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High-Redshift Protoclusters Traced by Submillimeter Galaxies

Tracing Star Formation Activity out to $z > 4$

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Abstract. Clustering analysis indicate that at $z \sim 2$ submm-selected galaxies (SMGs) reside in very massive halos ($M_{DM} > 5 \times 10^{13}$), suggesting that SMGs trace high-density environments that evolve into rich galaxy clusters. Conversely, recent work suggests that SMGs are tracers of a broader range of environments, including structures with more modest masses caught in highly active periods; since galaxies in these structures are likely caught during episodes of peak starbursts, SMGs may be tracers of a wider range of environments beyond the progenitors of todays very rich clusters, opening a window for a more complete exploration of the details underpinning the process of galaxy evolution in concert with the assembly of the large scale structure (LSS). We have undertaken a large observing program comprising deep narrow-band Ly-alpha imaging and multi-object spectroscopy using Palomar/Keck/Magellan/Gemini telescopes to probe for galaxy overdensities in SMG environments at $z \sim 1-5$. With ~200 spectroscopically-confirmed Ly-alpha emitters, we are in a position to gauge the level of galaxy overdensity in these regions.

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1. Introduction

Galaxy evolution is intimately connected to the environment. To understand the origin of the galaxy-environment relation, we need to look back at the epoch of galaxy formation ($z > 1$), where the local high-density environments of well-established, virialized clusters give way to looser large-scale structures (LSS) extending over regions of several Mpc in size (protoclusters). Different tracers have been used to map $z > 2$ LSS; in particular, powerful radio galaxies (e.g., Venemans *et al.* 2007). Considering that these objects are only visible for a short period in the evolution of a massive galaxy, there is a significant fraction of forming clusters that remain unexplored. To identify the typical overdense regions at $z > 2$ we need tracers that are more abundant than these extreme objects.

SMGs, with robust redshifts, provide a rich and largely un-tapped resource for the study of protocluster formation and evolution at $z > 1$ (see also Blain *et al.* 2004). The process of LSS virialization extends over several Gyrs: e.g., a protocluster member-galaxy with a relative velocity of 500 km s^{-1} needs at least ~ 4 Gyr to cross a few-Mpc-sized structure. Considering that at $z \sim 5$ the universe is merely 1 Gyr old, we need to study multiple galaxy overdensities spread over a large redshift range to start getting a true insight into the evolution of galaxy properties as a function of an evolving, underlying LSS. For this reason, we have initiated a program that entails a major study of the distribution in galaxy properties as a function of local environment within galaxy-overdense regions surrounding SMGs at $z \sim 1-5$. Through this redshift range we trace the universe as it ages by > 4 Gyr to a stage where LSS slowly approach virialization

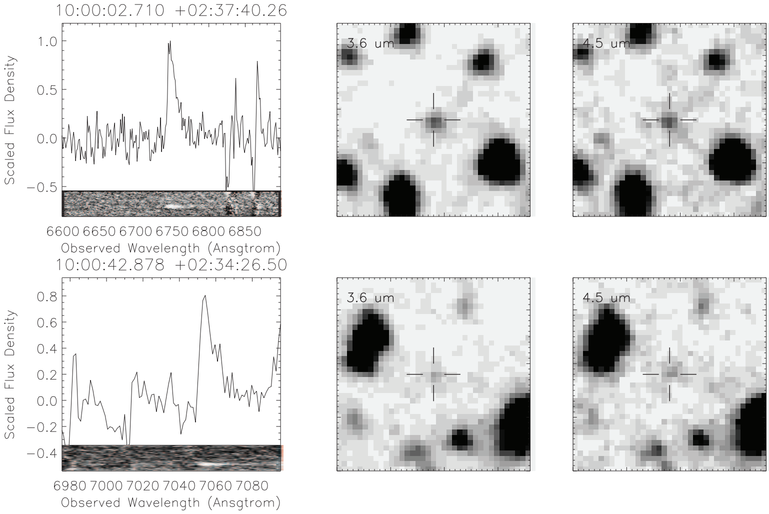

Figure 1. Two spectroscopically–confirmed Lyman-α emitters (LAEs) from our Magellan/IMACS program on the COSMOS field, based on continuum selection. Spectra (left panels) display the characteristic asymmetry of the Ly-α emission, while the Spitzer/IRAC $3.6, 4.5\mu$m bands (center and right panels) show clear detection of individual LAEs.

Lyman-α emitters (LAEs) dominate the faint end of the luminosity function ($L_{bol} \sim 10^{10}\ L_{\odot}$) and have been shown to be unbiased tracers of the underlying galaxy population (e.g., Gawiser *et al.* 2007). Although they do not provide a comprehensive census of the galaxy populations present, they provide insight to the more normal (garden-variety) galaxies: the less-luminous (and more numerous) LSS members.The most efficient method for finding large numbers of galaxies at a given redshift is to use wide-field narrow-band Ly-α imaging (e.g., Rhoads *et al.* 2000). Thanks to progress in photometric redshift determination techniques, an alternate route is spectroscopic follow-up of good photometric candidates, whose broad/medium-band photometric fluxes set them at a high likelihood of being at a specific redshift. We have an on-going investigation of 3 SMG environments at $z = 2, 2.5, 4.5$ (HDF-N, ELAIS-N2, COSMOS) using LRIS/Keck, IMACS/Baade, LFC/Palomar and GMOS/Gemini-N instruments. For this we use the two approaches to identify LAEs in the vicinity of SMGs and have now identified a total of ~ 200 LAEs.

We have also initiated a detailed study of the distribution in galaxy properties according to the maturity and evolving stage of LSS traced by SMGs, in an effort to explore the way galaxy and local environment relate to each other within the broader picture of a cosmologically-evolving LSS. For this we exploit publicly available Spitzer/IRAC data (see Figure 1) with the aim of constraining LAEs individual (and stacked) properties.

Preliminary results point to a factor of ~ 3 more LAEs in the vicinity of SMGs, relative to the field (e.g., Rhoads *et al.* 2000), supporting the idea that SMGs are tracers of a wider range of environments beyond the progenitors of todays rich clusters (Chapman *et al.* 2009). This opens a window for a more complete exploration of the details underpinning the process of galaxy evolution in concert with the assembly of LSS.

References

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