The signature of Reionization in galactic Lyα emission

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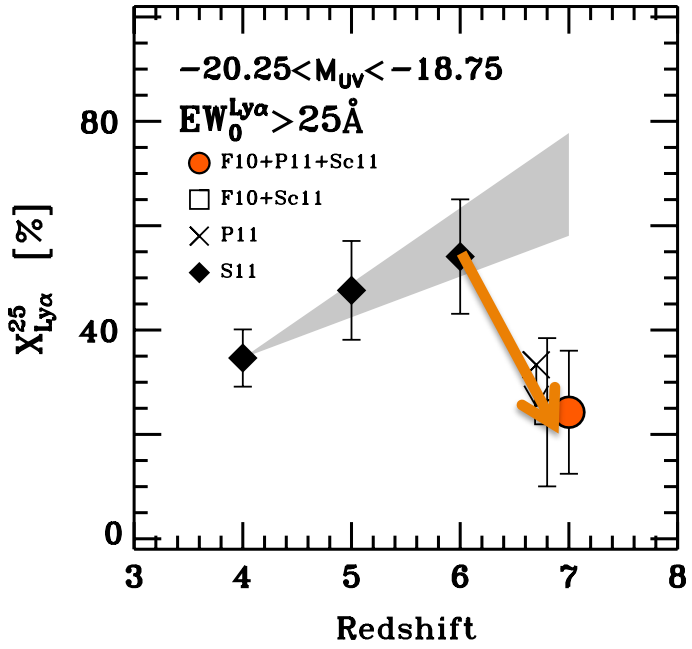
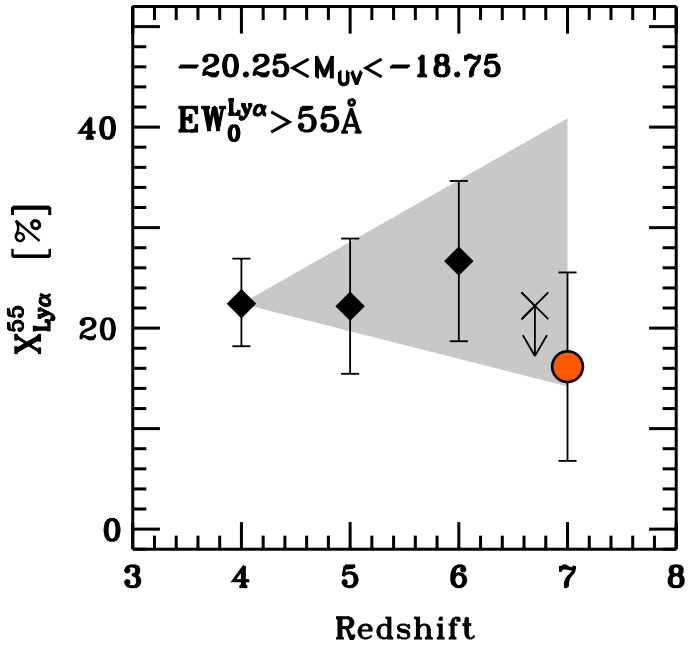
The “problem”?



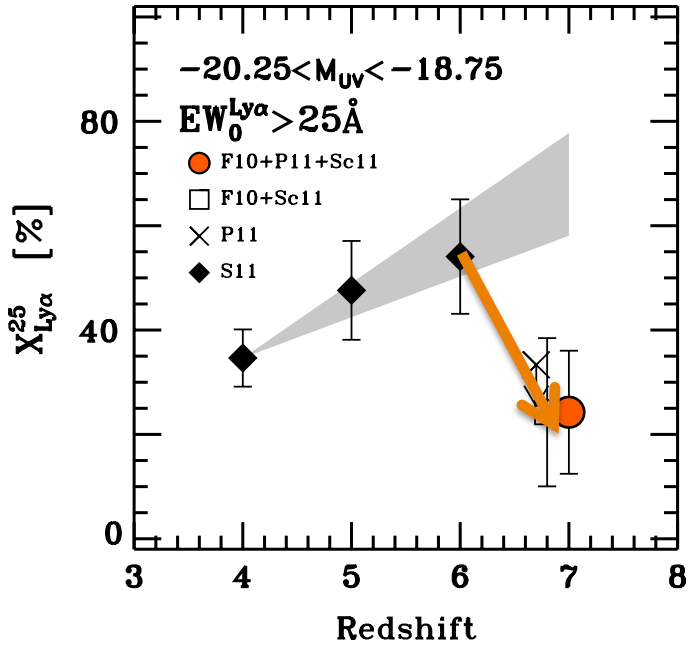


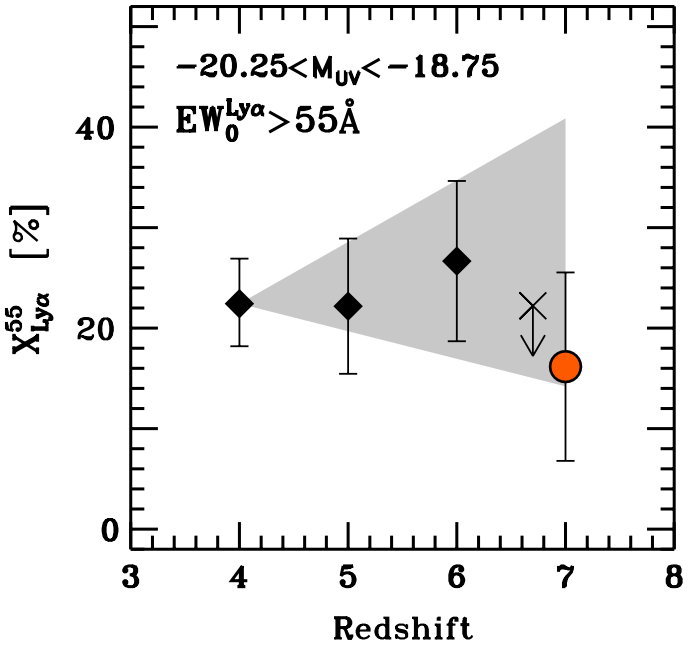
Drop in the fraction of UV faint galaxies with REW>25 A from z=6→7

Ono+2012 (see also, e.g. Stark+2010; Pentericci+2011; Schenker+2014…)

The “problem”?

“”→ only a ~1.5 sigma signal





Drop in the fraction of UV faint galaxies with REW>25 A from z=6→7

Ono+2012 (see also, e.g. Stark+2010; Pentericci+2011; Caruana+2013; Schenker+2014…)

The “solution”?

- Evolution in the IGM neutral fraction from an incomplete reionization (e.g. Dijkstra, AM+2011)
- Evolution in the ionizing background, i.e. the abundance of self-shielded systems, (e.g. Bolton & Haehnelt 2011)
- Evolution in galaxy properties (e.g. Jones+2012; Finkelstein+2012)
- Co-evolution (e.g. Dijkstra+2014)

The "solution"?

""→ preliminary studies suggested *extreme* evolution

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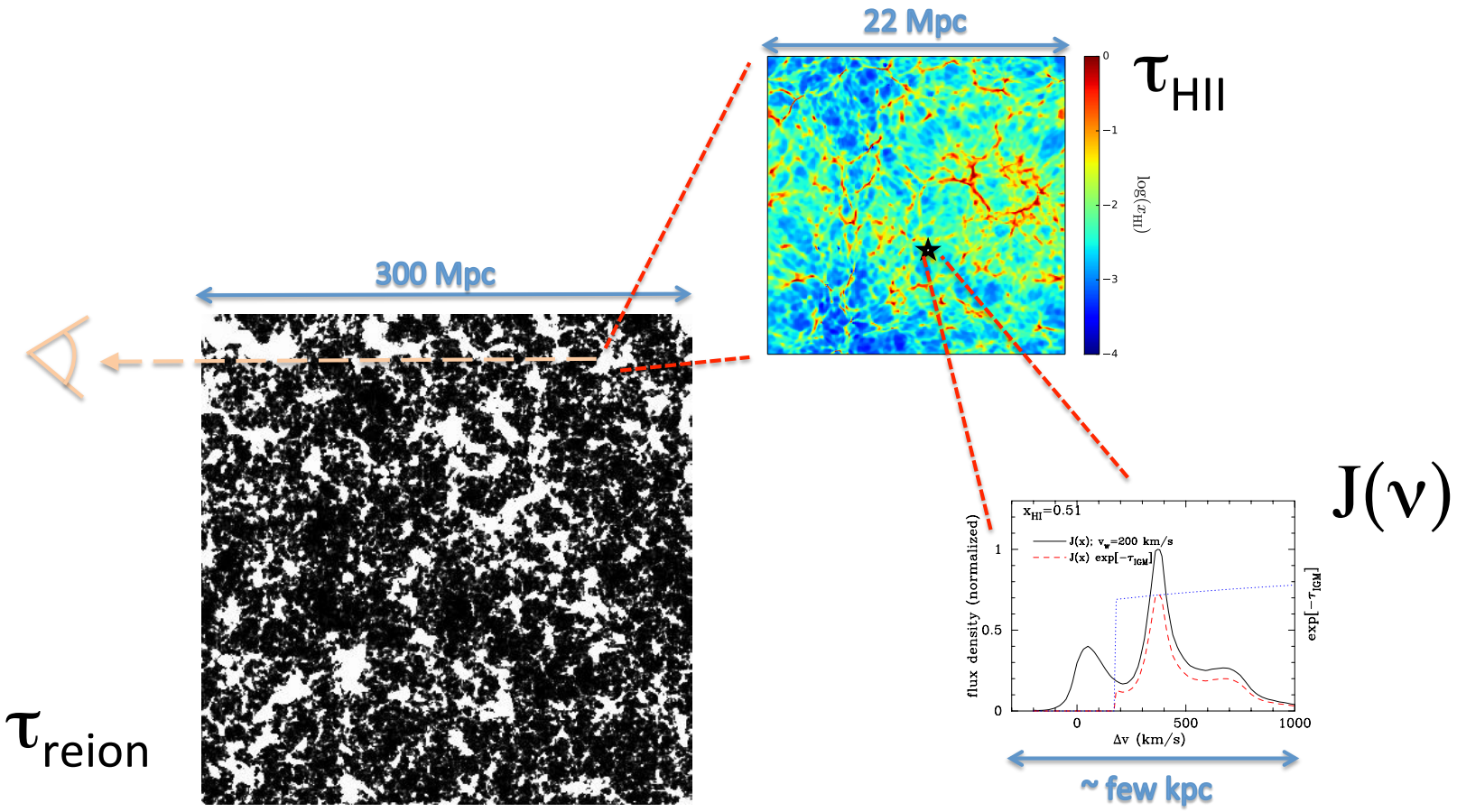
Complete model of IGM absorption



Multi-scale approach

$$T_{\rm IGM} = \int d\nu J(\nu) \exp[-\tau_{\rm reion}(\nu) - \tau_{\rm HII}(\nu)]$$

AM+2015

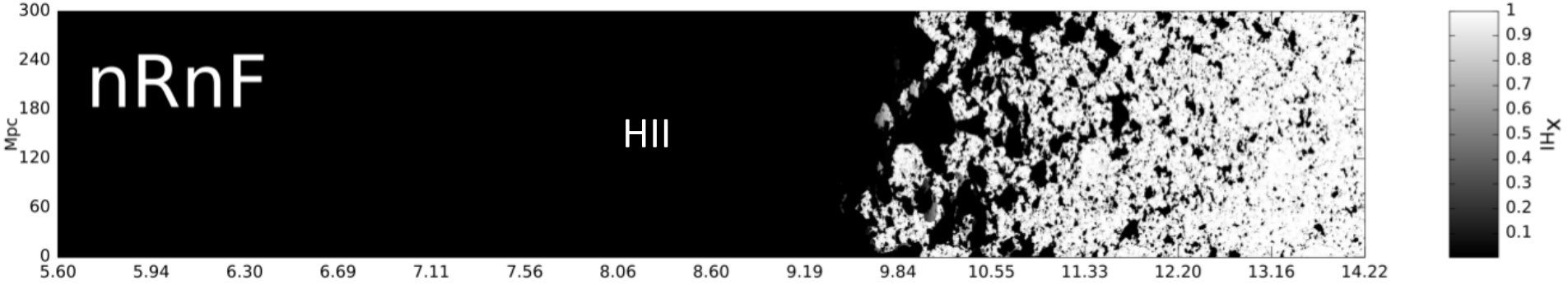
Most complete model: Non-standard ingredients

- Vary Q_{HII} , Γ_{12}, and $J(\nu)$
- Physically-motivated reionization morphologies including UVB feedback and inhomogeneous recombinations (Sobacchi & AM 2014)

AM+2015

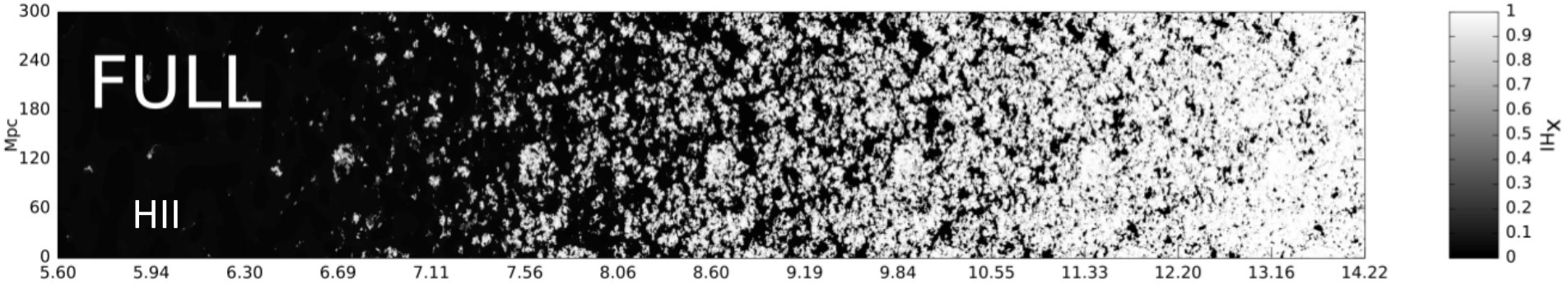
New reionization morphologies from sub-grid physics

Crude sub-grid physics, ~ current RT sims of reionization



Sobacchi & AM (2014)

Including sub-grid physics (recombinations and UV photo-heating feedback on galaxies)



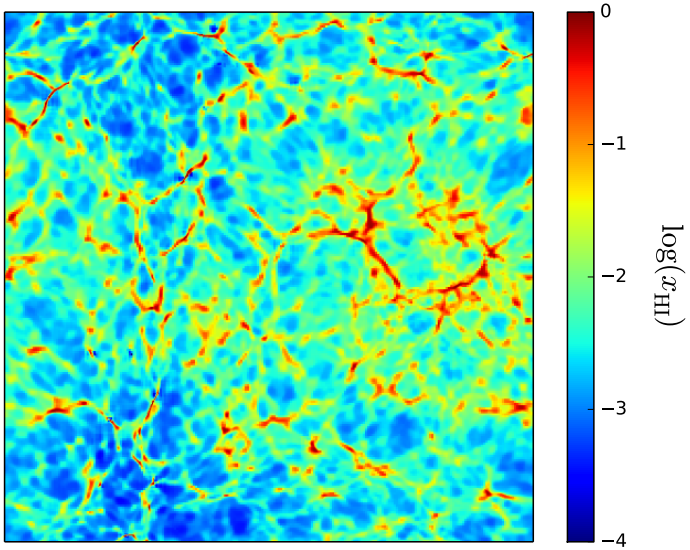
Non-standard ingredients

- Vary Q_{HII} , Γ_{12}, and $J(\nu)$
- Physically-motivated reionization morphologies including UVB feedback and inhomogeneous recombinations (Sobacchi & AM 2014) ✚
- Calibrated self-shielding prescription (Rahmati +2013)

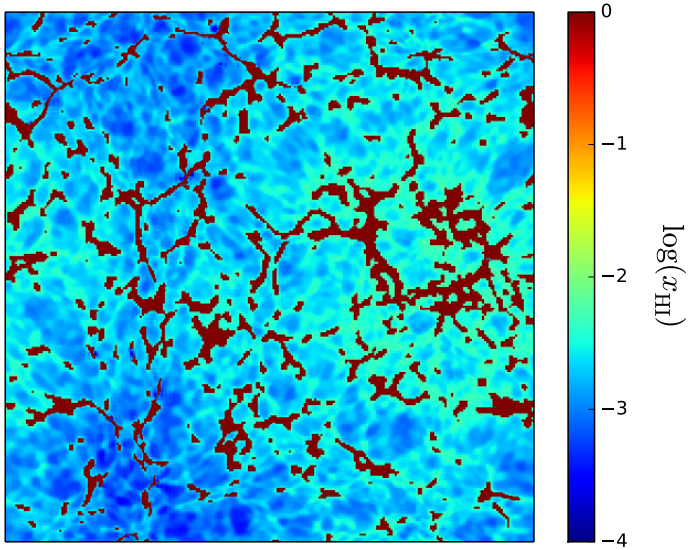
✚ increases Lyα fraction drop

▬ decreases Lyα fraction drop

Continuous self-shielding prescription



continuous



step-function: x_{HI}=1 at $\Delta>\Delta_{SS}$
(c.f. Bolton & Haehnelt 2011)

$$\frac{\Gamma_{\rm ss}}{\Gamma} = 0.98 \times \left[1 + \left(\frac{\Delta}{\Delta_{\rm ss}}\right)^{1.64}\right]^{-2.28} + \\ + 0.02 \times \left[1 + \frac{\Delta}{\Delta_{\rm ss}}\right]^{-0.84} \quad (4)$$

Rahmati+2013

where $\Delta_{\rm ss}$ is the overdensity above which the gas begins to self-shield (Schaye 2001):

$$\Delta_{\rm ss} \approx 15 \left(\frac{\Gamma_{\rm HII}}{0.1}\right)^{2/3} \left(\frac{T}{10^4{\rm K}}\right)^{-0.13} \left(\frac{1+z}{7}\right)^{-3} . \quad (5)$$

AM+2015

Non-standard ingredients

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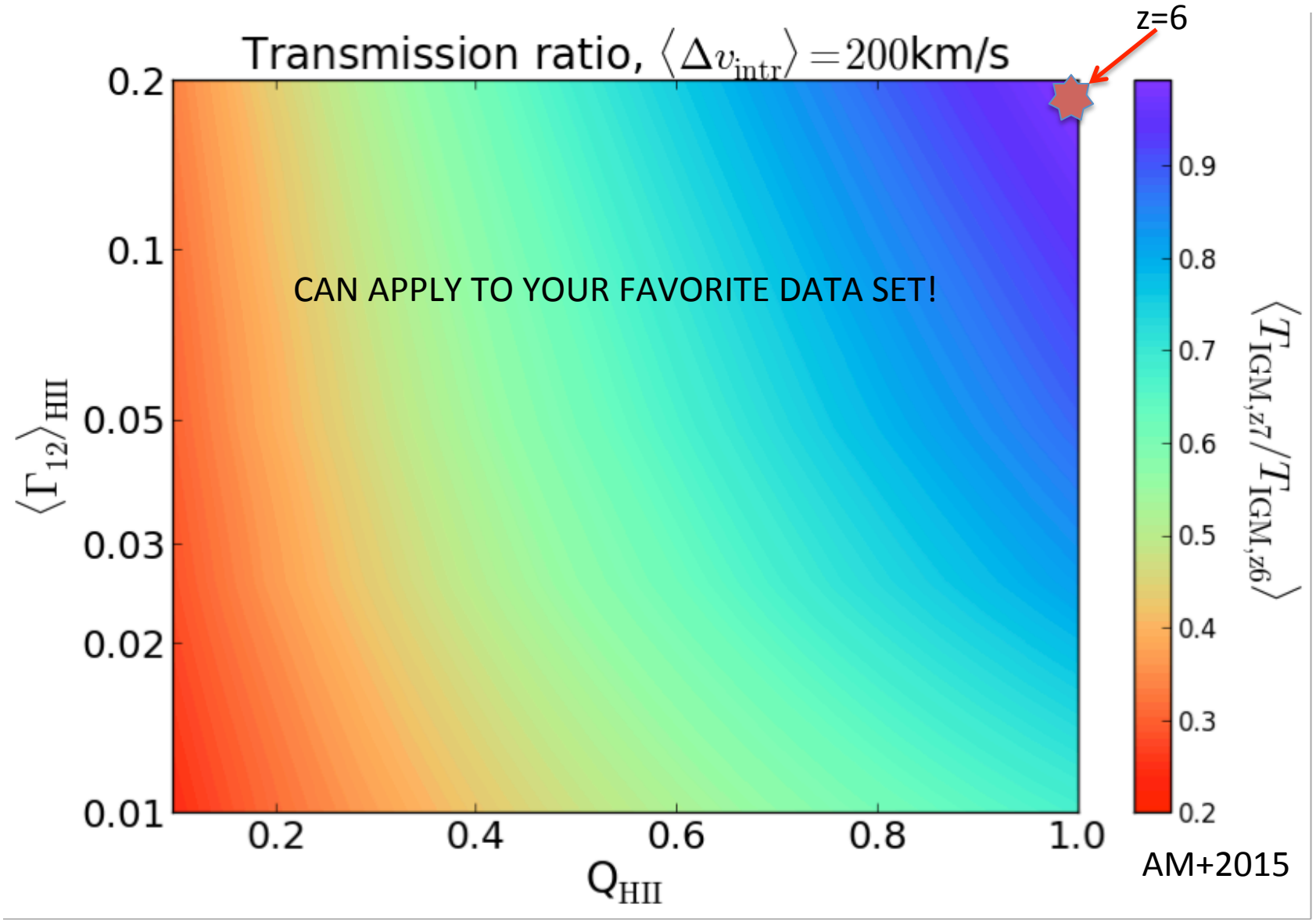
Non-standard ingredients

- Vary Q_{HII} , Γ_{12}, and $J(\nu)$
- Physically-motivated reionization morphologies including UVB feedback and inhomogeneous recombinations (Sobacchi & AM 2014) ✚
- Calibrated self-shielding prescription (Rahmati +2013) ▬
- IGM absorption at z=6: Q_{HII} =1, Γ_{12}=0.2 ▬
- Evaluate J(ν) over range of ν ▬

✚ increases Lyα fraction drop

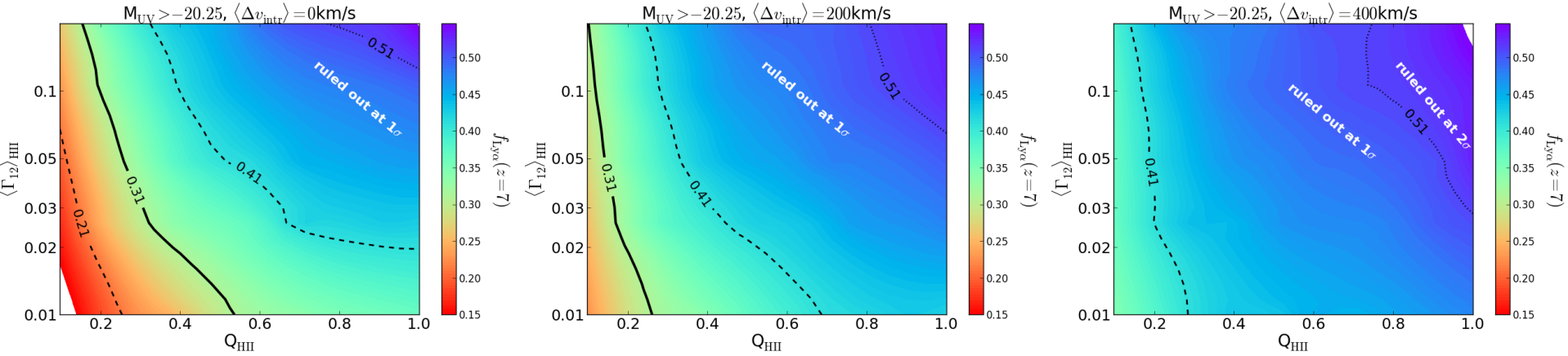
▬ decreases Lyα fraction drop

IGM transmission ratio



z=7 Lyα fraction

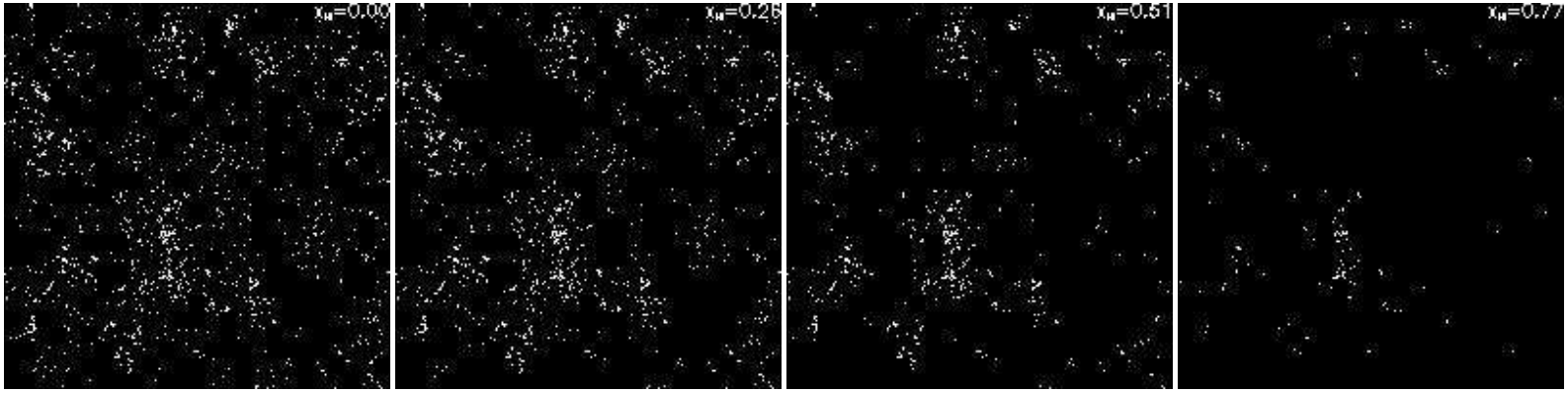
Line offset from systemic redshift →



- Difficult for the IGM to cause the Lyα fraction to drop by more than a factor of ~2
- Self-shielded systems cannot by themselves cause the drop (at 1σ)
- All parameter space is within 2σ (need more data!)
- Marginalizing over Γ, we get $Q_{HII,z7} < 0.6$ (68% C.L.)

LAE clustering as a signature of reionization

← Q_{HII}



AM & Furlanetto (2008)

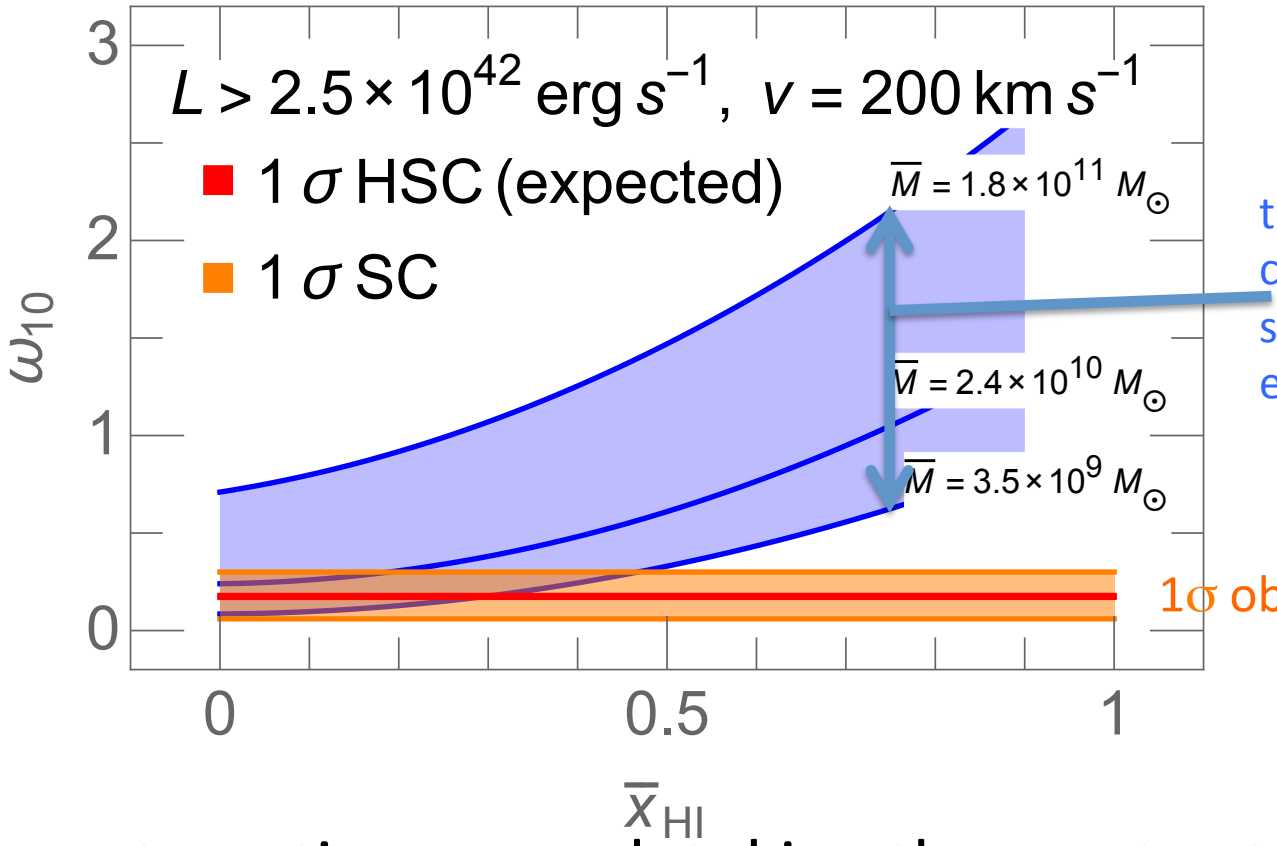
- The distribution of observed LAEs is modulated by the cosmic HII regions on large-scales → clustering increases during reionization (e.g. Furlanetto+2006; McQuinn+2007, AM & Furlanetto 2008; Jensen+2013)

LAE clustering is a more robust probe than evolution in number density

- Clustering of DM halos is well-understood: the intrinsic correlation function of the host halos only varies by a factor of ~few, making the additional contribution from reionization easier to identify
- The uncertain galactic environment has a much weaker signature on large-scale clustering, than on the observed Lyα emission

Subaru current and upcoming constraints on LAE clustering

Sobacchi & AM(2015, in prep)



theoretically allowed correlation function, spanned by most extreme models

1σ observations Ouchi+2010

- systematic approach taking the most extreme models for reionization morphology and for L_α<->M_{halo}

Subaru current and upcoming constraints on LAE clustering

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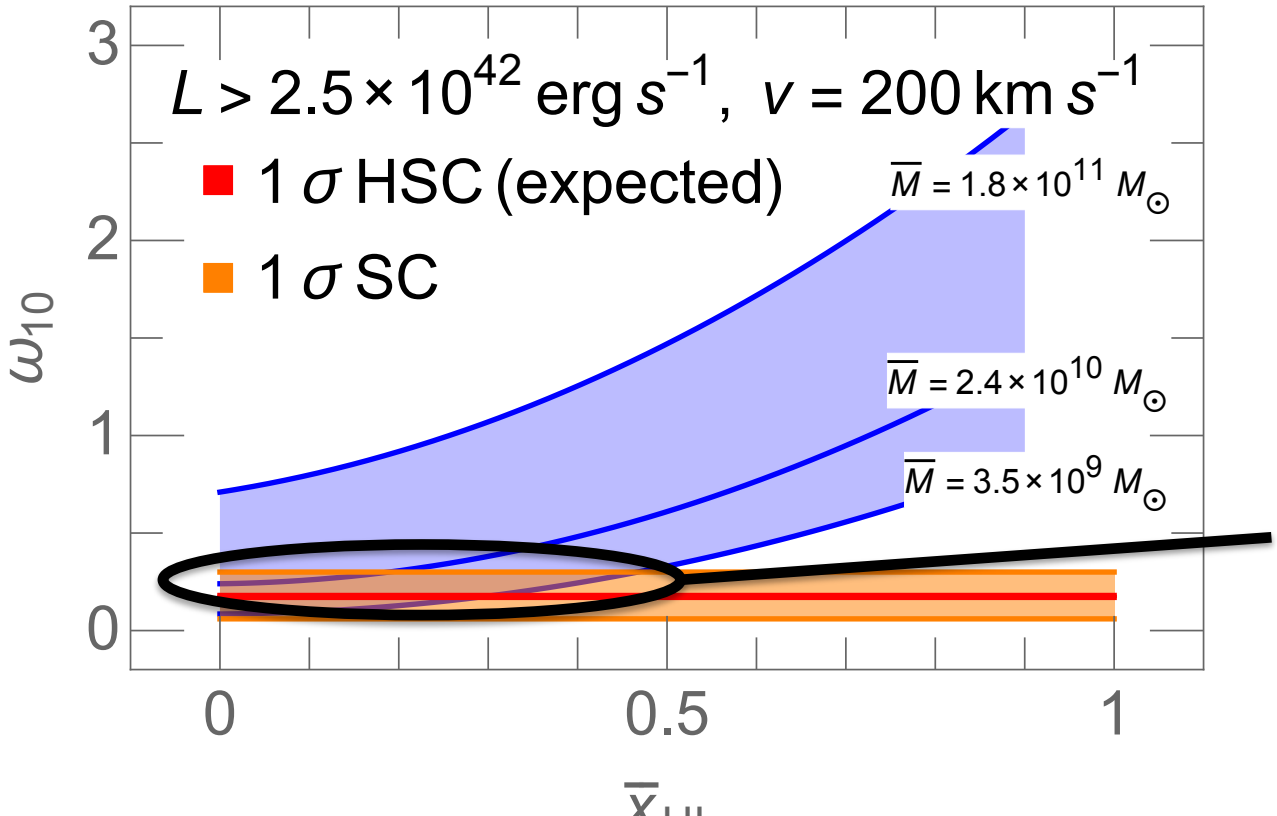
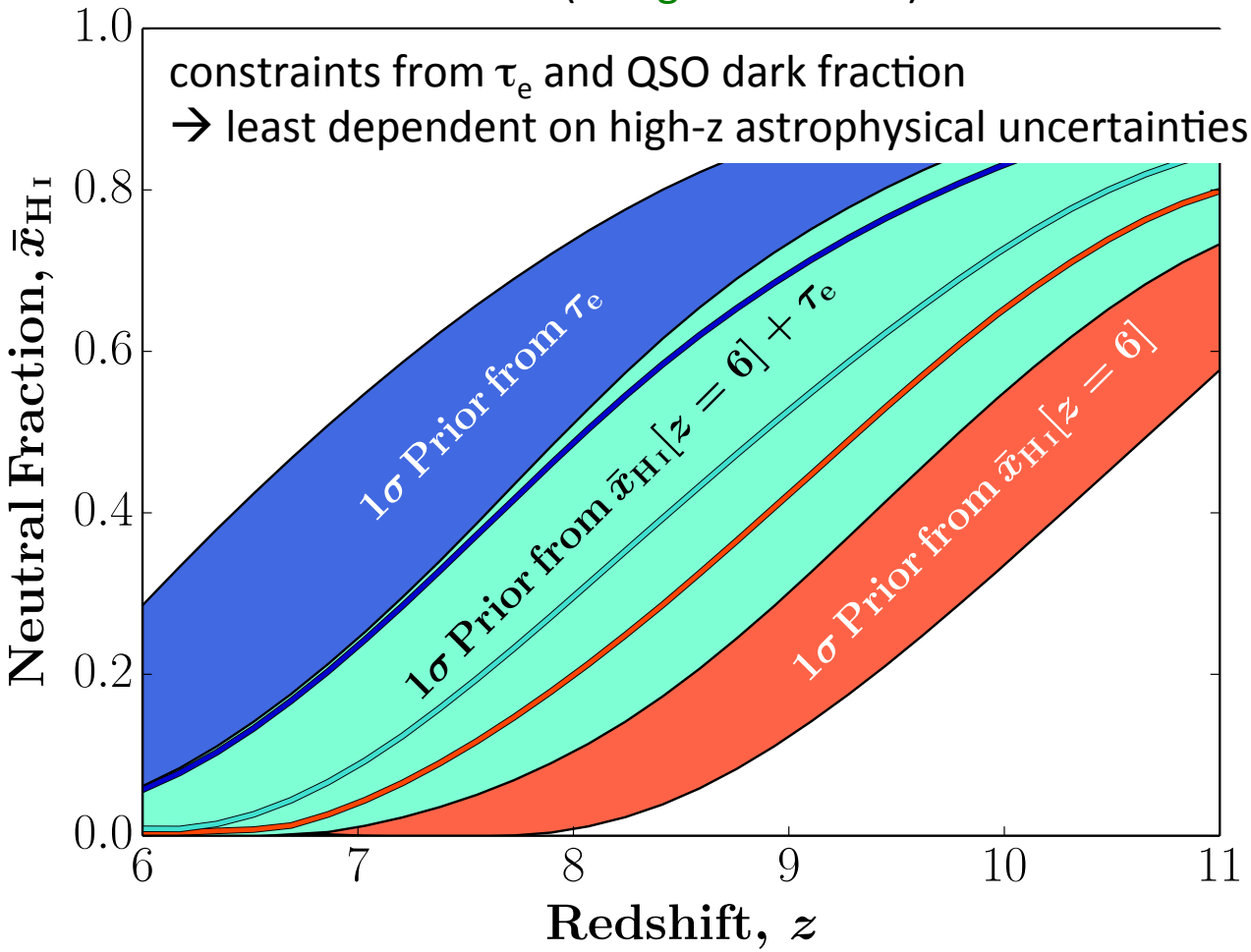


- clustering implies $Q_{HII,z7} > 0.5$, with with limits potentially improving by ~ 50% with HSC
- observed LAEs are hosted by much smaller DM halos than LBGs

Constraining reionization history

MCMC framework with 21CMMC (Greig & AM 2015)



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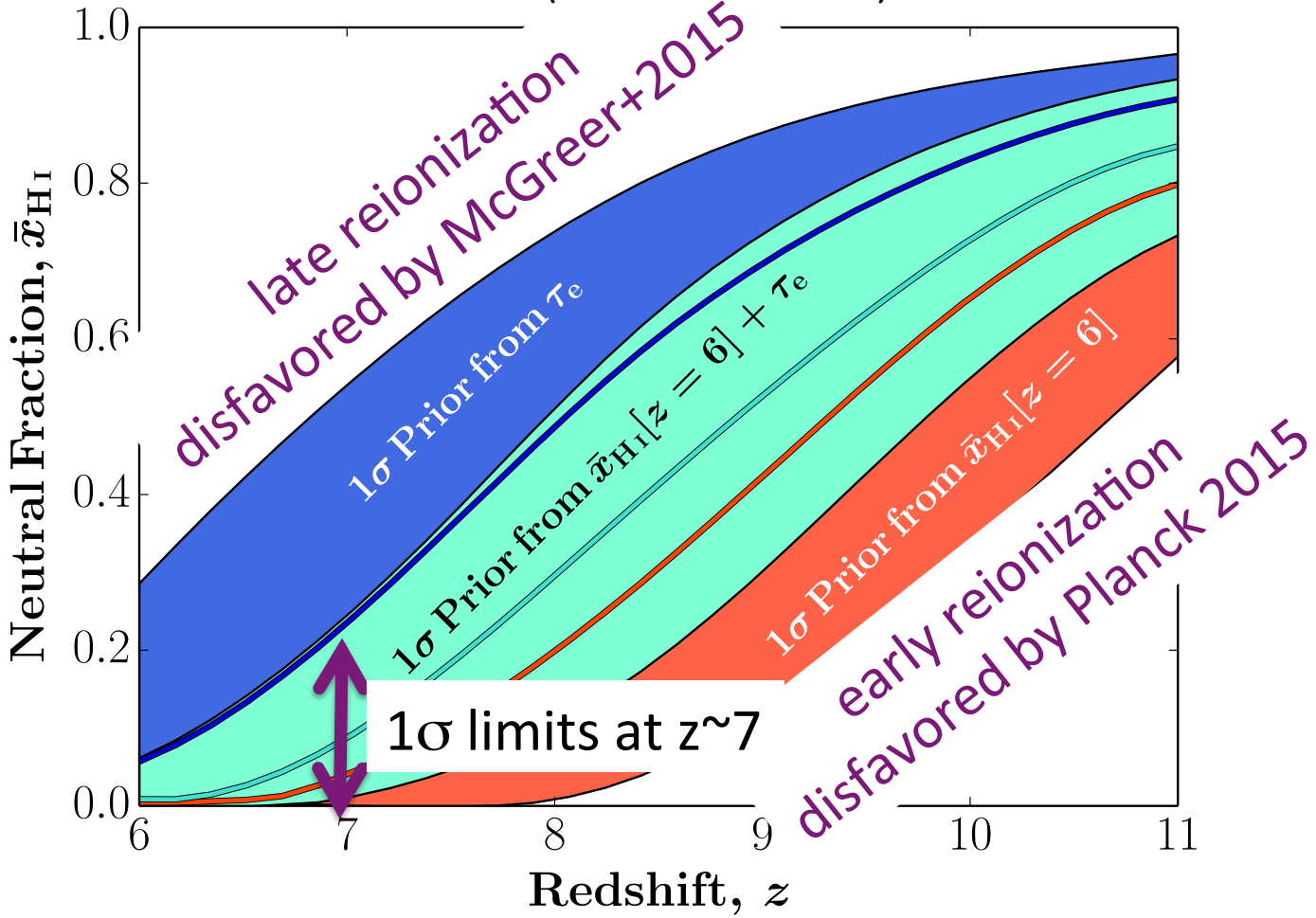
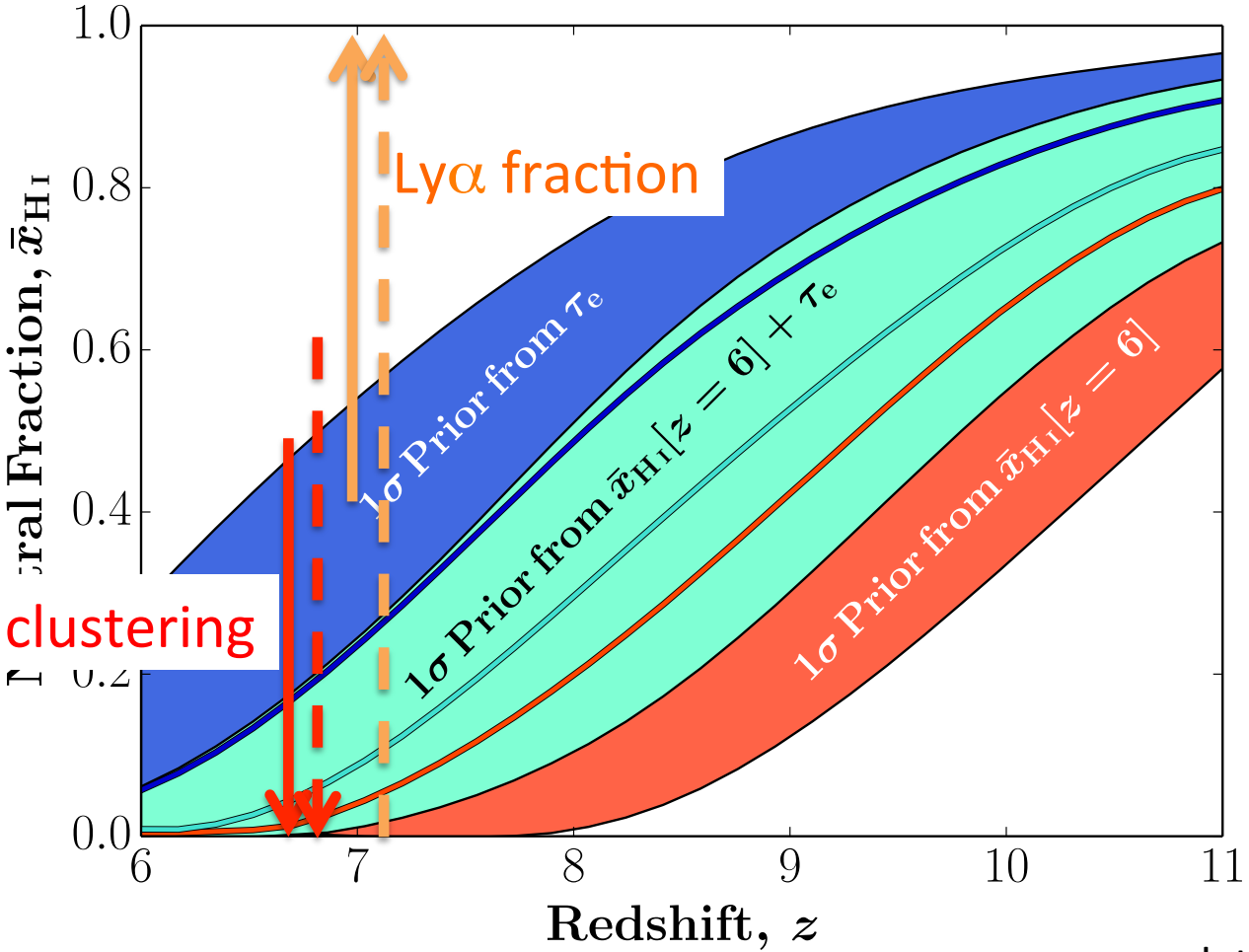


Greig, AM, Pober, in prep (2015)

1 & 2σ Lyα constraints at z~7

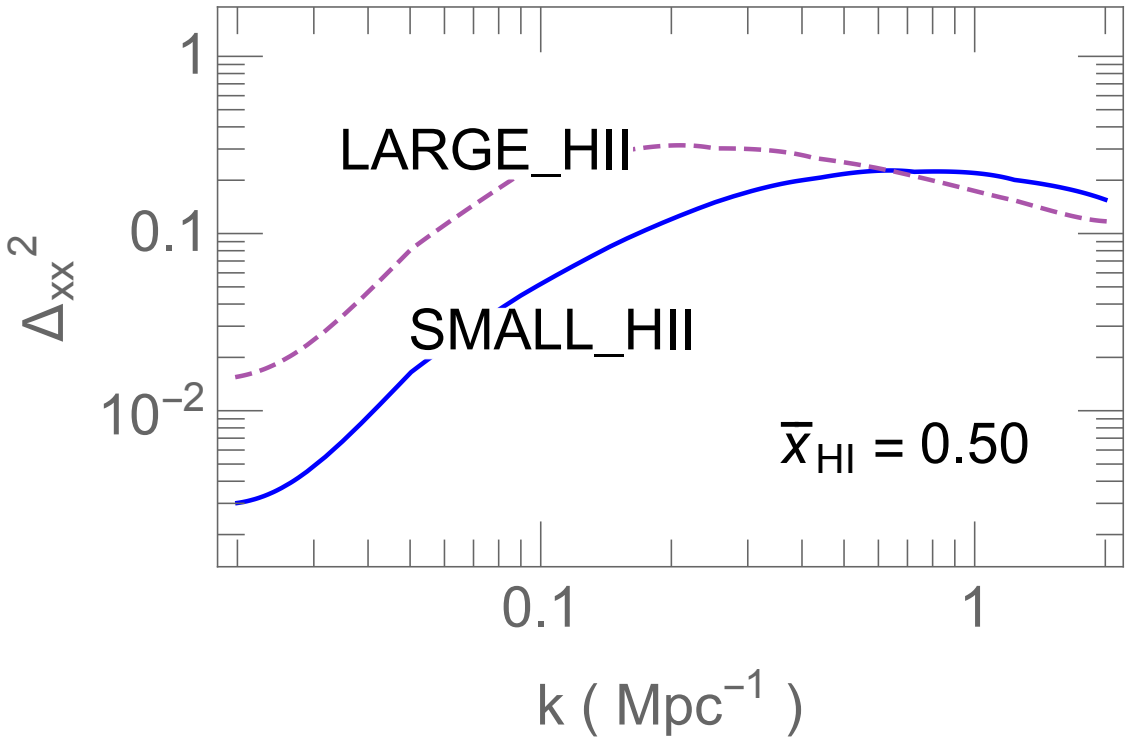


data is still preliminary
larger samples will help

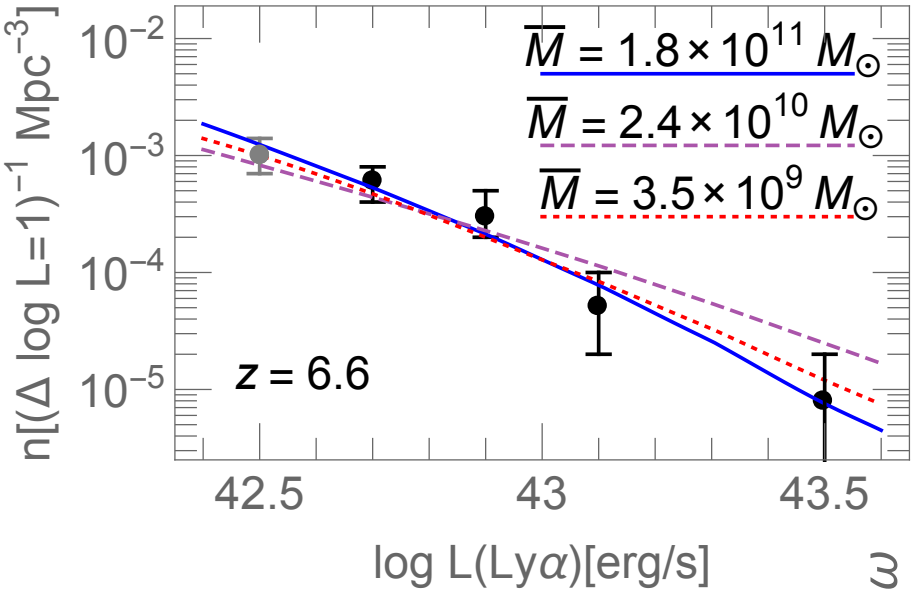
Conclusions

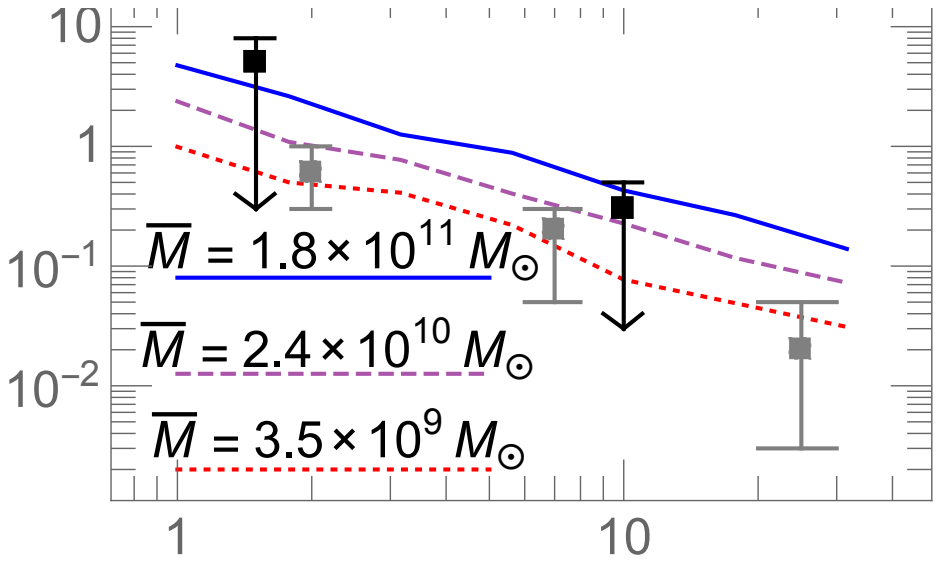
- Most complete model for IGM absorption. Can easily be used to interpret new data.
- Difficult for the IGM to cause the Lyα fraction to drop by more than a factor of ~2
- Self-shielded systems cannot by themselves cause the drop (at 1σ)
- All parameter space is within 2σ (need more data!)
- Marginalizing over Γ, we get $Q_{HII,z7} < 0.6$ (68% C.L.), which is in mild tension with other constraints from QSO spectra and LAE clustering
- LAE clustering measurements with Subaru constrain $Q_{HII,z7} > 0.5$ (68% C.L.), with limits potentially improving by ~ 50% with upcoming HSC survey
- DM halos hosting LAEs at z~7 have small masses, ~10^9—10^{10} M_{sun} → better tracers of reionizing galaxies?

Extreme reionization morphologies

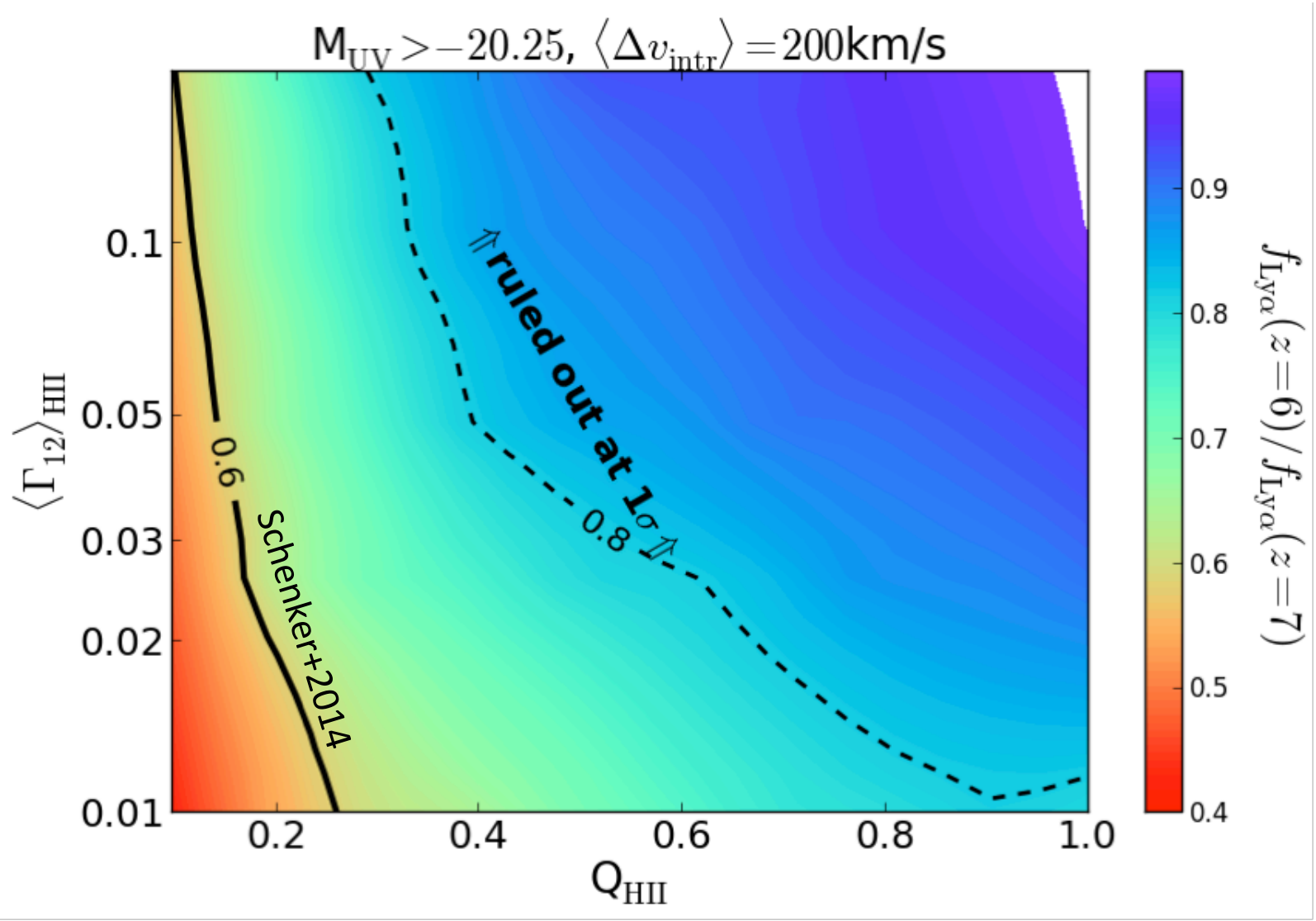


L<->M


$\overline{M} = 1.8\times10^{11}\,M_\odot$
$\overline{M} = 2.4\times10^{10}\,M_\odot$
$\overline{M} = 3.5\times10^{9}\,M_\odot$
$z = 6.6$
10^{-2}
10^{-3}
10^{-4}
10^{-5}
42.5
43
43.5
log L(Lyα)[erg/s]
n[(Δ log L=1)$^{-1}$ Mpc^{-3}]


10
1
10^{-1}
10^{-2}
$\overline{M} = 1.8\times10^{11}\,M_\odot$
$\overline{M} = 2.4\times10^{10}\,M_\odot$
$\overline{M} = 3.5\times10^{9}\,M_\odot$
1
10

Lyα fraction drop



z=6 REW data from Vanzella+, in prep

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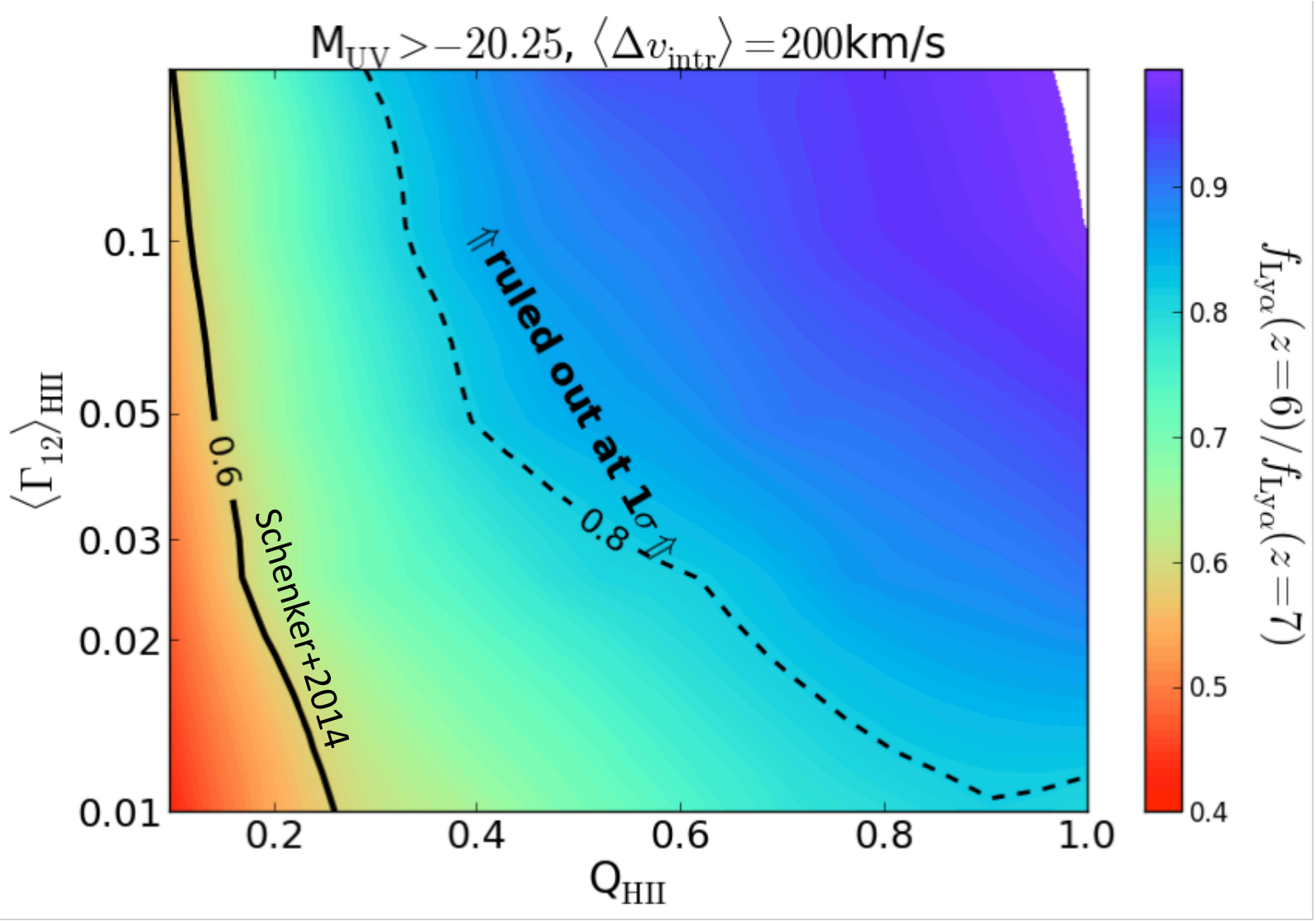

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