



The unforeseen IGM

constraining Cosmic Reionization through
quirks of the inter-galactic medium

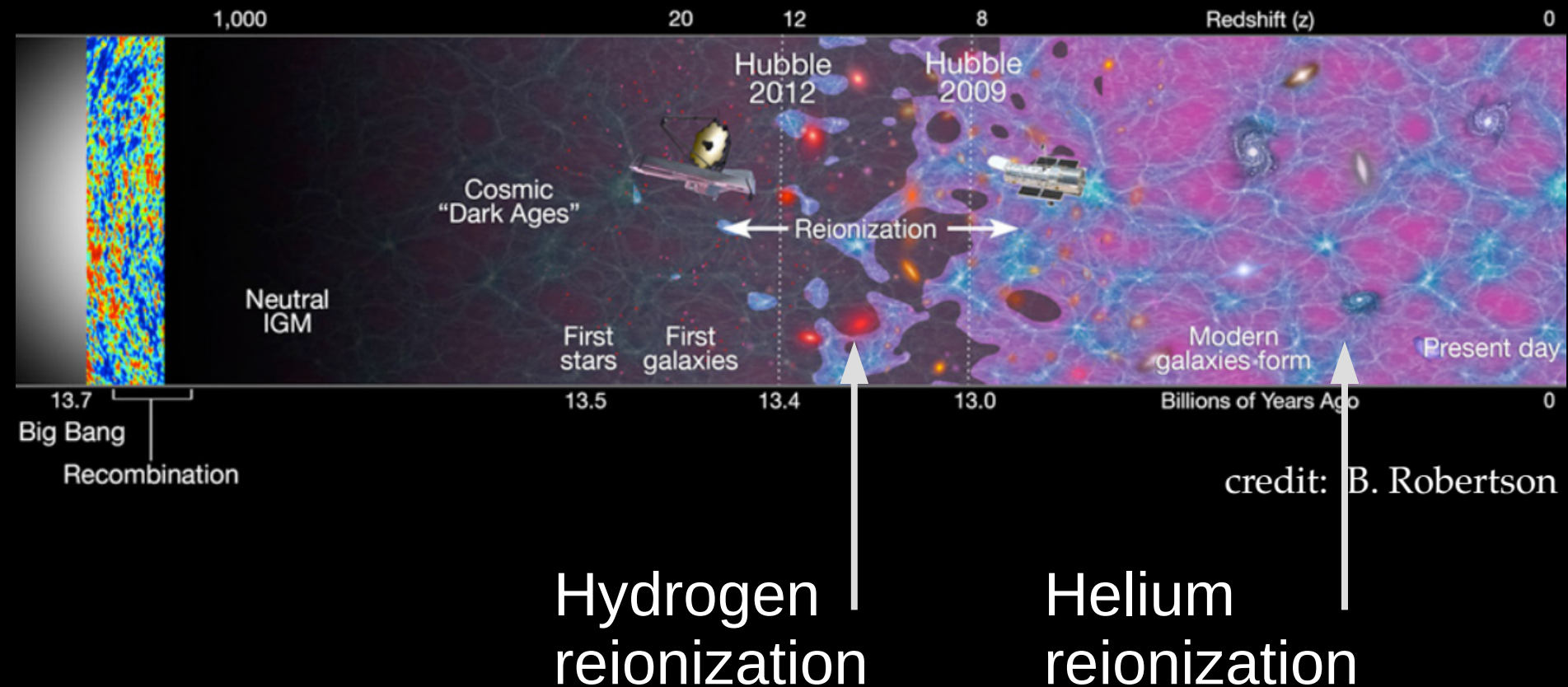
Enrico Garaldi | Bonn University



@enreecog

+ Michele Compostella, Cristiano Porciani,
Nickolay Gnedin, Piero Madau

The standard reionization model

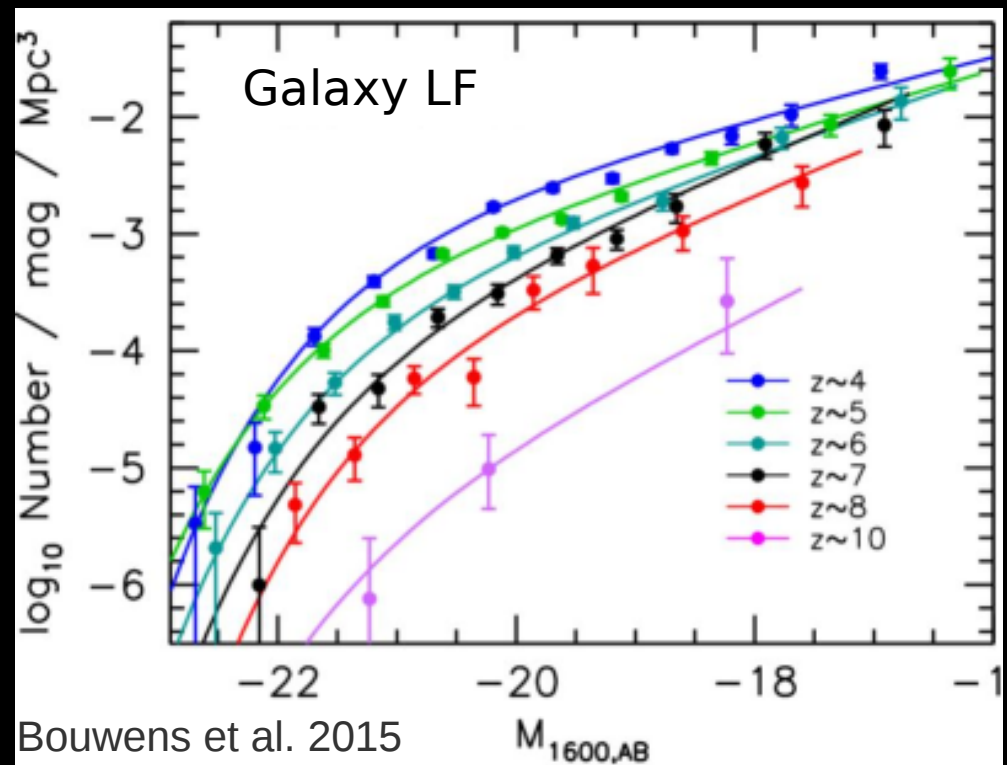


Sources: star-forming galaxies

- predicted by galaxy formation models & simulations
- observed up to $z \sim 11$ (Oesch et al. 2016)
- uncertain properties (mainly f_{esc})

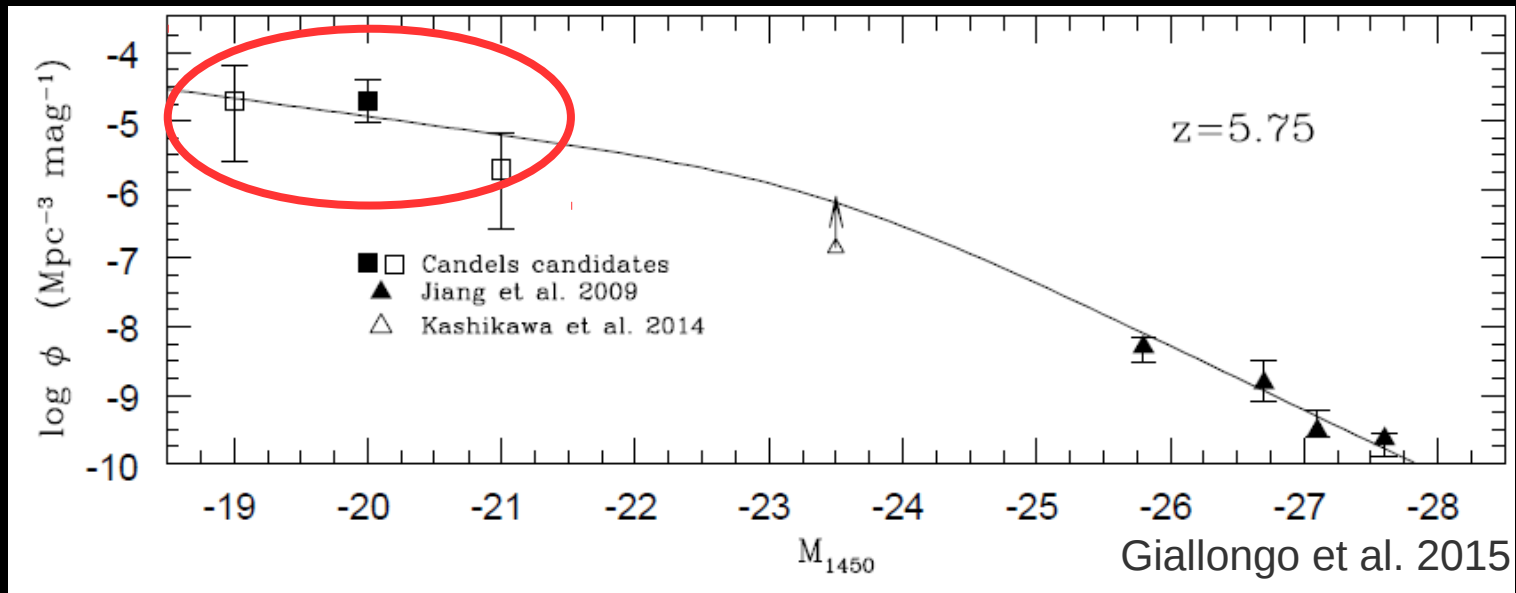
Promisingly
steep faint end \rightarrow

(e.g. Ma et al. 2015, Grazian et al 2015, Bouwens et al. 2015, Vanzella et al. 2010, Izotov et al. 2016, Rutkowski et al. 2017 and many more..)



Sources: high-z quasars

- bright quasars (QSOs) are rare at $z > 4$
- faint QSOs may be more common
(Giallongo et al. 2015, Chardin et al. 2016 but see Parsa et al. 2017, Onoue et al. 2017, Khaire 2017, BH progenitors?)



- If you are optimistic, they will do all the job!
(Madau&Haardt 2015)

“We don’t have large radiative-transfer simulations of QSOs reionization”

G. Worseck, ~20 mins ago

Part 1:

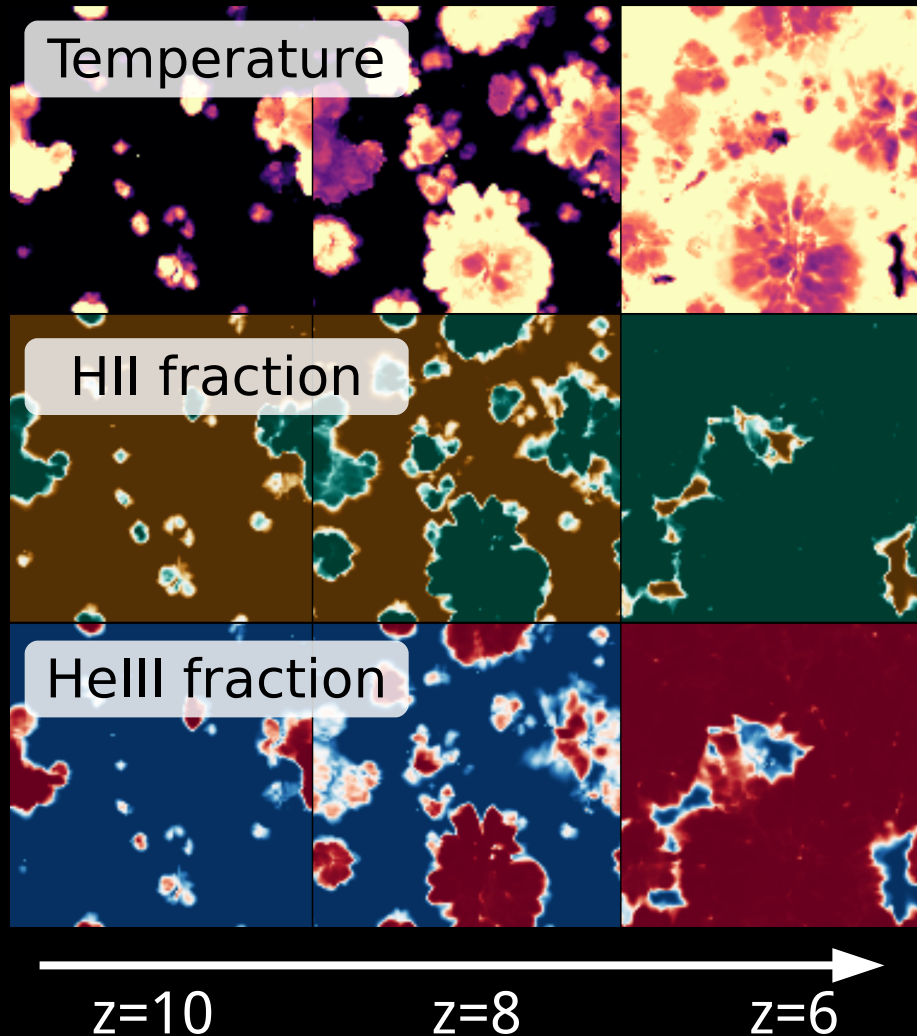
Quasars at cosmic dawn

Garaldi, Compostella, Porciani, 2018, *in prep.*

“We need to go to 100 Mpc box with large frequency coverage and (possibly) non-equilibrium solvers.”

G. Worseck, ~21 mins ago

Simulating the QSOs at Cosmic Dawn



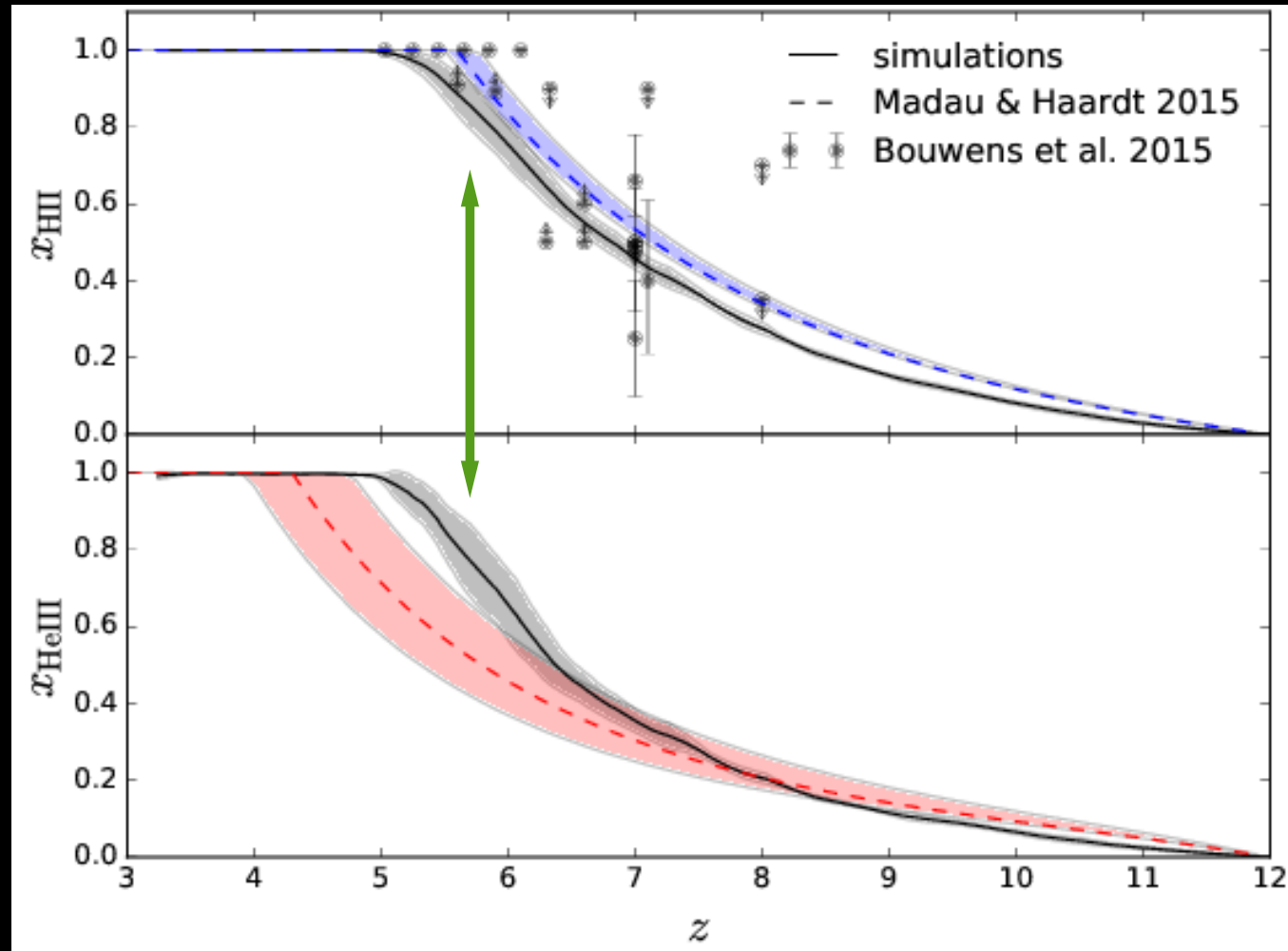
Hydro + radiative-transfer
(RAMSES + RADAMESH)

- 4 x 100 Mpc/h boxes
- Planck cosmology
- Multi-species, multi-wavelength (1-40 ryd)
- Non-equilibrium
- QSO abundance matching

Validation

Good match
with analytical
predictions.

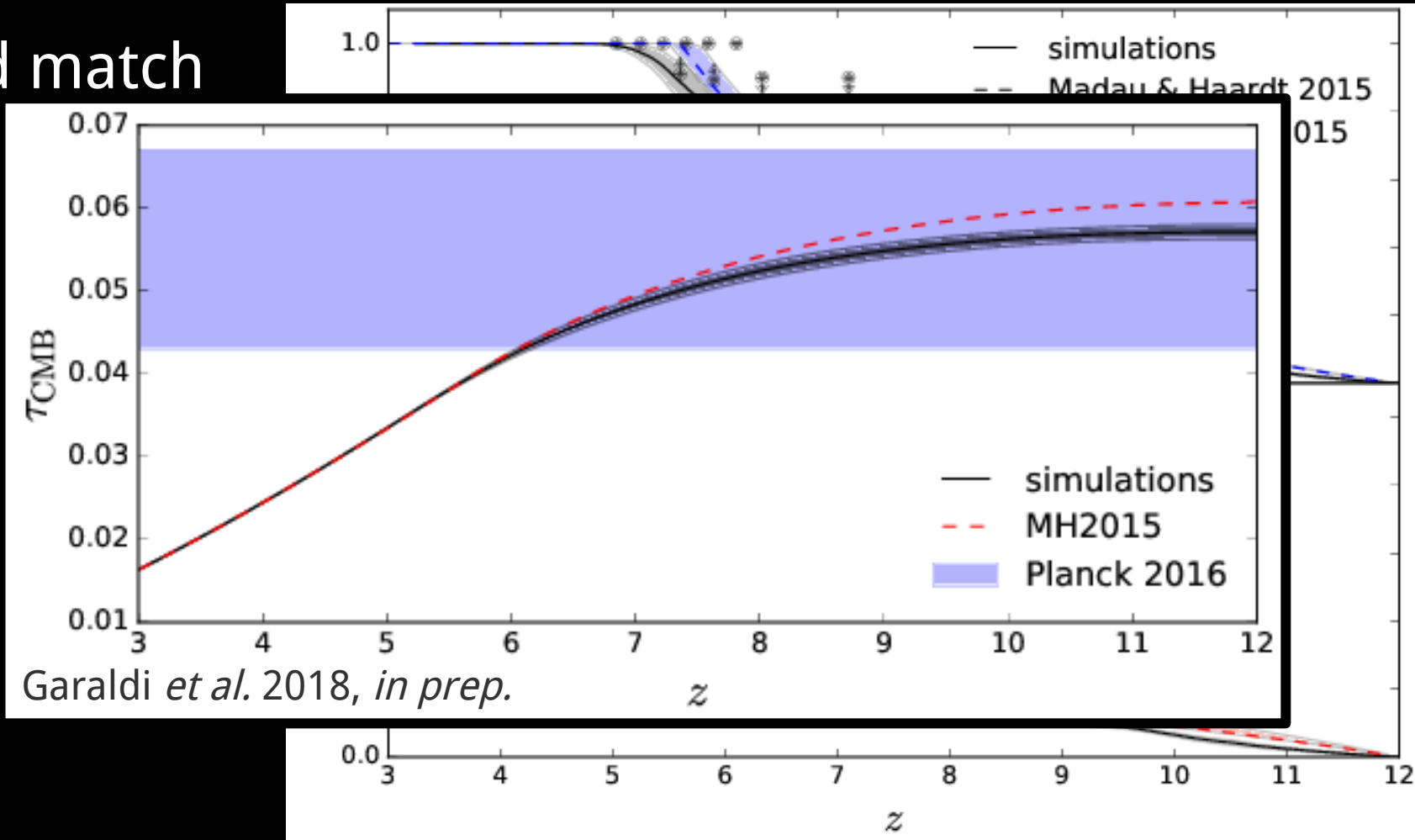
HI and HeII
reionization
are very close
in time.



Garaldi *et al.* 2018, *in prep.*

Validation

Good match
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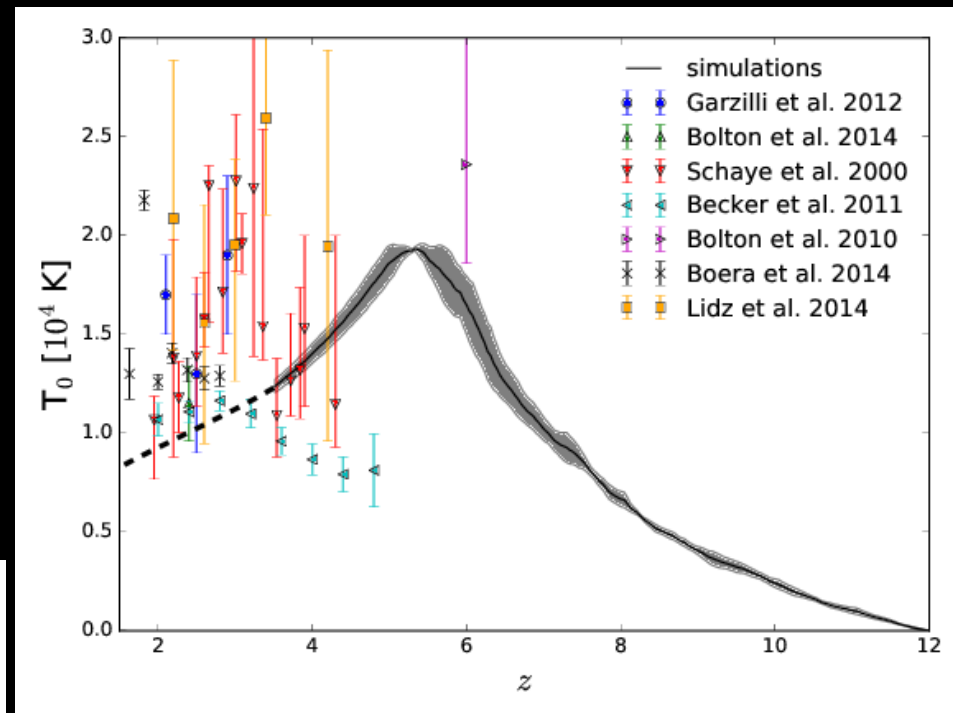
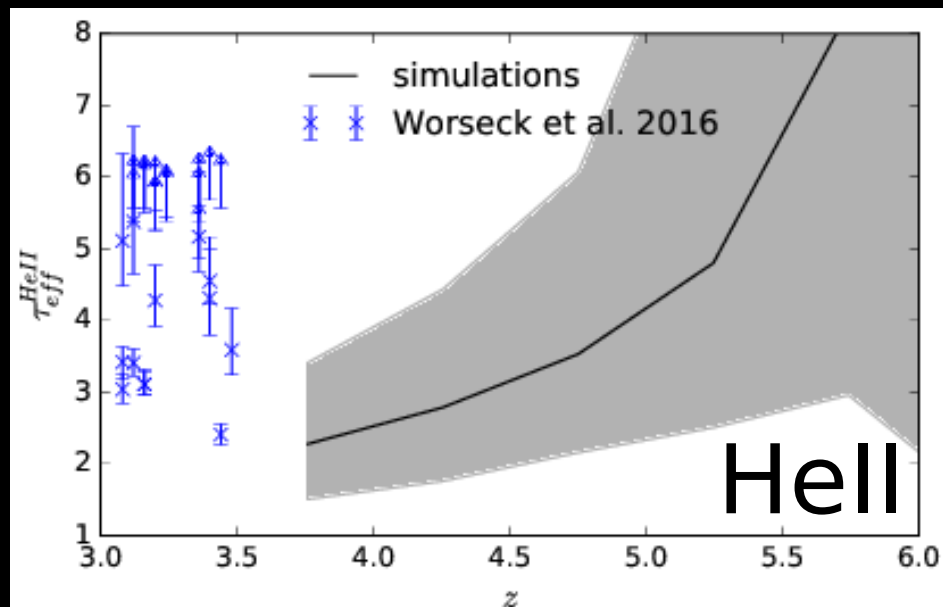


Garaldi *et al.* 2018, *in prep.*

Garaldi *et al.* 2018, *in prep.*

(Too) early Helium Reionization

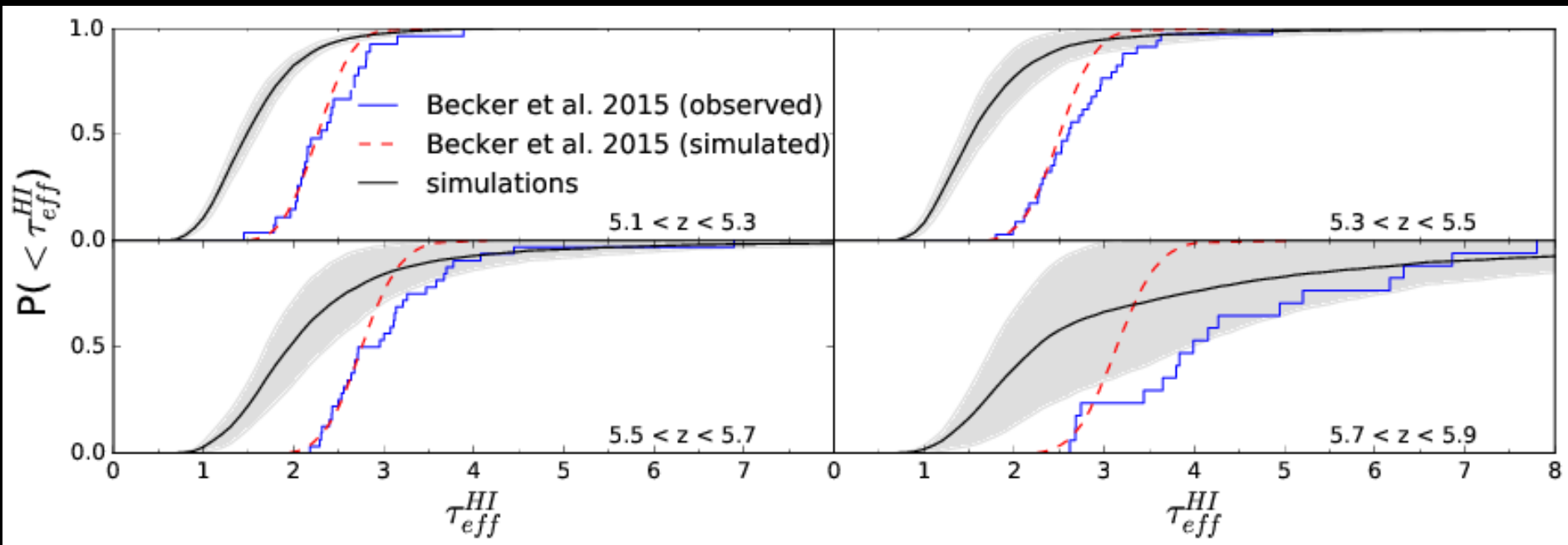
The IGM is heated at $z \sim 5.5$ by HI and HeII simultaneously



Garaldi et al. 2018, in prep.

Low HeII Ly- α optical depth

QSOs as sources of IGM dark regions?

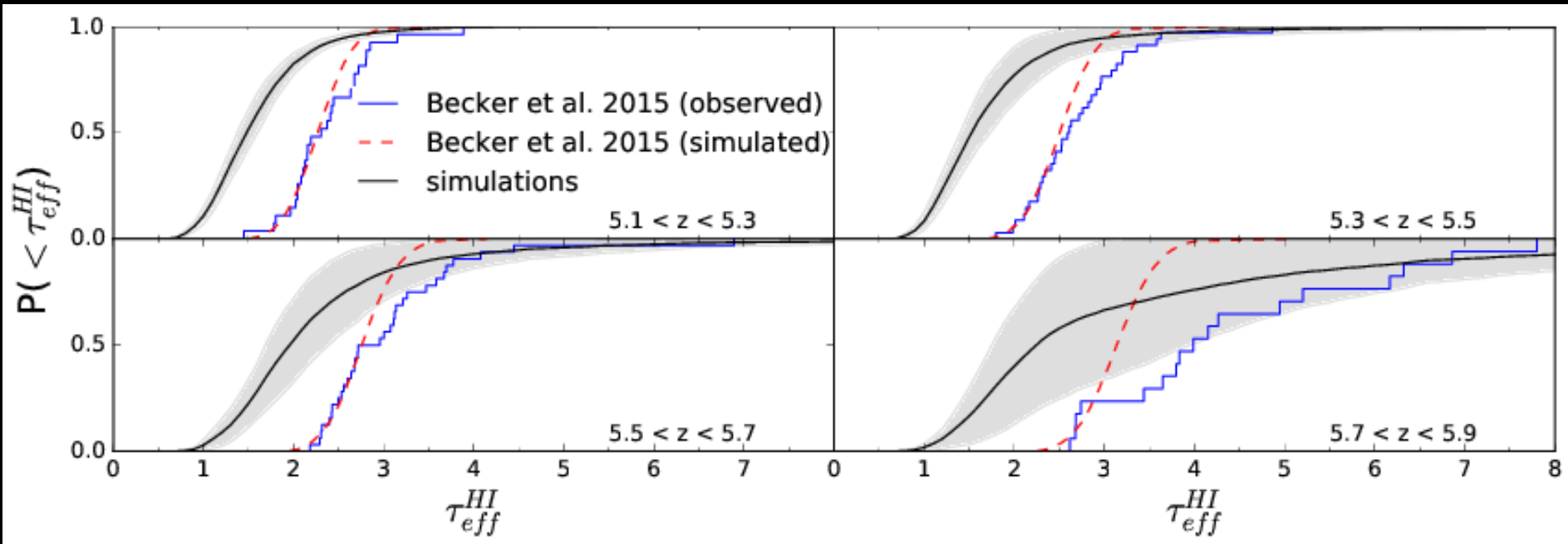


Garaldi *et al.* 2018, *in prep.*

Early QSOs may explain the obscured IGM regions observed at $z > 5$

See Bosman+2018 for recent observations

QSOs as sources of IGM dark regions?

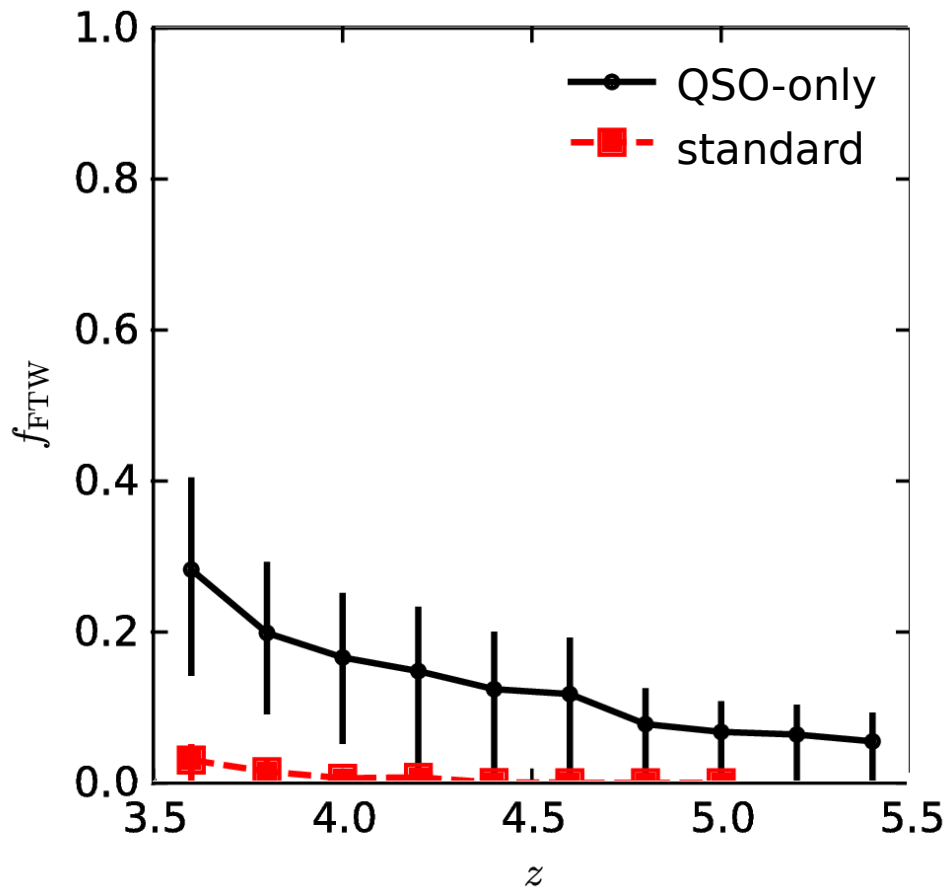


Garaldi *et al.* 2018, *in prep.*

Early QSOs may explain the obscured IGM regions observed at $z > 5$

Can we gauge the QSO contribution?

Gauging QSOs: HeII Ly-alpha forest



Garaldi *et al.* 2018, *in prep.*

FTW = Flux Transmission Window

- Sensitive to timing of HeII reionization
- Increasing difference at low redshift
- Need low- z predictions from hybrid reionization scenarios

PRELIMINARY

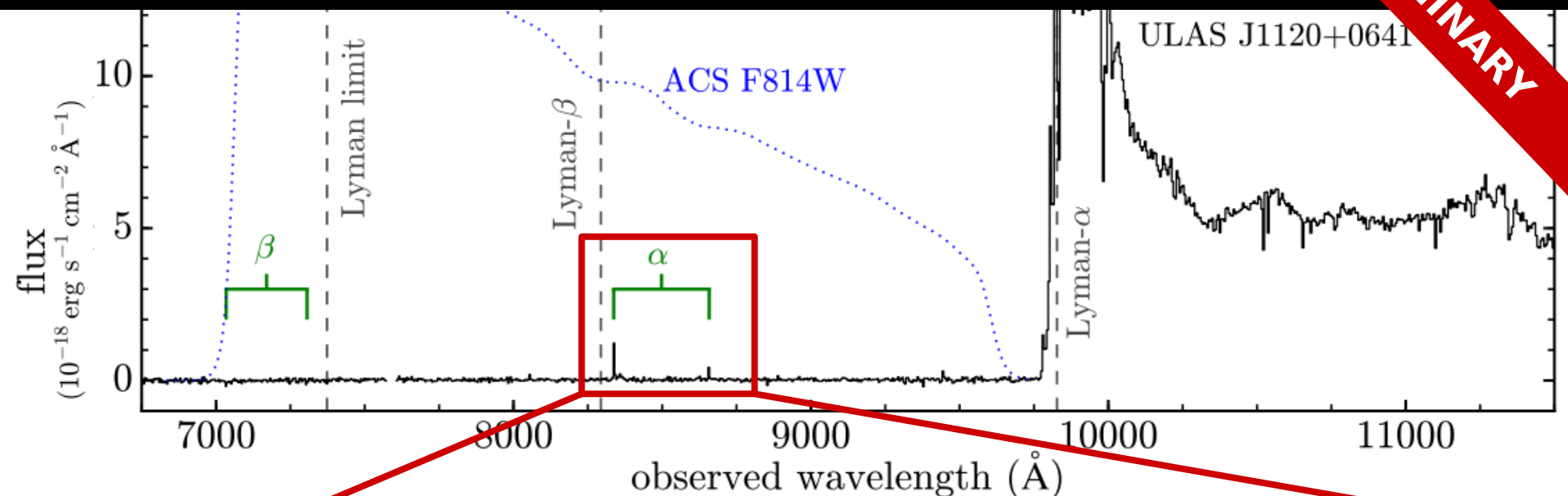
Part 2:

Properties of the high- z IGM

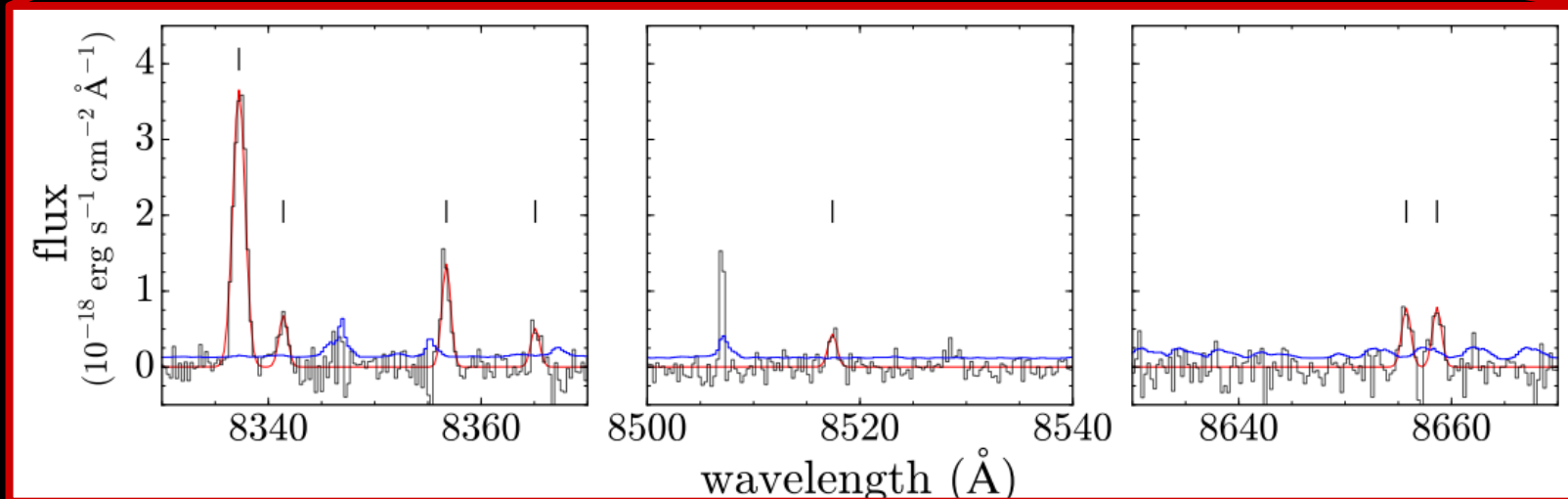
Garaldi, Gnedin, Madau, *in prep.*

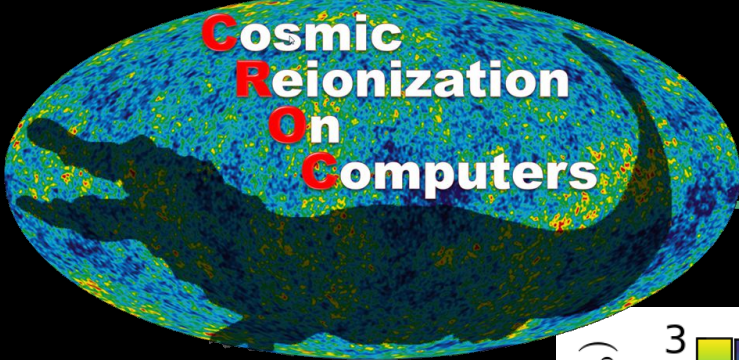
7 high-z spikes within a GP trough

PRELIMINARY



Barnett *et al.* 2017





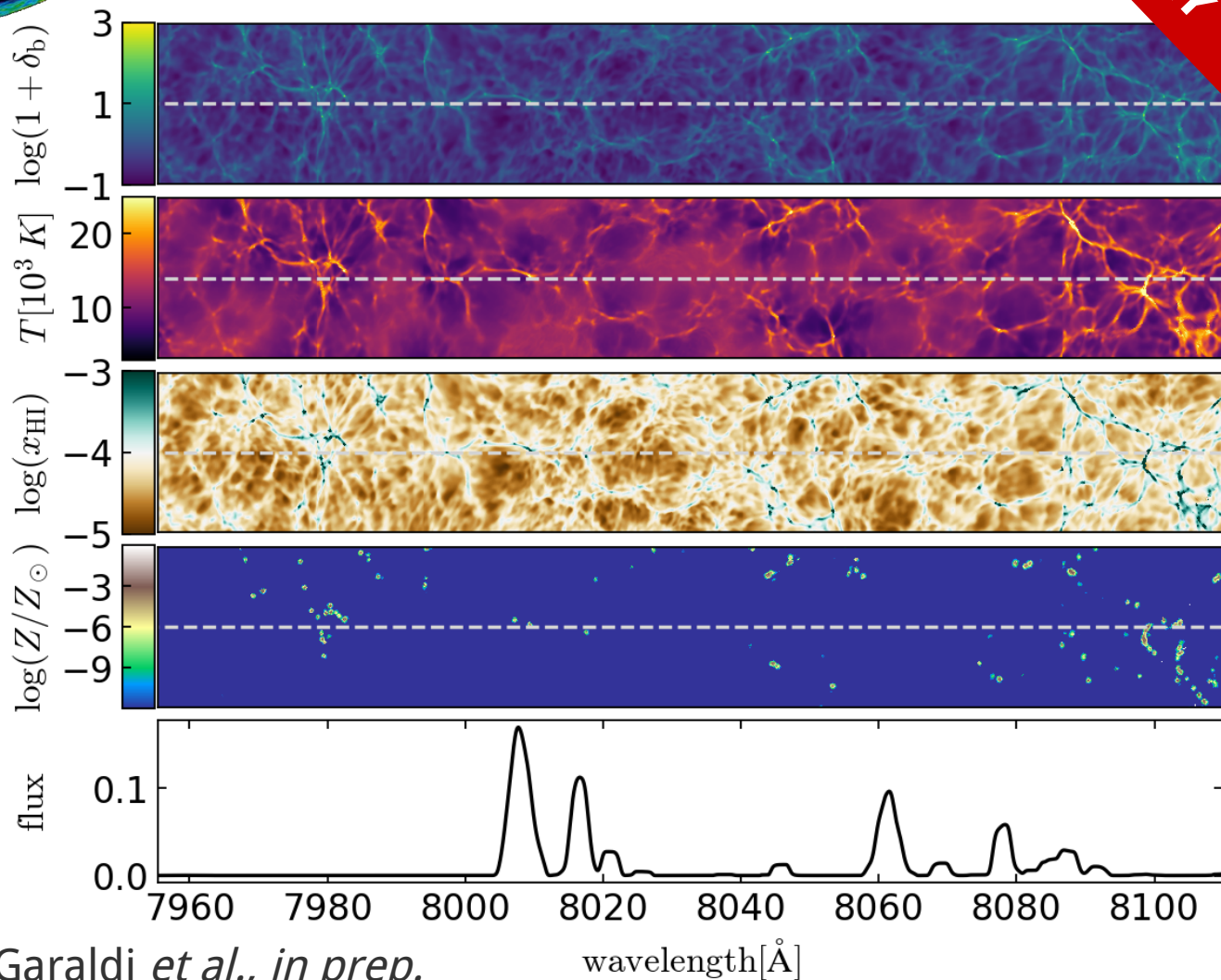
CROC simulations

PRELIMINARY

Hydro & RT
coupled

40 Mpc/h
box

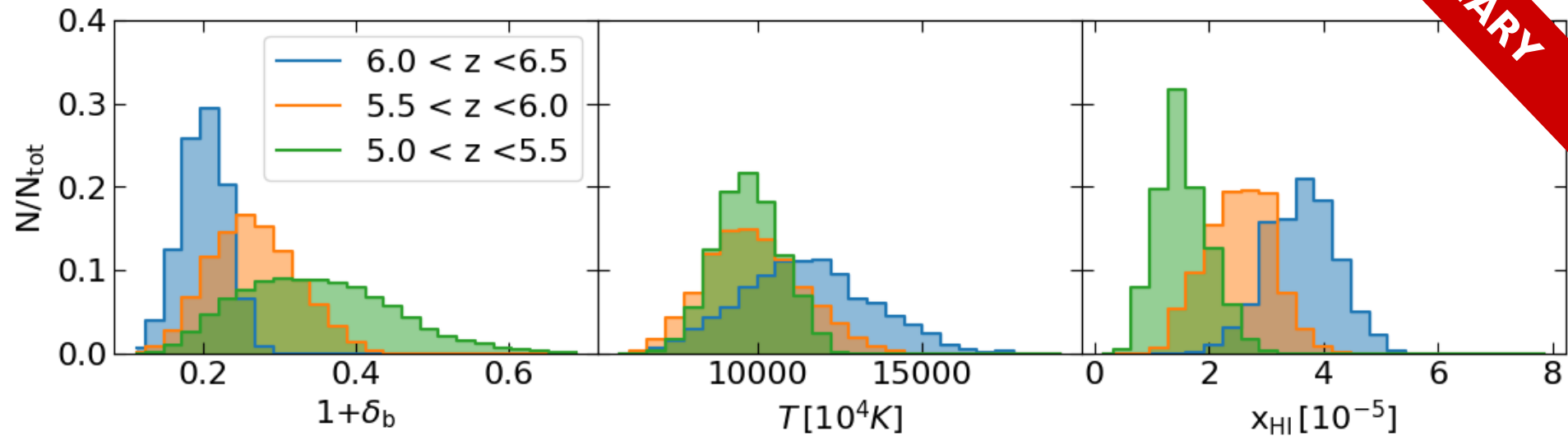
Random LOS
at $6.5 < z < 5$



Garaldi *et al.*, in prep.

The underlying IGM – evolution

PRELIMINARY



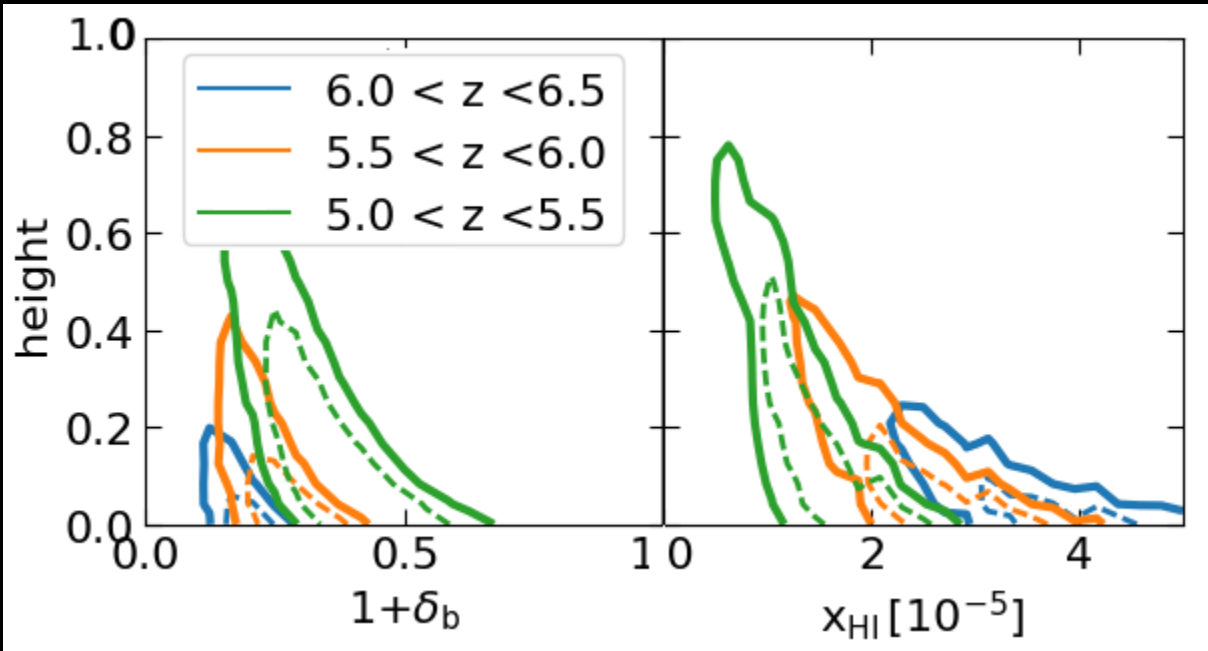
Garaldi *et al.*, *in prep.*

Strong redshift evolution of the IGM properties

Peaks are produced by underdense regions *with a bright source nearby*

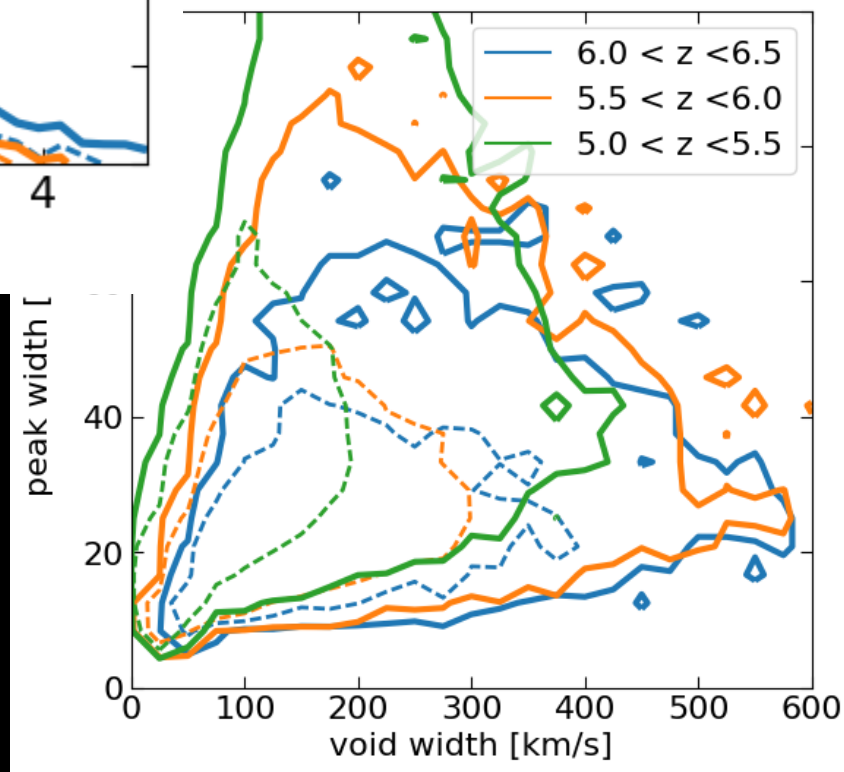
The underlying IGM – correlations

PRELIMINARY



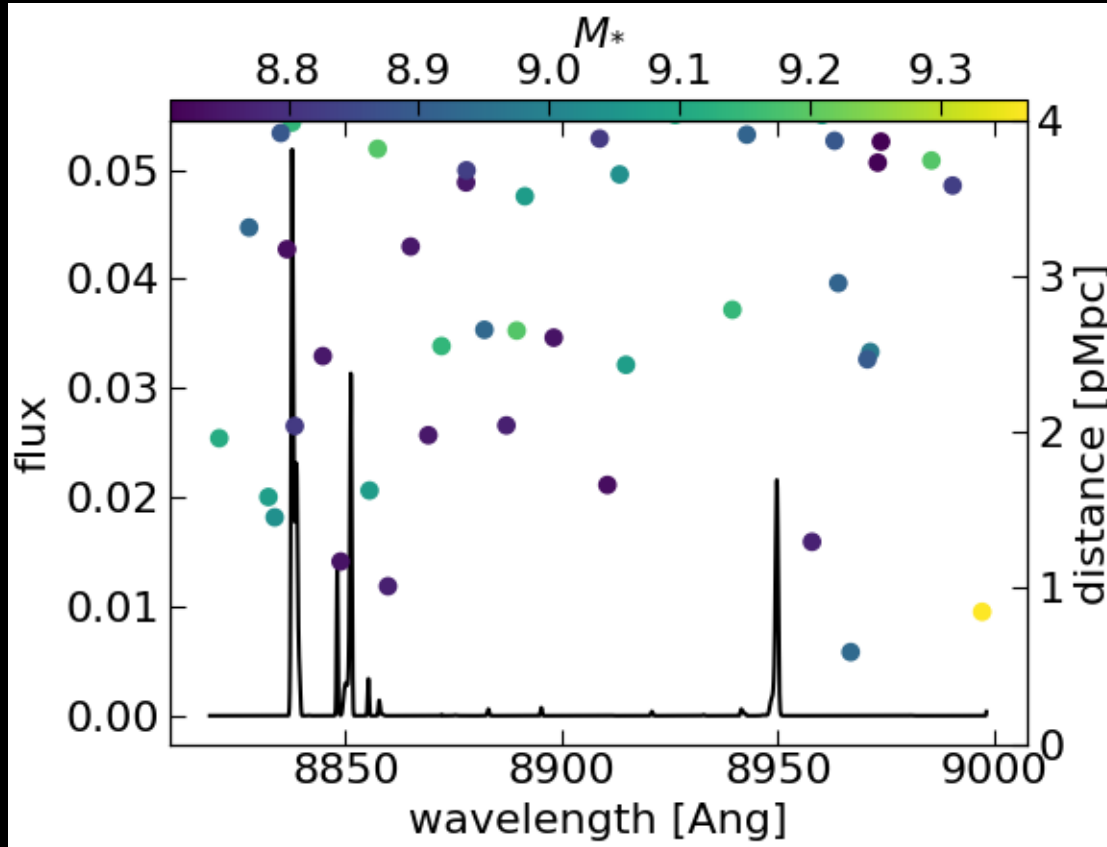
Garaldi *et al.*, *in prep.*

Peaks are produced by underdense regions *with a bright source nearby*



Probing the sources of reionization

PRELIMINARY



Garaldi *et al.*, *in prep.*

Correlation between flux and nearby galaxies/ QSOs is a powerful probe of reionization sources

(see Kakiichi's talk for an observational perspective)

Summary

- QSOs-only reionization very unlikely (early HeII reionization → wrong T_0 , optical depth)
- High- z QSOs may explain the obscured IGM at $z > 5$
- High- z QSOs contribution can be constrained by the HeII Ly α forest even at $z < 3.5$
- High- z Ly α spikes are produced by underdense, highly-ionized IGM
- High- z spikes are a powerful probe of the sources of reionization

