Probing reionization with Lyman-alpha and 21cm emission/absorption

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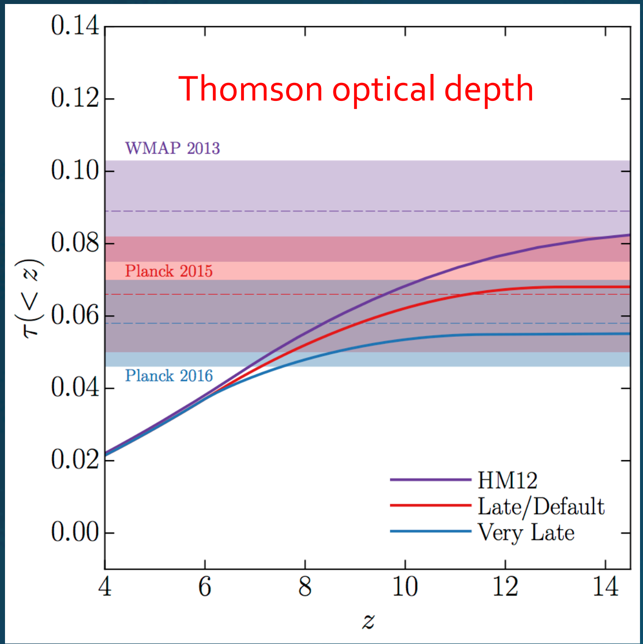
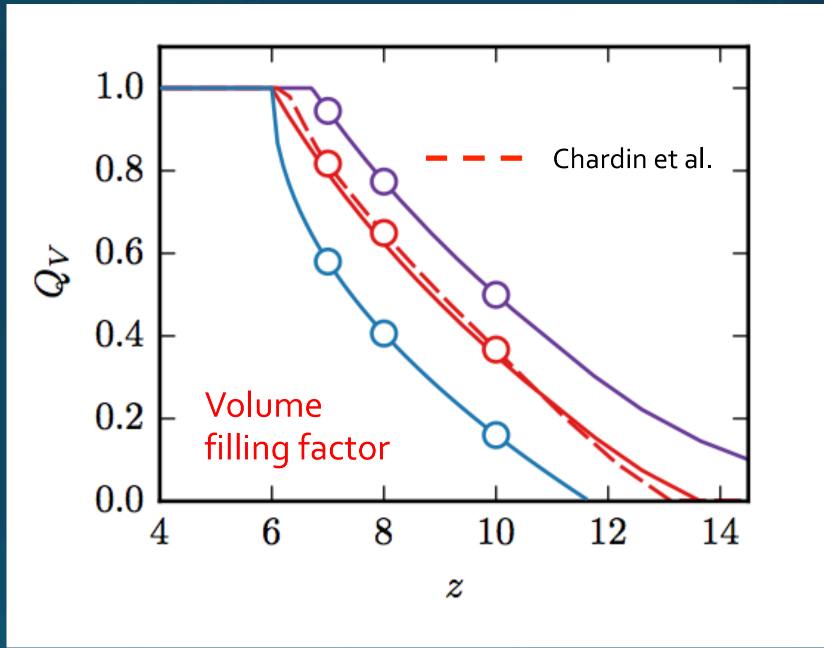
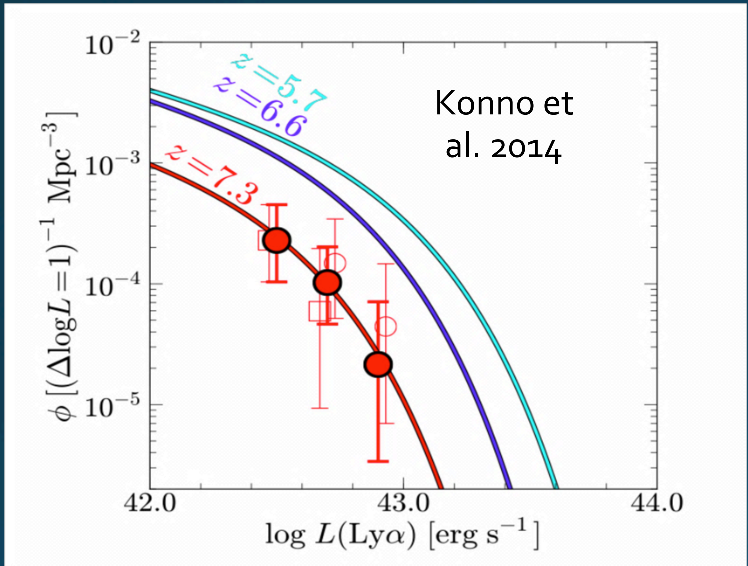
Homing in on the reionization history

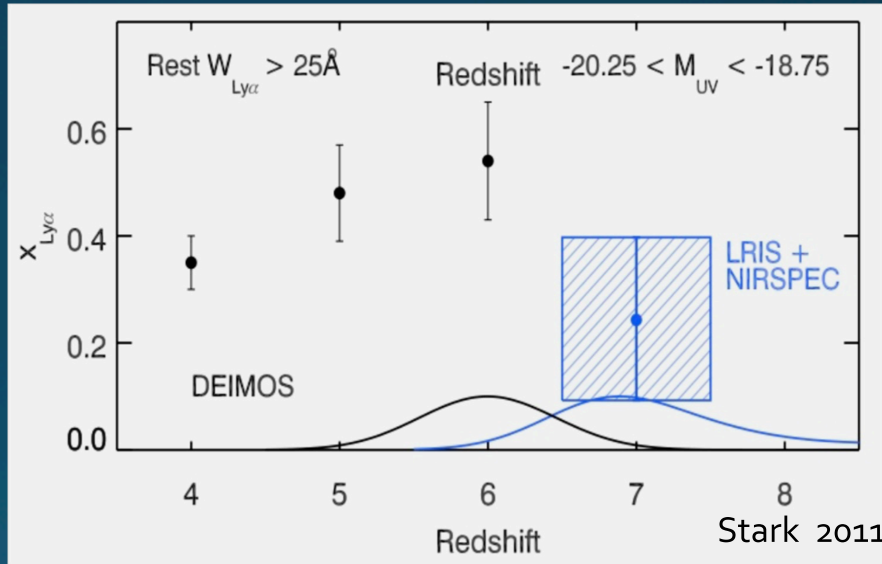




Haardt & Madau 2012 appears to reionize somewhat too early.

The rapid demise of Lyα emission at z>6

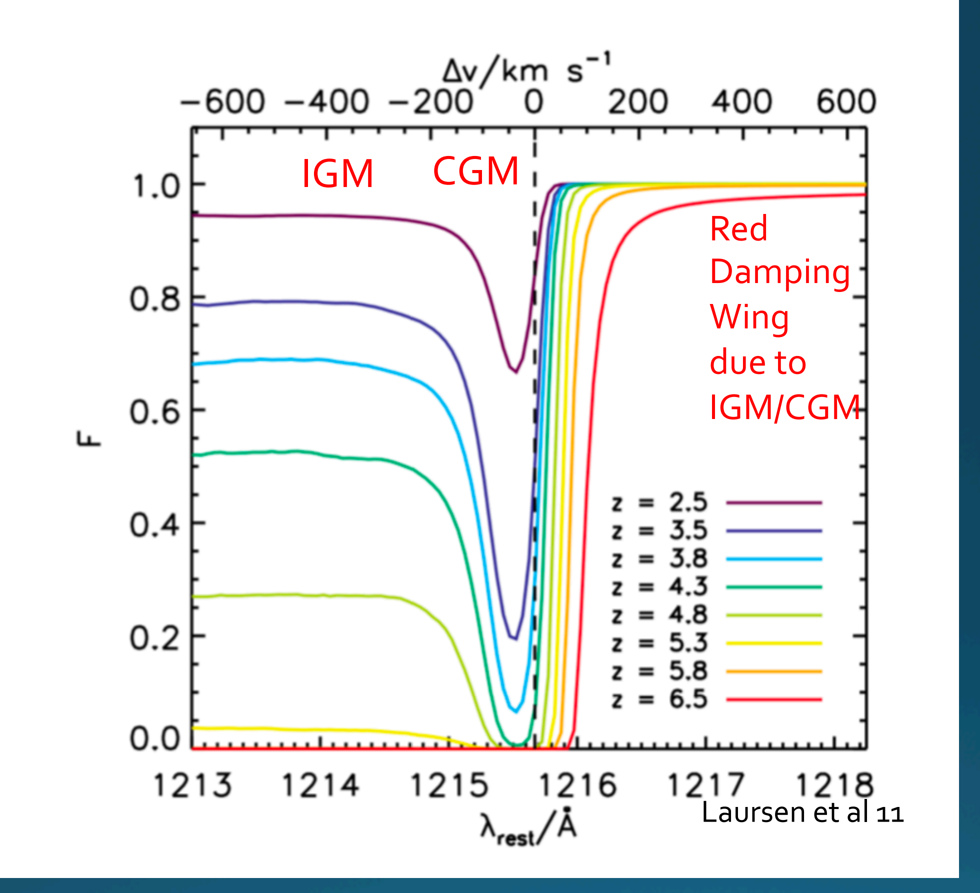




Stark 2011

Unlike continuum selected galaxies Lyman-alpha emitters (LAE) appear to "disappear" very rapidly at z>6. This has been claimed not to be the case for very bright LAEs.

Lyman-alpha transmission fraction



$$e^{-\tau}$$

Suppression has to be calculated in velocity space so peculiar velocities are important.

Lyman-α emitters gone missing: the different evolution of the bright and faint populations

Lewis H. Weinberger[1⋆], Girish Kulkarni[1], Martin G. Haehnelt[1], Tirthankar Roy Choudhury[2] and Ewald Puchwein[1]
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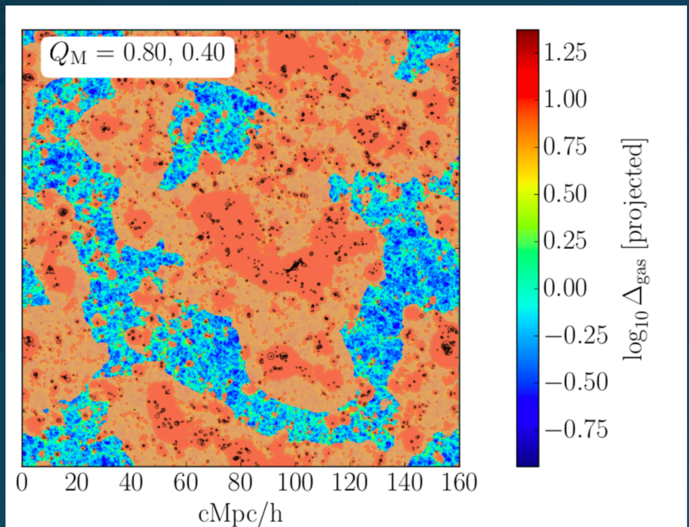

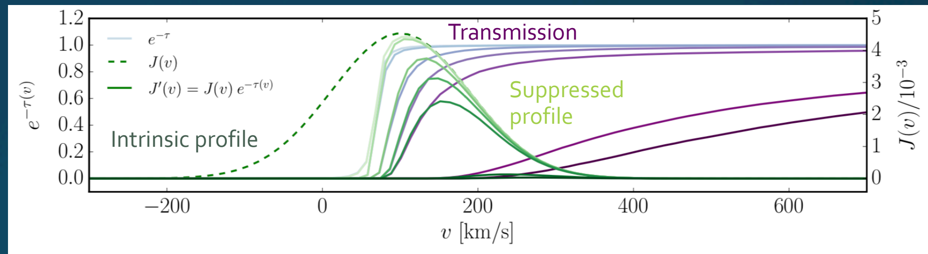

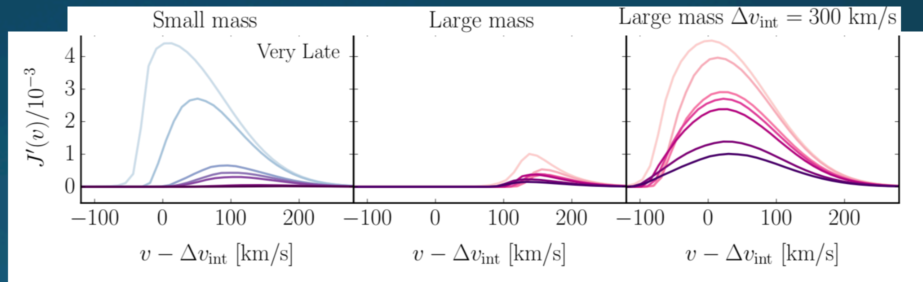

Lyman-α emitters gone missing: the different evolution of the bright and faint populations

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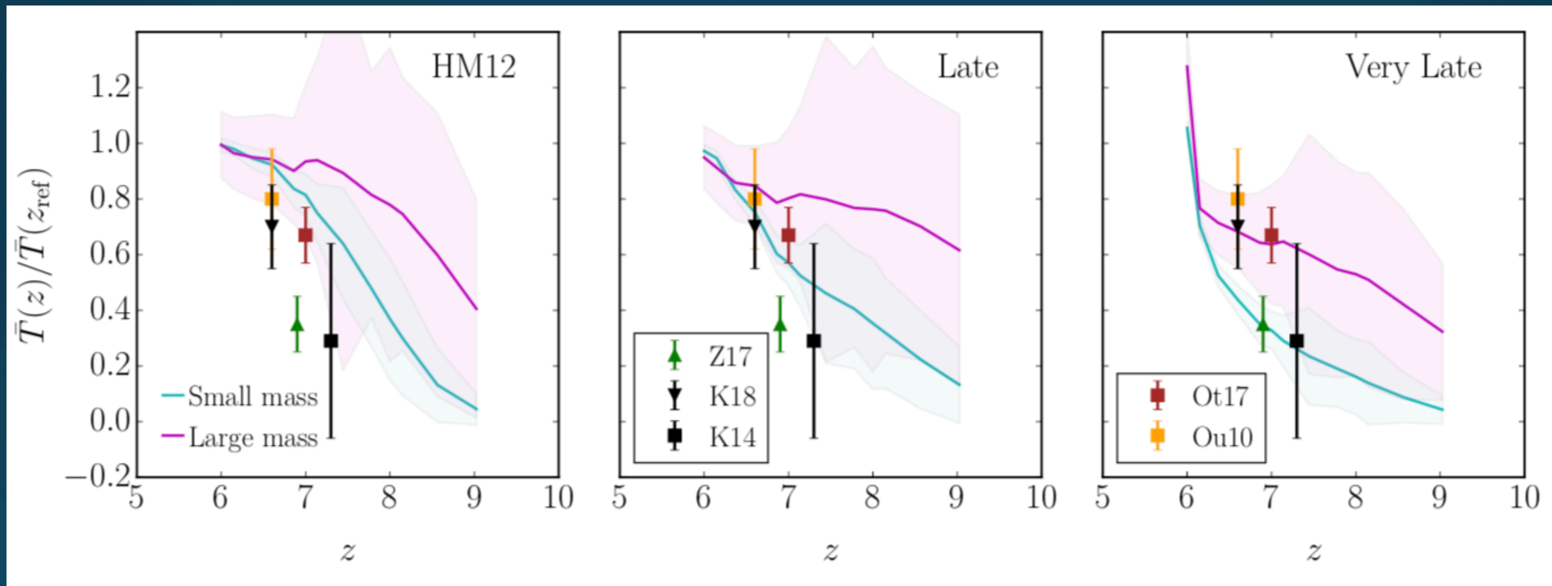
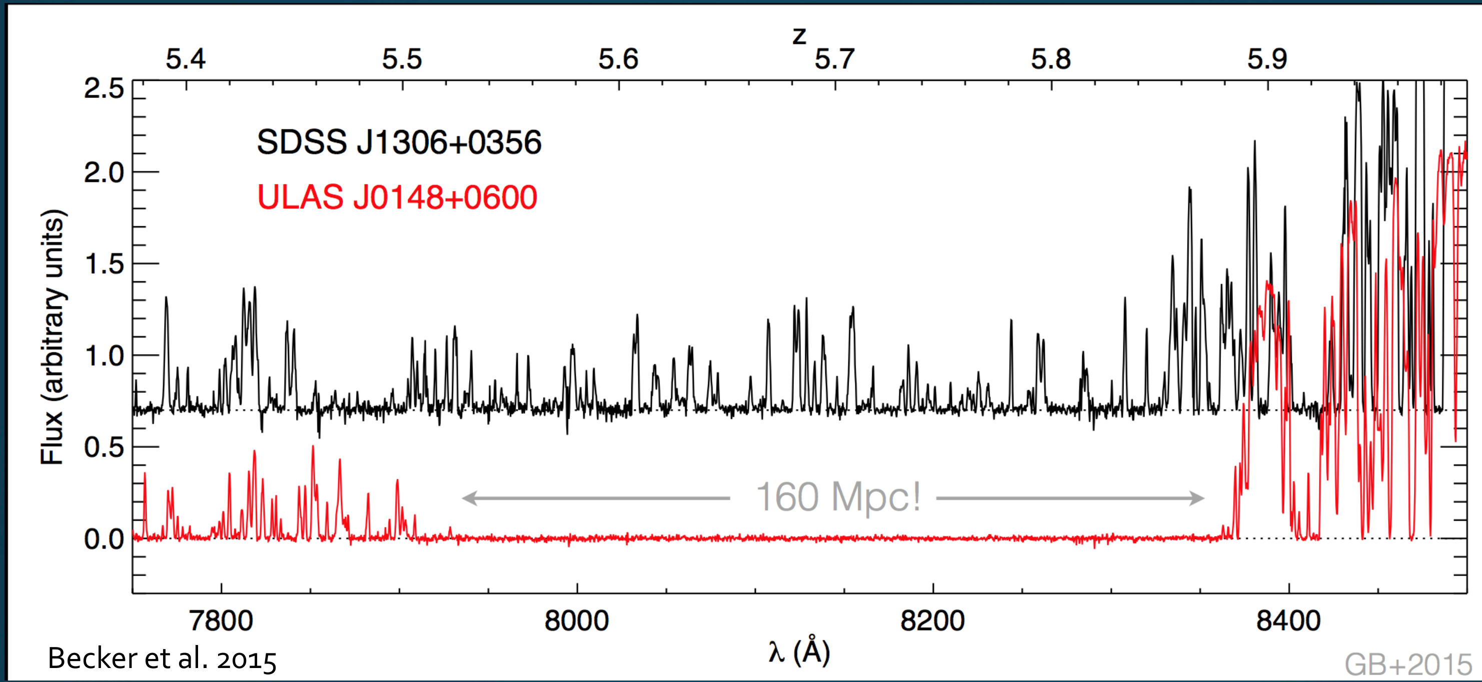
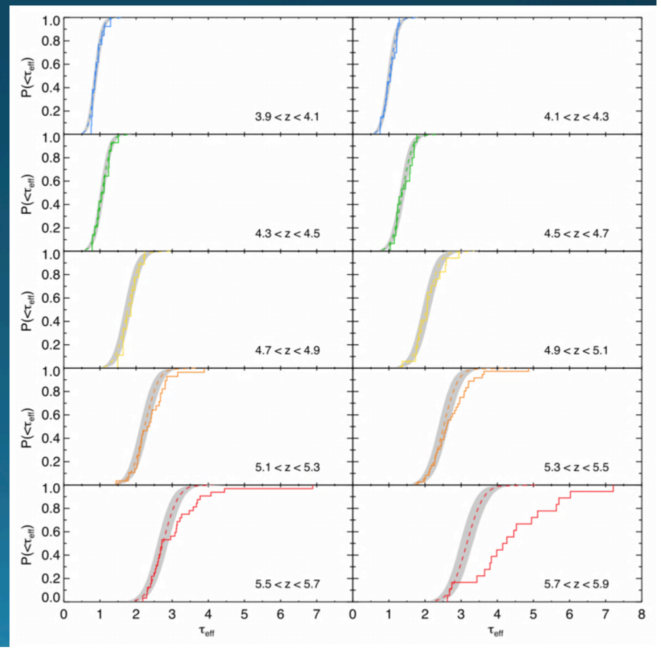


- ➢ The transmission fraction drops less rapidly for LAEs hosted by more massive haloes.
- ➢ Rather late reionization histories are favoured.



The large fluctuations of the optical depth extend to surprisinglylarge scales.

Are there still large completely neutral regions even at z~5.5?



Calibrating cosmological radiative transfer simulations with Lyα forest data: Evidence for large spatial UV background fluctuations at $z \sim 5.6 - 5.8$ due to rare bright sources

Jonathan Chardin[1]*, Martin G. Haehnelt[1], Dominique Aubert[2] and Ewald Puchwein[1]
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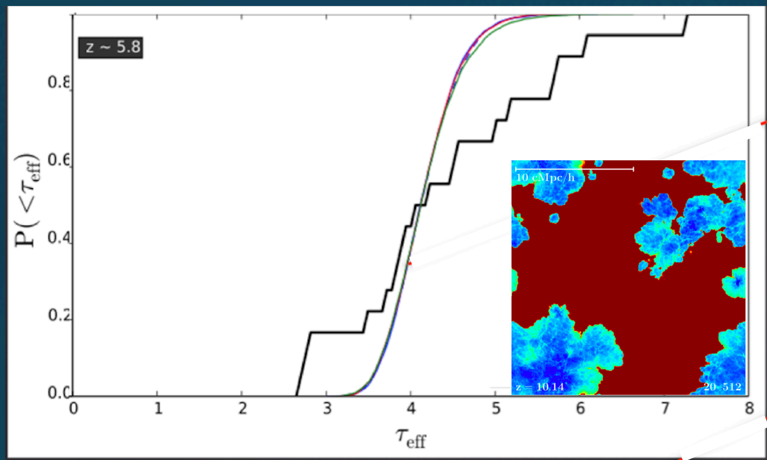
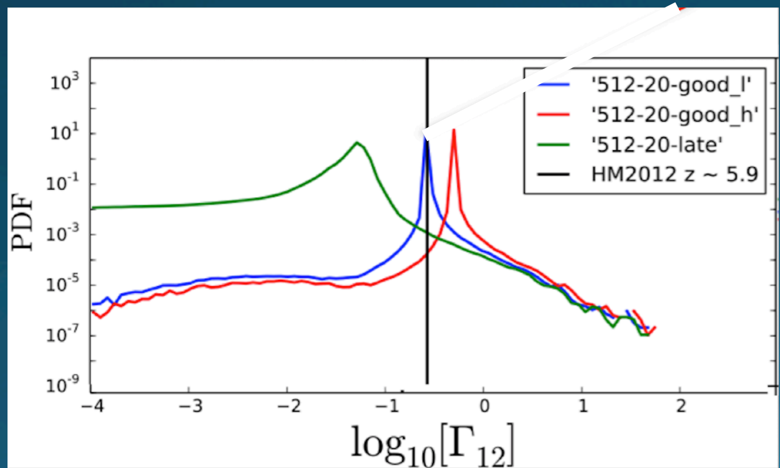




Bad Surprise:

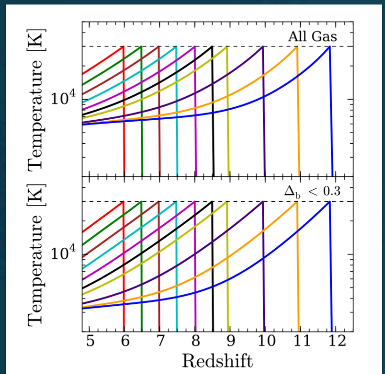
PDF is very similar to that of optically thin simulations without RT and not as broad as observed.

UV fluctuations damp out very quickly following percolation of HII regions as marked by the rapid rise of the mean free path.

LARGE OPACITY VARIATIONS IN THE HIGH-REDSHIFT LYα FOREST: THE SIGNATURE OF RELIC TEMPERATURE FLUCTUATIONS FROM PATCHY REIONIZATION

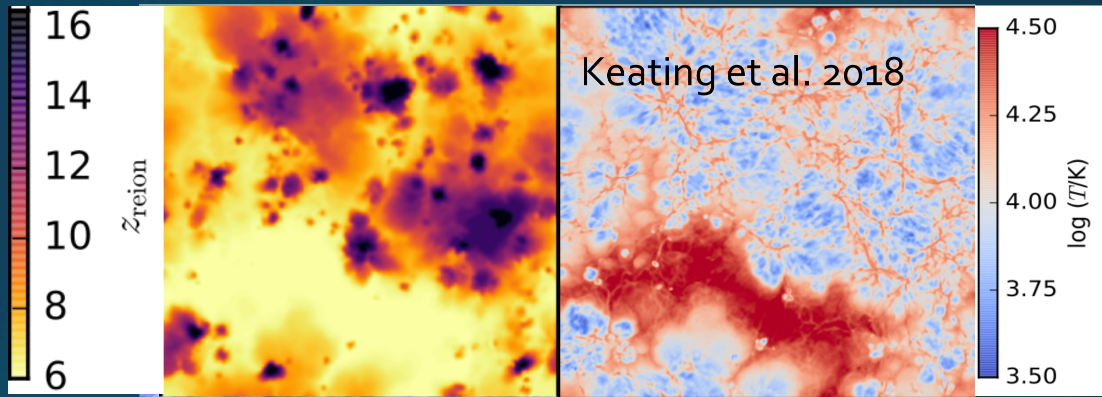
ANSON D'ALOISIO[1†], MATTHEW MCQUINN[1], & HY TRAC[2]

Draft version December 2, 2015



Temperature dependence of recombinations

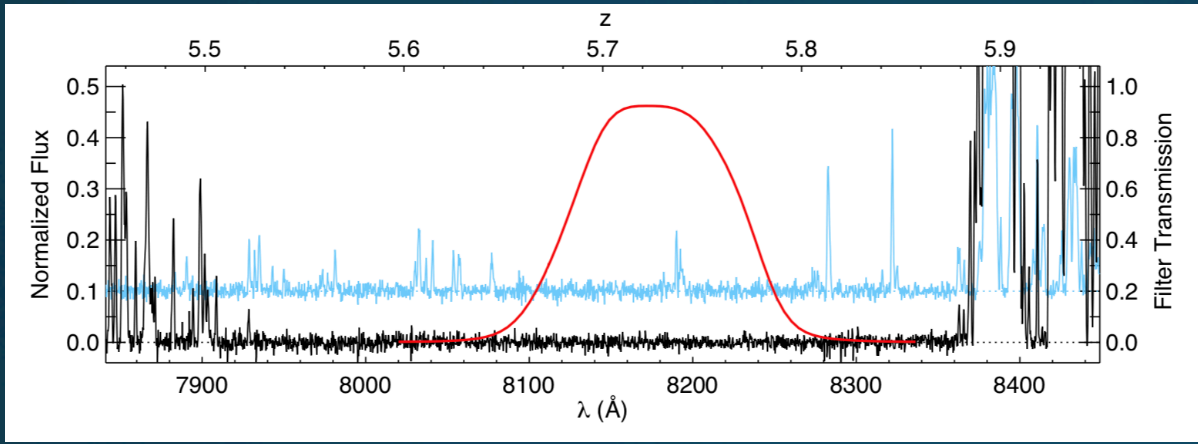
$n_{HI} \propto T^{-0.7}$

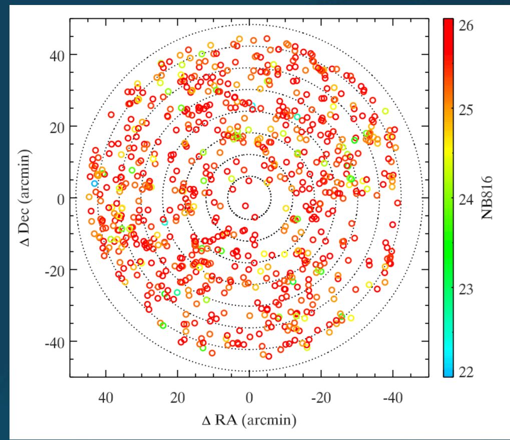


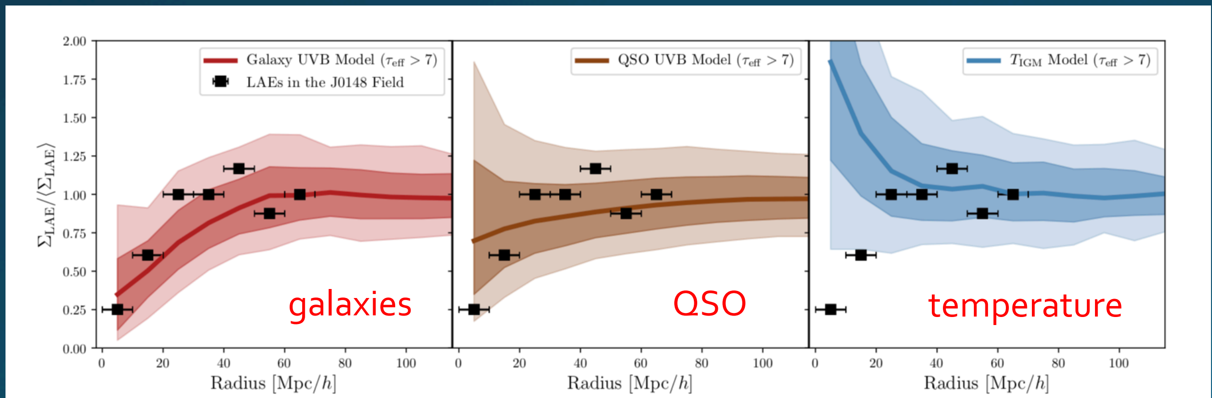
Adiabatic cooling following very high initial temperatures
+
extended reionization with wide spread of reionization redshifts
=
large opacity fluctuations

For realistic assumptions temperature fluctuations are not large enough for this to work.

Large-Scale Deficit of Lyman-alpha emitters coinciding with absorption trough







Narrow-band imaging with SUBARU by Becker et al. 2018

Model where trough is due to low temperatures in early ionized regions is apparently ruled out.

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Large fluctuations in the hydrogen-ionizing background and mean free path following the epoch of reionization

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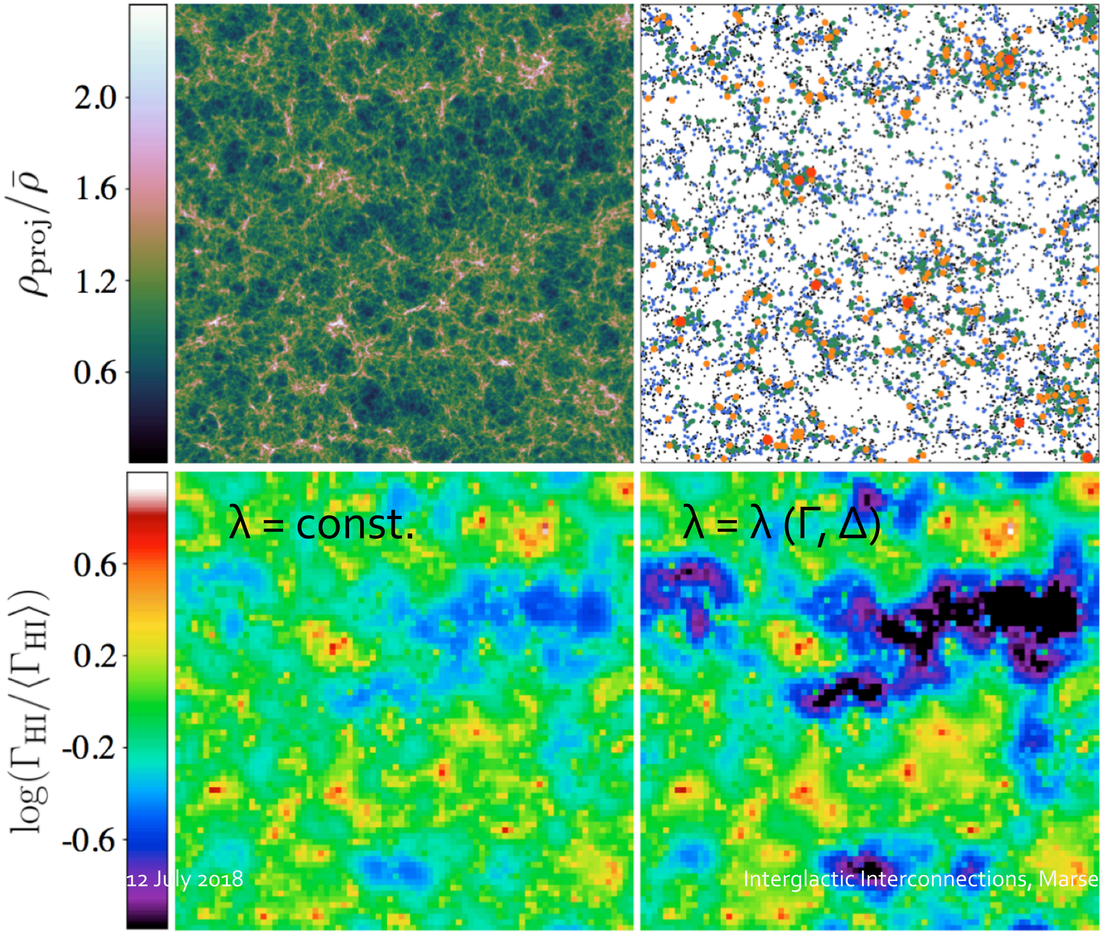
[2] *Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany*



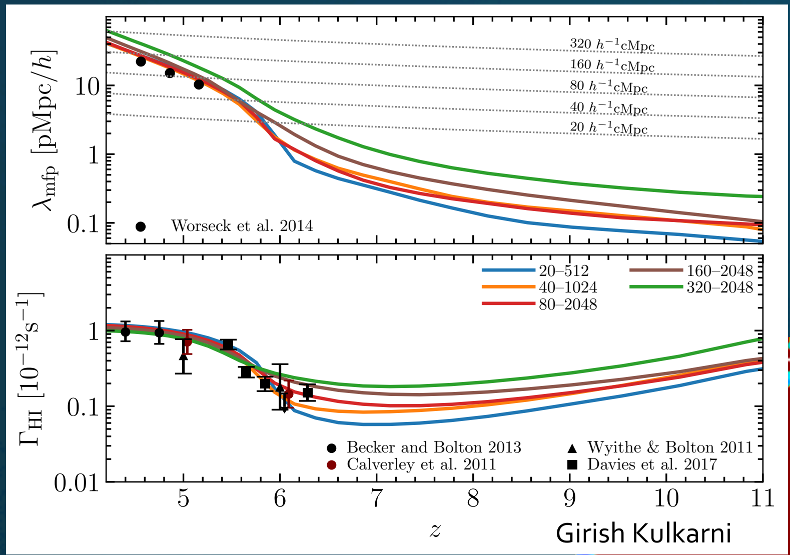
$$\Gamma_{phot} \propto \varepsilon_{ion}\ \lambda_{mfp}$$

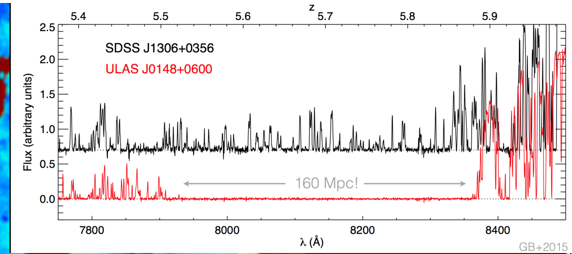
$$\lambda\,(\Gamma, \Delta) = \lambda_o\,(\Gamma/\Gamma_o)^{2/3}\Delta^{-1}$$

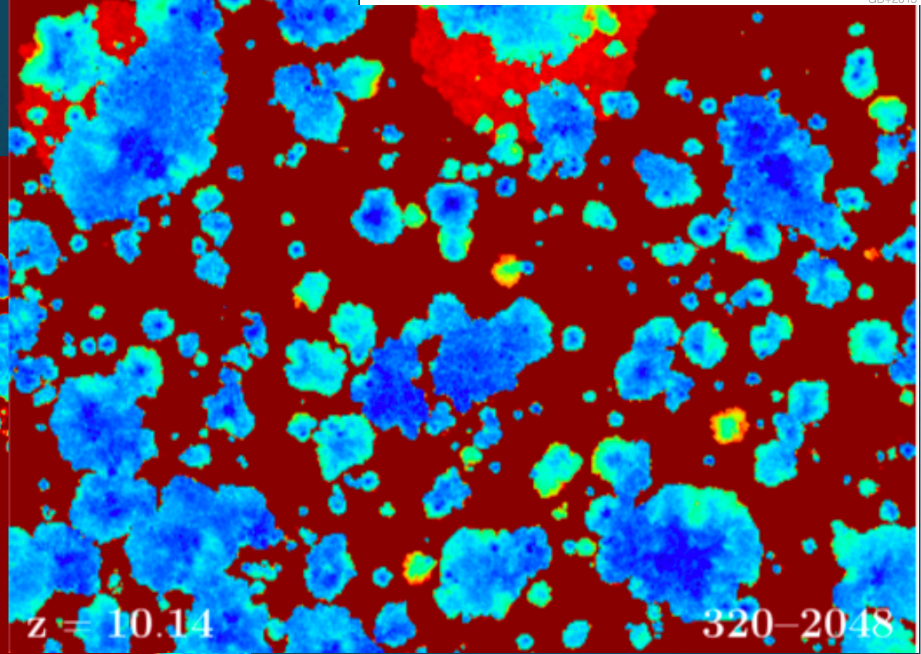
λ_o=15Mpc (comoving)

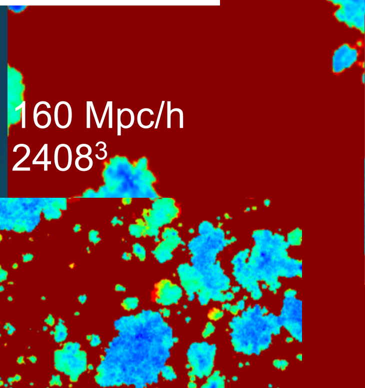
- very short mean free path in underdense regions

- non-linear relation of photo-ionization and emissivity amplifies fluctuations

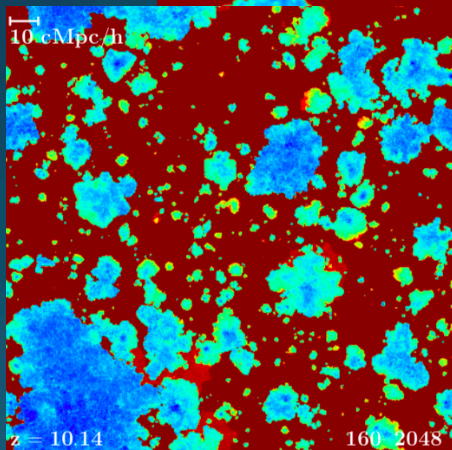








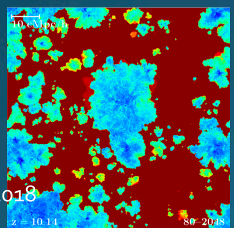
160 Mpc/h
2408^3



Z=10.14

320 Mpc/h
2048^3

80 Mpc/h
2048^3



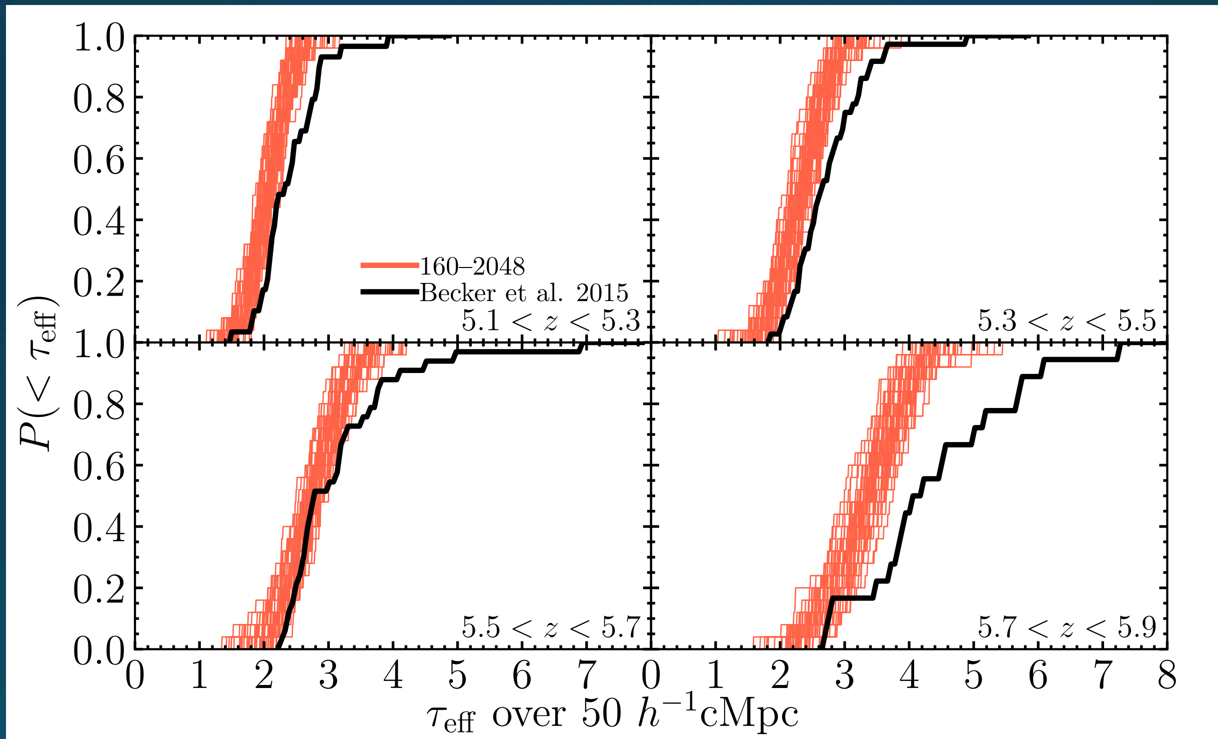
20 Mpc/h
512^3

A carefully calibrated suite of simulations

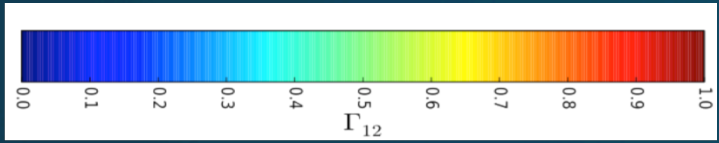
Sherwood post-processed with ATON

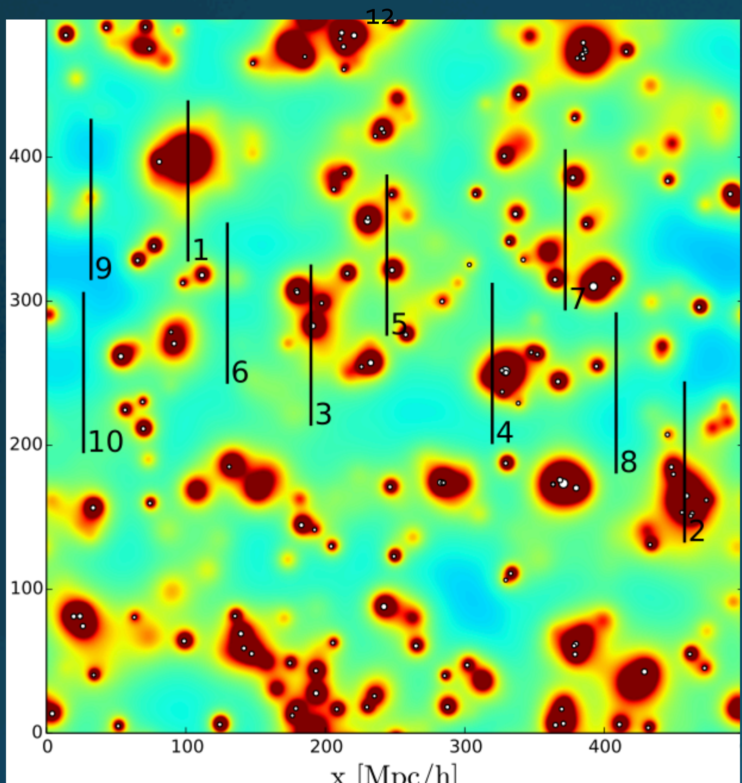
Another Bad Surprise

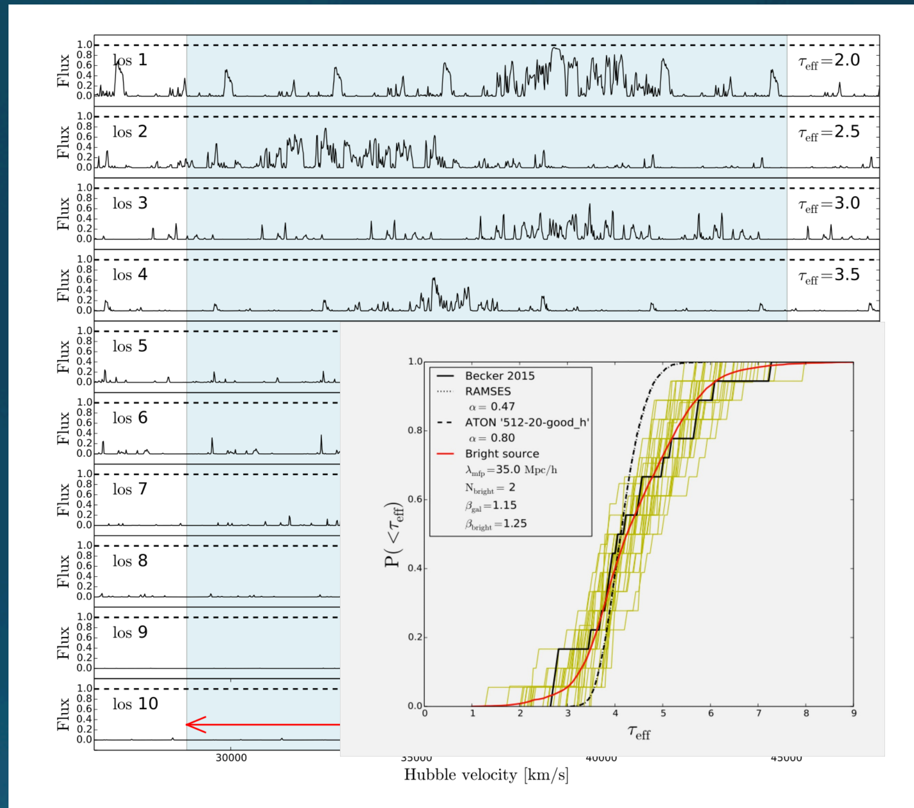
160 Mpc/h - 2048^3



PDF is still significantly narrower than observed. This gets worse with the Bosman et al. sample. Something has to give.



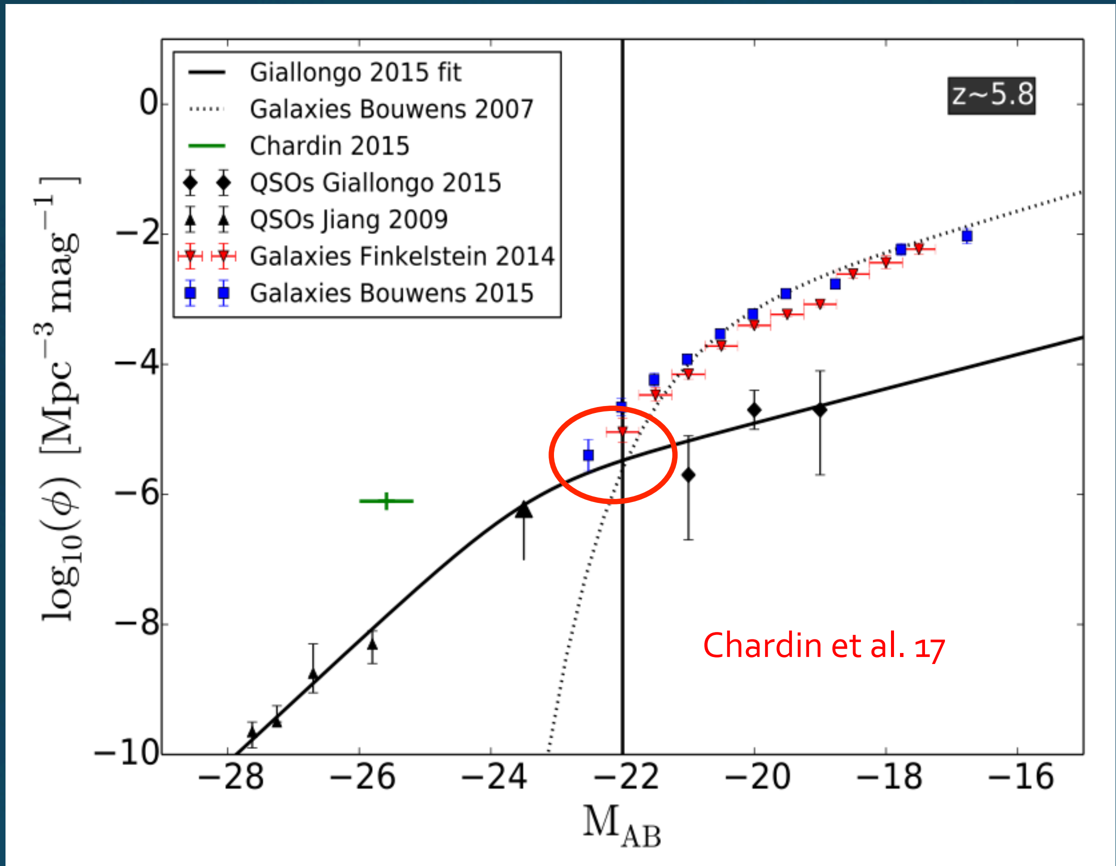




Chardin et al. 17

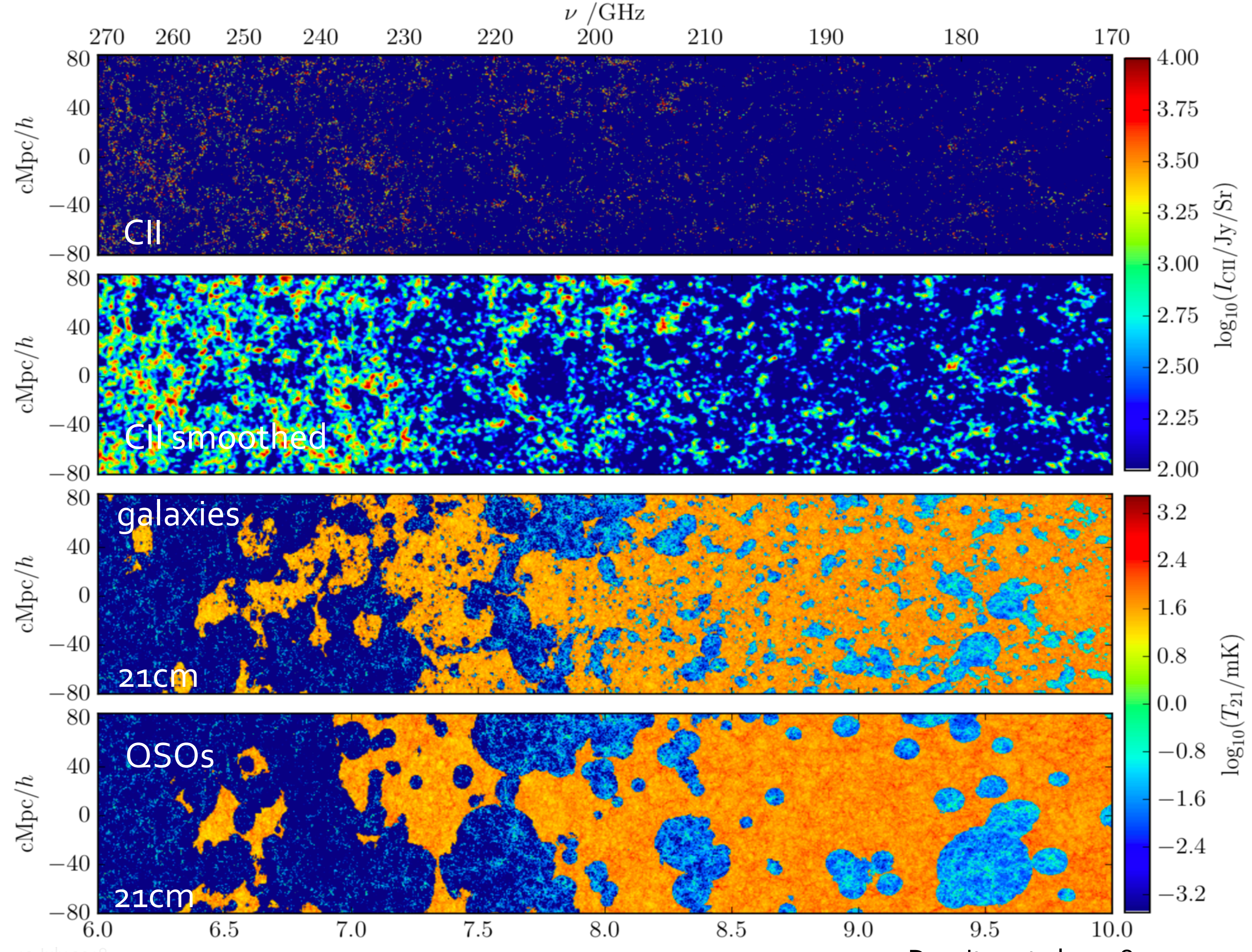
Opacity fluctuation on large scales → QSOs?

Are there enough QSOs? Helium reionization too early?

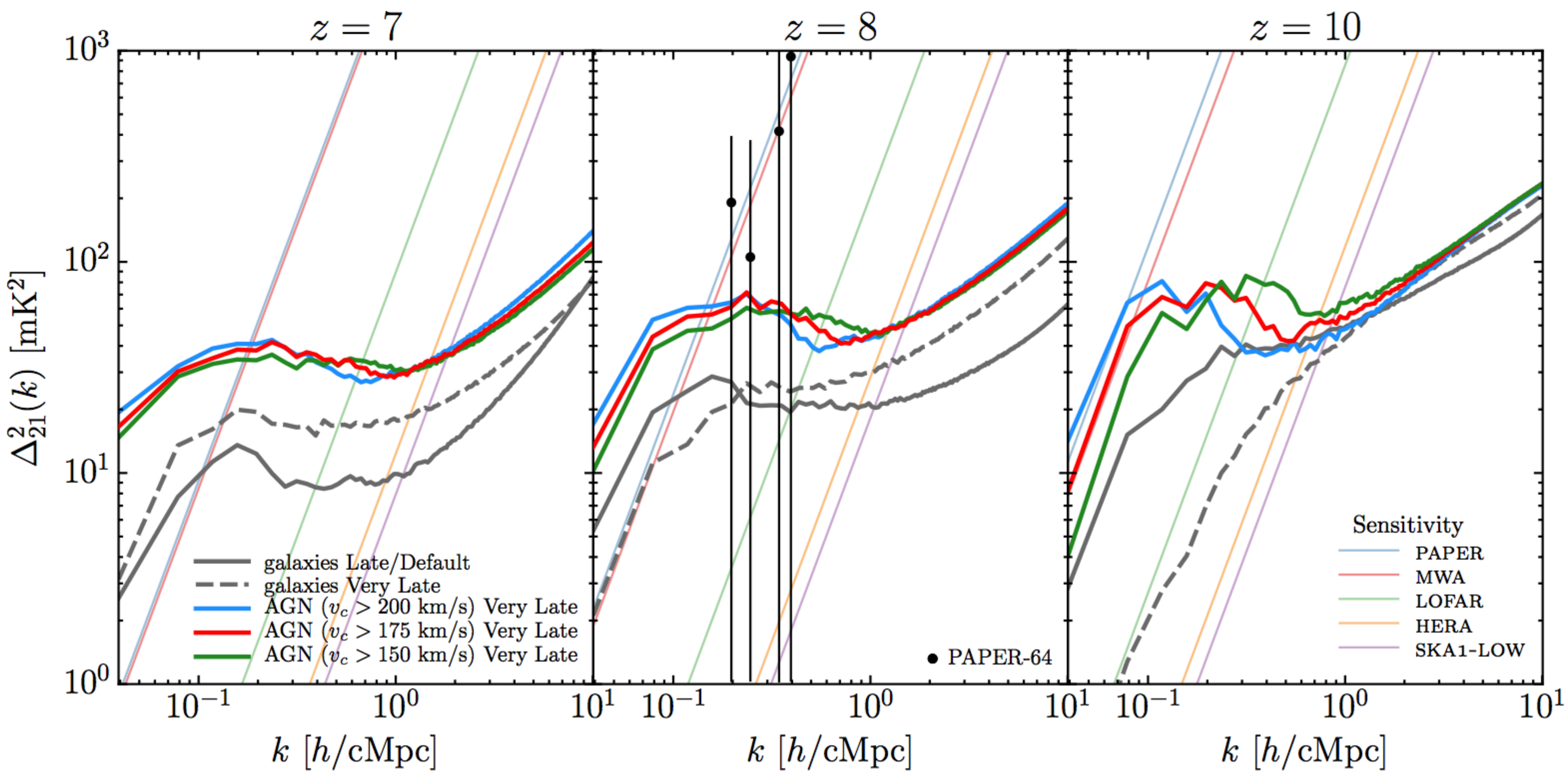


What appears to be needed is bright 1 Rydberg sources wit space density ~ 10^{-6} Mpc^{-1} that contribute little to the 4 Rydberg/HeII ionizing background. Large escape fraction in the brightest galaxies? New Class of AGN?

The Future: Intensity mapping and 21cm



Dumitru et al. 2018

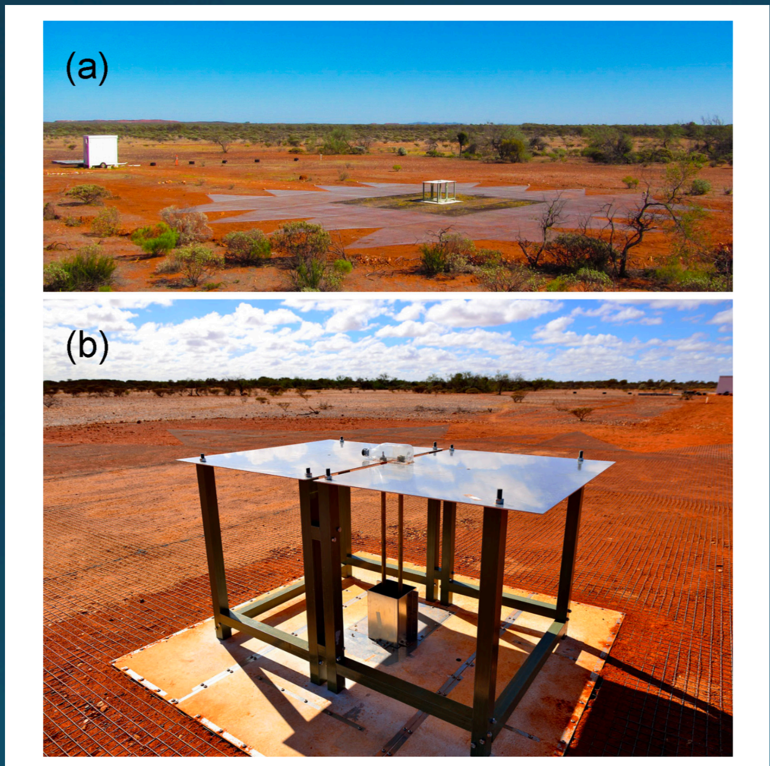


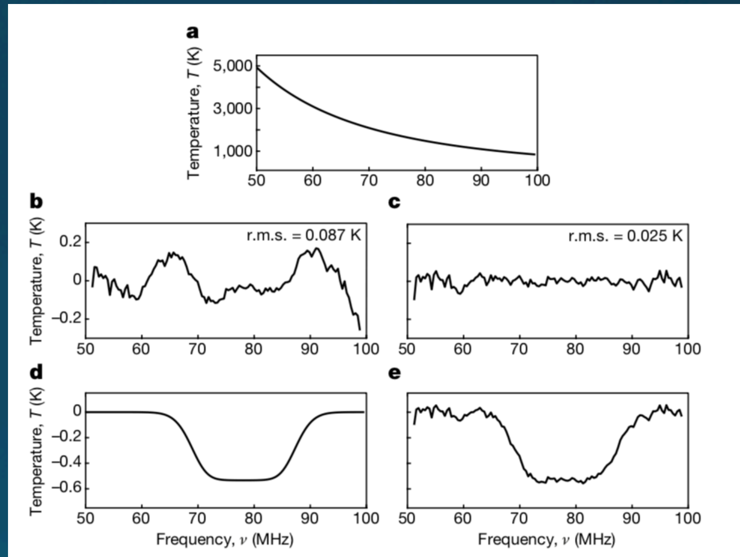
Kulkarni et al. 2016 ,2017

Measurements are getting close! Cross-correlation probably most promising route to first detection.

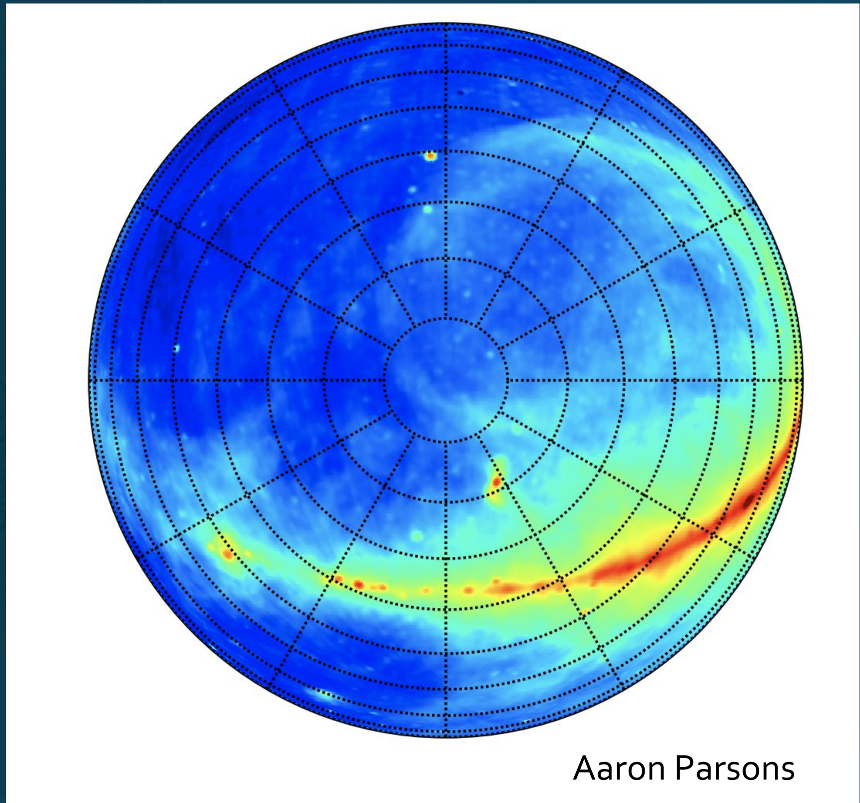
An absorption profile centred at 78 megahertz in the sky-averaged spectrum

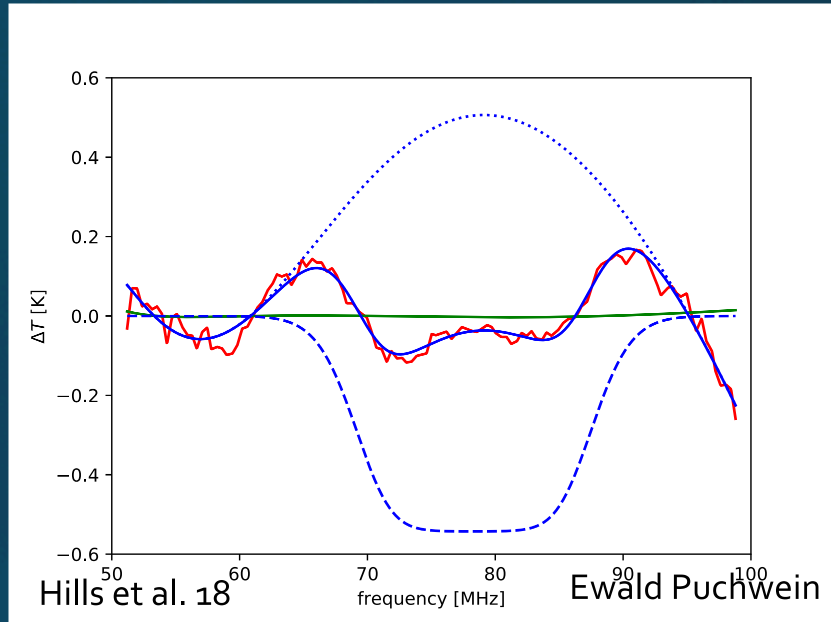
Judd D. Bowman[1], Alan E. E. Rogers[2], Raul A. Monsalve[1,3,4], Thomas J. Mozdzen[1] & Nivedita Mahesh[1]





If true, star formation at z~17 is required to couple spin temperature to gas temperature and then to heat the gas not much later. This is consistent with ΛCDM. The shape and depth of the trough are not.





Assumed foreground modelling
implies (almost mirror-symmetric)
peak in foreground emission
of similar amplitude as
absorption feature.

Galactic Synchroton radiation
is four orders of magnitude s brighter
and rather complex.

Summary

- evidence is building for rather late reionization
- broad flux PDF at z≈5.6-5.8 may require substantial contribution of bright rare (~10^{-6} Mpc^{-3}) 1Ryd sources to photoionization rate, temperature fluctuations are too small and appear to be ruled out by strong anti-correlation of Lyman-alpha opacity and LAEs
- modelling of mean free path fluctuations during the percolation of HII regions is challenging and requires considerable resources ➔ work in progress
- 21cm sensitivity at 6<z<10 is getting close to model predictions
- exiting possible detection of 21cm absorption trough at z~17