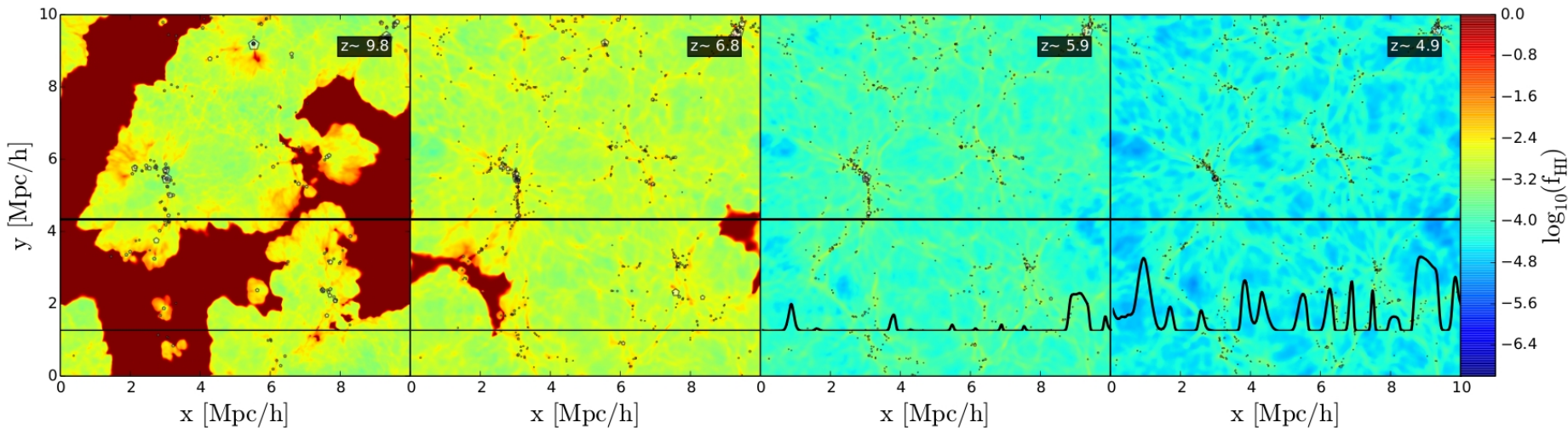


Large scale opacity fluctuations in the Lyman alpha forest : Does the QSOs dominate the UVB at $z=5.5-6$?

Jonathan Chardin with Martin Haehnelt and Ewald Puchwein

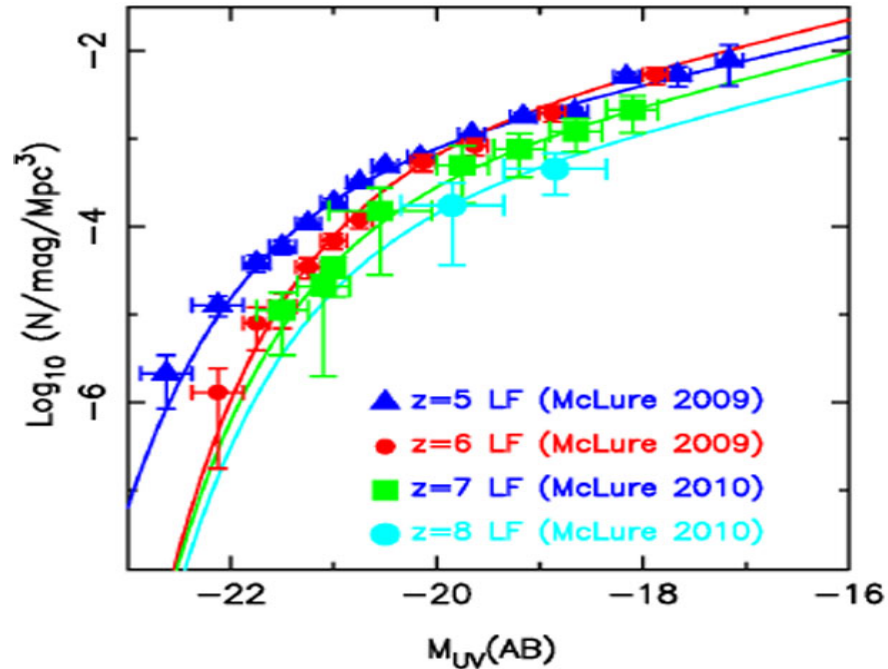


Outline

- Introduction
- Radiative transfer simulations
- A model of the UVB with QSOs and galaxies
- The Lyman alpha forest in the model
- Conclusion

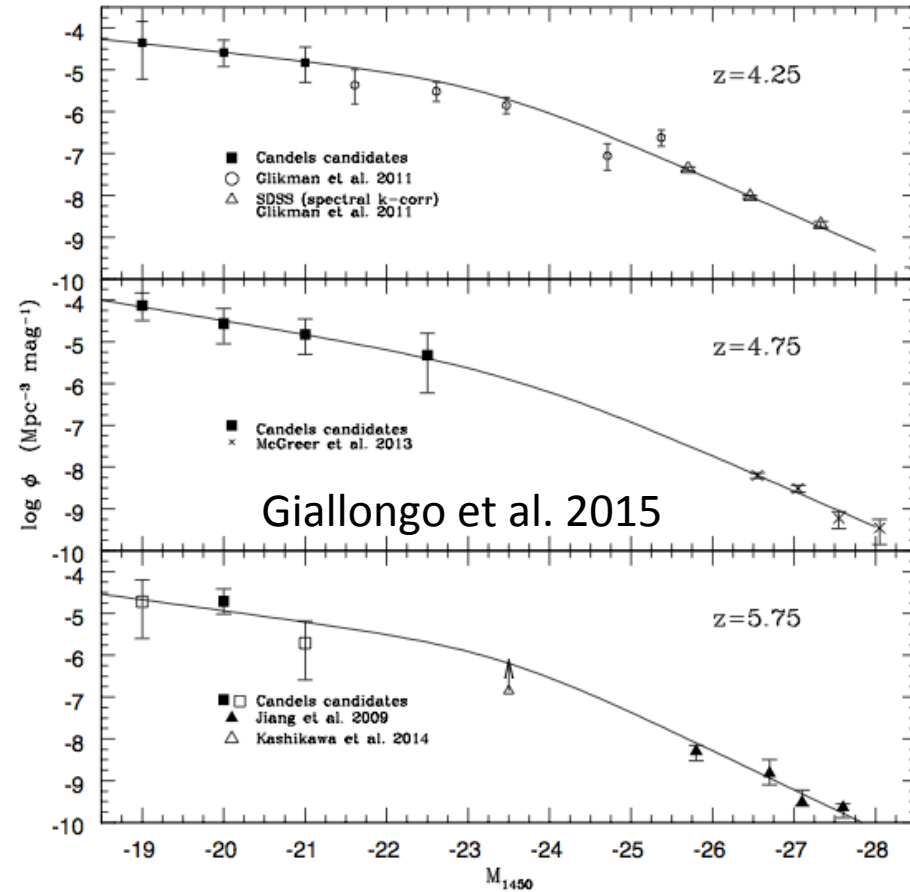
The sources of reionization

Galaxies as the main driver of reionization



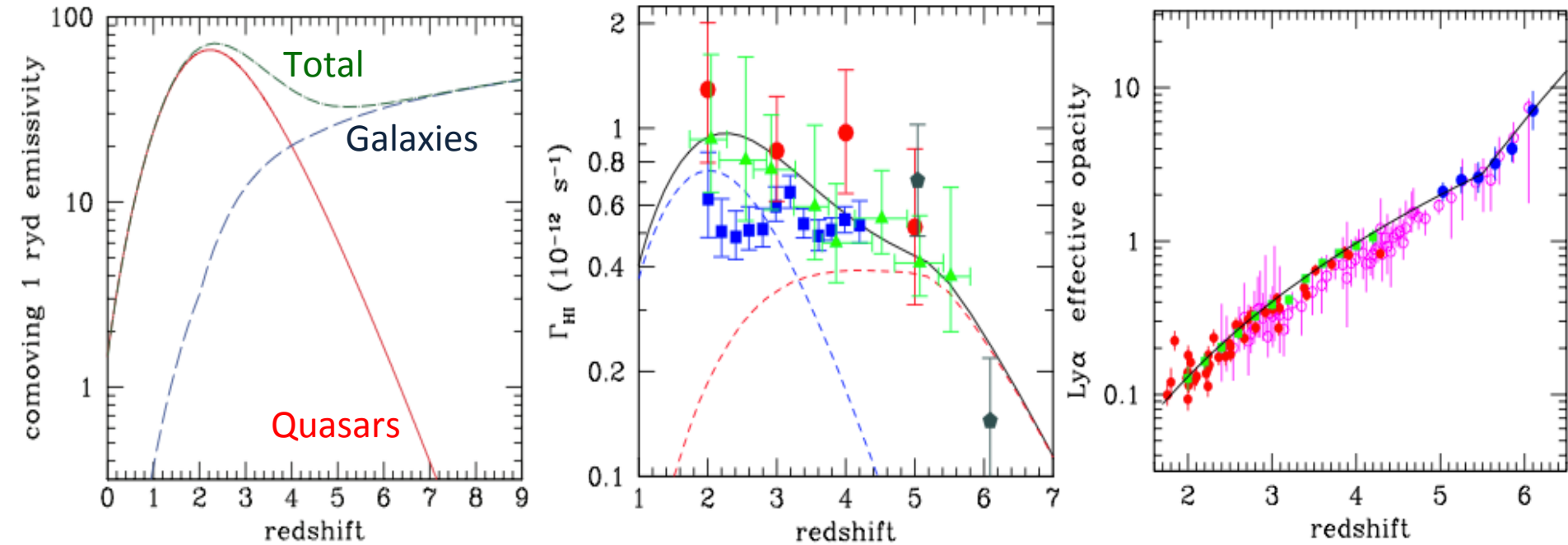
- Extrapolation of the LF at the faint end needed
- High escape fraction needed $> 10\%$
- Local measure : $<5\%$

The QSO luminosity function



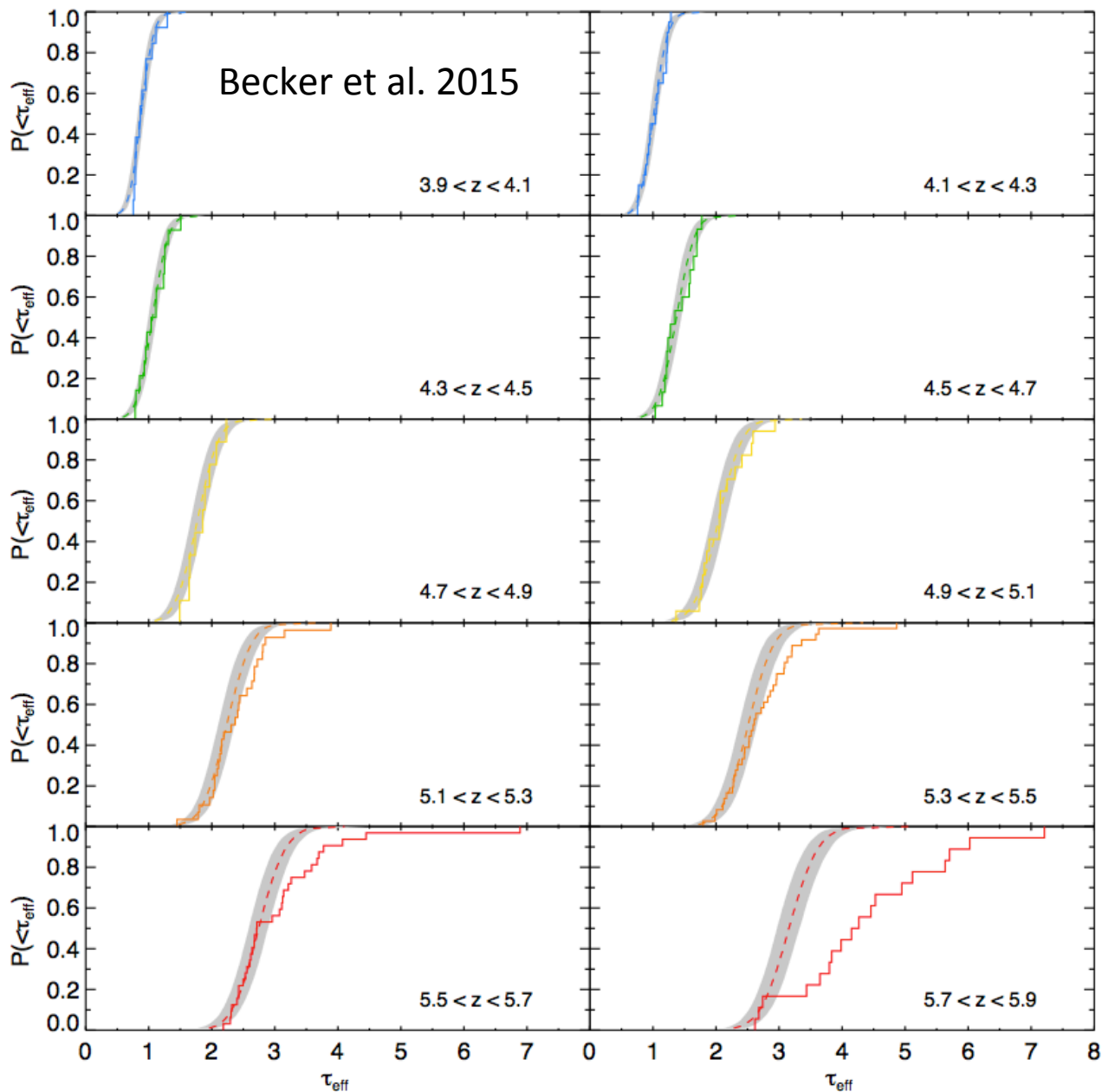
- L^* still poorly constrained

The benchmark



- Empirical emissivity of Haardt & Madau 2012
- Fit a lot of observational constraints

New Ly α forest data



PDF of the effective
optical depth in 50
Mpc/h chunks



Difficult to match at z
 $\sim 5.4 - 5.8$ with
uniform background
model



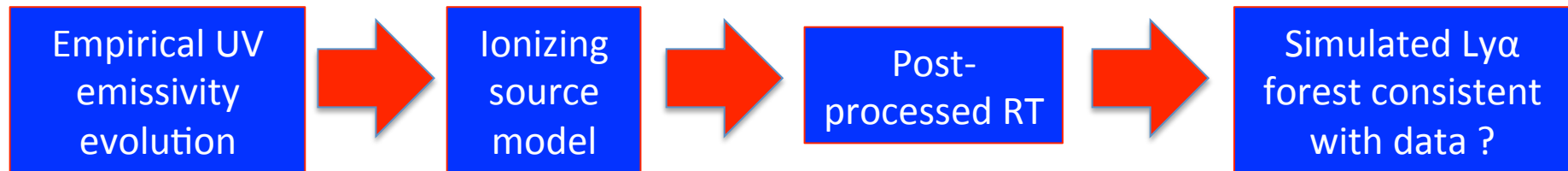
Still open to
interpretation

Our Approach

- Calibrating radiative transfer simulations to be consistent with post-reionization Ly α forest data

Methodology :

- Adjust the HM2012 emissivity evolution injected in RT numerical simulation in order to fit Ly α forest data



- What can we learn about the sources of reionization ?

The simulations

Nbody/hydro

- RAMSES 512³ (no refinement)
- UV background of Haardt & Madau 2012



Source model

- DM haloes
- Emissivity proportional to halo masses
- Total comoving emissivity scaled to the evolution of H&M2012

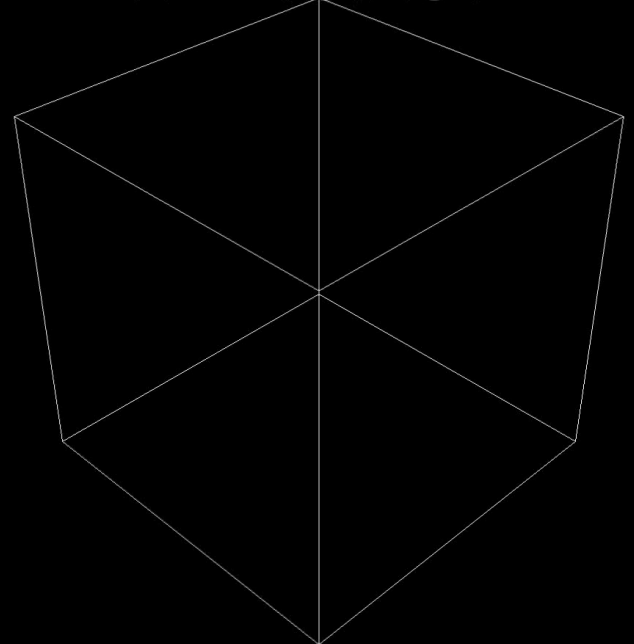


Radiative transfer

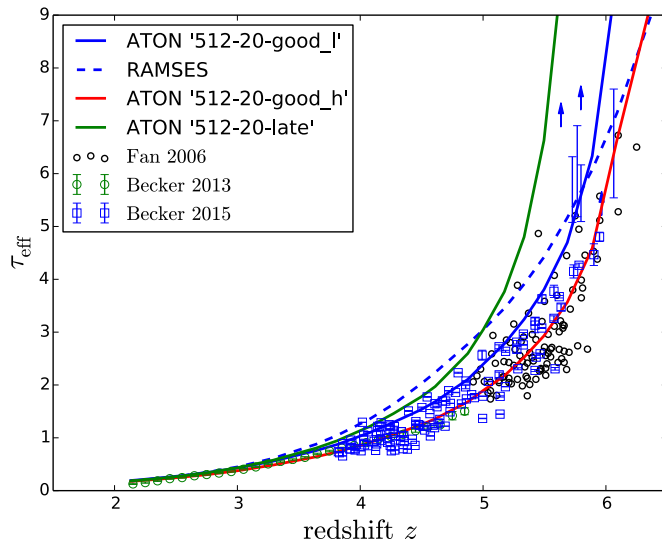
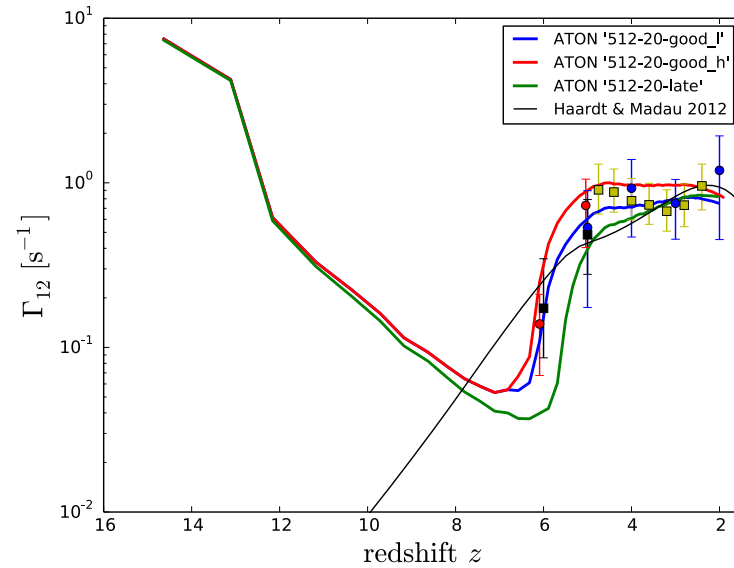
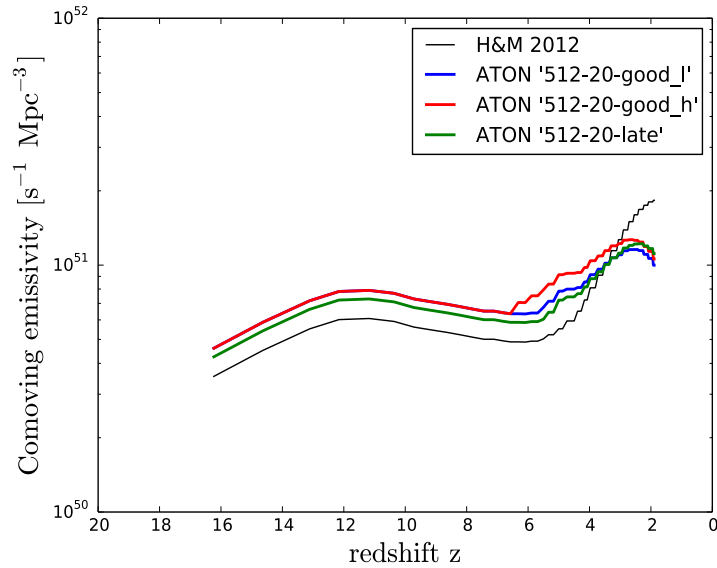
- ATON on GPU architecture
- Moment based method
- Monofrequency RT with $E=20.27$ eV



$z = 13.269$

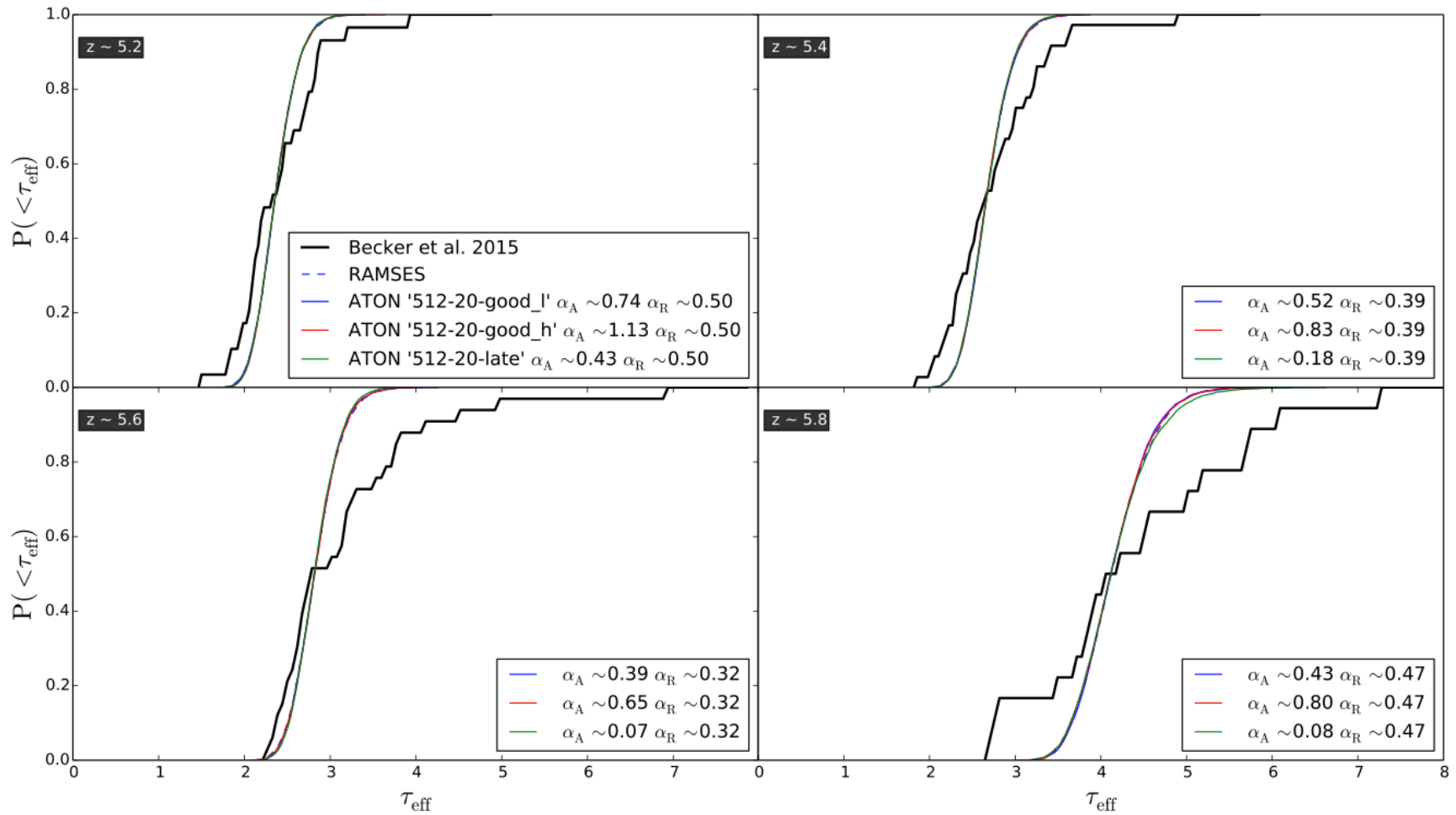


Main properties



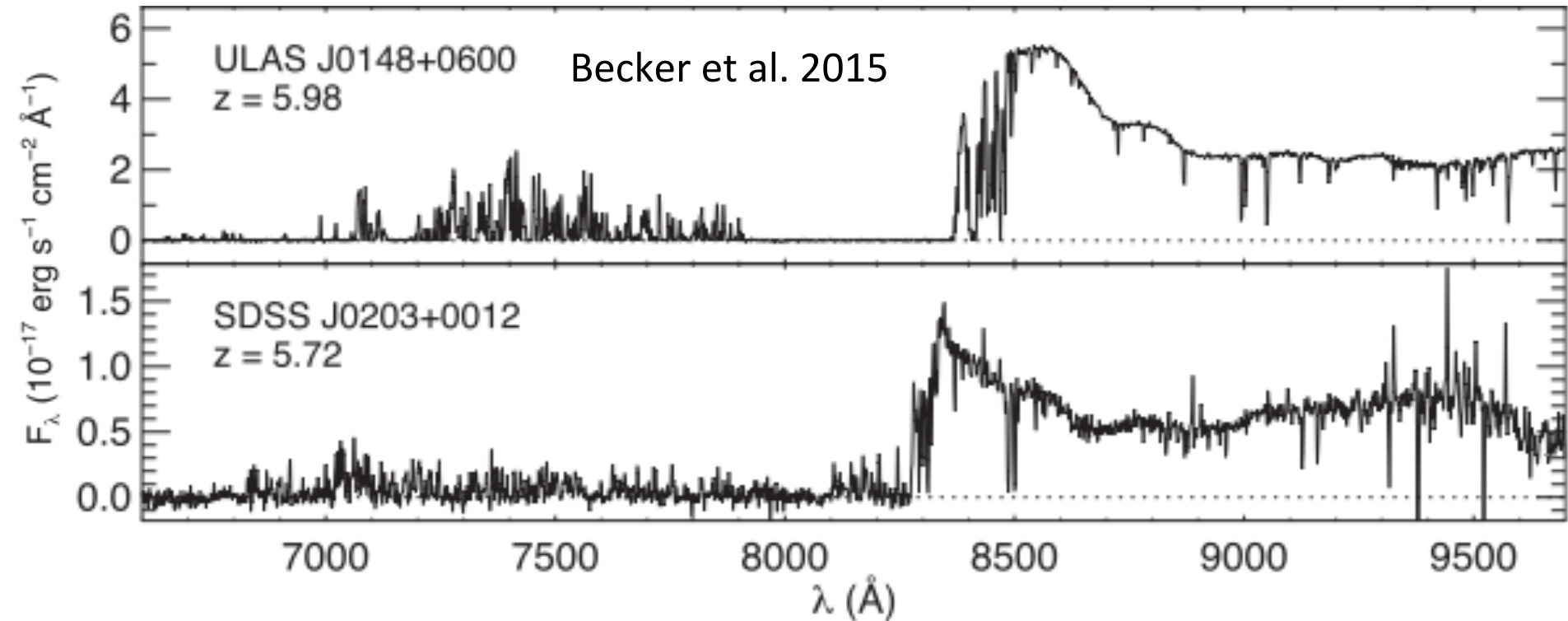
- Moderate rescaling of H&M needed
- Good fit of $\Gamma(z)$ and Ly α forest mean opacity with redshift
- Late reionization disfavored

The Ly α forest opacity PDF



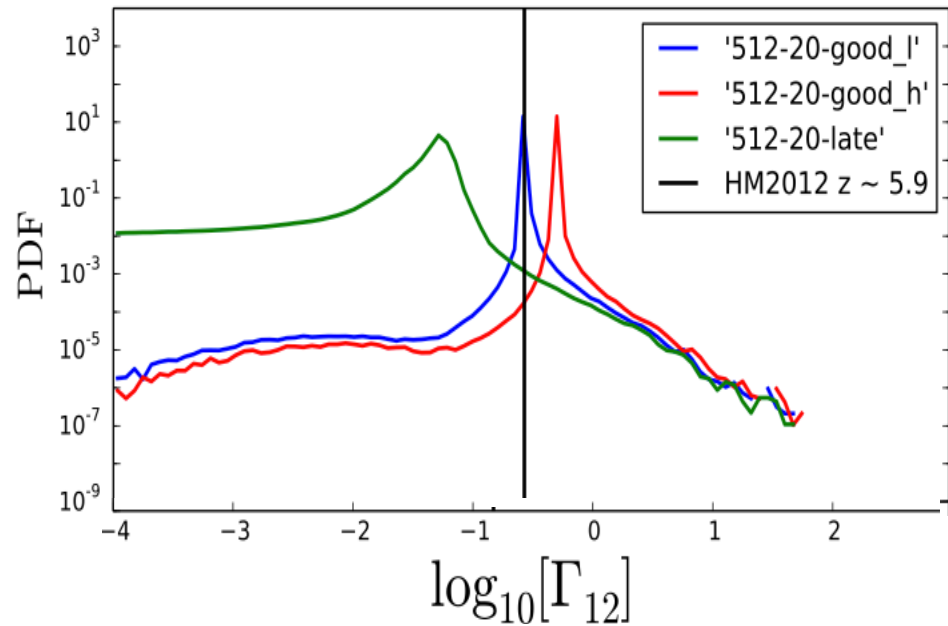
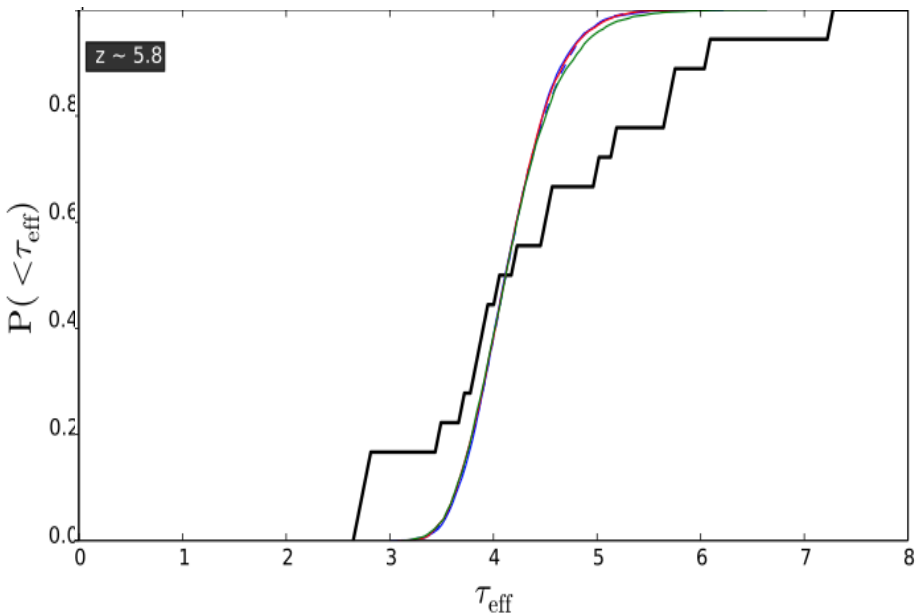
- RT effect not sufficient to explain the broad distribution

Opacity variation in the Ly α forest



- Spectra to spectra variations after overlap on large scales
- What can be the cause of these variations ?

A model of the UVB with QSOs and galaxies



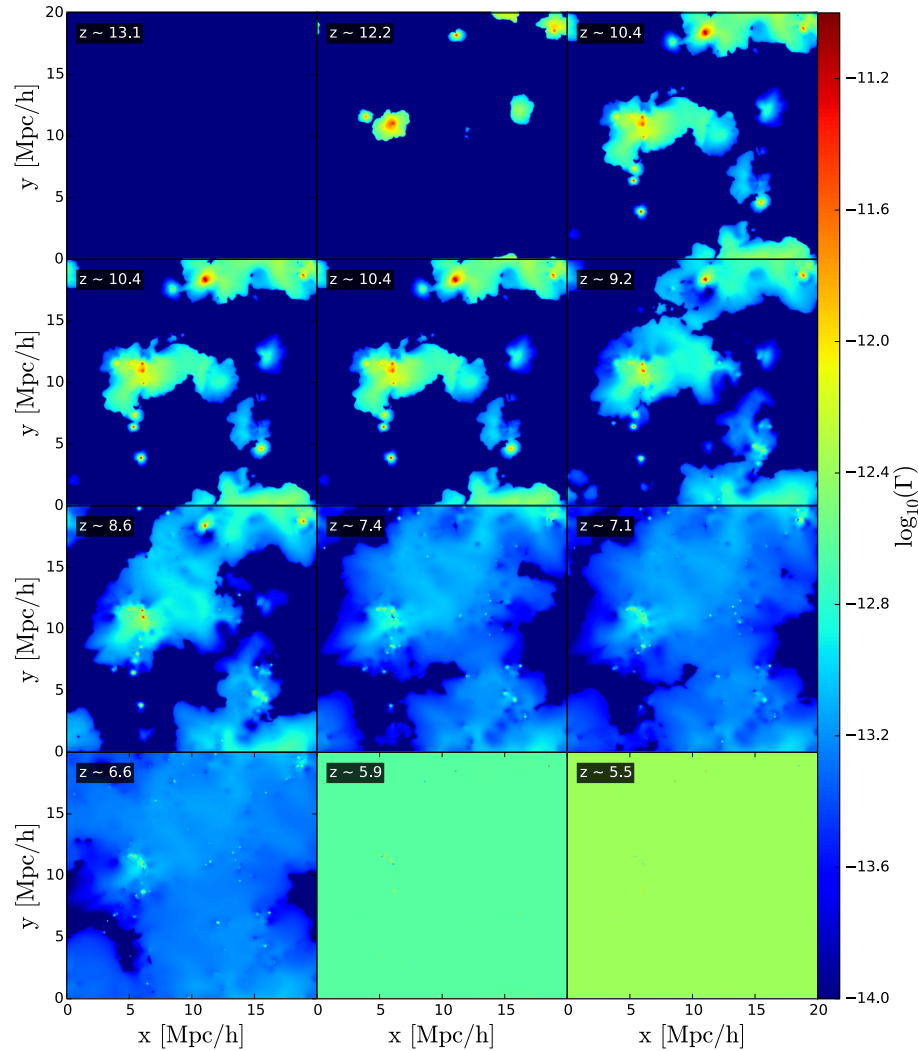
Opacity and Γ PDF very peaked after overlap



Testing whether large scale Γ fluctuations due to QSOs can explain the opacity variation from spectra to spectra in the Ly α forest at the tail end of reionization

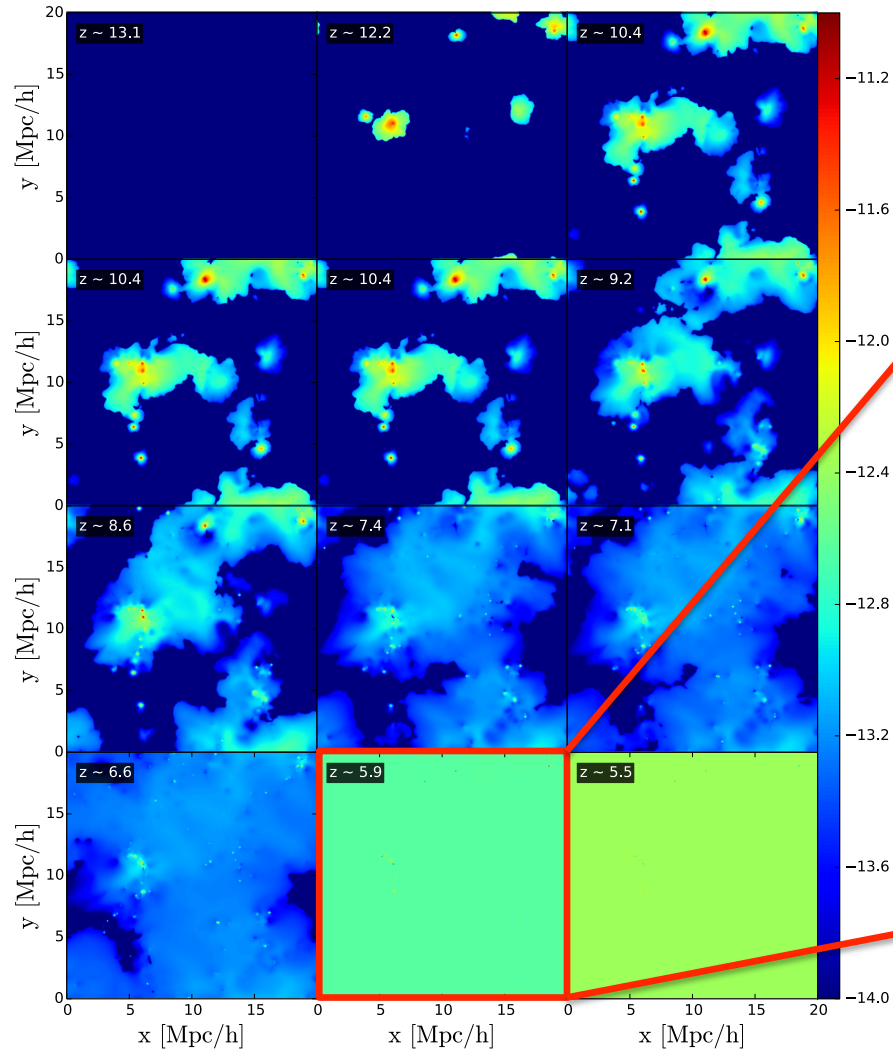
Constructing the model

The photoionization rate in the RT simulation

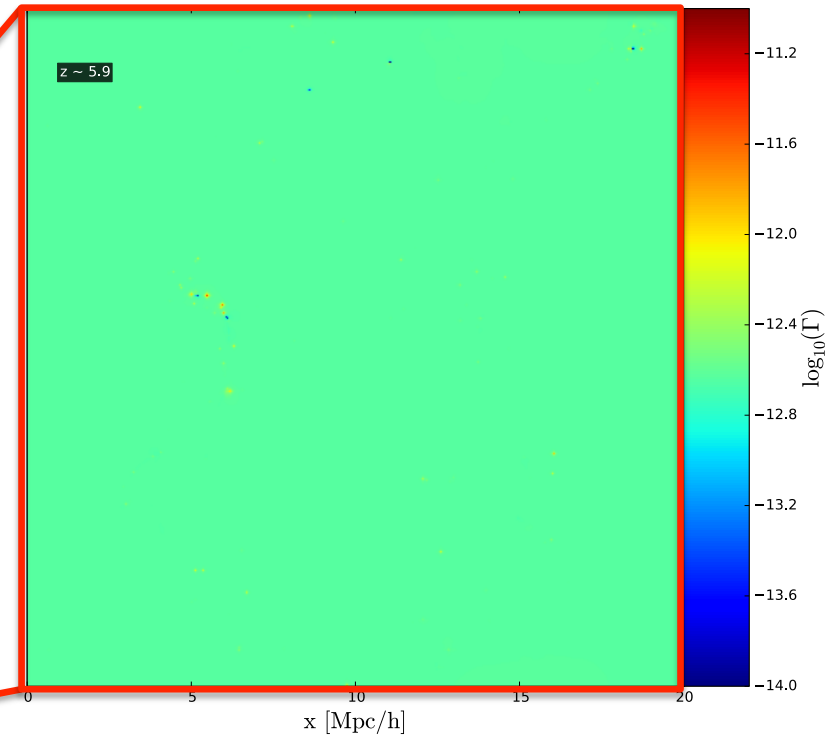


Constructing the model

The photoionization rate in the RT simulation

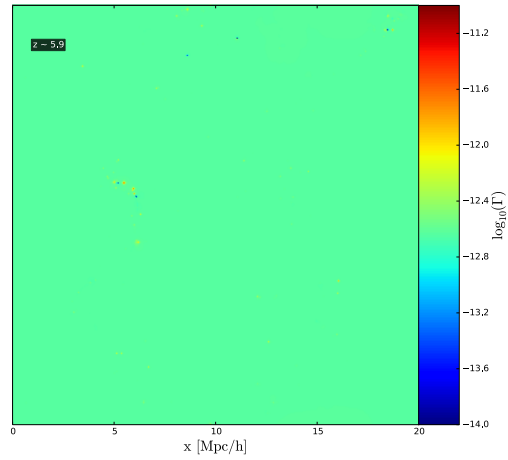


Uniform UVB after overlap



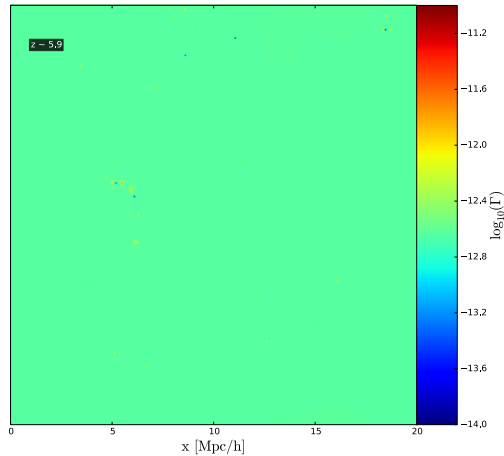
Constructing the model

Galaxies



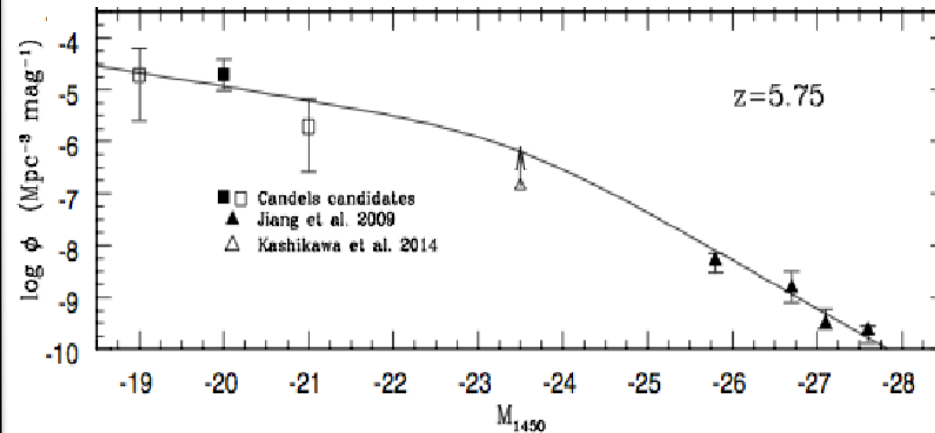
Constructing the model

Galaxies



QSOs

Abundance match the QSOs LF of Giallongo et al. 2015 in the Millenium volume



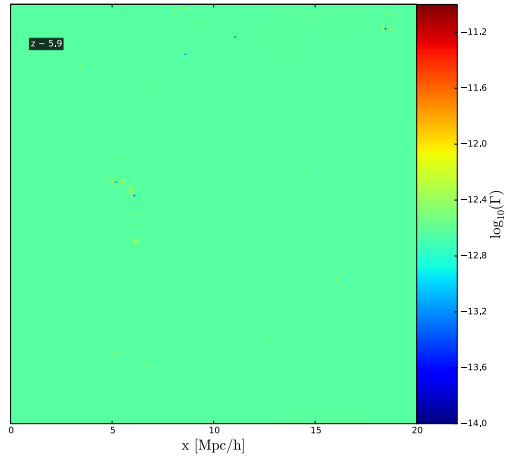
Choose a mean free path for ionizing photons and a QSO SED



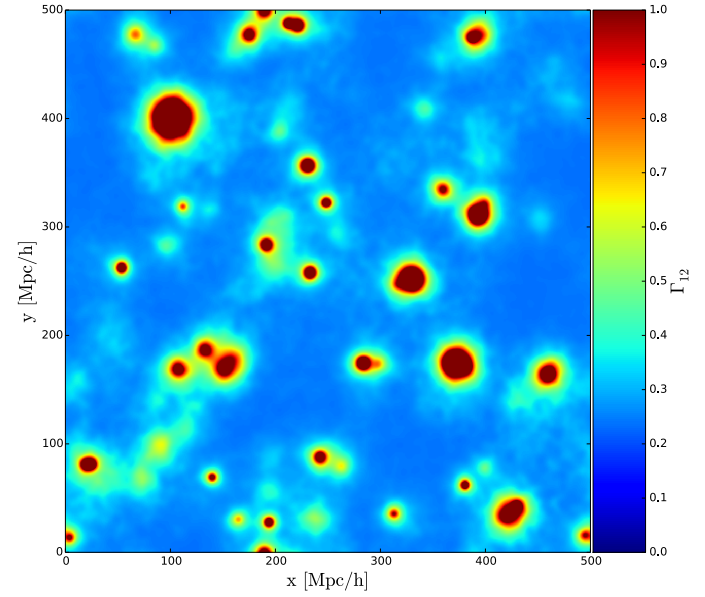
Calculation of Γ QSOs

Constructing the model

Galaxies

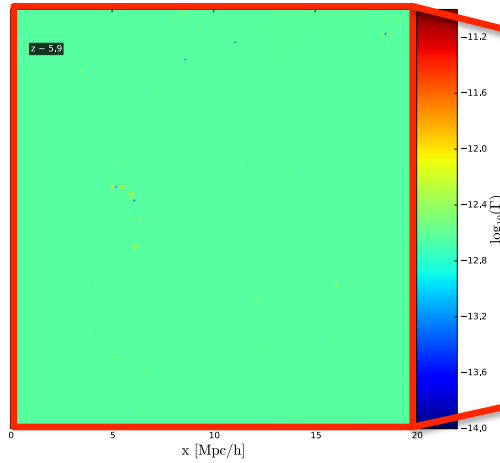


QSOs



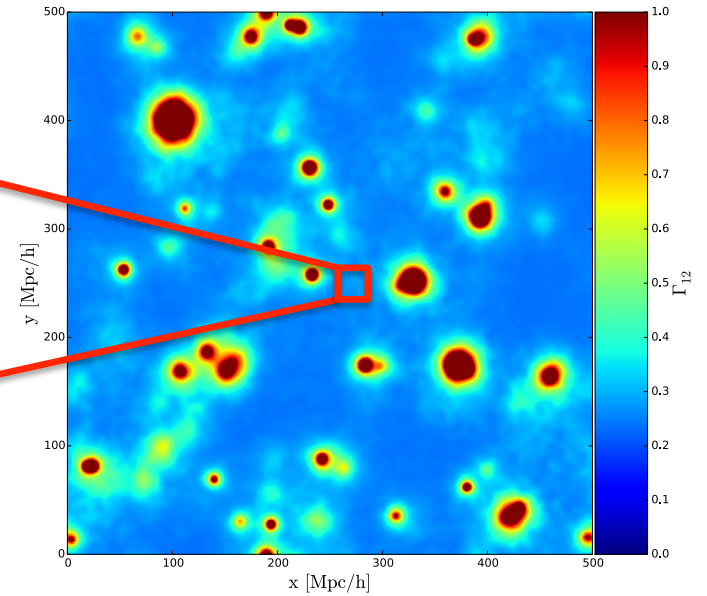
Constructing the model

Galaxies



Small scale Γ

QSOs

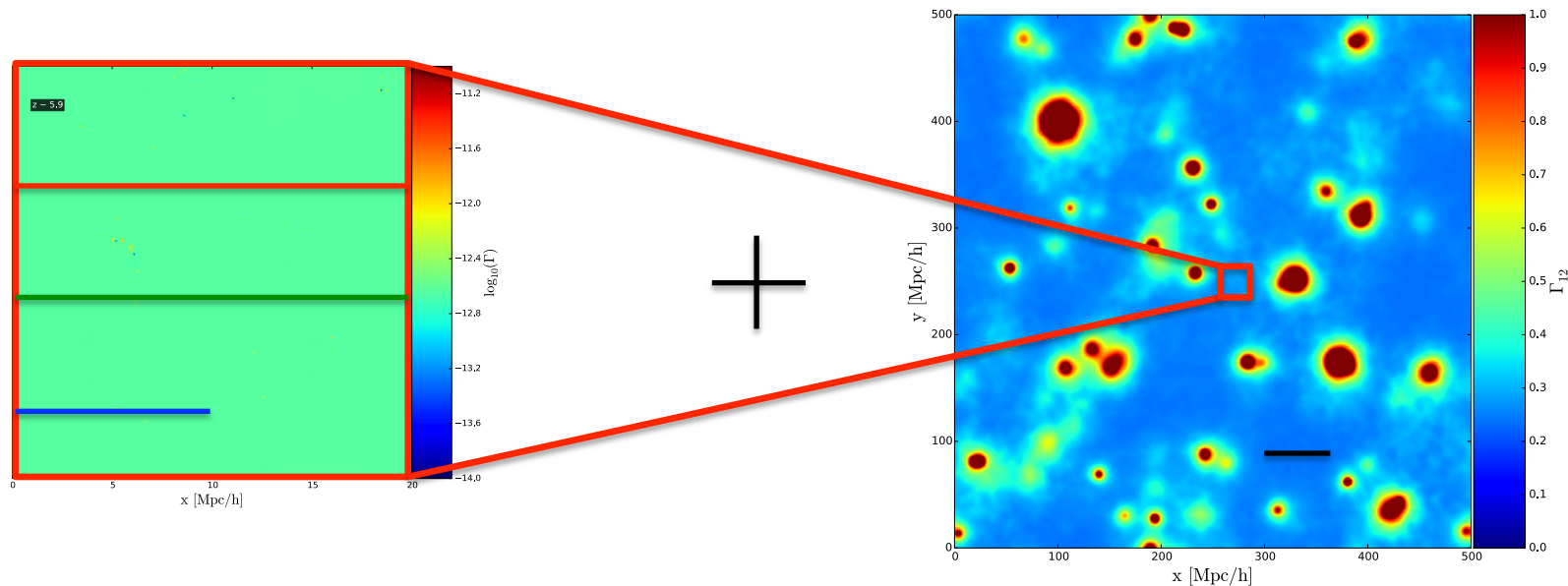


Large scale Γ

Constructing the model

Galaxies

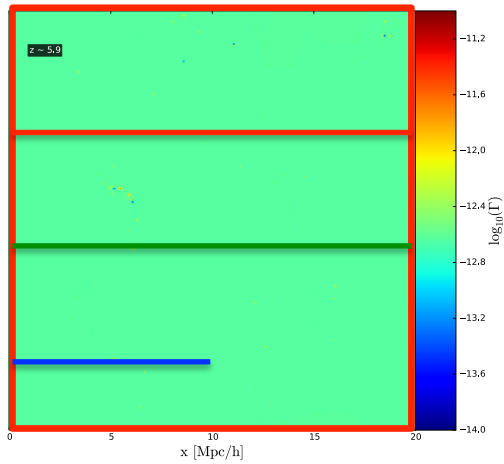
QSOs



Total Γ over one line of sight of 50 Mpc/h

$$\beta_{\text{gal}} \times \left[\begin{array}{|c|c|c|c|} \hline & & & \\ \hline \end{array} \right] + \left[\begin{array}{|c|c|c|c|} \hline & & & \\ \hline \end{array} \right] + \left[\begin{array}{|c|c|} \hline & \\ \hline \end{array} \right] + \beta_{\text{QSO}} \times \left[\begin{array}{|c|c|c|c|c|c|c|c|} \hline & & & & & & & & \\ \hline \end{array} \right] = \left[\begin{array}{|c|c|c|c|c|c|c|c|} \hline & & & & & & & \\ \hline \end{array} \right]$$

Constructing the model



density



Temperature



velocity



Total Γ QSO
+ galaxies



Ionization Equilibrium

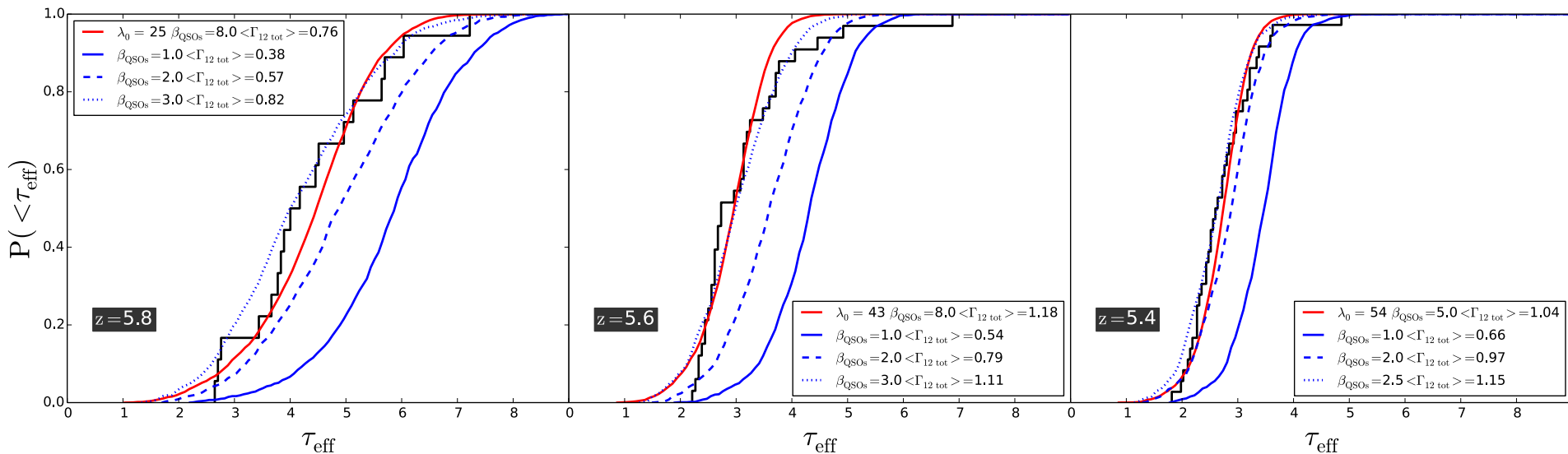


Ionization
fraction



$\text{Ly}\alpha$ forest
opacity τ

A Γ dependant mean free path model



Davies and Furlanetto 2015.

$$\lambda_{mfp}(\Gamma) = \lambda_0 (\Gamma / \Gamma_0)^{2/3} \Delta^{-1}$$

Iterative scheme

Moderate rescaling of the QSO LF to match the data at all redshift

Caveats

- No light beam effects
- No light travel effects
- Duty cycle of QSOs
- Photoheating due to QSOs

Conclusion

- UVB fluctuation due to QSOs during reionization could explain the broad distribution of opacity in the high redshift Ly α forest.
- A moderate rescaling of the QSO LF is needed in our best model compared to the most recent observational fit
- There is room for a significant number of L* QSOs that are potentially still undetected
- Upcoming observations would clarify this point
- Future high resolution simulations with QSOs and galaxy have to be undertaken to explore this idea