Discovery of a Damped Lyα absorber at z =3.3 along a galaxy sight-line in the SSA22 field

(Mawatari et al. 2016, ApJ, accepted)

Ken Mawatari, Akio Inoue（Osaka Sangyo Univ）、

K. Kousai, T. Hayashino, T. Yamada（Tohoku Univ）、

R.Cooke, J.X.Prochaska(UCSC)、

Y. Matsuda（NAOJ）

DLA in a galaxy sight-line

DLAs, neutral HI absorbers with $\log(N_{HI}/cm^{-2}) > 20.3$, is considered to be associated with galaxy halos and play an important role in converting gas to stars in high-z universe.

DLAs have been identified along sight-lines of very bright (rare) objects.

background source need not necessarily be QSO (GRB)

●Potential merits of galaxy-DLAs (gal-DLAs)

- Size constraint (thanks to extended background sources)
- Counterpart galaxy search at small impact parameter (thanks to low brightness contrast between counterpart and bkg galaxies)
- High spatial resolution mapping of DLAs

Observation

VLT VIMOS observation in 2008

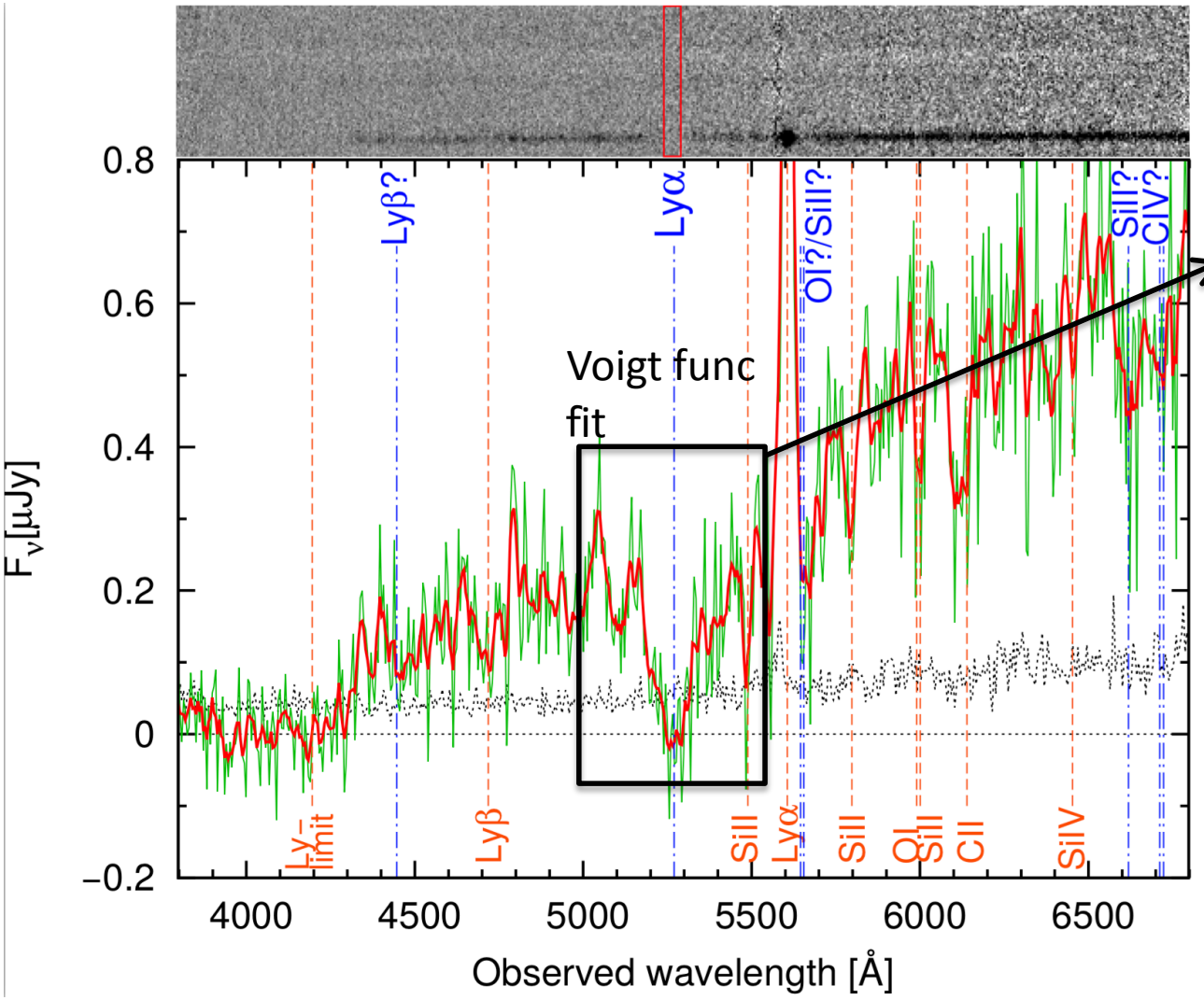
- R = 180
- Target = 163 LBGs
  selected using Subaru Scam images

※Synergy of Subaru and VLT

- Redshifts are determined in the 80 LBGs
- By visual inspection of the 80 LBGs with significant redshift, 1 gal-DLA was identified.
- World 2nd sample (1st gal-DLA is reported in Cooke & O'Meara 2015)

Galaxy-DLA identification

1 gal-DLA was identified among the 80 LBG spectra obtained in VIMOS2008 observation. (2nd sample in the world)



bkg LBG is at z=3.604.

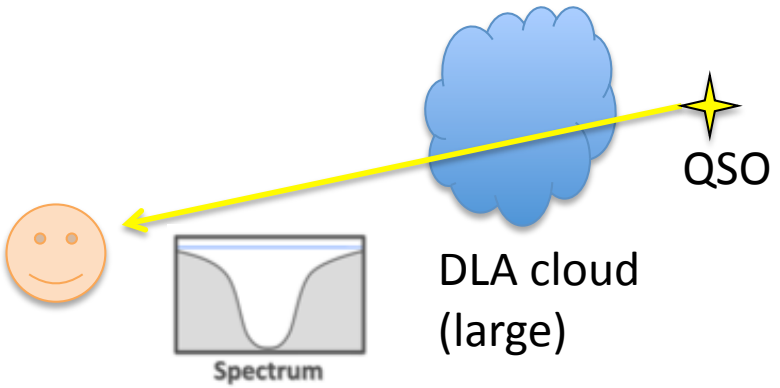
DLA is
at z=3.335+-0.007,
$\log(N_{HI}/cm^{-2})$=21.68+-0.17

No significant metal abs line is detected.
3σ upper limit of
EW_0(metal)<1.4Å
: consistent with the observed metal line EWs for QSO-DLA (Kaplan+10,Lu+96)

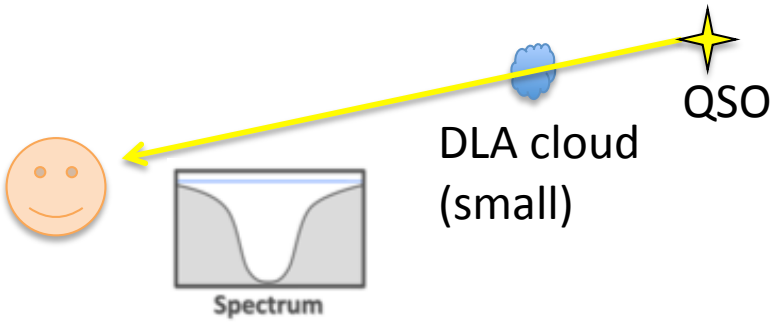
DLA covering fraction (size constraint)

The residual flux in Lyα trough ⇔ DLA covering fraction over the bkg LBG

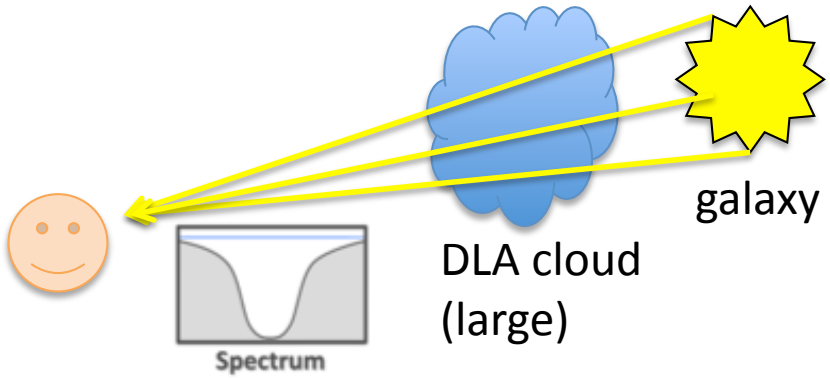
QSO-DLA



DLA absorption profile is not affected by the DLA size.

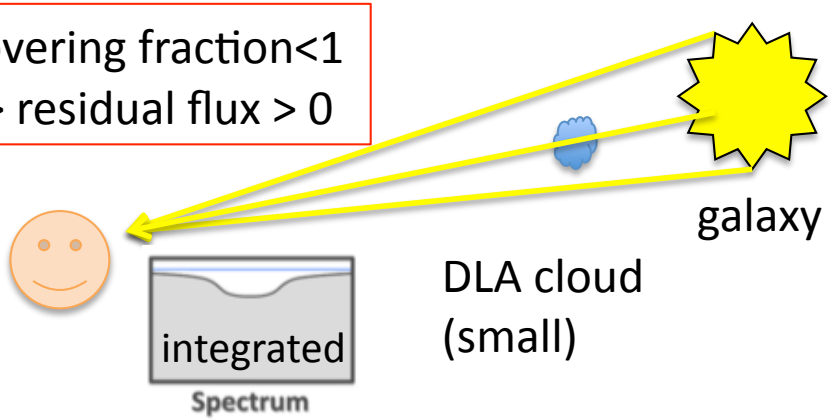


gal-DLA



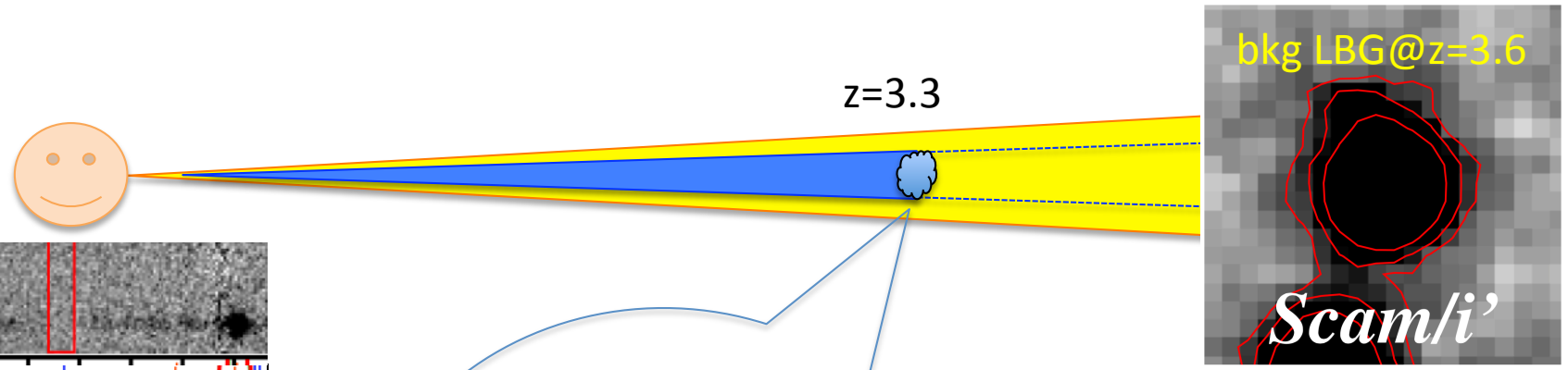
DLA absorption profile is affected by the DLA size.

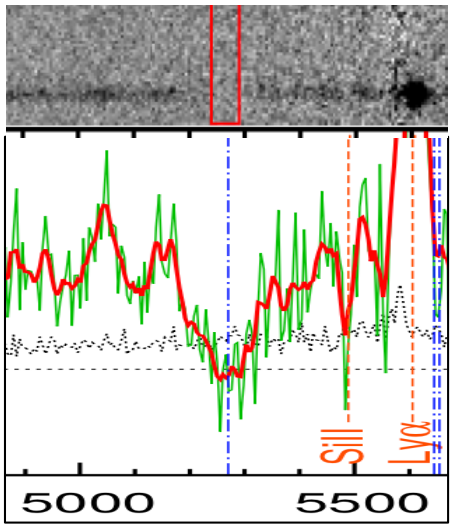
covering fraction<1
=> residual flux > 0



Ken made this figure after being inspired by Jeff Cooke and John O'Meara

DLA covering fraction (size constraint)





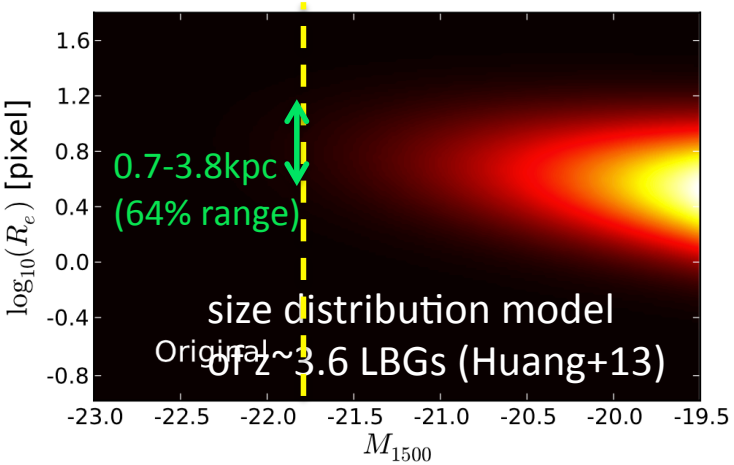
gal−DLA area
bkg LBG area x
covering fraction x
$(D_A(z=3.3)/D_A(z=3.6))^2$
$\sim$ 1 kpc^2
(lower limit)

bkg LBG size
cannot be measured directly (marginally resolved).
We used a 1σ lower limit of z~3.6 LBG size as a conservative estimate (Re=0.7kpc).

$$F_{\rm res}^{\rm upp} = 0.1\,\mu{\rm Jy}$$

$$f_{\rm cov}^{\rm low} = 1 - F_{\rm res}^{\rm upp}/F_{\rm cont} = 0.7$$

Covering fraction is 70%
(2σ lower limit)

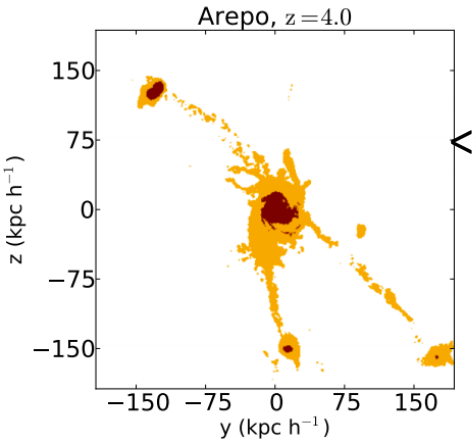


Comparison with the previous studies

Our gal–DLA size estimate (Area > 1kpc^2) is consistent with

Simulations, R = 1.1 – 1.8 kpc (Bird+13),

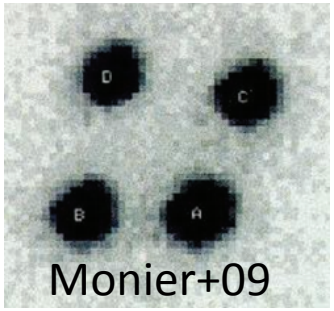
R >> 1 kpc (Pontzen+08, Rahmati+14)



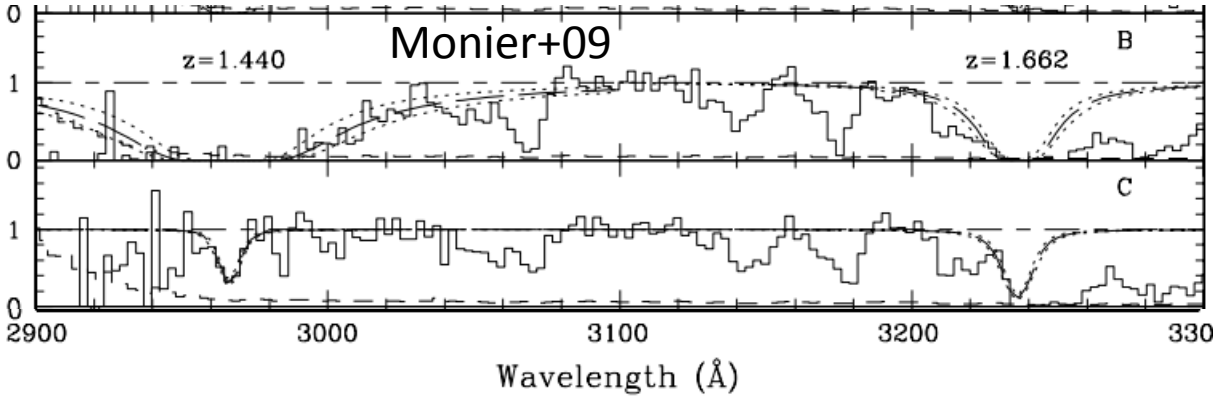
<= Red shade is DLA area (Bird+13)

QSO–DLA size measured using gravitationally lensed QSO pairs,

R = 5 +– 3 kpc (Cooke+10)

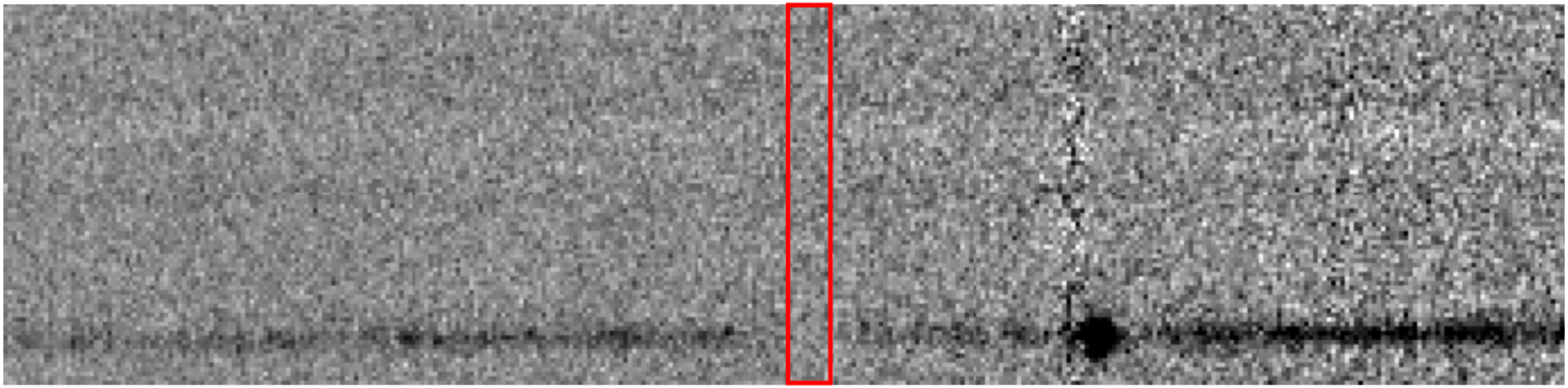


Monier+09



The area of another gal–DLA, a few ~ 100 kpc^2 (Cooke & O'Meara 2015)

Counterpart galaxy of gal-DLA



(1) No LAE in the Ly α trough

=> No counterpart in the slit

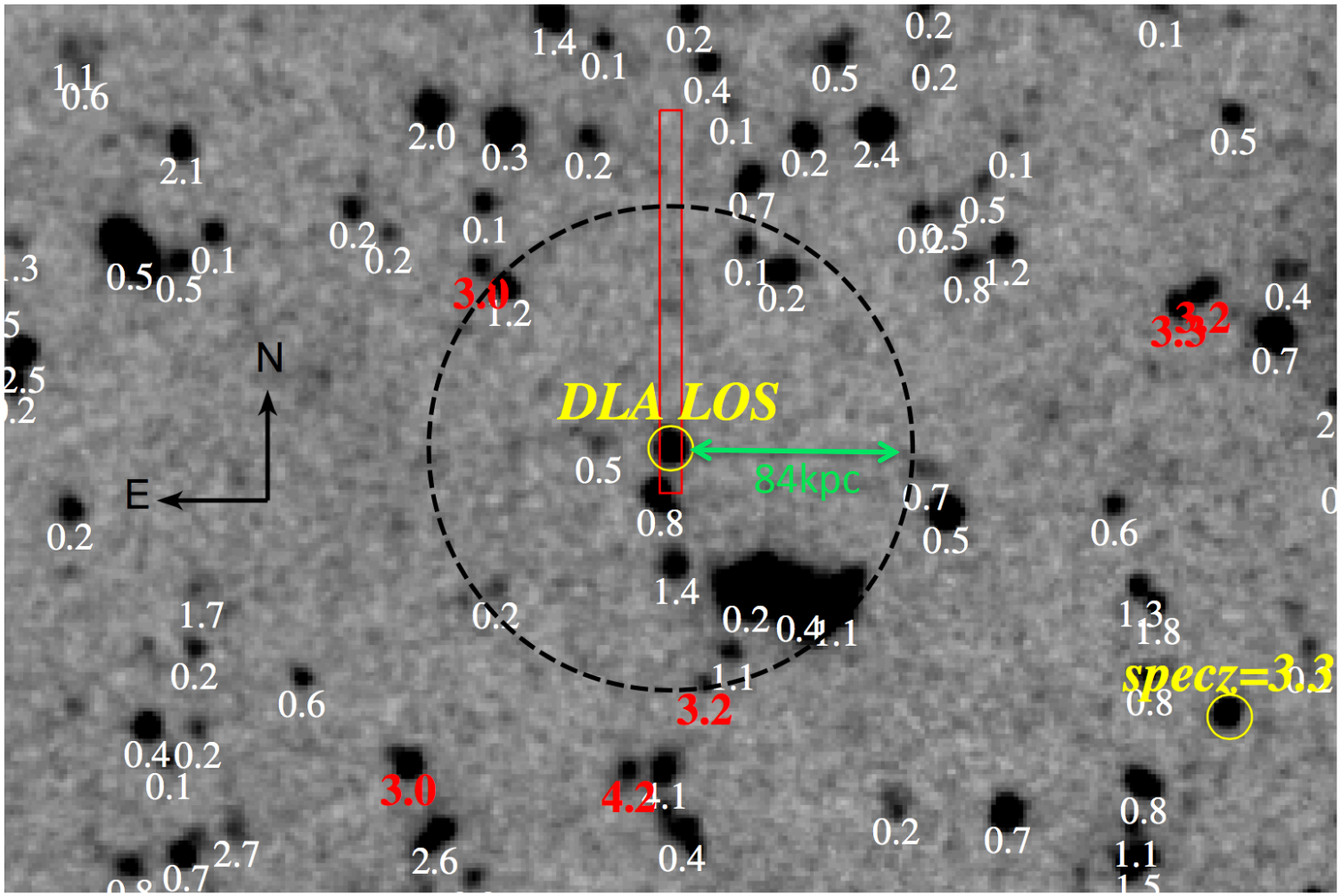
down to

$$F_{\mathrm{Ly}\alpha} = 1.9 \times 10^{-18}\,\mathrm{erg\,s^{-1}\,cm^{-2}}\ (3\sigma)$$

or SFR=4Msun/yr (assuming fesc=0.05)

Counterpart galaxy of gal-DLA

(2) Nearest candidate whose photo-z is consistent with z=3.33 lies at b=84kpc considerably more distant than the previous reports (<25kpc; Krogager+12)

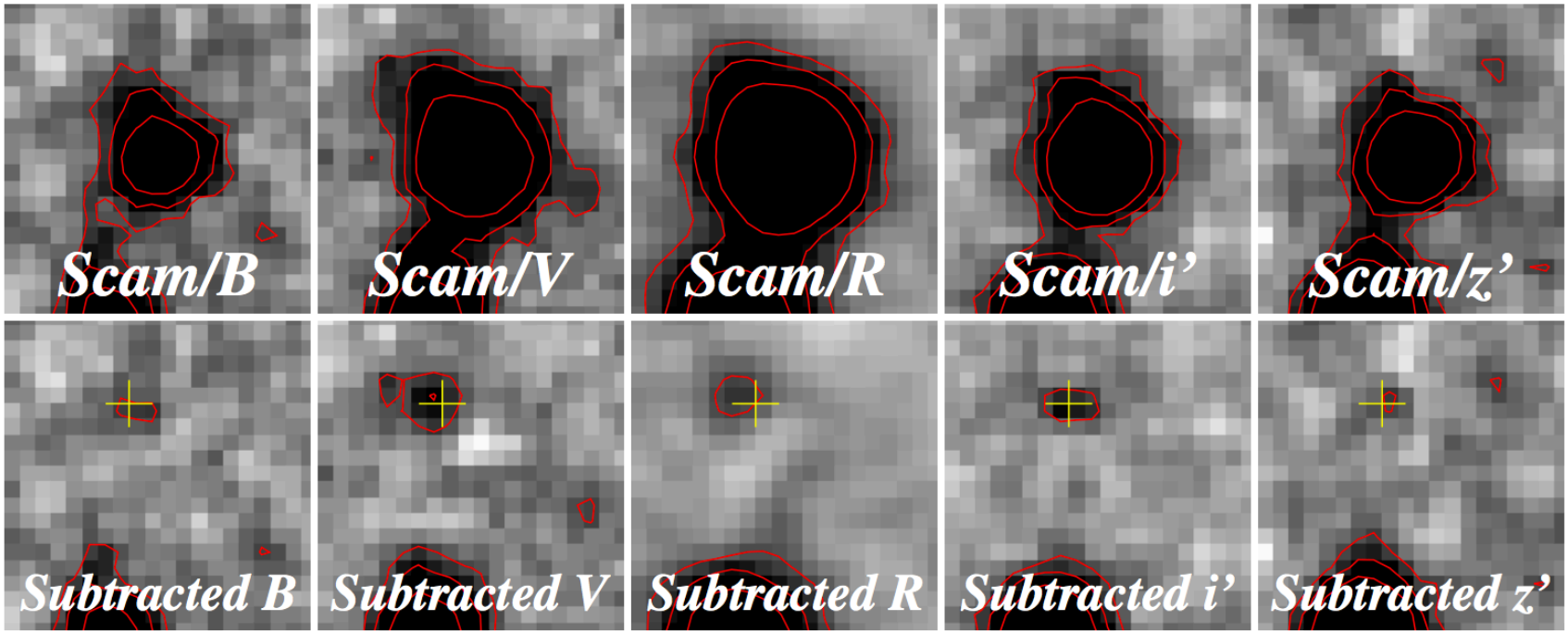


Counterpart galaxy of gal-DLA

(3) Sub-component in the bkg LBG image

=> too faint to distinguish counterpart galaxy at z=3.3 from sub-structure of bkg LBG at z=3.6 (but most important candidate), SFR < 1.3Msun/yr

consistent with previous work (Fumagalli+14)



Occurrence rate of gal-DLA

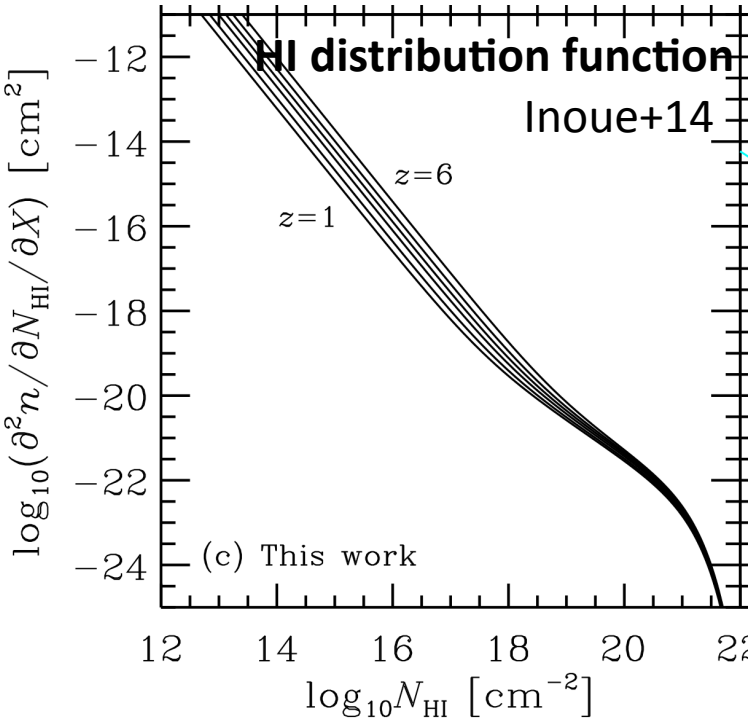
Working hypothesis:

DLA occurrence rate does not depend on their bkg light sources.

not obvious!!

We estimated the number of DLAs among the 80 LBGs from the QSO-DLA distribution function (Inoue+14).

$$n_{DLA} = \sum_{i=1}^{80} \int_{z_{min,i}}^{z_{max,i}} \int_{N_{min}}^{\infty} \frac{\partial^2 n}{\partial z \partial N_{\rm HI}} dz dN_{\rm HI}$$



i is the index of the LBGs,

N_{min} = 21.34 (observed 2σ lower limit)

n_{DLA} = 0.26

: Our finding of 1 gal-DLA may be explained under the working hypothesis (poisson probability = 20%).

Summary

- We identified a DLA along a galaxy sight-line (2nd sample in the world).

- log(NHI)=21.68+-0.17, z=3.335+-0.007, metal abs line EW_0 < 1.4Å (3σ)

- Covering fraction over the bkg LBG = 70% (2σ lower limit), yielding a conservative lower limit of the gal-DLA area of ～1 kpc^2.

- We cannot identify the counterpart galaxy,
  but put the SFR limit as SFR < a few Msun/yr.

- The occurrence rate of the gal-DLA is compatible with that of QSO-DLAs.

A large number of gal-DLAs will be identified in archival and future large spectroscopic survey data.

On-going large survey: HIT

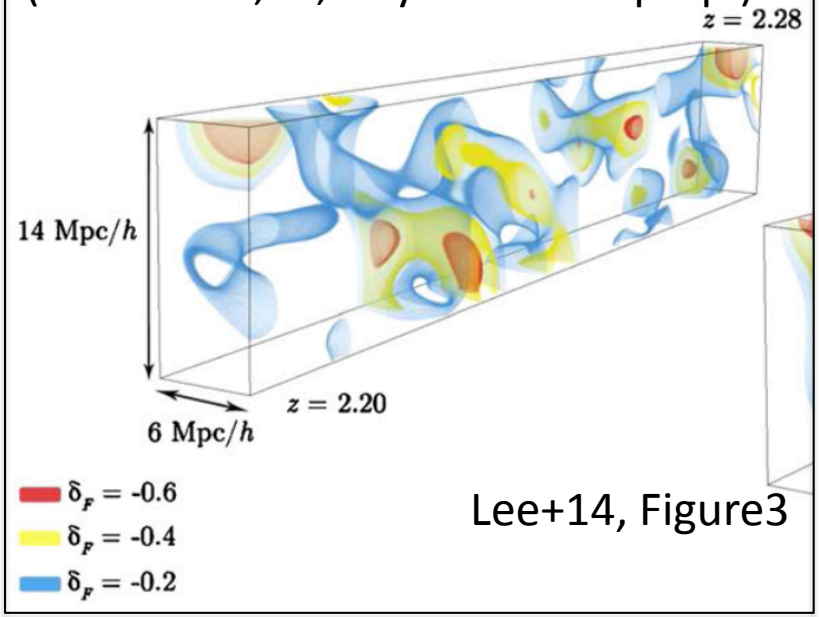
HI Tomography (HIT) survey with Keck/DEIMOS

T.Yamada、D.Schlegel、A.Inoue、J.X.Prochaska、T.Hayashino、K.G.Lee、N.Kashikawa、N.Tejos、
Y.Matsuda、J.Hennawei、I.Iwata、Y.Tamura、Umehata、K.Mawatari、T.Otsuka、S.Yamanaka

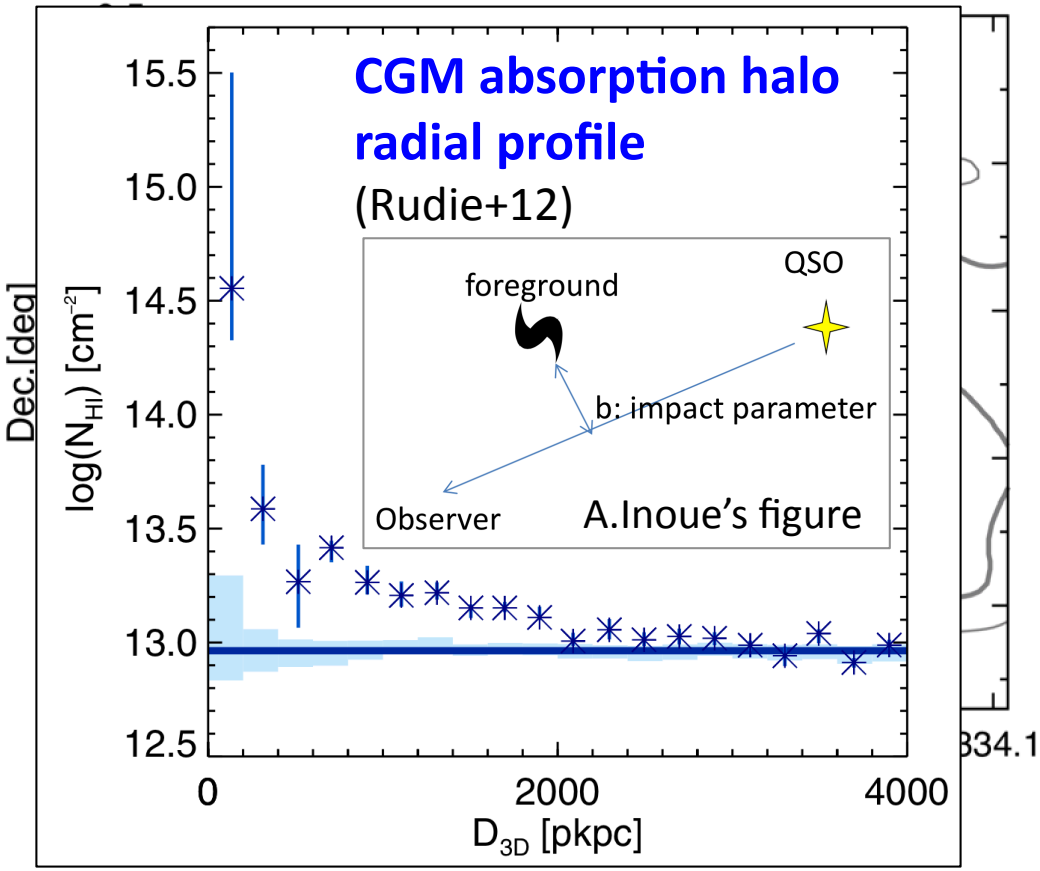
Panoramic survey of both HI and galaxies at z = 2.5 – 5.5

2+3 nights obs was conducted in 2015B.
2nights in 2016A are awarded.

large-scale HI 3D mapping
(c.f. Lee+14,15, Hayashino+ in prep.)



Lee+14, Figure3

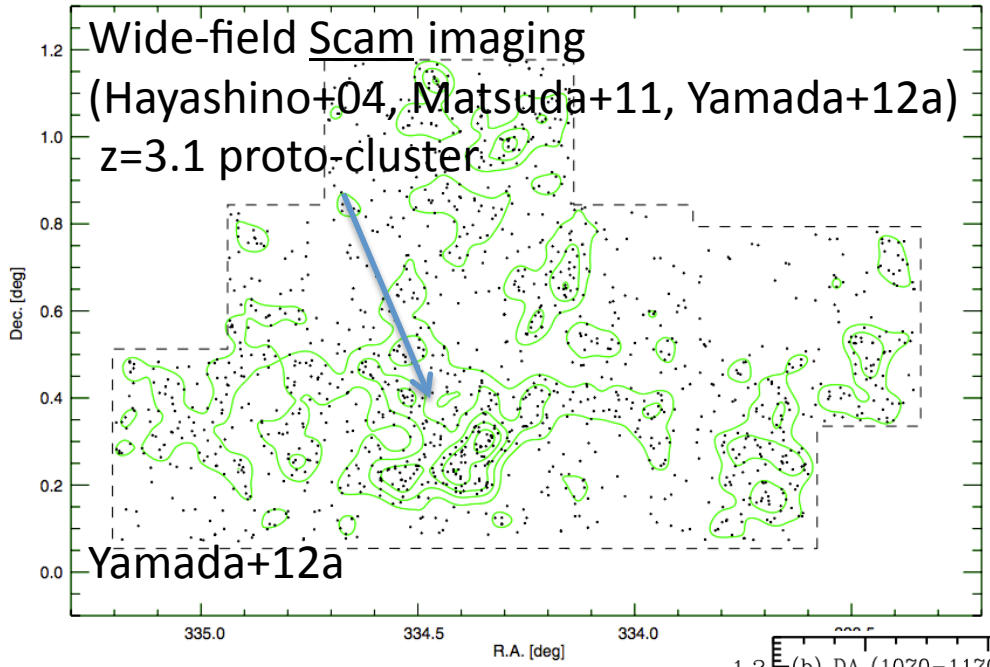


Also gal-DLAs will be identified (>~10)!

Thank you!

Supplements

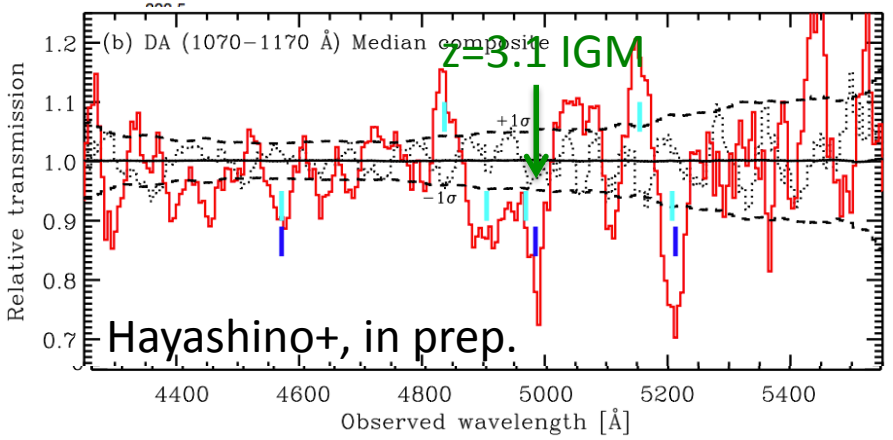
Synergy of Subaru and VLT/Keck in the SSA22 field



FOCAS & Keck DEIMOS spec
=> Lya line profile study
(Matsuda+06,Yamada+12b)

MOIRCS img/spec
Massive galaxies' assembly
(Uchimoto+12,Kubo+15,16)
New LAE population?
(Otsuka+, in prep.)

VLT VIMOS spec (R=180)
HI absorption system study
HI-gal correlation
(Hayashino+, in prep.)



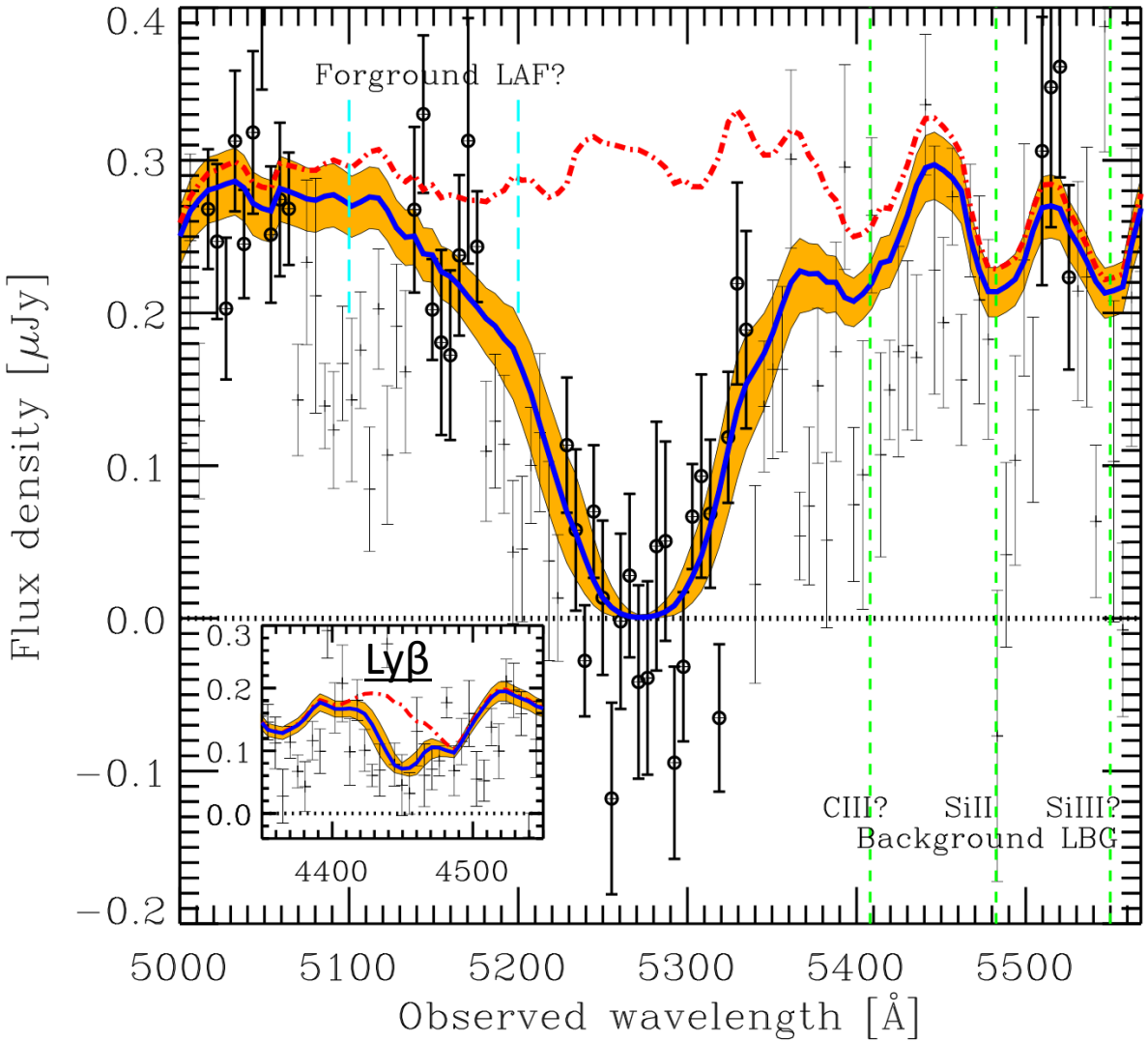
<= Stacked Lya absorption spectrum

Densest HI absorber, DLA
(Mawatari+16)

On-going
Keck DEIMOS spec (R=600) for HI tomography

gal-DLA gas content

The Voigt function–fit for the DLA Lyα absorption



The composite LBG spectrum is used as a continuum.
Free parameters are DLA redshift, DLA N_{HI}, and bkg LBG continuum level.

z_{DLA} = 3.335+-0.007
$\log(N_{HI}/cm^{-2})$=21.68+-0.17

Environment