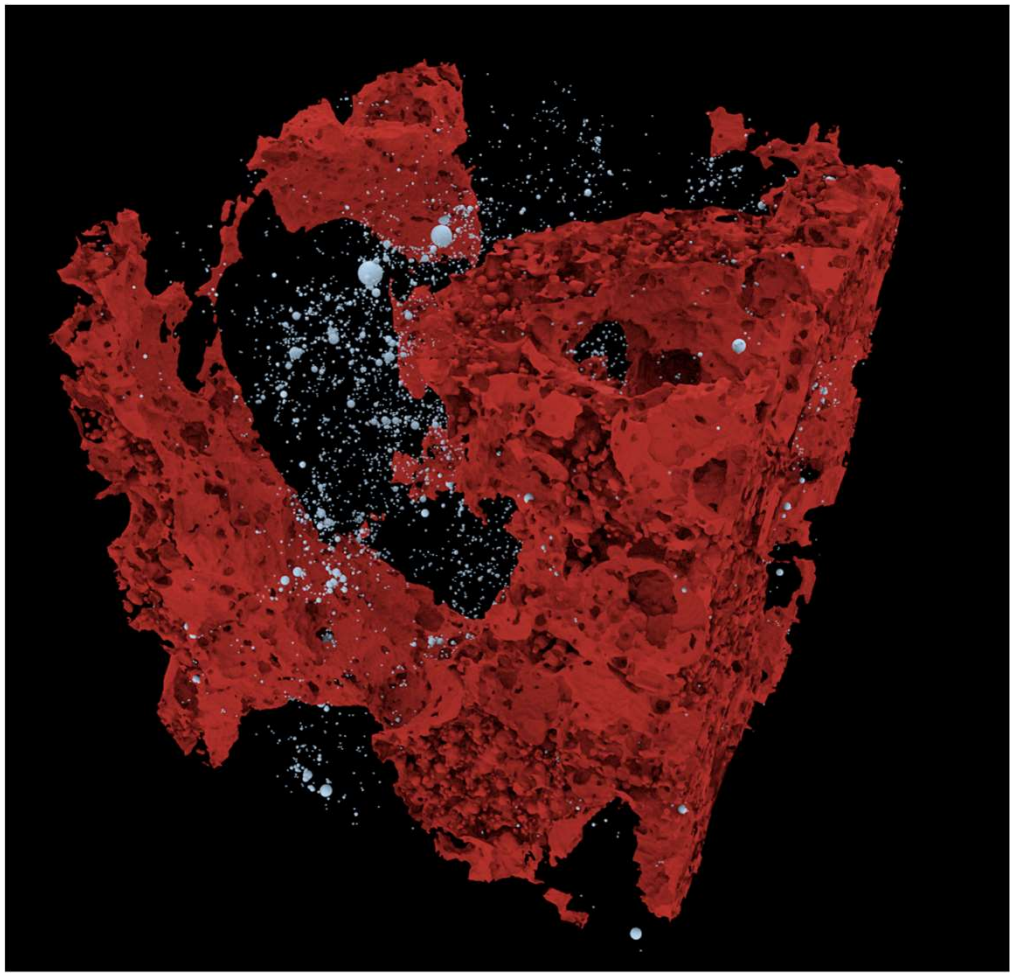
Galaxy Formation and Reionisation

ASTRO 3D



Stuart Wyithe

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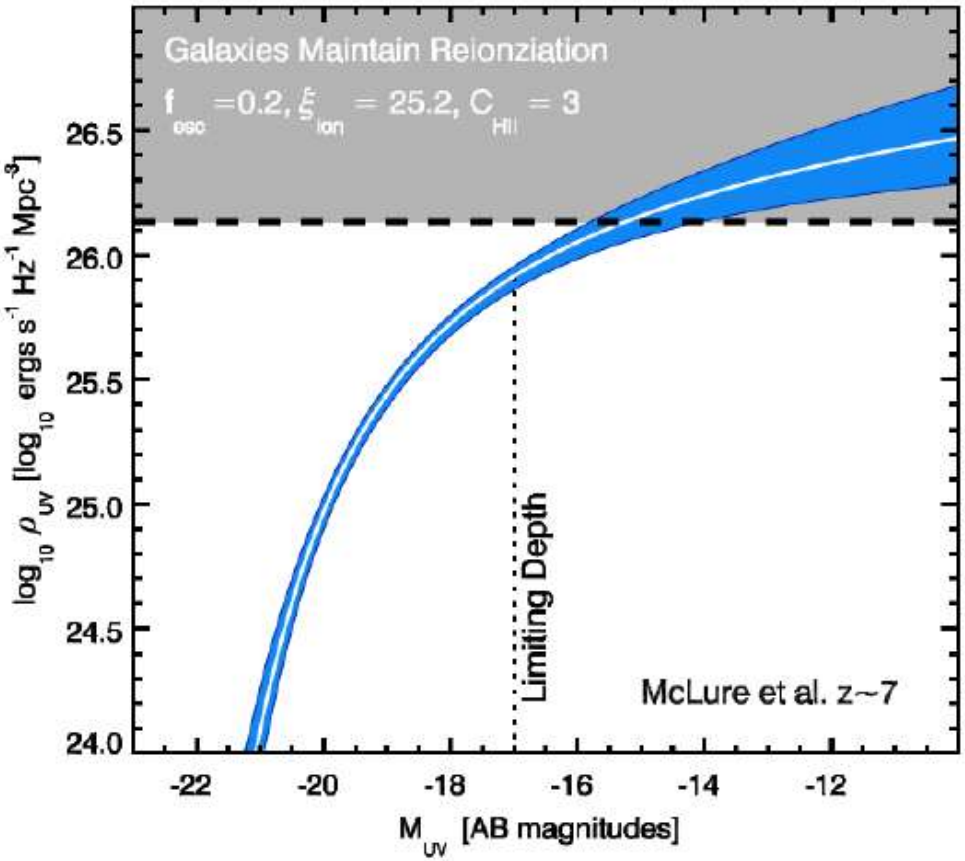
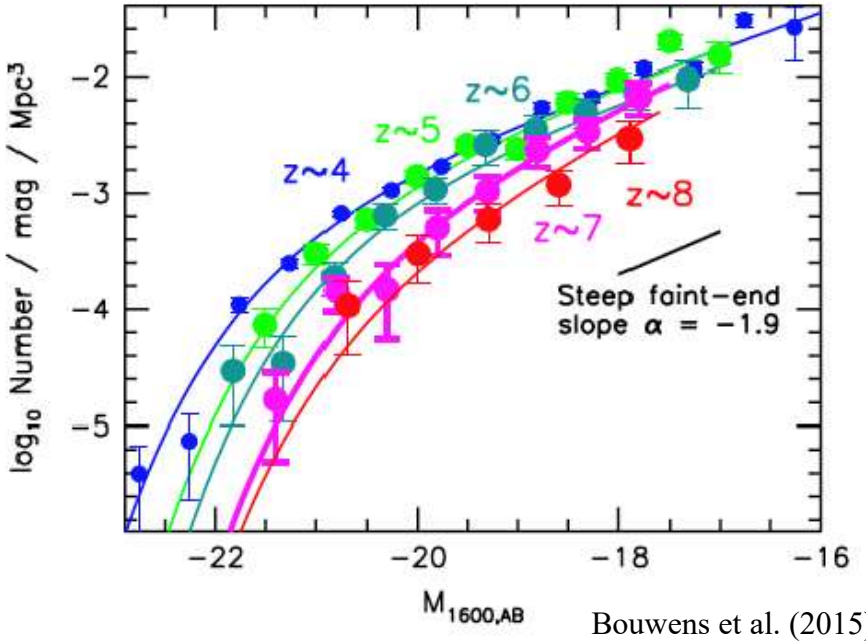
RESEARCH in the national interest – enabling the future

THE UNIVERSITY OF MELBOURNE SCHOOL OF PHYSICS

Reionization by galaxies



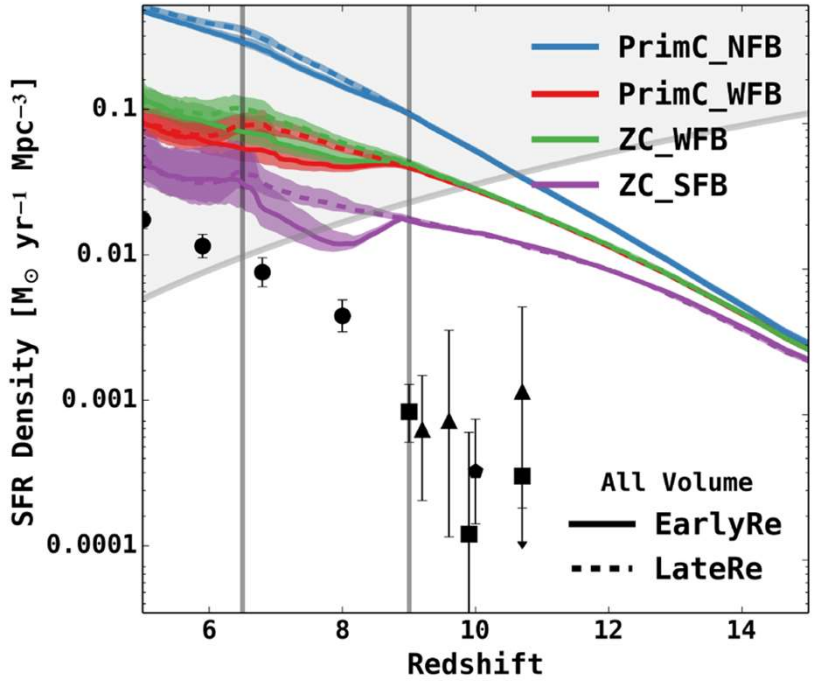
Robertson et al. (2015)



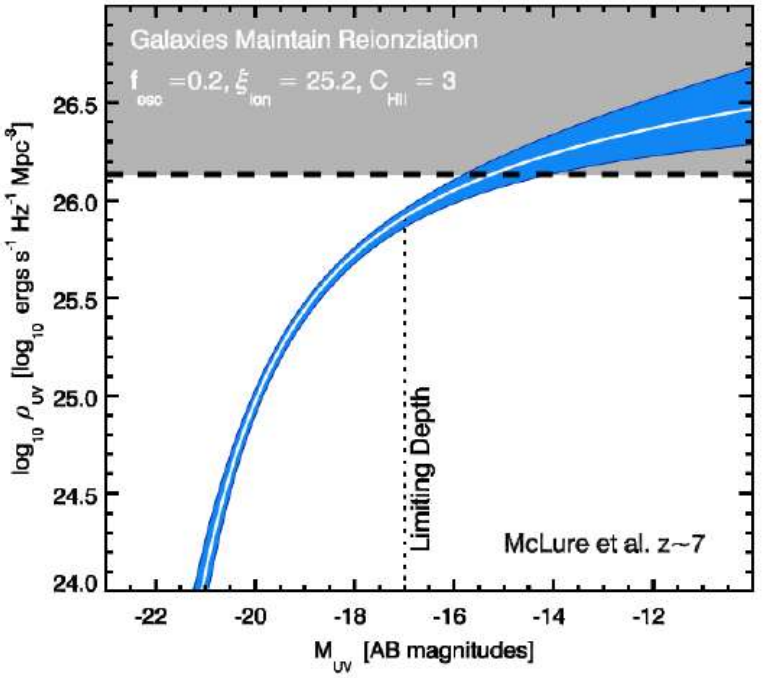
Bouwens et al. (2015)

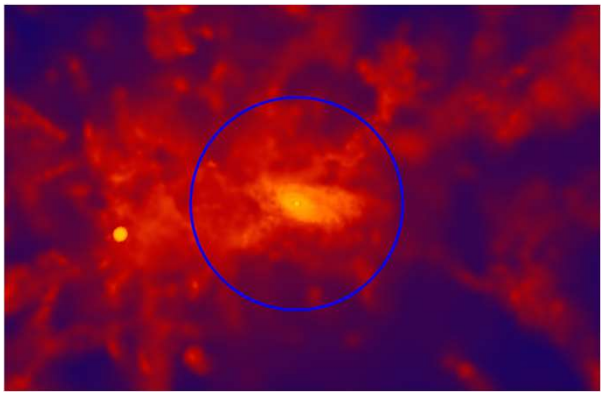
- Empirical extrapolations of the luminosity function imply that faint galaxies can reionize hydrogen
- Conclusions are sensitive to the unknown escape fraction

Enough stars to reionise the Universe?



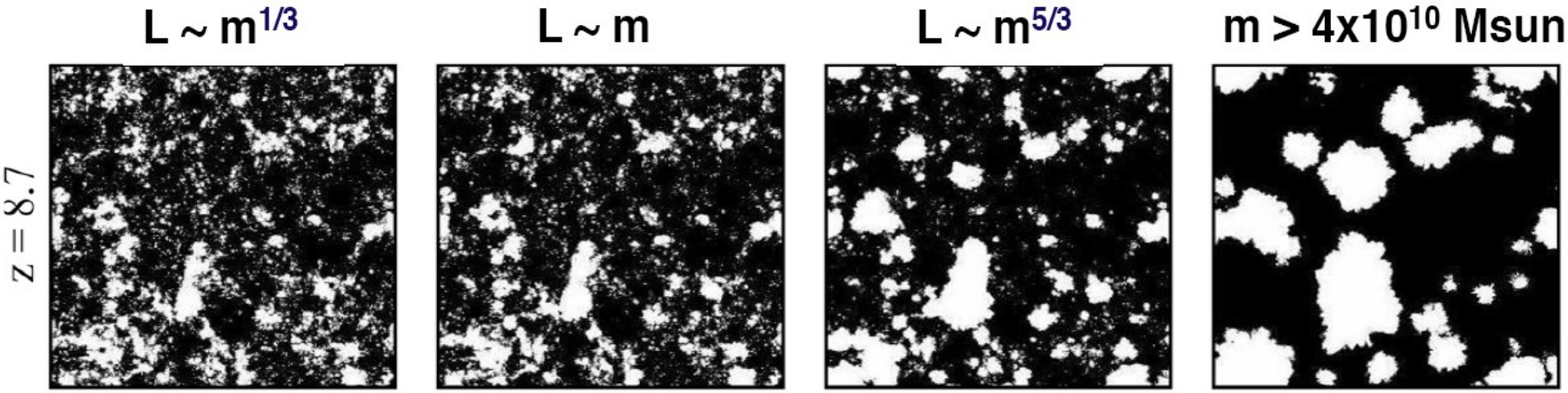
Duffy et al. (2014)





- Hydrodynamical simulations suggest most star-formation is in galaxies below the detection threshold of current surveys

Structure of IGM sensitive to galaxy formation

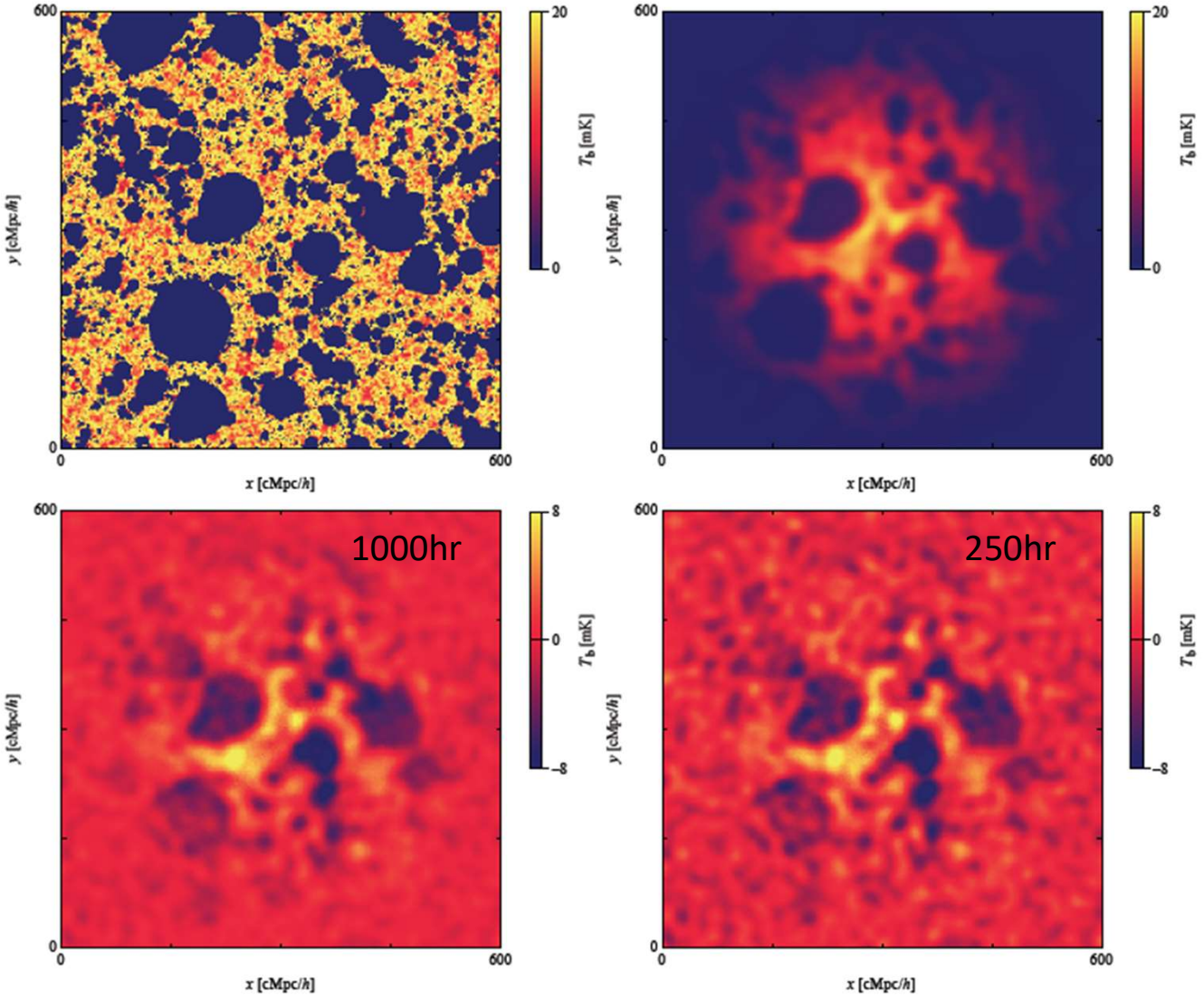


McQuinn et al. (2007)

- Properties of galaxies impact on the spatial fluctuations in ionization
- Infer galaxy properties of galaxy formation from 21cm fluctuations

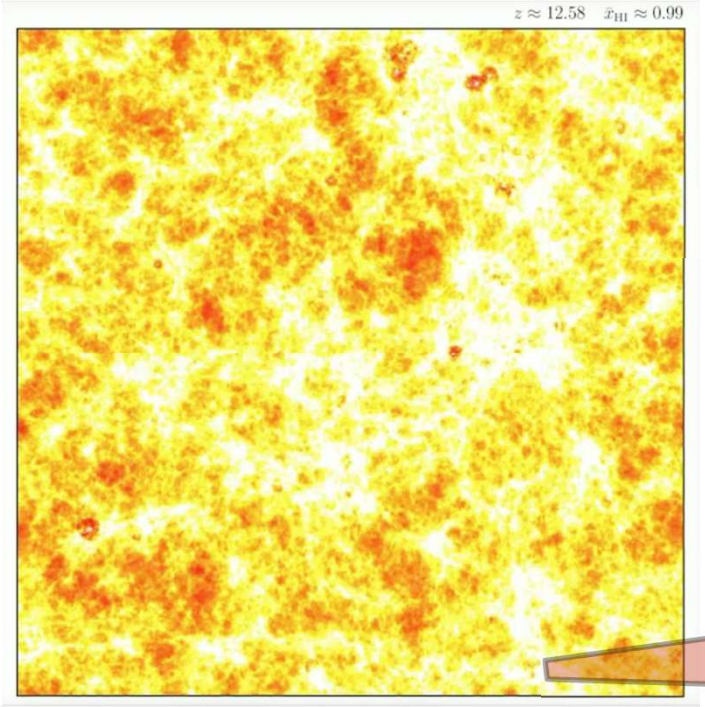
Redshifted 21cm imaging with SKA

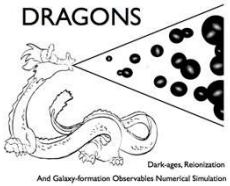
ASTRO 3D

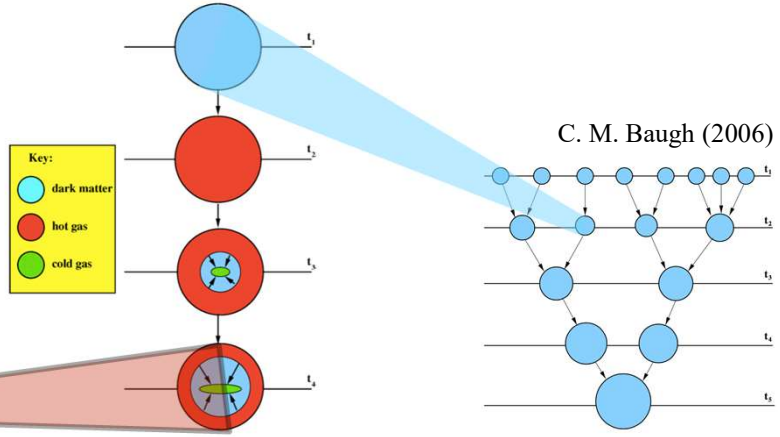


Joint SAM for galaxies and reionization

ASTRO 3D





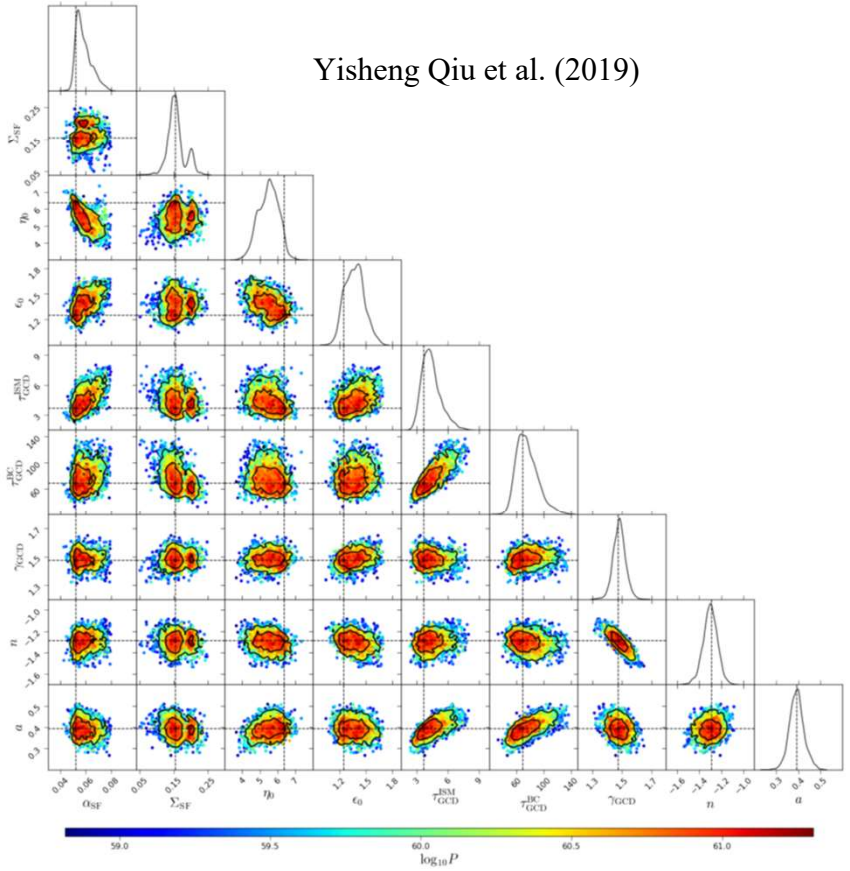


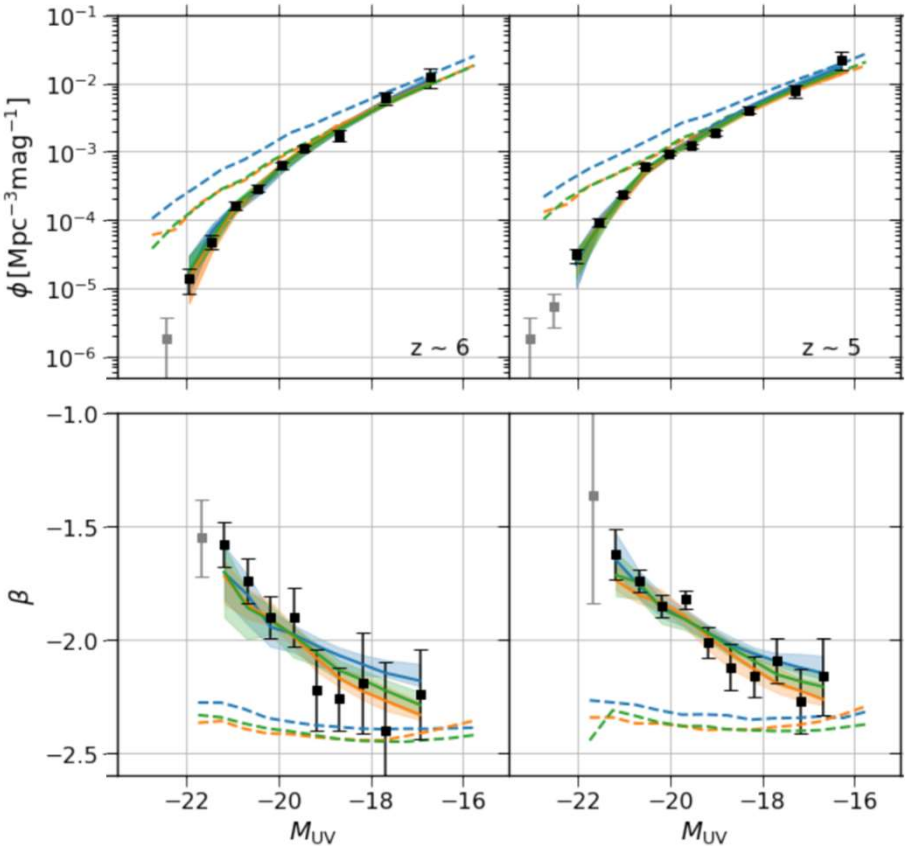
- Based on the “Munich model”, as described in Guo et al. (2011). Additions for high-z
  - Coupled, spatially dependent reionisation, and feedback with 21cmFAST;
  - Implemented within “horizontal” dark matter trees with high time resolution;
  - No instantaneous mass recycling, with time resolved SNe feedback;

Mutch et al. (2015)

Constraints against the Luminosity function

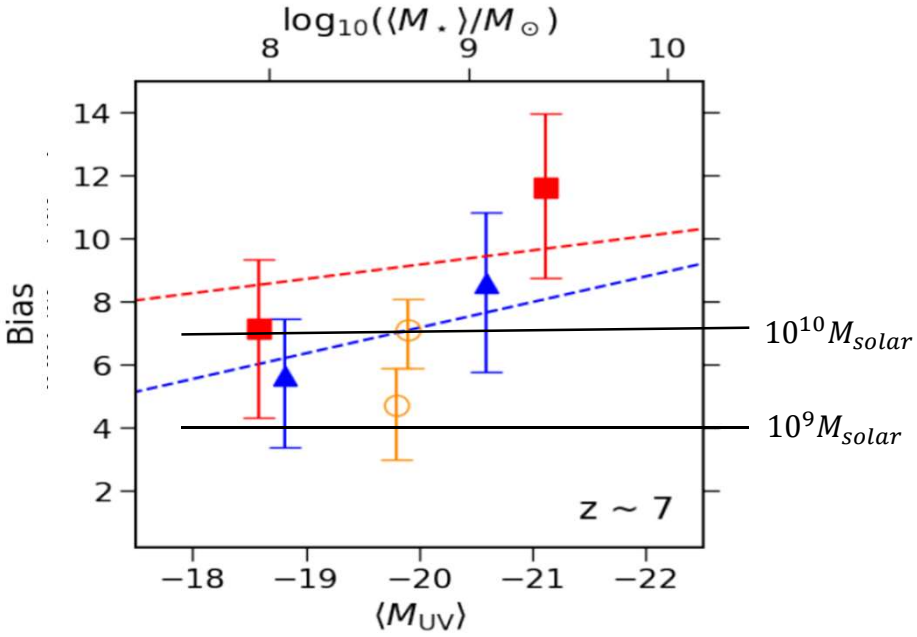
Yisheng Qiu et al. (2019)

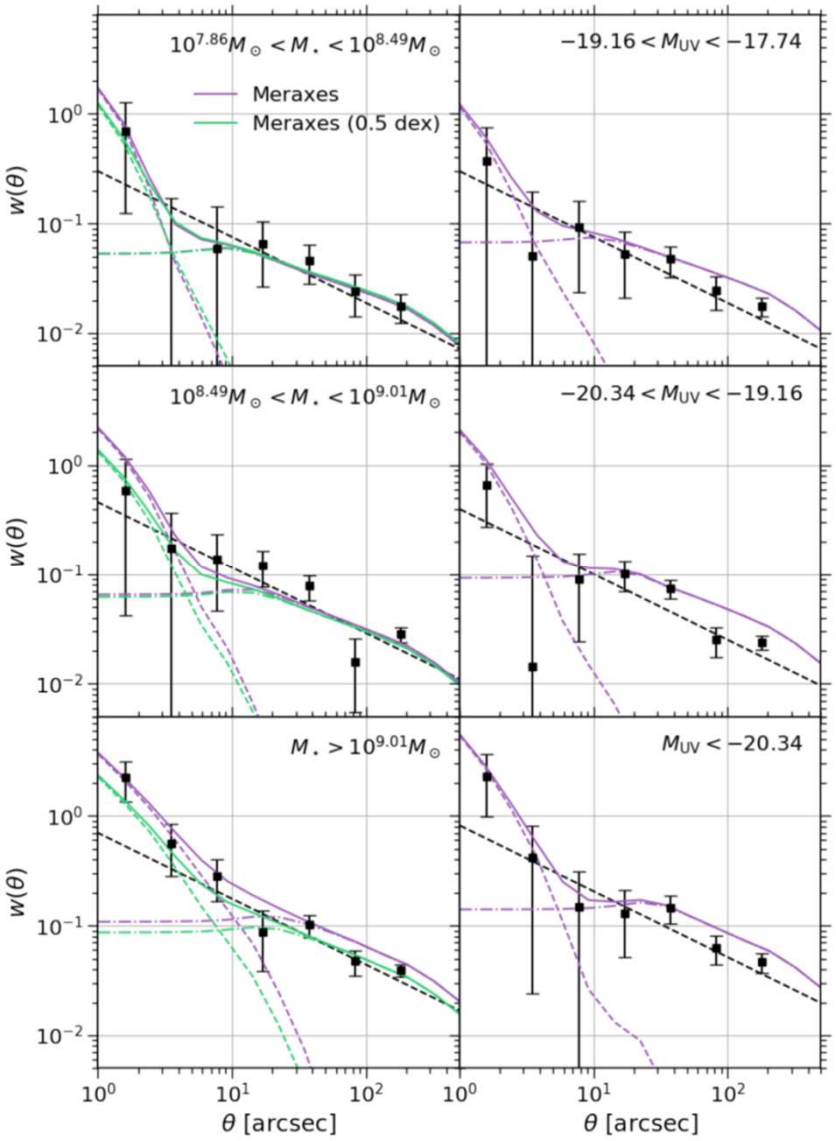




- Charlot & Fall dust model, with dust optical depths, linked to star formation rate, dust-to-gas ratio and gas column density respectively
- Reproducing the LF requires strong SNe feedback

Clustering at high redshift



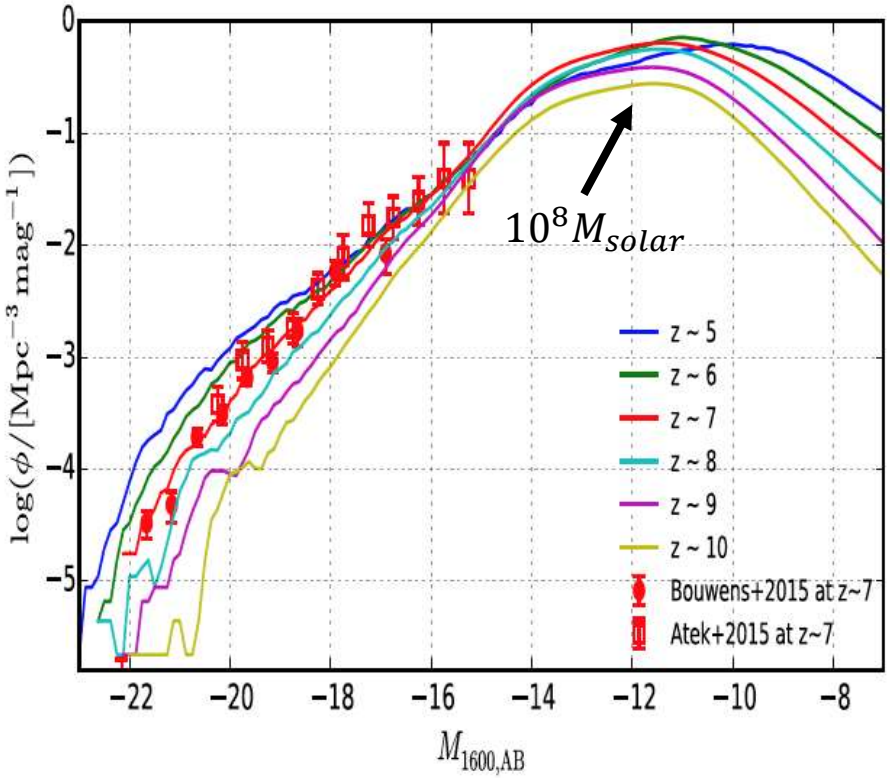


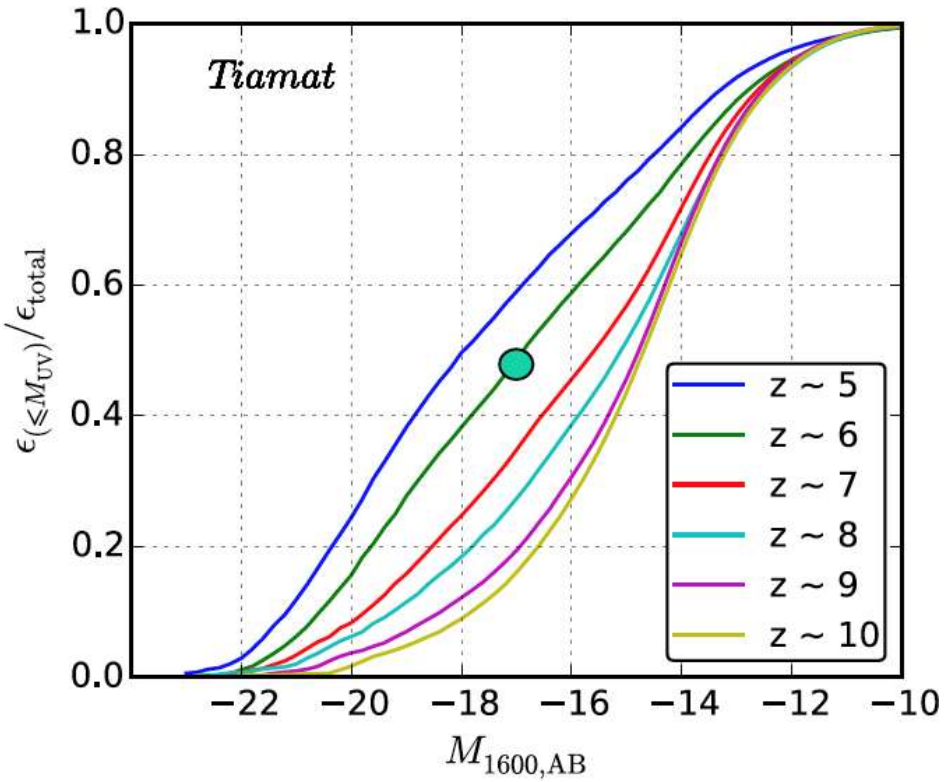
- Clustering consistent with masses of ~10^{10} solar masses
- Dependance of bias on flux limit consistent with observations

Enough stars to reionise the Universe?

ASTRO 3D

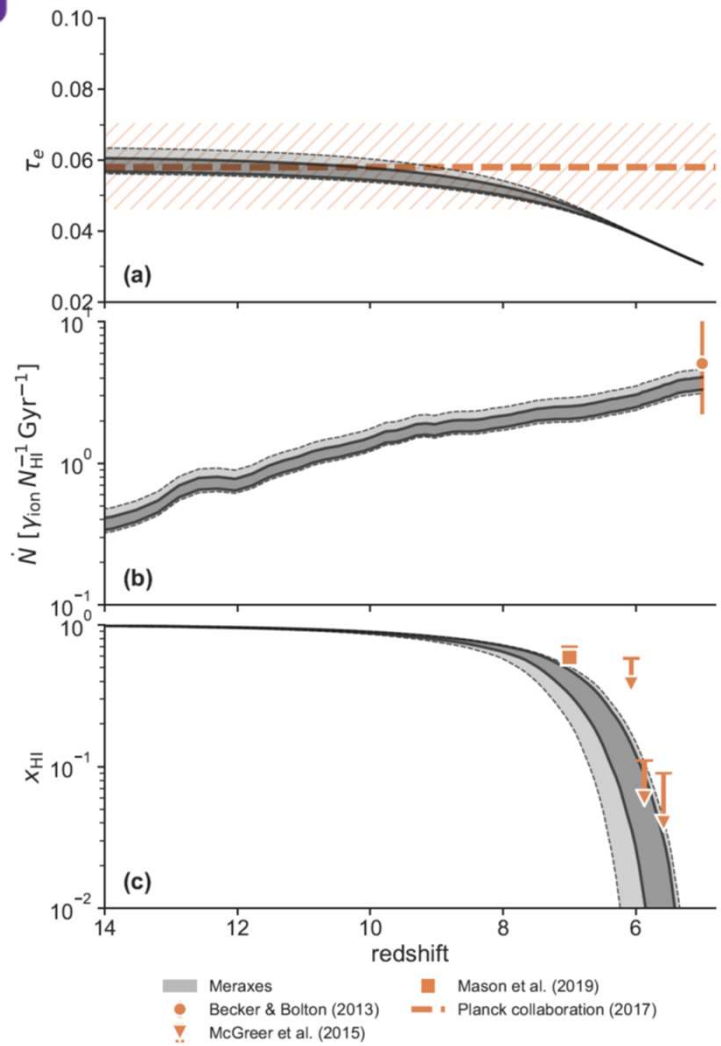
Liu et al. (2017)

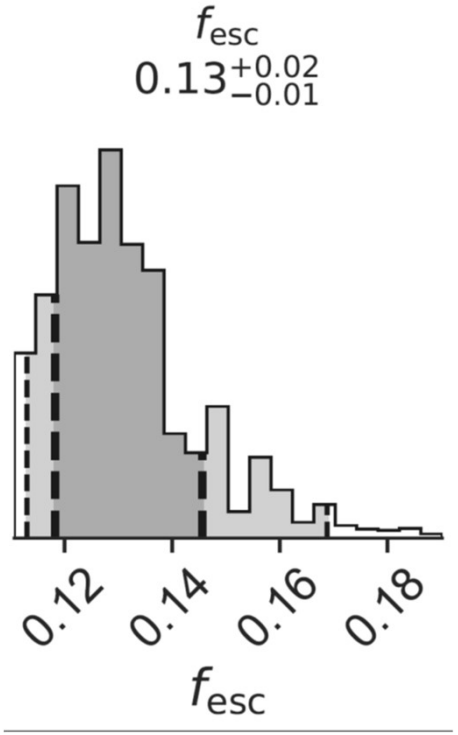




- The model luminosity function turns over at low luminosities, due to the minimum cooling mass for galaxy formation.
- Approximately half of the star-formation rate density has been observed at z~6

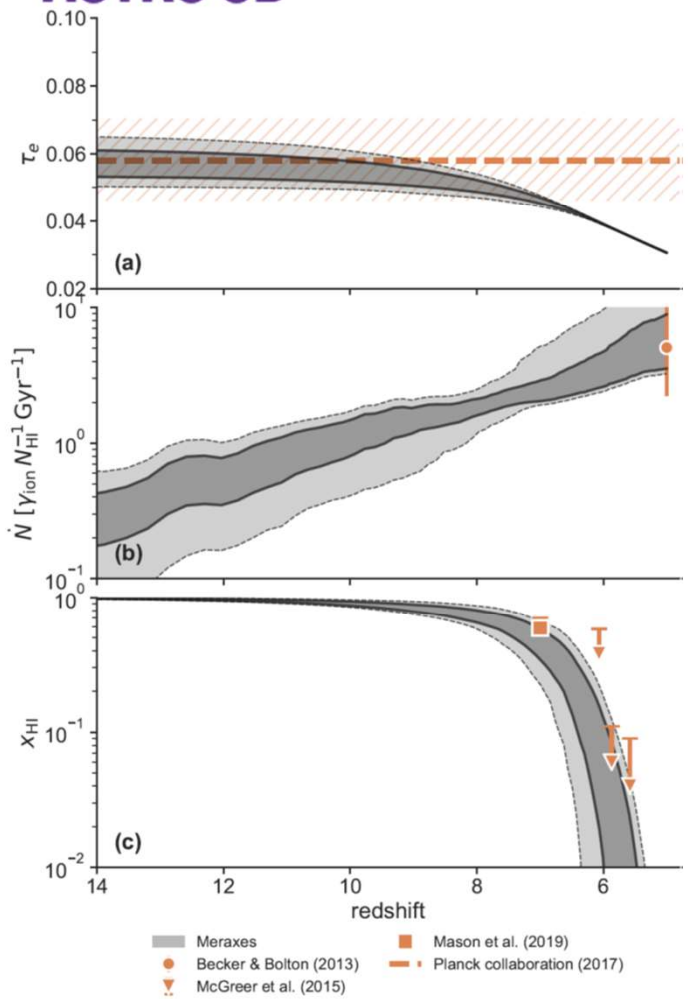
Constraints on escape fraction



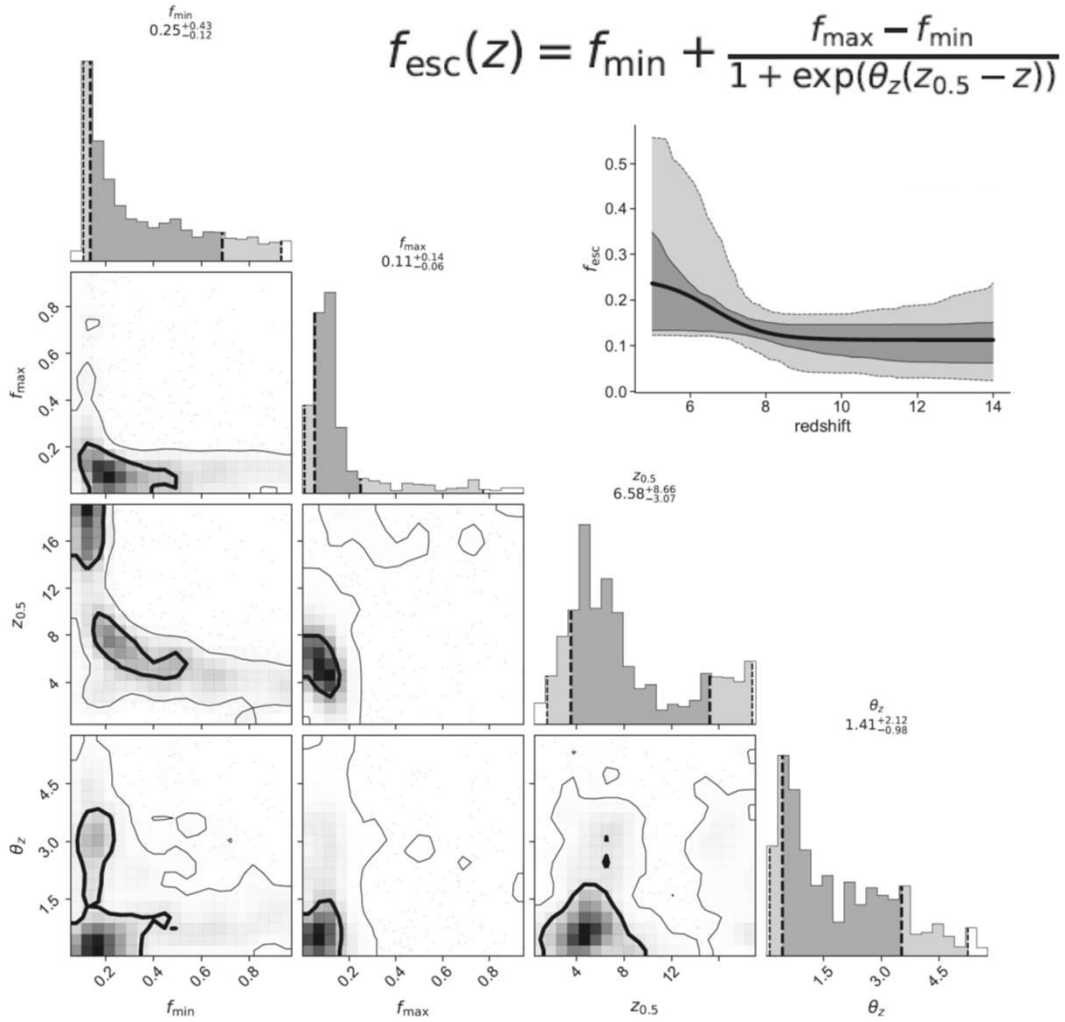


- Simultaneously predicting the LF, neutral fraction and CMB optical depth suggests an escape fraction of ~13% assuming constant value with redshift

Constraints on escape fraction

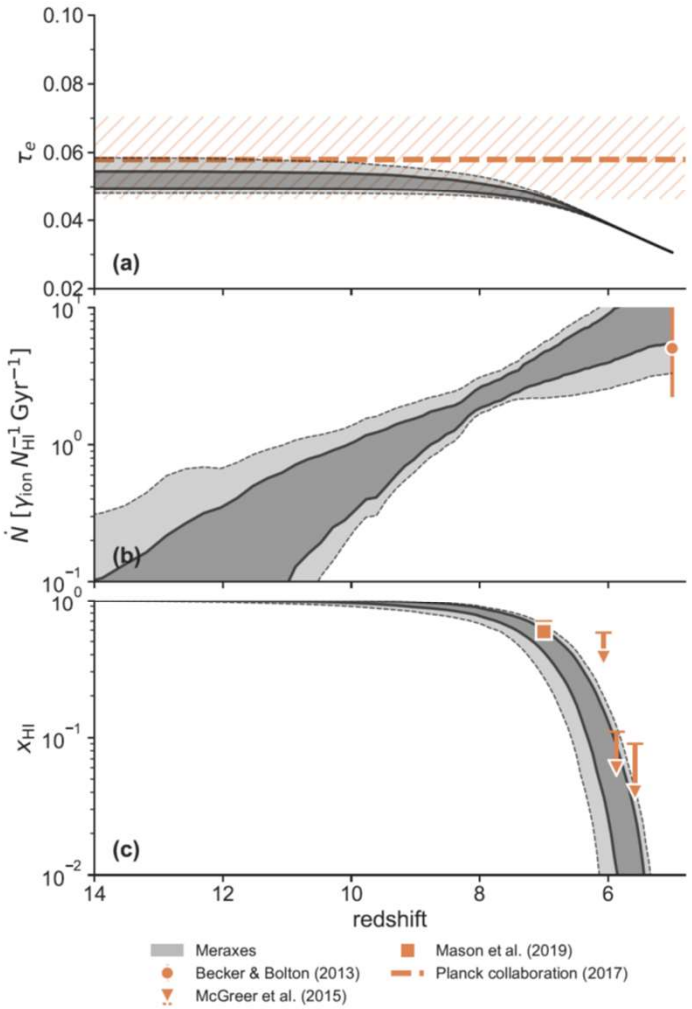


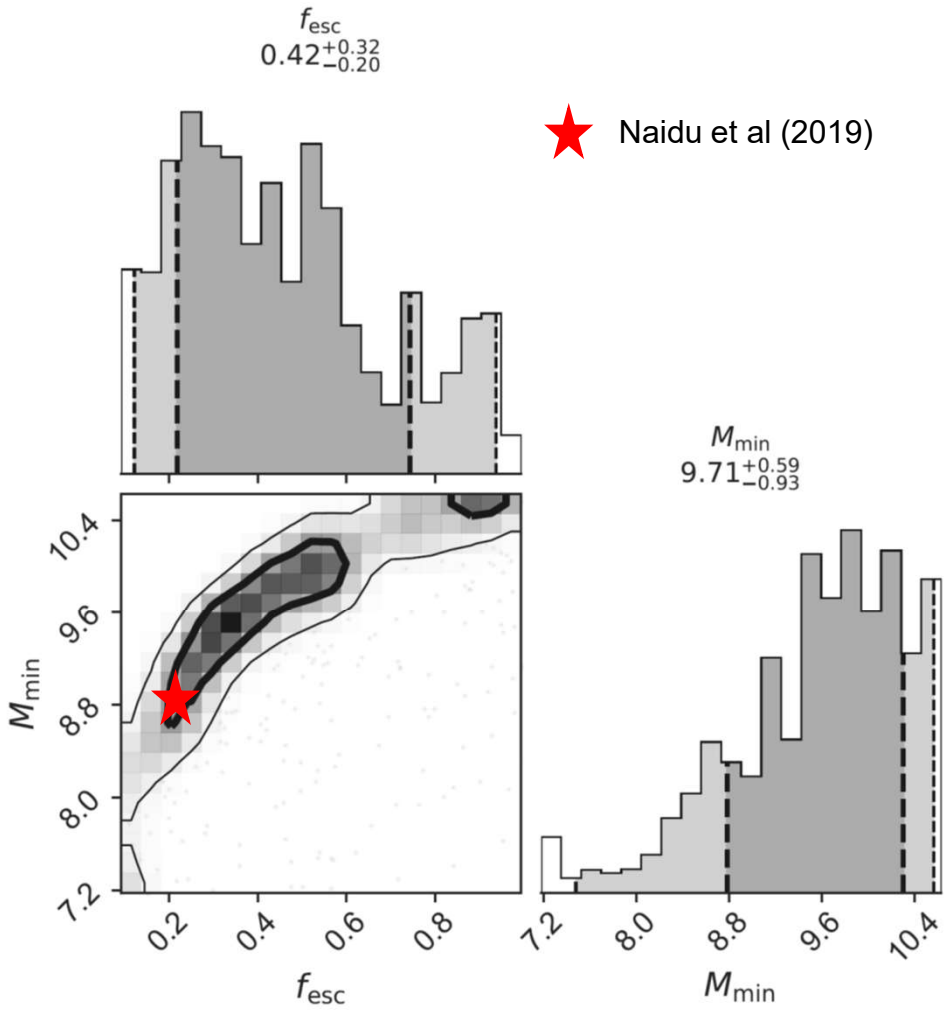
$$f_{\rm esc}(z) = f_{\rm min} + \frac{f_{\rm max} - f_{\rm min}}{1 + \exp(\theta_z(z_{0.5} - z))}$$



- Using a flexible function suggests an escape fraction of ~20% at z~6 decreasing towards high redshift

Constraints on escape fraction

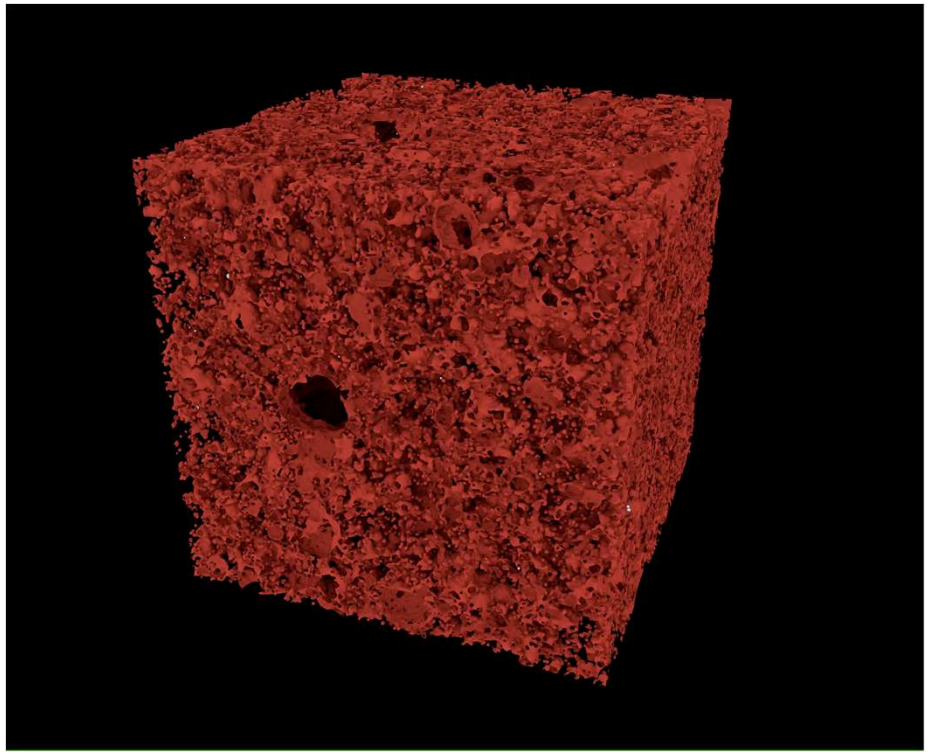




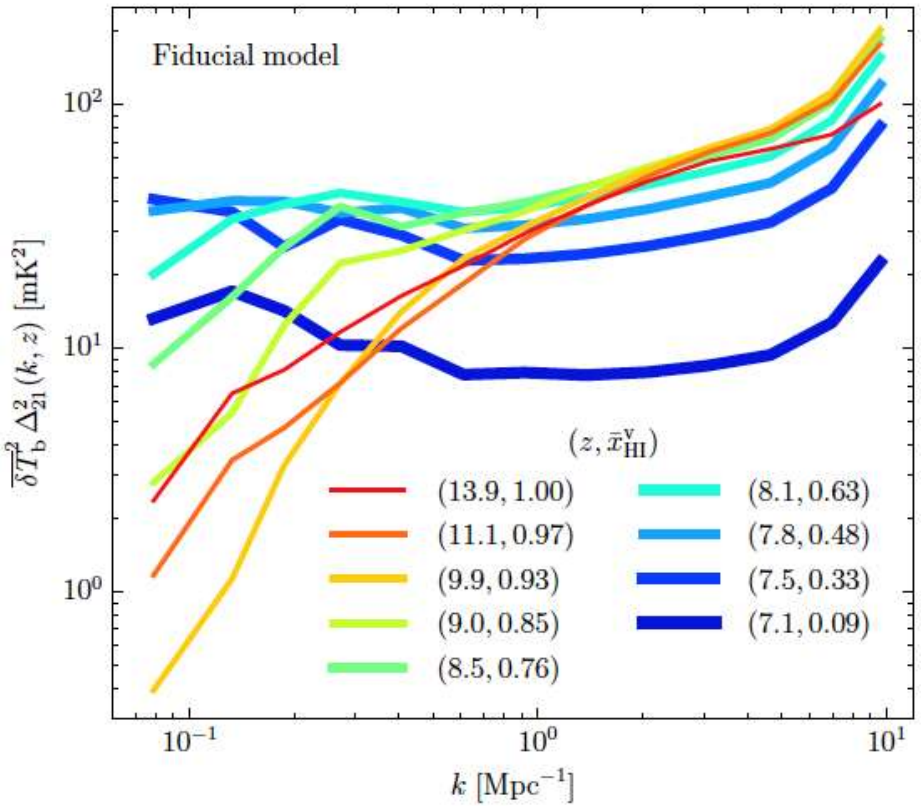
- Assuming a minimum mass cuttoff for escaping photons suggests an escape fraction of ~20-50% above M~$10^{9-10} M_{solar}$ (corresponding to M_{UV} ~ -14→-18)

21cm power-spectrum and galaxy formation

ASTRO 3D



Geil et al. (2015)

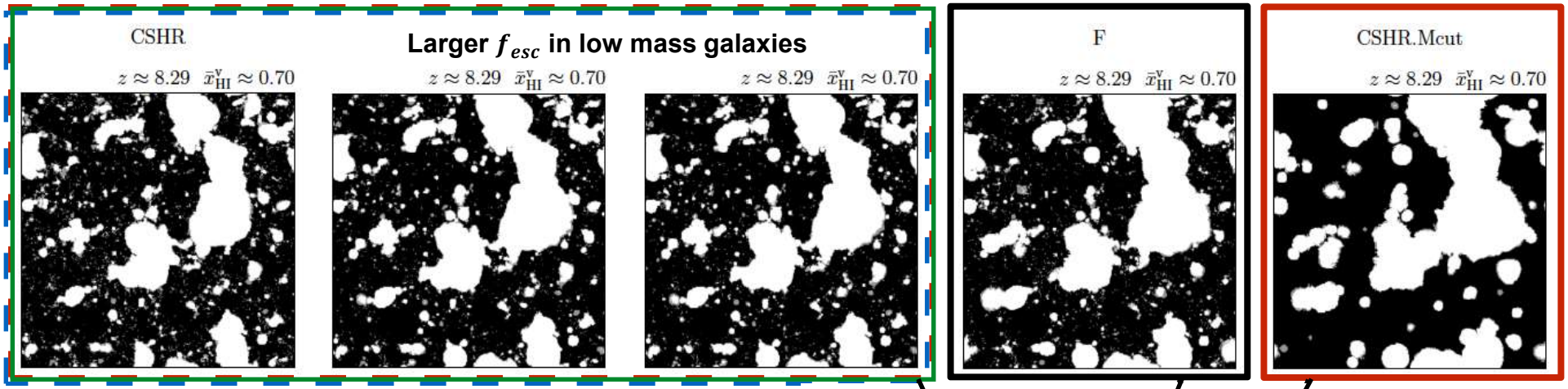


- Reionization leaves a distinct mark on the power-spectrum of 21cm fluctuations
- Galaxy evolution drives the shape of the 21cm power-spectrum
- Goal to provide a connection between galaxy formation and ionised structure

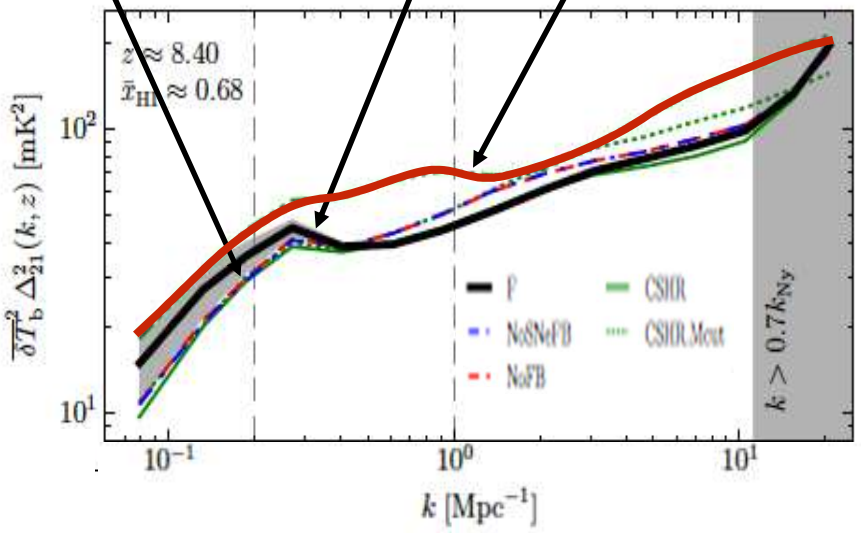
21cm power-spectrum and galaxy formation

ASTRO 3D

Increasing feedback and typical galaxy mass

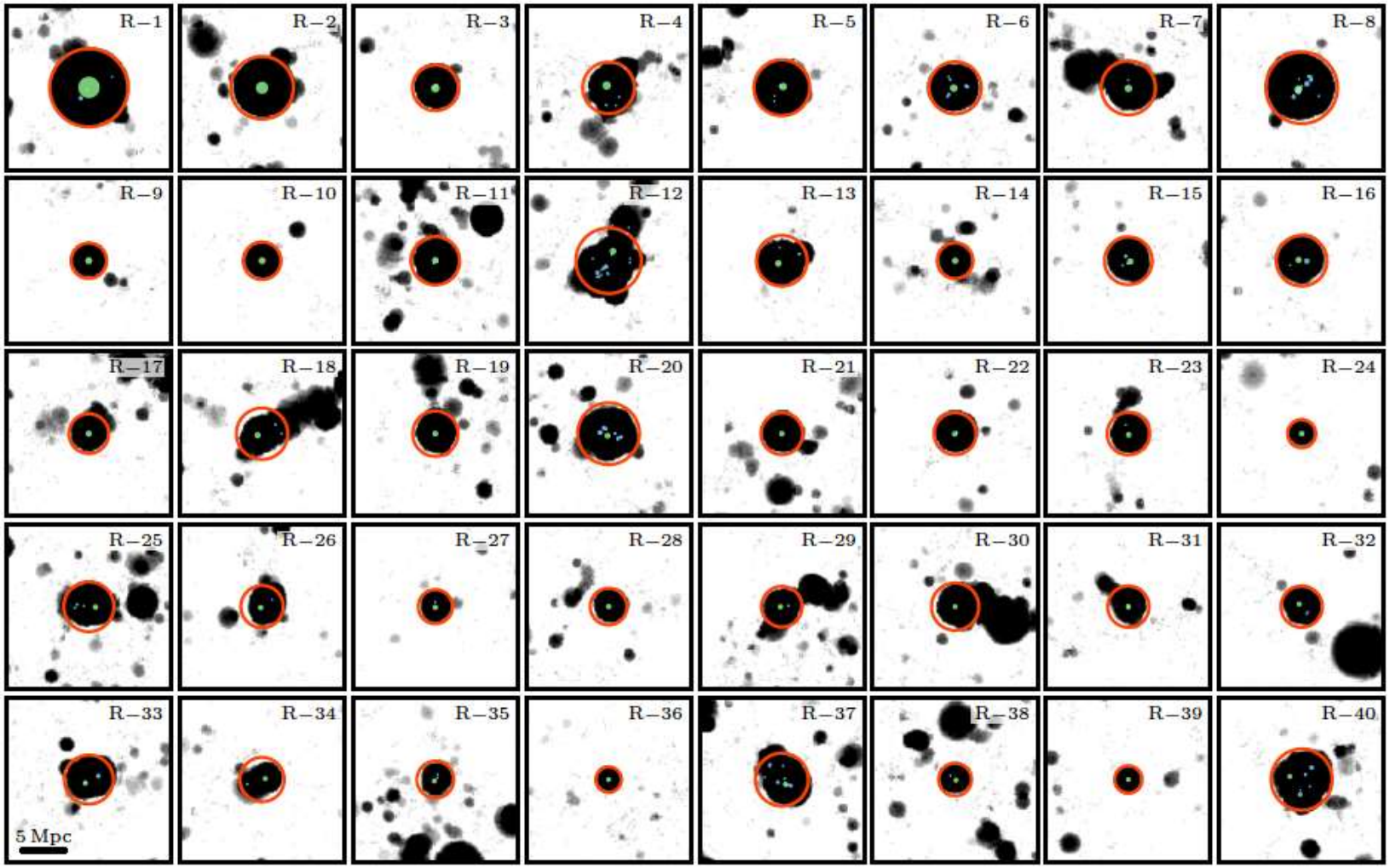


- More clustered galaxies in massive dark matter halos result in larger HII regions
- Power-spectrum is sensitive to the ionizing contribution from small galaxies



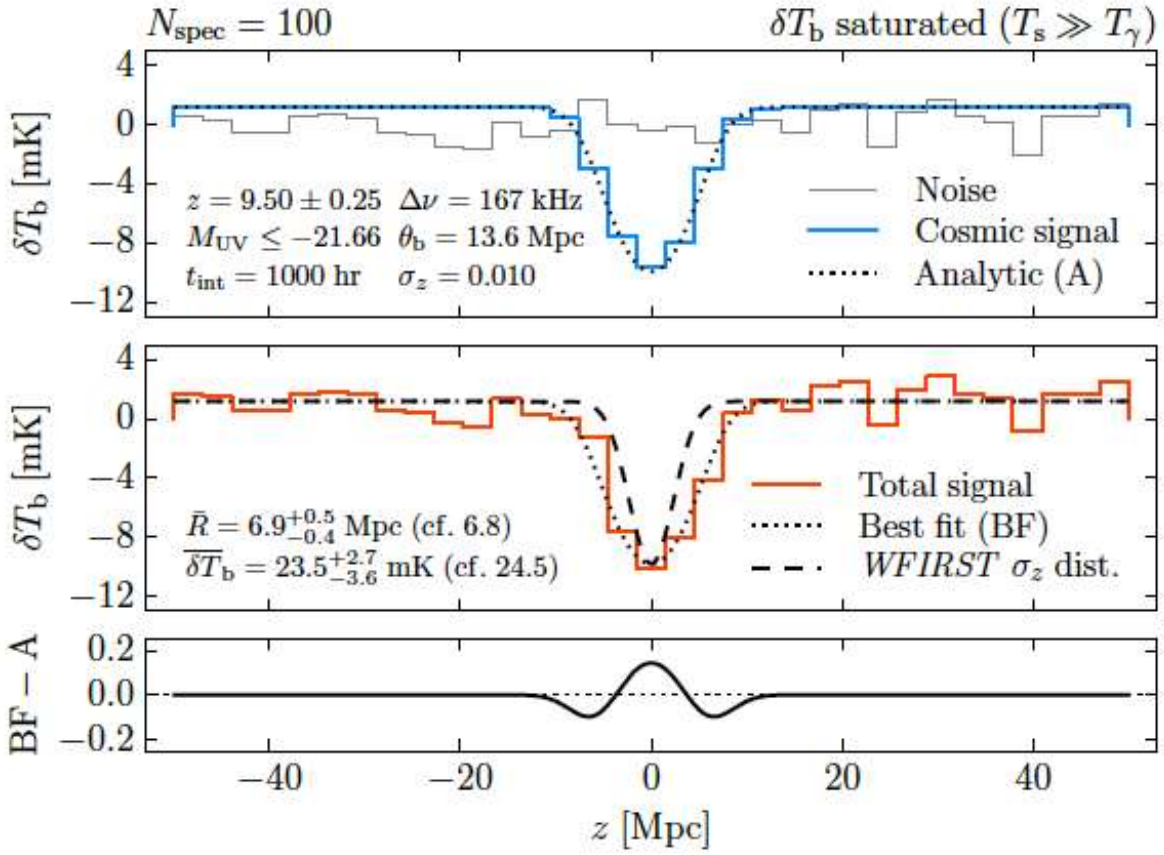
Geil et al. (2015)

HII regions around luminous galaxies



- Probe reionization through searches for large HII regions around massive galaxies

HII regions around luminous galaxies

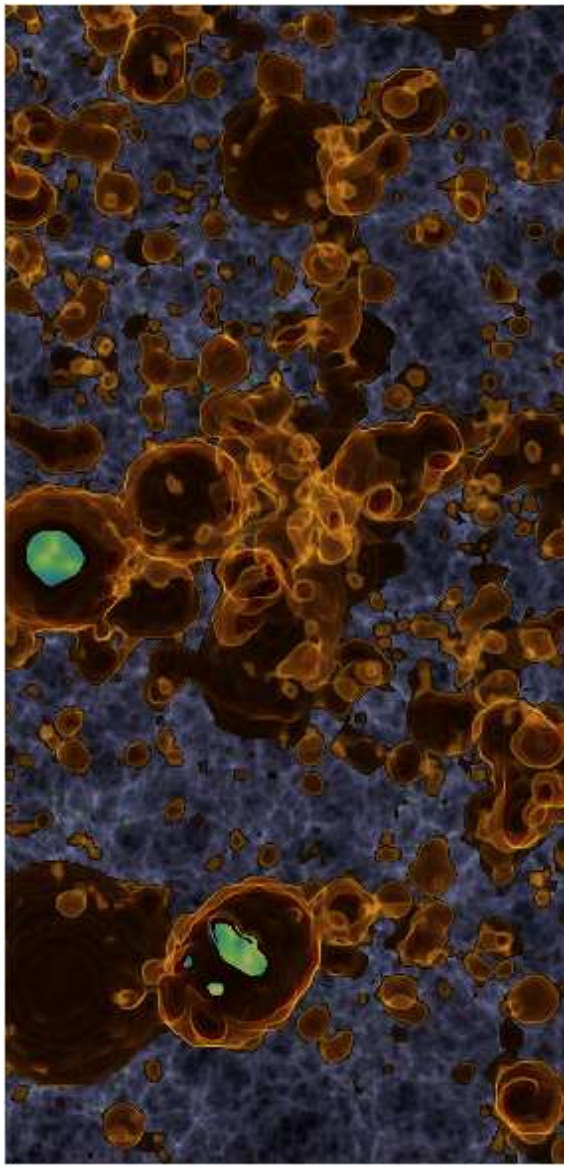


- Hundreds of luminous galaxies in an SKA field to be discovered by WFIRST
- HII regions will be detectable in stacked spectra along the line-of-sight to the most luminous galaxies

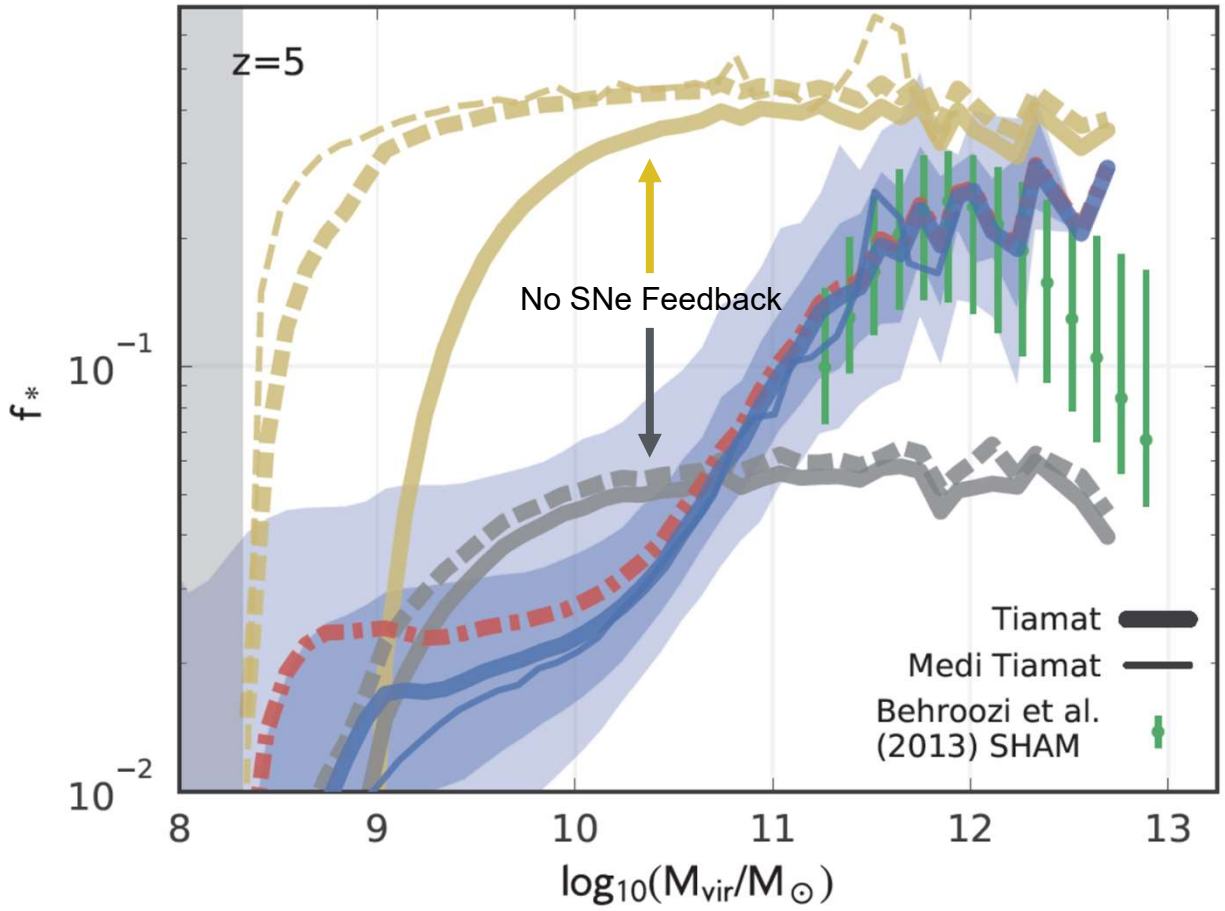
Summary

ASTRO 3D

- Low luminosity galaxies likely played a key role in the reionization of hydrogen.
- Simulations suggest only half of this starformation has been observed, but that the average escape fraction from high redshift galaxies may have been lower than at z~5-6.
- Simulations can also be used to link galaxy formation with ionisation structure to be measured with SKA, providing a probe of the contribution of the faintest high-z galaxies.



Star formation efficiency



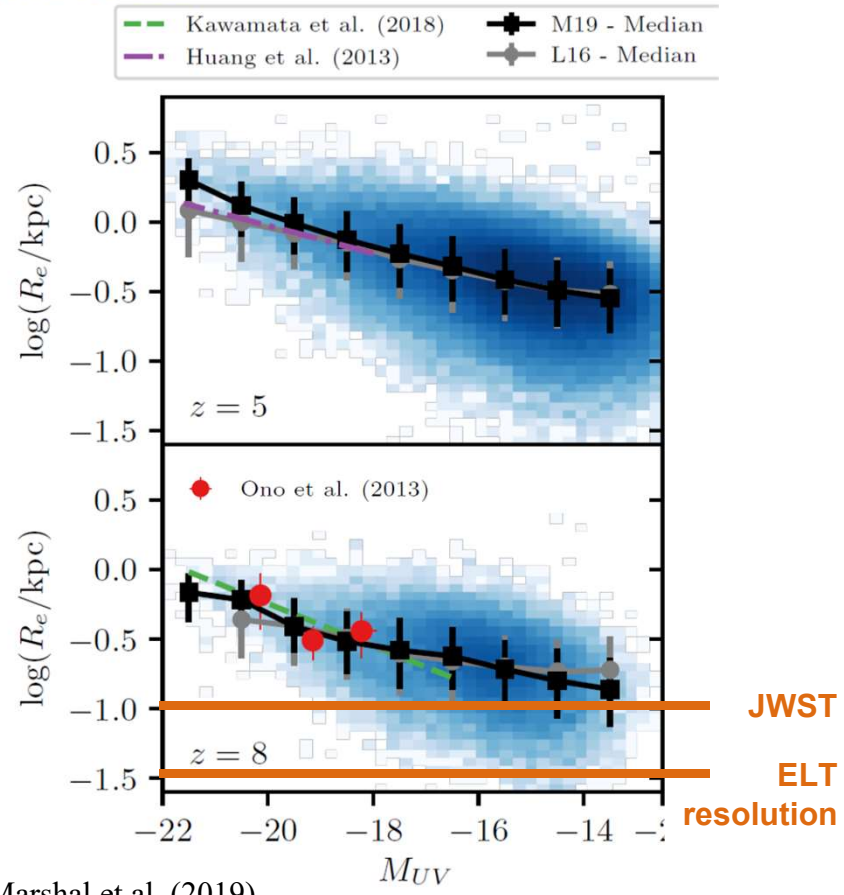
Two modes of feedback

Reionization feedback: suppression of gas accretion onto small halos from a hot IGM

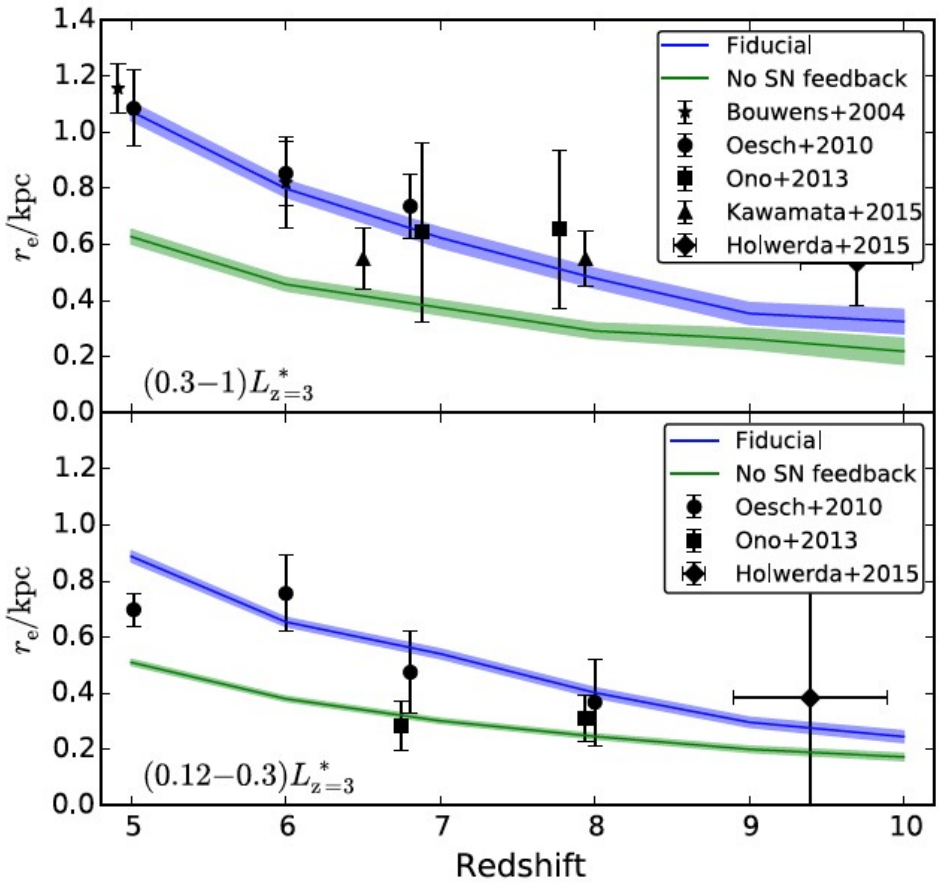
SNe feedback: suppression of star formation in small halos

- SNe feedback yields a rising stellar fraction, agreeing with Halo Abundance Matching

Sizes of galaxies



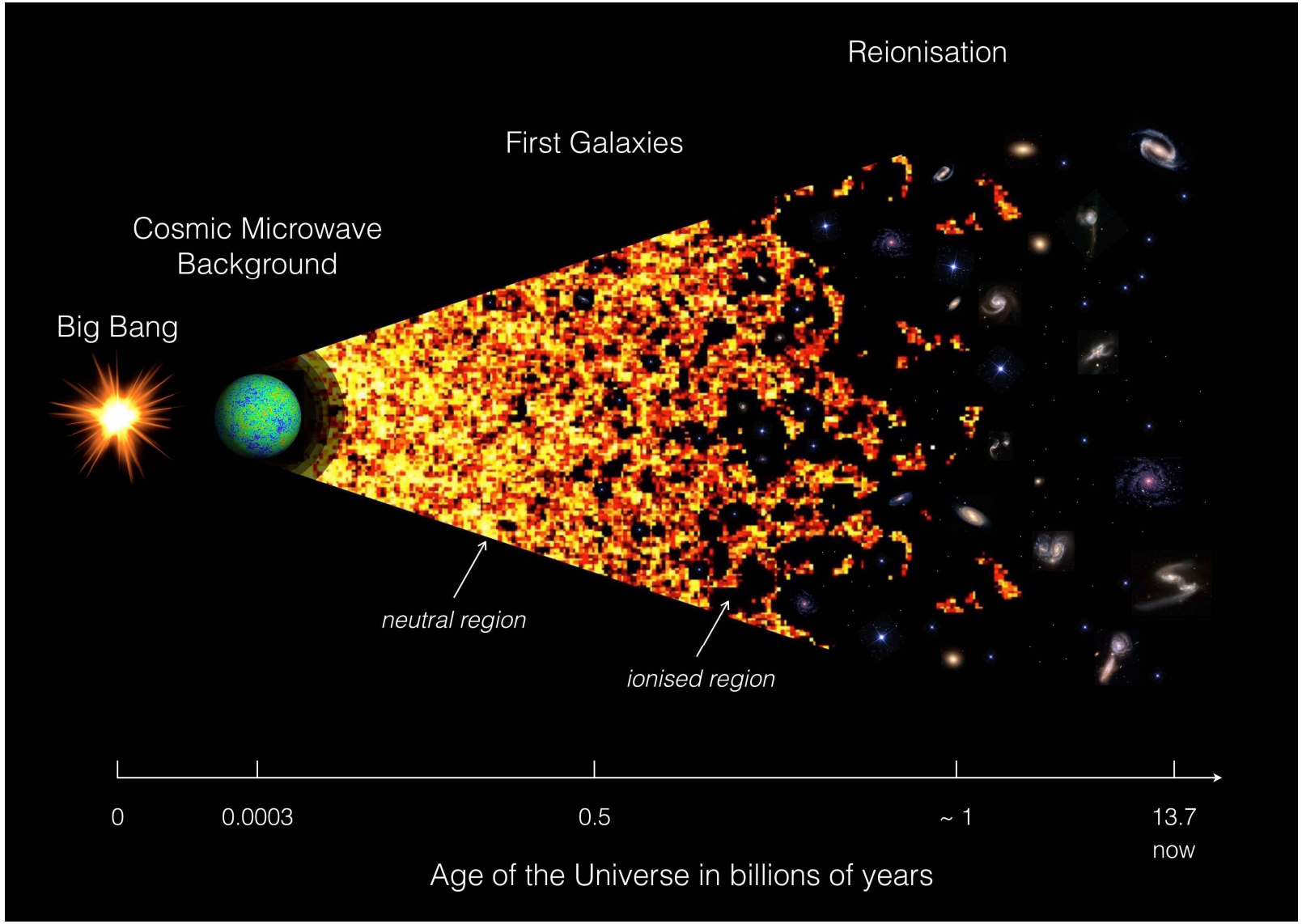
Marshal et al. (2019)



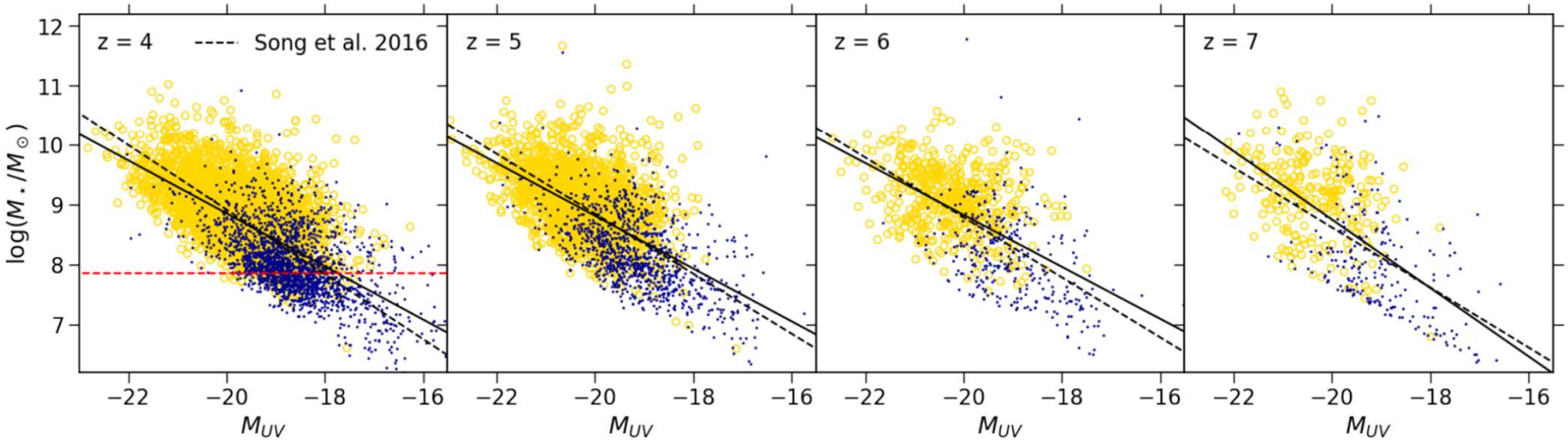
Lui et al. (2016)

- Sizes, based on DM halo properties, and their evolution agree with observations
- SNe feedback is needed to get the correct redshift evolution at fixed luminosity

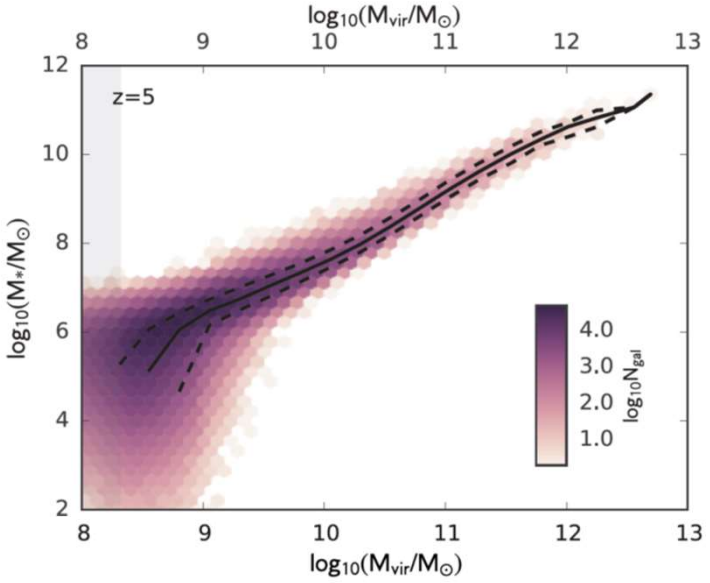
Reionization



21cm power-spectrum and galaxy formation

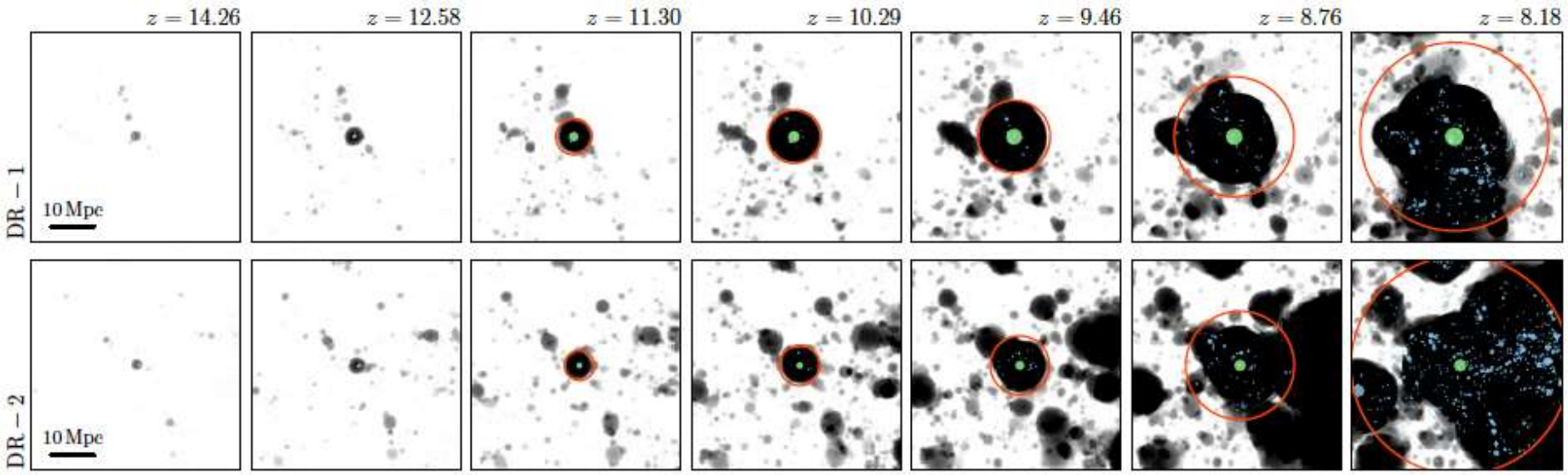


Yisheng Qi et al. (2018)



- Significant scatter in halo mass – luminosity and halo mass – stellar mass relations
- Scatter reduces dependence of 21cm power-spectrum on galaxy properties

HII regions around luminous galaxies



- Luminous high-z galaxies lie at the center of large isolated regions until late in reionization

Redshifted 21cm imaging with SKA

ASTRO 3D