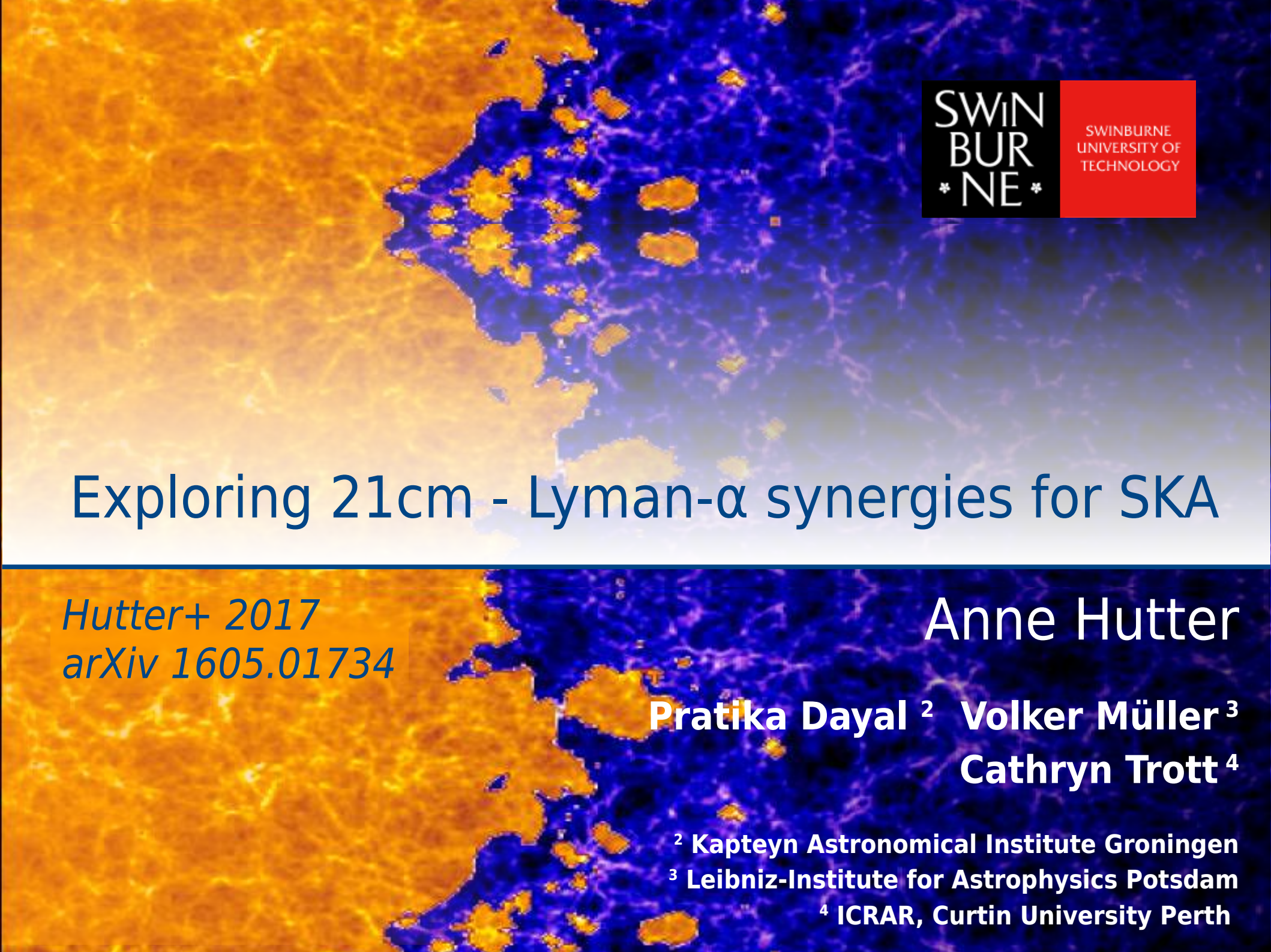


Exploring 21cm - Lyman-α synergies for SKA

Hutter+ 2017
arXiv 1605.01734

Anne Hutter

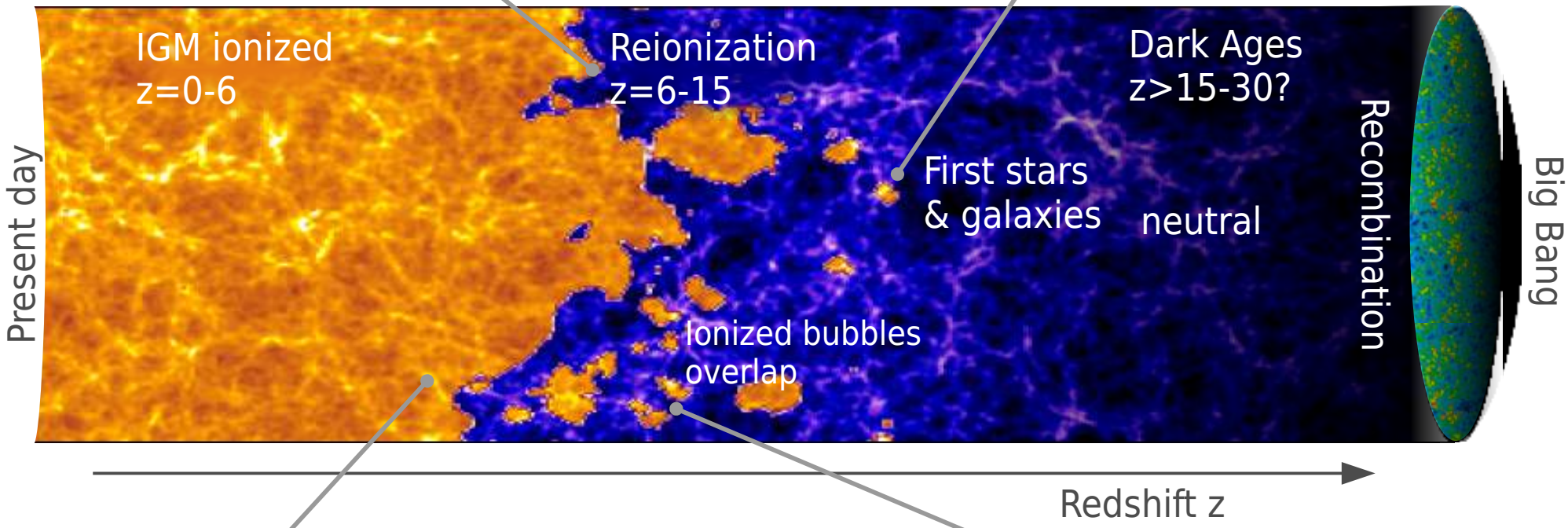
Pratika Dayal [2] **Volker Müller [3]**
Cathryn Trott [4]

[2] Kapteyn Astronomical Institute Groningen
[3] Leibniz-Institute for Astrophysics Potsdam
[4] ICRAR, Curtin University Perth

The Epoch of Reionization

When did reionization *start* & *end*?

Which were the *sources* of ionizing radiation?
Escape fraction of ionizing photons?



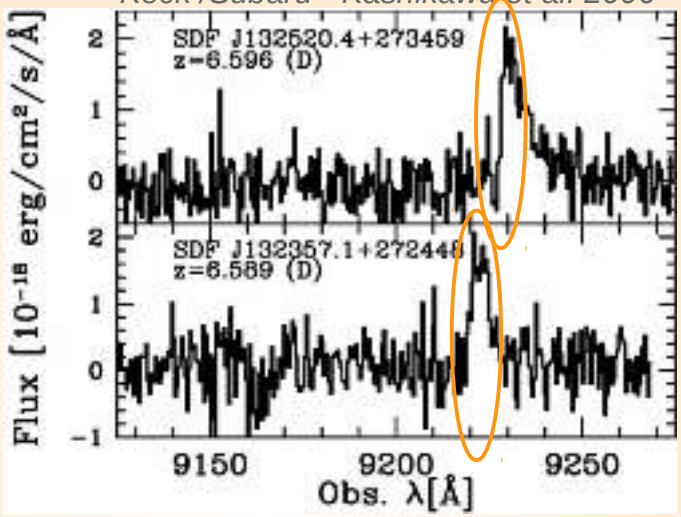
How does reionization impact *galaxy formation*?

How does the *topology* of ionized regions look like?

Constraining reionization & high-z galaxies

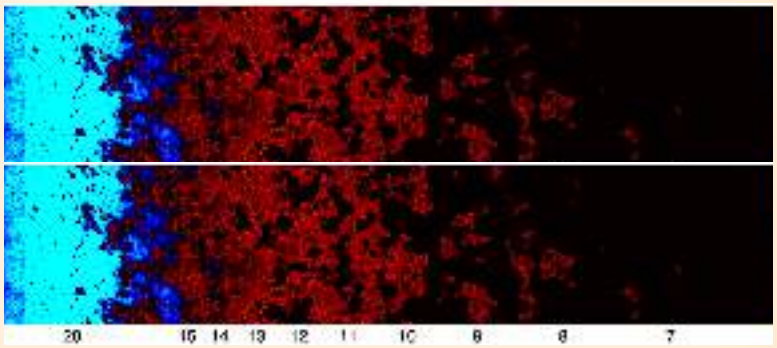
OBSERVATIONS

Keck /Subaru • Kashikawa et al. 2006



LYMAN ALPHA EMITTERS (LAEs)

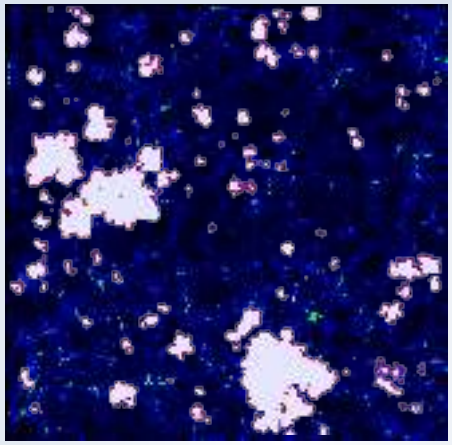
Pritchard 2012



21cm RADIATION

COMPARISON

MODELS & SIMULATIONS

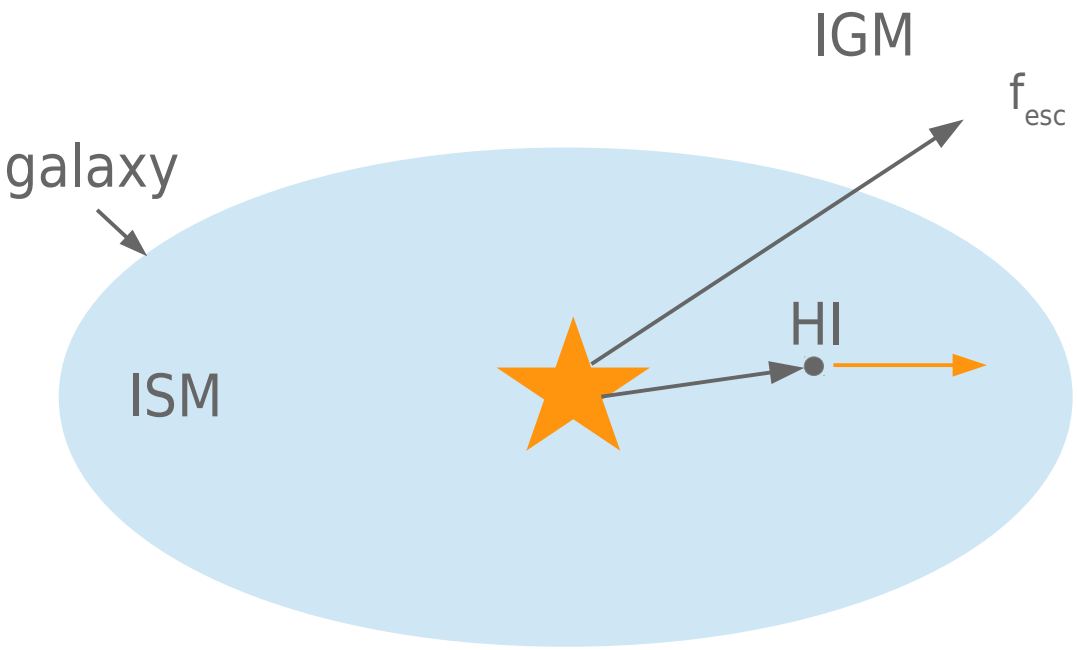


INTERGALACTIC MEDIUM

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

GALAXY PROPERTIES

Lyman α emitters (LAEs) in the intergalactic medium



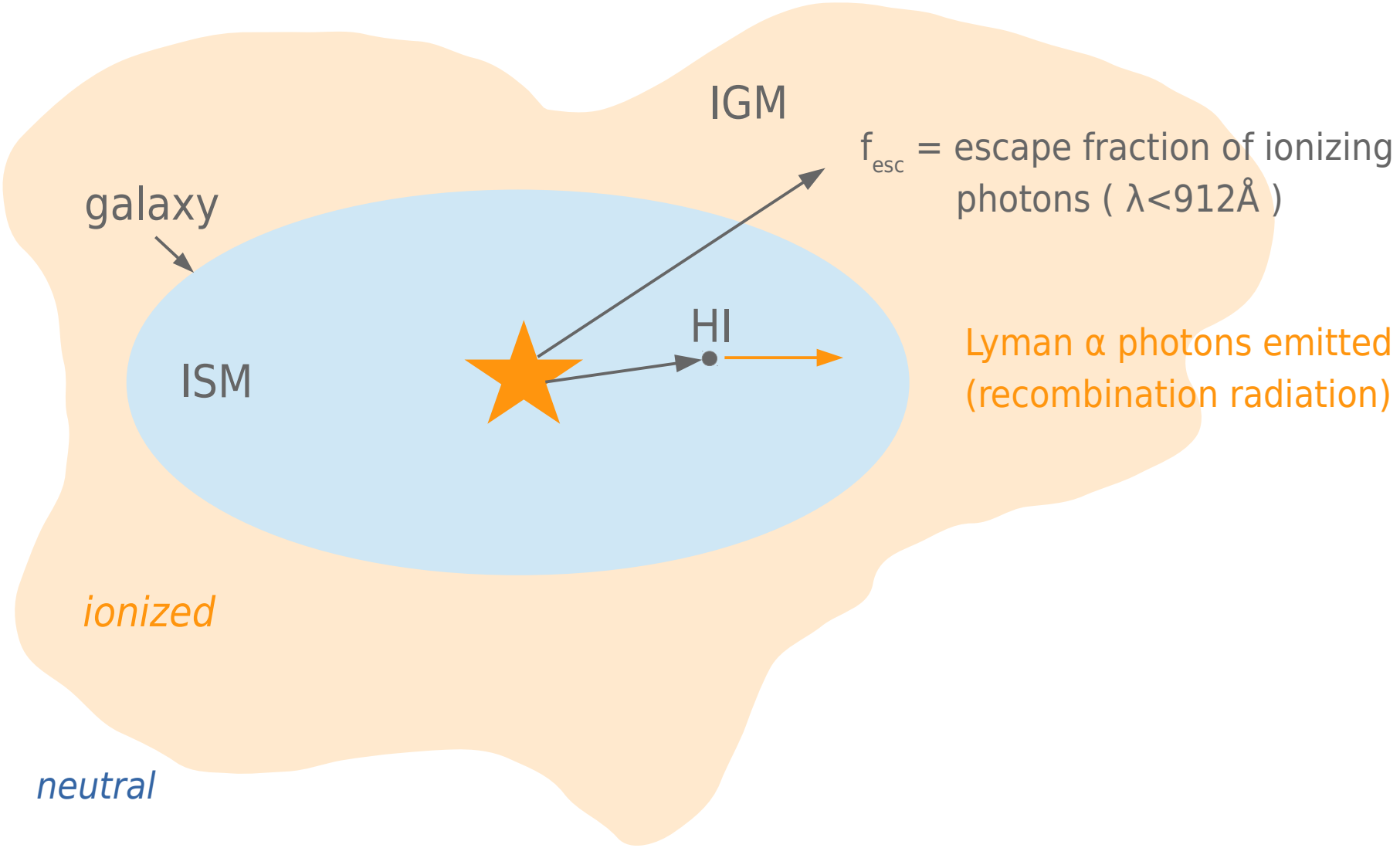
f_{esc} = escape fraction of ionizing photons (λ<912Å)

Lyman α photons emitted (recombination radiation)

ISM = interstellar medium
IGM = intergalactic medium

Hutter+ 2014

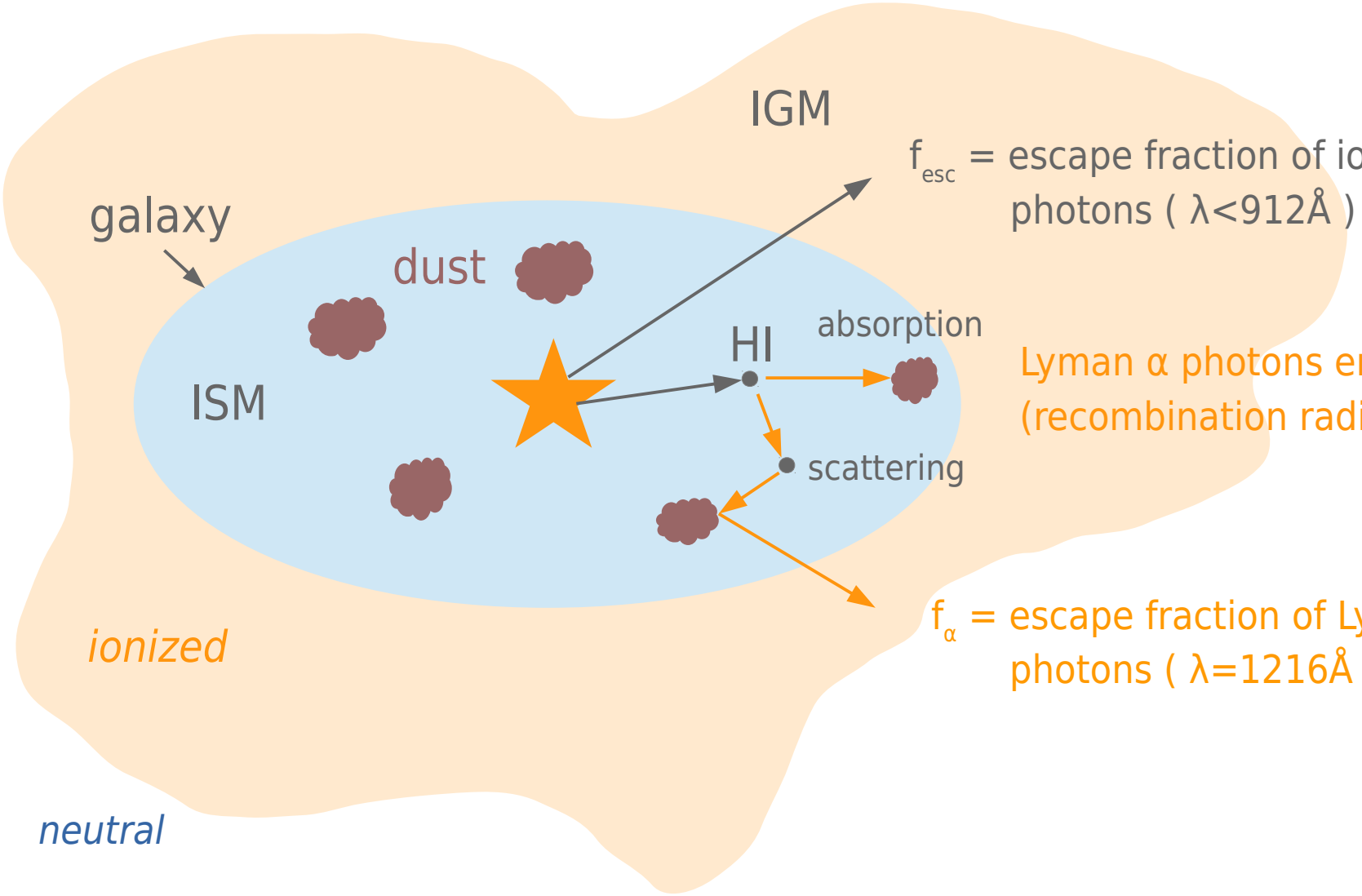
Lyman α emitters (LAEs) in the intergalactic medium



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)

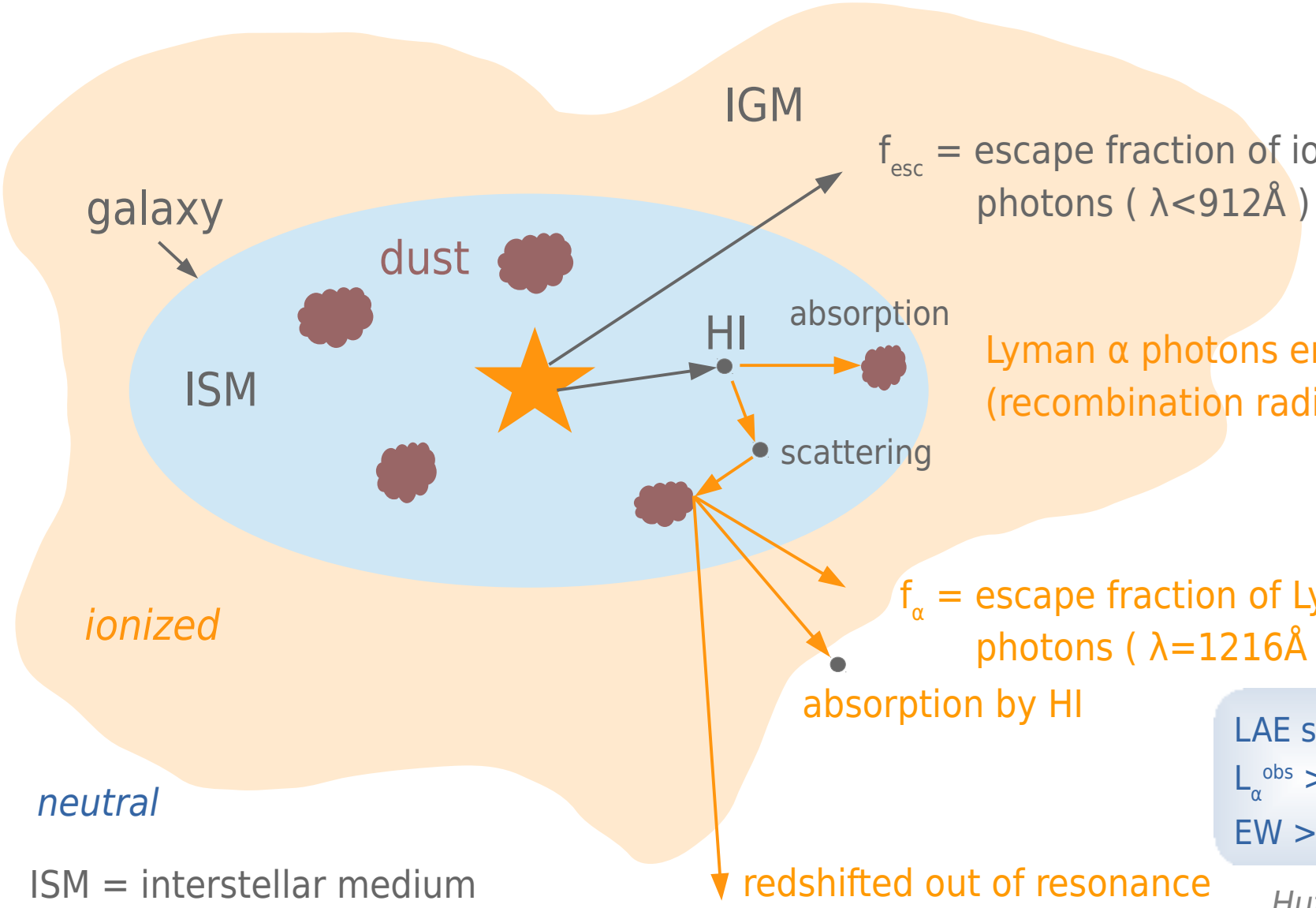
Lyman α photons emitted (recombination radiation)

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

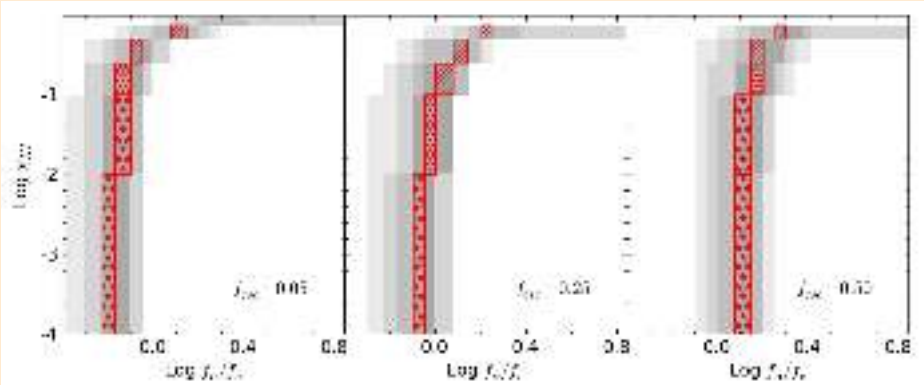


LAE selection criteria:
$L_{\alpha}^{obs} > 10^{42}$ erg s^{-1}
EW > 20 Å

Hutter+ 2014

ISM = interstellar medium
IGM = intergalactic medium

21cm-LAE synergies

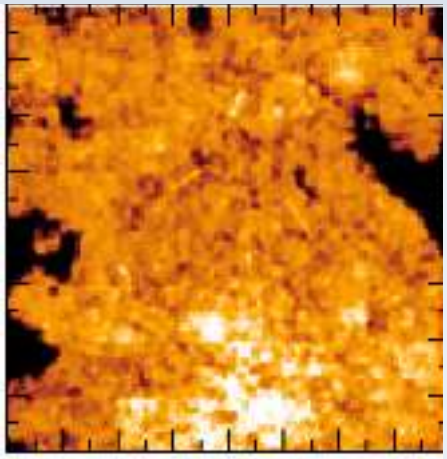


Constraints from Lyα luminosity function
& LAE angular correlation function at z≃6.6

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}

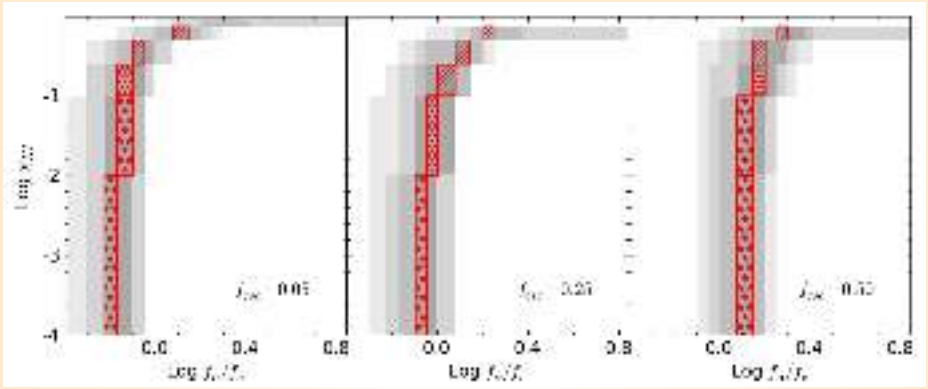
21cm

Differential 21cm brightness temperature:

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

Hutter+ 2016

21cm-LAE synergies



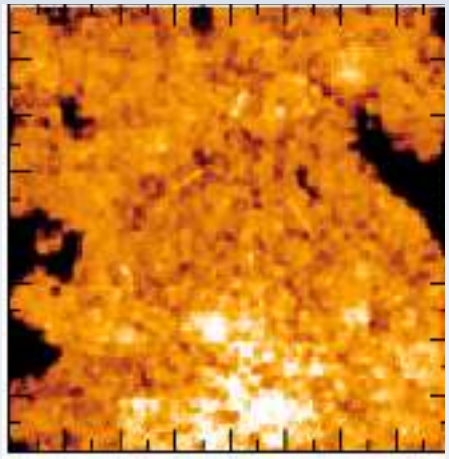
Constraints from Lyα luminosity function
& LAE angular correlation function at z≃6.6

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?



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

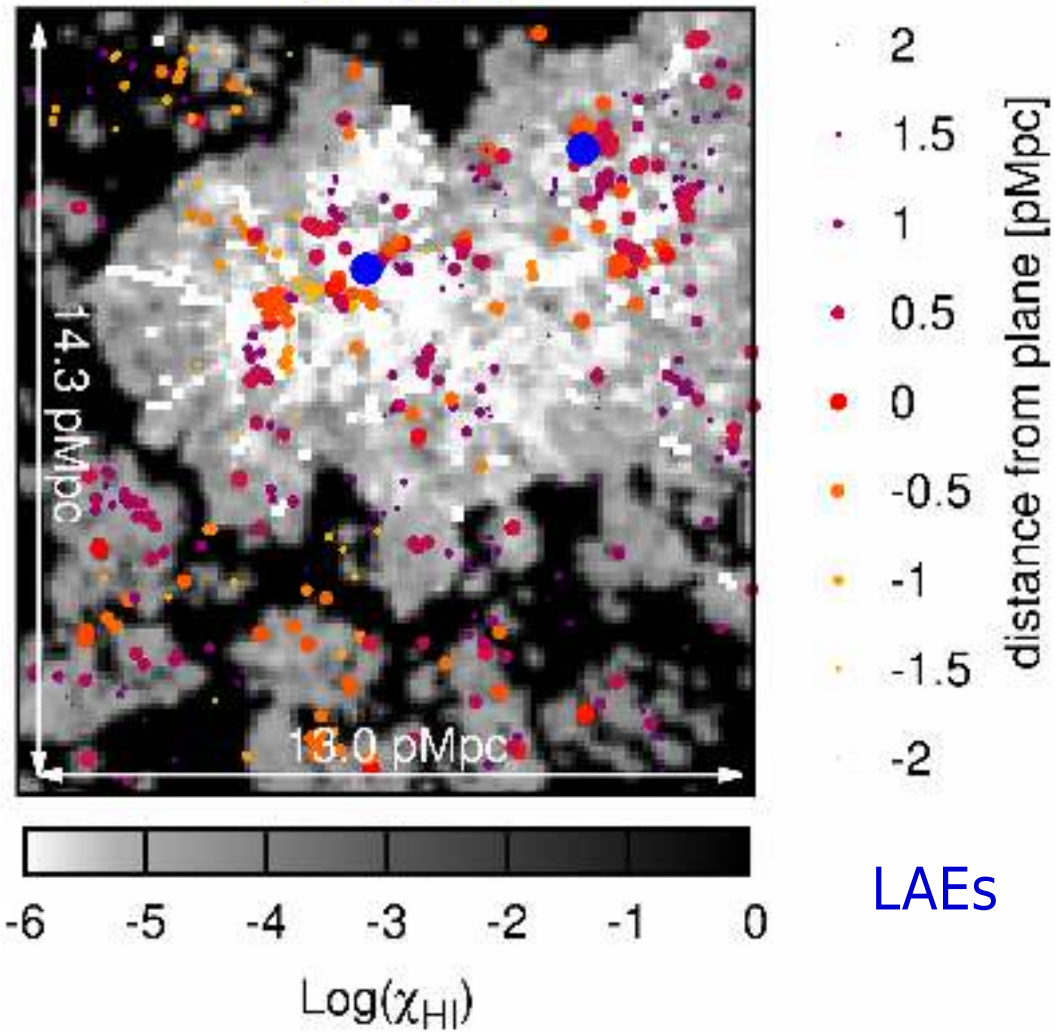
Questions

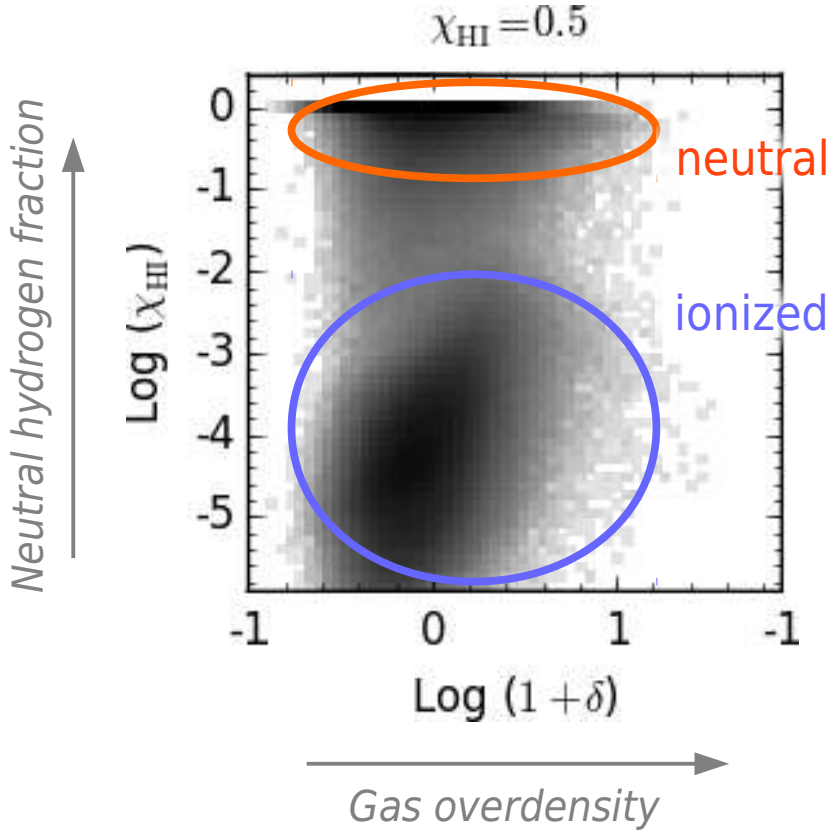
- Which galaxies are identified as LAEs?
  Where in the IGM are LAEs located during reionization?
  Is this reflected in the cross correlations between LAEs and 21cm signal?
- Can we constrain galaxy properties by cross correlating LAE and 21cm data?
- Can we learn something about reionization topology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

Where are LAEs located in the IGM?

z ~ 6.6

Castellano+ 2016

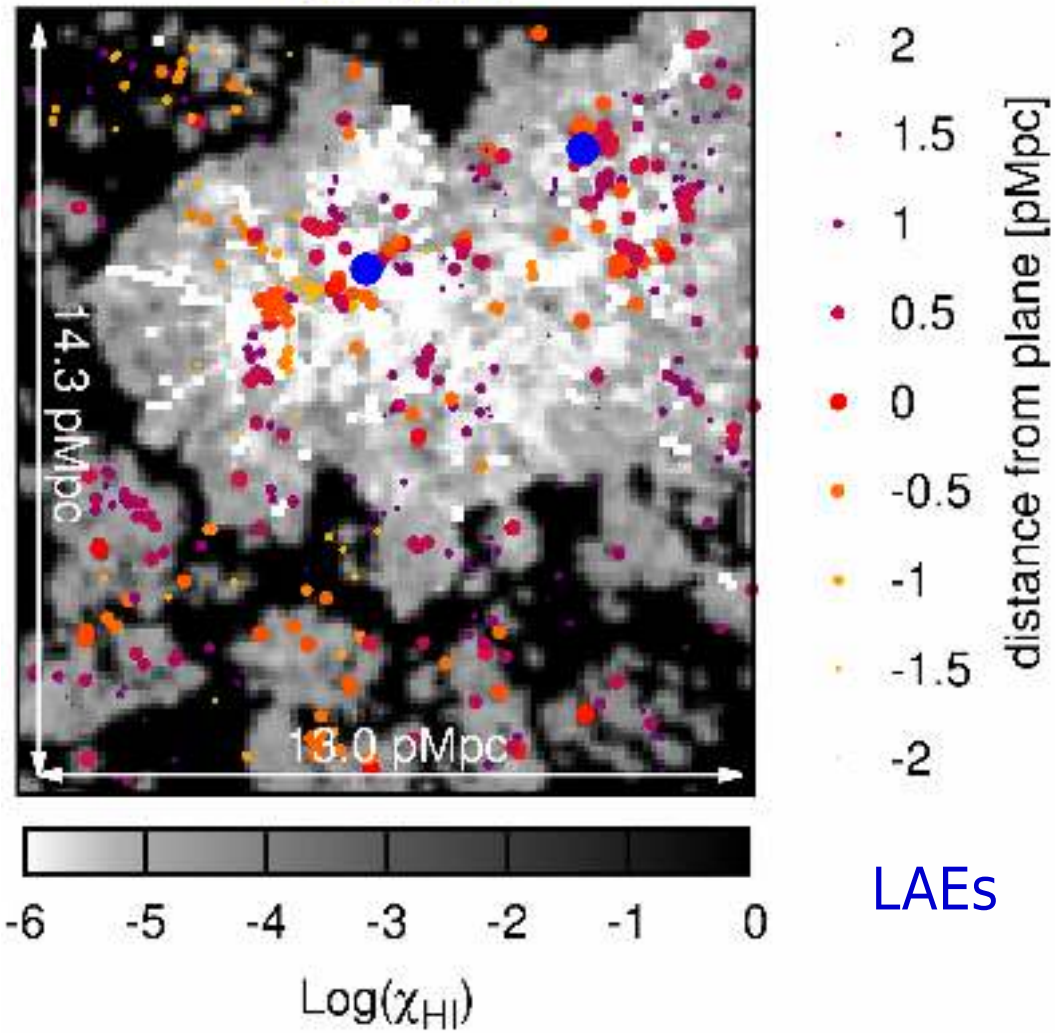


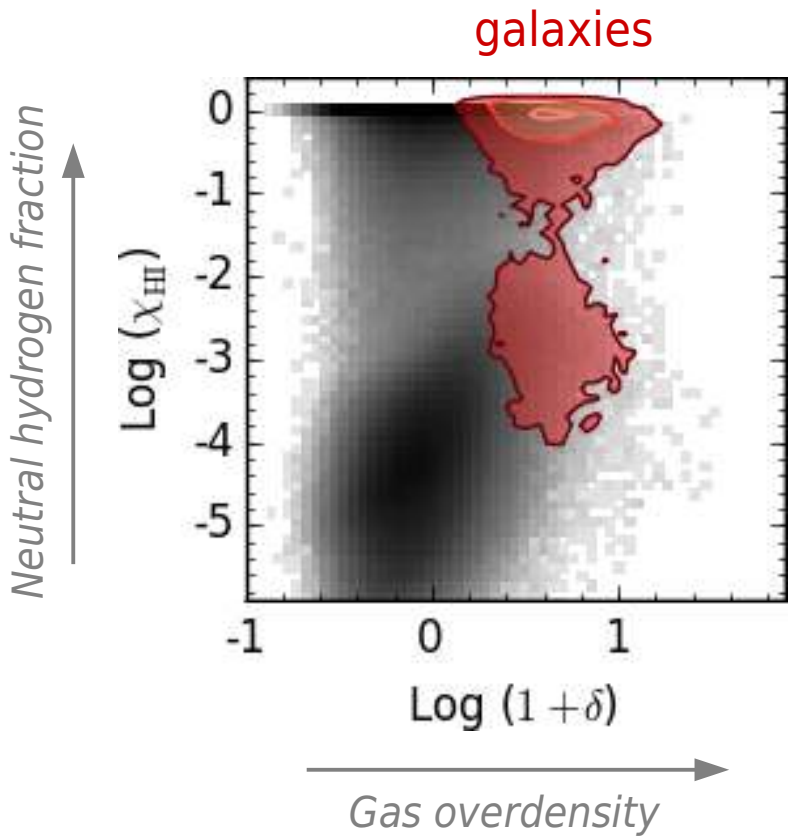


Where are LAEs located in the IGM?

z ~ 6.6

Castellano+ 2016

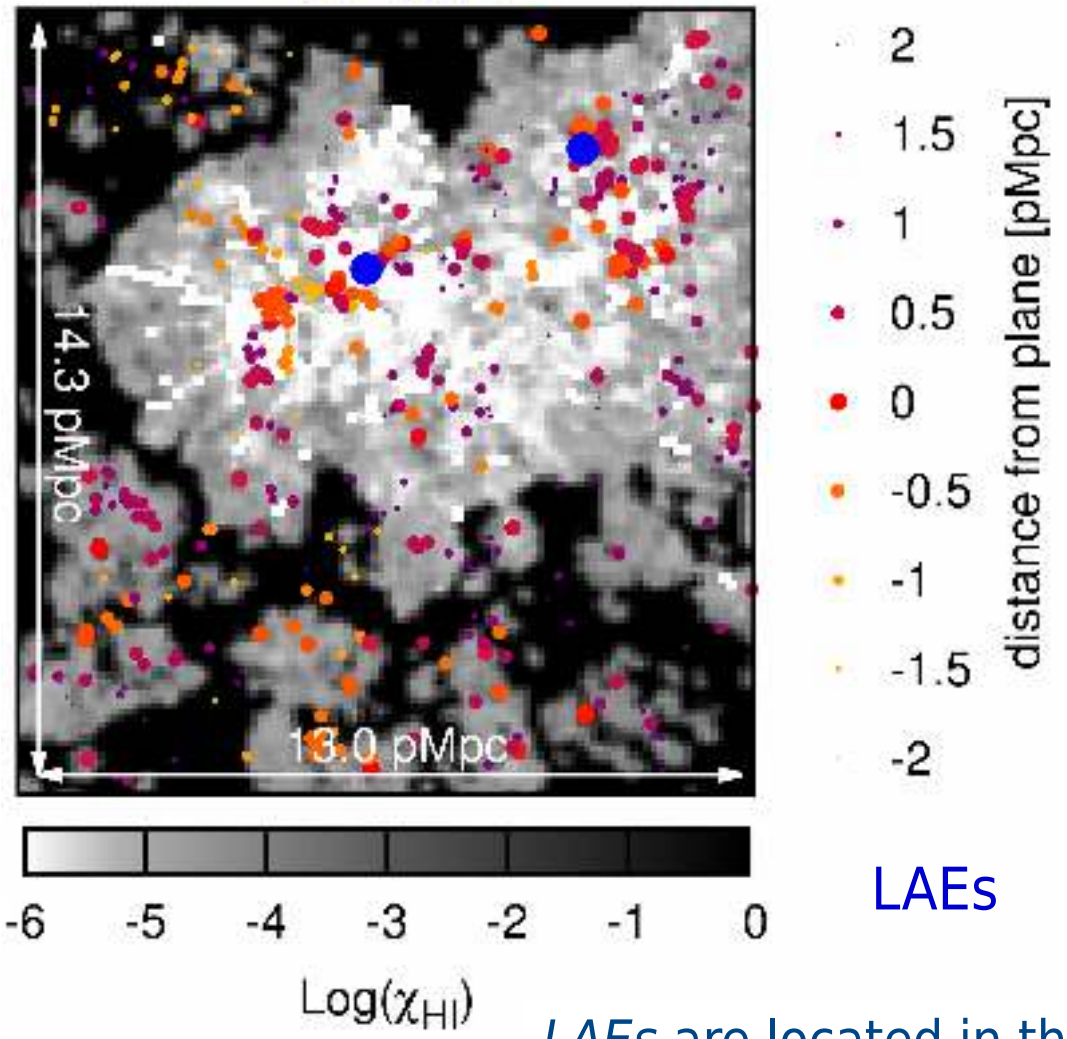


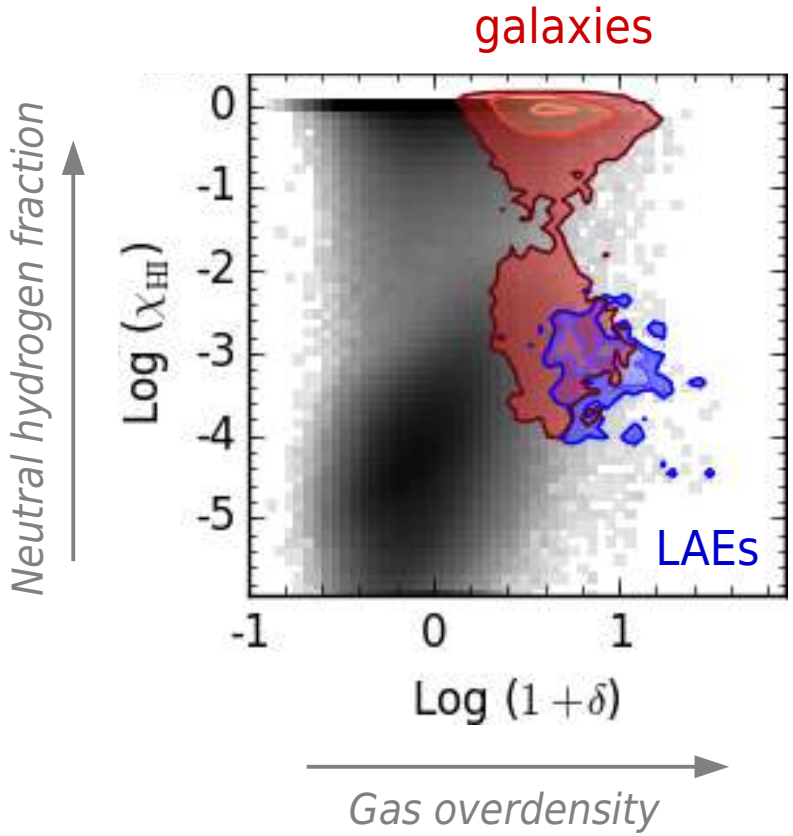


Where are LAEs located in the IGM?

z ~ 6.6

Castellano+ 2016

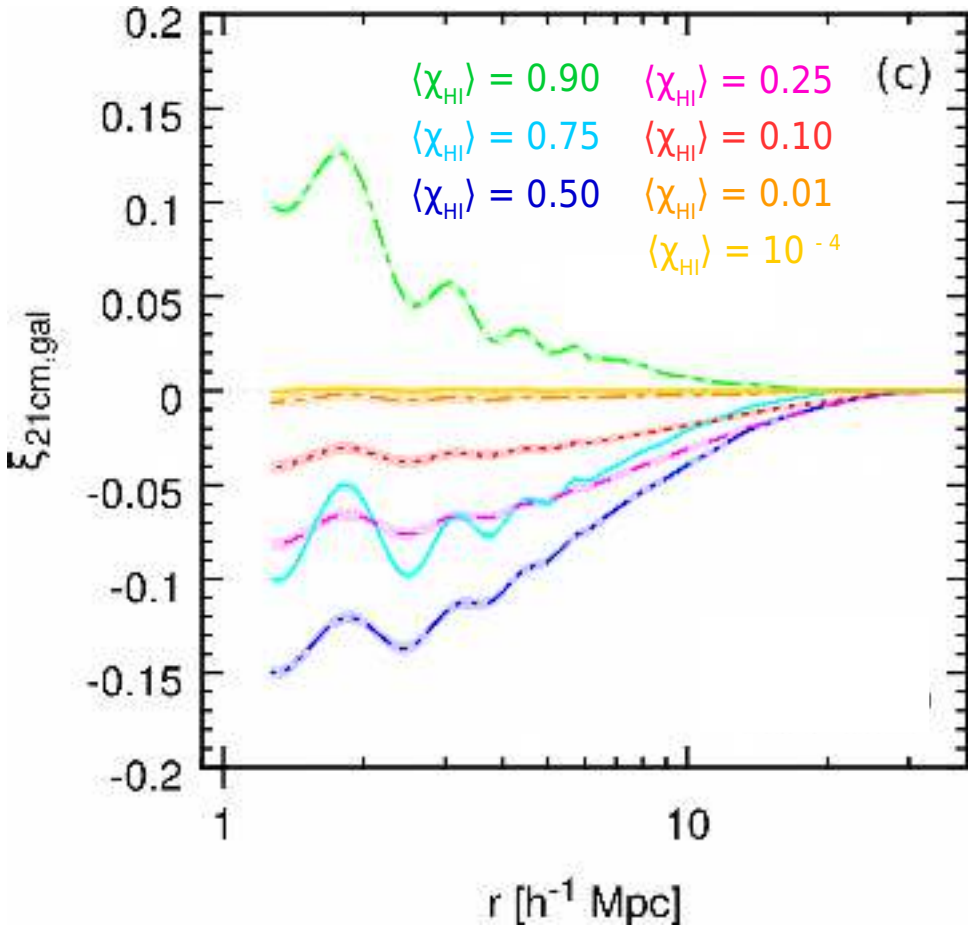




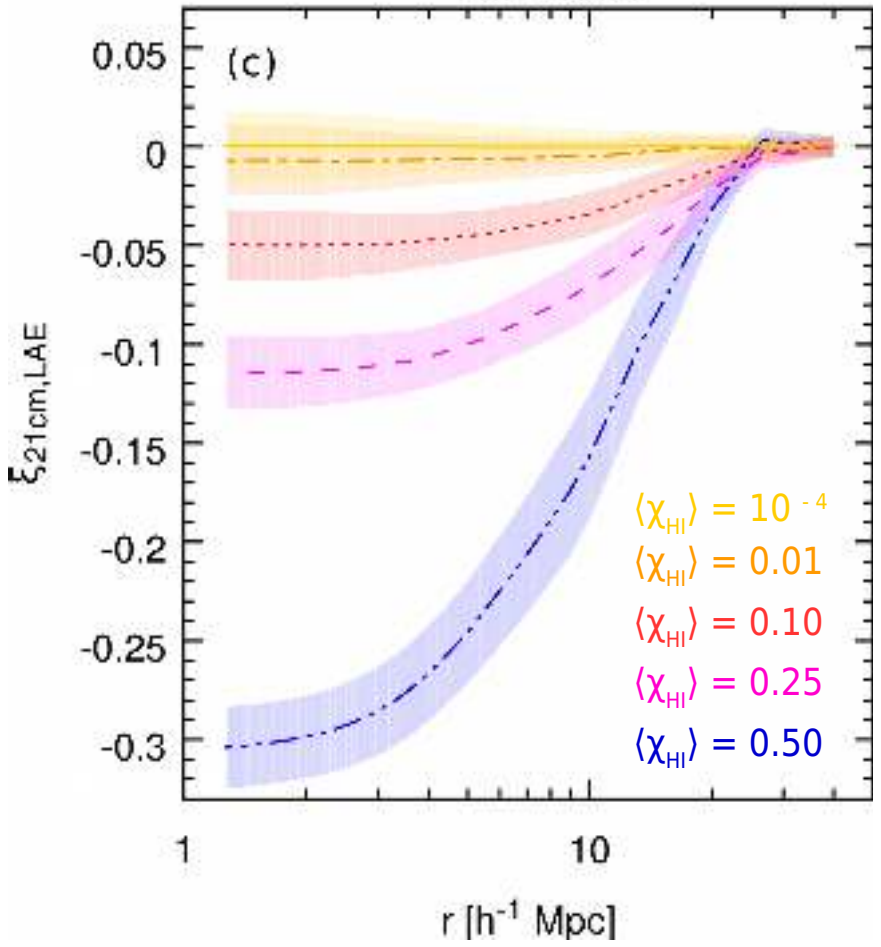
LAEs are located in the *ionized & most overdense* regions

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

galaxies

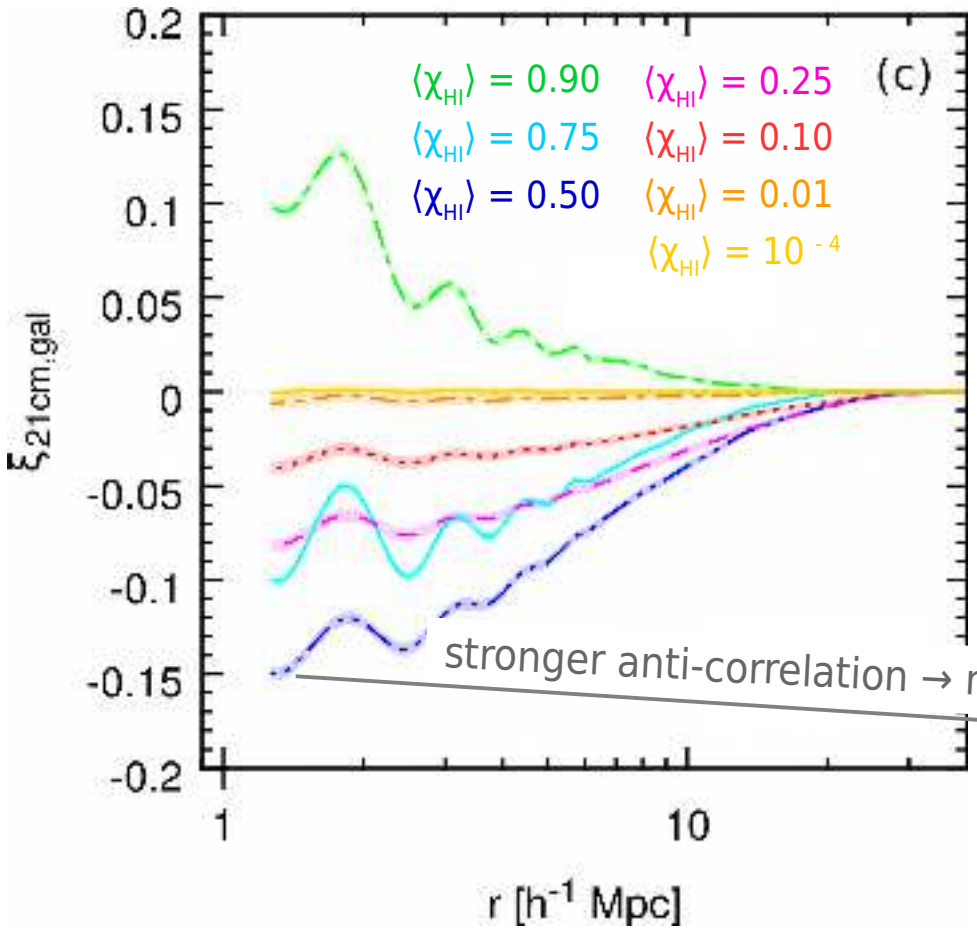


LAEs



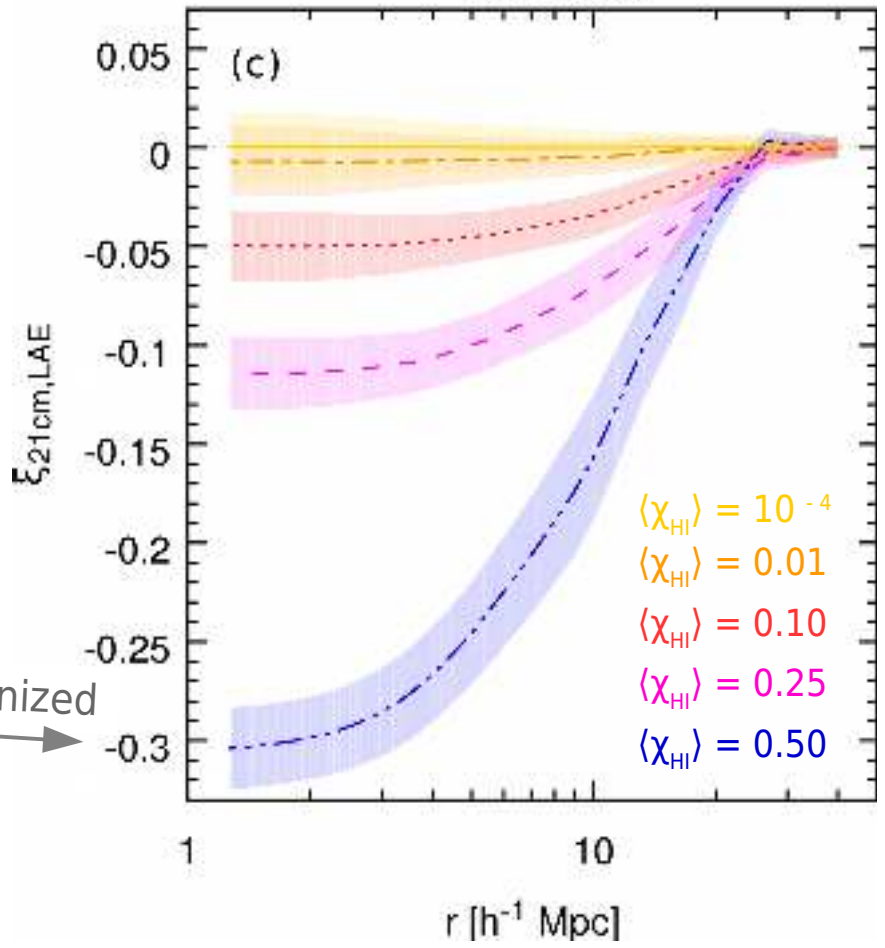
Where are LAEs located in the IGM?
21cm cross correlations with galaxies and LAEs

galaxies



stronger anti-correlation → more ionized

LAEs



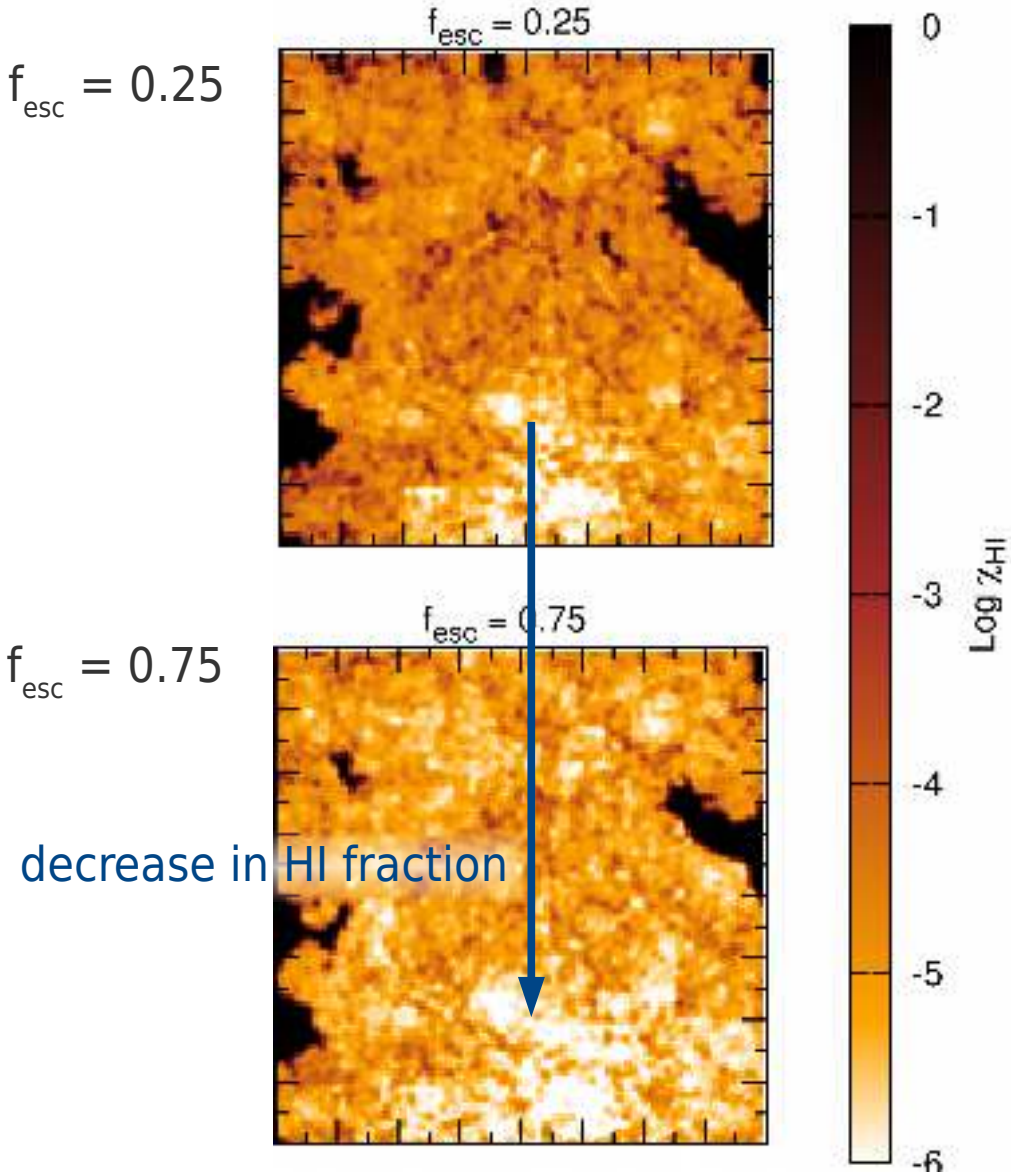
21cm – LAE cross correlations depend on f_{esc}?

Differential 21cm brightness temperature:

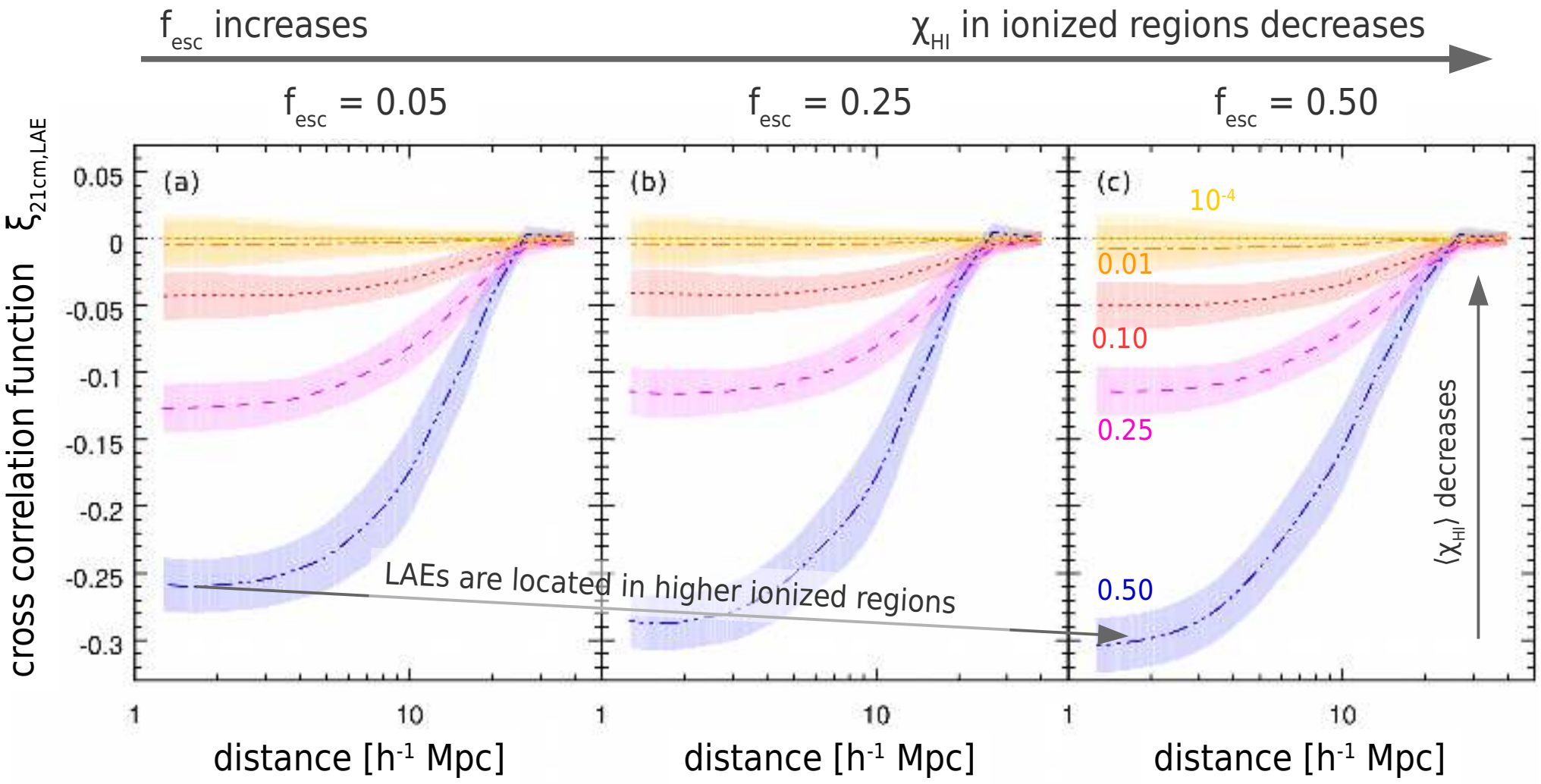
$$\delta T_b = T_0 \langle \chi_{HI} \rangle (1+\delta)(1+\delta_{HI})$$

χ_{HI} decreases with increasing fesc

21cm differential brightness temperature decreases with increasing fesc



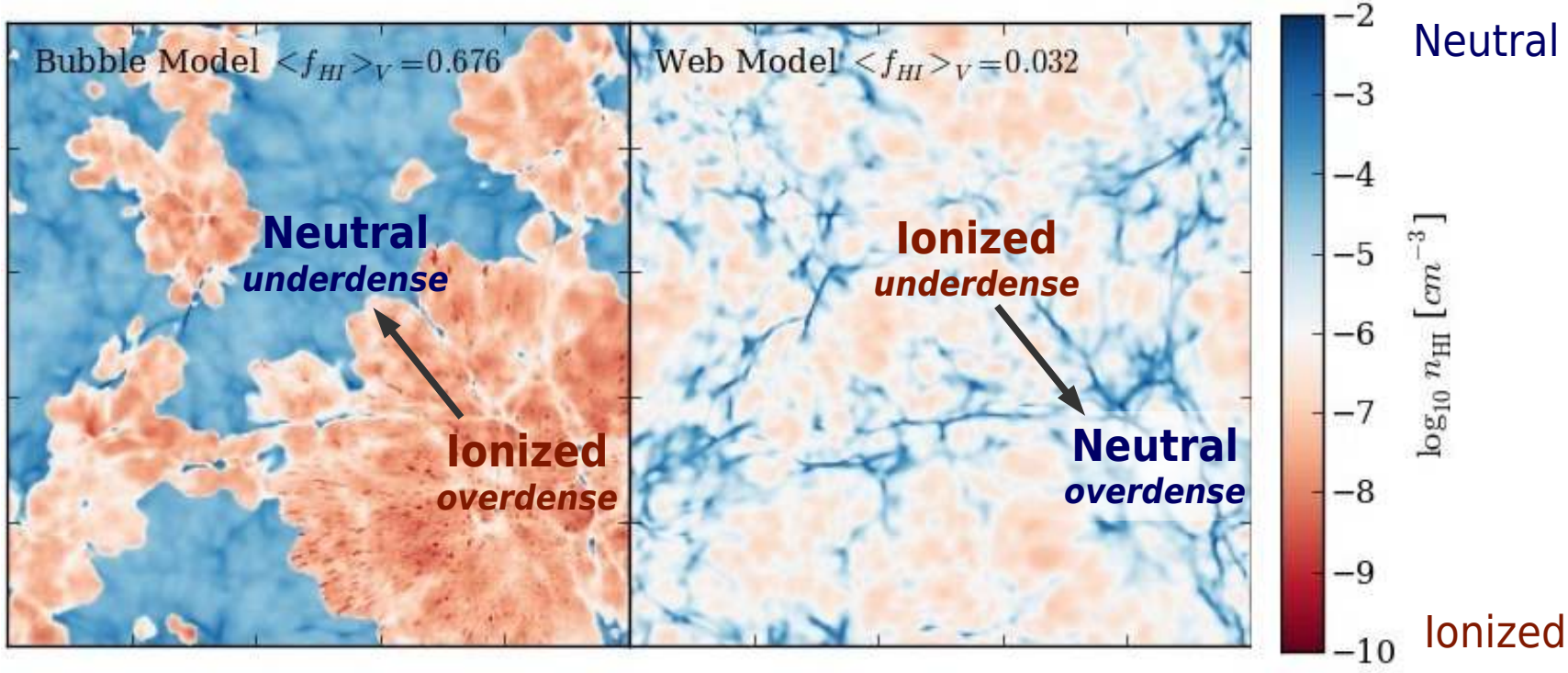
21cm – LAE cross correlations



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

Topology of reionization

Kakiichi+ 2016



Inside-out

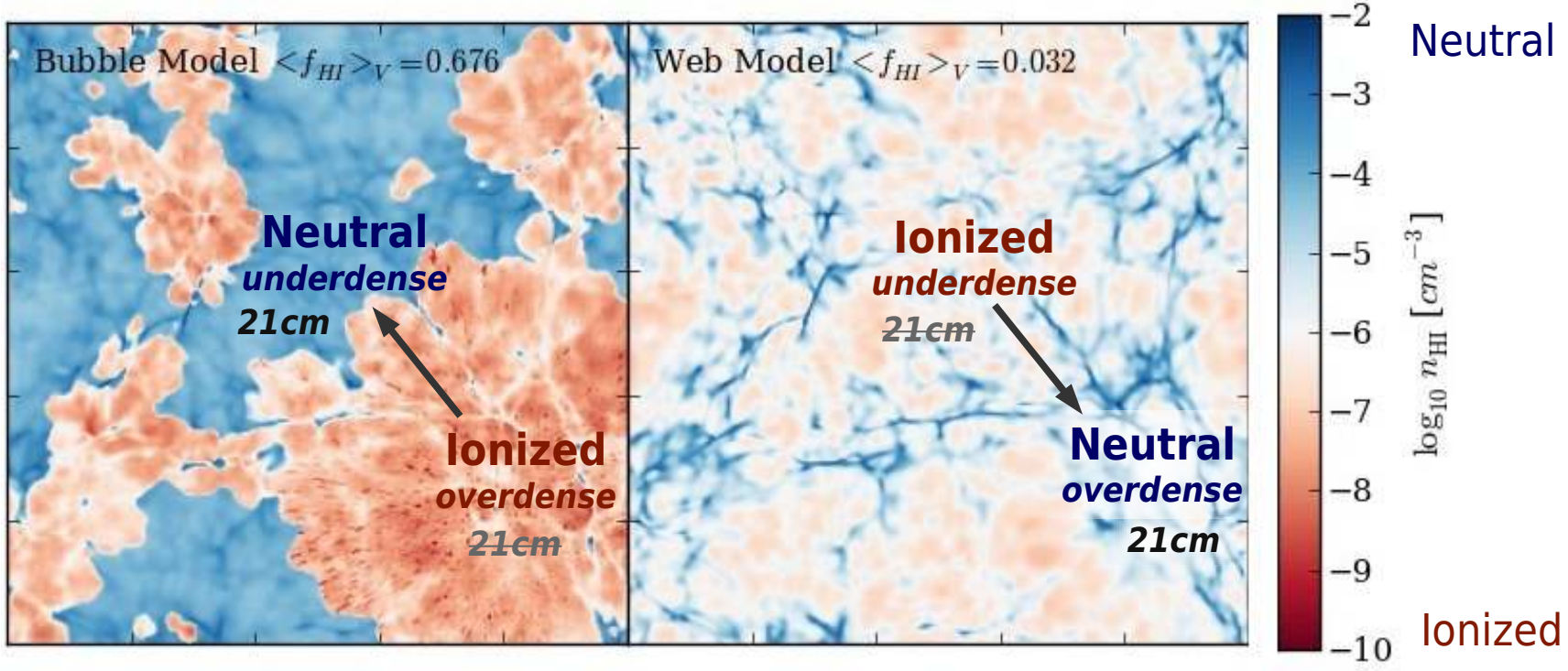
Overdense (small scales)
regions are ionized first

Outside-in

Underdense (large scales)
regions are ionized first

Topology of reionization

Kakiichi+ 2016



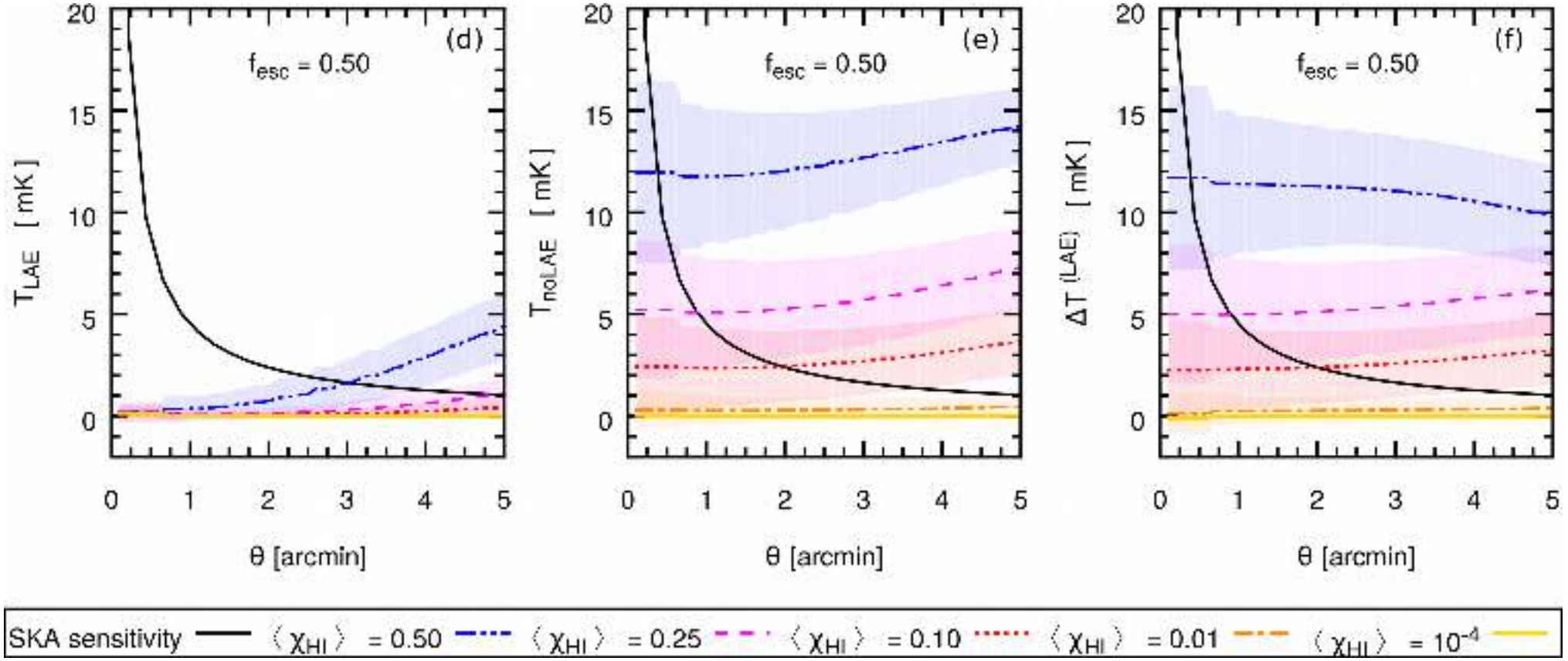
Inside-out

Overdense (small scales)
regions are ionized first

Outside-in

Underdense (large scales)
regions are ionized first

Measuring topology using 21cm correlations with overdensities 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.