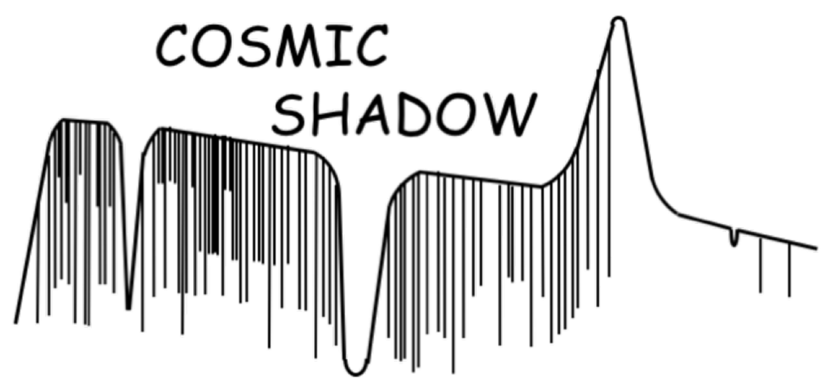
Review: Current status of QALs (2)

The connection between Star-forming galaxies, environments and DLAs

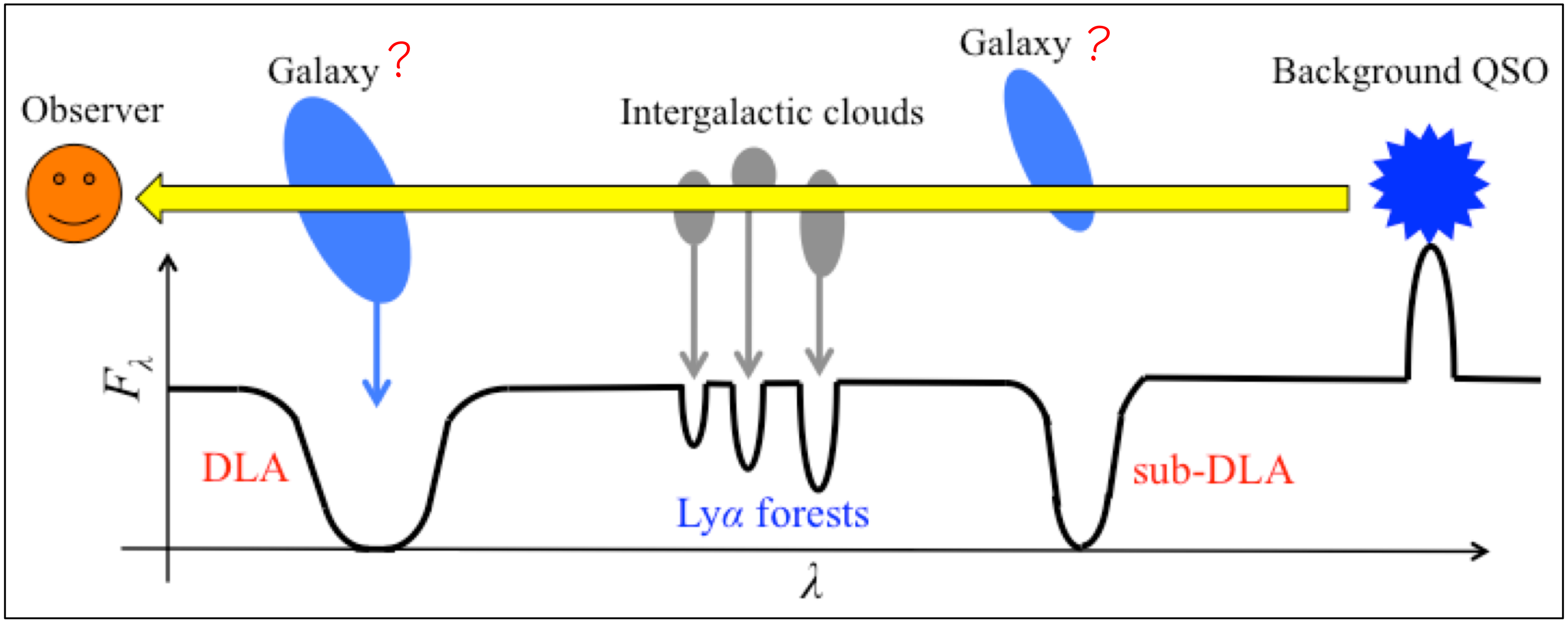
Kazuyuki Ogura (Bunkyo Univ.)
Katsuya Okoshi (Tokyo Univ. of Science)



2018.11.24-25
Cosmic Shadow 2018 in Ishigaki island

DLA and Quasar absorption line systems

- Schematic picture of (intervening) QALs
  (intrinsic absorbers: Horiuchi-san's review)



・Intervening gas-rich objects make absorption lines on the spectra of background sources (QSOs, GRBs, galaxies)

→ A strong tool to recognize the gas at high redshift

DLA and Quasar absorption line systems

Classes of intervening H I absorbers

- classified by its H I column density, N_{HI}

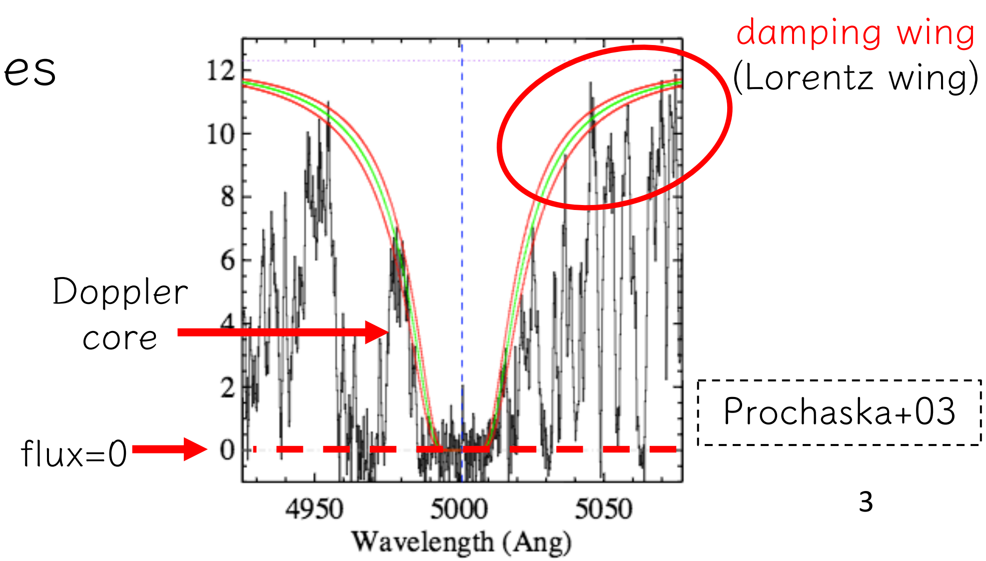
> - $N_{HI} < 10^{17}$ cm^{-2}: Ly α forest
> - $10^{17} < N_{HI} < 2 \times 10^{20}$ cm^{-2}: Lyman limit system
> - $N_{HI} \geq 2 \times 10^{20}$ cm^{-2}: DLA
>   - $10^{19} < N_{HI} < 10^{20.3}$ cm^{-2}: sub-DLA (or "super-LLS")

DLA: the highest N_{HI} class

- DLA = damped Ly α absorption system
  (or "damped Ly α system", "damped Ly α absorber")

- similar N_{HI} with disks of local galaxies

→ high-z DLAs are progenitors of present-day disc galaxies??



> ★Note
> - $N_{HI} \sim 10^{17}$ cm^{-2}: $\tau = 1$ @Lyman limit
> - $N_{HI} \sim 10^{19}$ cm^{-2}: $\tau = 1$ @Damping wing

DLA and Quasar absorption line systems

● DLAs and sub-DLA

DLA: $N_{HI} \geq 2 \times 10^{20}$ cm^{-2} -- historical threshold

- N_{HI} at a limiting radius of the Westerbork interferometer observations
- the Lyα absorption line is broadened enough to be detected by relatively low spectral resolution

→ Wolfe+86: search for "Lyα disks" to find 15 DLAs

sub-DLA: $10^{19} \leq N_{HI} < 2 \times 10^{20}$ cm^{-2} (Peroux+02, 03)

- The deference between DLAs and sub-DLAs

Wolfe+05

- DLA: the gas is mainly neutral
- sub-DLA: the gas is mainly ionized

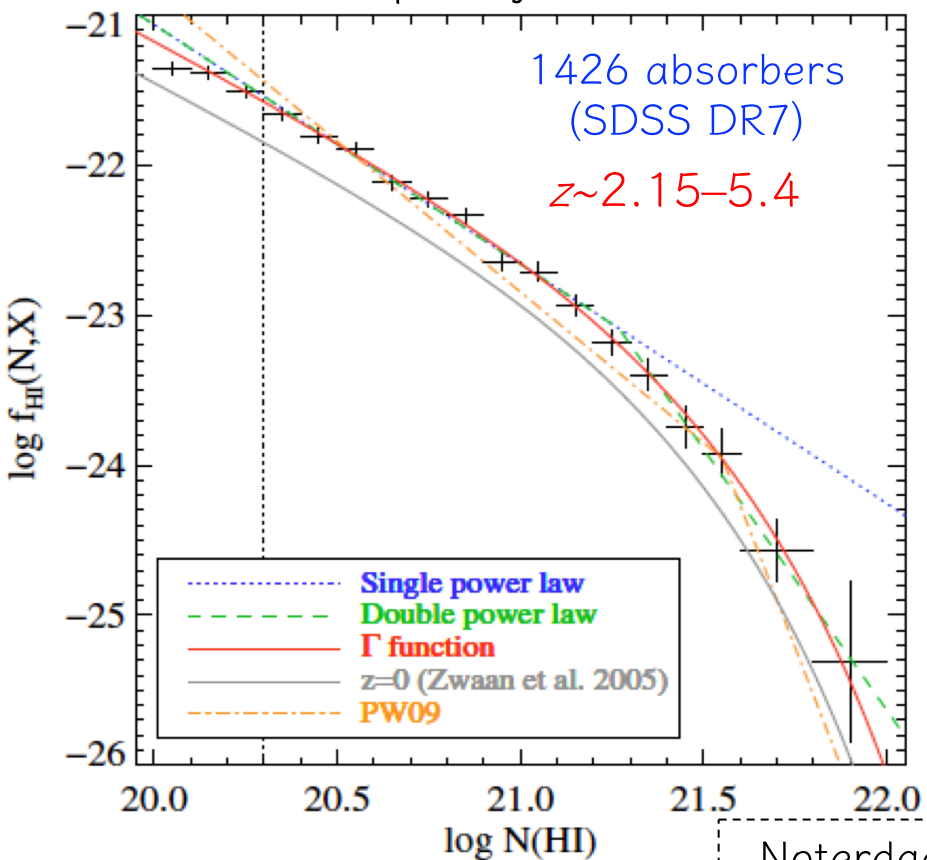
Depend on the model of the background radiation

- Viegas+95: most of the gas likely to be neutral for $N_{HI} > 10^{19.5}$ cm^{-2}
- $N_{HI} \geq 2 \times 10^{20}$ cm^{-2} corresponds to critical surface-density limit for star-formation (Noterdaeme+09)

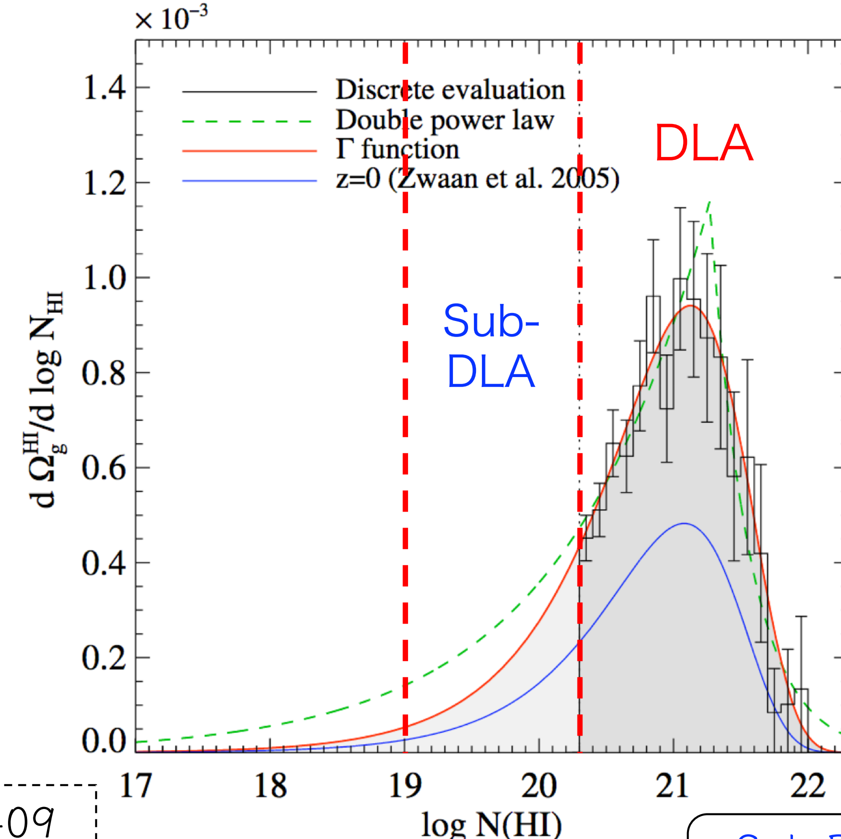
DLA and Quasar absorption line systems

- Neutral gas content of high-z DLAs
  - DLAs dominate the neutral gas content of the Universe

H I frequency distribution



Cosmological mass density in absorbers of different N_{HI}



Noterdaeme+09

  - DLAs contribute ~70–80% of H I content of the z>2 Universe

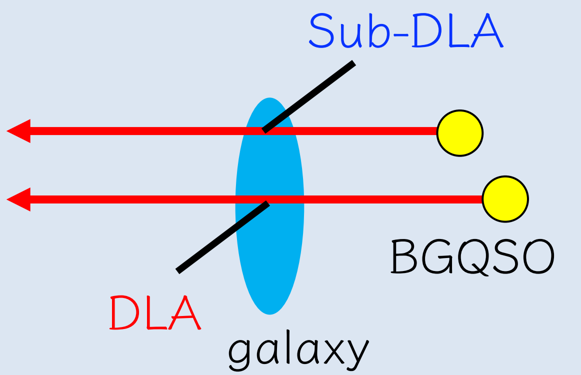
Sub-DLA ~20-30%

DLAs are gas-reservoir for the star-formation

The origin of DLAs

- some possible scenarios

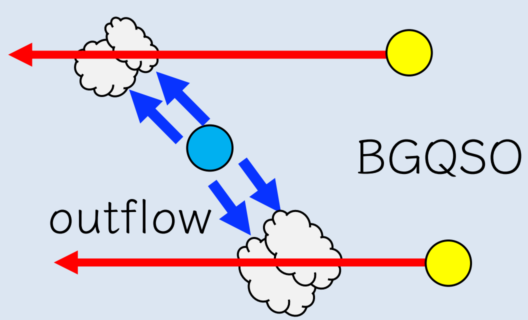
① Disks of galaxies



- A classical scenario (Prochaska&wolfe98)
- DLA counterparts show various morphology (from low-*z* studies)
  - normal galaxies
  - dwarf galaxies
  - LSBs

  (e.g., Impey&Bothun89, Jimenez+98,99, Matteucci+97)

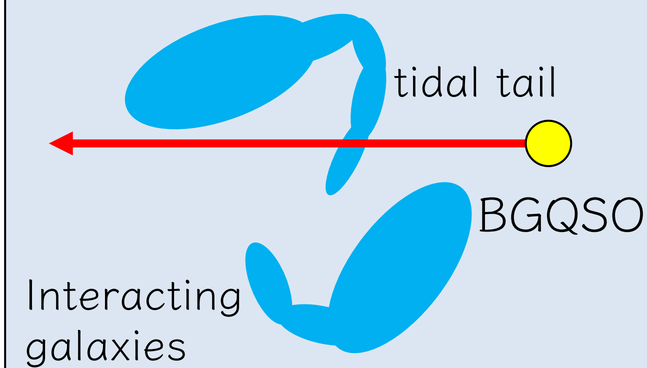
② Outflows



- Some evidence for outflowing gas from high-*z* DLA counterparts
  - double peak emission
  - extended emission

  (e.g., Kashikawa+14, Krogager+13)
- Superwind model (Taniguchi&Shioya00, 01)

③ Tidal tails



- Suggested by Kacprezac+10
- Only 1 example to date (z~0.3)

The major origin of DLAs
Is still under discussions
→ because of **difficulty in identifying DLA counterparts**

Identifying optical counterparts of DLAs

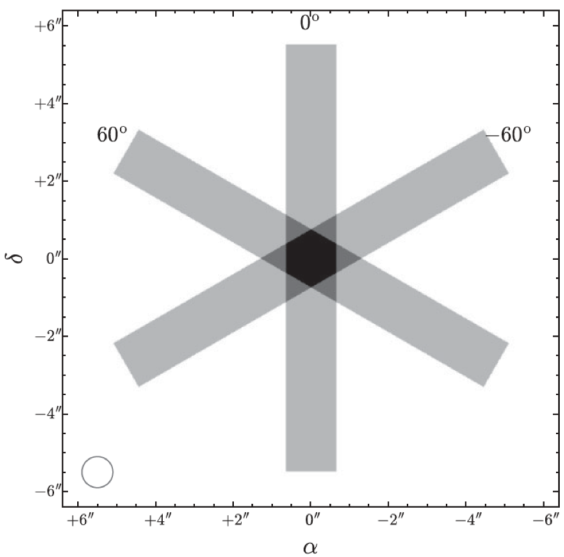
DLA counterparts

- Galaxies associated to DLAs
  (“DLA galaxy”, “host”, or “galaxy counterpart”)

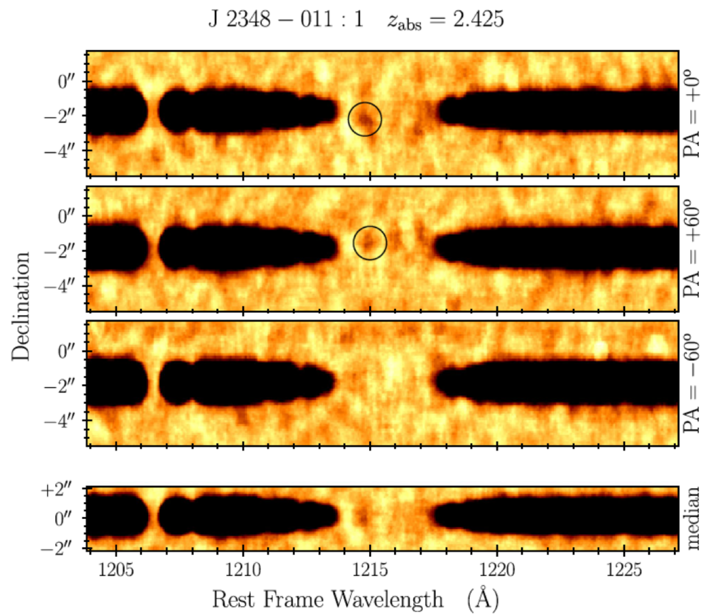
Classical effort (at high-*z*): Long-slit spectroscopy

- Take spectra with different position angle (PA)

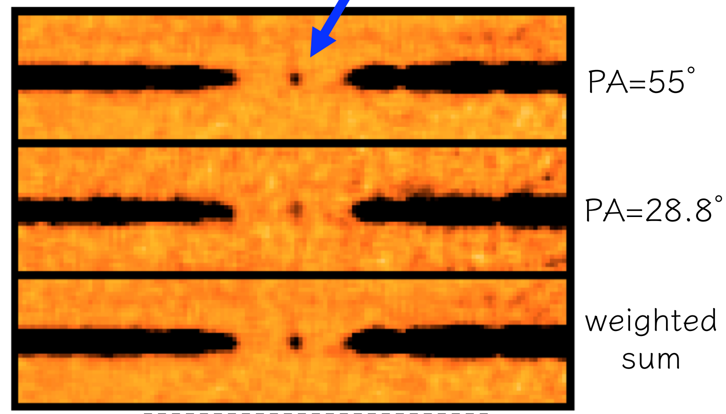
Krogager+17



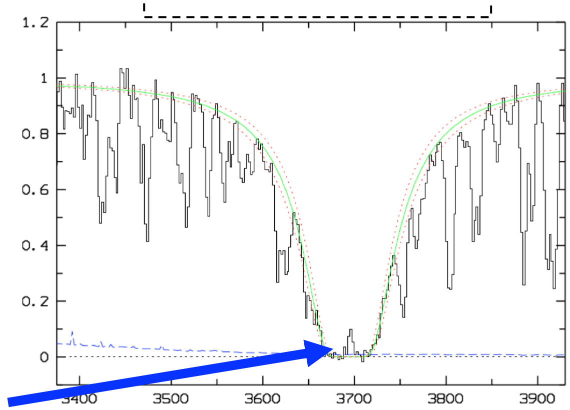
An example of the layout of slit position



Lyα emission from the counterpart



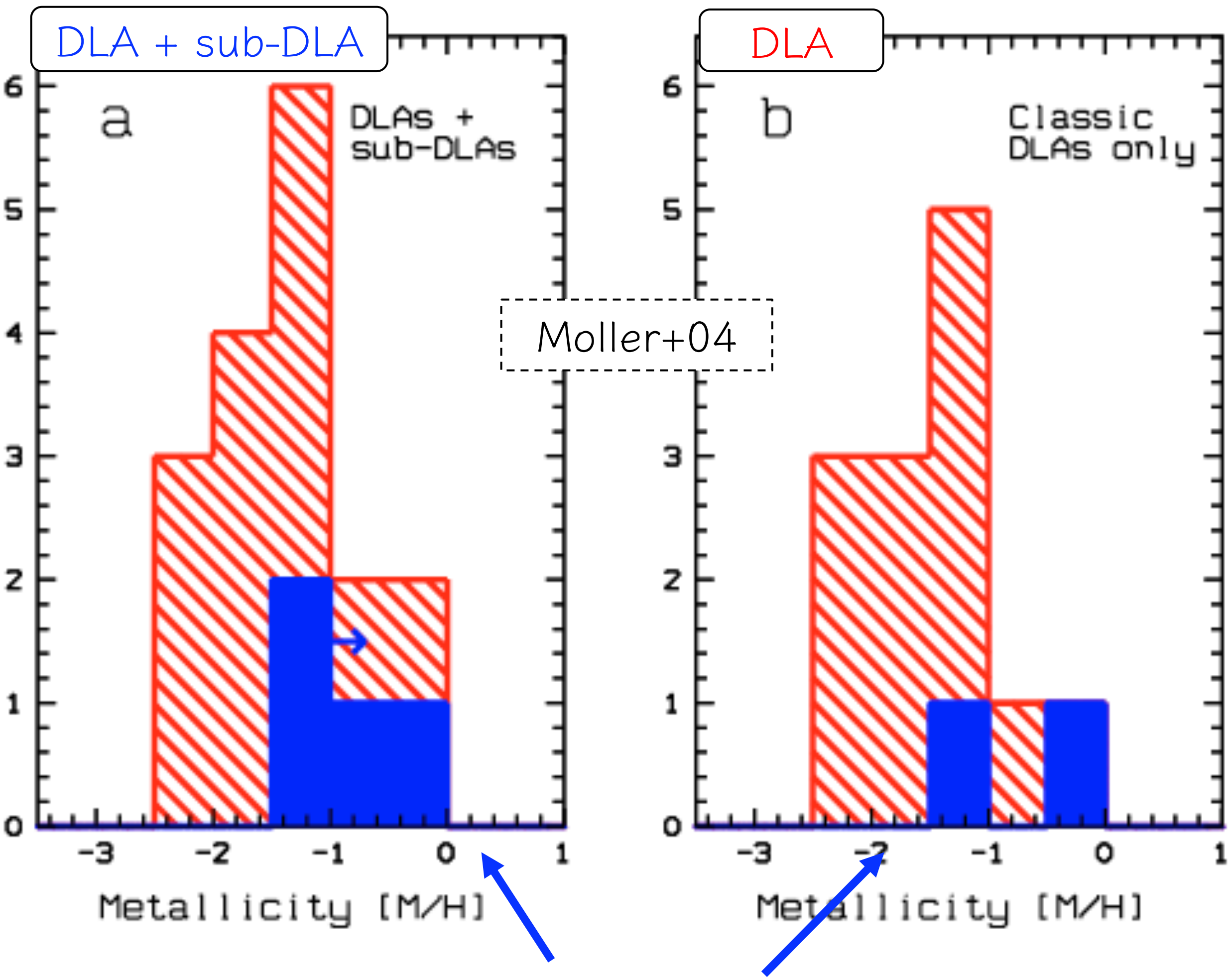
Moller+04



Lyα emission from the counterpart

Identifying optical counterparts of DLAs

- **Metallicity-luminosity relation of DLA**
  - DLAs with detected Lyα emission tend to have higher metallicity



Blue : detected Lyα emission

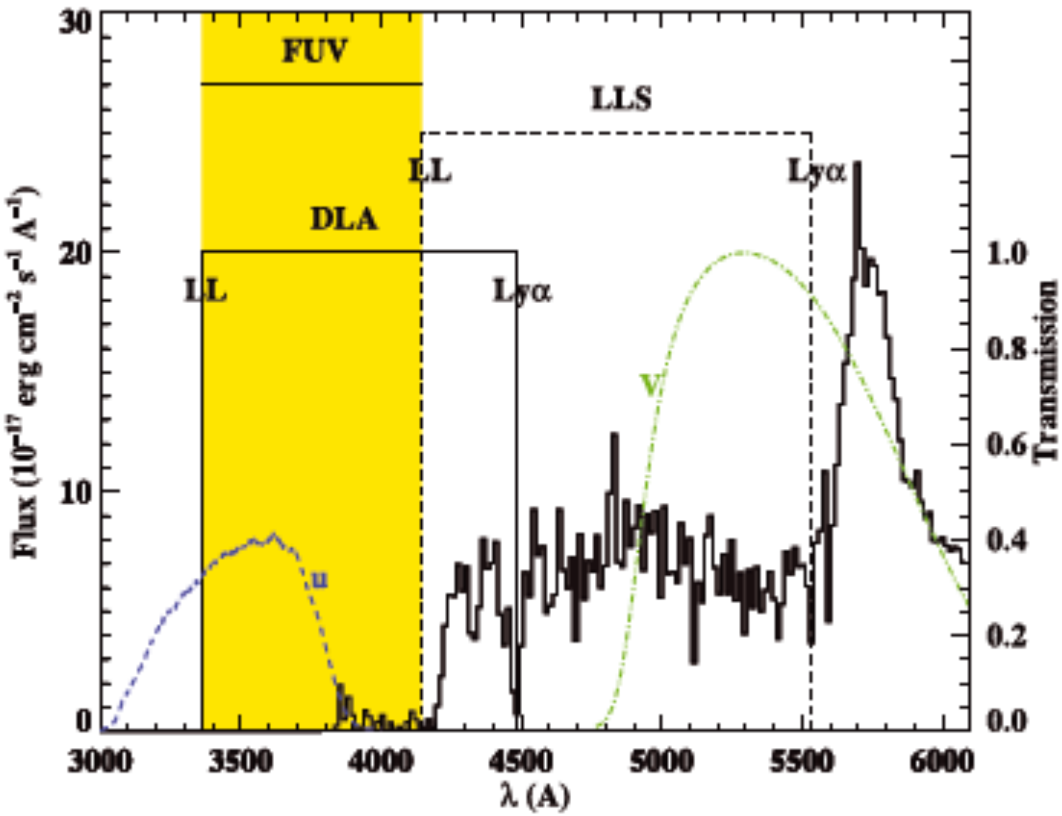
Krogager+17

- Detection rate of counterparts is significantly high when we focus on high-metallicity DLA
  → ~64% (7/11)
  - blind survey: <10%
- Metallicity-luminosity relation of DLA counterparts can be reproduced by a simple model
  - $M_{UV} = -5 \times ([M/H]+0.3) - 20.8$

High-metallicity DLA are meaningly selected for target of counterpart surveys (maybe biased)

Identifying optical counterparts of DLAs

- "Double-DLA" technique (Fumagalli+10)
  - Focusing on the QSO sightlines with multiple optically thick systems



- A sightline which have a LLS between the target DLA and the BGQSO

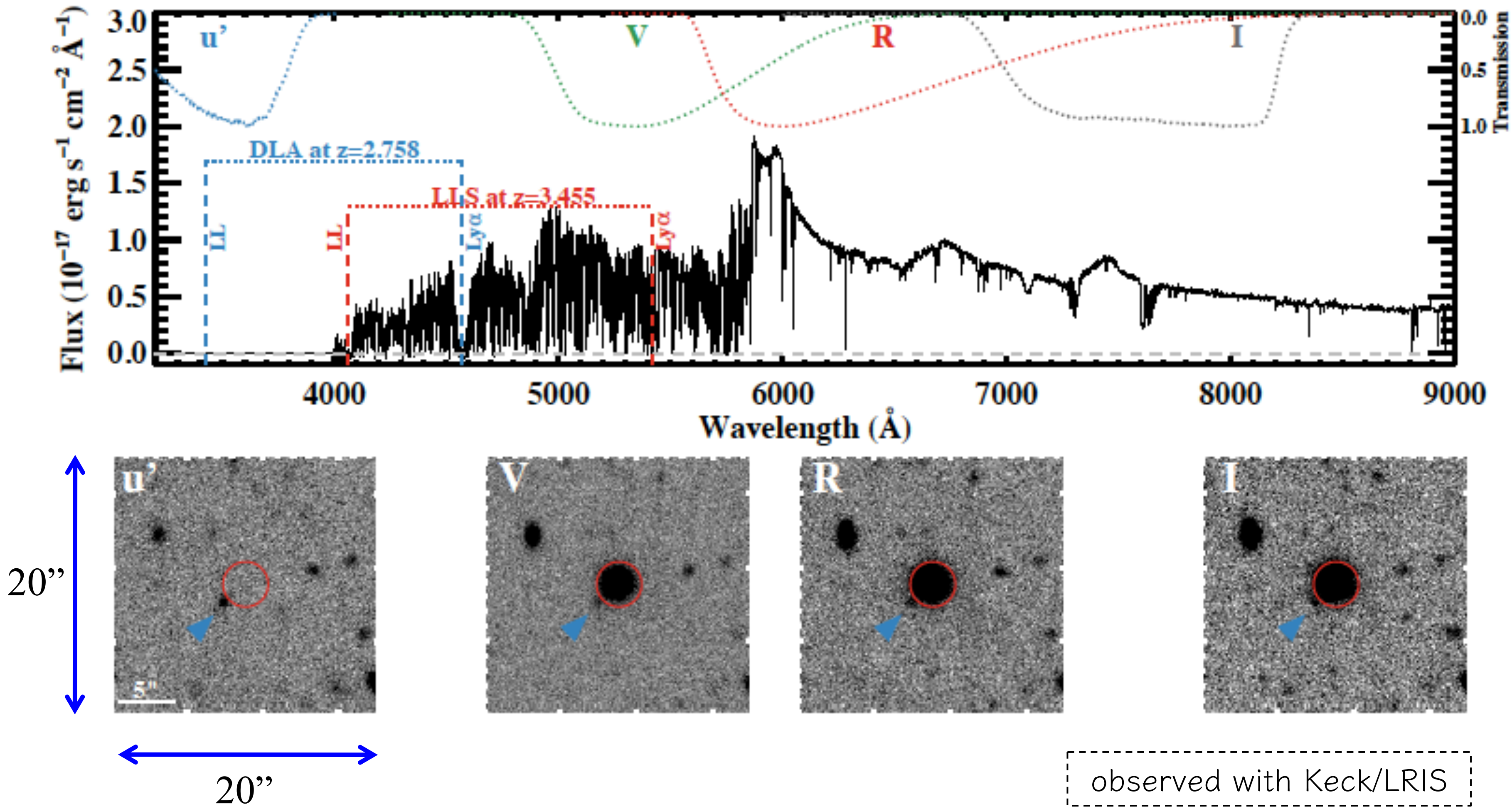
→ Lyman limit (LL) of DLA --- LL of LLS --- Lyα absorption of DLA

free from BGQSO radiation

Identifying optical counterparts of DLAs

- "Double-DLA" technique
  - An example

Fubagalli+10

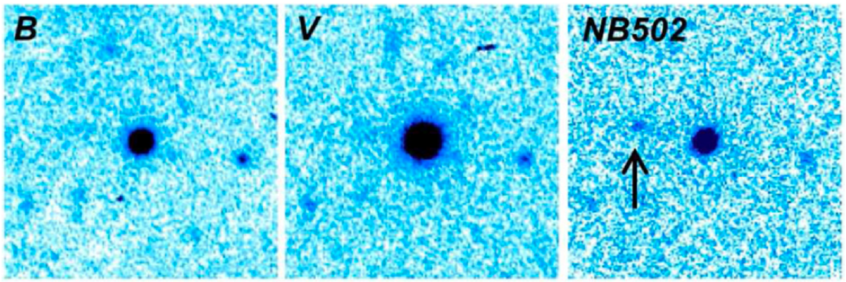


observed with Keck/LRIS

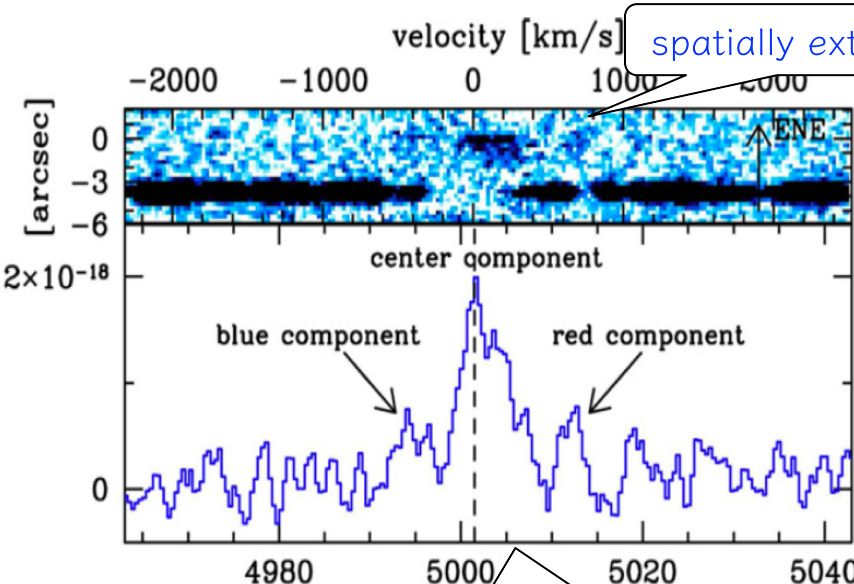
Identifying optical counterparts of DLAs

- NB imaging, Integral field spectroscopy, and ALMA observations

Kashikawa+14: NB + spectroscopic follow-up



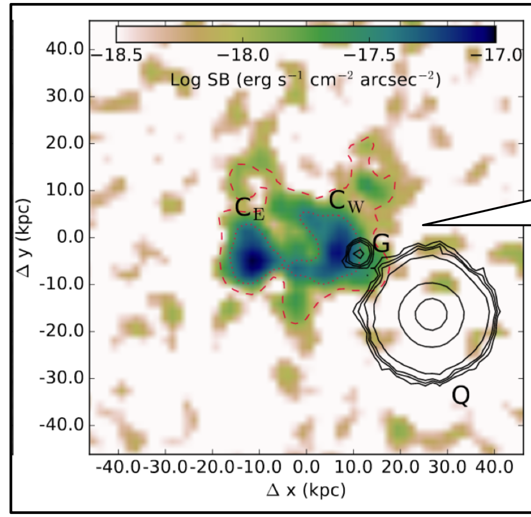
sub-DLA at z=3.115, b~28 kpc



spatially extended

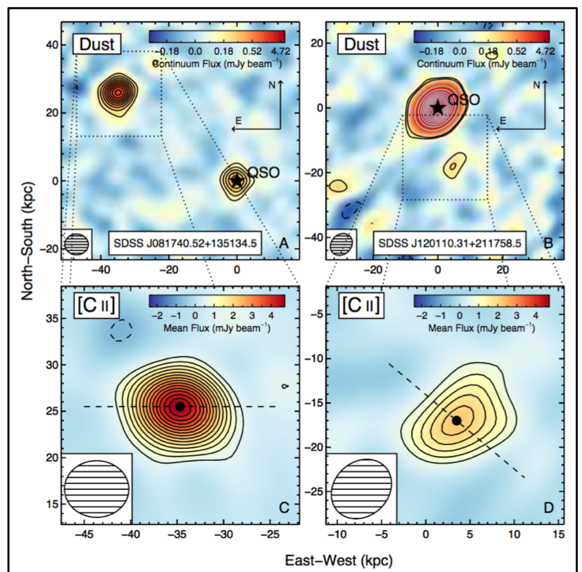
Asymmetric line profile

Fumagalli+17: VLT/MUSE



- DLA at z=3.25
- b~30.5 kpc

Extended Ly α nebula (~37 kpc)



Neelman+17:ALMA

[C II] and dust continuum from z~4 DLA galaxies

left: z=4.26, b=42 kpc
right: z=3.80, b=18 kpc

Identifying optical counterparts of DLAs

- A list of spectroscopically identified DLA counterpart at z>2
  - Only <20 counterparts at z>2 have been identified! (as of Mar. 2018)

Quasar	z_{QSO}	z_{abs}	$\log N_{HI}$	θ (")	b (kpc)	References	Emission lines
Q2233+131	3.298	3.15	20	2.51	18.52	Djorgovski+96	Ly α
Q2206–1958	2.559	1.92	20.65	0.99	8.09	Møller+02	Ly α
PKS 0458–02	2.286	2.04	21.65	0.31	2.44	Møller+04	Ly α
Q2222–0946	2.926	2.354	20.65	0.8	6.67	Fynbo+10	Ly α, [O III], H α
J0918+1636	3.086	2.583	20.96	1.98	16.2	Fynbo+11,13 Sommer-Larsen & Fynbo17	[O II], [O III], H β, H α
J1135-0010	2.888	2.207	22.1	0.1	0.9	Noterdaeme+12b	Ly α, [O III], H α
J0338–0005	3.068	2.22	21.05	0.49	4.12	Krogager+12	Ly α
HE 2243-6031	3.01	2.329	20.62	3.1	26	Bouche+13	H α
J0918+1636	3.086	2.412	21.26	<0.25	<2.0	Fynbo+13	[O III]
J0310+0055	3.782	3.115	20.05	3.8	28	Kashikawa+14	Ly α
J2358+0149	3.255	2.979	21.69	1.5	21	Srianand+16	Ly α
J0817+1351	4.398	4.26	21.3	6.2	42	Neeleman+17	[C II] 158 μm
J1201+2117	4.579	3.798	21.35	2.5	18	Neeleman+17	[C II] 158 μm
J0255+0048	3.996	3.255	20.85		19.1	Fumagalli+17	Ly α
J2059-0528	2.539	2.210	21.00	<0.8	<6.3	Krogager+17	Ly α
J2348-0111	3.01	2.425	20.53	0.7	5.9	Krogager+17	Ly α
J1230-1139	3.52	2.193	20.60	3.5	30	Neelman+18	CO(3-2)

Maybe biased toward high-metallicity DLA and counterparts with emission lines

Systematic surveys for DLA counterparts are important
to understand the nature of DLAs

Identifying optical counterparts of DLAs

Why is the detection rate of DLA counterparts so low ??

- Most of DLA counterparts are too faint to detect even with 8-10 m telescope (?)

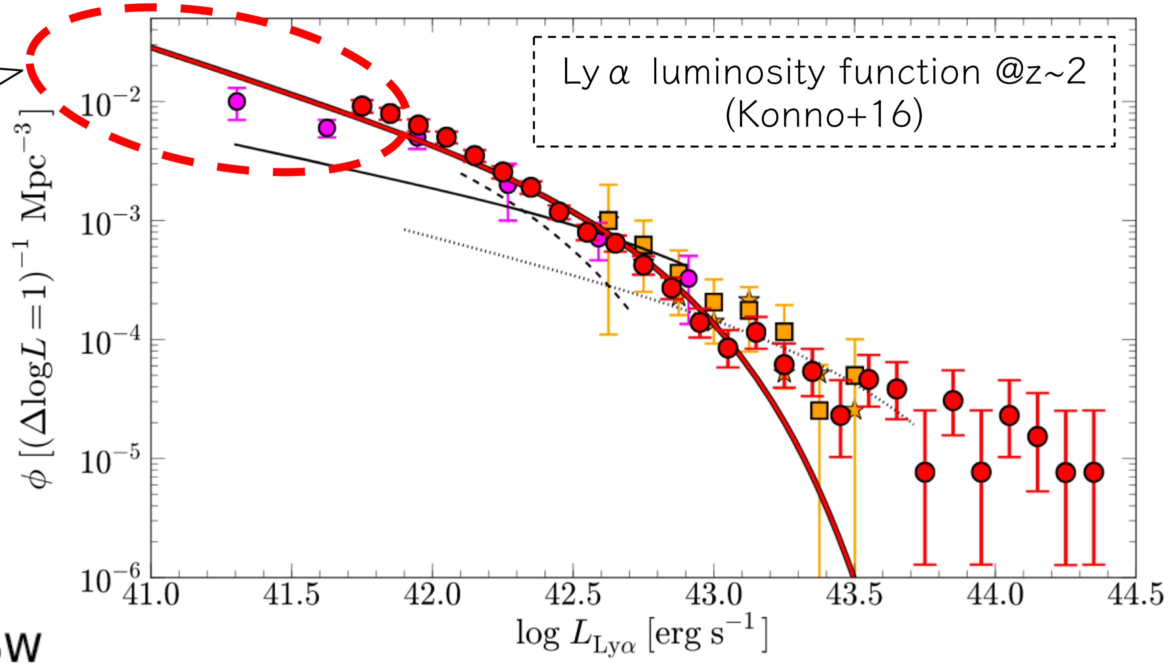
- We miss counterparts with (relatively) large impact parameter (?)

Identifying optical counterparts of DLAs

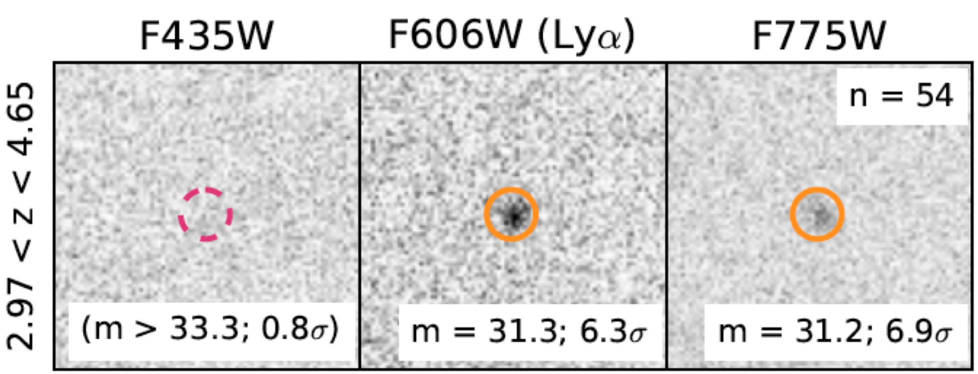
Why the success rate of identifying DLA counterparts is so low?

- DLA counterparts are too faint to detect 8-10 m telescope??

(For example…)
Very faint LAEs are major origin of DLA?
(see also Rauch+08)



- "Ultra-Faint" LAEs (Maseda+18)
  - MUSE detect emission lines without continuum counterparts
  - stacking HST images to confirm faint UV continua (M_{UV}~ -15)



HST stacking images for HST non-detected LAEs (Maseda+18)

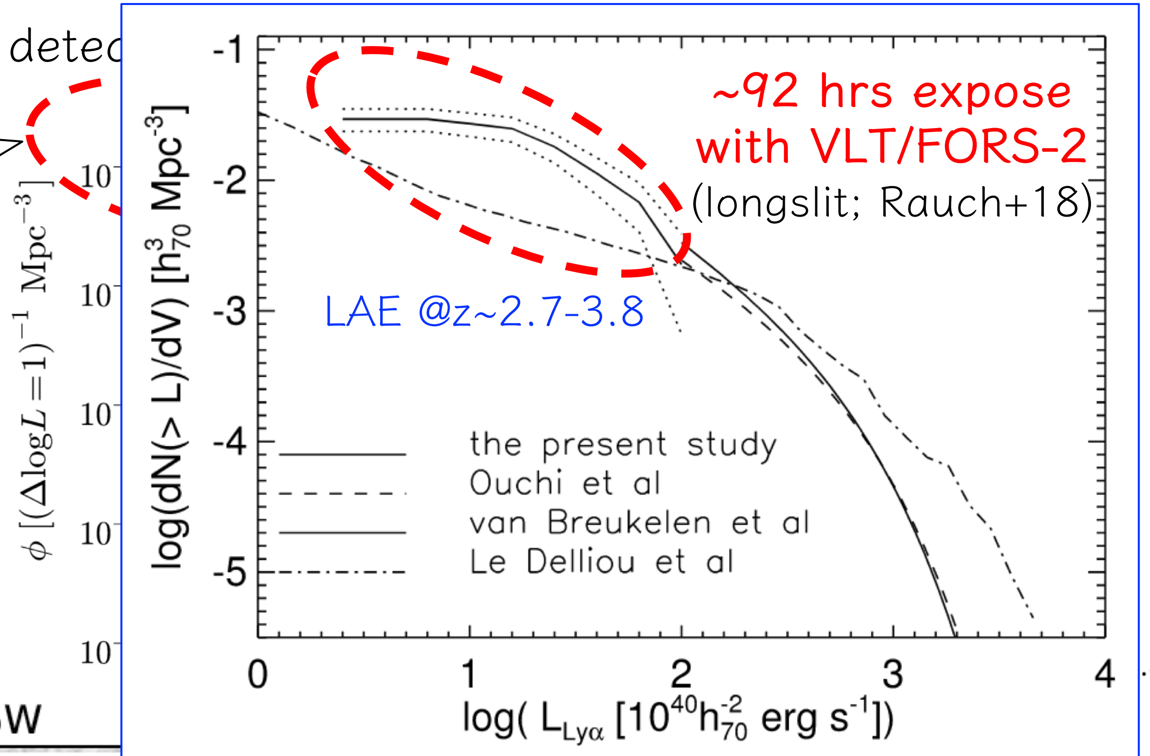
Ultra faint LAEs could be a major origin of the DLAs which have not been identified optical counterparts

Identifying optical counterparts of DLAs

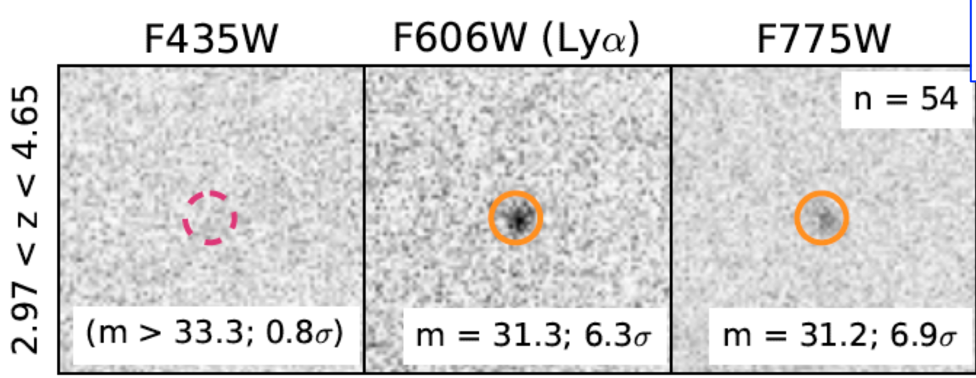
Why the success rate of identifying DLA counterparts is so low?

- DLA counterparts are too faint to detec

(For example…)
Very faint LAEs are major origin of DLA?
(see also Rauch+08)



- "Ultra-Faint" LAEs (Maseda+18)
- MUSE detect emission lines without continuum counterparts
- stacking HST images to confirm faint UV continua (M_{UV}~ -15)

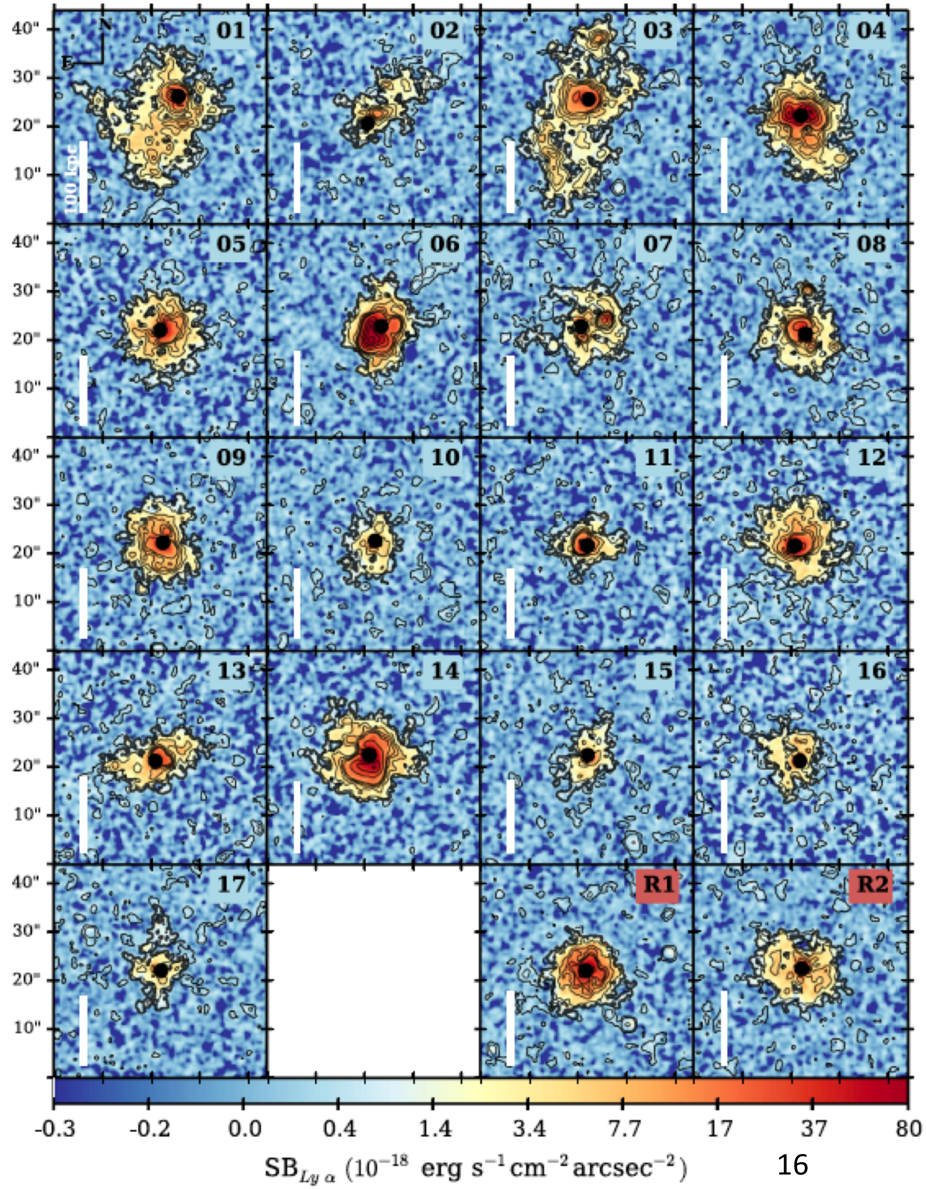


HST stacking images for HST non-detected LAEs (Maseda+18)

Ultra faint LAEs could be a major origin of the DLAs which have not been identified optical counterparts

Giant Ly α nebulae

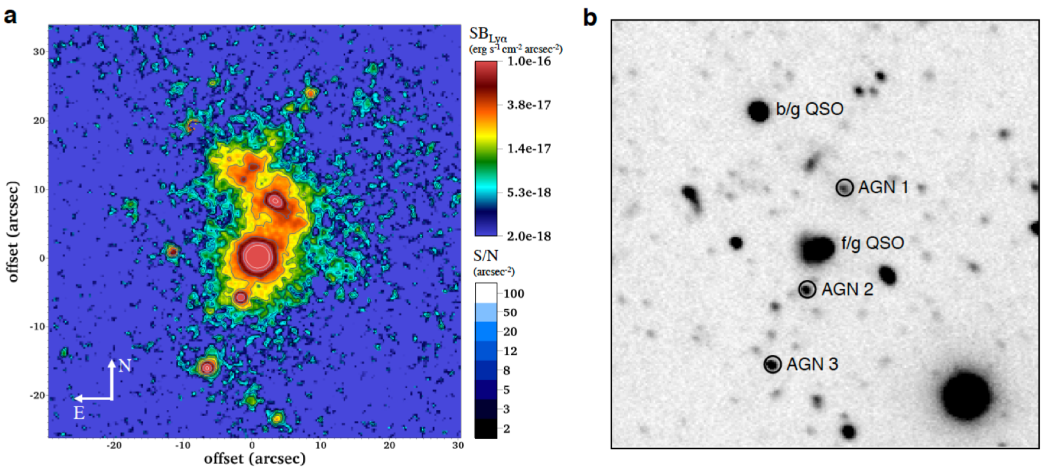
GLANe @z~3-4 (Borisova+16; MUSE)



Giant Ly α nebula (GLAN)

- Extended Ly α source with size of ~100 kpc and $L_{Ly\alpha}$ ~ 10^{44} erg s^{-1}
- commonly found around high-z radio galaxies and *z*>3 luminous QSOs
- only few GLANe have been found around *z*~2 QSOs
- *z*~2 GLANe tend to reside in **overdense regions of QSOs/AGNs**

GLAN @z~2.05 (Hennawi+15)



NB370 image (Keck/LRIS)

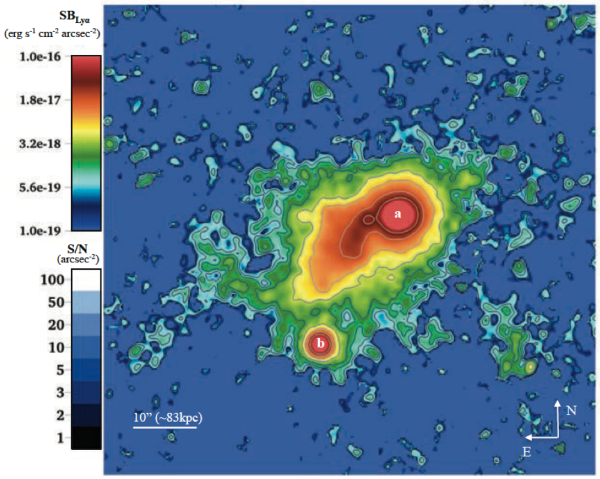
V-band continuum image

4 AGNs in the GLAN

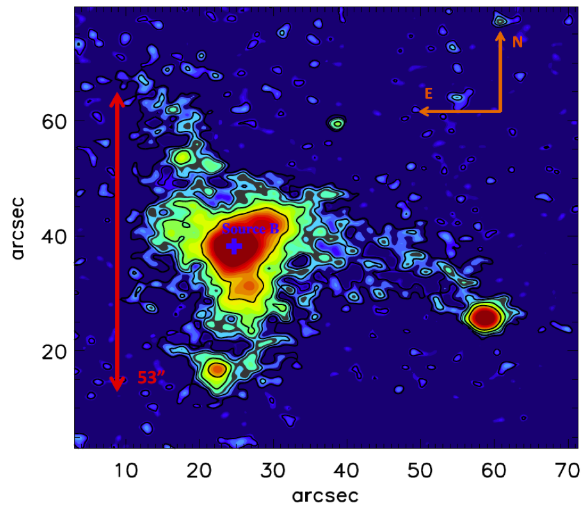
Ly α nebulae and the large-scale structure

Enormous Ly α nebulae: ELANe

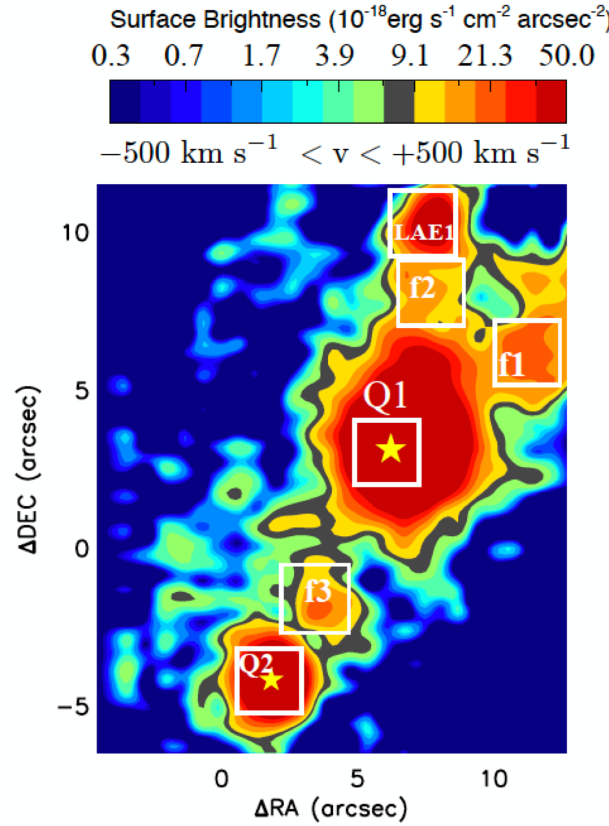
- ELAN: LAN whose size exceeds the diameter of its dark matter halo
  - size > 200 kpc, $L_{Ly\alpha}$ > 10^{44} erg s^{-1}



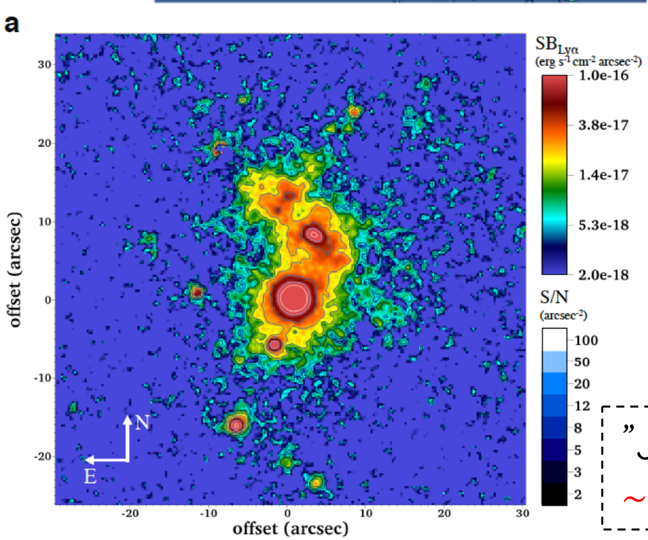
"Slag nebula" @z~2.3
~460 kpc (Cantalupo+14; NB)



MAMMOTH-1 @z~2.3
~440 kpc (Cai+17; NB)



ELAN0101+0201 @z~2.45
~230 kpc (Cai+18; KCWI)



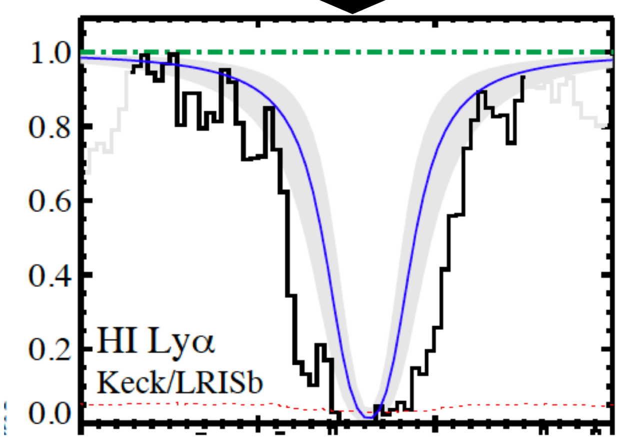
"Jackpot nebula" @z~2
~350 kpc (Hennawi+15; NB)

Lyα nebulae and absorbers

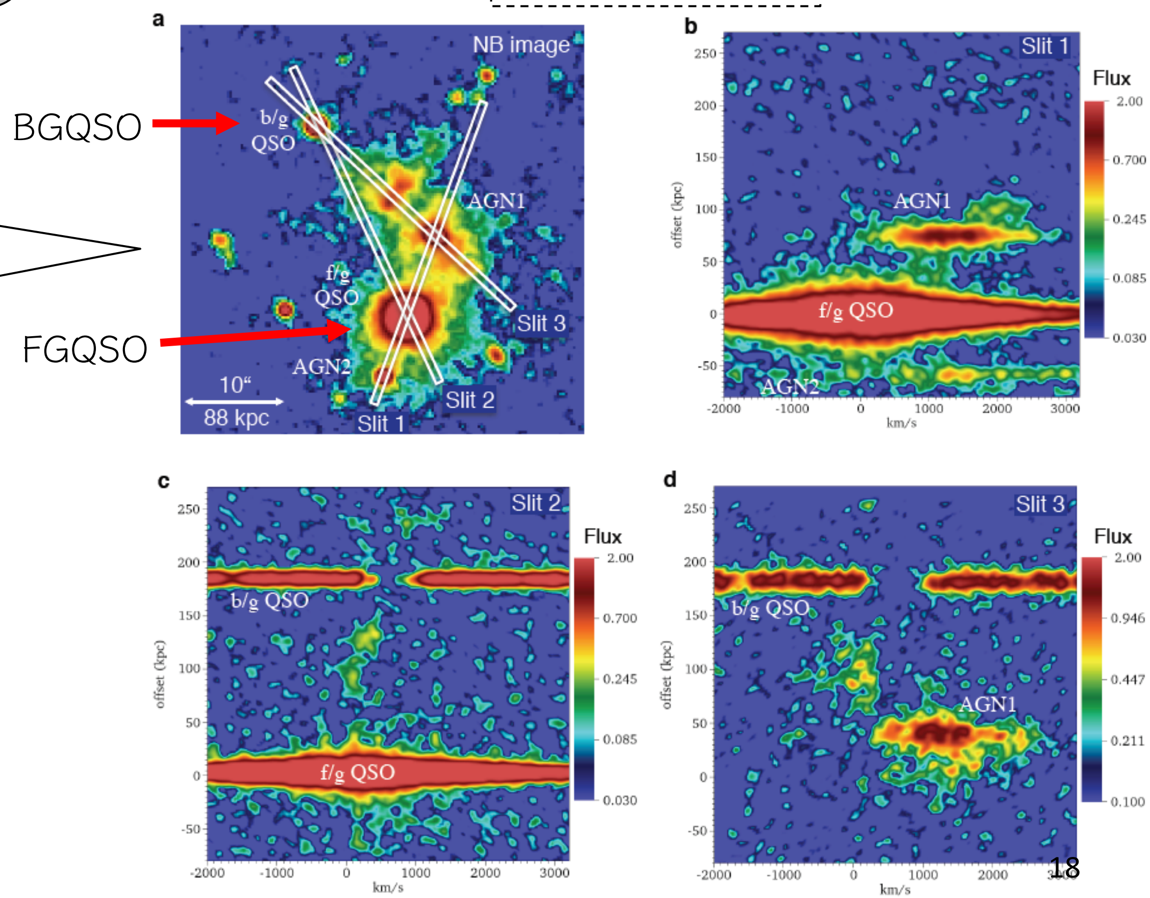
● QPQ: Quasar Probing Quasar

・Using distant QSOs to probe the CGM of foreground QSOs

・BGQSO @z~2.2
・FGQSO @z~2.0
→ an intervening absorber at z~2.0 is detected on the spectrum of the BGQSO



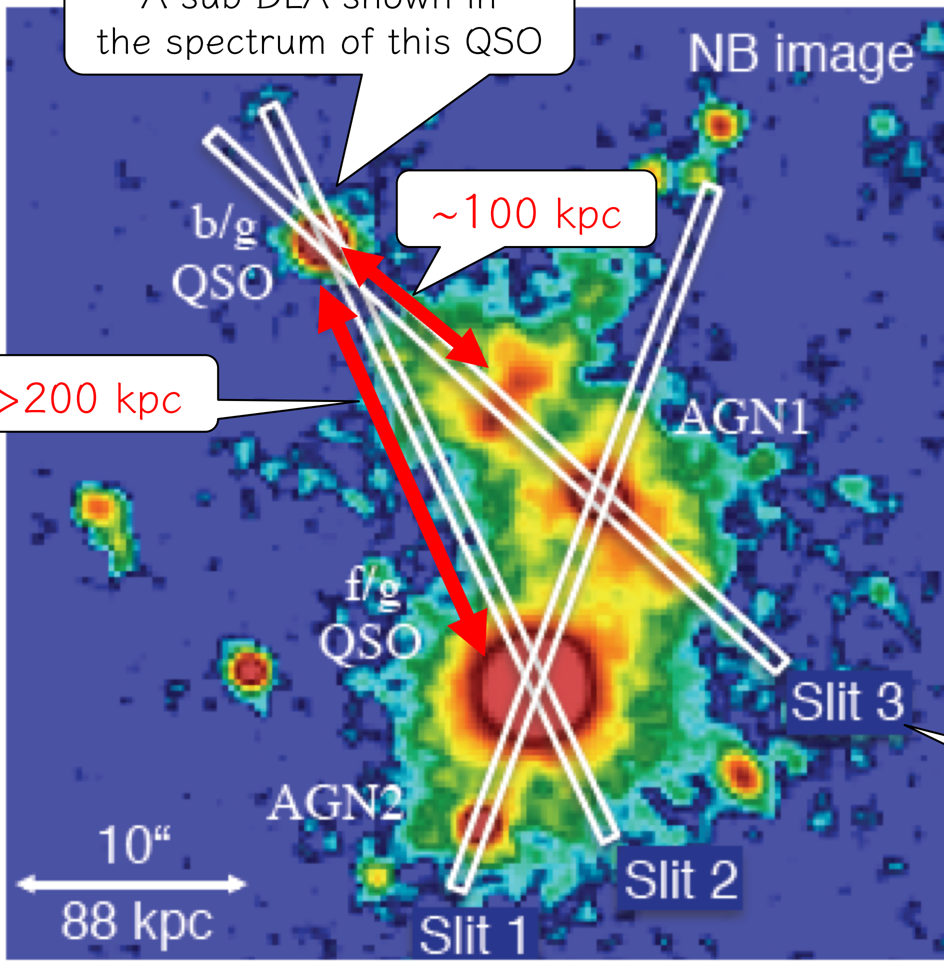
$\log N_{HI}$ =19.2 (sub-DLA)



Ly α nebulae and absorbers

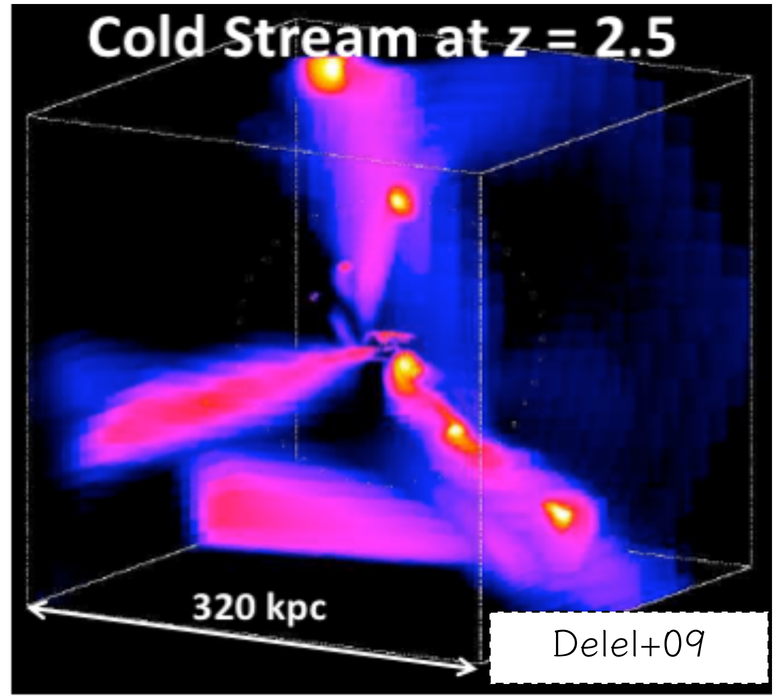
- The LAN also could be a origin of DLAs
  (but not a major contribution?)

A sub-DLA shown in the spectrum of this QSO



Hennawi+15

GLANe/ELANe correspond to the Cosmic filament (?)



Dekel+09

No optical counterparts within ~100 kpc from the BGQSO

We cannot recognize H I gas without any illuminating sources (QSO, galaxies…)

Investigating the relation between DLAs and star-formation

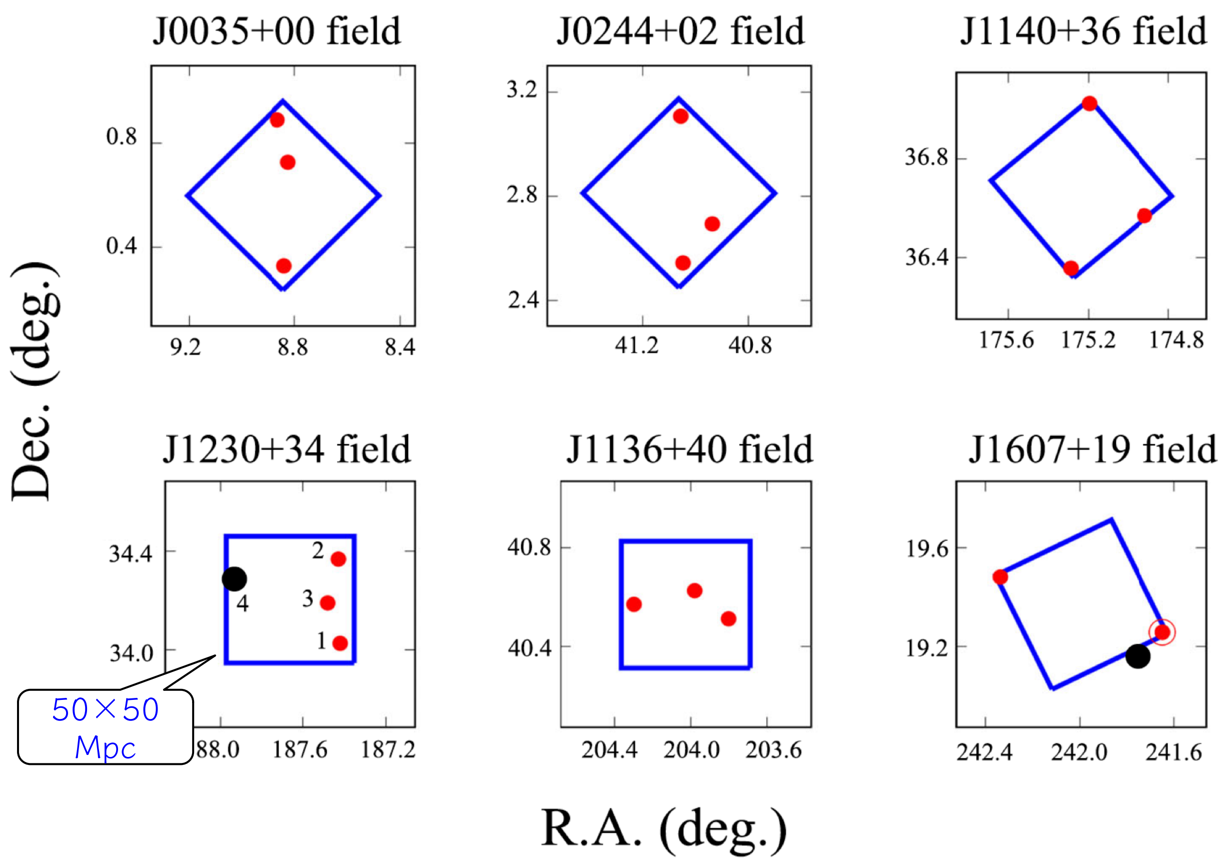
● DLA-concentrated region: Ogura+17

- A region where 3 or more DLAs distribute within (50 Mpc)^3 box

Why are the concentrated regions interesting?

(1) high-density environment is a key component of the CDM cosmology
(2) good laboratory to study the physical relationship between DLAs and star-forming galaxies
(3) enable us to search for counterparts of DLAs effectively

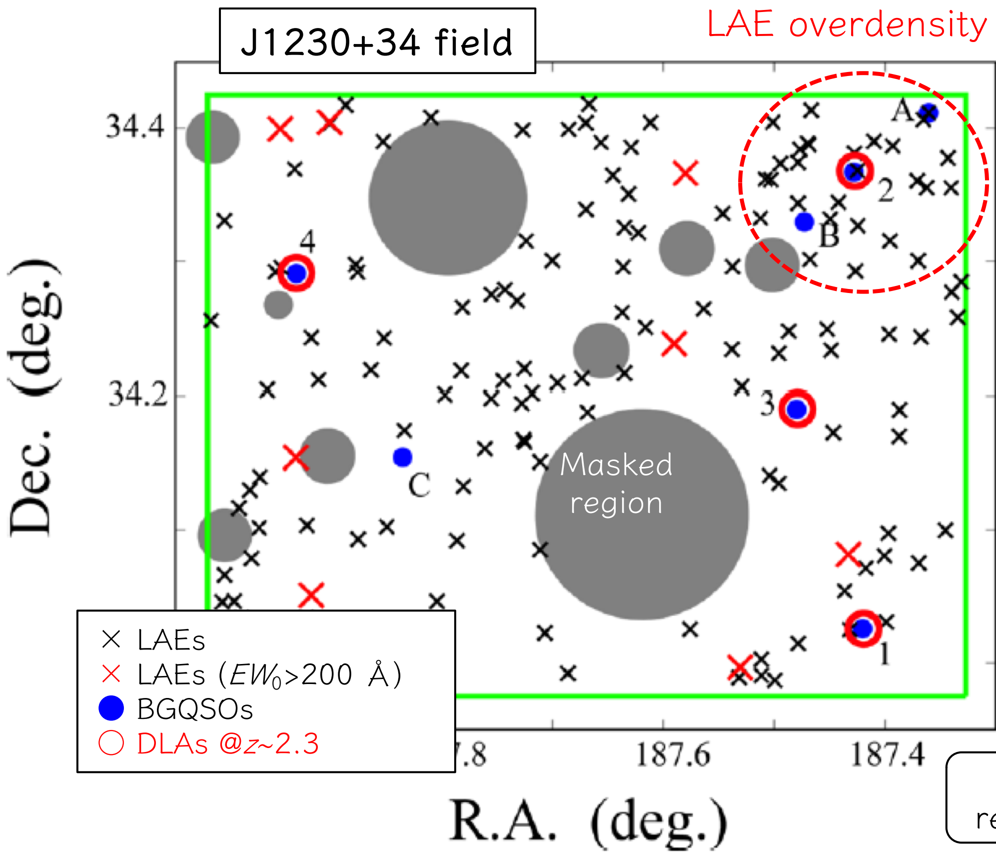
Example of DLA-concentrated regions (z~2.3)

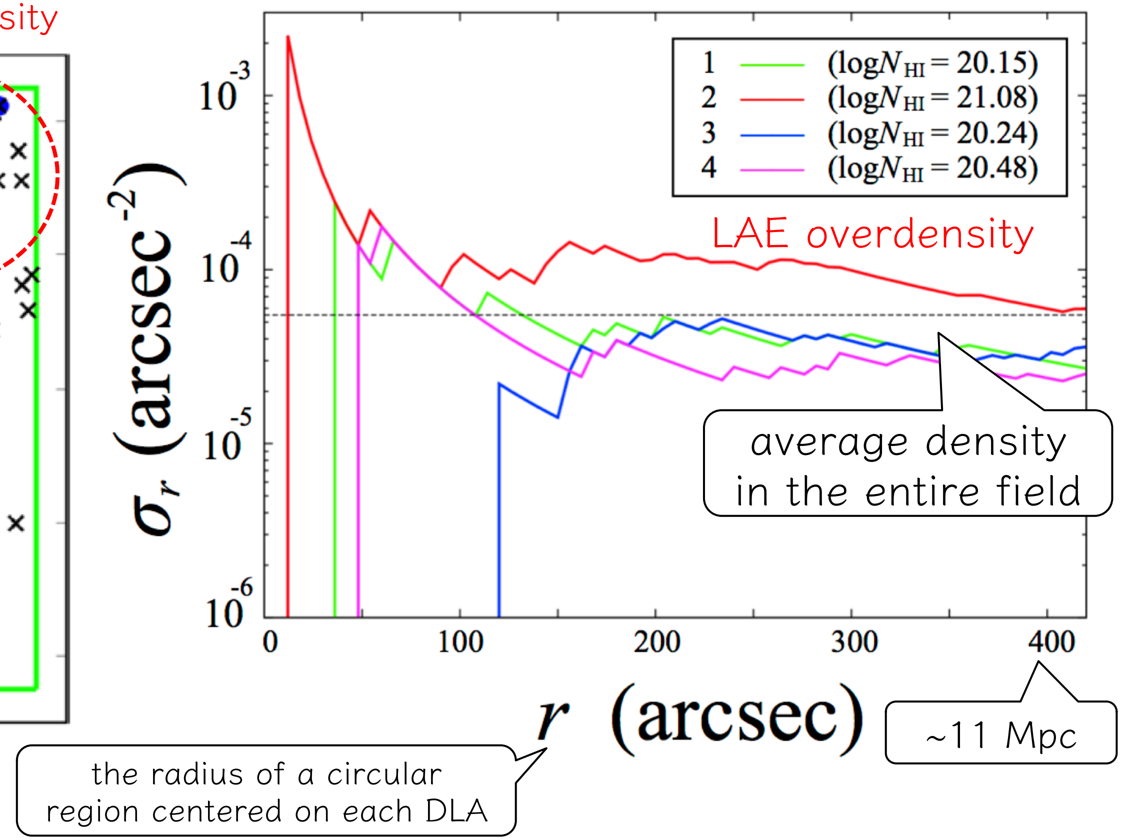


●: DLAs within (50 Mpc)^3、 ● :DLAs at $2.255 < z < 2.330$

Investigating the relation between DLAs and star-formation

- A LAE overdensity around a strong DLA



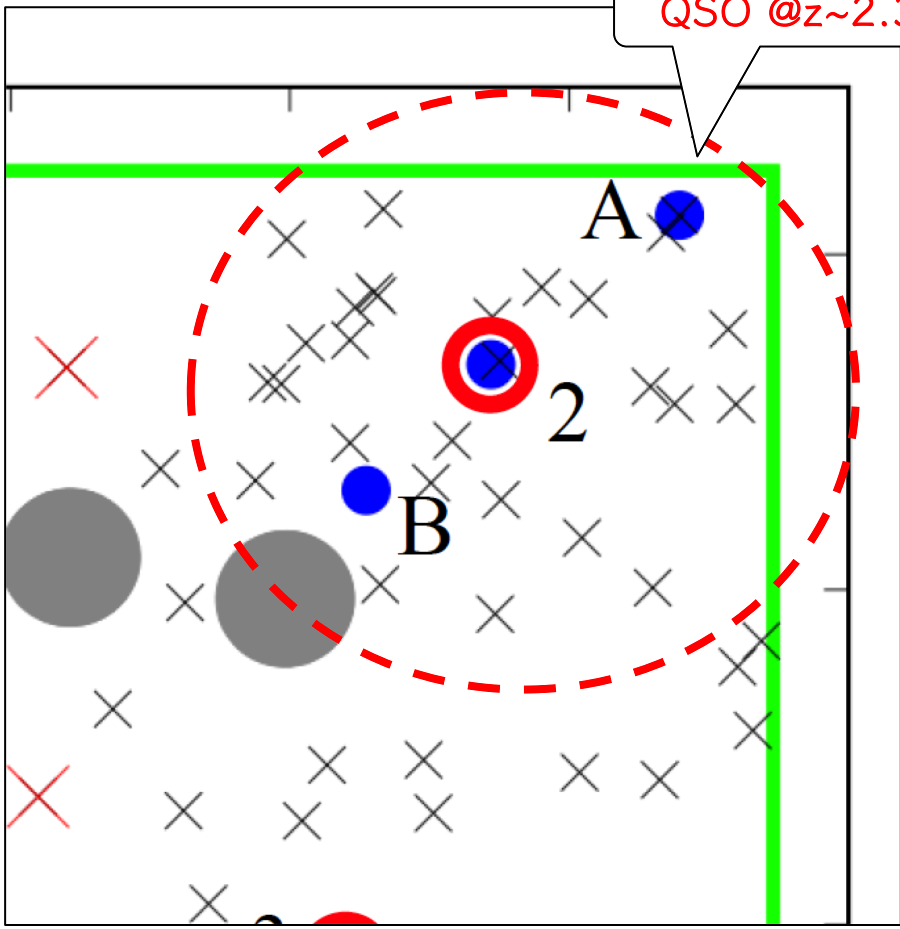


- Possible LAE overdensity around a DLA with highest N_{HI} in the target field
- No overdensity around remaining 3 DLAs

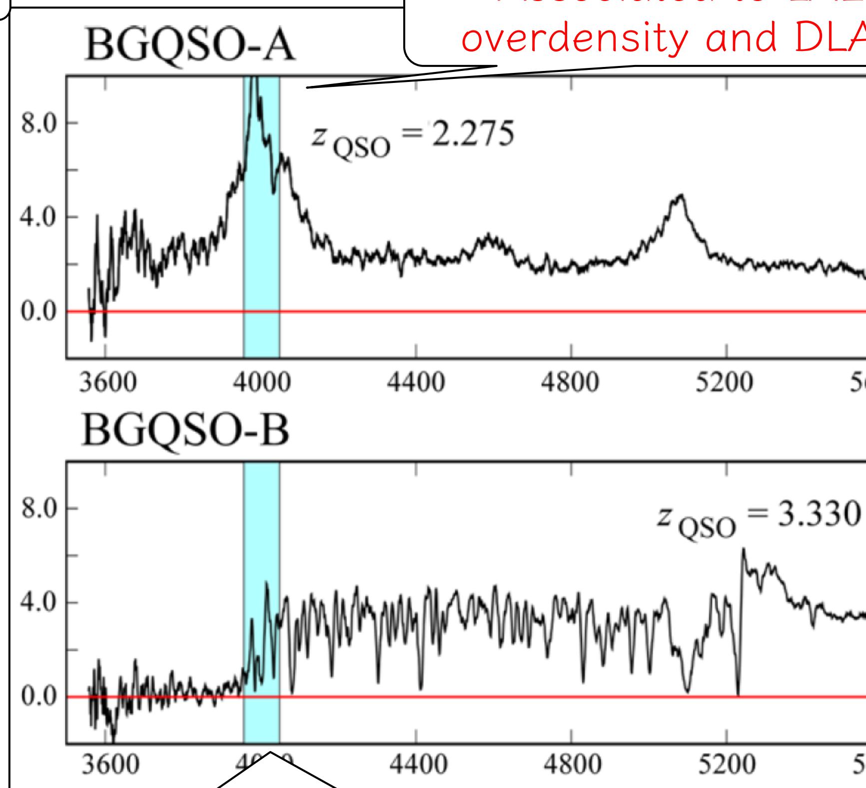
Investigating the relation between DLAs and star-formation

- A QSO near the LAE overdensity around a strong DLA

QSO @z~2.3



Associated to LAE overdensity and DLA?



poor S/N to examine whether or not absorber exist

How do DLAs, QSOs, and LAEs are connected??

DLA-concentrated regions are interesting target for the future surveys

Summary

- The DLA is an important population to understand the early stage of the galaxy evolution

- The origin of DLAs is still under the discussion with some possible scenarios
  - mainly due to the difficulty in identifying DLA counterparts

- Ly α nebulae and environments are also interesting to understand the origin of DLAs

- Systematic surveys for DLA counterparts are required to confirm the major origin of DLAs
  - HSC-SSP, PSF, …