van Zee 2001).
2. LCBGs in Galaxy Clusters: New Clues on LCBGs Descendants

Because of the extreme density of galaxy clusters, they offer a distinctly different, yet heretofore unexplored environment in which to study the nature of LCBGs. For our purpose, there are two salient differences in galaxy populations in rich clusters and the field: First, the morphology-density relationship describes a decreasing fraction of spirals with increasing local surface density of galaxies (Dressler 1980). Second, the dwarf-galaxy population is much richer in clusters. Dwarf galaxies are the most numerous type of galaxy regardless of environment, but the ratio of dwarf to giant galaxies increases with the overall density (e.g., Trentham and Hodgkins 2002). Because the relative densities of the two proposed descendants of LCBGs (lower-mass spheroidals and spiral bulges) are different in galaxy clusters and the field, the number density of LCBGs in intermediate galaxy clusters make the connection between the past (LCBGs) and today (either low-mass spheroidals or spirals). Specifically, if LCBGs are relatively more numerous in intermediate-redshift clusters than in the field, this provides independent evidence that LCBGs are associated with today’s lower-mass spheroidal population.

We currently are analyzing imaging data on 10 intermediate redshift galaxy clusters from the WIYN Long Term Variability Survey (WLTV) to search for cluster LCBGs. Each cluster has been repeatedly imaged over 5 years in a 10 arcmin field with the WIYN 3.5m telescope. We have a total of 2 – 5 hrs integration per target in each of the UBRIz bands taken under excellent seeing.
conditions (typically $< 0.75''$). Deep, archival HST images are available of each cluster core. We are in the process of gathering rest-frame O II and continuum narrow-band images of the 6 deepest clusters, four of which are visible to SALT.

We have completed the first stage of an LCBG search in cluster MS0451, at $z = 0.53$. We frame our analysis in the measurement of galaxy enhancement. The enhancement is the number of galaxies at a given redshift divided by the expected number in the field at that redshift (estimated from comparable deep images without rich clusters). Hence, if there is no galaxy over-density, the enhancement is one. Figure 2 shows the enhancement of LCBGs in the field of MS0451. This is a robust, differential measurement, which, for this cluster appears to support the hypothesis that LCBGs evolve into Sphs.

We also have calculated the photometric and structural characteristics of the LCBGs appearing in the inner 0.75 Mpc of MS0451 using F702 WFPC2 images. Cluster LCBGs also have similar colors, sizes, and profiles (based on image concentration) to field LCBGs, but somewhat lower luminosities or surface-brightnesses (see Figures 1 and 3). Are these differences indicative of a more rapid pace of “down-sizing” in clusters, akin to the environmental dependence of star formation rates (Balogh et al. 1998, Martin et al. 2000)? To differentiate between an accelerated downsizing scenario and environmental effects of truncated or quenched star-formation (due, e.g., to stripping), star formation
rates and mass measurements of cluster LCBGs are required. These measurements, well suited to PFIS, will tell us what differs between cluster and field: the mass-function of star-bursts, or the star-formation rate at a given mass?

3. LCBG Properties: The Future with PFIS

Preliminary results from our survey raise several important questions about cluster LCBG requiring spectroscopic measurements on 10m-class telescopes to answer. SALT’s Prime Focus Imaging Spectrograph (PFIS) will enable the needed high throughput, medium-resolution spectroscopy. Here we outline how we plan to use PFIS for our LCBG studies.

- **Mass Uniformity:** Our initial evidence indicates photometric differences in cluster and field LCBGs. We can characterize this difference more meaningfully by comparing field to cluster LCBG masses. In making this measurement for several clusters, we will map how the mass of star-bursting galaxies evolves with redshift and environment. Because of their small sizes, LCBG virial masses are measured by combining spatially-unresolved emission line-widths and HST or WIYN size measurements. The highest spectral resolutions of PFIS are ample for LCBG line-width measurements. By using PFIS’s bank of narrow band (Δλ ≈ 50) filters, we can limit the range of the dispersed spectra on the detector to ∼75 Å (rest-frame) around the [OII]λ3727 emission line for each cluster. This allows us to increase the spatial multiplexing of our multi-object masks (see the MMS concept described by Bershady et al., these proceedings) – and hence also our survey efficiency – by about a factor of 4. The minimum source spatial separation in the dispersion direction is ∼1 arcmin at the highest spectral resolutions (grating angle α = 50°), and decreases linearly with resolution (∝ sina/cosa, i.e., the Littrow condition for the VPH gratings). At the resolution used by Guzman et al. (1998), the minimum separation is 10 arcseconds.

- **Star Formation Rates:** If field and cluster LCBGs have similar size and mass functions, luminosity or surface-brightness differences are caused by lower star-formation rates – plausibly due to gas stripping in the dense clusters environments. We can measure these rates via low-resolution PFIS MOS observations that capture [OII]λ3727 and other blue nebular lines that will allow us also to determine metallicity and estimate extinction. Combined mass, size, shape, color, star-formation characteristics will allow us to carefully quantify physical differences between field and cluster LCBGs, and determine if they share similar histories of stellar processing of baryonic matter.

- **Origins: Cluster Accretion?** There is ample evidence in low redshift clusters that blue, star-forming galaxies are on the periphery of these systems, and just falling in. One way to test for an accretion origin of intermediate-redshift cluster LCBGs is to compare their velocity dispersion to the red cluster population (for which some measurements already
exist, and will be augmented). LCBG velocity dispersions can be calculated efficiently from the MOS measurements described above, or via Fabry-Perot (FP) scanning with the lowest-resolution PFIS etalon. The advantage of the latter is the gain in spatial multiplex over the full 8 arcmin PFIS field, thereby providing complete kinematic characterization of the emission-line population in the cluster out to several cluster radii.

4. Summary

We have presented the initial results from the WLTV survey that will provide an extensive catalog of \( \sim 200 \) cluster and field LCBGs with high quality photometric information in areas around 10 clusters between \( 0.3 < z < 1 \). With cluster LCBGs and over-densities identified from these photometric data, we plan to use PFIS to answer deeper questions about LCBGs: Are cluster and field LCBGs the same? Does the evolution of cluster and field LCBGs differ? What is the origin of cluster LCBGs? The answers to these questions tie in with parallel studies of other cluster and field populations, and will yield a cohesive picture of galaxy evolution over the past 3-7 Gyr.

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