Outskirts of Galaxy Clusters: Intense Life in the Suburbs
Proceedings IAU Colloquium No. 195, 2004
A. Diaferio, ed.

DOI: 10.1017/S1743921304001012

Extended Lyman-alpha emitters in and around a proto-cluster at z=3.1

T. Yamada[1], Y. Matsuda[1,2] and T. Hayashino[2]

[1]National Astronomical Observatory of Japan, Mitaka, Tokyo 181-8588, Japan

[2] Research Center for Neutrino Science, Graduate School of Science, Tohoku University, Aramaki, Aoba, Sendai 980-8578, Japan

Abstract. Here we present our result of deep and wide-field narrow-band imaging of the region of the 'proto-cluster' at $z = 3.1$ around the SSA22 field. We detected 283 highly confident Lyα emitter candidates (LAEs) and discovered that the belt-like high surface density region of these LAEs extends over ≈ 60 Mpc in comoving scale, which is much larger than it was known previously. We then successfully detected the 35 extended Lyα blobs (LABs) which are larger than 16 arcsec^2 in isophotal area and brighter than 0.7×10^{-16} ergs s^{-1} cm^{-2}. The distributions of average surface brightness and morphology are widespread from relatively compact high surface brightness objects to very diffuse low surface brightness ones. For one third of these 35 LABs, simple photo-ionization by massive stars is not sufficient to explain the Lyα luminosities, and other mechanisms, such as gravitational heating or superwind must be considered. From their large size and strong spatial clustering, we consider that these LABs are objects closely related to the massive galaxies in their forming phase in the environment of the proto-cluster or large-scale structure.

1. Introduction

Properties of galaxies in the outskirt of clusters should be considered in the context of biased galaxy formation at an early epoch followed by continuous infall of galaxies from the surrounding region. To understand the whole story of the evolution processes in high-density regions of the universe, it is the most direct way to observe the clusters and their progenitors at sufficiently large scale at various epochs from low to high redshift and trace the properties of galaxies there.

In this contribution, we present the results of Subaru deep and wide-field narrow-band imaging of the region of the 'proto-cluster' at $z = 3.1$ around the SSA22 field (Steidel et al. 1998; 2000). The structure was first recognized as the highest density 'spike' in the redshift distribution of Lyman Break galaxies (LBG; Steidel et al. 1998). The following narrow-band image by Steidel et al. (2000) showed that the overdensity of Lyα emitters (LAE) is as large as that of LBGs. However, there is no conspicuous concentration of LAEs and LBGs *on the sky* in their observed field of view and it was unknown whether the region is a very central part of the proto cluster or just a part of larger-scale structures. It is clearly an important next step to reveal the distribution of star-forming galaxies in a wider area to see the whole extent of the high density region. We therefore conducted the deep Lyα emission-line imaging observation with Subaru Suprime-Cam to study about ten times as large volume as that in the previous one. We here show the distribution of the 283 robust sample of LAEs in the field as well as the 35 extended Lyα emitters, or 'Lyα blobs' (LABs) obtained in the study.

This talk is based on our recent two papers, Hayashino et al. (2004) and Matsuda et al. (2004), and we thank the co-authors of these papers for allowing us to present the results at this conference.

2. Data

We obtained a wide-field and deep narrow-band image centered at $(\alpha,\delta) = (22^{\mathrm{h}}17^{\mathrm{m}}.6, +00^{\circ}17')$ (J2000.0) with the 8.2 m Subaru telescope equipped with the prime-focus camera, Suprime-Cam. We used our custom narrow-band filter ($NB497$), whose central wavelength is 4970Å and FWHM is 80Å to detect Lyα emission line at $z = 3.05 - 3.12$. The total exposure time was 7 hours for $NB497$ and the limiting magnitudes after correcting for Galactic extinction is $NB497$=26.2 for 5σ in a $2''$ diameter aperture. The FWHM seeing was 1′′. The total size of the field is $32'$ by $24'$, which corresponds to comoving transverse dimensions of 59.3 $h_{70}^{-1} \times 45.5 h_{70}^{-1}$ Mpc at $z = 3.1$ and the total solid angle is 770 arcmin^2. The effective comoving volume covered by the narrow-band image, whose half-power width corresponds to a comoving depth along the line of sight of 61.0 h_{70}^{-1} Mpc, is 165,000 h_{70}^{-3} Mpc^3.

3. Sky distribution of Lyα emitters and absorbers

We selected the 283 robust candidates of LAE at $z = 3.1$ mainly by the criteria (i) $NB497 < 25.8$ (S/N> 7.5) and (ii) $BV - NB497 > 1.2$, which corresponds to the observed equivalent width limit of $EW_{obs} > 160$ Å, or the rest frame EW limit of $EW_0 >$ 40 Åfor Lyα. More detailed description is found in Hayashino et al. (2004).

These 283 strong LAE are distributed in the Suprime-Cam field of view as shown in Fig. 1 with the filled circles. The curved lines delineate the high density region (HDR) where the mean number density of emitters in this field after smoothing with a Gaussian kernel with $\sigma = 1.5$ arcmin is larger than the average. We see a belt-like large structure of LAEs with 60 Mpc long and 15-20 Mpc wide in comoving scale running from NW to SE, together with a rather orthogonal structure with 30 Mpc by 15 Mpc from the field center to NE. The average number density of the emitters in this HDR is found to be three times as large as that of a blank field. We found that the probability of finding such a large-scale high density peak is as small as 0.1% in context of CDM structure formation scenario even if we assume that the distribution of Lyα emitters is biased to mass with linear bias parameter $b \sim 4$. This structure is really a rare peak which may evolve into a massive supercluster at later epoch. The SSA22a area studied by Steidel et al. (2000), which is about $9' \times 9'$ square near the center of this figure, is turned out to be part of this large-scale structure of LAEs.

We also search for Lyα absorbers, namely, narrow-band deficit objects in the field (open circles in Fig. 1). It is remarkable that their distribution is very similar to that of the Lyα *emitters*, which strongly suggests that the HDR of the strong LAEs is a real large-scale structure and these absorbers are associated with it.

4. Lyα blobs

We also detected the 35 highly confident candidates of extended Lyα blobs (LABs) in the field which are larger than 16 arcsec^2 in isophotal area and brighter than 0.7×10^{-16} ergs s^{-1} cm^{-2}. Fig. 2 shows their isophotal area and magnitude distribution and Fig. 3 shows the montage of all the 35 LABs. Eight of these 35 candidates, including the two gigantic 'Lyα blobs' discovered by Steidel et al., are associated with the known Lyman break galaxies at $z = 3.1$. These two Lyα blobs are the most luminous and the largest emitters in our survey volume.

The distributions of average surface brightness and morphology are widespread from relatively compact high surface brightness objects to very diffuse low surface brightness

https://doi.org/10.1017/S1743921304001012 Published online by Cambridge University Press

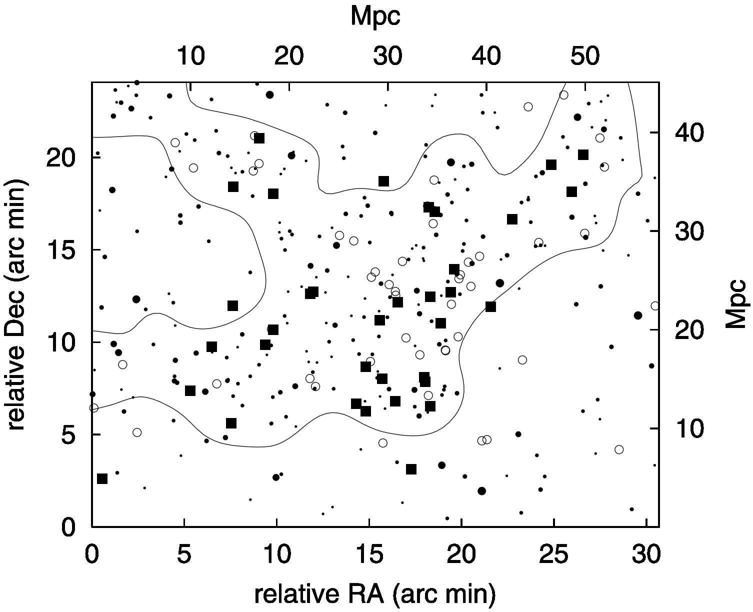

Figure 1. Spatial Distribution of the 283 LAE in the Suprime-Cam field of view (filled circles). The curved lines delineate the high density region of the LAEs. Open circles and filled squares show the distribution of Lyα absorbers and Lyα blobs (LABs), respectively.

ones. The physical origins of these LABs may be (i) photo-ionization by massive stars or active galactic nuclei, or (ii) Lyα cooling radiation by gravitationally heated gas, or (iii) shock heating by starburst driven galactic superwind. Scattering by surrounding neutral gas affects their appearance for all these cases. The case of cooling radiation and superwind represents rather early and late stage of intensive star formation in proto-galaxy while photo-ionization by internal sources reflects on-going events. Sources of photo-ionization may be massive stars or AGNs inside the galaxies, or the background diffuse UV emission. It is interesting to see the objects in the same large-scale structure and may be at different phases of galaxy formation.

In Fig. 4, we plot R versus $NB_{\rm corr}$ for these 35 LABs. If the origin of the Lyα emission is photoionization by massive stars, we may translate the $NB_{\rm corr}$ and R magnitude into the equivalent star formation rates (SFR) at $z = 3.1$, assuming the same Salpeter initial mass function with mass limits 0.1 and 100 $M_{\odot}$, solar metallicity, no extinction, and case B recombination in the low density limit. Very interestingly, one third of them are apparently not associated with ultra-violet continuum sources that are bright enough to produce Lyα emission, assuming a Salpeter initial mass function. Other mechanisms, such as gravitational heating or superwind activity, may contribute to the excess. We revealed the internal structure of the two gigantic blobs (Steidel et al. 2000) and indeed discovered some bubble-like features, which suggests that intensive starburst and galactic superwind phenomena occurred in these objects in the past.

We also see the sky distribution of the LABs in Fig. 1: 90% of them are located inside the HDR of the 283 relatively compact and strong Lyα emitters. This suggests that LABs very strongly trace the large-scale structure at high redshift where galaxy formation may occur preferentially; in other words, we may be witnessing galaxy formation activity in proto-cluster environment.

https://doi.org/10.1017/S1743921304001012 Published online by Cambridge University Press

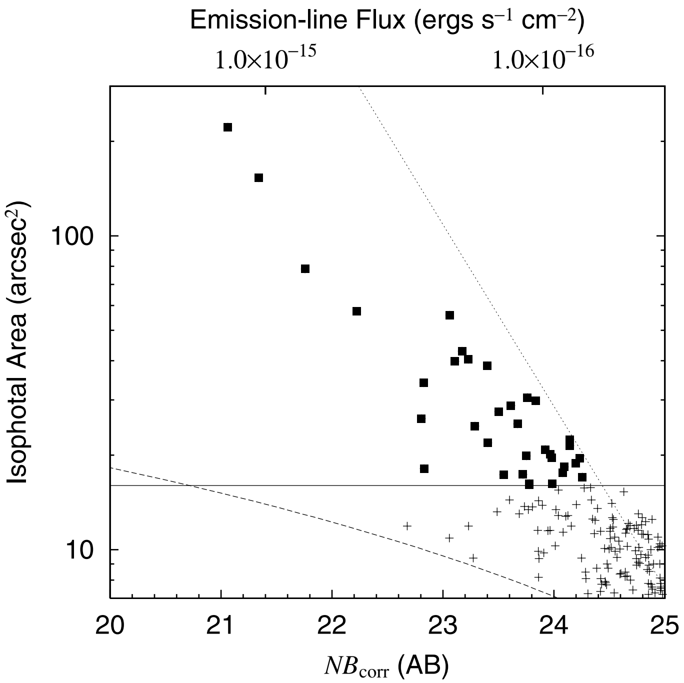

Figure 2. Distribution of isophotal area and narrow-band magnitude of the LABs (filled squares). The dashed line shows the expected value for point sources. The dotted line shows the 8 σ noise level.

Acknowledgements

The co-authors of the two papers on which the contribution is based are as follows: Ajiki, M., Fujita, S., Murayama, T., Nagao, T., Ohta, K., Okamura, S., Ouchi, M., Shimasaku, K., Shioya, Y., Tamura, H., Taniguchi, Y., and Yamauchi, R.

References

Hayashino, T., et al. 2004, *Astron. J.*, submitted.

Matsuda, Y., et al. 2004, *Astron. J.*, in press.

Steidel, C. C., Adelberger, K. L., Dickinson, M., Giavalisco, M., Pettini, M., & Kellogg, M. 1998, *Astrophys. J.*, **492**, 428

Steidel, C. C., Adelberger, K. L., Shapley,A. E., Pettini, M., Dickinson, M., & Giavalisco, M. 2000, *Astrophys. J.*, **532**, 170

https://doi.org/10.1017/S1743921304001012 Published online by Cambridge University Press

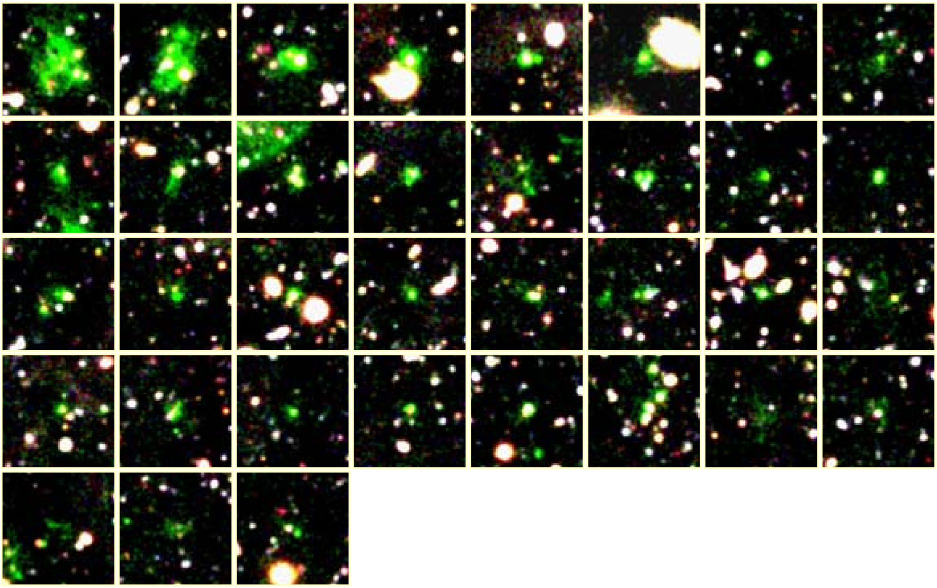

Figure 3. Montage of the 35 LABs. They are B, $NB497$, V composit color images and the green shows the Lα emission.

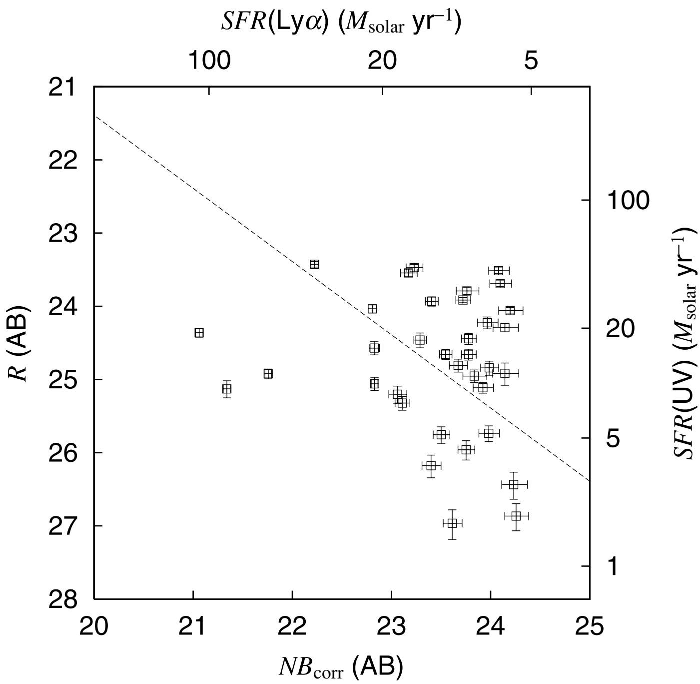

Figure 4. Distributions of R and NB magnitudes of the 35 LABs. R magnitudes are those of continuum sources nearest to the Lyα peak or the known LBGs at $z = 3.1$. The dashed line shows $SFR(\text{Ly}\alpha) = SFR(\text{UV})$.