Title: Patchy Blazar Heating

Date: Mar 15, 2016 02:00 PM

URL: http://pirsa.org/16030101

Abstract:

Warming-up the IGM with patchy blazar heating

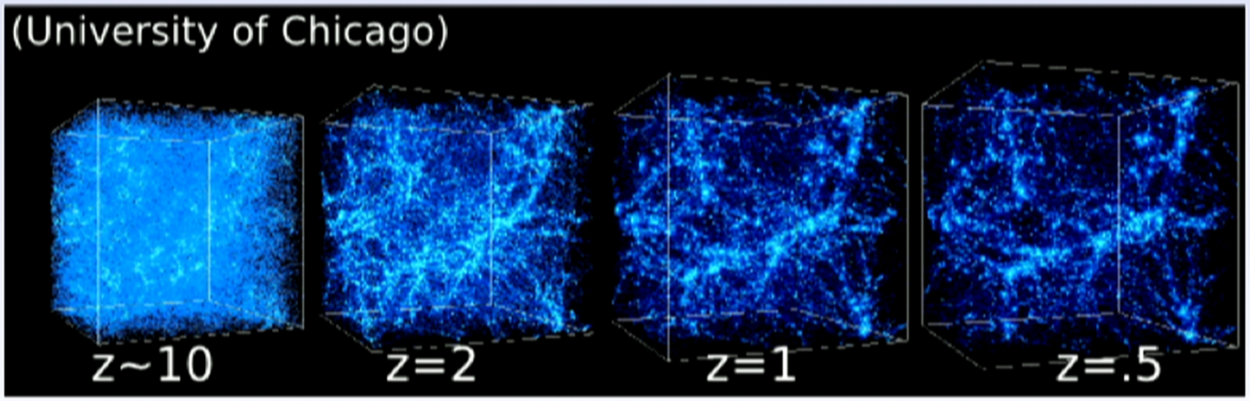
Astrid Lamberts
TAPIR GROUP- CALTECH

Phil Chang (UWM) - Avery Broderick (Perimeter Institute)
Christoph Pfrommer (Heidelberg) -Ewald Puchwein (Cambridge)

Perimeter Institute - March, 15th, 2016

Caltech

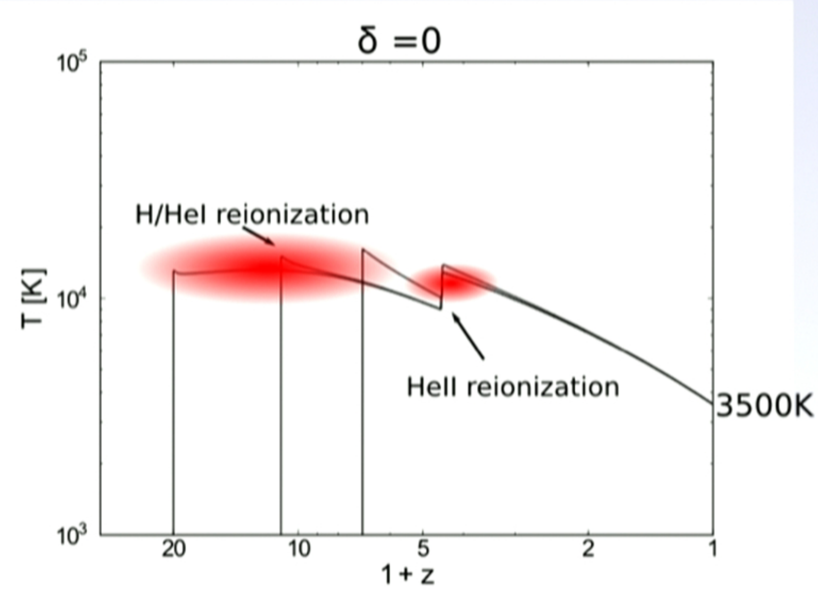
The Intergalactic medium



- majority of baryons $\rightarrow$ reservoir for structure formation/evolution
- Long-term thermal memory $\rightarrow$ probe of re-ionization, star formation...
- Quasi-linear evolution

(Brief) thermal history of the IGM

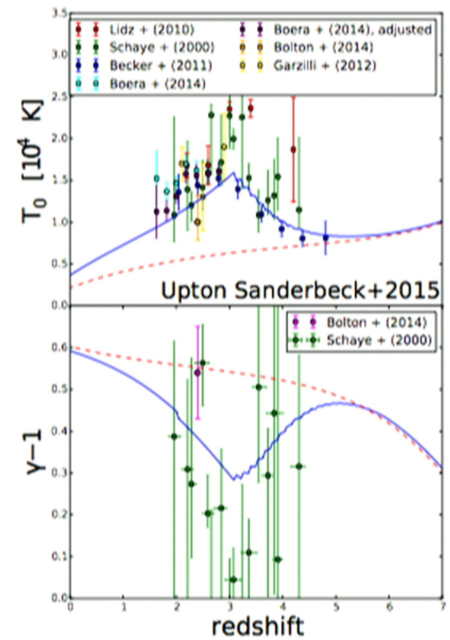
Competition between heating and cooling : re-ionization, photoheating, adiabatic cooling



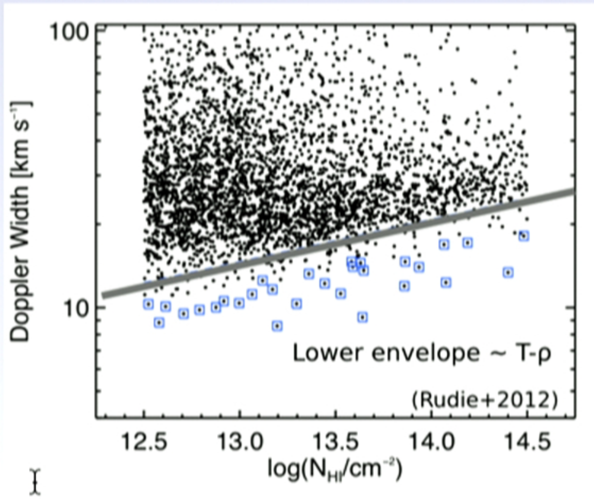
$T = T_0(\rho/\bar{\rho})^{\gamma-1} \rightarrow$ Major questions: T_0, γ.

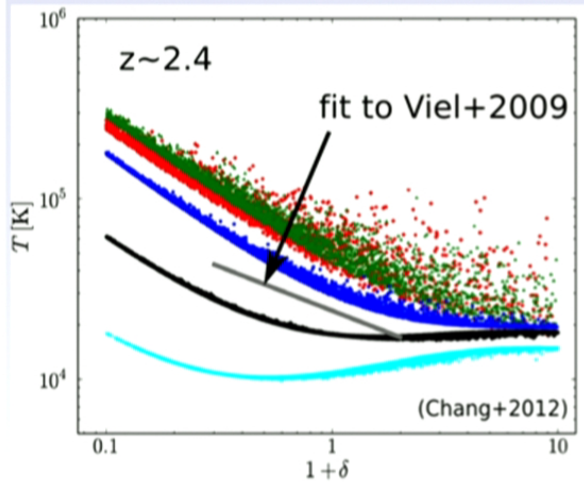
Challenges

- Mainly absorption: Ly_α forest
  - mostly $1.5 \leqslant z \leqslant 3 \rightarrow$ no full history
  - sensitive to $\delta \geqslant 0$, lower δ need *HeII*
  - Uncertainties ionizing background
- Analysis: column density + Doppler width $\neq$ density + temperature
- Simulations are required to calibrate T and γ estimates $\rightarrow$ physical assumptions, numerical uncertainties



Observational discrepancy





Recent observations of Ly_α → apparent contradiction
What is the thermal state/evolution of the intergalactic medium?

Motivations

- IGM structure is fundamental for understanding Large Scale Structure
- intuitive understanding
- Calorimeter $\rightarrow$ measure of blazar heating, number of blazars beyon $z = .5$

Outline

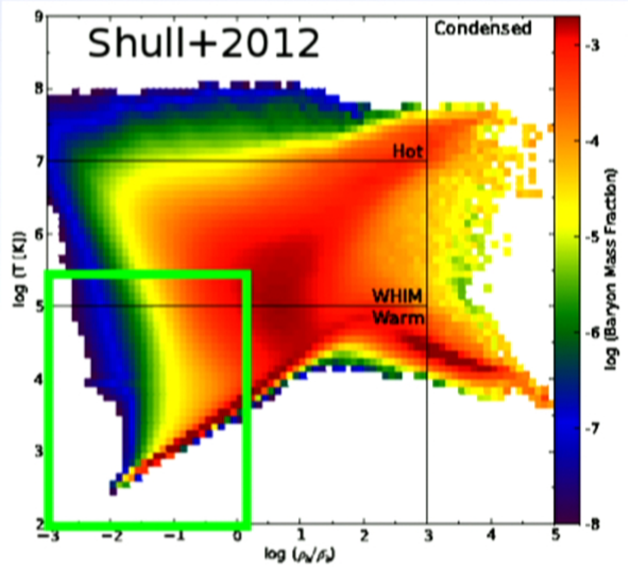
1. Uniform heating models
2. Inpact of clustering: patchy heating

Where?

AGN (roughly) uniformly distributed + uniform extragalactic background

$\Rightarrow$ blazar heating is uniform (to first order) $\rightarrow$ volumetric

$\Rightarrow$ impacts mainly low density regions



Where

Mean free path for pair creation

$$D_{pp}(E,z) = 35\left(\frac{E}{1\ \mathrm{TeV}}\right)^{-1}\left(\frac{1+z}{2}\right)^{-\xi}\ \mathrm{Mpc}$$

$$\xi = 0 \quad \mathrm{z}<1 \quad \xi = 3.5 \quad \mathrm{z}>1$$

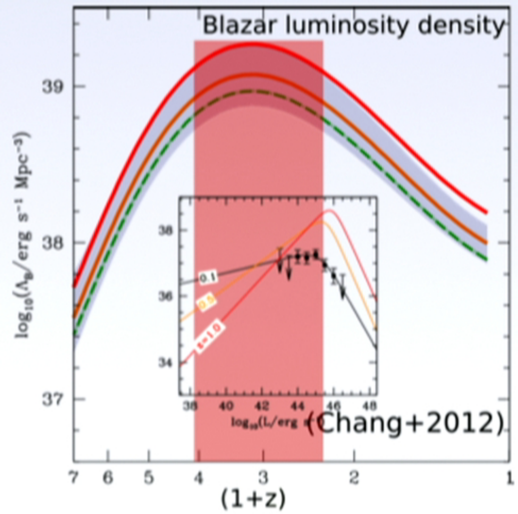
→ heating occurs far from sources, very different from other AGN feedback mechanisms

When?

Limit: number of blazars

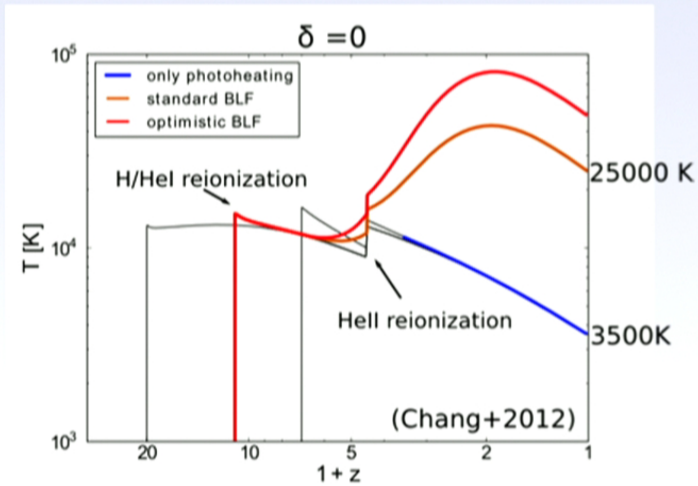
- TeV-Blazars unobservable at high z: evolution?
- At $z = 0$ $L_{blazar} \simeq 10^{-3} L_{quasar}$
- Blazars $\simeq$ Quasars (accretion physics)

$\rightarrow$ Assumption : Blazars follow evolution of quasars with scaled luminosity density $\rightarrow$ low, intermediate, high blazar heating models
$\rightarrow$ peak after $z \simeq 3$



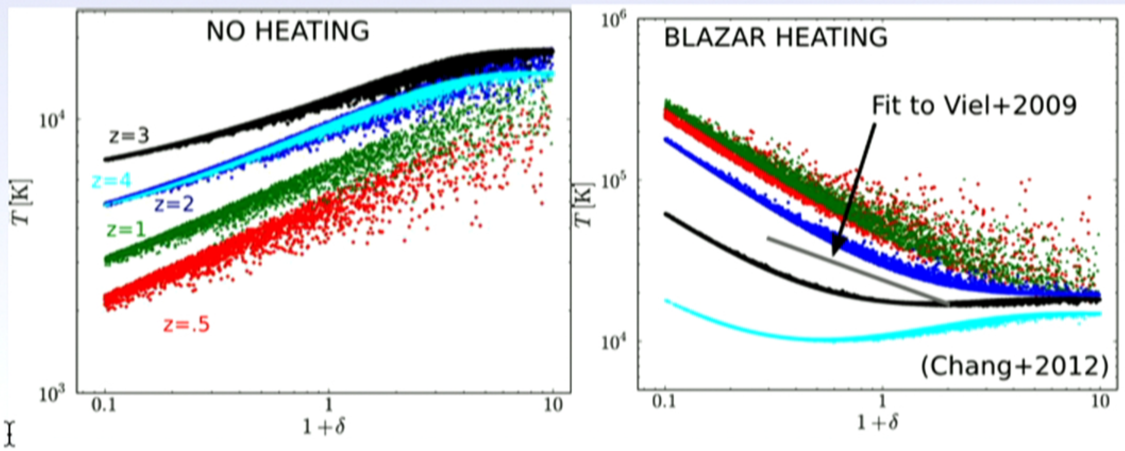
Temperature of IGM

TeV sources $\longrightarrow$ estimate local heating rate $\longrightarrow$ add in simple model of IGM (Hui, Gnedin, 1997)



$\Rightarrow$ Significant heating for $z \leqslant 3$

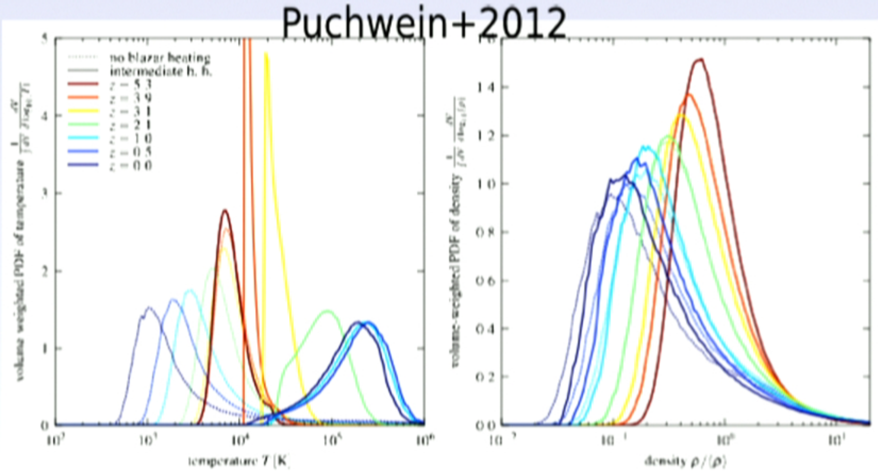
Temperature-Density distribution



→ inverted temperature-density relation

impact on IGM

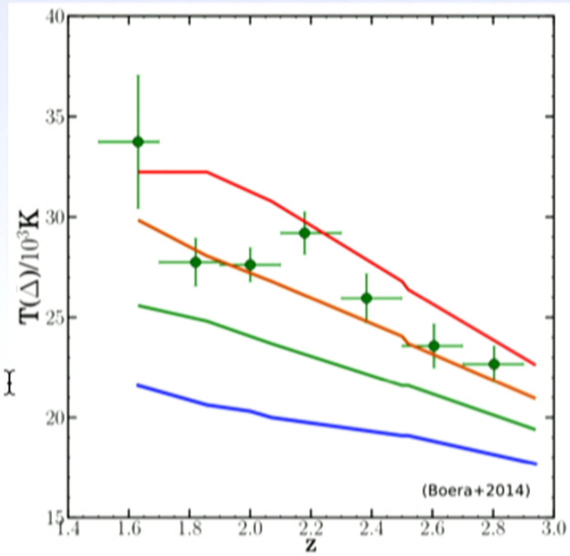
Puchwein+2012

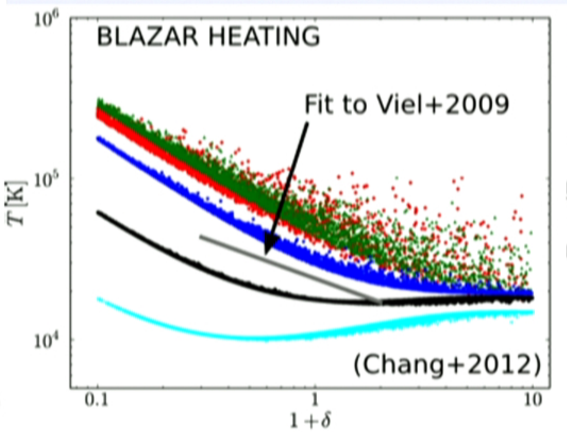


Higher temperature at all z, limited impact on density distribution

observational constraints: T_0, γ

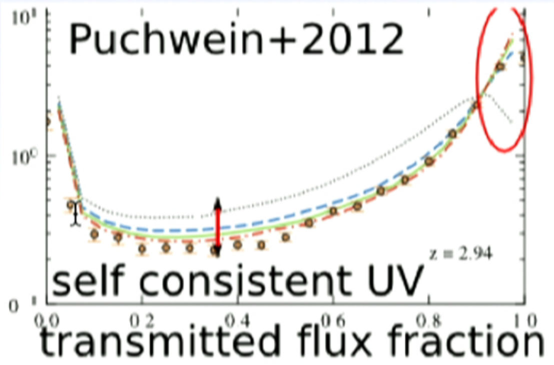
Higher T_0 and inverted $T - \rho$ suggested by some recent results (Boera+2012, Viel+2009,Becker+2007, Bolton+2008...)

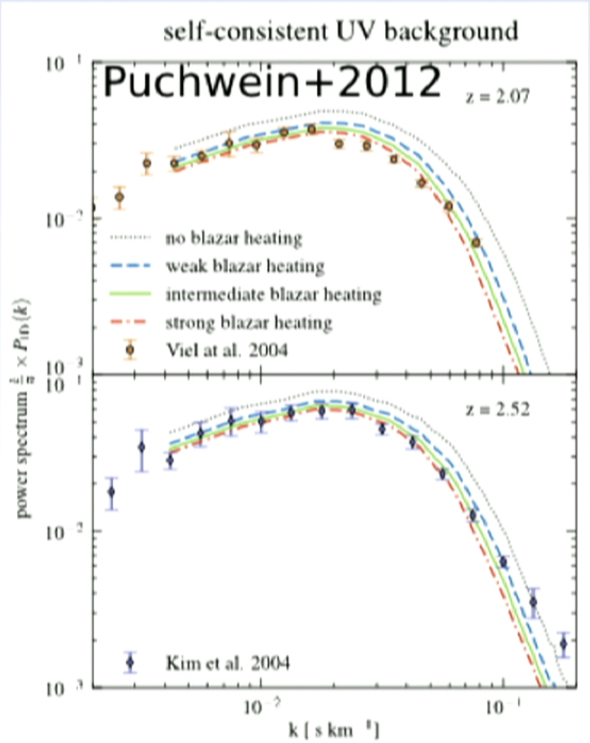




Impact on Ly$_\alpha$ statistics

no need for UV flux adjustments, better agreement for weakest absorbers, good agreement for powerspectrum

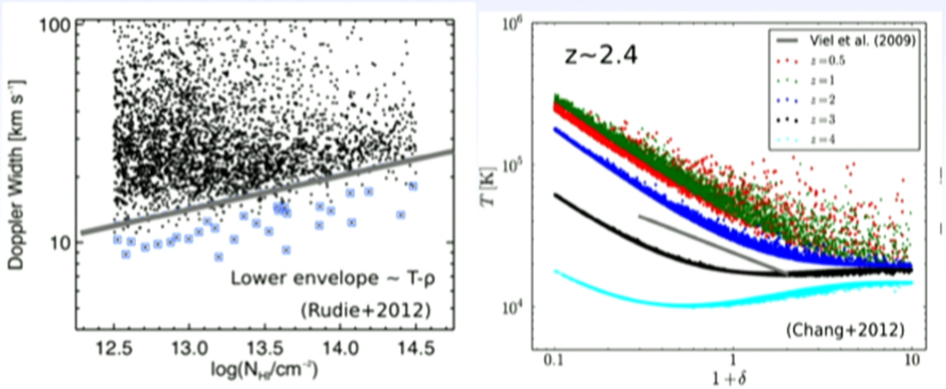




A more complex thermal history for the IGM

TeV blazars efficiently heat IGM

- Additional heating after $z \simeq 3$
- inverted $T - \rho$

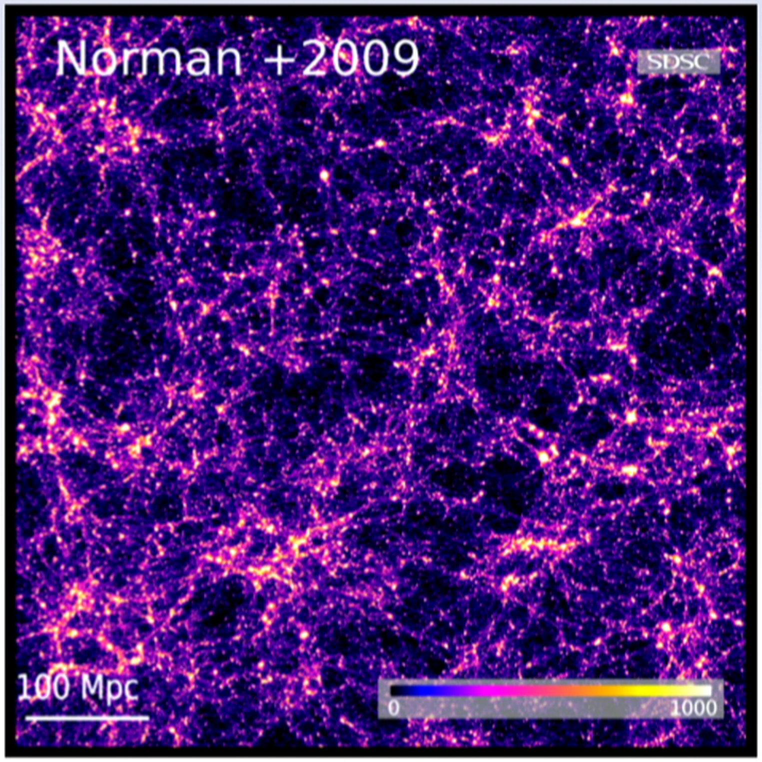


→ fits some data, problems with Voigt profile fitting → scatter in $T - \rho$?

Outline

1. Uniform heating models
2. Inpact of clustering: patchy heating

Origin of the fluctuations



$H = \bar{H} + \delta_H$

Proximity to source → increased flux → increased heating

Idea : $\delta_H = f(\delta_{DM})$
heating at given point $\rightarrow$Integral on all sources
Ex static universe :

$$\delta_H(\mathbf{x}) = \frac{\dot{Q}(\mathbf{x}) - \bar{\dot{Q}}}{\bar{\dot{Q}}} = \frac{1}{4\pi \bar{\dot{Q}} D_{pp}} \int_\Omega d\Omega \int_0^{r_{max}} dr' (\mathcal{E}(\mathbf{r}' + \mathbf{x}) - \bar{\mathcal{E}}) e^{-\tau}$$

$$= \frac{1}{4\pi \bar{\dot{Q}} D_{pp}} \int_\Omega d\Omega \int_0^{r_{max}} dr' \delta_E(\mathbf{r}' + \mathbf{x}) \bar{\mathcal{E}} e^{-\tau}$$

Then Fourier transform $\rightarrow \tilde{\delta}_H = \tilde{W}_{blazar} \tilde{\delta}_{DM}$

Filtering function (Lamberts+2015, inspired by Furlanetto+2007, Barkana+2005)

Expanding universe

$$\tilde{W}_H(k,z) = \frac{1}{\bar{X}} \int_{E_{min}}^{E_{max}} dE \int_{z}^{z_{max}} dz' \frac{dX(E,z,z')}{dz'} \times \frac{D(z')}{D(z)} \left((b(z) + \frac{f}{3}) j_0(kr) - f j_2(kr) \right)$$

with

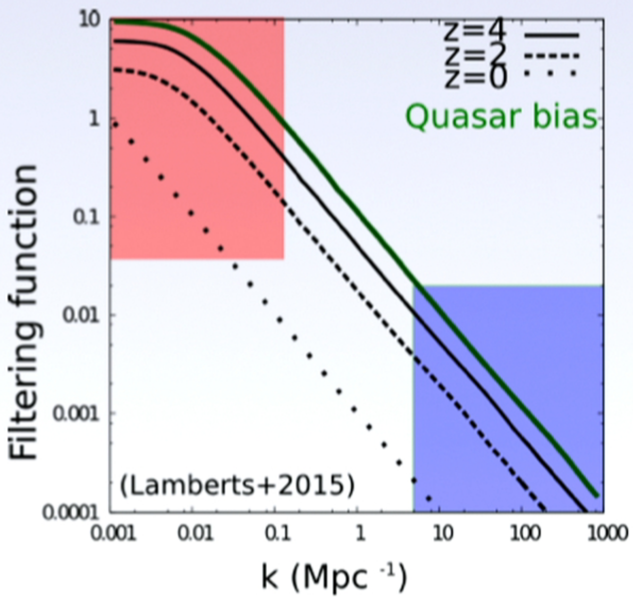
$$X(E,z',z) = \frac{\mathcal{E}(E',z') e^{-\tau(z,z',E)}}{D_{pp}} \frac{c(1+z)^3}{H(z')}$$

- integral on blazar spectrum
- bias, redshift-space distortions, increased area
- linear growth of DM perturbations
- expansion universe
- received energy

Filtering function

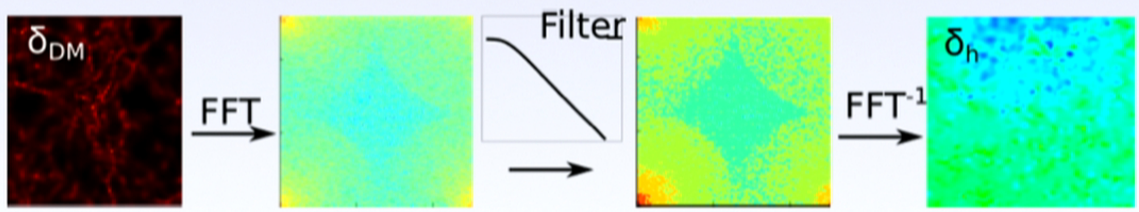
Naturally selects relevant length scales

→ High quasar bias → more power
→Scales below ≃ 10 Mpc have little impact
→ Large scale δ_h follow δ_{DM}



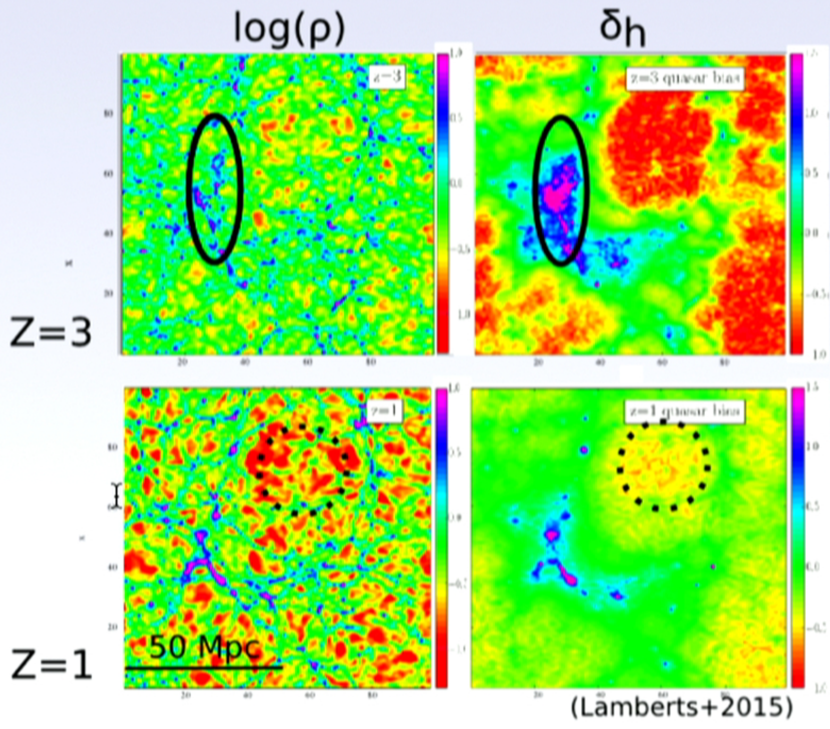
Implementation in Gadget

Gadget-3 (Springel+2005) SPH code, "copy" FFT used to solve Poisson equation



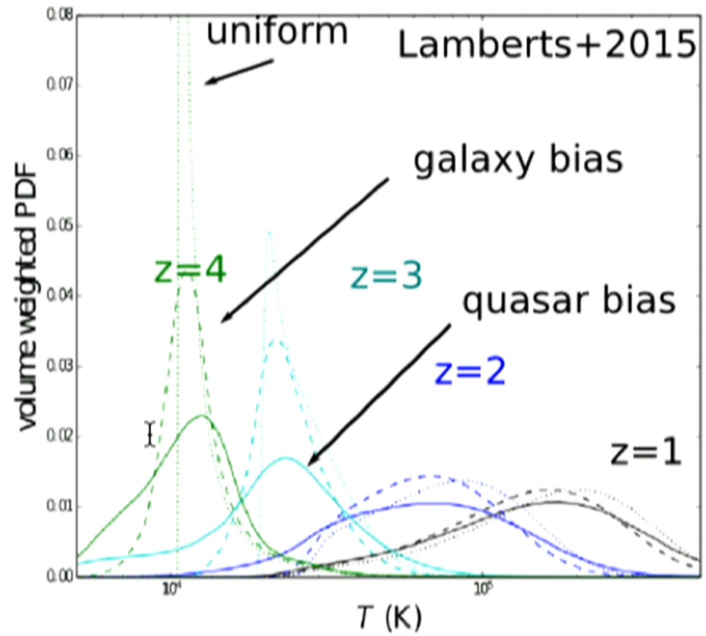
Alternative to subgrid model, computationally cheap
L_{box} =100 Mpc, 2×512^3 particles, simplified star-formation.
simulations with two bias models

Accounting for clustering



- bias : $\delta \geq 1$: more heat
- $\delta \leq 1$: no small scale fluctuations
- $\delta \leq 1$: heating impacts strongly

temperature distribution

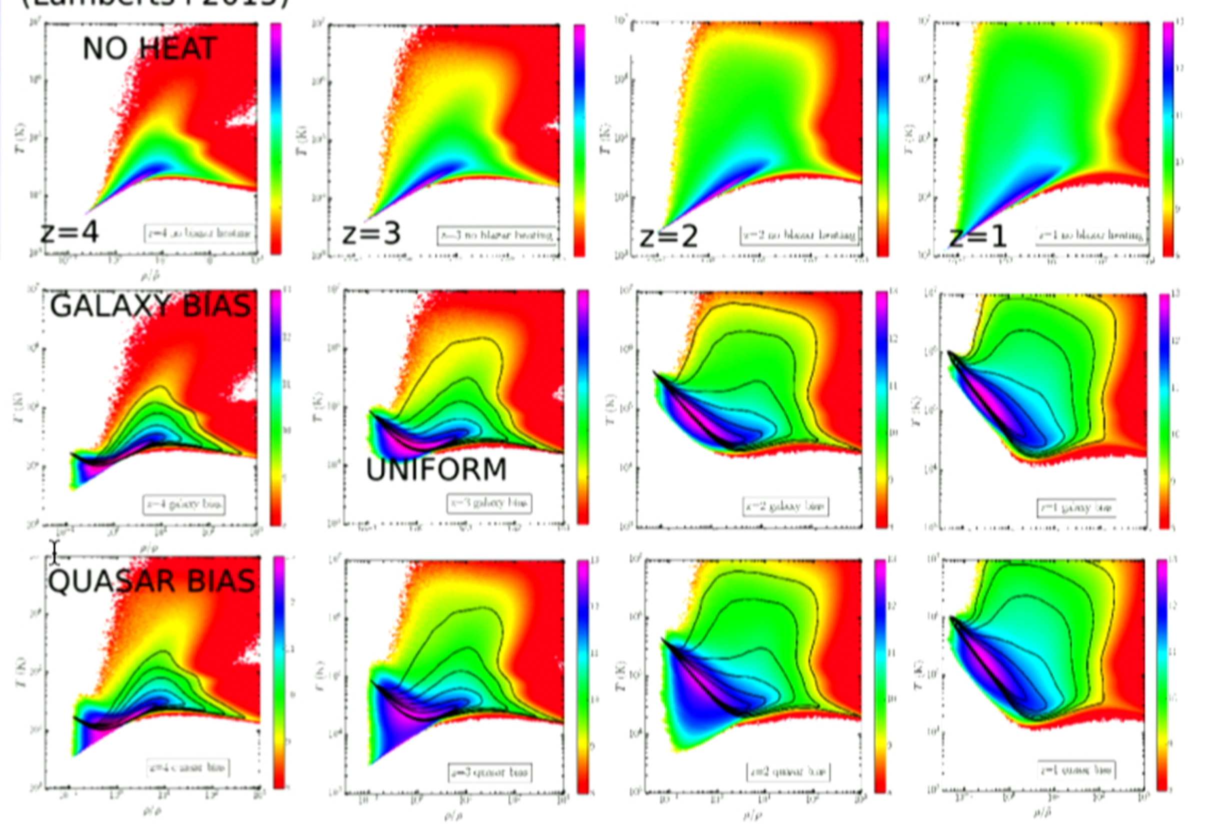


Temperature: integrated impact of blazar heating

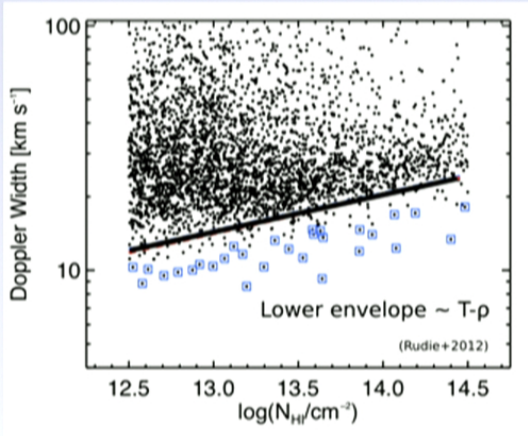
- Larger scatter than uniform heating
- Average lower T than uniform heating (for $z \leq 1$)

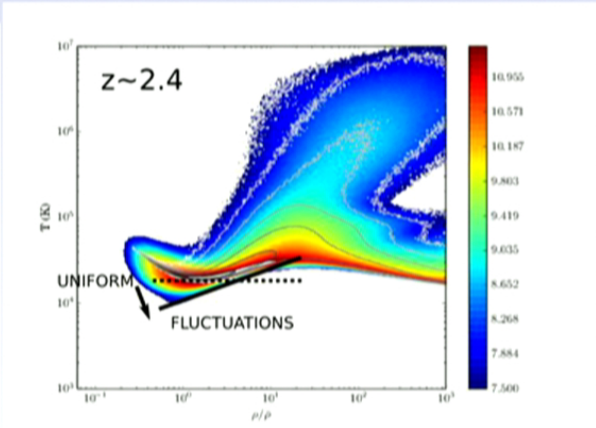
Temperature-Density distribution

(Lamberts+2015)



Observational impact

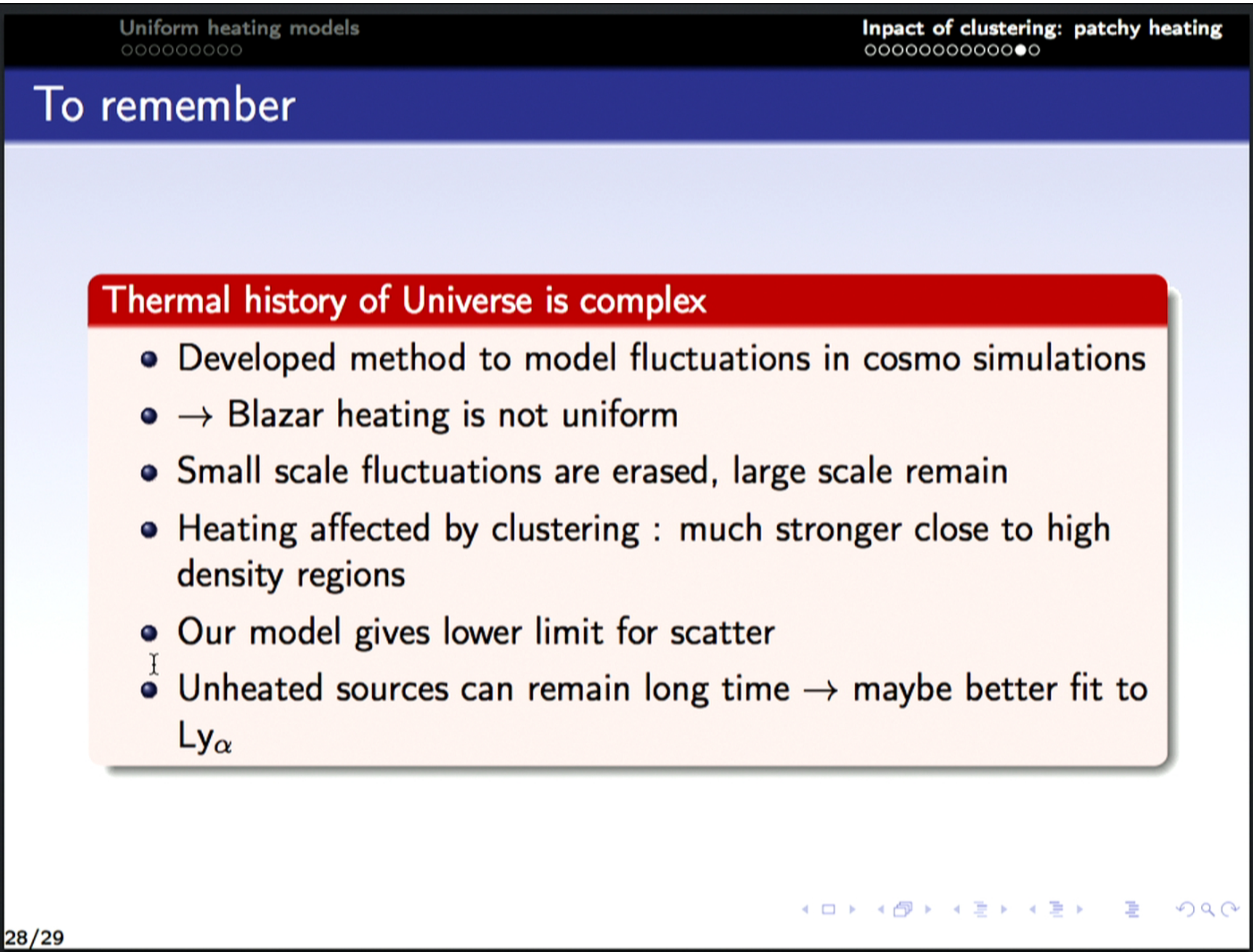




- Increased scatter → fits lower envelope obtained with line profile fitting
- High T fits with curvature methods (Boera+2014)
- "By eye" fits : to be confirmed with Ly_α simulations

To come: confronting to Lyα data

Models of Lyα need higher resolution simulations: 1280^3 for 100^3 Mpc box.
Trace lines-of -sight trough simulation$\rightarrow$ computed transmitted flux $\rightarrow$ fit spectra (vpfit) $\rightarrow$ compute statistics
Differente statistics are sensitive to different things and have different limits and caveats.


Uniform heating models
Impact of clustering: patchy heating
To remember
Thermal history of Universe is complex
Developed method to model fluctuations in cosmo simulations
→ Blazar heating is not uniform
Small scale fluctuations are erased, large scale remain
Heating affected by clustering : much stronger close to high density regions
Our model gives lower limit for scatter
Unheated sources can remain long time → maybe better fit to Lyα
28/29

To come

Comparison with observations

- Impact on Ly_α : large scale cosmo simulation currently analyzed
- Other observational probes
  - He II forest traces lower ρ
  - 21 cm line : Canadian Hydrogen Intensity Mapping Experiment (CHIME) : large scale Hydrogen fluctuations
- Handle on blazar luminosity density