Robustness of Reionization Constraints from Lyα Emitters in the Roman Era

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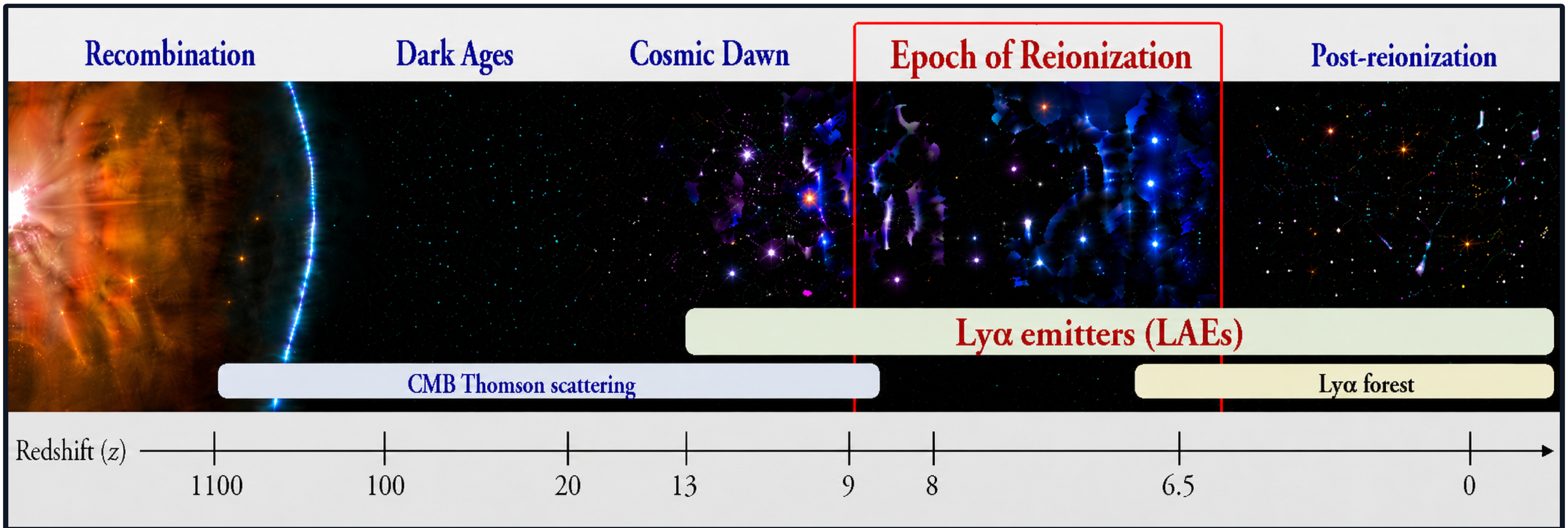


Cosmic timeline: Roman-era wide-field surveys connect large high-z LAE catalogs to reionization observables

1. Why LAEs?

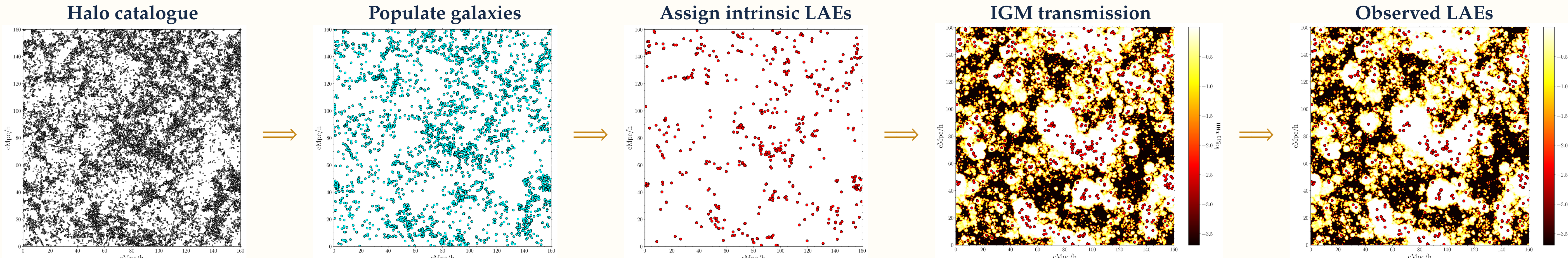
- Lyα transmission is resonantly scattered by neutral hydrogen, making LAE visibility directly susceptible to the neutral IGM.
- LAE statistics evolve with the IGM ionization, making them an excellent probe of epoch of reionization.
- JWST observations demonstrate LAE detectability up to $z \sim 13$,, giving them an edge over other probes.

2. Why Roman?

- Roman's prism will detect Lyα line at redshifts as low as $z \sim 5.2$ (end of EoR), while its grism can detect LAEs as far as $z \sim 14.8$, spanning the EoR.
- Roman's $\simeq 0.28\,\mathrm{deg}^2$ WFI (Wide Field Instrument) field of view will build large LAE catalogs across many sightlines, reducing cosmic variance.

3. LAE model

Halo catalogue ⟹ Populate galaxies ⟹ Assign intrinsic LAEs ⟹ IGM transmission ⟹ Observed LAEs



Halo catalogue: 21cmFAST reionization volumes provide halo positions and masses.

$L = 160\,h^{-1}$cMpc
$\{M_h, x, y, z\}$

Populate galaxies: UV luminosities are assigned by halo–UV abundance matching.

$$\epsilon_{DC}\int_{M_h}^{\infty} n(M,z)\,dM = \int_{L_{UV}}^{\infty}\phi(L,z)\,dL$$

Assign intrinsic LAEs: Each UV galaxy draws an REW from an empirical distribution.

$W \sim P(W|M_{UV}, z)$
$L_\alpha \propto L_{UV}\,W$

IGM transmission: Sightlines through IGM fields are used to calculate Lyα attenuation.

$$T_{IGM} = \frac{\int J(v)e^{-\tau(v)}dv}{\int J(v)dv}$$

Observed LAEs: The transmitted luminosities define mock Lyα LFs for Bayesian comparison to data.

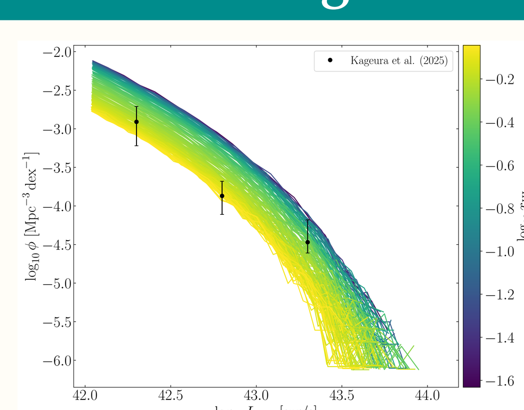
$L_\alpha^{obs} = T_{IGM}L_\alpha, \qquad \phi(L_\alpha^{obs}|x_{HII})$

4. LF data

- This analysis uses the LF constraints derived by Kageura et al. (2025) using LAE catalogs from JWST surveys.
- It consolidates LAE objects from multiple JWST surveys (JADES, GLASS, CEERS etc.) observing different independent sky fields into a single LF data set.
- These are the only Lyα LF constraints in the literature probing at $z > 8$.

Kageura et al. (2025) provides high-z Lyα LF constraints, with multi-field catalogs reducing cosmic variance.

5. Inference engine



LF likelihood

⟹

$$l = -\sum_i \frac{\left(\log_{10}\phi_i^{mock} - \log_{10}\phi_i^{obs}\right)^2}{2\sigma^2_{\log\phi,i}}$$

$$P(x_{HII}\mid\phi) \propto P(\phi\mid x_{HII})P(x_{HII})$$

Each IGM realization produces a mock Lyα LF. Comparing them to the observed LF converts these reionization models directly into a posterior on the global ionized fraction.

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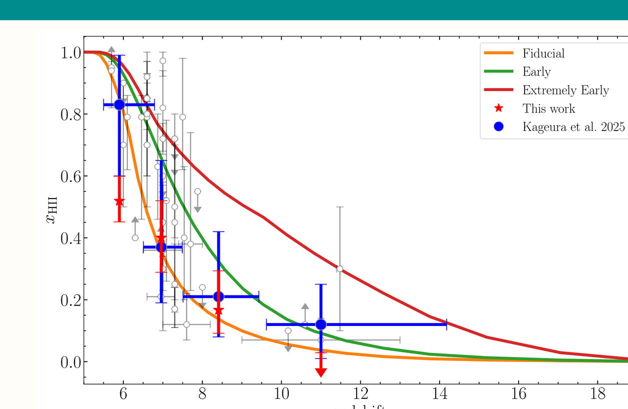


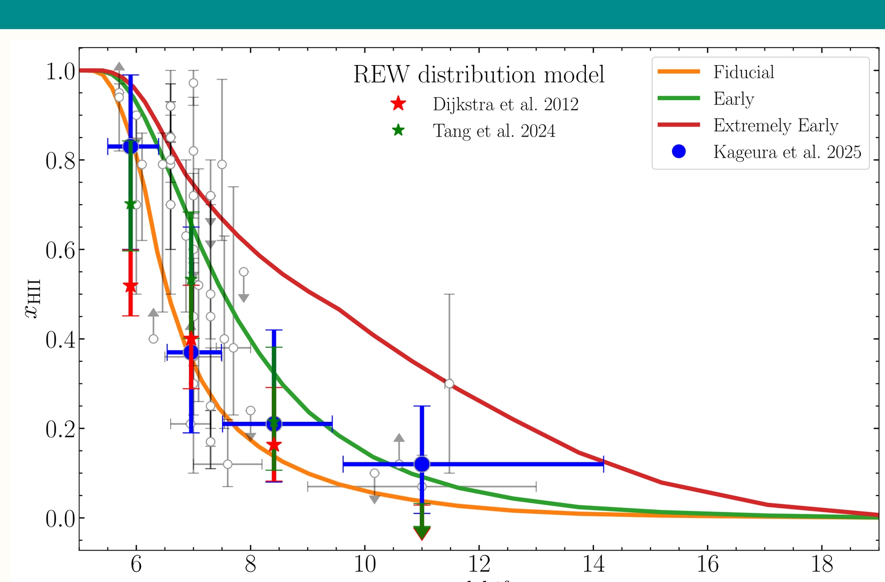
Inferred ionization history

6. Dependence on REW distribution

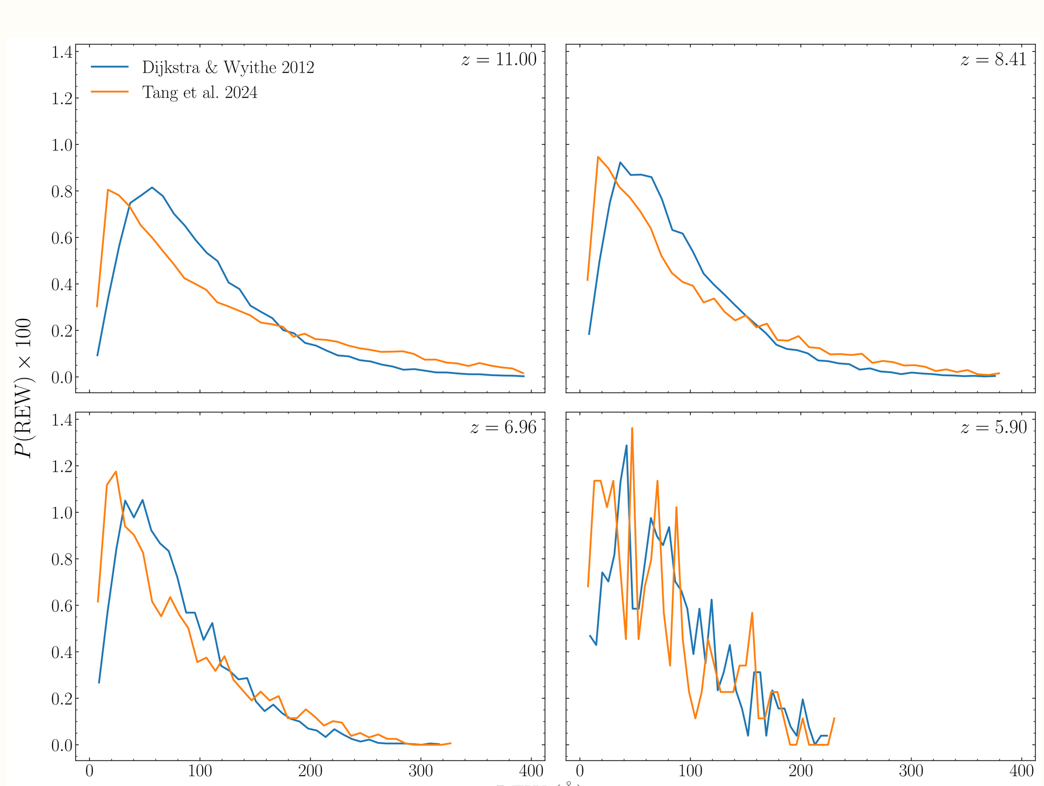
- JWST has significantly extended the LAE catalog, which motivates an updated REW distribution model.

$$P_{exp}(W|M_{UV}, z) \propto e^{-W/W_c} \Longrightarrow \mathbf{P_{logN}(W)} \propto \frac{1}{W\sigma}e^{-(\ln W-\mu)^2/2\sigma^2}$$

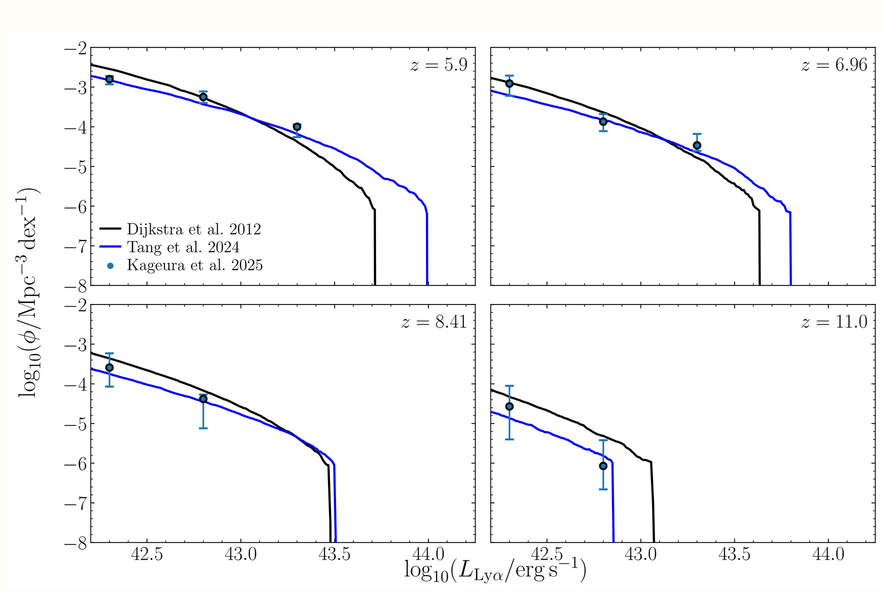
- Here, the fiducial REW prescription is updated to test its effect on the x_{HII} constraints
- A heavier high-W tail moves more UV-faint galaxies into bright L_α bins, shifting the LF and hence the inferred x_{HII}.



Posterior response of x_{HII}



Comparison of observed REW distributions



Lyα LF from fiducial vs alternate REW

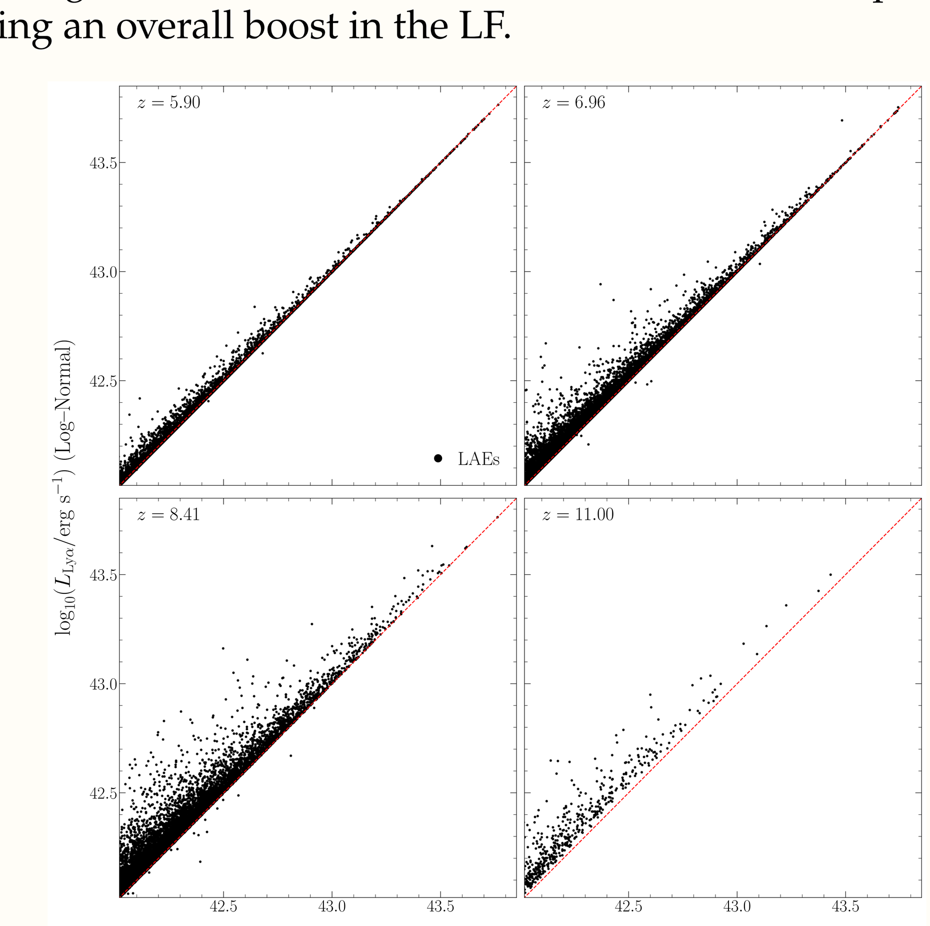
Changing the REW distribution changes the intrinsic LAE sample, so the model already deviates from the fiducial intrinsic LF before IGM attenuation.

7. Dependence on line profile

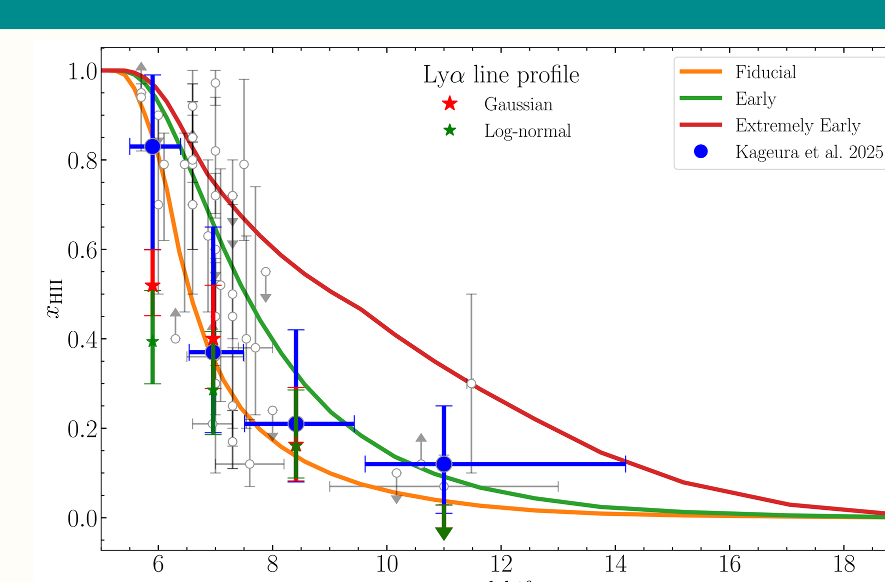
- RT simulations favor asymmetric Lyα profiles; here the Gaussian form is replaced with a log-normal profile.

$$J_G(v) \propto e^{-(v-\Delta v)^2/2\sigma_v^2} \Longrightarrow \mathbf{J_{logN}(v)} \propto \frac{1}{v}e^{-(\ln v-\ln\Delta v)^2/2s^2}$$

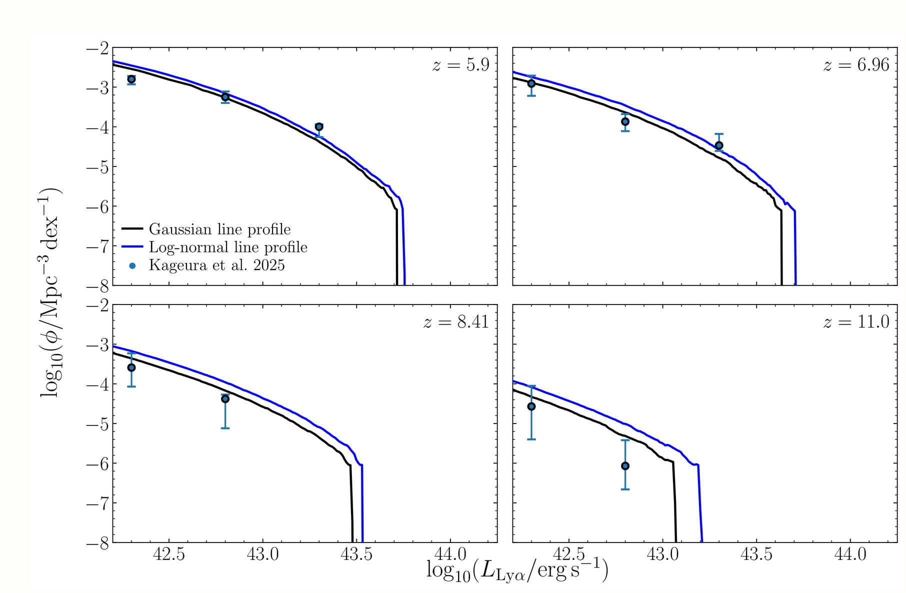
- Longer red tail increases transmitted luminosities, producing an overall boost in the LF.



Individual LAE luminosity response



Posterior response of x_{HII}



Lyα LF from Gaussian vs asymmetric line profiles

Asymmetric line profile increases T_{IGM} and lifts the LF; because the intrinsic LAE sample is fixed, the resulting x_{HII} shift remains subdominant to the REW prescription.

8. Summary

For currently plausible, observationally motivated intrinsic Lyα models, the systematic shift in inferred $\langle x_{HII}\rangle$ is comparable to or larger than the statistical errors, and dominates line-profile/kinematic uncertainties. Therefore, a robust LAE-modelling pipeline is needed before Roman data arrives to turn these samples into ionization-history constraints.

9. Acknowledgements

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10. References

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