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# Investigating the early phase of the galaxy evolution through high-$z$ damped Ly$\alpha$ absorption systems

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**Abstract.** We present the physical properties of Ly$\alpha$ emitters (LAEs) in a "DLA-concentrated regions" where there are 3 or more DLA within (50 Mpc)$^3$ cubic box. We observed LAEs in a DLA-concentrated region at $z = 2.3$, the J1230+34 field, with Subaru/Suprime-Cam. In the 50 Mpc scale, we found no deferences in properties of LAEs such as Ly$\alpha$ luminosity function in the DLA-concentrated region compared to other fields at similar redshift. On the other hand, we found a ∼10 Mpc scale LAE overdensity around a strong DLA with $N_{\rm HI} = 10^{21.08}$ cm$^{-2}$.

**Keywords.** quasars: absorption lines, galaxies: emission lines, galaxies: formation, large-scale structure of universe

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## 1. Investing the properties of galaxies in "DLA-concentrated regions"

The damped Ly$\alpha$ absorption (DLA) system is a class of quasar absorption systems with HI column density of $N_{\rm HI} \geqslant 2 \times 10^{20}$ (e.g., Wolfe *et al.* 2005). Since DLAs dominate the neutral gas content of the Universe (e.g., Noterdaeme *et al.* 2009), they are interesting systems as rich gas reservoirs for the star-formation. However the connection of DLAs with star-forming galaxies because identifying optical counterparts of DLAs is difficult (e.g., Krogager *et al.* 2017).

For investigating the relationship between DLAs and galaxies, we define a "DLA-concentrated region" as a region where 3 or more DLAs exist within a (50 Mpc)$^3$ box (Ogura *et al.* 2017). This definition is based on the size of high-$z$ protoclusters (e.g., Overzier (2016); Franck & McGaugh 2016). DLA-concentrated regions are interesting because (1) we can effectively search for optical counterparts of DLAs there, (2) they are good laboratories to study the connection of DLAs with galaxies, and (3) the high-density environment is a key component in the context of the $\lambda$CDM cosmology. We found six DLA-concentrated regions at $2.255 \leqslant z \leqslant 2.330$ (the Ly$\alpha$ line at this redshift can be



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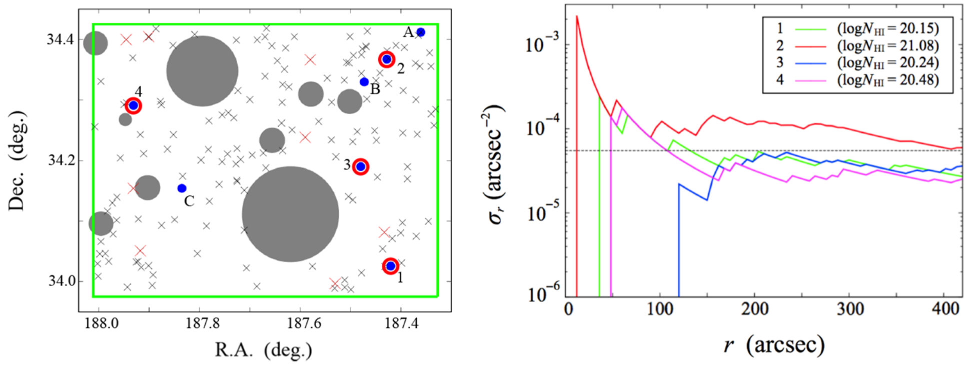


**Figure 1.** [**Left:**] Spatial distribution of LAEs (black crosses) and background quasars (blue filled circles) in the J1230+34 field. The blue circles with surrounding red circles show the position of DLAs at $z \sim 2.3$. LAEs shown by large red crosses have $EW_0 \geqslant 200$ Å. The green box shows the field of view of Suprime-Cam and gray filled circles show masked areas. [**Right:**] The surface number density of LAEs around each DLA in the J1230+34 field. The vertical axis indicates the surface number density of LAEs within a circular region at $r$. The horizontal axis indicates the radius of the circular region from the position of each DLA. The dotted horizontal black line indicates the average of the LAE density calculated for the entire J1230+34 field.

covered by the NB400 filter of Subaru/Suprime-Cam) from the the DLA catalog based on the BOSS (Noterdaeme *et al.* 2012). Among six fields we found, the J1230+34 field with 4 DLAs at $z \sim 2.3$ is the most interesting target because there are more absorbers in the J1230+34 field than the other five fields. We investigate the properties of Ly$\alpha$ emitters (LAEs) in the J1230+34 field through the narrow-band imaging observations with Suprime-Cam using the NB400 filter ($\lambda_{\rm eff} = 4003$ Å and $FWHM = 92$ Å).

## 2. Result and Discussion

We detected 149 LAEs in the J1230+34 field. The left panel of Fig. 1 shows the spatial distribution of LAEs, DLAs and background quasars. Based on this LAE sample, we derived the Ly$\alpha$ luminosity function (LF) and study the frequency distribution of the rest-frame equivalent width ($EW_0$) of the Ly$\alpha$ emission. In the result, we found no difference in the Ly$\alpha$ LF and the $EW_0$ distribution compared to those in other fields at similar redshift. We then investigate the surface number density of LAEs around each DLA (the right panel of Fig. 1). LAEs around DLA 2, which is the most gas-rich system in the J1230+34 field, show a density excess over $\sim$400″ ($\sim$11 Mpc) relative to the average density of LAEs in the entire target field. This may correspond to the gas-rich young protocluster firstly traced by the DLA. Contrary, we found no LAE overdensity around other DLAs. Due to the resonant nature of the Ly$\alpha$ photon, LAEs may not be a good tracer of galaxies in the gas-rich environment such as regions around DLAs. Further observations without relying on the Ly$\alpha$ emission (e.g., H$\alpha$ emitters LBGs, and so on) is interesting to investigate detailed structures in the DLA-concentrated regions. DLA-concentrated regions are interesting target for studying the early phase of the galaxy evolutions in the future large surveys with Subaru/PFS, TMT, EELT, GMT and so on.

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