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LyC detections at high redshift: precise escape fractions for individual leakers?

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Mahdi Qezlou, Gwen Rudie, Drew Newman, Alice Shapley, Michael Topping, Charles Steidel, Naveen Reddy, Yuguang Chen, Leonardo Clarke, Ryan Sanders, Gabriel Brammer, Emily Kehoe

Escape of Lyman radiation from galactic labyrinths
4/10/2025

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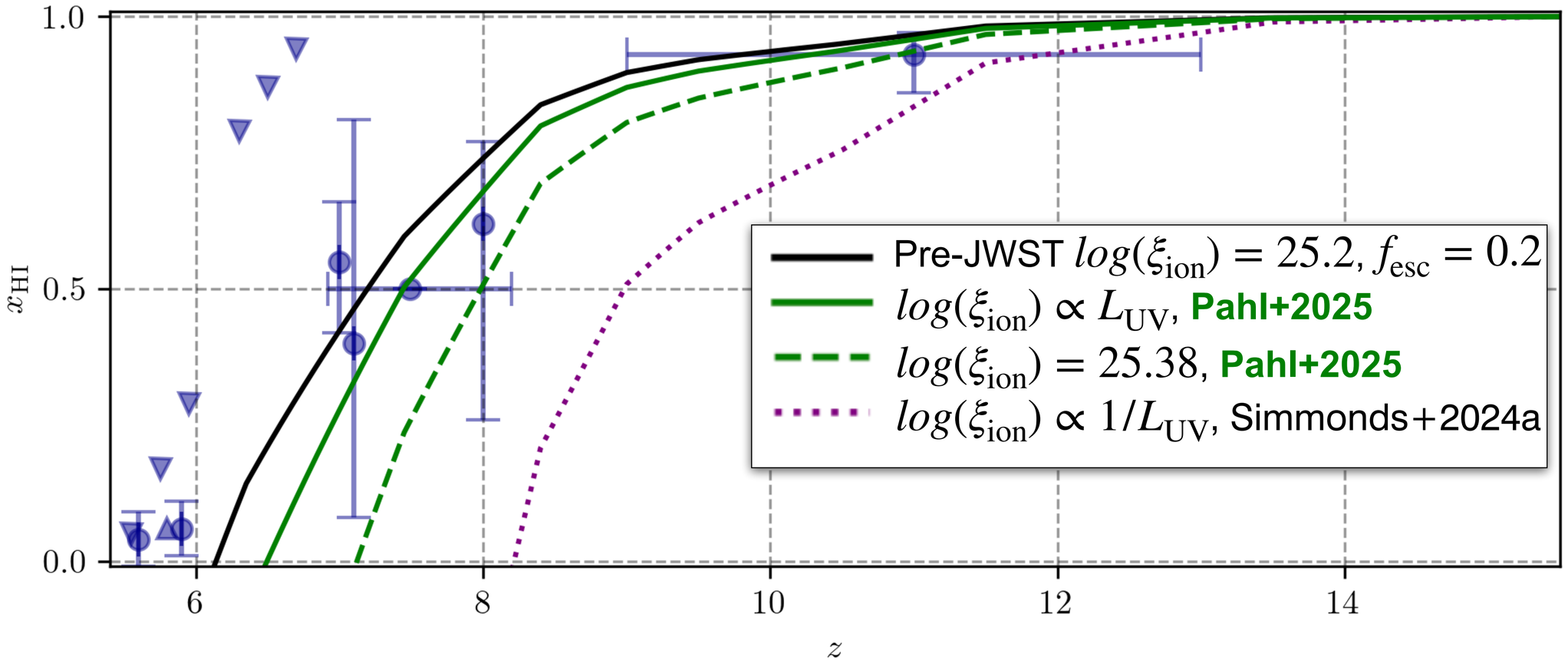
New $\xi_{\rm ion}$ constraints from NIRSpec sample with Balmer decrements imply a reionization history consistent with observations



Pahl et al. 2025

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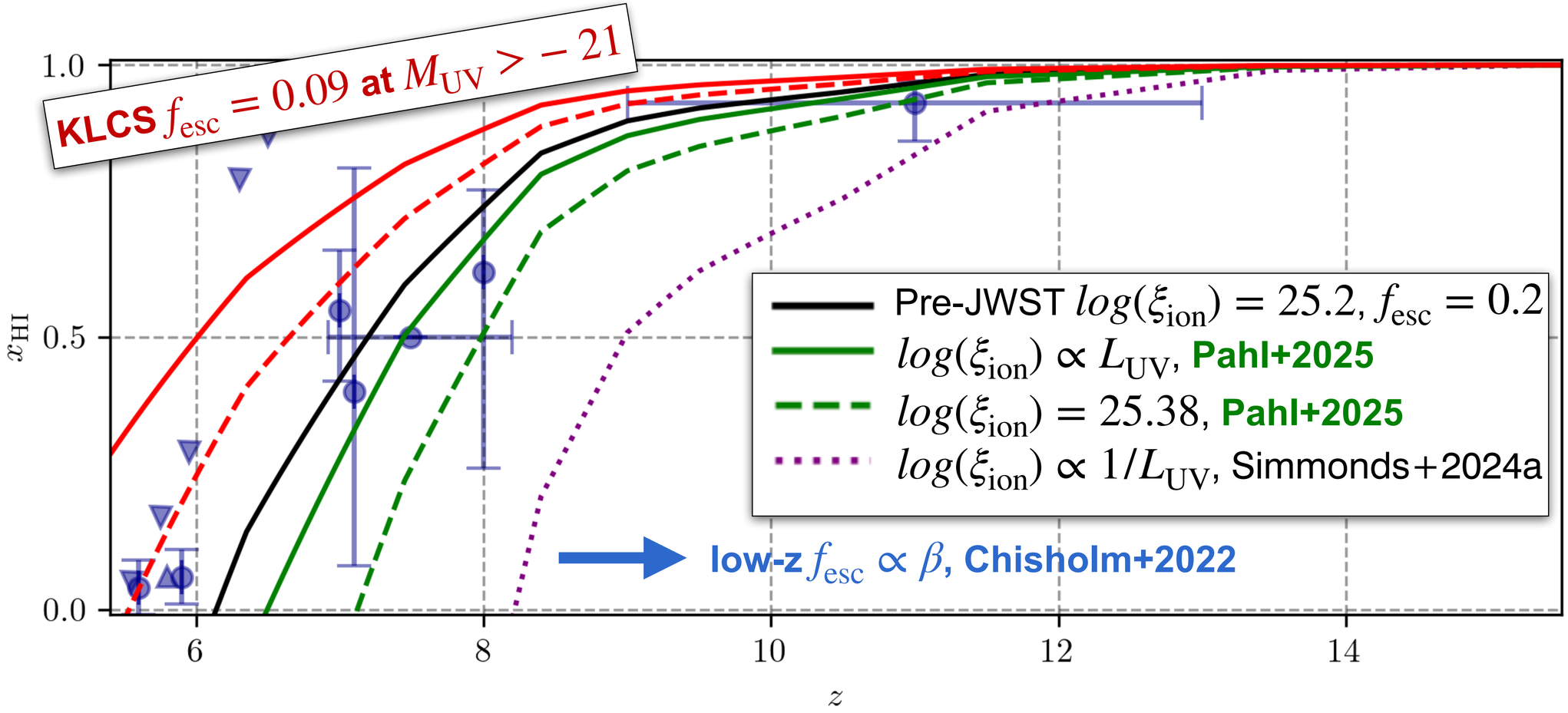
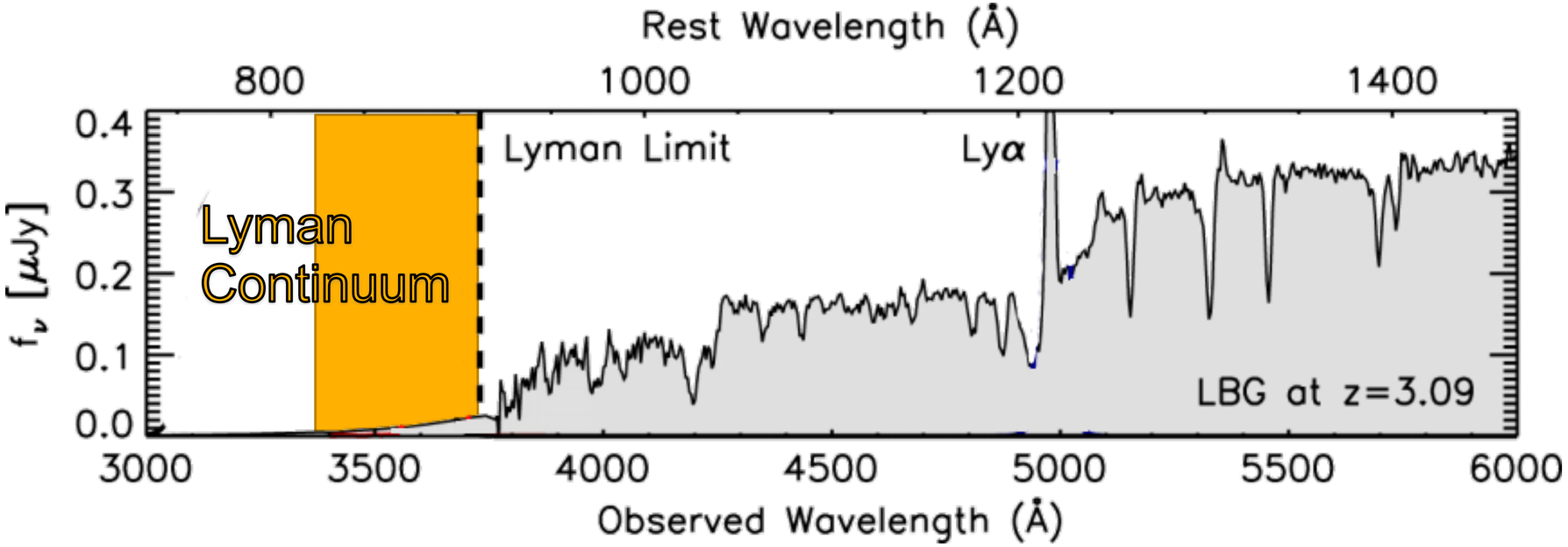
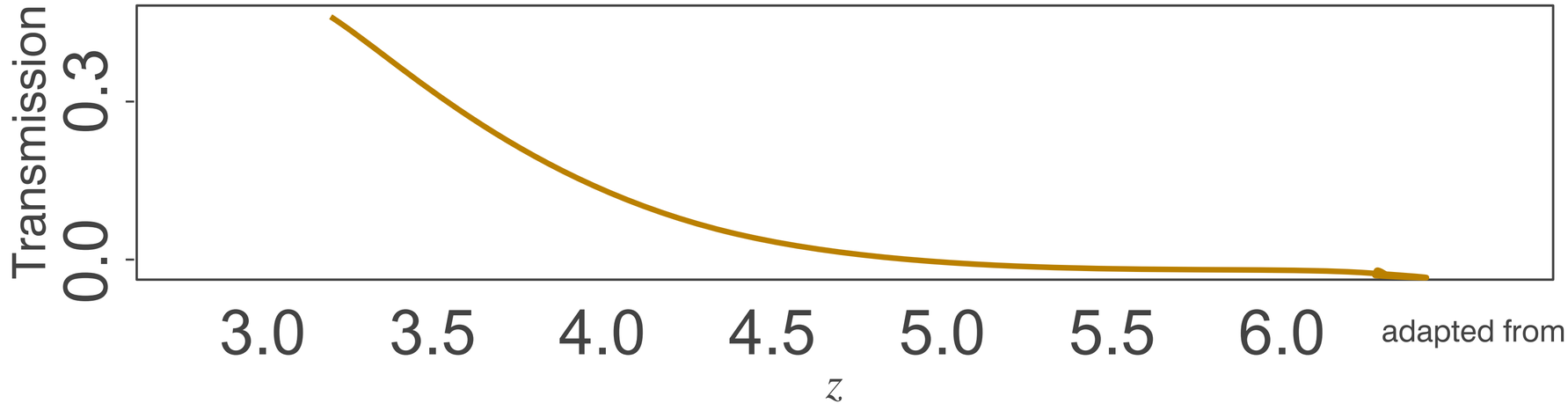


Pahl et al. 2025

Escape fraction remains best studied through $z \lesssim 3$ analogs





adapted from Vanzella et al. (2012)

Which galaxy properties correlate with $f_{\rm esc}$?

Low-redshift Lyman Continuum Survey (LzLCS)

- 66 galaxies at $z \sim 0.3$
- selected for high O32, blue UV slope, high $\Sigma_{\rm SFR}$
- HST/COS

Flury et al. 2022a,b; Chisholm et al. 2022

Keck Lyman Continuum Spectroscopic Survey (KLCS)

- 120 SFGs at $z \sim 3$, 13 3σ LyC detections
- LBG selected
- Keck/LRIS

Steidel et al. 2018, Pahl et al. 2021,2023

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$f_{\rm esc}$ relates to…

$\Sigma_{\rm SFR}$ $\quad$ β $\quad$ $v_{\rm sep}$ $\quad$ $\mathrm{EW}_{\mathrm{Ly}\alpha}$ $\quad$ $E(B-V)$ $\quad$ M_* $\quad$ $L_{\rm UV}$

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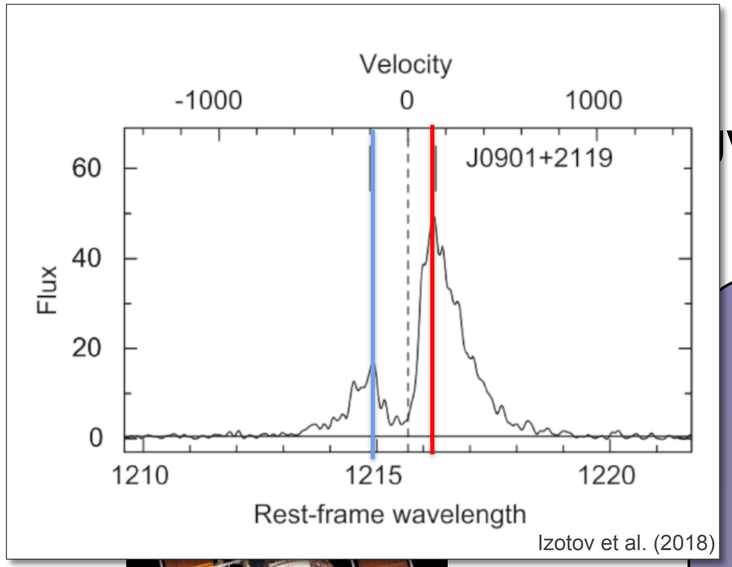

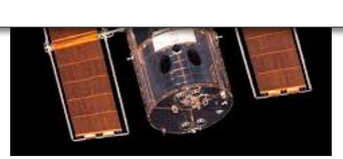

V slope, high

$f_{\rm esc}$ relates to…

$\Sigma_{\rm SFR}$

β

$v_{\rm sep}$

$\mathrm{EW_{Ly\alpha}}$

M_*

$E(B-V)$

$L_{\rm UV}$

e.g. Flury et al. 2022a,b; Chisholm et al. 2022

Keck Lyman Continuum Spectroscopic Survey (KLCS)

- 120 SFGs at $z \sim 3$, 15 3σ LyC detections
- LBG selected
- Keck/LRIS

Steidel et al. 2018, Pahl et al. 2021, 2022, 2023, 2024

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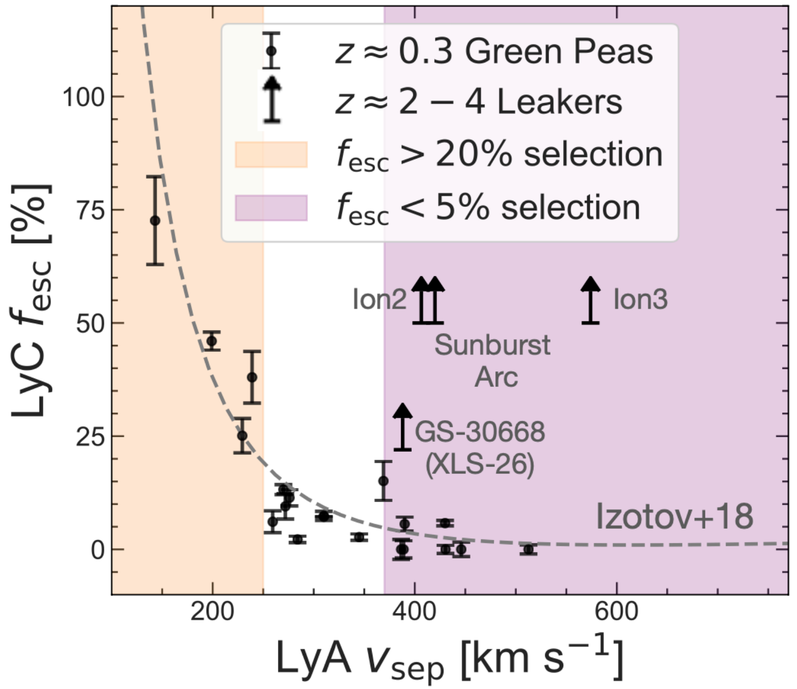
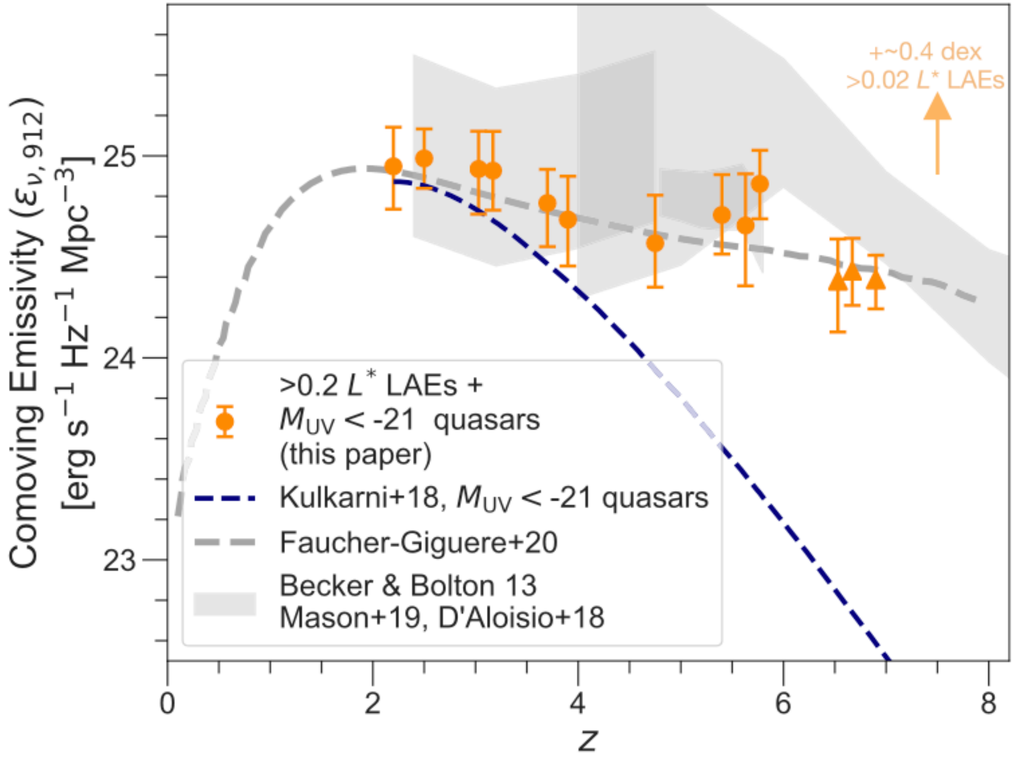
Half of bright LAEs may have extreme (>50%) escape fractions, based on their Lyα profile shapes

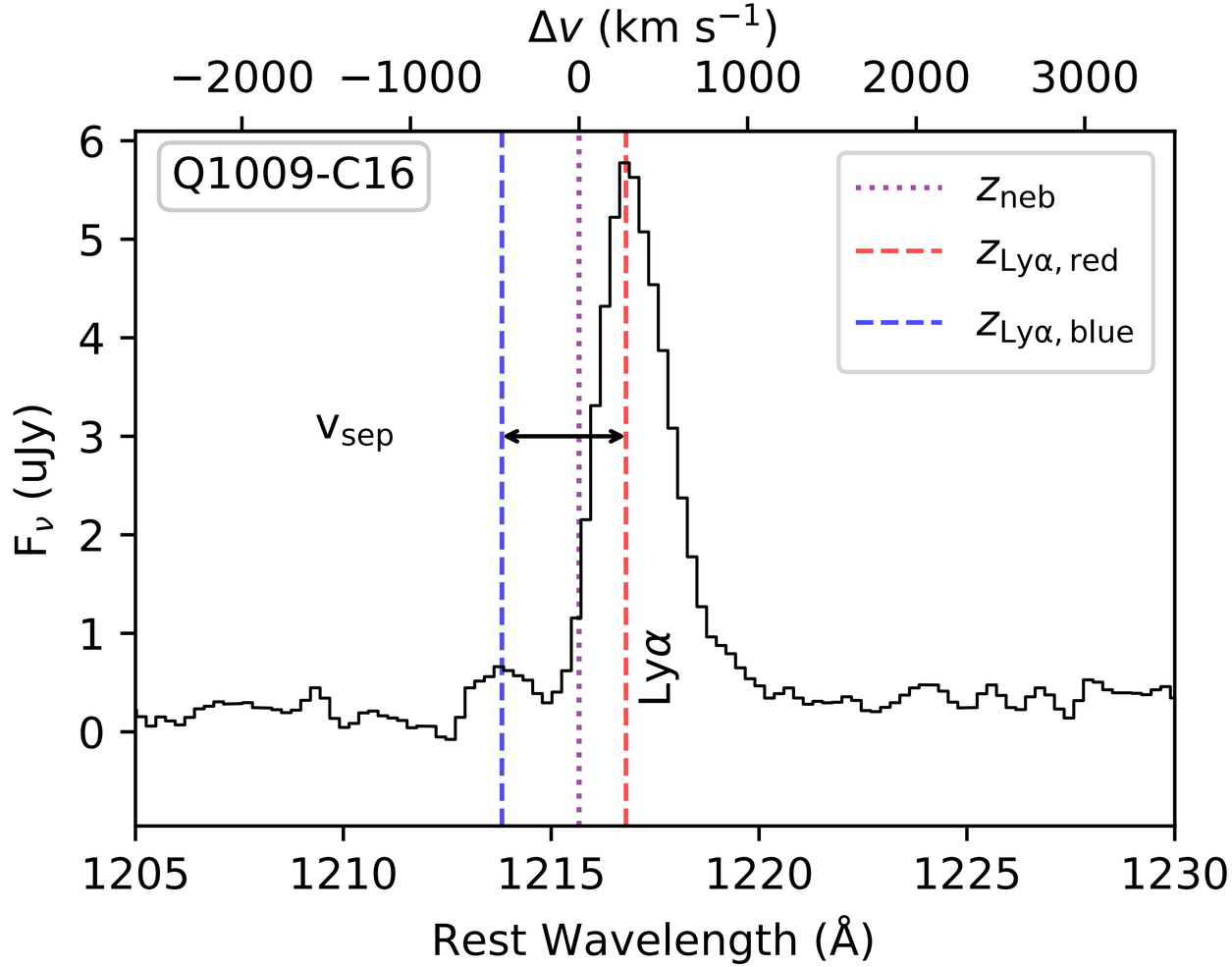


Naidu et al. 2022



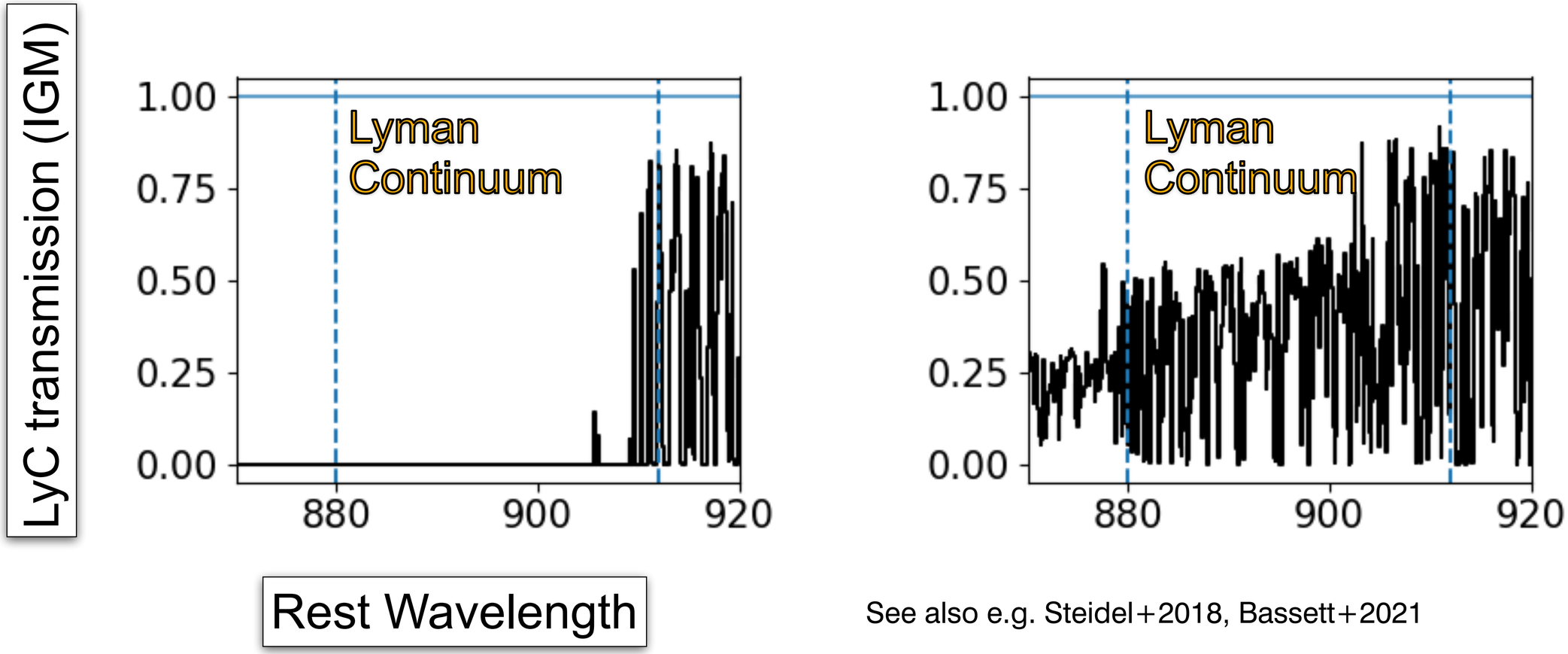
Matthee et al. 2022

The KLCS has deep spectroscopic coverage of both Lyα and LyC (R~1000)



Pahl et al. 2024

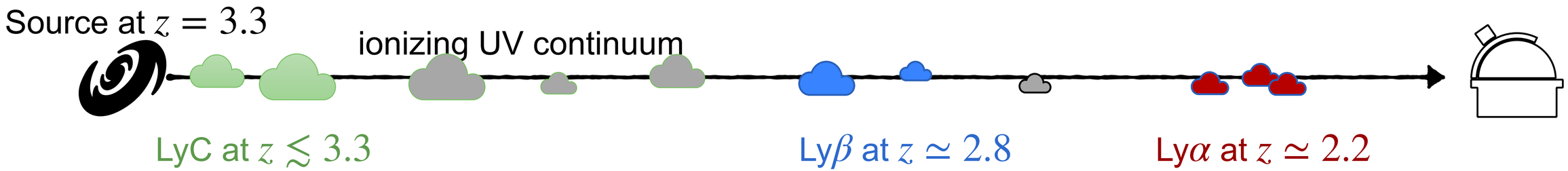
LyC flux for individual objects is highly uncertain at $z \sim 3$



See also e.g. Steidel+2018, Bassett+2021

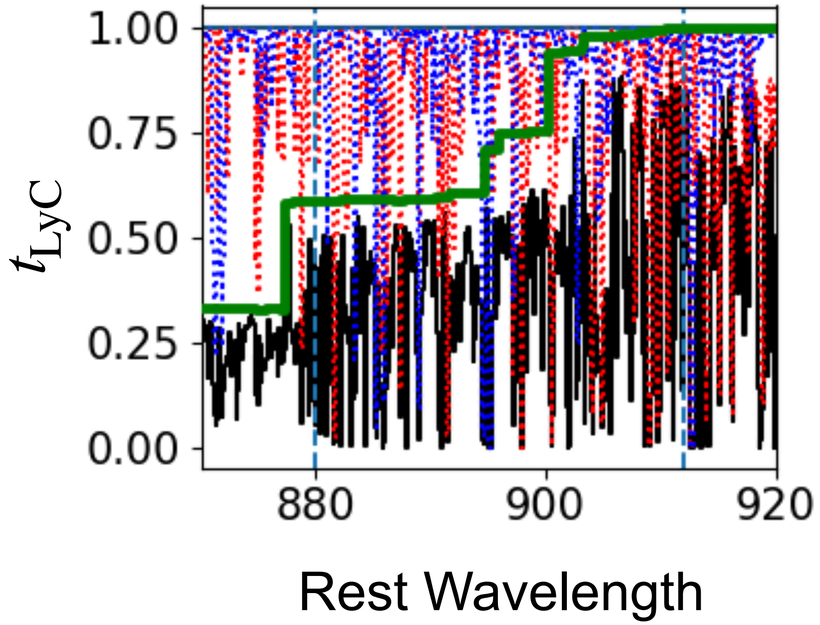
Pahl et al. in prep

The high variability of LyC transmission through the IGM is typically calculated via this Monte Carlo method



$f(N_{\rm HI}, X)$ from quasar absorption lines, with a redshift correction

Rudie et al. 2013



$\langle t_{\rm LyC} \rangle = 0.321 \pm 0.192$

Shapley et al. 2006, Rudie et al. 2013, Steidel et al. 2018
also see Inoue et. 2014, Bassett et al. 2021

Pahl et al. in prep

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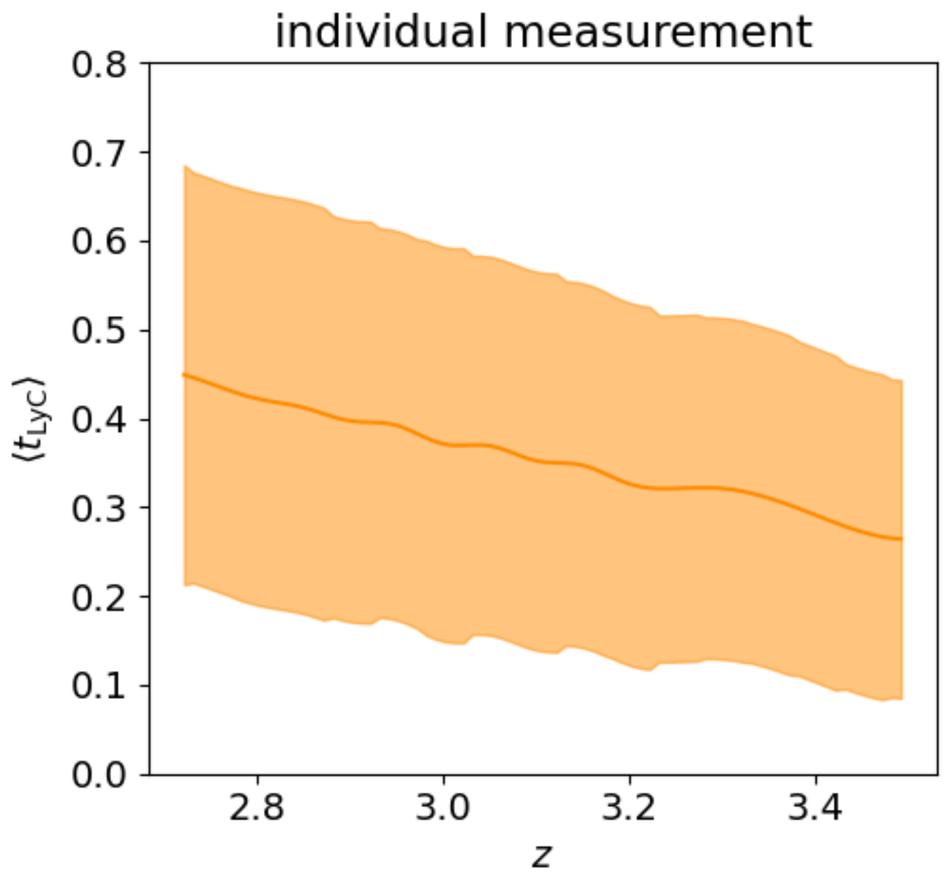
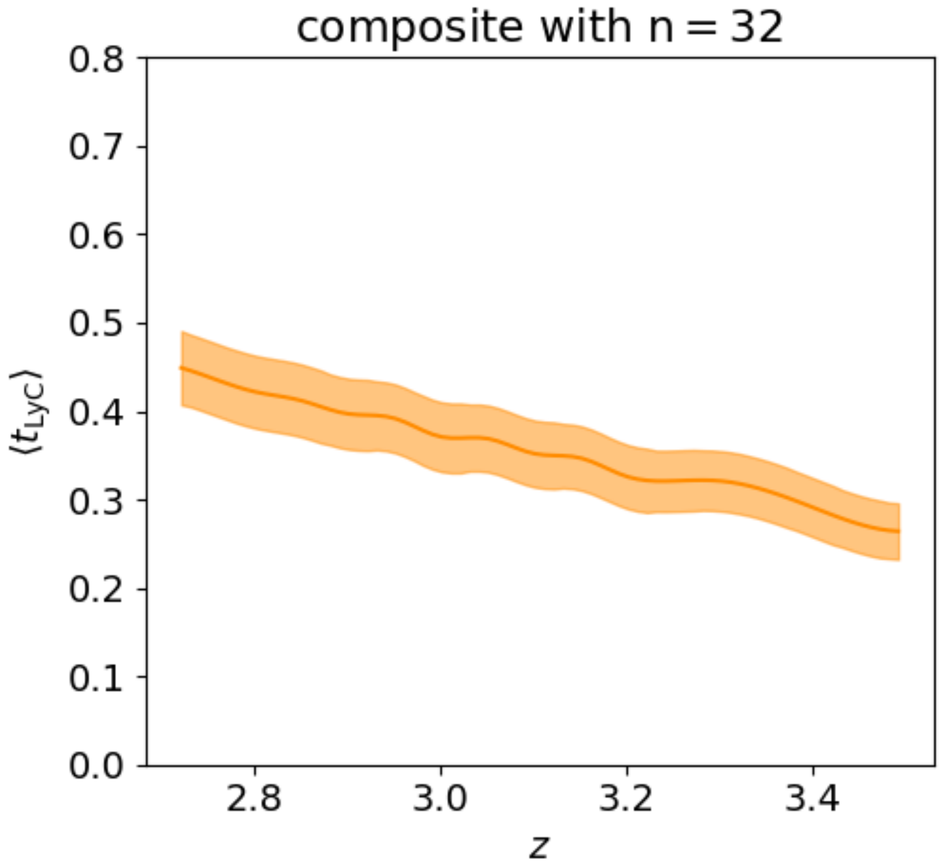
Stacked spectra of ~30 objects are required to reduce uncertainty of LyC transmission at $z \sim 3$





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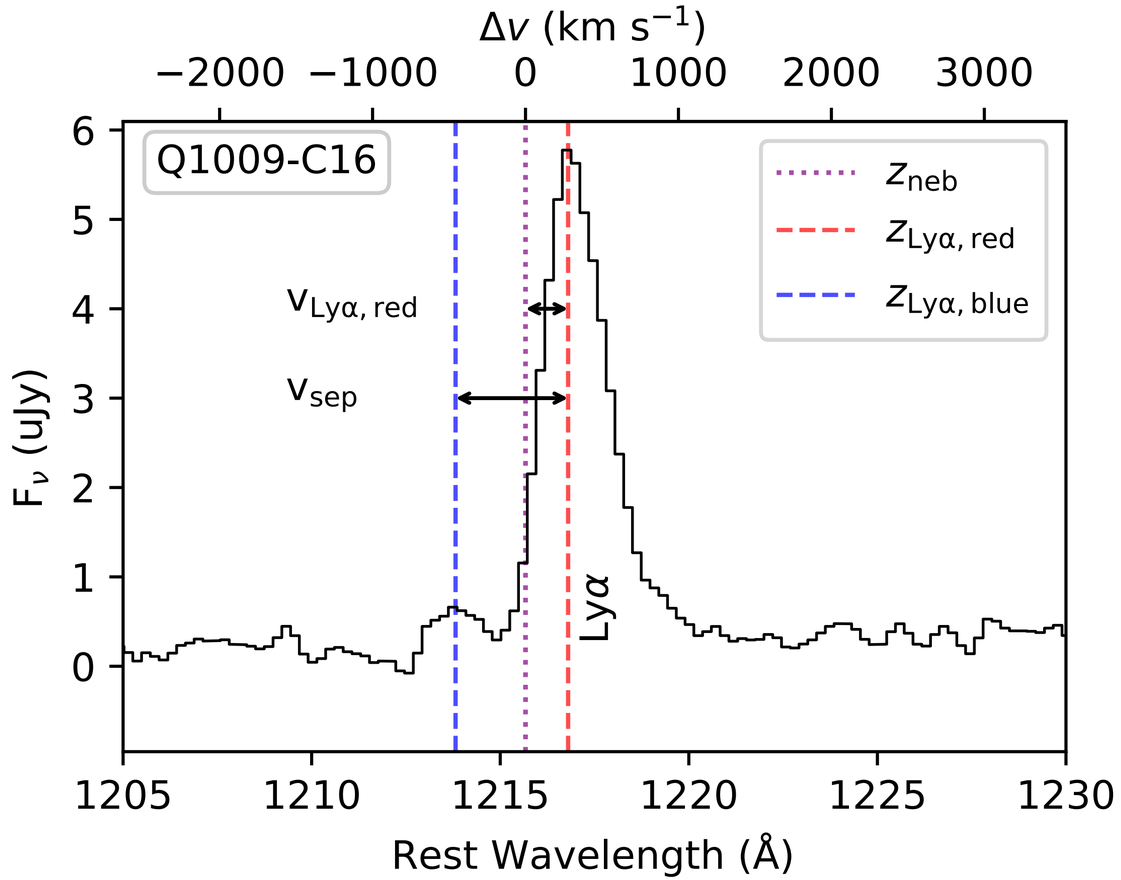

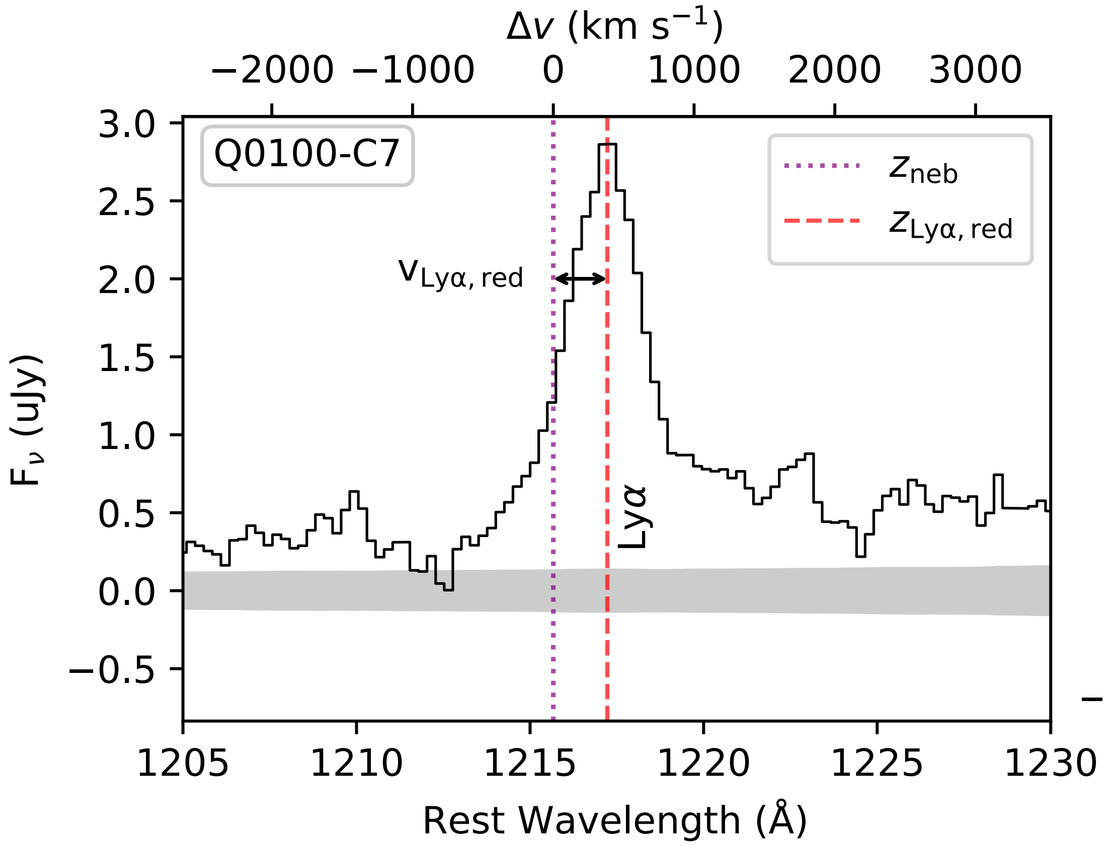

Pahl et al. 2024

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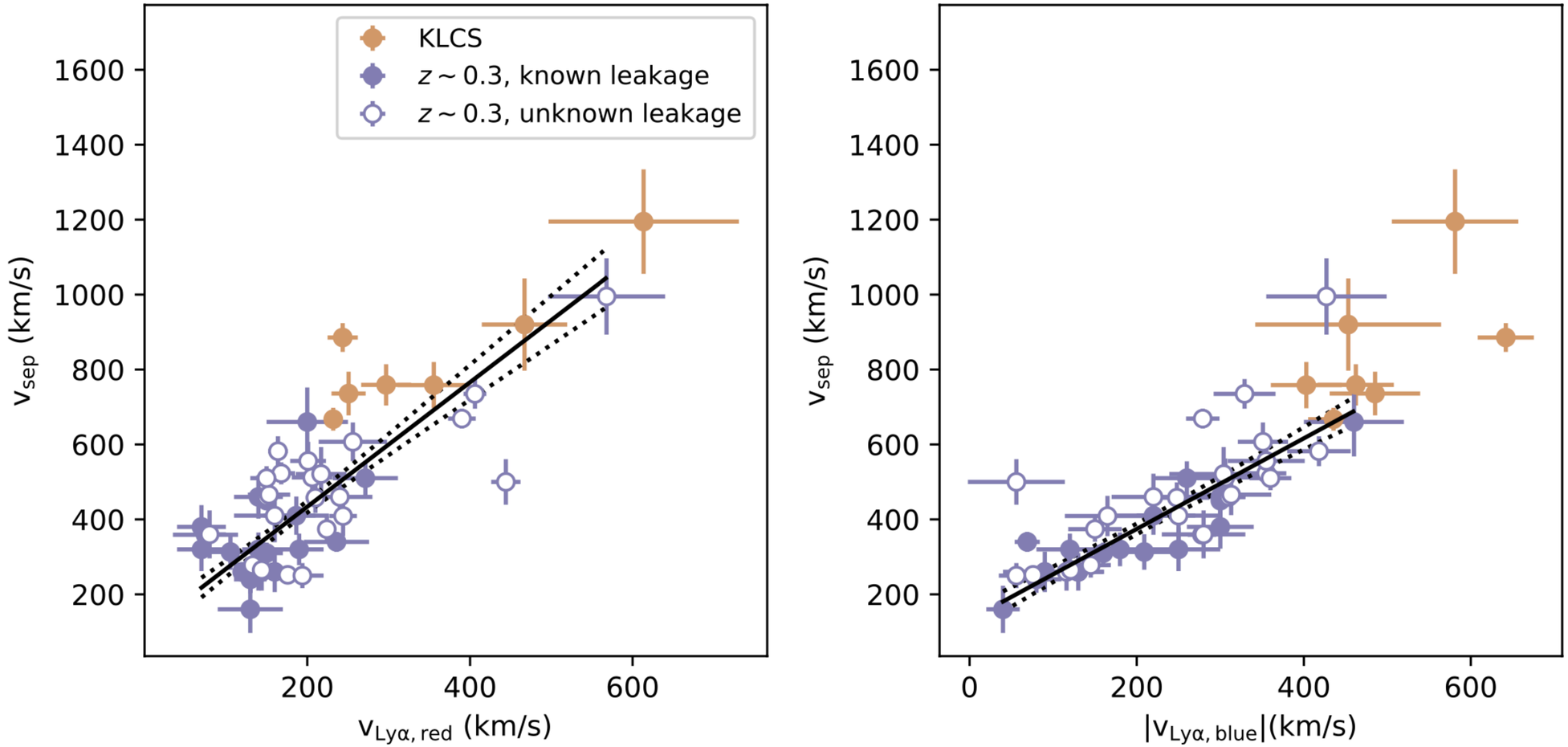
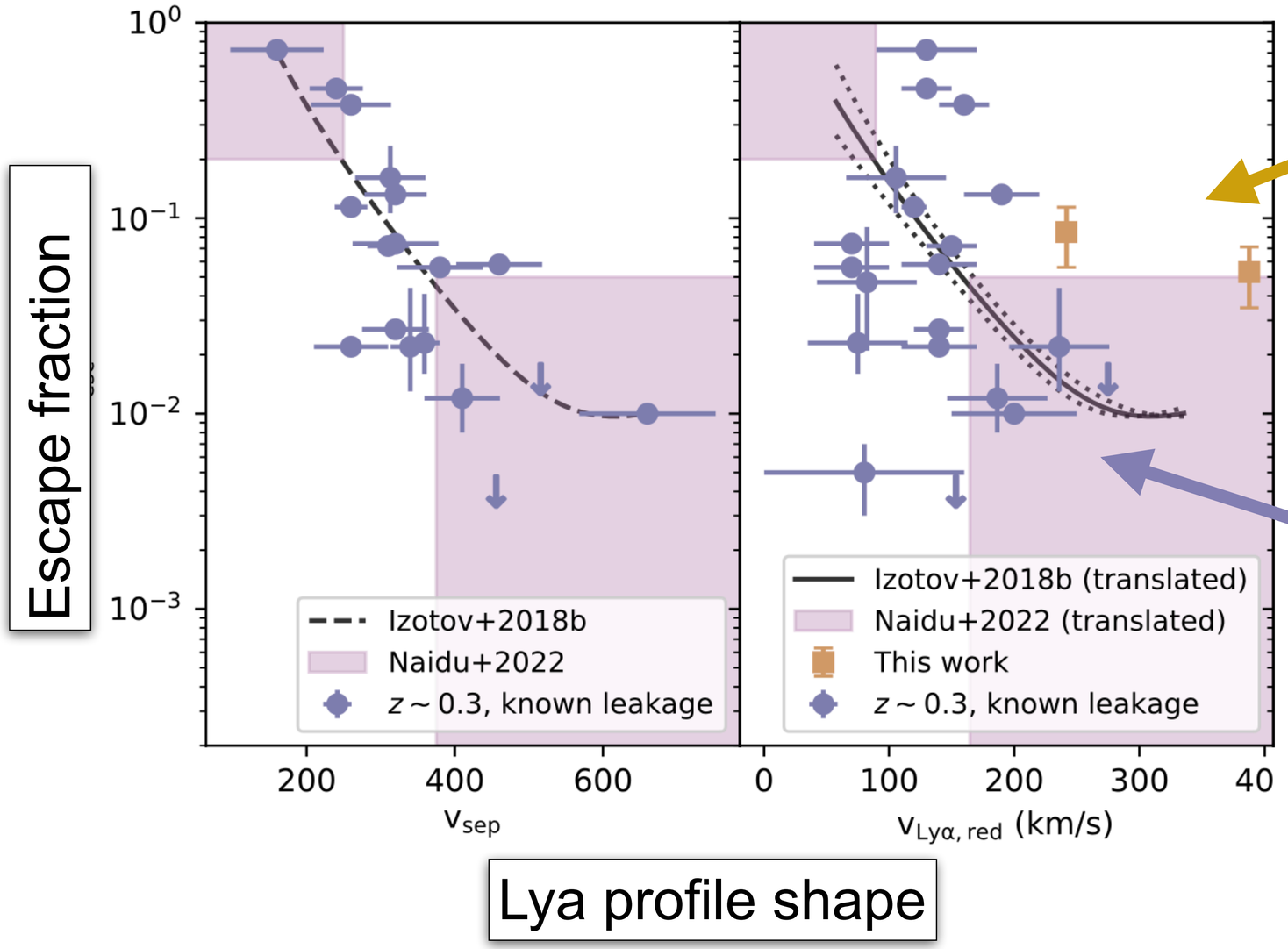
KLCS has larger $v_{\mathrm{Ly}\alpha,\mathrm{red}}$ than $z \sim 0.3$ leakers, nonleakers; few objects with resolved double peaks



Pahl et al. 2024

Recent results from the KLCS indicate that trends with f_{esc} and Lyα property may evolve with redshift



$z \sim 3$, **KLCS**

$z \sim 0.3$, **LzLCS+others**

Pahl et al. 2024

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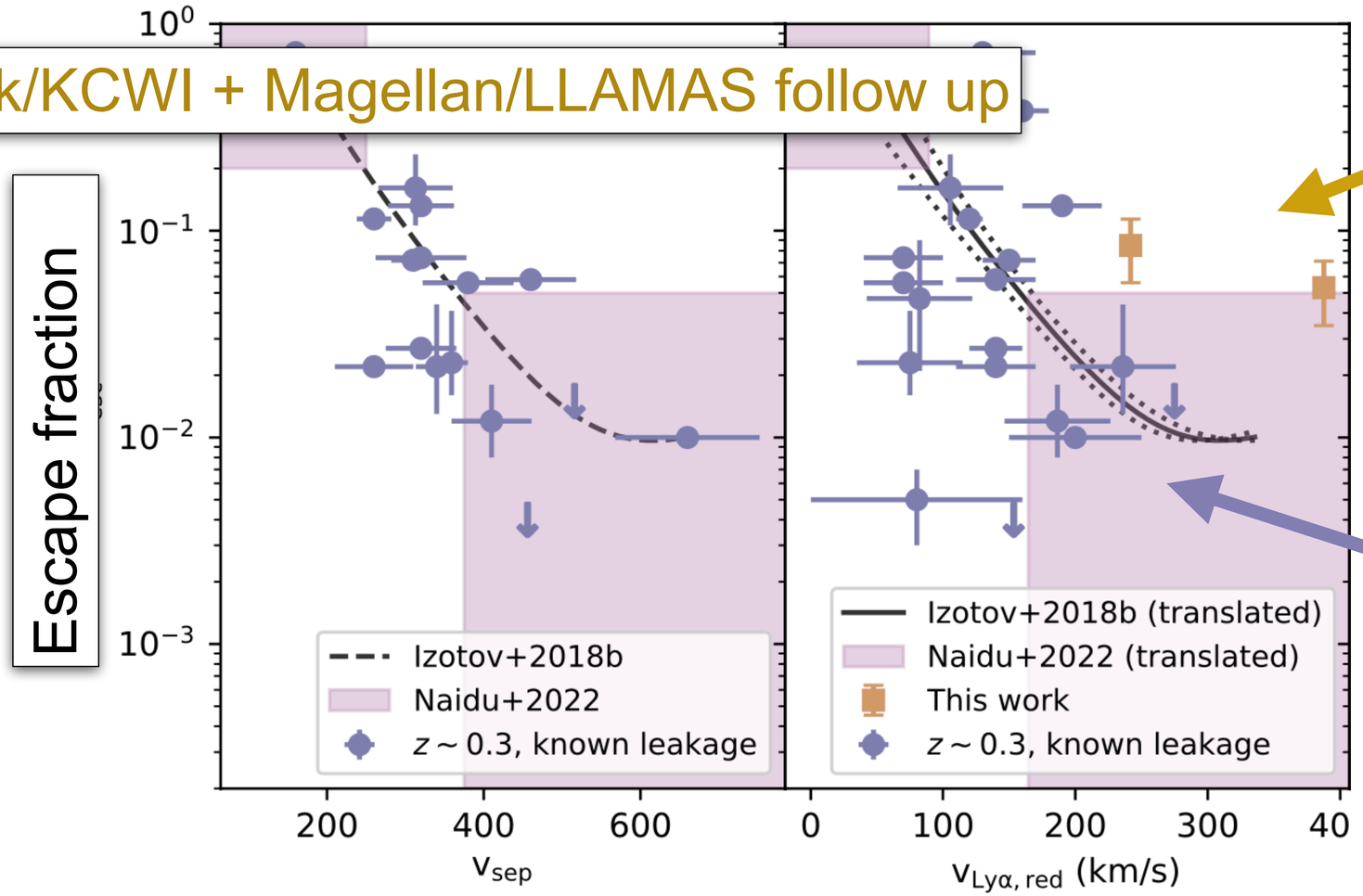
Keck/KCWI + Magellan/LLAMAS follow up



$z \sim 3$, **KLCS**

$z \sim 0.3$, **LzLCS+others**

Lya profile shape

Pahl et al. 2024

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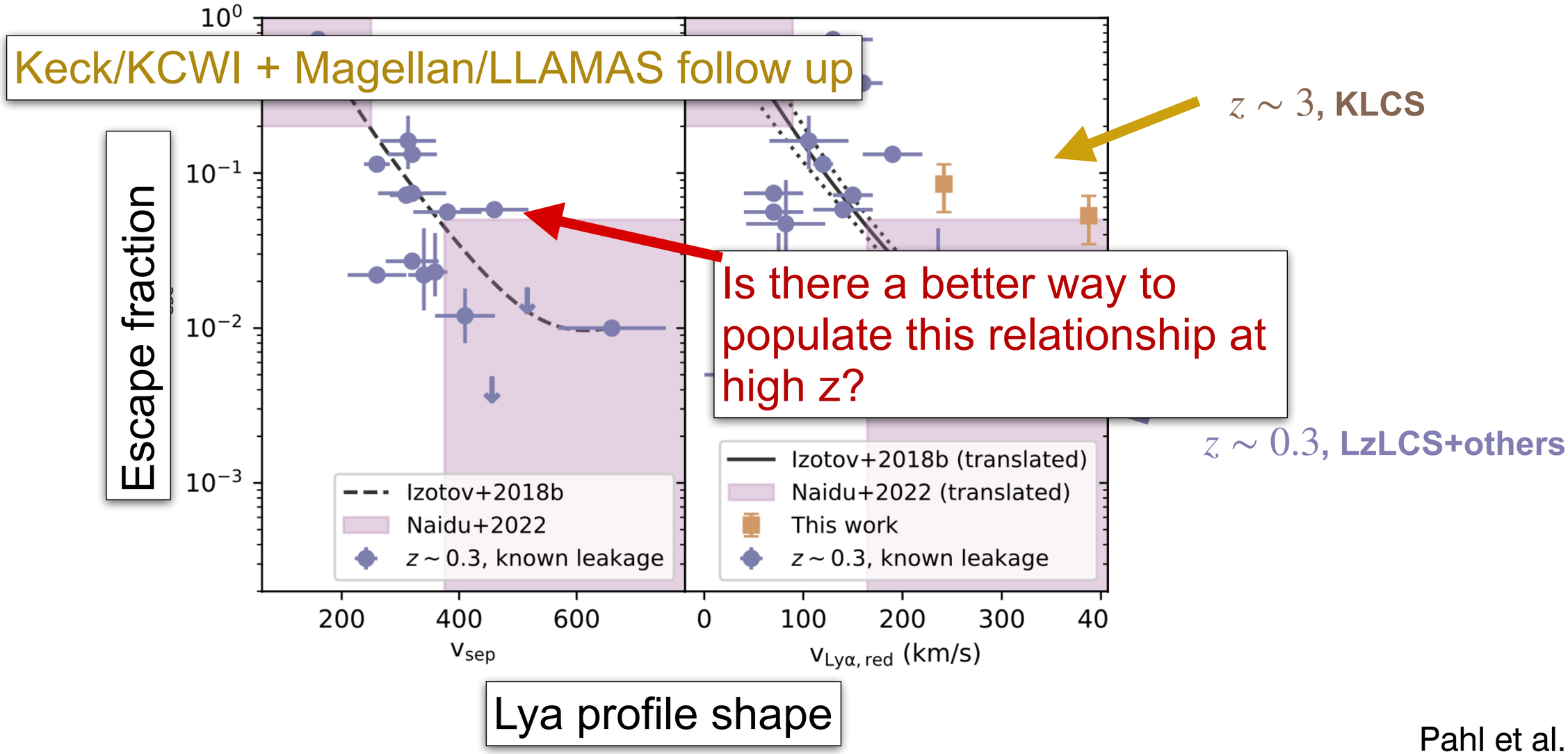
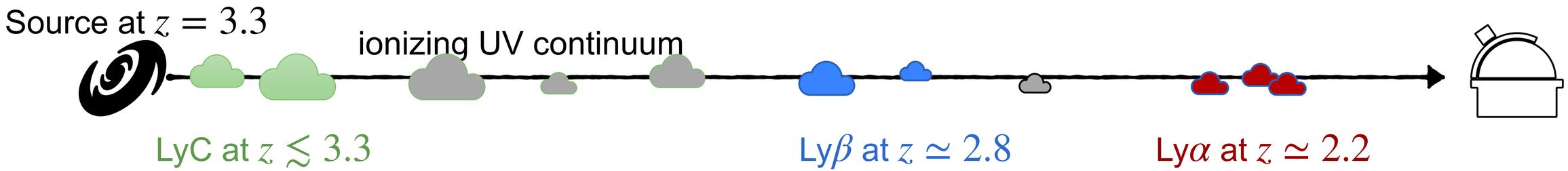


Pahl et al. 2024

Neutral Hydrogen absorbers are randomly sampled along the LOS in the Monte Carlo simulations



$f(N_{\rm HI}, X)$ from quasar absorption lines, with a redshift correction

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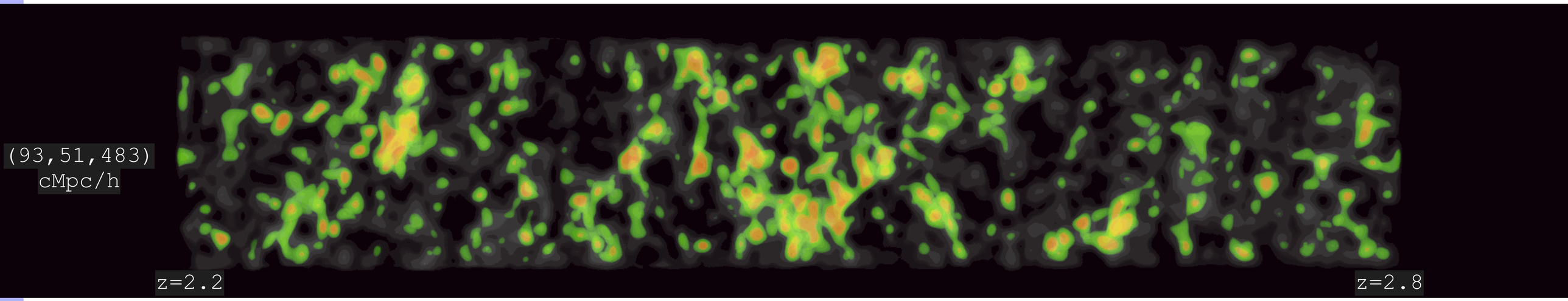
Neutral Hydrogen is spatially correlated, unlike assumptions made by MC codes

LATIS - the Lyman Alpha Tomography IMACS Survey (Newman+2020)



Mapping foreground HI via the Lyα forest in the spectra of numerous background Lyman-Break Galaxies and QSOs.

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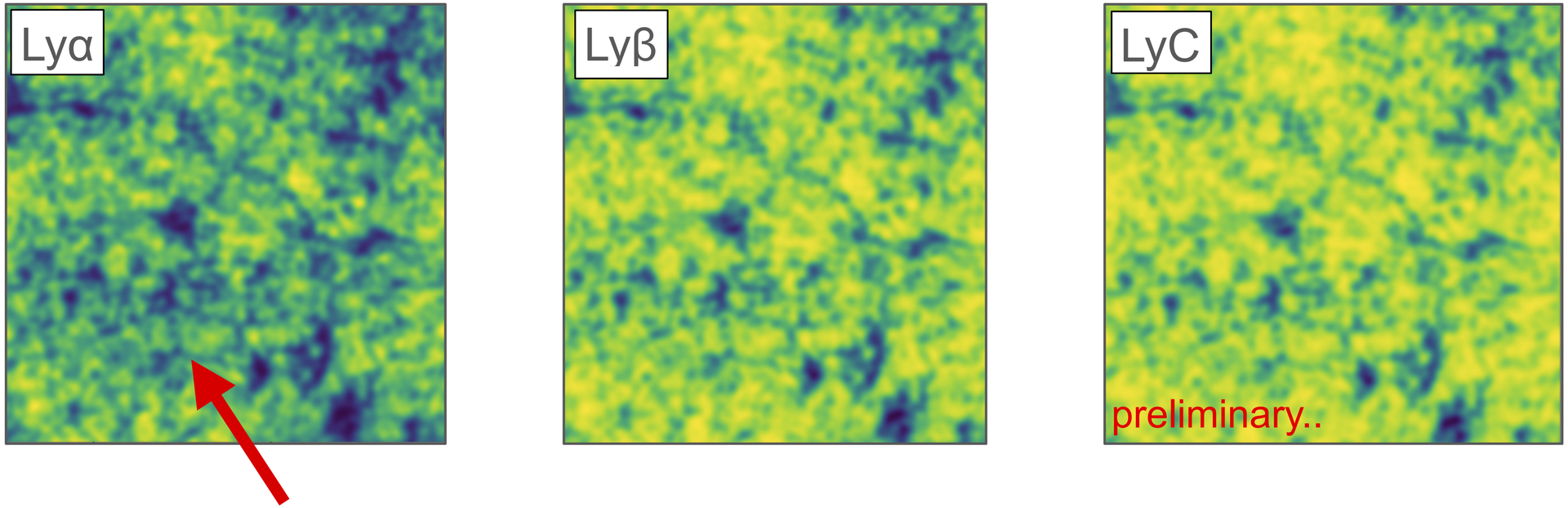
Can LyC transmission be predicted from Lyα flux maps?

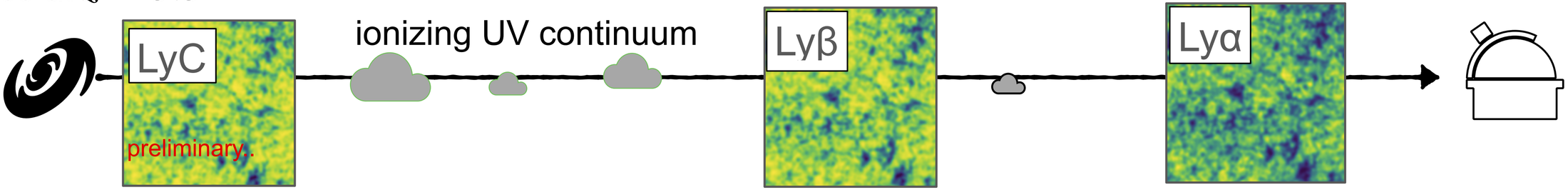
ASTRID - largest full-physics hydrodynamic simulation ran to the present day
250 Mpc/h box with 2×5500^3 particles.



39 ckpc/h resolution

IGM attenuation on LyC can be determined directly from ASTRID simulations

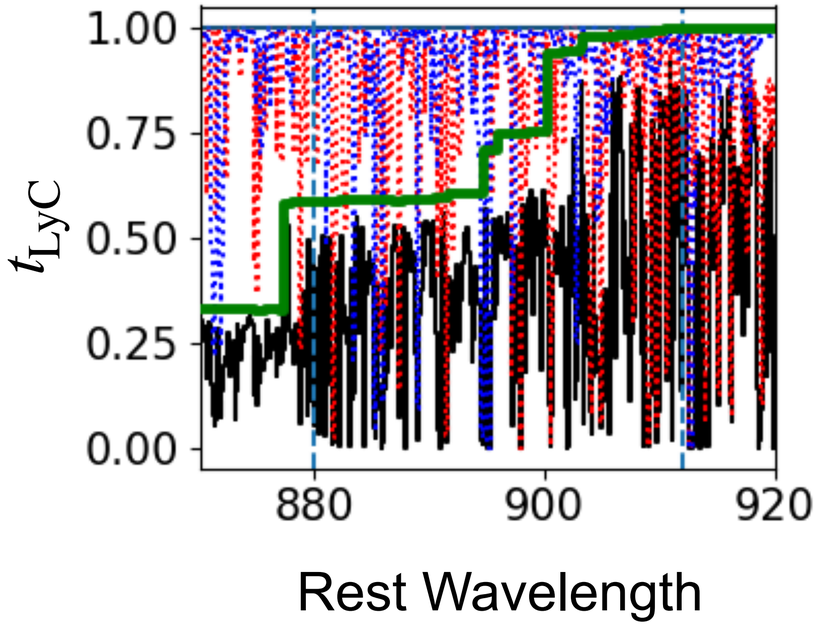
Source at $z = 3.3$



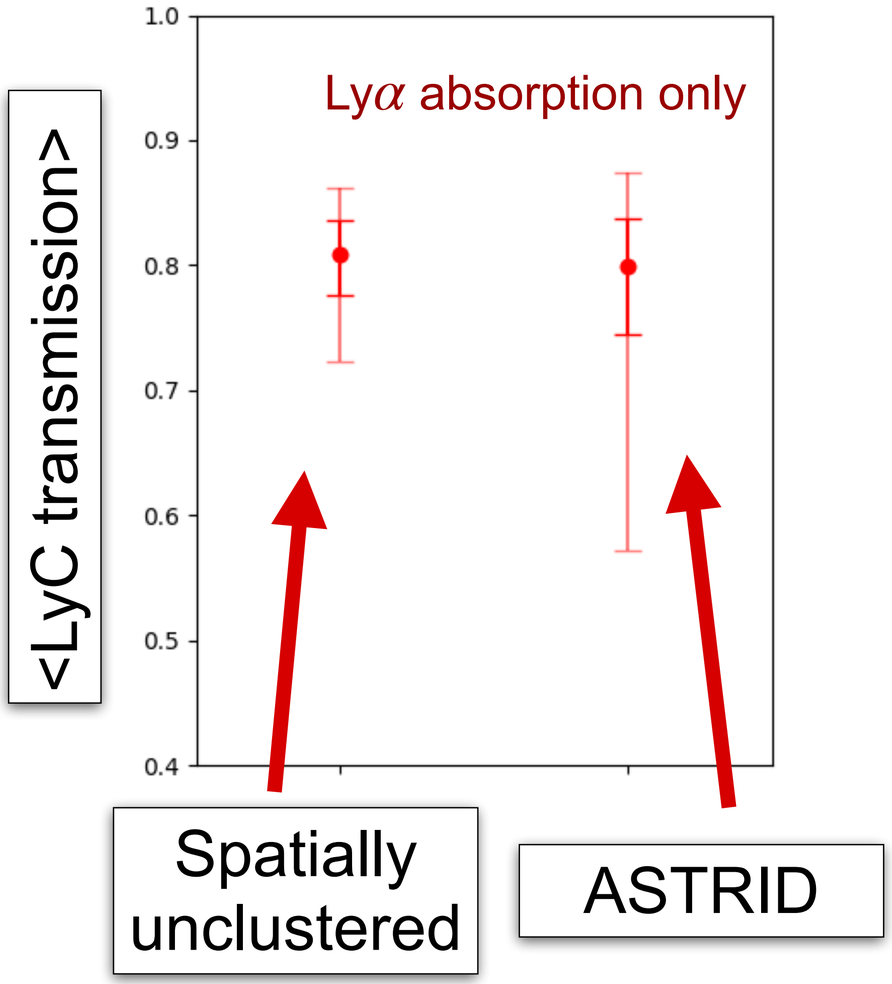
LyC at $z \lesssim 3.3$

Lyβ at $z \simeq 2.8$

Lyα at $z \simeq 2.2$



Spatial correlations in the IGM drive higher variance in Lya absorption in the LyC region



preliminary

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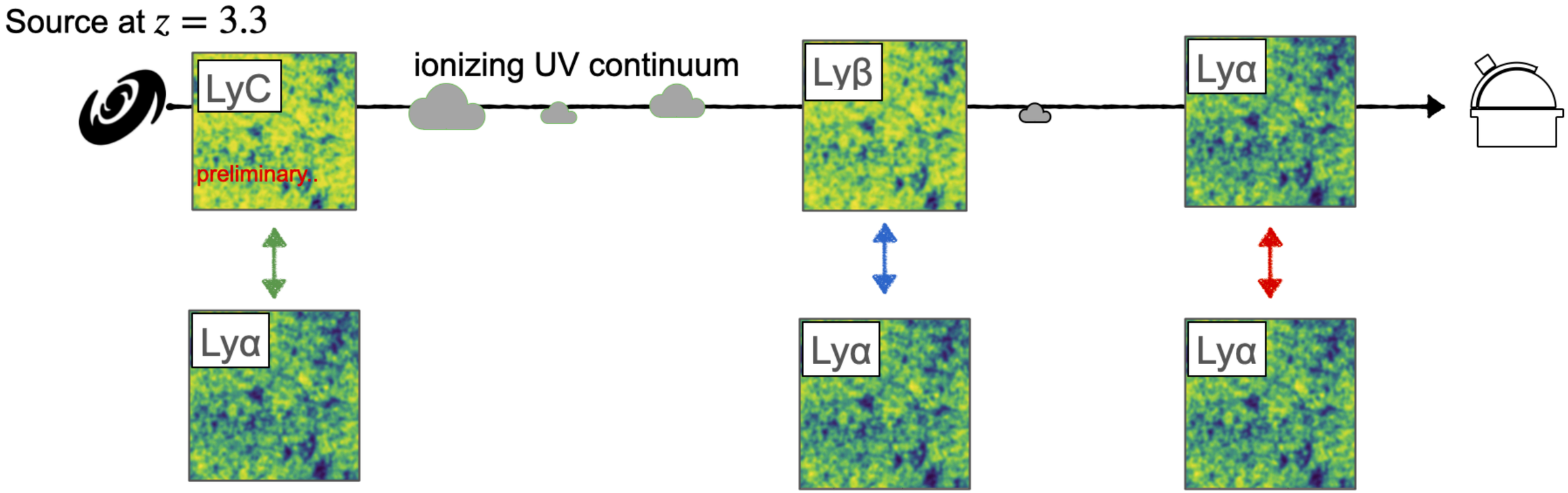
By correlating different types of absorption with Lyα flux maps, we can reduce uncertainty on LyC transmission for individual observations



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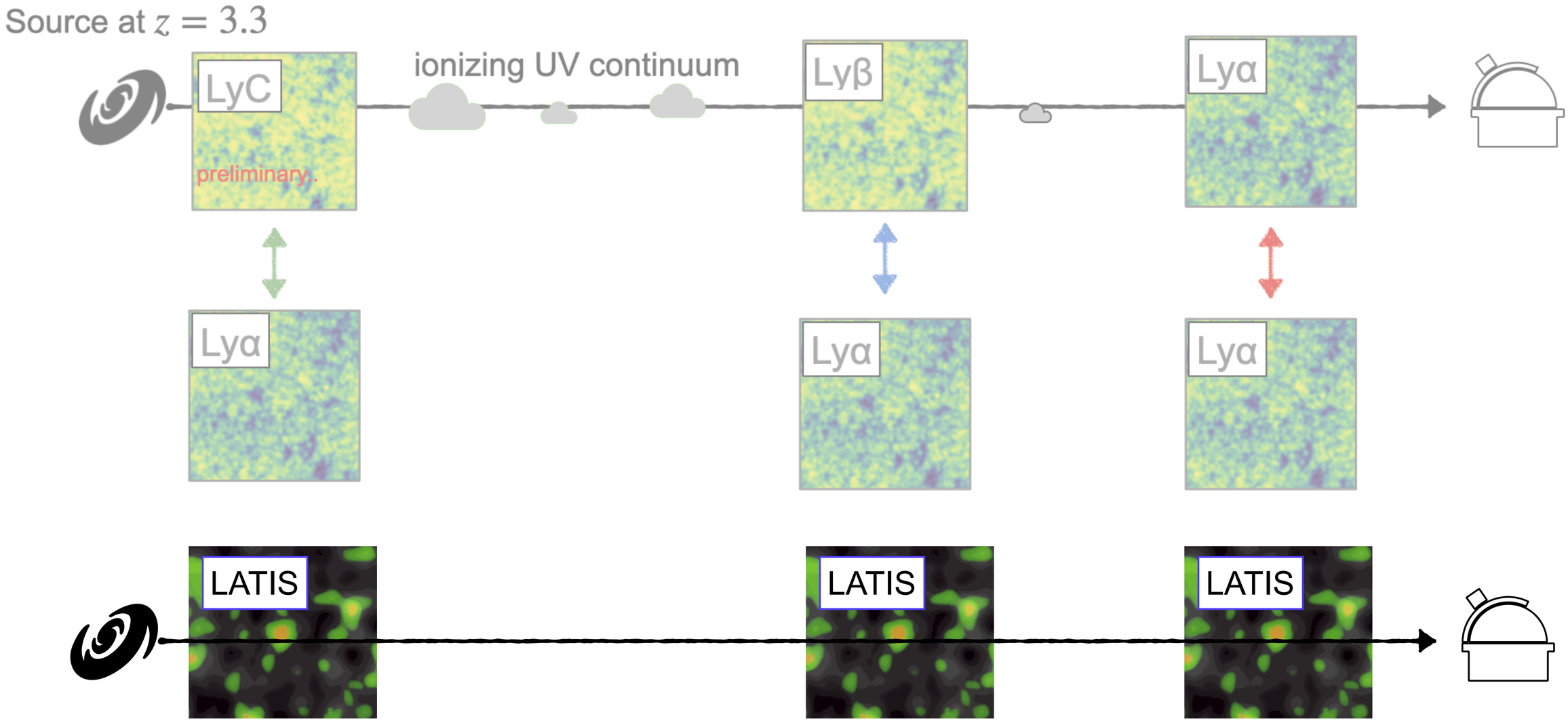

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Summary

- JADES+CEERS NIRSpec-based $\xi_{\rm ion}$ and KLCS-based $f_{\rm esc}$ imply reionization ends at $z \sim 5-7$
- Trends between $f_{\rm esc}$ and Lyα profile shape within the KLCS suggests that $f_{\rm esc}$ relations vary across redshift
- Individual LyC signals at z~3 are affected by large variances in IGM transmission, which is spatially correlated
- We can develop more precise constraints on LyC flux (and $f_{\rm esc}$) by leveraging the Lyα tomography and cosmological simulations.