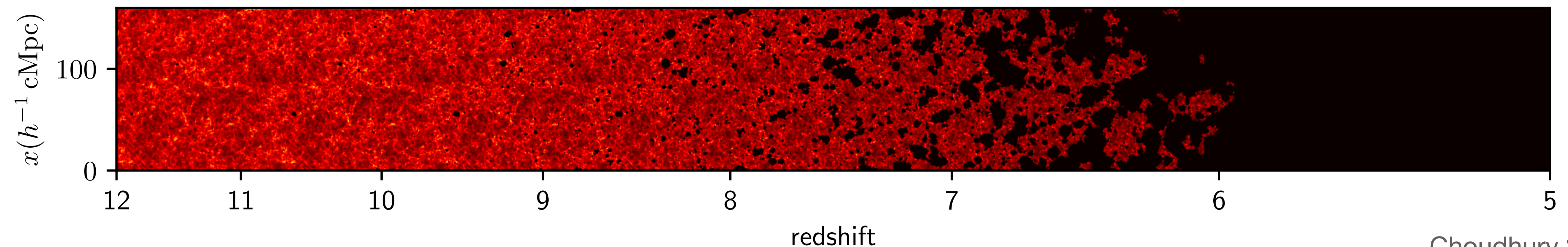
A black hole with a bright accretion disk and a jet of light. The background is dark with some distant stars.

Learning reionization history from high-redshift quasars

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Supervisor: Joseph F. Hennawi

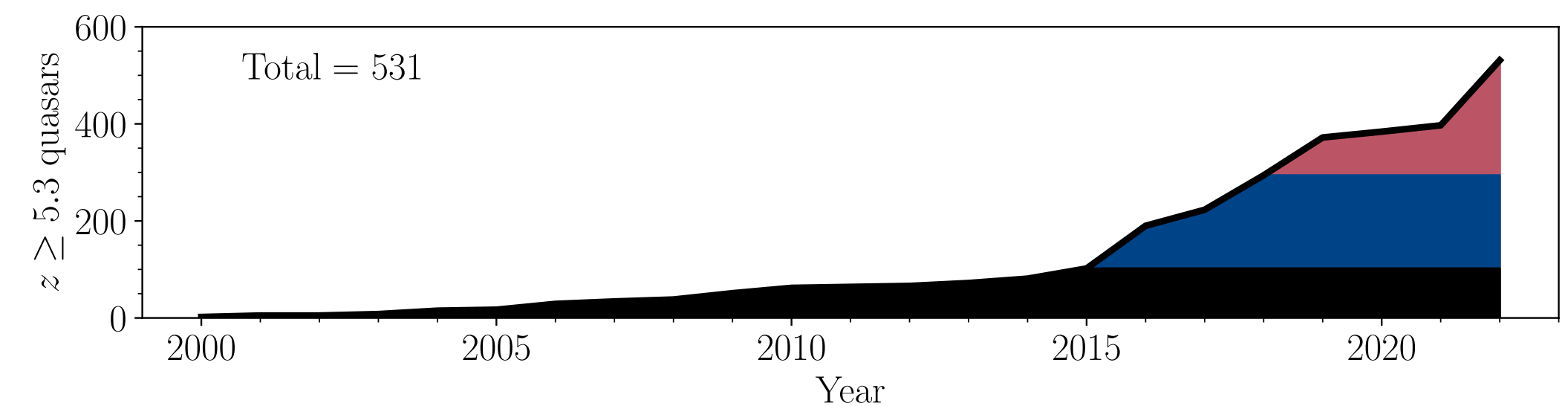
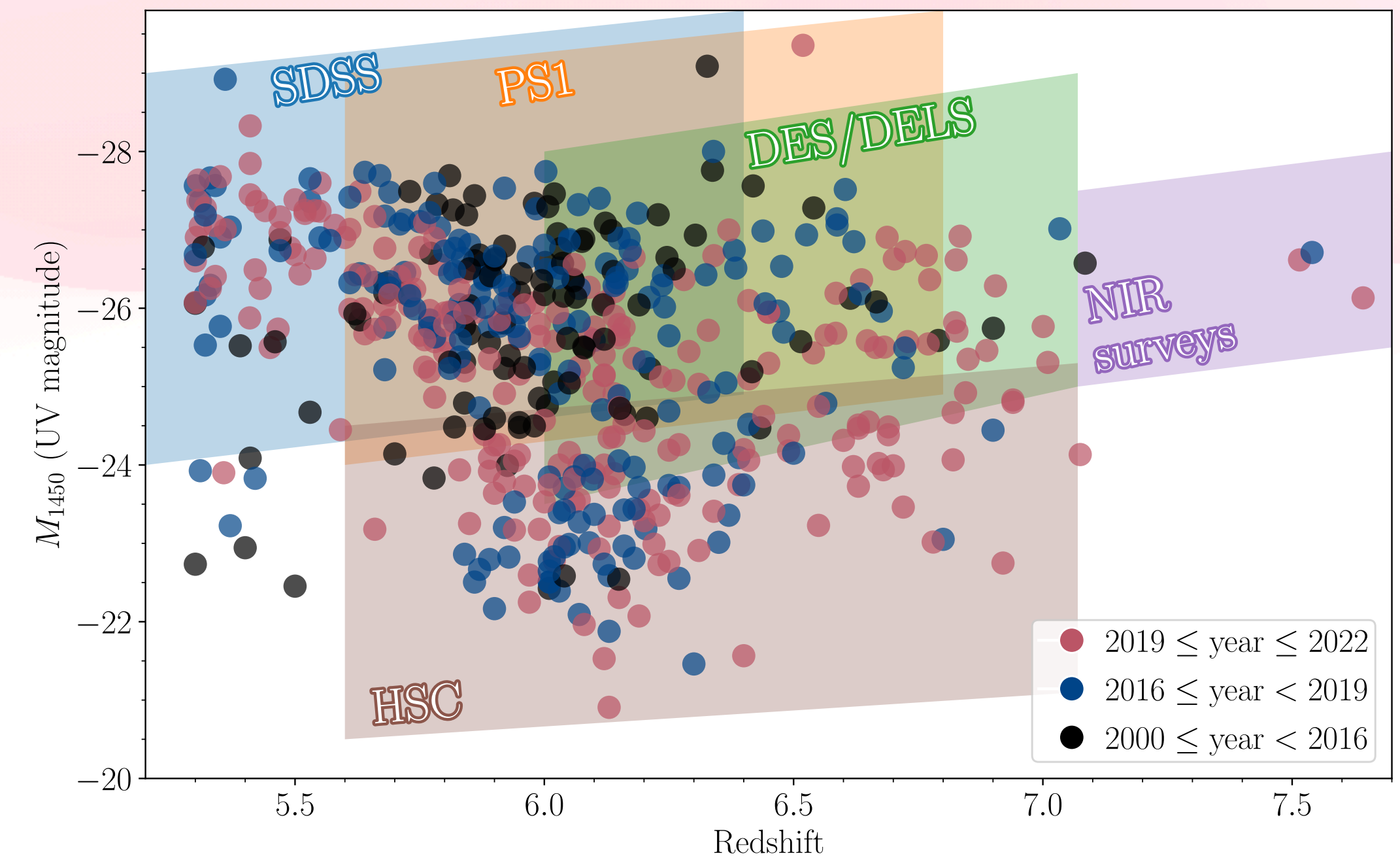
The Epoch of Reionization

- Radiation from the first stars and galaxies ionizes hydrogen in the intergalactic medium (IGM)
- Timing of reionization so far not very well constrained, mean reionization redshift $z_{\text{re}} \sim 6 - 10$
- Reionization is completed by $z_{\text{end}} \sim 5 - 6$



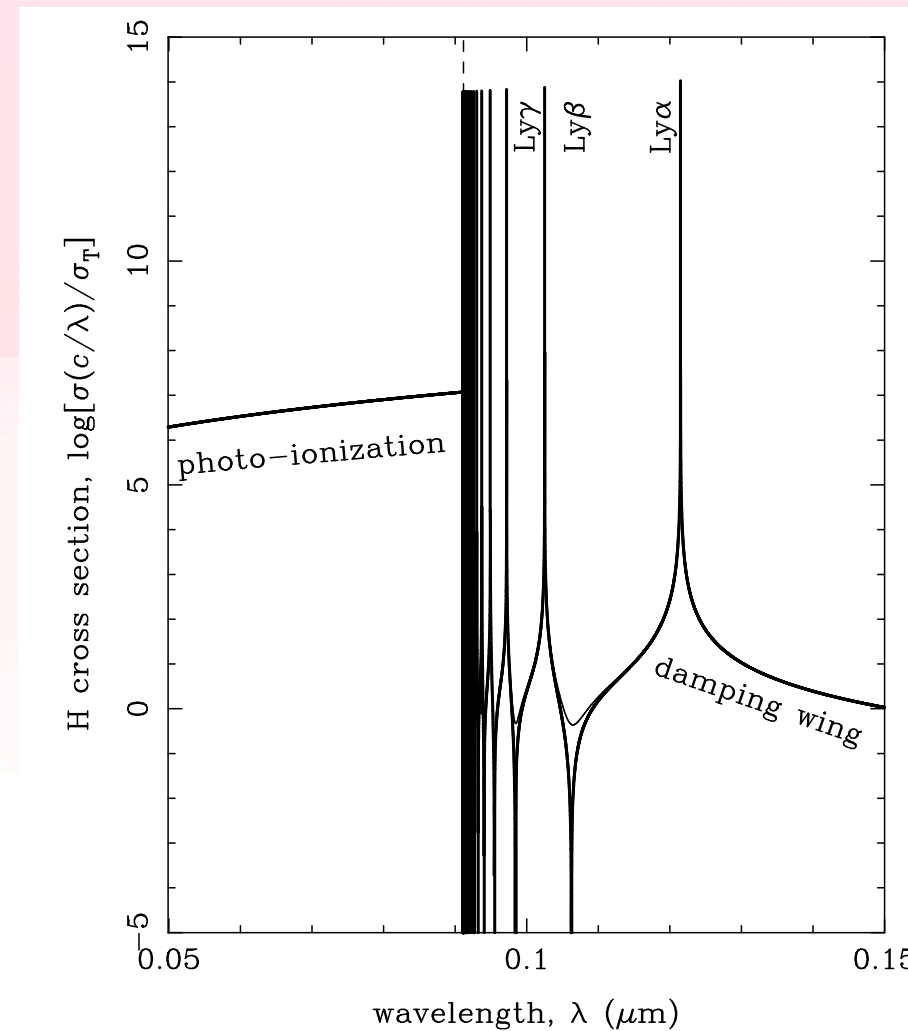
Why quasars?

- extraordinarily bright objects
- found at high-redshift
- currently more than 250 quasars known at $z > 6$
- many more to be found by upcoming surveys such as Euclid

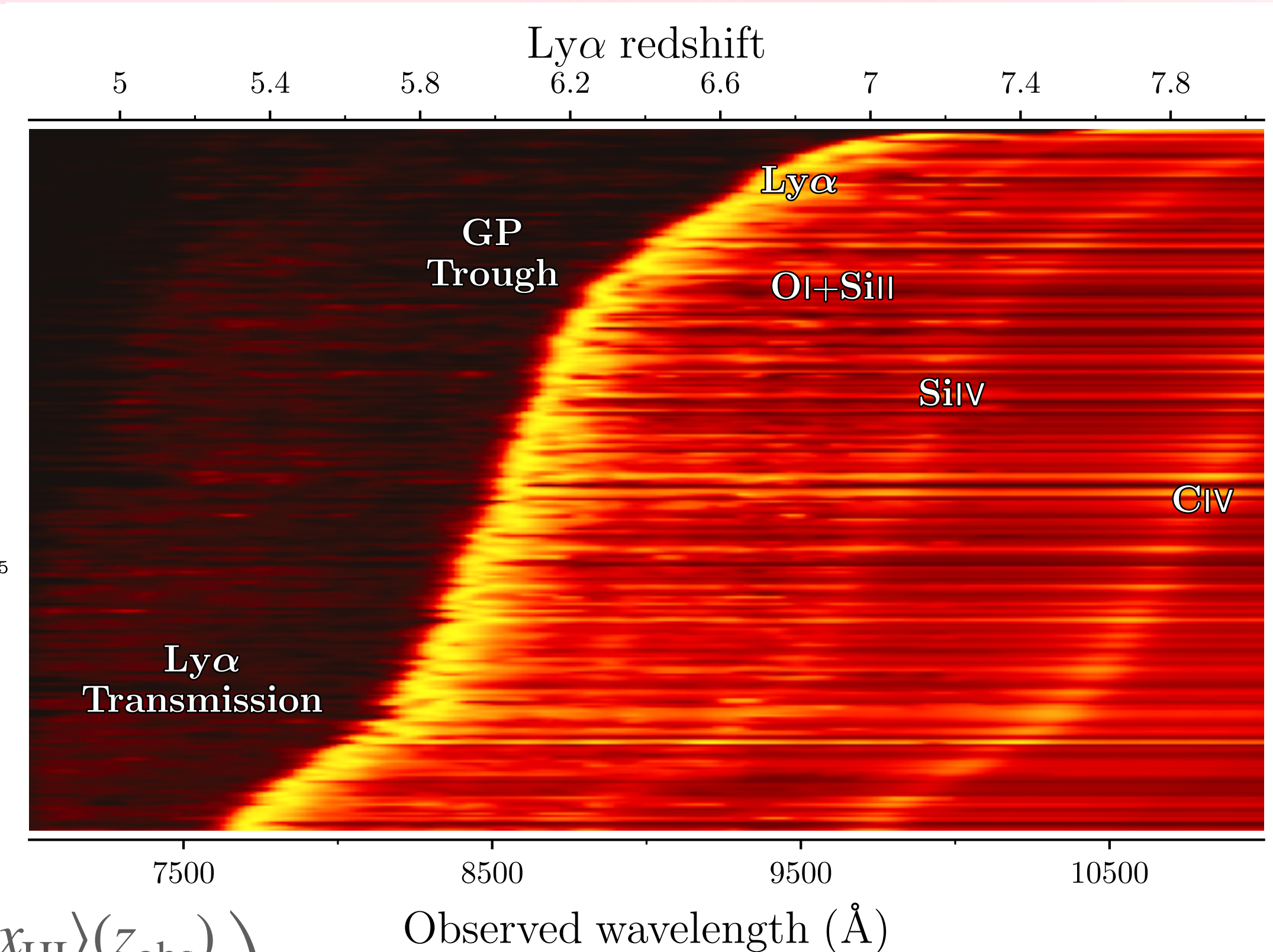


Probing the EoR with high-redshift quasars

- characteristic spectra with little redshift evolution, strong Lyman- α and other smooth emission lines
- $z \lesssim 5$: Lyman- α forest blueward of the Lyman- α line
- $z \gtrsim 6$: Gunn-Peterson trough



Mortlock 2015



Fan+ 2022

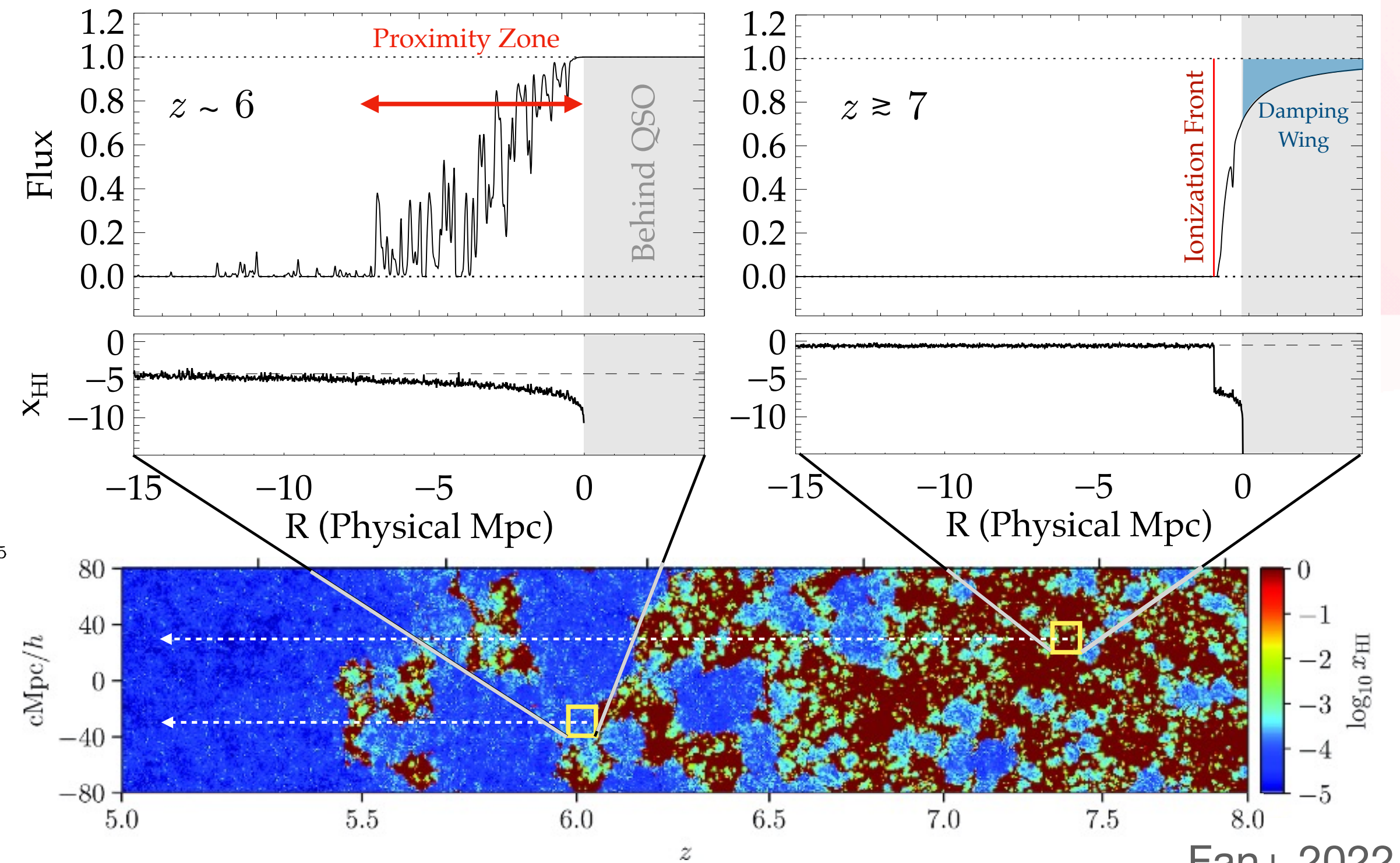
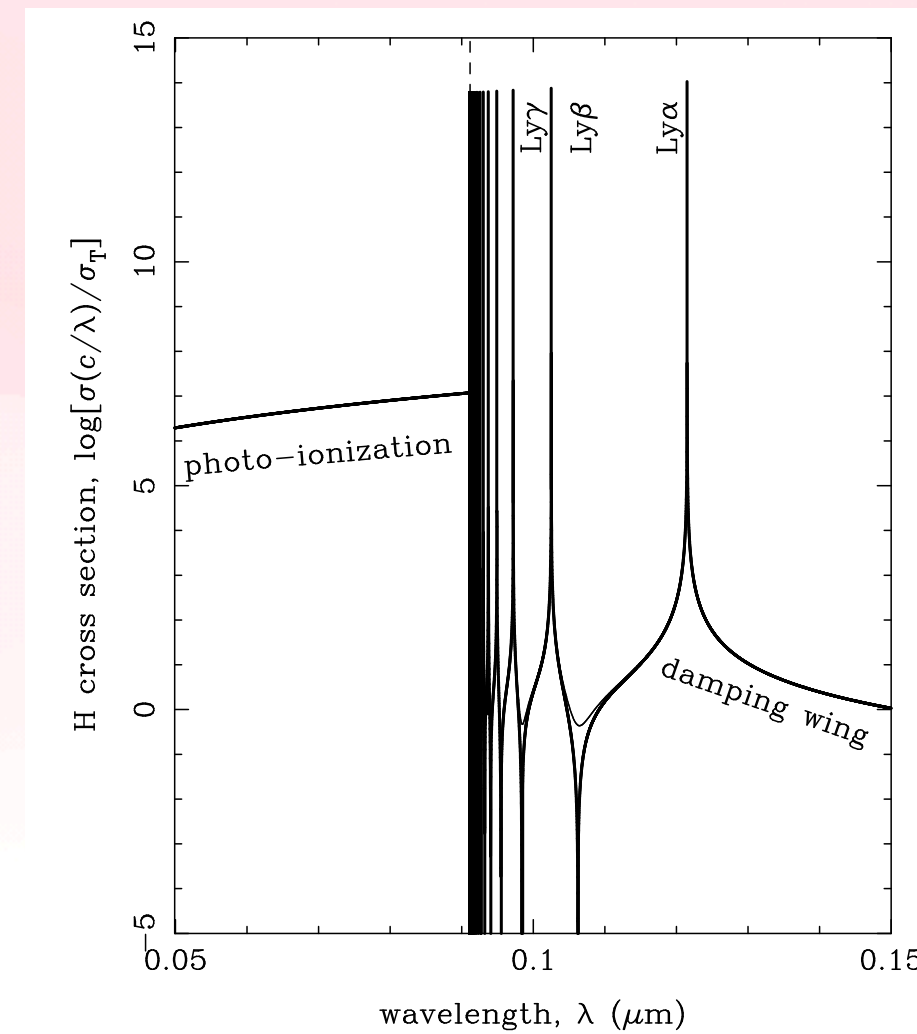
- optical depth: $\tau_{\text{GP}}(z_{\text{obs}}) = 3.9 \times 10^5 \left(\frac{1 + z_{\text{obs}}}{1 + 6.0} \right)^{\frac{3}{2}} \left(\frac{\langle x_{\text{HI}} \rangle(z_{\text{obs}})}{1.0} \right)$

→ bounds on the end of reionization

Probing the EoR with high-redshift quasars

proximity zone:

- mostly ionized IGM
→ light from the quasar enhances ionization



damping wing:

- significantly neutral IGM
→ region around the quasar ionized by its ionization front
- high absorption cross section of neutral hydrogen causes absorption beyond Lyman- α line

Inference Procedure

- simulating high-redshift quasar spectra with damping wing absorption and comparing to observed spectra allows us to infer reionization history

• Bayes' Theorem:
$$P(\Theta | X) = \frac{L(X | \Theta) \cdot P(\Theta)}{P(X)} \sim L(X | \Theta) \cdot P(\Theta)$$

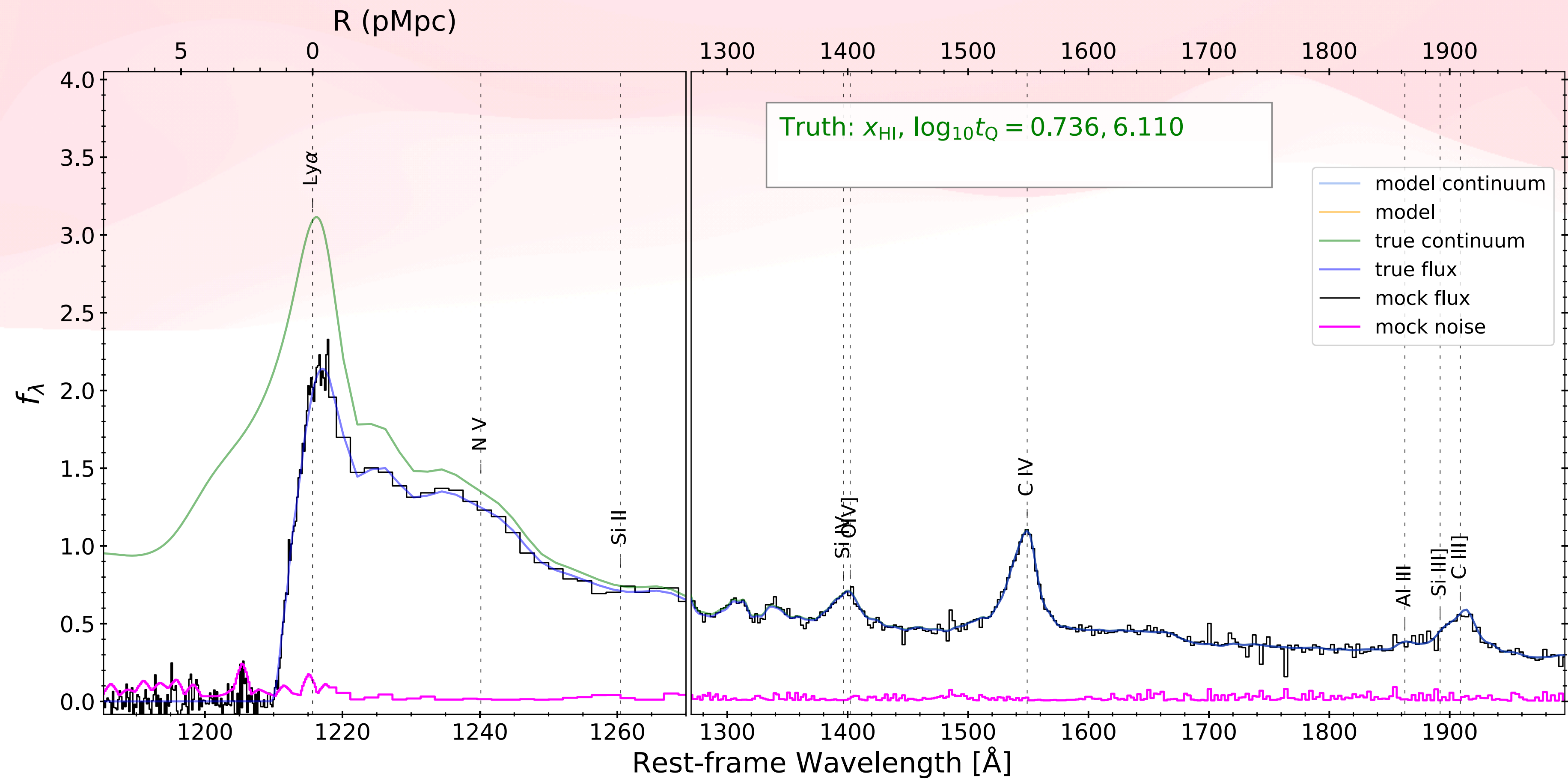
$$\Theta = (\langle x_{\text{HI}} \rangle, t_{\text{Q}}, \alpha)$$

parameters: global IGM neutral hydrogen fraction
 quasar lifetime
 nuisance parameters

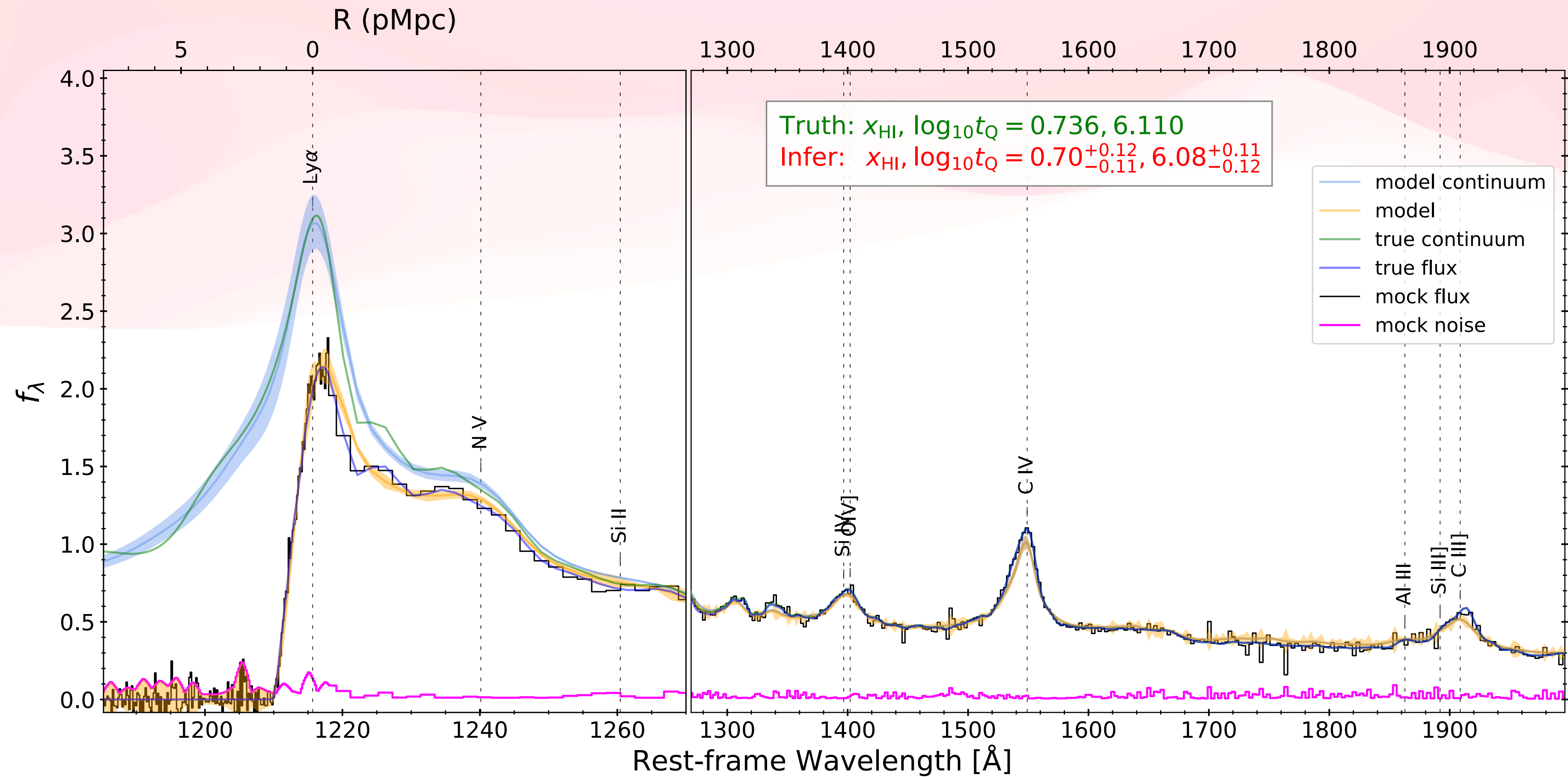
$$X = f$$

data: observed spectrum

A (mock) quasar spectrum

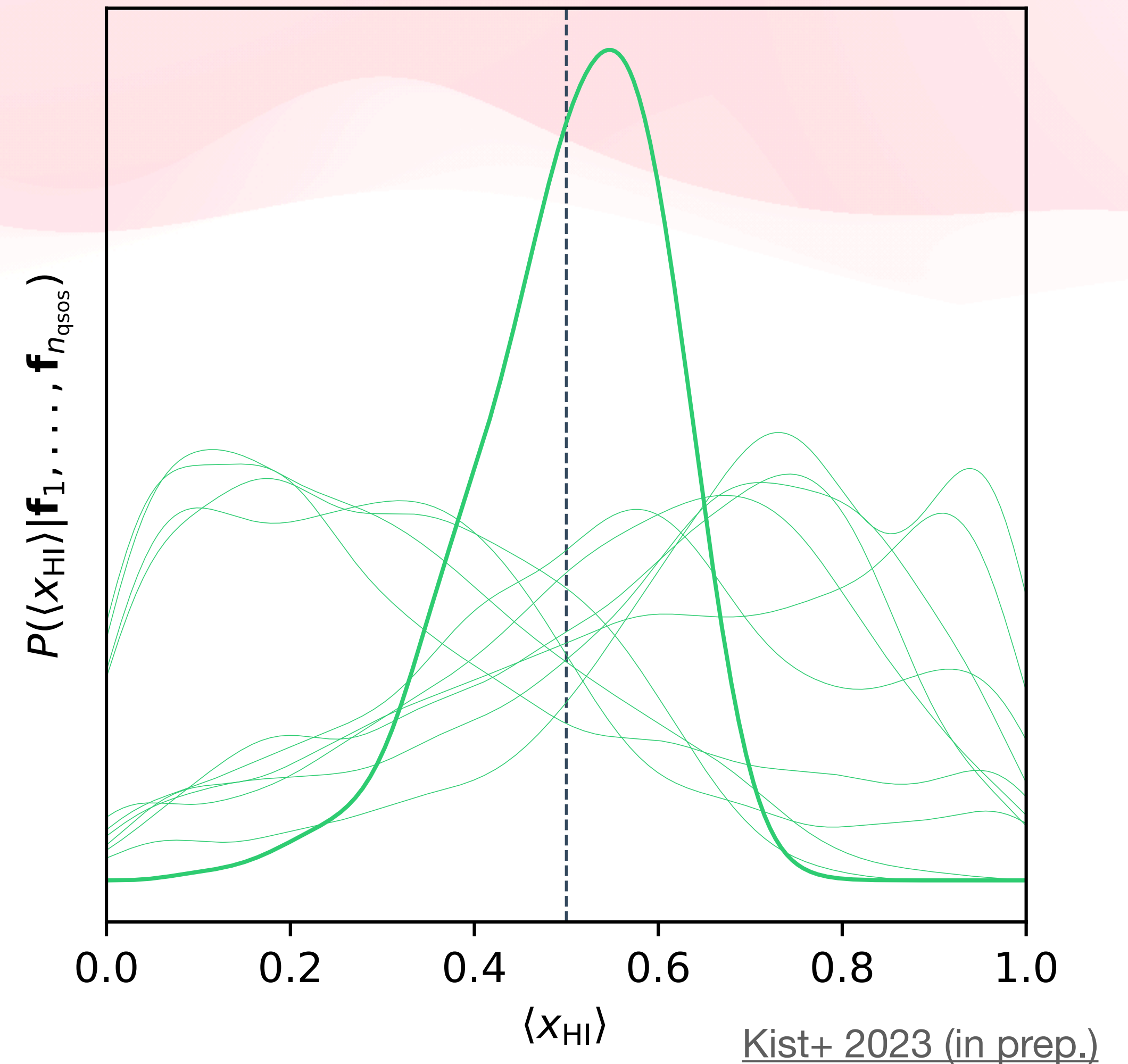


Parameter inference from a quasar spectrum



Forecasting reionization history

- assume a reionization history
- generate mock quasar spectra resembling the anticipated Euclid observations
- run our inference pipeline on these quasars to infer $\langle x_{\text{HI}} \rangle(z)$ in different redshift bins
- here: 10 quasars at $z = 7.54$
(assuming that $\langle x_{\text{HI}} \rangle(z = 7.54) = 0.5$)



Constraints on reionization history

