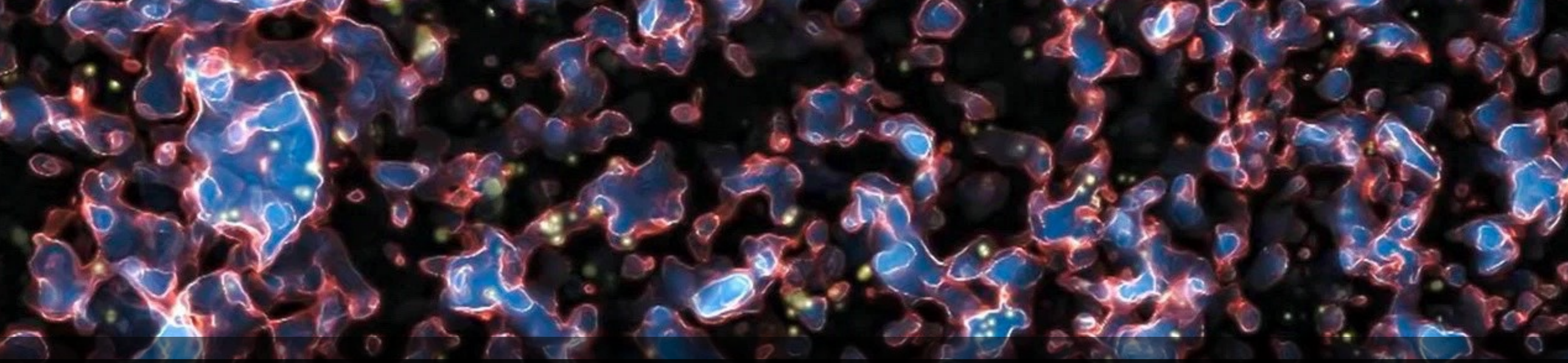


Charlotte Mason
Hubble & CfA Fellow

CENTER FOR ASTROPHYSICS
HARVARD & SMITHSONIAN

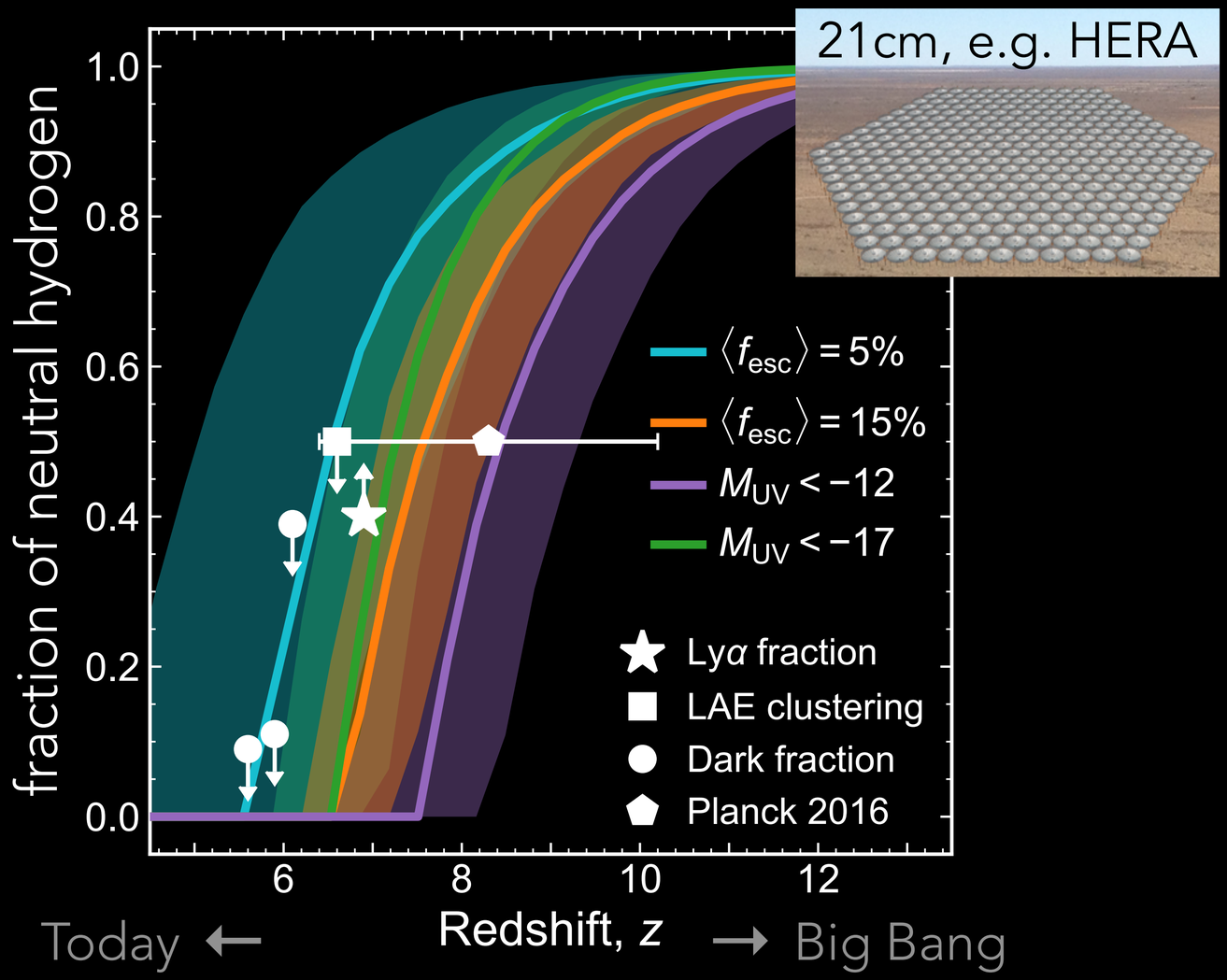
What can galaxies tell us about reionization?

with Tommaso Treu, Adriano Fontana, Mark Dijkstra, Andrei Mesinger,
Rohan Naidu, Lily Whitler, Austin Hoag + GLASS & BoRG teams

Alvarez (2009)

fewer ionizing photons get out of galaxies

more galaxies



What is the timeline of reionization?

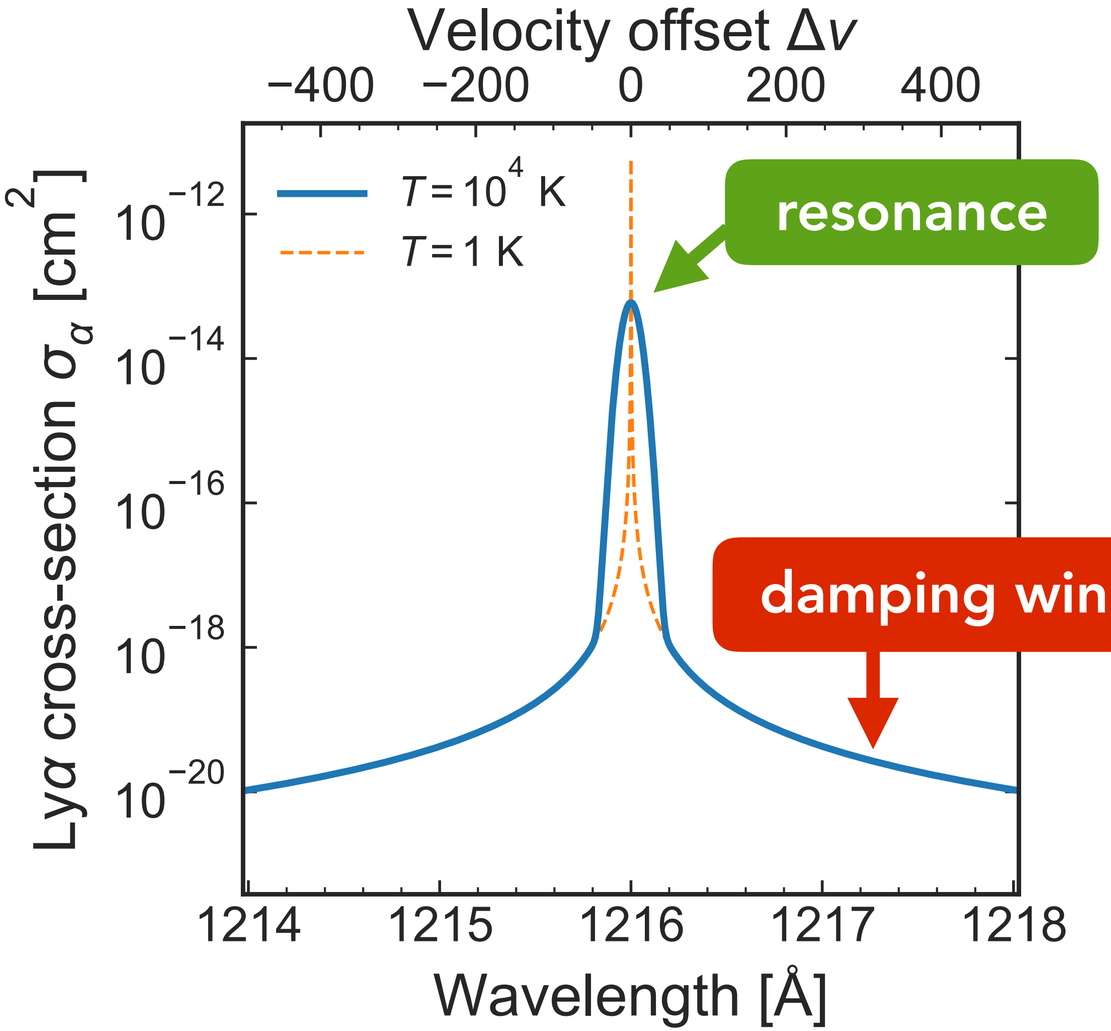
Models from Mason+15, constraints from Ouchi+10, McGreer+2014, Mesinger+15, Sobacchi+15

What is the timeline of reionization?

Observe imprint of neutral IGM on galaxies (+quasars, GRBs)

Forward modelling Bayesian framework to connect Lyα observations to IGM state

Lyα photons are absorbed by neutral hydrogen, a potential tracer of the evolving IGM



Gunn-Peterson troughs

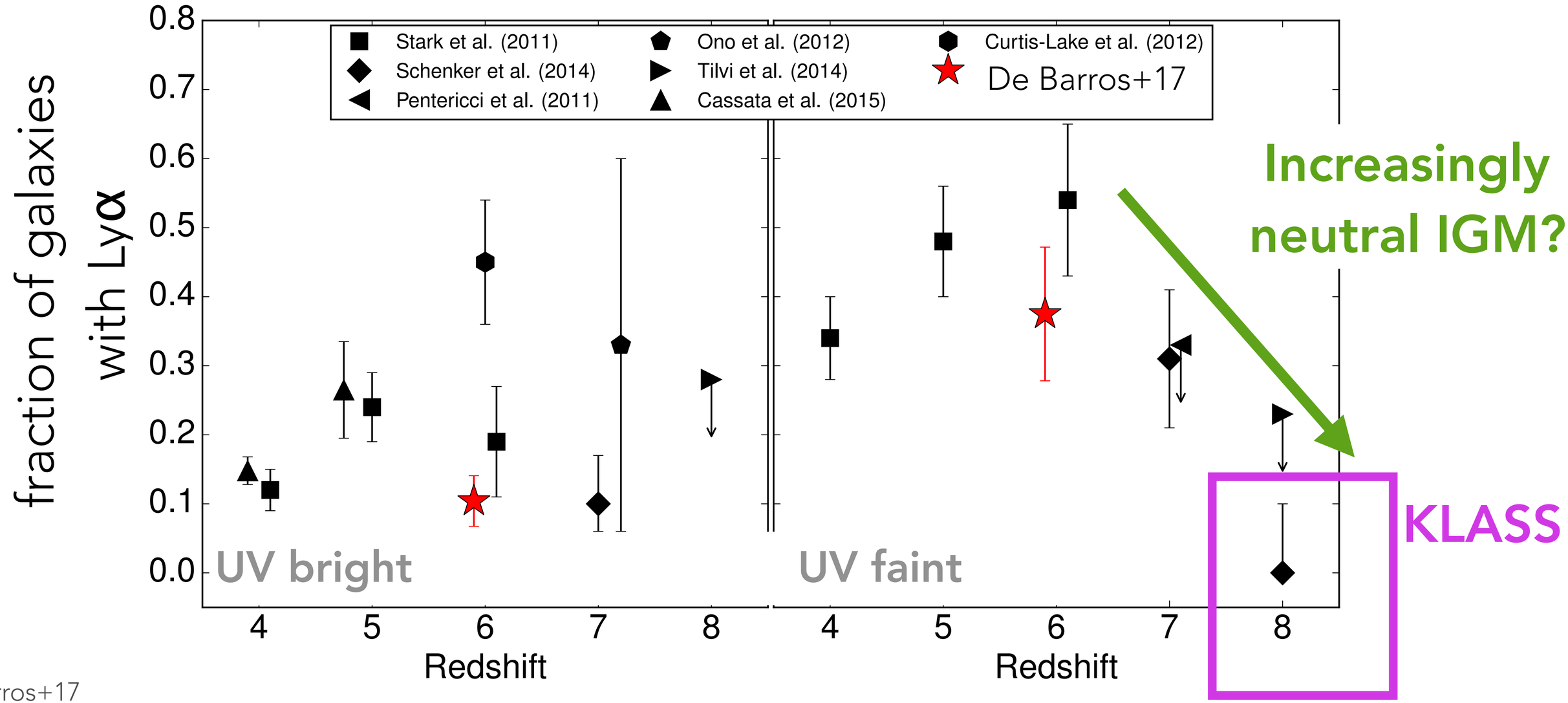
$x_{HI} > \sim 10^{-4}$

$x_{HI} \sim 0.1\text{-}1$

$$\tau_\alpha(\lambda_{\rm obs}) = \int_0^\infty ds\; x_{\rm HI}(s) n_{\rm H}(s) \sigma_\alpha(\lambda_{\rm obs}[s])$$

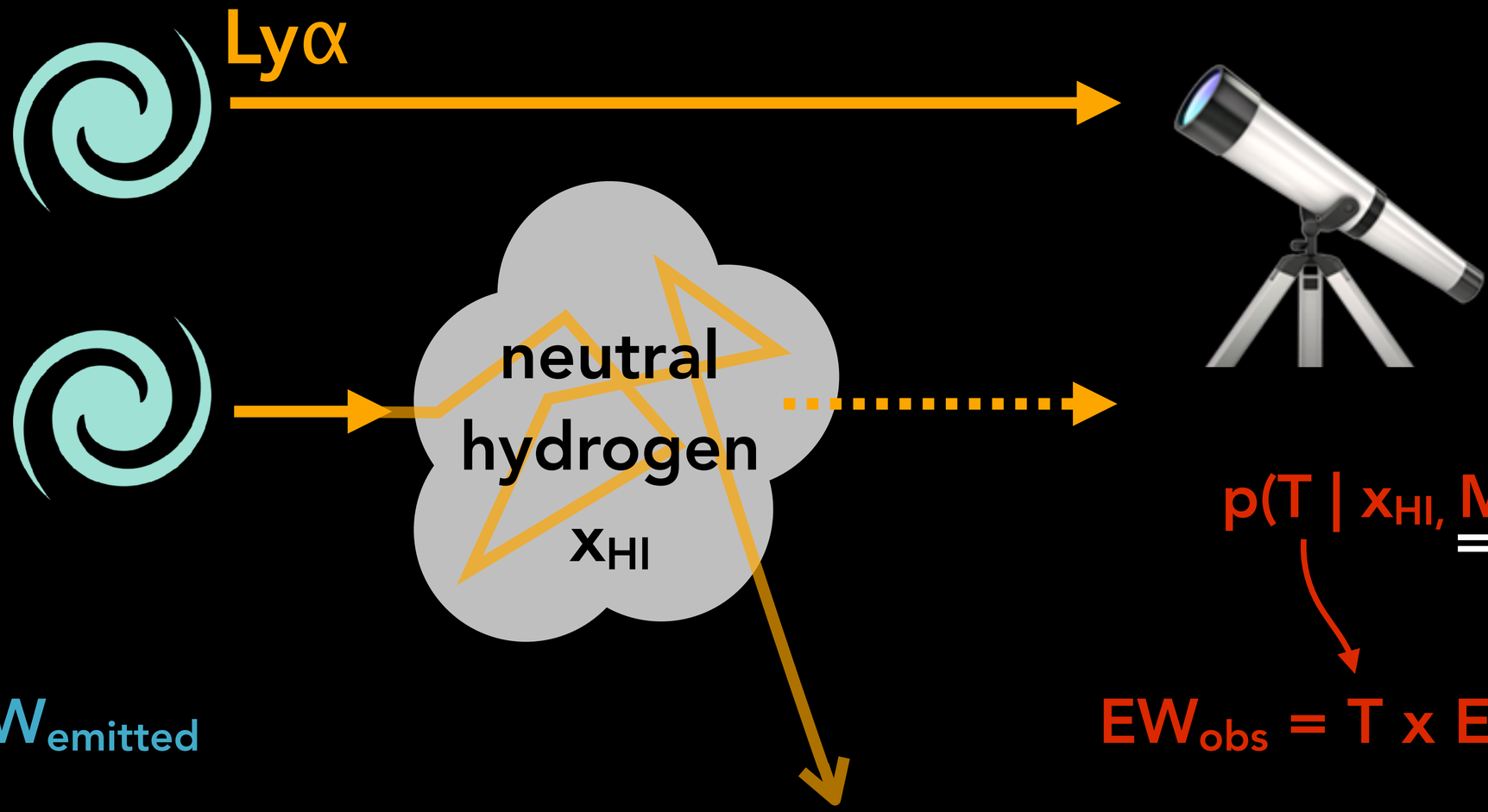
see e.g. Miralda-Escudé 98; Madau & Rees 00; Dijkstra+11; Bolton & Haehnelt 13; Jensen+13, Choudhury+15

A sudden reduction in Lyα emission from galaxies at z>6 (or z>5.5)



De Barros+17

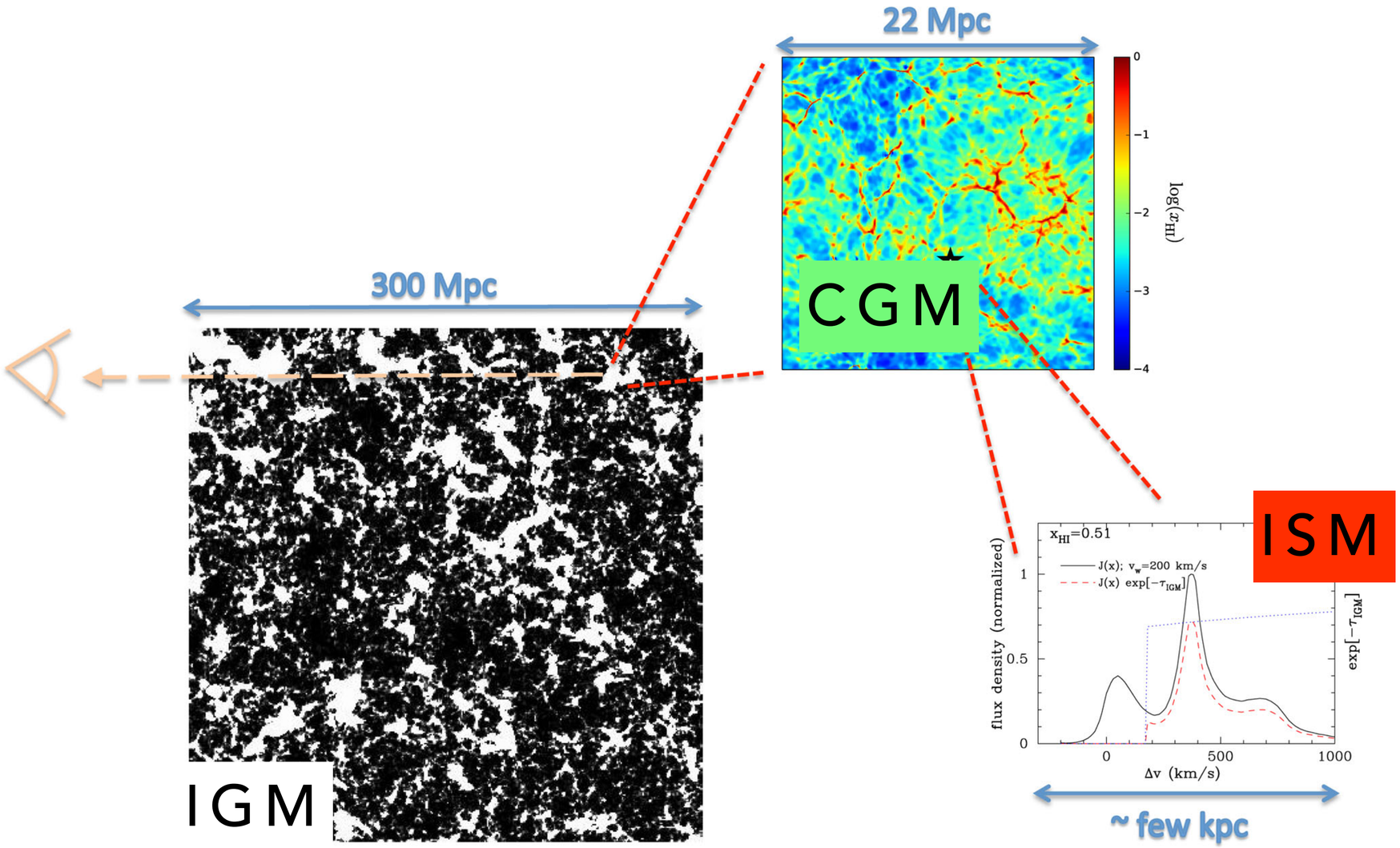
How do we connect Lyα observations to the neutral fraction?



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

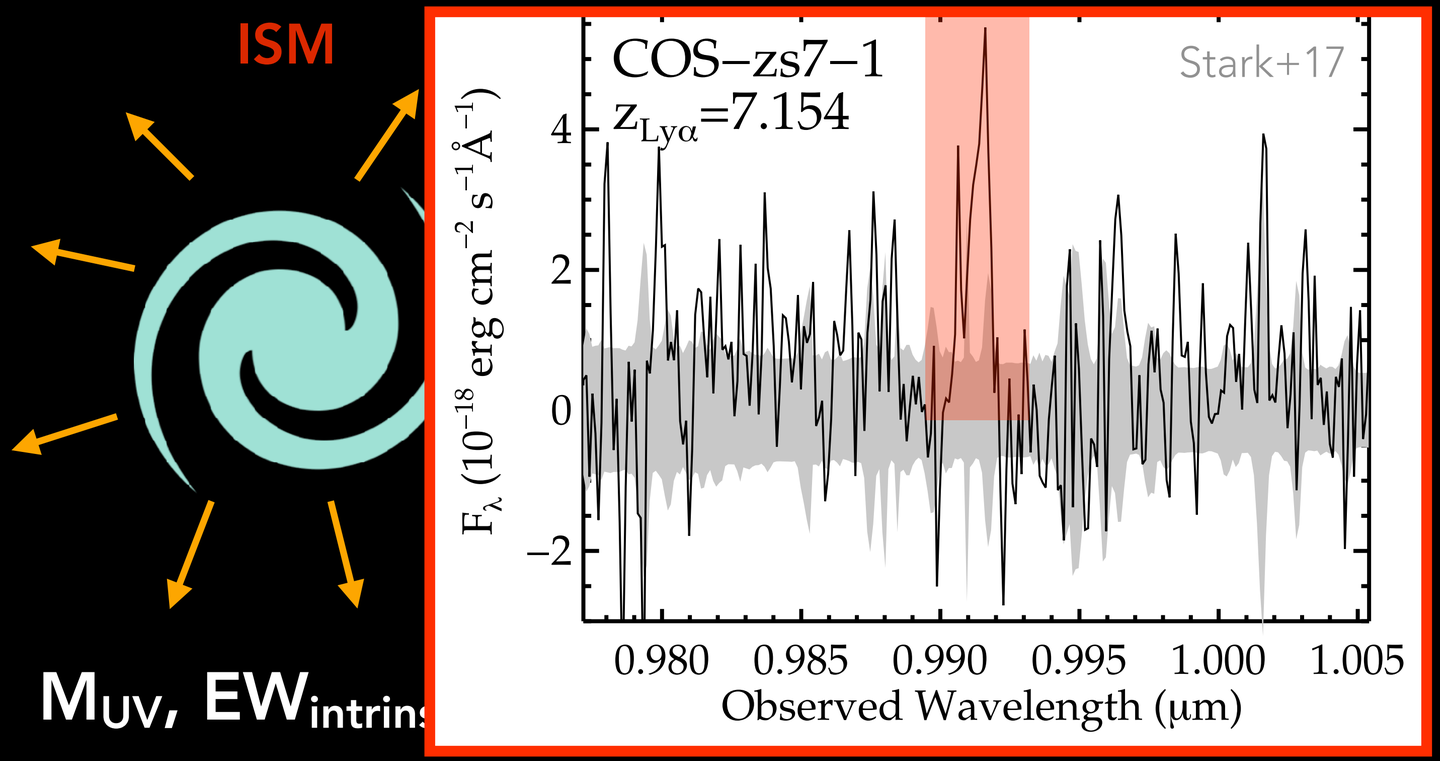
see e.g. Dijkstra+11; Bolton & Haehnelt 13; Jensen+13, Choudhury+15; Weinberger+19

Realistically modelling reionization impact on Lya emission requires a multi-scale approach



Mesinger+15

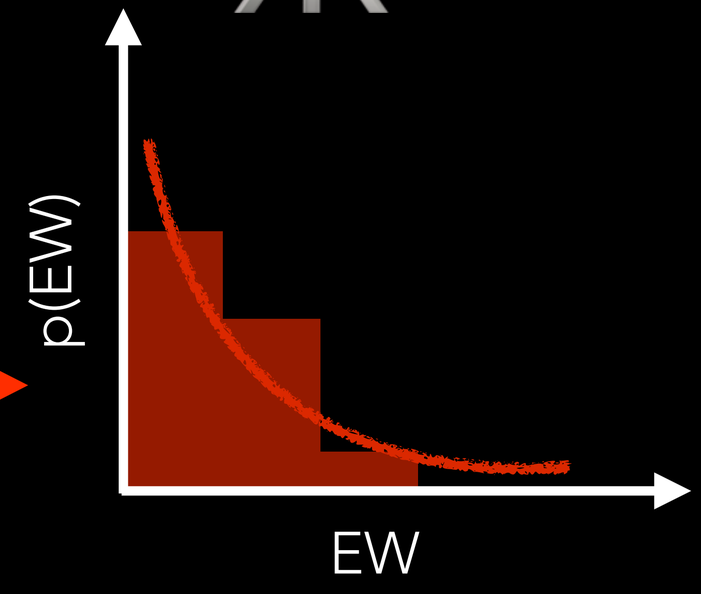
Combine galaxy models + IGM simulations to forward-model observed Lyα and infer neutral fraction



(Mesinger+)

forward model $p(EW_{obs} \mid x_{HI}, M_{UV})$

$p(x_{HI} \mid \{EW, M_{UV}\})$?



Mason+18a,b,+19a, see also Greig+17,18, Davies+18 for quasars

Marginalising over many uncertainties...

Observations

Upper limits, noise

Photometric redshifts for non-detections

Wavelength dependent sensitivity

Incomplete wavelength coverage

Unknown line width for non-detections

Astrophysics

Lyα offsets from systemic velocity

Gravitational lensing magnification

Galaxy luminosity - halo scatter

Whitler, CM+in prep

...

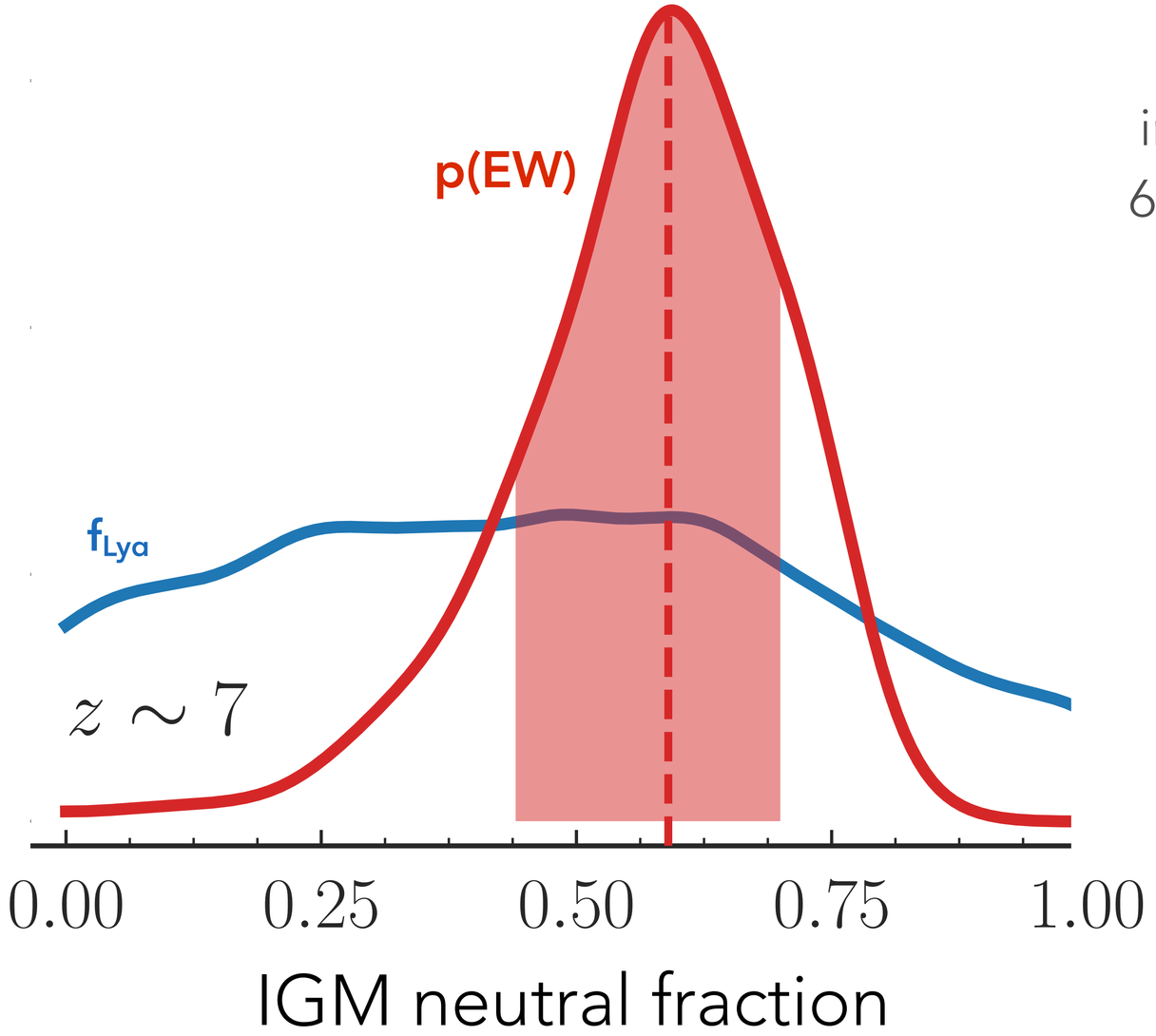
To-do Evolving CGM?

(Weinberger+18, Becker+19)

Lyα becoming more diffuse?

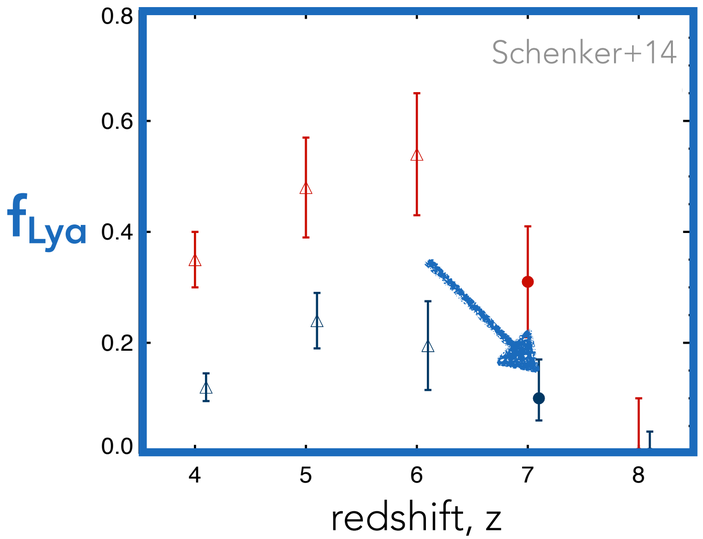
Mason+2018a,+2019a

Using the full distribution of Lyα EW (+ non-detections) places tight constraints on the neutral fraction at z~7*



inferred from sample of
68 Lyman break galaxies
(Pentericci+14)

*different evolutional from z~6



Mason+2018a

KLASS

KMOS survey searching for z>7.5 Lyα

PI: Adriano Fontana
ESO 120 hr Large Program, P96 - 99
Fields of 6 massive clusters (incl. 4 Frontier Fields)

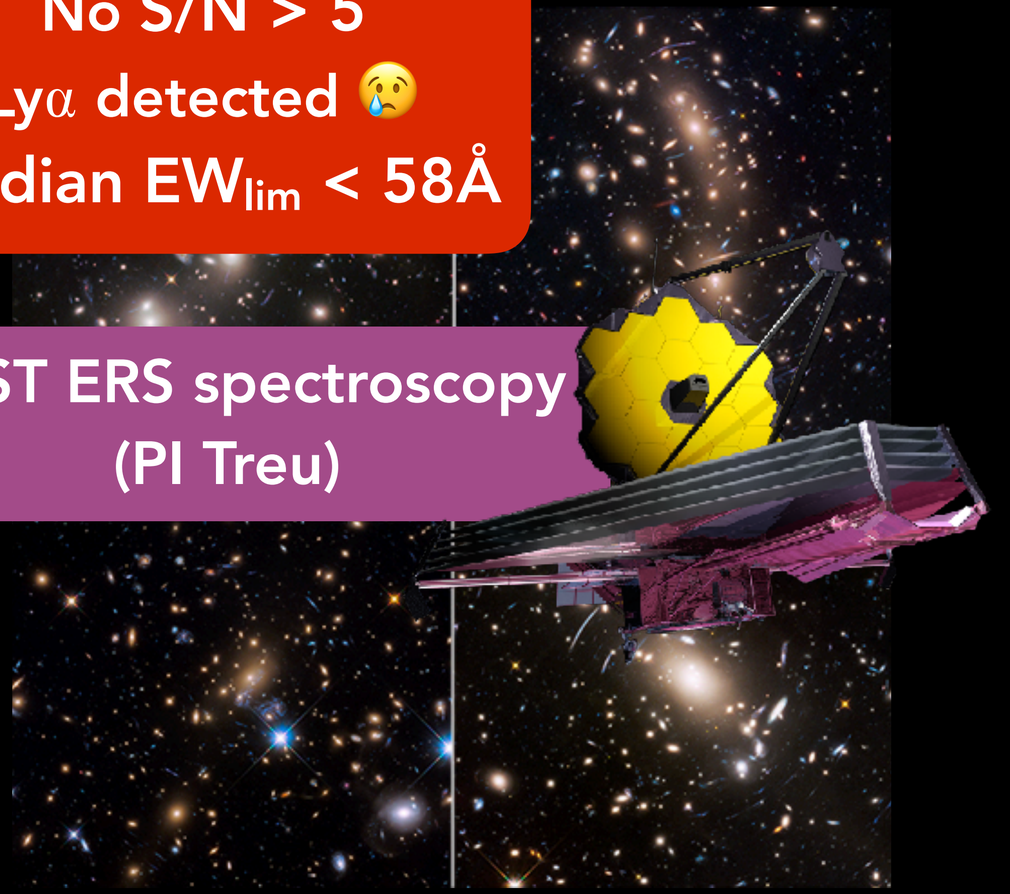
Search for Lyα to measure timeline of reionization
53 faint z > 7 photometric candidates (Mason+19a)
– 3 confirmed with ALMA

Kinematics of low mass star-forming galaxies
~70 z=1-2 targets (Mason+17, Girard, Mason+ in prep)

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

No S/N > 5
Lyα detected 😢
Median EW_{lim} < 58Å

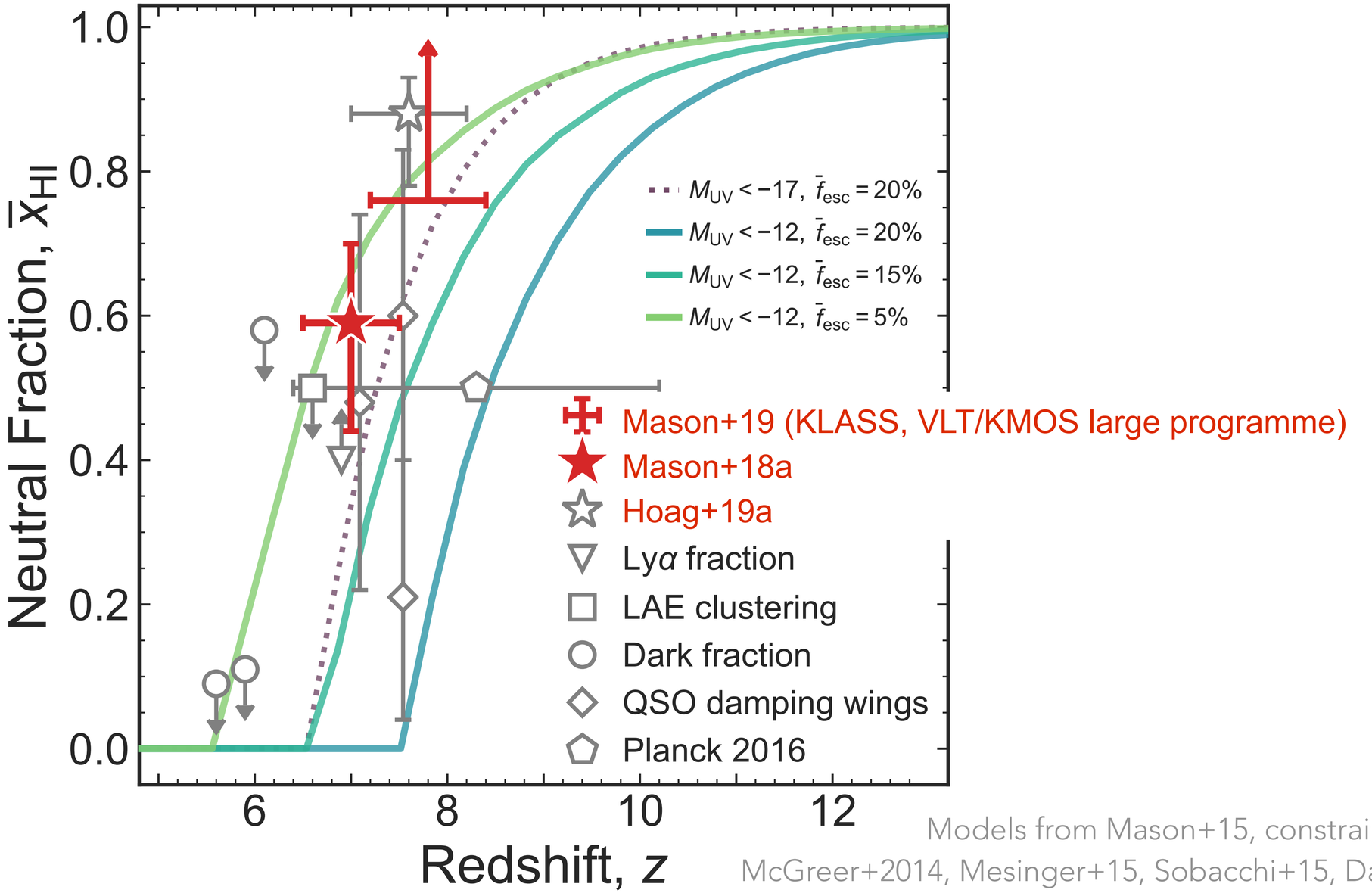
JWST ERS spectroscopy
(PI Treu)



Following-up HST
photometric + grism targets

GLASS
glass.astro.ucla.edu

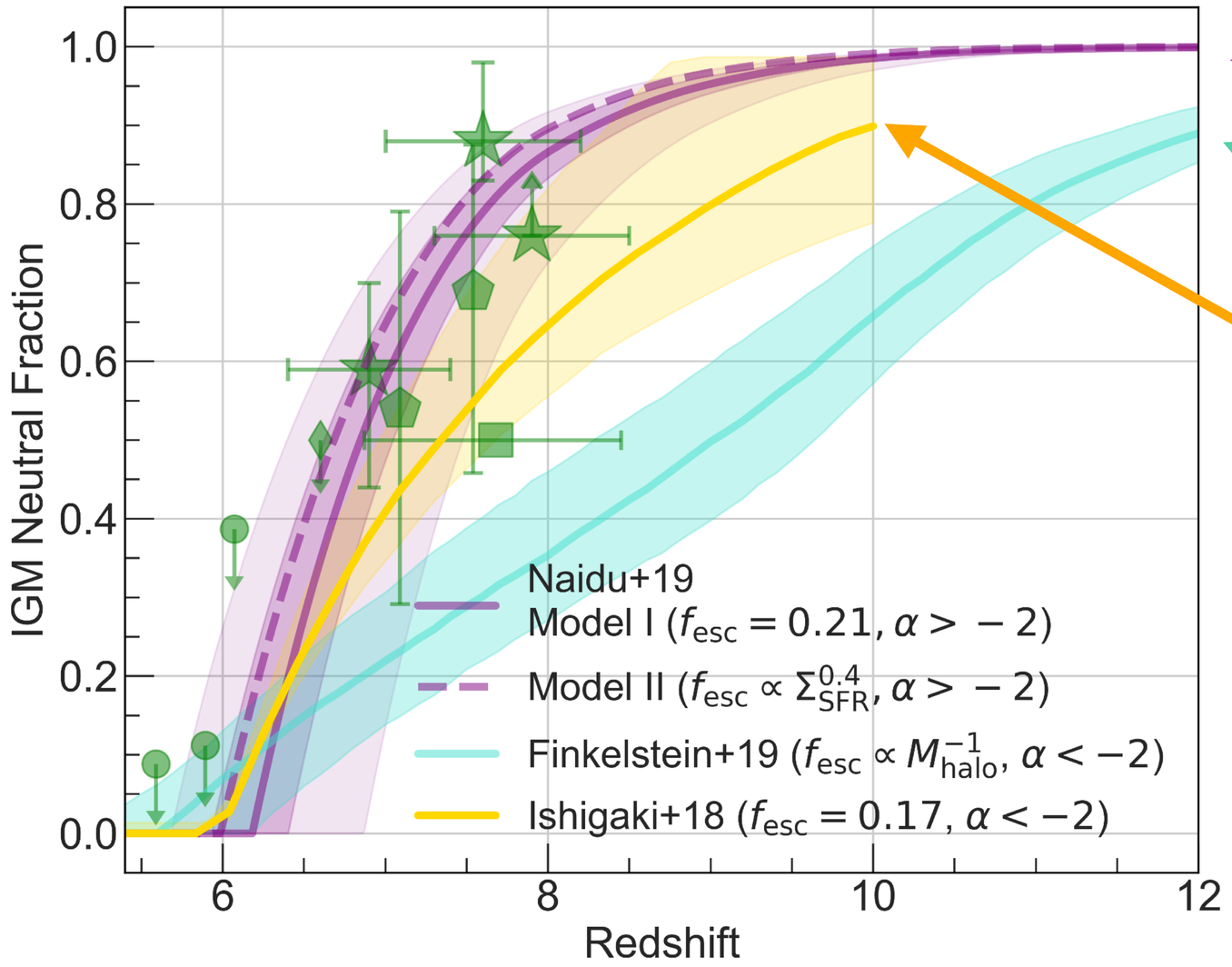
The universe was still pretty neutral at z>7...



Models from Mason+15, constraints from Ouchi+10, McGreer+2014, Mesinger+15, Sobacchi+15, Davies+18, Greig+18

Mason+2019a

The universe was still pretty neutral at z>7… consistent with ≲20% average ionizing photon escape fraction, but rapid build-up of photons



f_{esc} ~ star formation rate surface density, shallow LF

f_{esc} ~ $1/M_h$, steep LF

20% f_{esc}, steep LF

Naidu, Tacchella, CM+2019; Mason, Naidu +2019b

Evolving Lyα transmission contains information about **reionization**

- **IGM and ISM** effects forward-modelled to infer IGM neutral fraction from Lyα observations in Lyman-break galaxies

Lack of Lyα from z>6 galaxies favours **late, fairly rapid, reionization**

- Rapid build up of ionizing photons - don't need "ultra-faint" galaxies?