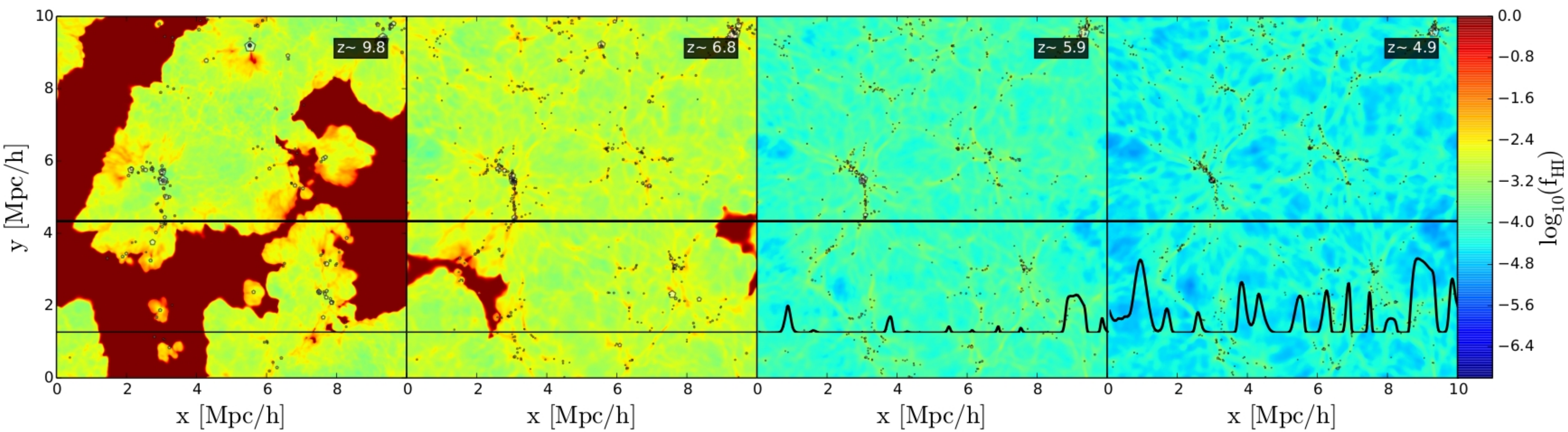
Large scale opacity fluctuations in the Lyman alpha forest : Does the QSOs dominate the UVB at z=5.5-6 ?

arXiv:1606.08231

Jonathan Chardin with Martin Haehnelt and Ewald Puchwein



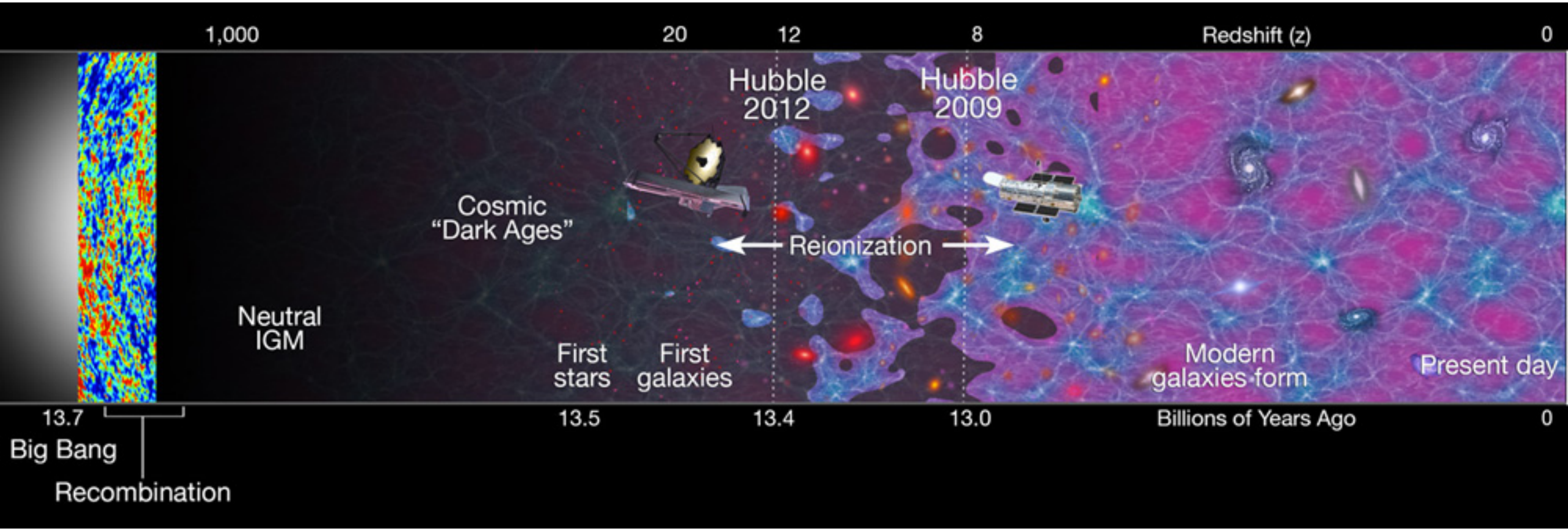
RUM 2016

Paris 07/10/2016

Outline

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

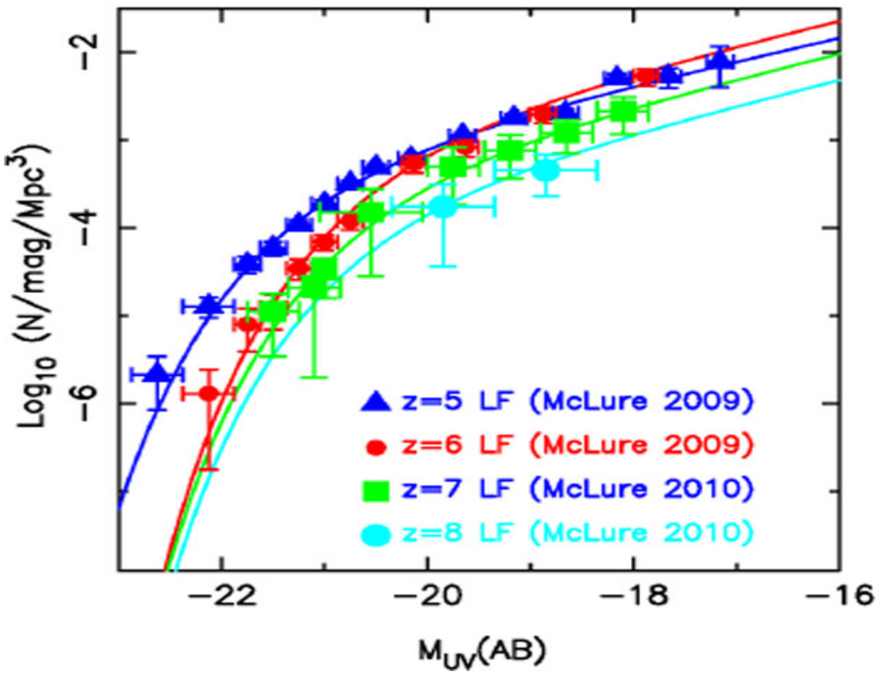
The epoch of Hydrogen reionization



- **First billion years of the Universe : from z ~ 20 (?) until z ~ 6**
- **Hydrogen is ionized by the first sources emitting UV radiation**
- **Competition between ionizing source and sinks of ionizing photons**

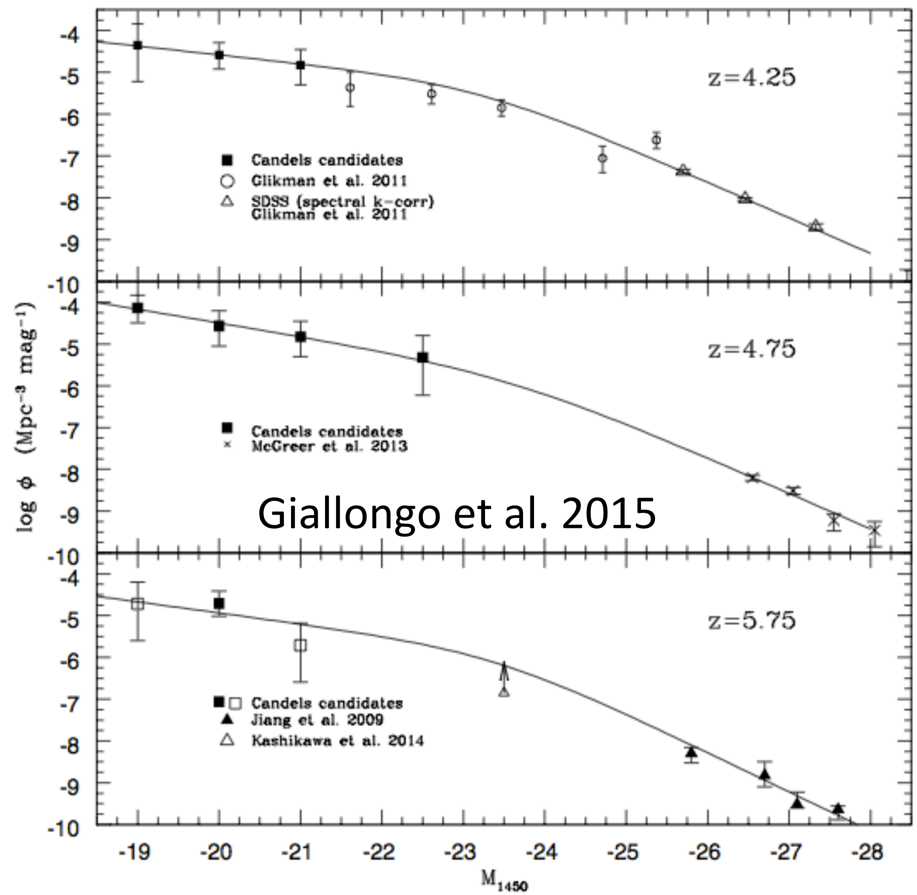
The sources of reionization

Galaxies as the main driver of reionization



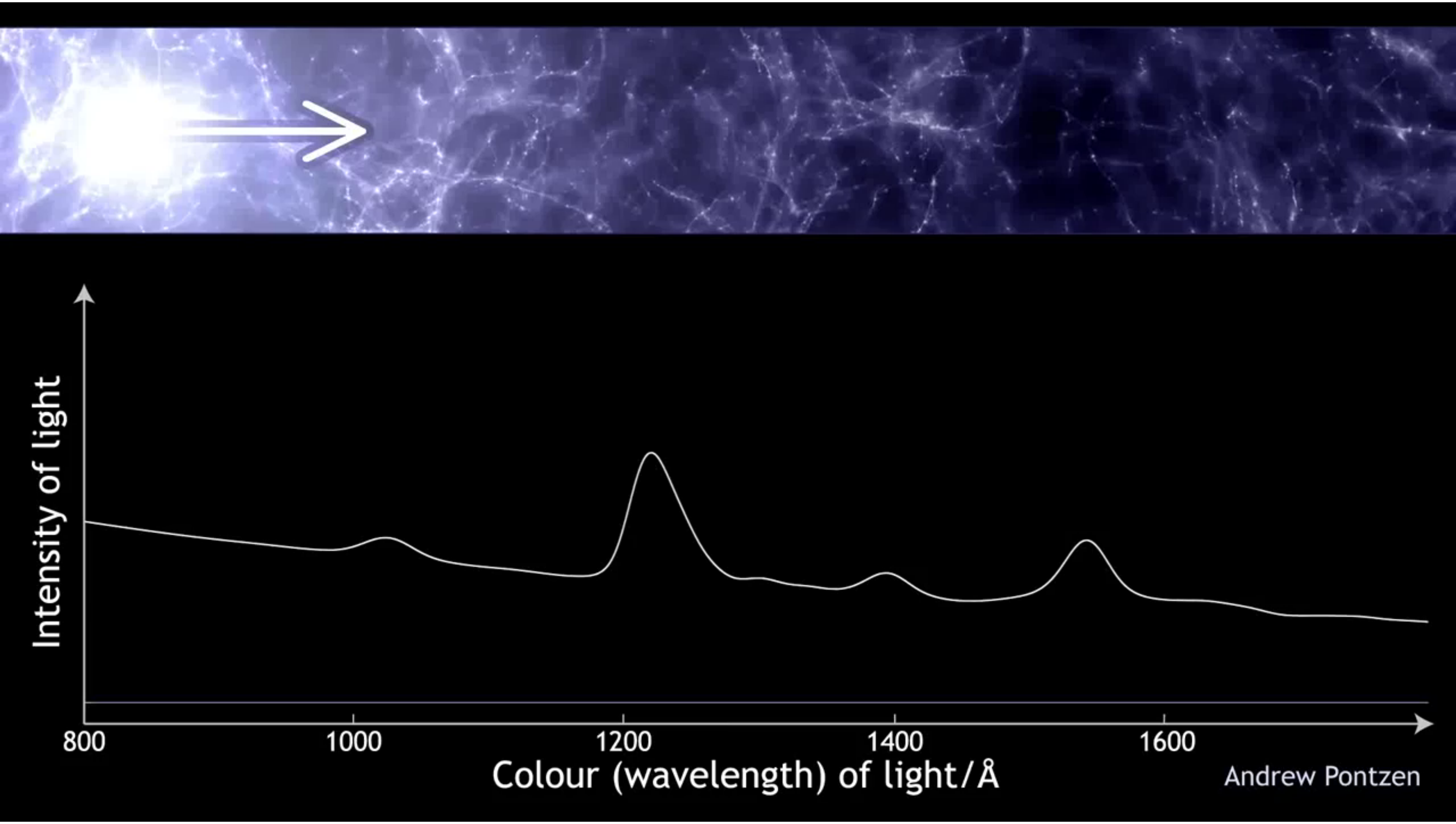
- Extrapolation of the LF at the faint end needed
- High escape fraction needed > 10%
- Local measure : <5%

The QSO luminosity function

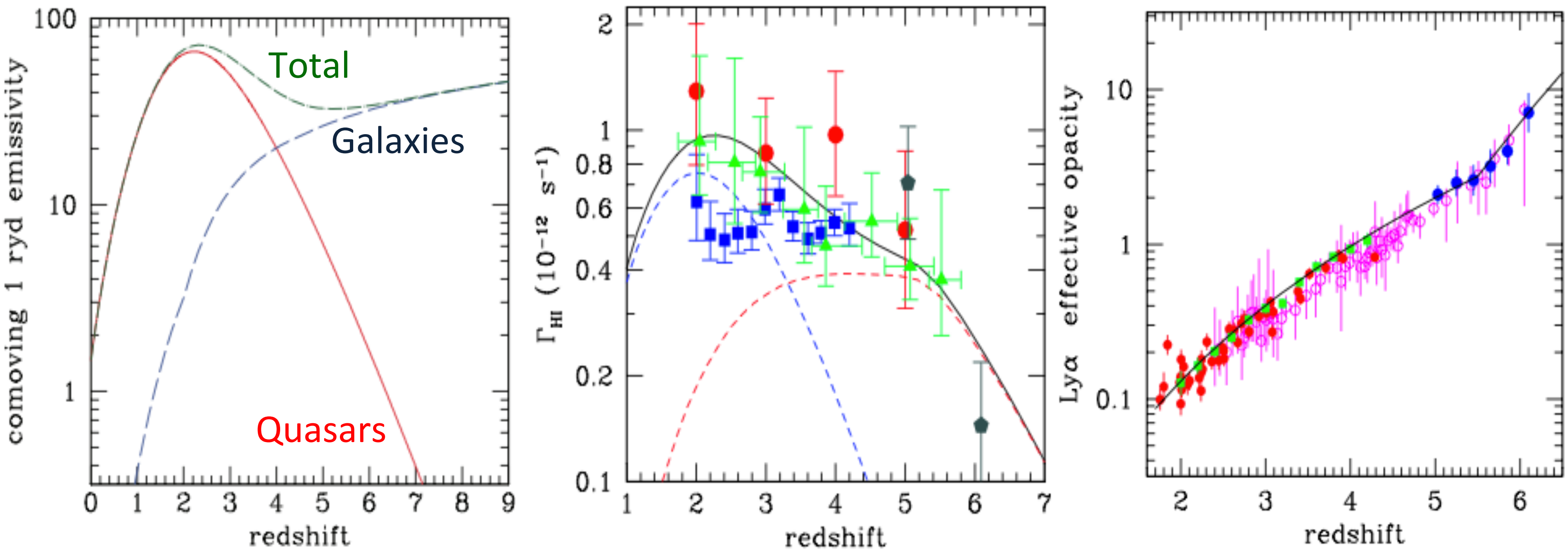


- L* still poorly constrained

The Lyman alpha forest

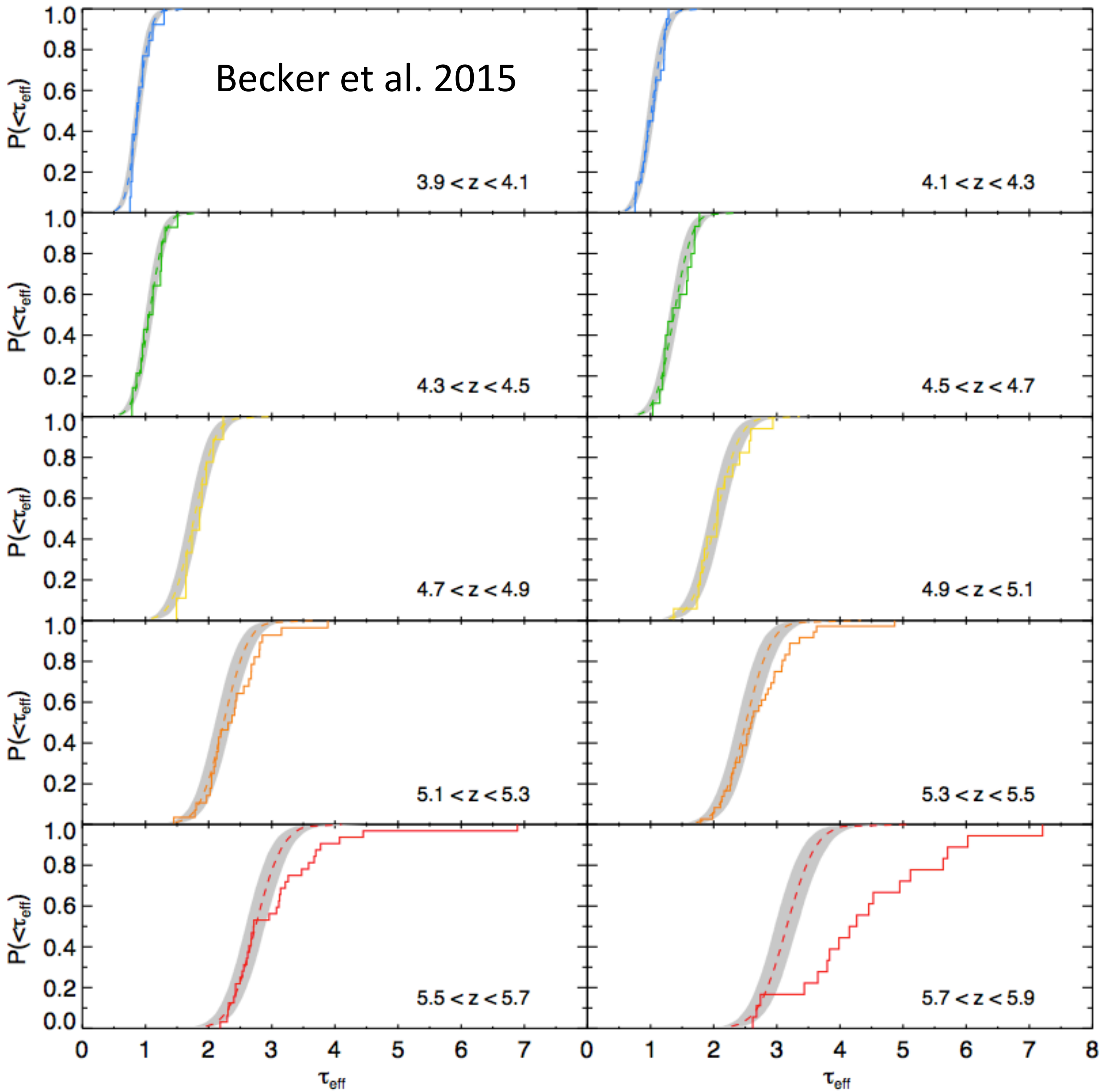


The benchmark



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

New Lyα forest data



PDF of the effective optical depth teff=-ln(<F>) in 50 Mpc/h chuncks

Difficult to match at z ~ 5.4 – 5.8 with uniform background model

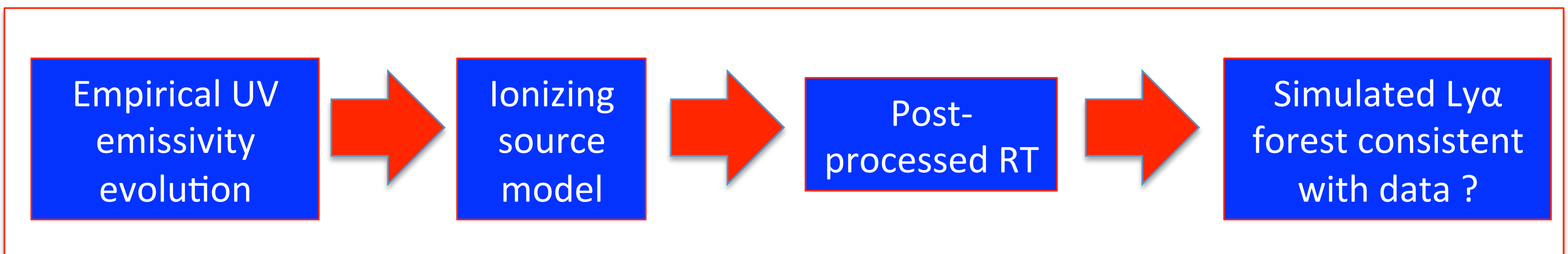
Still open to interpretation

Our Approach

- **Calibrating radiative transfer simulations to be consistent with post-reionization Lyα forest data**

Methodology :

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



- **What can we learn about the sources of reionization ?**

The simulations

Nbody/hydro

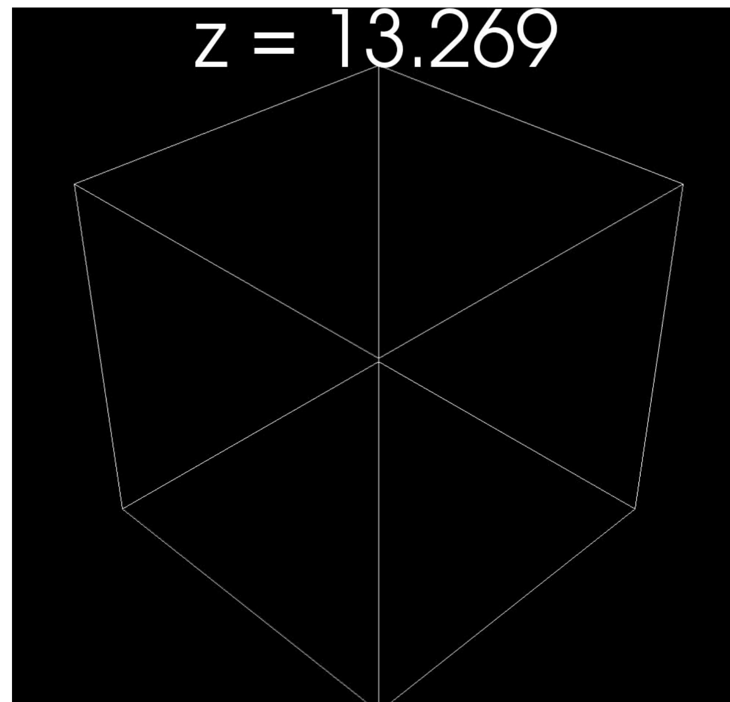
- RAMSES 512^3 (no refinement)
- UV background of Haardt & Madau 2012

Source model

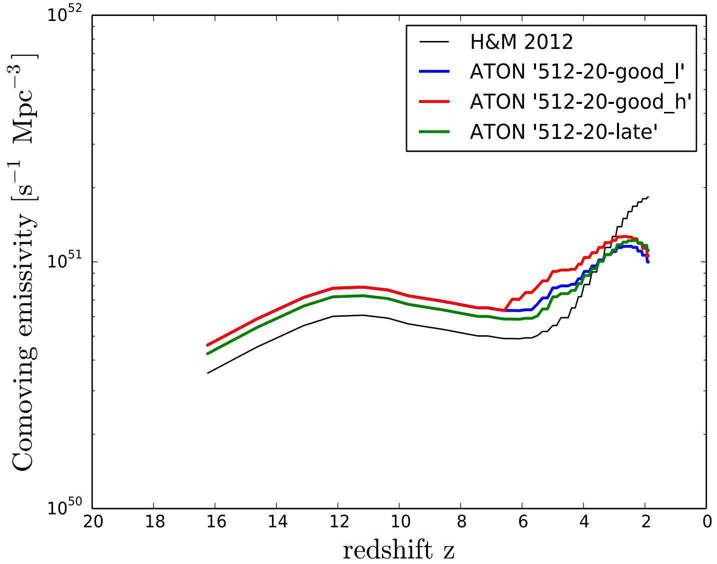
- DM haloes
- Emissivity proportional to halo masses
- Total comoving emissivity scaled to the evolution of H&M2012

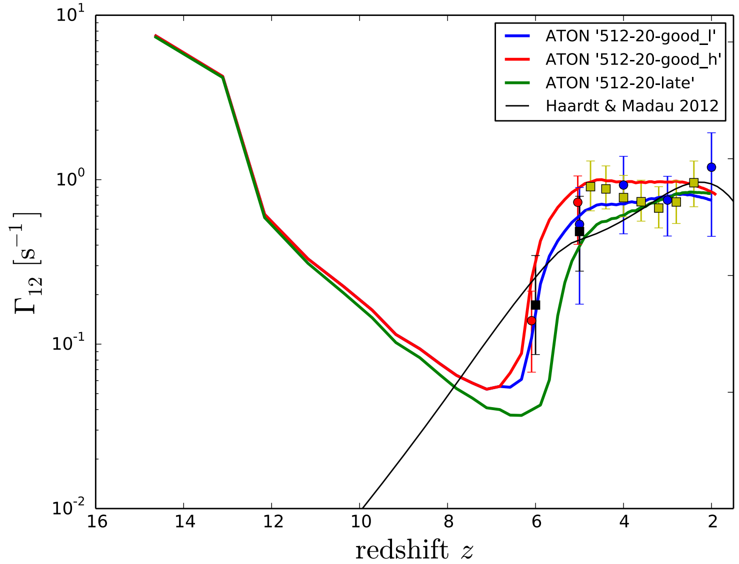
Radiative transfer

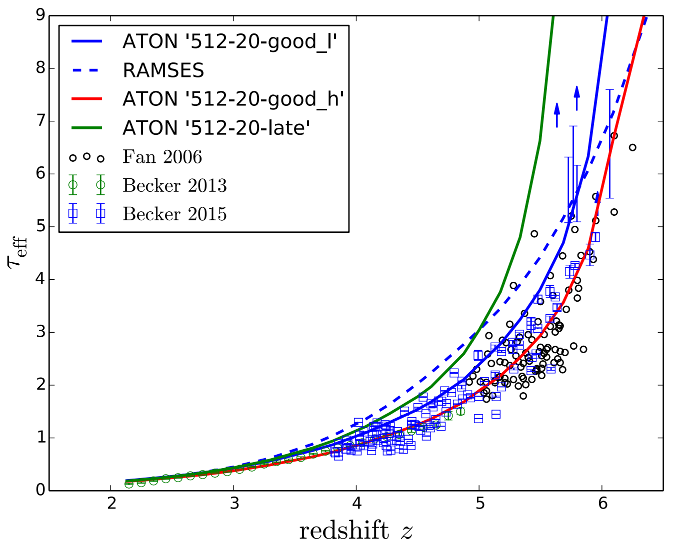
- ATON on GPU architecture
- Moment based method
- Monofrequency RT with E=20.27 ev



Main properties

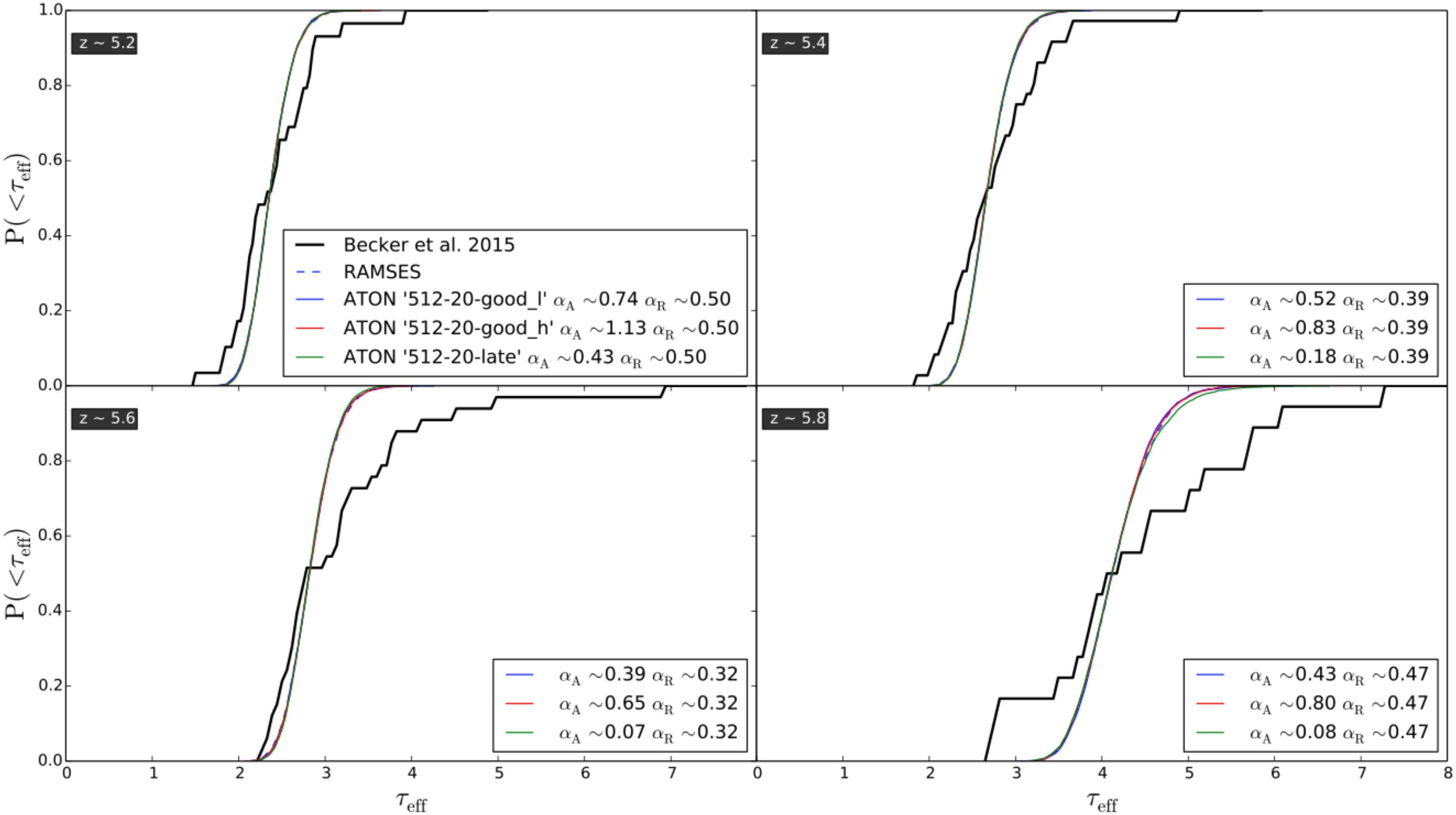






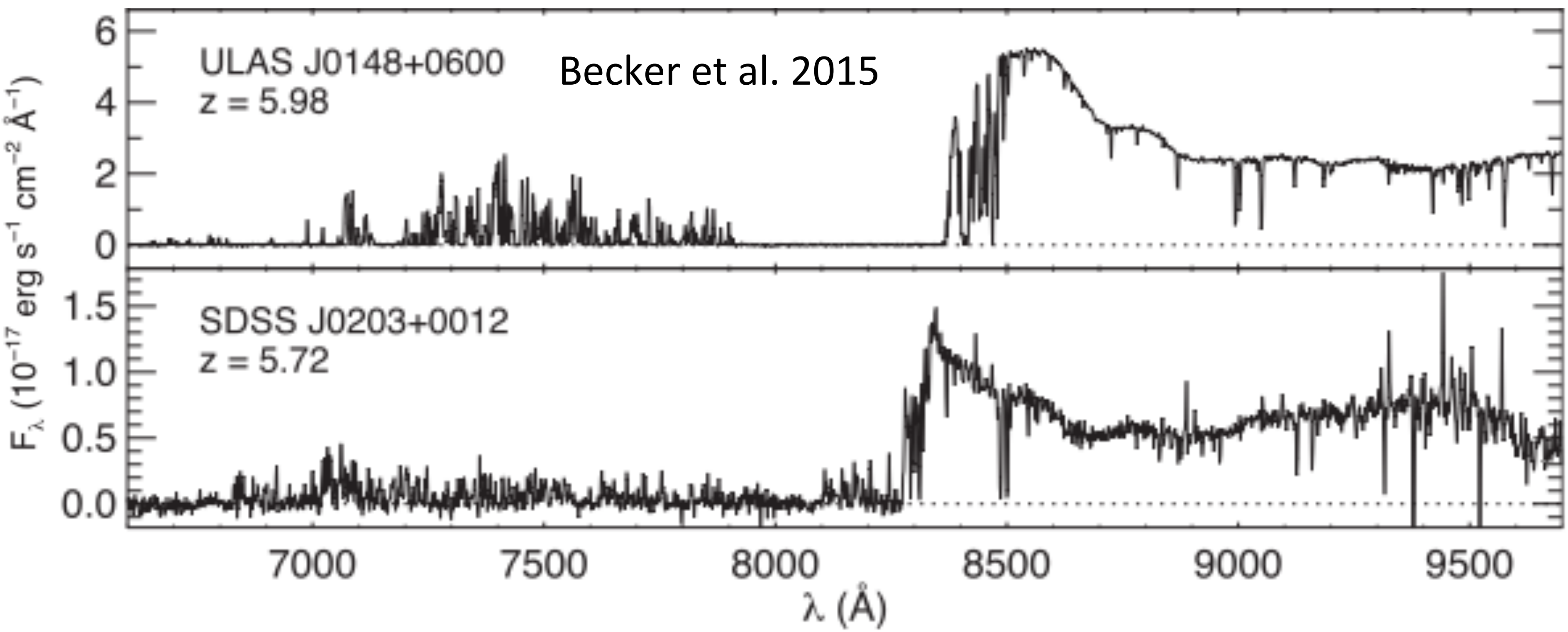
- Moderate rescaling of H&M needed
- Good fit of Γ(z) and Lyα forest mean opacity with redshift
- Late reionization disfavored

The lyα forest opacity PDF



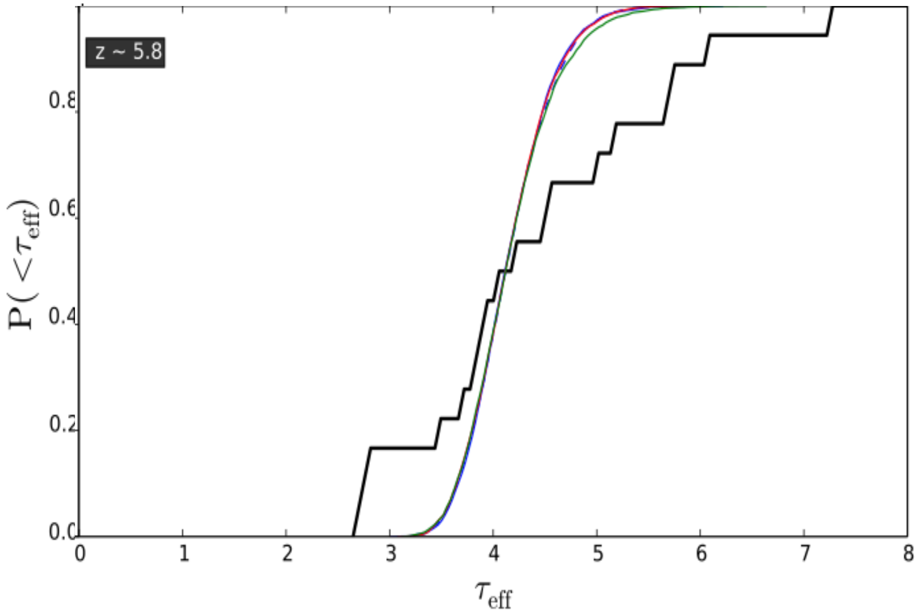
- RT effect not sufficient to explain the broad distribution

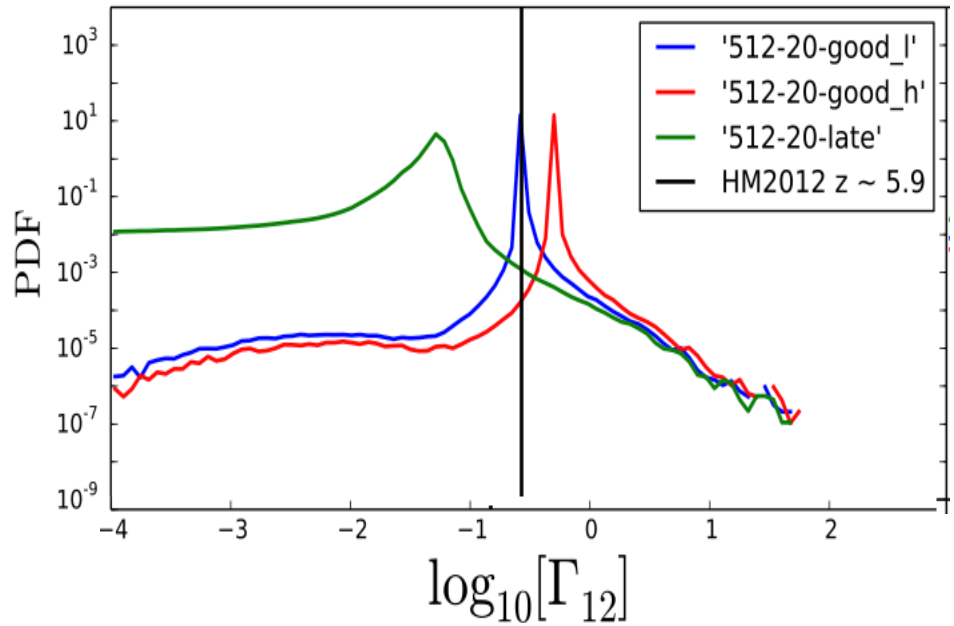
Opacity variation in the Lyα forest



- **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



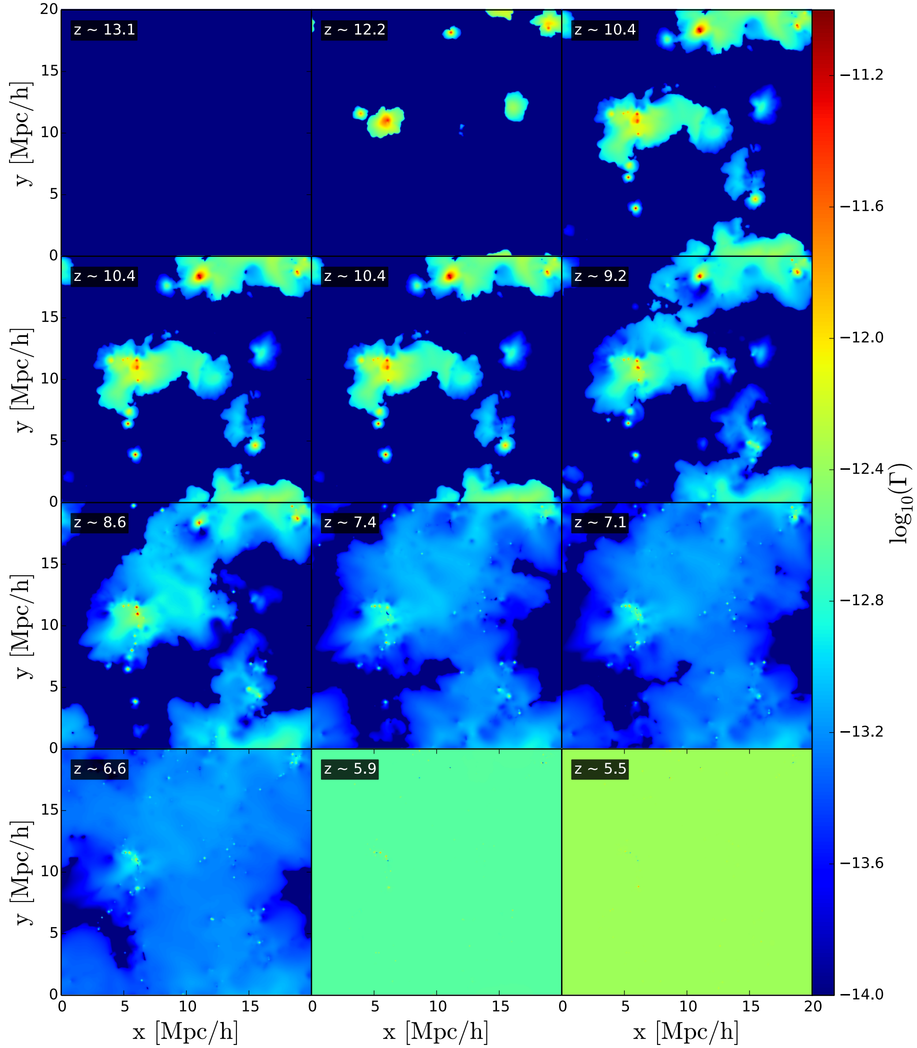


Opacity and Γ PDF very peaked after overlap

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

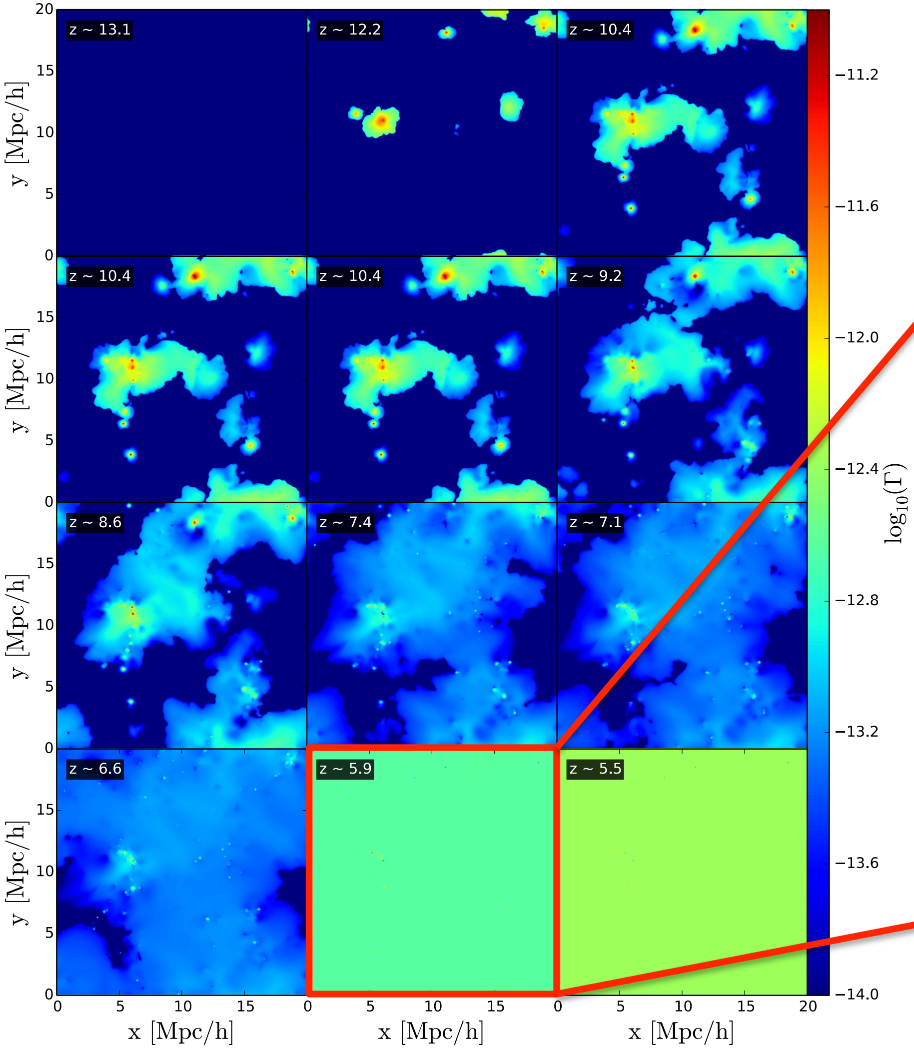
Constructing the model

The photoionization rate in the RT simulation

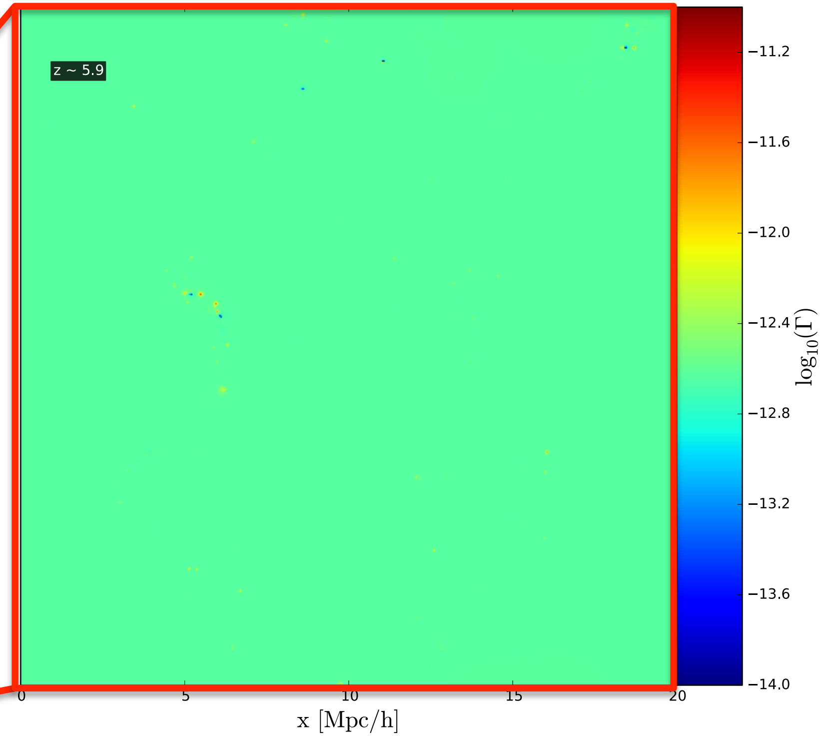


Constructing the model

The photoionization rate in the RT simulation

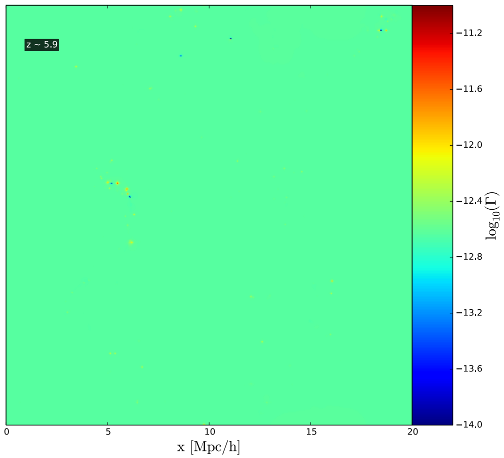


Uniform UVB after overlap



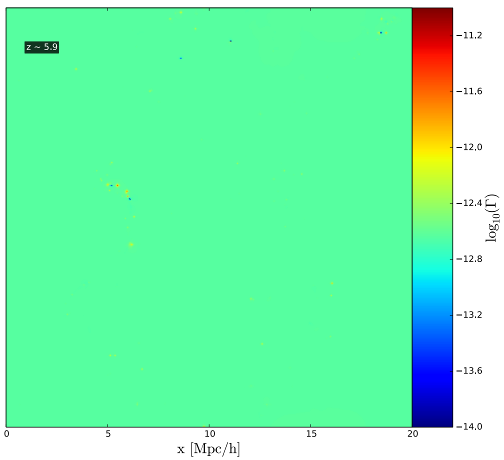
Constructing the model

Galaxies



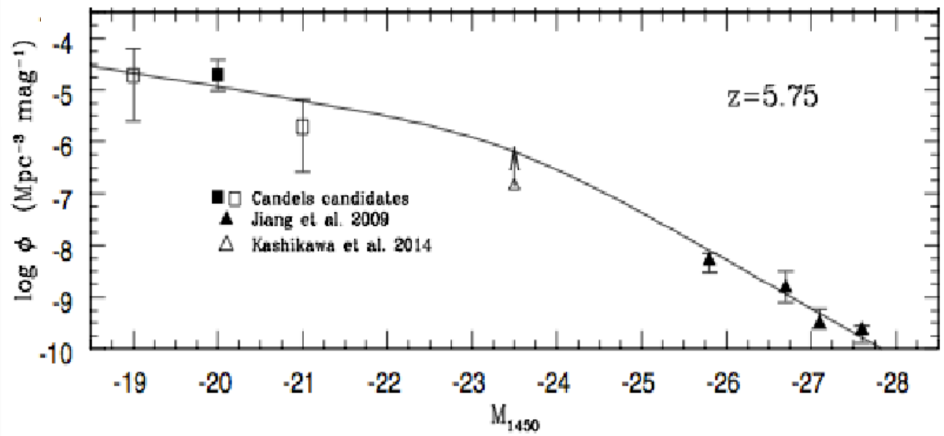
Constructing the model

Galaxies



QSOs

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

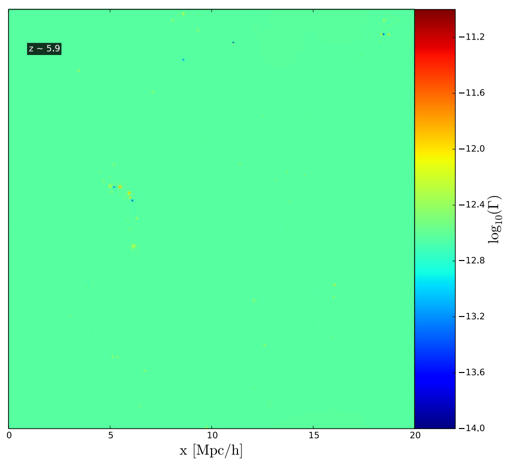


Choose a mean free path for ionizing photons and a QSO SED

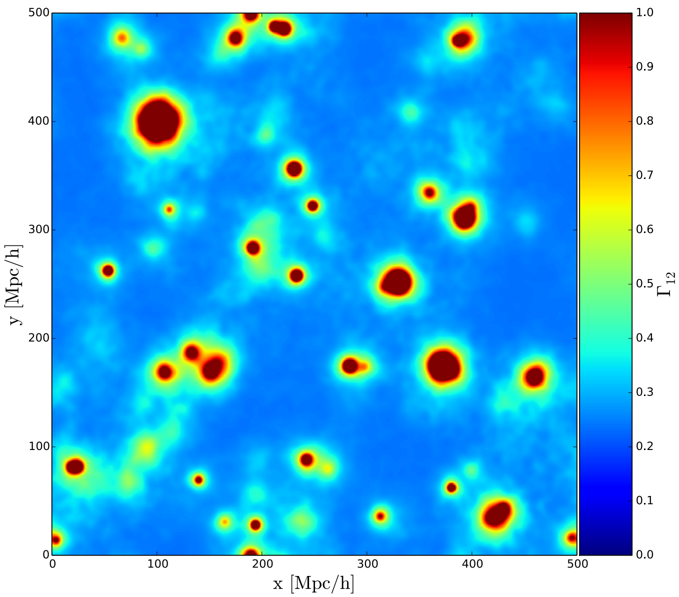
Calculation of Γ QSOs

Constructing the model

Galaxies

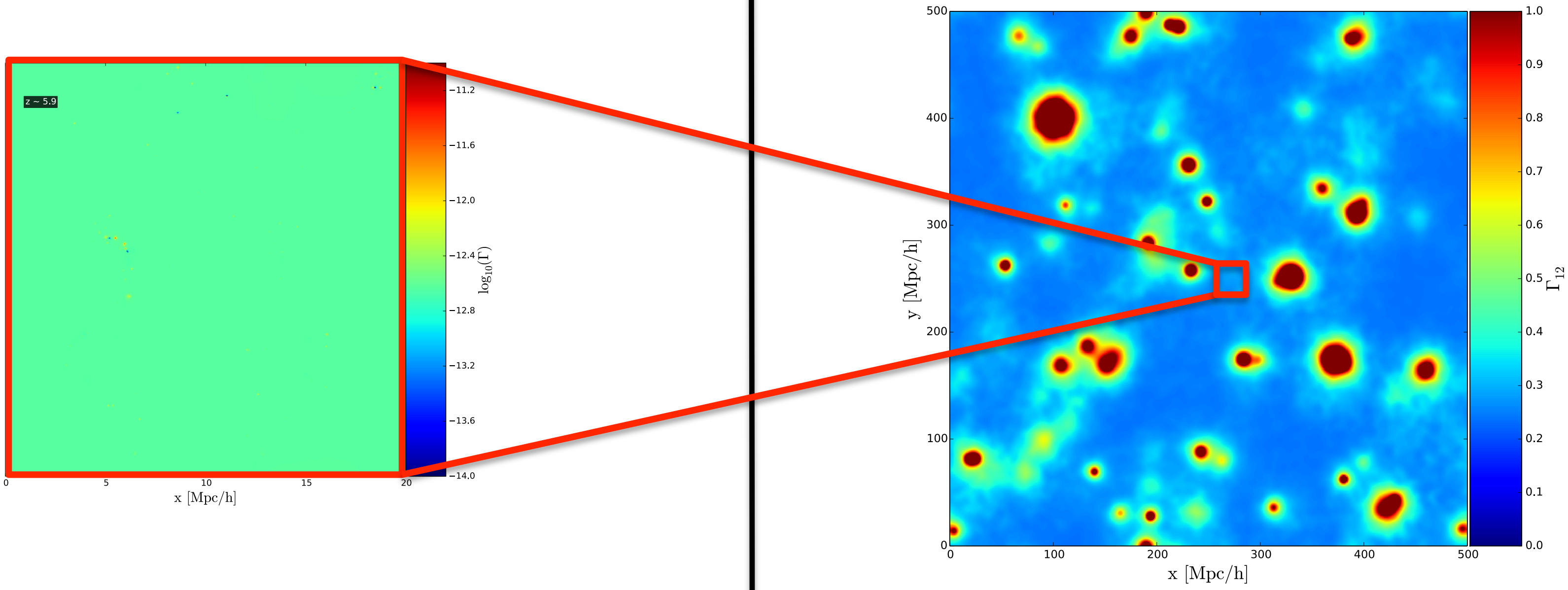


QSOs



Constructing the model

Galaxies | **QSOs**

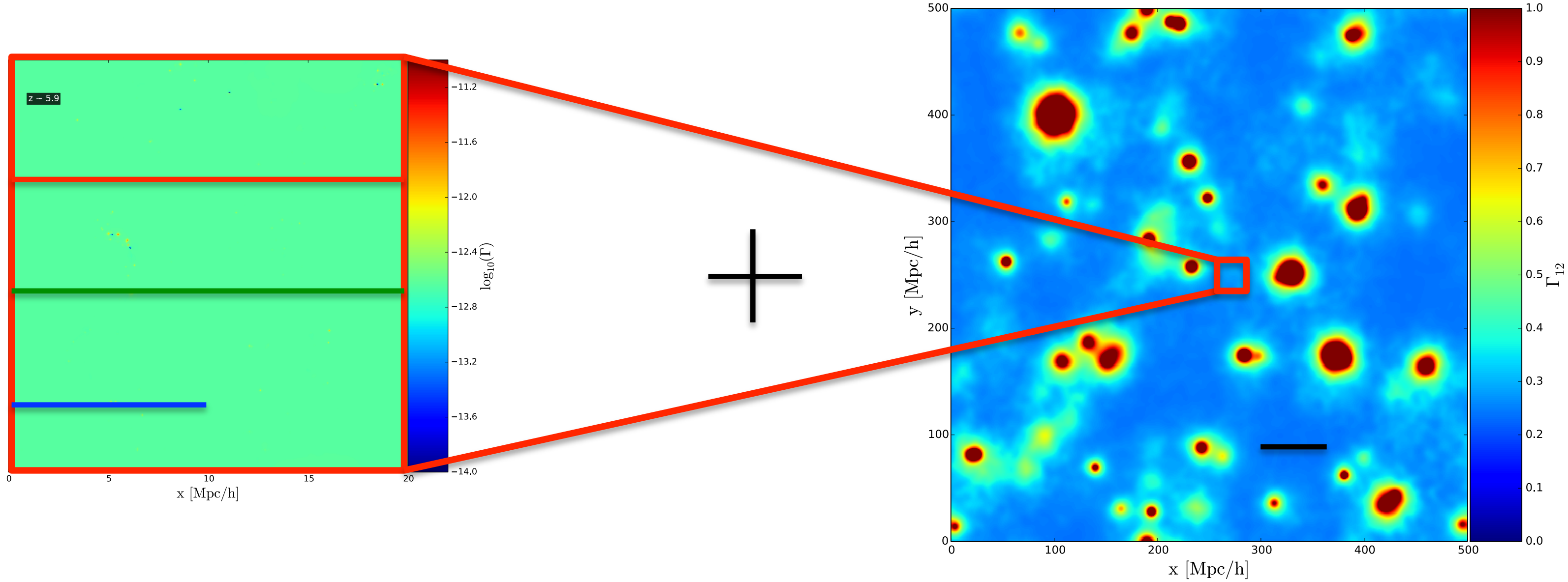


Small scale Γ

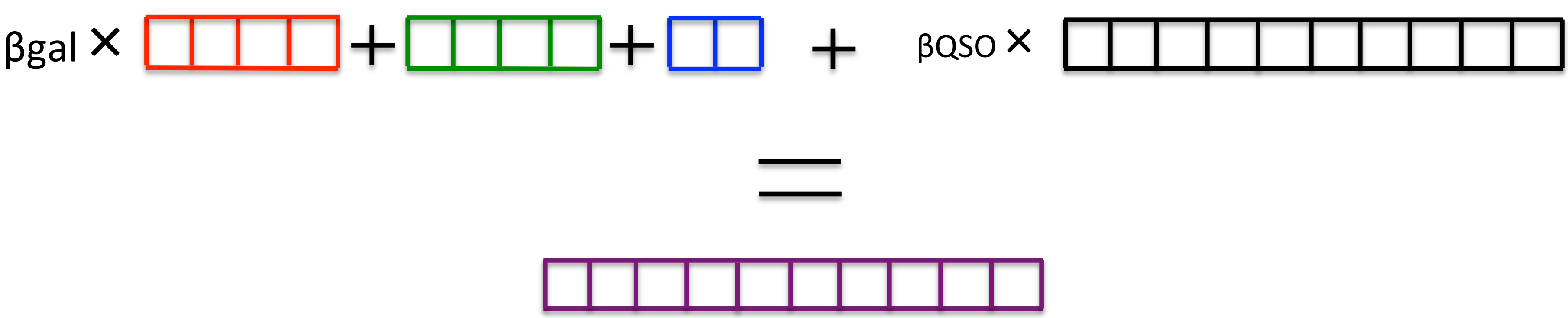
Large scale Γ

Constructing the model

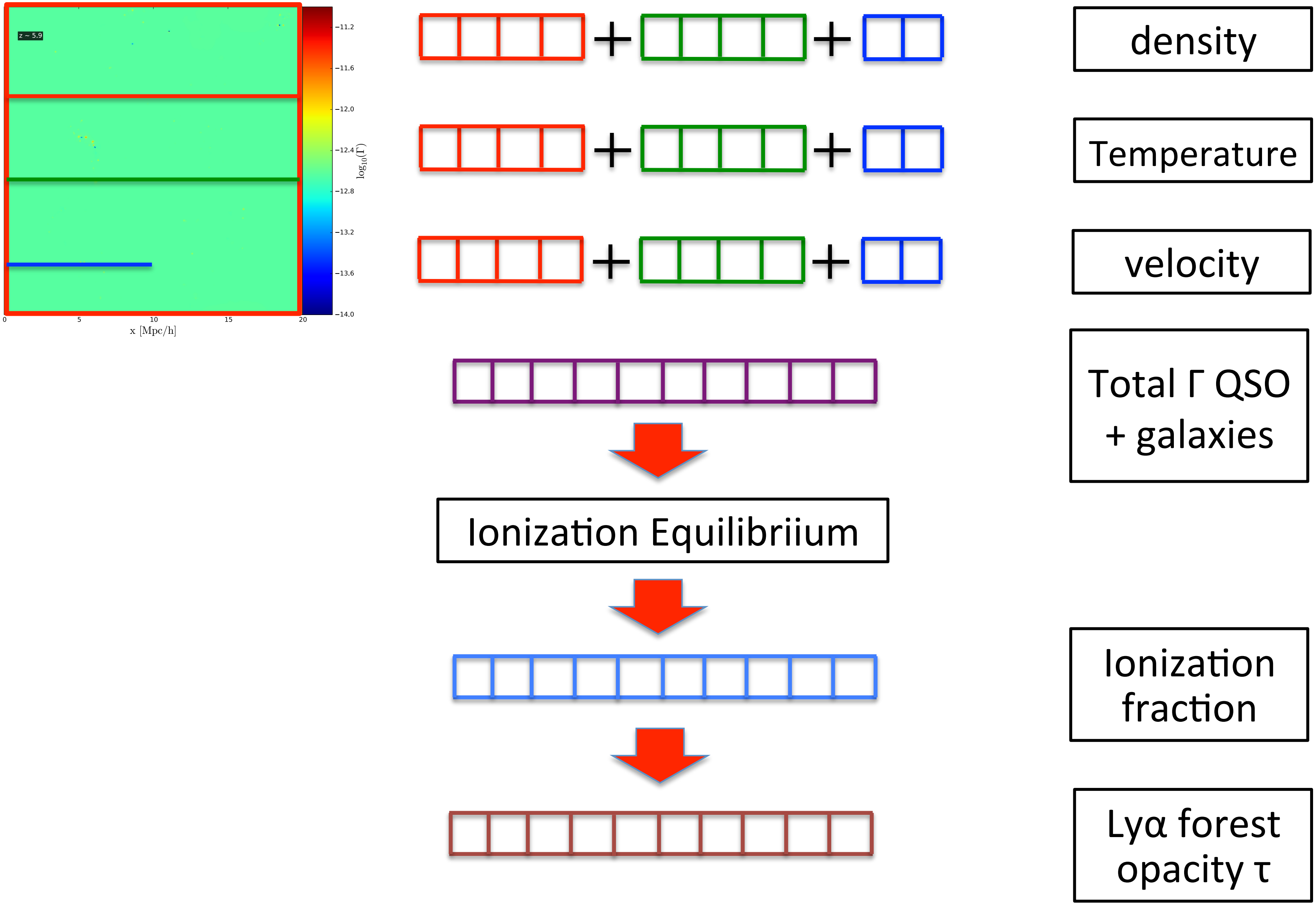
Galaxies | **QSOs**



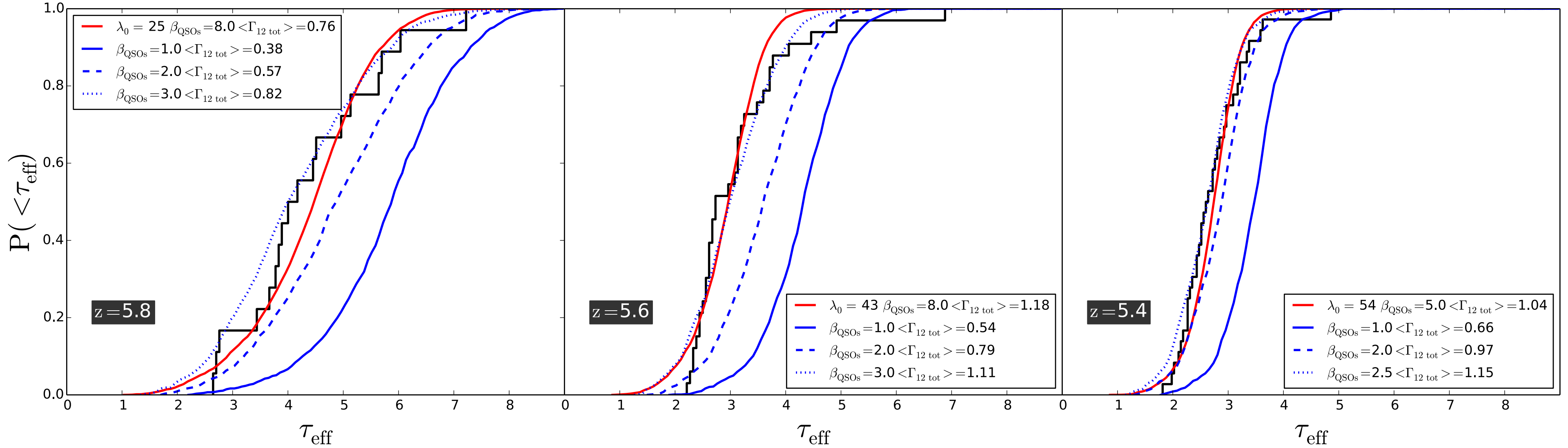
Total Γ over one line of sight of 50 Mpc/h



Constructing the model



A Γ dependant mean free path model



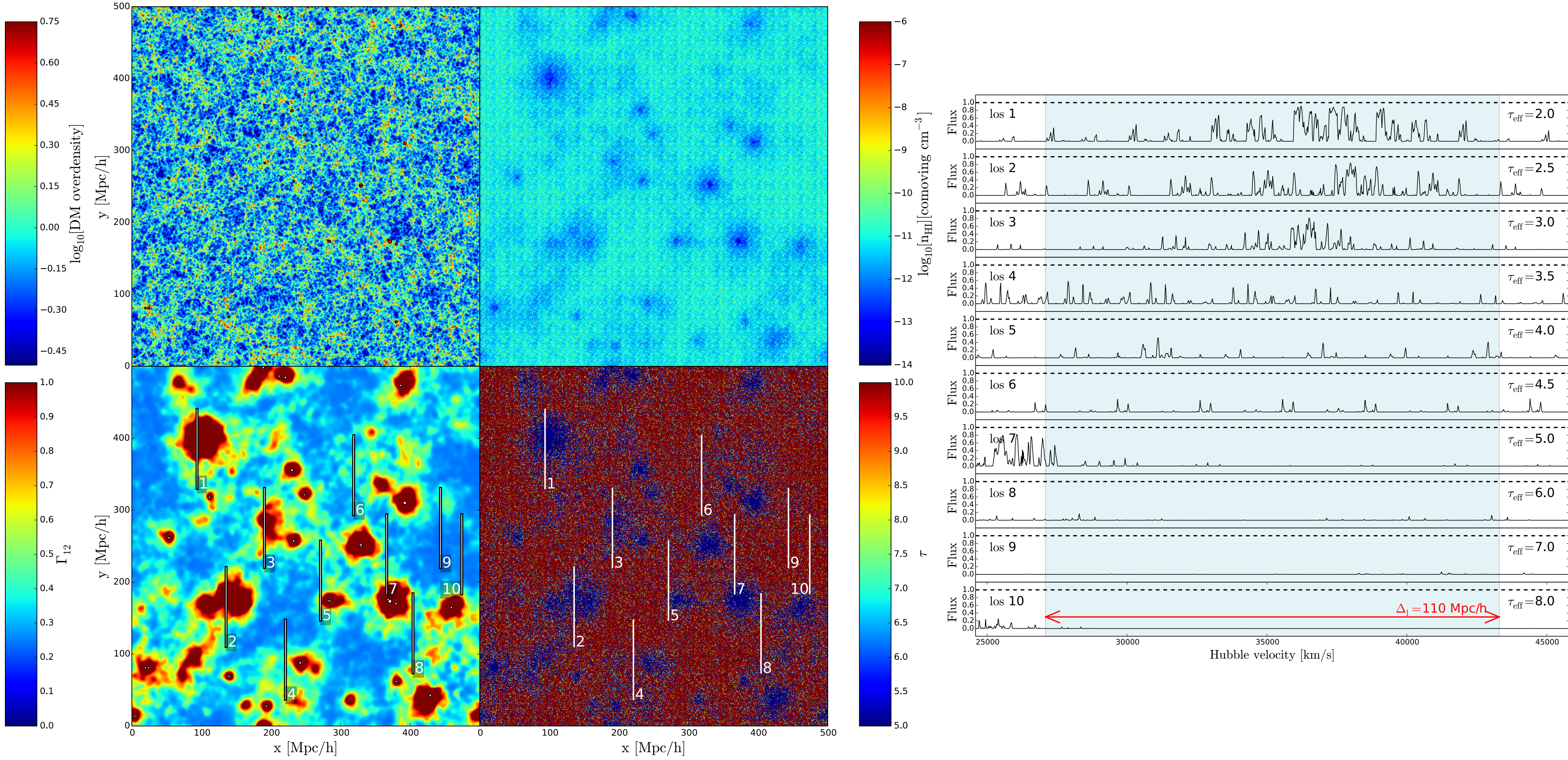
Davies and Furlanetto 2015.

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

Iterative scheme

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

The spectra in the model



Large Gunn peterson troughs (~ 110Mpc/h) can be found as in ULAS J0148+0600

Caveats

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

Alternative explanations

3 Theoretical models

	Observables signatures
1. UVB fluctuation due to QSOs (Chardin et al. 2015,2016)	QSO transverse proximity effect
2. Galaxies Mean free path fluctuations (Davies & Furlanetto 2015)	Anti-correlation between galaxy ionizing emissivity and dark troughs in large under-dense regions
3. Temperature fluctuation (D'aloisio et al. 2015)	Correlation between over-dense cold gas and dark troughs

Conclusion

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