Reionization and the Thermal History of the IGM

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KICC 10th Anniversary

The Case for "Late" ($z_{end} \sim 6$) Reionization

$$\tau_{es} = 0.054 \pm 0.007$$

Planck Collaboration (2018)

- Evolving Ly-alpha fraction

  (e.g. Ouchi et al. 2010; Stark et al. 2010; Bolton & Haehnelt 2013; Mesinger et al. 2015; Mason et al. 2018)

- Quasar damping wing studies

  (e.g. Banados et al. 2018; Davies et al. 2018; Mortlock et al. 2011)

- Forst opacity fluctuations?

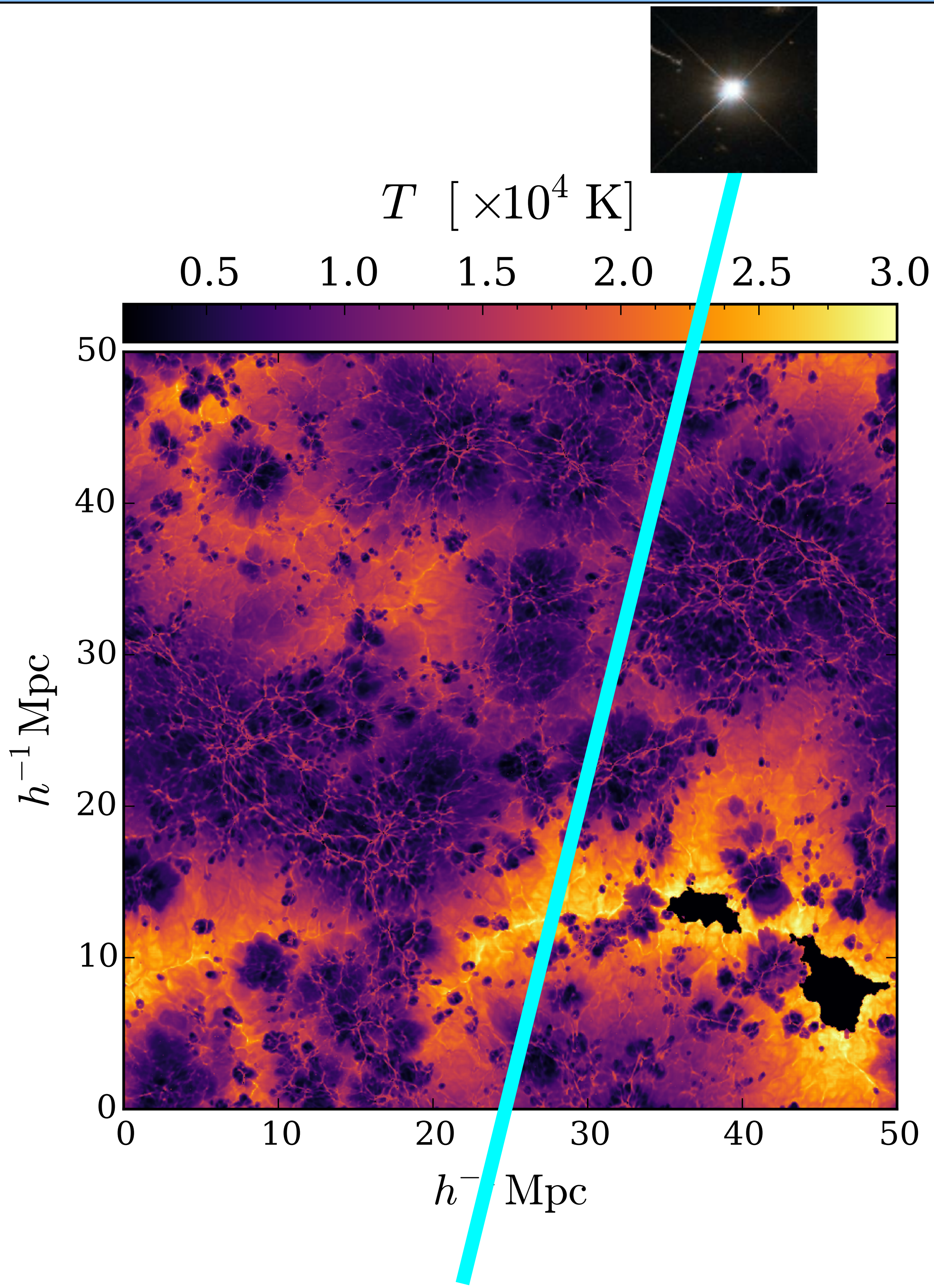
  (e.g. Fan et al. 2006; Becker et al. 2015; Bosman et al. 2018; Eilers et al. 2018)

The Case for "Late" (z_{end} ~ 6) Reionization

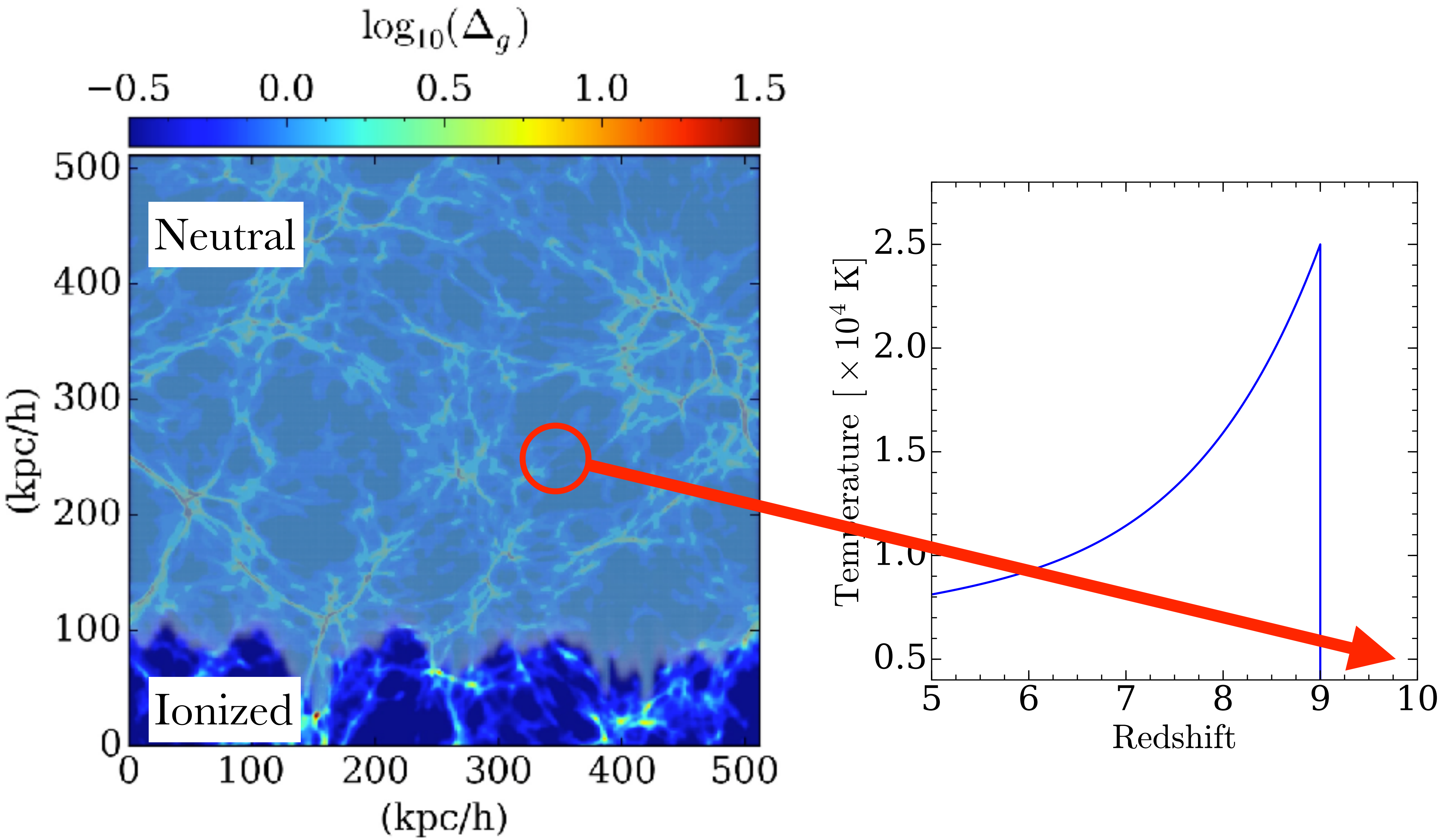
- Late-ending? Might be able to constrain reionization with high-z Ly-alpha forest.

- One possibility: look for its heating effects on the IGM

e.g. Miralda-Escudé & Rees 1994; Hui & Gnedin 1997; Trac et al. 2008; Furlanetto & Oh 2009; Lidz & Malloy 2014; D'Aloisio et al. 2015; Keating et al. 2018



Heating by Reionization



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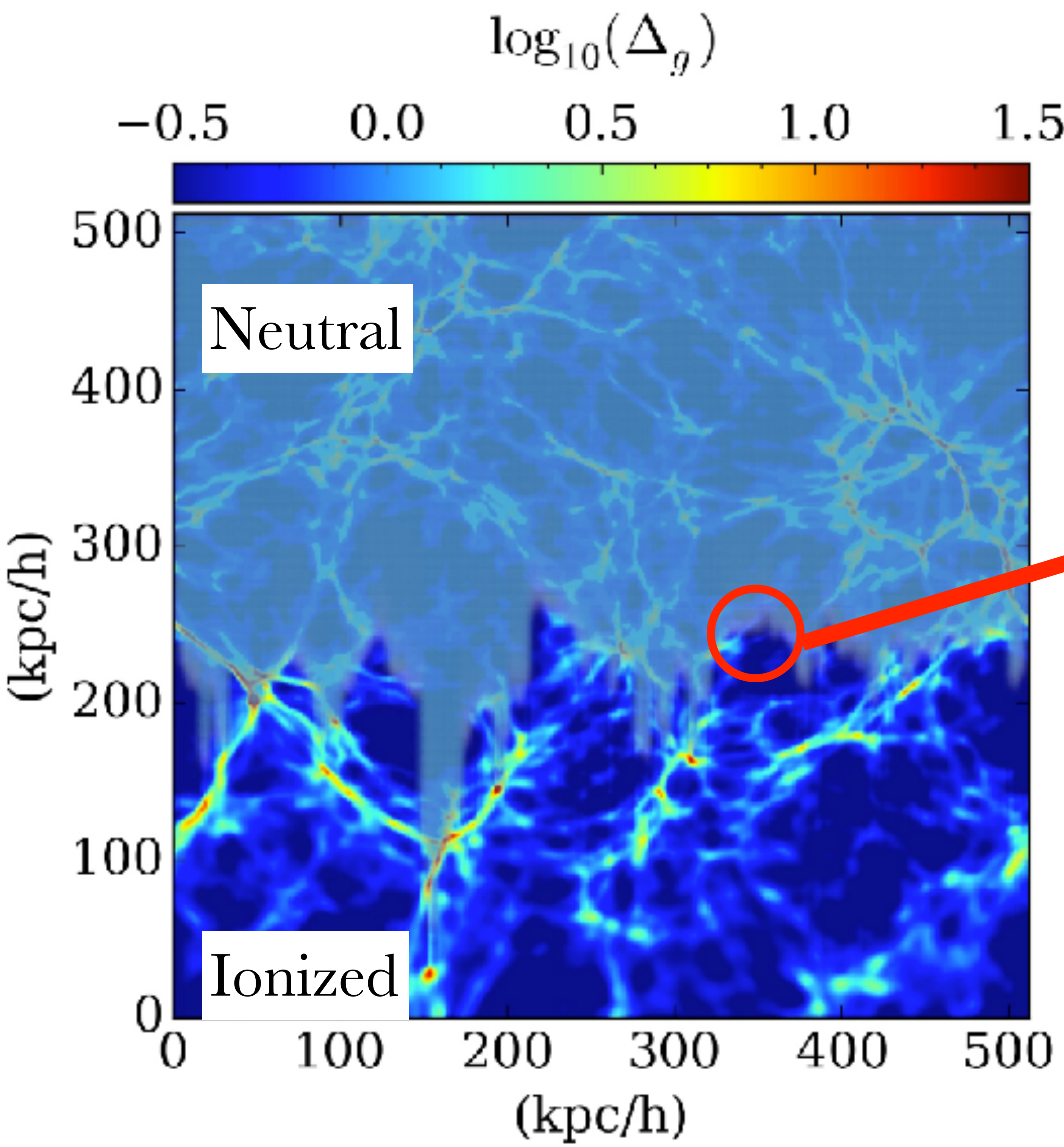
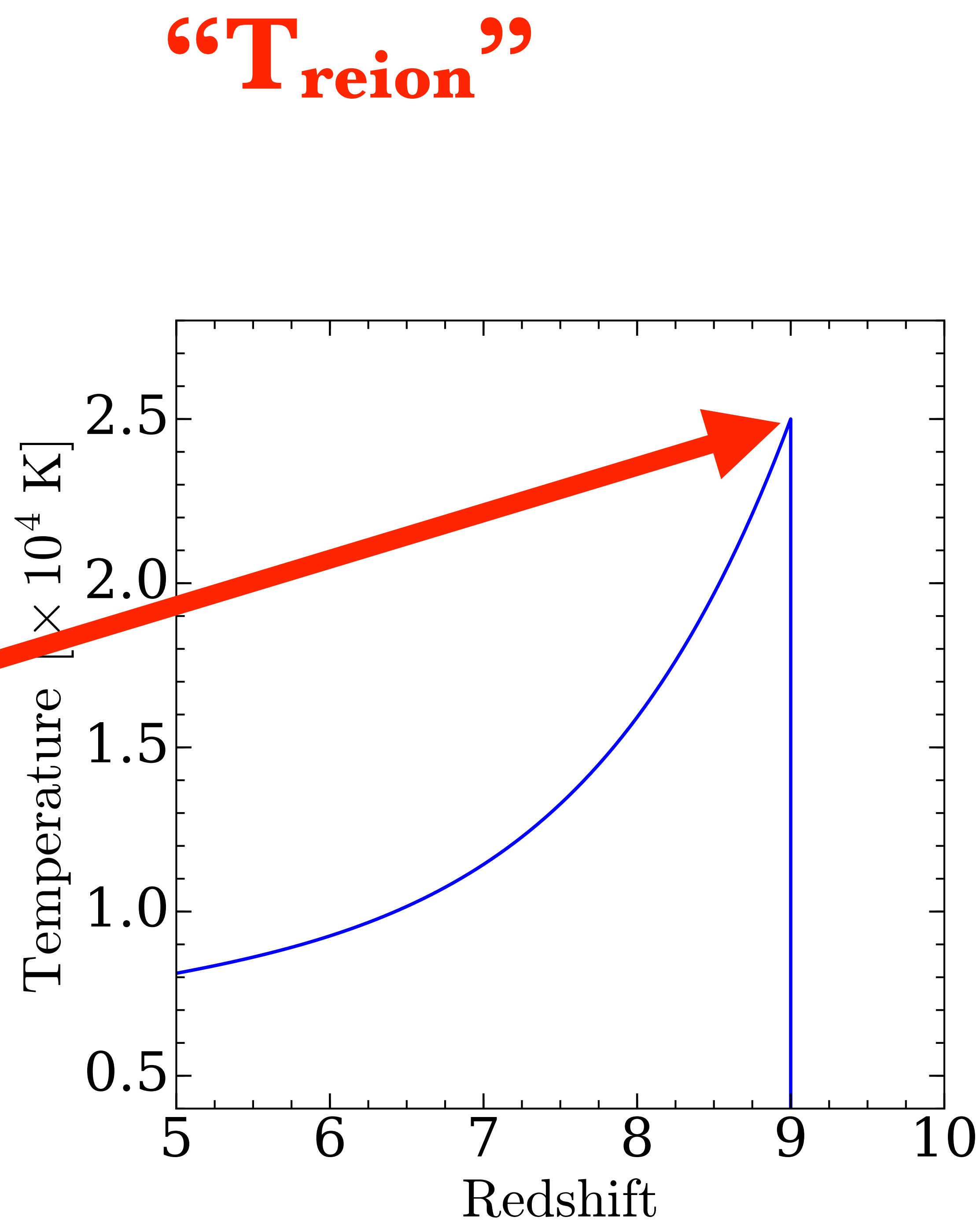
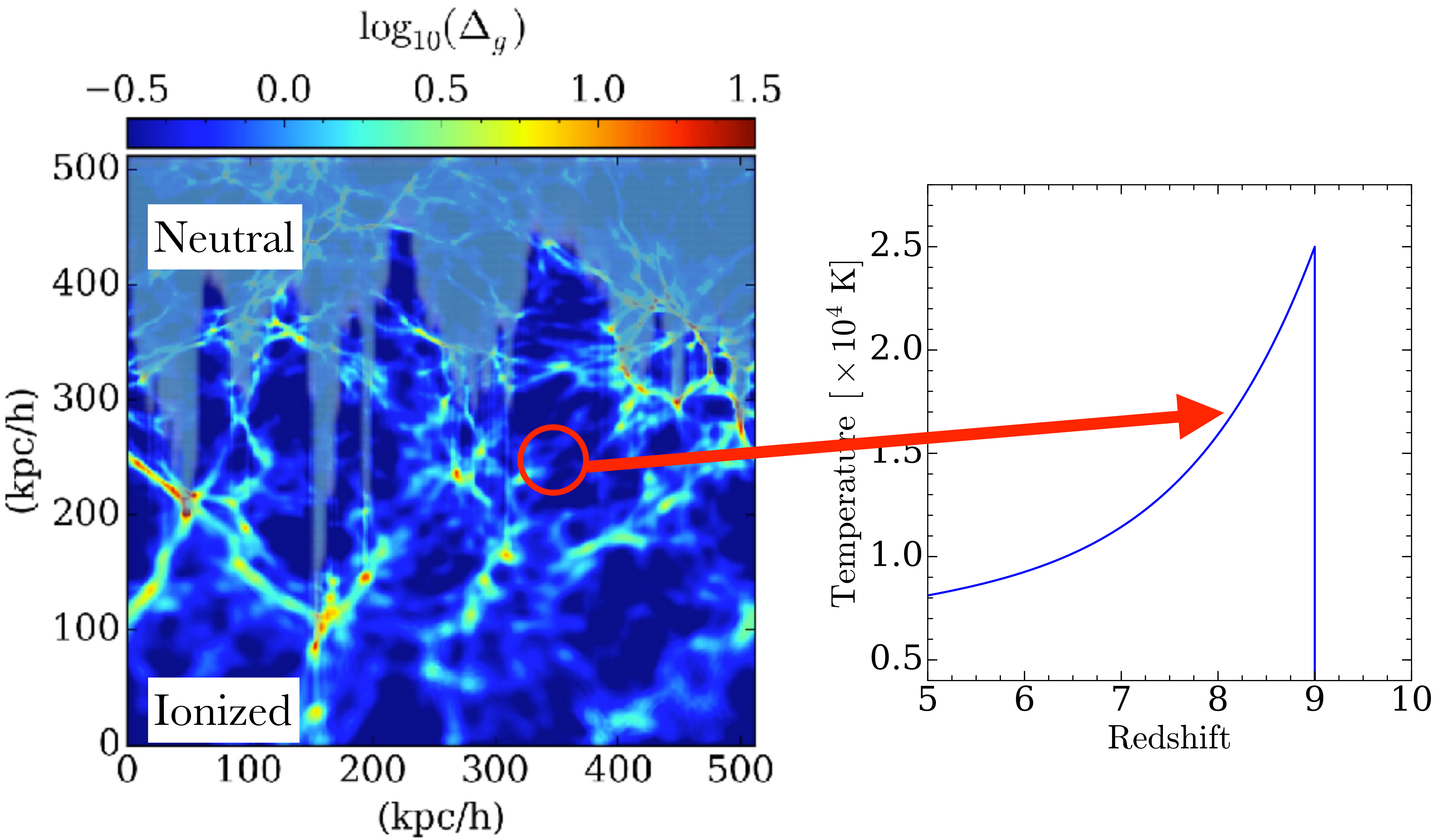
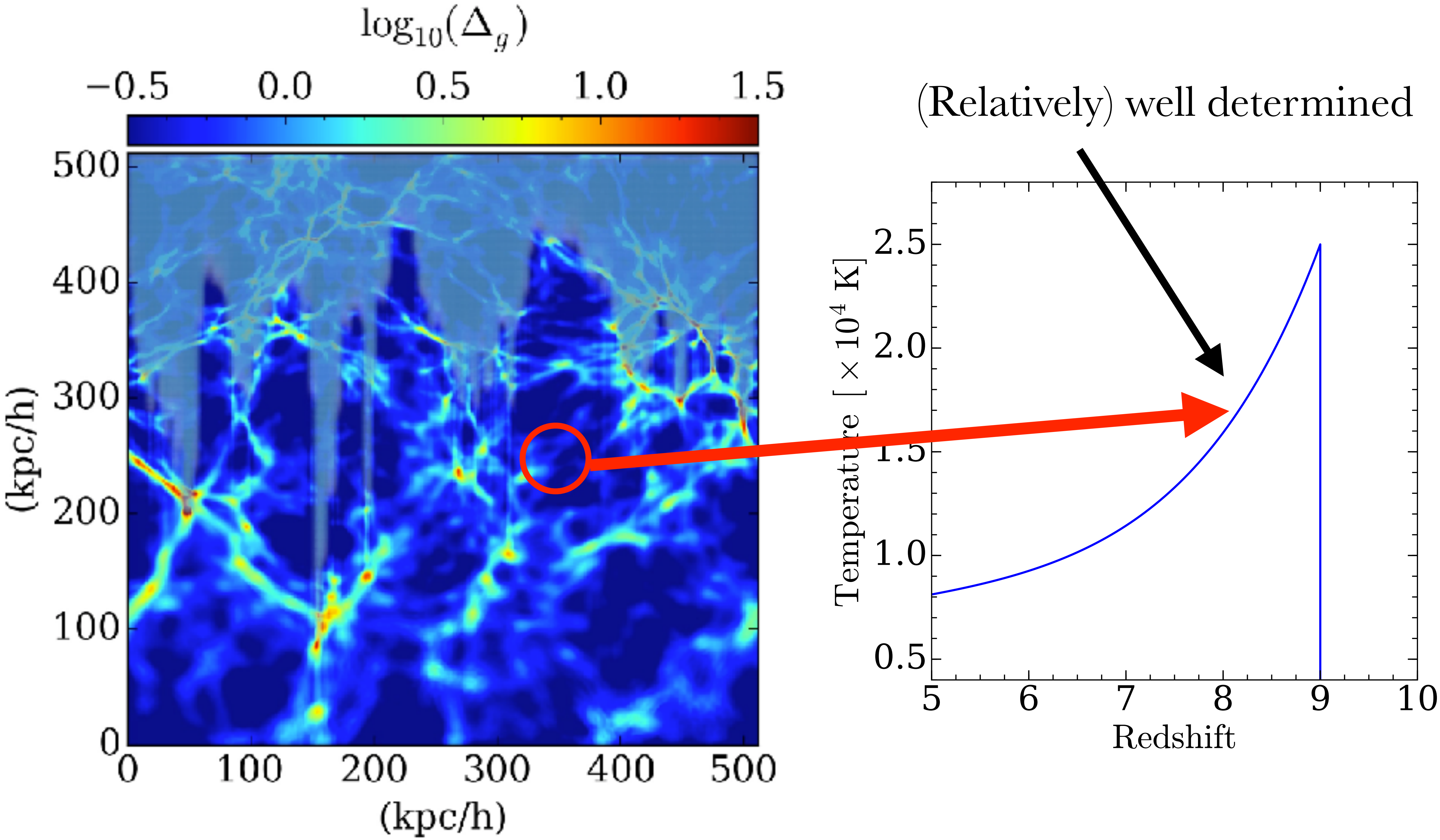




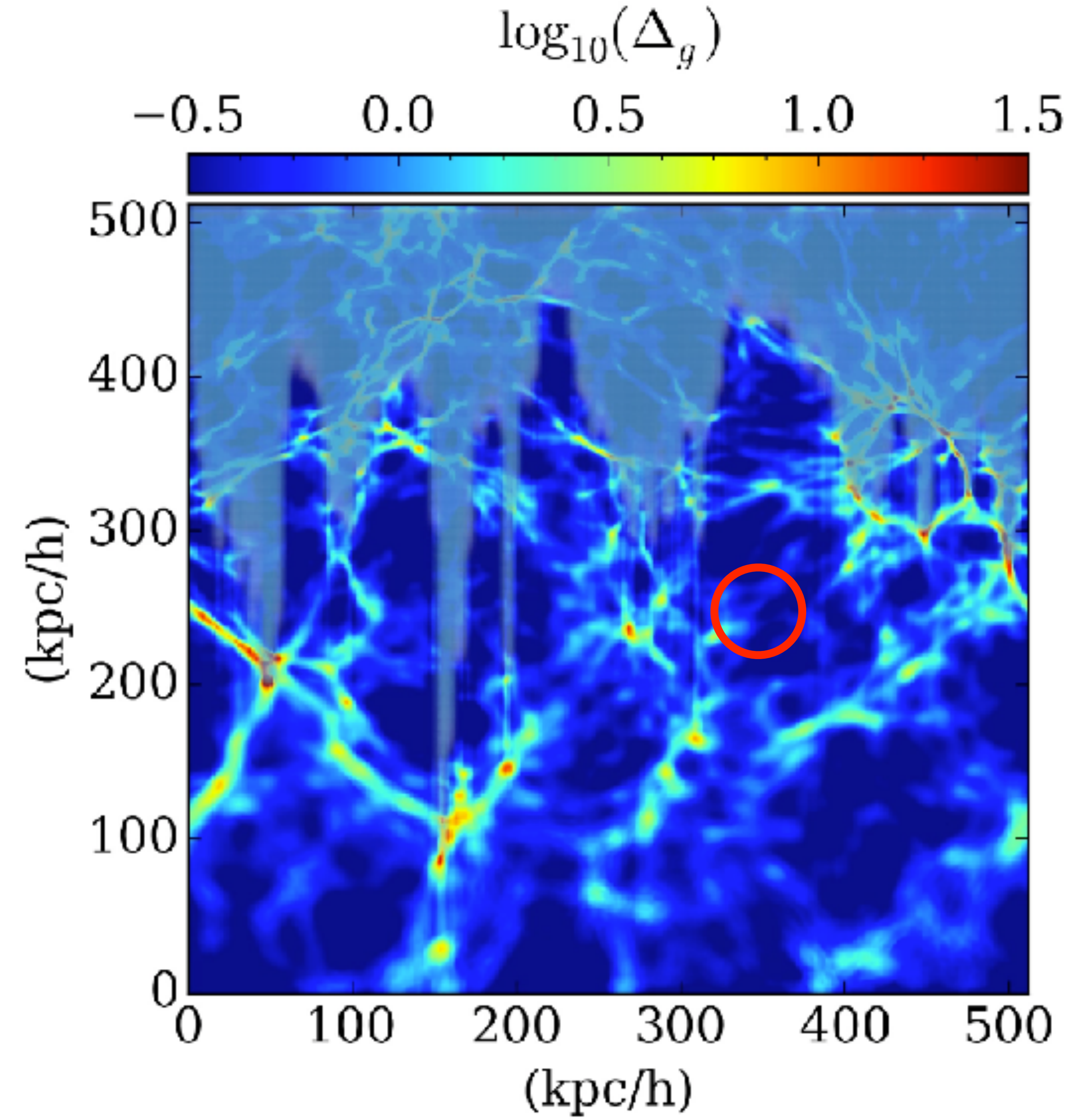
Heating by Reionization



Heating by Reionization

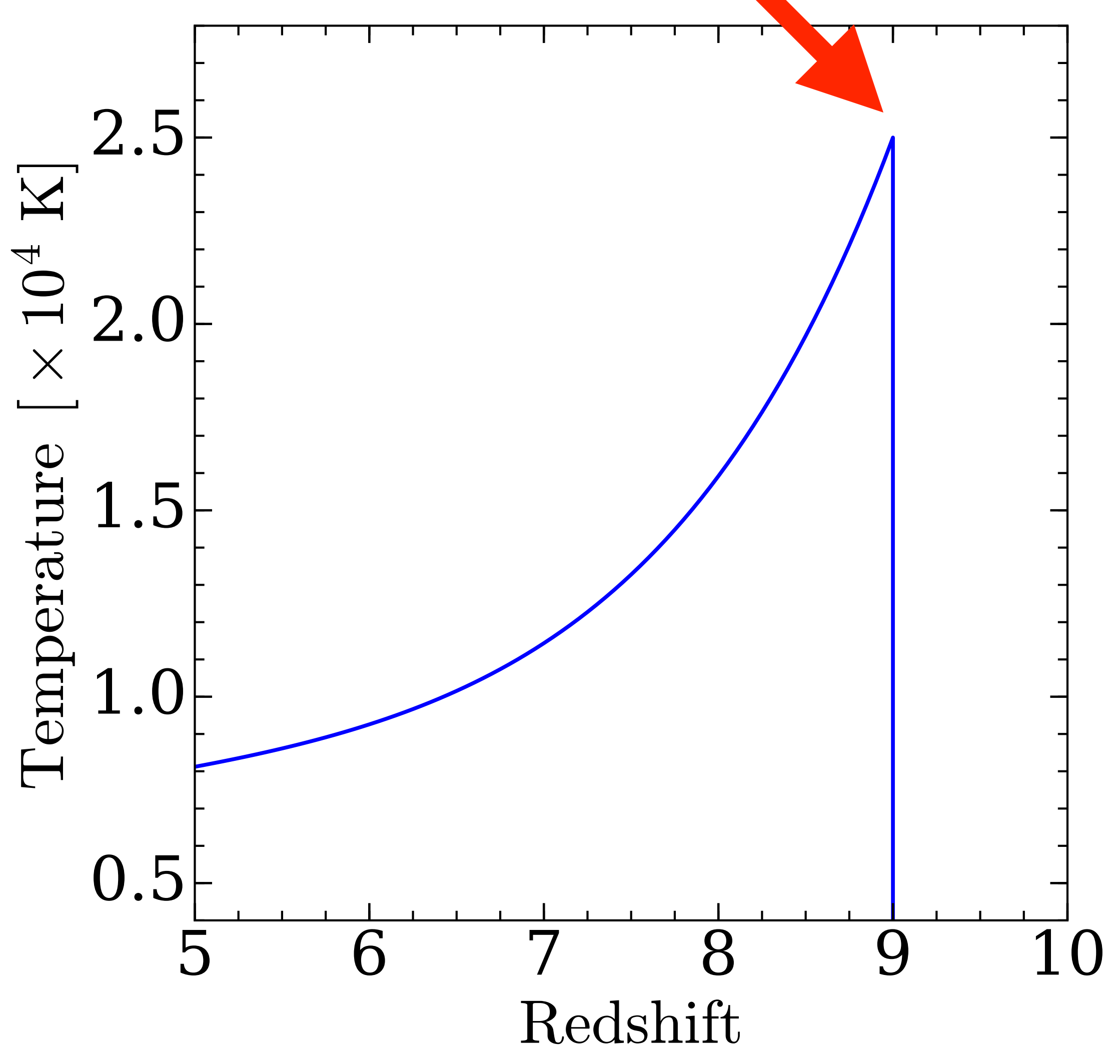


Heating by Reionization

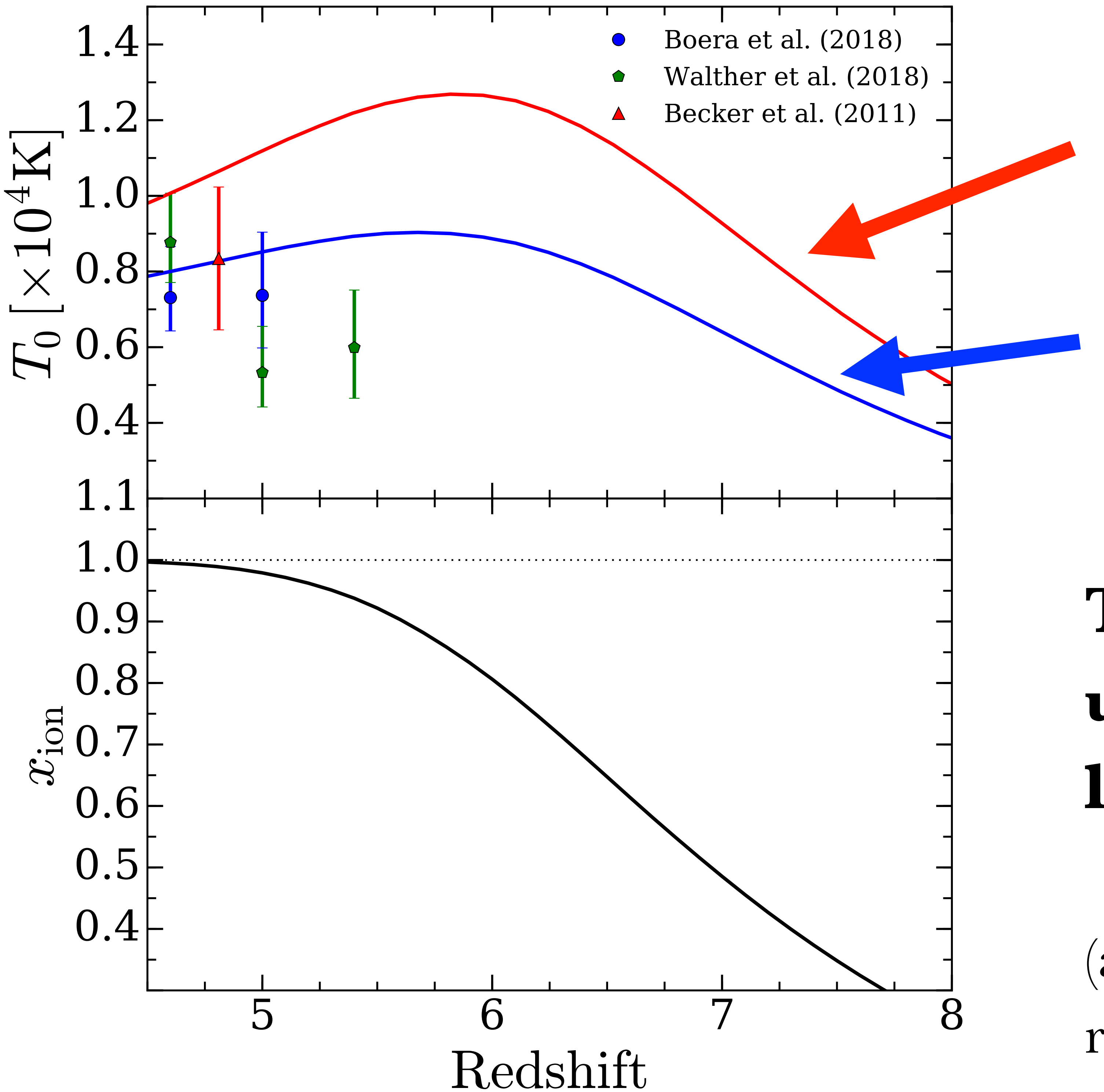


"T_{reion}" (uncertain)

Cannot resolve in cosmo. RT sims.



T_{reion} uncertainties in global history



T_{reion} = 25,000 K

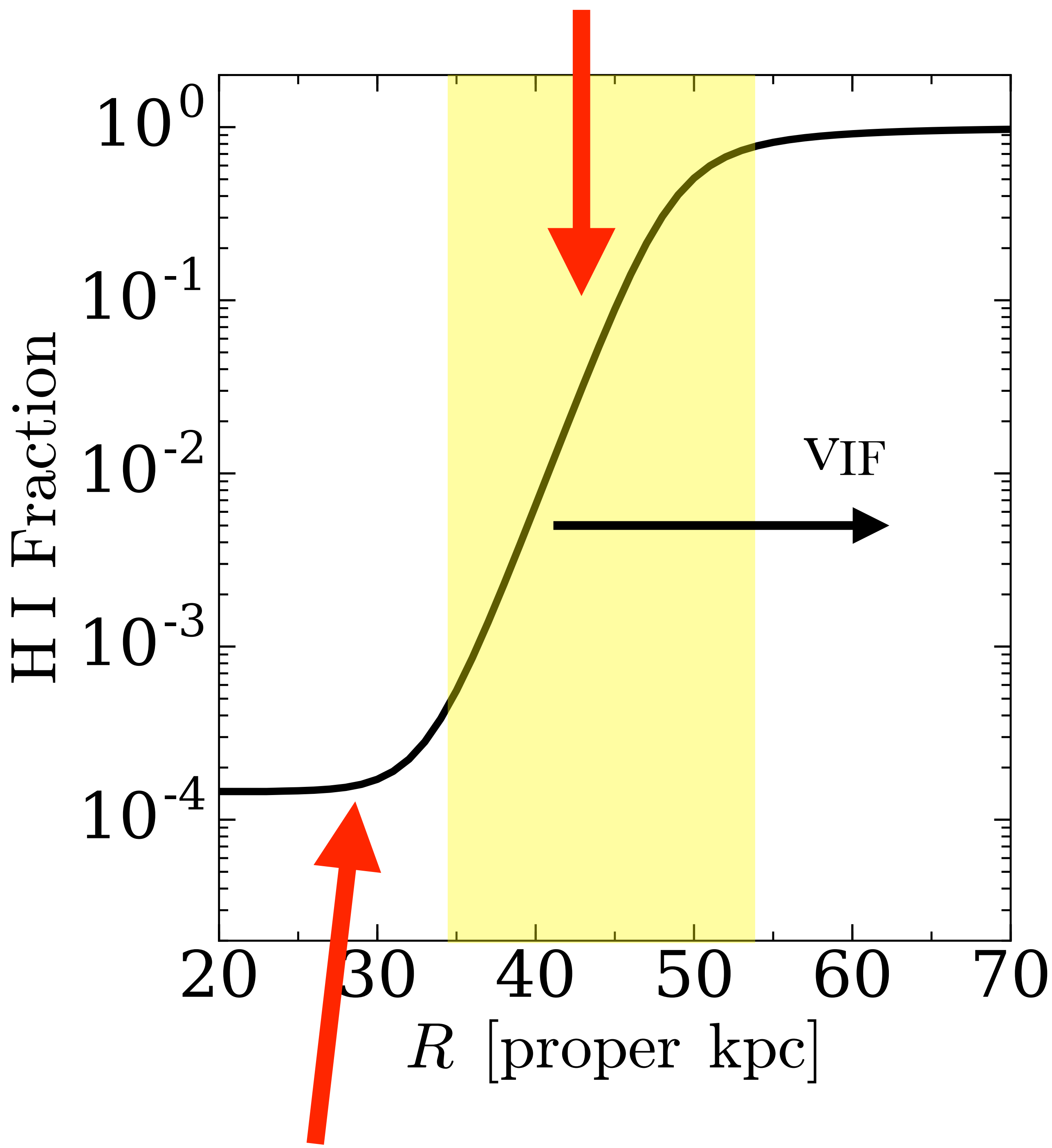
T_{reion} = 15,000 K

T_{reion} is dominant uncertainty for late-reion. models

(assuming galaxies drove reionization)

What Sets T_{reion}?

I-front heating and cooling



(See Miralda-Escudé & Rees 1994)

Main processes:

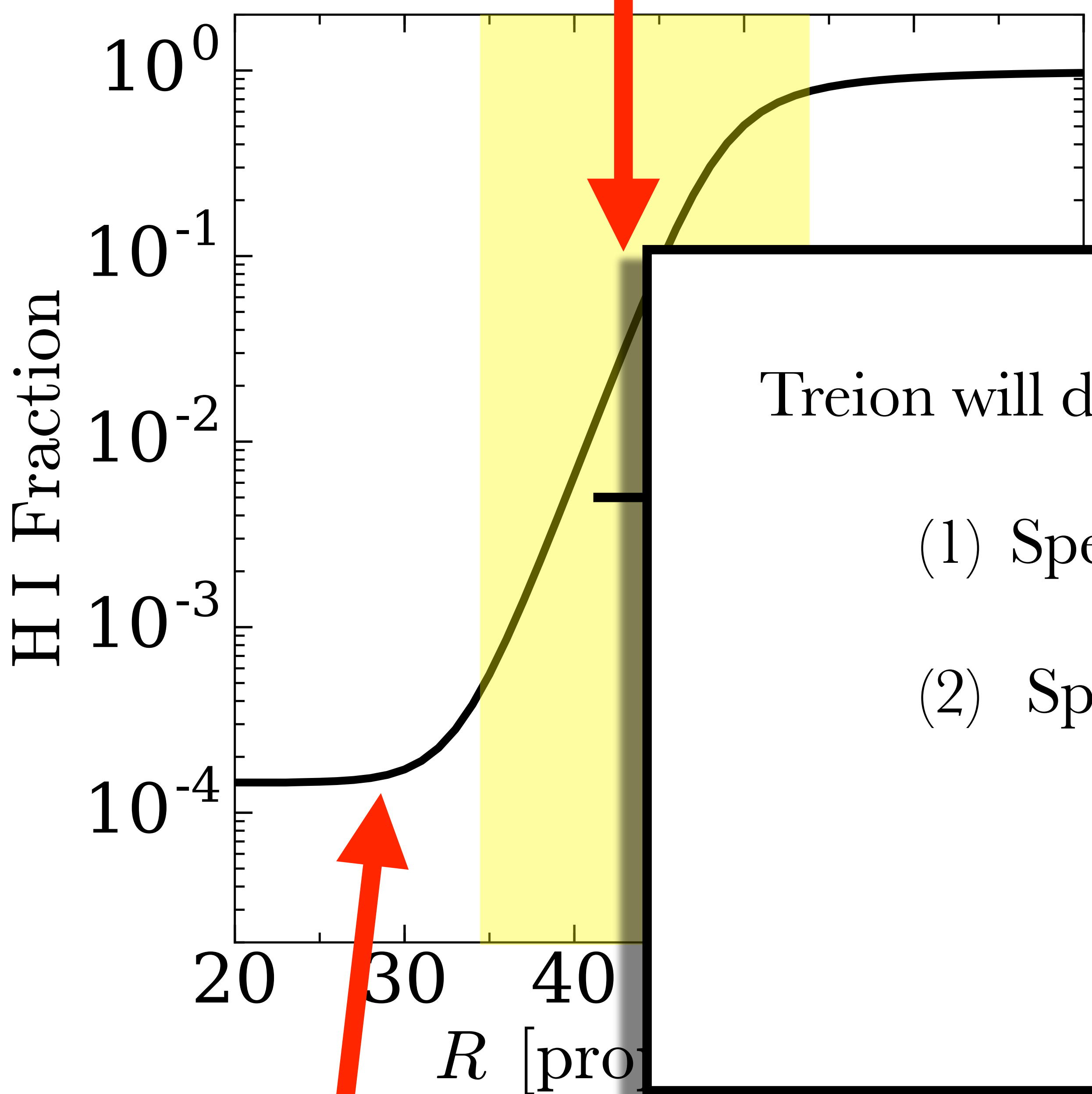
Photoheating

Collisionally excited line cooling

T_{reion} = temperature behind I-front

What Sets T_{reion}?

I-front heating and cooling



(See Miralda-Escude & Rees 1994)

Treion will depend on:

(1) Spectrum of ionizing radiation

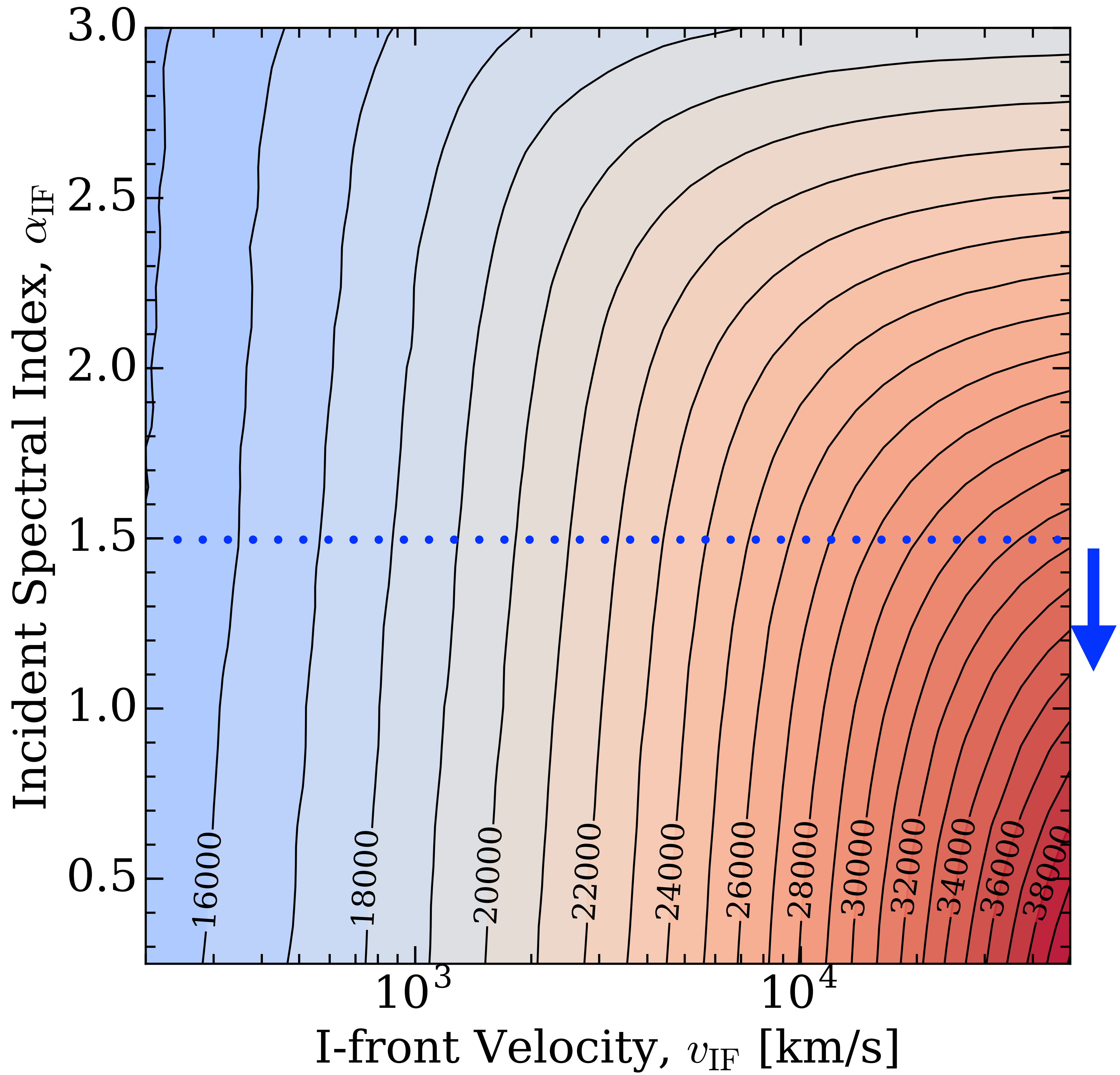
(2) Speed of I-front

T_{reion} = temperature behind I-front

Parameter Space of T_{reion}

D'Aloisio+19 (1807.09282)

- Suite of 1D high-res RT sims



$J_\nu \propto \nu^{-\alpha_{IF}}$

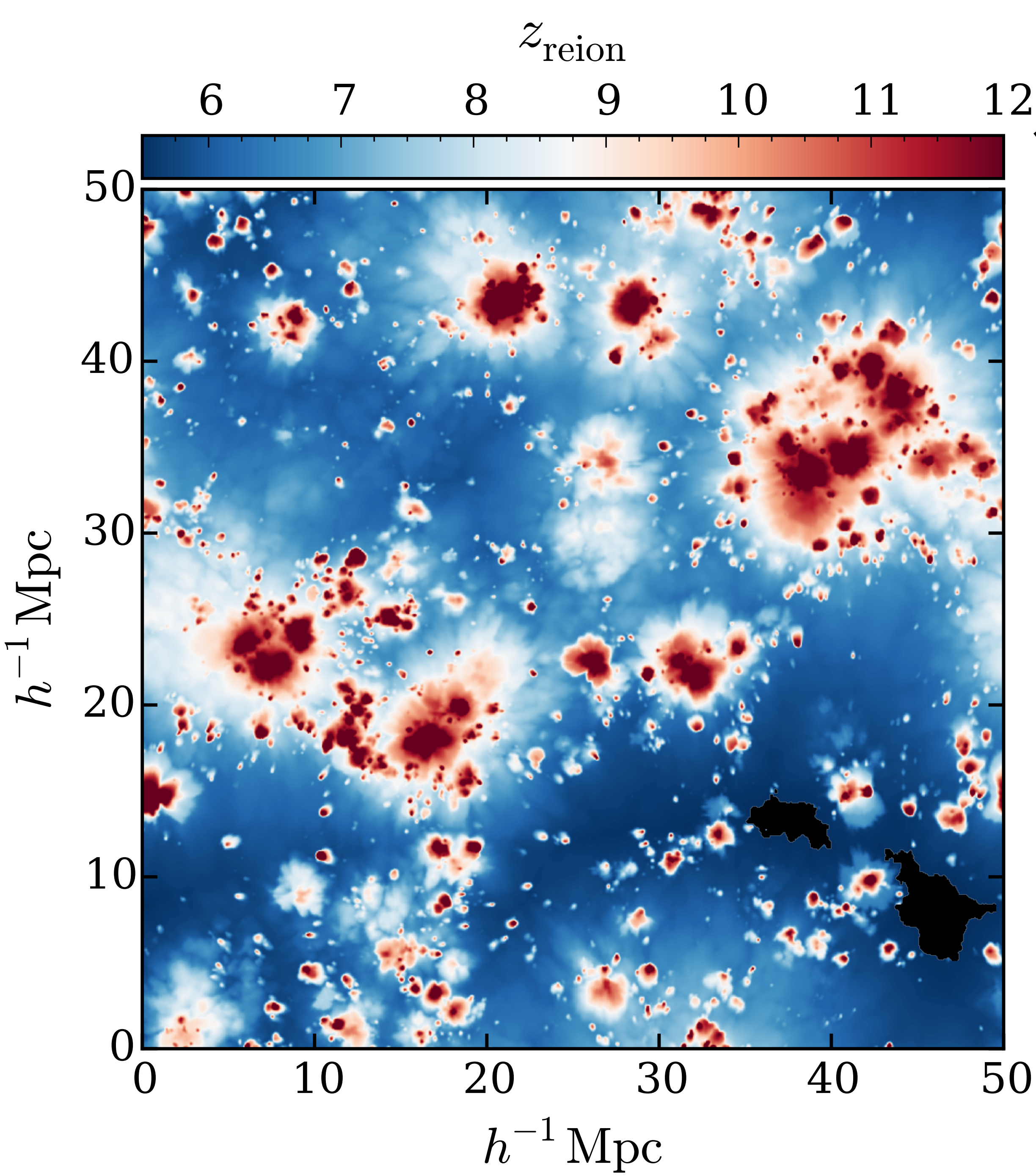
(1 - 4 Ry)

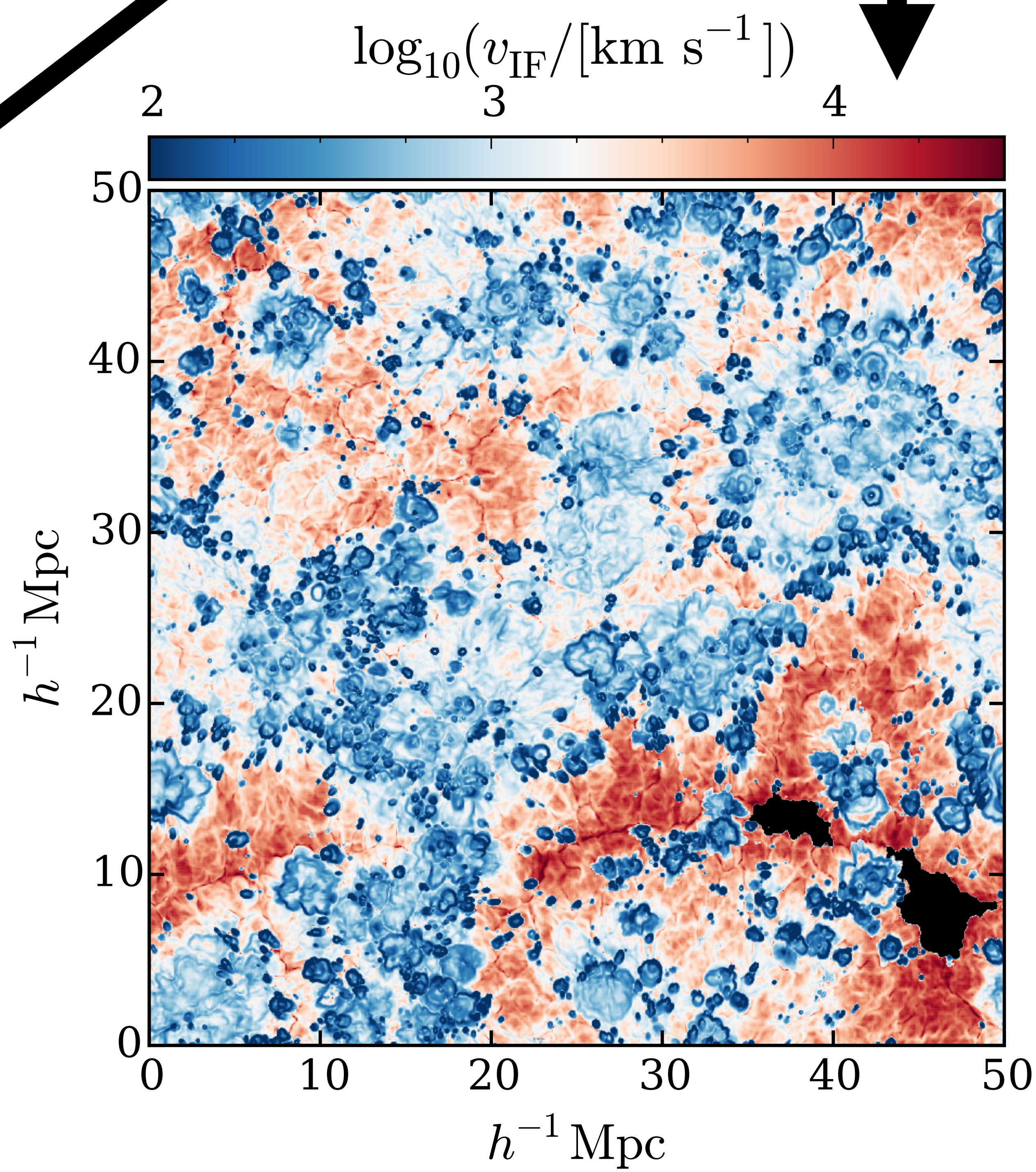
Application to Reionization Models

- SCORCH simulation suite.

(Trac et al. 2015; Price et al. 2016; Doussot et al. 2017

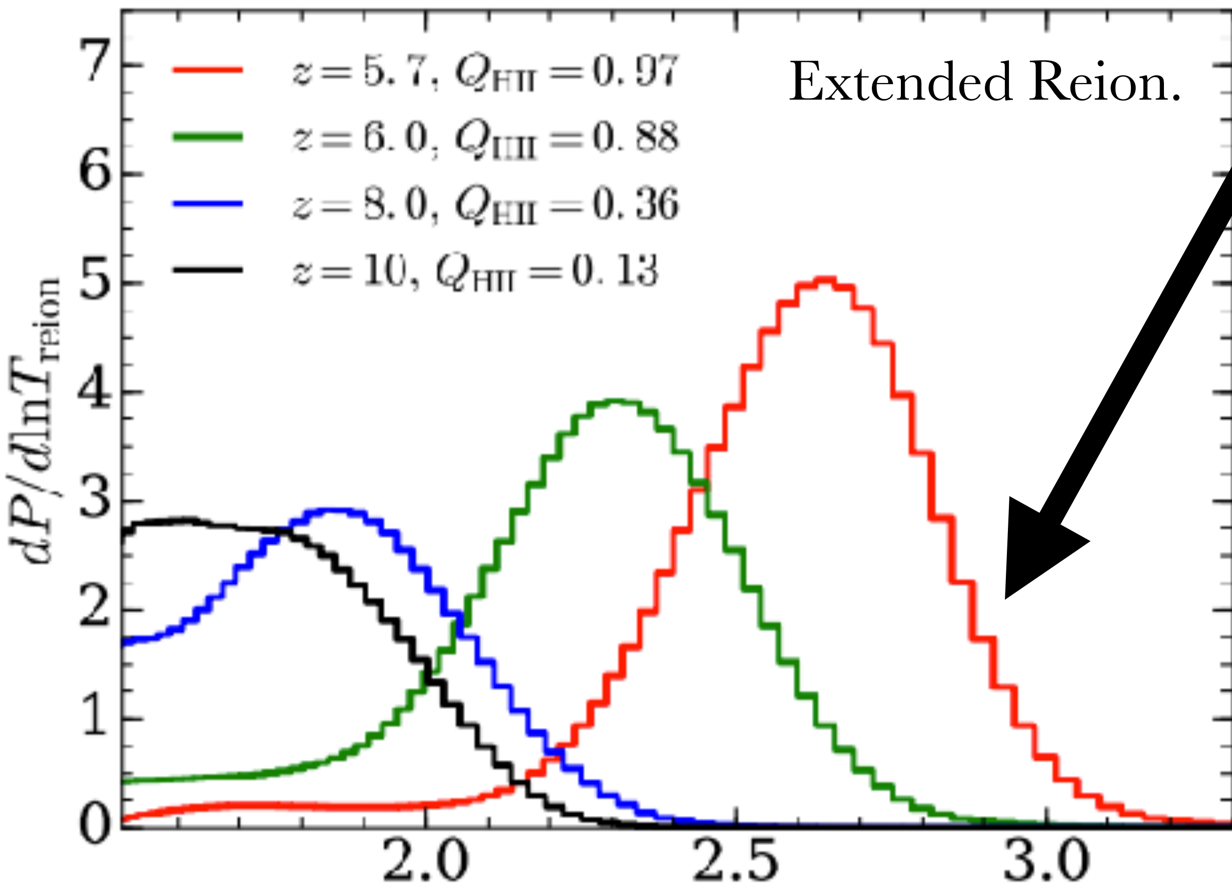
$$v_{\rm IF} = \frac{a}{|\nabla z_{\rm reion}|}\frac{dz}{dt}$$

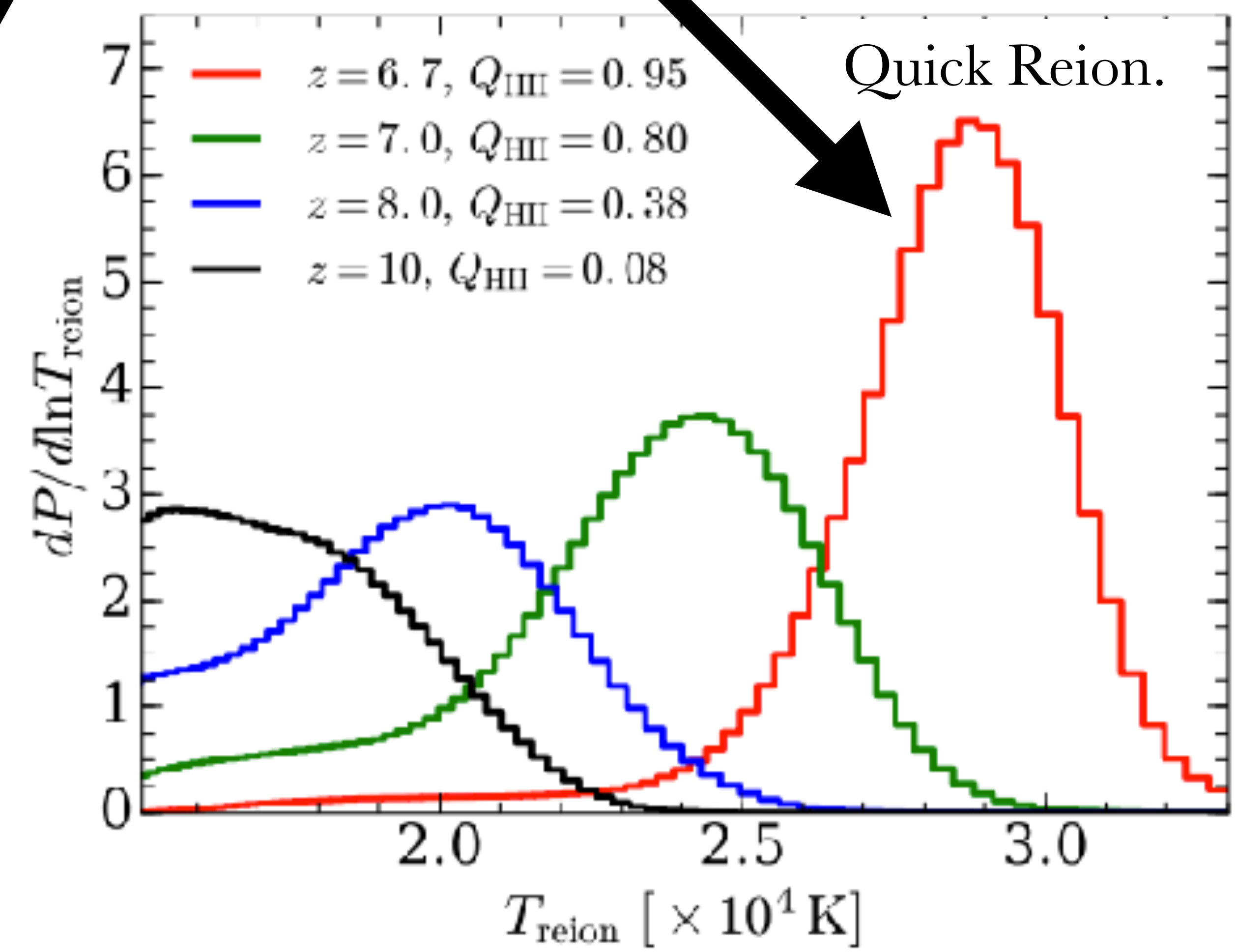




T_{reion} = 20,000 - 30,000 K

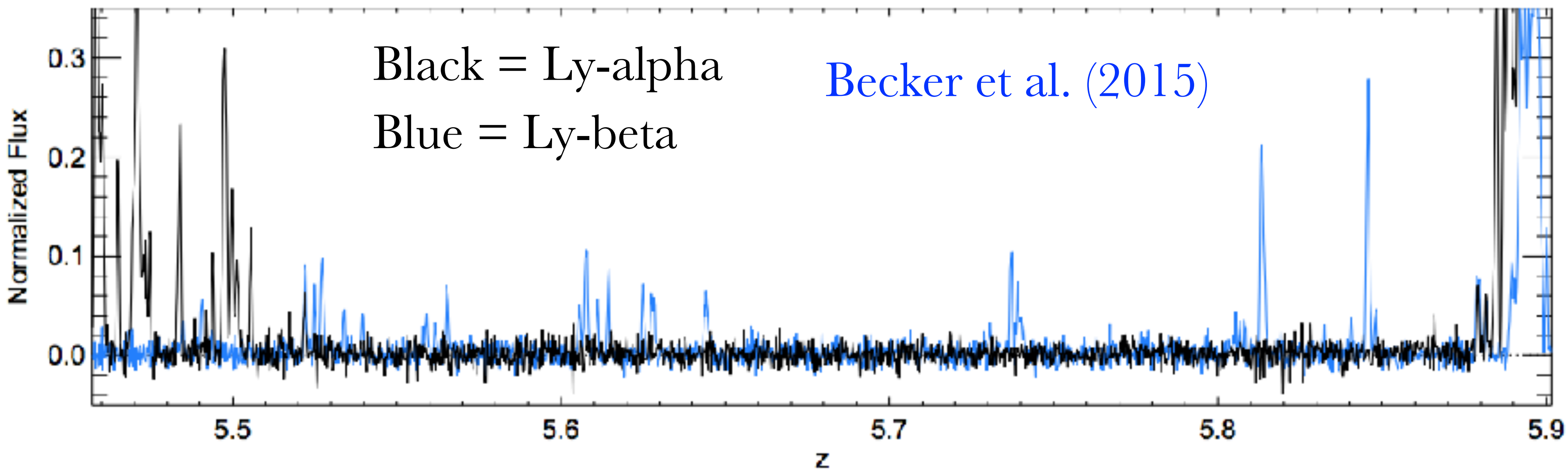
Voids





D'Aloisio+19 (1807.09282)

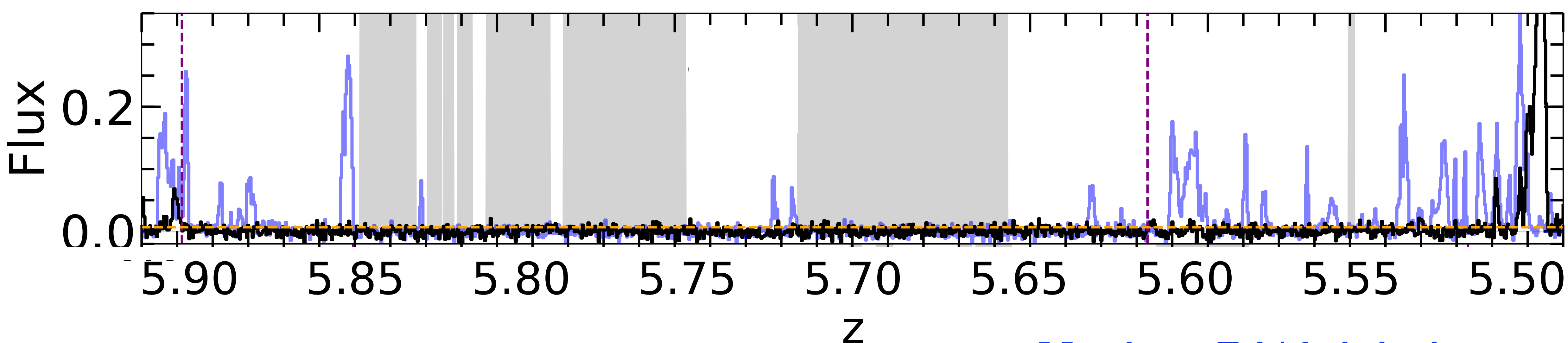
Reionization ongoing at z < 6? (ULAS J0148)



150 Mpc!

Neutral islands

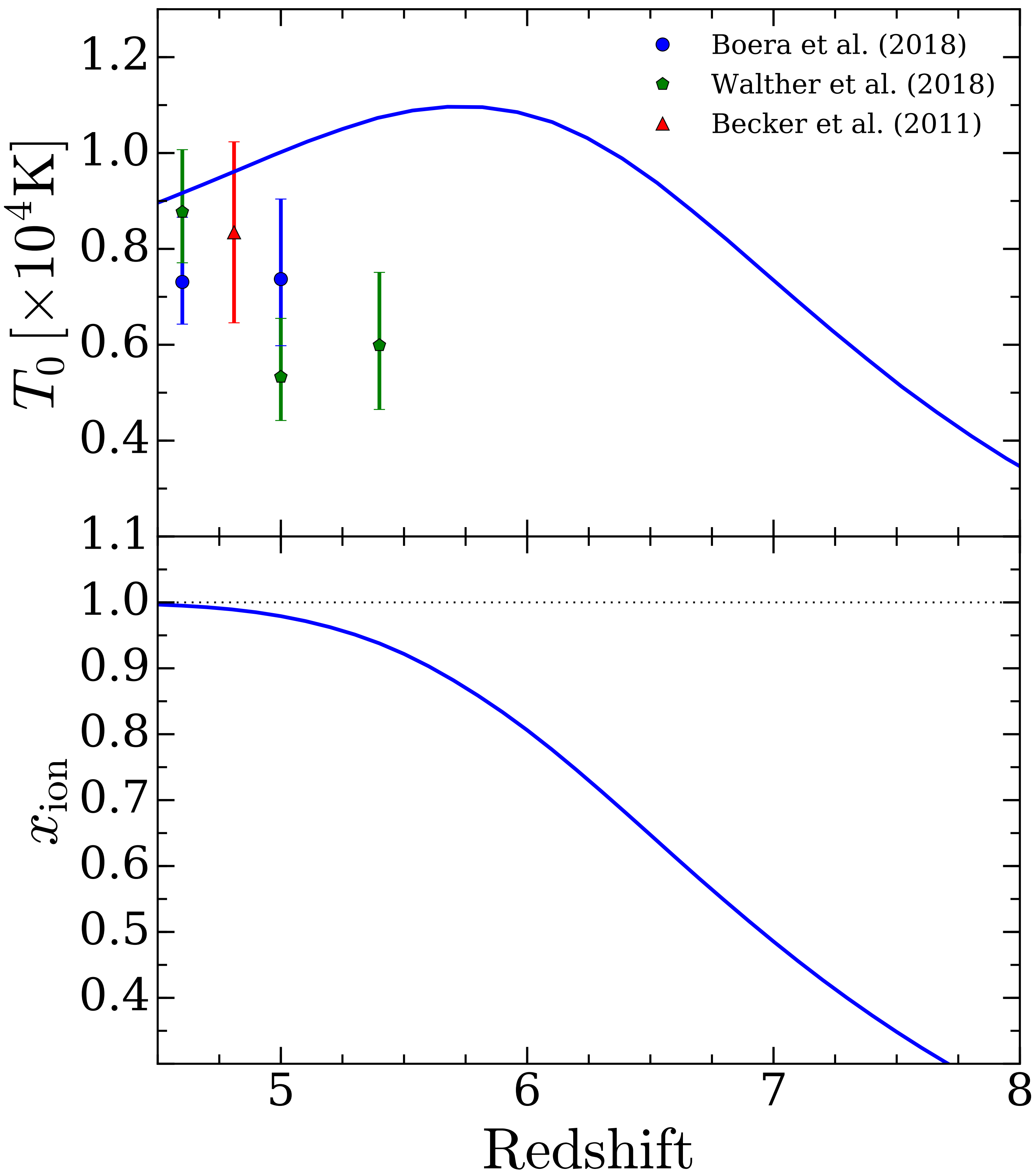
Simulated



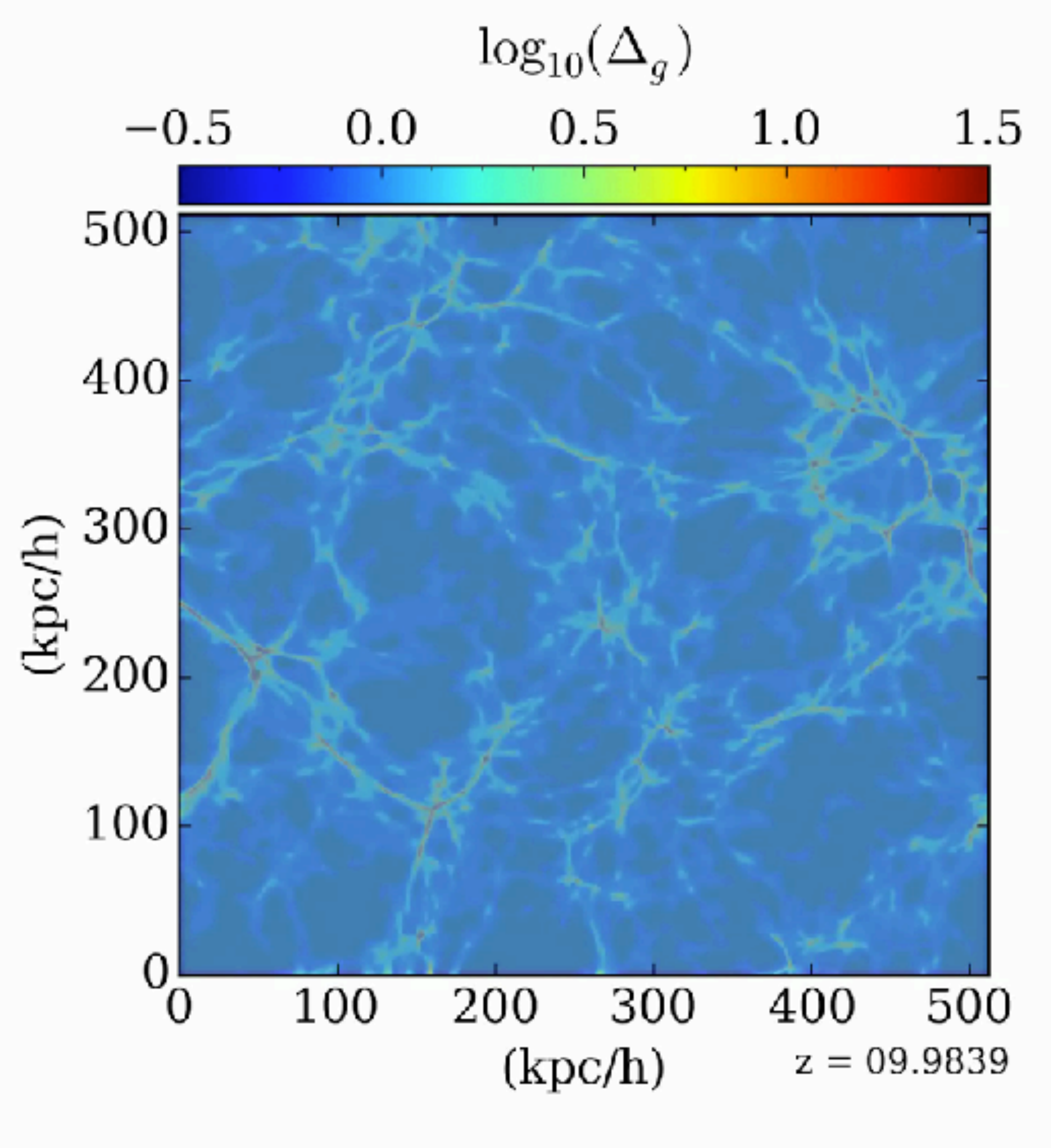
Nasir & D'Aloisio in prep.

See also Kulkarni+2019; Keating+2019

Thermal History Constraints on Late Reionization



Pressure Smoothing Effects



I-front speeds:

$$v_{\mathrm{IF}} = \left(5.7 \times 10^3 \frac{\mathrm{km}}{\mathrm{s}}\right) \Delta^{-1} \left(\frac{1+z}{7}\right)^{-3} \left(\frac{\Gamma_{-12}}{0.1}\right)$$

Sound speed:

$$c_s \approx \left(22 \frac{\mathrm{km}}{\mathrm{s}}\right) \left(\frac{T}{20,000\mathrm{K}}\right)^{1/2}$$

Summary

- Observations are converging on late reionization.
- To better constrain models with the forest, we need to nail down their expected thermal histories.
- T_{reion} is an important piece of the modeling.
- Gas relaxation effects may be important for modeling reionization and interpreting the forest.