Variation in LAE-IGM HI Correlation at z≈2 Mapped by Subaru/HSC

and More from MAMMOTH-Subaru

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Collaborators

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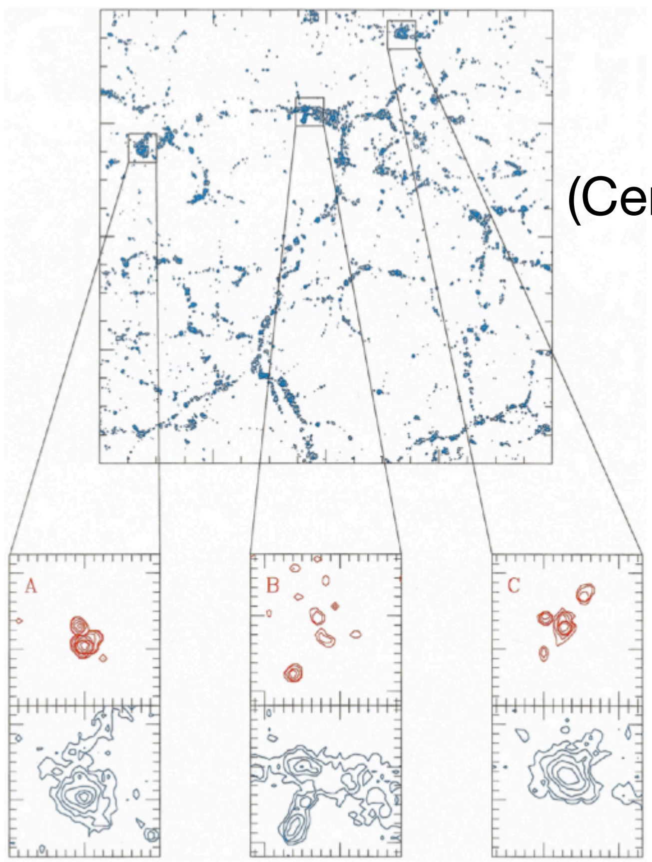
See more in

- Liang et al. 2021, ApJ, 907, 3
- Liang et al. 2023, in prep.
- Li et al. 2023, in prep.
- Zhang et al. 2023a, arXiv: 2301.07358
- Zhang et al. 2023b, arXiv: 2301.07359
- Ma et al. 2023, arXiv: 2301.07360

2023/02/02 Subaru UM2022 @NAOJ, Mitaka

Background: Structure Formation

- **Structure formation & evolution**



(Cen & Ostriker 2000)

Simulation

galaxy density

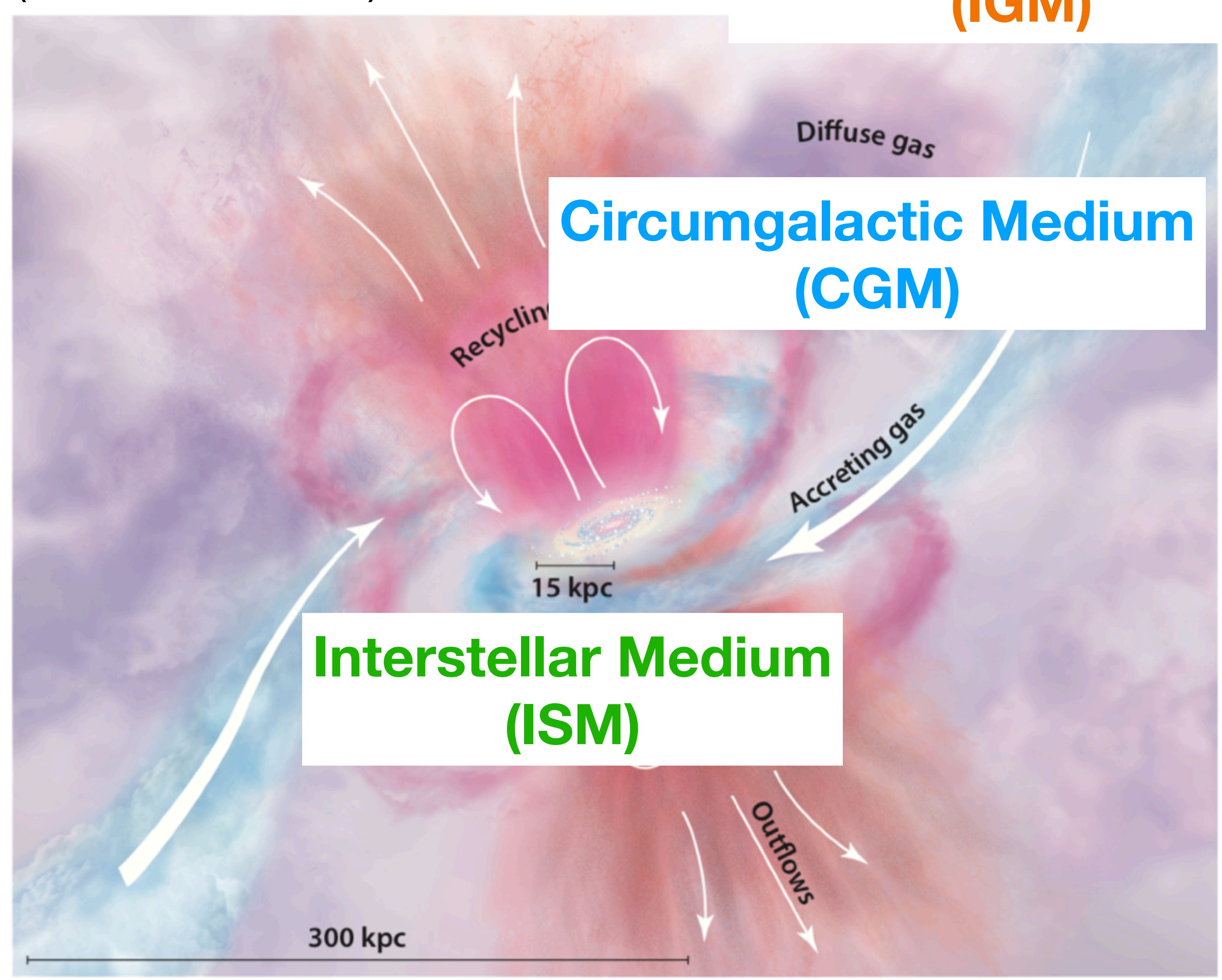
DM density

- Galaxies tend to form at the nodes of filamentary and sheet-like structures.

→ **Overdense regions** are essential laboratories.

(Tumlinson+2017)

Intergalactic Medium (IGM)



Circumgalactic Medium (CGM)

Interstellar Medium (ISM)

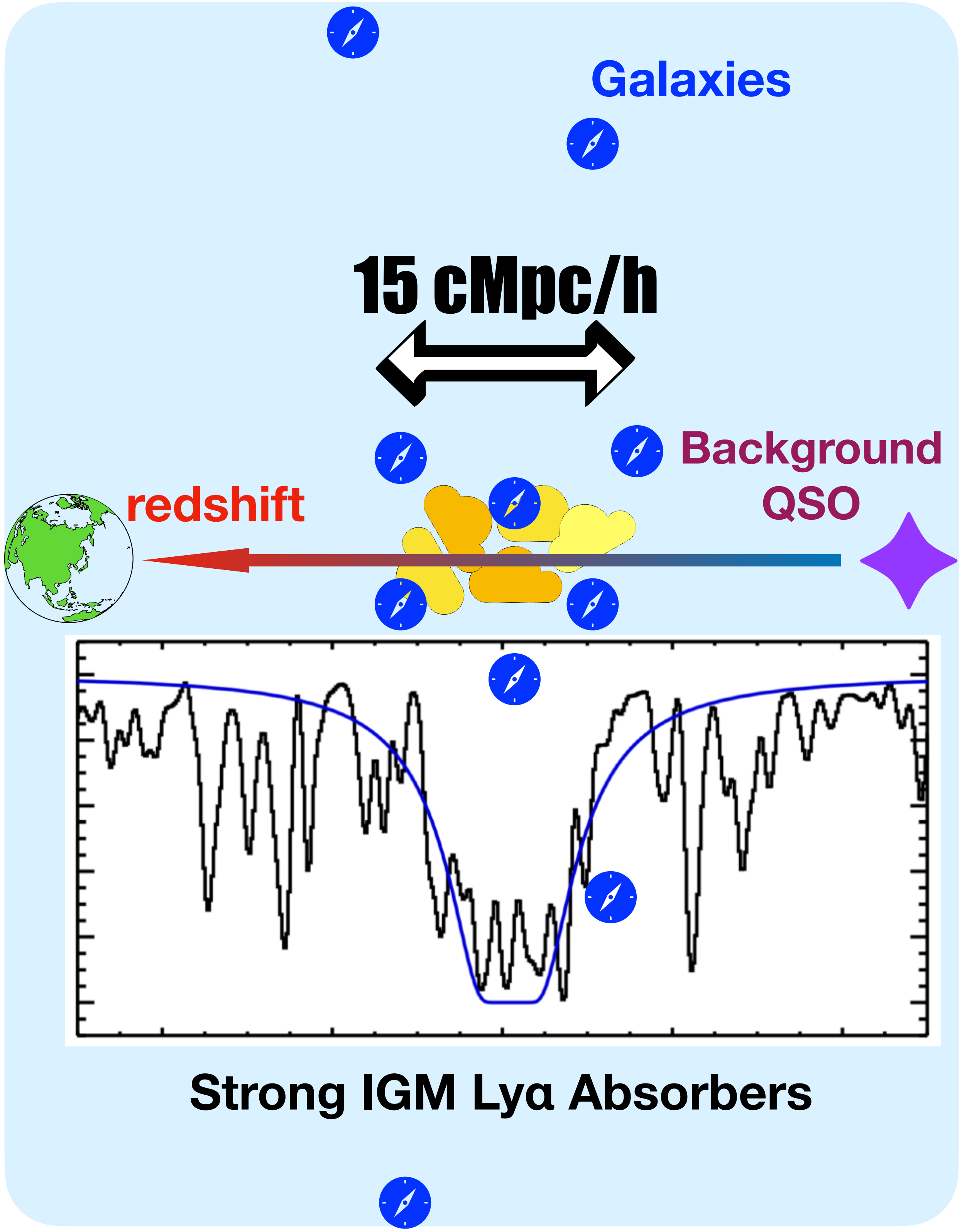
- **Mass assembly history of galaxy & gas?**

Should be correlated,
BUT there are:
→ Galactic in/outflow
→ SF/AGN feedbacks
→ Mergers …

Active@z~2-3

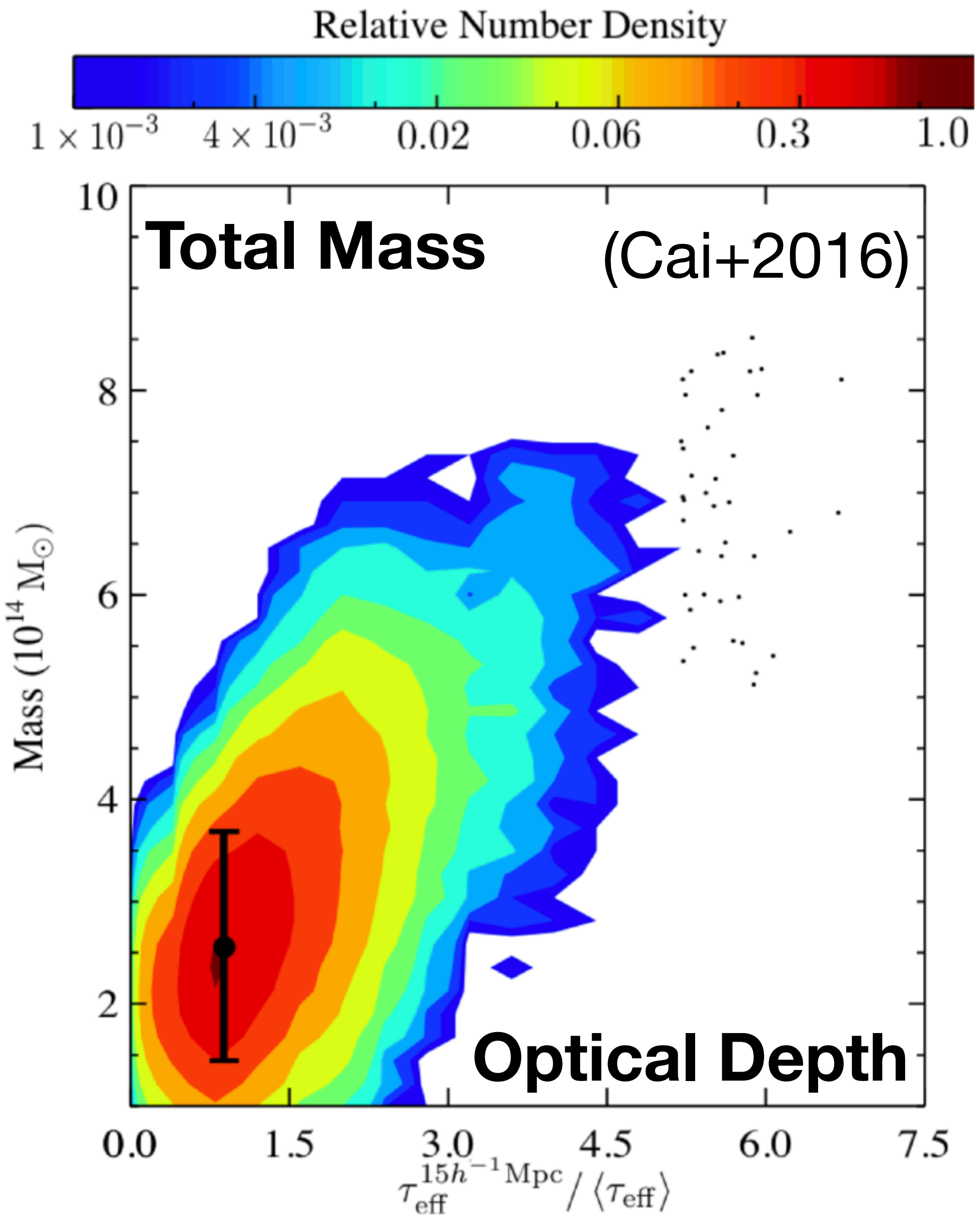
Background: Galaxy-IGM HI Correlation

- **MAMMOTH Project**



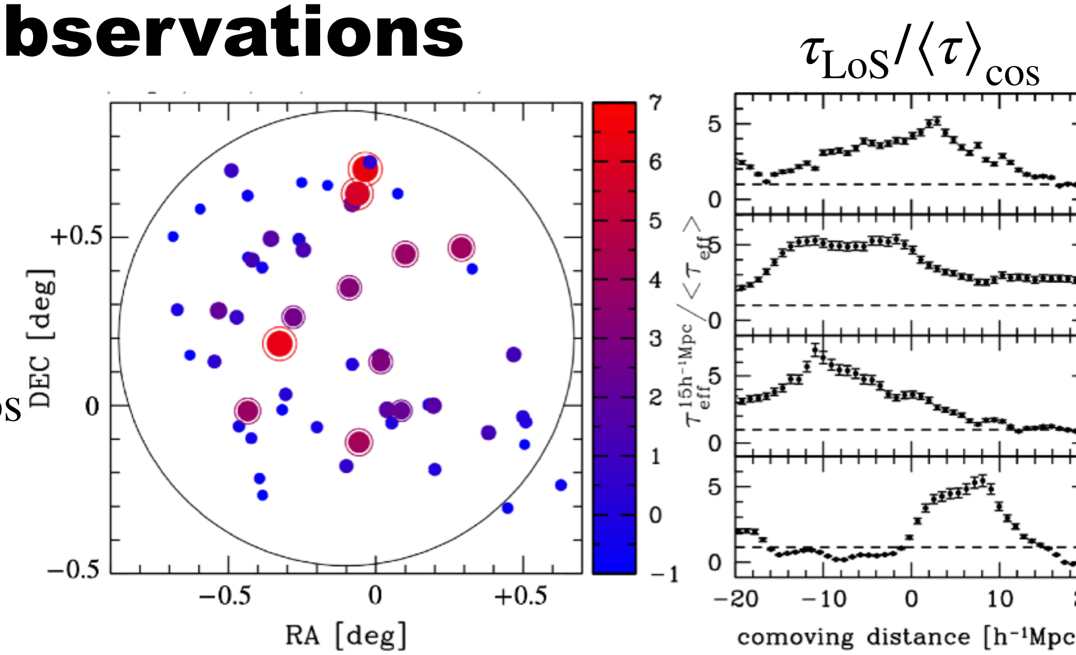
- **Simulations:** IGM and underlying structures (e.g., galaxies) are well correlated on scales of >15 h^{-1}cMpc.

→ **Strong IGM Lyα absorber effectively trace high-density region**



Data & Observation

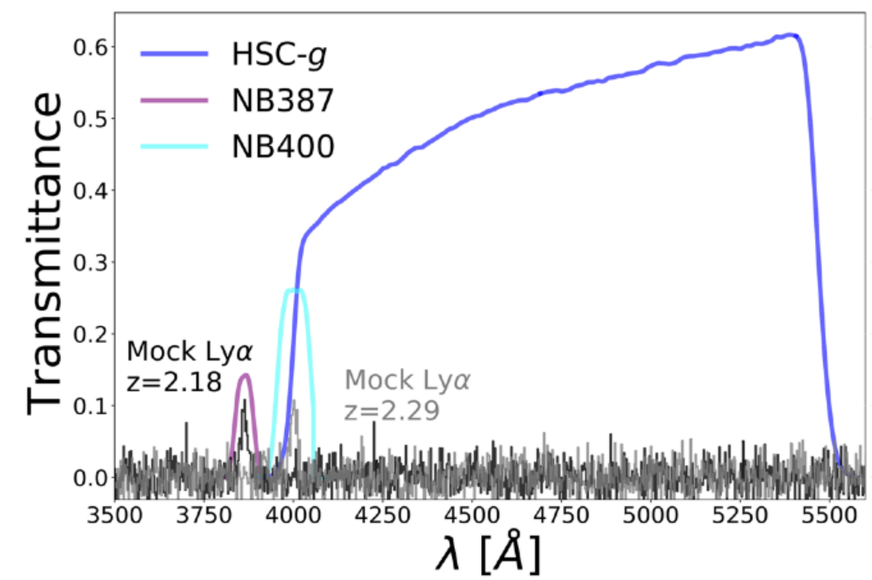
- **Subaru/Hyper Suprime-Cam (HSC) Observations**



  - **Field Selection**

    Mainly by containing LoSs with $\tau_{\rm LoS} > 3\,\langle\tau\rangle_{\rm cos}$

  - **Observation**
    - **Subaru/HSC FoV**:
      D=**1.5 deg ~ 150 cMpc** @z=2
    - **Long exposure** with NBs & HSC-g band
      ~3 hrs/field → 5σ Limiting Mag: NB387**~24.5**; NB400**~25.6**
      20-40 min/field → 5σ Limiting Mag: HSC-g**~26.6**



    - **Actual runs**

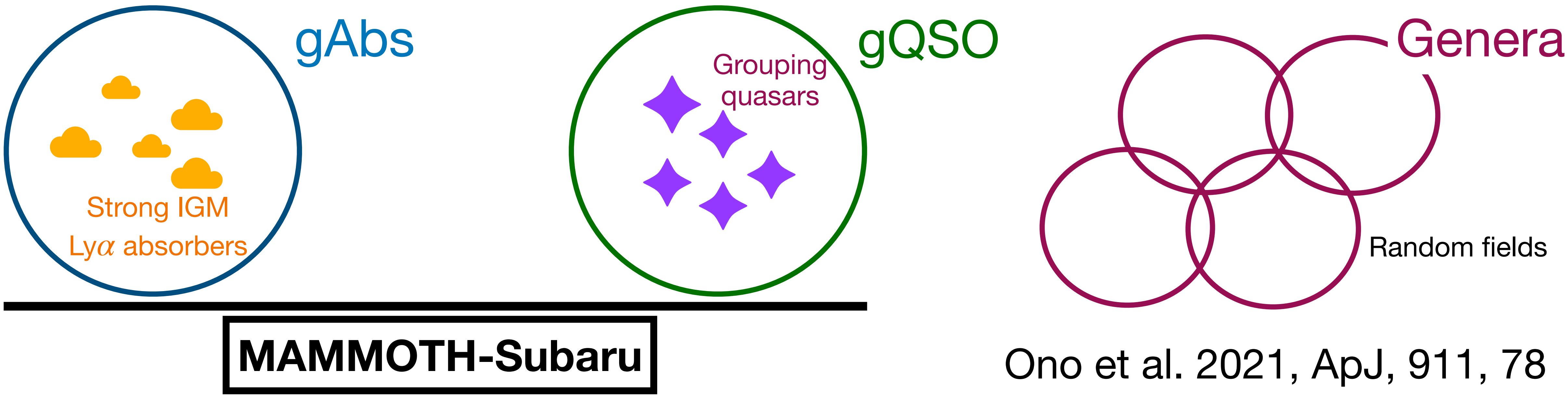
Proposal ID	PI	Allocated Time	Completion
S17B-041Q	N. Kashikawa (Tokyo)	18 hrs in Rank A	30%
S19A-TE288 (Keck)	X. Prochaska (UCO/Lick)	1 night	100%
S19B-CN TAP*	Z. Cai (Tsinghua)	2 nights	50%
S20A-108N	Y. Liang (SOKENDAI -> ICRR)	1 night	100%

* Data from TAP time are for grouping quasar fields

Sample Construction

We study galaxy—IGM HI correlation at $z = 2$ based on the largest samples of LAEs from Subaru/HSC & LoSs with Lyα absorption estimated from SDSS/BOSS in three different environments.

Lyα absorber-trace fields (4 pointings; NB387)	Grouping quasar fields (2 pointings; NB400)	General fields (11 pointings; HSC-SSP)



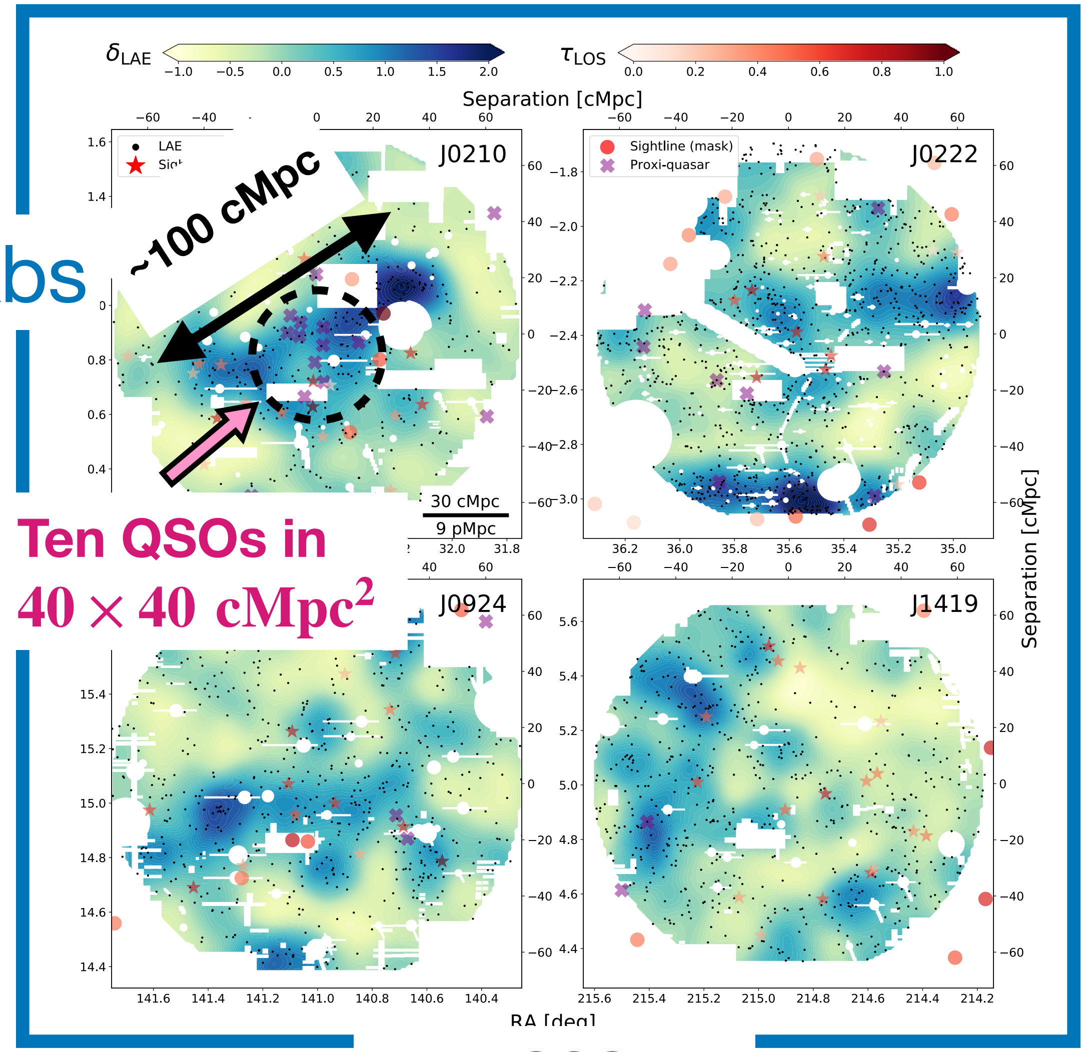
Ono et al. 2021, ApJ, 911, 78

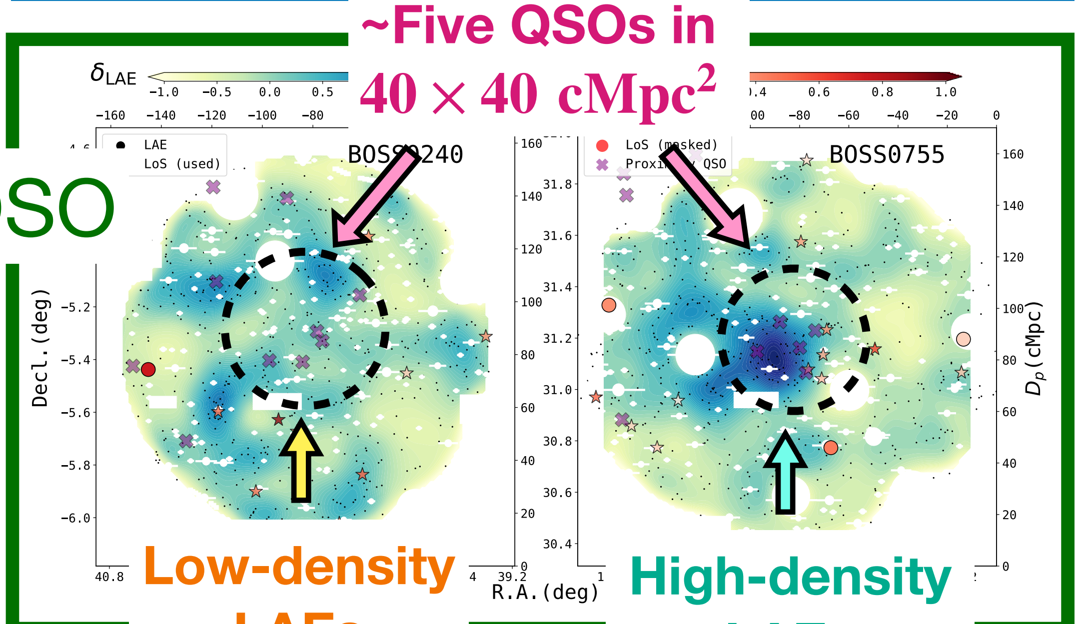
- **Distinctive to previous studies**

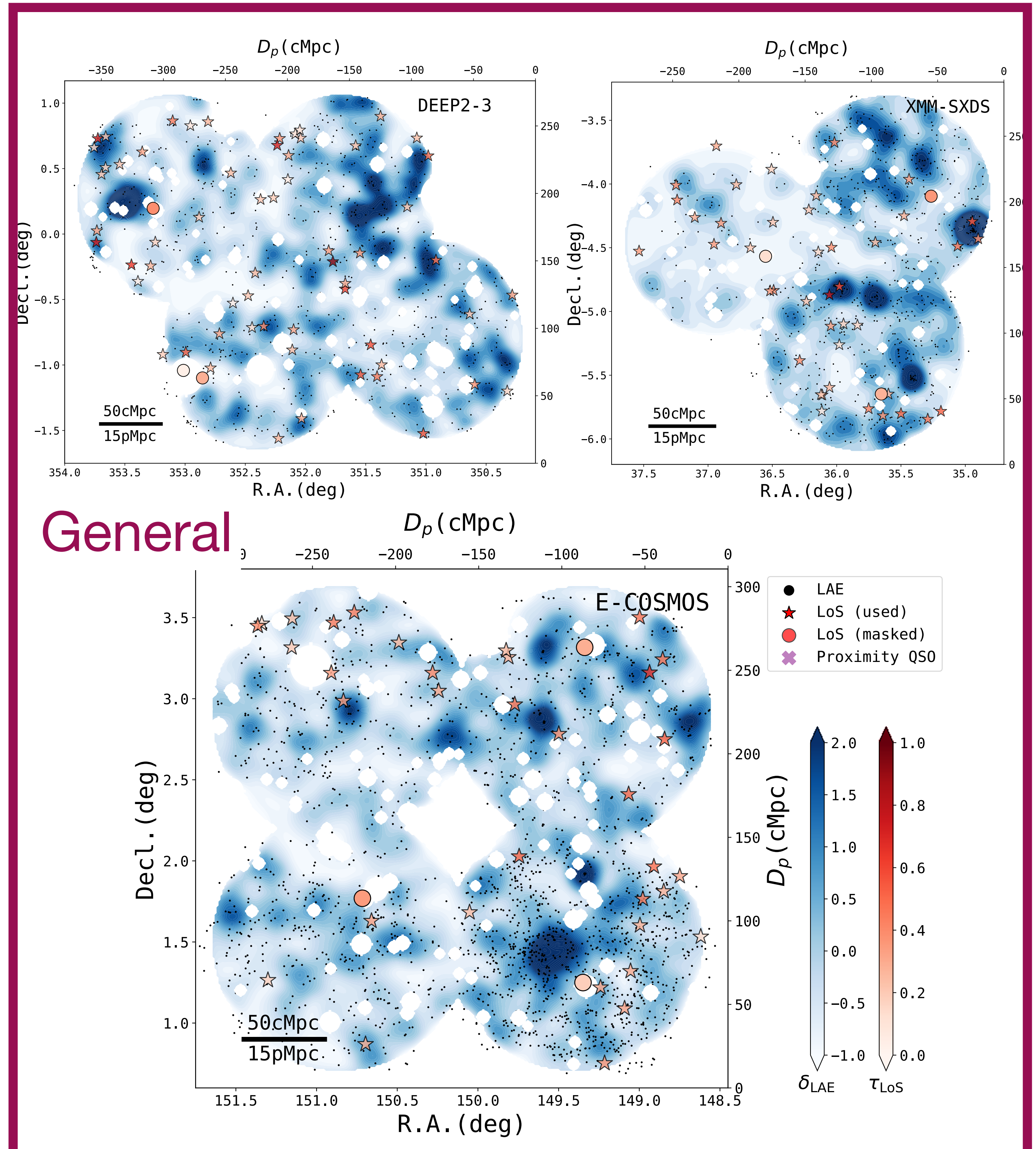
  - The largest LAE sample at $z \sim 2$ and ~15X LoSs & survey areas
  - Three distinct environments to address
  - Large-scale structures and their environments to 150 cMpc in one pointing

Subaru/HSC NB Imaging Data

- **LAE Overdensity Map**

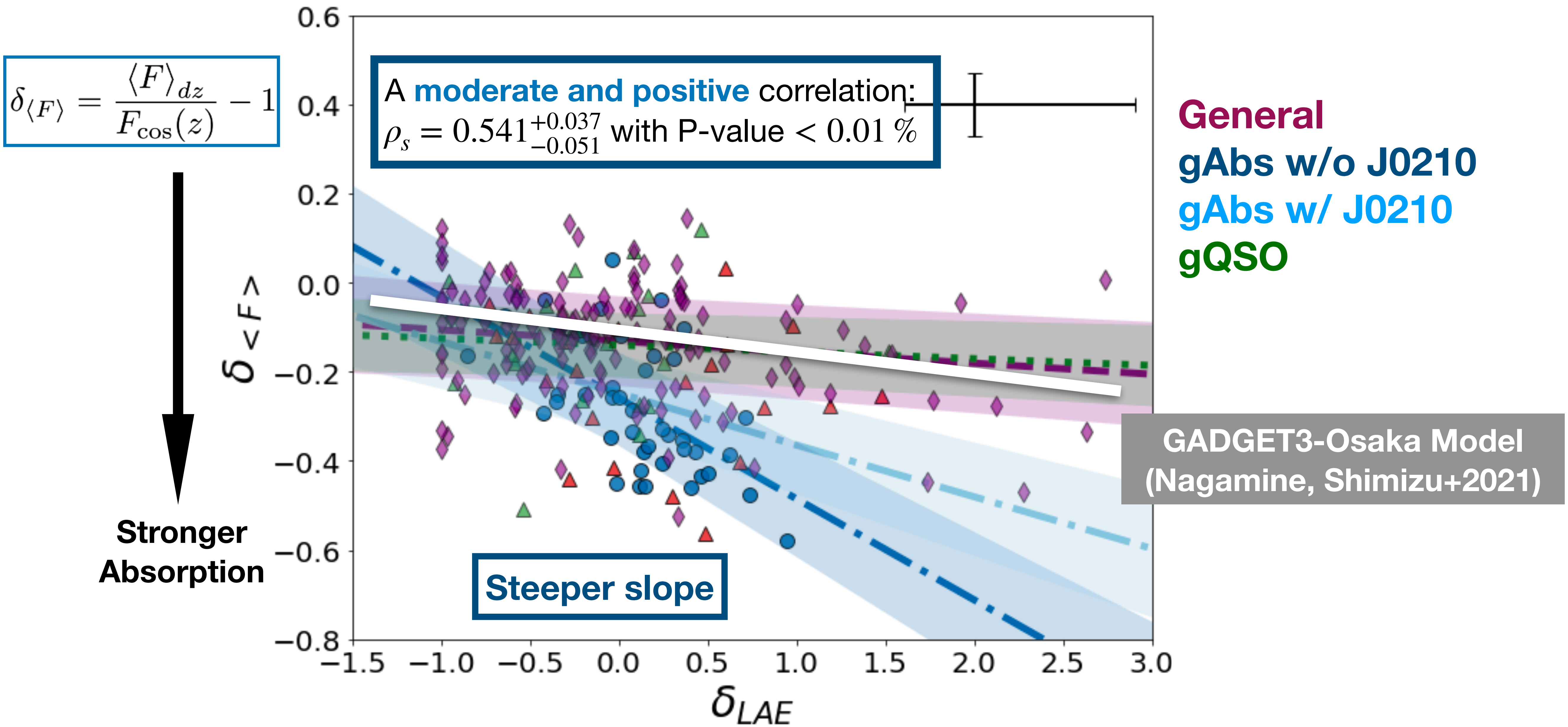






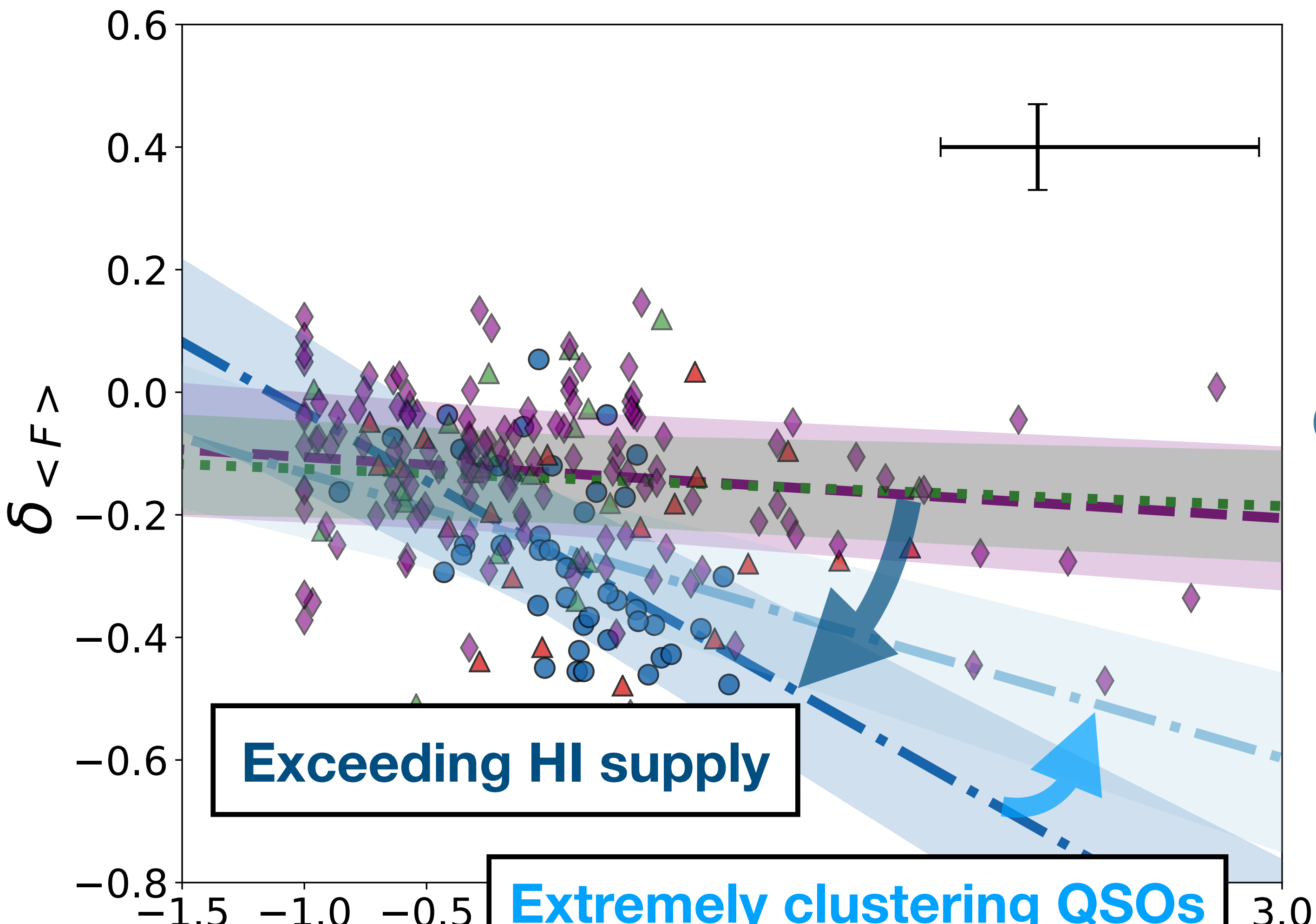
OD-OD Correlation

- **Correlation between δ_{LAE} and $\tau_{\mathrm{LoS,eff}}$ & $\delta_{\langle \mathrm{F} \rangle}$ (OverDen-OptDepth)**
  - A moderate and positive correlation in HI rich regions.
  - Grouping quasars → flatten relation: feedback effects?



Discussion: Underlying Physics

- **The positive correlation variation**



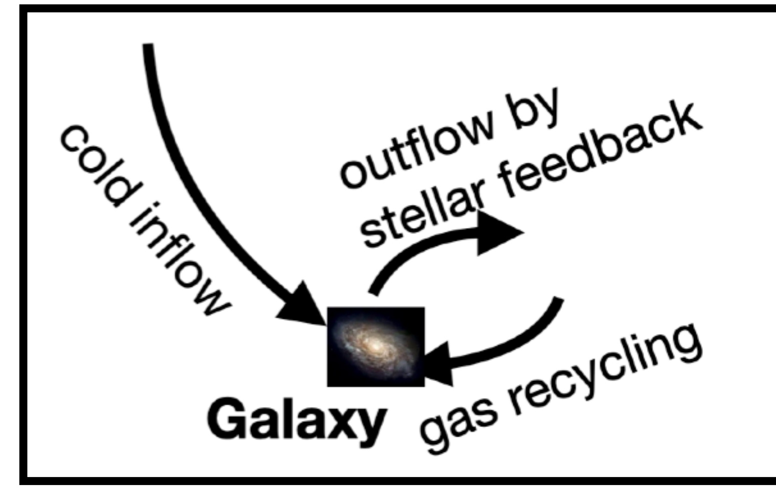
Exceeding HI supply

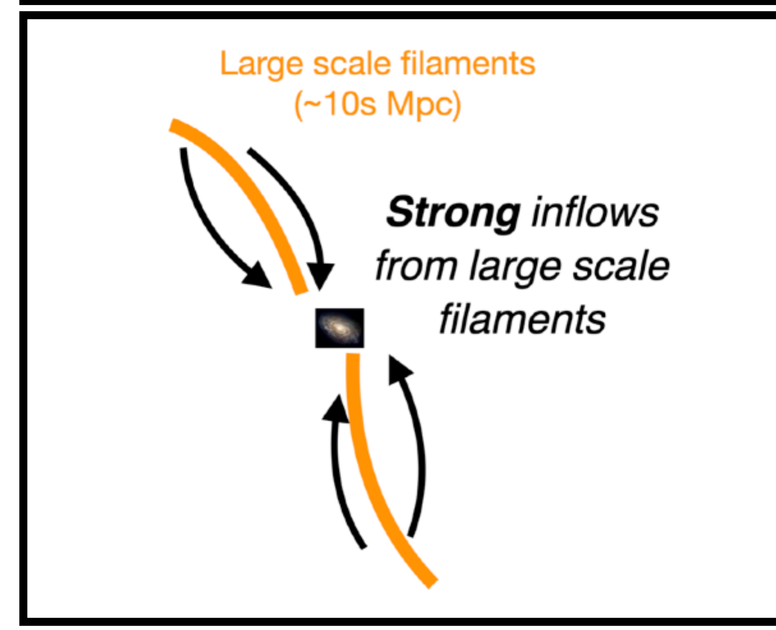
Extremely clustering QSOs
→ preheating?

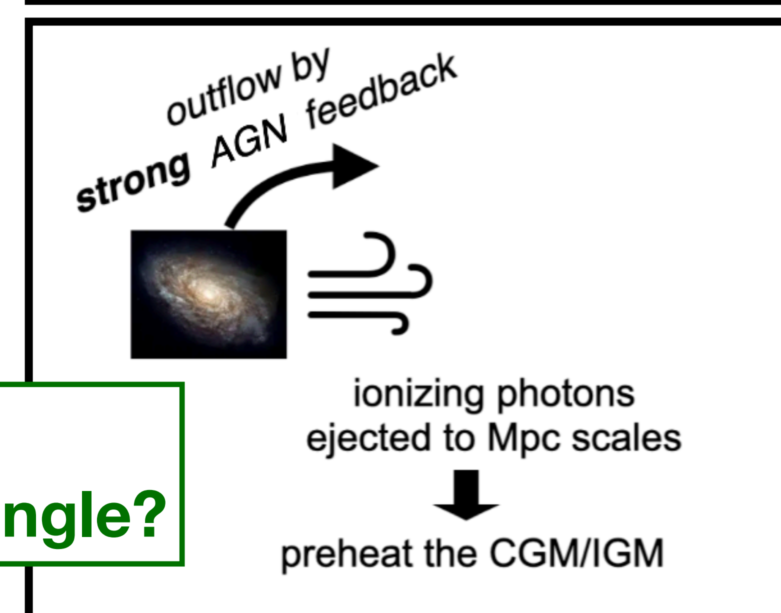
① General

② Exceeding Accretion

③ Preheating





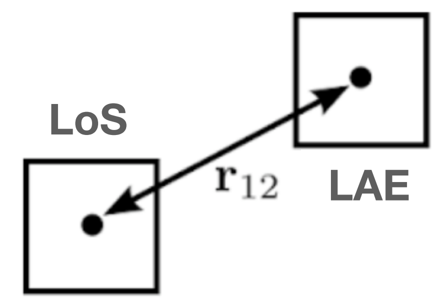


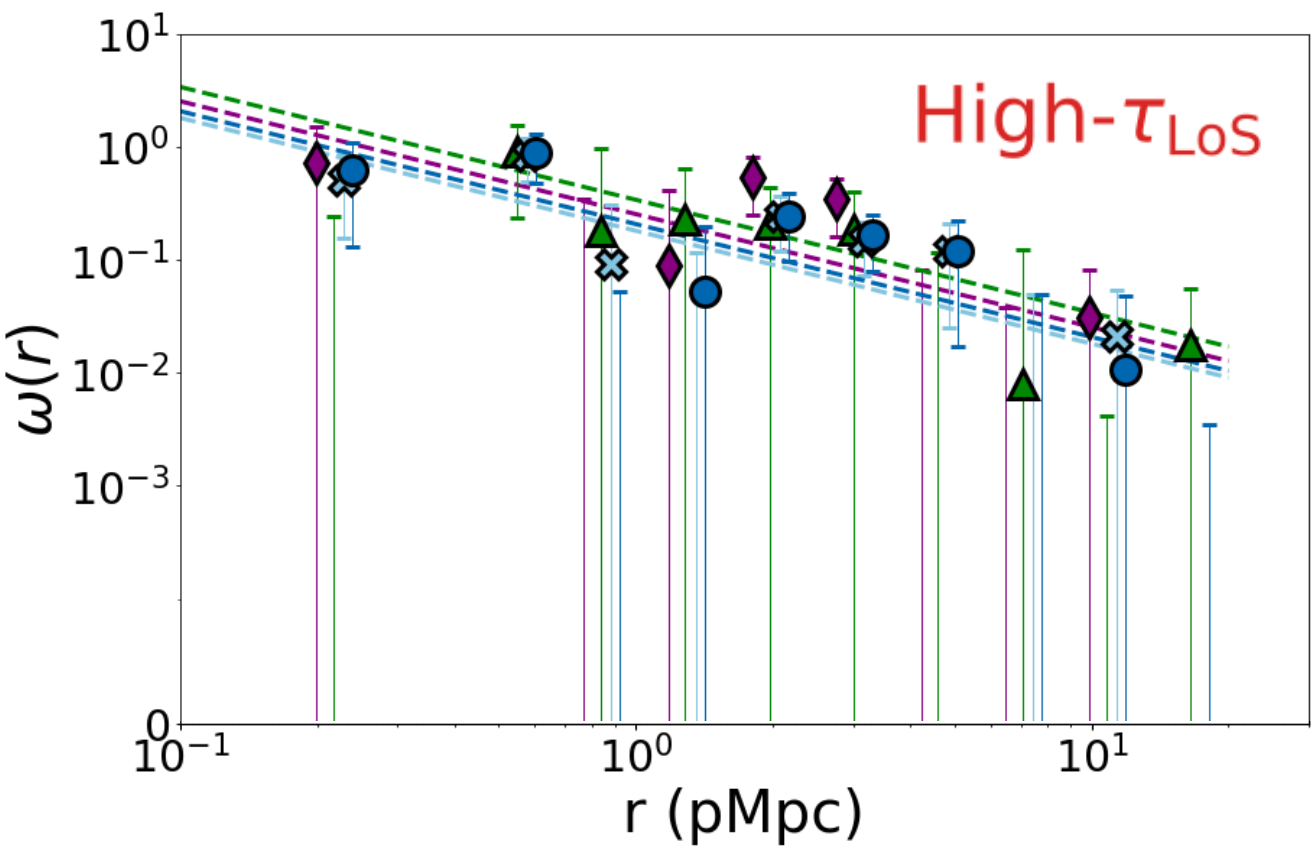
Local effects?
Dependent on opening angle?

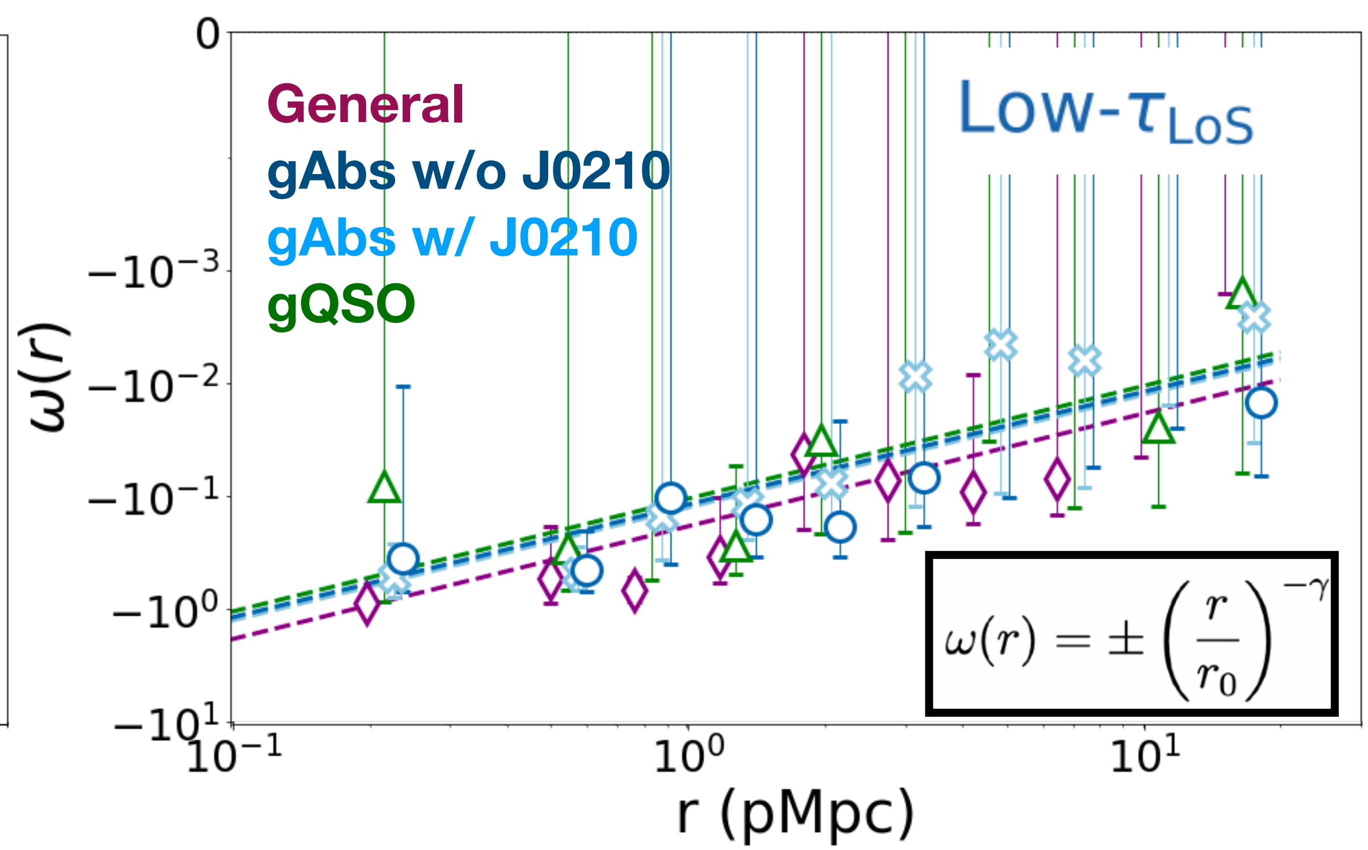
2P-CCF between LoS and LAE

- **Two-point cross-correlation function (2P-CCF)**
  - Constantly positive/negative signals
  - Signals broadly follow power-law relations

$$\Delta P = n^2 \left[1 + \xi\left(r_{12}\right)\right] \Delta\mathcal{V}_1 \Delta\mathcal{V}_2$$



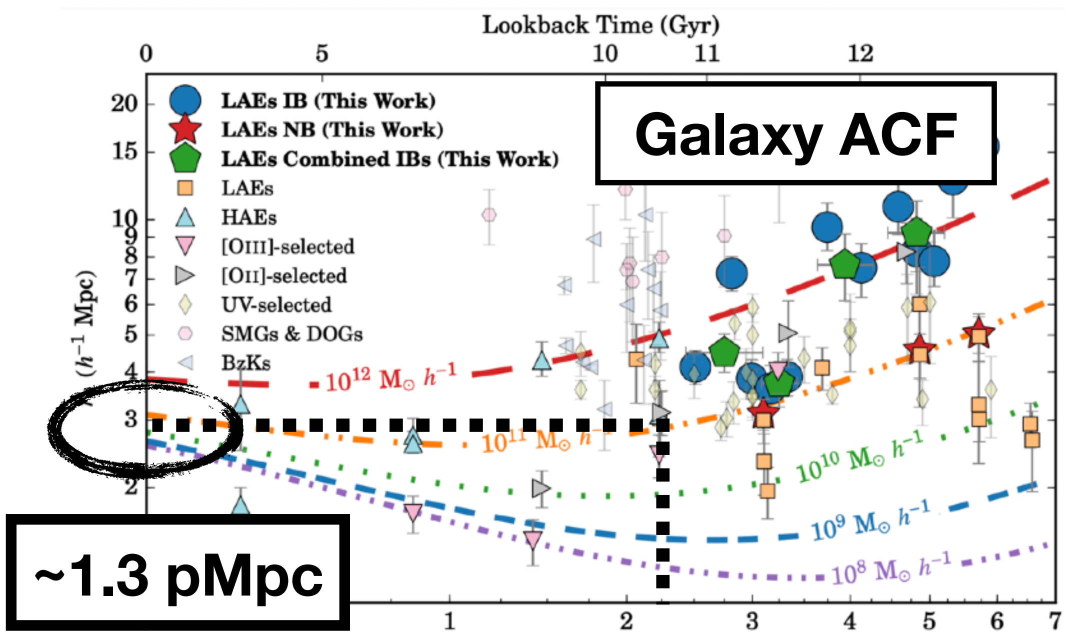




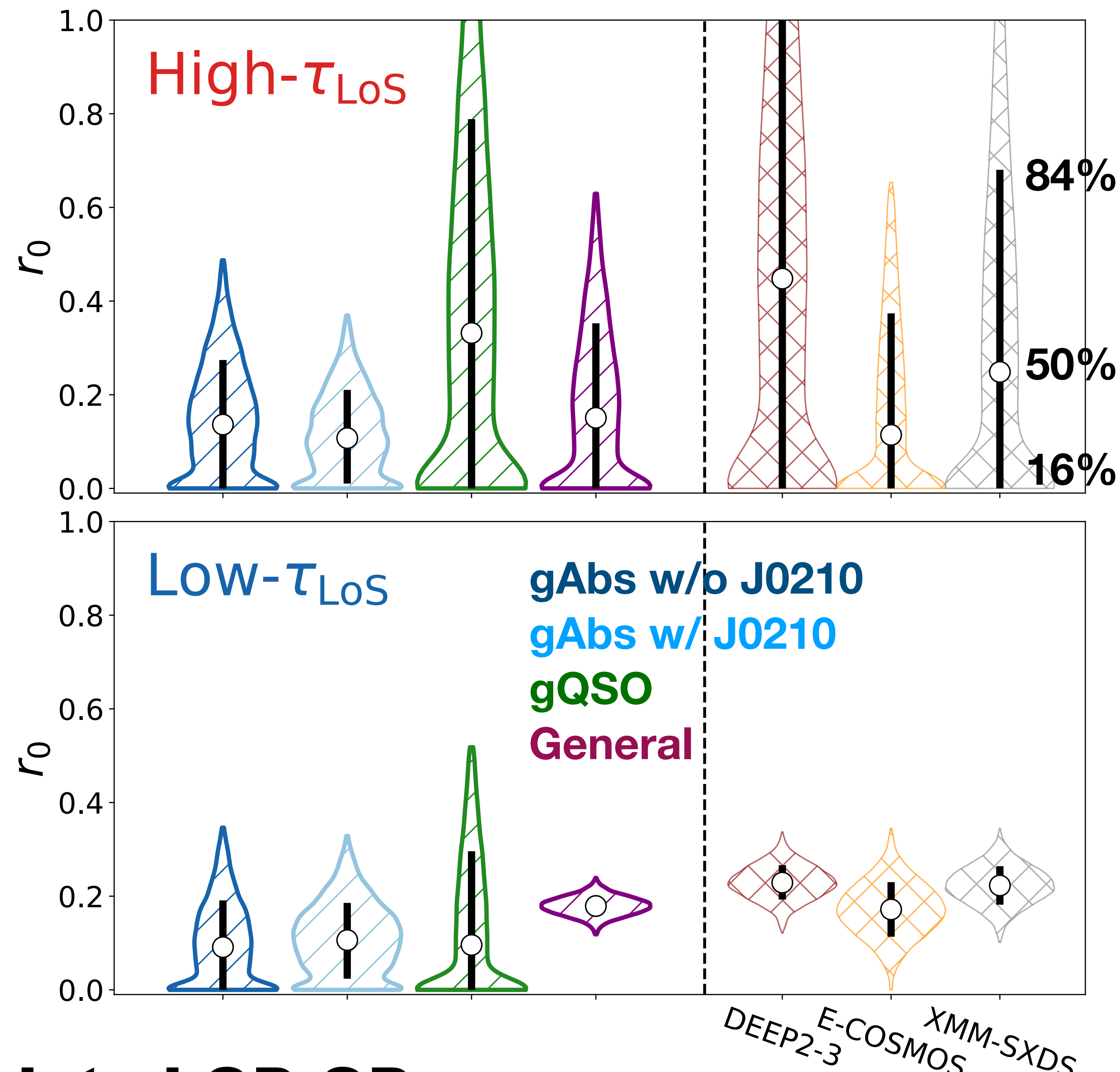
Galaxies tend to cluster around High-τ_{LoS} LoSs, but avoid low-τ_{LoS} LoSs.

2P-CCF between LoS and LAE

- **Two-point cross-correlation function (2P-CCF)**
  - r_0 fitting



(Khostovan+2018)



  - IGM HI is more smoothly distributed than galaxies

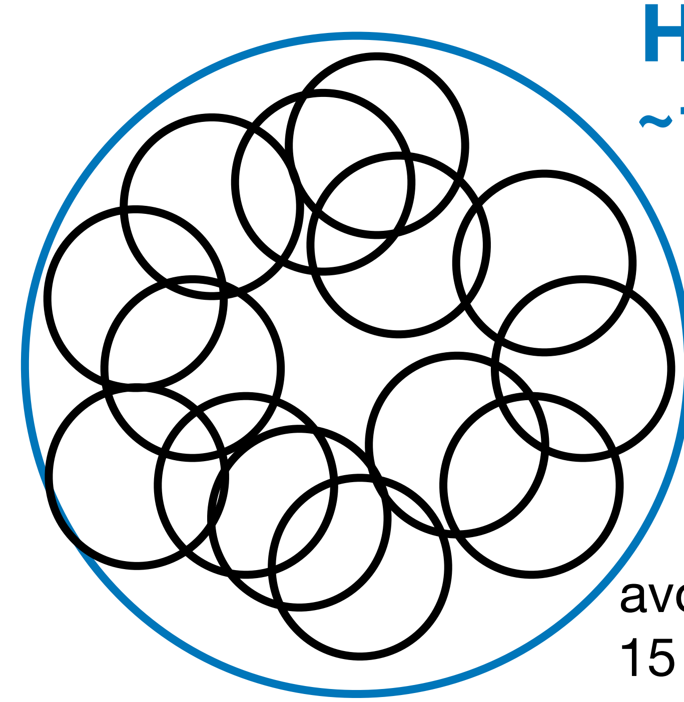
- **Similar power-law CCFs + Variated OD-OD**
  - Underlying halos dominate the galaxy—IGM HI correlations
  - Dense HI & quasar feedback play roles in secondary effects

More from MAMMOTH-Subaru

- **LAE LFs and Cosmic variance**

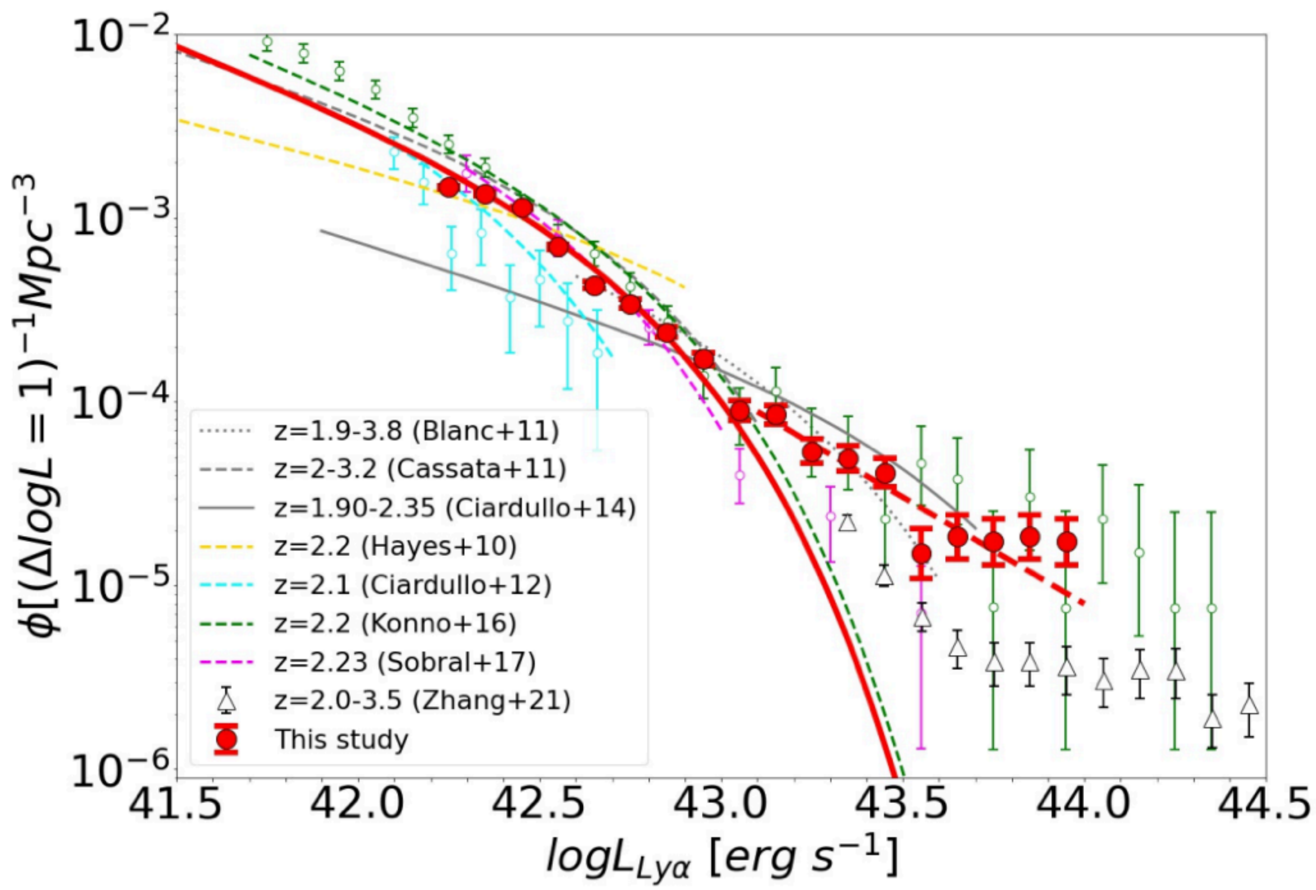
	α	L^* [10^{42} erg s^{-1}]	ϕ^* [10^{-4} Mpc^{-3}]	A_{tot} [deg^2]	V_{tot} [10^6 Mpc^3]
This study	-1.75 (fixed)	$5.18^{+0.43}_{-0.40}$	$4.87^{+0.54}_{-0.55}$	11.62	8.71
Blanc et al. (2011)	-1.7 (fixed)	$16.3^{+94.6}_{-10.8}$	$1.0^{+5.4}_{-0.9}$	0.047	1
Cassata et al. (2011)	$-1.6^{+0.12}_{-0.12}$	5.0 (fixed)	$7.1^{+2.4}_{-1.8}$	0.78	2.3
Ciardullo et al. (2014)	-1.6 (fixed)	$39.8^{+98.2}_{-16.4}$	0.36	0.044	1.03
Hayes et al. (2010)	$-1.49^{+0.27}_{-0.27}$	$14.5^{+15.7}_{-7.54}$	$2.34^{+5.42}_{-1.64}$	0.016	0.005
Ciardullo et al. (2012)	-1.65 (fixed)	$2.14^{+0.68}_{-0.52}$	$13.8^{+1.7}_{-1.5}$	0.36	0.17
Konno et al. (2016)	$-1.75^{+0.10}_{-0.09}$	$5.29^{+1.67}_{-1.13}$	$6.32^{+3.08}_{-2.31}$	1.43	1.32
Sobral et al. (2017)	$-1.75^{+0.25}_{-0.25}$	$3.89^{+1.73}_{-0.65}$	$9.13^{+3.09}_{-4.41}$	1.43	0.73

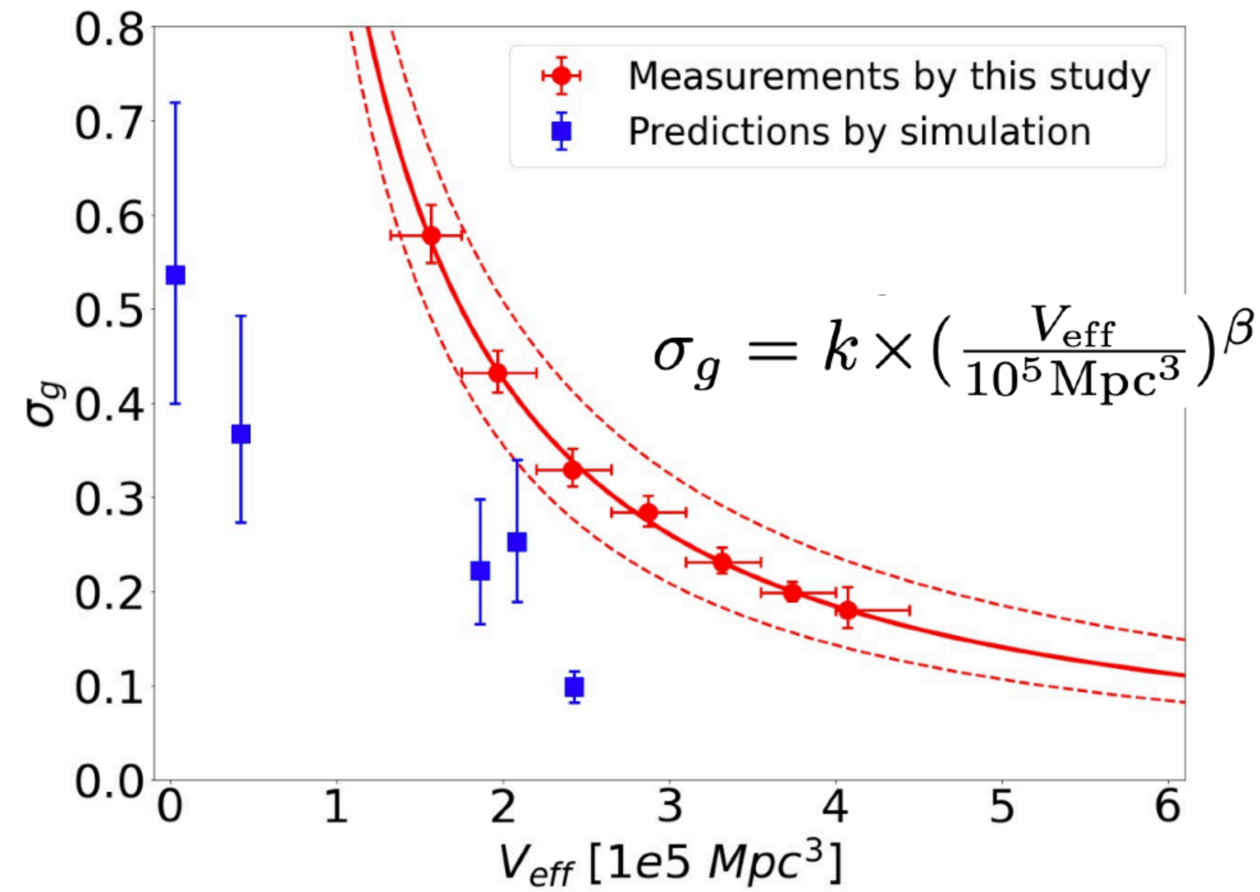
HSC FoV
~150 cMpc



Random Apertures

avoid the central 15 cMpc regions



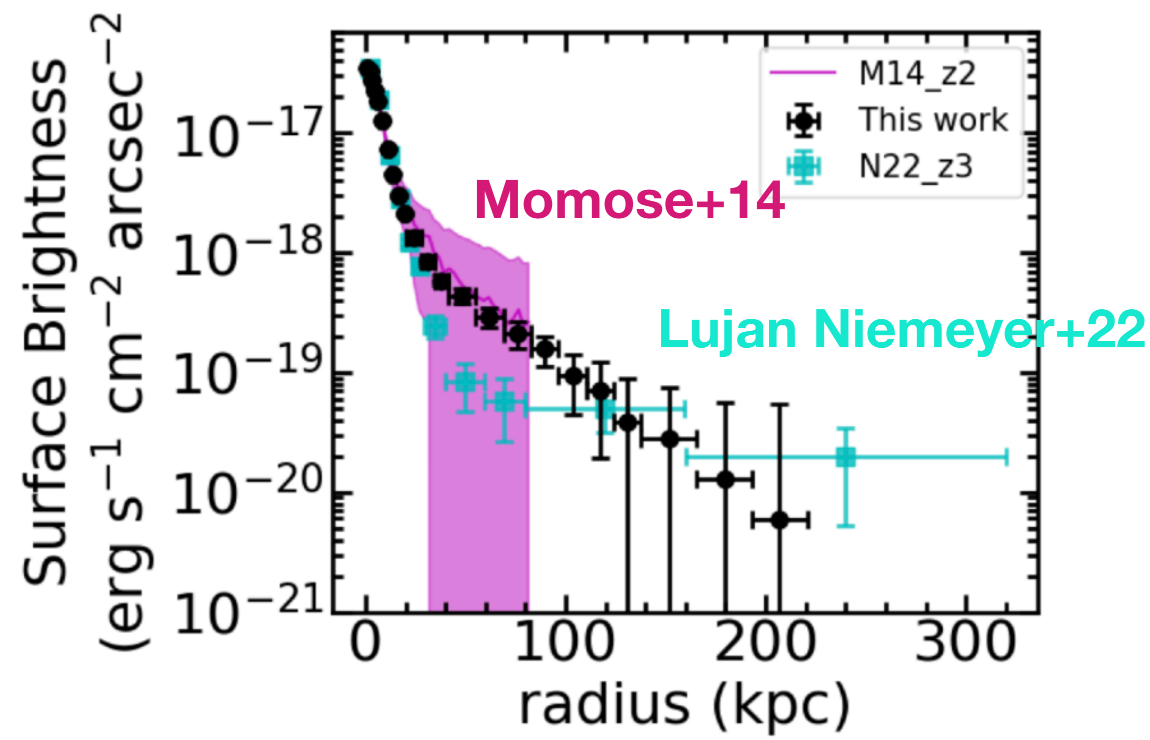


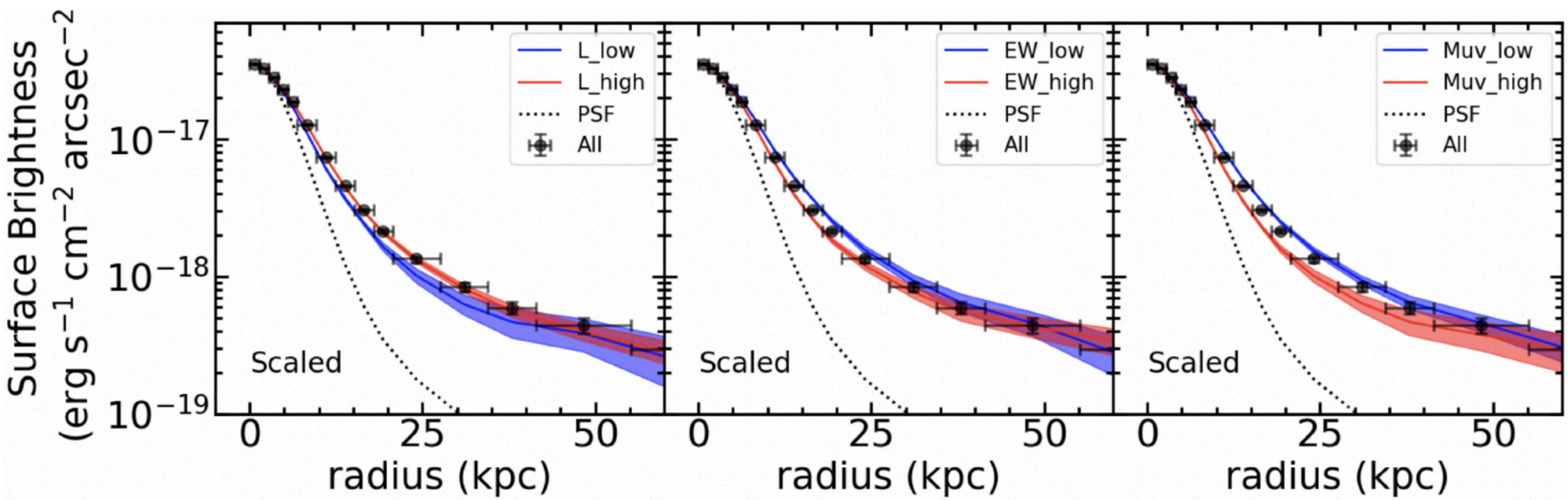
Ma et al. 2023, arXiv: 2301.07360

- Cosmic variance of LAE likely larger than general SFGs

More from MAMMOTH-Subaru

- **Extended Lya Halo from Stacking Images**
  - Lya from stacking ~3300 LAE images
  - LAEs are extended up to ~200 kpc at SB~10^{-20} erg s^{-1} cm^{-2} arcsec^{-2}
  - Higher $L_{\mathrm{Ly}\alpha}$, lower EW_0, and brighter M_{UV} cause more extended halos





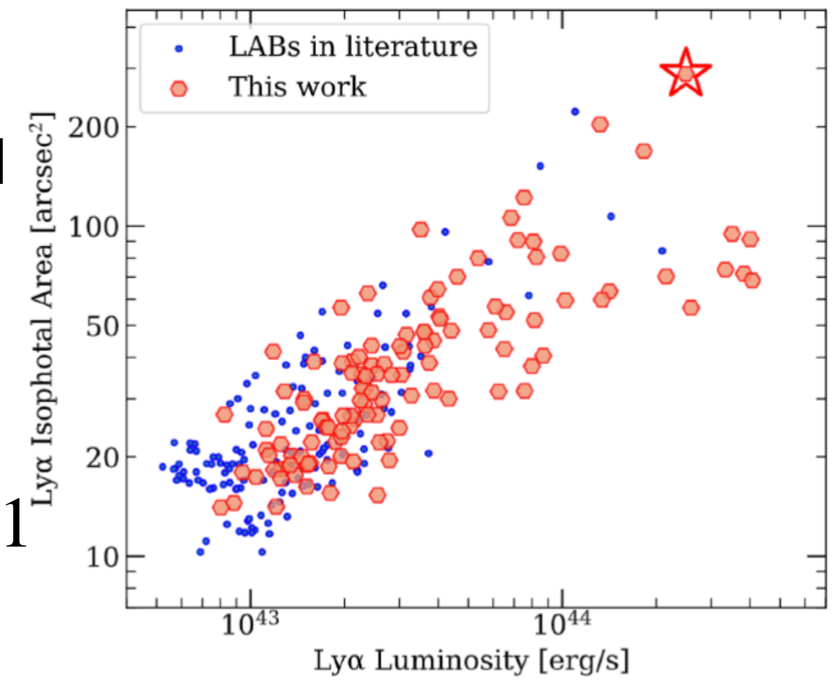
Zhang et al. 2023a, arXiv: 2301.07358

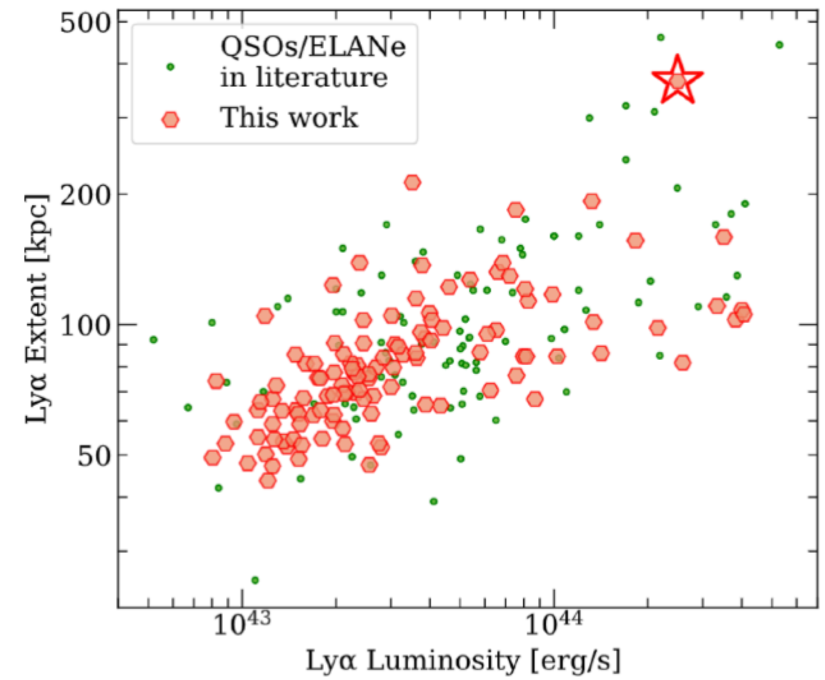
More from MAMMOTH-Subaru

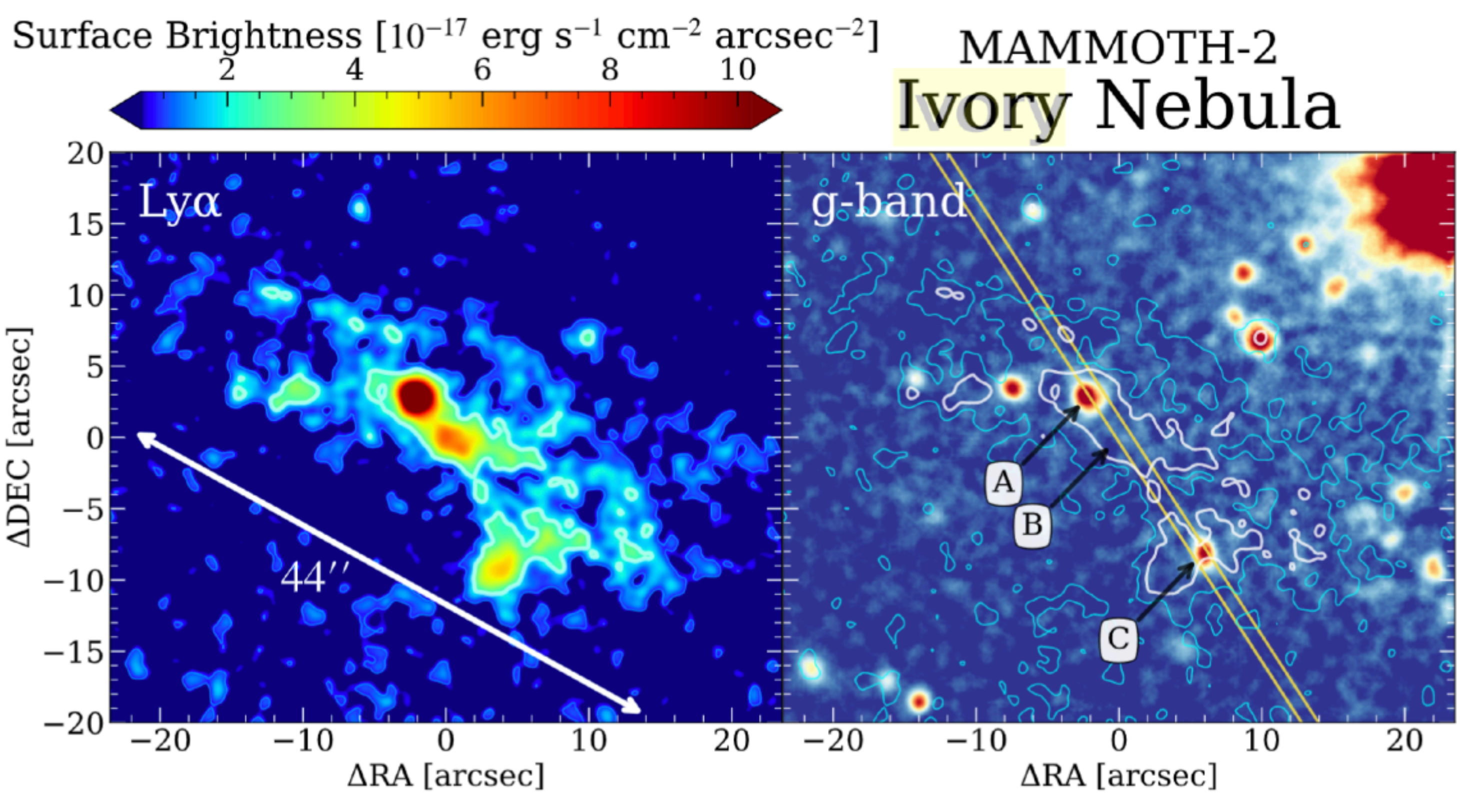
- **A Large Lyman-Alpha Blob (LAB) Sample**
  - 117 LABs
  - 7/7 gets spec confirmed w/ Binospec & IMACS
  - Most extended one (Ivory Nebula):

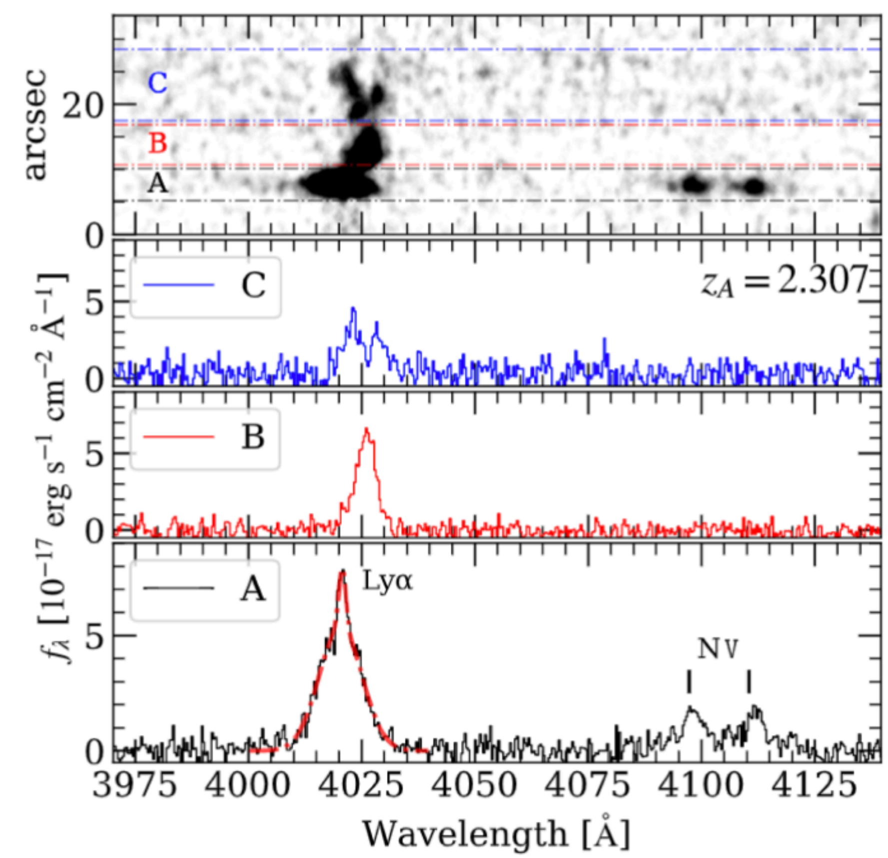
$$L_{\mathrm{Ly}\alpha} = 2.5 \times 10^{44} \text{ erg s}^{-1}$$

$$D \approx 365 \text{ kpc}$$









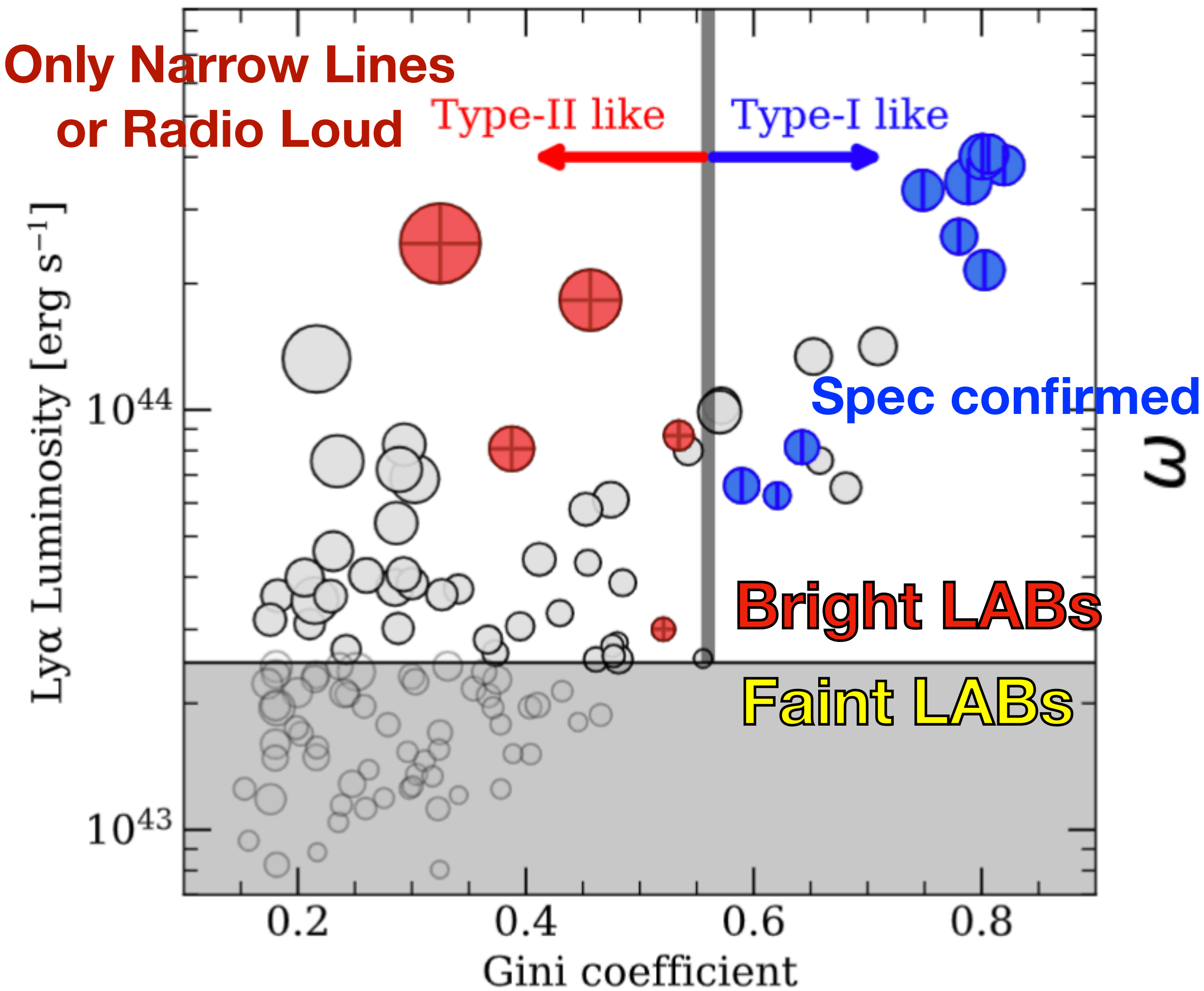
Li et al. 2023 in prep.

More from MAMMOTH-Subaru

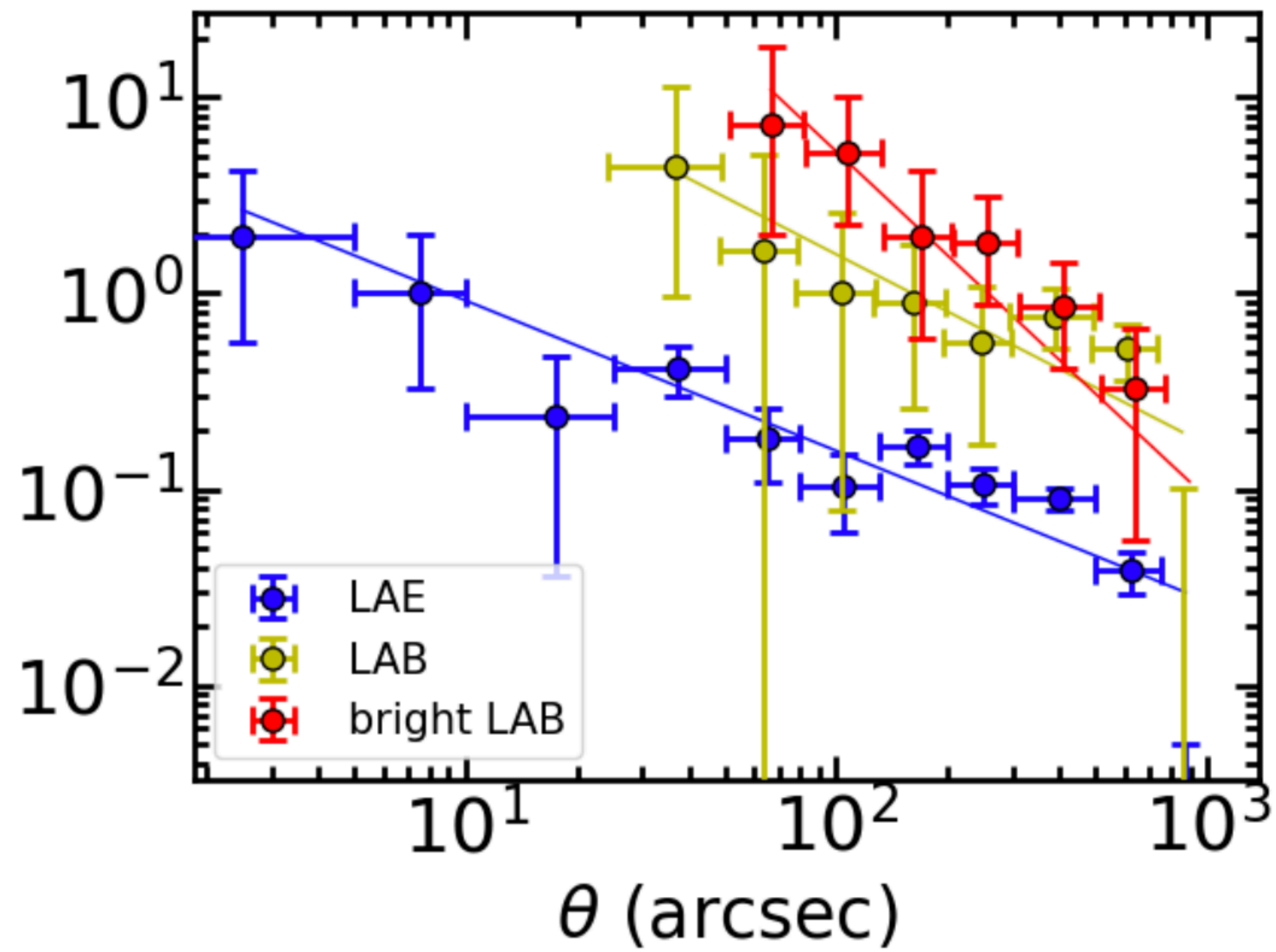
- **LAB Statistics: Gini Index and CCF**
  - Concentration quantified by Gini index

$$G = \frac{2\sum_{i=1}^{n} i p_i}{n\sum_{i=1}^{n} p_i} - \frac{n+1}{n}$$

  - 58/117 bright LABs ($L_{\mathrm{Ly}\alpha} > 10^{43.4}$ erg s^{-1})
  - Bright LABs are more clustered than normal LABs and LAEs
  - LABs have x10 larger galaxy bias than LAEs -> strong variance



Li et al. 2023 in prep.



Zhang et al. 2023b, arXiv: 2301.07359

Summary

In this work, we study galaxy—IGM HI correlation at $z = 2$ based on the largest samples of LAEs from Subaru/HSC & LoSs with Lyα absorption estimated from SDSS/BOSS in three distinct environments.

- **Take Home Message**
  - **Moderate and positive correlation between LAEs and IGM HI**
  - **Existence of variation:**
    - LAE overdensity is more sensitive to IGM HI absorption in large-scale HI-rich environments.
  - **Underlying halos dominates the correlation**
- **And More about MAMMOTH-Subaru**
  - We can test the cosmic variance effects on LAE LFs.
  - We find the extended Lya emission up to 200 kpc by stacking NB imaging over 3300 LAEs.
  - We construct a large and homogeneous LAB catalog including 117 LABs, which is powerful to detect unique ELAN and do statistics.