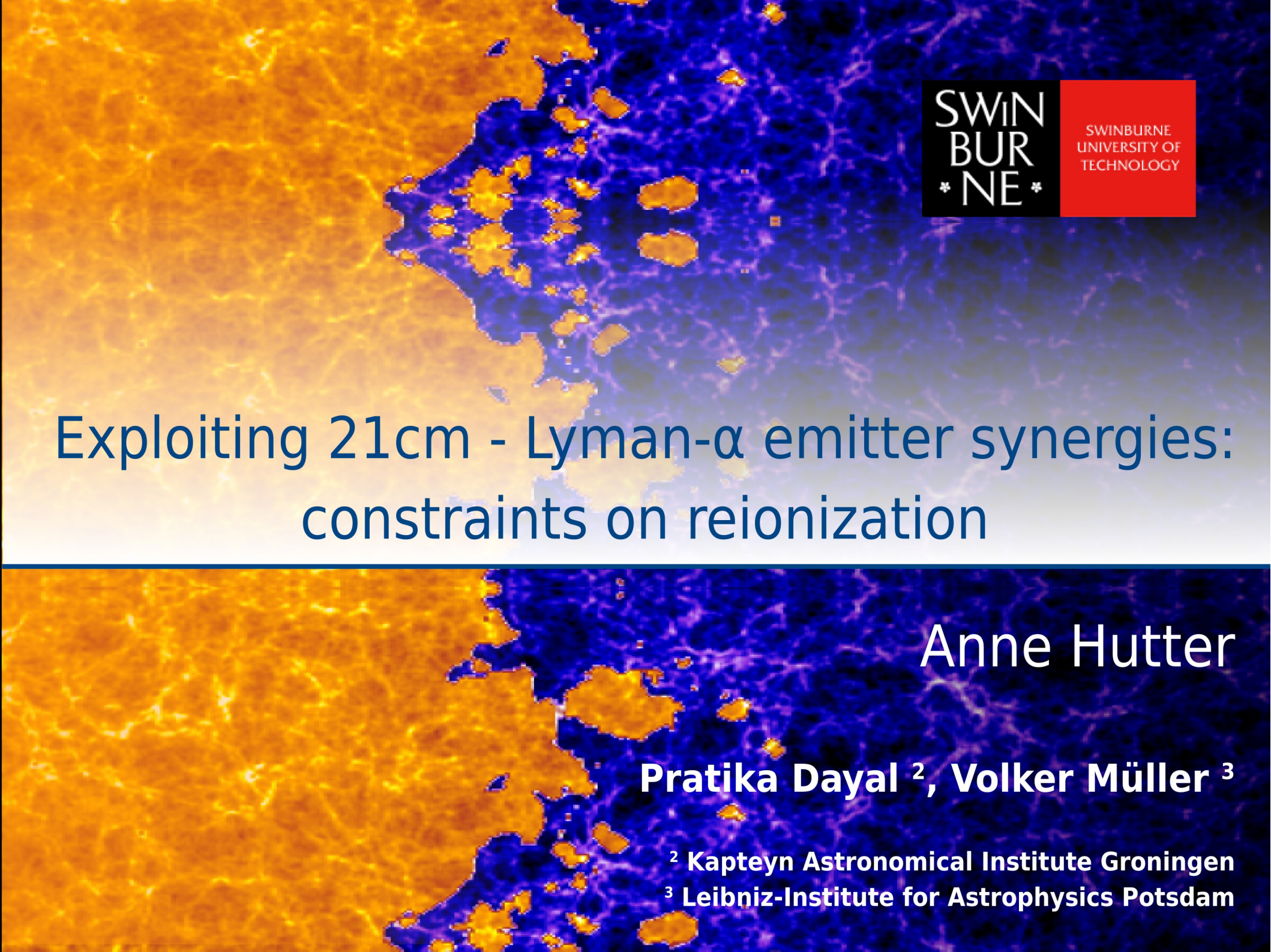


Exploiting 21cm - Lyman-α emitter synergies: constraints on reionization

Anne Hutter

Pratika Dayal [2], Volker Müller [3]

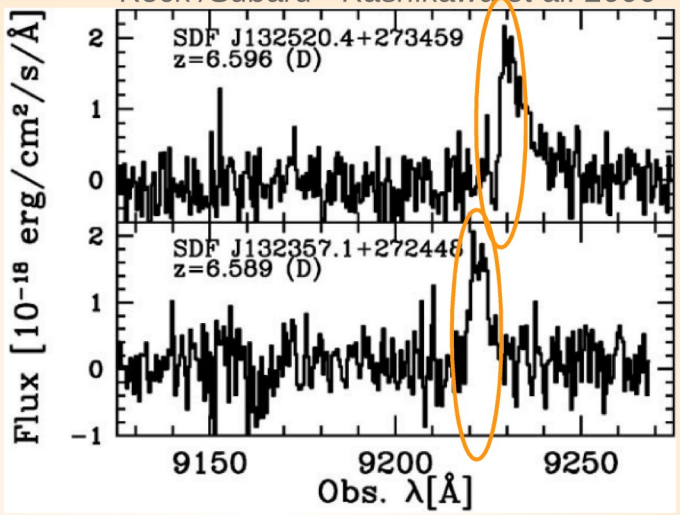
[2] Kapteyn Astronomical Institute Groningen

[3] Leibniz-Institute for Astrophysics Potsdam

Constraining reionization & high-z galaxies

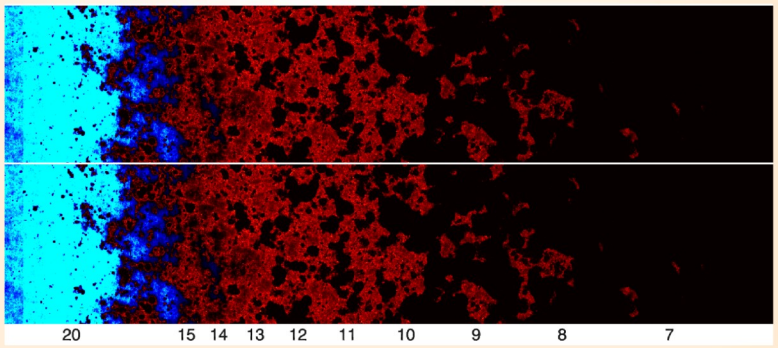
OBSERVATIONS

Keck /Subaru • Kashikawa et al. 2006



LYMAN ALPHA EMITTERS (LAEs)

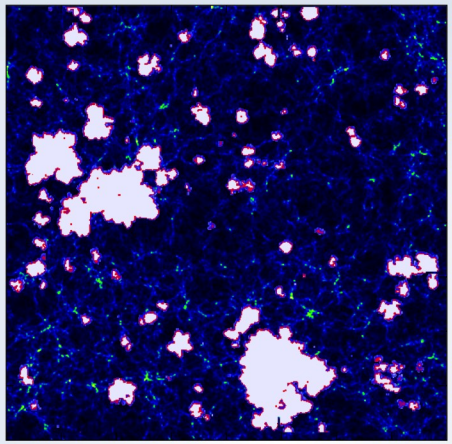
Pritchard 2012



21cm RADIATION

COMPARISON

MODELS & SIMULATIONS

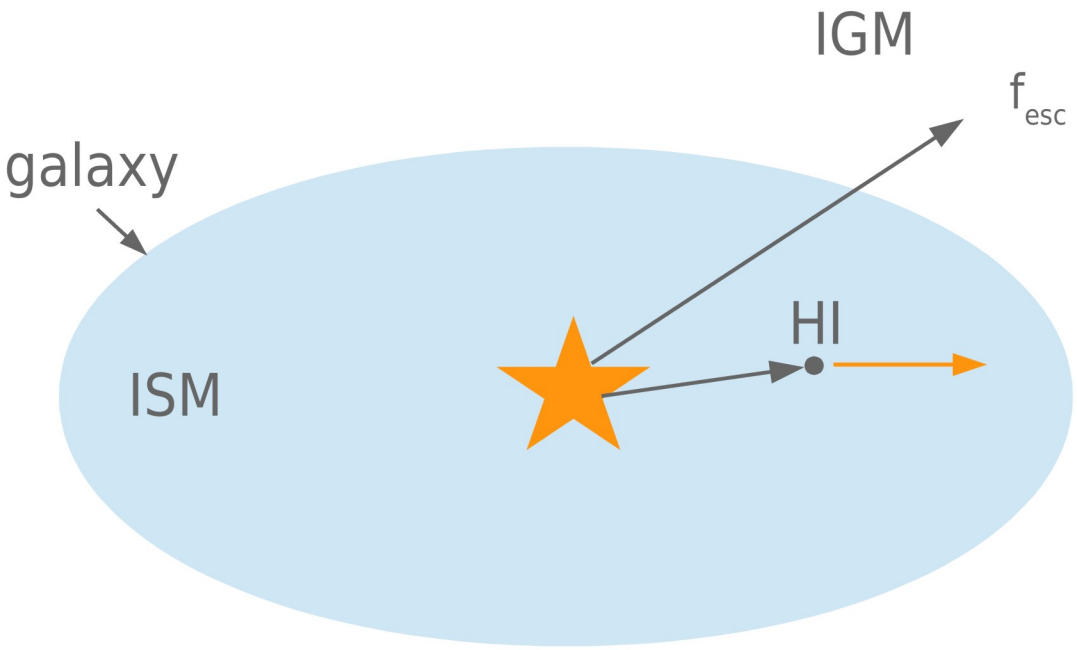


INTERGALACTIC MEDIUM

C. Hawk (JHU), B. Savage (U. Wisconsin), N. A. Sharp (NOAO)/MTN/NOAO/NSF

GALAXY PROPERTIES

Lyman α emitters (LAEs) in the intergalactic medium



f_{esc} = escape fraction of ionizing photons (λ<912Å)

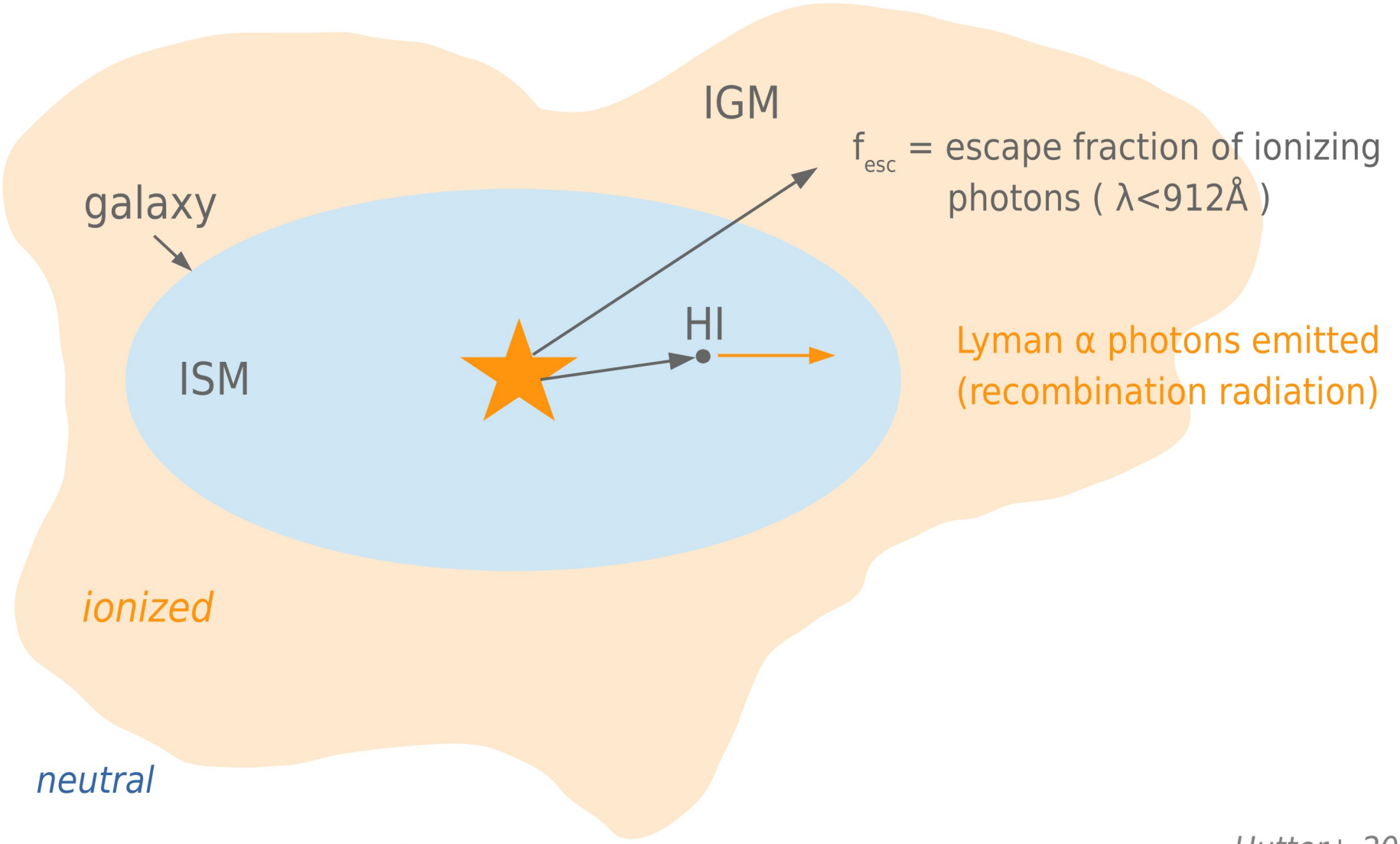
Lyman α photons emitted (recombination radiation)

ISM = interstellar medium

IGM = intergalactic medium

Hutter+ 2014

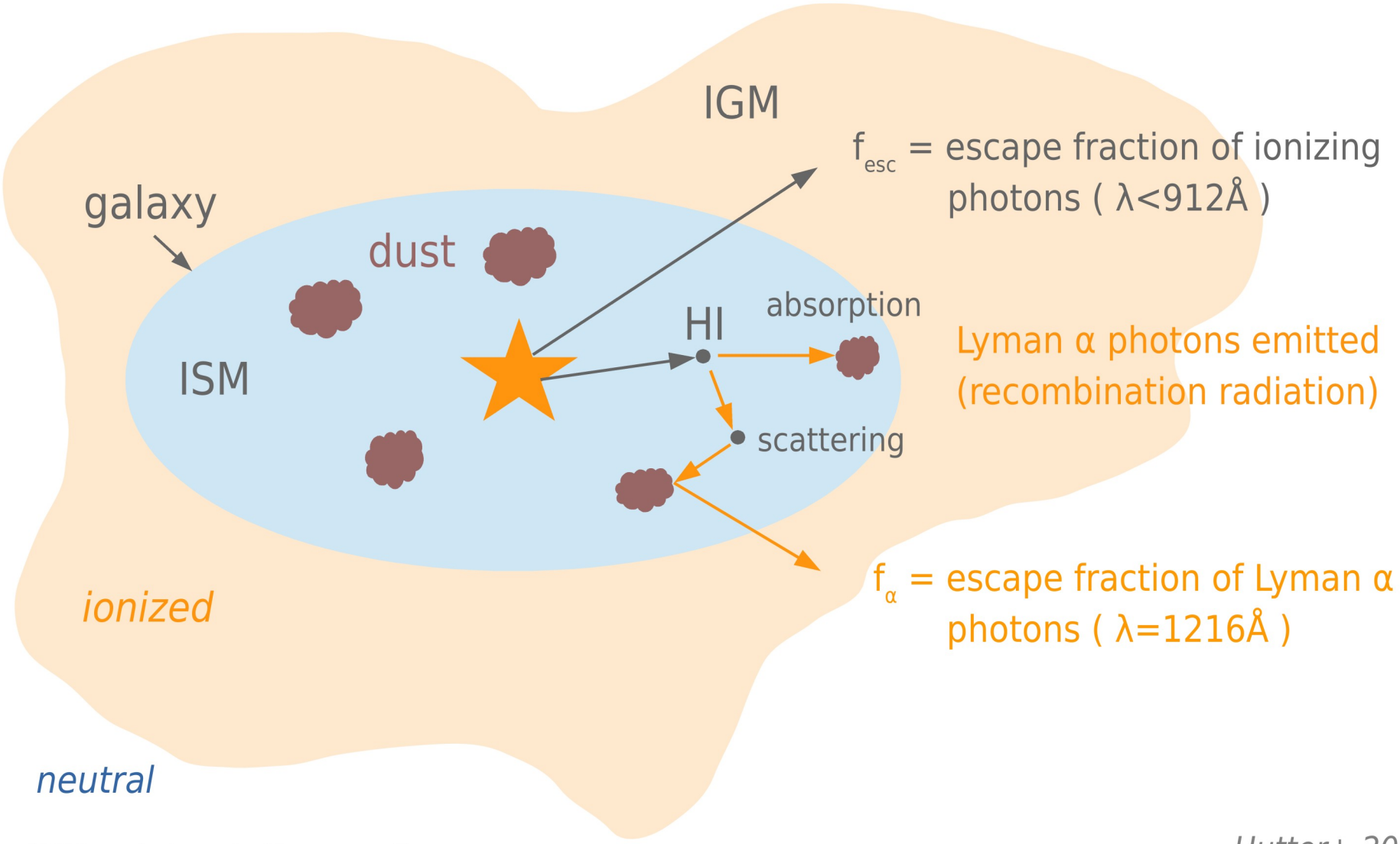
Lyman α emitters (LAEs) in the intergalactic medium



ISM = interstellar medium
IGM = intergalactic medium

Hutter+ 2014

Lyman α emitters (LAEs) in the intergalactic medium



f_{esc} = escape fraction of ionizing photons (λ<912Å)

Lyman α photons emitted (recombination radiation)

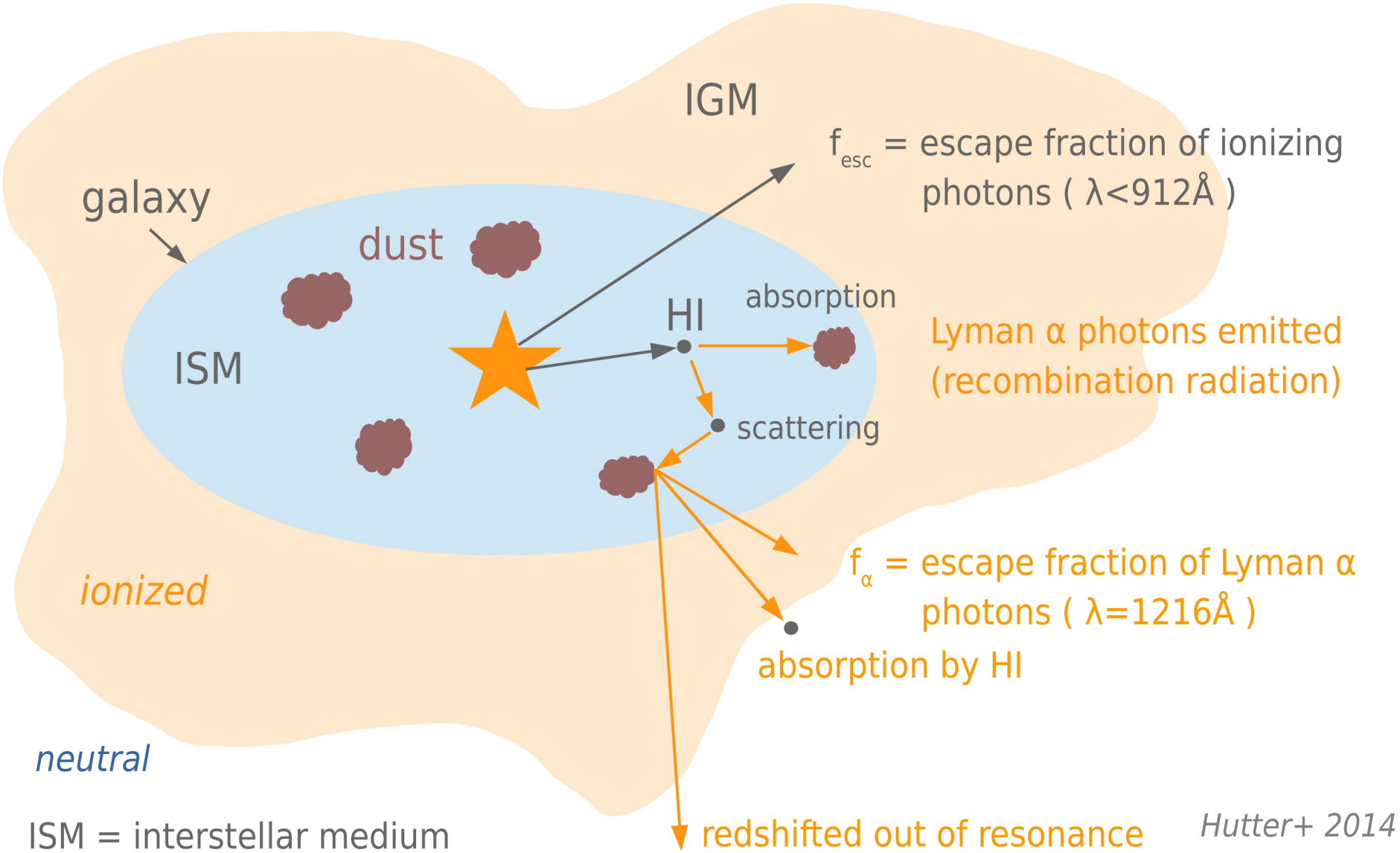
f_{α} = escape fraction of Lyman α photons (λ=1216Å)

ISM = interstellar medium

IGM = intergalactic medium

Hutter+ 2014

Lyman α emitters (LAEs) in the intergalactic medium



ISM = interstellar medium
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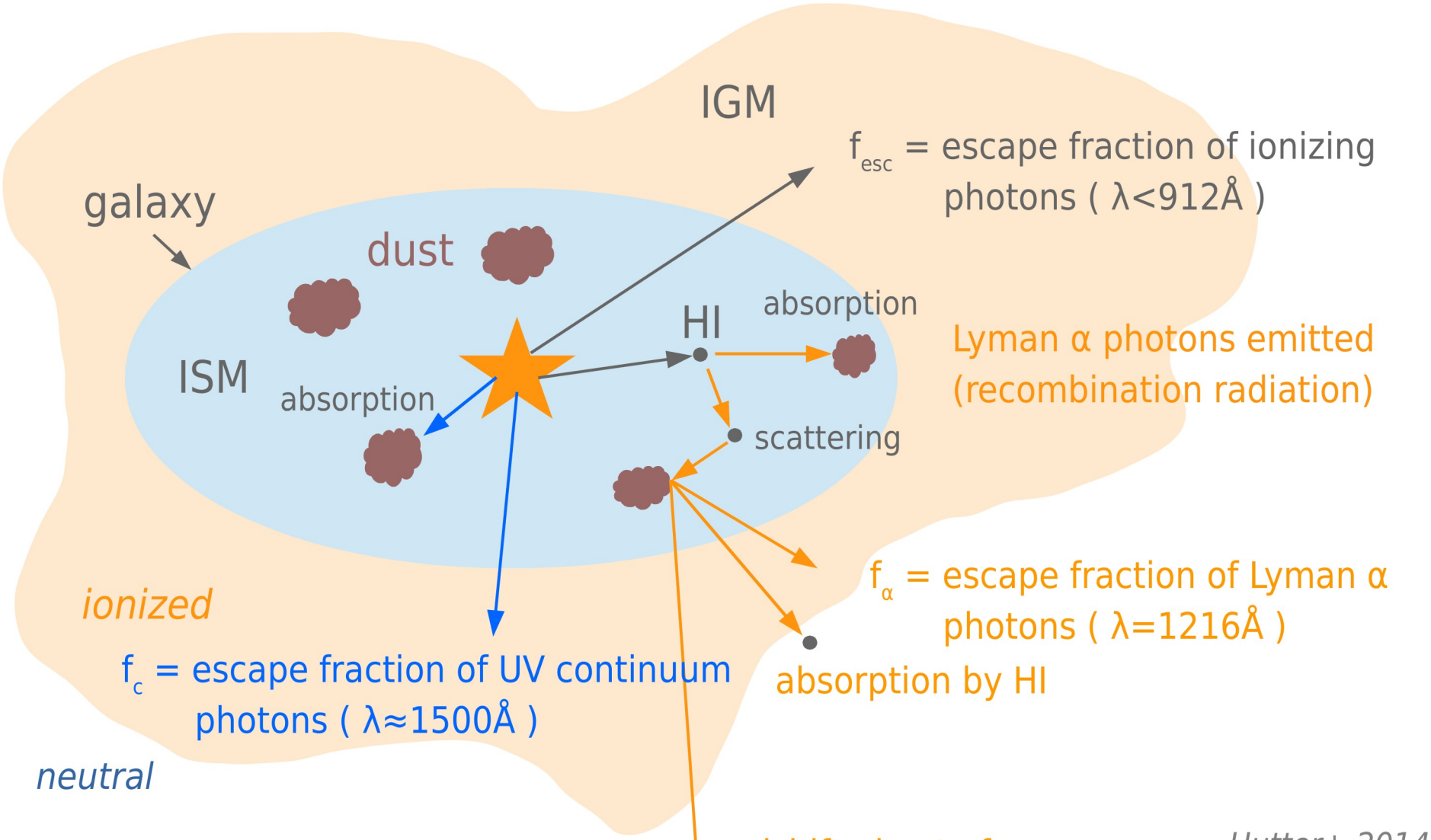
Hutter+ 2014

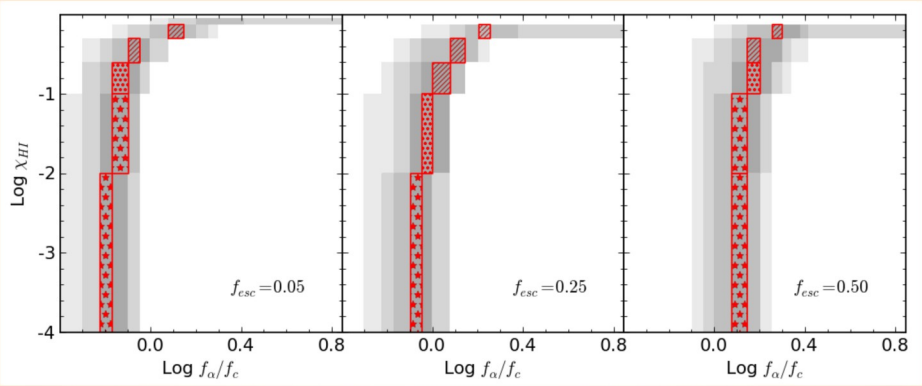
Lyman α emitters (LAEs) in the intergalactic medium



ISM = interstellar medium
IGM = intergalactic medium

Hutter+ 2014

21cm-LAE synergies

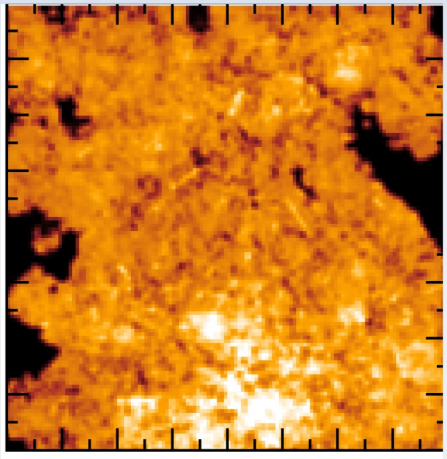


Constraints from Lyα luminosity function
& LAE angular correlation function

LAEs

3D DEGENERACY between
reionization $\langle\chi_{HI}\rangle$,
escape fraction of ionizing photons f_{esc}
& dust f_α/f_c

Hutter+ 2014, 2015



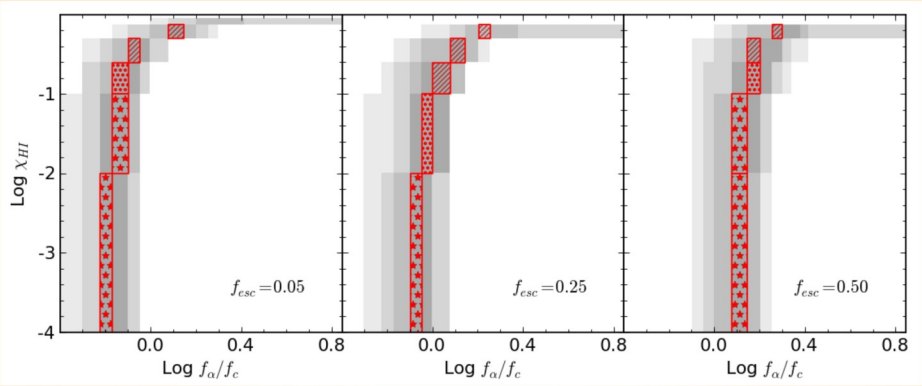
Ionization fields differ for different f_{esc}

21cm

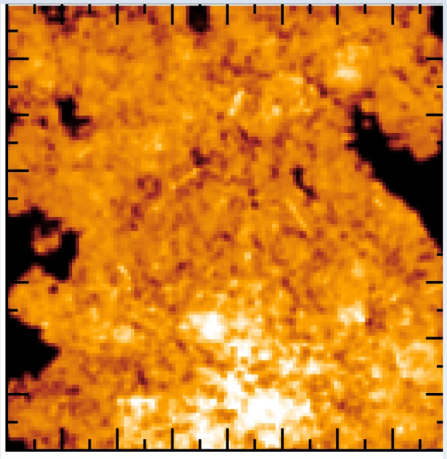
Differential 21cm brightness temperature:

$$\delta T_b = T_0 \langle\chi_{HI}\rangle (1+\delta)(1+\delta_{HI})$$

21cm-LAE synergies



Constraints from Lyα luminosity function & LAE angular correlation function



Ionization fields differ for different f_{esc}

LAEs

3D DEGENERACY between reionization $\langle\chi_{HI}\rangle$, escape fraction of ionizing photons f_{esc} & dust f_α/f_c

Hutter+ 2014, 2015

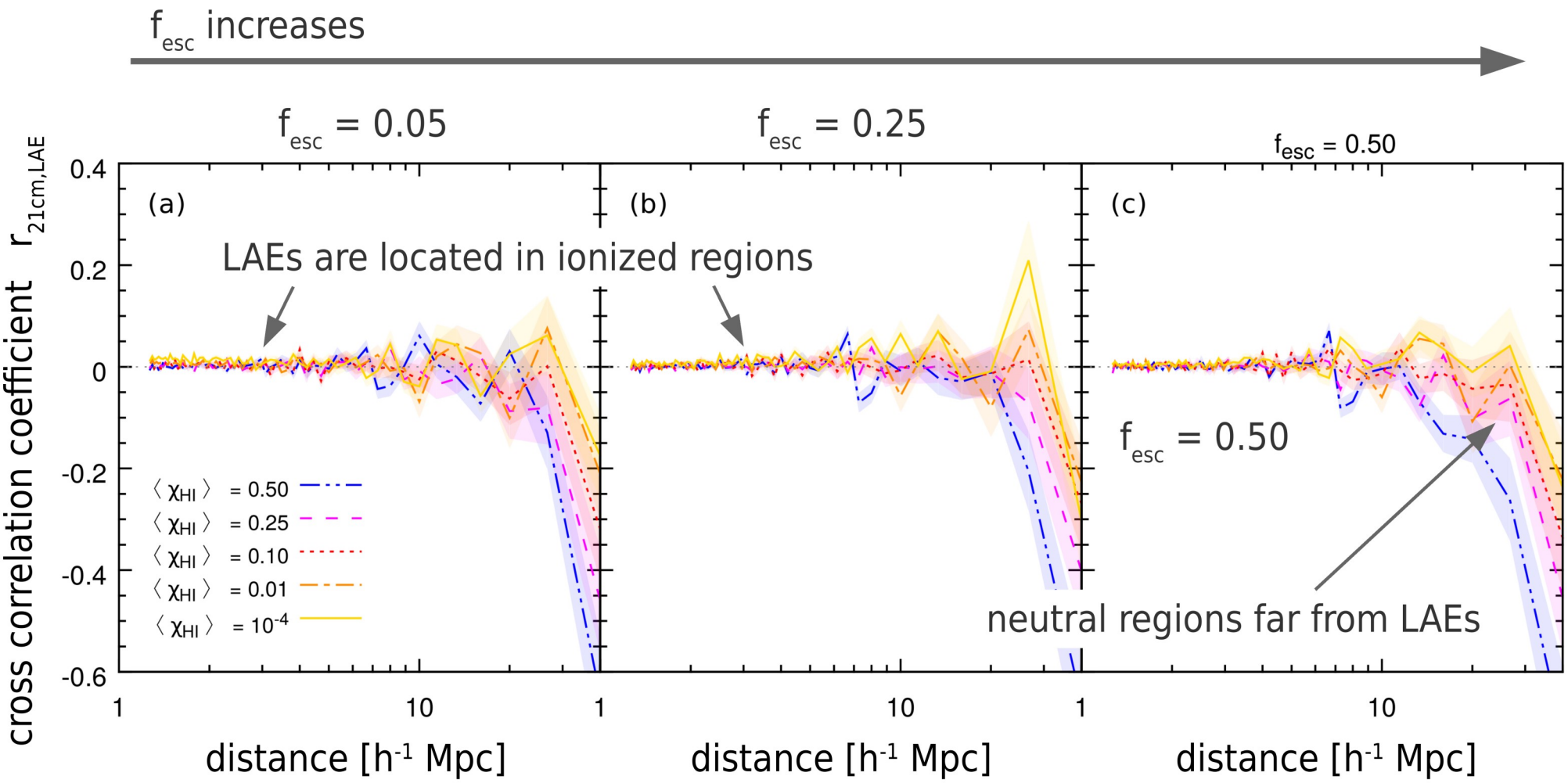
Connection between galactic & intergalactic properties imprinted in 21cm-LAE cross correlations?

21cm

Differential 21cm brightness temperature:

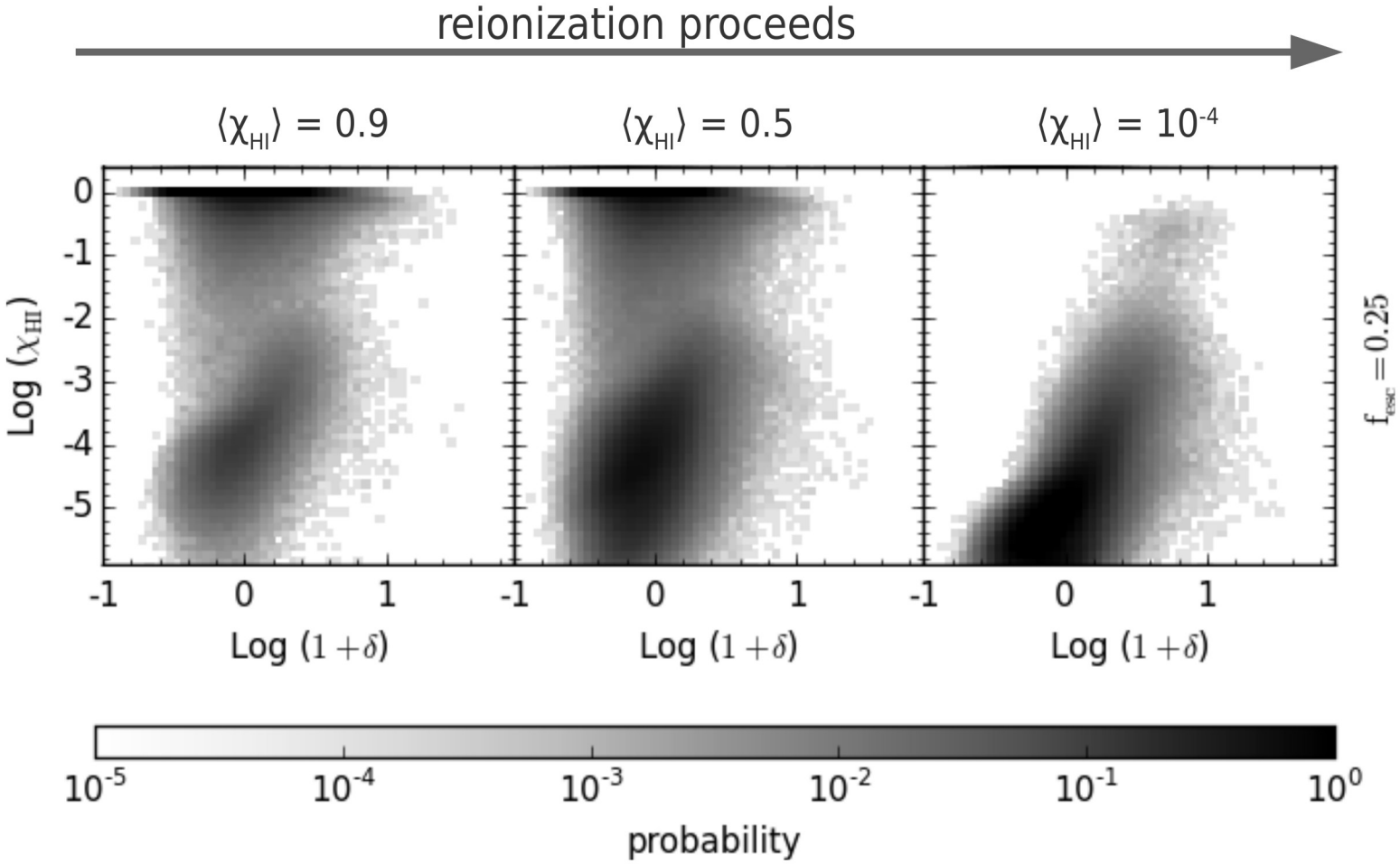
$$\delta T_b = T_0 \langle\chi_{HI}\rangle (1+\delta)(1+\delta_{HI})$$

21cm – LAE cross correlations

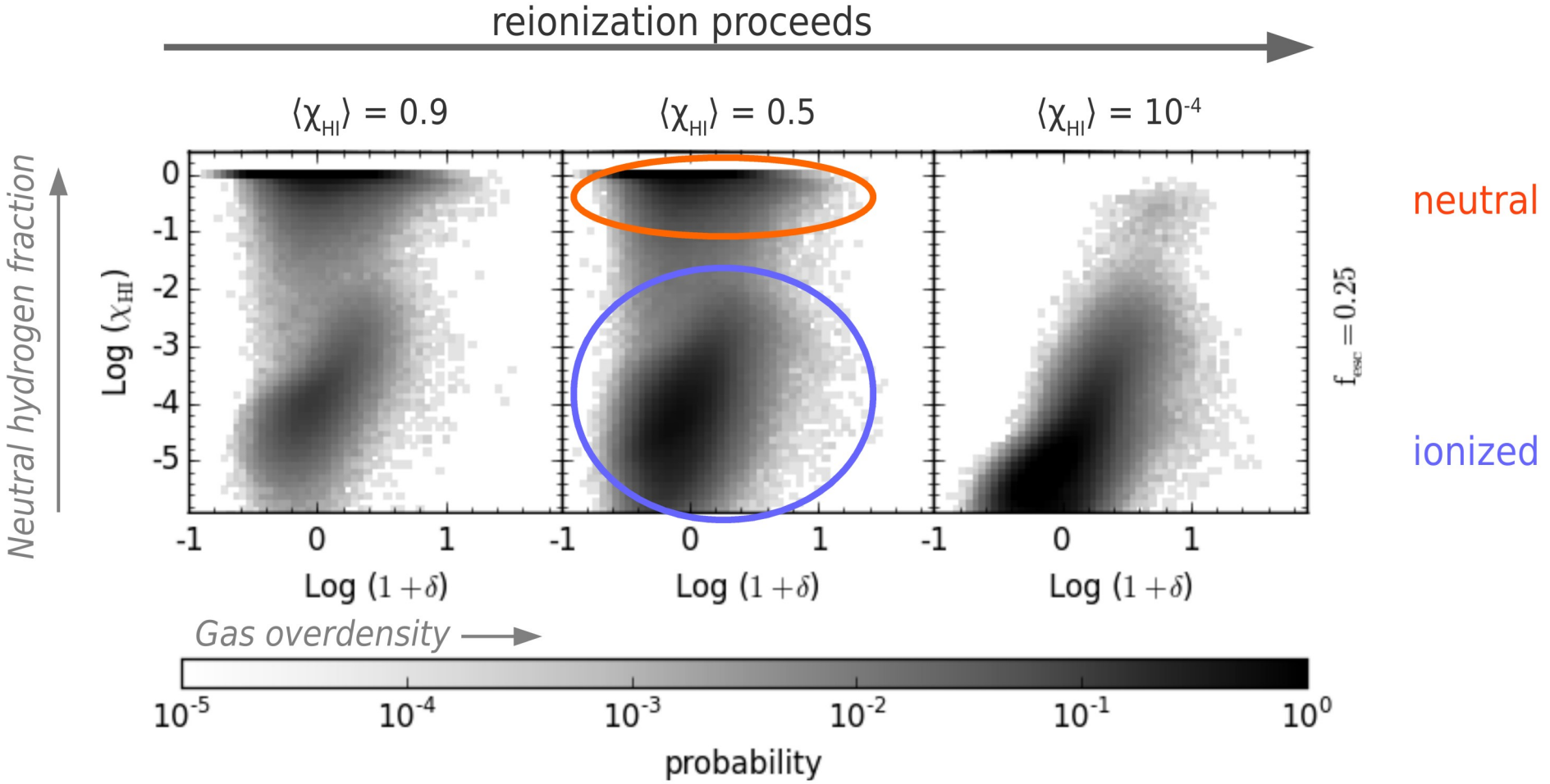


Simulated *21cm-LAE cross correlations* depend *not* on galactic properties...

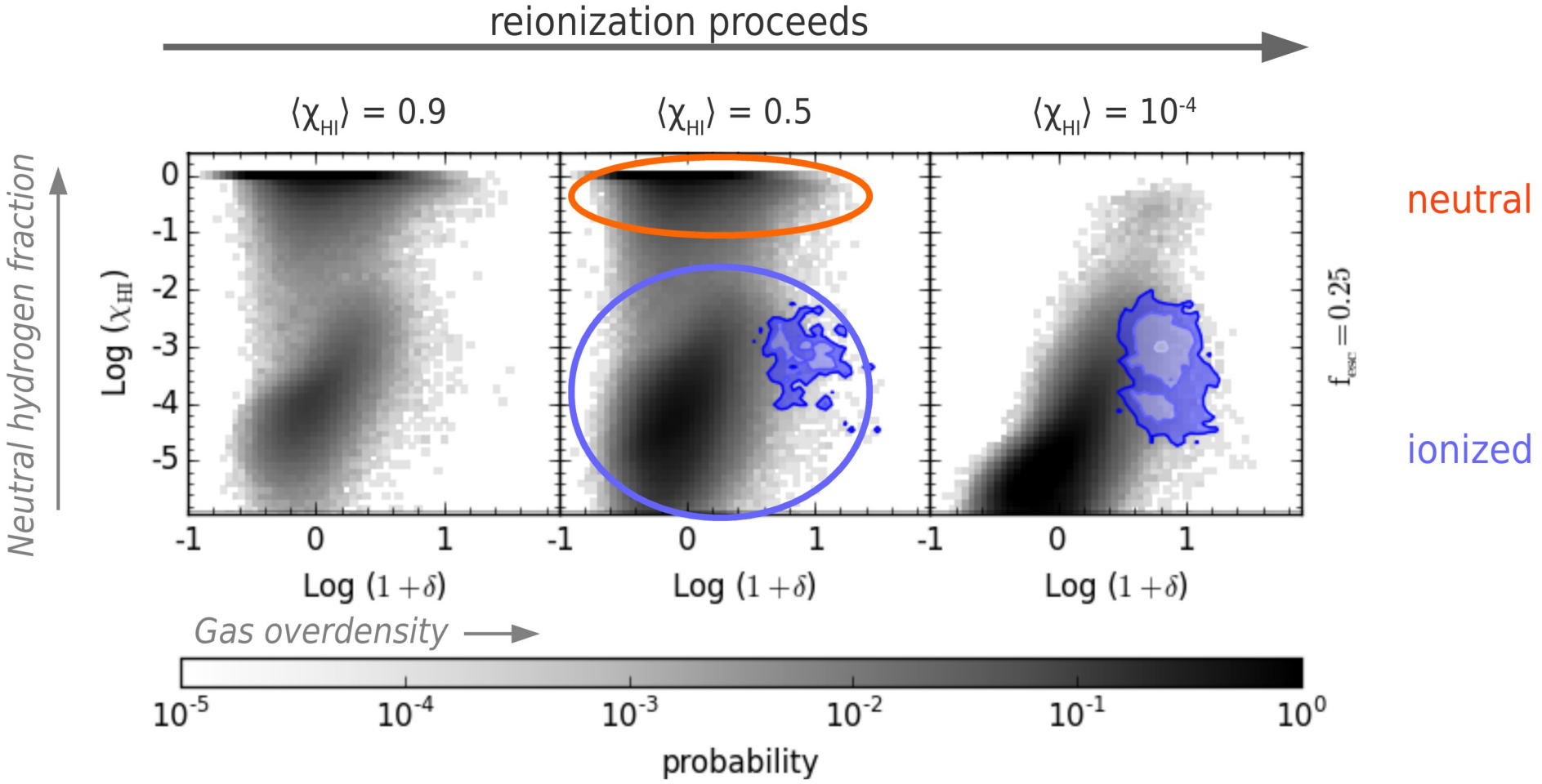
Location of LAEs in the IGM during reionization



Location of LAEs in the IGM during reionization

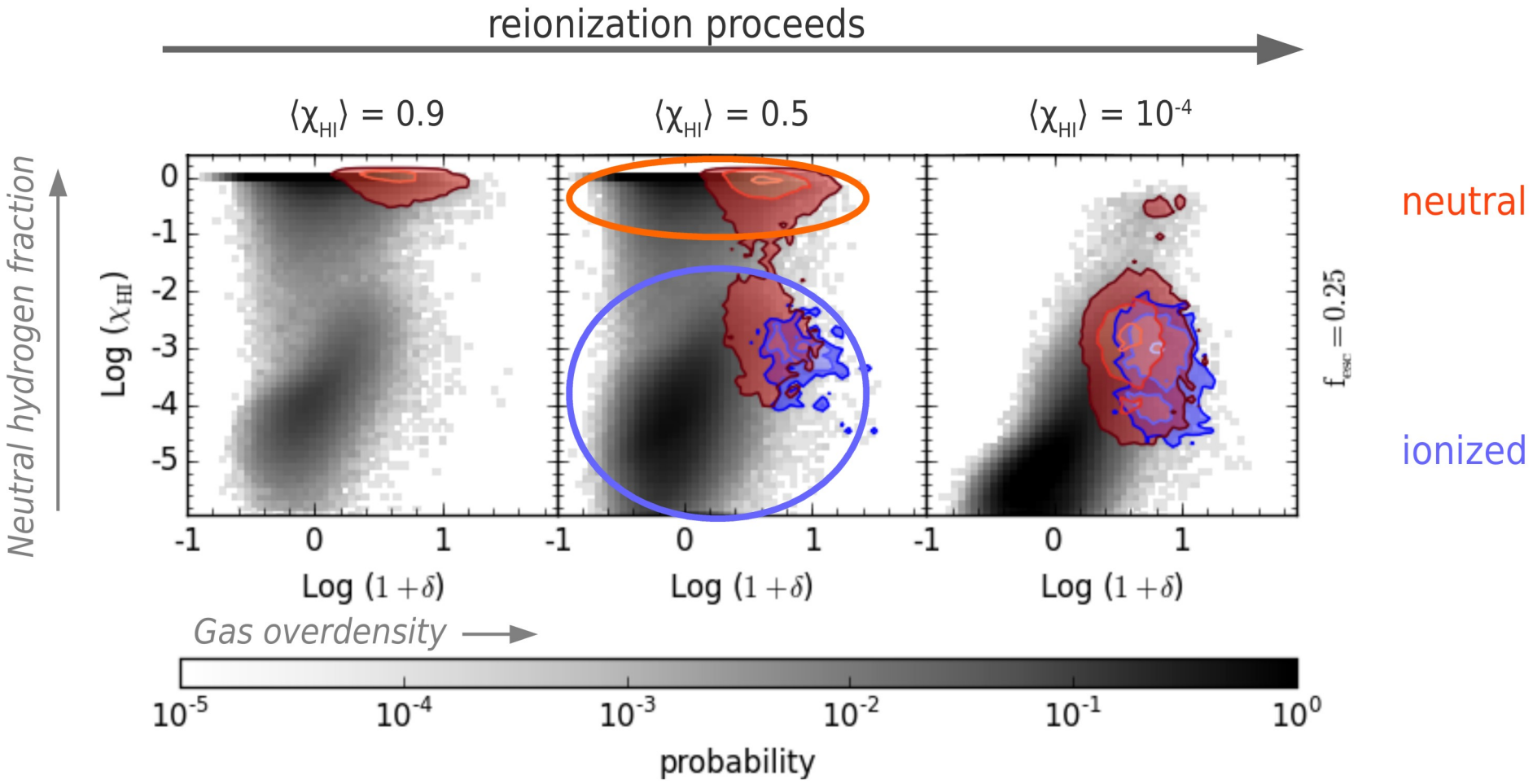


Location of LAEs in the IGM during reionization



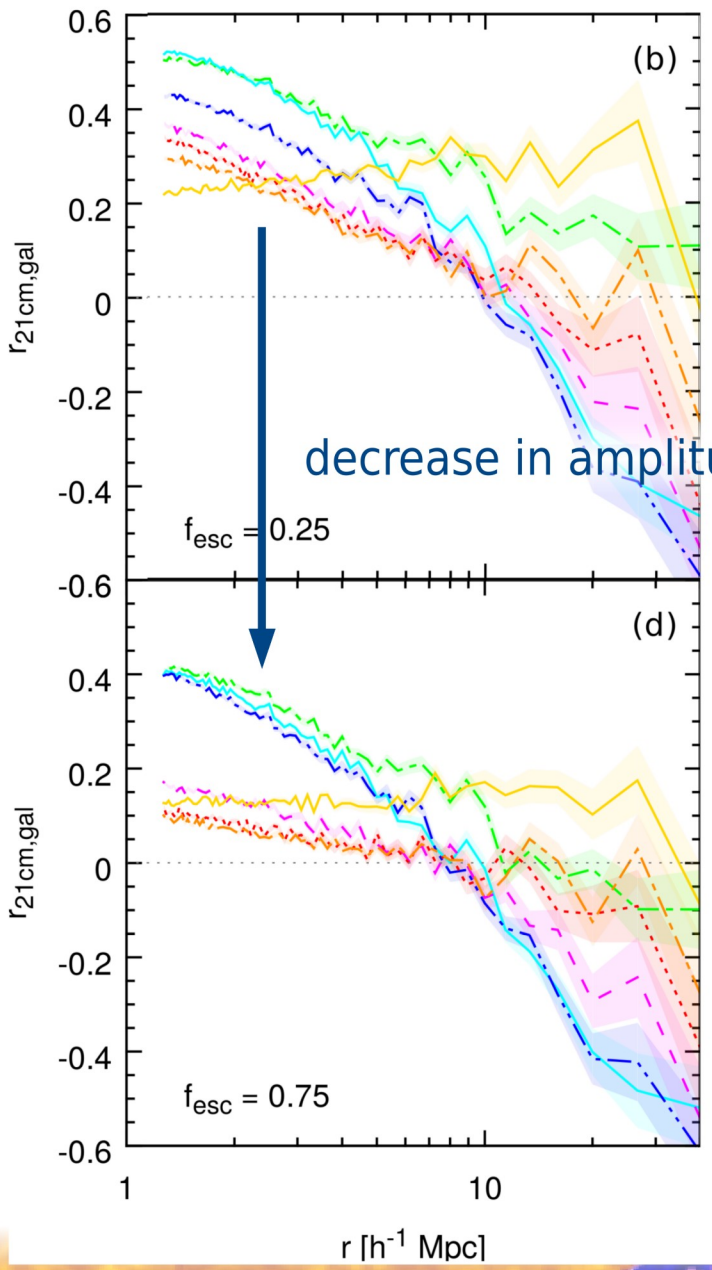
LAEs are located in the ionized and most overdense regions

Location of galaxies in the IGM during reionization



galaxies are located in the most overdense regions

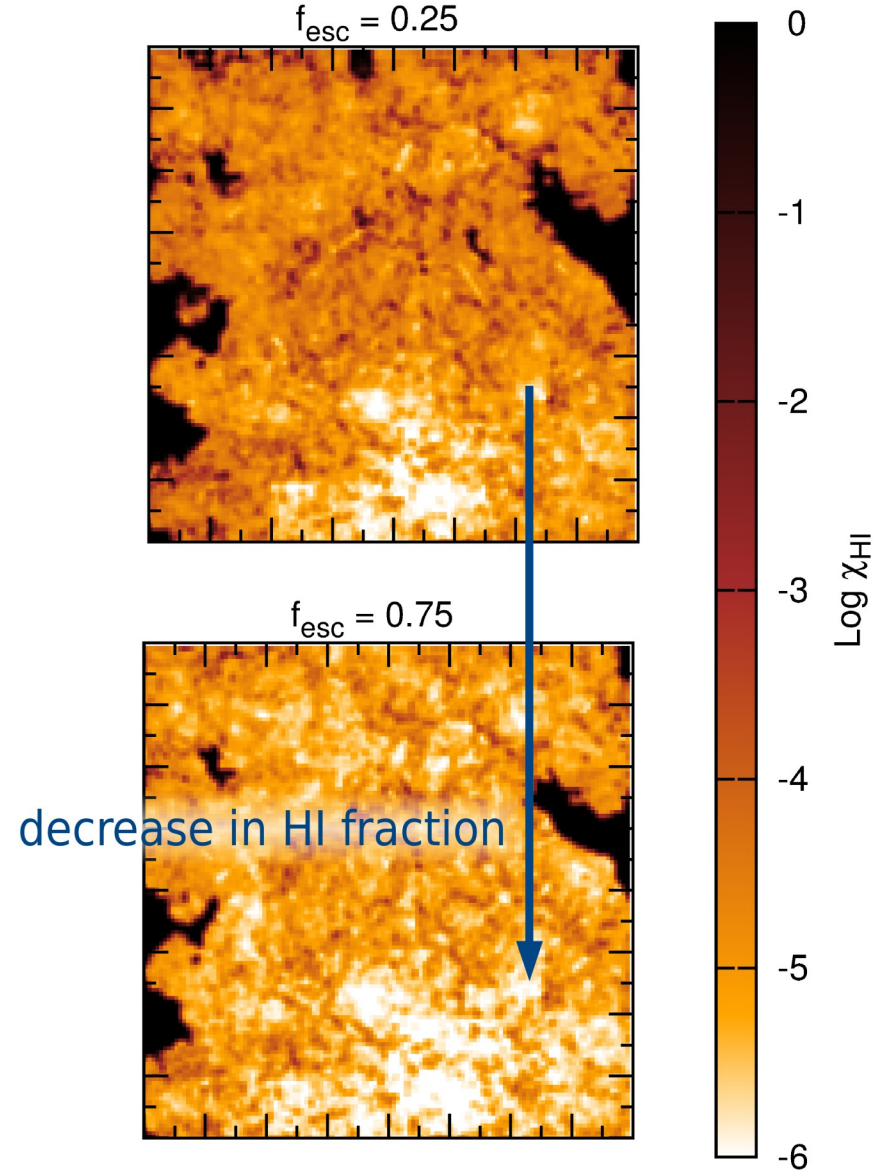
21cm – galaxy cross correlations depend on f_{esc}?



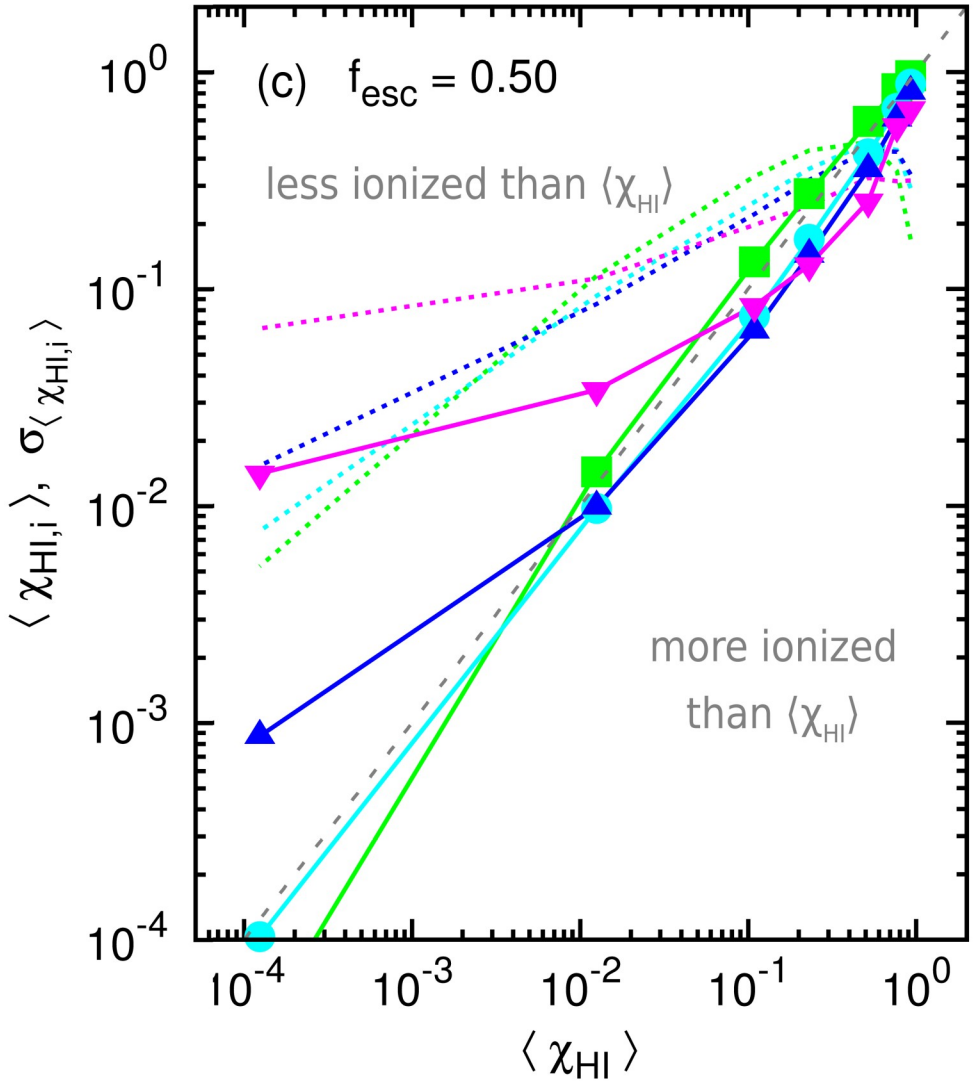
f_{esc} = 0.25

f_{esc} = 0.75

$\langle \chi_{HI} \rangle$ = 0.90
$\langle \chi_{HI} \rangle$ = 0.75
$\langle \chi_{HI} \rangle$ = 0.50
$\langle \chi_{HI} \rangle$ = 0.25
$\langle \chi_{HI} \rangle$ = 0.10
$\langle \chi_{HI} \rangle$ = 0.01
$\langle \chi_{HI} \rangle$ = 10^{-4}



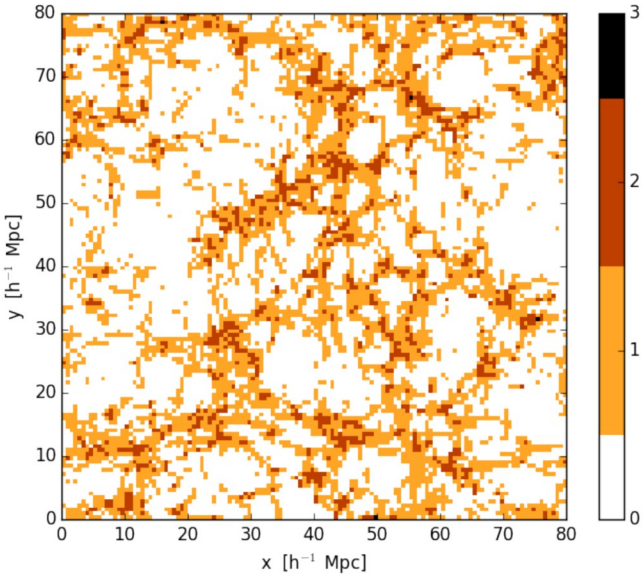
Topology of reionization



Tidal field tensor

Nuza+ 2014

Cosmic web

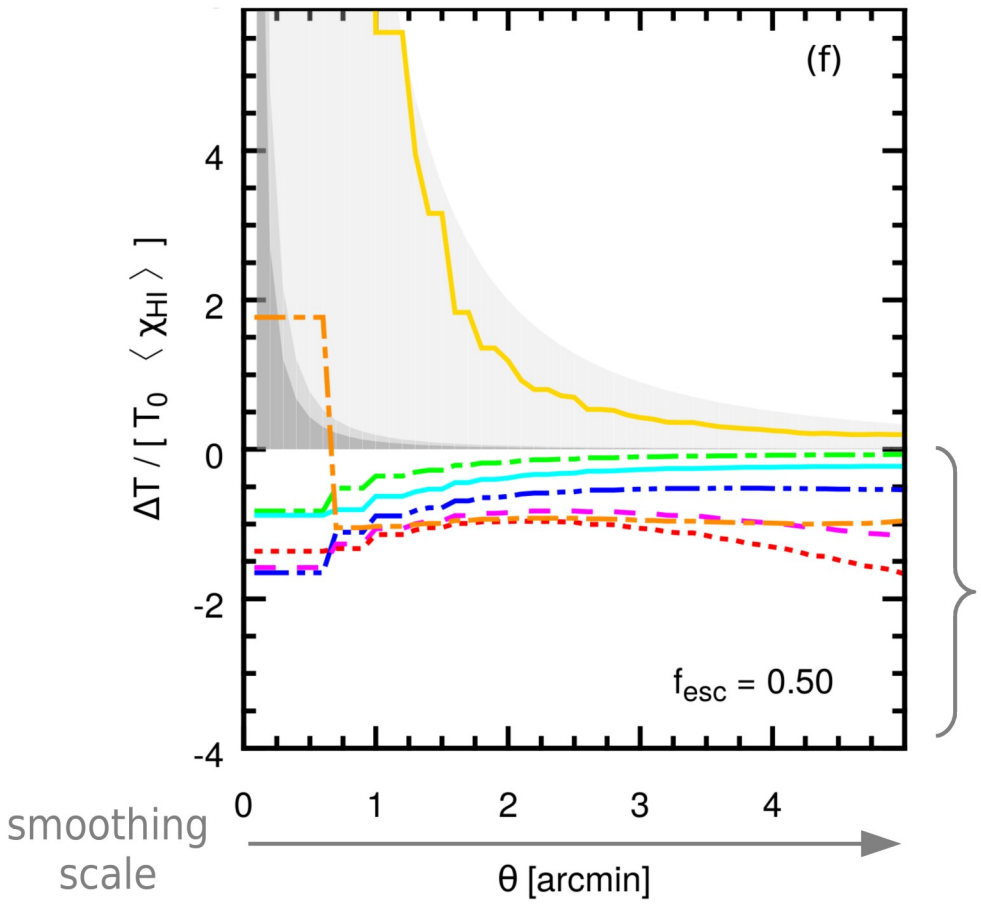


IONIZATION HISTORY in the cosmic web:

- knots
- filaments
- sheets
- voids

REIONIZATION proceeds INSIDE-OUT

Measuring topology using 21cm correlations with overdensities and voids



Difference between regions containing and not containing galaxies:

Wyithe & Loeb 2007

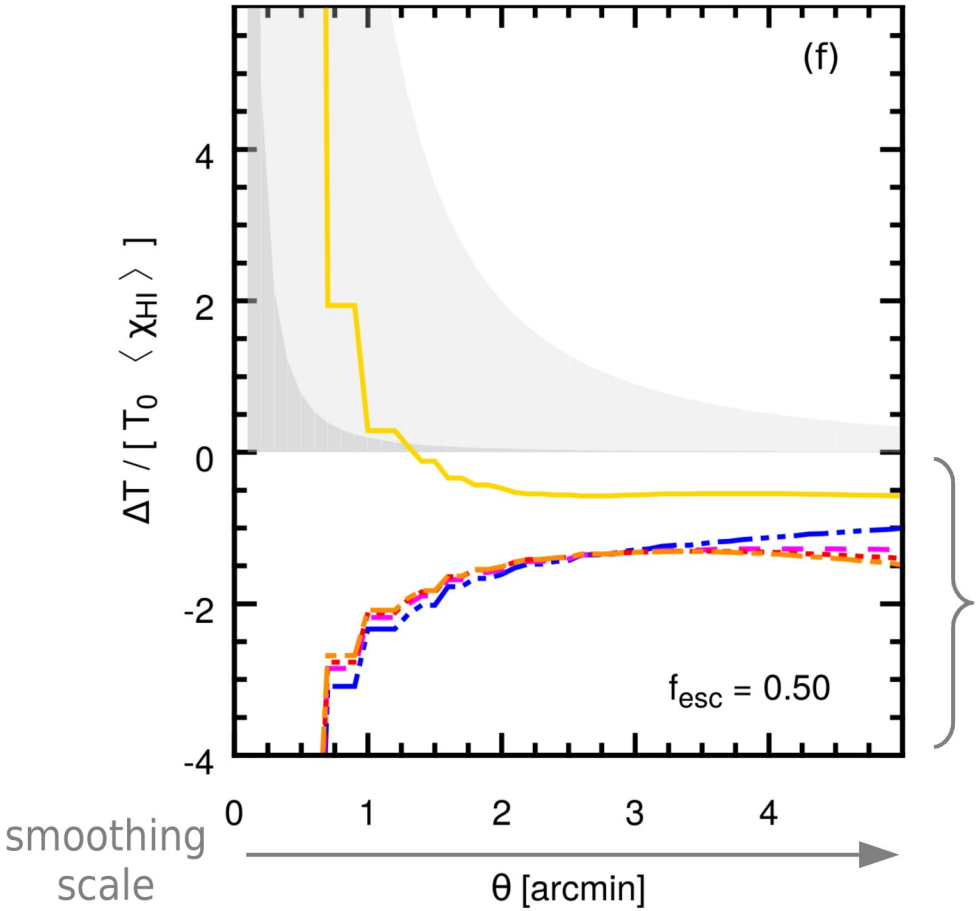
$$\Delta T = \underbrace{(T_{gal} - T_{gal,intr})}_{\text{dominates due to higher } \delta \text{ on small smoothing scales}} - \underbrace{(T_{nogal} - T_{nogal,intr})}_{\text{shaped by } \langle \delta_{HI} \rangle_{nogal} \text{ on larger smoothing scales}}$$

$$\langle \delta_{HI}(\mathbf{x})\, \delta(\mathbf{x}) \rangle_{\mathbf{x} \in Vgal} - \langle \delta_{HI}(\mathbf{x})\, \delta(\mathbf{x}) \rangle_{\mathbf{x} \in Vnogal} < 0$$

→ overdense regions are ionized before underdense regions

$\langle \chi_{HI} \rangle$ = 0.90 — $\langle \chi_{HI} \rangle$ = 0.75 — $\langle \chi_{HI} \rangle$ = 0.50 — $\langle \chi_{HI} \rangle$ = 0.25 — $\langle \chi_{HI} \rangle$ = 0.10 — $\langle \chi_{HI} \rangle$ = 0.01 — $\langle \chi_{HI} \rangle$ = 10^{-4}

Measuring topology using 21cm correlations with overdensities and voids



Difference between regions containing and not containing LAEs:

Wyithe & Loeb 2007

$$\Delta T = \underbrace{(T_{LAE} - T_{LAE,intr})}_{\text{dominates due to higher } \delta \text{ on small smoothing scales}} - \underbrace{(T_{noLAE} - T_{noLAE,intr})}_{\text{shaped by } \langle \delta_{HI} \rangle_{noLAE} \text{ on larger smoothing scales}}$$

$$\langle \delta_{HI}(\mathbf{x})\, \delta(\mathbf{x}) \rangle_{\mathbf{x} \in VLAE} - \langle \delta_{HI}(\mathbf{x})\, \delta(\mathbf{x}) \rangle_{\mathbf{x} \in VnoLAE} < 0$$

→ overdense regions are ionized before underdense regions

$\langle \chi_{HI} \rangle$ = 0.50 — $\langle \chi_{HI} \rangle$ = 0.25 — $\langle \chi_{HI} \rangle$ = 0.10 — $\langle \chi_{HI} \rangle$ = 0.01 — $\langle \chi_{HI} \rangle$ = 10^{-4}

Conclusions

21CM CROSS CORRELATION WITH GALAXIES AND LAES

- *21cm-galaxy cross correlation* depends on *reionization*
- Faint field galaxies are not able to ionize their surrounding sufficiently, which introduces a *correlation signal* between the 21cm signal and galaxies on small scales.
- *LAEs* lie in the most *overdense and ionized regions*, where the suppressed 21cm signal causes the cross correlation signal to vanish on small scales.

TOPOLOGY OF REIONIZATION

- With the 21cm signal being significantly lower in regions containing than regions lacking galaxies, the corresponding difference in the *21cm signal in overdensities and voids* provides an “observable” for reionization topology.