IGM TOMOGRAPHY WORKSHOP 2016

Cosmic Galay-IGM HI Relation at z~2−3 Probed in the COSMOS/UltraVISTA 1.6 deg2 Field

Shiro Mukae (ICRR/Univ. Tokyo)

I. Galaxy-IGM HI Relation in Large-scale

II. Galaxy-IGM Correlation for HETDEX survey

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I. Galaxy-IGM HI Relation in Large-scale

Collaborator:

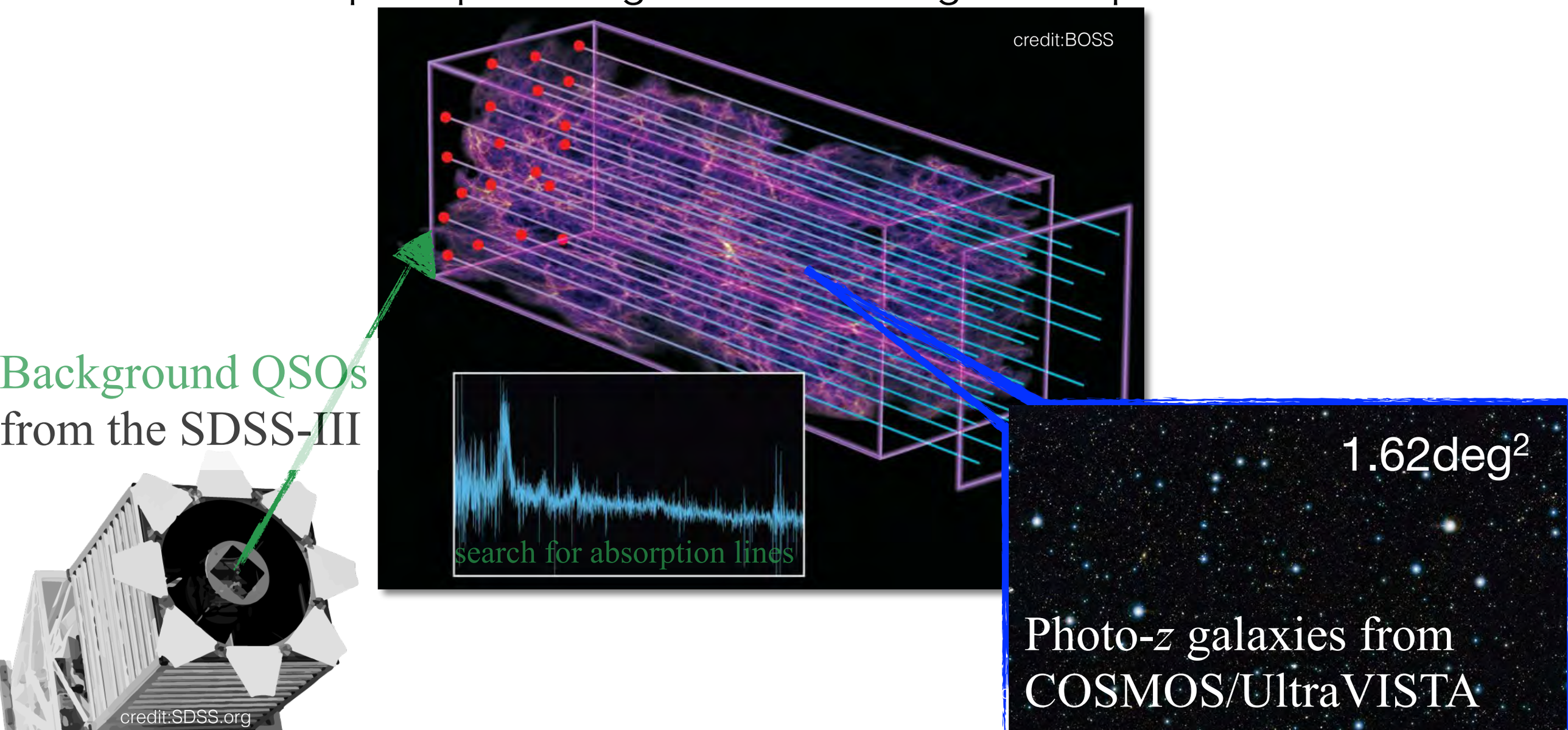
Masami Ouchi (ICRR), Koki Kakiichi (MPA), Nao Suzuki (Kavli IPMU),
Yoshiaki Ono(ICRR), Zheng Cai(UCO/Lick Observatory), Akio K. Inoue(Osaka Sangyo Univ.),
Yi-Kuan Chiang(Texas Univ.), Takatoshi Shibuya(ICRR), Yuichi Matsuda(NAOJ)

This is precursor study for PFS & HETDEX

What is "galaxy-IGM HI relation in large-scale at high-z" like?

As a first step,

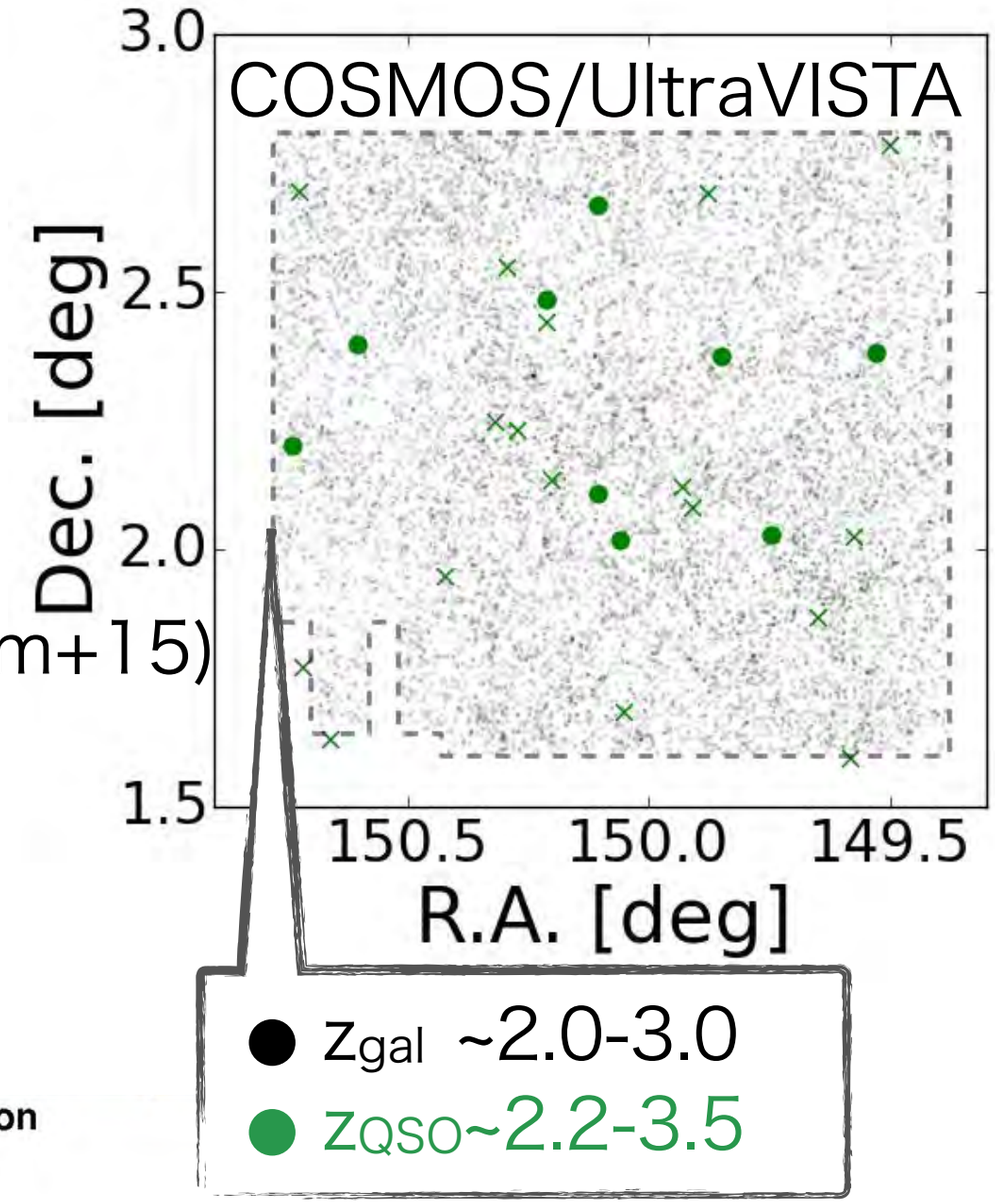
- We investigate spatial correlations of galaxies and IGM HI in one large field contiguously covering large-scale structures
- In the COSMOS/UltraVISTA field covering the 1.62deg^2, we use compiled photo-z galaxies & Background quasars from SDSS-III

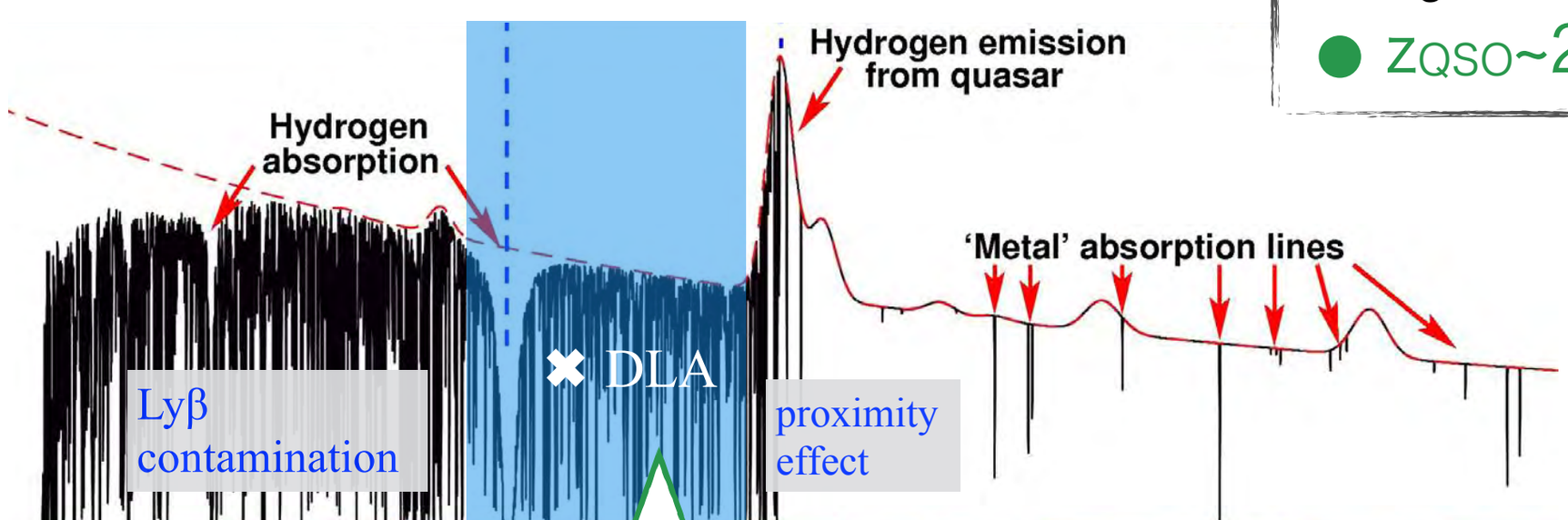


Data

- 13,415 photo-z galaxies at z~2-3 with Ks < 23.4 (Muzzin+13)

- 9 (out of 26) background quasar spectra from BOSS&SDSS (R~2000) (KG+13, Alam+15)
- We do not use spectra with…
  damped Lyα systems(DLAs)
  broad absorption lines(BALs)





Lyα forest wavelength range: 1041-1185 Å in the quasar rest frame

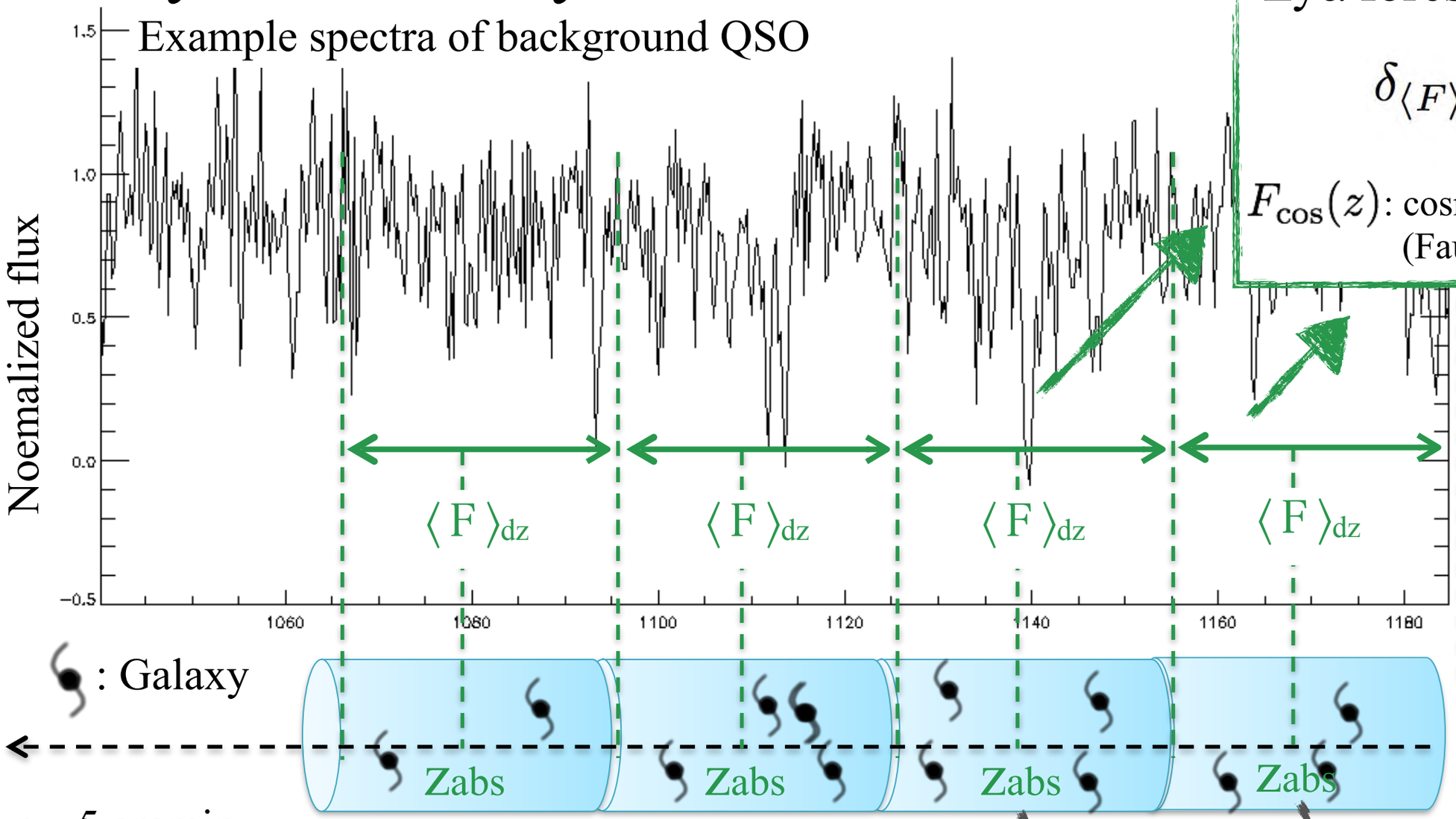
Galaxy Overdensity and HI Estimation

Example spectra of background QSO

Lyα forest fluctuation

$$\delta_{\langle F \rangle} \equiv \frac{\langle F \rangle_{dz}}{F_{\cos}(z)} - 1$$

$F_{\cos}(z)$: cosmic mean flux (Faucher-Giguère+08)



$S/N_{\langle F \rangle} \geq 4$

$S/N_{\langle F \rangle} \equiv (1 - \langle F \rangle_{dz}) / \langle \sigma_F \rangle_{dz}$

Background QSO

r = 5 arcmin
(~2.5 pMpc at z~2.5)

dz = σ_z = 0.025(1+z)

Chiang+14

Galaxy Overdensity Estimation: $\delta_{\rm gal} \equiv \frac{n_{\rm gal}}{\overline{n}_{\rm gal}} - 1$

The length of the cylinder along the line of sight is given by the average photometric redshift uncertainty

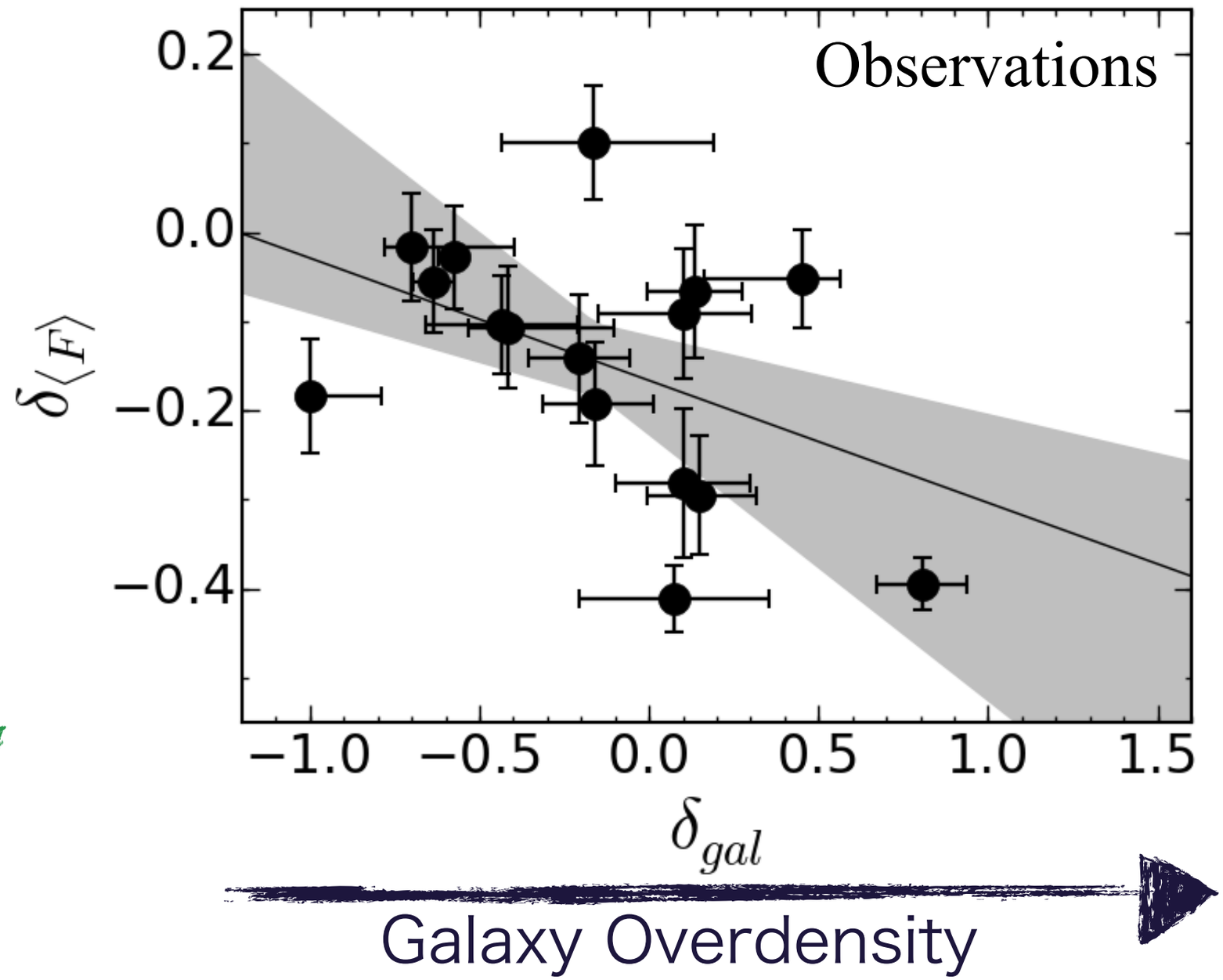
Galaxy-IGM HI Correlation

HI absorption Estimation:

$$\delta_{\langle F \rangle} \equiv \frac{\langle F \rangle_{dz}}{F_{\cos}(z)} - 1$$

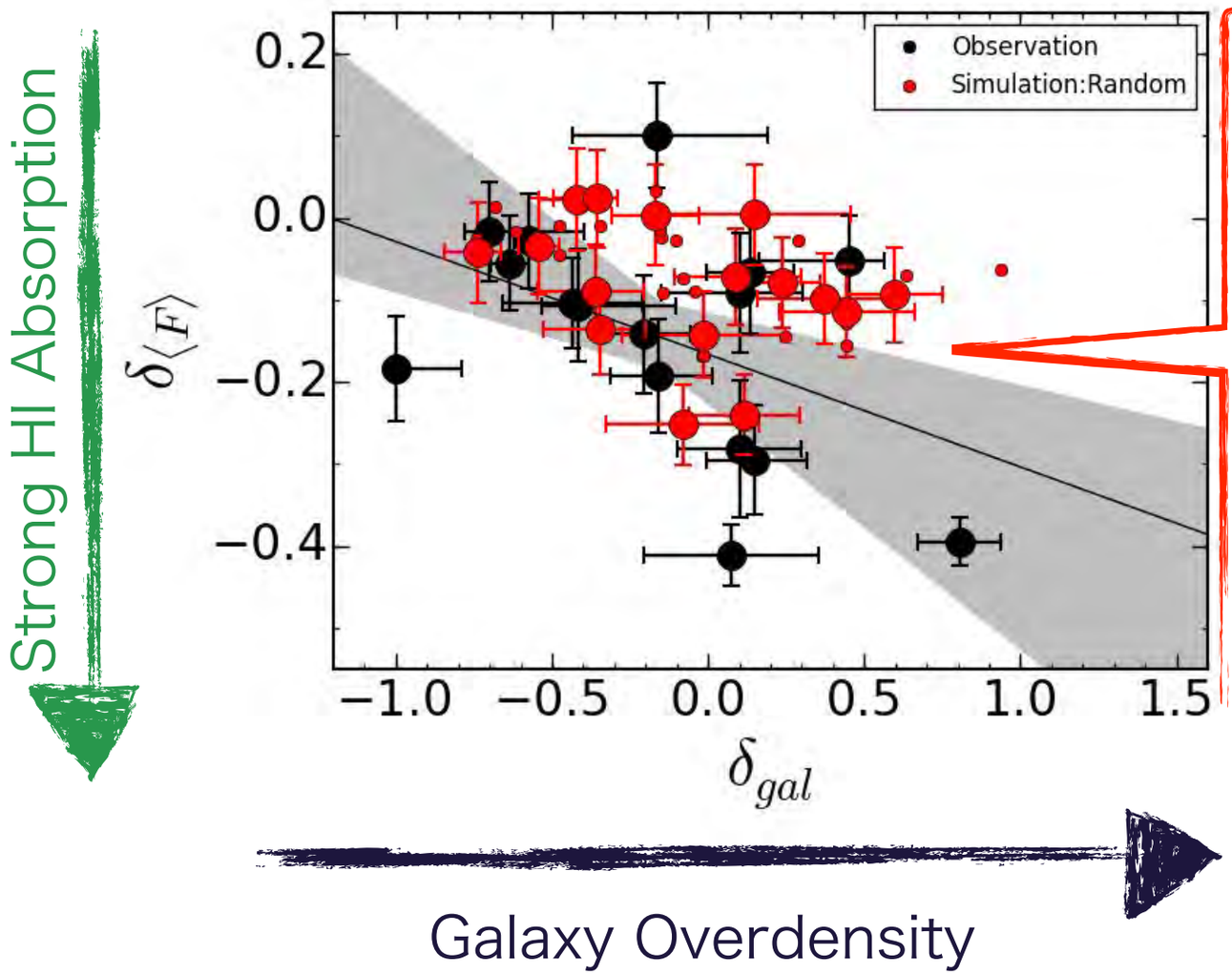
$F_{\cos}(z)$: cosmic mean flux (Faucher-Giguère+08)

Strong HI Absorption



- weak spatial anti-correlation between $\delta_{\rm gal}$ and $\delta_{\langle F \rangle}$
- Spearman's rank correlation coefficients $\rho_{\rm obs}$ = - 0.39 (~90% c.l.)
- high-z galaxies exist around an excess of HI gas in the Lyα forest

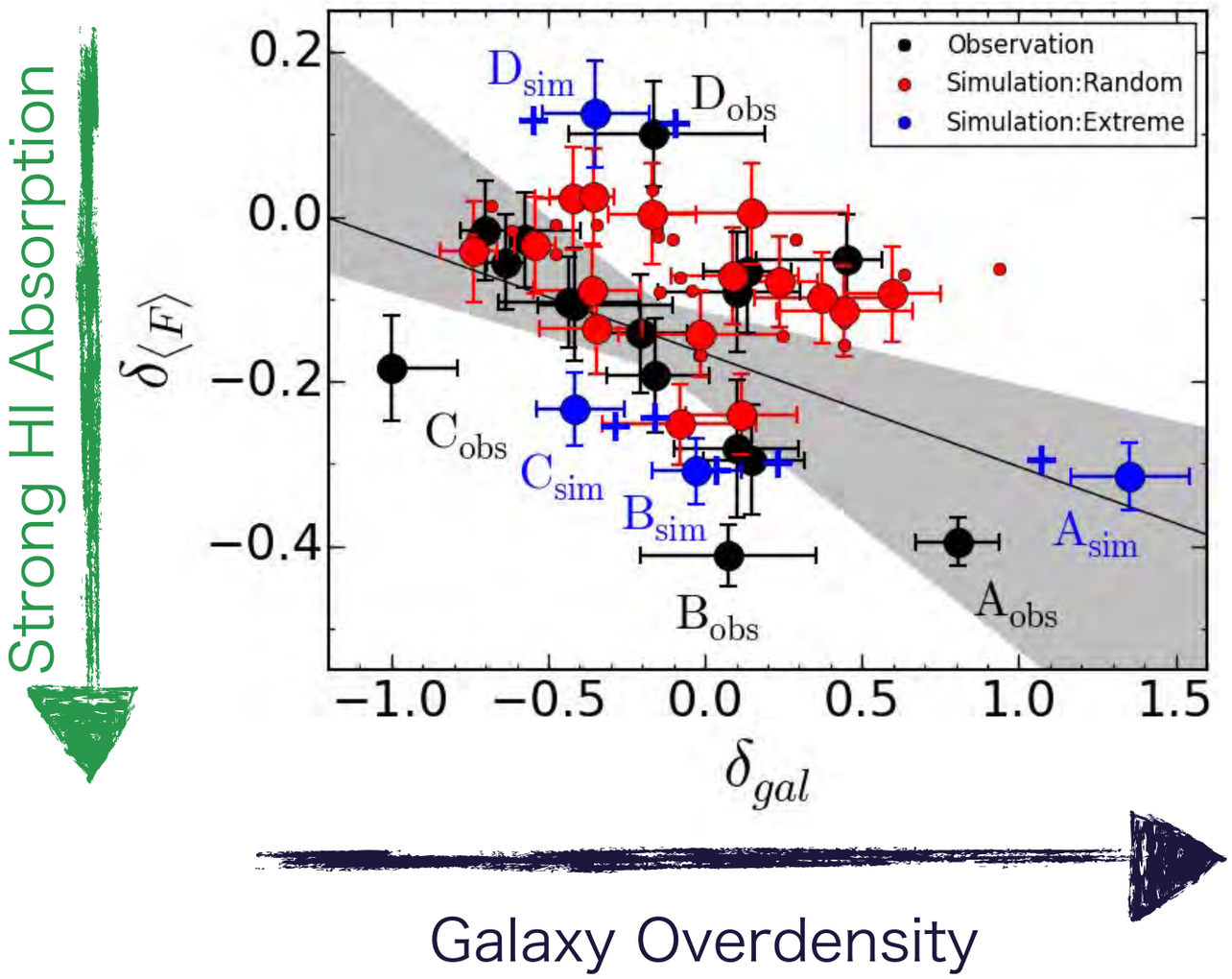
Simulated Galaxy-IGM HI Correlation

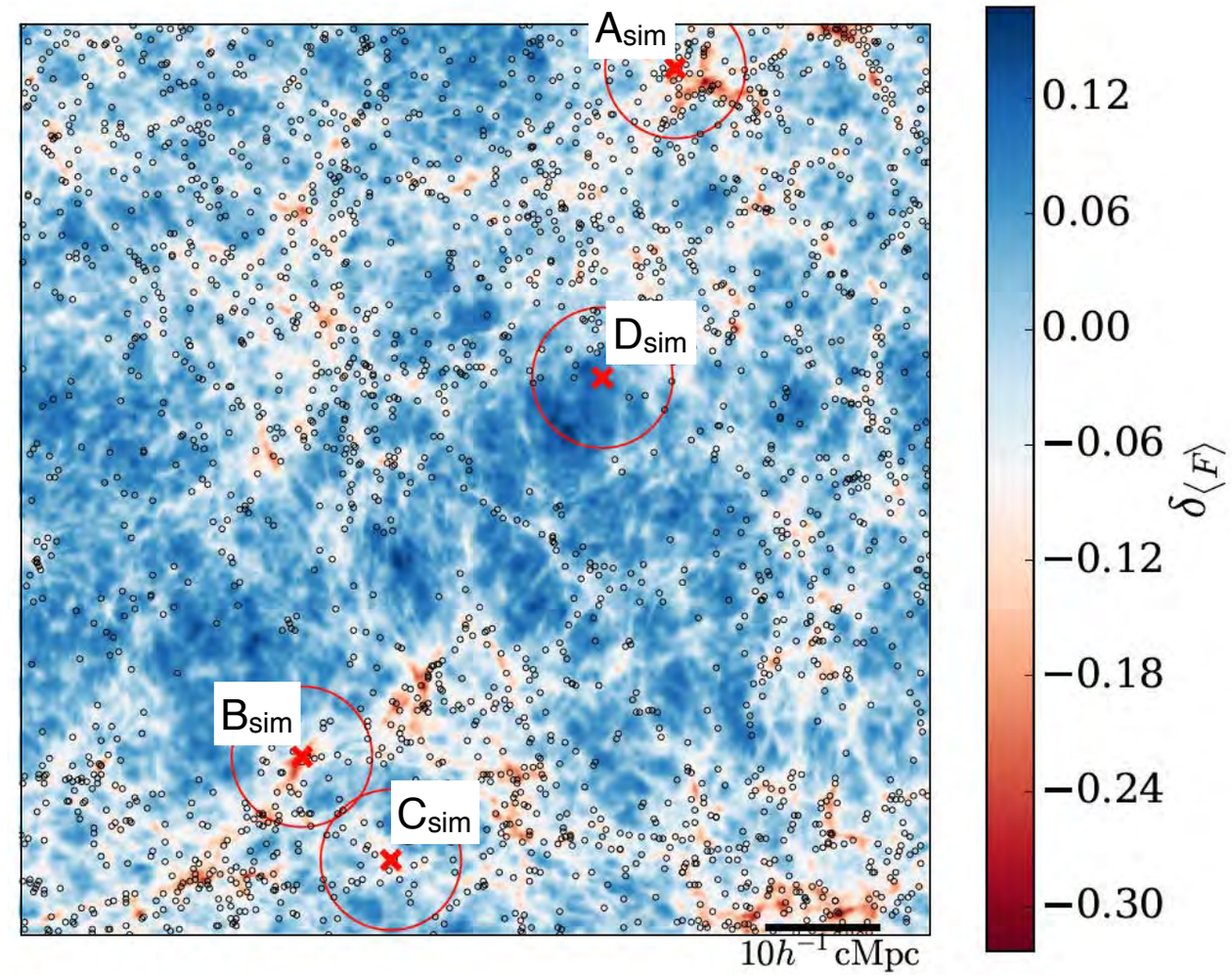


Cosmological hydrodynamical simulation:
RAMSES code
Volume: z=2.4-2.5 $(80h^{-1}\mathrm{cMpc})^3$
Particle count (DM + Gas): 2×512^3
UV background: Haardt & Madau (1996) &
Photo ionization equilibrium & Optically thin limit
Galaxy:
Stellar-to-halo mass ratio & Abundance matching
Optical depth:
Fluctuating Gunn-Peterson approximation

- To investigate the spatial correlations of our observational results, we perform cosmological hydrodynamical simulation
- weak spatial anti-correlation agreeing with the observational results

Possible physical pictures



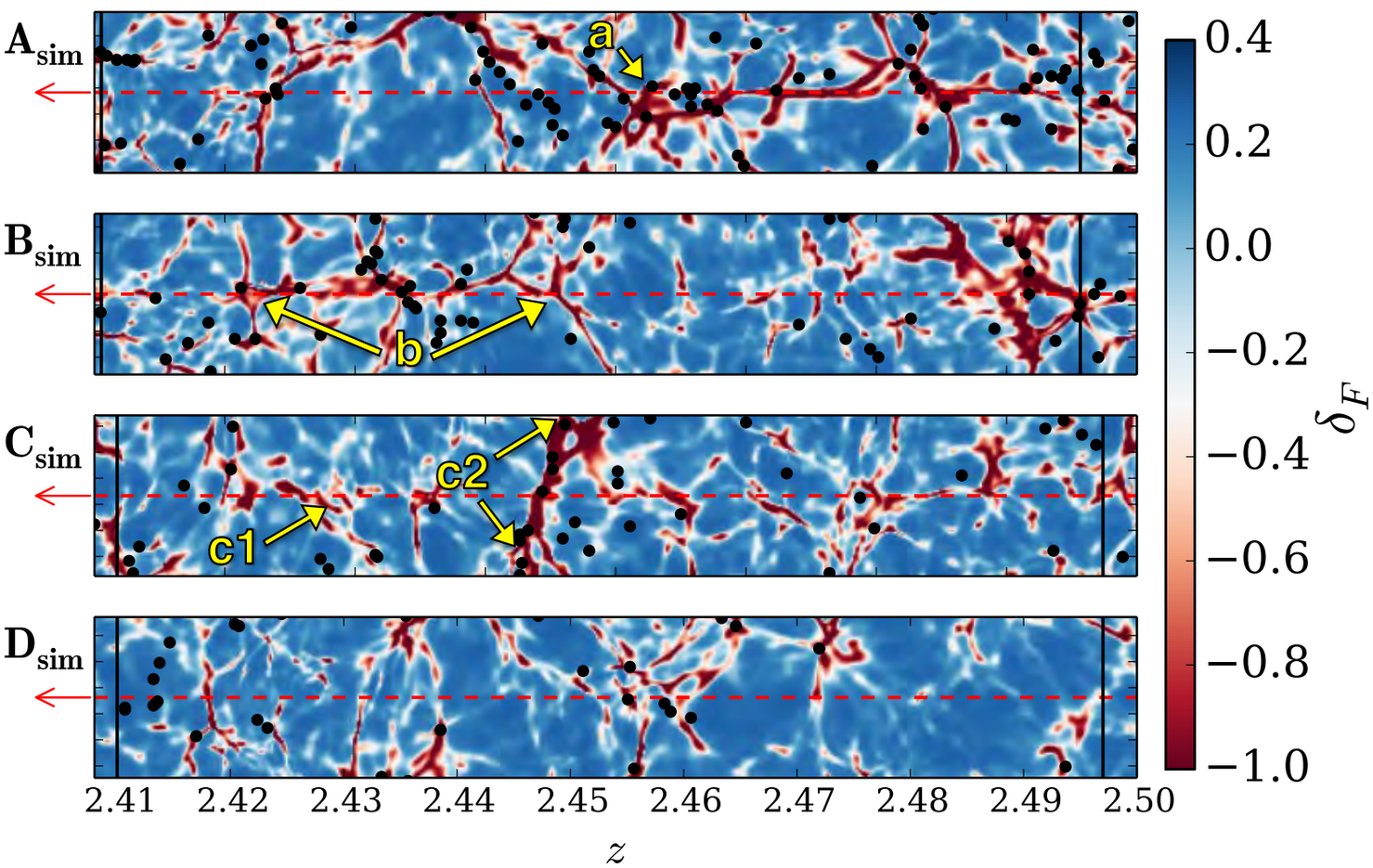


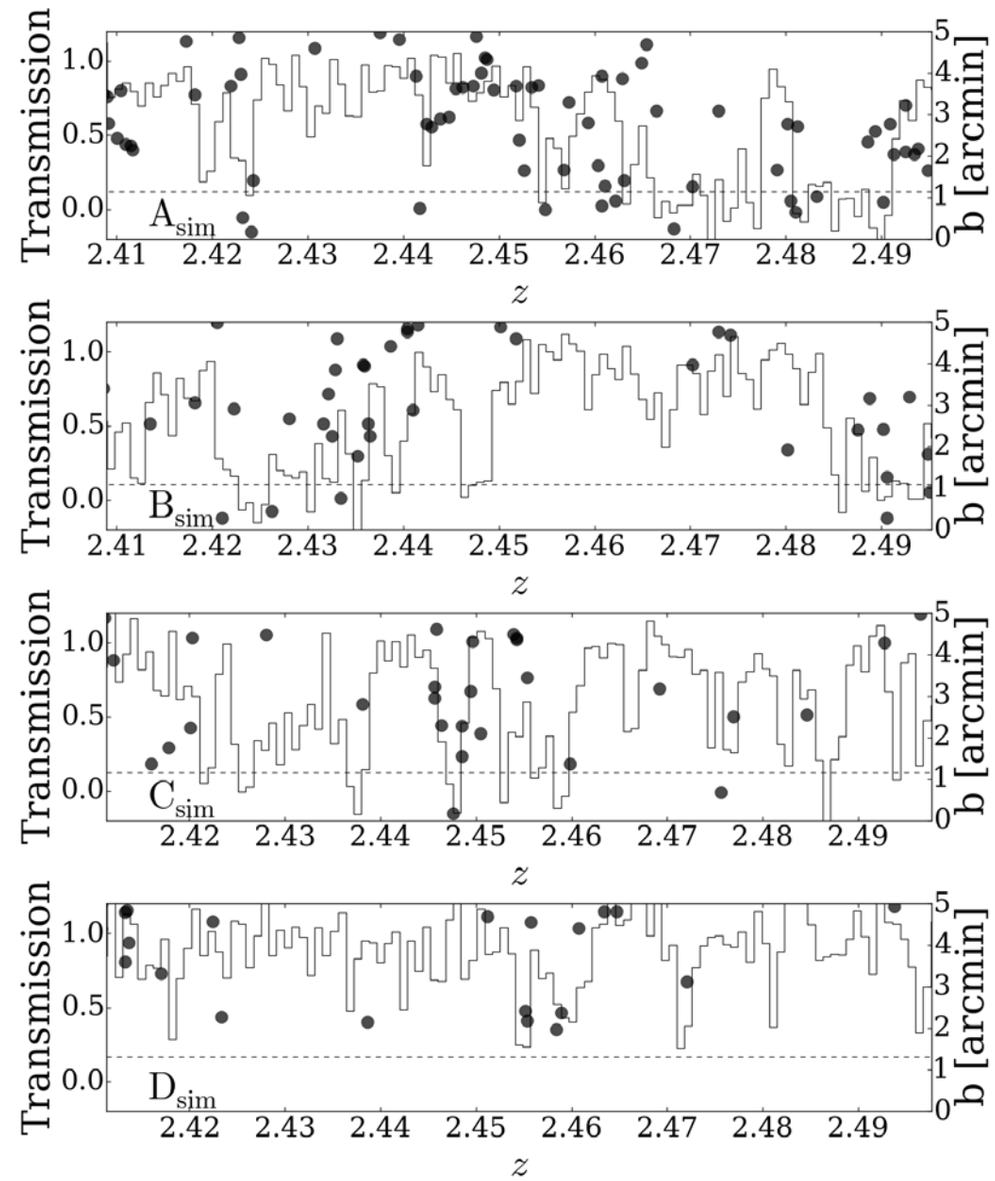
● mock galaxy

Background color scale: $\delta_{\langle F \rangle}$

- We find 4 cylinders with labels of A_{obs}, B_{obs}, C_{obs}, and D_{obs} that have the largest (smallest) values of galaxy overdensity and Lyα forest fluctuation.
- We use the simulations and search for cylinders whose $\delta_{\rm gal}$ - $\delta_{\langle F \rangle}$ values are similar to the 4 cylinders from observational results

Possible physical pictures





- simulations suggest that the observations would penetrate…
  (A) a galaxy overdensity like a proto-cluster, (B) gas filaments,
  (C) a large void, and (D) orthogonal low-density filaments
- filamentary large-scale structures and observations sightline effects

Summary:I Mukae et al. 2016 (arXiv:1605.00379)

We investigate spatial correlations of galaxies and IGM HI in the COSMOS/UltraVISTA 1.62 deg^2 field at z~2-3

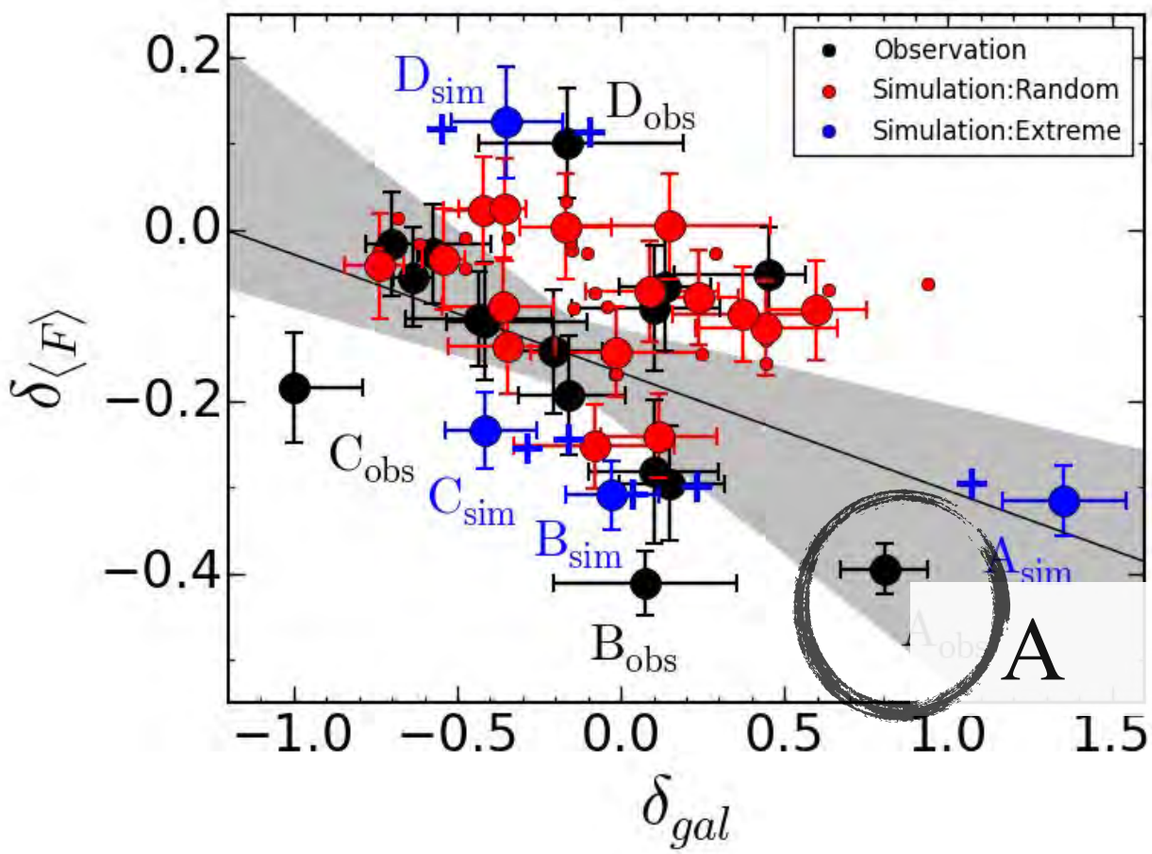
1. **an weak anti-correlation between δ_{gal} and $\delta_{\langle F \rangle}$ confirmed by observations**
2. **an weak anti-correlation between δ_{gal} and $\delta_{\langle F \rangle}$ confirmed by simulations**
3. **4 cosmic volumes that have the largest(smallest) values: sightlines would penetrate a galaxy overdensity /gas filaments/a large void/orthogonal low-density filaments**

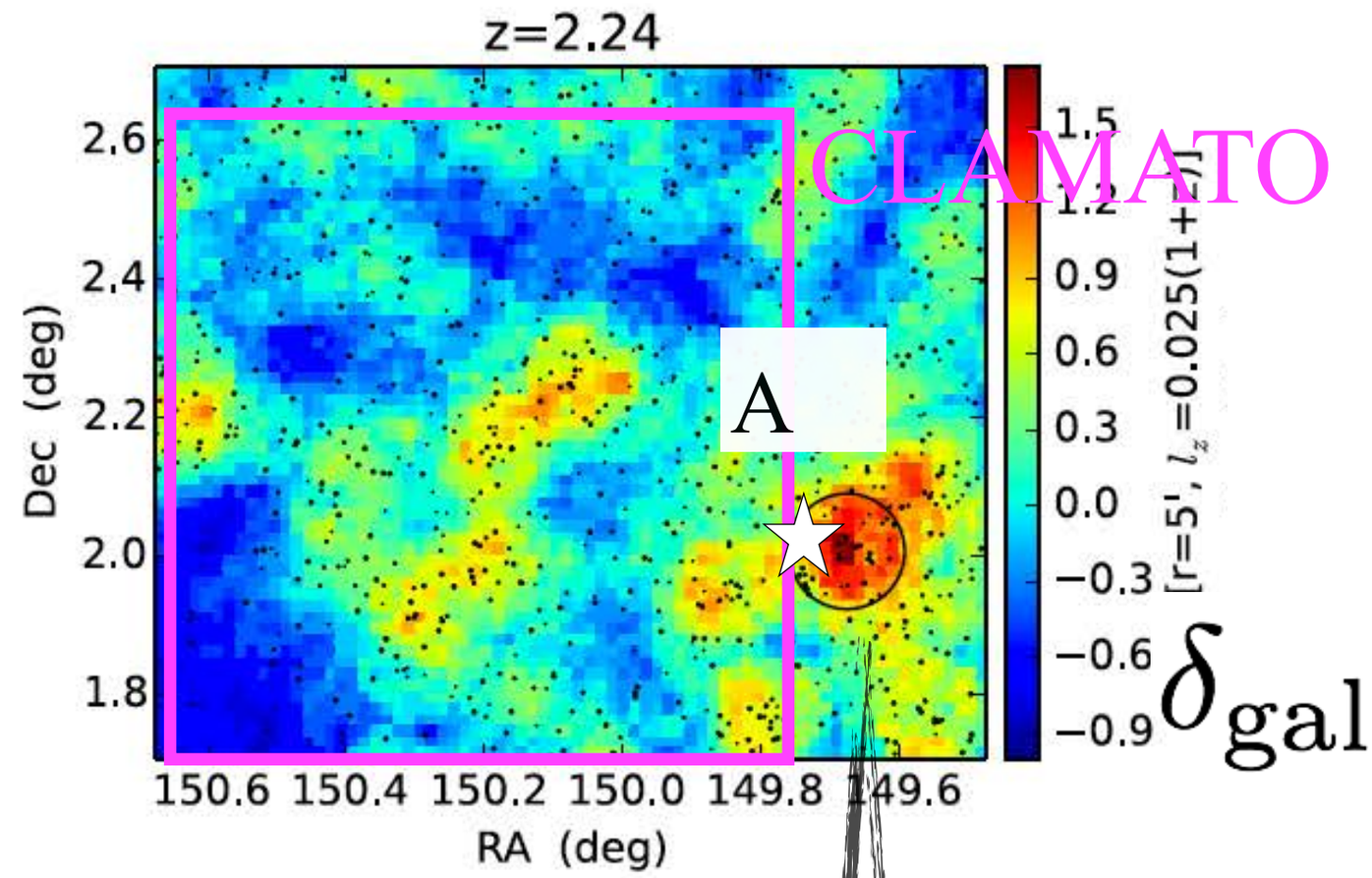
We study a spatial relation between galaxies and IGM HI gas in large field
—> We provide great laboratories for the IGM tomography

Next Study 1: Galaxy Overdensity at z ~ 2.2

A_{obs} coincides with one of the proto-cluster candidates (Chiang+14)

Large galaxy overdensity is associated with the large amount of HI gas



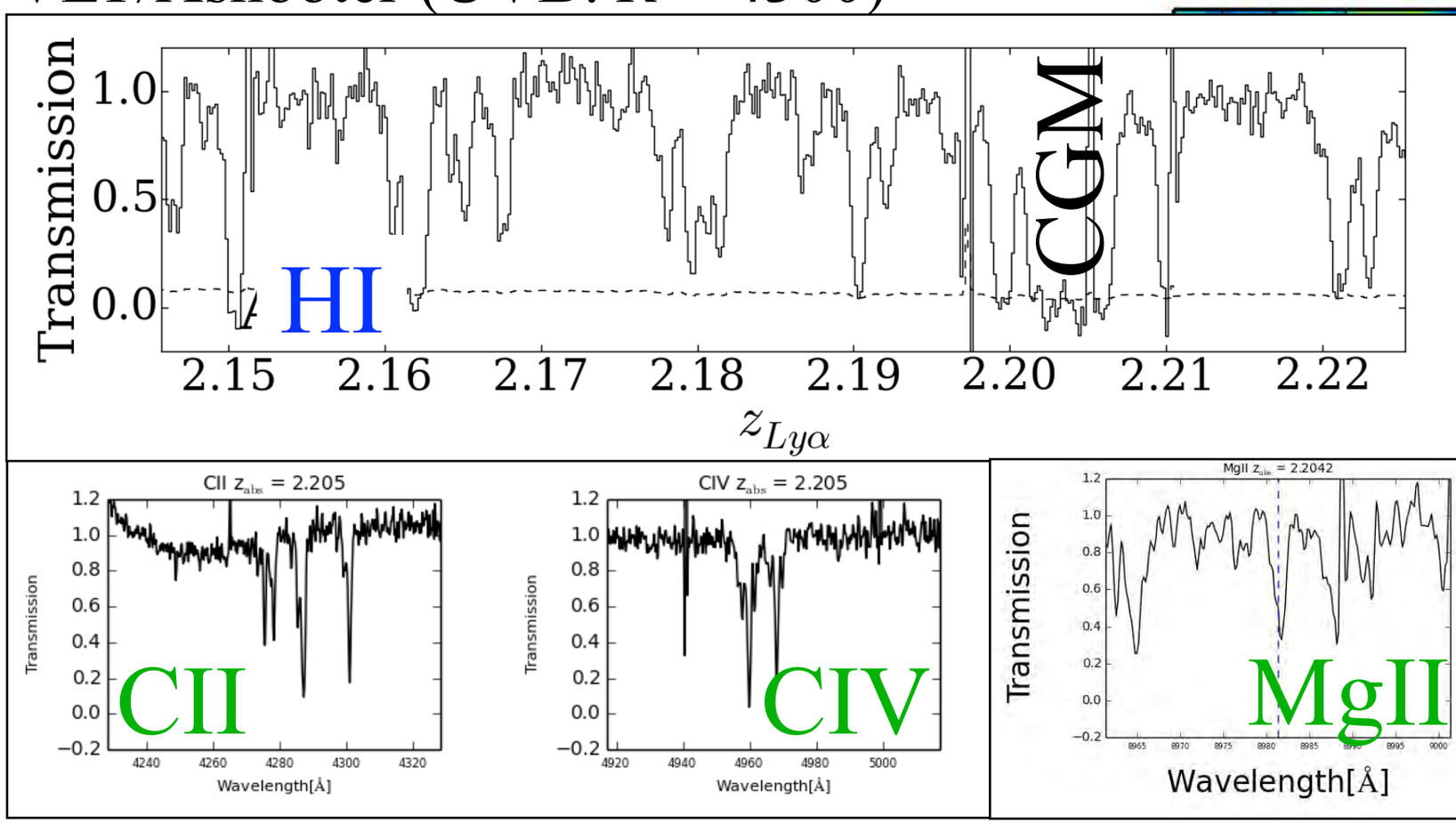


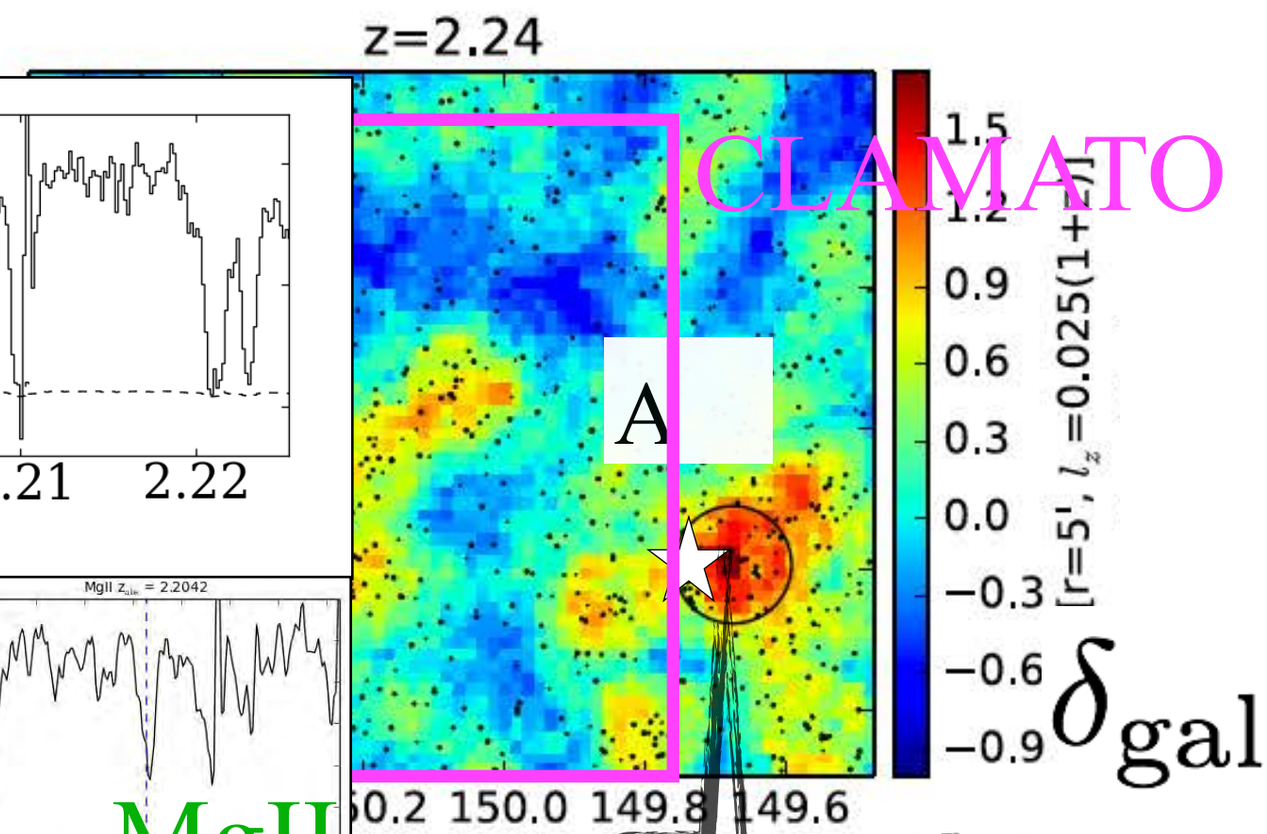
Densest structures in COSMOS/UltraVISTA in redshift range of z~2-2.5 (Chiang+14)

Next Study 1: Galaxy Overdensity at z ~ 2.2

Background quasar spectra of Aobs shows strong HI absorption lines and metal absorption lines (CII, CIV, MgII) associated with the structures

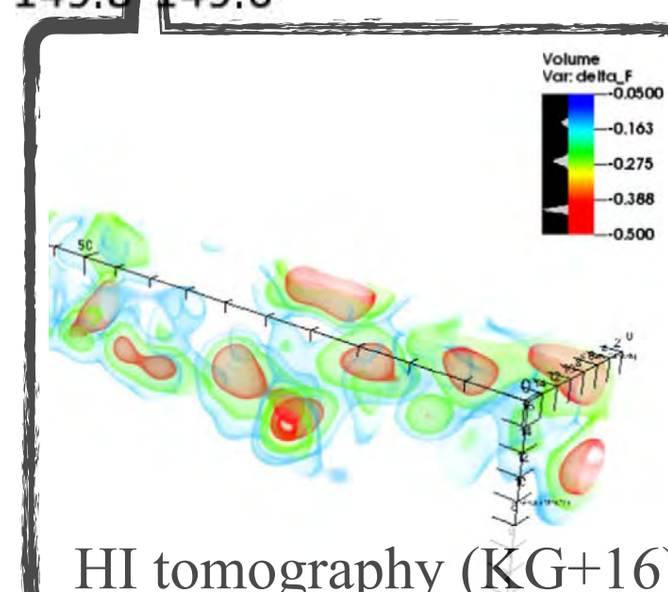
VLT/Xshooter (UVB: $R = 4300$)





We are preparing Keck/LRIS (Subaru ex) proposal to observe background & foreground galaxies, AND to conduct **IGM tomography** (Mukae, Ouchi, KG et al.)

We probe galaxy overdensity, HI and metal absorbers, ***simultaneously***



HI tomography (KG+16)

Next study 2: HSC Imaging and Galaxy overdensity-HI/metal relation

HSC-SSP data

LBG(u-drop out) at z~3 & BXBM at z~2

to be compiled by **December 2016**

Deep + UltraDeep: ~30deg^2

u-drop: (Deep) 0.098million +(UD) 0.22 million

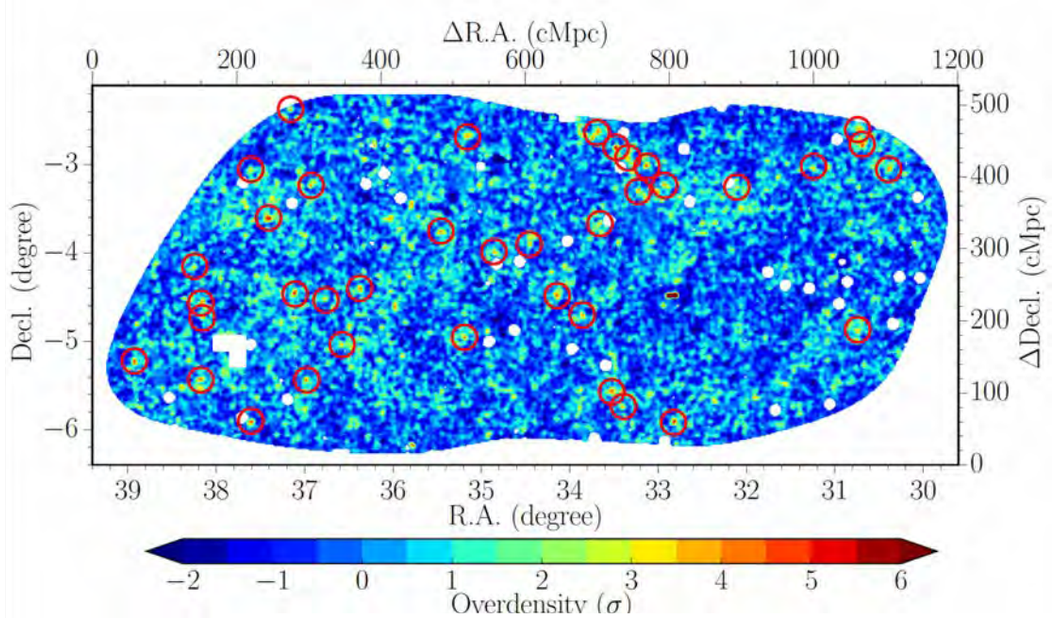
BX/BM: (Deep) 0.8million +(UD) 0.9 million

Overdensity measurement: fixed aperture method

30deg^2 have ~100 galaxy overdensity

It would be interesting to study galaxy-IGM relation in galaxy-overdensities with SDSS background quasar data

—>that covers wide field!



From Toshikawa-san's slide

II. Galaxy-IGM Correlation for HETDEX survey

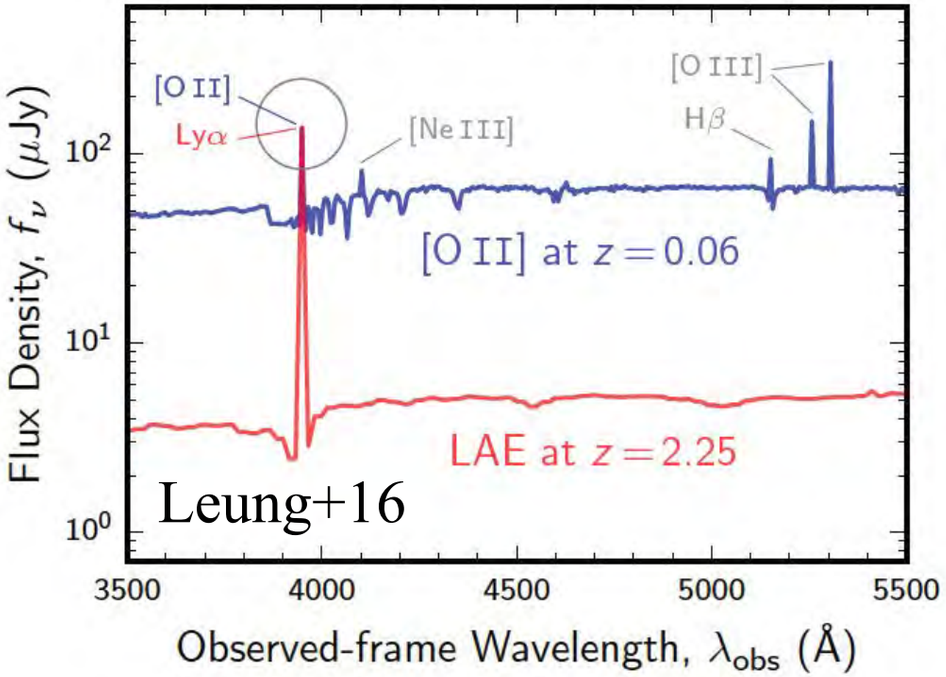
Collaborator:

Masami Ouchi (ICRR), Andreas Schulze (Kavli IPMU)

Galaxy-IGM Correlation for HETDEX survey

HETDEX (Hobby-Eberly Telescope Dark Energy Experiment)

is a survey to study the evolution of Dark Energy between 1.9 < z < 3.5 with the new instrument VIRUS on the Hobby -Eberly telescope(HET)



78IFUs x 448Fibers/IFU~35,000 fibers

Spectral resolution: R~800

Blind spectrographic survey over 3 years

294(Spring field)+140(Fall field)= 434 deg^2

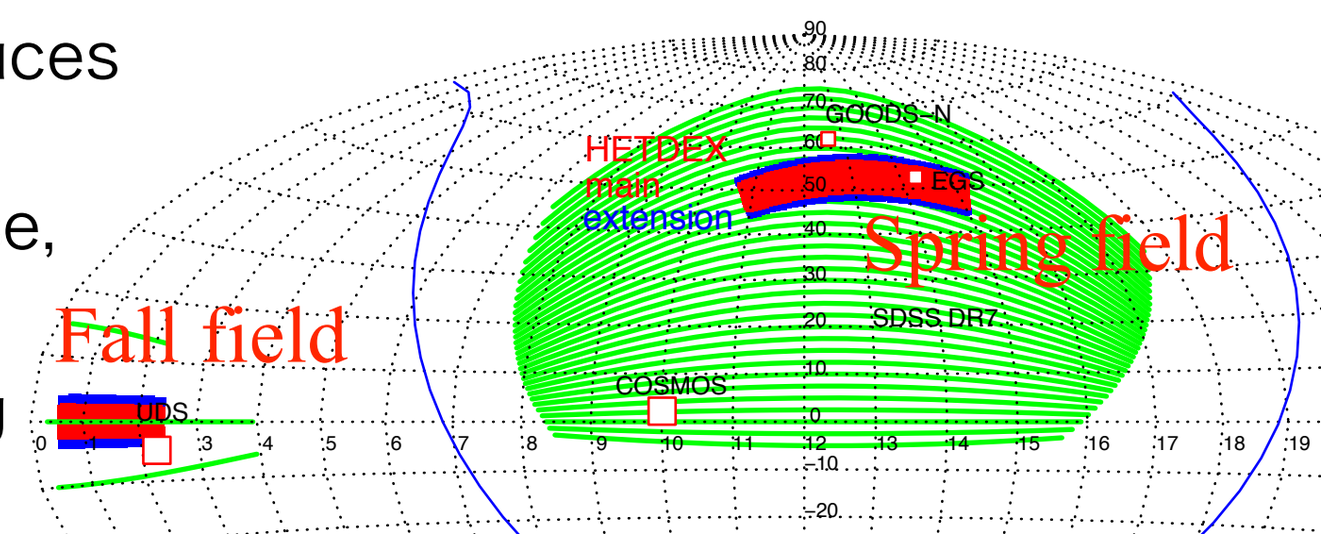
0.8M Lyman-α emitters at z=1.9-3.5

1.0M [OII] emitters at z<0.5

the power spectrum at high-z produces a percent level measurement of the expansion history of the universe, and dark energy equation of state

Instrument commissioning: Ongoing

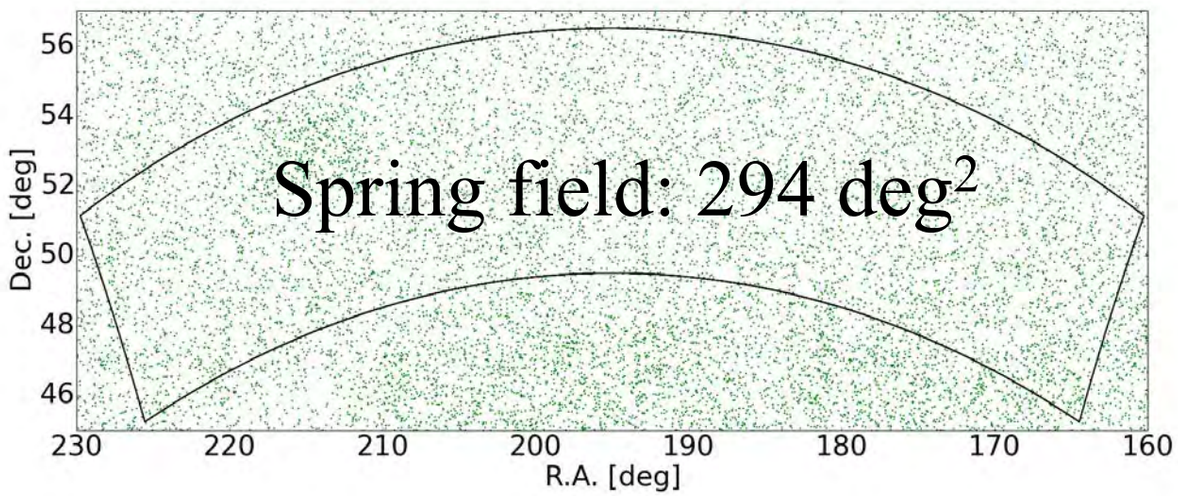
Observing TIMELINE: 2017-2019

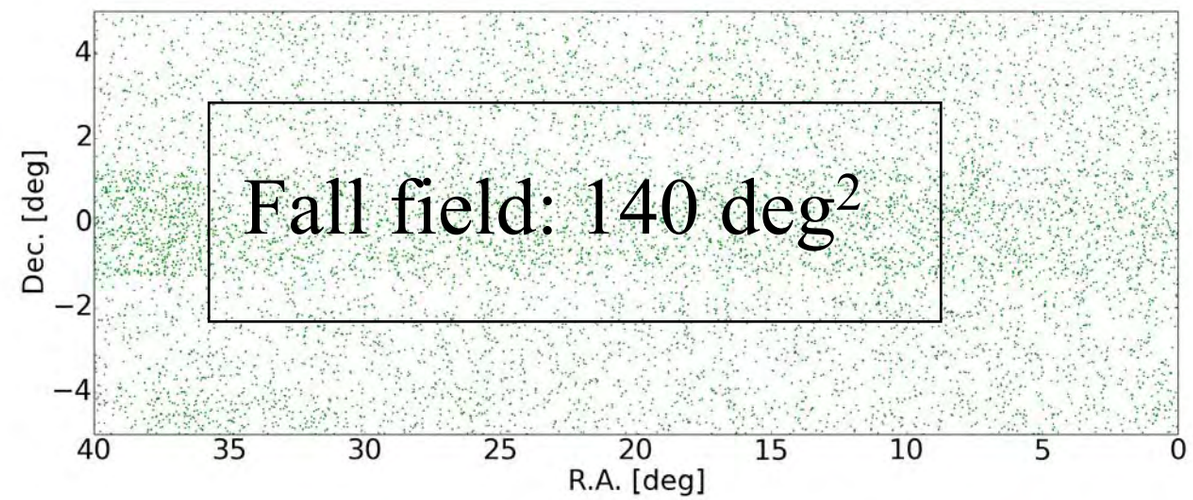


Galaxy-IGM Correlation for HETDEX survey

Correlation studies of z~2-3 galaxies and HI/metal absorbers

- HETDEX provides a large amount of spectroscopically identified LAEs at 1.9 < z < 3.5.
- It would be interesting to study
  - connection between HI distribution and LAEs: **Galaxy formation**
  - galaxy-IGM relation in a number of **proto-clusters: Proto-ICM**
  - IGM metal(MgII, CIV) in **voids** in the LSSs: **Metal enrichment**





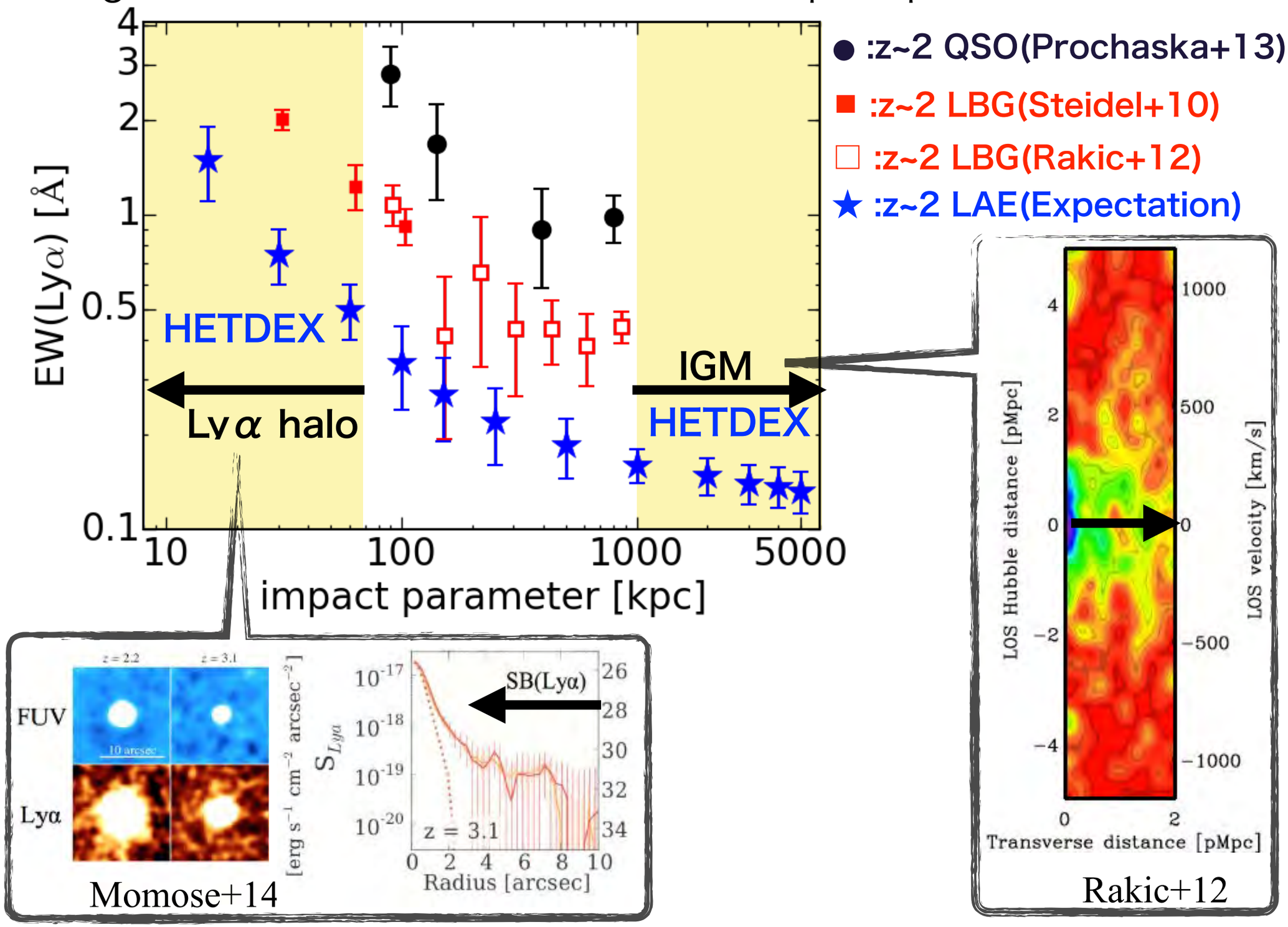
- We find ~6000 background quasars from SDSS in the HETEDEX field
  If you assume LAE uniform distribution, there will be 0.5 LAEs/arcmin2
  —> 1.60LAEs within 1 arcmin (per quasar sightline)
  —> 9760LAEs within 1 arcmin (entire quasar sightlines)

1 arcmin ~ 0.5pMpc at z = 2.5

Galaxy-IGM Correlation for HETDEX survey

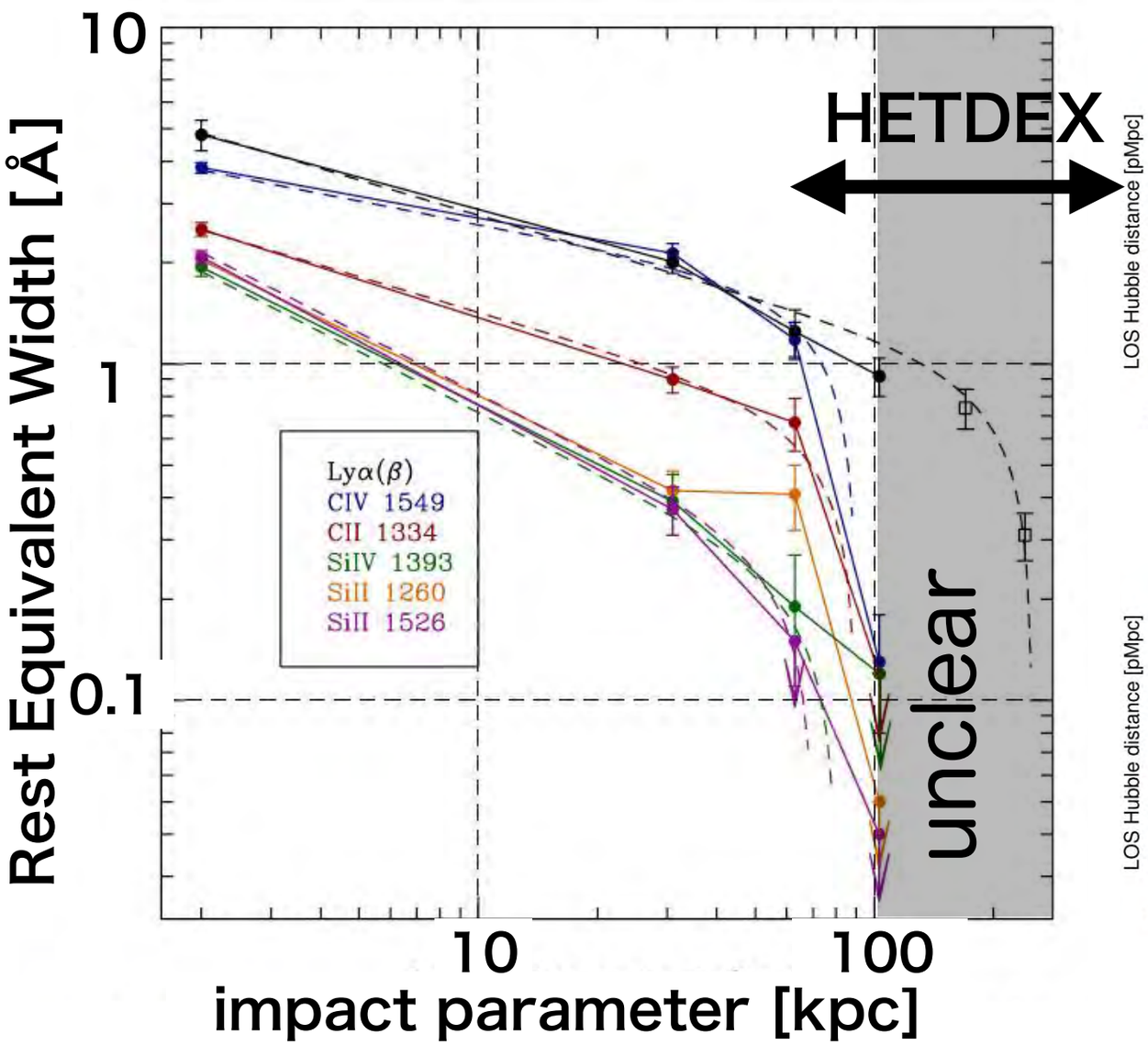
From Lyα halo to IGM

- By making composite spectra of the background quasars in the rest-frame of the foreground LAEs as a function of the impact parameter from the LAEs

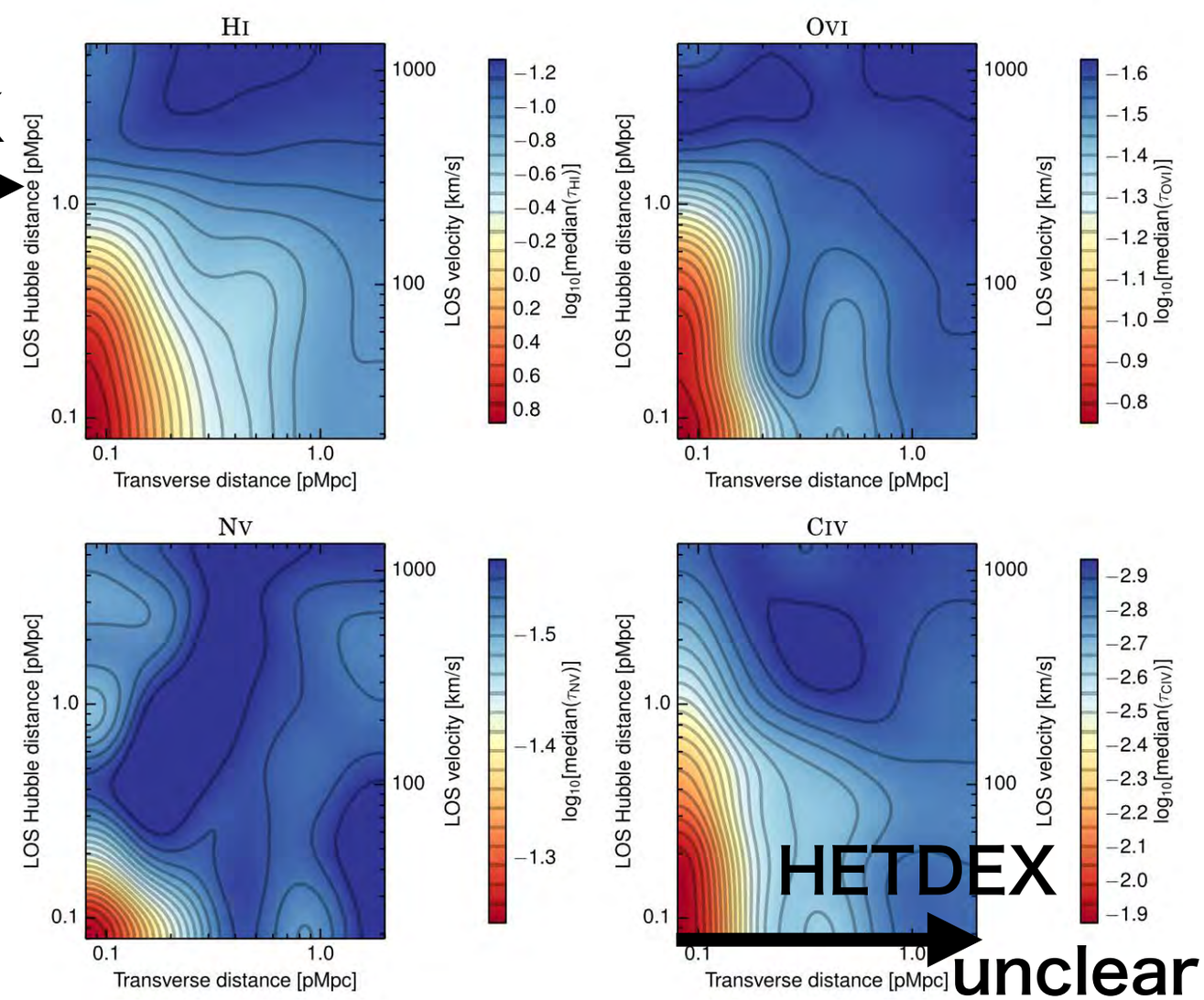


Circumgalactic Medium

- With the composite spectra, you can also investigate the distribution of metal absorbers around LAEs
- You can study metal gas distribution around LAEs



Steidel+10



Turner+14

Summary:II

- Correlation studies of z~2-3 galaxies and HI/metal absorbers with HETDEX LAEs + SDSS background QSO spectra

- **Galaxy-IGM relation in large-scale structures**:
  - link connection HI distribution and LAEs
  - galaxy-IGM relation in a number of proto-clusters
  - metal(MgII, CIV) in voids in the large-scale structures
- Systematic Survey:
  - **LAE-HI correlation:** stacking, cross-correlation
  - **LAE-metal correlation:** stacking, cross-correlation

We mainly study sparce but wide study of galaxy-IGM relation in large-scale structures
*—> We provide **a number of** great laboratories for the IGM tomography*

Summary: I + II

I. Galaxy-IGM HI Relation in Large-scale

- Large-scale spatial correlations of galaxies and IGM HI
- Galaxy-IGM HI/Metal relation in galaxy overdensity

II. Galaxy-IGM Correlation for HETDEX survey

- Correlation studies of z~2-3 galaxies and HI/metal absorbers with LAEs from HETDEX + SDSS QSO
- Large-scale structures and systematic survey