



A narrow-band imaging of Ly α emitters around a possible DLA cluster

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Co-Investigators

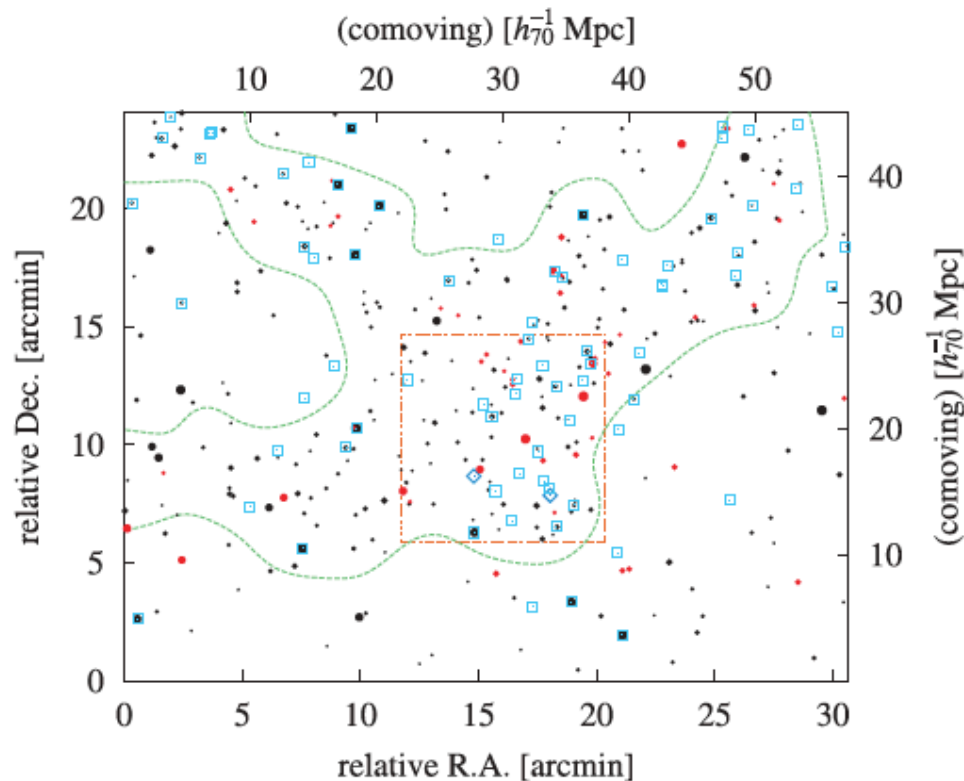
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Over-density region (proto-cluster)

★ A key component of the structure formation

- Over-density regions correspond to density peak of dark matters
- Interesting regions where structure formation had evolved in the high- z Universe



An example of over-density regions
(SSA22 @ $z=3.1$, Hayashino+04, ApJ, 128, 2073)

★ Searches for high- z over-density regions

- Focusing on the number excess of LBGs (e.g., Steidel+98, Toshikawa+12)
- Focusing on the number excess of LAEs (e.g., Shimasaku+03, Ouchi+05)
- Searching for galaxies around radio galaxies or QSOs (e.g., Venemans+07, Mawatari+12)

→ We need emission from stars in galaxies

- In the high- z Universe, a large fraction of baryons in galaxies could be in the gas-phase

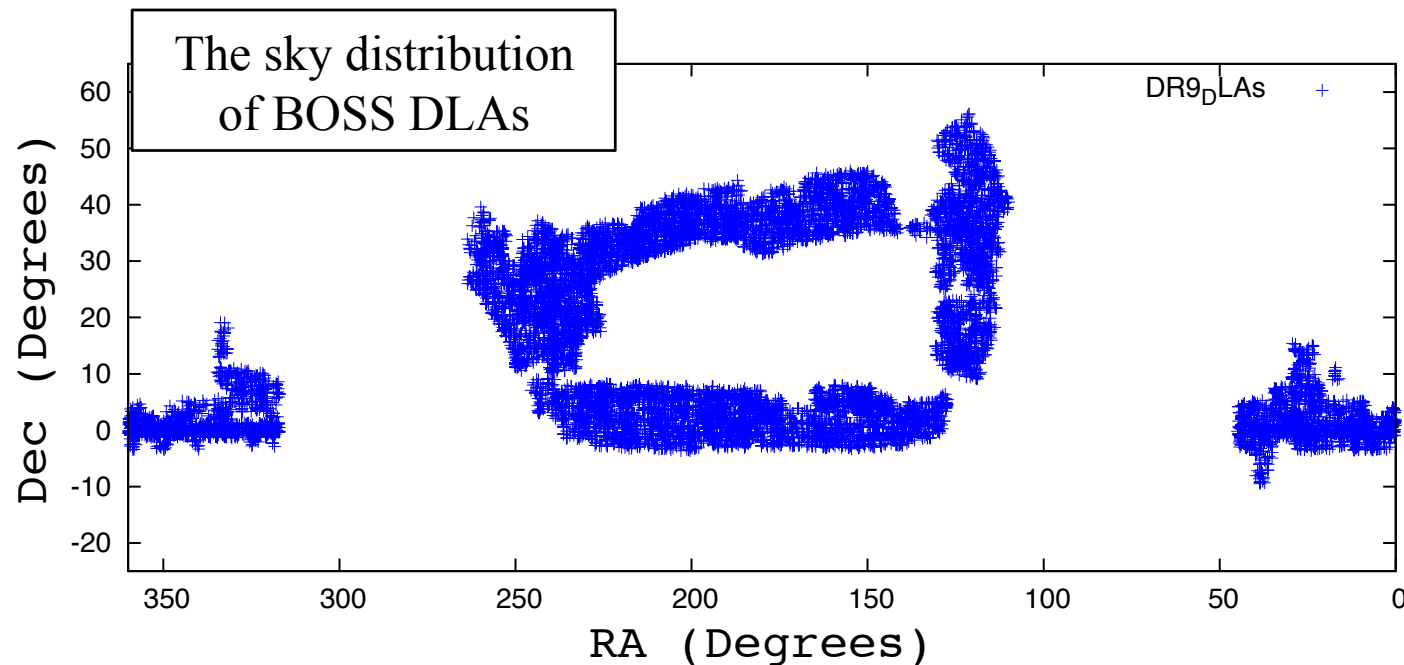
→ These surveys are possibly biased toward “well-matured” systems

⇒ Focusing on DLAs

BOSS DLA sample

★BOSS DLA catalog (Noterdaeme+12)

- We can identify the DLA only when the system have a background QSO...
- SDSS-III, BOSS (Baryon Oscillation Spectroscopic Survey)
 - From $\sim 87,822$ QSO spectra (DR9), **12,081** DLA ($1.95 < z < 5.34$) are found.



Enable us to investigate the nature of DLA based on large sample

Searching for candidates of DLA clusters

★Our strategy

- Searching for regions where there are some DLAs at same redshift in narrow region
 - Size of proto-clusters in high- z Universe
 - Prescott+08 (ApJL, 678, L77): proto-cluster extended 20×50 cMpc ($z=2.75$)
 - Lee+14 (ApJ, 796, 126): 3 proto-cluster within $72 \times 72 \times 25$ cMpc³ ($z=3.8$)
 - Example of proto-cluster survey
 - Franck+16 (ApJ, 817, 158): Circular region with $R=20$ cMpc
- ⇒ Subaru/Suprime-Cam is powerful !
FoV of $\sim 34' \times 27'$ corresponds to 50 cMpc \times 40 cMpc at $z=2$

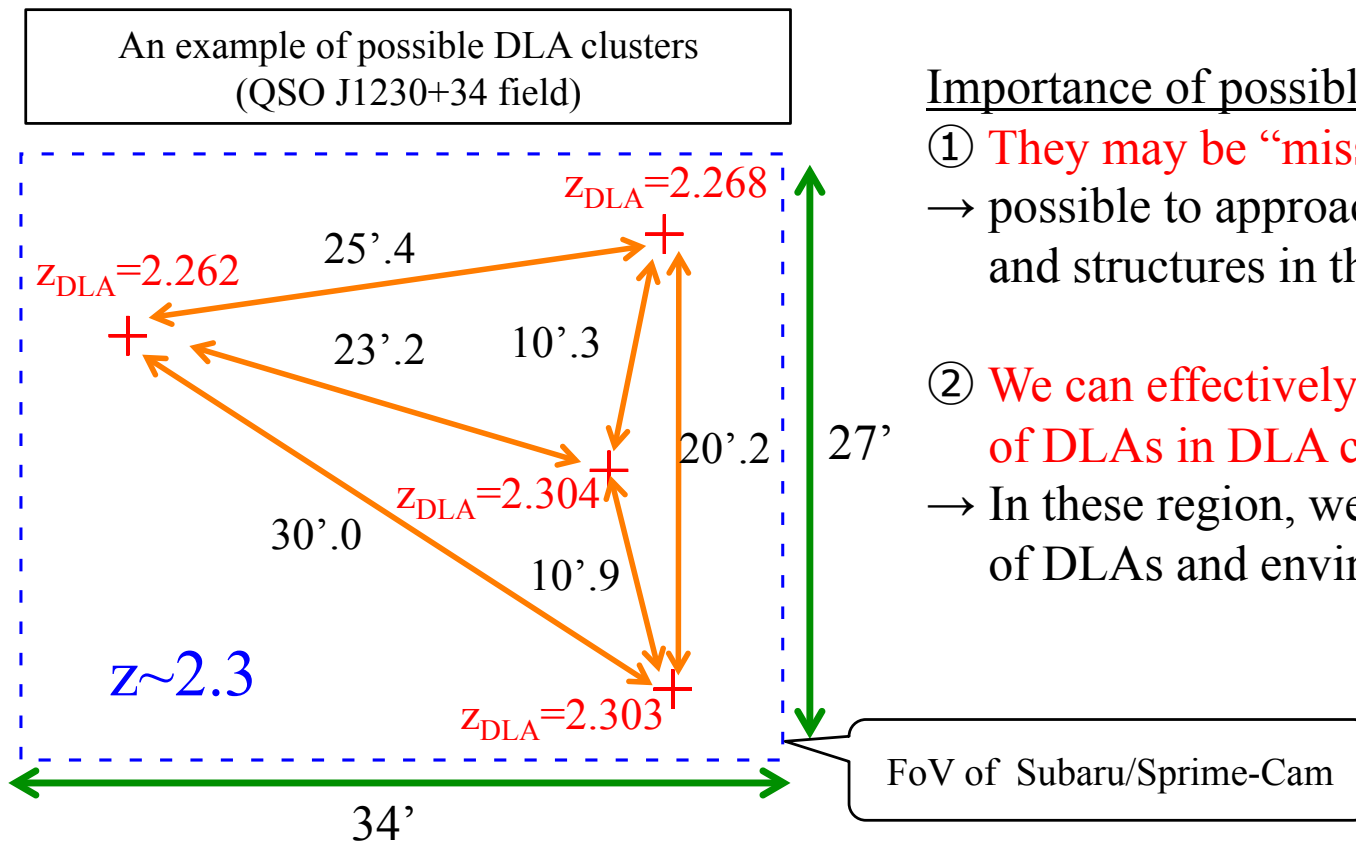
The DLA cluster candidate

- The region with > 3 DLAs within 1 FoV of Suprime-Cam
- Redshift range of DLAs can be covered with NB filter of Suprime-Cam

The Possible DLA cluster

★ Spatial and redshift distribution of DLAs

- Based on the DLA catalog, we check the spatial and redshift distribution of DLAs
- we found some possible DLA cluster regions where 3 – 4 DLAs at same redshift distribute very narrow region

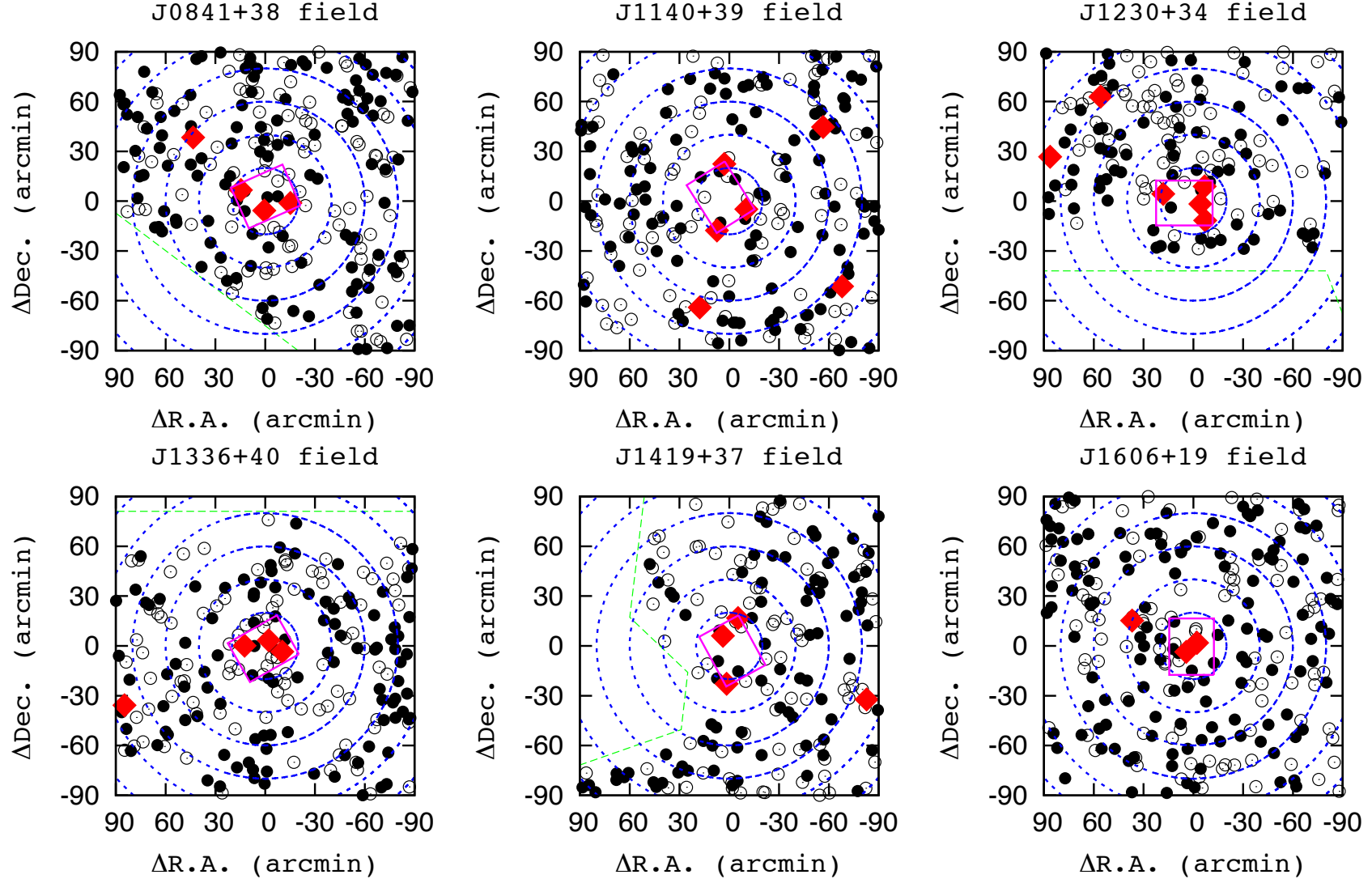


Importance of possible DLA clusters

- ① They may be “missing” over-density regions
→ possible to approach the nature of galaxies and structures in the early phase of evolution
- ② We can effectively survey counterparts of DLAs in DLA clusters
→ In these region, we can investigate properties of DLAs and environments around DLAs

The Possible DLA cluster

★6 candidates of DLA cluster are found ($z = 2.3$)



◆: DLAs, ●: back ground QSOs ($2.255 < z < 3.339$), ○: other BOSS QSOs
—: FoV of Suprime-Cam, ---: Circles with radii of every 20 arcmin

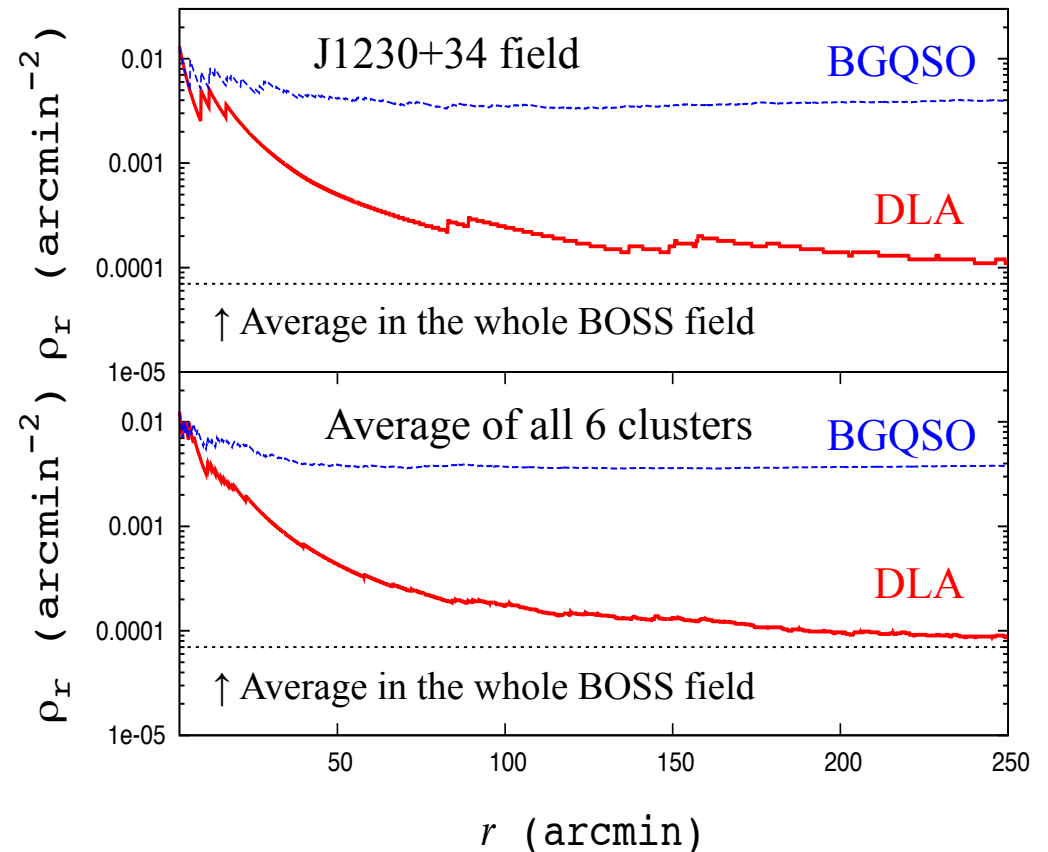
The Possible DLA cluster

★Rarity of DLA clusters

- Whole BOSS field
824 DLA and 47376 BGQSOs
→ incidence of $z=2.3$ DLA is 1.7%
- QSOs (BGQSO) within 1 FoV of S-Cam
→ 6 – 8
- Expected number of DLAs within
1 FoV of Suprime-Cam
→ 0.10 – 0.14
- Actual number of DLA within
1 FoV of Suprime-Cam
→ 3 – 4

DLA clusters are very rare

★Surface density of DLA and BGQSO



Clustering of DLAs is independent of BGQSO's spatial distribution

Our work

Observation with Subaru/Suprime-Cam

★ Narrow-band imaging of line-emitting galaxies in possible DLA clusters

Target

- a DLA cluster at $z \sim 2.3$
- redshifted Ly α emission is covered with NB400 ($\lambda_{\text{eff}} = 4003 \text{ \AA}$, FWHM = 92 \AA)

Our immediate objectives

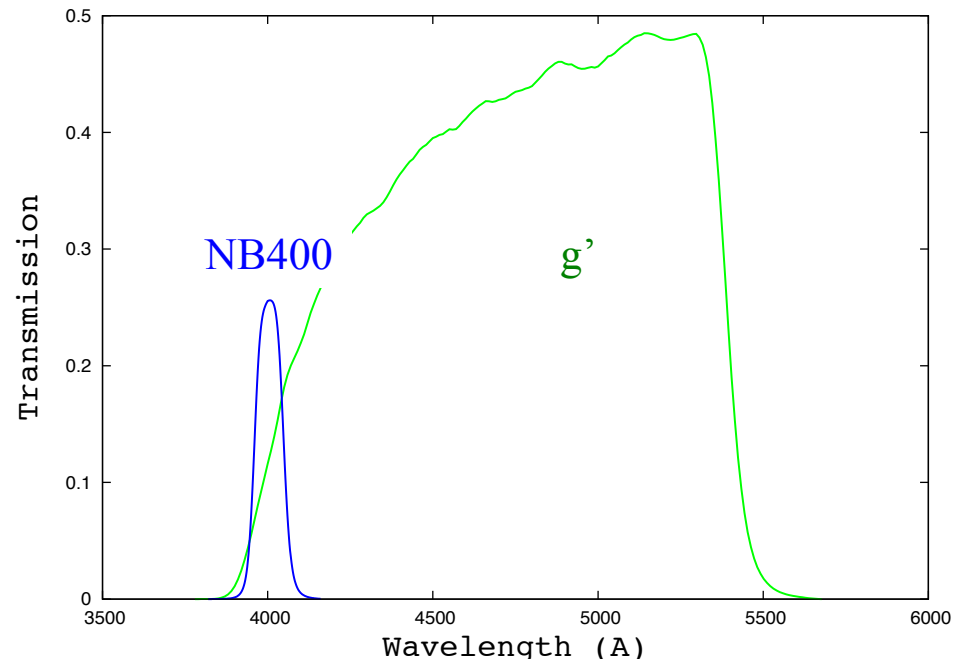
- ① Examining whether or not the number density excess of LAEs is found in the possible cluster
- ② Identifying the counterparts of DLAs in the possible cluster

Observation

- Instrument: Suprime-Cam (NB400, g imaging)
- Date: 15-16 April 2015 (HST)

	NB400		g'	
Target	exposure	seeing	exposure	seeing
J1230+34 field	4.6 hrs	0".7-1".0	1.0 hrs	0".5-0".7

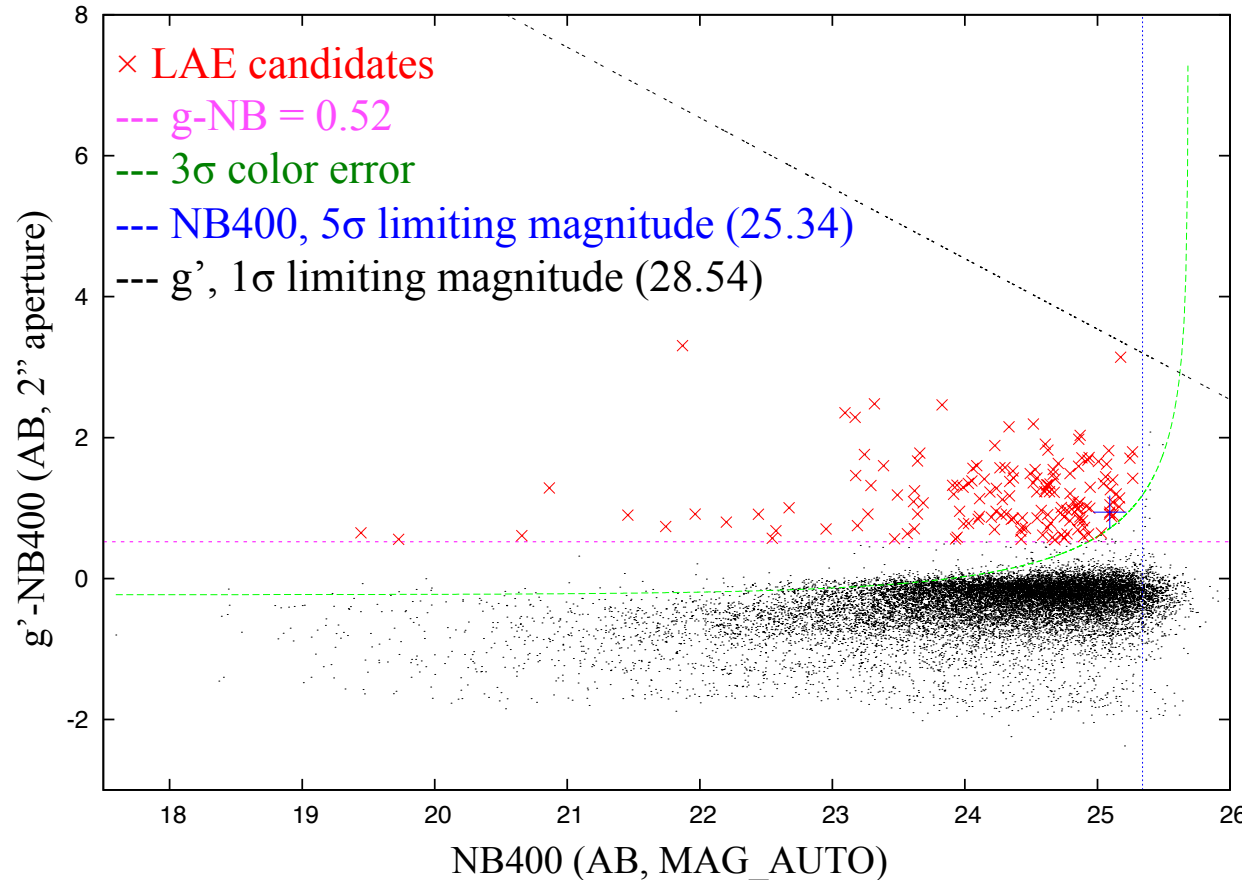
- Total integration time of the reduced image: NB400 → 185 min, g' → 54 min
- Limiting magnitude (5σ , AB mag): NB400 → 25.34, g' → 26.69
- PSF size of the reduced image : $\sim 0''.9$
- Aperture size for the photometry: $2''.0$



Sample Selection

Selection of Ly α emitters (LAEs)

★ Selection based on the color-magnitude diagram (g'-NB400 vs. NB400)



Selection criteria

- $g'-NB400 \geq 0.522$
- $EW_0 \geq 20 \text{ \AA}$
- $NB400 \leq 25.34$
- 5 σ limit
- $g'-NB400 \geq -0.23 + 3\sigma \text{ color-error}$
(-0.23 is the median of the g-NB of objects with $24.0 \leq NB400 \leq 25.0$)

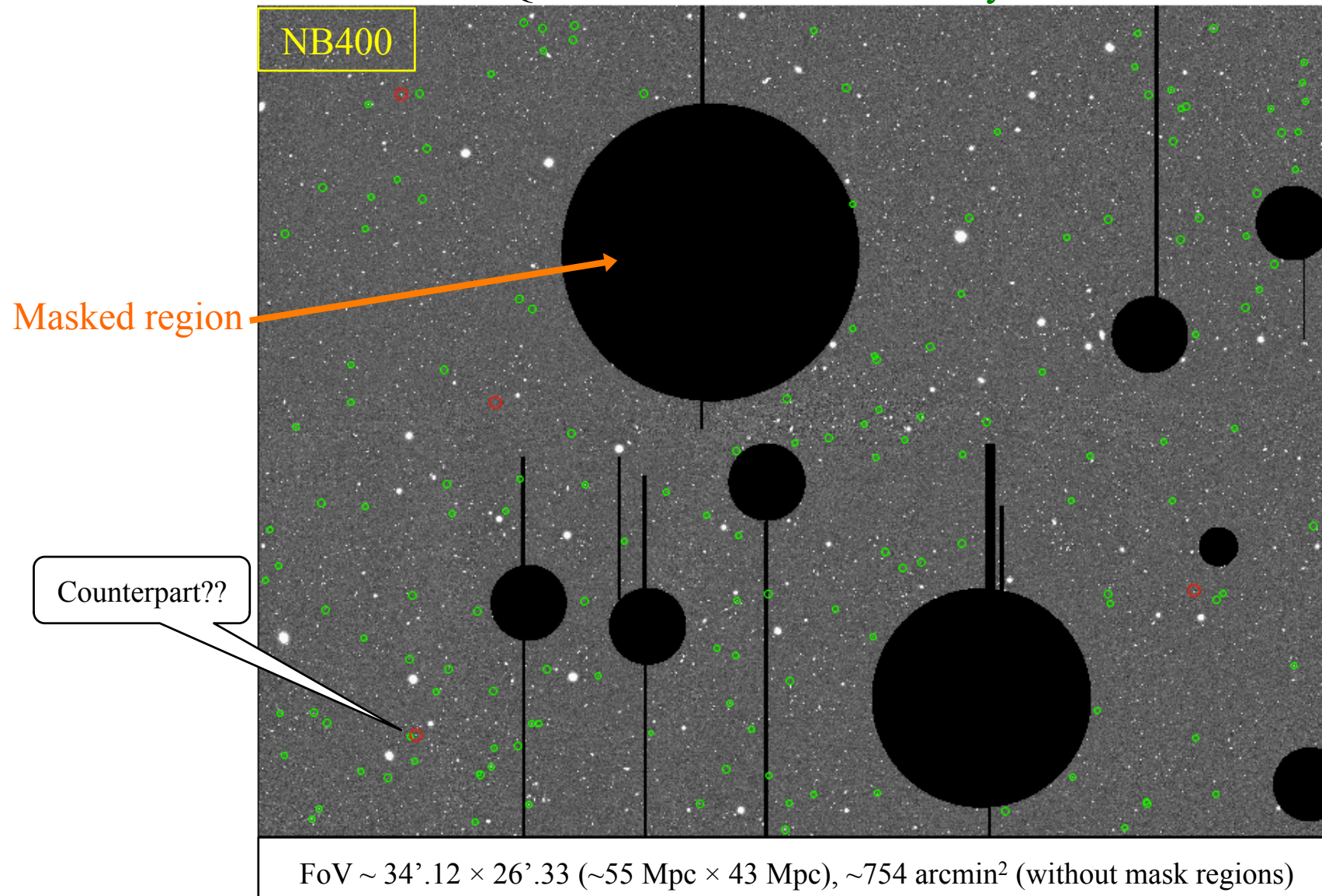
- Using SExtractor, 16912 objects are detected and LAE candidates from color selection are 154
→ After the visual inspection, **149 objects are selected as LAEs at $z \sim 2.3$**
(Remove the object located at the limb of mask region or image)

Result

The spatial distribution of LAEs

★ The spatial distribution of LAE candidates (154 candidates based on color selection)

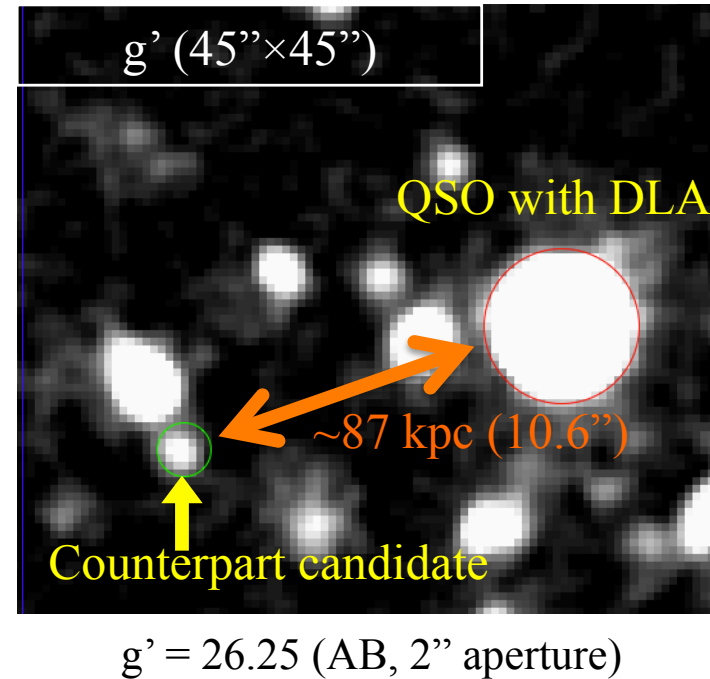
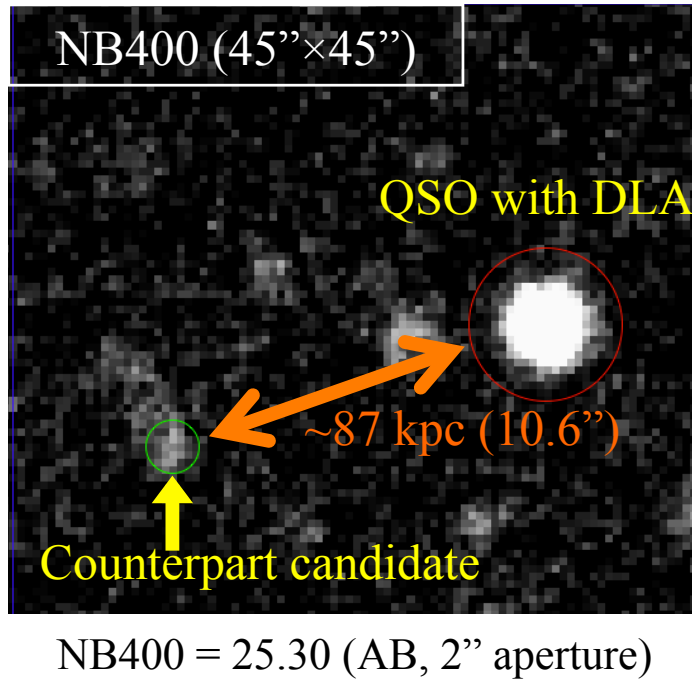
- Red circle: QSOs with DLAs, Green circle: LAE candidates



Result

A candidate of DLA counterpart

★ Counterpart candidate of 1 of 4 DLAs is found

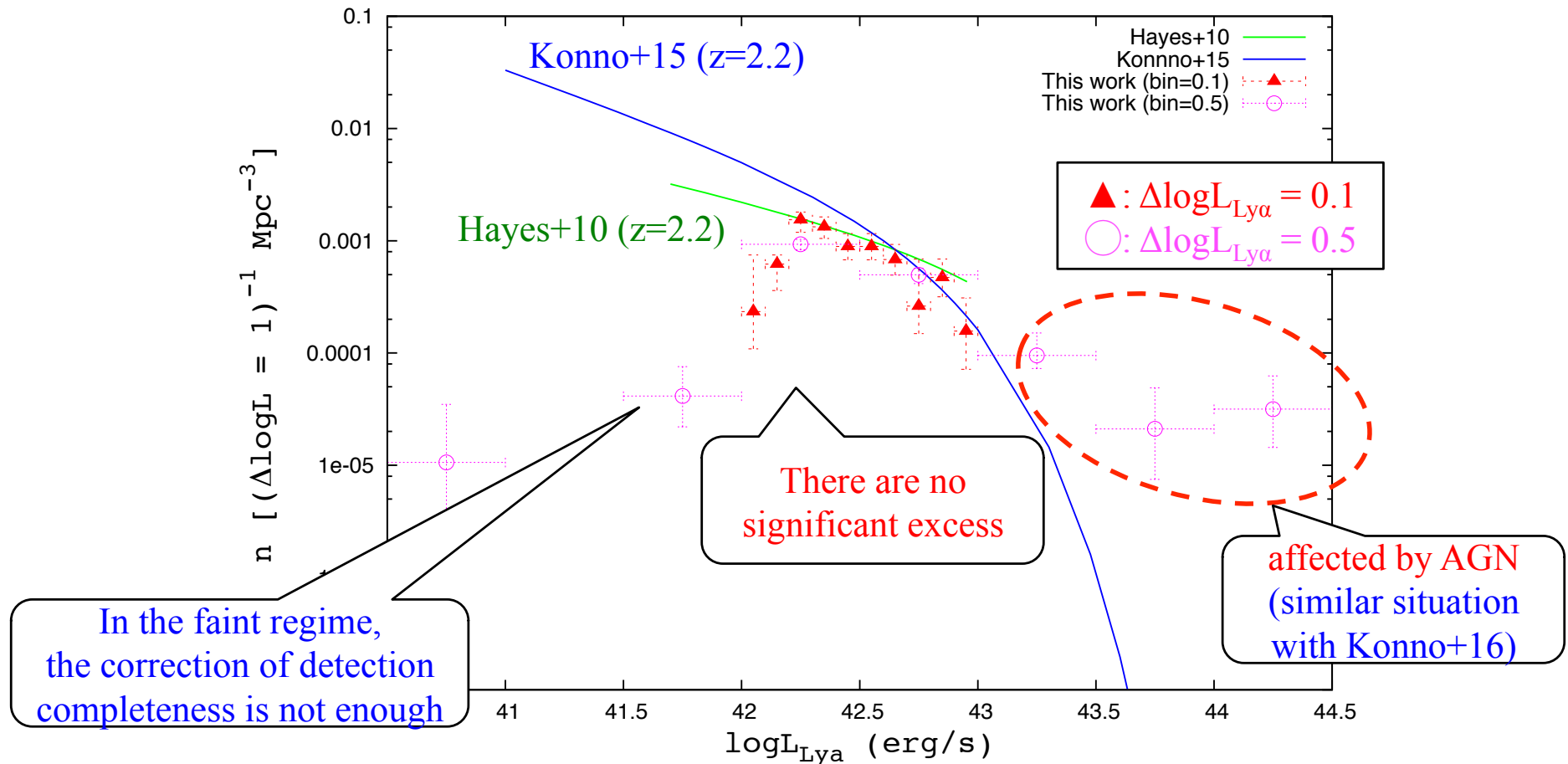


- Impact parameter: ~87 kpc
 - Spectroscopic follow-up observations are required
- confirming the redshift of the candidate and investigating its properties
- 3 of 4 DLAs have no optical counterparts
- They are very young and have not started star-formation (?)

Result

Ly α luminosity function

★ Luminosity function of Ly α emitters (the detection completeness is corrected)



- Comparing with luminosity functions at near redshift (Konno+15, Hayes+10)
→ No significant excess is found

Discussion

Interpretations of luminosity function

★ Why over-density of LAEs do not found in possible DLA cluster?

Galaxies in this region are **so young that they have not started star-formation**

To examine this scenario...

→ Investigating the stellar population of LAEs in the DLA cluster

1) The distribution of equivalent width (EW) of Ly α emission

→ Younger LAEs tend to have larger EWs

(Malhotra & Rhoads 02, ApJ, 565, L71)

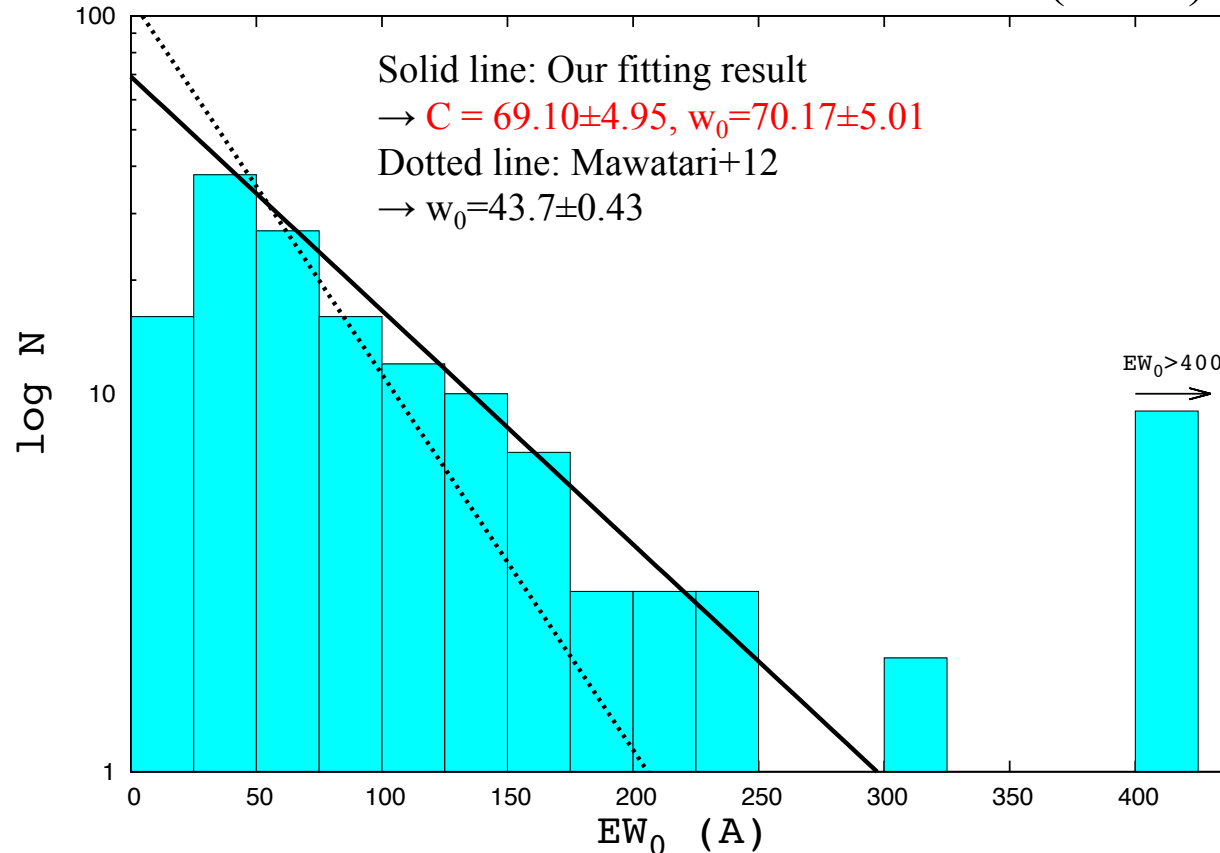
2) UV-slope

→ Younger LAEs tend to have bluer UV-slope

Equivalent width distribution of Ly α emission

★ Distribution of EW

- Comparison with the EW distribution of Mawatari+12 ($z \sim 2.4$)



- Fitting with $N = C \times \exp(-EW/w_0)$
→ This work: $w_0 = 70.17 \pm 5.01$, Mawatari+12: $w_0 = 43.7 \pm 0.43$
- From the EW_0 distribution, LAEs in this work are thought to be young

Summary

Summary and future works

- Based on the BOSS DLA catalog, we found some possible DLA clusters, where some DLAs at same redshift distribute very narrow regions
- To examine these regions are really over-density regions, we carried out the NB imaging observation of LAEs
→ Unexpectedly, no over-density of LAE is found in a possible DLA cluster
- Possible scenarios for DLA cluster with no LAE number density excess
→ Most of gases in the galaxies in DLAs have not converted to stars
- Based on the EW distribution of Ly α , LAEs detected in the DLA cluster are thought to be young

Future works

- Investigating local density
- Investigating the spatial distribution of other population of galaxies
(e.g., H α emitters, LBGs)
- Spectroscopic follow-up for the candidate of DLA counterpart