Title: TBA

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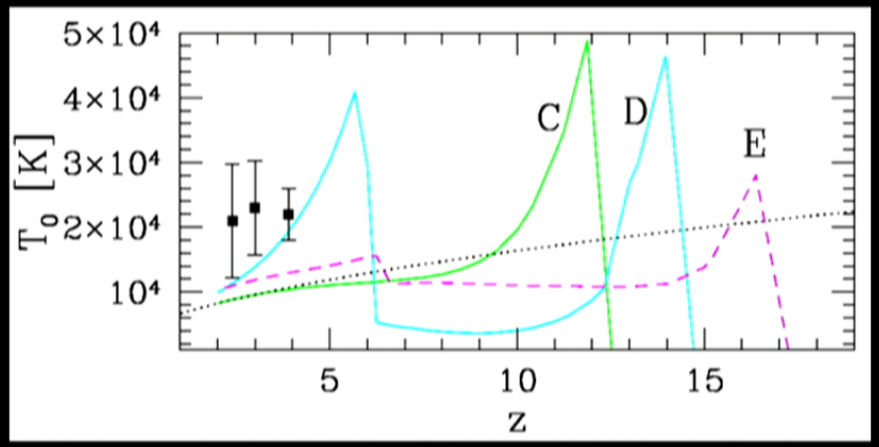
Abstract: TBA

In standard story, principles that shape the thermal history of IGM are simple

(elucidated largely in Miralda-Escude & Ostriker '93 and Hui and Gnedin '98)



Hui & Haiman '03

- ionization of hydrogen (and an e^- of He) around galaxies heats gas to 20-30,000 K, with different regions heated at different times
- subsequently, gas cools by Compton cooling and adiabatic expansion
- residual photoheating as gas recombines and is ionized
- helium doubly ionized later by quasars. We know a lot about quasars.

the thermal history of the IGM

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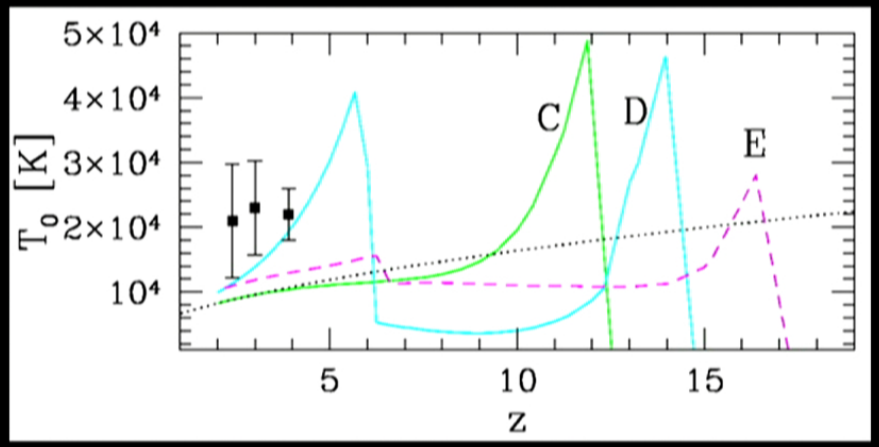
Anson D'Aloisio, Phoebe Upton Sanderbeck

Disclaimer: There will be astrophysics!

In standard story, principles that shape the thermal history of IGM are simple

(elucidated largely in Miralda-Escude & Ostriker '93 and Hui and Gnedin '98)



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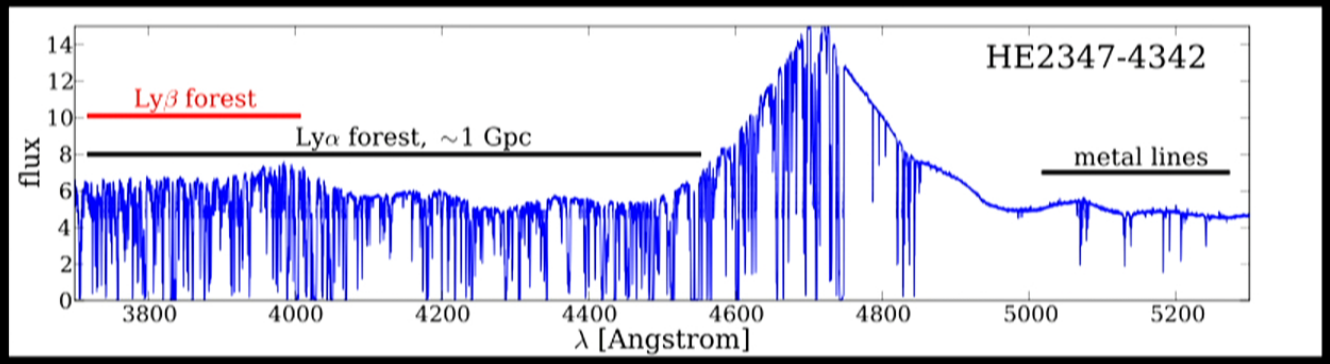
How the IGM temperature is measured



Many attempts, especially around turn of the century:
Schaye et al 00, Ricotti et al 00, McDonald et al 00,
Zaldarriaga et al 01, Lidz et al '10 -- factor ~2 precision

What we do
(to compare in T_0 space)

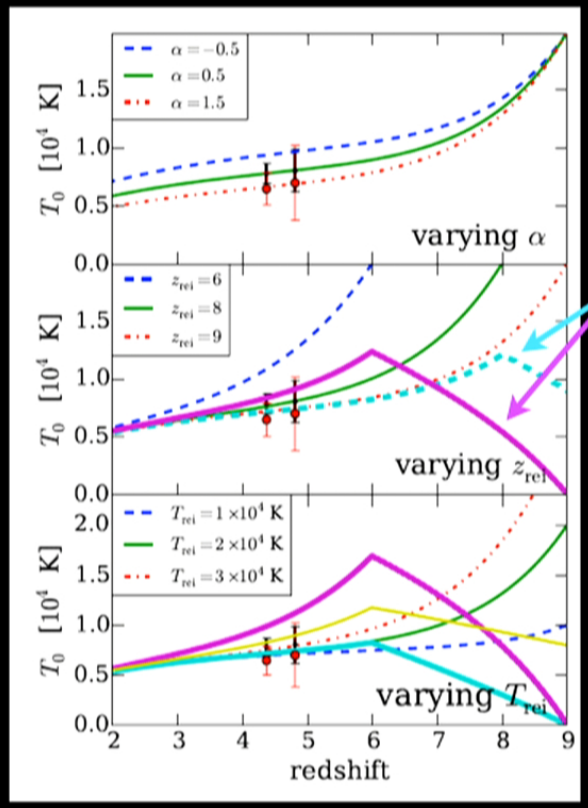
- follow density evolution of Lagrangian gas elements using Zeldovich approximation
- heat and cool gas based on simple rules
- extrapolate measured $T(\Delta_*)$ to T_0 using effective γ from model
- plot "average" temperature (Becker method essential measures average temperature)

Let's try to model this considering only hydrogen reionization

varying post-reionization ionizing background

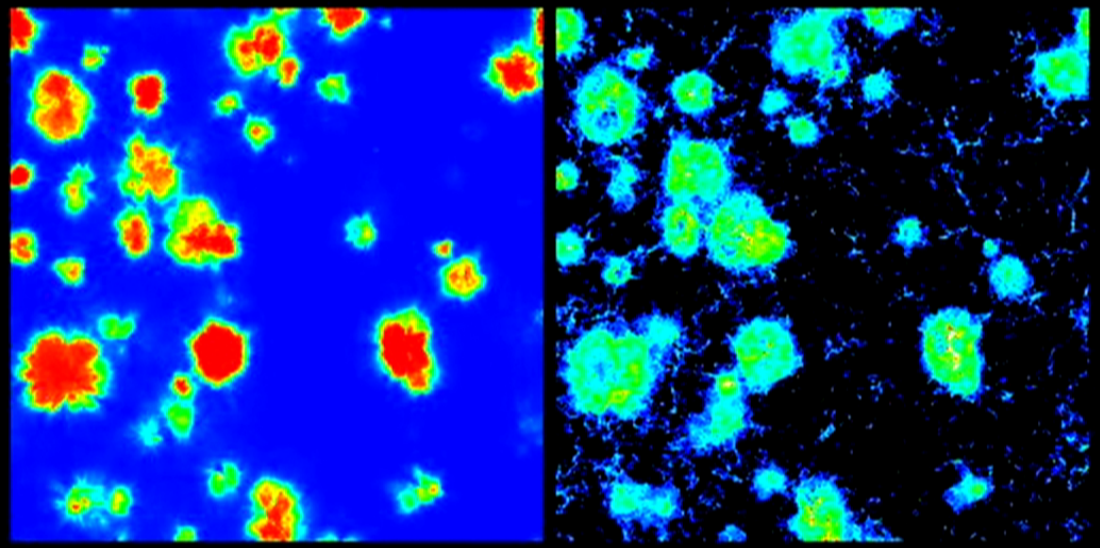
varying redshift of reionization

varying temperature of reionization



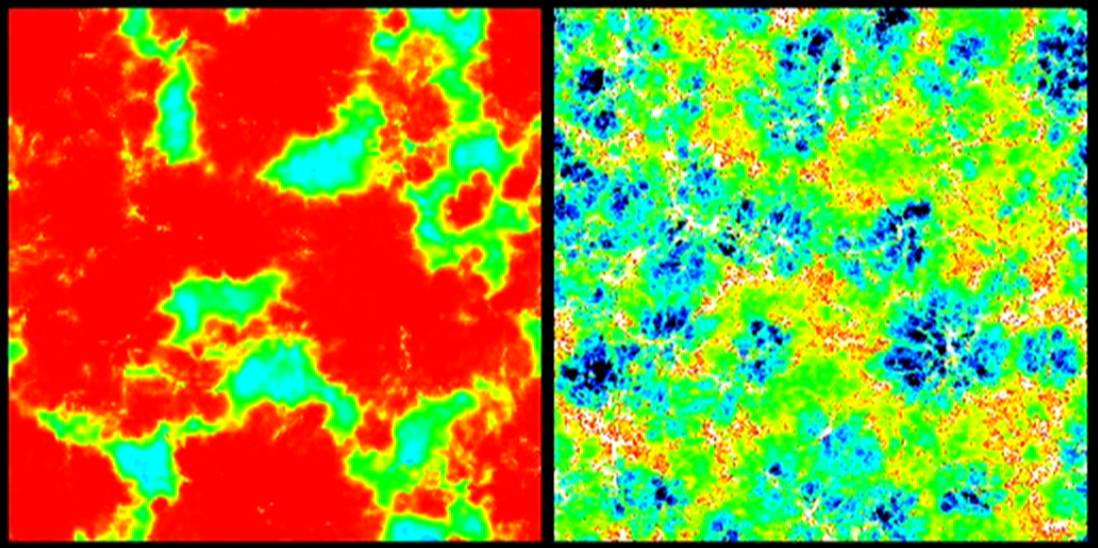
extended histories: assume gas is locally heated to T_{rei}, but that gas elements are ionized over some history

helium reionization model

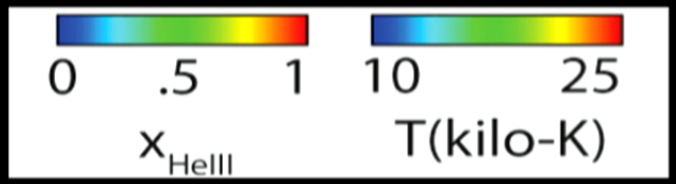


two phase model: local ionization near quasar plus
uniform heating of HeII gas by (hard) long mfp photons

helium reionization model



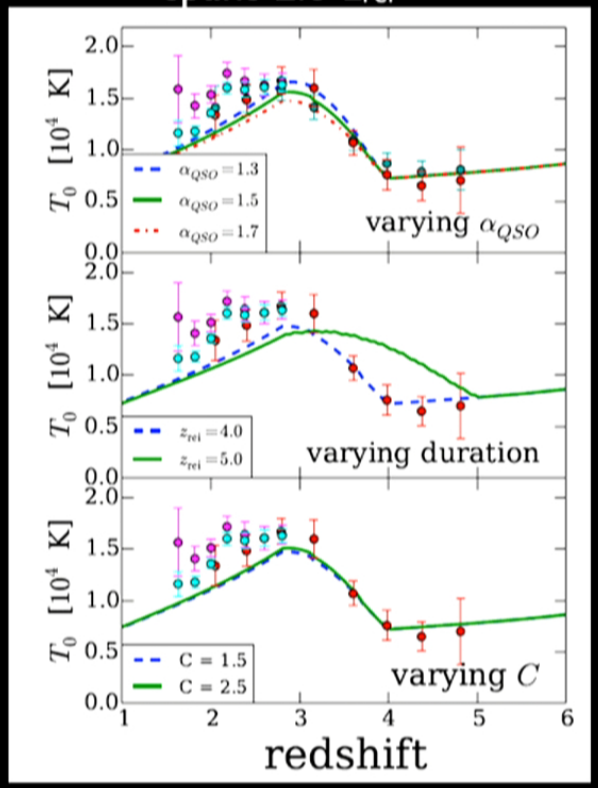
430 Mpc box



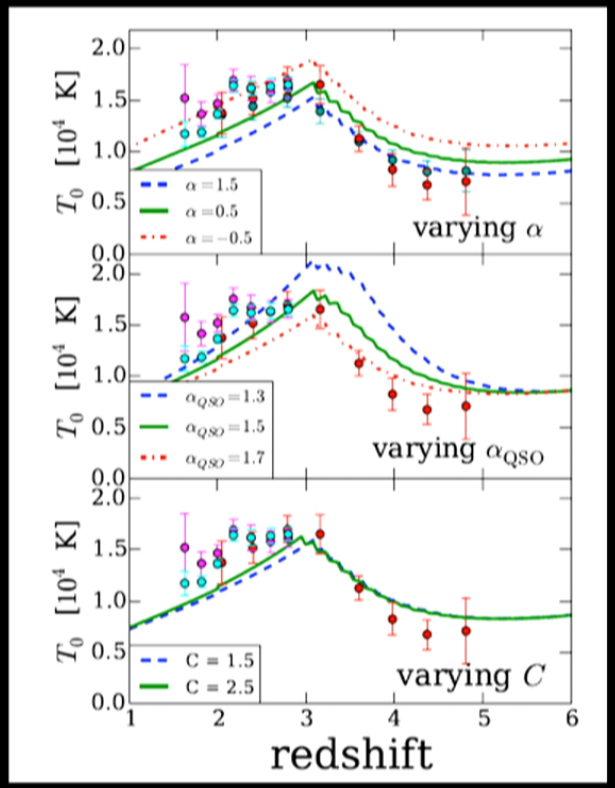
two phase model: local ionization near quasar plus uniform heating of HeII gas by (hard) long mfp photons

full history

assuming linear HeII ionization history that spans 2.8-z_{rei}



using best constraints on quasar emissivities



Sanderbeck & McQuinn '15

z>5 Ly-α Forest

Huge variance in slightline-to-sightline opacity.

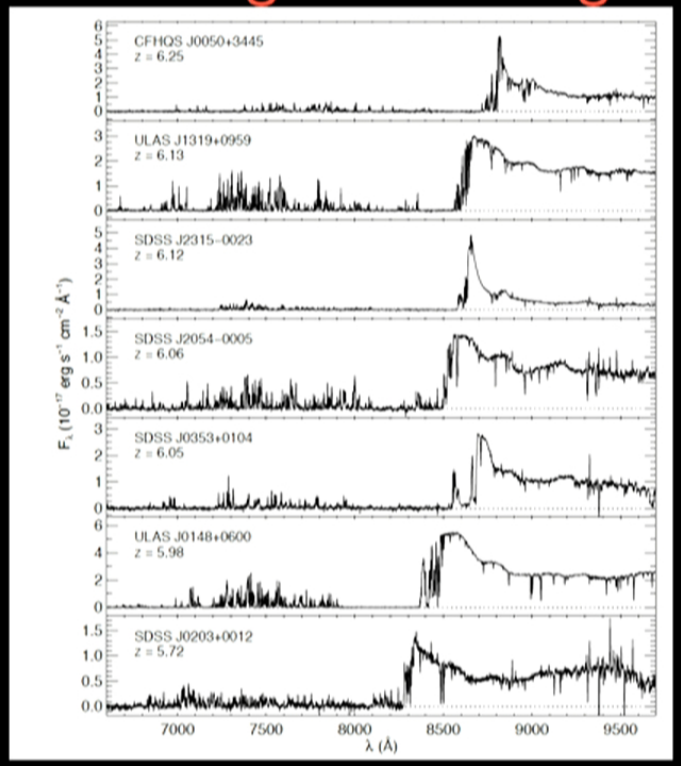


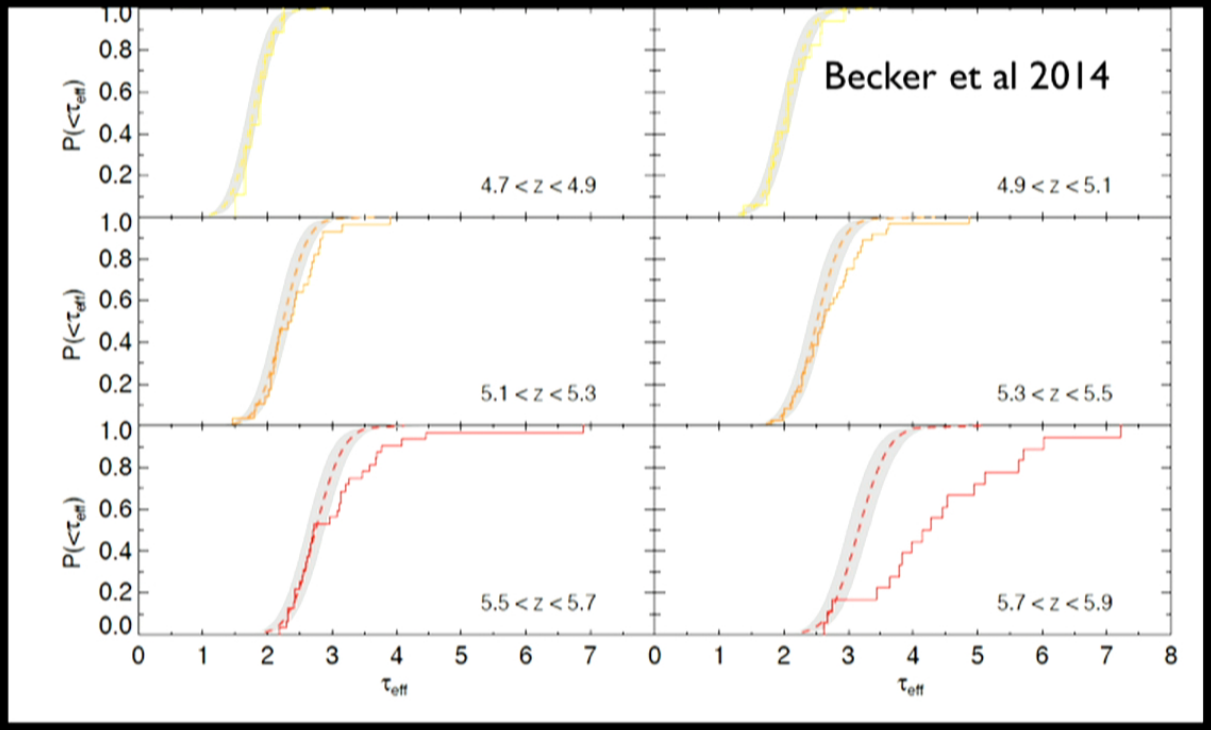
figure from
Becker et al 2014

$$x_{\rm HI} = \frac{\alpha(T) n_e}{\Gamma}$$

Fluctuations can owe to fluctuations in density, ionizing background or temperature

The PDF of τ_{eff}=-ln[<Transmission>],

where Transmission is measured in 50/h Mpc segments.



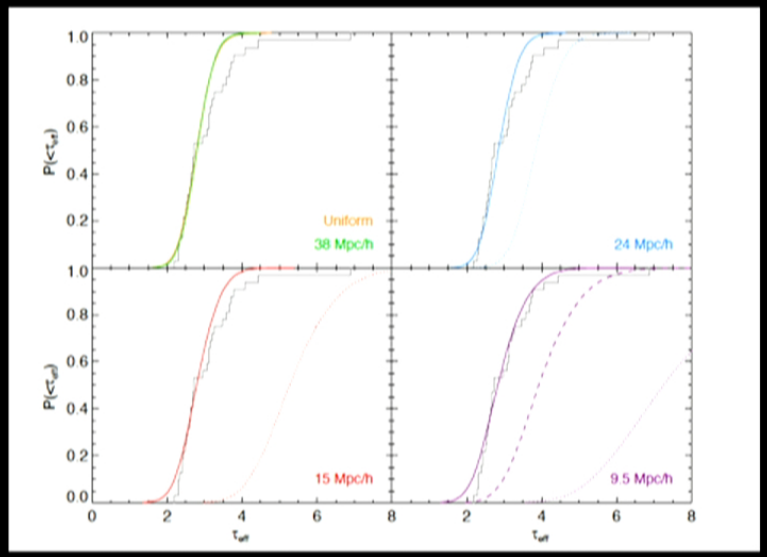
dashed = simulation with density fluctuations only

solid histogram = measured PDF

People have been trying to explain with fluctuations in UV background:
fixing sources, changing mean free path

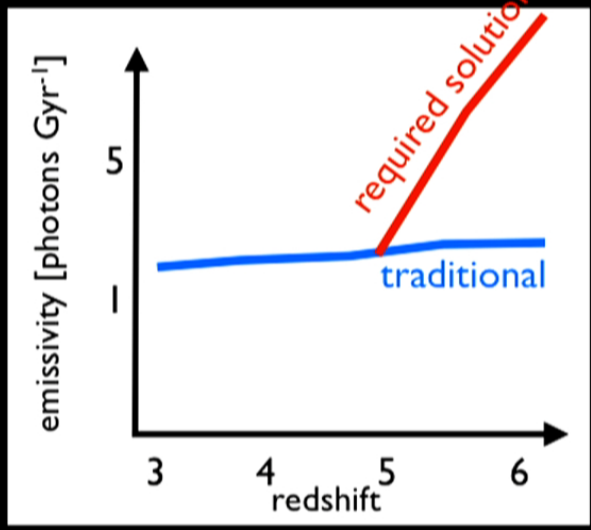
$$x_{\rm HI} = \frac{\alpha(T) n_e}{\Gamma} \qquad \Gamma \propto \text{source emissivity} \times \text{mean free path}$$

cummulative $P(\tau_{\rm eff})$ @ z=5.6



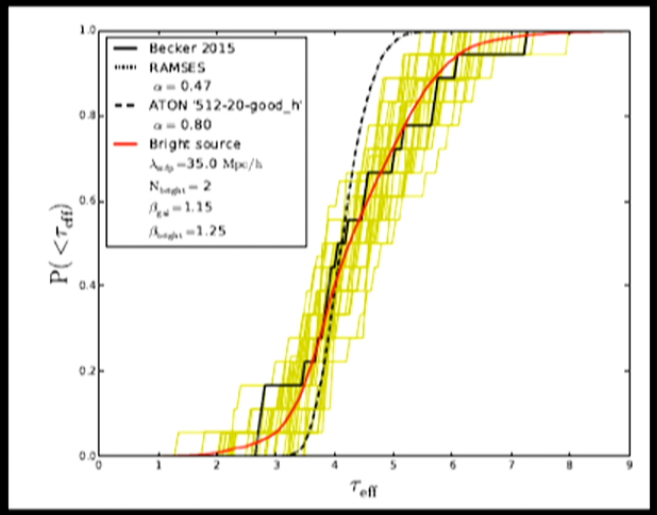
Becker et al 2014

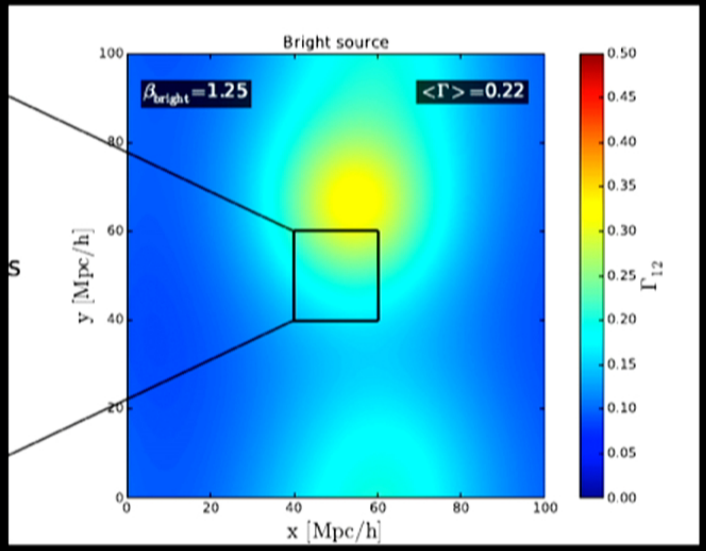
What mfp=9.5 Mpc/h requires



People have been trying to explain with fluctuations in UV background:
fixing mean free path, changing rarity of sources

Choudin et al '15 found they could only reproduce level of fluctuations at z=5.6 with source density of 2 per (100/h Mpc)^3.





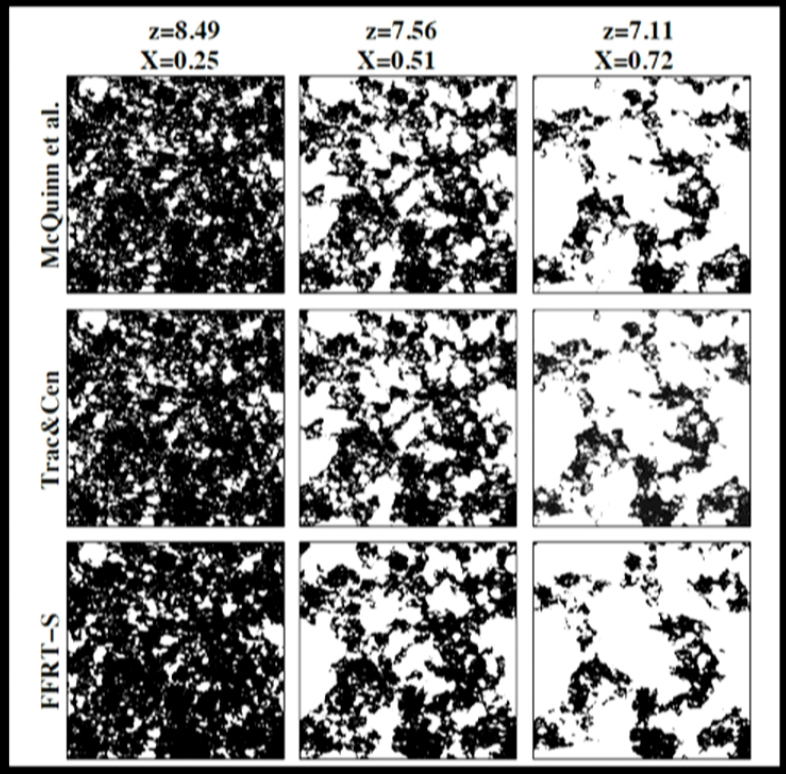
Choudin et al. '15

Structure determined by source clustering

radiative transfer simulation

radiative transfer simulation

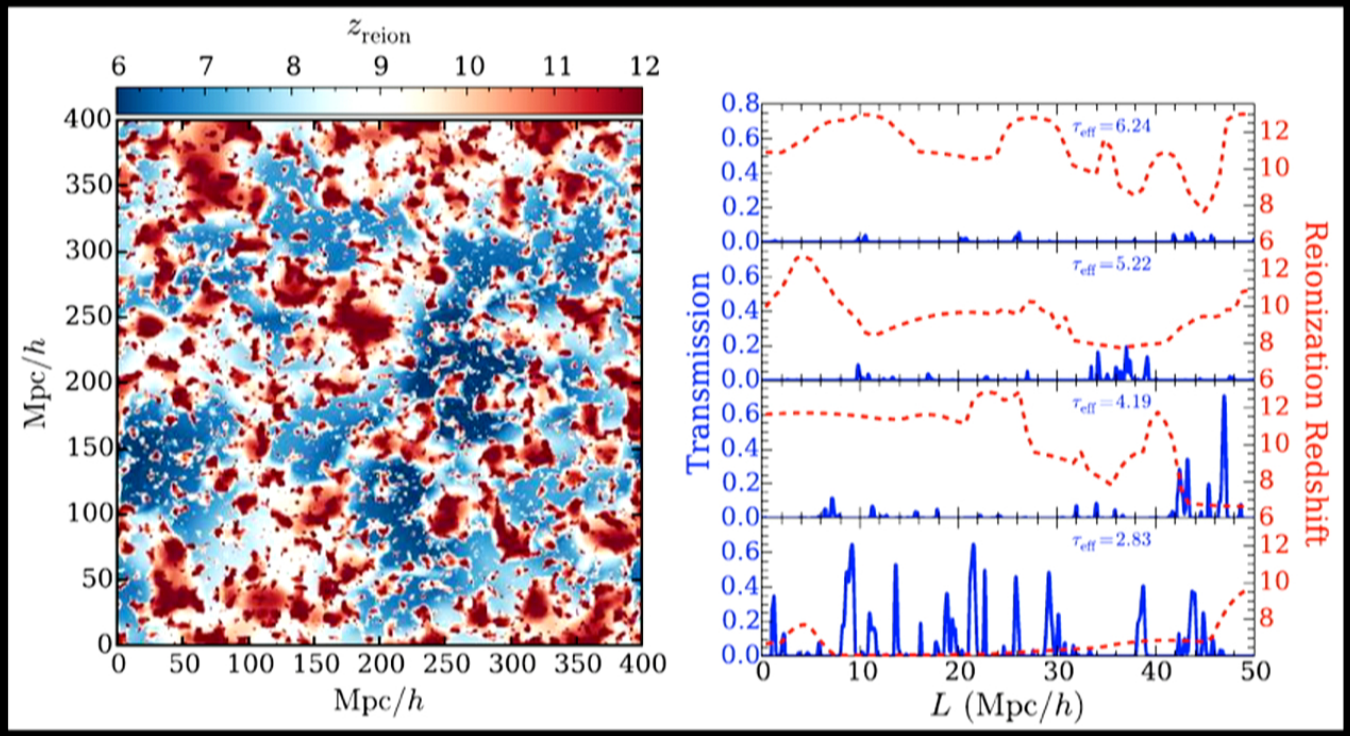
semi-numeric model



each panel 100/h Mpc

Zahn, Mesinger, MM, et al '12

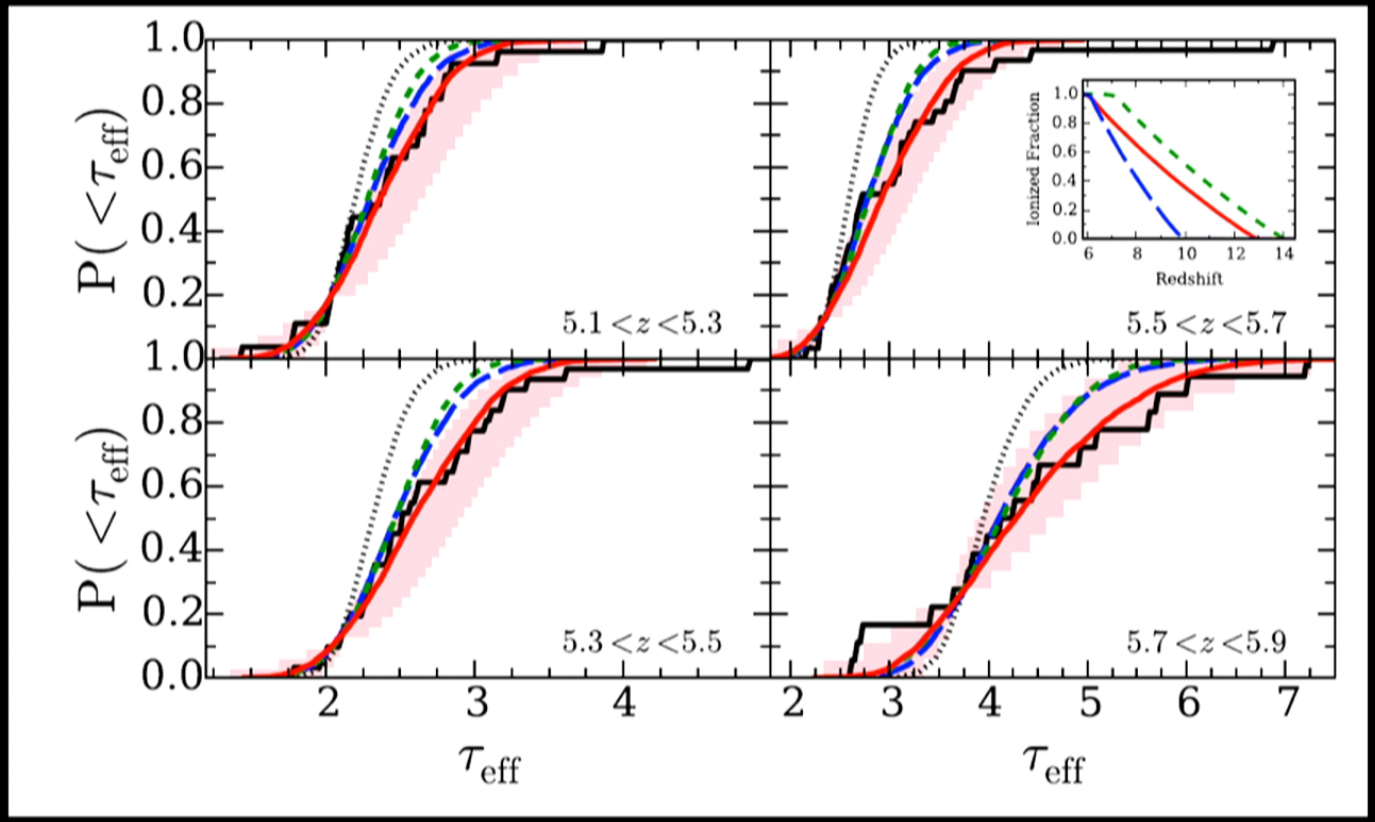
Our interpretation: temperature fluctuations



$$x_{\rm HI} = \frac{\alpha(T) n_e}{\Gamma} \qquad \alpha(T) \propto T^{-0.7}$$

D'Aloisio, MM & Trac '15

Our interpretation, temperature fluctuations



D'Aloisio, MM & Trac '15

Conclusions

- Thermal history in simple models in excellent agreement with measurements
- ~1eV per particle can be injected into mean density IGM by z=2 by something other than photoheating
- the large opacity fluctuations in the z>5 IGM owe to the temperature fluctuations that are an inevitable byproduct of reionization