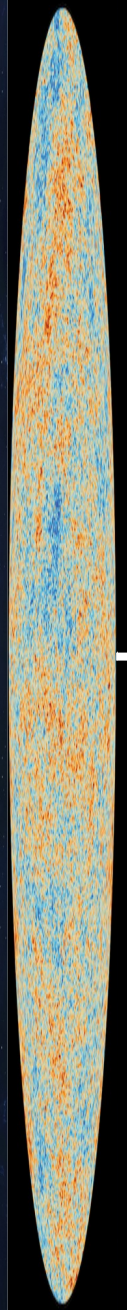


DAWN

The sensitivity of the 21cm signal – LAE cross correlations to the ionisation topology

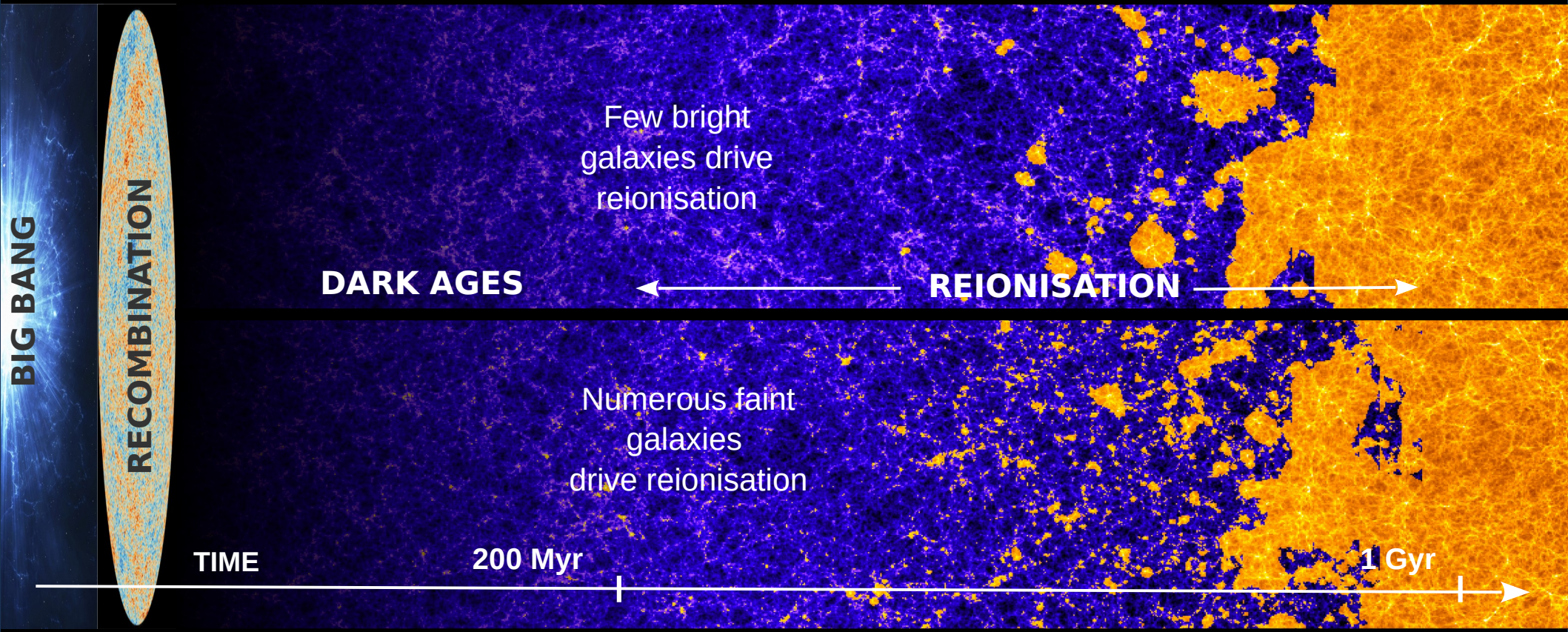
Anne Hutter

Cosmic Dawn Center, University of Copenhagen

Collaborators: Caroline Heneka, Astraeus Team (Pratika Dayal, Maxime Trebitsch, Stefan Gottlöber, Gustavo Yepes), Andrei Mesinger

UNIVERSITY OF COPENHAGEN

Was reionisation driven by the numerous faint or the few bright galaxies?



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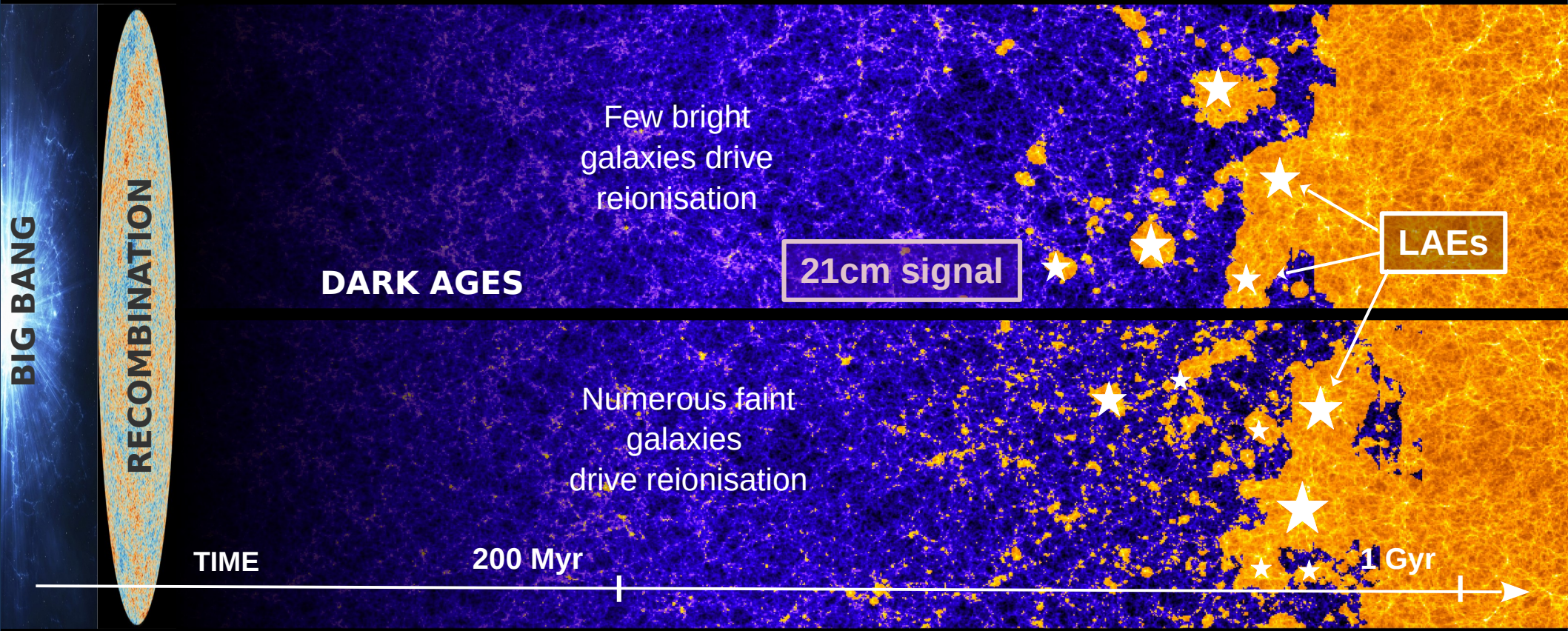
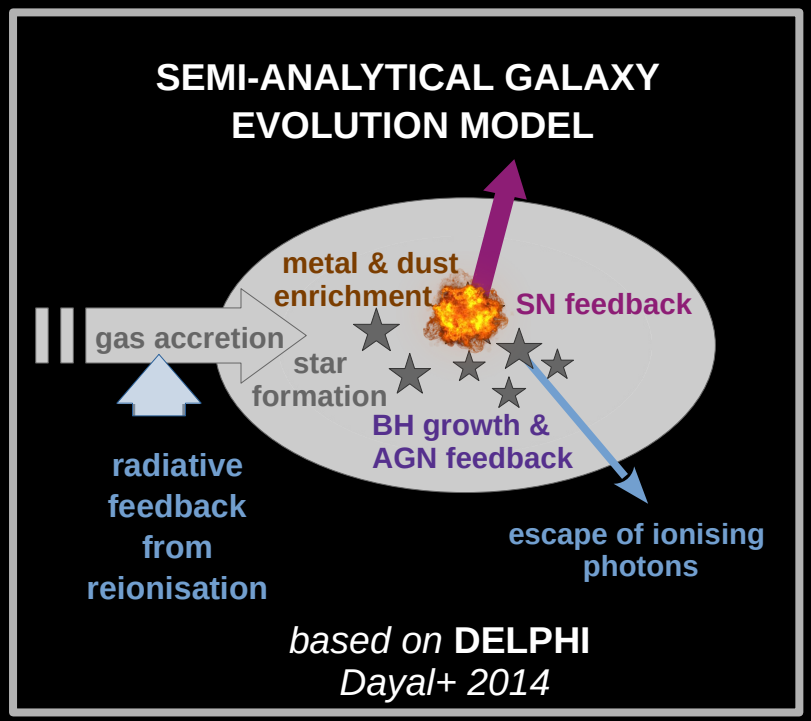


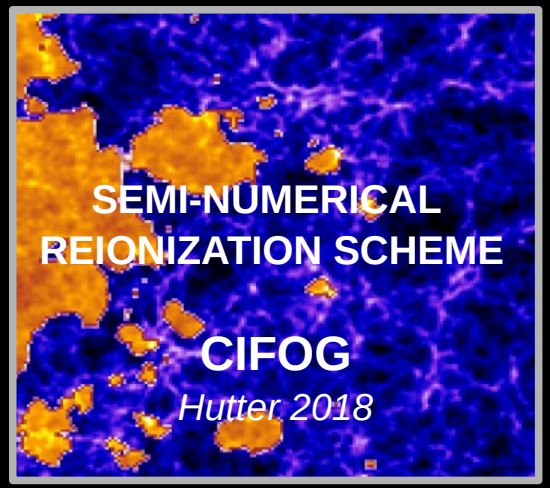
Astraeus framework: simulating the evolution of galaxies and the IGM



ionising emissivity distribution

COUPLING

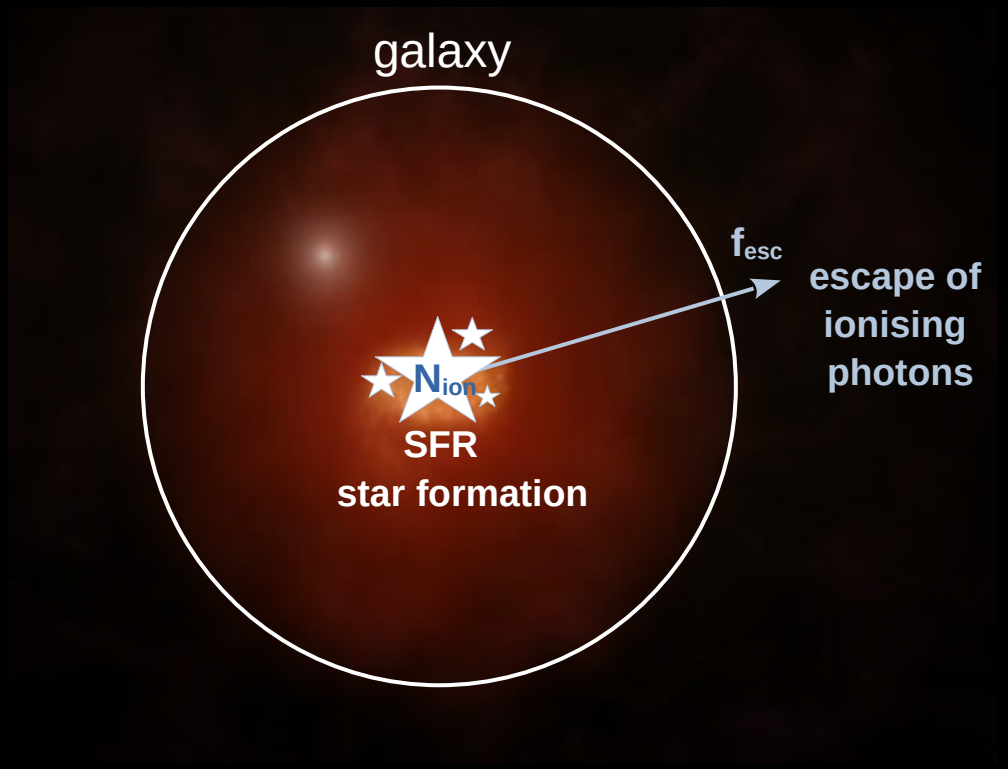
feedback from reionisation



evolving IMF

Hutter+ 2021a, Ucci+2023, Hutter+ 2023a, Trebitsch+2023, Cueto+2023

What determines the ionising nature of the first galaxies?



ionising escape fraction
feedback processes?

ionising emissivity
stellar populations (IMF, binaries)

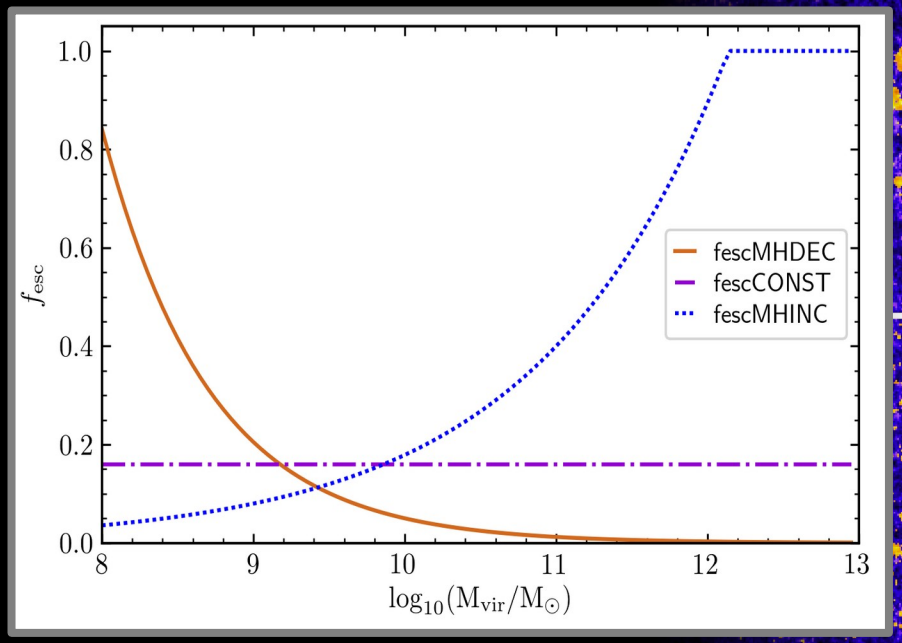
$$N_{ion}^{esc} = f_{esc}\ N_{ion}\ SFR$$

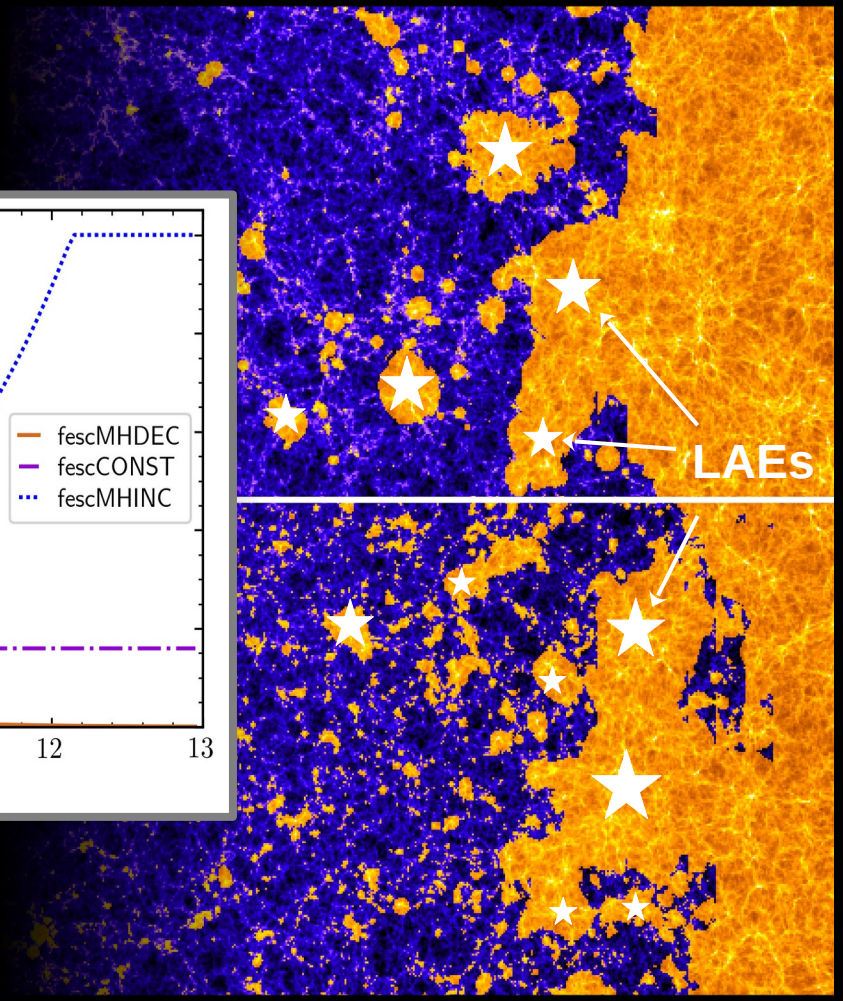
star formation rate
feedback processes (SN, radiative, AGN), accretion

Is the visibility of Lyman-α emitters sensitive to ionisation topology?

f_{esc} increases with halo mass MHINC

f_{esc} decreases with halo mass MHDEC





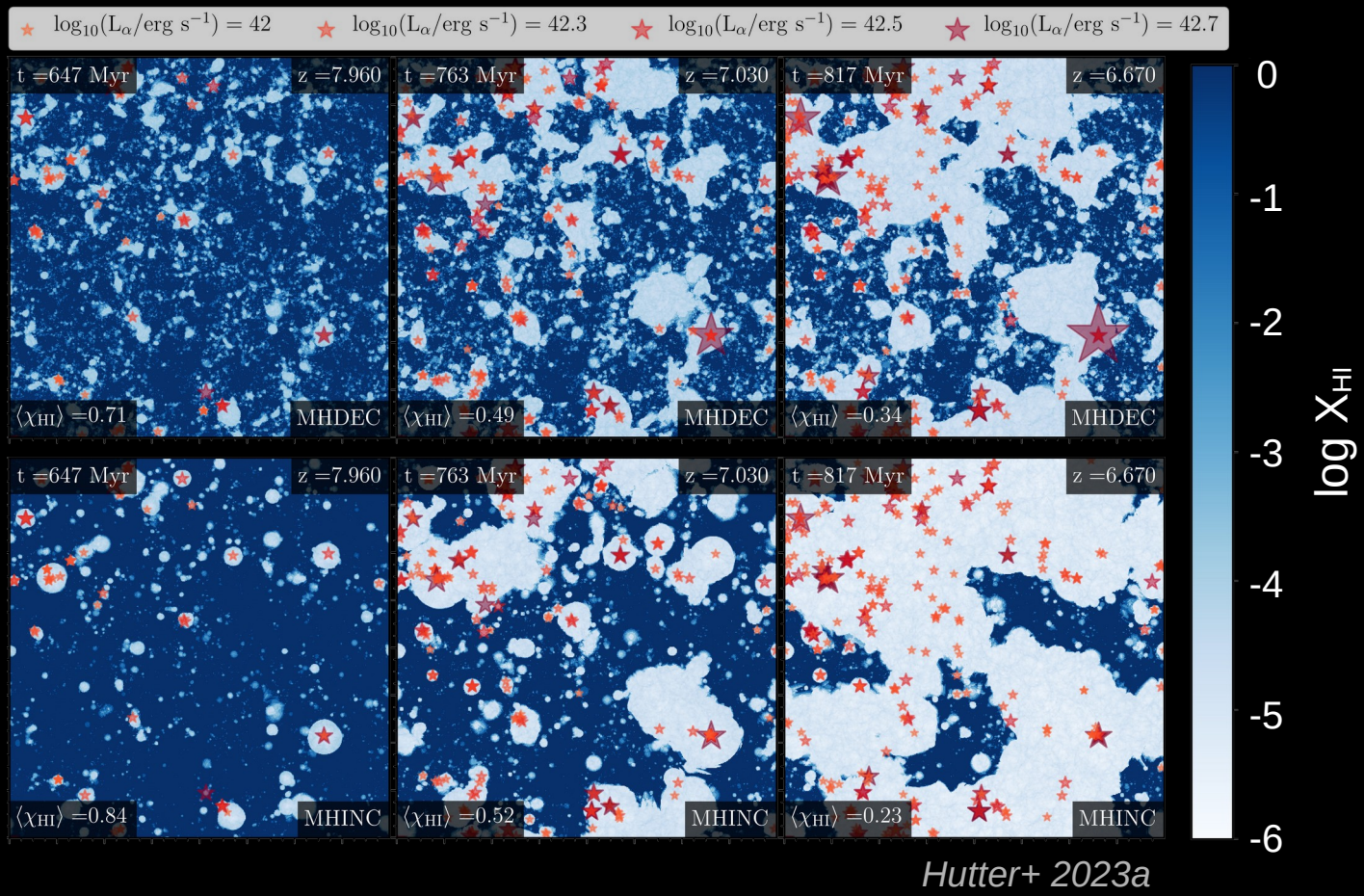
Hutter+ 2023a

Lyman-α emitter distribution hardly traces the ionisation topology!

f_{esc} decreases with halo mass
MHDEC

Astraeus simulations

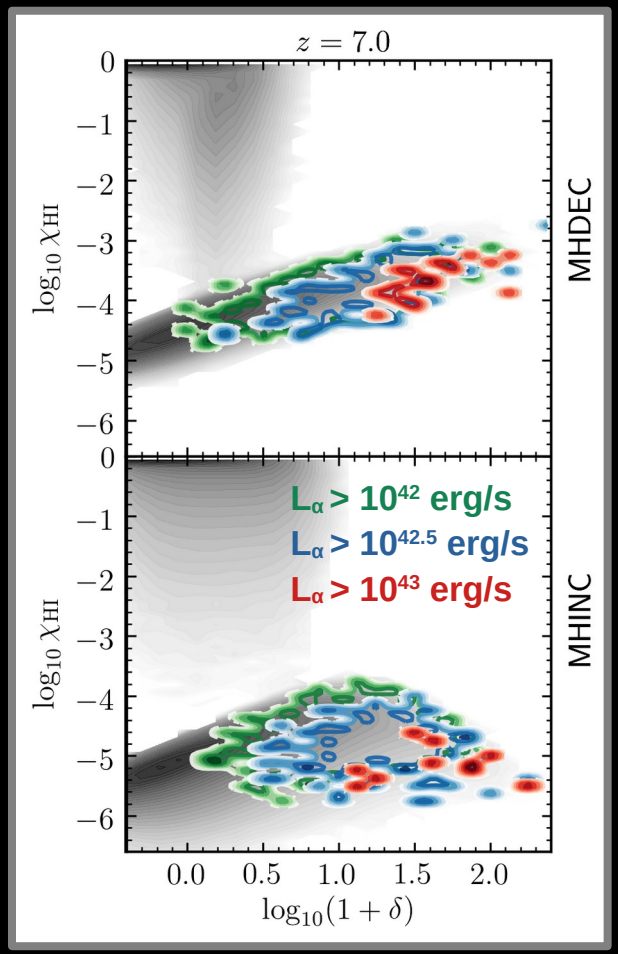
f_{esc} increases with halo mass
MHINC



Hutter+ 2023a

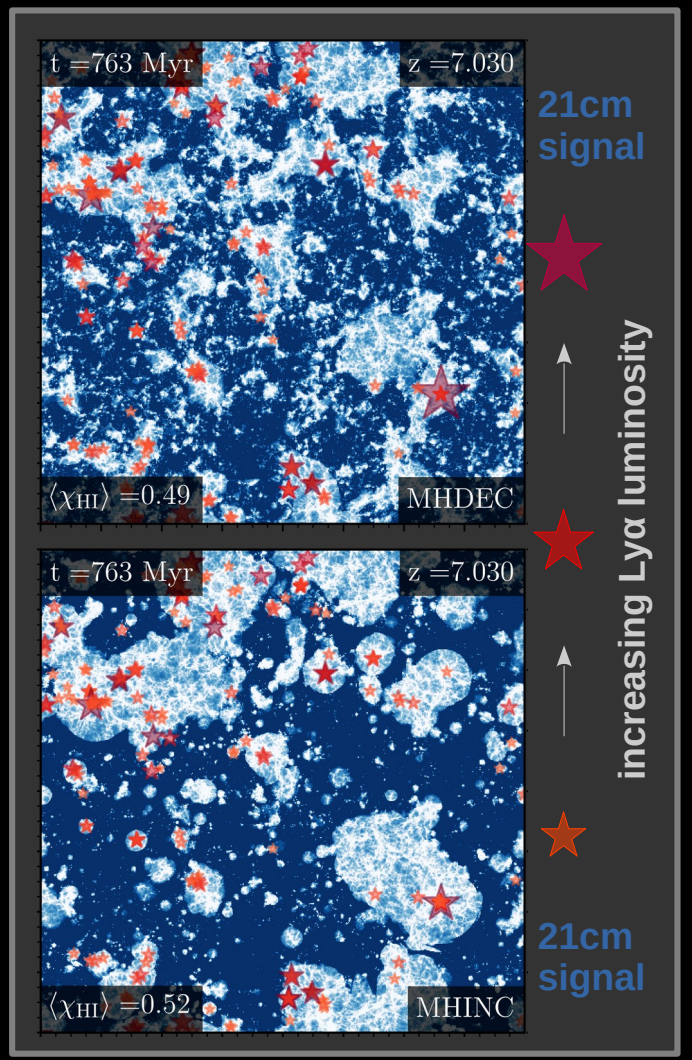
As LAEs ($L_\alpha > 10^{42}$ erg/s) are the most massive galaxies, their spatial distribution depends mostly on the global ionisation state of the IGM.

Where are Lyman-α emitters located in the IGM?



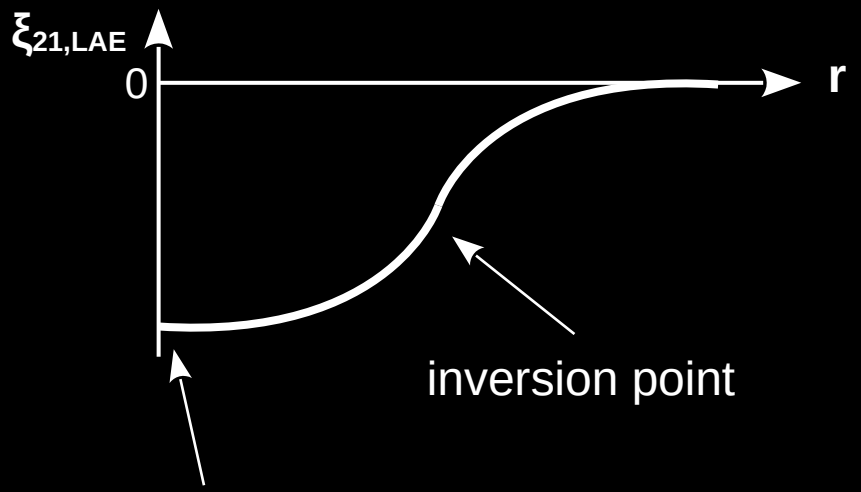
LAEs are located in the most ionised overdense regions

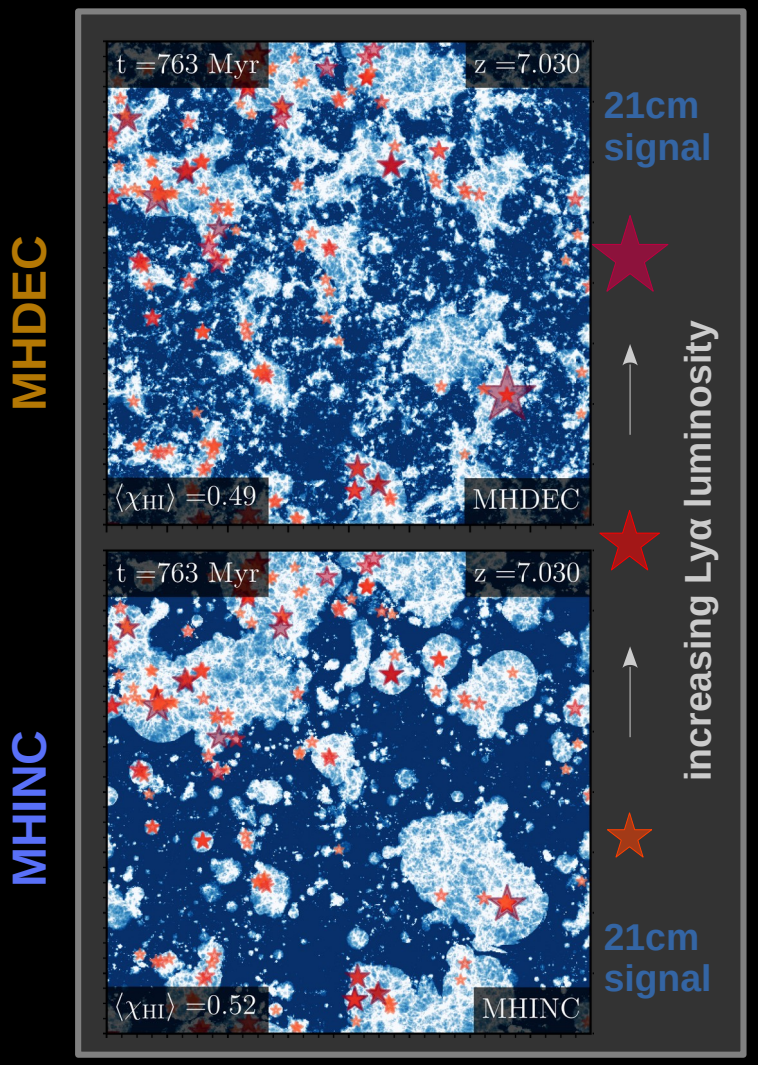
no 21cm signal



Hutter+ 2023a,b

21cm – LAE cross correlation function: characteristics

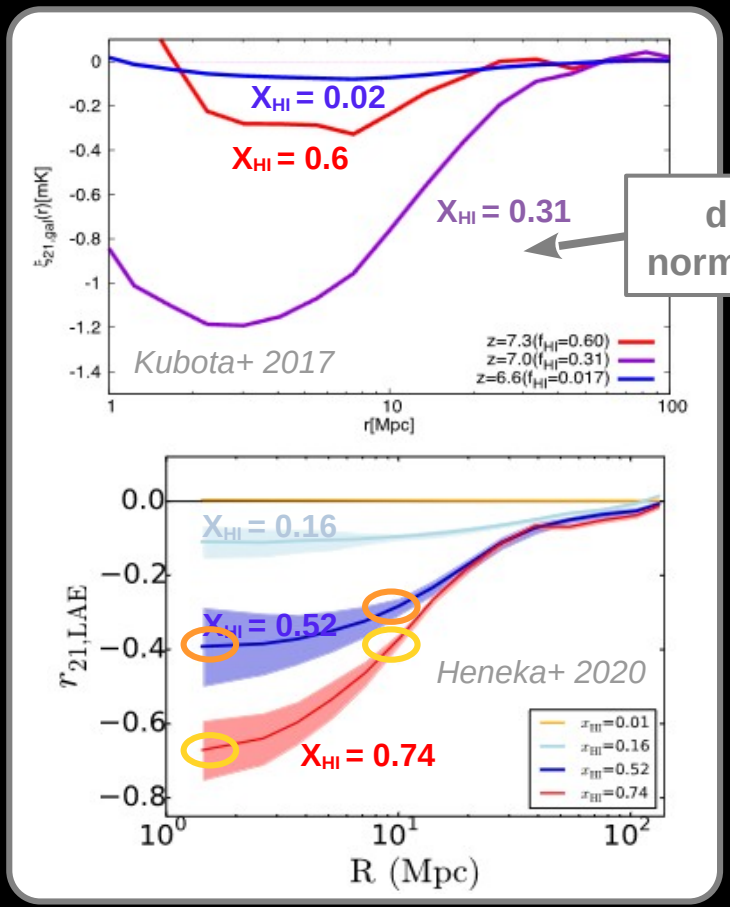




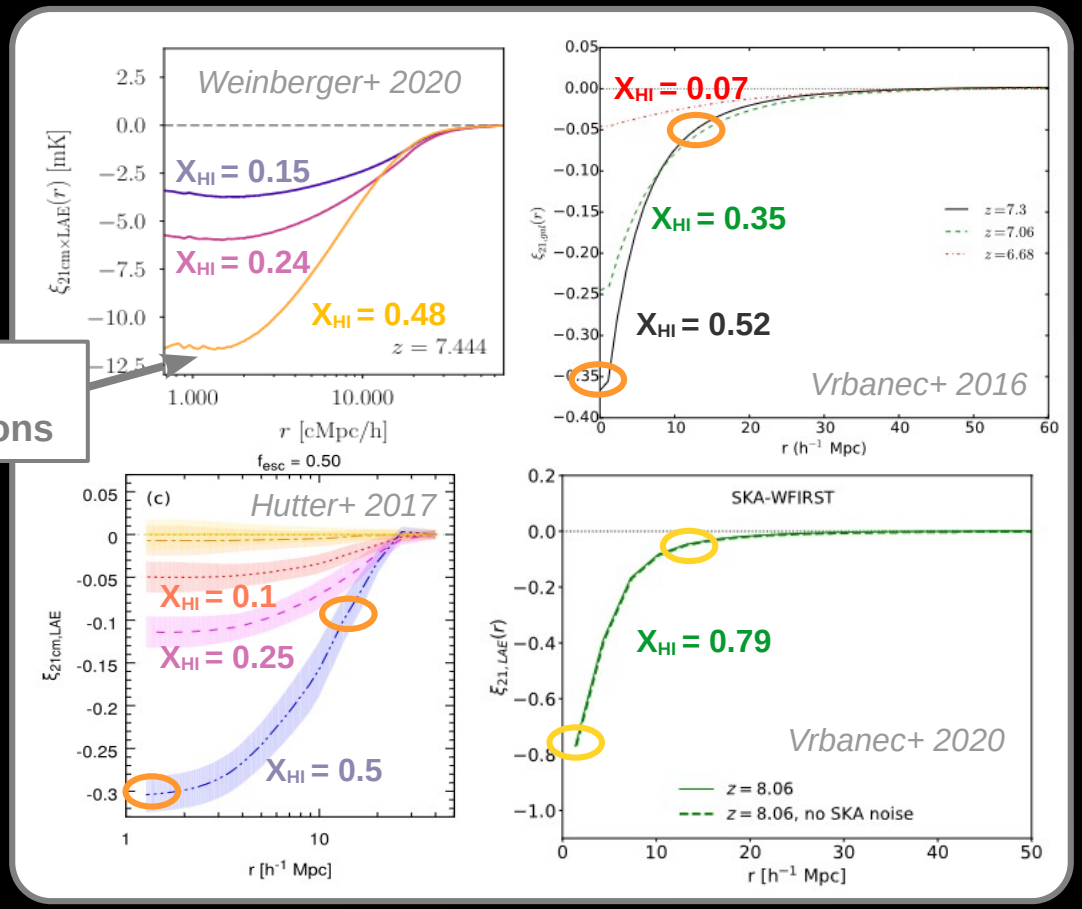
Hutter, Heneka+ 2023

21cm – LAE cross correlation function: similar but different

21cm-LAE cross correlation functions from different models/simulations differ.



different normalisations

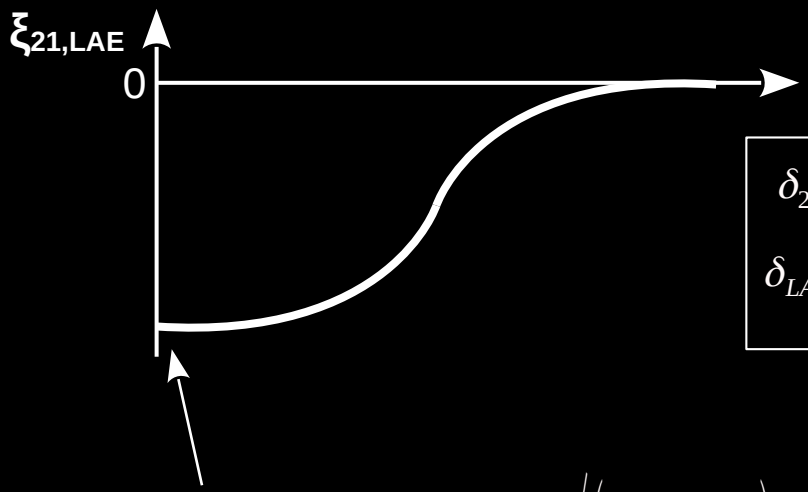


Overall shape agrees BUT amplitudes differ

WHY? What would we expect?

normalisation, box size, physics (ionisation, LAE identification)?

21cm – LAE cross correlation functions: small-scale amplitude



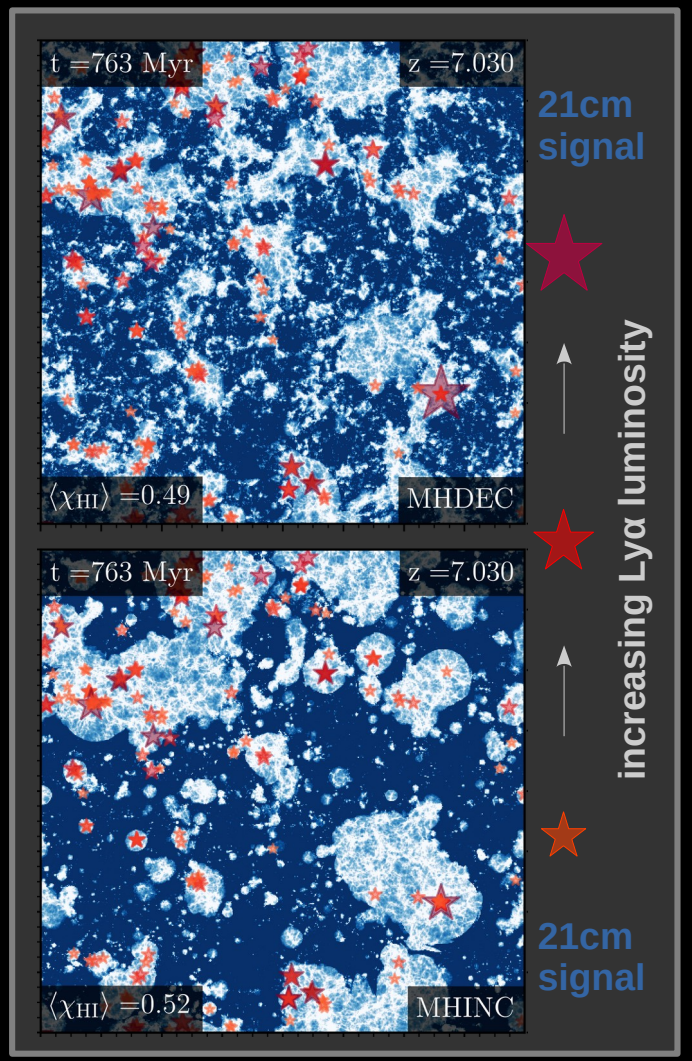
$$\delta_{21}(x) = \delta T_b(x)/T_0$$

$$\delta_{LAE}(x) = \frac{n_{LAE}(x)}{\langle n_{LAE}\rangle} - 1$$

$$\xi_{21,LAE}(r\approx 0) \approx -\langle \chi_{HI}\rangle \left\langle \left(1-\frac{T_{CMB}}{T_s}\right)(1+\delta)\right\rangle_{HI}$$

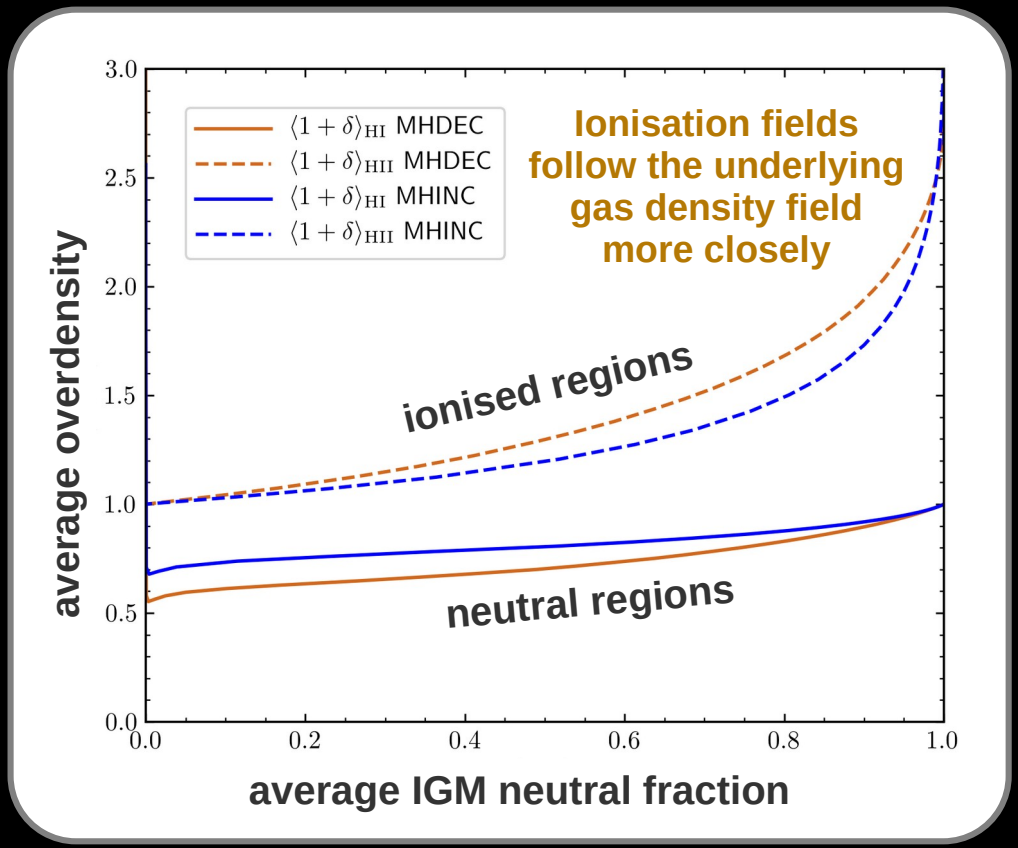
During reionisation:

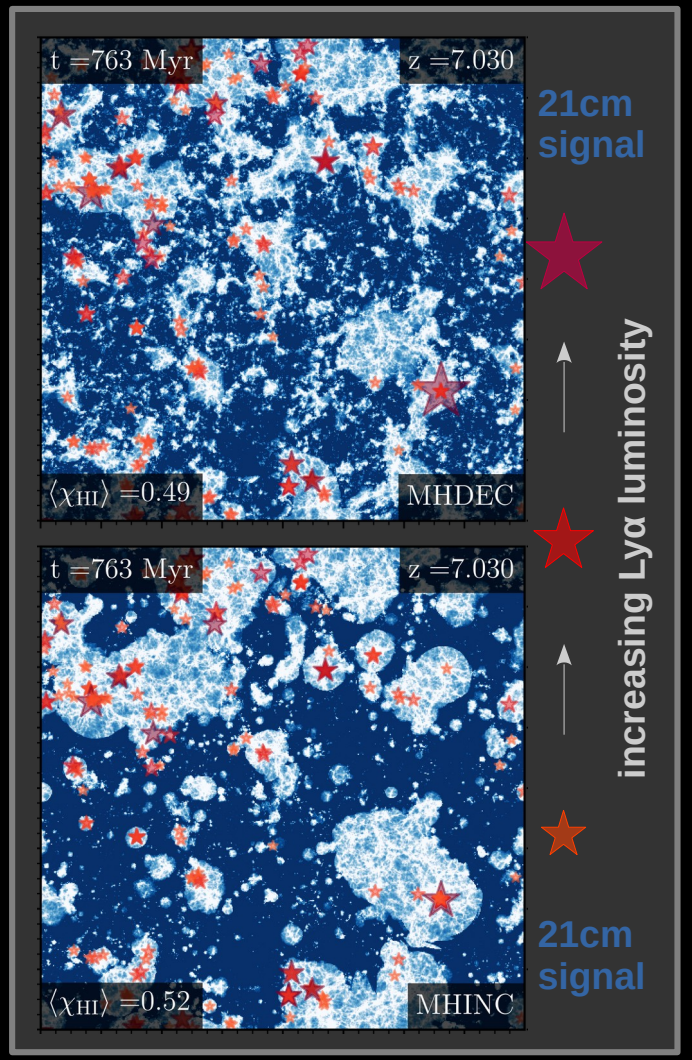
$$\xi_{21,LAE}(r\approx 0) \approx -\langle \chi_{HI}\rangle \langle 1+\delta\rangle_{HI}$$



Hutter, Heneka+ 2023

21cm – LAE cross correlation function: small-scale amplitude traces ionisation topology!

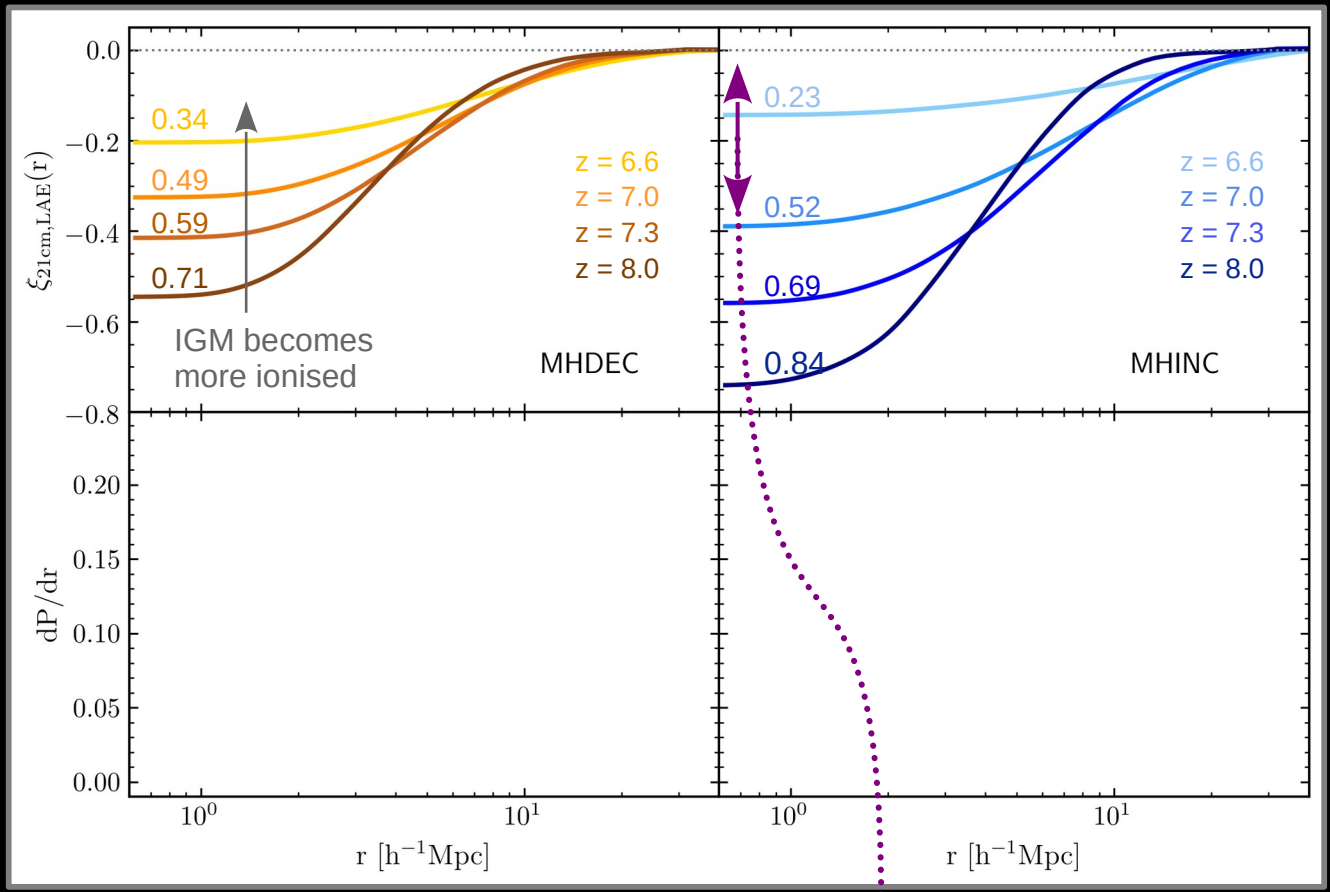




Hutter, Heneka+ 2023

21cm – LAE cross correlations are sensitive to ionisation topology!

21cm-LAE cross correlation function



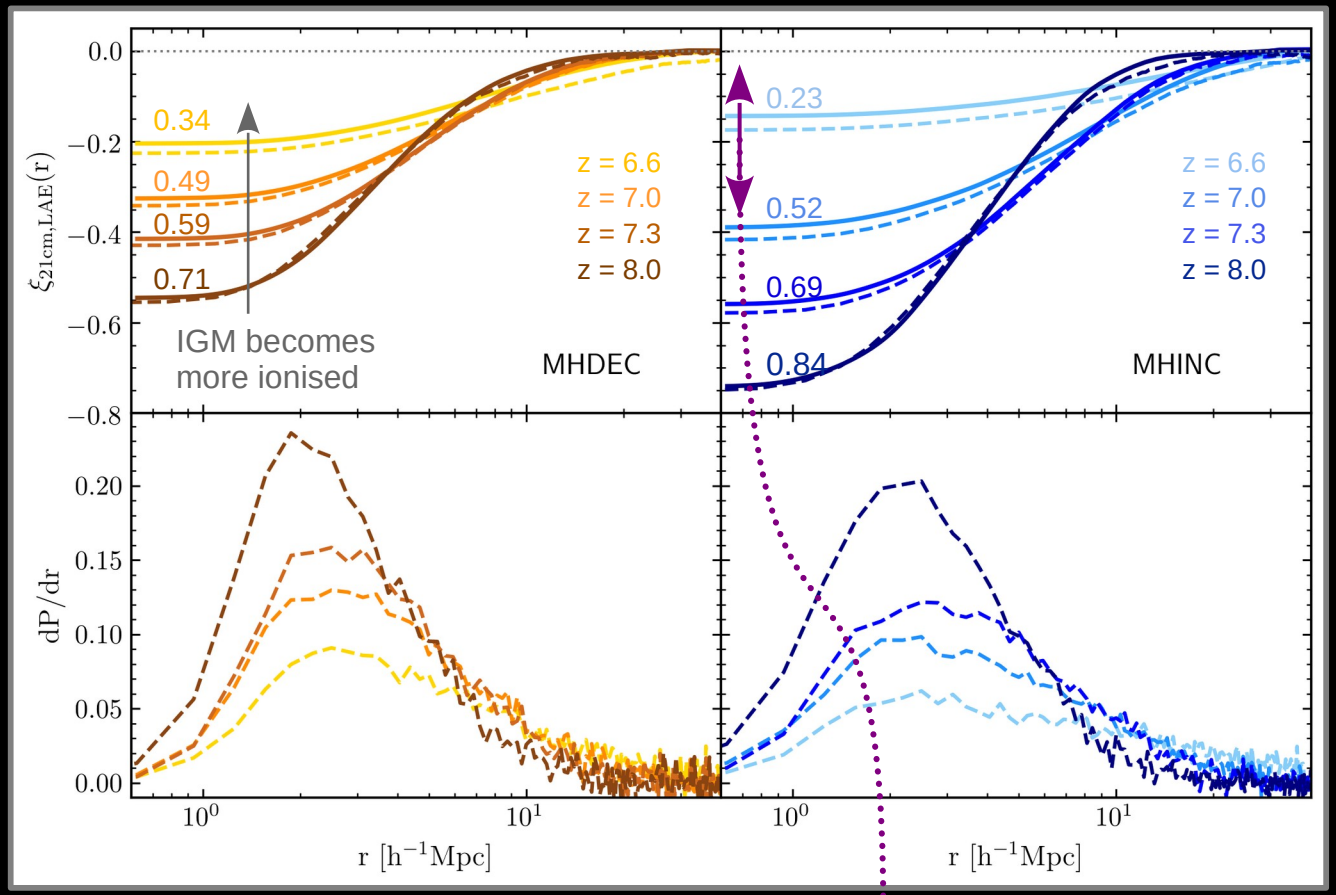
Hutter, Heneka+ 2023b

Analytical limit: $\xi_{21,LAE}(r \approx 0) \approx -\langle \chi_{HI} \rangle \langle 1+\delta \rangle_{HI}$

21cm – LAE cross correlations are sensitive to ionisation topology!

21cm-LAE cross correlation function

size distribution of ionised regions around LAEs



Hutter, Heneka+ 2023b

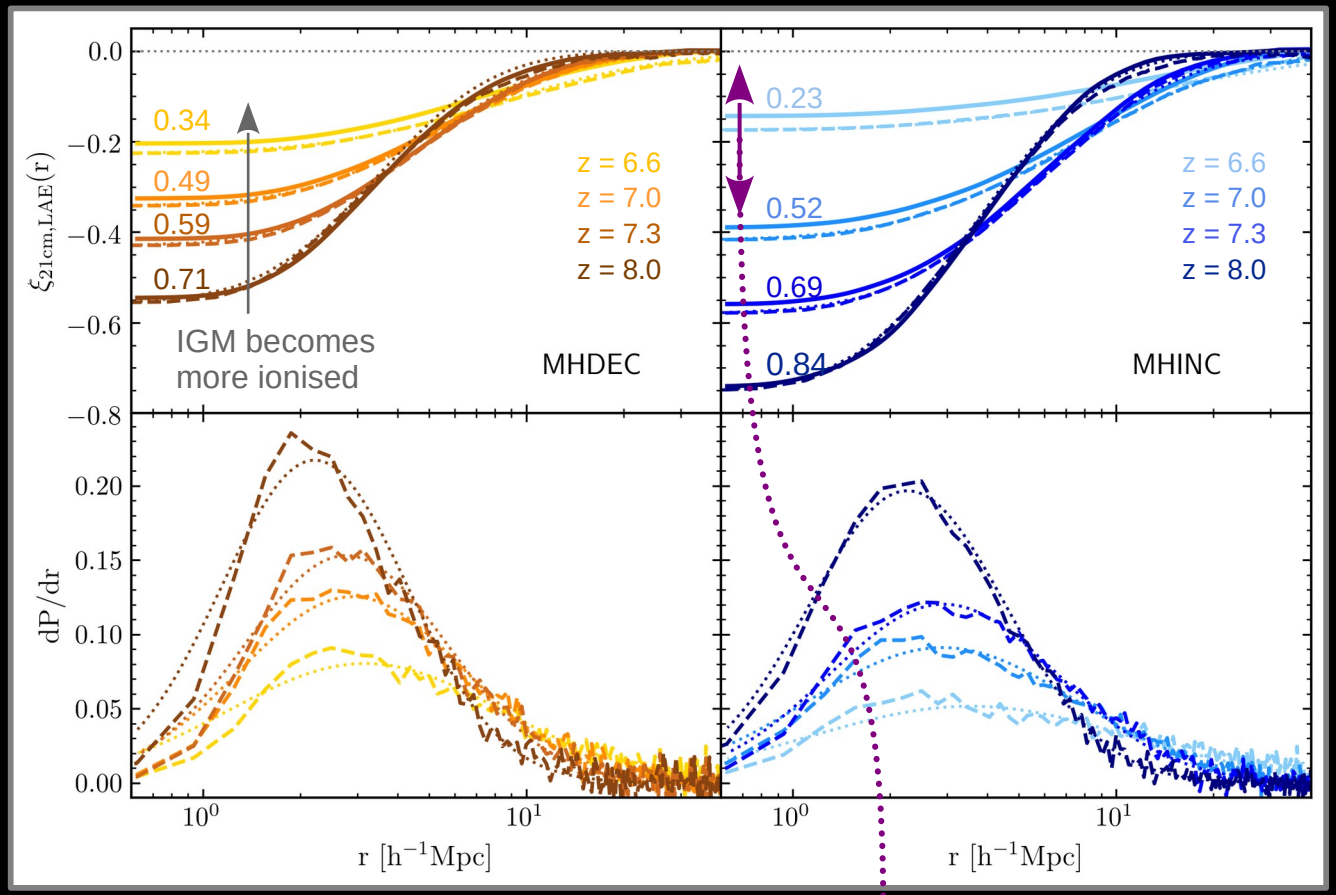
Cumulative distribution function of size of ionised regions around LAEs

Analytical fitting function: $\xi_{21,LAE}(r) \approx -\langle \chi_{HI} \rangle \langle 1+\delta \rangle_{HI} \left[1 - \langle \chi_{HI} \rangle CDF(r) \right]$

21cm – LAE cross correlations are sensitive to ionisation topology!

21cm-LAE cross correlation function

size distribution of ionised regions around LAEs



Hutter, Heneka+ 2023b

Cumulative distribution function of size of ionised regions around LAEs

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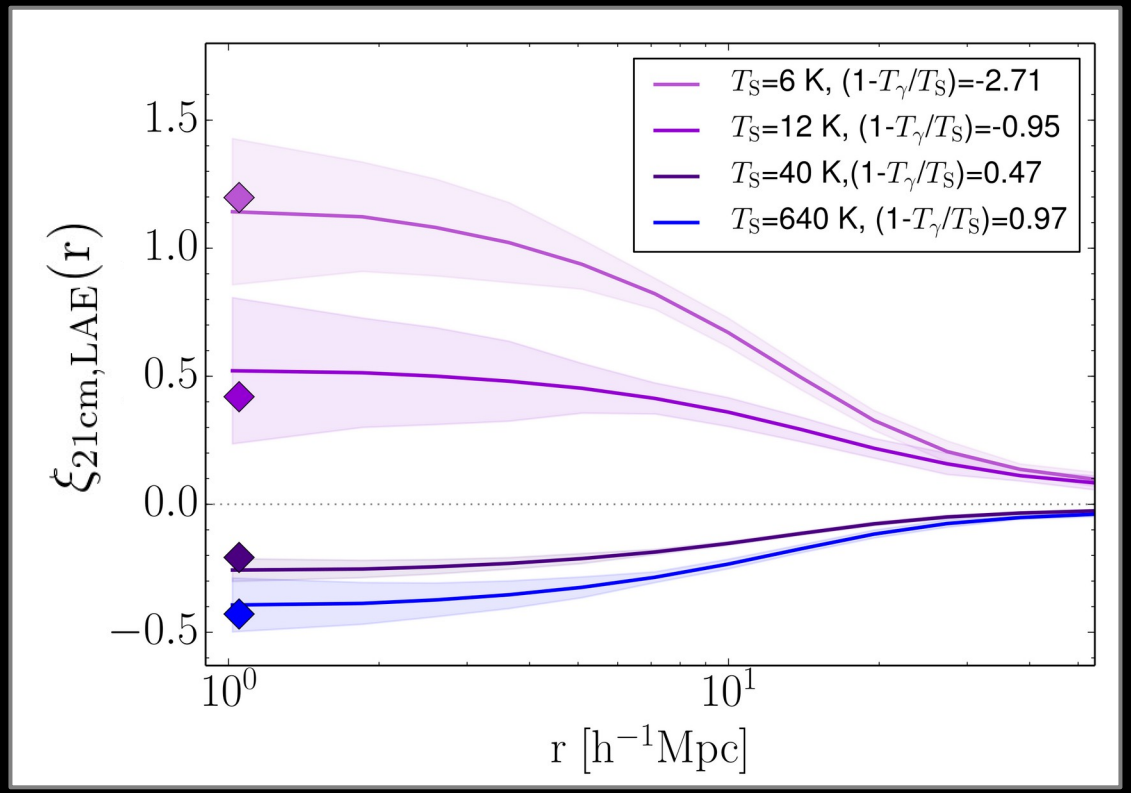
Analytical 21cm – LAE cross correlation small-scale amplitude also valid when spin temperature fluctuations dominate!



EOS simulations with 21cmFAST

$(1.6\ \mathrm{Gpc})^3$ with 1024^3 cells

Mesinger+ 2016

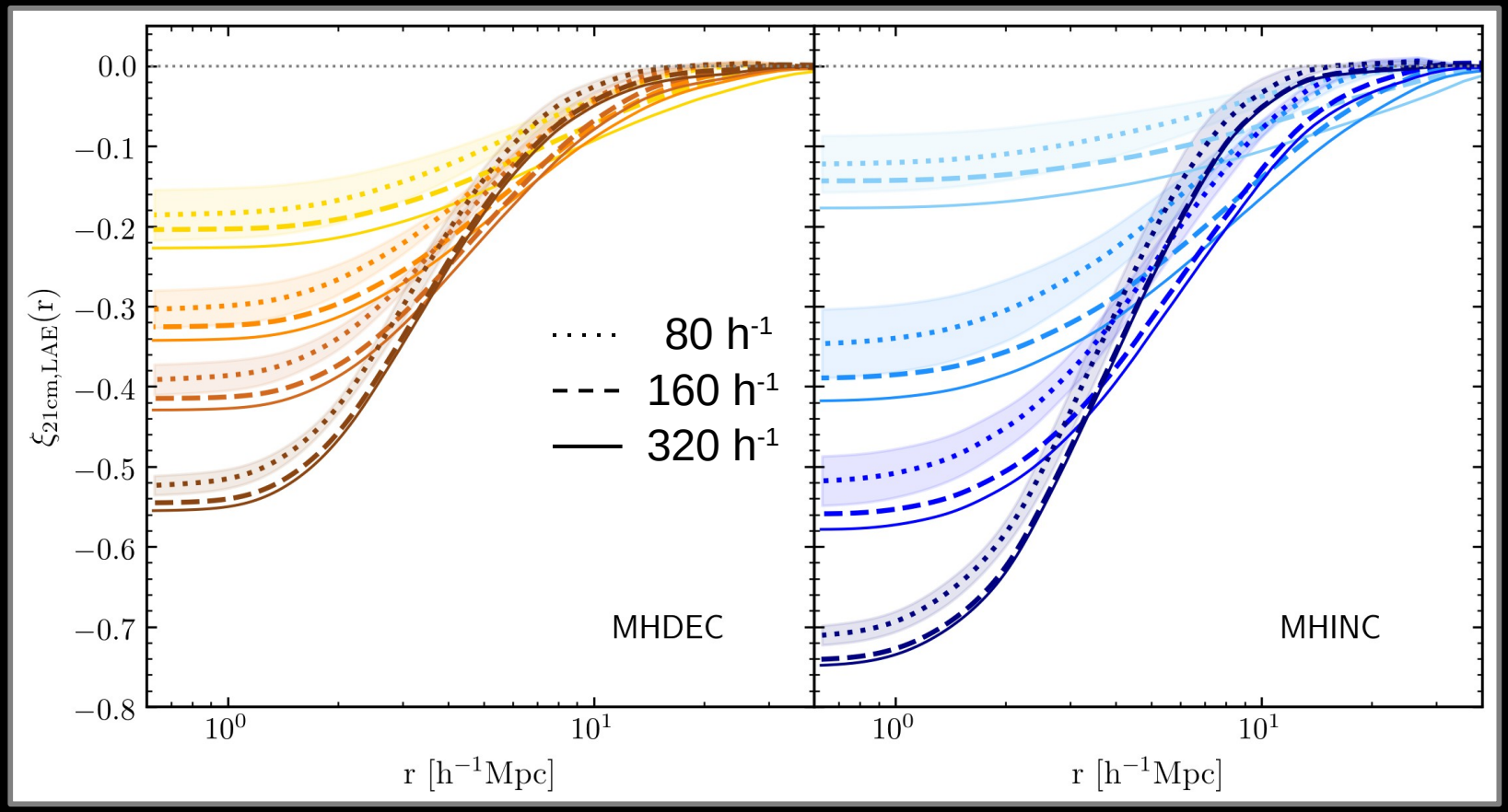
LargeHII scenario:

only halos with $T_{vir} > 2 \times 10^5$ K are sources

Analytical limit: $\xi_{21,LAE}(r \approx 0) \approx -\langle \chi_{HI} \rangle \left\langle \left(1 - \frac{T_{CMB}}{T_s}\right)(1+\delta) \right\rangle_{HI}$

Hutter, Heneka+ 2023

Too small boxes underestimate 21cm – LAE cross correlation amplitudes due to missing large-scale power



Simulation volumes of larger than ~(250 cMpc)^3 needed.

Conclusions

LAEs ($L_\alpha > 10^{42}$ erg/s) are the most massive galaxies.

- They are located in the most ionised overdense regions.
- Spatial distribution is mostly sensitive to the the global ionisation state of the IGM.

Hutter+ 2023a, arXiv:2209.14592

21cm-LAE cross correlation function amplitude is sensitive to:

- ionisation history
- ionisation topology
- IGM heating

$$\xi_{21,LAE}(r) \approx -\langle \chi_{HI} \rangle \langle 1+\delta \rangle_{HI} \left[1 - \langle \chi_{HI} \rangle CDF(r) \right]$$

$$\xi_{21,LAE}(r \approx 0) \approx -\langle \chi_{HI} \rangle \left\langle \left(1 - \frac{T_{CMB}}{T_s} \right) (1+\delta) \right\rangle_{HI}$$

Hutter, Heneka+ 2023, arXiv:2306.03156