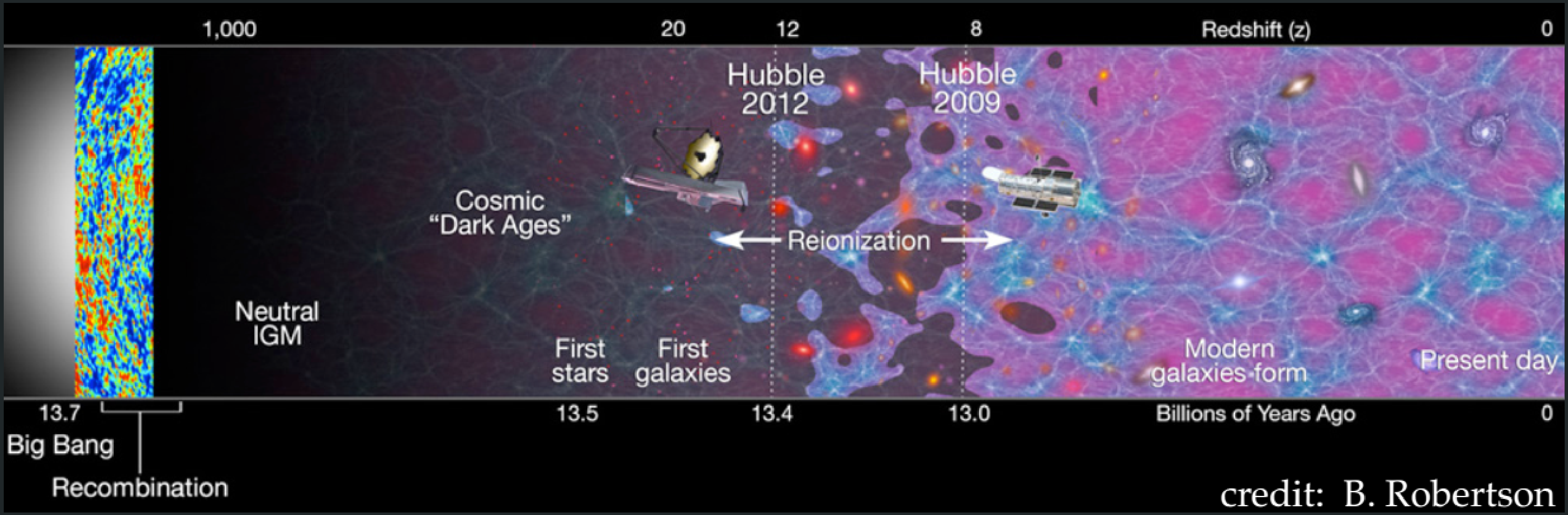
Quasars at the Cosmic Dawn

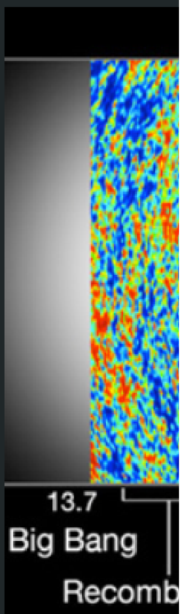
Enrico Garaldi

Michele Compostella
Cristiano Porciani

The usual reionization picture...



The usual reionization picture...

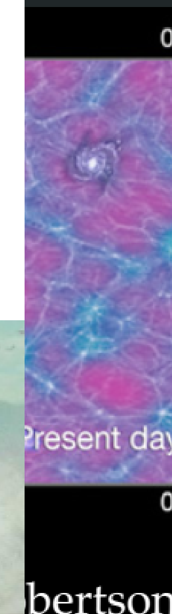


The Flood Is Coming

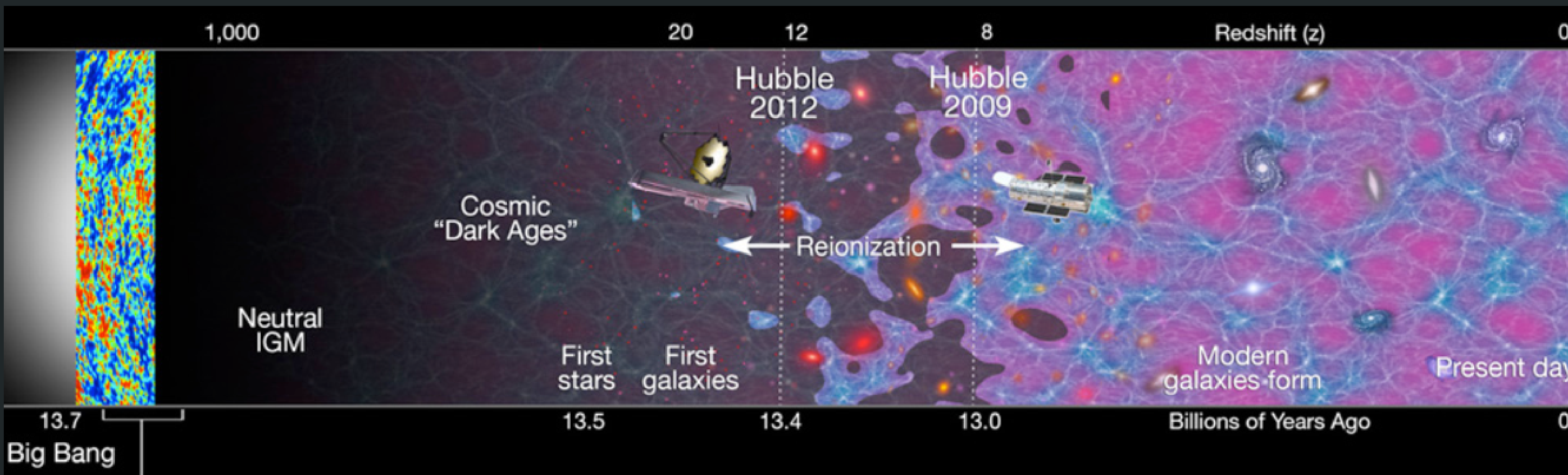
- What we know now is just a light rain before **THE FLOOD:**

- **JWST:** Spring 2019
- 21 cm: ~2020
- GSMT: 2021-2025 (GMT, TMT, E-ELT)
- WFIRST: ~2025

Credit: N. Gnedin



The usual reionization picture...



credit: B. Robertson

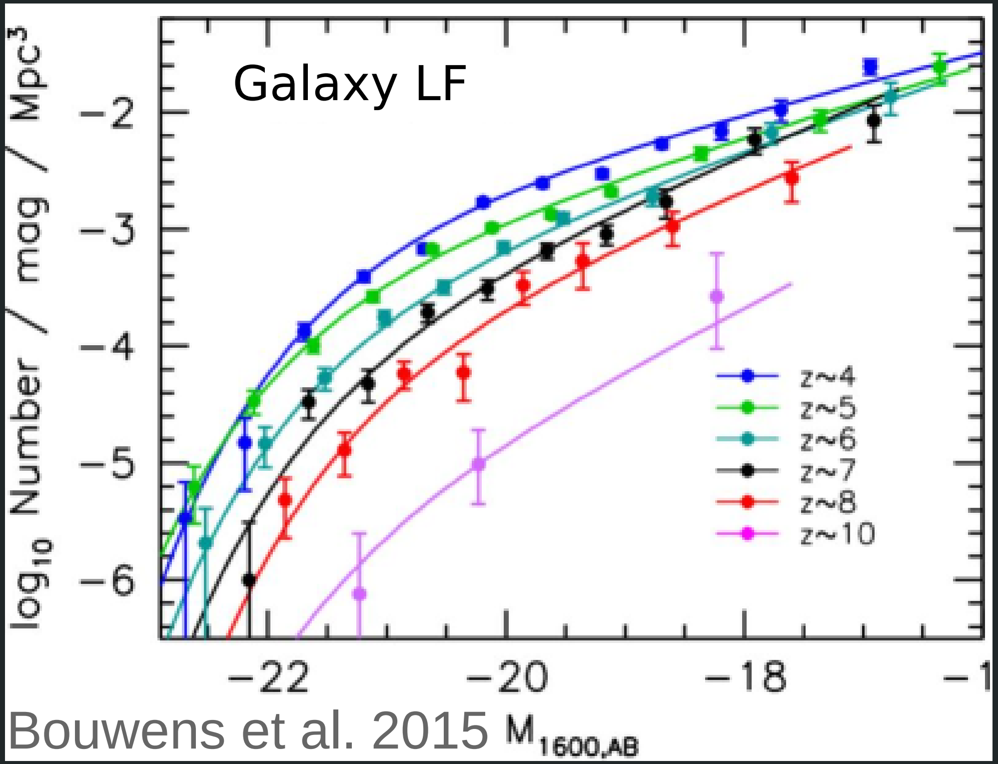
The fundamental questions:

- *Sources?*
- Timing?
- Physics?

Sources: star-forming galaxies

- predicted by galaxy formation models & simulations
- observed up to z ~ 11 (Oesch et al. 2016)
- uncertain properties (mainly f_{esc} and ς_{ion})

Promisingly steep faint end →



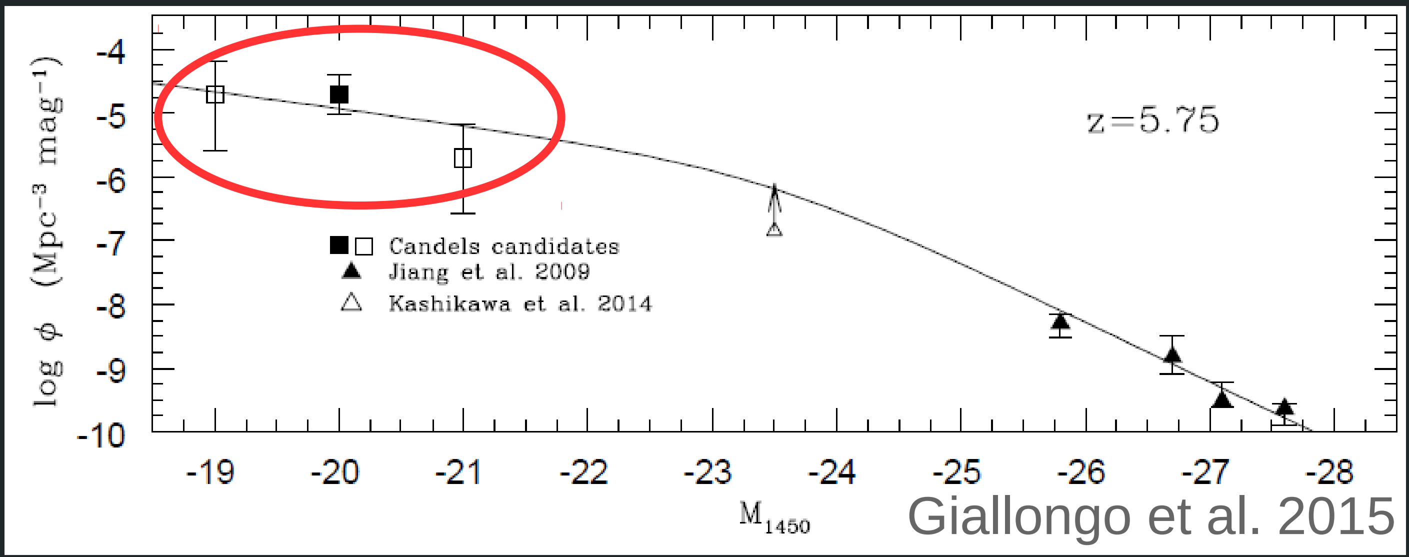
Bouwens et al. 2015

(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?)



Giallongo et al. 2015

- If you are optimistic, they will do all the job!

  (Madau&Haardt 2015)

The problem

- Galaxies can fuel the Hydrogen EoR
- Faint QSOs can do the same

hence:

There are too many ionizing photons.

What are we doing wrong?

The problem

- Galaxies can fuel the Hydrogen EoR
- Faint QSOs can do the same

hence:

There are too many ionizing photons.

What are we doing wrong?

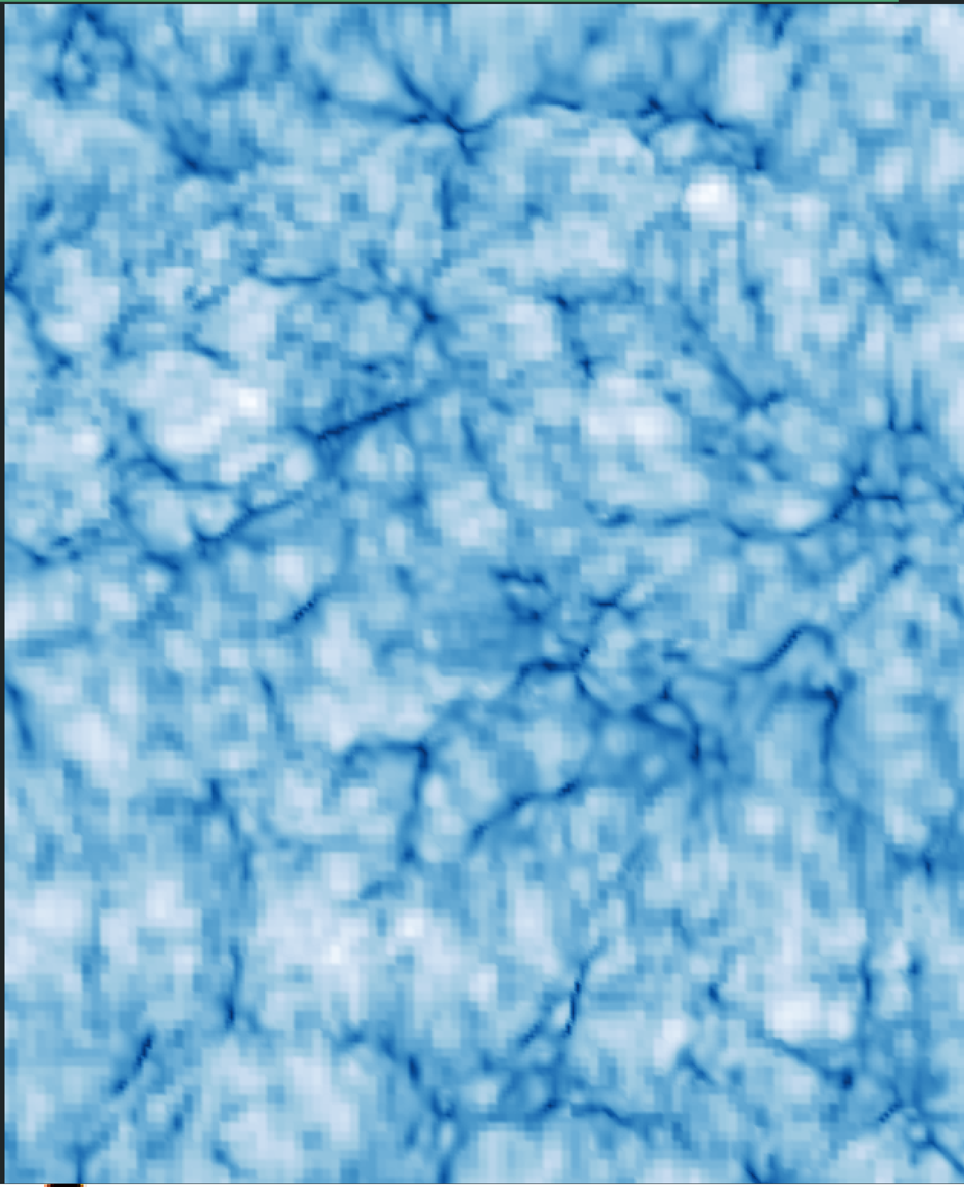
The plan: simulate galaxy- and QSO-dominated reionization and compare them to observation

Simulating the QSOs at Cosmic Dawn

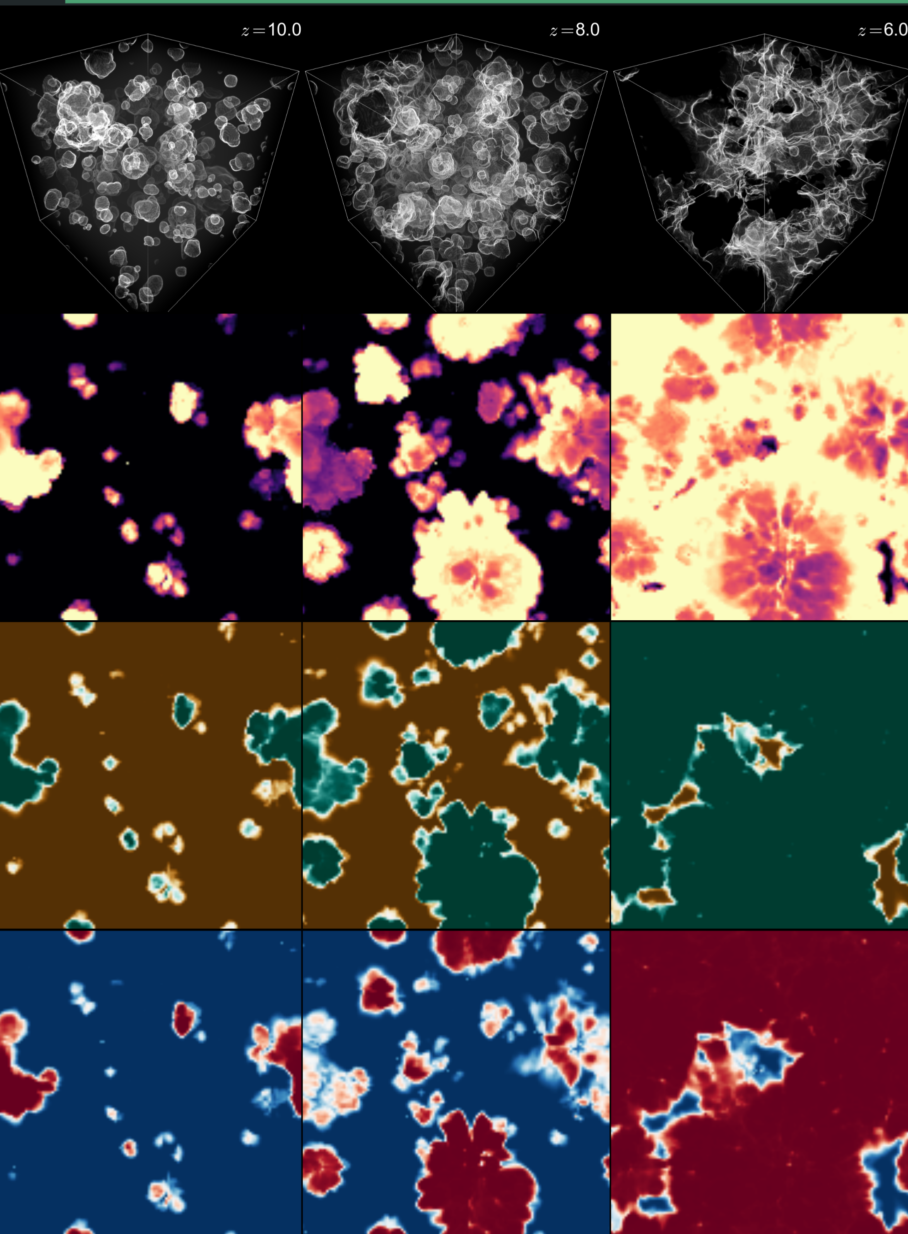
Hydrodynamic simulations (RAMSES)

- Large (4 x 100 Mpc/h)
- High-resolution (3 kpc/h)
- Realistic (Planck 2015 cosmology)

Baryonic overdensity →



Simulating the QSOs at Cosmic Dawn



Radiative-transfer (RADAMESH)

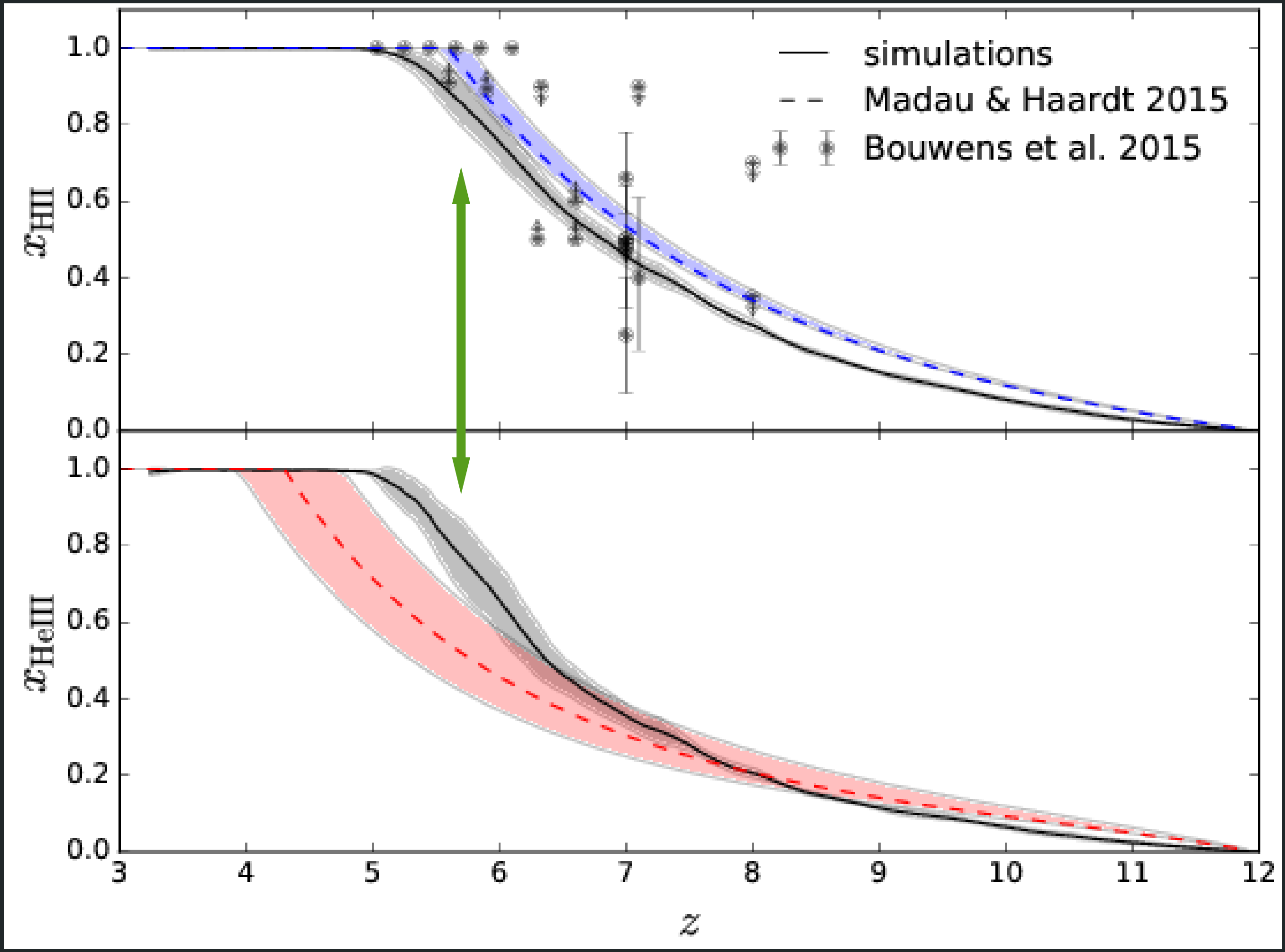
- cell-by-cell Monte Carlo
- Multi-species
- Multi-wavelength (1-40 ryd)
- Non-equilibrium

⬅ Ionization front
Temperature
HII fraction
HeIII fraction

Validation

Good match with analytical predictions.

HI and HeII reionization are very close in time.

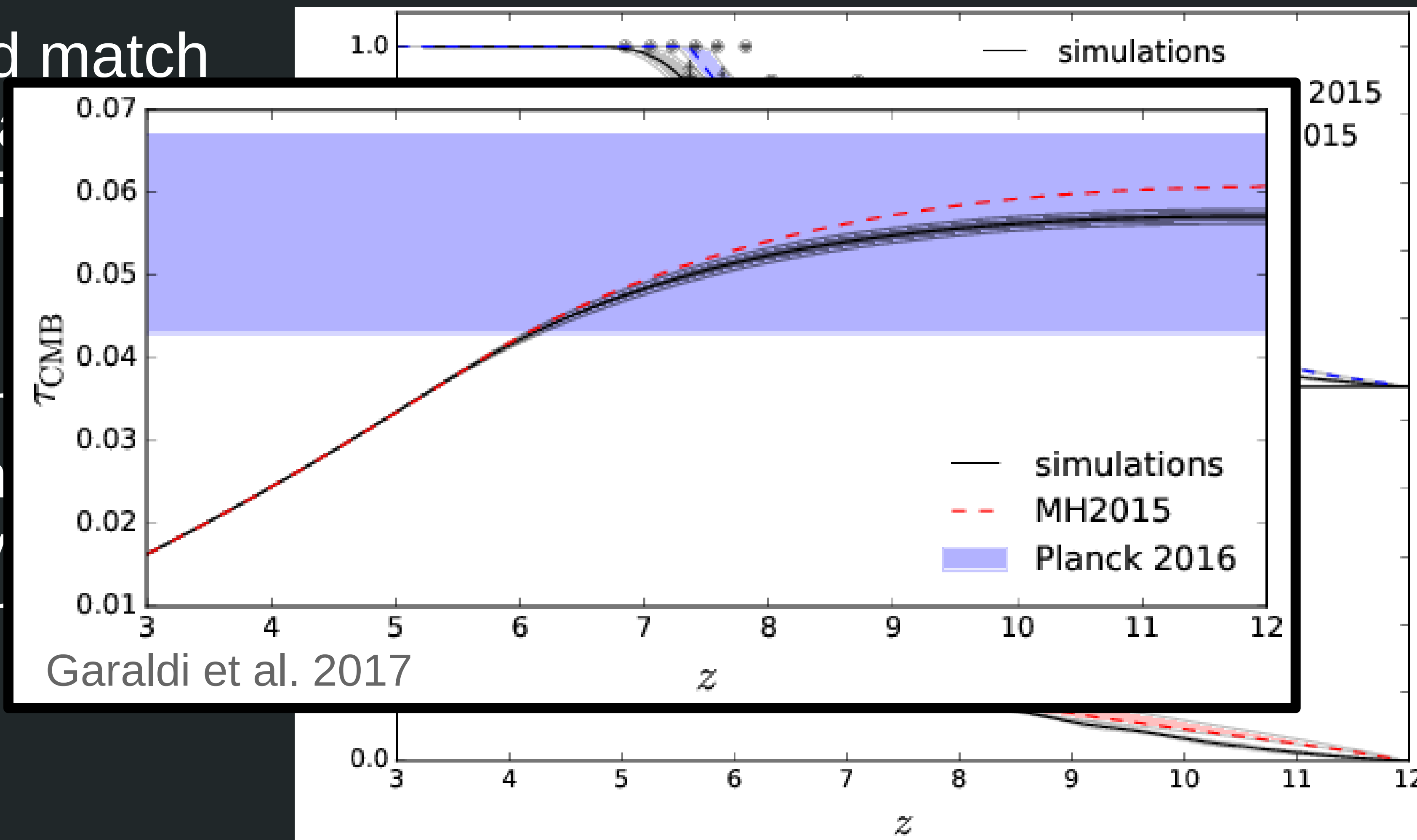


Garaldi et al. 2017

Validation

Good match
with a
predi

HI ar
reion
are v
in tim



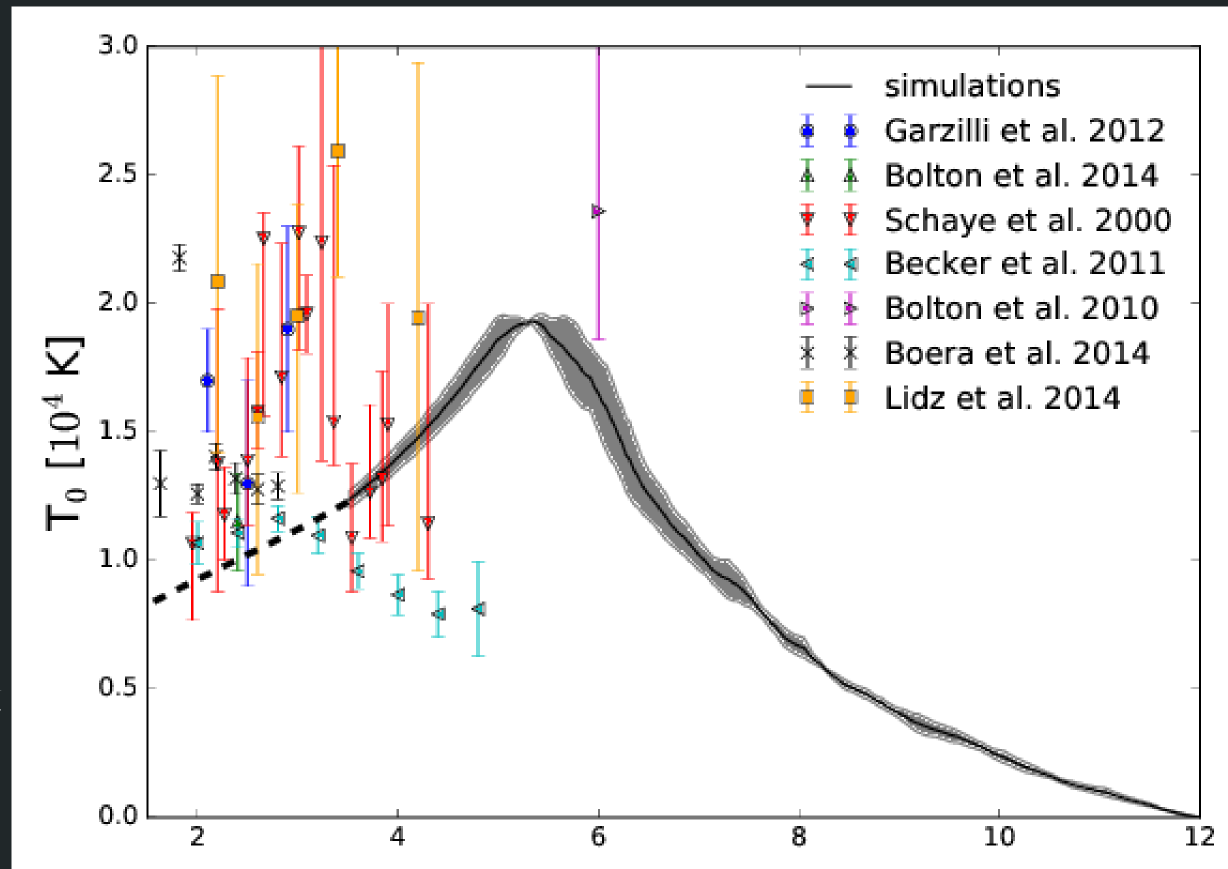
Garaldi et al. 2017

Garaldi et al. 2017

(Too) early IGM heating

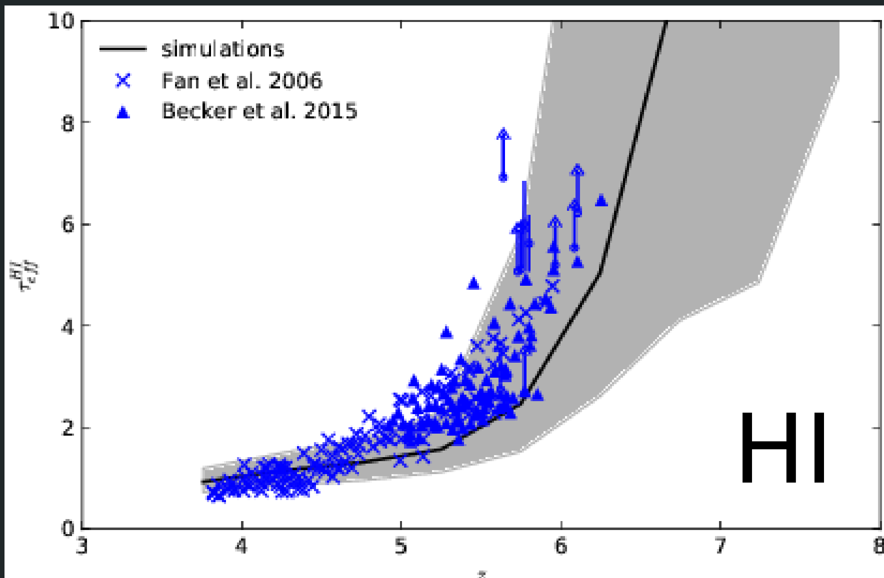
The intergalactic medium (IGM) is heated at z~5.5 by HI and HeII simultaneously

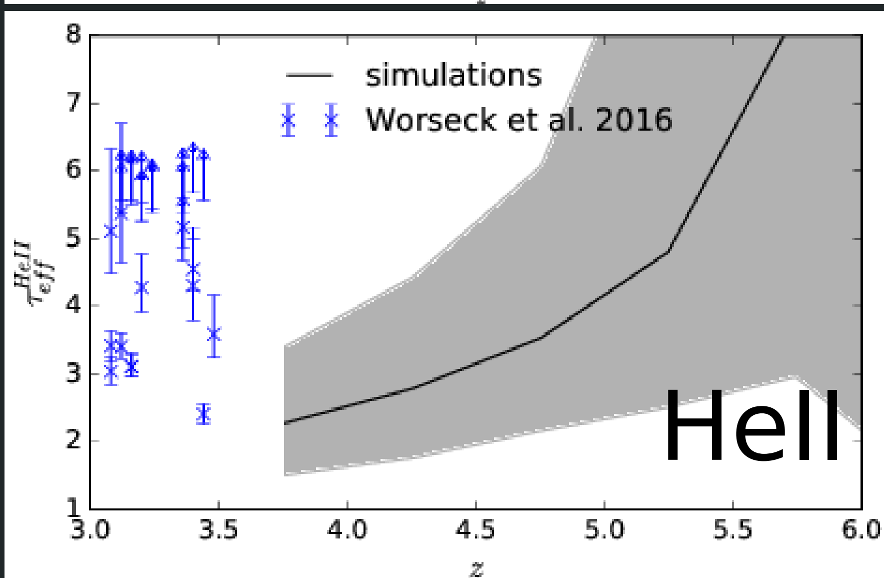
temperature at mean density →



Garaldi et al. 2017

QSOs have problems with the HeII





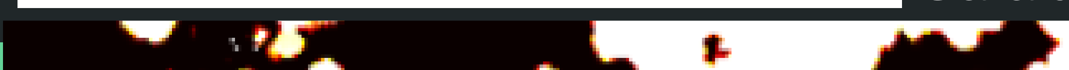
$$\tau_{eff} = -\ln(F)$$

- HI optical depth agrees with data
- HeII optical depth is too low

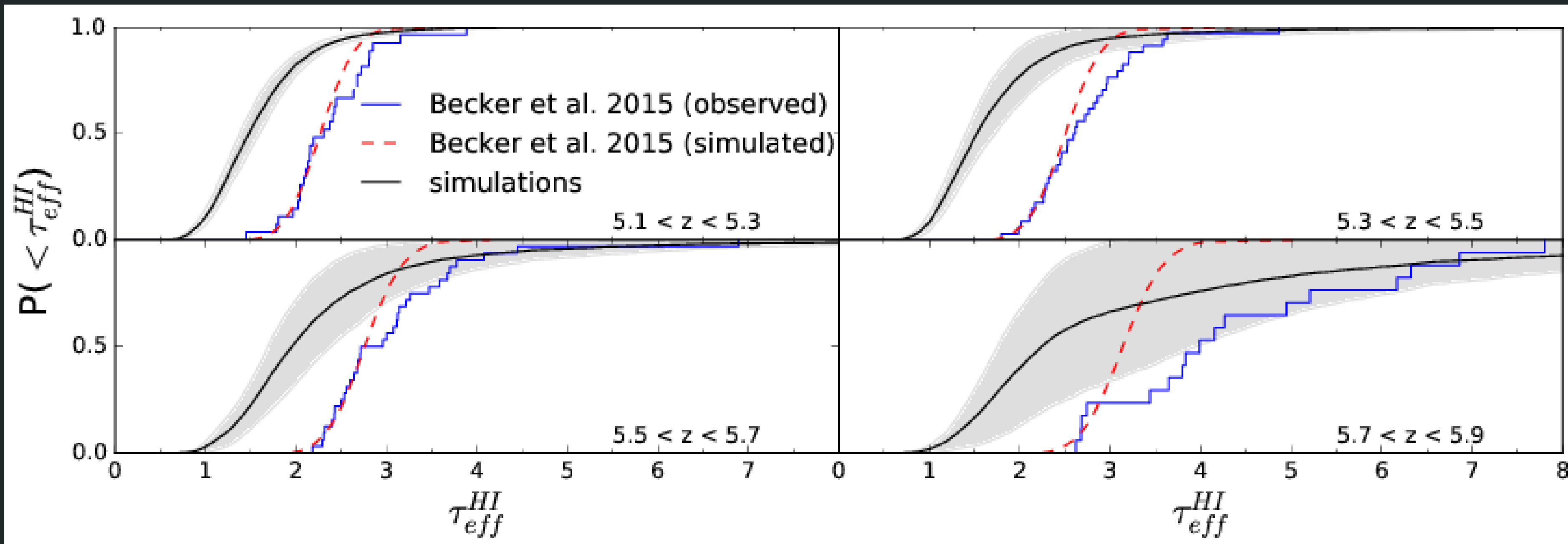
Take-home #1: QSOs reionization has problems with HeII

(probably not a surprise)

Garaldi et al. 2017



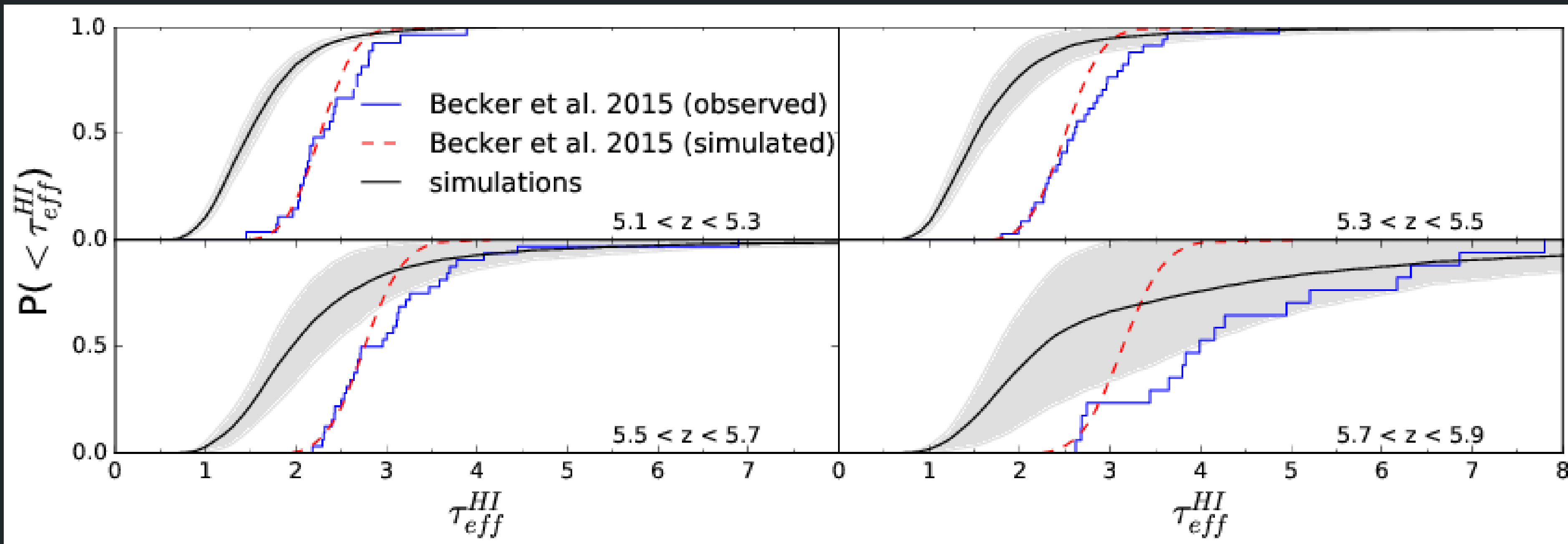
QSOs as sources of IGM dark regions



Garaldi et al. 2017

Take-home #2: QSOs may explain the obscured IGM regions observed at z > 5

QSOs as sources of IGM dark regions



Garaldi et al. 2017

Take-home #2: QSOs may explain the obscured IGM regions observed at z > 5

Question: Can we gauge the QSO contribution?

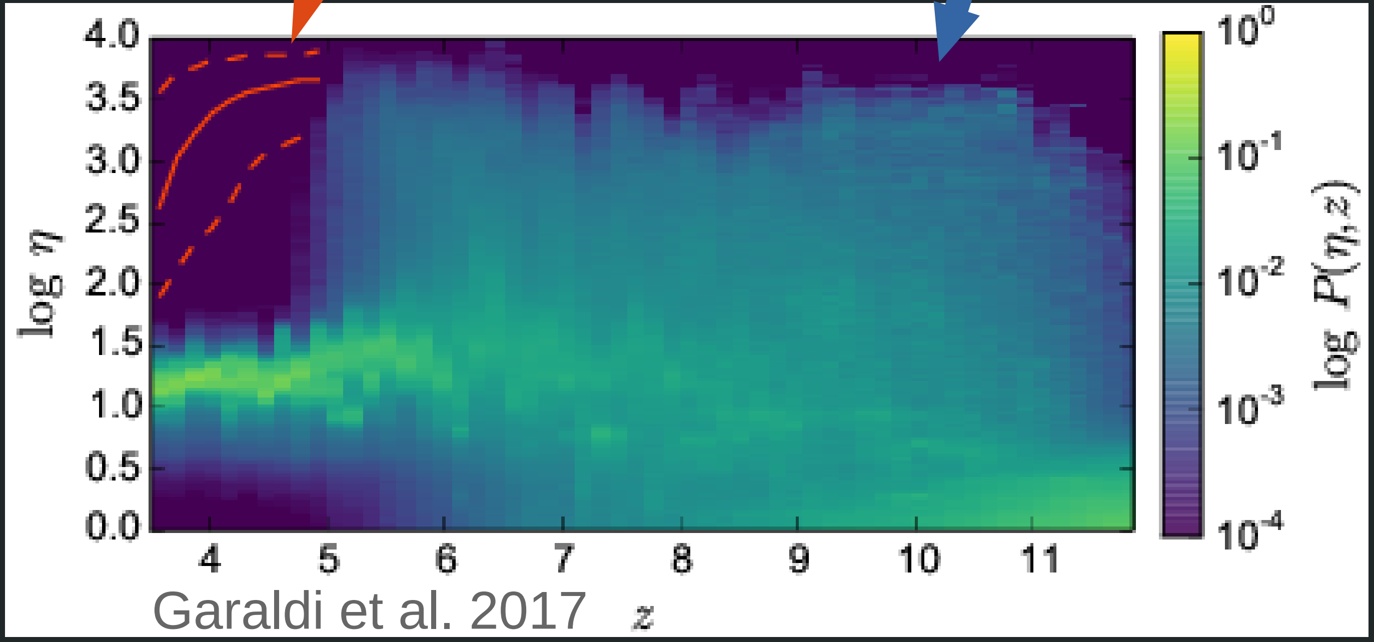
Gauging QSOs: column density ratio

η = HeII column density / HI column density

- Directly probe densities
- Insensitive at z ≲ 3.5

‘standard’ EoR

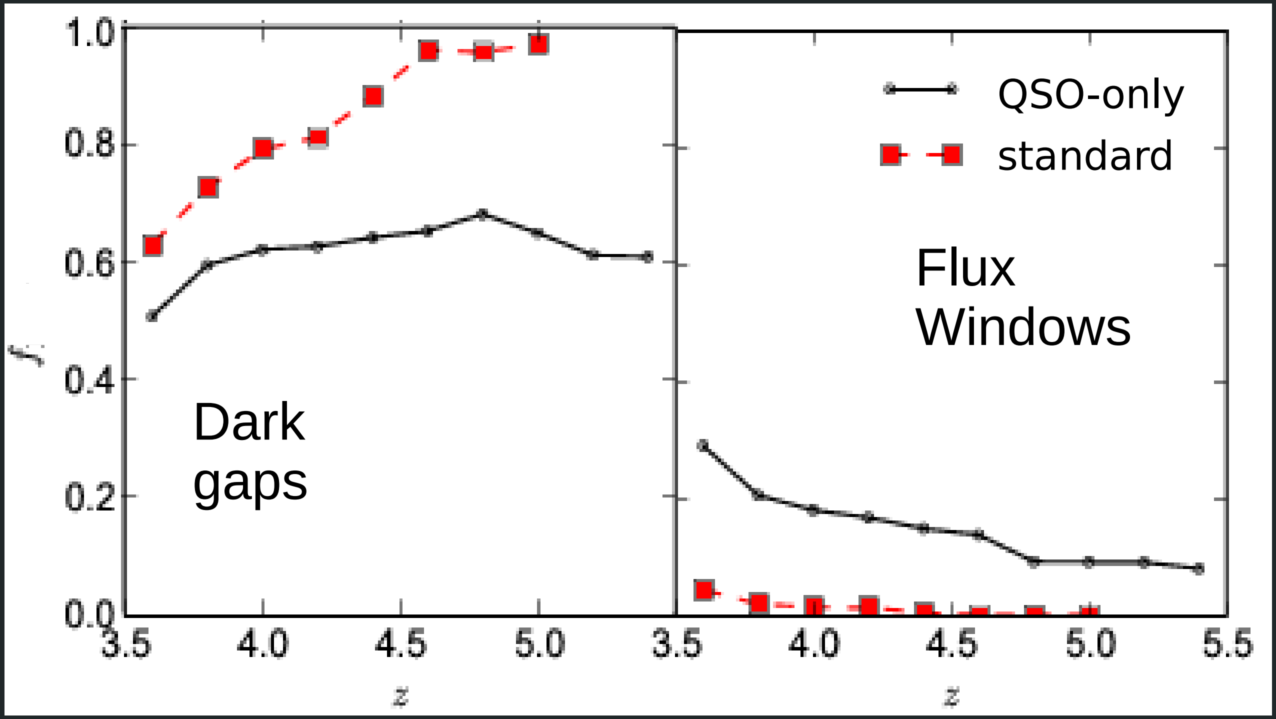
QSO-only EoR



Garaldi et al. 2017

Gauging QSOs: HeII Ly-alpha forest

Flux windows (dark gaps) = region of high (low) flux



Garaldi et al. 2017

- Sensitive to timing of HeII reionization
- Do-able with ~few spectra

Take-home #3: The QSO imprint on the Lyα forest is preserved until z<3.5

Summary

Large, self-consistent, hydro&RT simulations of quasar-only reionization tell us that QSOs...

- reionize HeII too early
- may explain the obscured IGM at $z > 5$
- can be constrained by the HeII Lyα forest even at $z < 3.5$