The Diversity of IGM-galaxy connection at redshift $z = 2$-3

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Based on RM+2021a, ApJ, 909, 117; RM+2021c, ApJL, 912, 24

in collaboration with
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K. Motohara, L. Spitler

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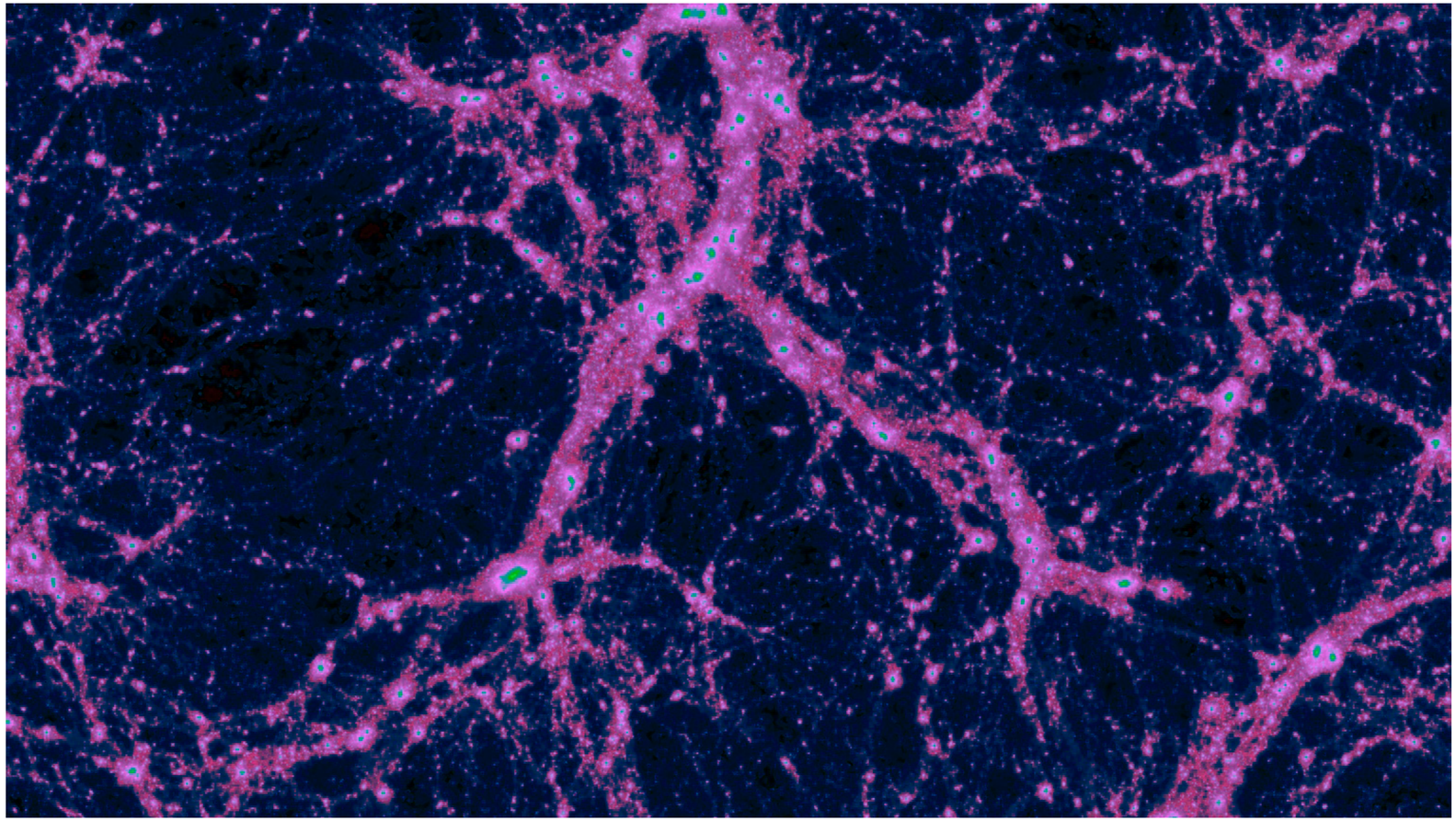
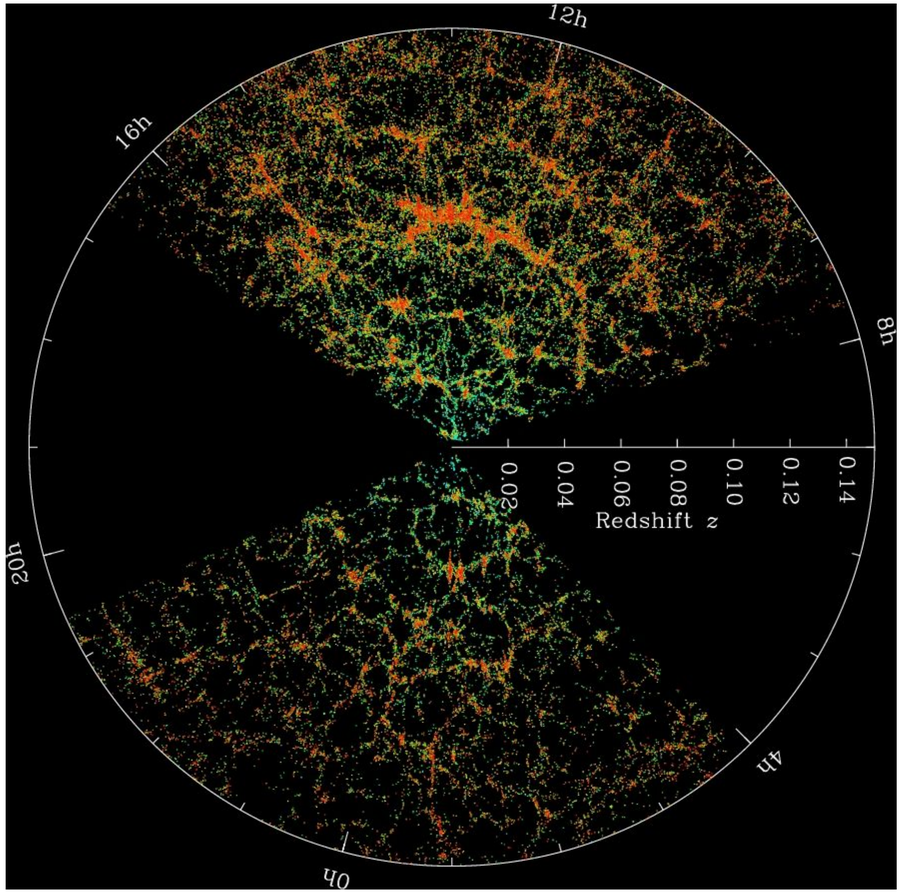
The Large-scale Structure or Cosmic Web

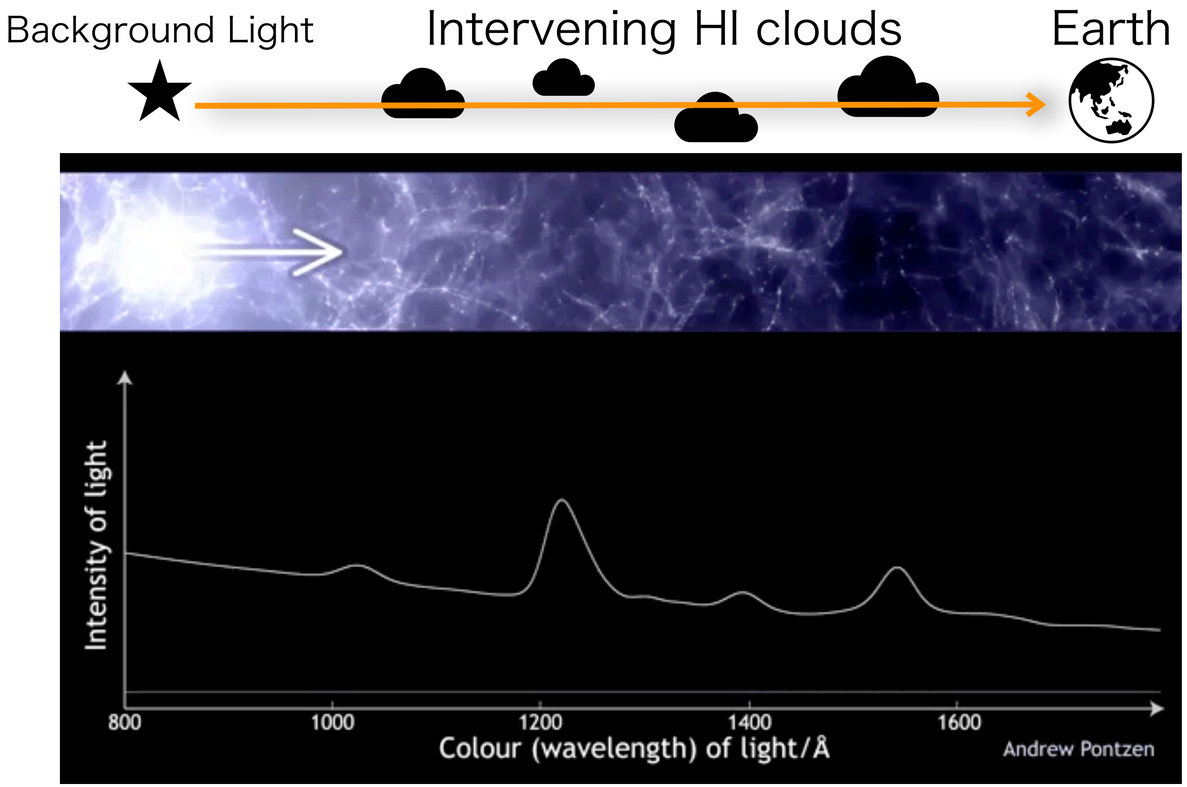


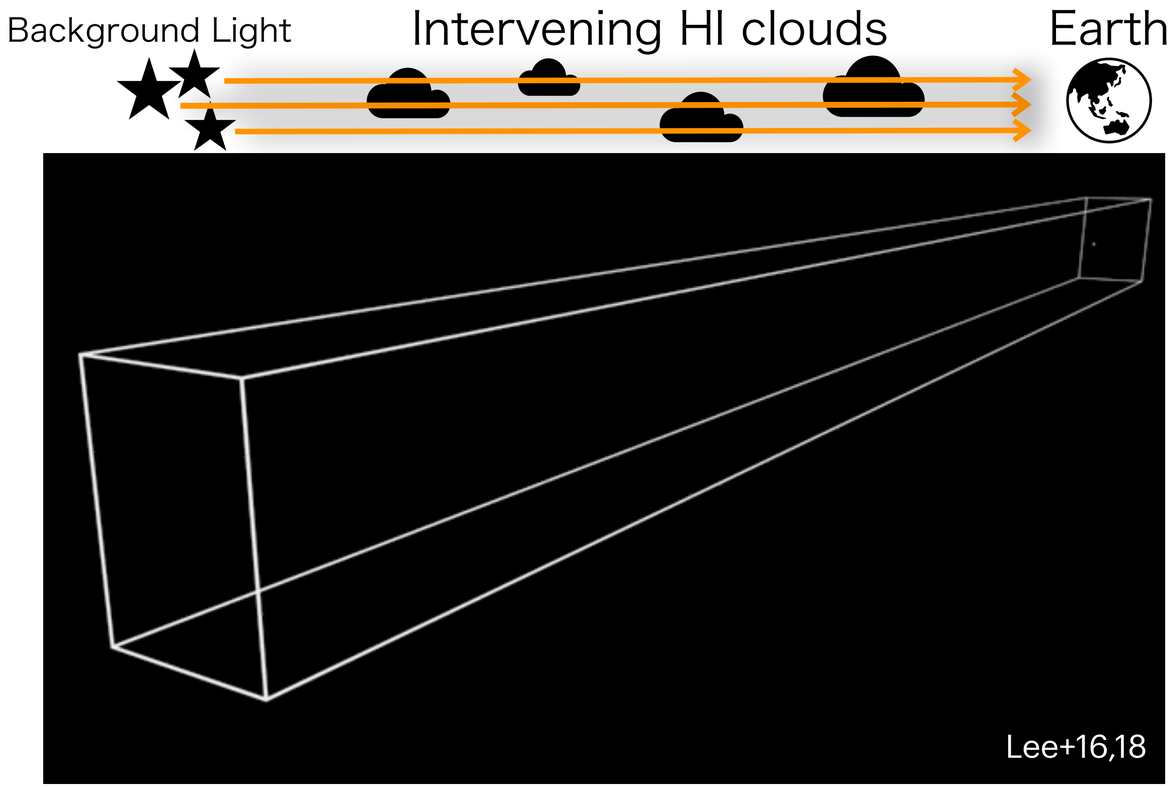
Shimizu+19; Nagamine+21



SDSS

The Cosmic Web traced by Neutral Hydrogen





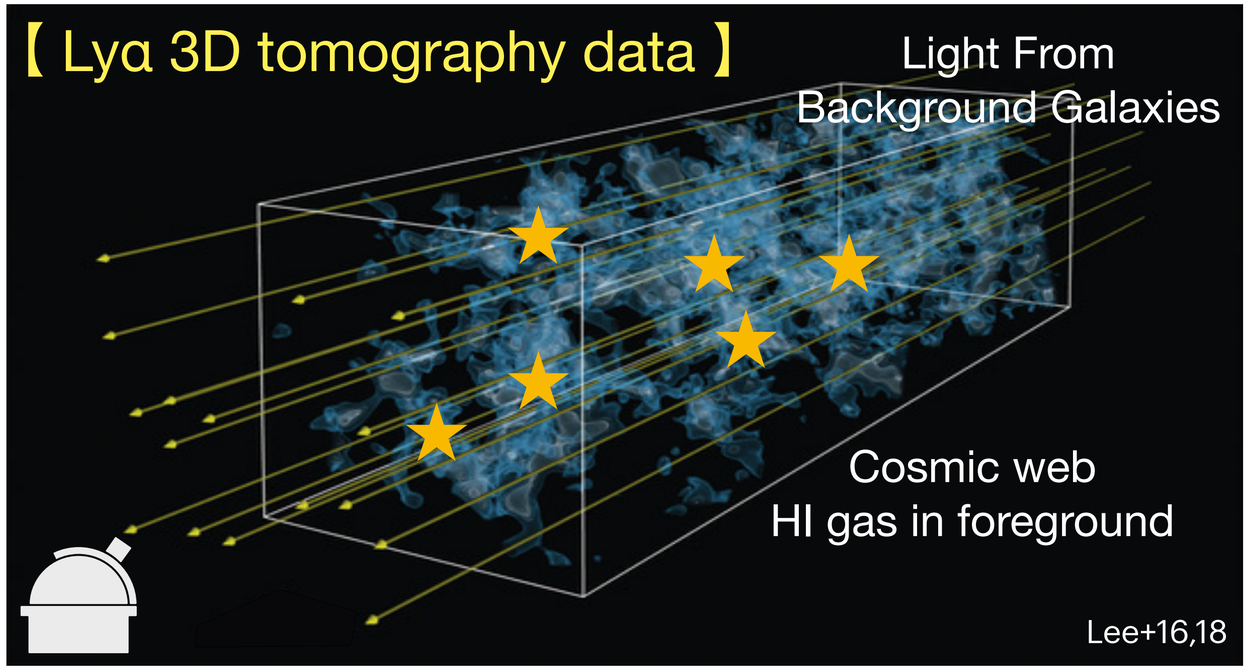
Lyα forest absorption

- HI clouds in the IGM cause the absorption
- The useful probe of the IGM
- One sightline

Lyα forest tomography

- Reconstruction of 3D Lyα forest absorption field with many sightlines
- Use bright galaxies and quasars

The Cosmic Web traced by Neutral Hydrogen



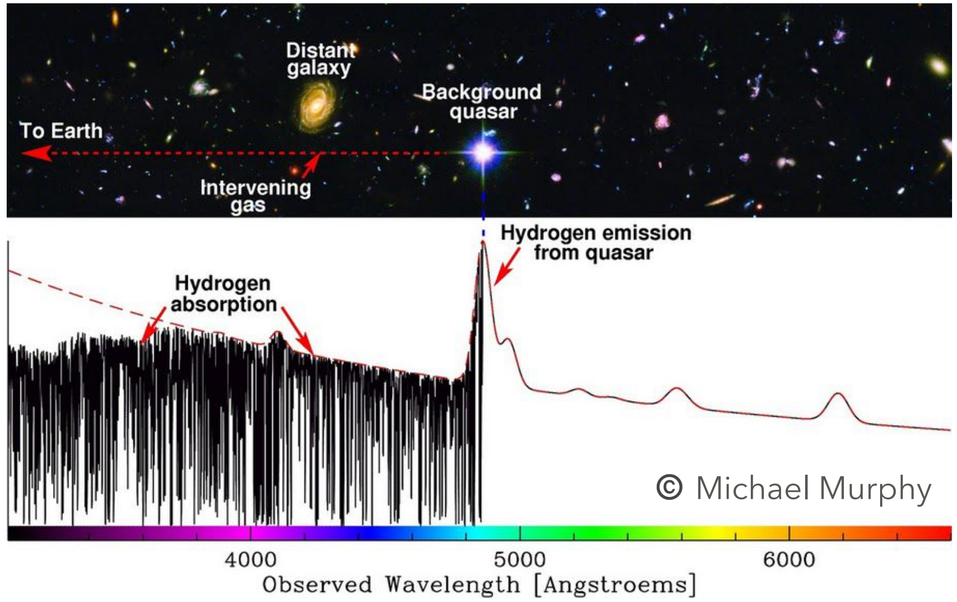
HI in the intergalactic medium

- Feedback by galaxies might ionize HI in the IGM, which results in the change of HI density

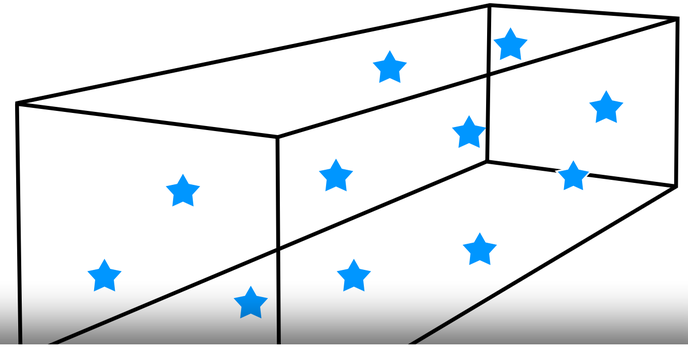
Galaxy distribution

- Galaxies distribution might not faithfully trace the underlying dark matter due to some observational restriction

Cross-Correlation Between Lyα Forest and Galaxies

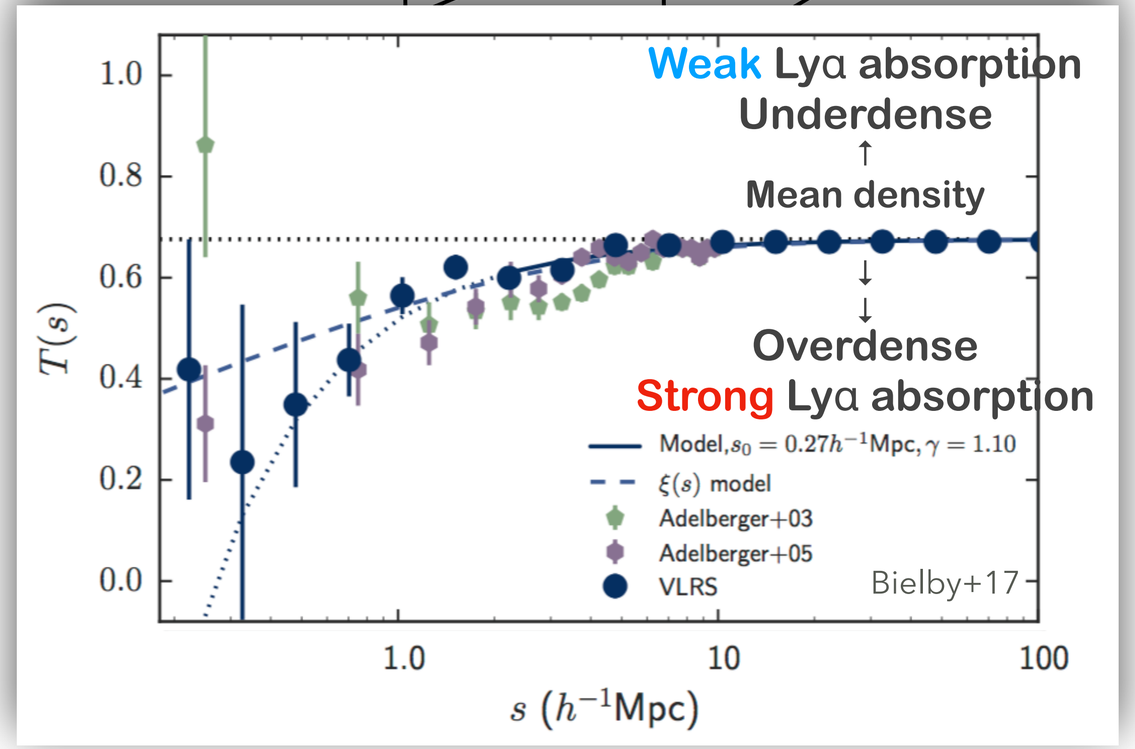


【 Spec-z catalogs of galaxies 】



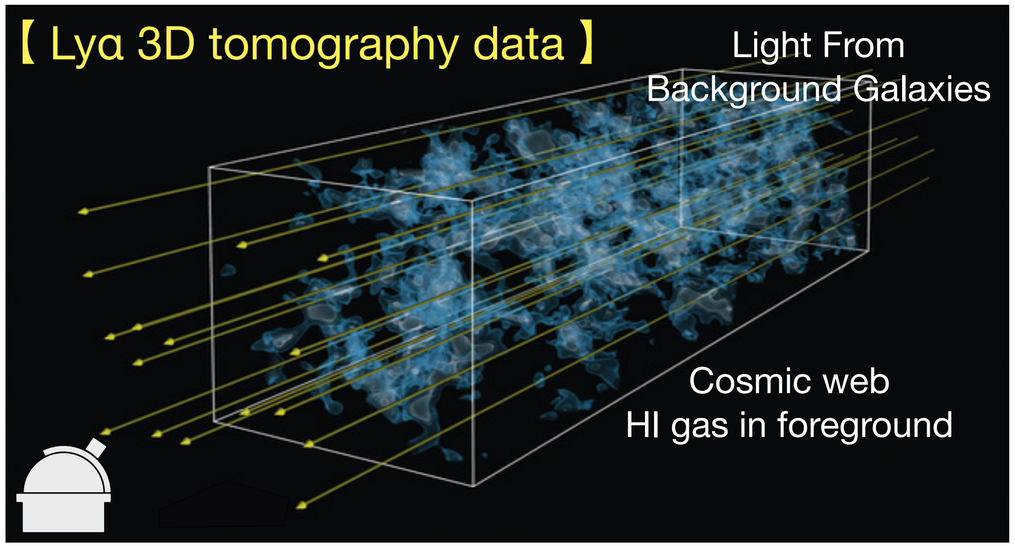
Observable of Lyα absorption

- Lyα flux transmission (T or F): $T(z)\ or\ F(z) = \frac{f(z)}{C(z)}$
  - Large：High transmission ~ low HI density
  - Small：Low transmission ~ high HI density
- Transmission fluctuation/excess (δ_F): $\delta_F = \frac{F(z)}{\langle F_z(z) \rangle} - 1$
  - +：Weaker absorption than mean ~ low density
  - –：Stronger absorption than mean ~ high density



This Study: Cross-Correlation Analysis

The cross-correlation between Lyα 3D tomography map and galaxies



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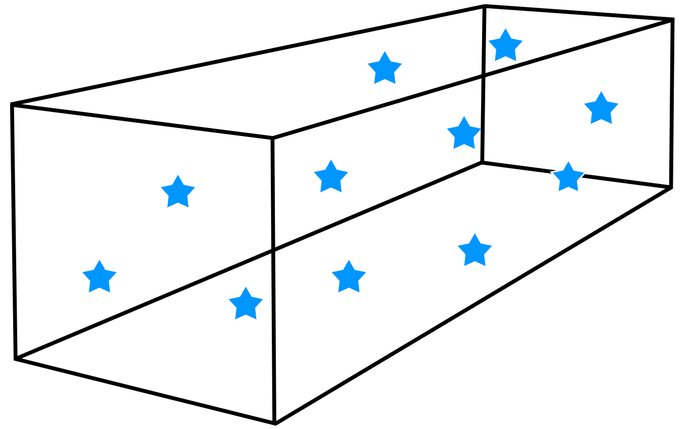


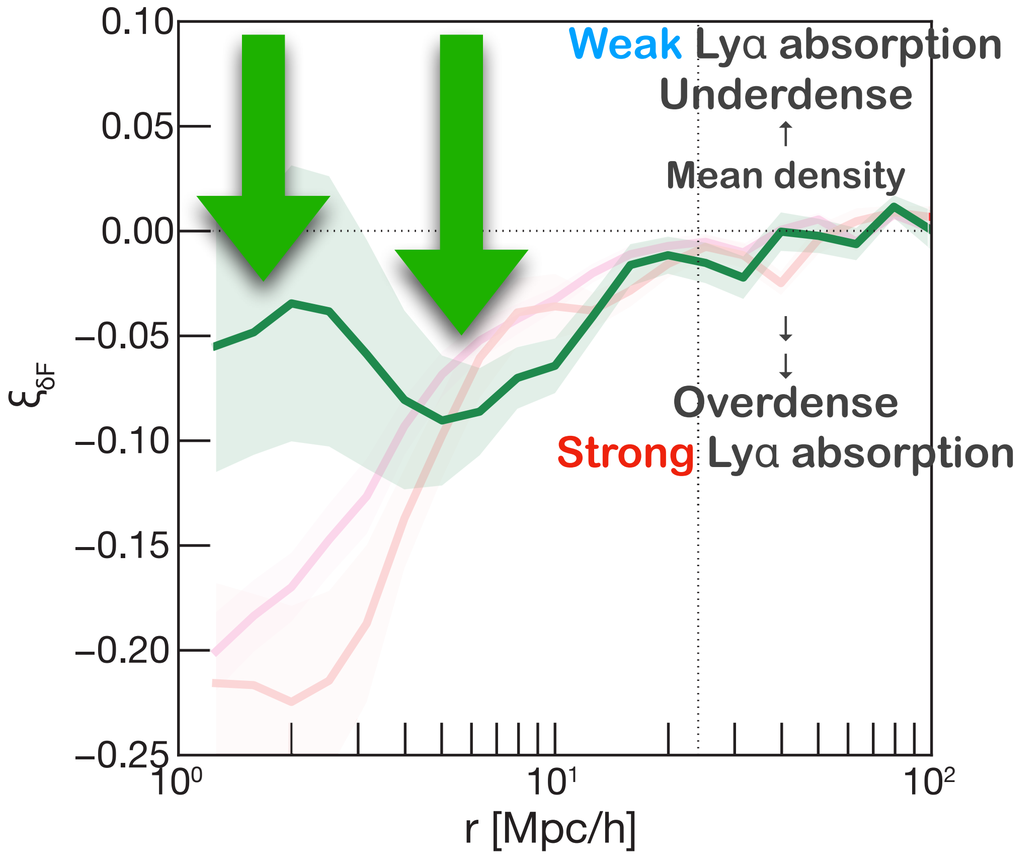
CLAMATO (Lee+16, 18)

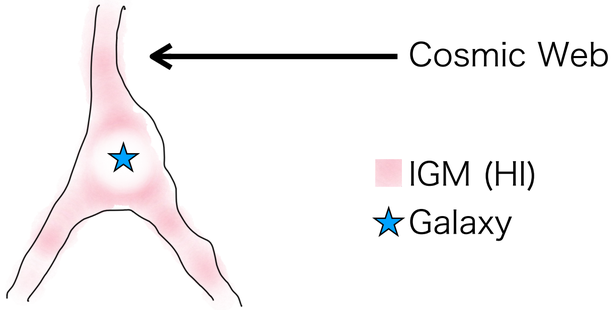
- Footprint: 0.157 deg^2 in the COSMOS field
- Volume : 3.15 x 10^5 h^{-3} Mpc^3
- Redshift : $2.05 < z < 2.55$

Galaxy populations

- **[OIII] emitters** (**O3Es**: star-forming galaxies bright in [OIII])
- **Lyα emitters** (**LAEs**: star-forming galaxies bright in Lyα)
- **Active galactic nuclei** (**AGN**: galaxies with AGNs)

Diversity of IGM-galaxy connection among the population





AGNs (M_{DH} = 10^{12}–10^{13} M◉)

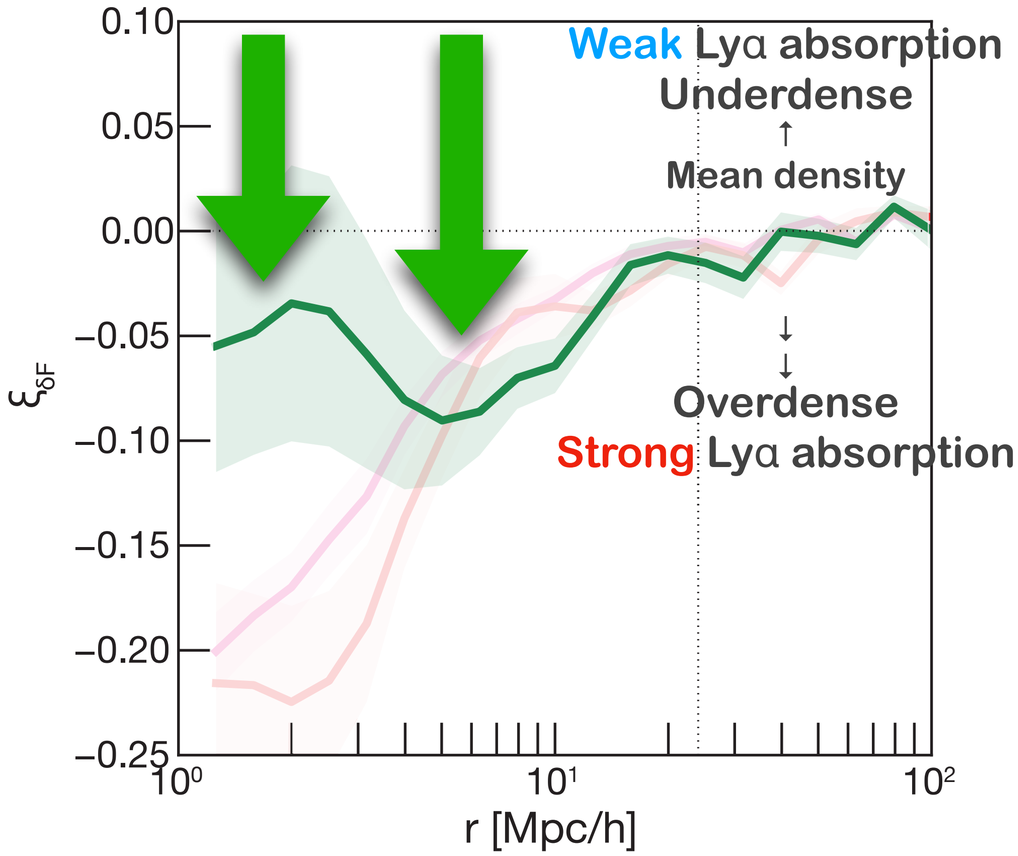
- ✦ Weak Lyα absorption at their position
- ✦ The strongest Lyα absorption at r = 5-7 Mpc
- ✦ IGM HI photoionization (proximity effect)

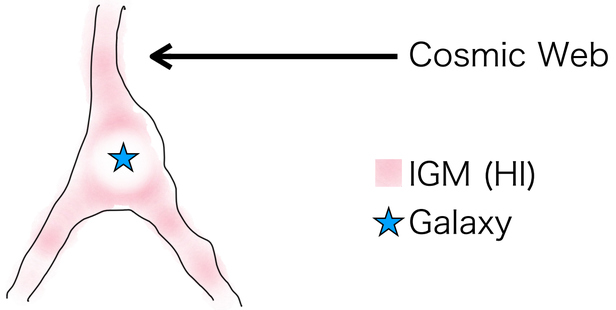
[OIII] emitters (M_{DH} = 10^{11}–10^{12} M◉)

- ✦ Monotonically decline of Lyα absorptions
- ✦ Correlate with the IGM density distribution

RM+21a

Diversity of IGM-galaxy connection among the population





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- ✦ Mc
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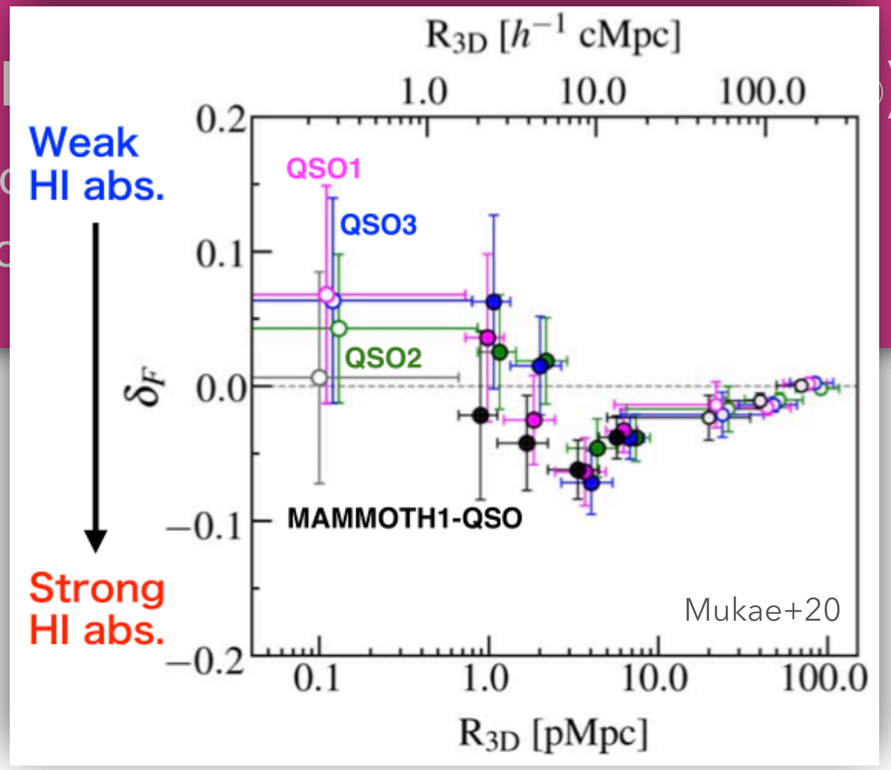

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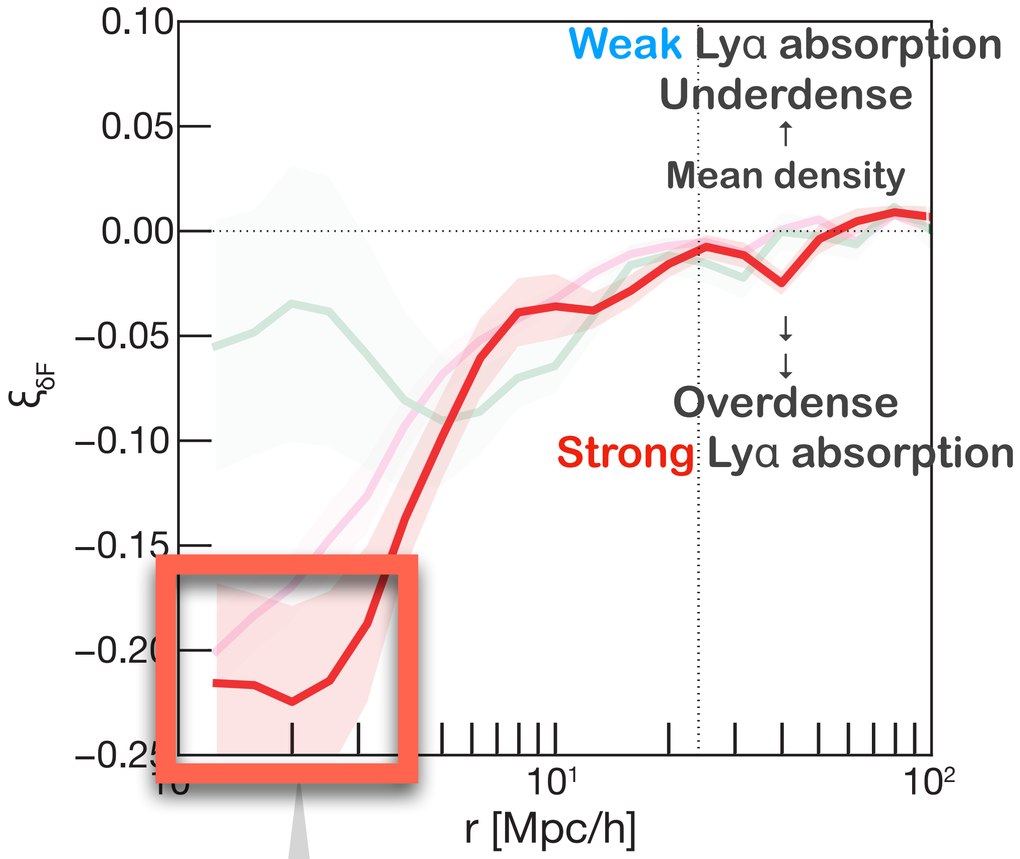
Diversity of IGM-galaxy connection among the population



Possible explanations

1. Low matter density but with high HI fractions
2. Associating massive halos
3. Cosmic variance by small samples

AGNs (M_{DH} = 10^{12}–10^{13} M◉)

- ✦ Weak Lyα absorption at their position
- ✦ The strongest Lyα absorption at r = 5-7 Mpc
- ✦ IGM HI photoionization (proximity effect)

[OIII] emitters (M_{DH} = 10^{11}–10^{12} M◉)

- ✦ Monotonically decline of Lyα absorptions
- ✦ Correlate with the IGM density distribution

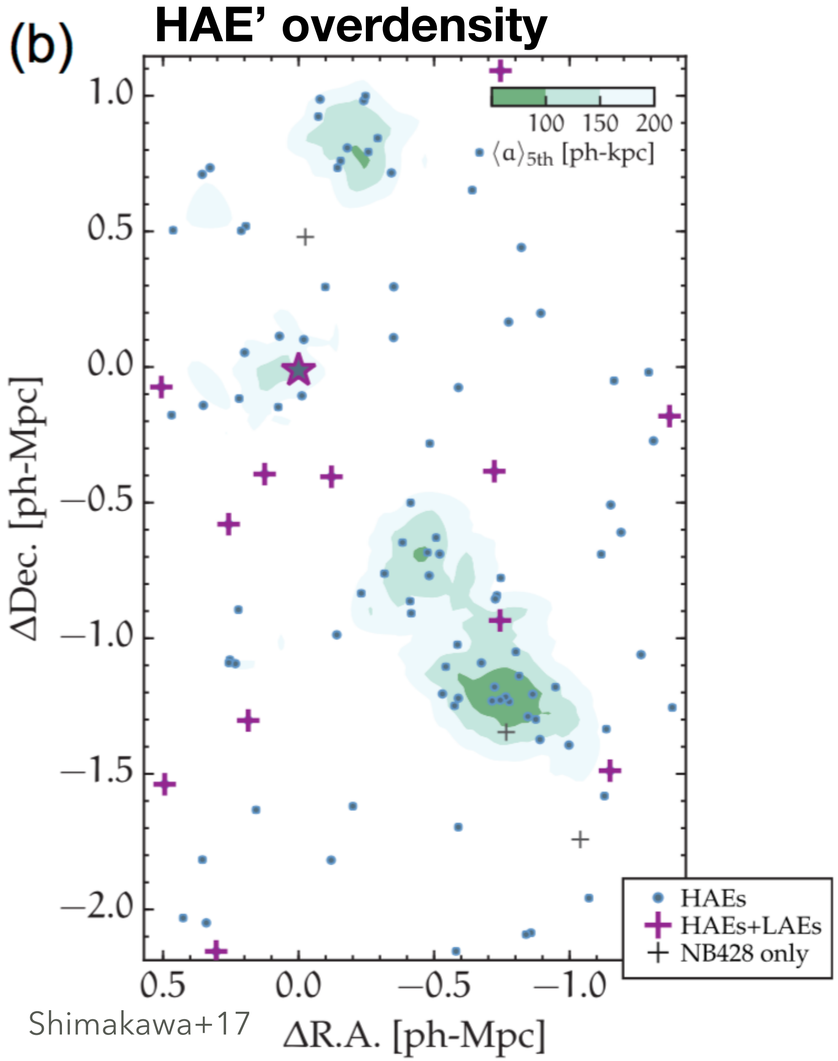
Lyα emitters (M_{DH} = 10^{10}–10^{11} M◉)

- ✦ Strongest absorption among these three
- ✦ Continuous strongest absorptions up to r = 3-4 Mpc
- ✦ LAEs locate a few Mpc away from overdensities

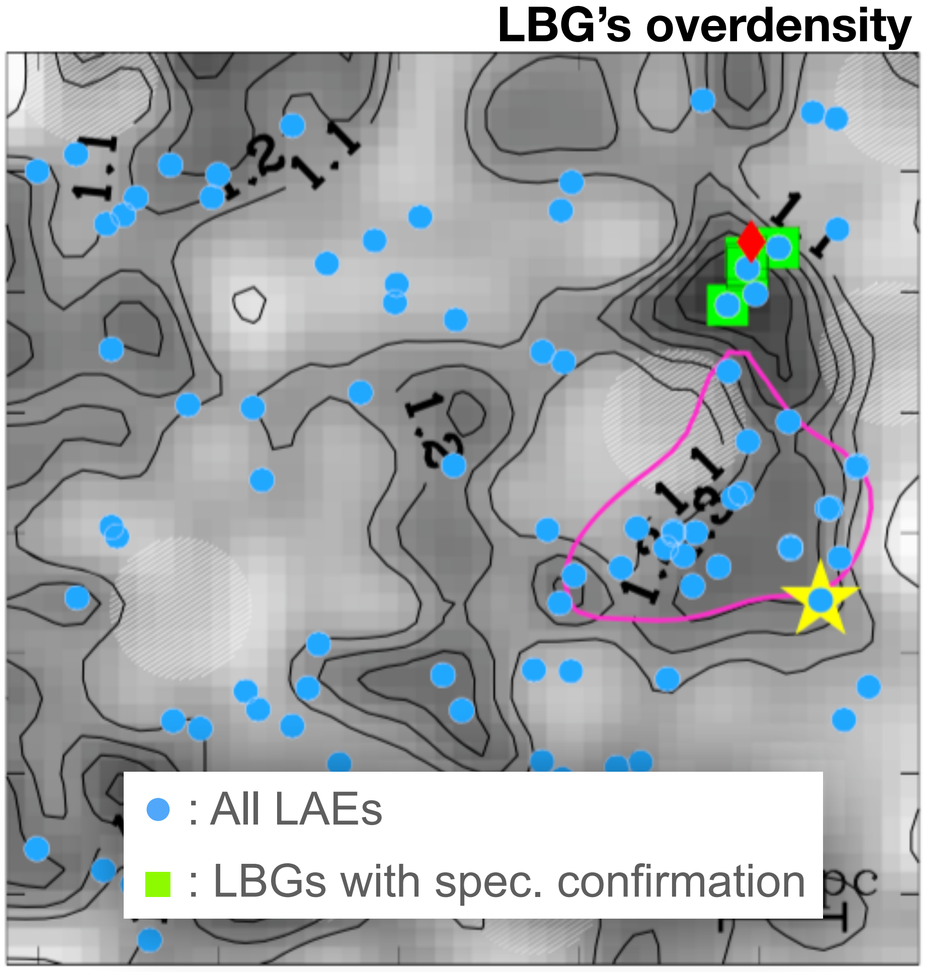
RM+21a

Discordances of Overdensities Between LAEs and Other Galaxy Populations

(proto) cluster regions



Shimakawa+17



Shi+19

Discordances of Overdensities Between LAEs and Other Galaxy Populations

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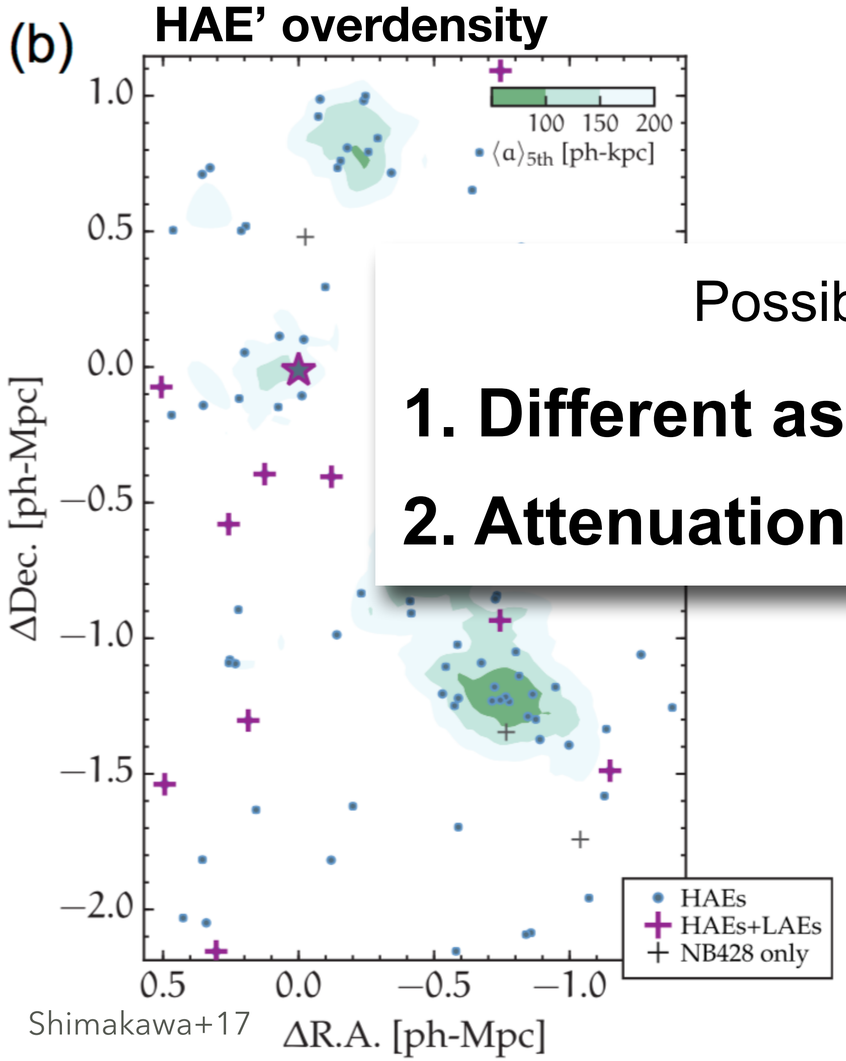
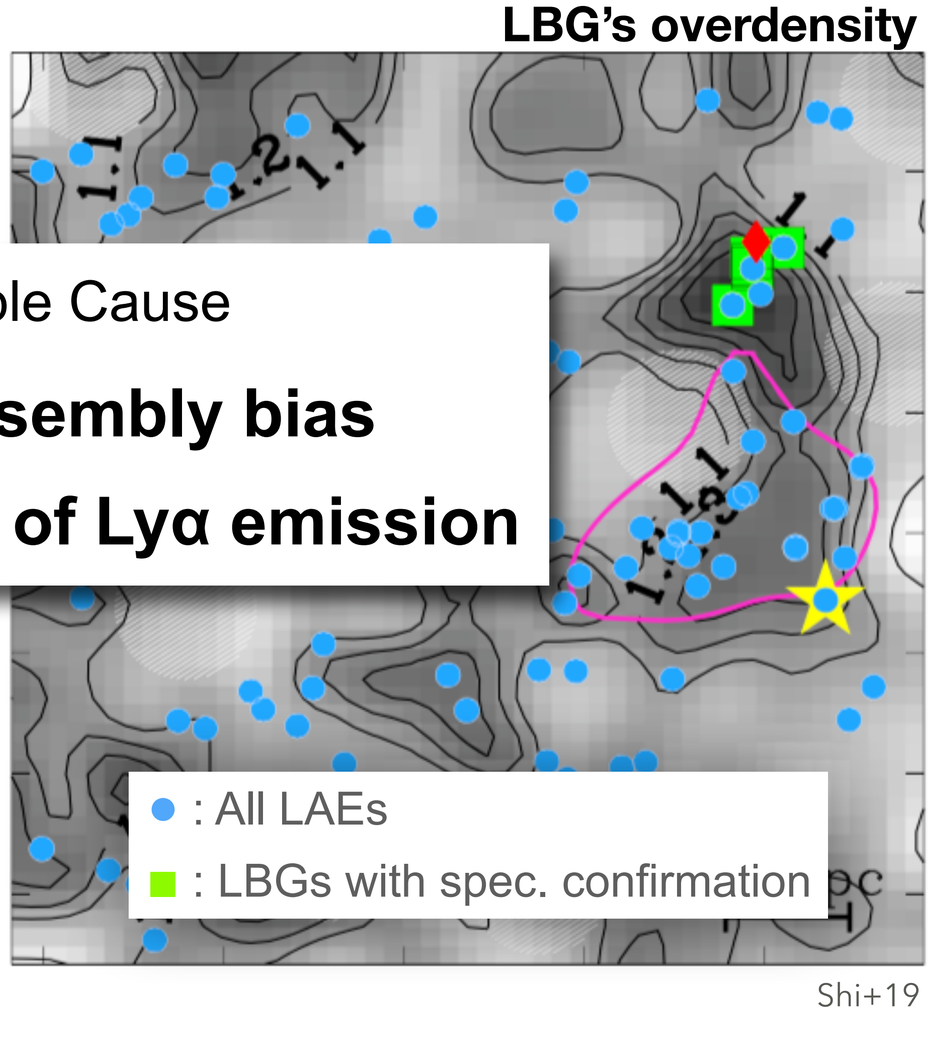




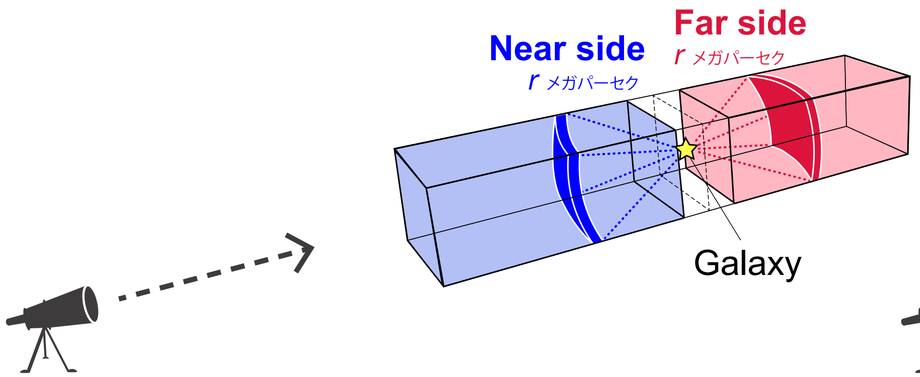
Possible Cause

1. Different assembly bias

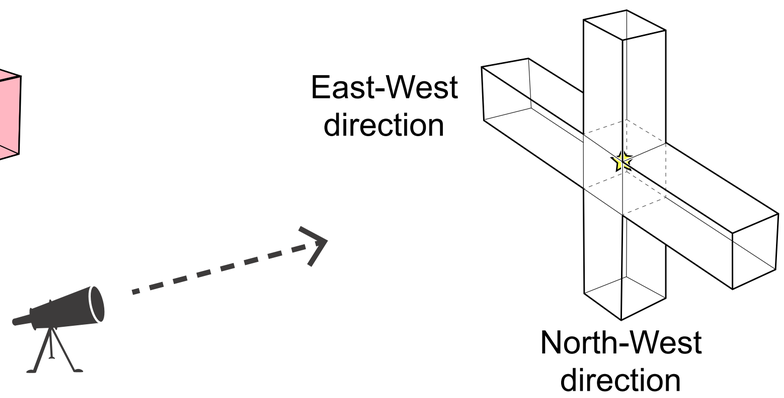
2. Attenuation of Lyα emission

Detail Analyses of the IGM-LAEs Connection

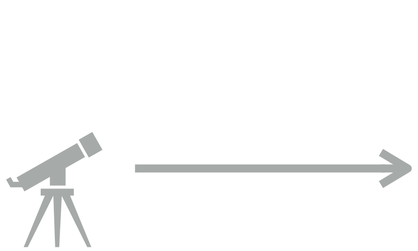
1) Line-of-sight

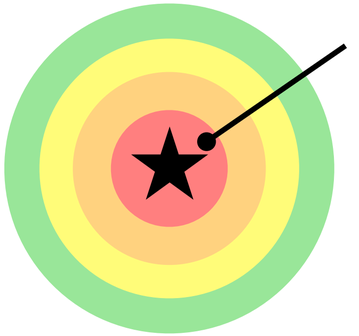


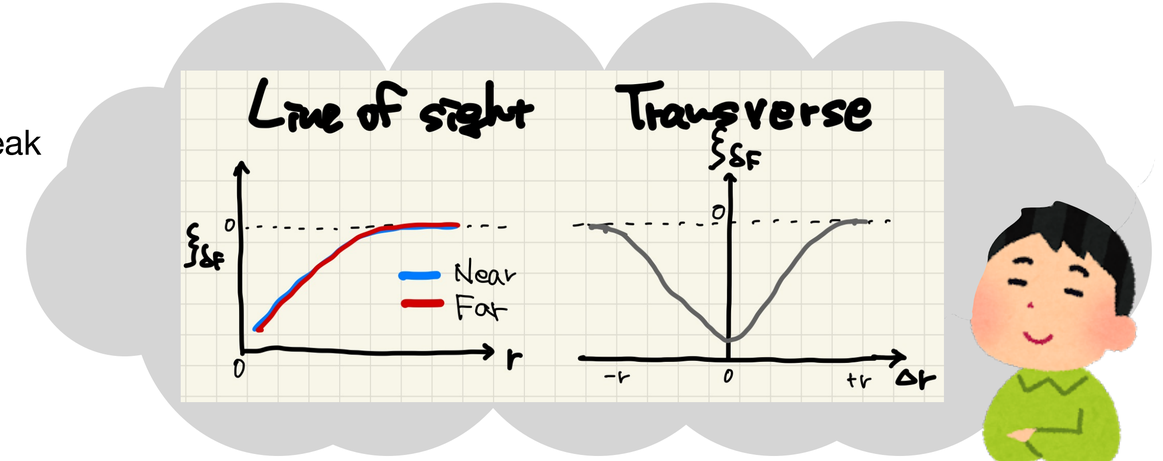
2) Transverse directions



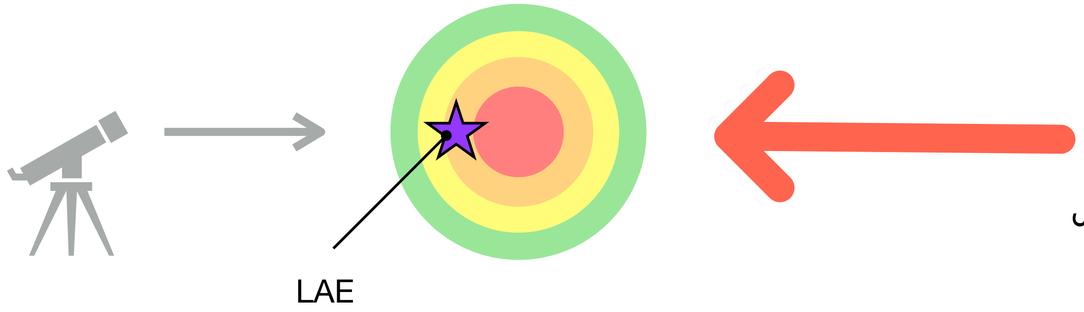
- Calculate the CCF along the line-of-sight (but near- and far-sides separately) and along with transverse directions
- Investigate this calculation for LAEs and O3Es







Detail Analyses of the IGM-LAEs Connection



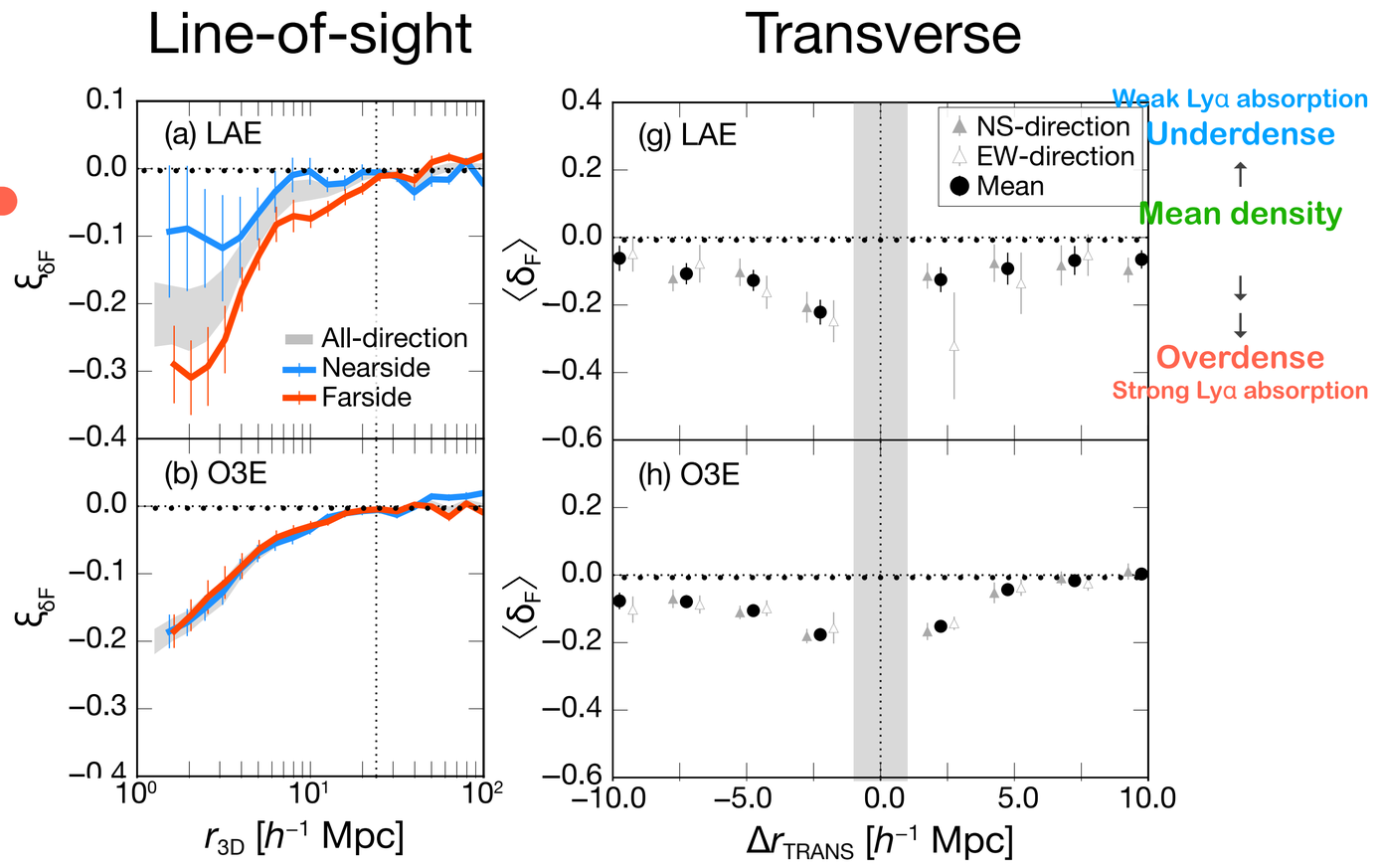
Transverse

- Symmetric CCF centering around galaxies

Line-of-sight

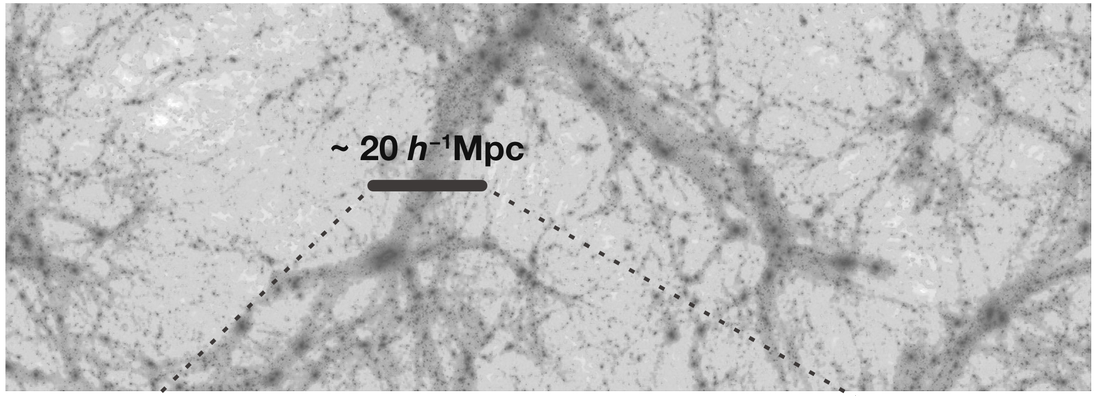
- O3E:
  Comparable CCFs in near and far sides
- LAE: CCF signal is weak in the near side
  than the far side up tp r ~ 3-4 Mpc

- **Higher density in the far side than in the near side**
  ~ LAEs are generally in the near-side of density peaks



RM+21c

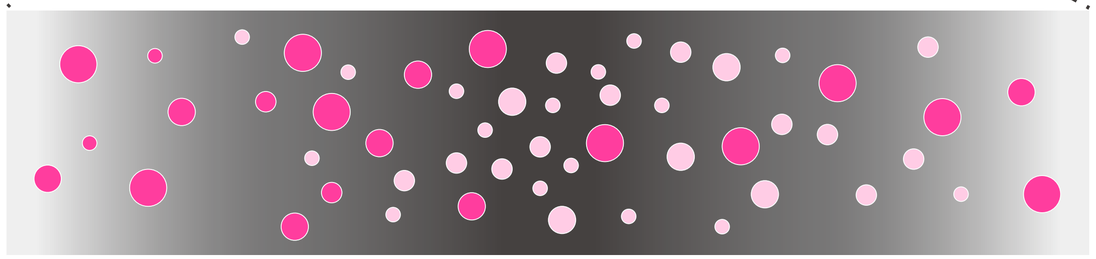
Detail Analyses of the IGM-LAEs Connection



O3Es

Mock LAEs

【Nearside】 【Density Peak】 【Farside】

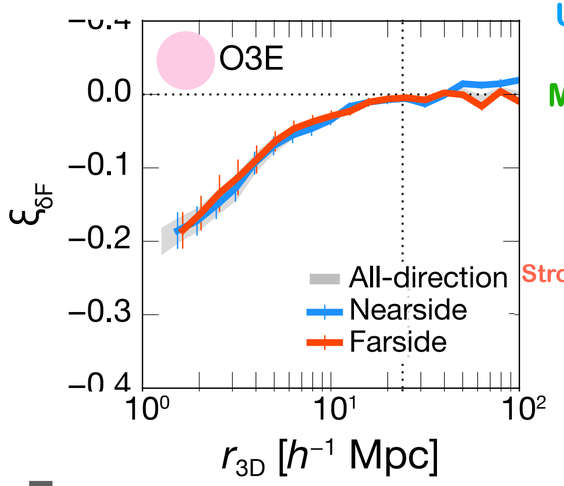


The direction of propagation of Lyα photons in the IGM

※ Size of circles ◯: Lyα luminosity

HI density

Low High

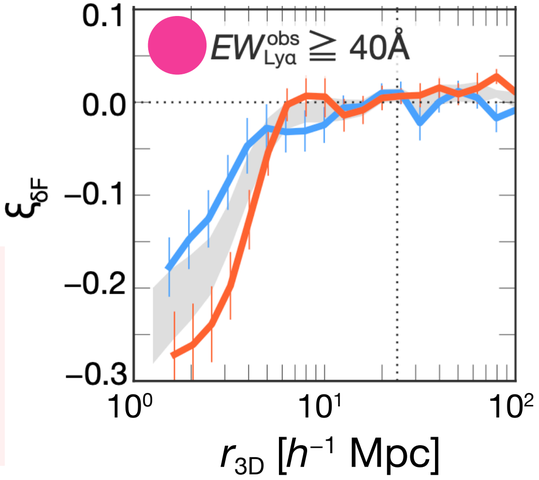


Weak Lyα absorption
Underdense
↑
Mean density
↓
↓
Overdense
Strong Lyα absorption

↓ Select O3Es with $EW_{Ly\alpha} \geqq 40$ Å

↓ Regard O3E as mock LAEs

↓ Calculate CCF along LoS and transverse



- Galaxies are in the IGM following its density
- Galaxies bright in Lyα are on the near side in general

RM+21c

Summary

The cross-correlation analyses between Lyα forest absorption and galaxies have been inestigated

✦ **Diversity** of cross-correlation functions among galaxy populations

- O3Es well trace the IGM density
- Although HI density of AGNs is generally high, its proximity regions are low due to the IGM HI photoionization
- LAEs have the strongest Lyα absorption at the center among all galaxy populations used in this study, though its reason has not been resolved
- LAEs locate a few Mpc away from overdensities of the IGM HI

✦ **Anisotropy** of HI density distribution only around LAEs

Thank you!