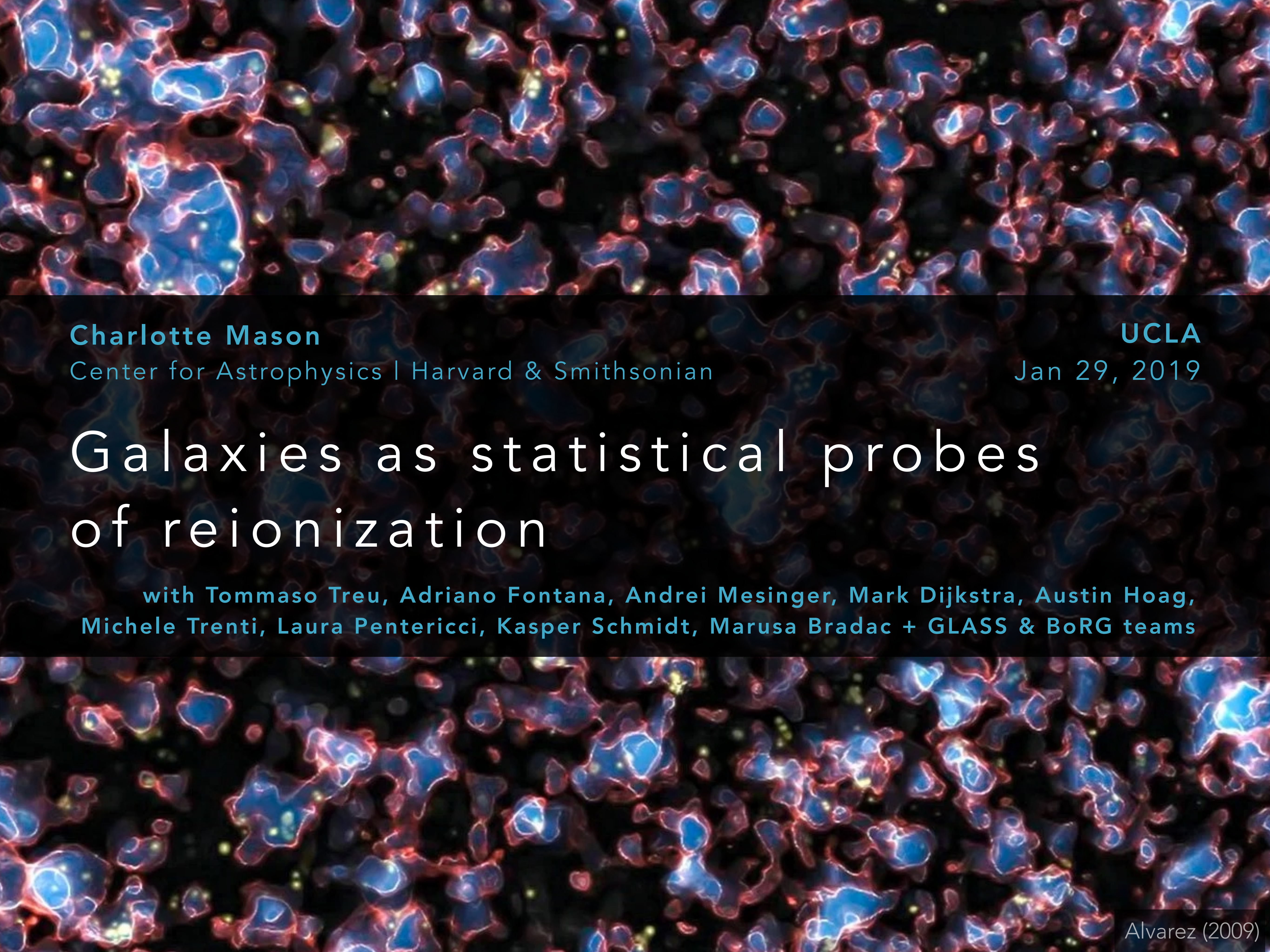


Charlotte Mason
Center for Astrophysics | Harvard & Smithsonian

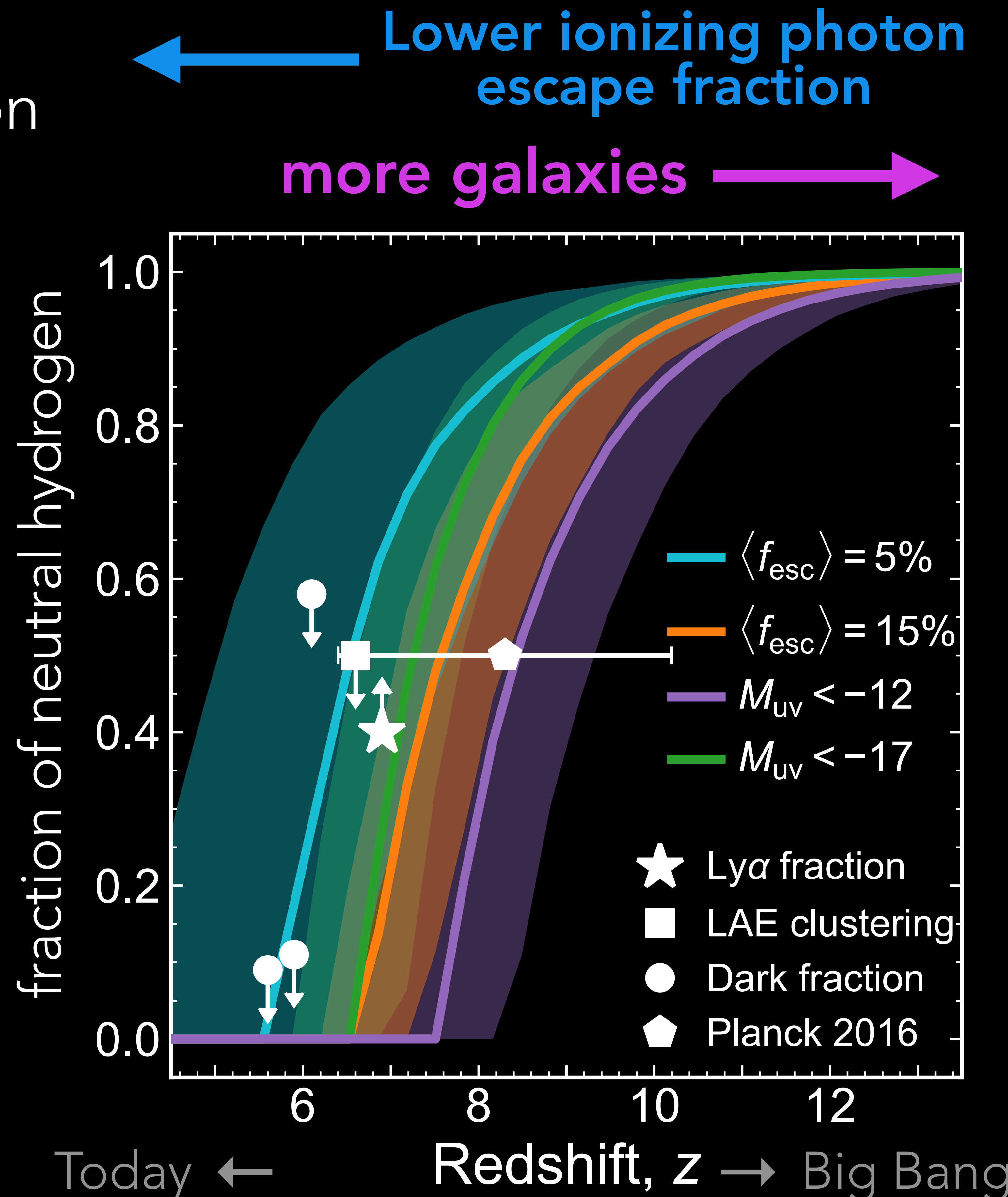
UCLA
Jan 29, 2019

Galaxies as statistical probes of reionization

with Tommaso Treu, Adriano Fontana, Andrei Mesinger, Mark Dijkstra, Austin Hoag, Michele Trenti, Laura Pentericci, Kasper Schmidt, Marusa Bradac + GLASS & BoRG teams

Alvarez (2009)

What is the reionization history of the IGM?



Constraints from Ouchi+10,
McGreer+2014, Mesinger+15, Sobacchi+15

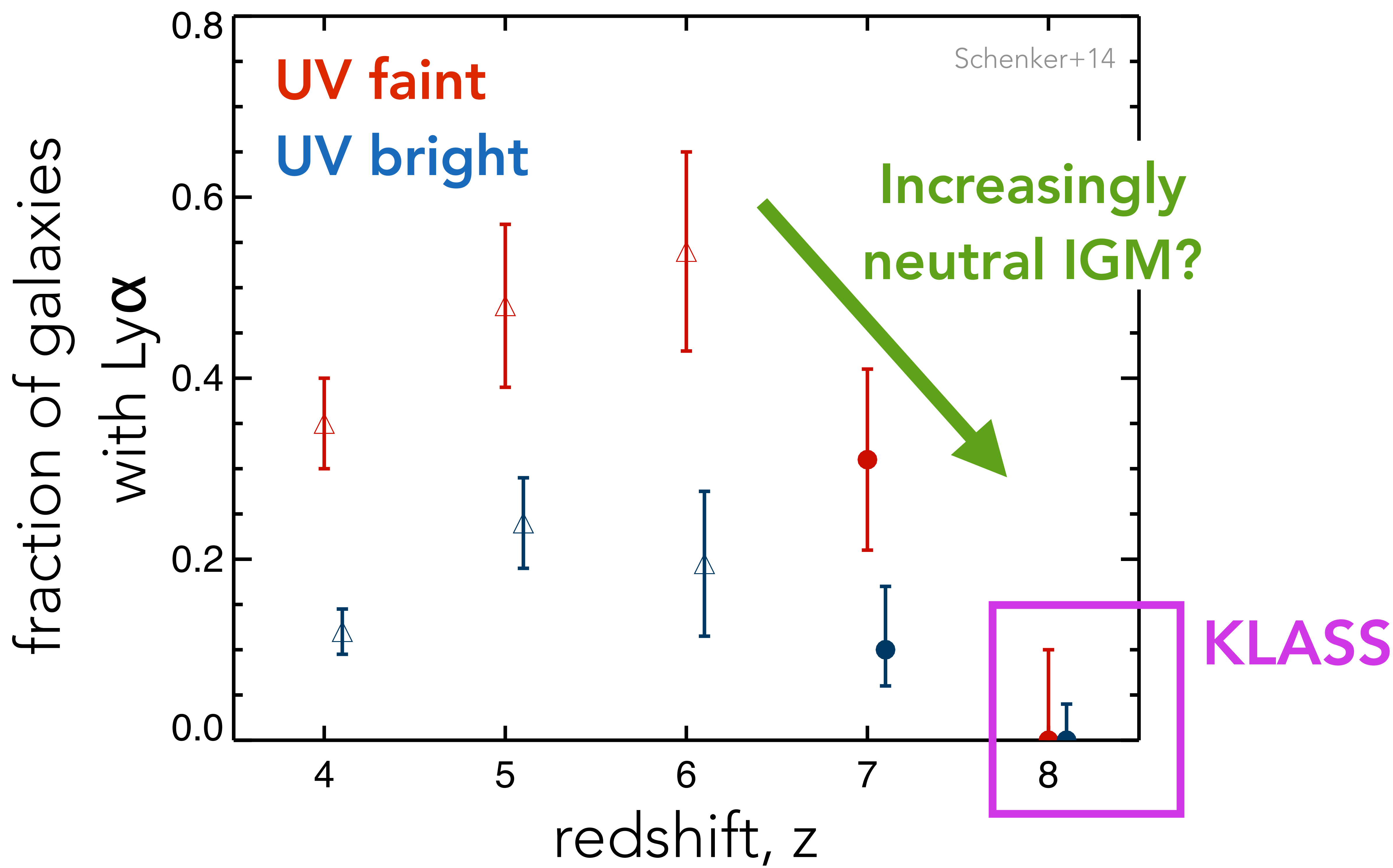
What is the reionization history of the IGM?

How will ELTs help?

Use galaxy spectral properties to constrain the IGM

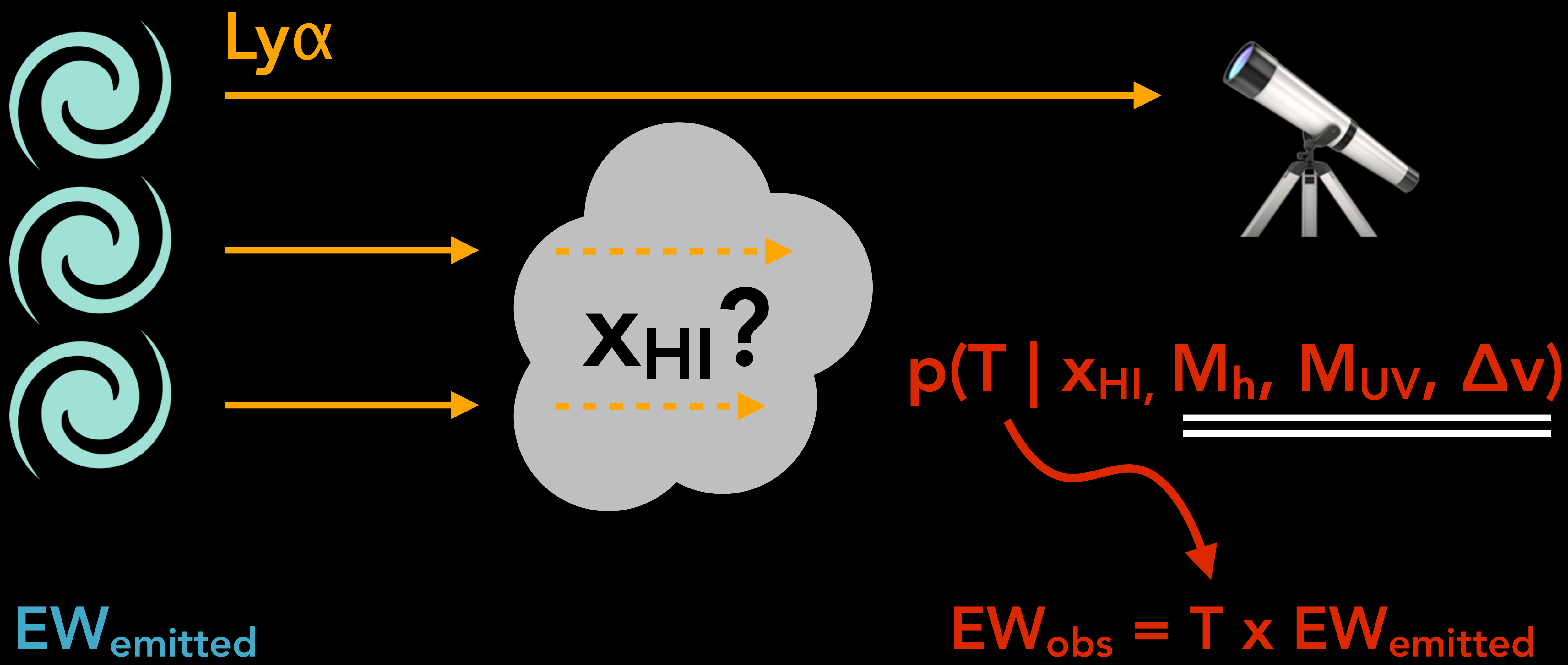
Forward modelling framework to connect Lyα observations to IGM state

Is the rapid decline in Lya visibility at z>6 due to reionization?



data from Stark+11, Schenker+14, see also Treu+13, Faisst+14, Tilvi+14, Pentericci+14,+18, de Barros+17

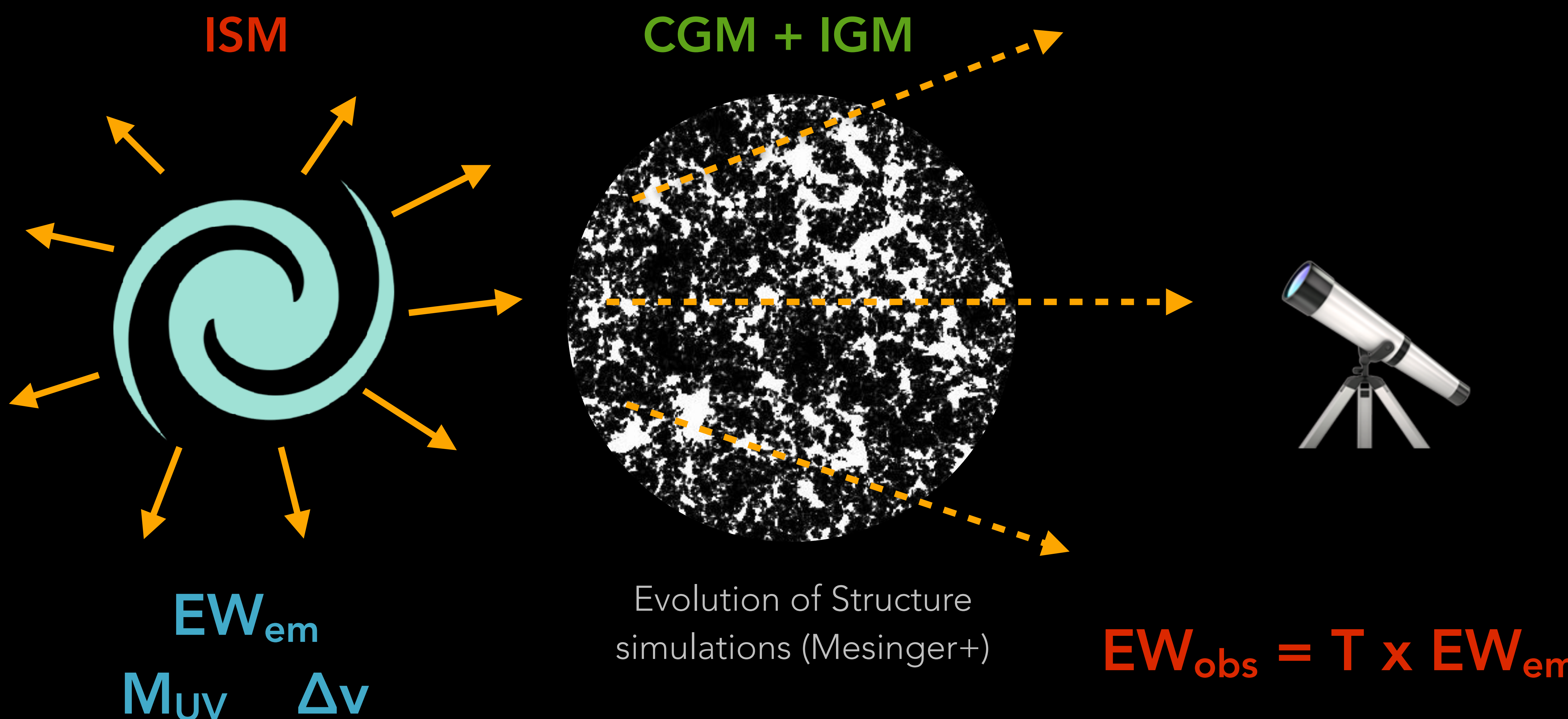
How do we connect Lya observations to the neutral fraction, x_{HI}?



$EW \sim f_{line}/f_{cont}$

see e.g. Dijkstra+11; Bolton & Haehnelt 13; Jensen+13

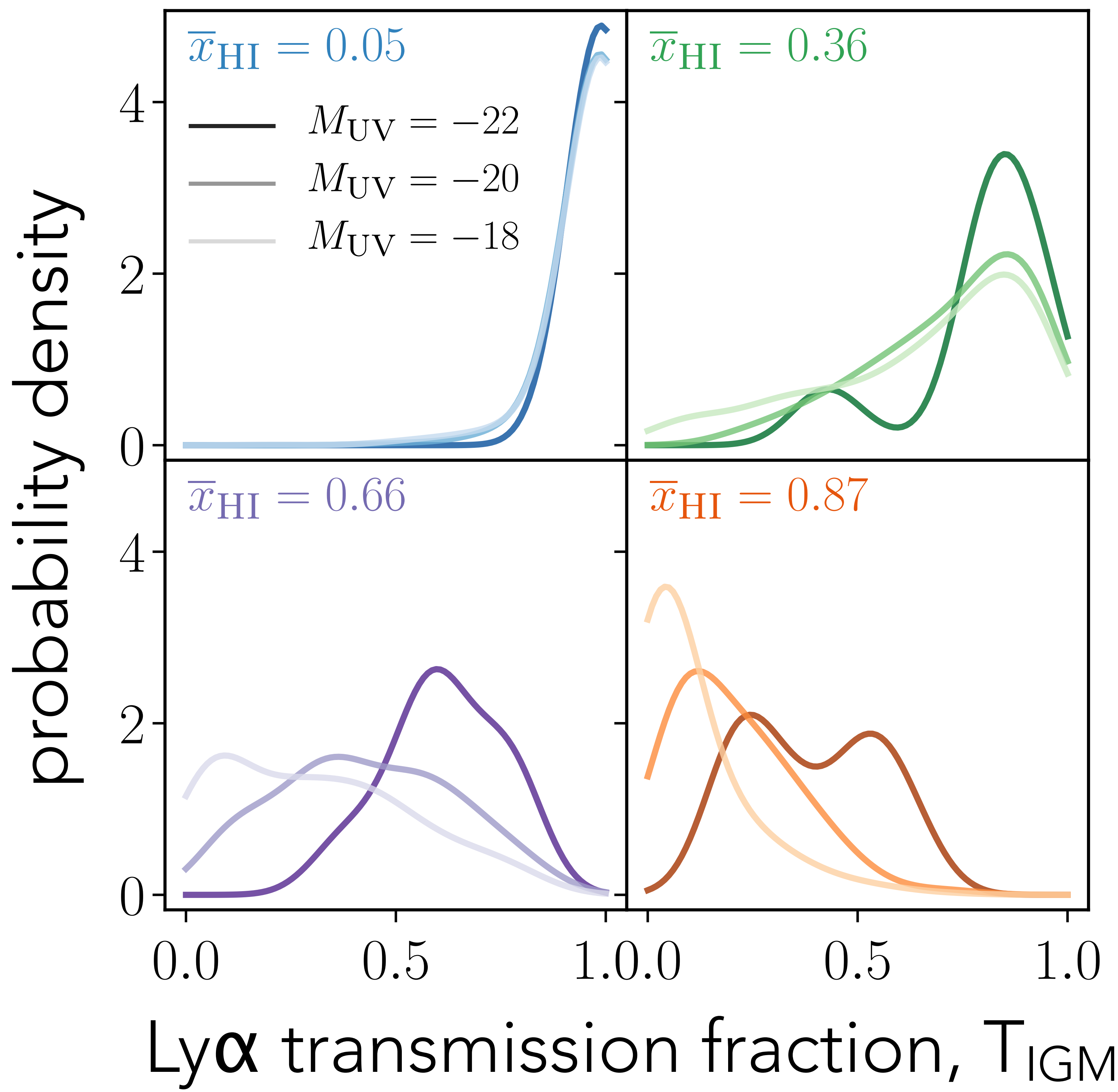
A new forward-modeling framework combining realistic IGM topologies and ISM properties



$$\mathcal{T}(\overline{x}_{\rm HI}, M_h, \Delta v) = \int dv \, J_\alpha(M_h, \Delta v, v) \, e^{-\tau_{\rm IGM}(\overline{x}_{\rm HI}, M_h, v)}$$

Transmission of Lya depends on galaxy luminosity via environment and velocity offset

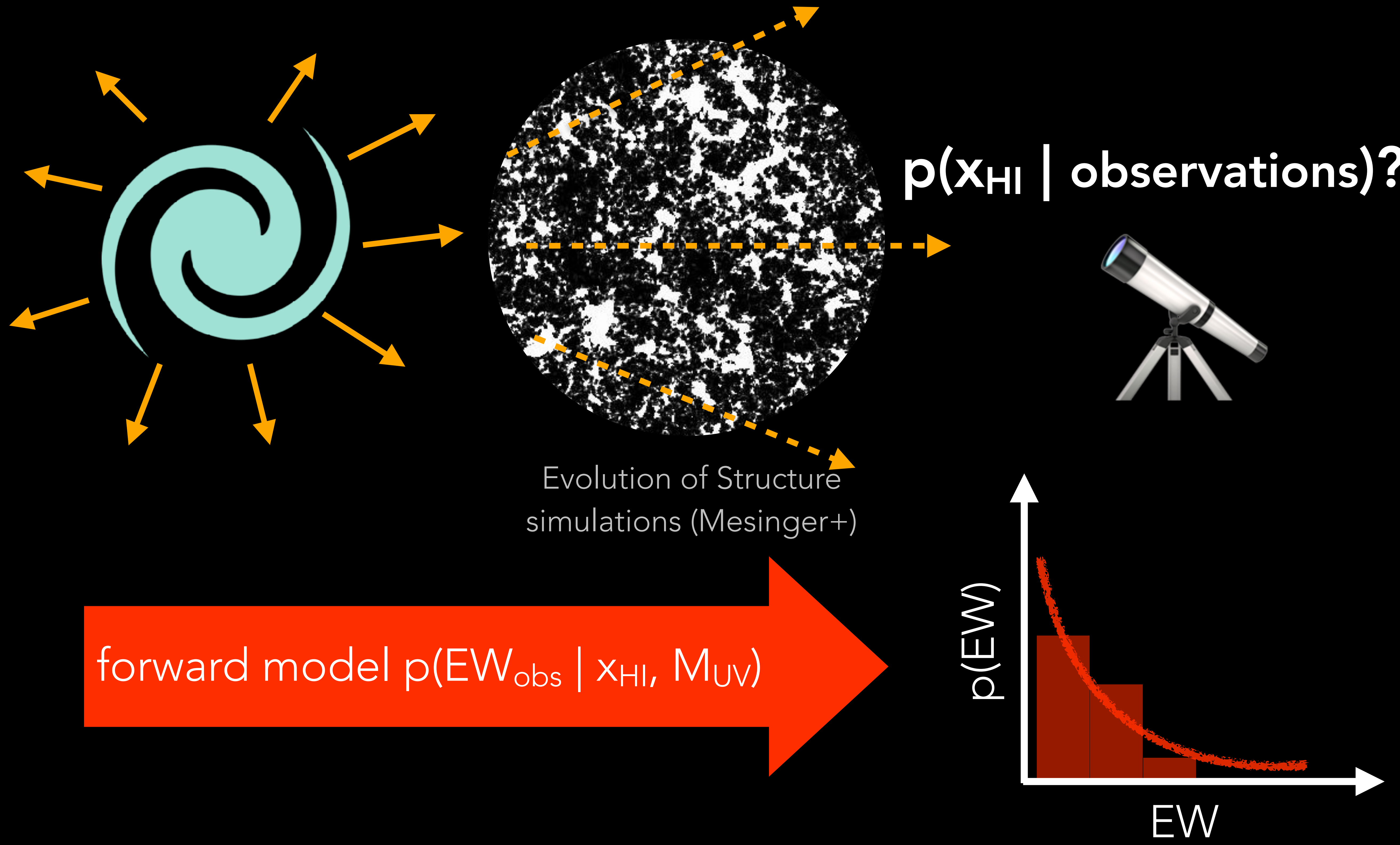
Mostly ionized



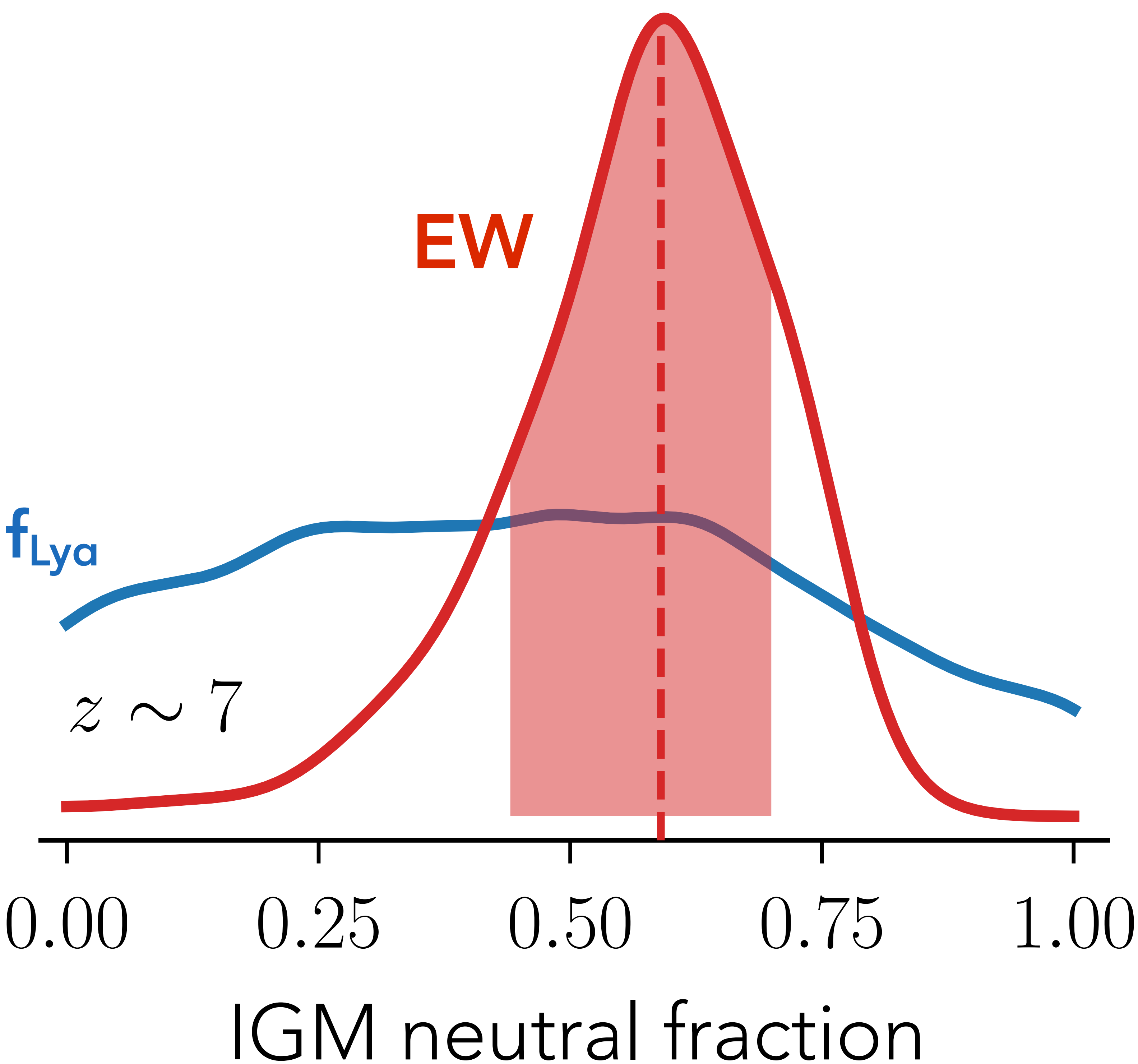
Mostly neutral

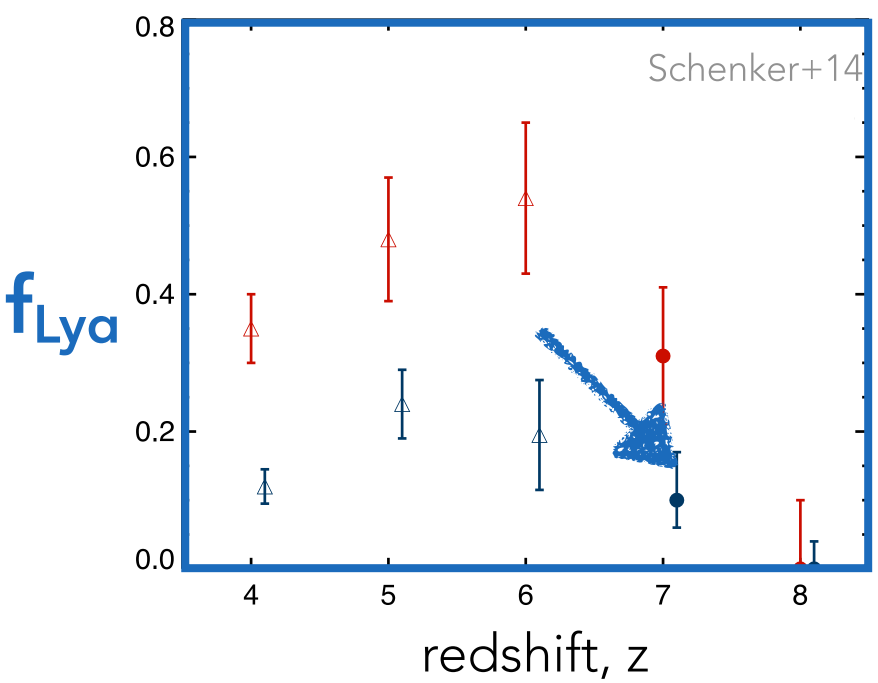
Mason+18a

Bayesian inference on Lya observations (via EW distribution) to infer the neutral fraction



Using the full distribution of Lya EW at z~7 places tight constraints on the neutral fraction

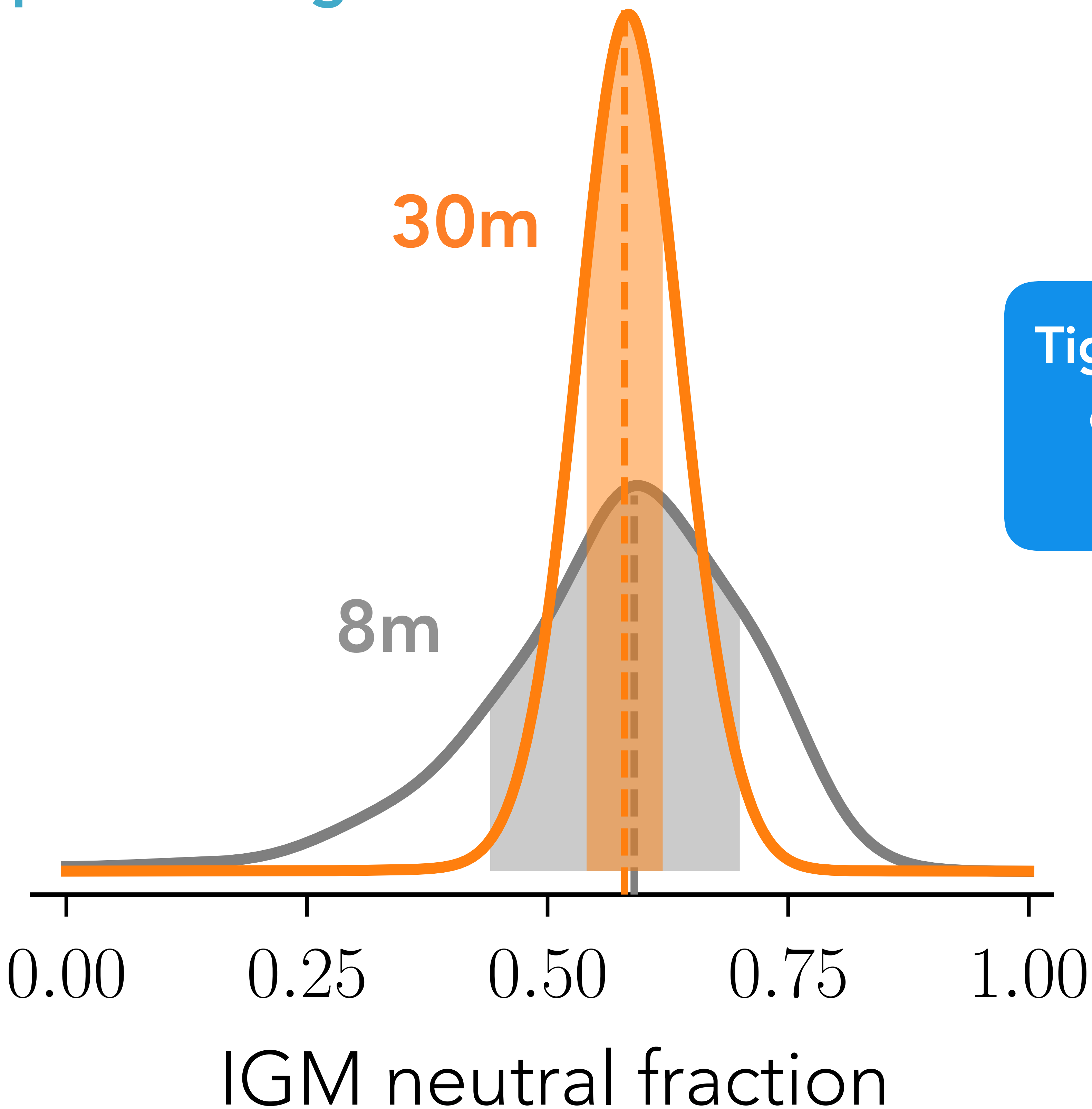




inferred from sample of
68 LBGs in Pentericci+14

Mason+2018a

Using the full distribution of Lya EW at z~7 places tight constraints on the neutral fraction



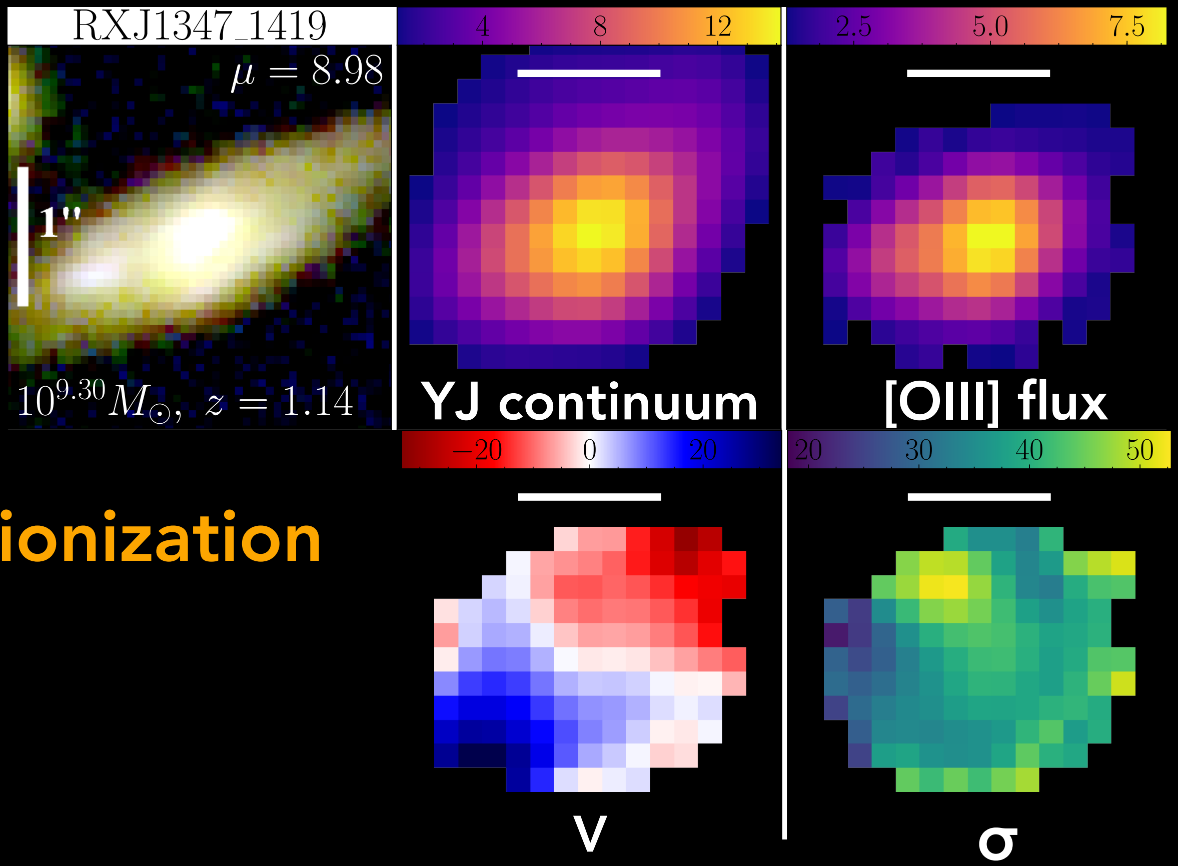
Tighten neutral fraction constraints, look at sightline variations

inferred from sample of 68 LBGs in Pentericci+14

Mason+2018a

KMOS lens-amplified spectroscopic survey

PI: Adriano Fontana
120 hr Large Program, P96 - 99
Fields of 6 massive clusters



Search for Lyα to measure timeline of reionization

53 z > 7 candidate targets
– 3 confirmed with ALMA

Kinematics of low mass star-forming galaxies

~70 z=1-2 targets (Mason+17, Girard+ in prep)

7 - 15 hr exposures, PSF ~ 0.6",
YJ: 1 - 1.35μm, R~3400

Following-up HST
photometric + grism targets

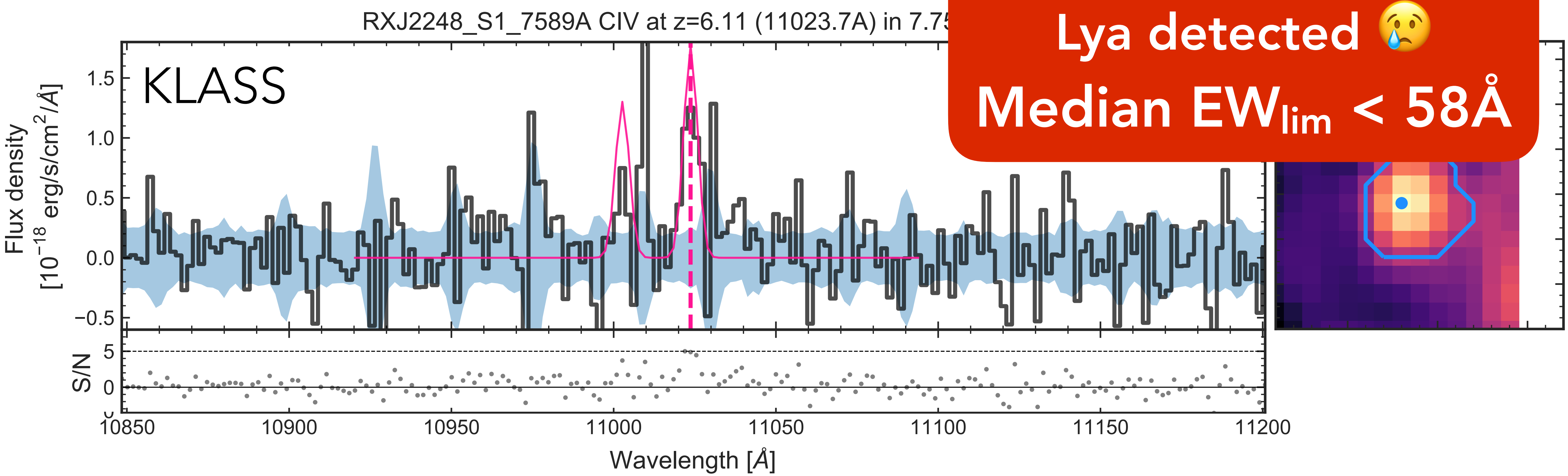
GLASS
glass.astro.ucla.edu

Highest redshift KMOS line confirmation?
CIV at z=6.11

No S/N > 5

Lya detected 😢

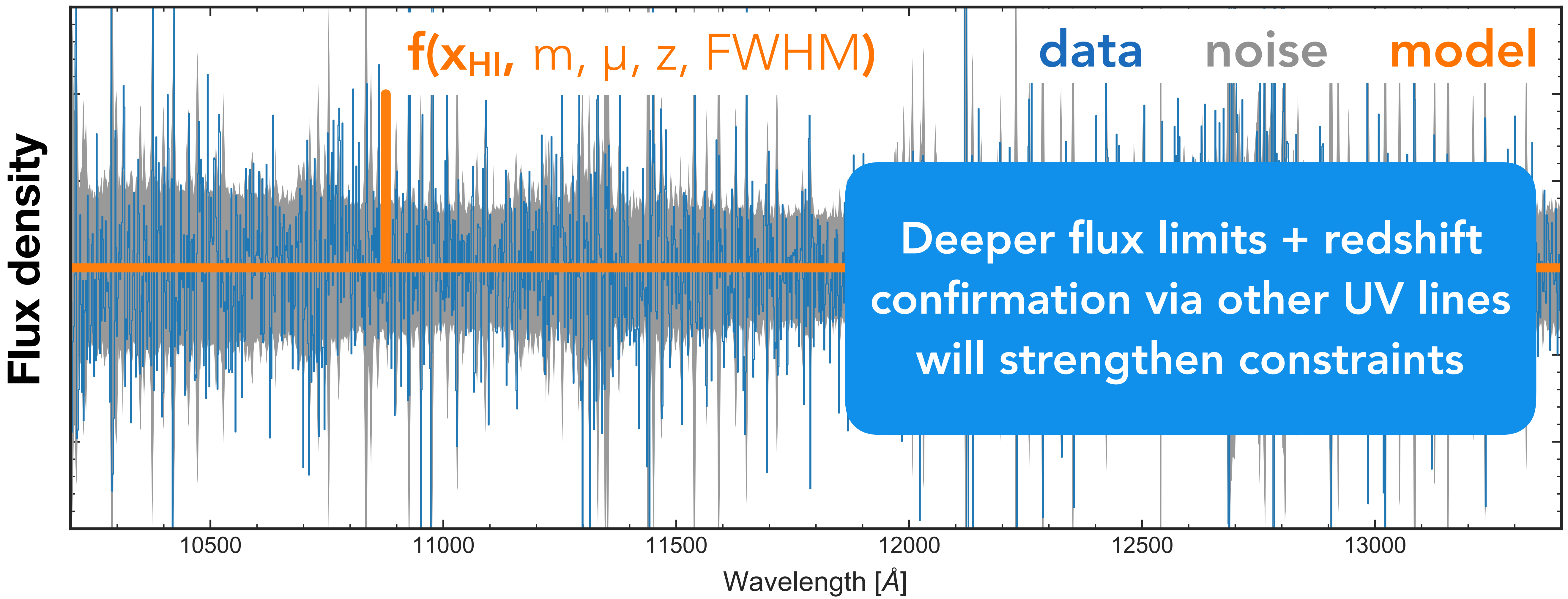
Median EW_{lim} < 58Å



- Indicates hard ionizing radiation from hot, massive, low metallicity stars
- Previously detected by Mainali+17, Schmidt+ 17

Mason+2019, submitted

Using full spectra in Bayesian inference, marginalize over redshift and linewidth



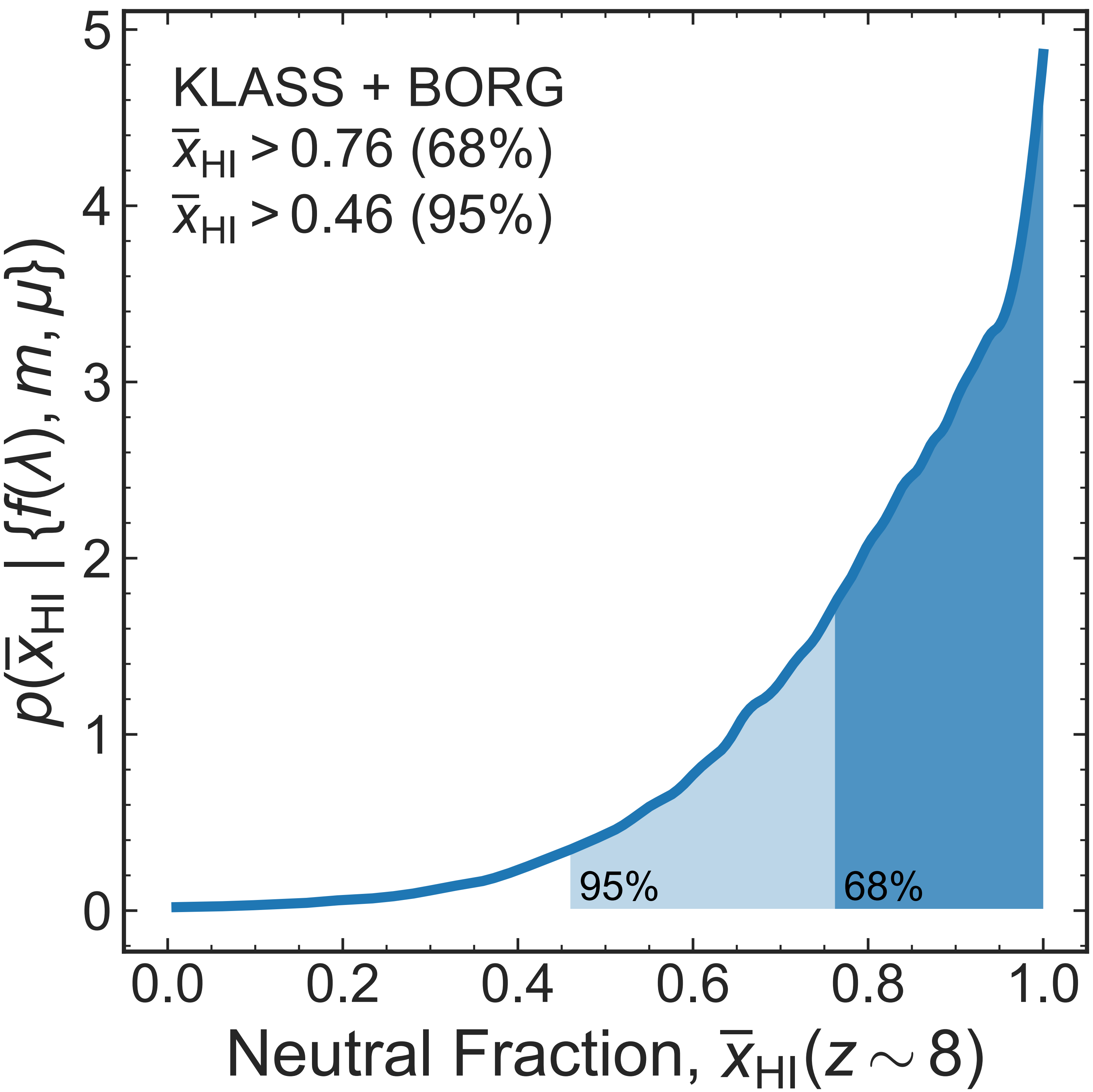
likelihood

probability of getting data: f(λ)
given IGM neutral fraction,
redshift and observed galaxy properties

priors

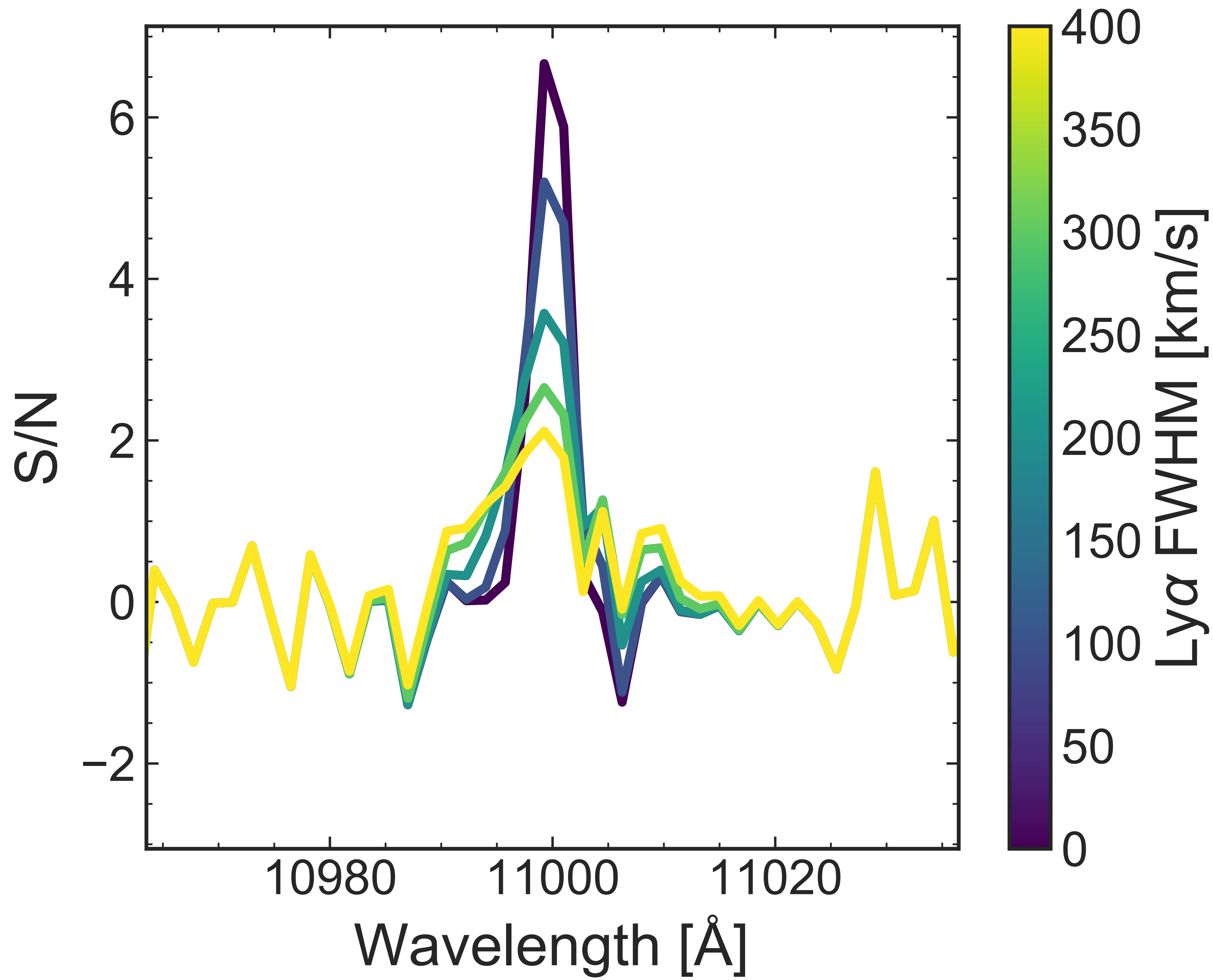
redshift - photo-z
FWHM - empirical
x_{HI} - uniform [0,1]

z~8 neutral fraction inferred from non-detections + marginalizing over redshift and FWHM



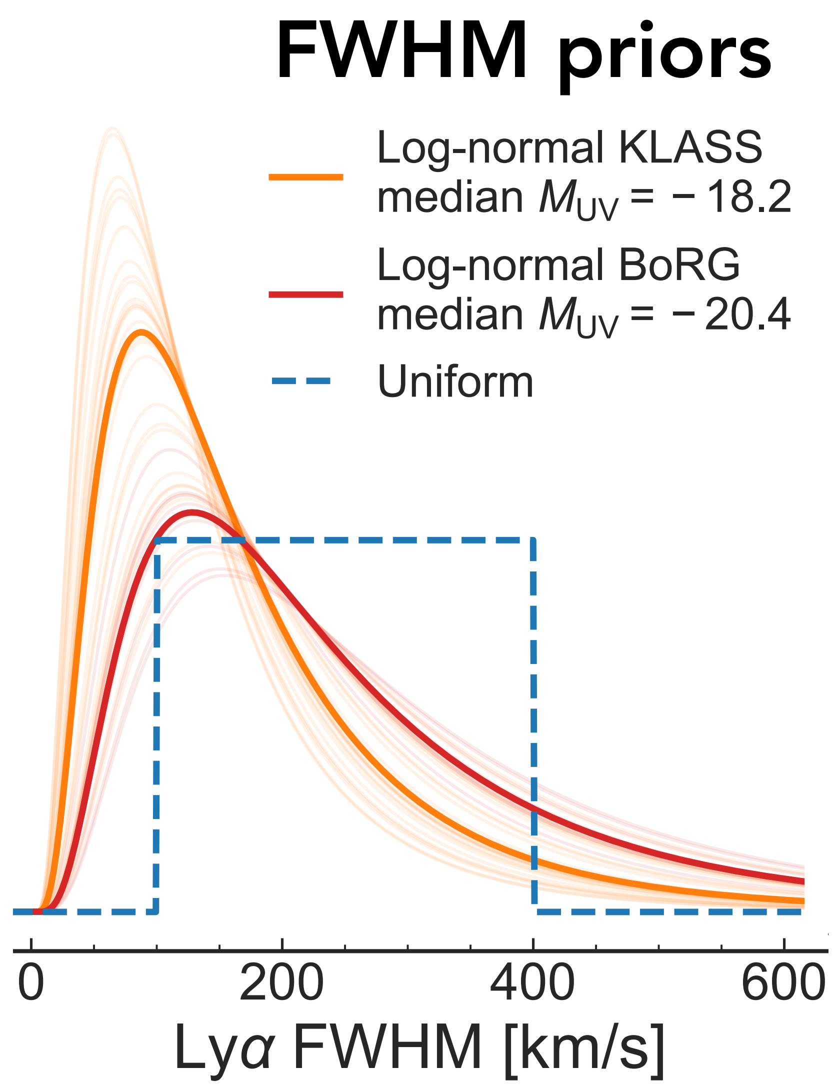
Mason+2019, submitted

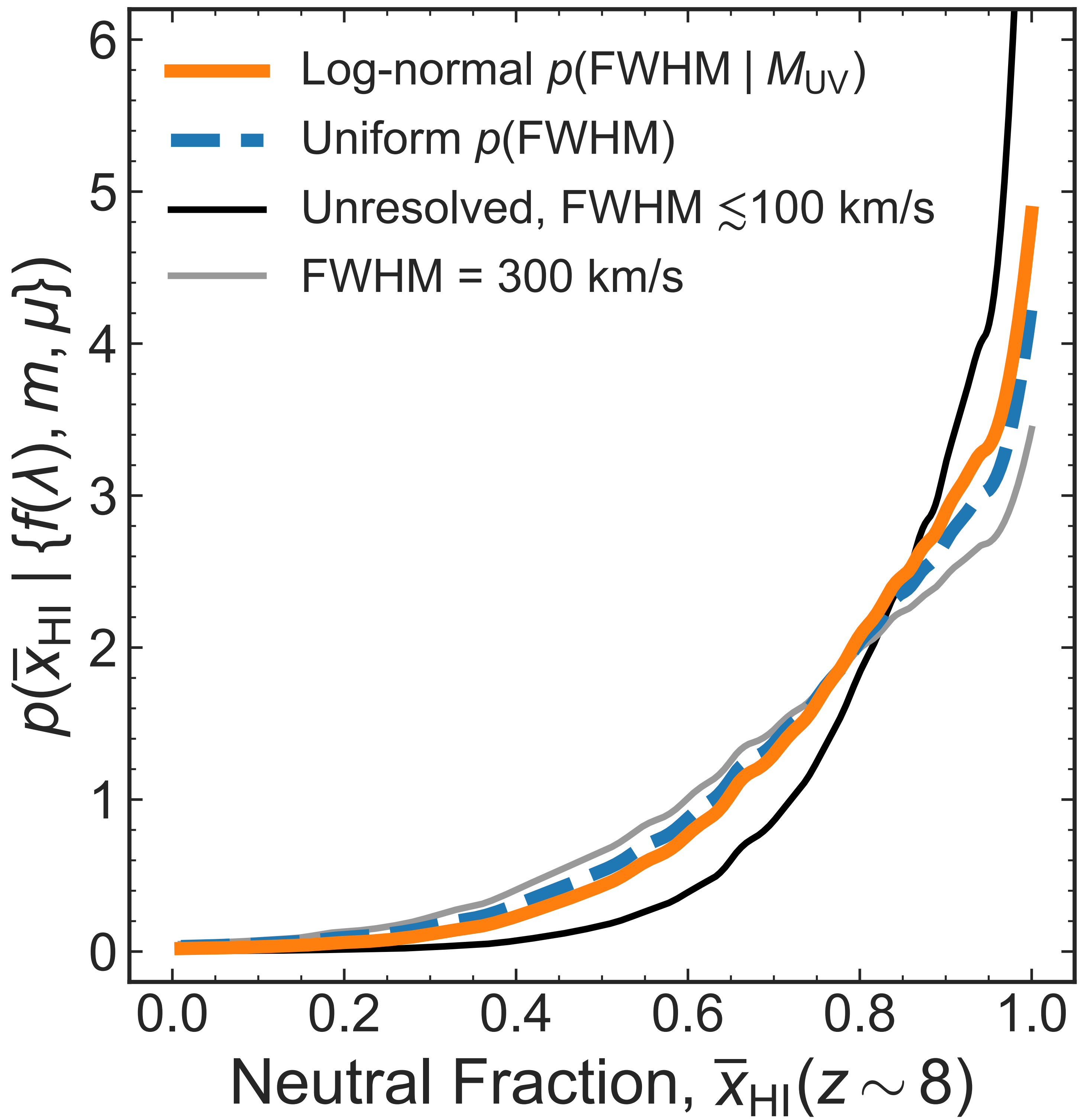
Lya linewidth impacts inference: Broader lines will have lower S/N



Posterior pretty insensitive for 100 < FWHM < 400 km/s

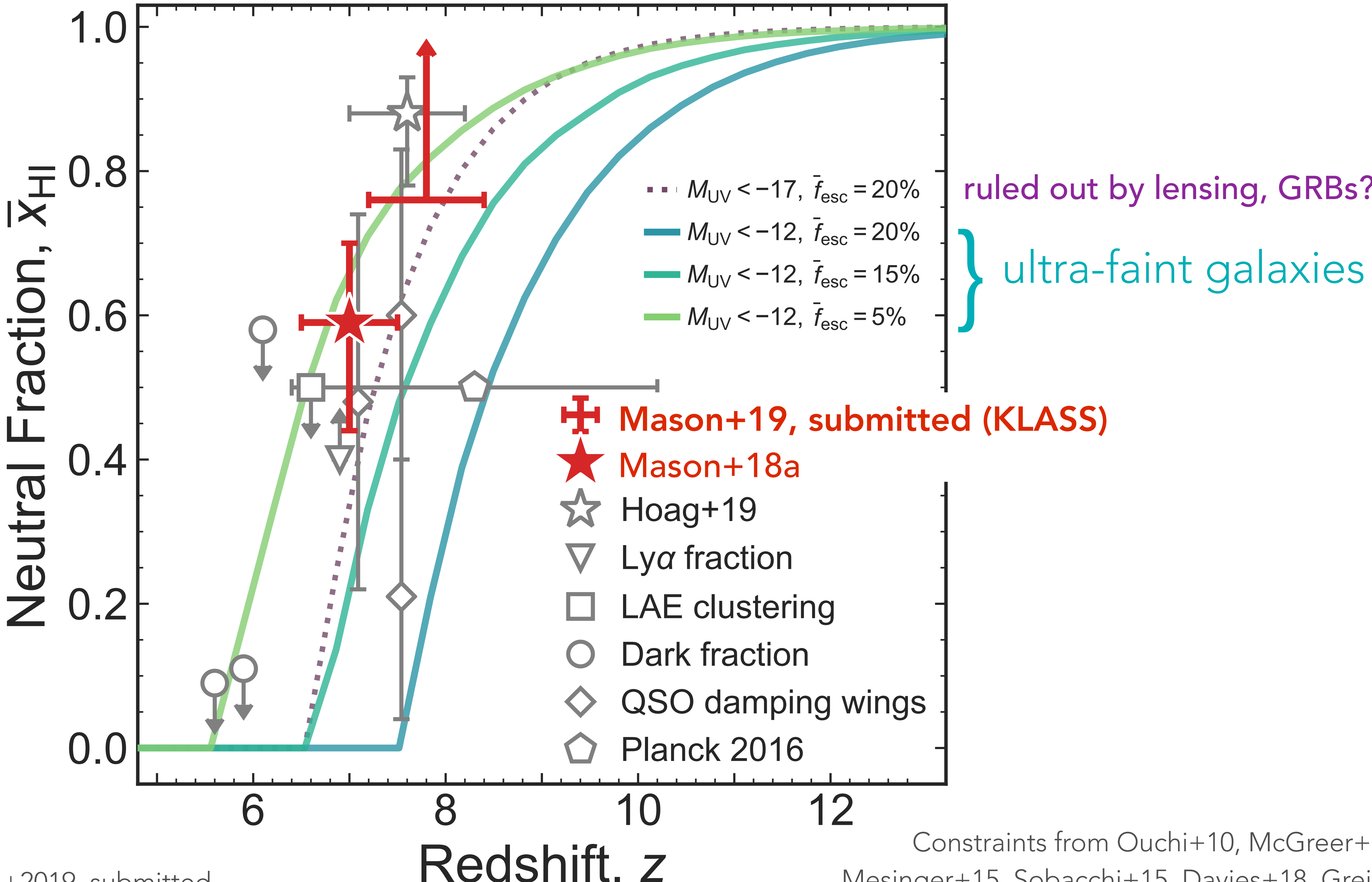
High R, deep data will resolve Lya lines





Mason+2019, submitted

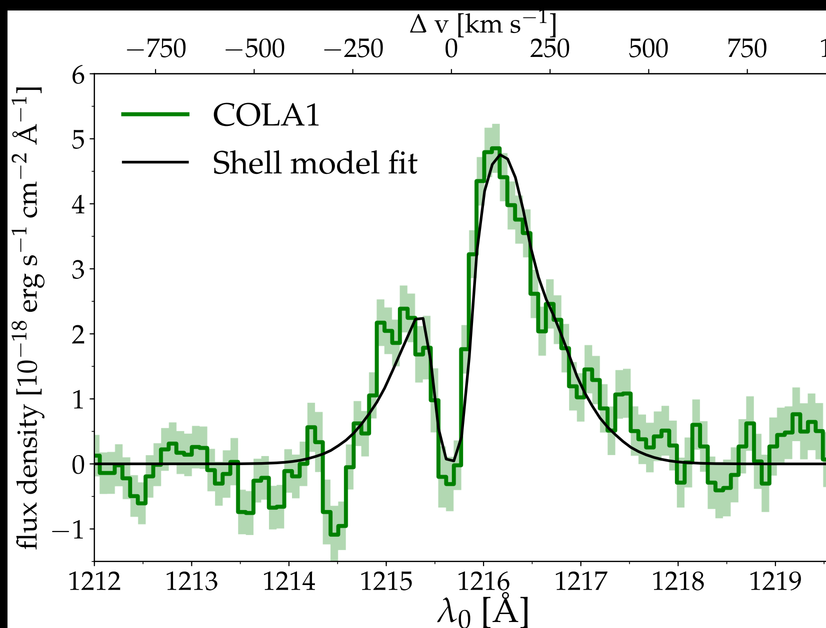
The universe is getting very neutral at z>6… consistent with low ionizing photon escape fraction



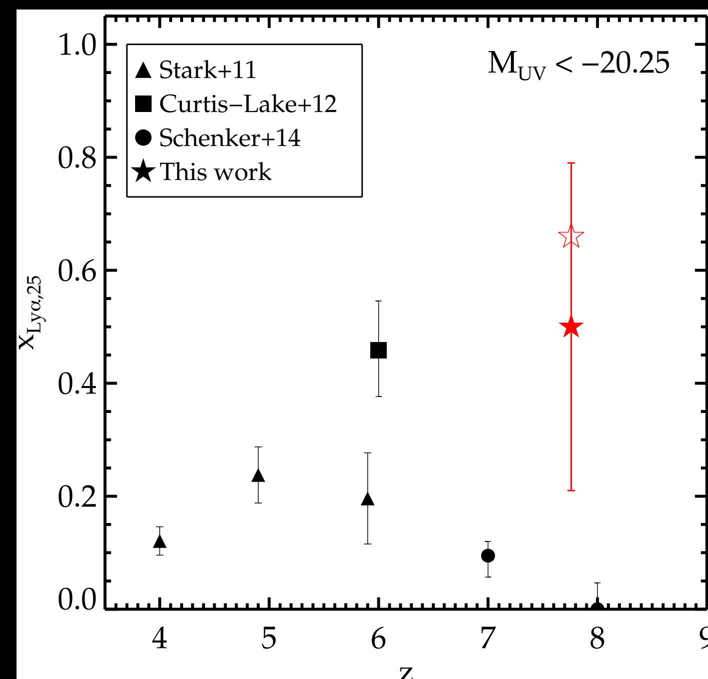
Mason+2019, submitted

Constraints from Ouchi+10, McGreer+2014, Mesinger+15, Sobacchi+15, Davies+18, Greig+18

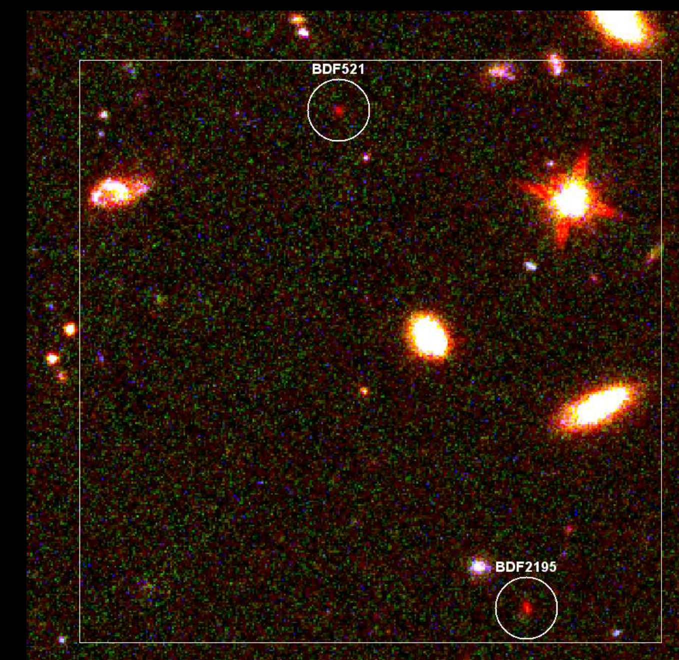
Puzzling z>6 Lyα detections reveal shortcomings in reionization models



Matthee+18



Stark+17



Castellano+18

blue Lyα peaks at z>6

direct evidence of >2 Mpc ionized bubble?

Lyα from z>7.5 UV bright galaxies

extreme Lyα emitters? larger ionized bubbles?

Lyα from only bright galaxies in overdensity

complex neutral hydrogen distribution?

Mason+18b

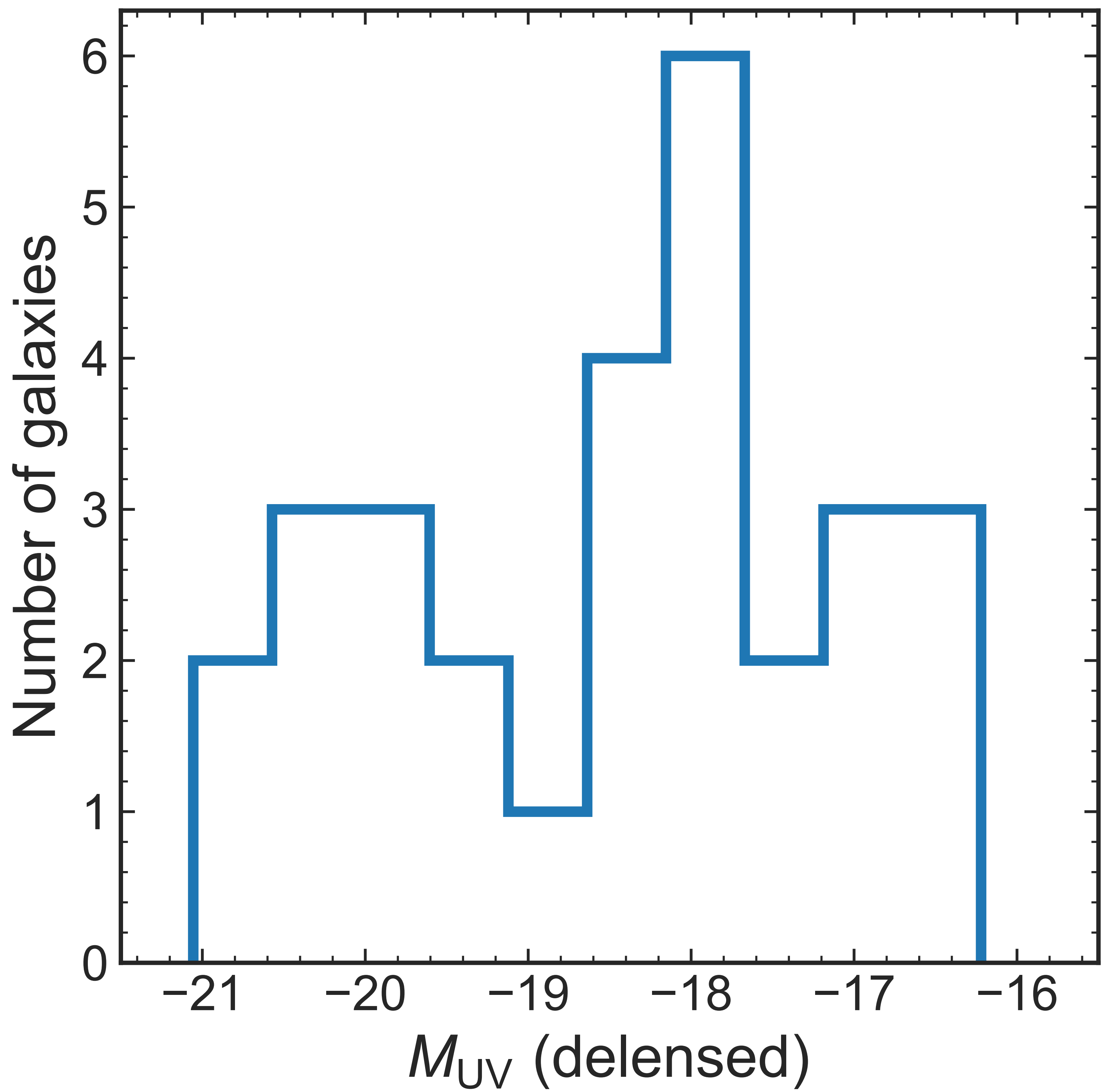
Summary

Evolving transmission of Lya from galaxies contains information about the **history of reionization**

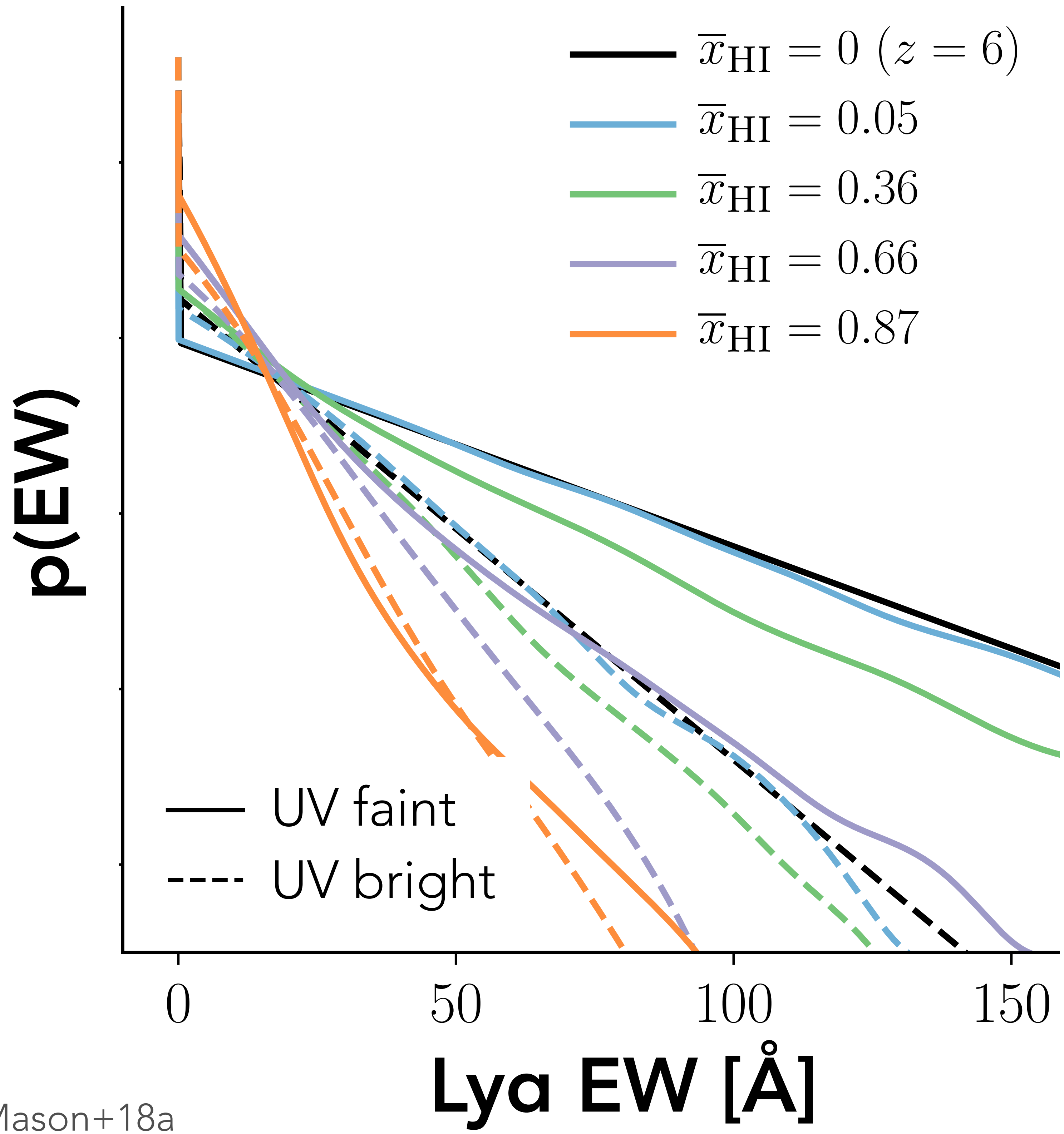
- **IGM and ISM** effects included via forward-modelling to make inferences from Lyα observation
- KLASS finds **no S/N > 5 Lyα** in 53 z > 7 LBG candidates. EW < 58Å
- Using non-detections to constrain IGM neutral fraction at z~8: **>76% neutral**

ELTs will **increase accuracy** of global + sightline reionization timeline, and enable **investigation of ionized bubbles** to constrain ionizing sources

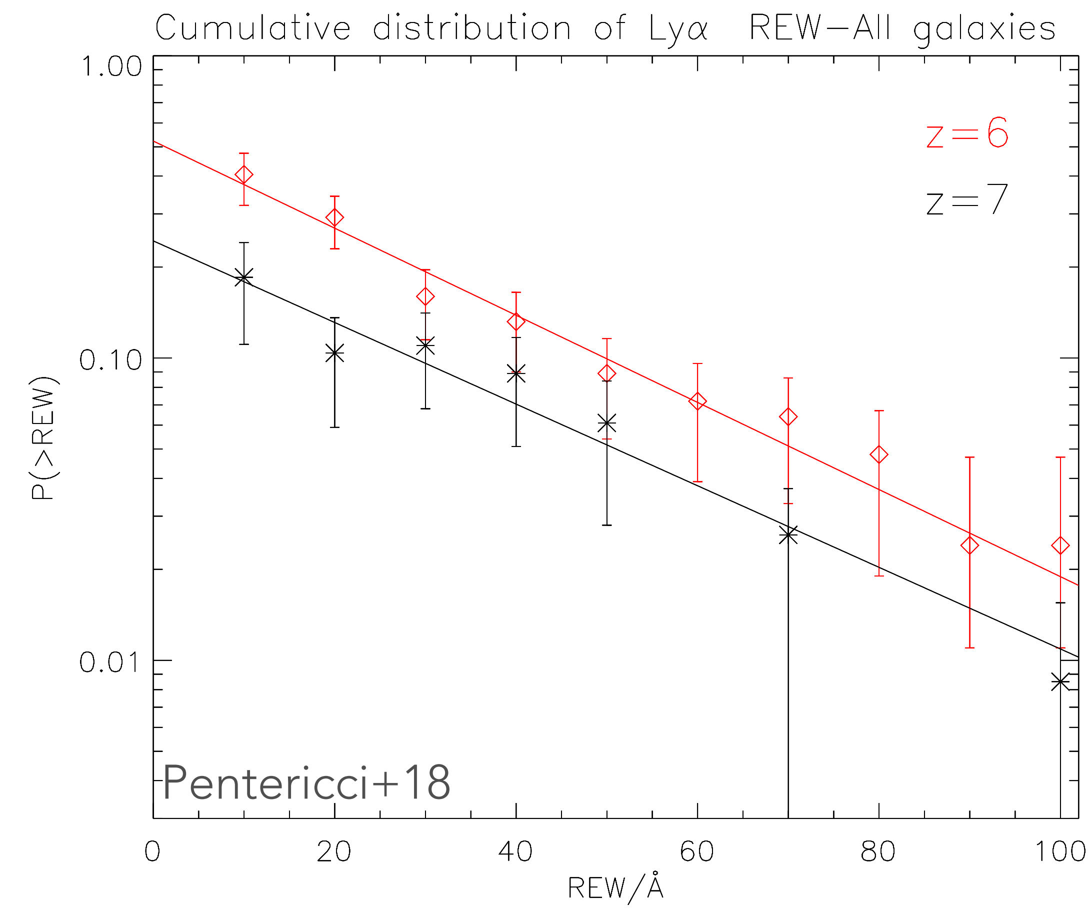
UV magnitude distribution peaks around -18 (delensed)



As the IGM becomes more neutral Lyα EWs decrease



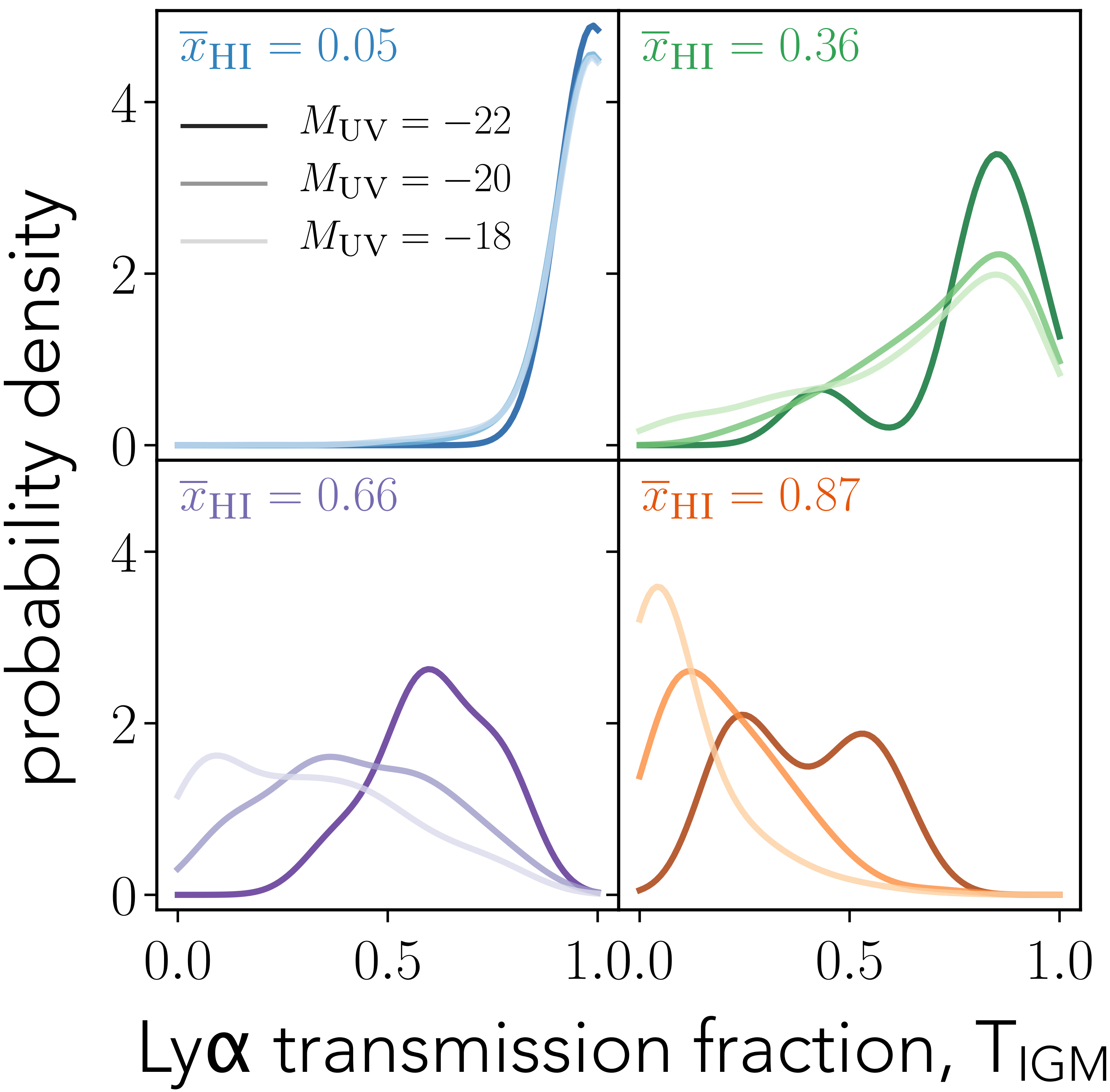
Mason+18a



Increasingly neutral IGM

Transmission of Lya depends on galaxy luminosity via environment and velocity offset

Mostly ionized

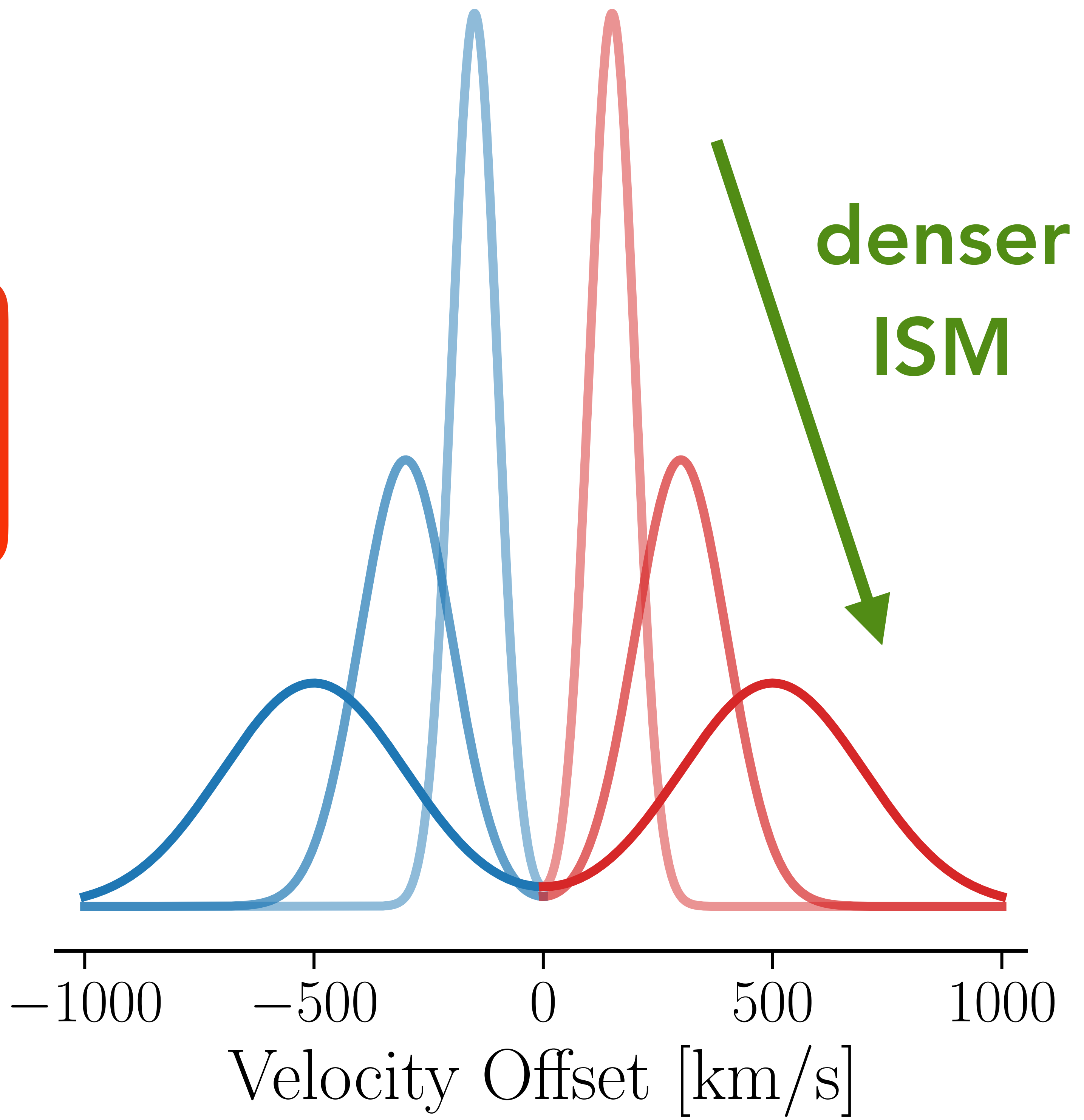


Mostly neutral

Mason+18a

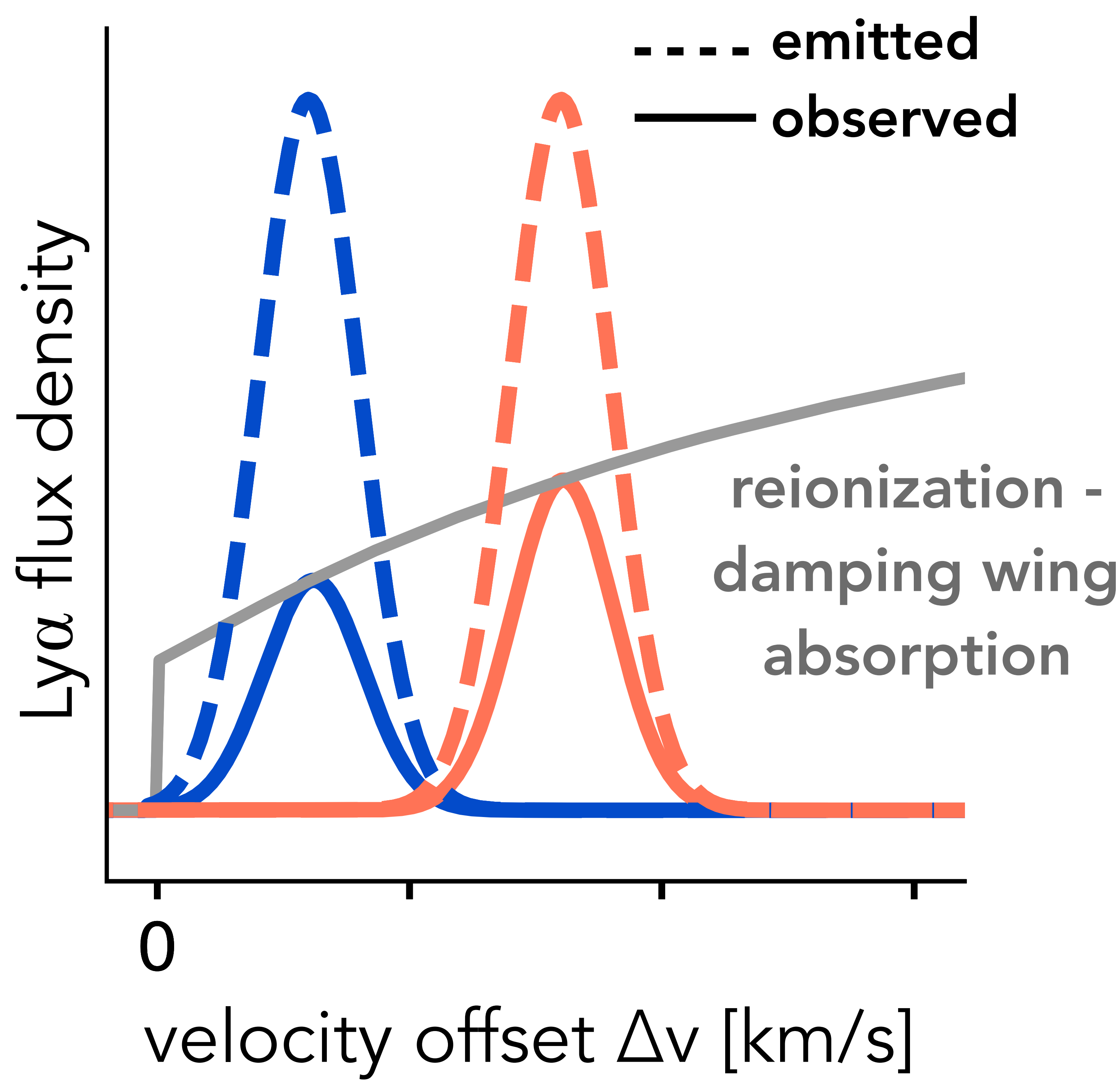
The shape of the Lya line emerging from the ISM affects the probability of transmission through the IGM

Lya photons must diffuse in frequency to escape dense ISM



The shape of the Lya line emerging from the ISM affects the probability of transmission through the IGM

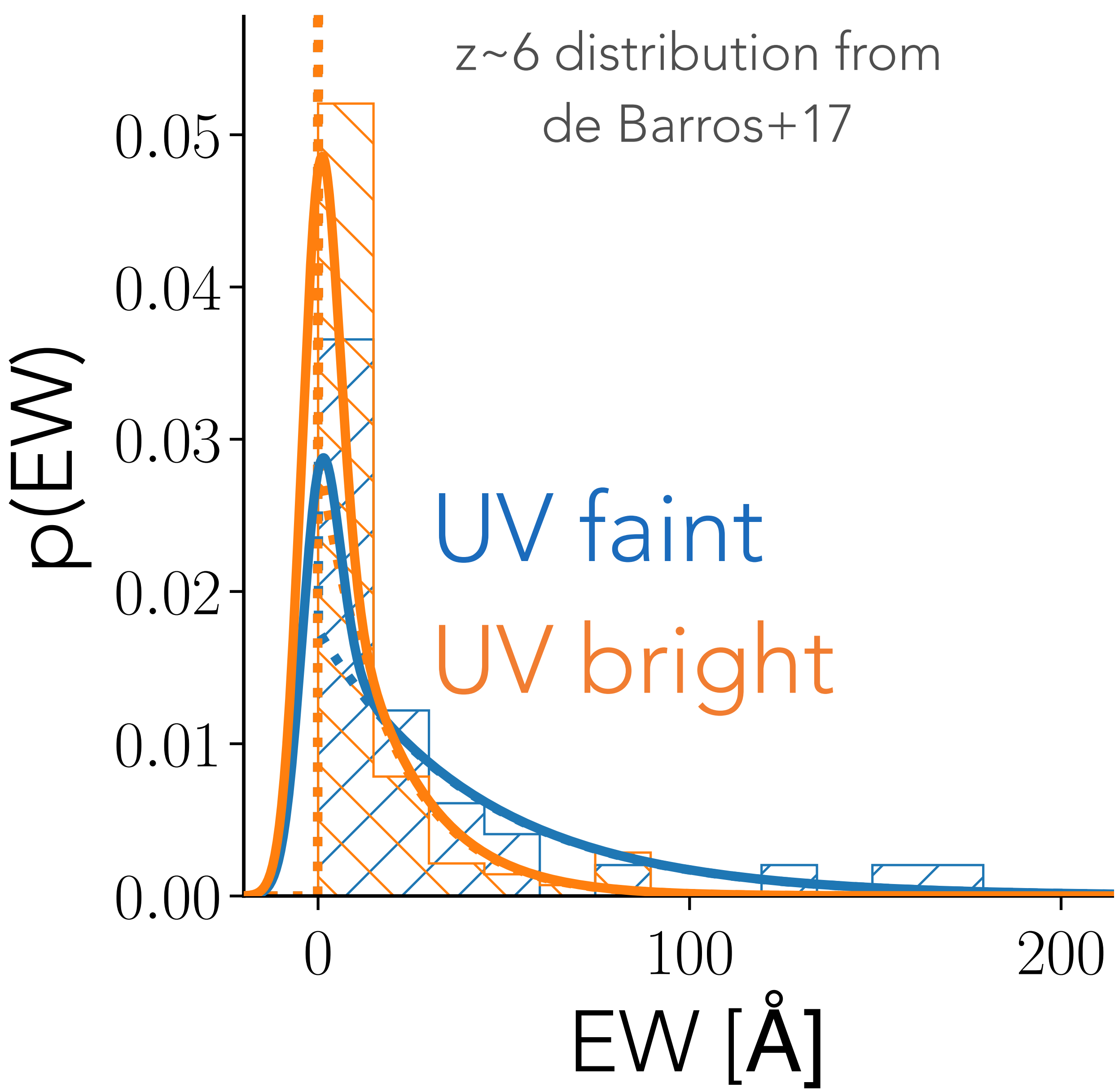
More Doppler-shifted lines are less affected by reionization



Mason+18b

Simulation halos are populated with realistic ISM properties

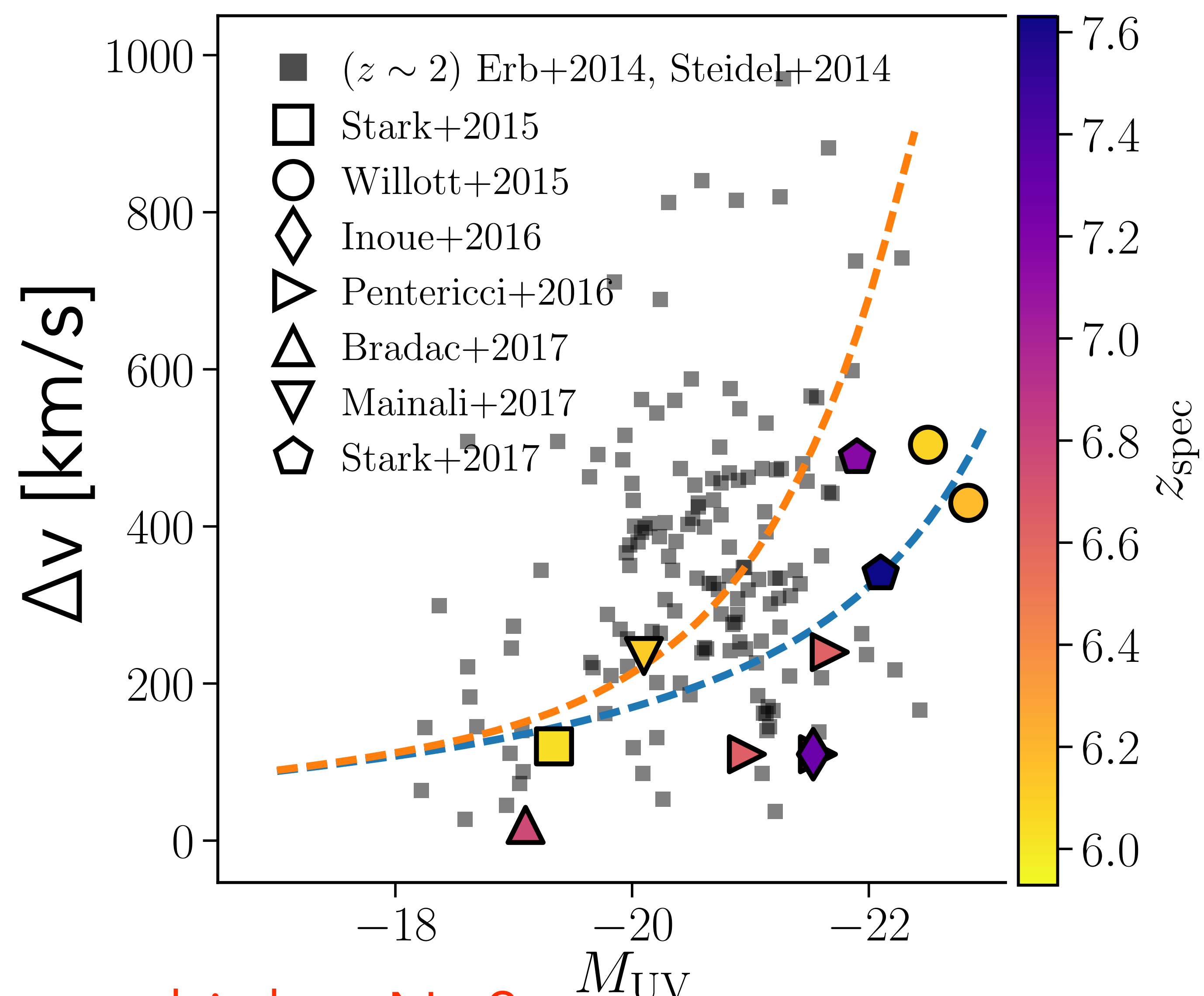
'Emitted' $EW_{Ly\alpha}$



+ UV magnitudes

from Mason+15b

Lyα velocity offsets



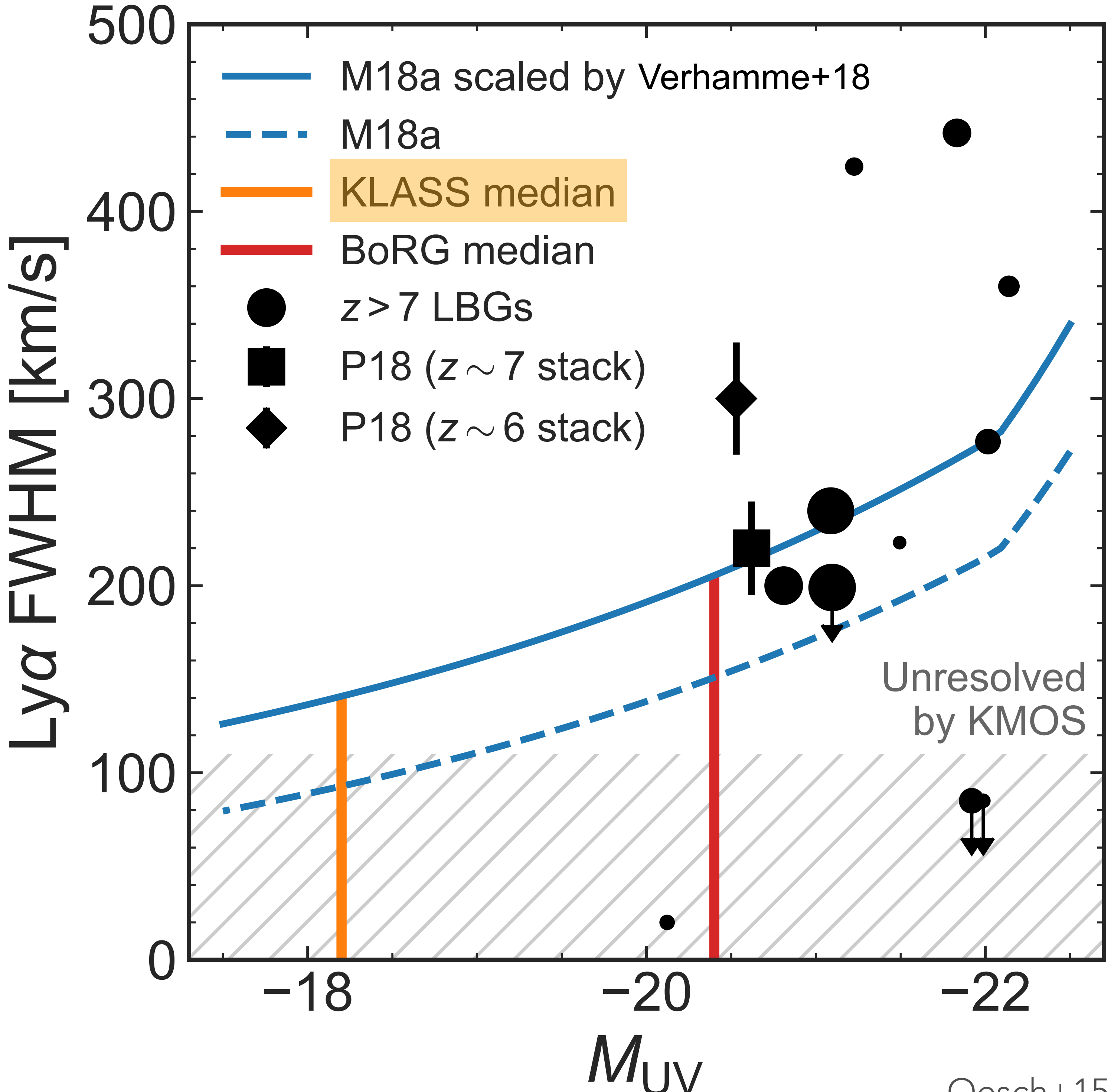
higher N_{HI}?

higher $f_{cov}(HI)$?

outflows?

Mason+2018a

Lya linewidth impacts inference: Use FWHM priors based on z>7 observations



z>7 detections span FWHM <100 - 450 km/s

High R, deep data will resolve Lya lines deep into EoR

Mason+2019, submitted

Oesch+15, Roberts-Borsani+16, Stark+17, Zitrin+15, Song+16, Finkelstein+13, Shibuya+12, Ono+12, Schenker+12, Vanzella+11,Laporte+17