Lyα Emission at $z\sim5-14$: Evolution of the Lyα LF and a Late Sharp Reionization

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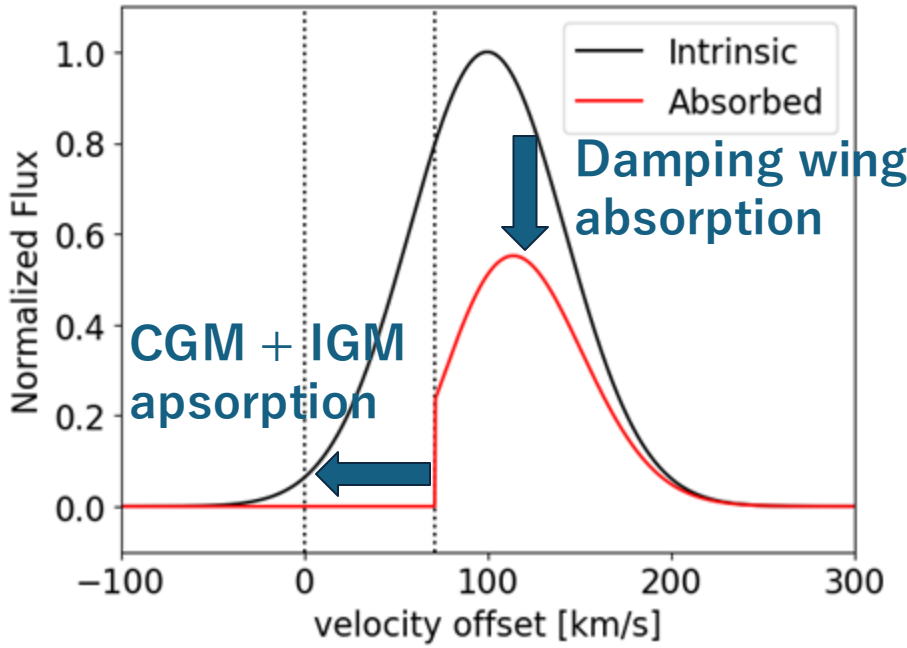
Kageura+25 ApJS in press (arXiv: 2501.05834)

Introduction

Ly α emission
→ probe of reionization history at high-z

Ly α line profile



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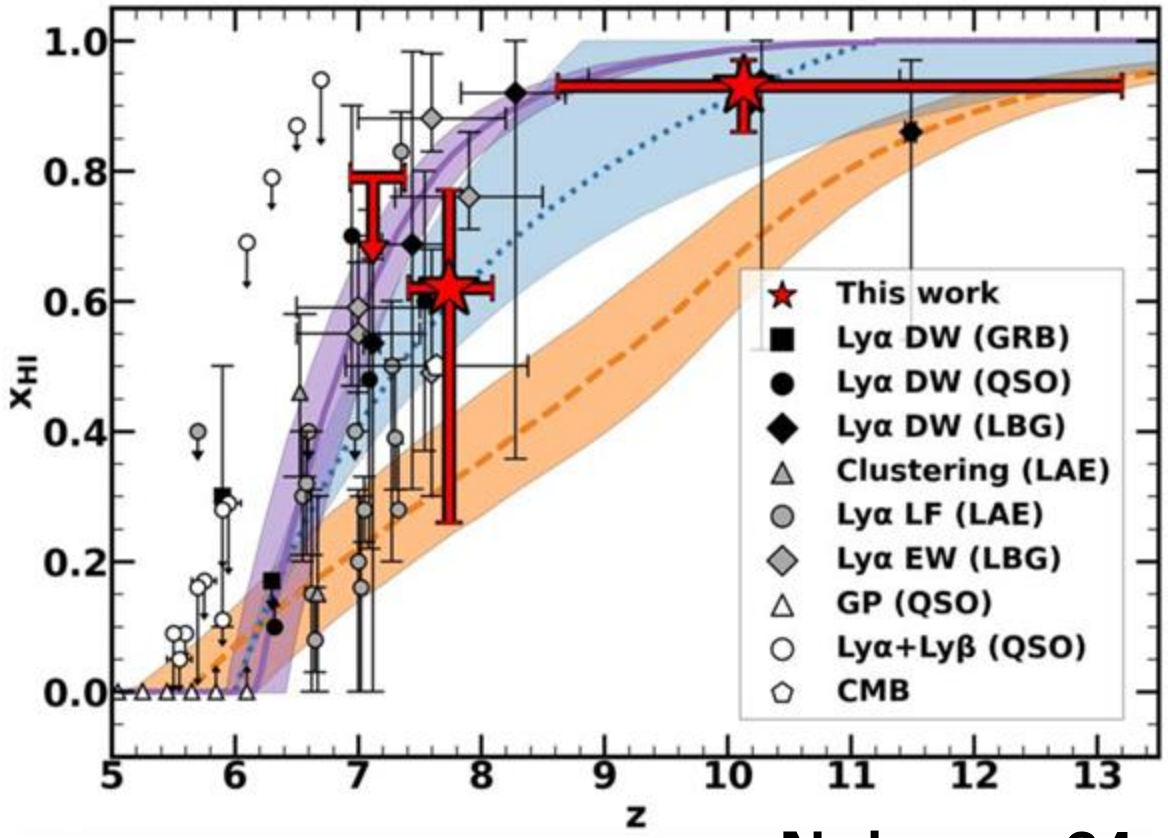
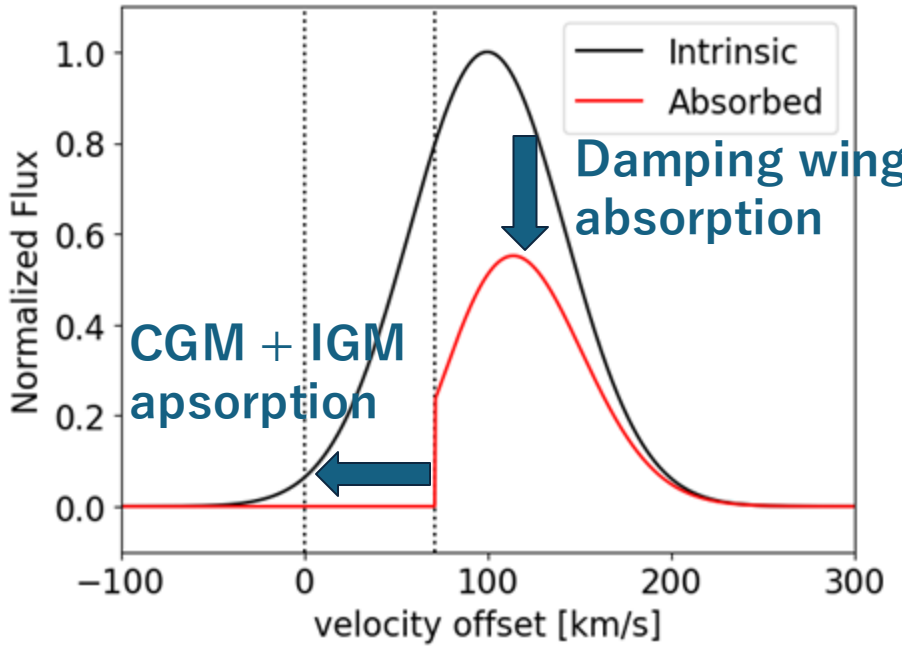


Nakane+24

Ly α line profile



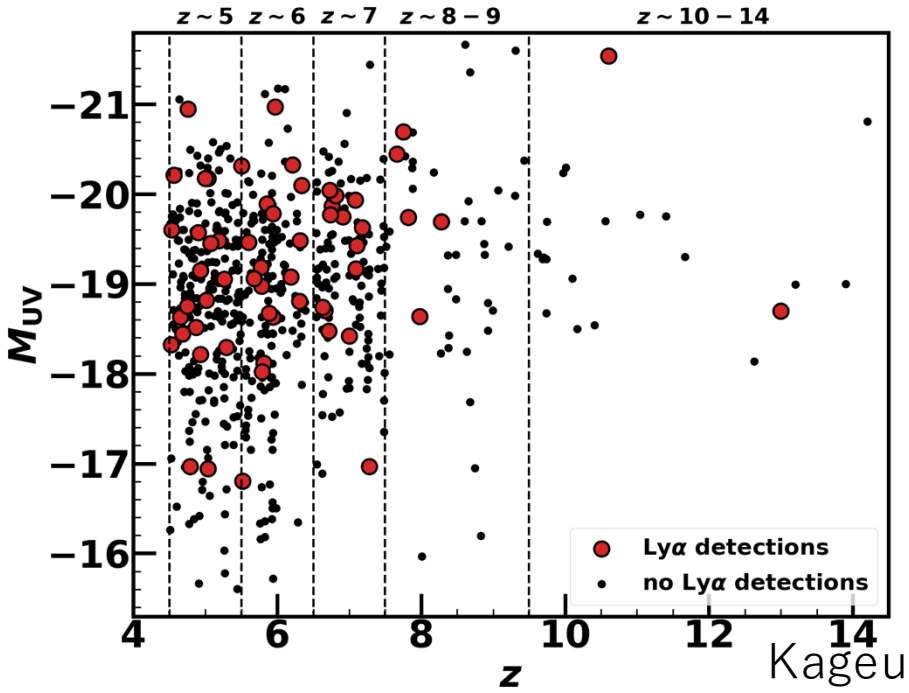
Previous works (e.g., Nakane+24, Tang+24, Jones+25):
$\sim 50-200$ galaxies at $z \sim 7-13$

This work:
largest sample (~ 600 galaxies) at $z \sim 5-14$

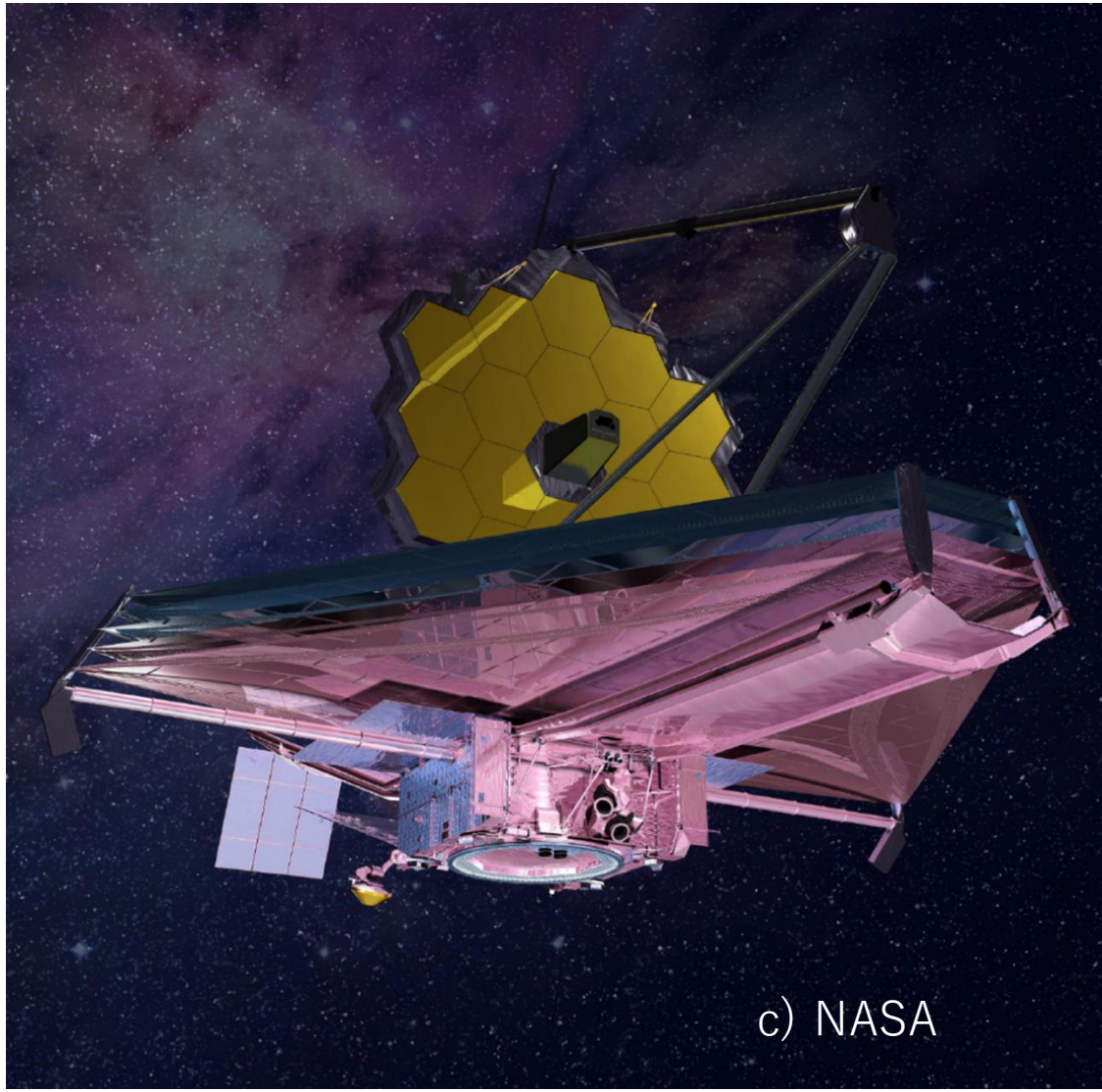
Observational Data

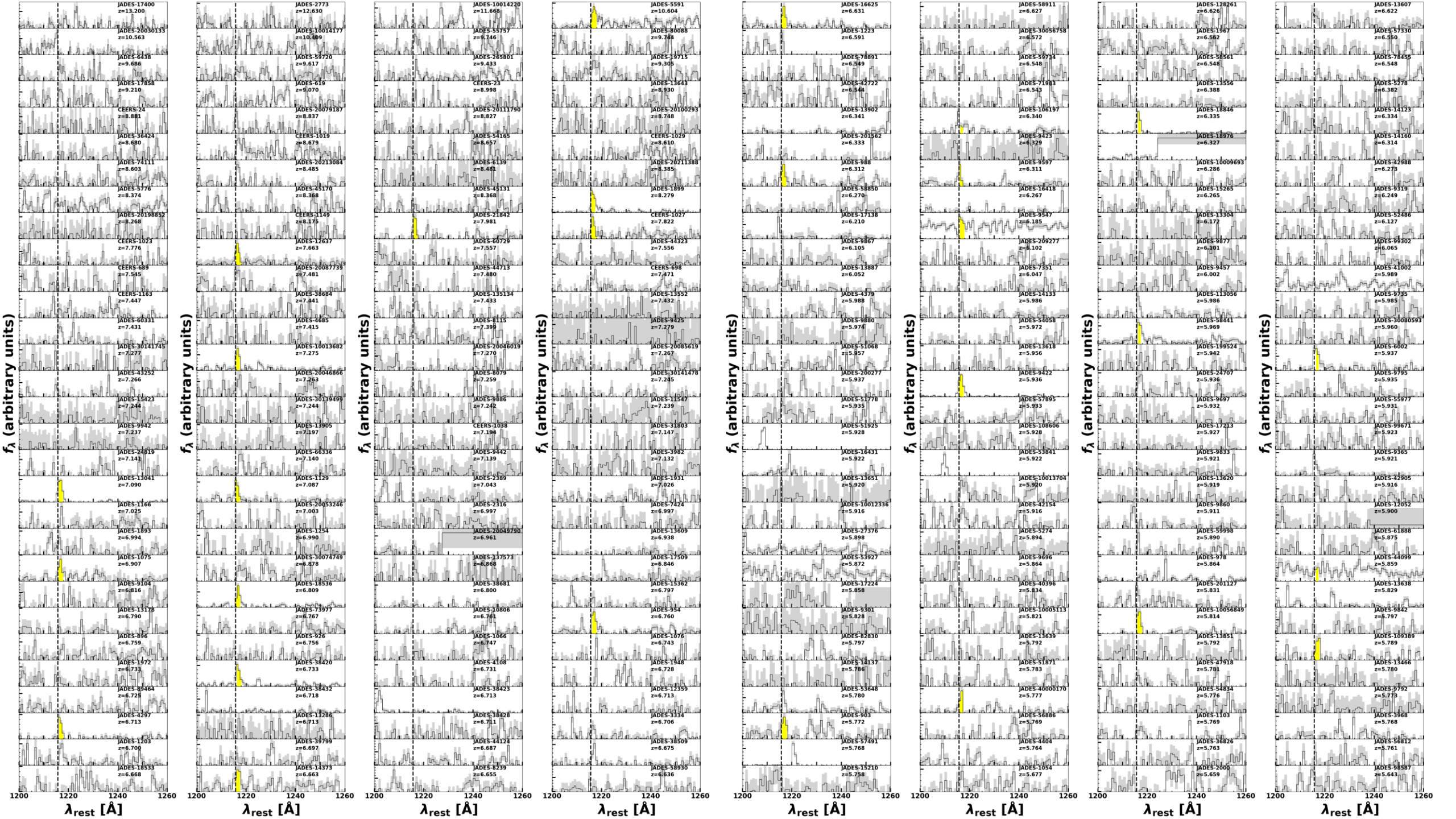
- JWST NIRSpec spectra
- JADES (D'Eugenio+24), CEERS (Finkelstein+23), GLASS (Treu+22), GO 1433 (Hsiao+24), DDT 2750 (Arrabal Haro+23)→2565 galaxies
- $z > 4.5$ w/ rest 1216 Å spec

→ **586 galaxies** ($z = 4.5 - 14.2$)



Kageura+25

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f_λ (arbitrary units)
$\lambda_{\rm rest}$ [Å]
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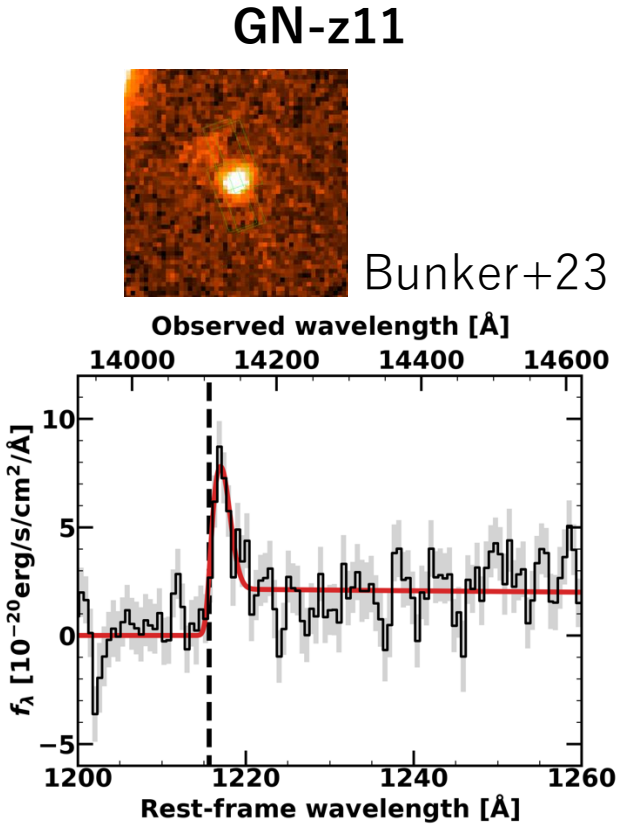
1220
1240
1260

Ly α Equivalent Widths (EWs)

Ly α EW measurements or upper limits



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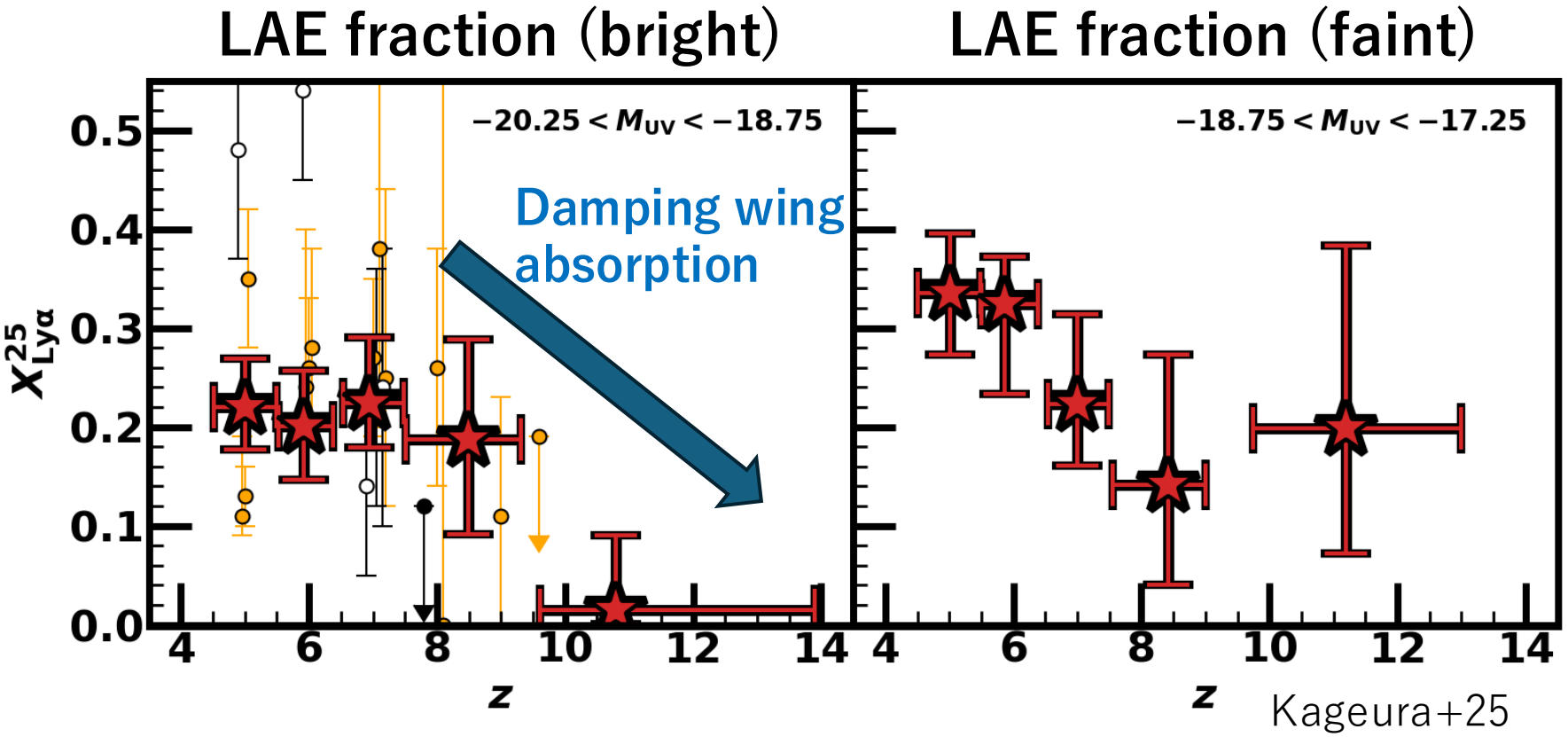

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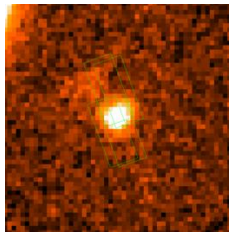
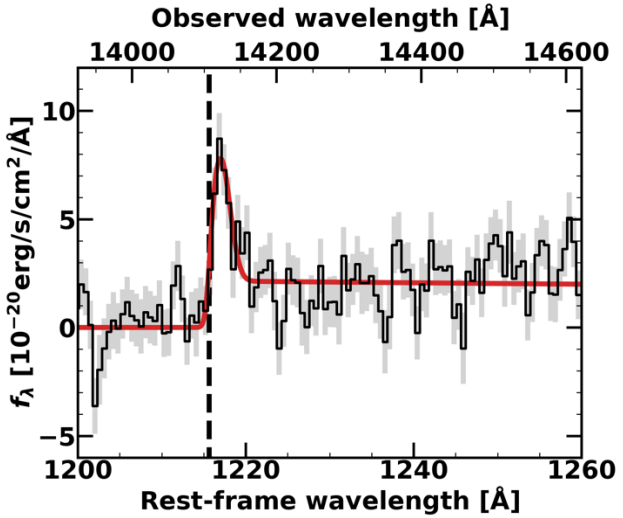
GN-z11



Bunker+23

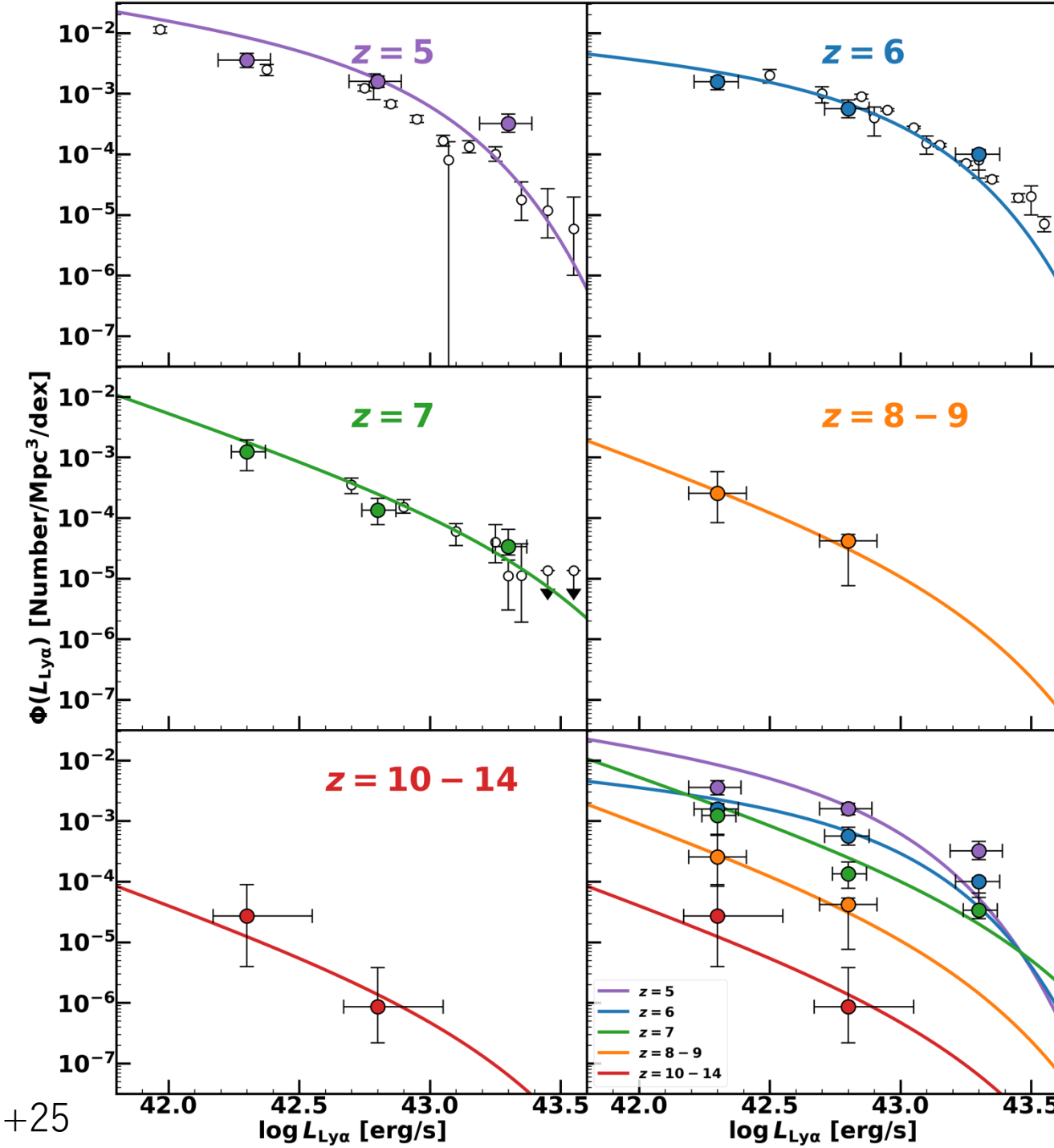


Ly α LFs

$$\Phi_{\mathrm{Ly}\alpha}(L_{\mathrm{Ly}\alpha}) = \int dM_{\mathrm{UV}} \Phi_{\mathrm{UV}}(M_{\mathrm{UV}})\ \mathrm{EW}\ p(\mathrm{EW}, M_{\mathrm{UV}})$$

Observed EW distribution

$\Phi_{\mathrm{Ly}\alpha}(L_{\mathrm{Ly}\alpha})$ decreases by ~ 3 dex
from $z \sim 5$ to $z \sim 10-14$
at $\log L_{\mathrm{Lya}}/(\mathrm{erg/s}) = 42-43$



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x_{HI} Estimate

- Bayesian approach (cf. Mason+18)

Ly α EW dist. at $z = 5$

Ly α EW dist. at $z \geq 6$

x_{HI} Estimate

- Bayesian approach (cf. Mason+18)

Ly α EW dist. at $z = 5$

IGM absorption for various x_{HI}: 21cmFAST

Ly α EW dist. at $z \geq 6$

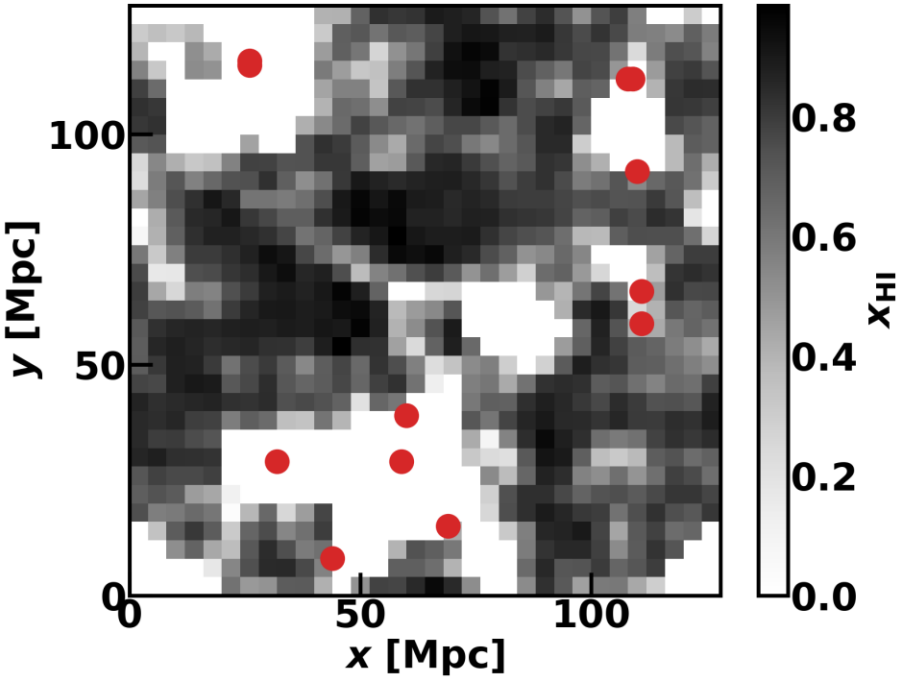
$\rightarrow$ x_{HI} estimate

x_{HI} Estimate

21cmFAST simulations

(w/ $\zeta = 20, T_{\mathrm{vir}}^{\mathrm{min}} = 5 \times 10^4\ \mathrm{K}, \lambda_{\mathrm{mfp}} = 15\ \mathrm{cMpc}$)

→reproduce UV LFs and CMB optical depth



→Ly α photon absorption for various x_{HI} values

$x_{\rm HI}$ Estimate

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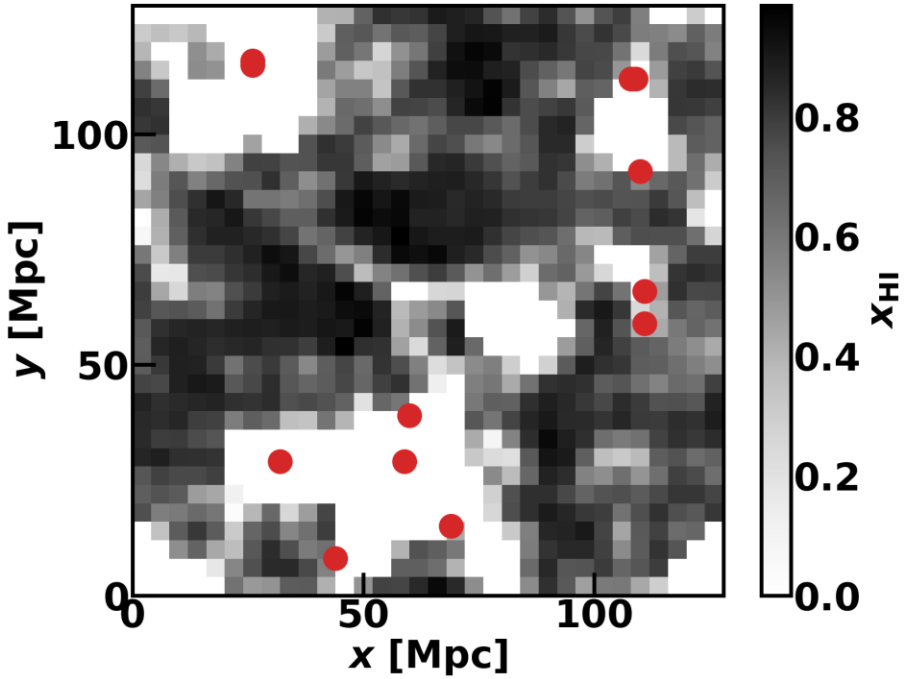
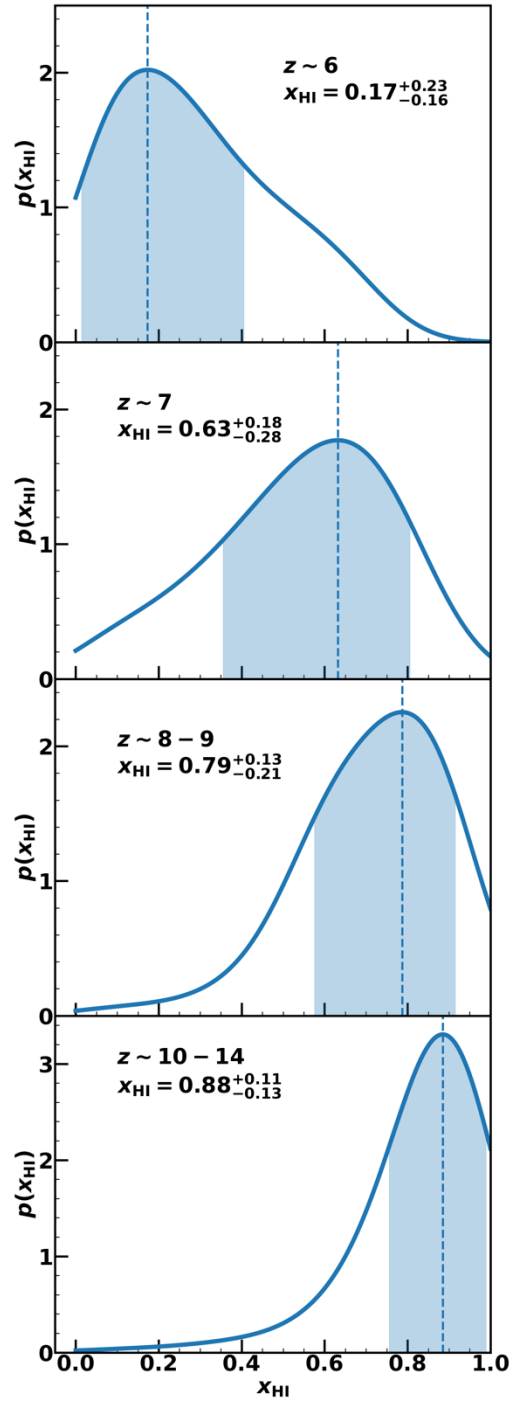


→Ly α photon absorption for various $x_{\rm HI}$ values



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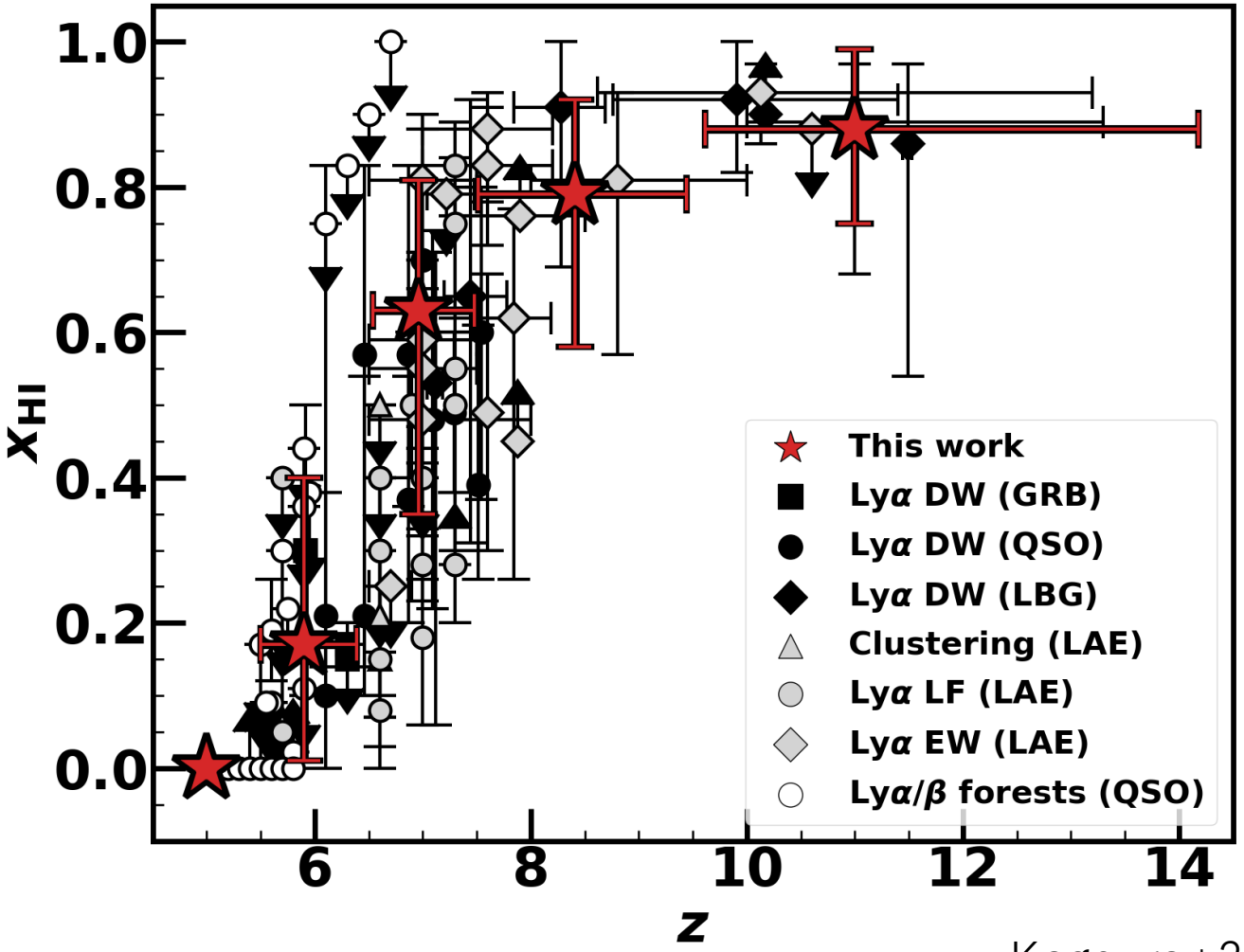
Cosmic Reionization History



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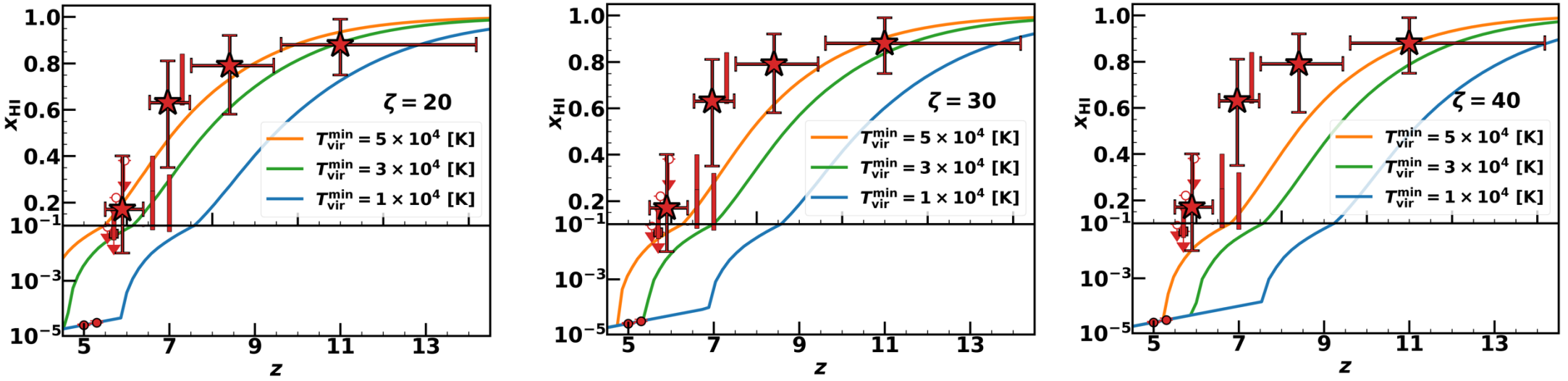
Large x_{HI} values
at $z \sim 7-14$
→**Late reionization**

consistent w/ other JWST high-z studies
(e.g., Tang+24, Jones+25, **Umeda+25b**)

Comparisons w/ Models



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- Observed $x_{\rm HI}$ evolution is sharper than fiducial models

→**Sharp reionization**

Late and Sharp Reionization?

Basic EoR parameters:

- Ionizing efficiency ζ
  - $\rightarrow \xi_{\mathrm{ion}}$ and f_{esc}
- Minimum virial temperature $T_{\mathrm{vir}}^{\mathrm{min}}$
  - $\rightarrow M_{\mathrm{UV,lim}}$ $(\rightarrow \rho_{\mathrm{UV}})$

- Ly α EWs (This work)
- Ly α LF + ACF (Umeda+25a)
- QSO Ly α / β forest (Zhu+22)
- CMB $\tau = 0.056$ (Planck Collaboration+20)

Late and Sharp Reionization?

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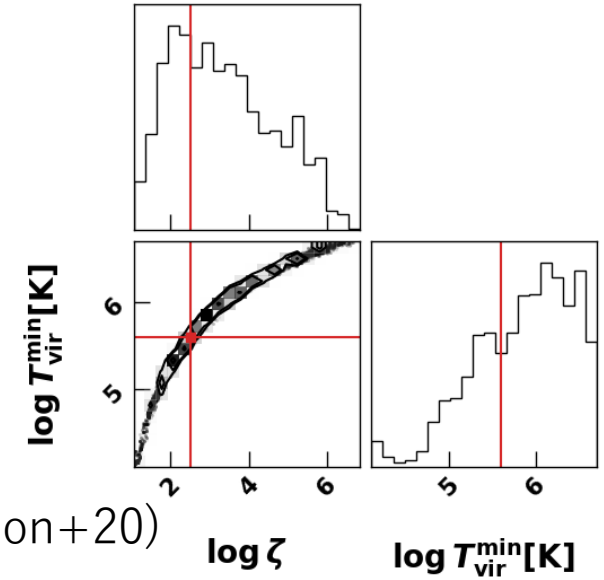


Basic EoR parameters:

- Ionizing efficiency ζ

  $\rightarrow \xi_{\rm ion}$ and $f_{\rm esc}$

- Minimum virial temperature $T_{\rm vir}^{\rm min}$

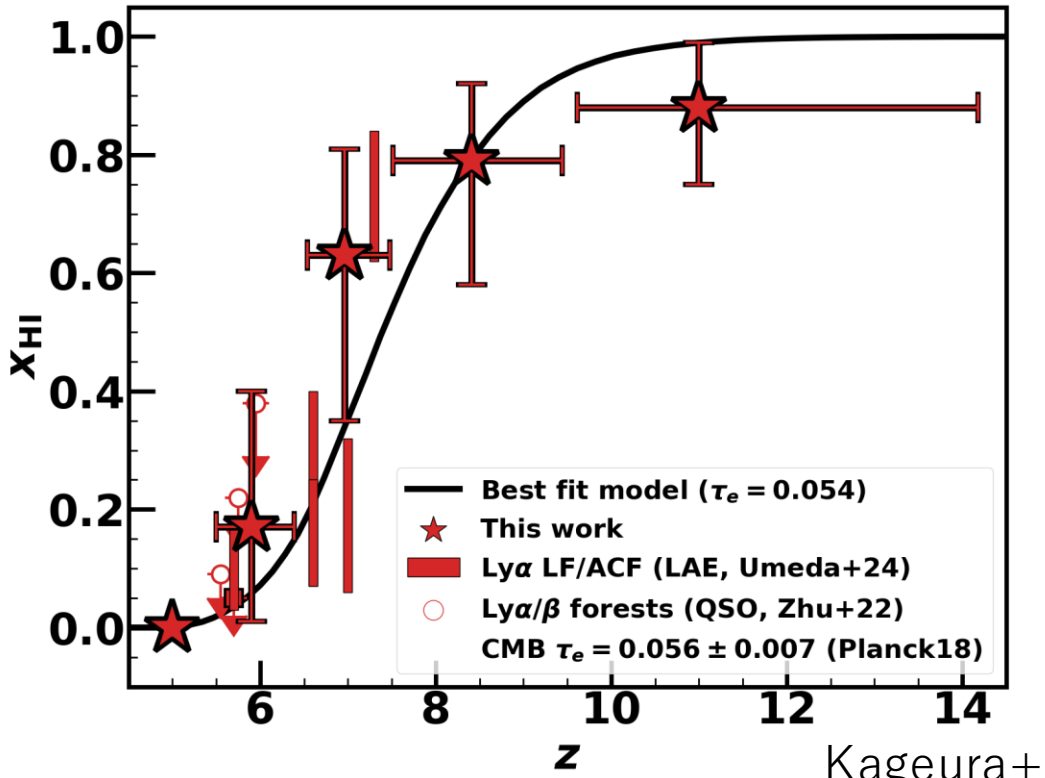
  $\rightarrow M_{\rm UV,lim}$ $(\rightarrow \rho_{\rm UV})$

$T_{\rm vir}^{\rm min} \sim 10^{5.6}$ K

Minimum halo mass at $z \sim 6$: $\sim 10^{10.5}\ M_\odot$

faintest ionizing sources at $z \sim 6$: -17 mag

<u>Massive halo dominant</u>



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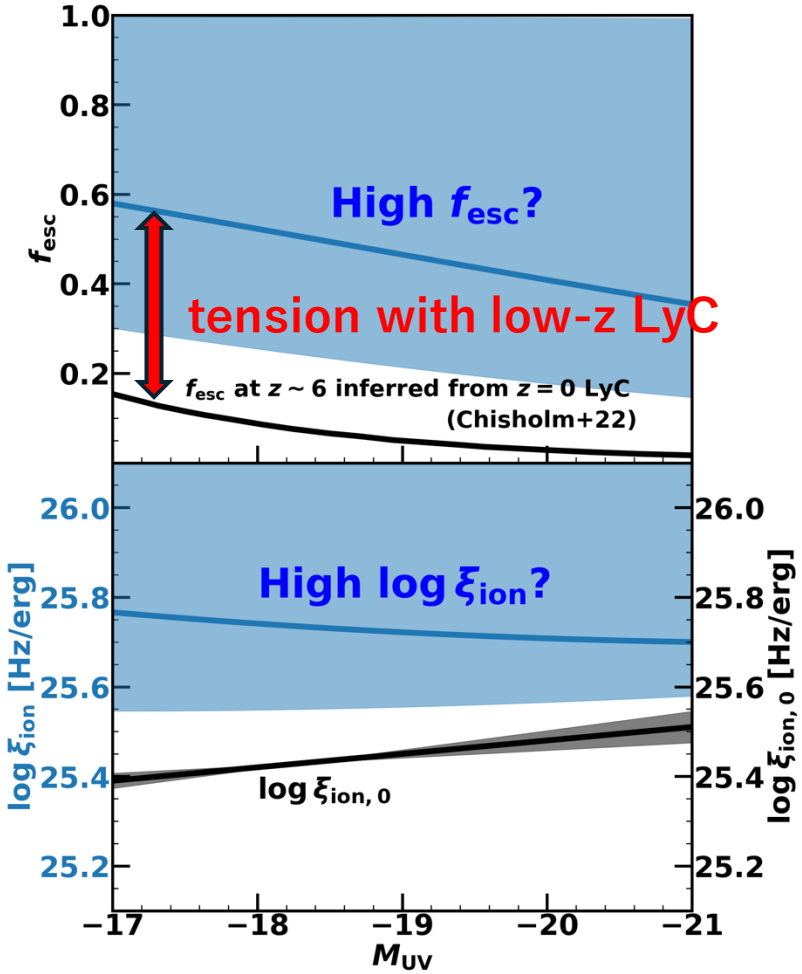
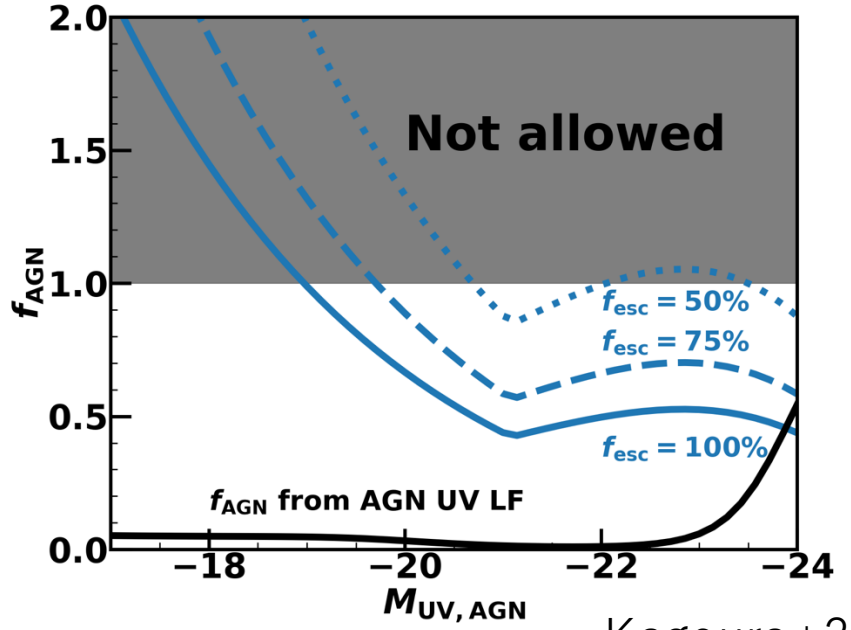
Ionizing Sources

Ionizing efficiency $\zeta \sim 10^{2.5}$

- star-forming galaxies



- AGNs



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Too large escape fraction or AGN duty cycle

Discussion

- Late and sharp reionization: not easily explained by faint galaxies, bright galaxies/AGNs

- Redshift evolution of f_{esc}?
- Type 2 AGNs?
- Alternative sources?

Summary

- Ly α EW measurements of 586 galaxies
  + simulation by 21cmFAST

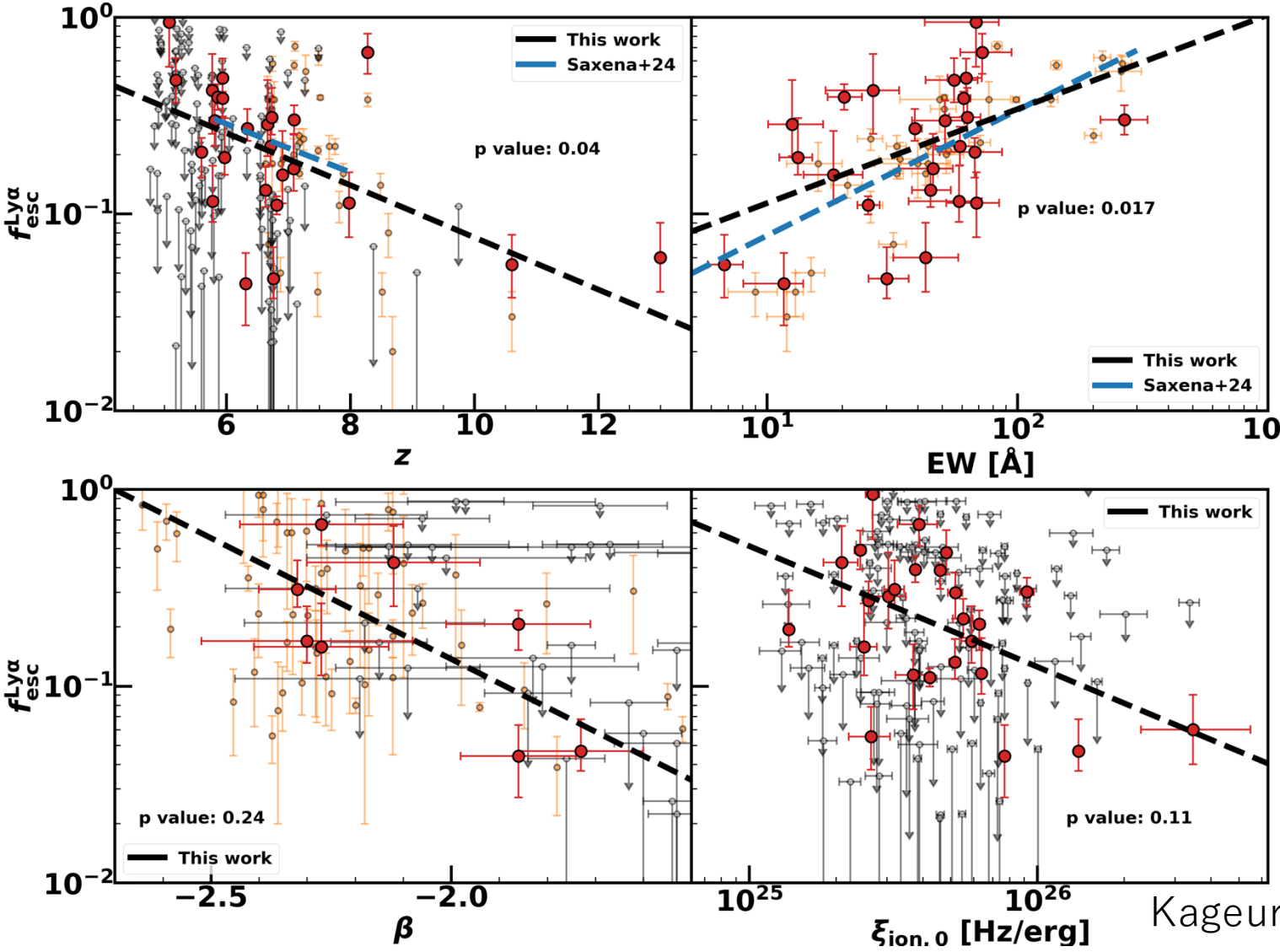
- x_{HI} estimates: high values at $z \sim 7 - 14$

- Late and sharp reionization: difficult to explain?

Kageura+25 ApJS in press (arXiv: 2501.05834)

Ly α Escape Fraction

(Ly α & Balmer line fluxes + case B assumption)



low $f_{esc}^{Ly\alpha}$ at high-z

→Absorption in the IGM

low $f_{esc}^{Ly\alpha}$ for galaxies w/ red UV, high $\xi_{ion,0}$

→Absorption in the ISM

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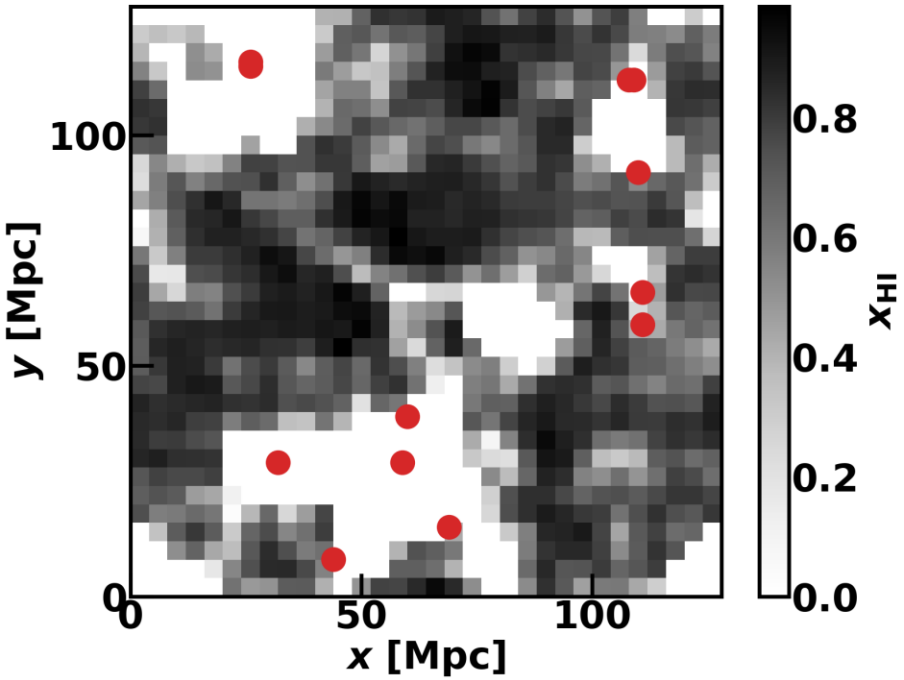
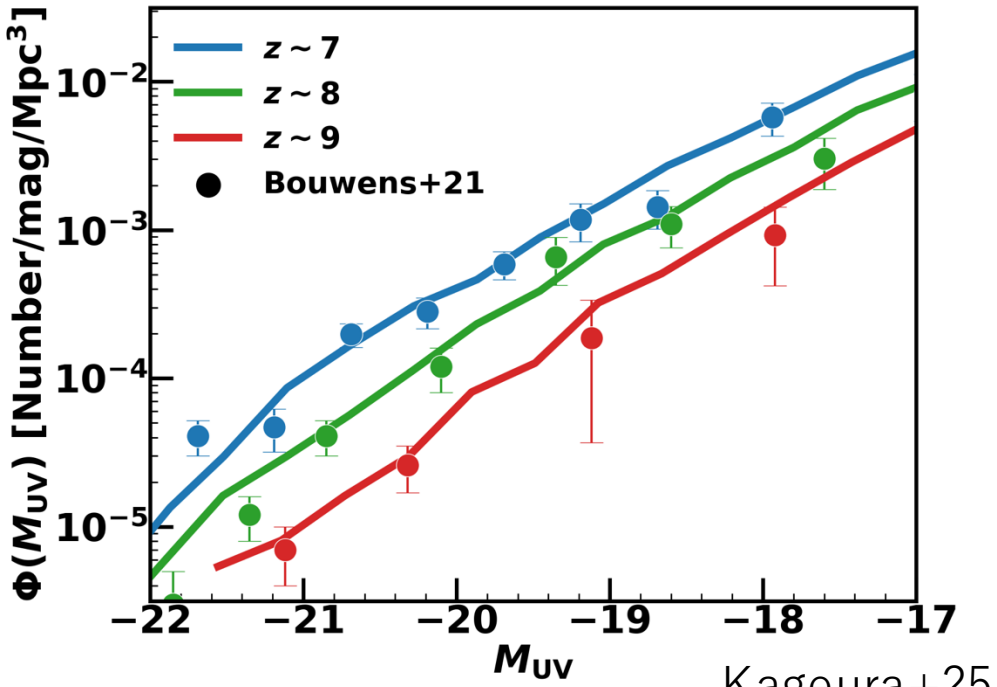
21cmFAST Simulations

21cmFAST simulations　(w/ $\zeta = 20, T_{\rm vir}^{\rm min} = 5 \times 10^4\ {\rm K}, \lambda_{\rm mfp} = 15\ {\rm cMpc}$)
→reproduce UV LFs and CMB optical depth





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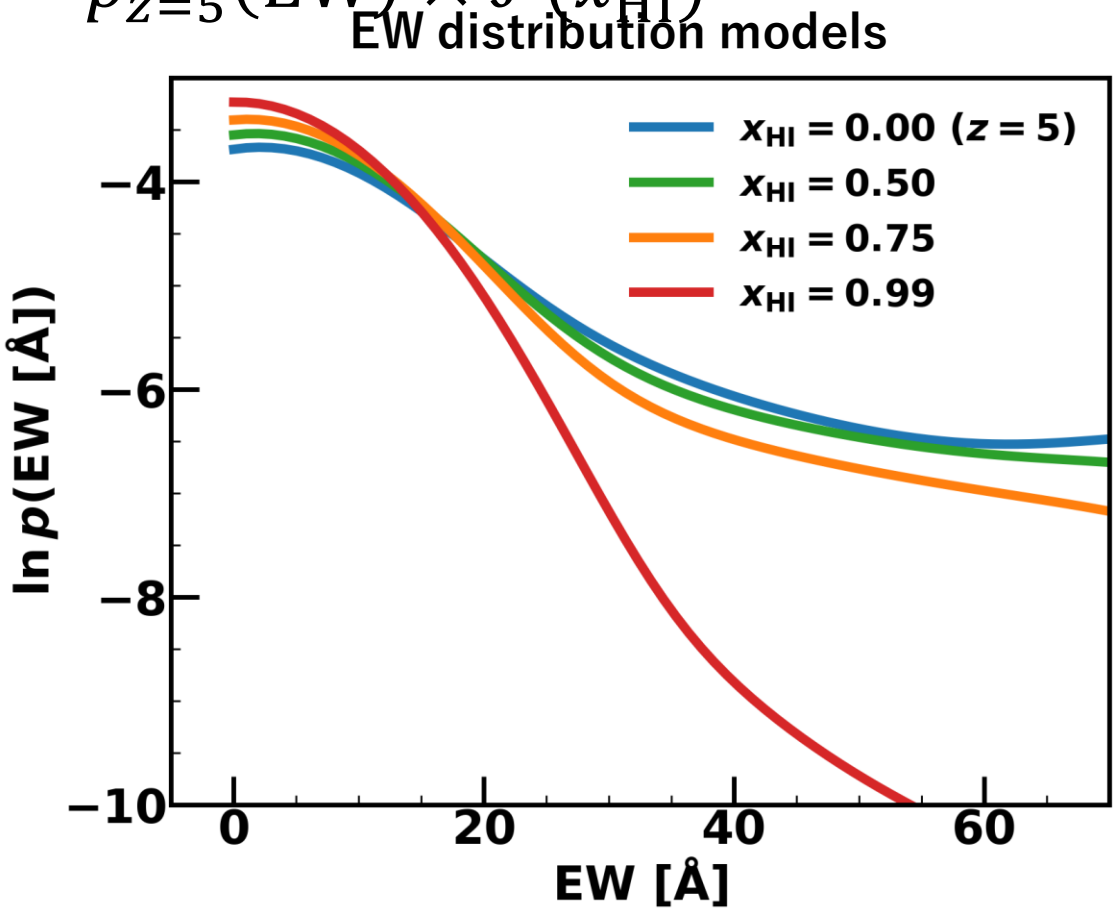
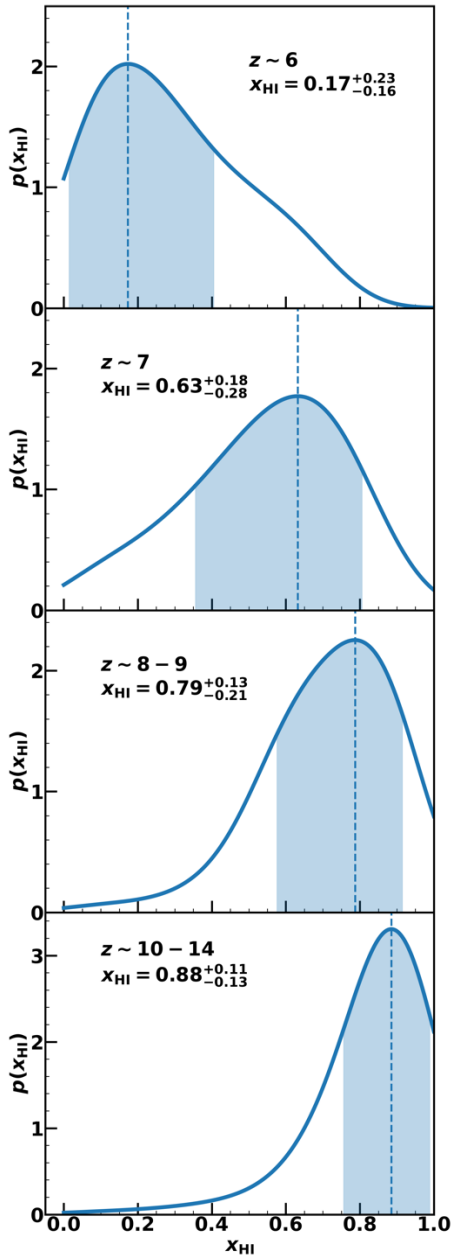
→Ly α photon transmittance for various $x_{\rm HI}$ values

x_{HI} Estimation

$$p(\mathrm{EW} \mid x_{\mathrm{HI}}) = p_{z=5}(\mathrm{EW}) \times \mathcal{T}(x_{\mathrm{HI}})$$



$$p(x_{\mathrm{HI}} \mid \{EW\}) \propto \prod p(EW_i \mid x_{\mathrm{HI}})$$



Kageura+25

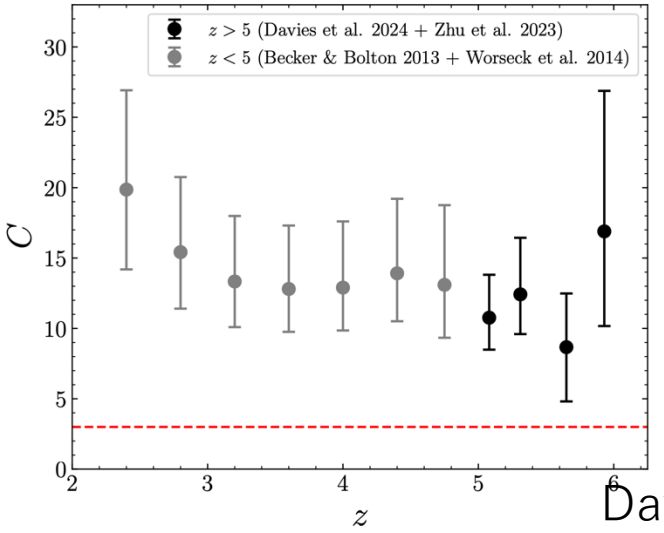
Clumping factor?

Recent report of high clumping factor ($C = 12$, Davies+24)

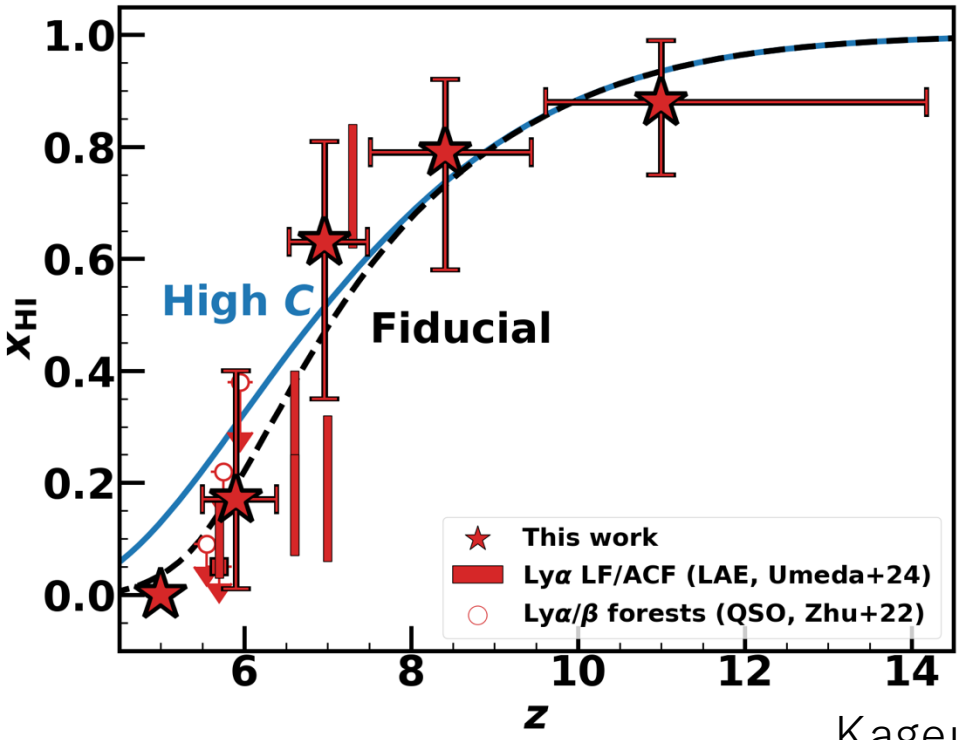
- caused by mean-free path $\lambda_{\rm mfp} = 6$ cMpc (Zhu+23)

21cmFAST model w/ $\zeta = 20, T_{\rm vir}^{\rm min} = 5 \times 10^4$ K, $\lambda_{\rm mfp} = 6$ cMpc

does not reporoduce the sharp reionization
(reionization does not complete at $z \sim 5-6$)



Davies+24



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