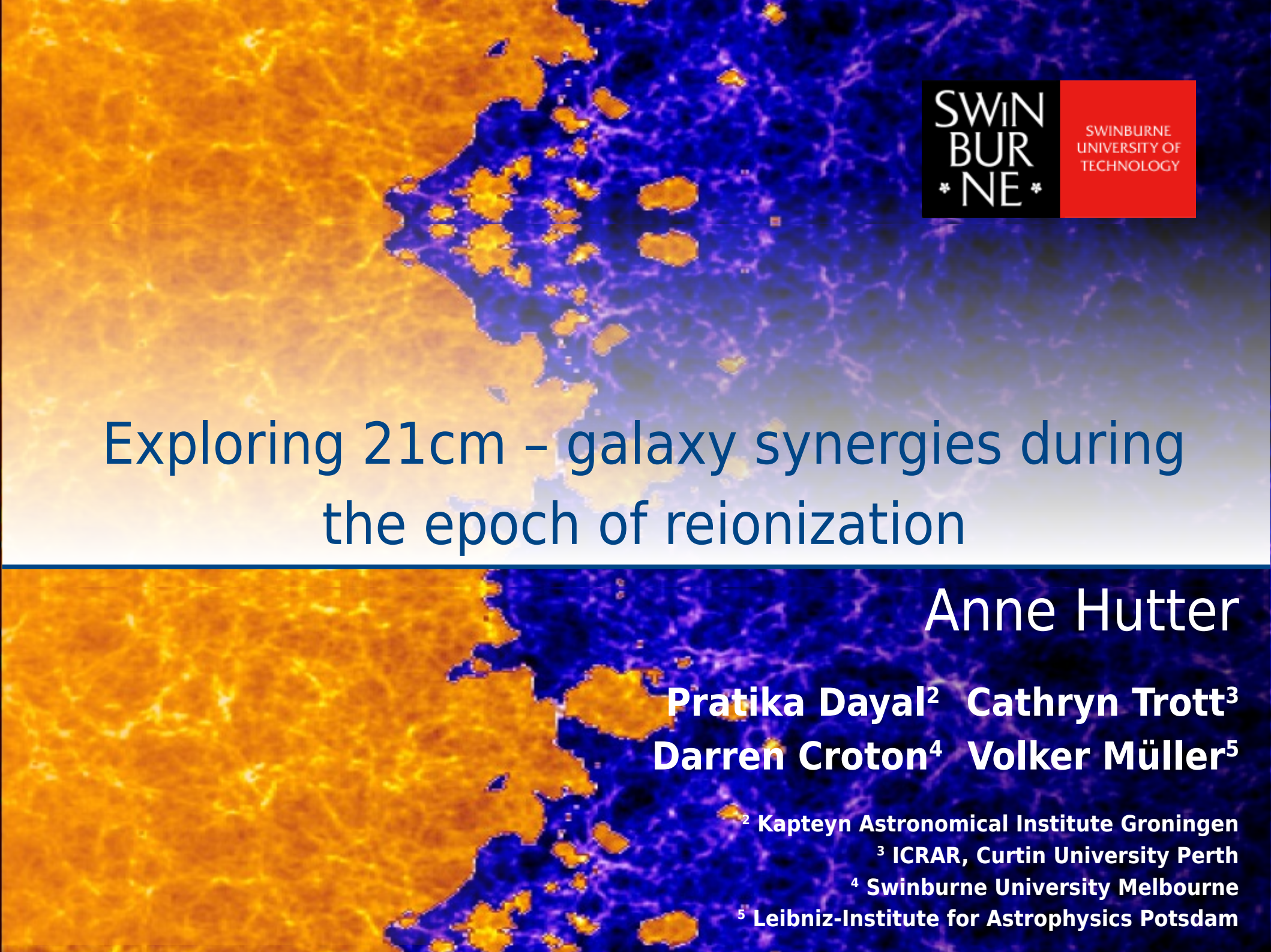

# Exploring 21cm – galaxy synergies during the epoch of reionization


Anne Hutter

**Pratika Dayal[2] Cathryn Trott[3]**
**Darren Croton[4] Volker Müller[5]**

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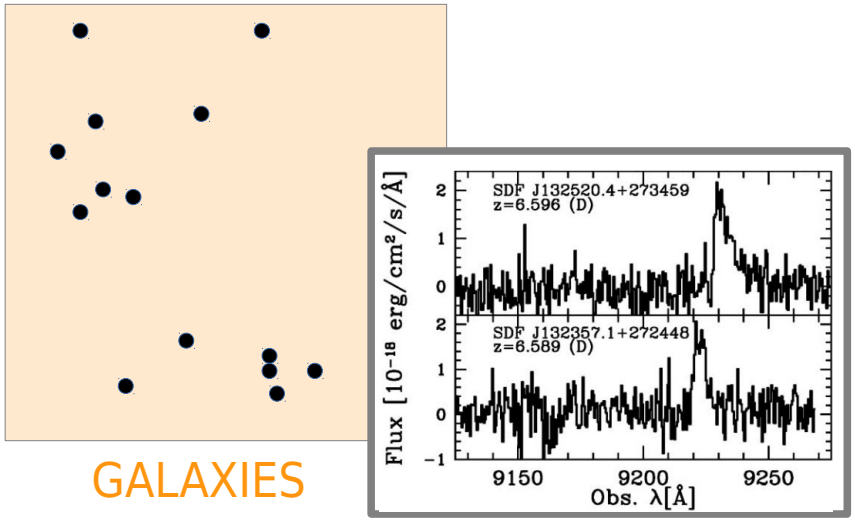
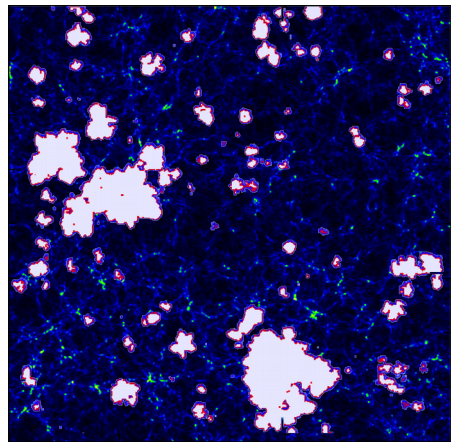
# Cross correlating 21cm with galaxies



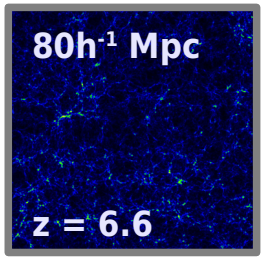

GALAXIES

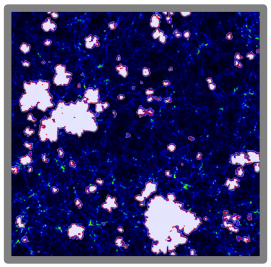
LYMAN-α EMITTERs (LAEs)



21CM SIGNAL

- Where are LAEs located in the IGM?
- What is the reionization topology?
- What is the impact of the escape fraction of ionizing photons?

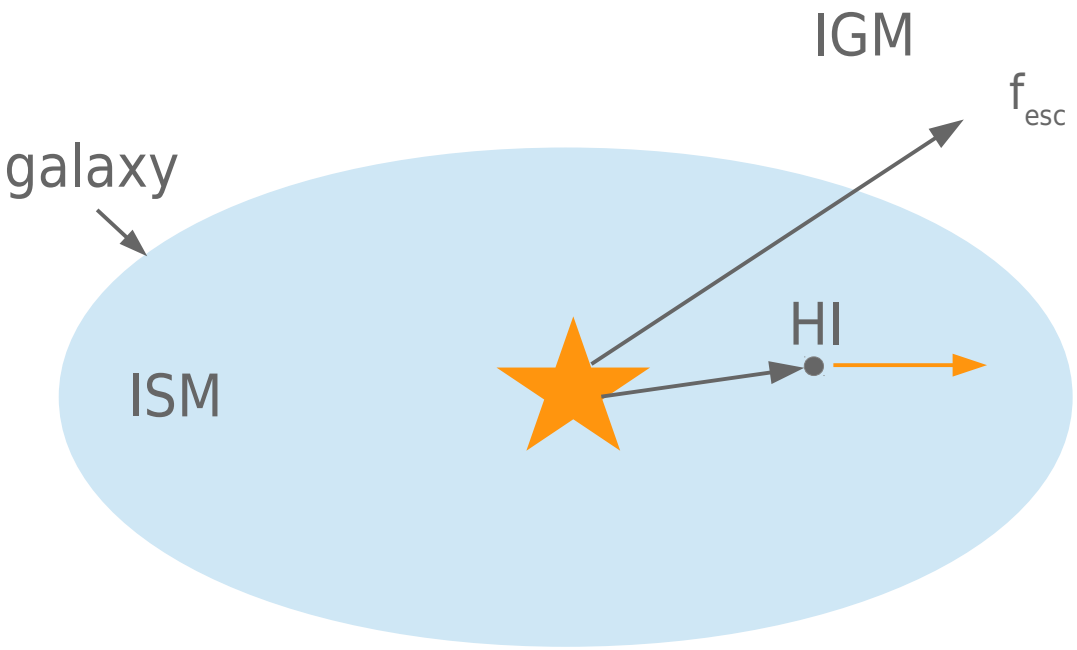


Model galaxies from hydrodynamical simulation

Model ionized regions with radiative transfer simulations

# Lyman α emitters (LAEs) in the intergalactic medium



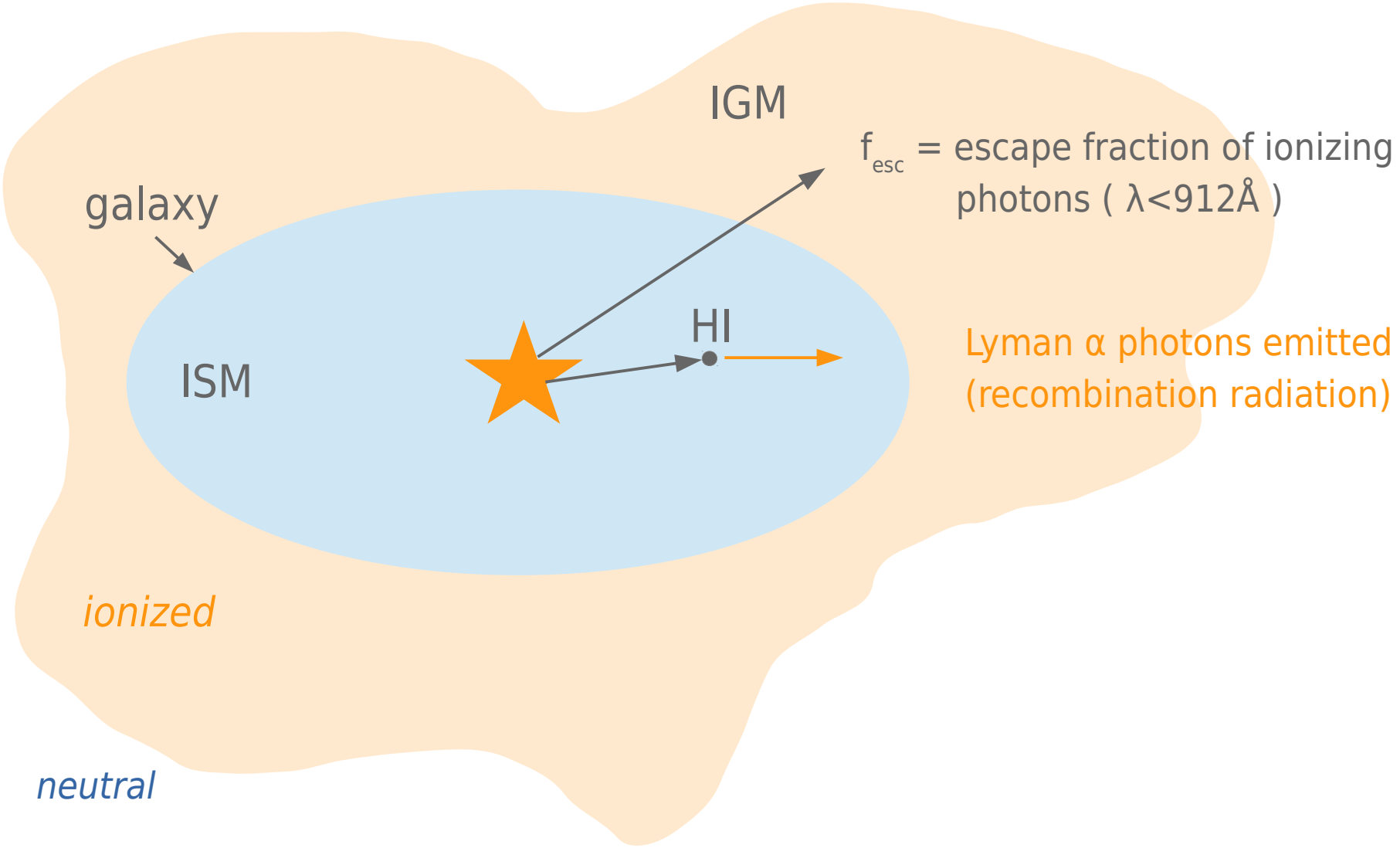

$f_{esc}$ = escape fraction of ionizing photons ( λ<912Å )

Lyman α photons emitted (recombination radiation)

ISM = interstellar medium
IGM = intergalactic medium

*Hutter+ 2014*

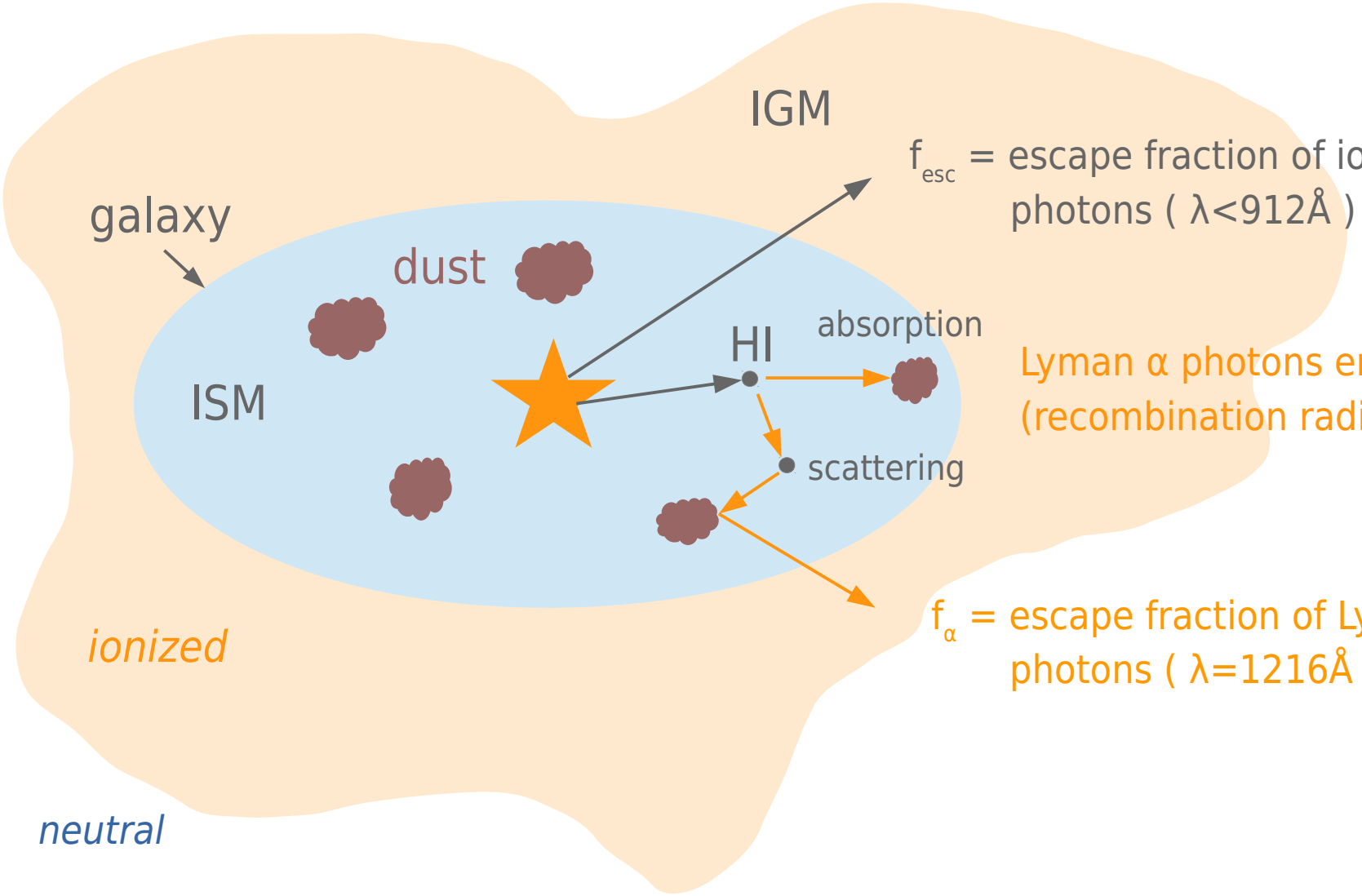
# Lyman α emitters (LAEs) in the intergalactic medium




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 )

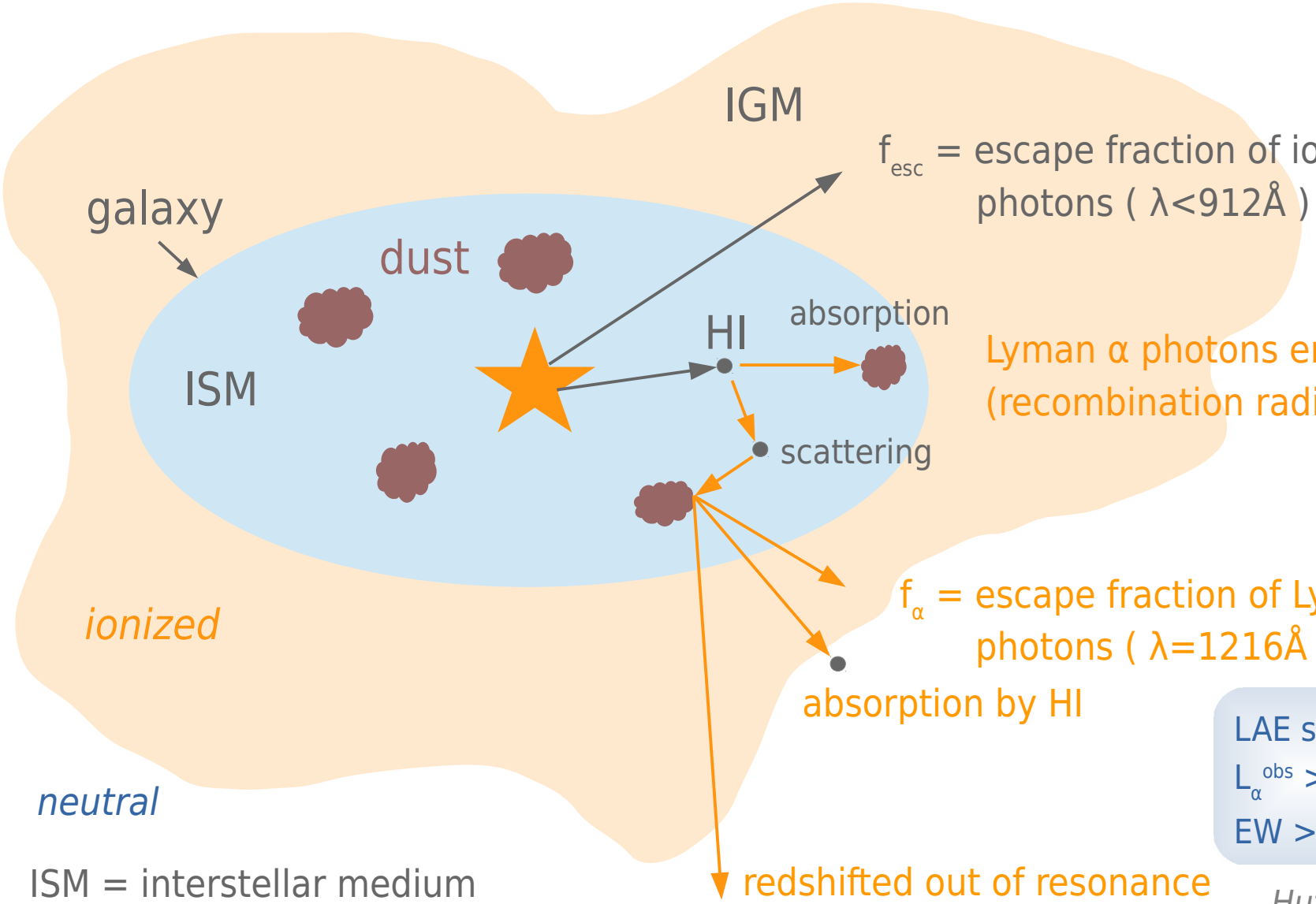
Lyman α photons emitted (recombination radiation)

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

ISM = interstellar medium
IGM = intergalactic medium

*Hutter+ 2014*

# Lyman α emitters (LAEs) in the intergalactic medium

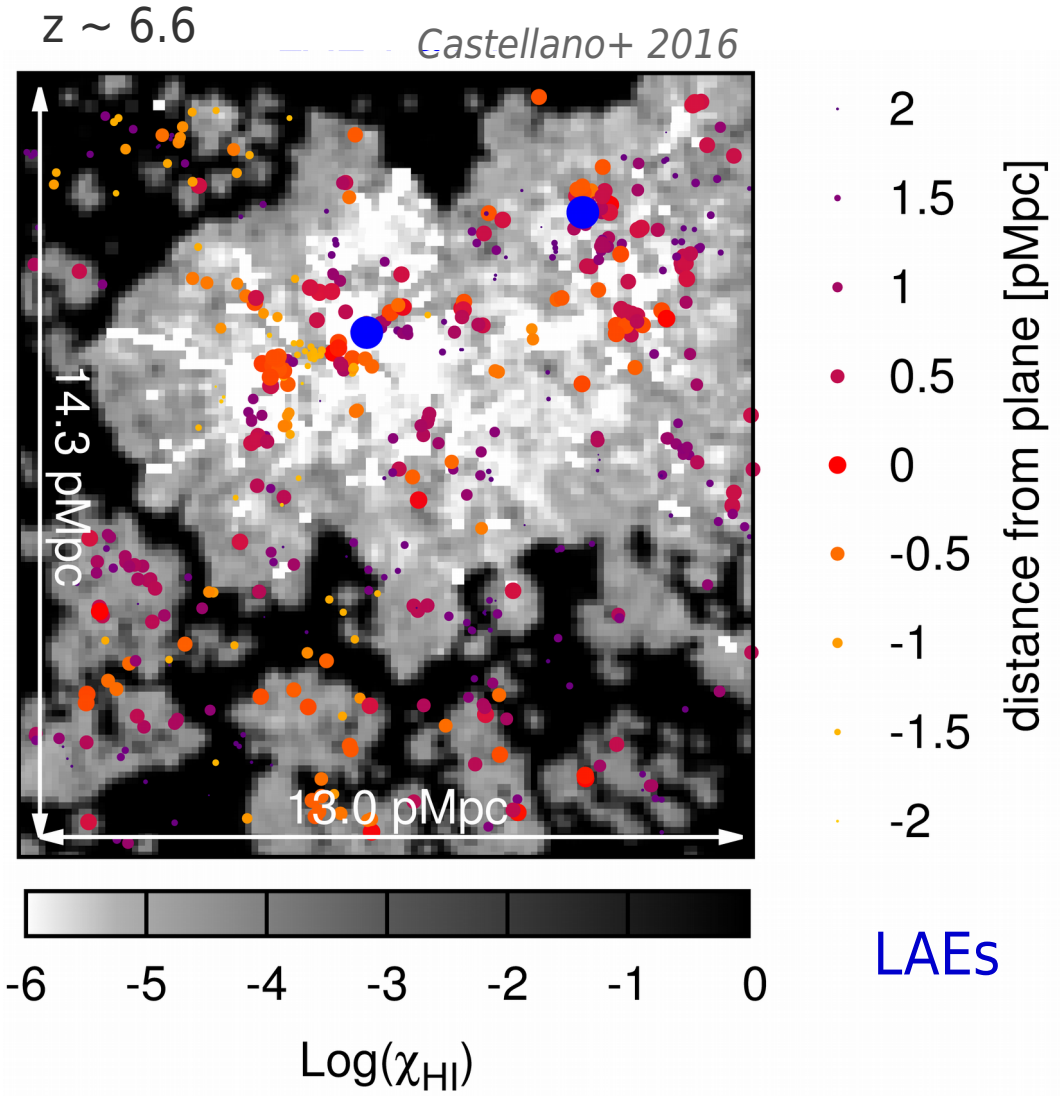


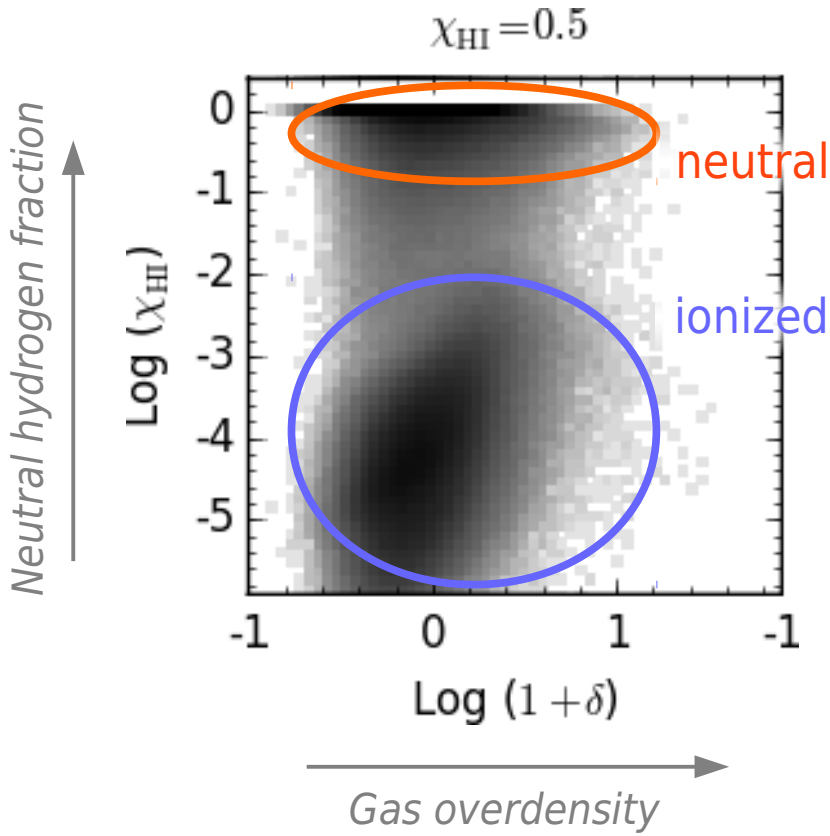

LAE selection criteria:
$L_{\alpha}^{obs} > 10^{42}$ erg $s^{-1}$
EW > 20 Å

*Hutter+ 2014*

ISM = interstellar medium
IGM = intergalactic medium

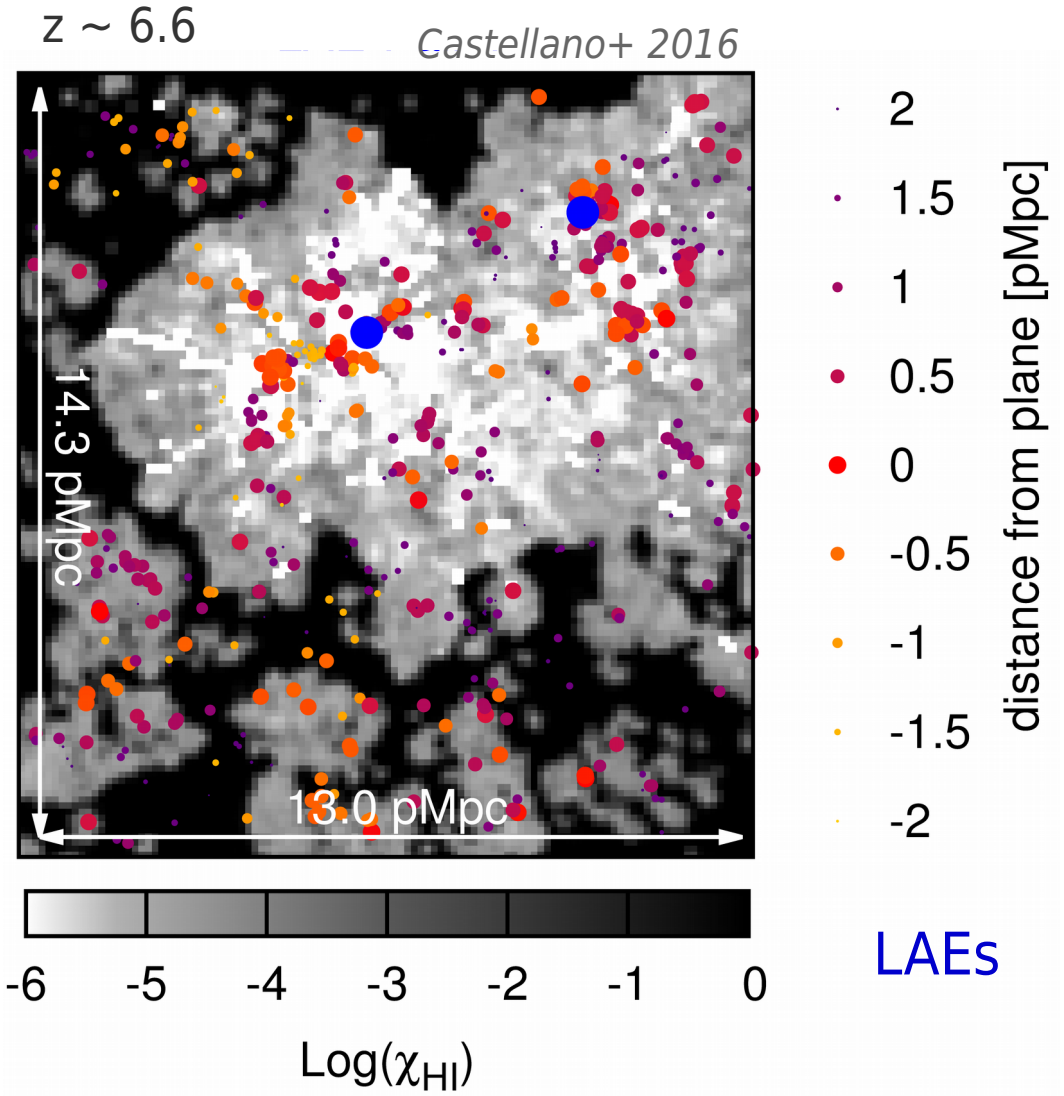
# Where are LAEs located in the IGM?

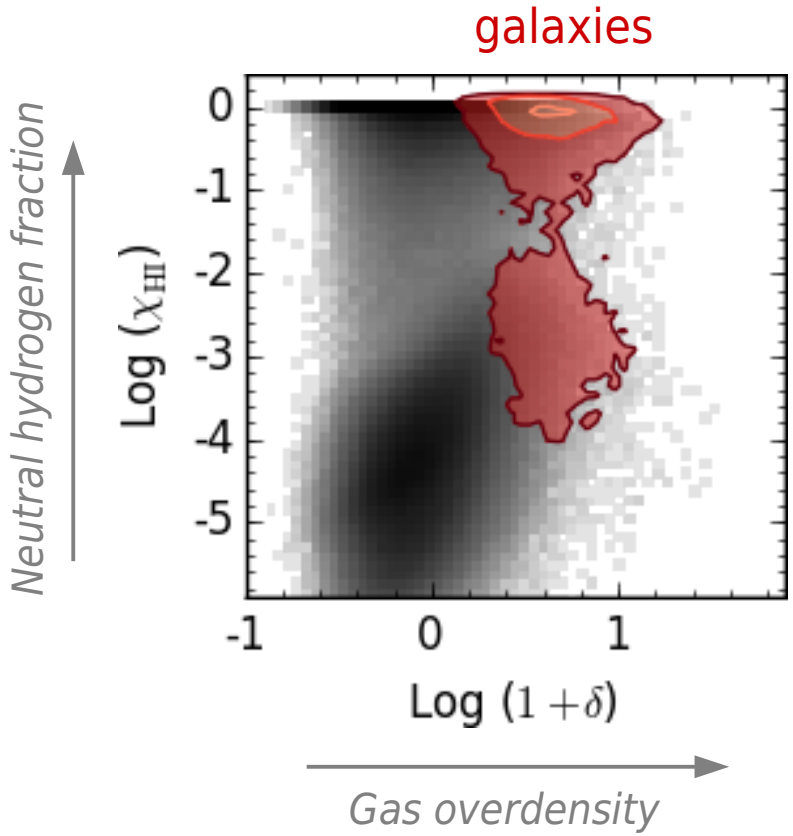



Hutter+ 2017

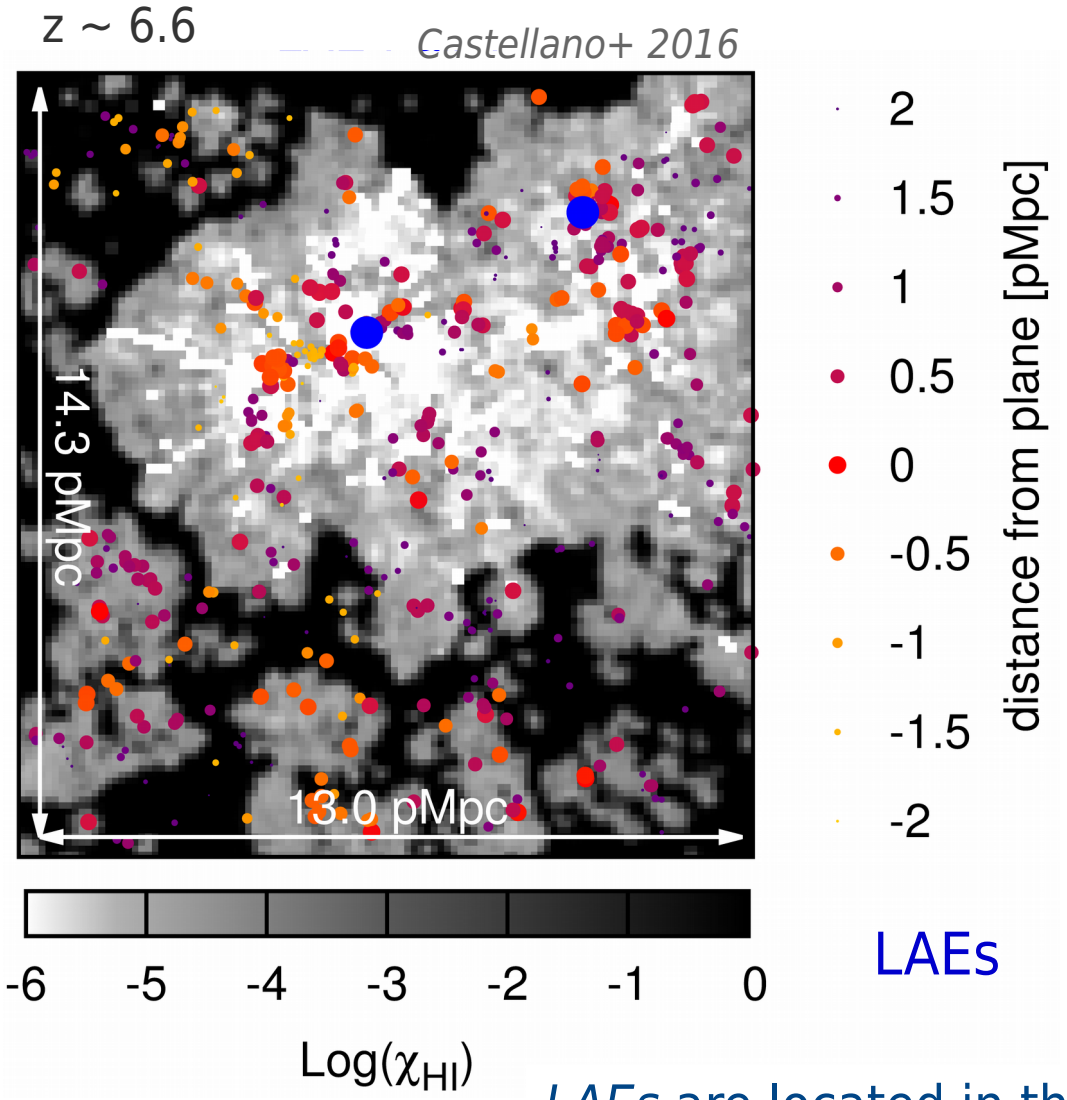
# Where are LAEs located in the IGM?

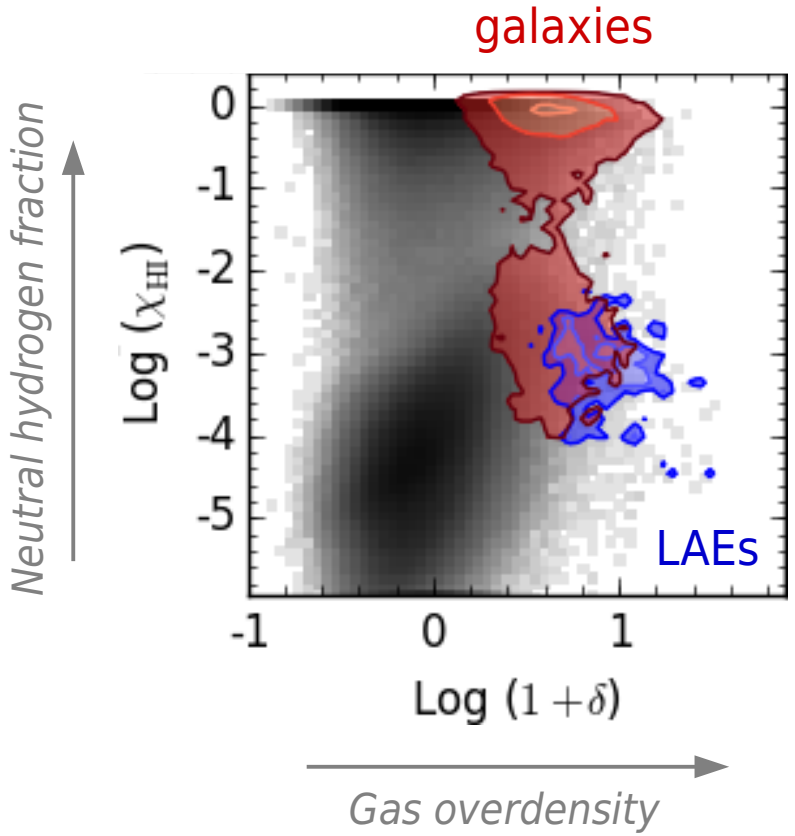



Hutter+ 2017

# Where are LAEs located in the IGM?

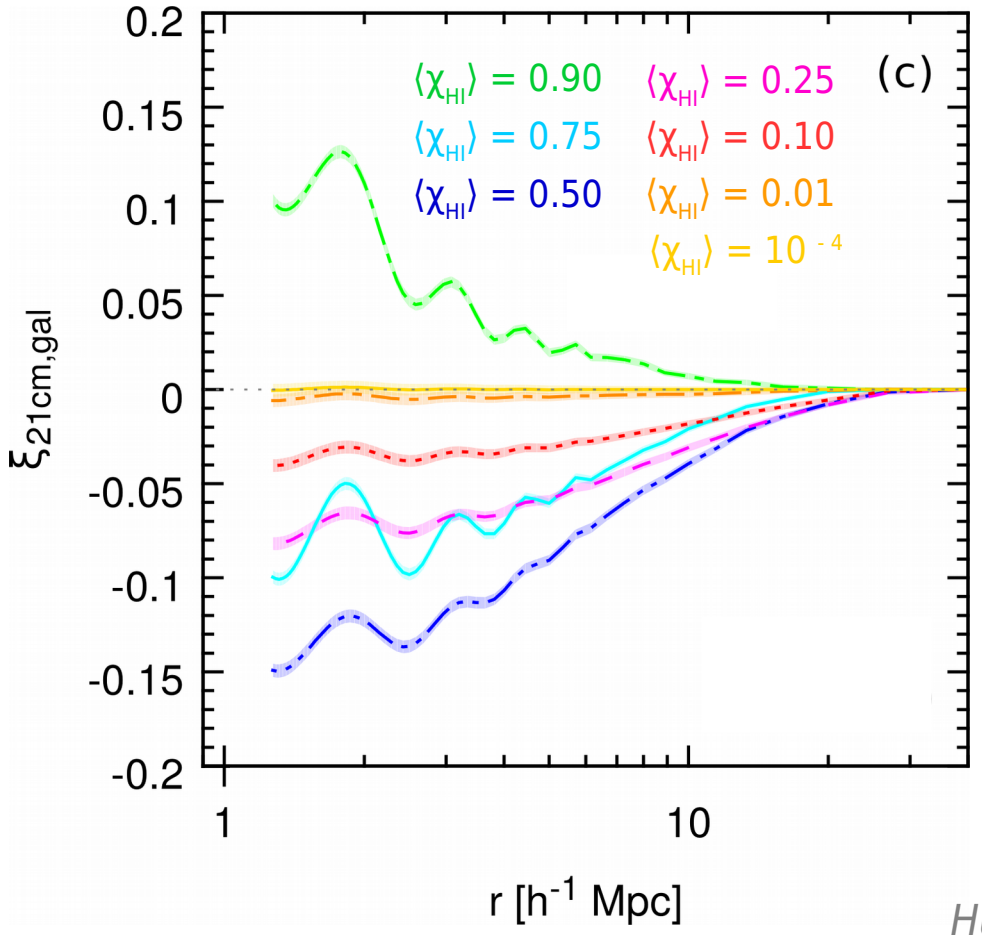


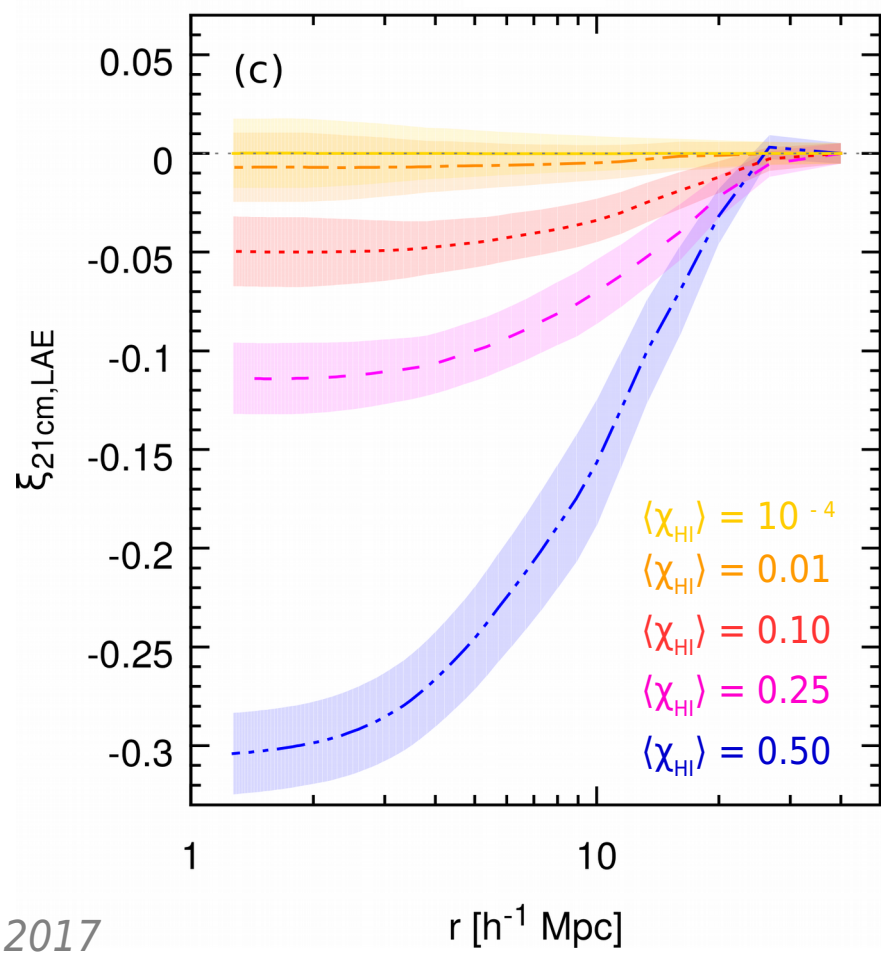

*LAEs* are located in the *ionized & most overdense* regions

# Where are LAEs located in the IGM?
# 21cm cross correlations with galaxies and LAEs

galaxies

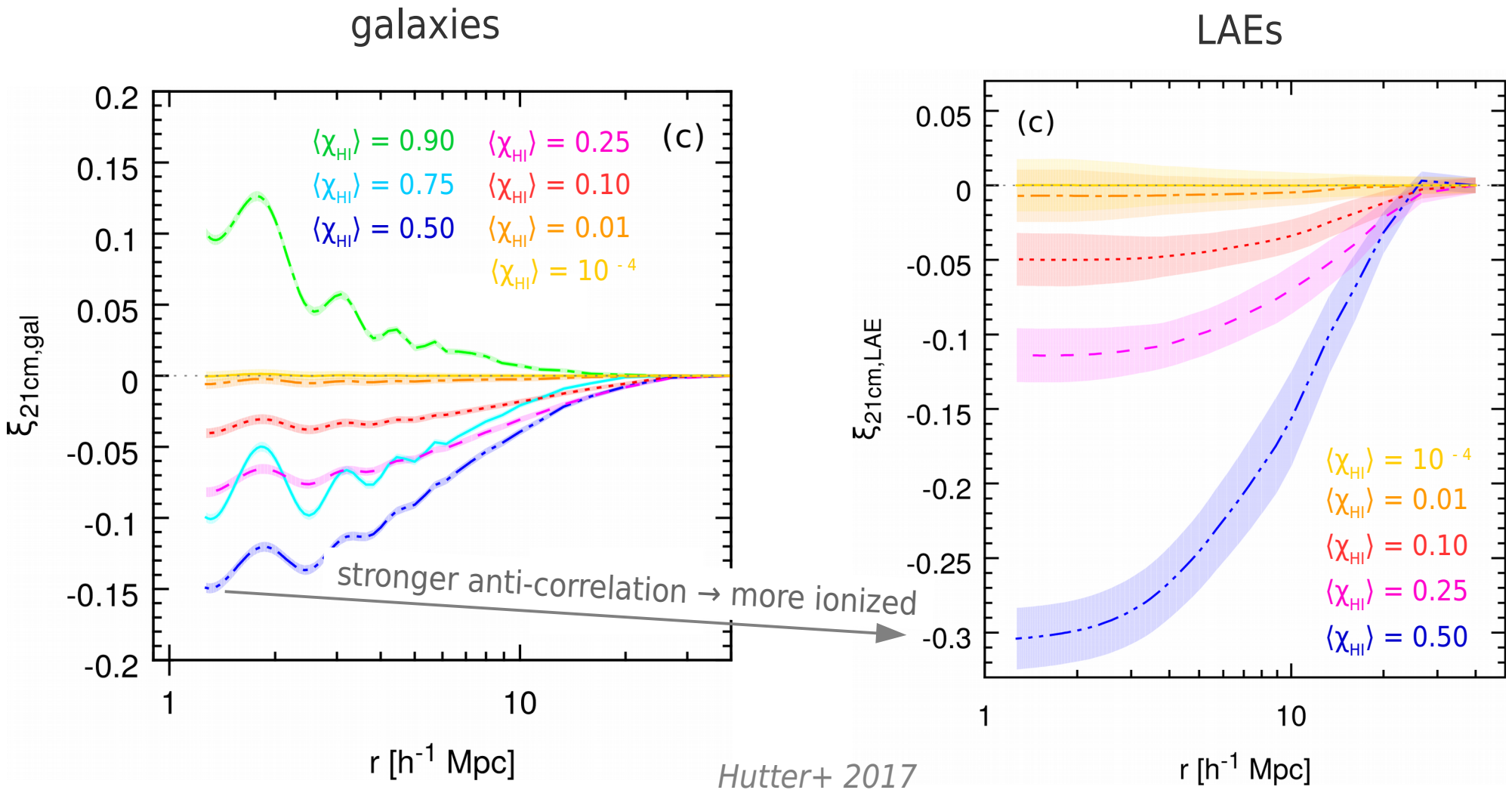



LAEs



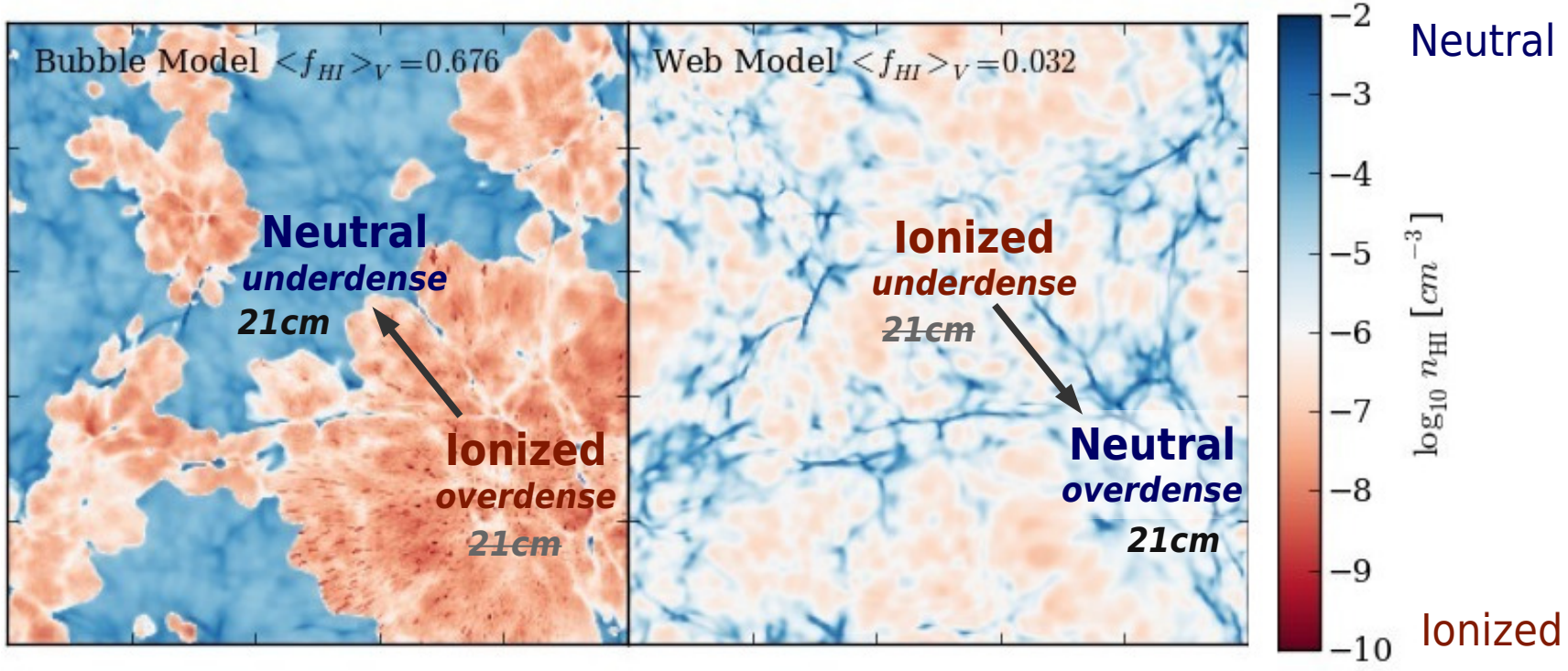

*Hutter+ 2017*

# Where are LAEs located in the IGM?
# 21cm cross correlations with galaxies and LAEs



# What is the topology of reionization?

*Kakiichi+ 2016*




## Inside-out

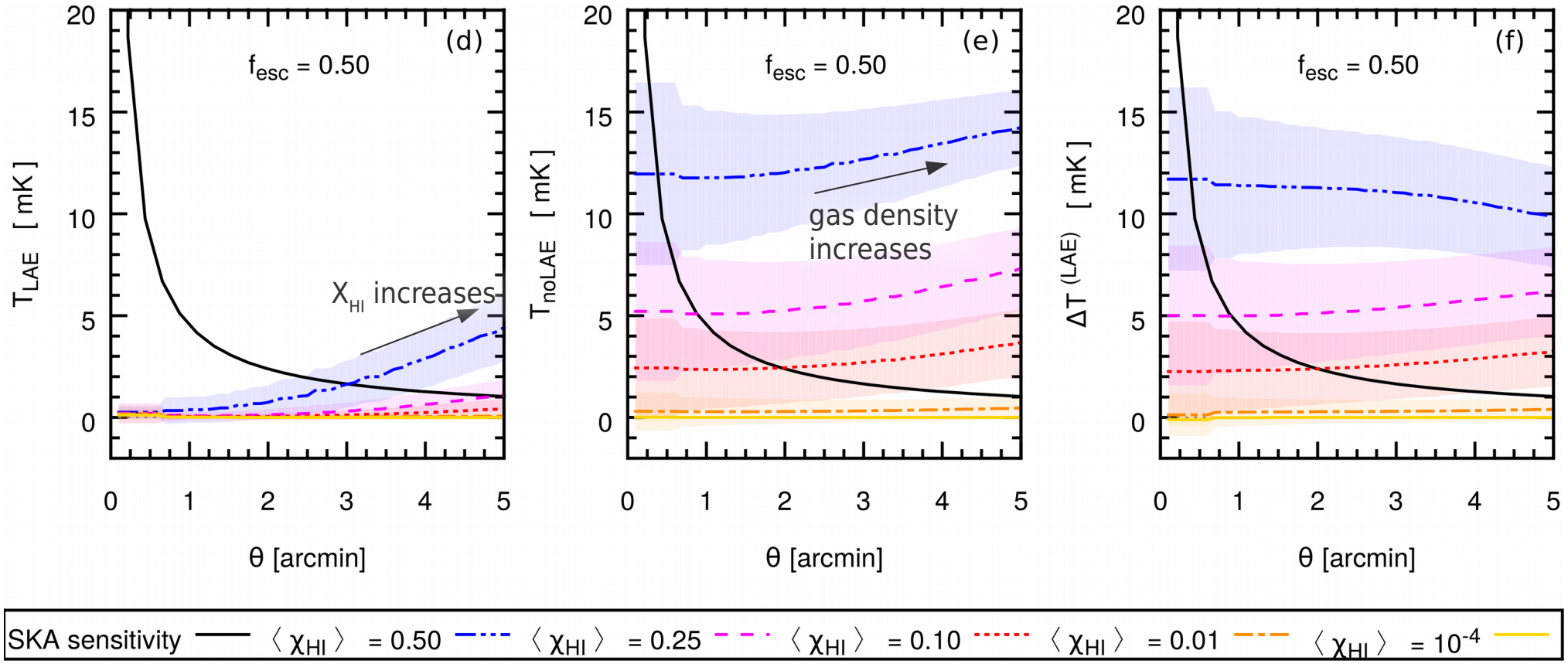
*Overdense (small scales)*
regions are ionized first

## Outside-in

*Underdense (large scales)*
regions are ionized first

# Measuring topology using 21cm correlations with overdensities (LAEs) and voids

*Hutter+ 2017*

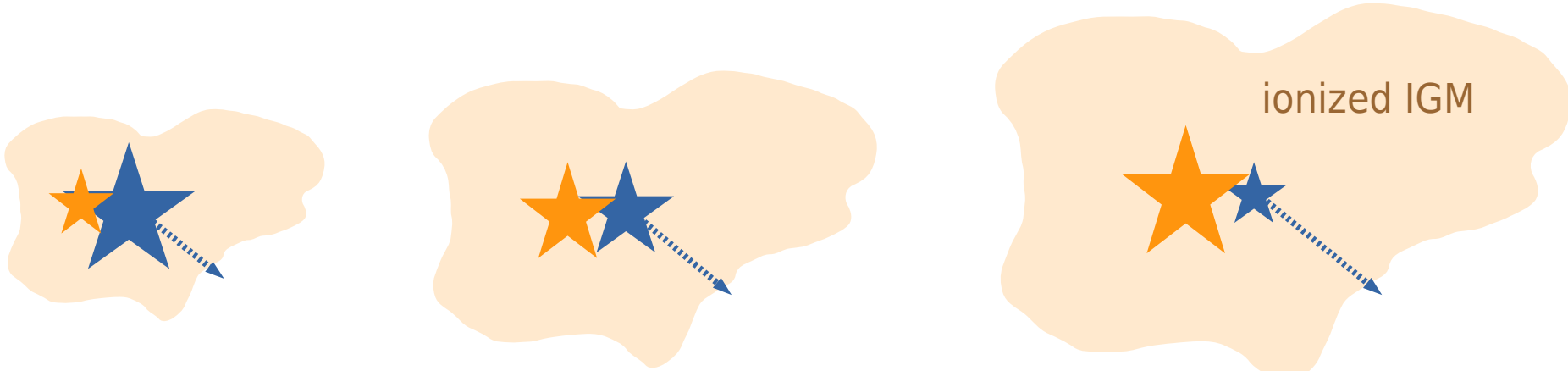



overdense regions are ionized before underdense regions

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

# Modelling Lyman α emitters (LAEs) during reionization

Escape fraction of ionizing photons $f_{esc}$ increases

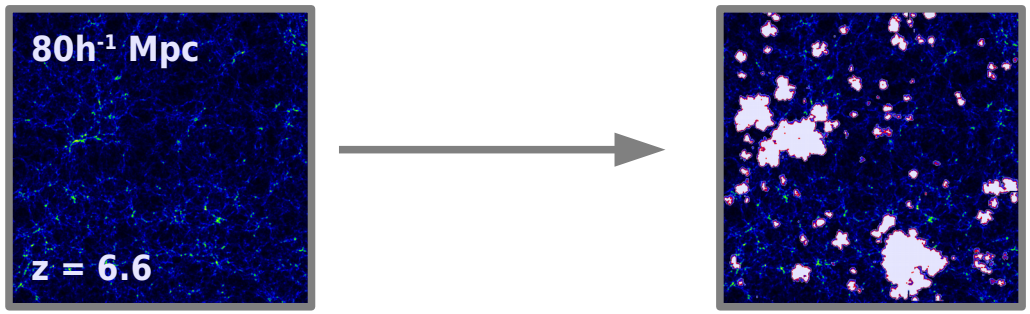



$$L_\alpha^{obs} = L_\alpha^{intr}\ T_{\alpha,IGM}\ f_{\alpha,ISM}$$

Intrinsic Lyman-α luminosity increases

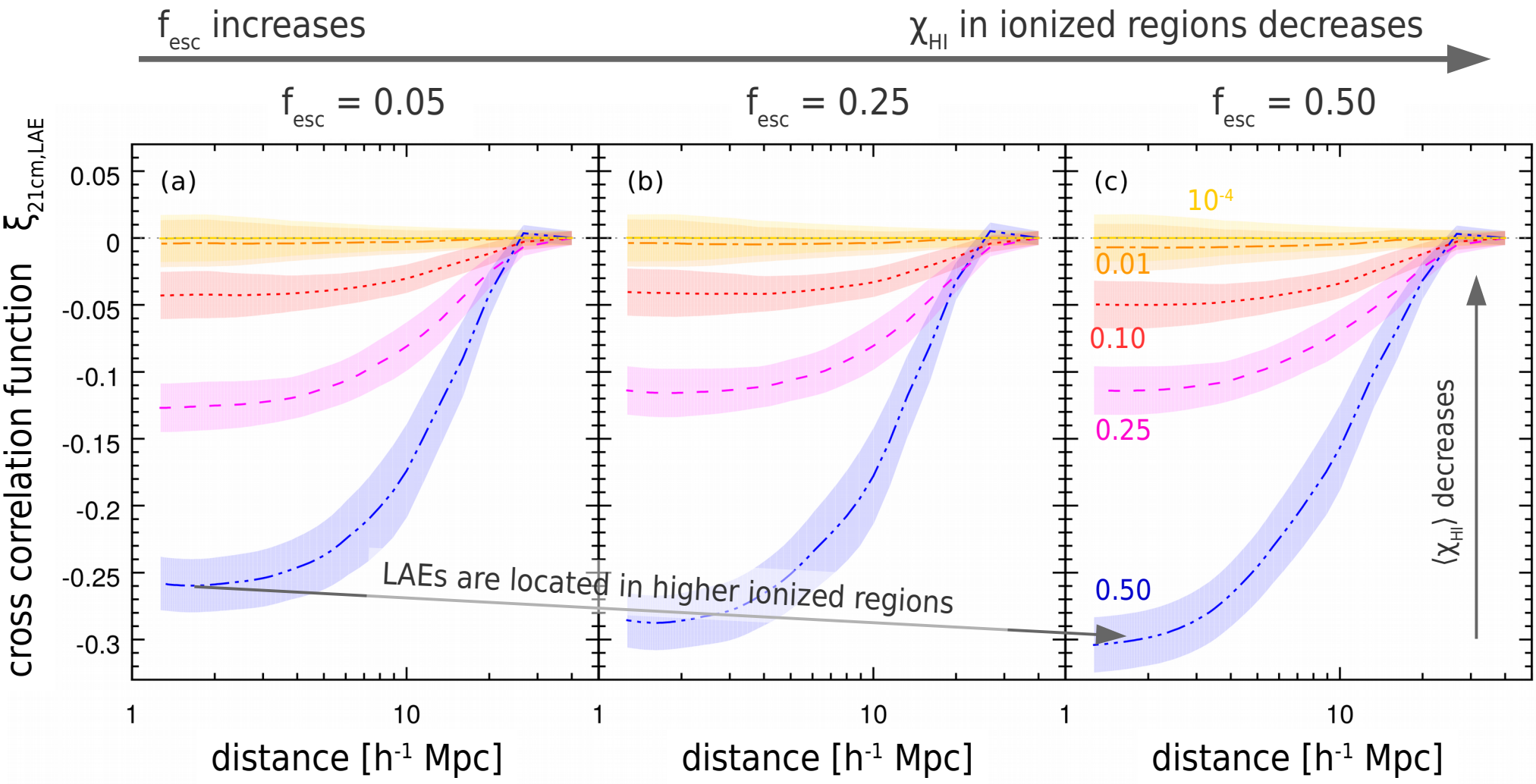
Model galaxies from hydrodynamical simulation

Reionization simulations for different constant $\mathbf{f_{esc}}$ values



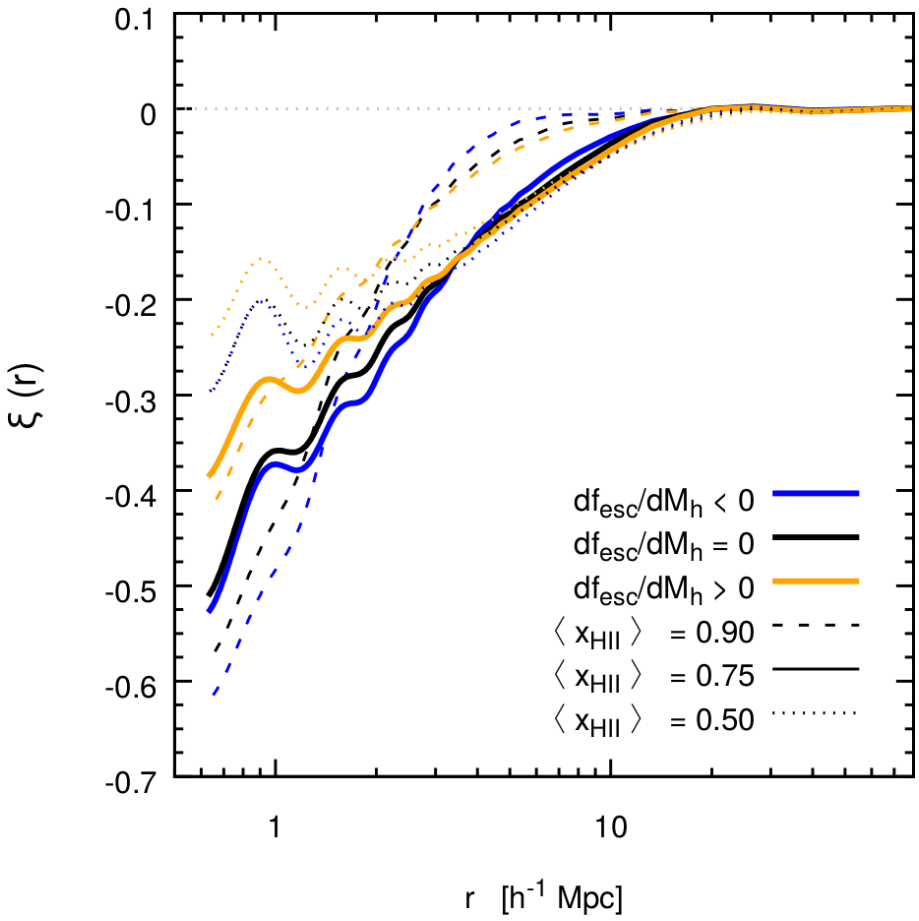

*IDENTIFY LAEs*

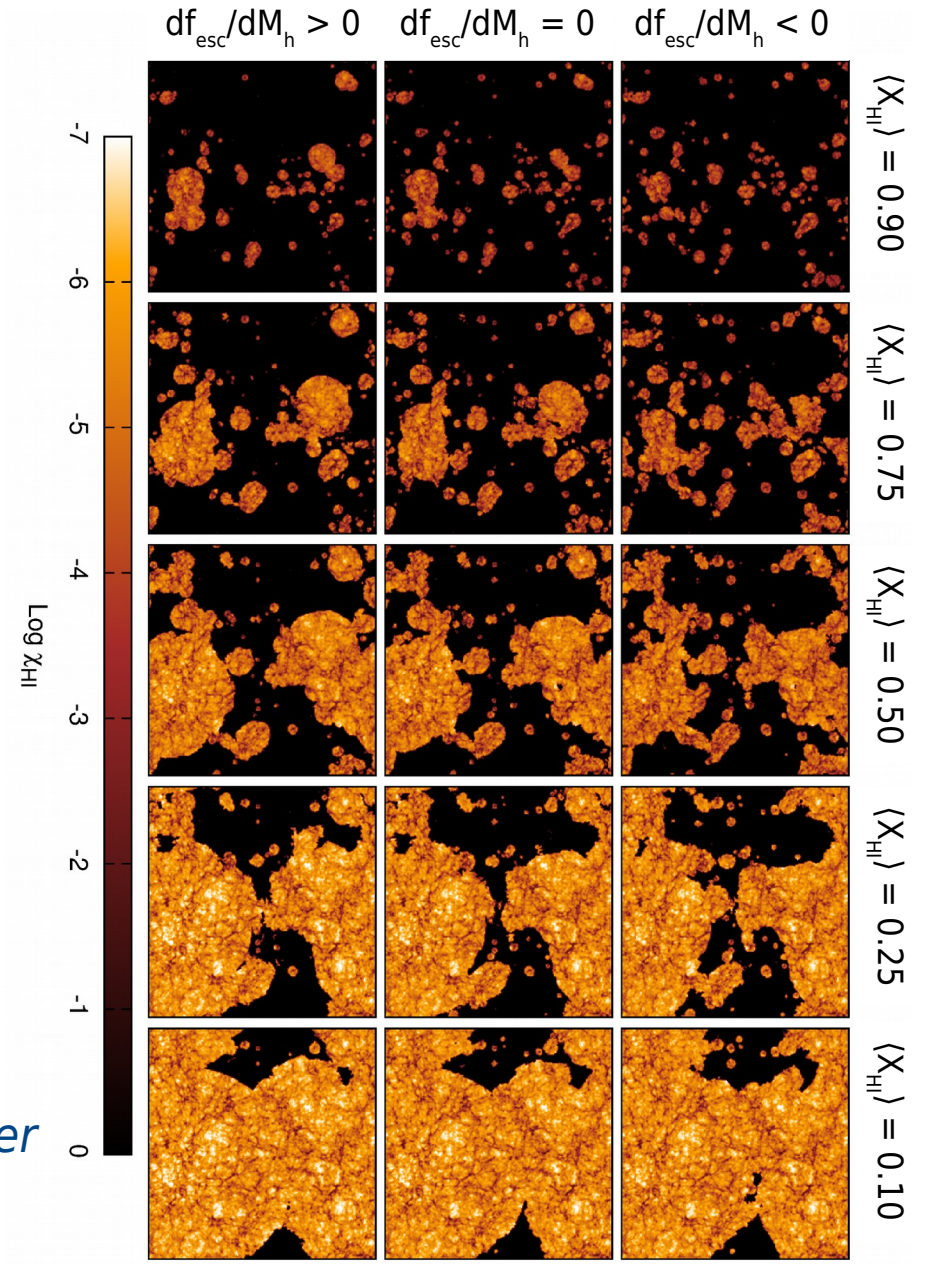
# 21cm – LAE cross correlations




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

# How do 21cm-galaxy cross correlations change for different $f_{esc}$ dependencies?



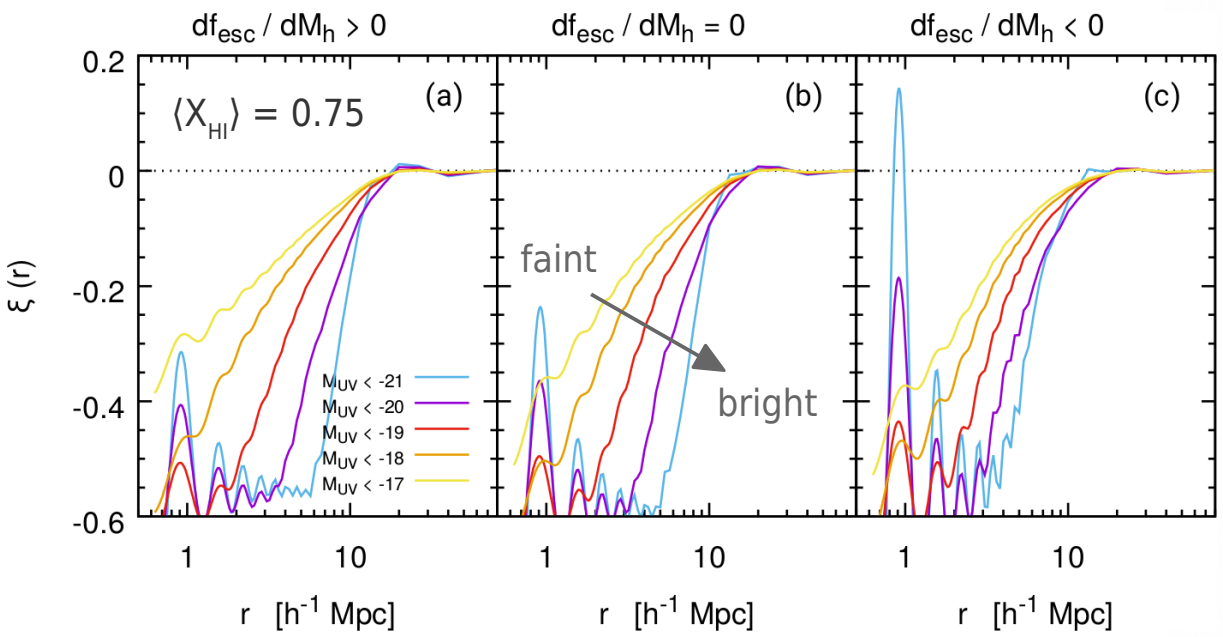



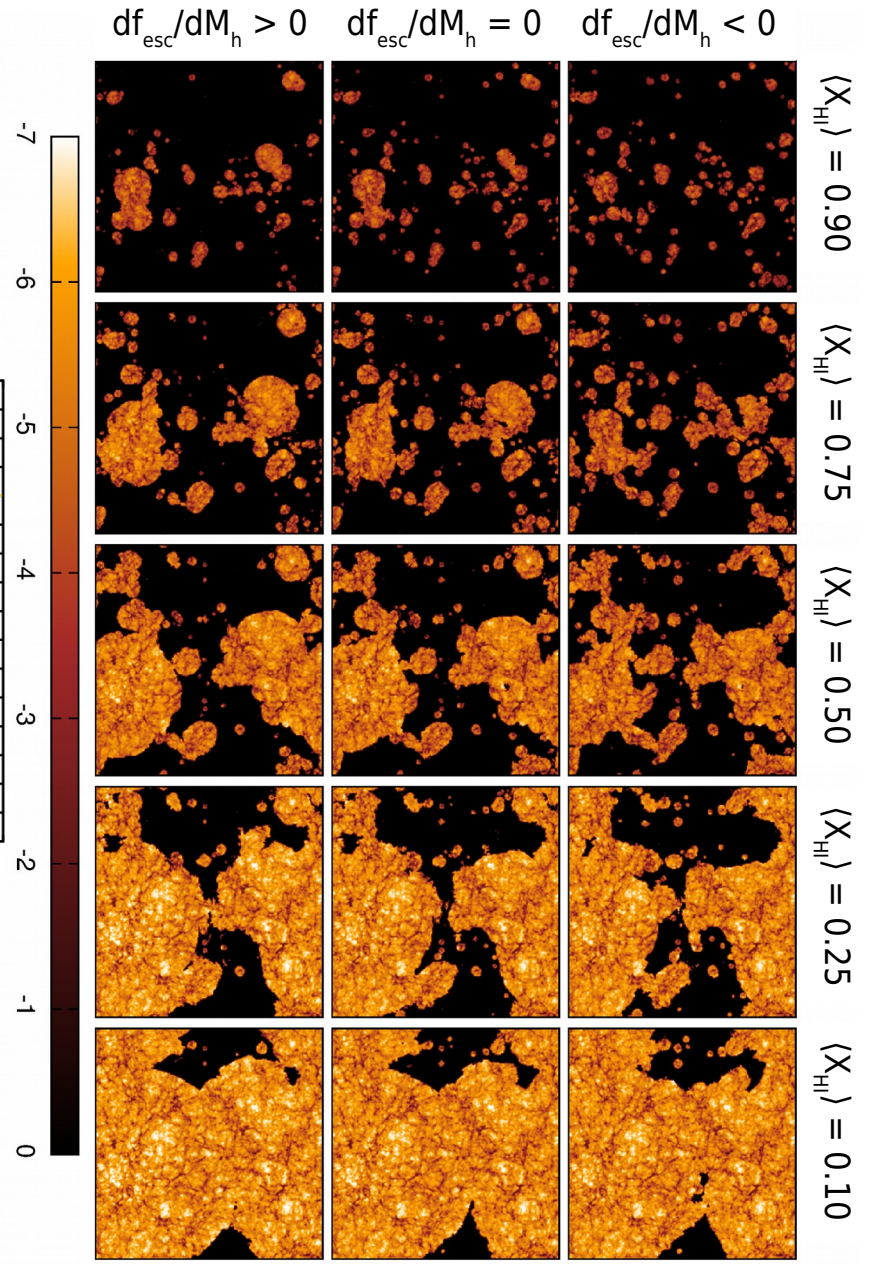

A *more biased* ionizing emissivity results in a *weaker but extending to larger scales* anti-correlation

# How do 21cm-galaxy cross correlations change for different $f_{esc}$ dependencies?

Ionizing emissivity is ...

more biased | reference | more homogeneous




Difference between brighter and fainter galaxies is *larger* for $f_{esc}$ values that *increase the luminosity bias of galaxies*

# Conclusions

LOCATION OF LAEs IN IGM:

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

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.

GALACTIC PROPERTIES:

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

ESCAPE FRACTION & TOPOLOGY OF REIONIZATION:

Considering the strength and size of the 21cm-galaxy anti-correlation (on small scales), the difference between brighter and fainter galaxies is larger for values of the ionizing escape fraction that increase the luminosity bias of galaxies