

# Exploiting 21cm - Lyman- $\alpha$ emitter synergies: constraints on reionization

*arXiv 1605.01734*

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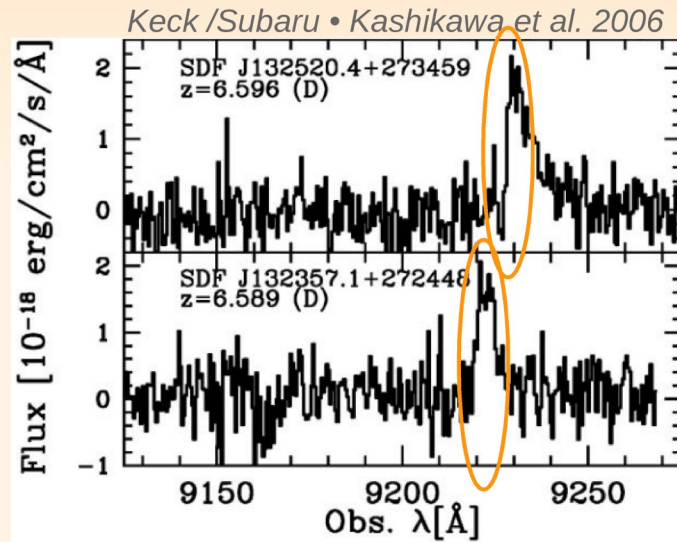
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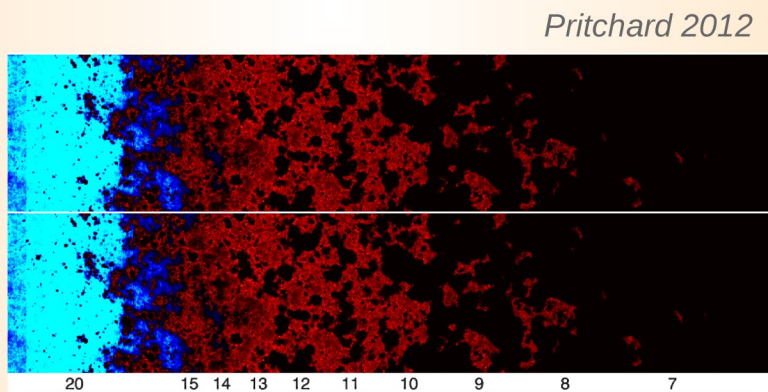
<sup>4</sup> ICRAR, Curtin University Perth

# Constraining reionization & high-z galaxies

OBSERVATIONS

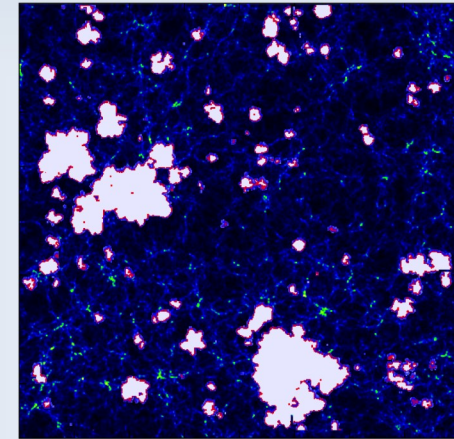


LYMAN ALPHA EMITTERS (LAEs)



21cm RADIATION

C  
O  
M  
P  
A  
R  
I  
S  
O  
N



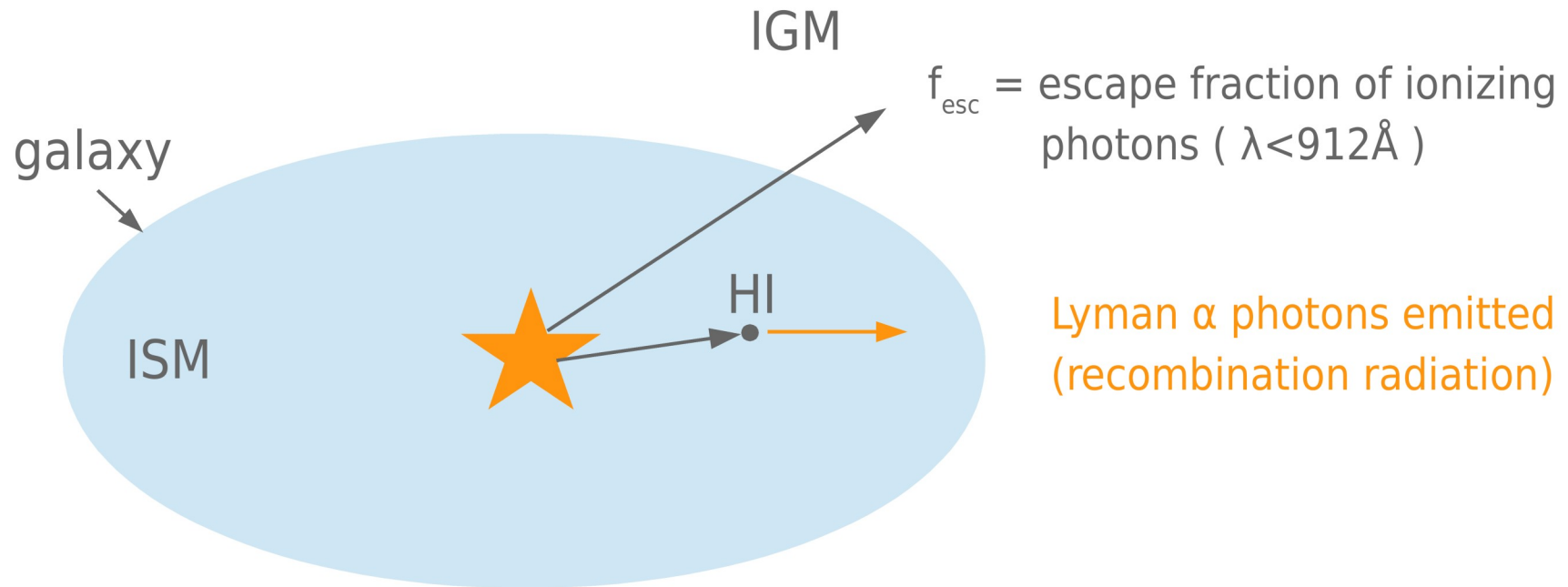
INTERGALACTIC MEDIUM



GALAXY PROPERTIES

MODELS & SIMULATIONS

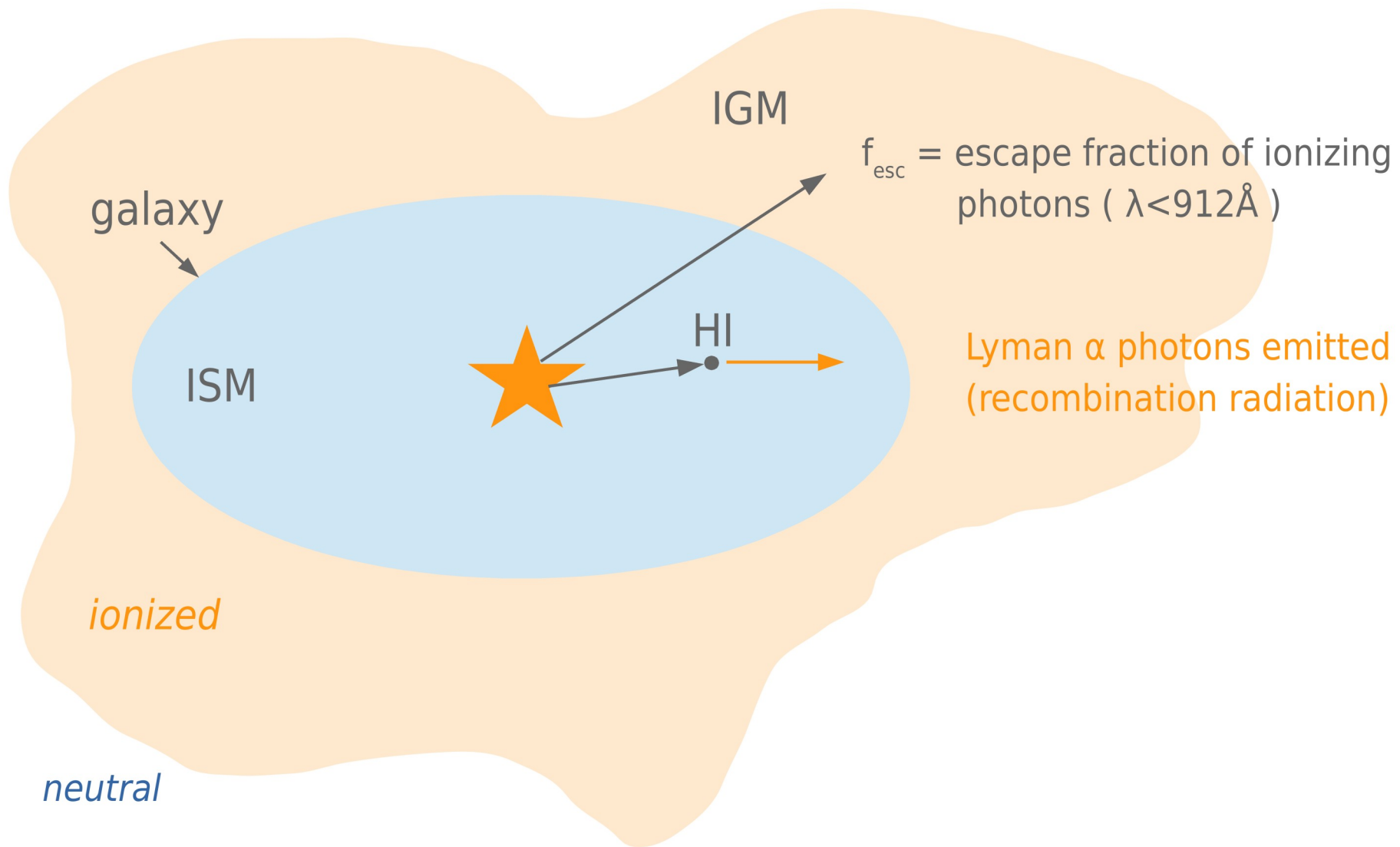
# Lyman $\alpha$ emitters (LAEs) in the intergalactic medium



ISM = interstellar medium  
IGM = intergalactic medium

*Hutter+ 2014*

# Lyman $\alpha$ emitters (LAEs) in the intergalactic medium

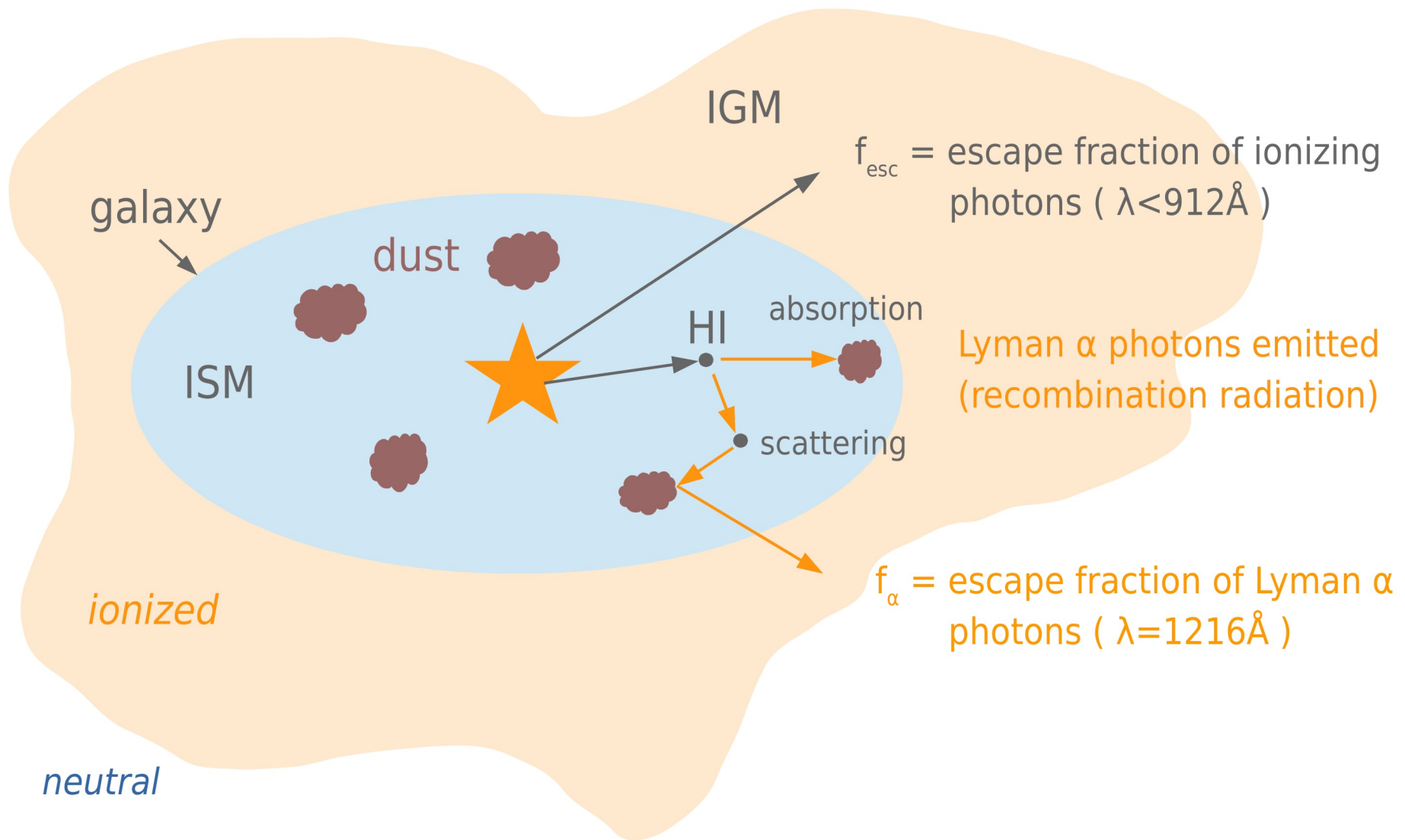


ISM = interstellar medium

IGM = intergalactic medium

Hutter+ 2014

# Lyman $\alpha$ emitters (LAEs) in the intergalactic medium

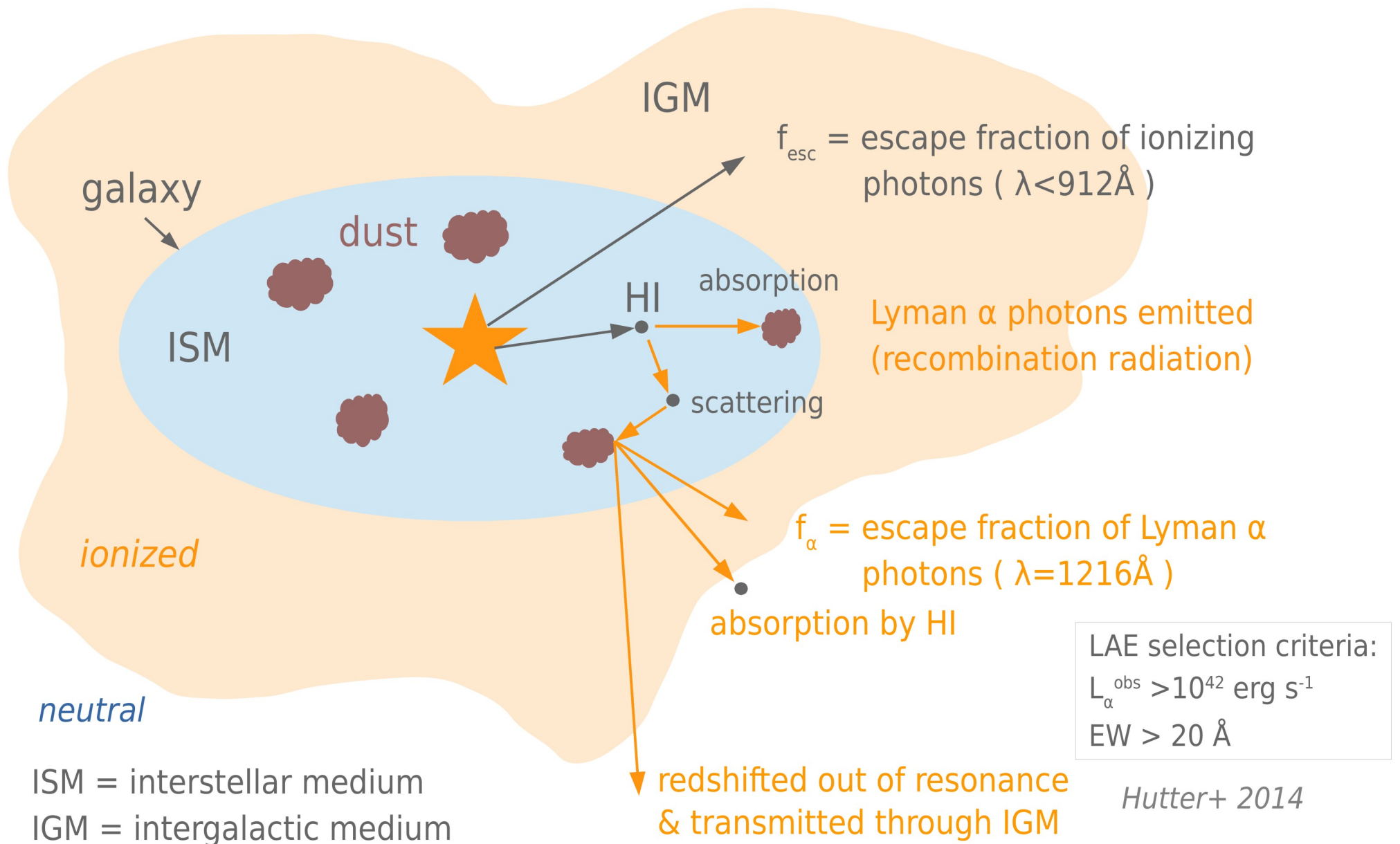


ISM = interstellar medium

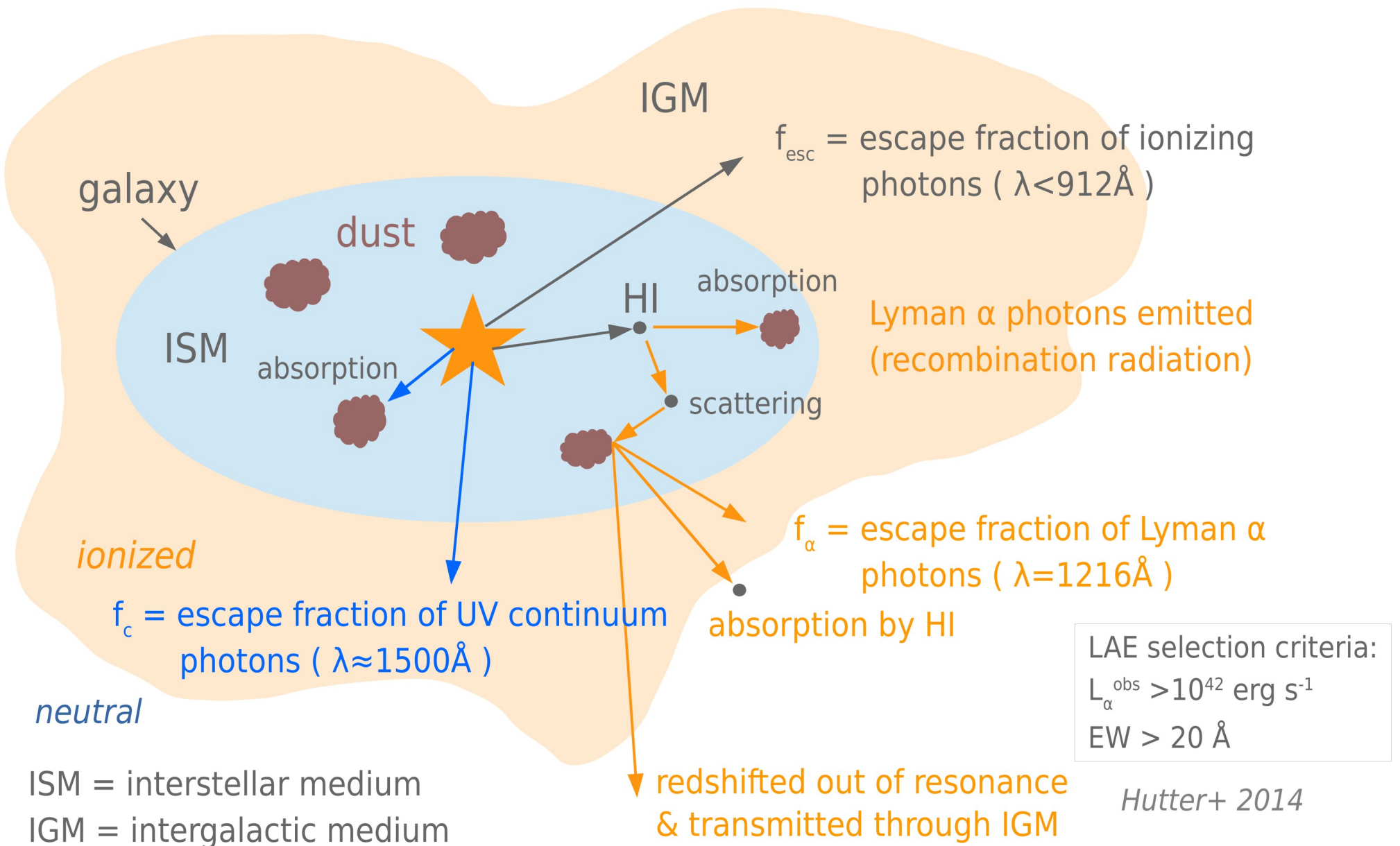
IGM = intergalactic medium

Hutter+ 2014

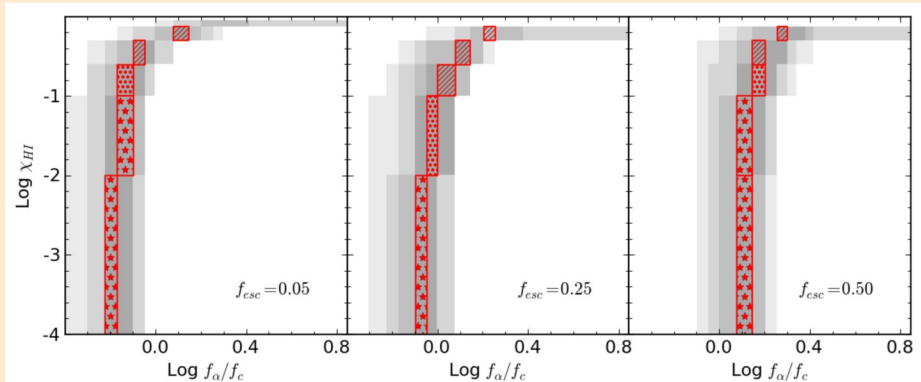
# Lyman $\alpha$ emitters (LAEs) in the intergalactic medium



# Lyman $\alpha$ emitters (LAEs) in the intergalactic medium



# 21cm-LAE synergies

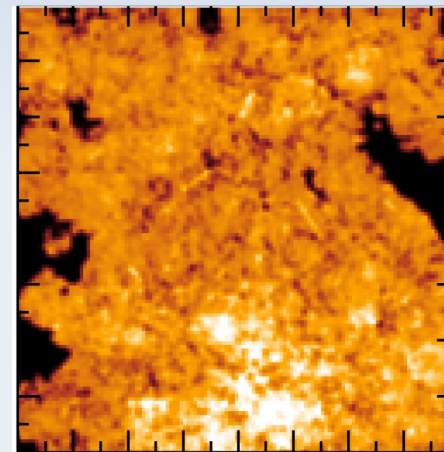


Constraints from Ly $\alpha$  luminosity function  
& LAE angular correlation function at  $z \approx 6.6$

## LAEs

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

Hutter+ 2014, 2015



Ionization fields differ for different  $f_{esc}$

## 21cm

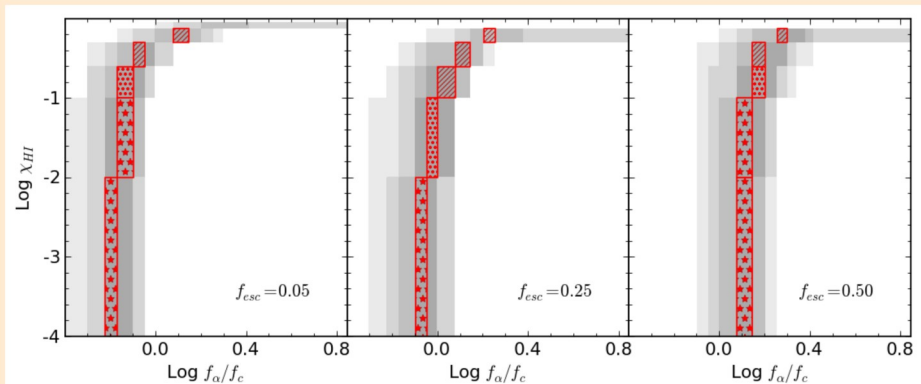
Differential 21cm brightness  
temperature:

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

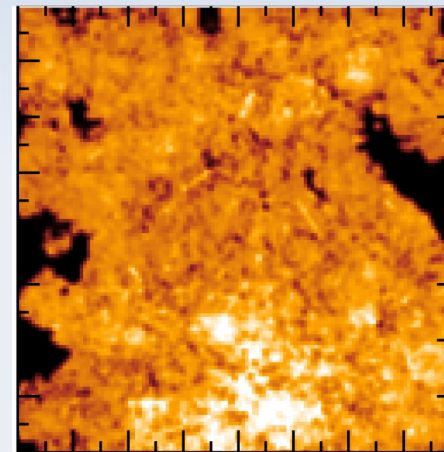
Hutter+ 2016



# 21cm-LAE synergies



Constraints from Ly $\alpha$  luminosity function & LAE angular correlation function at  $z \approx 6.6$



Ionization fields differ for different  $f_{esc}$

## LAEs

**Connection between galactic & intergalactic properties imprinted in**

## 21cm

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

Hutter+ 2014, 2015

**21cm-LAE cross correlations?**

Differential 21cm brightness temperature:

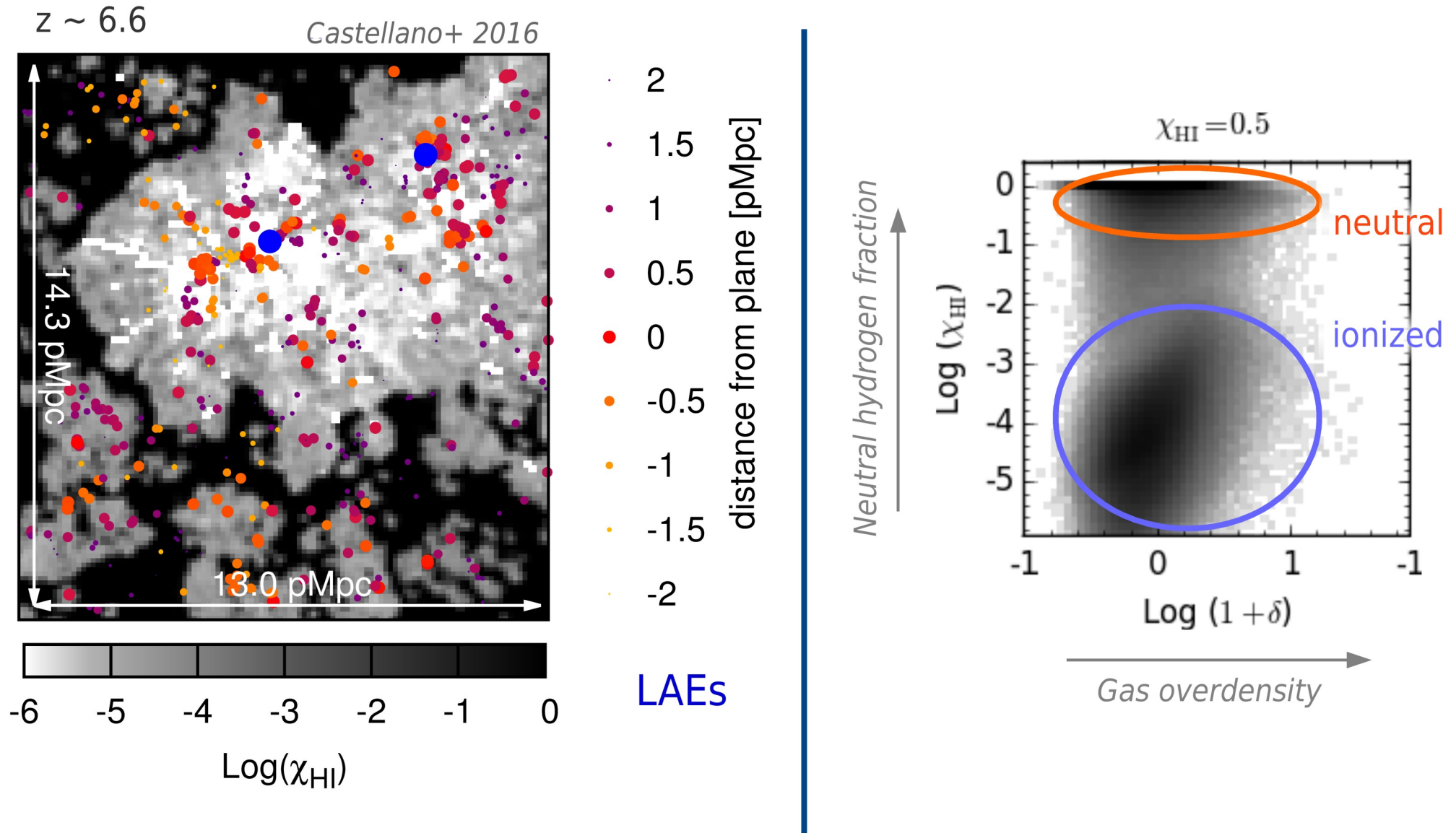
$$\delta T_b = T_0 \langle \chi_{HI} \rangle (1+\delta) (1+\delta_{HI})$$

Hutter+ 2016

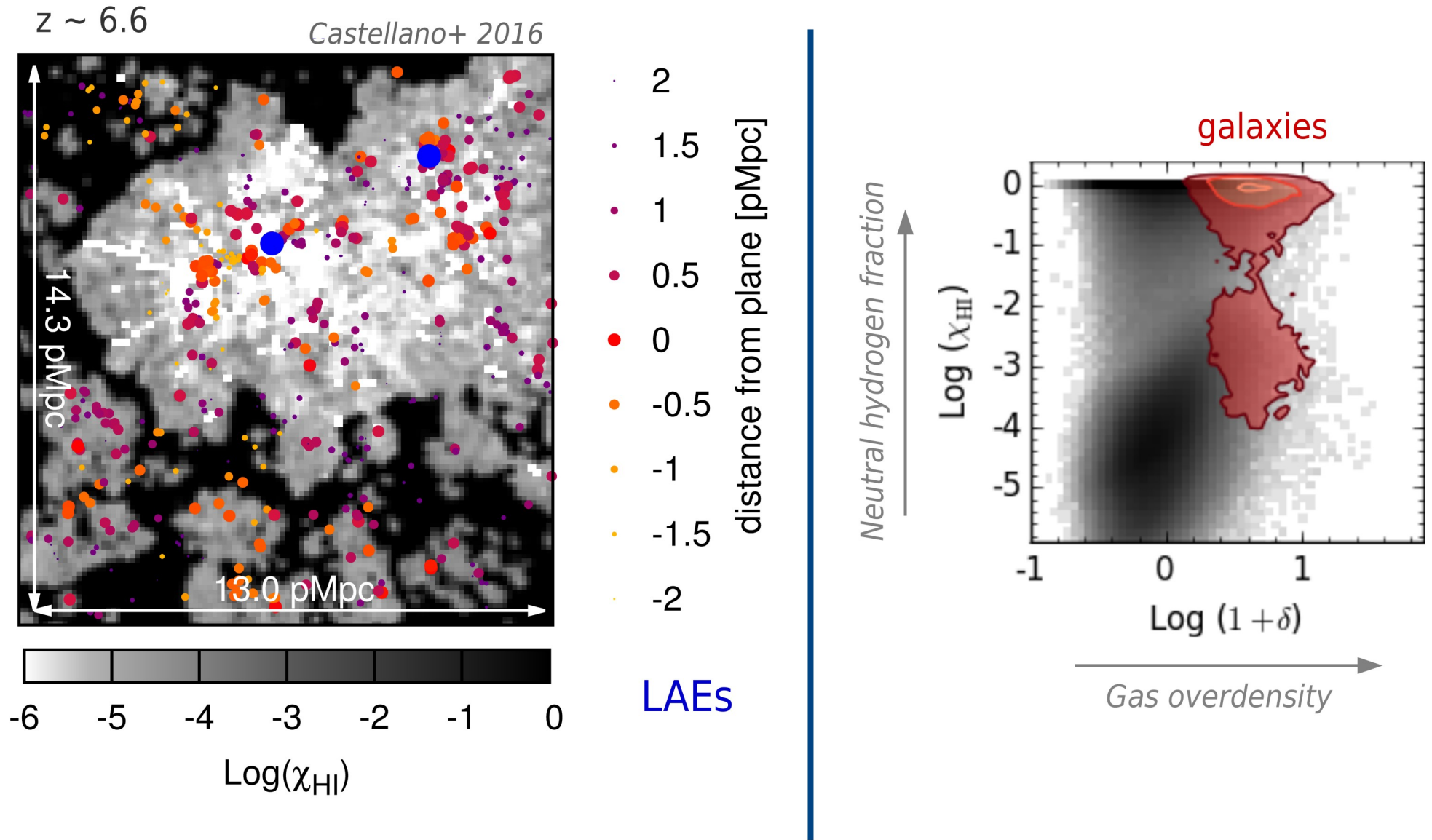
# Questions

- Where in the IGM are LAEs located during reionization?  
Is this reflected in the cross correlations between LAEs and 21cm signal?
- Can we constrain galaxy properties by cross correlating LAE and 21cm data?
- Can we learn something about reionization topology from cross correlating LAE and 21cm data?

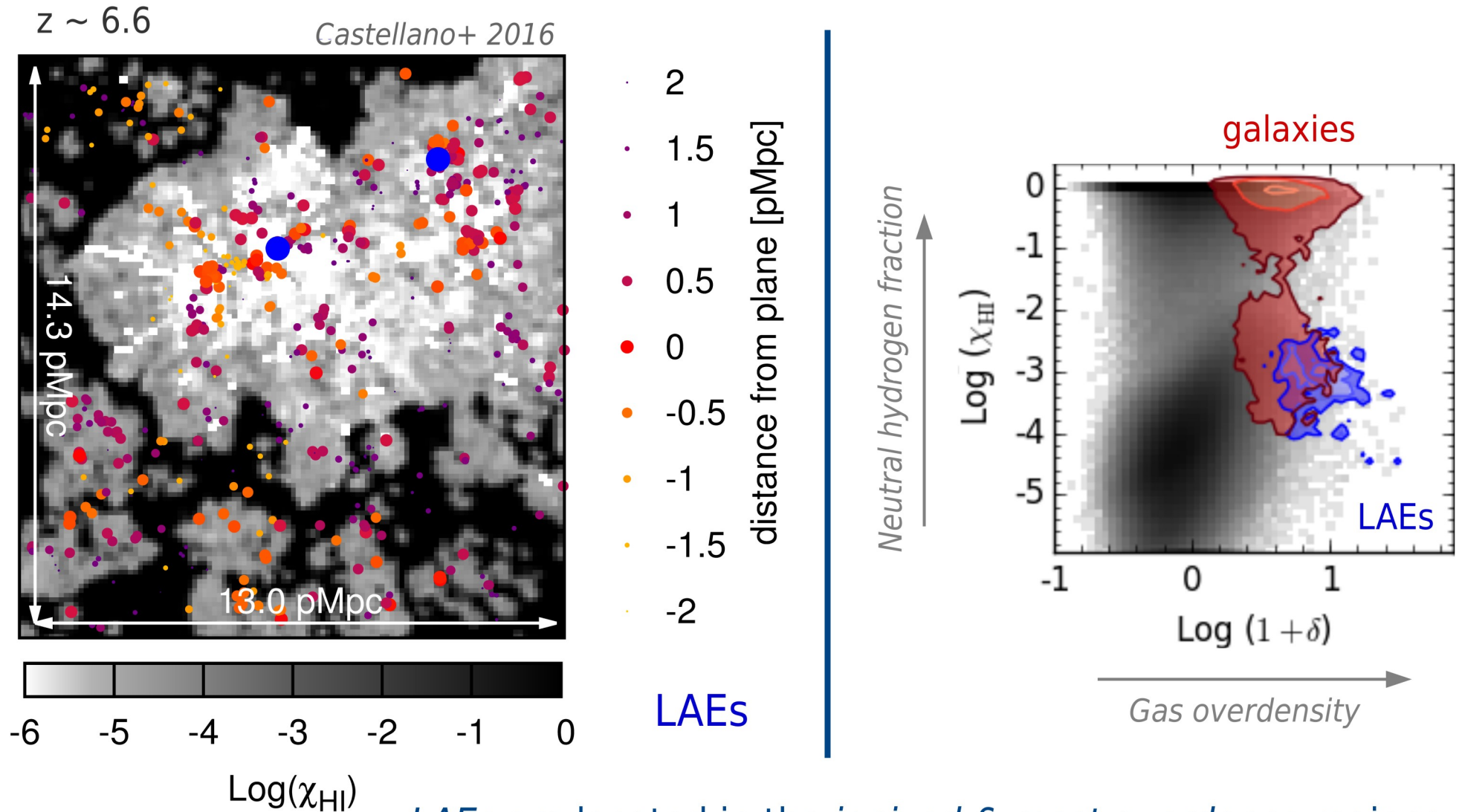
# Where are LAEs located in the IGM?



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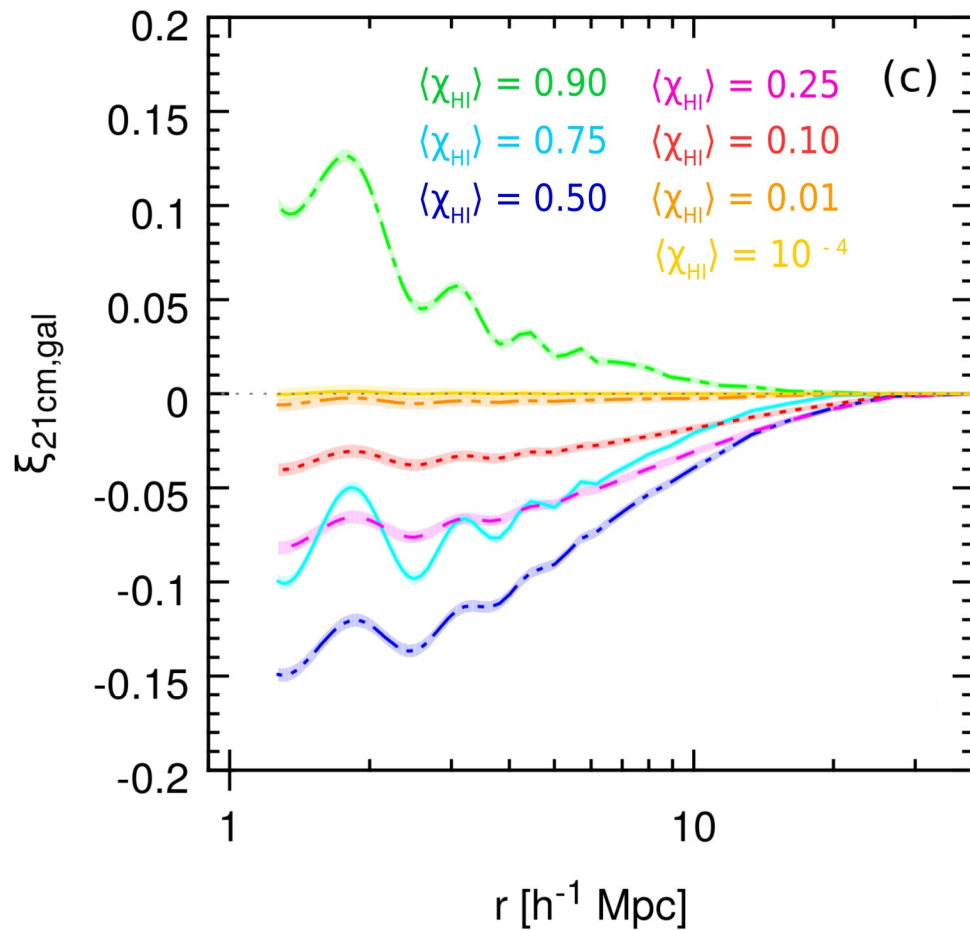


*LAEs are located in the ionized & most overdense regions*

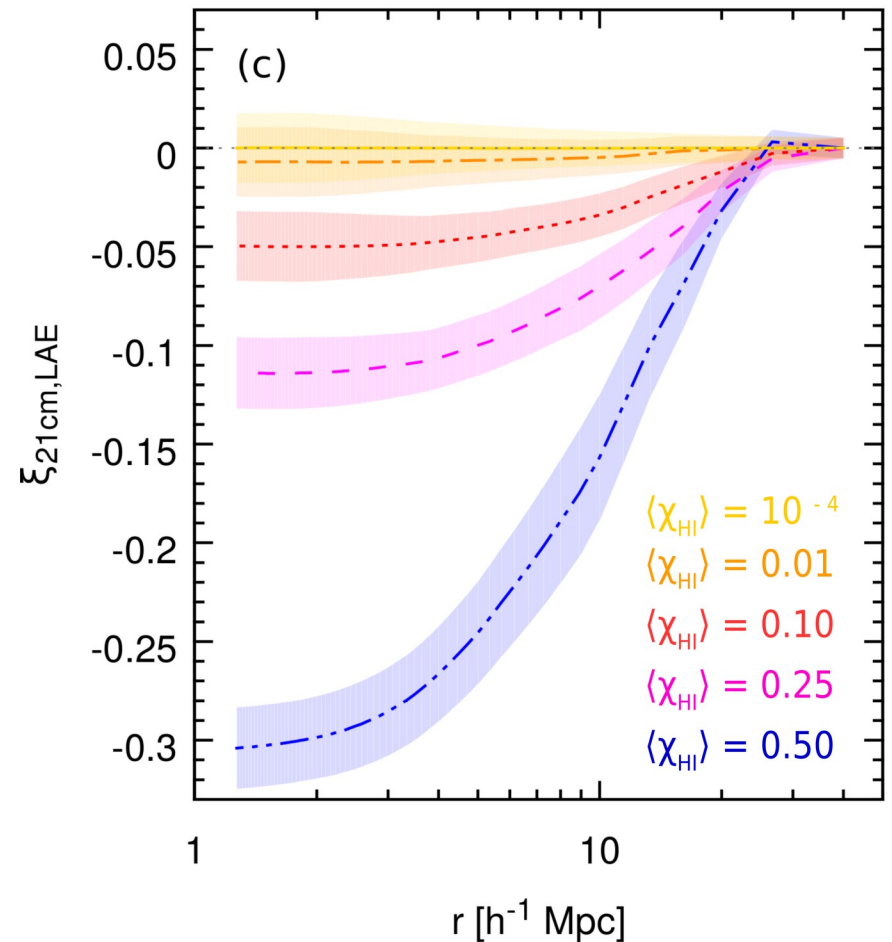
# Where are LAEs located in the IGM?

## 21cm cross correlations with galaxies and LAEs

galaxies

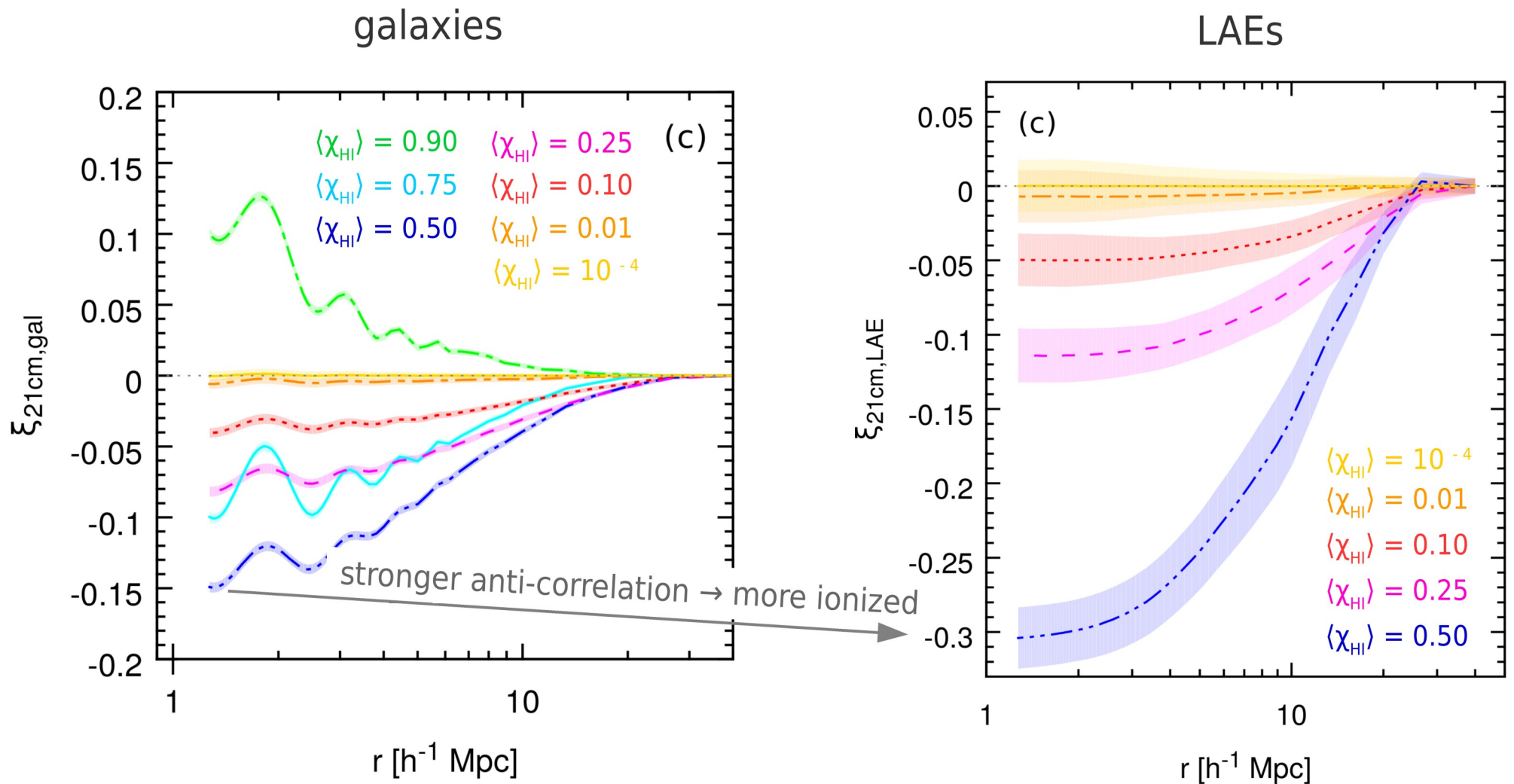


LAEs



# Where are LAEs located in the IGM?

## 21cm cross correlations with galaxies and LAEs



# 21cm - LAE cross correlations depend on $f_{\text{esc}}$ ?

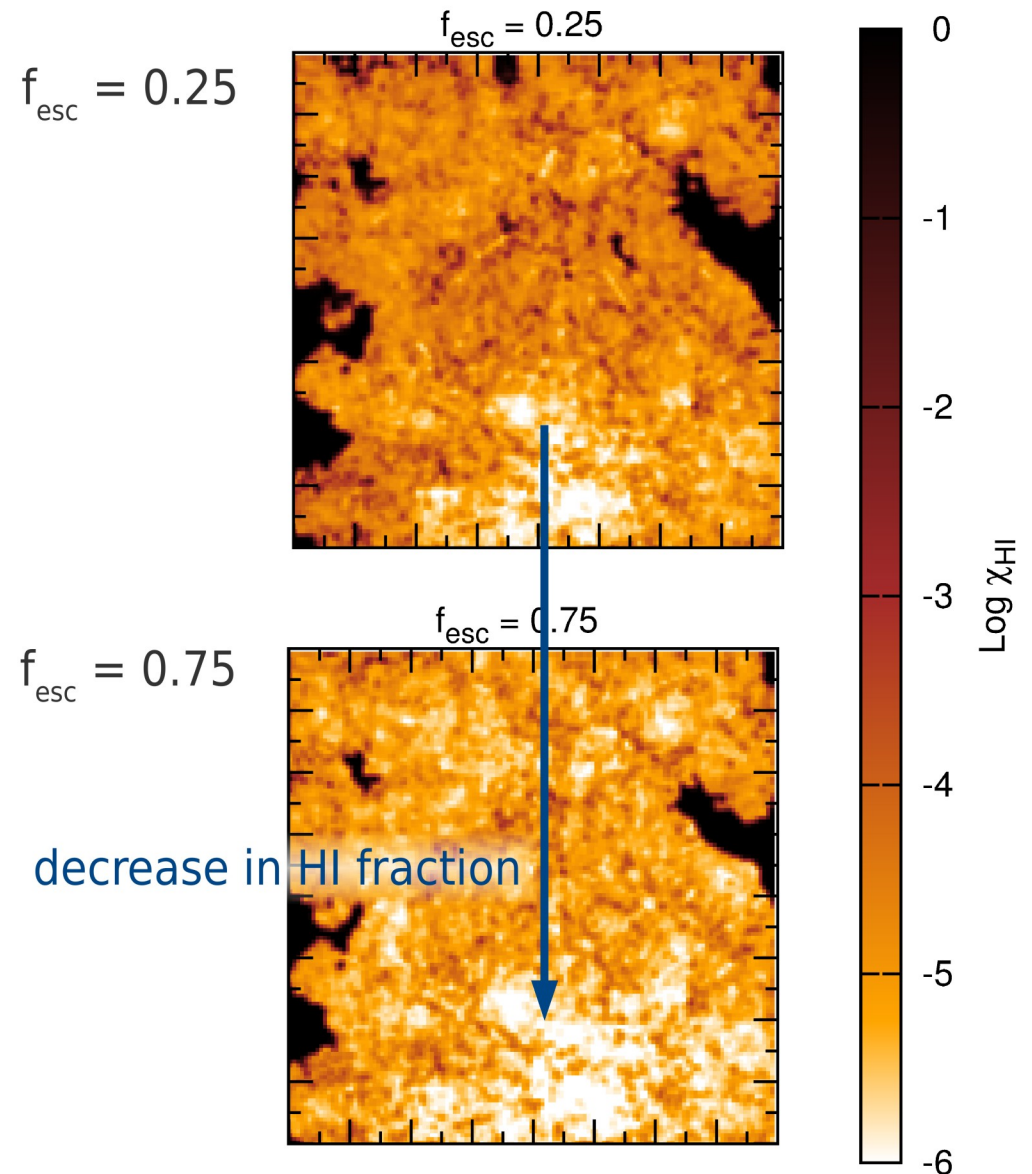
Differential 21cm brightness temperature:

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

$\chi_{\text{HI}}$  decreases with increasing  $f_{\text{esc}}$



21cm differential brightness temperature decreases with increasing  $f_{\text{esc}}$





# 21cm - LAE cross correlations

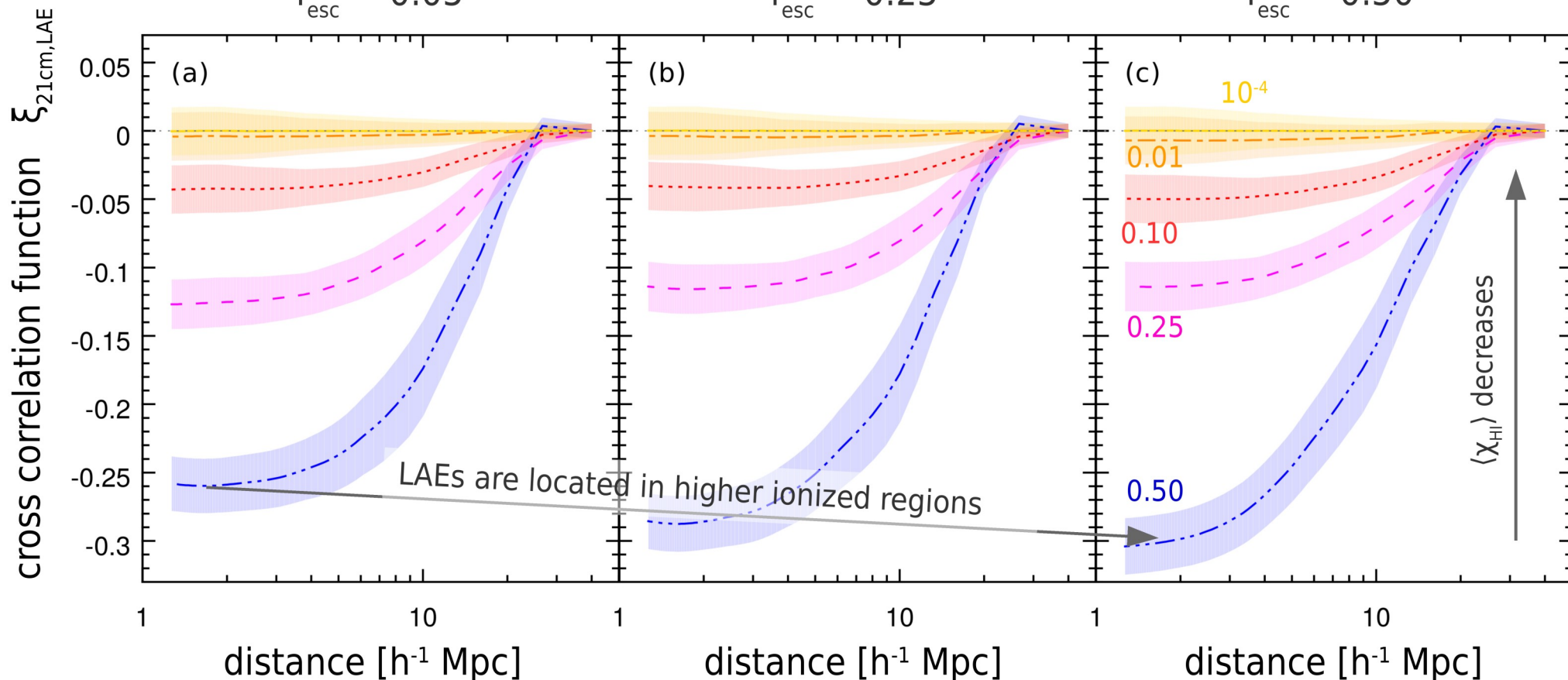
$f_{\text{esc}}$  increases

$\chi_{\text{HI}}$  in ionized regions decreases

$f_{\text{esc}} = 0.05$

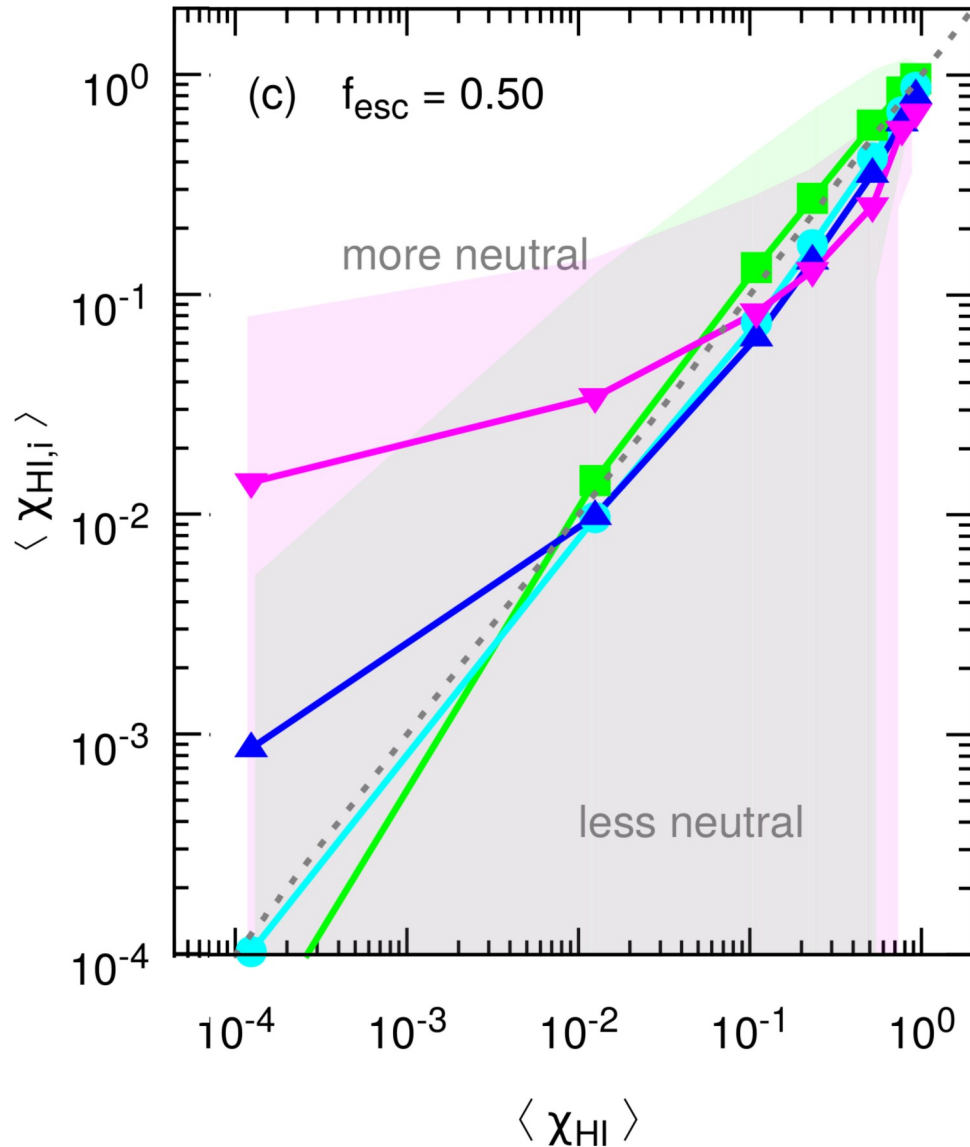
$f_{\text{esc}} = 0.25$

$f_{\text{esc}} = 0.50$

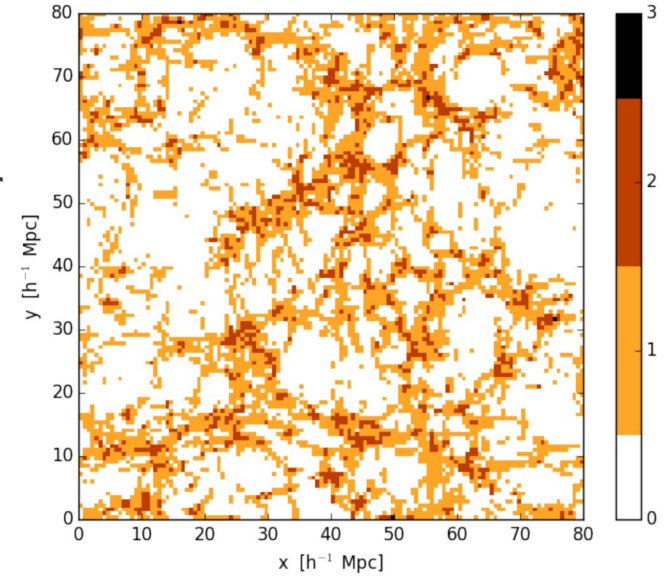


Simulated 21cm-LAE cross correlation function depend on galactic properties.

# Topology of reionization



Tidal field tensor  
 $\downarrow$  *Nuza+ 2014*  
 Cosmic web

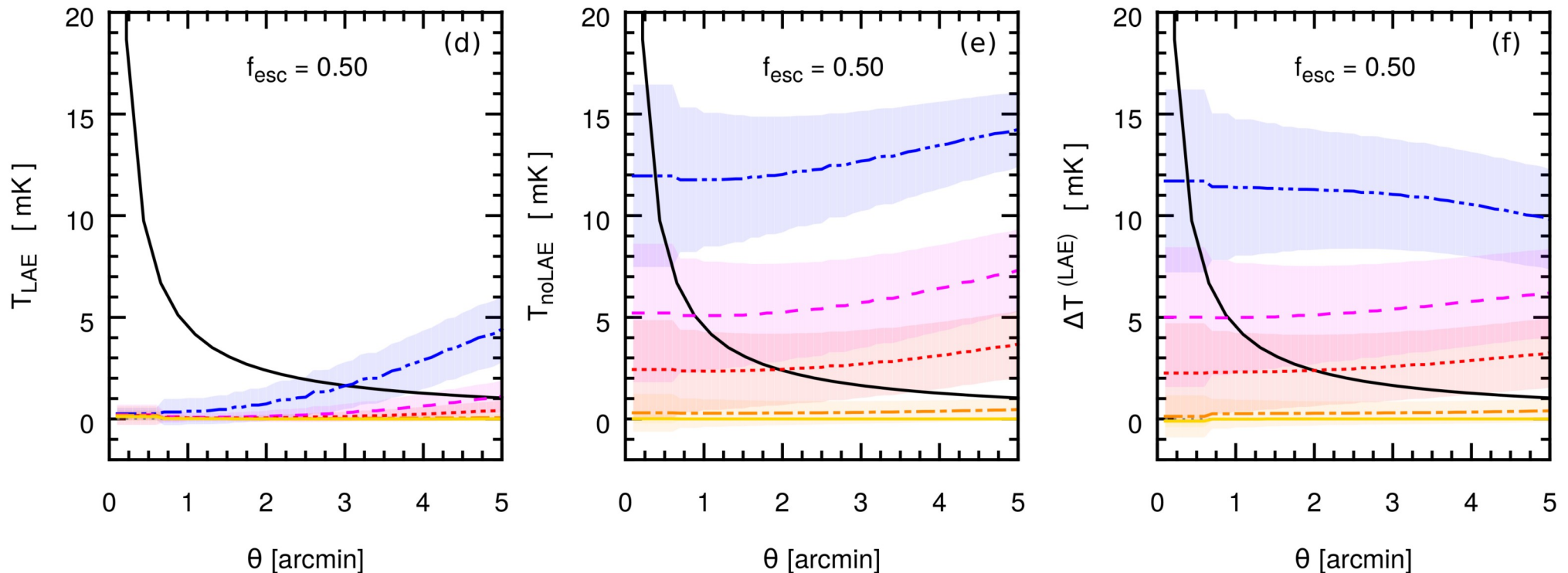


*Ionization history in the cosmic web:*

- knots
- filaments
- sheets
- voids

reionization proceeds inside-out

# Measuring topology using 21cm correlations with overdensities and voids



overdense regions are ionized before underdense regions

→ mean 21cm signal in *overdense regions* is lower than in *underdense regions*

# Conclusions – 21cm cross correlation with LAEs

## LOCATION OF LAEs IN IGM

- *LAEs* lie in the most *overdense and ionized regions*, where the 21cm signal is strongly suppressed.

## GALACTIC PROPERTIES

- *21cm-LAE cross correlations* are sensitive to galactic properties, e.g. the escape fraction of ionizing photons

## TOPOLOGY OF REIONIZATION

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