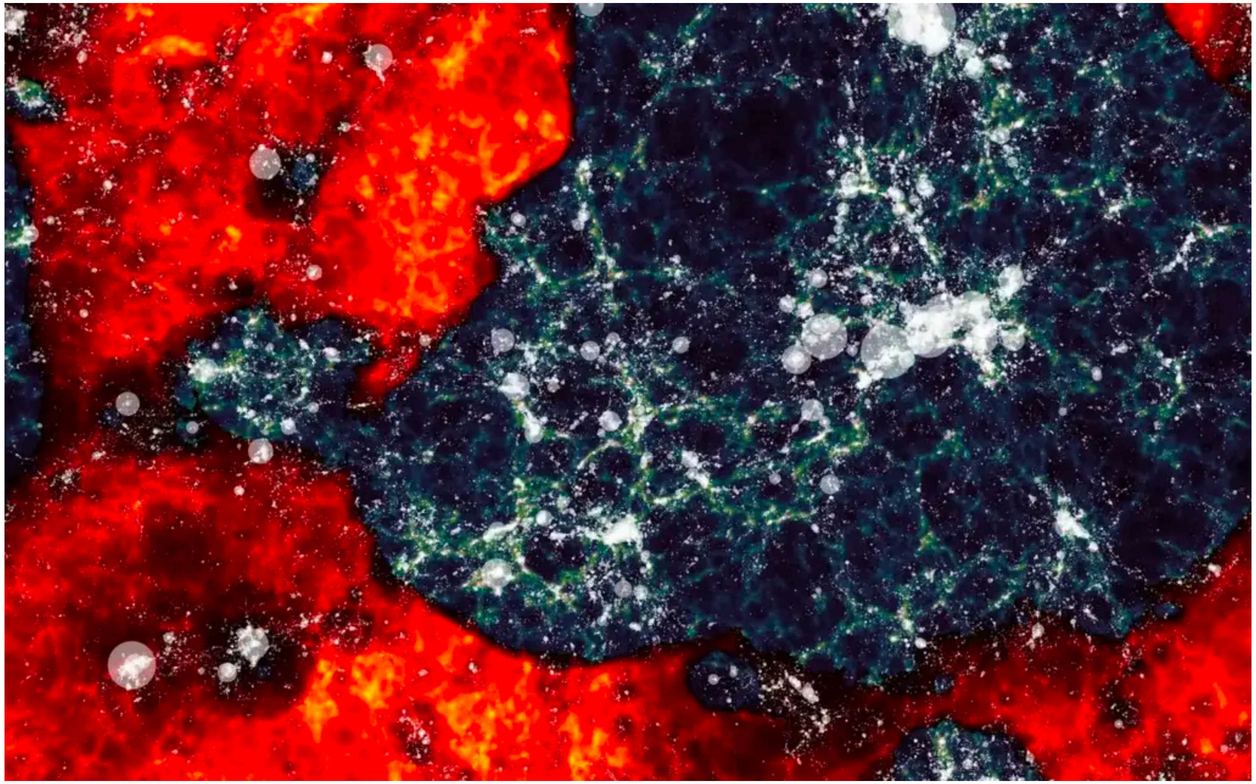
Galaxy Formation, Reionisation and MWA

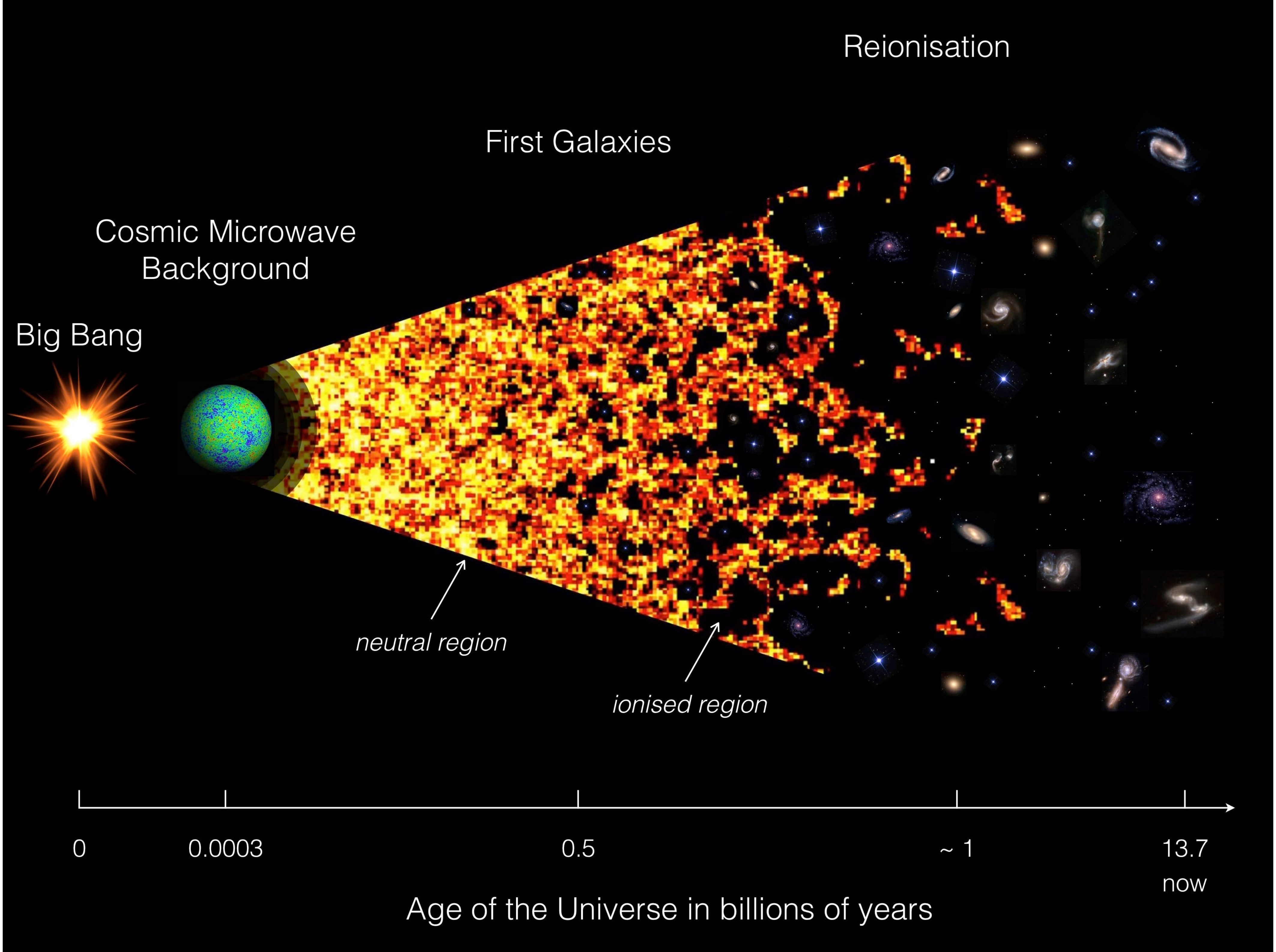


Stuart Wyithe

with thanks to:

Yuxiang Qin, Brad Greig,
Balu Sreedhar, Simon Mutch

EoR collaboration


Reionisation
First Galaxies
Cosmic Microwave
Background
Big Bang
neutral region
ionised region
0
0.0003
0.5
~ 1
13.7
now
Age of the Universe in billions of years

Outline

- Reionisation by stars
- Simulating galaxy formation and reionisation
- Constraining astrophysics of reionisation with the MWA
- Forecasting galaxy formation constraints from reionisation for the SKA

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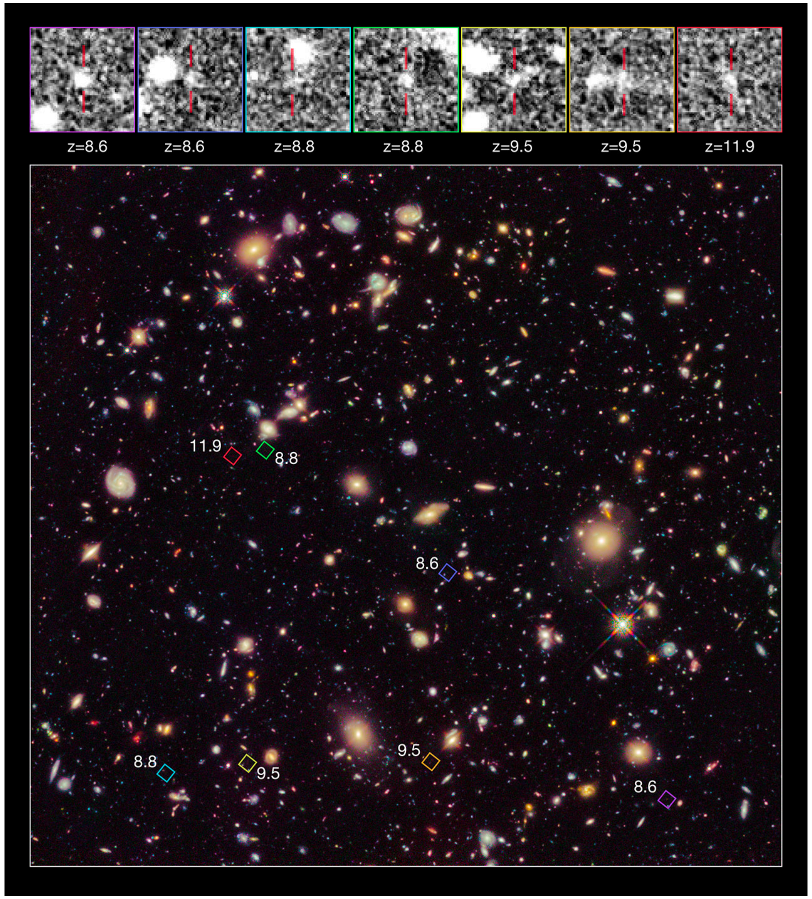
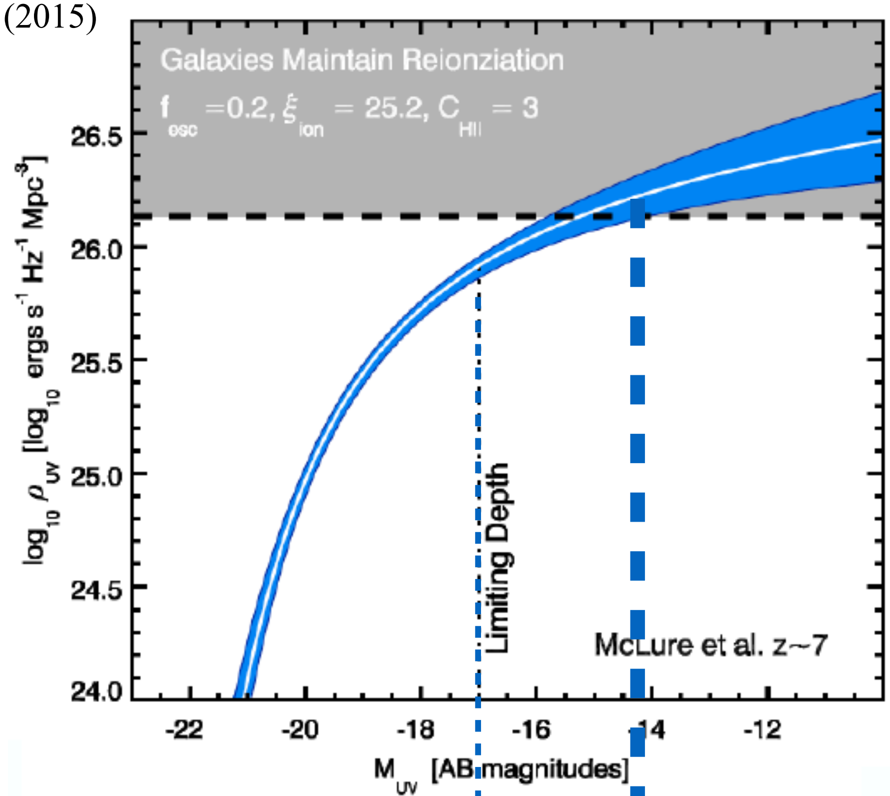
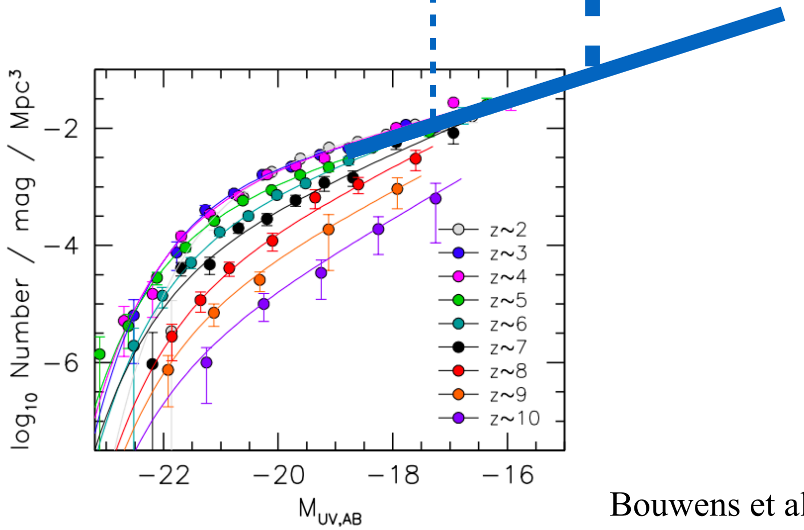
Reionization by galaxies?



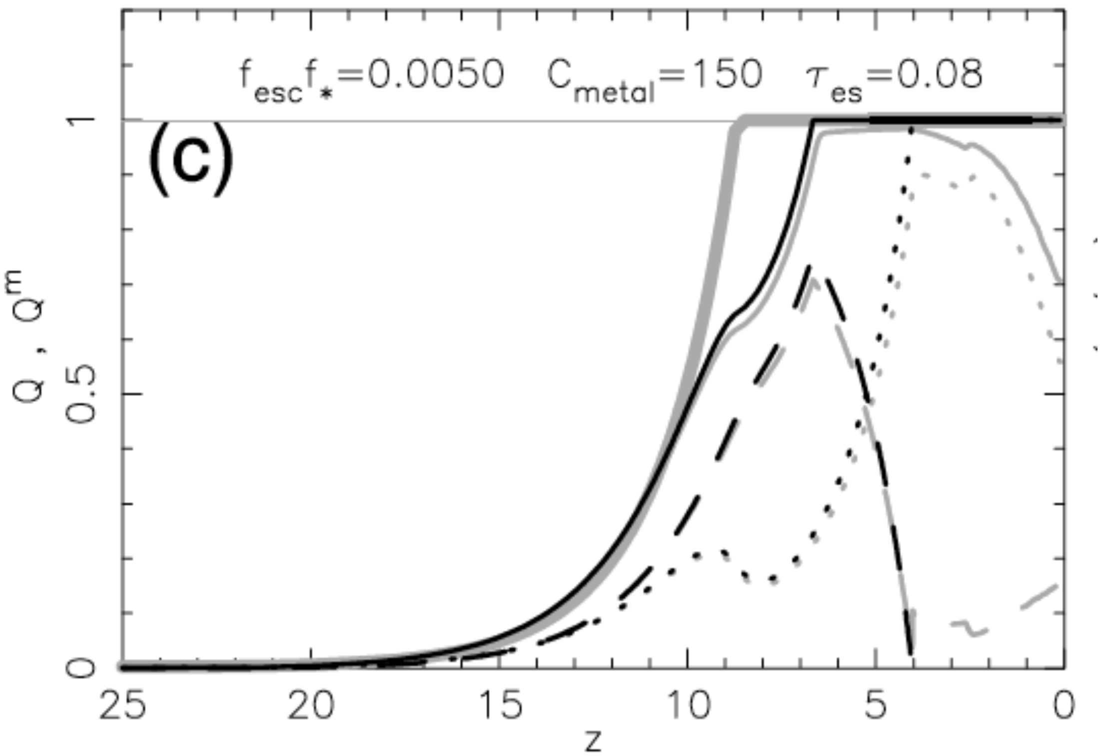
Robertson et al. (2015)

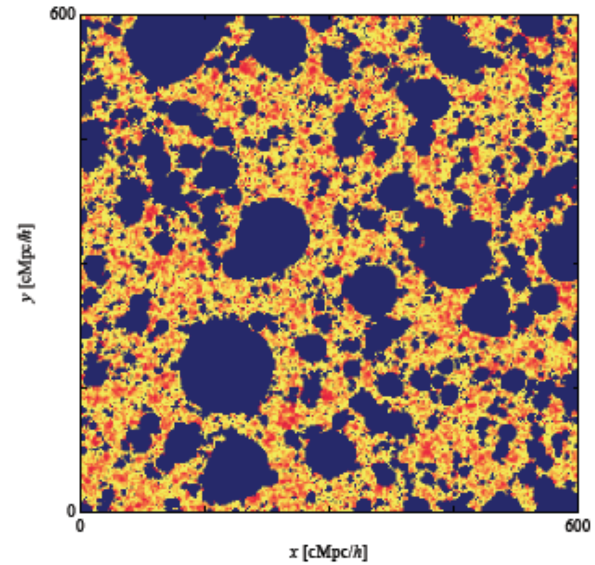




Bouwens et al. (2021)

- Empirical extrapolations of the LF imply that faint galaxies can reionize hydrogen
- Conclusions are sensitive to the unknown escape fraction, and faint end LF





Evolution in ionization given by the difference between ionization and recombination

$$\frac{dQ_i}{dz} = \frac{1}{n_0}\frac{dn_\gamma}{dz} - \alpha_B \frac{C}{a^3} Q_i n_e \frac{dt}{dz}$$

Star formation estimated from collapsed fraction above H-cooling limit

- Sensible SF efficiency (~0.1) and escape fraction (~0.1) can reionize hydrogen

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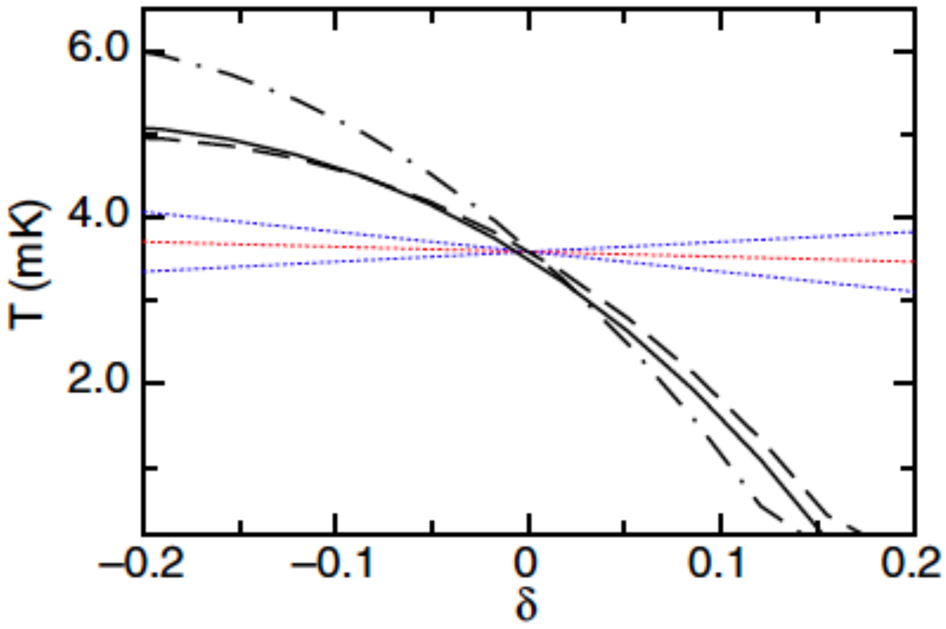
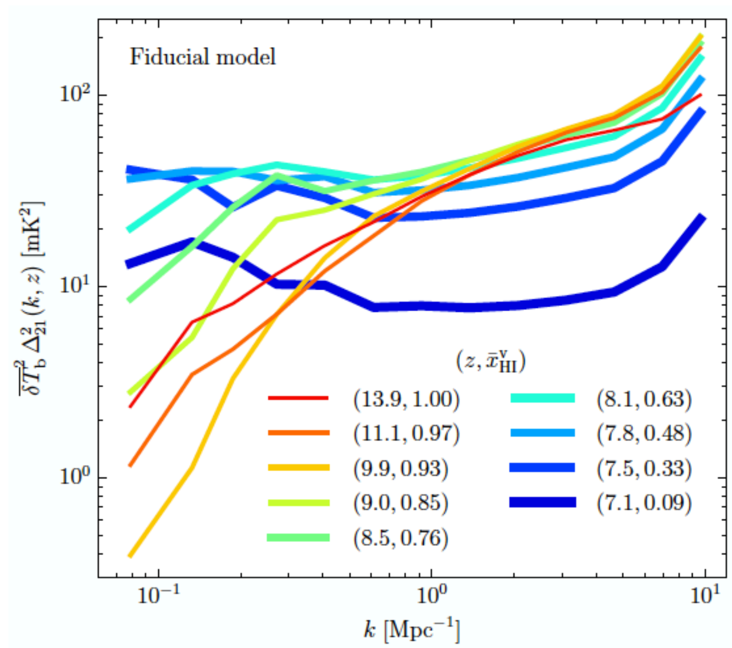


Star formation follows structure formation, which is subject to galaxy bias, and so sensitive to environment

$$\frac{dQ_{\delta,R}}{dt} = \frac{N_{\rm ion}}{0.76}\left[Q_{\delta,R}\frac{dF_{\rm col}(\delta,R,z,M_{\rm ion})}{dt} + (1-Q_{\delta,R})\frac{dF_{\rm col}(\delta,R,z,M_{\rm min})}{dt}\right] - \alpha_{\rm B}Cn_{\rm H}^{0}\left(1+\delta\frac{D(z)}{D(z_{\rm obs})}\right)(1+z)^3\,Q_{\delta,R},$$



- Overdense regions are reionized first
- Galaxy evolution drives the shape of the 21cm power-spectrum

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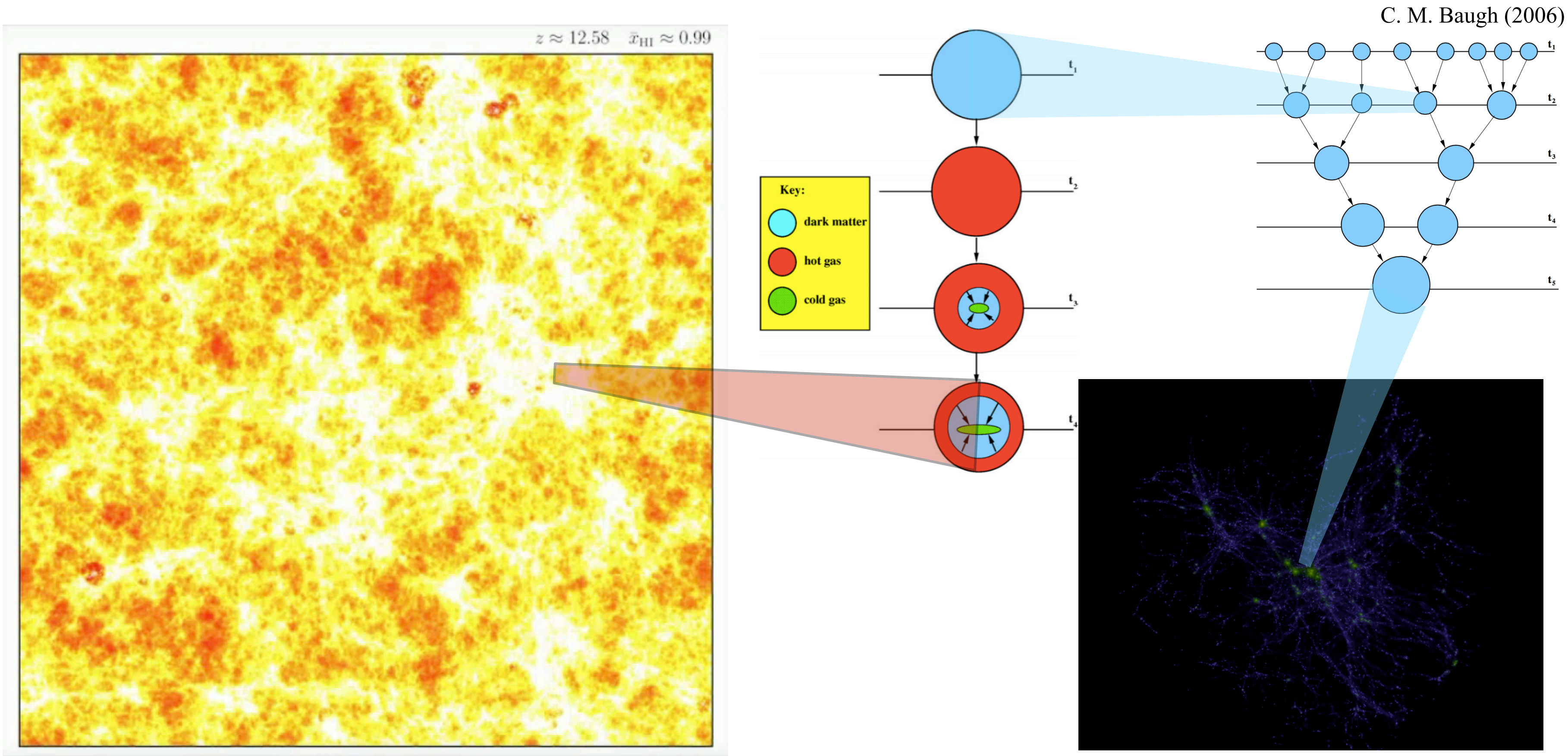
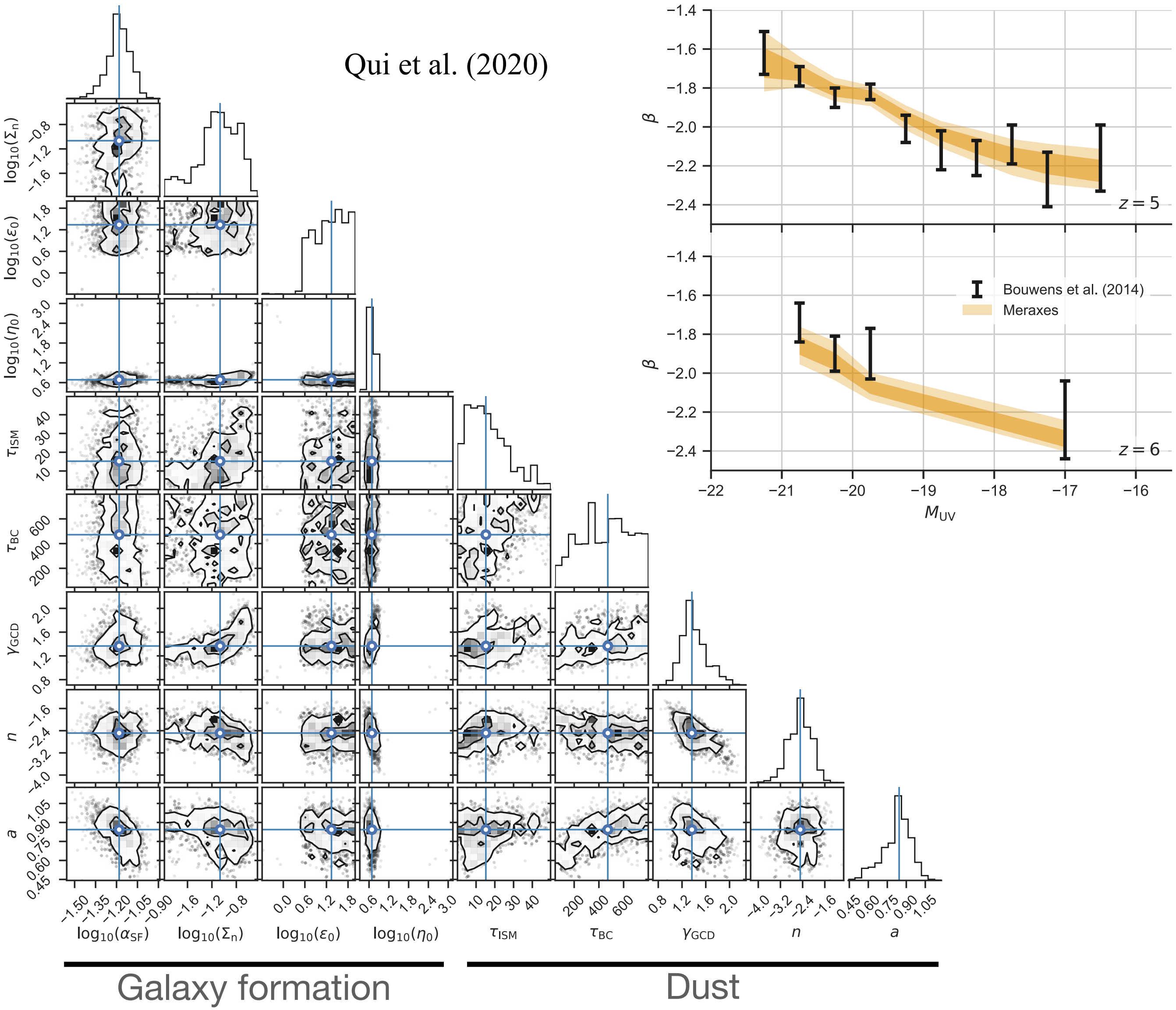
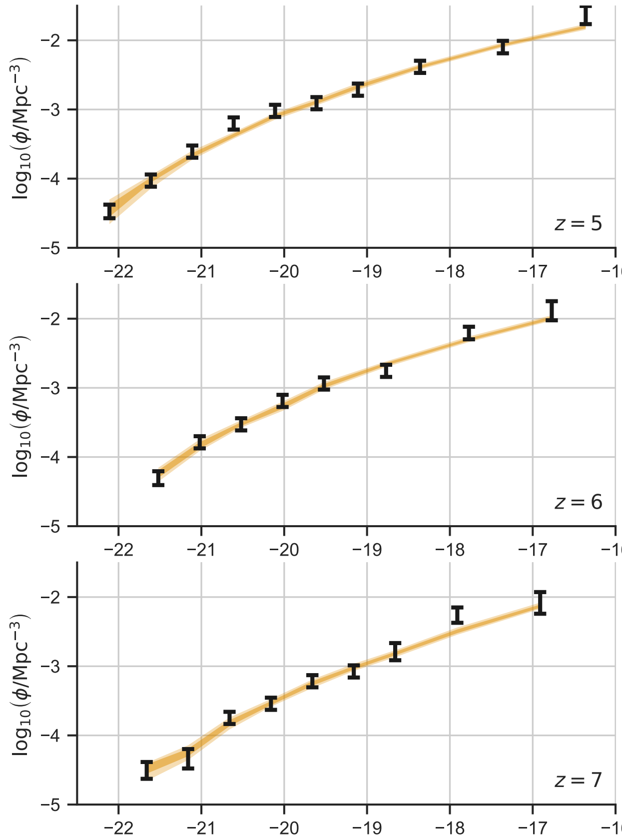
Semi-analytic Reionization and galaxy formation



- 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;

Constraints against the luminosity function





- Reproducing the LF requires strong SNe feedback

$\frac{L_X}{SFR}$: Galaxy X-ray luminosity per SFR
E_0 : Minimum X-ray photon energy in eV
$f_{esc,0}$: Escape fraction normalisation
α_{esc} : Escape fraction redshift scaling
Σ_{SF} : Critical mass normalisation
α_{SF} : Star formation efficiency
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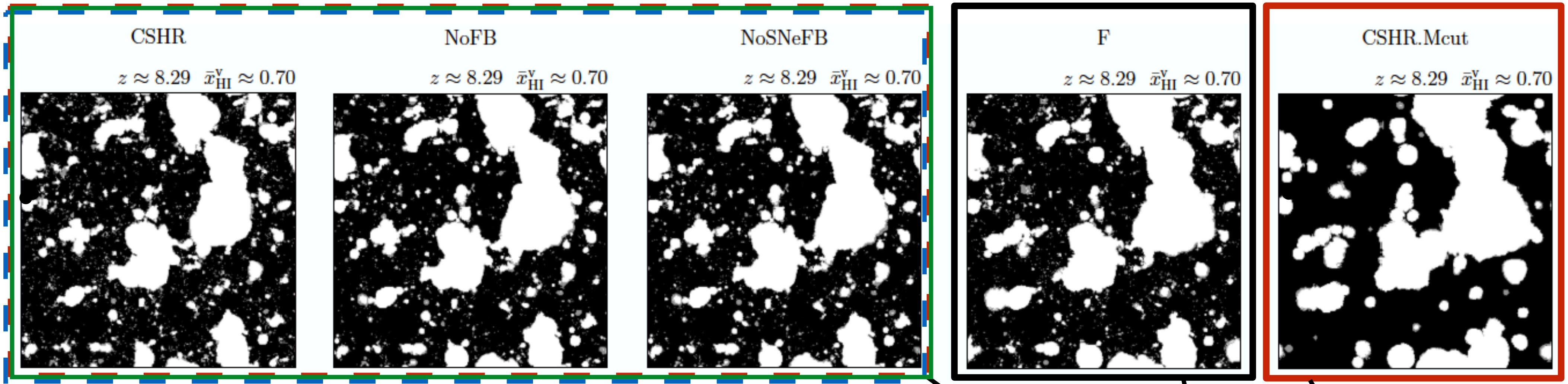
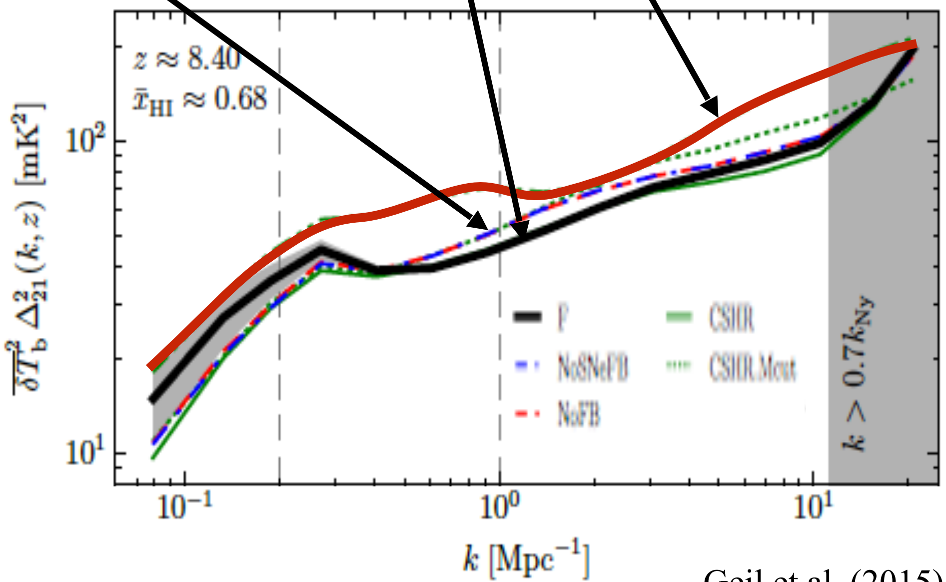
Increasing feedback and typical galaxy mass

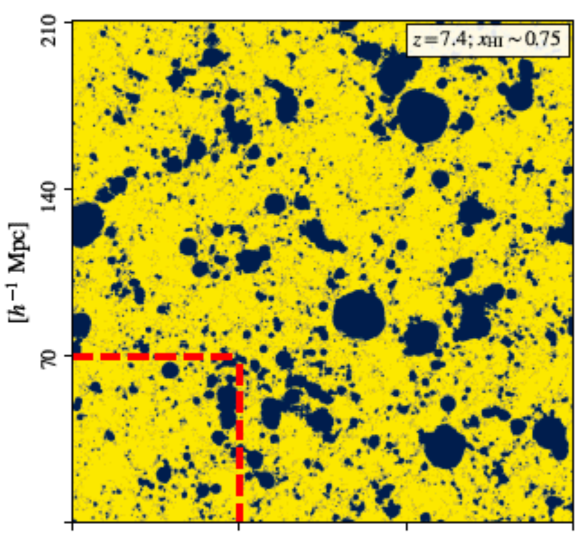


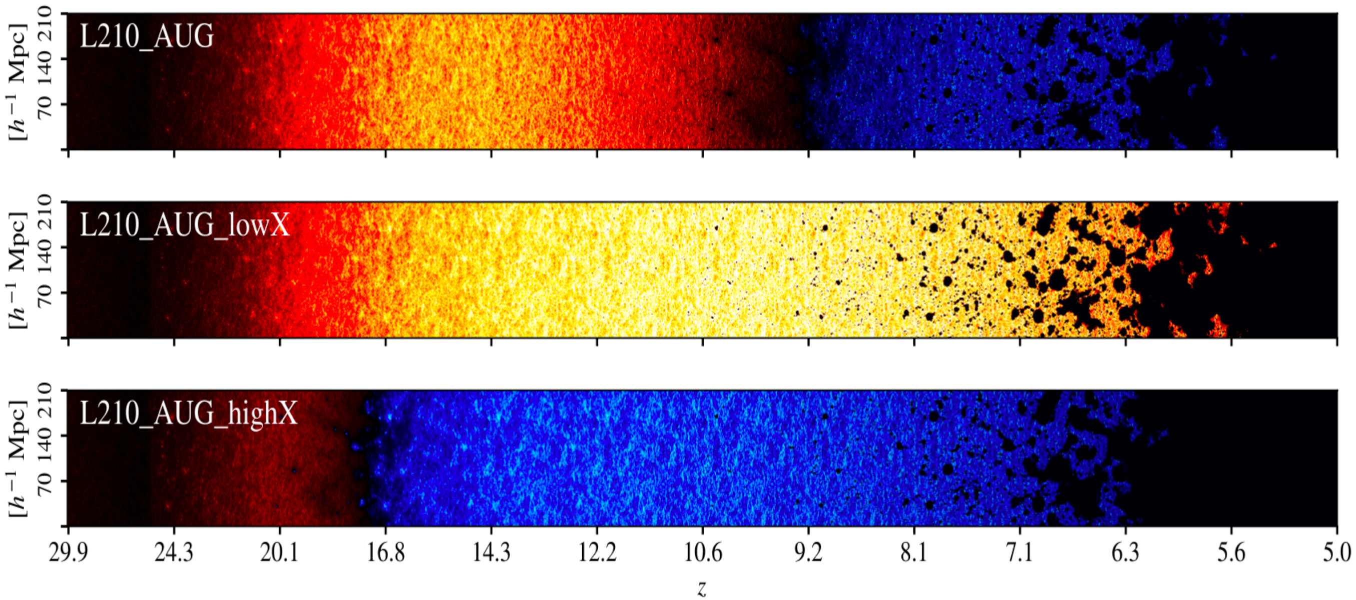
- More clustered galaxies in massive dark matter halos result in larger HII regions
- Power-spectrum is sensitive to the ionizing contribution from small galaxies



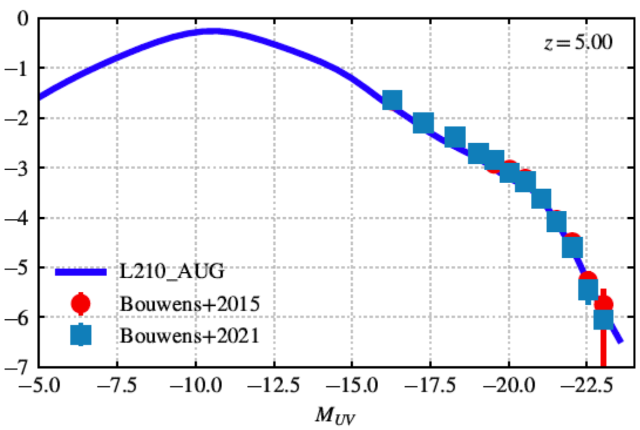
Geil et al. (2015)

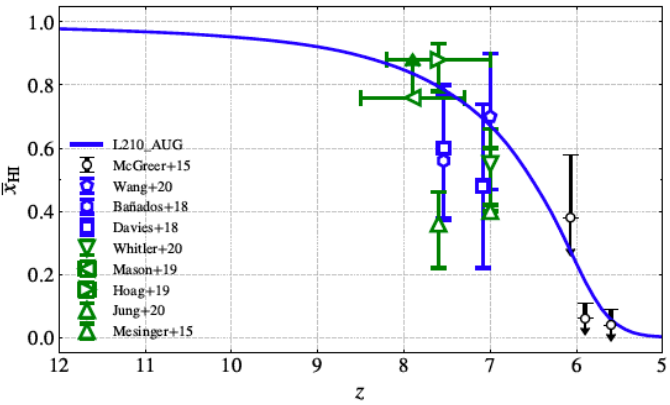
Large reionization simulations with X-rays

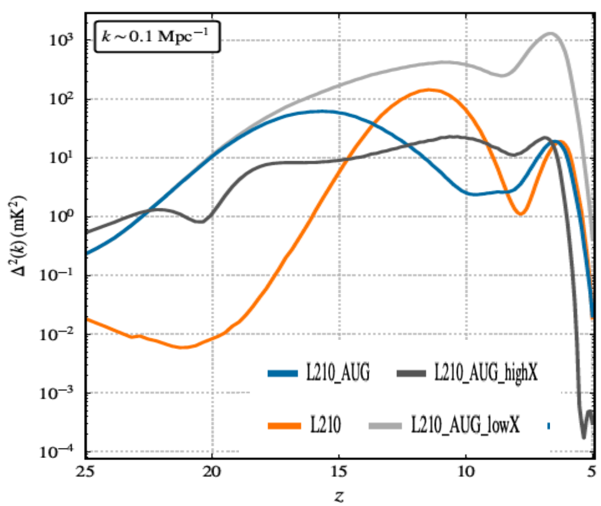




Balu et al. (2022)







- X-rays have significant influence on the 21cm PS amplitude and evolution

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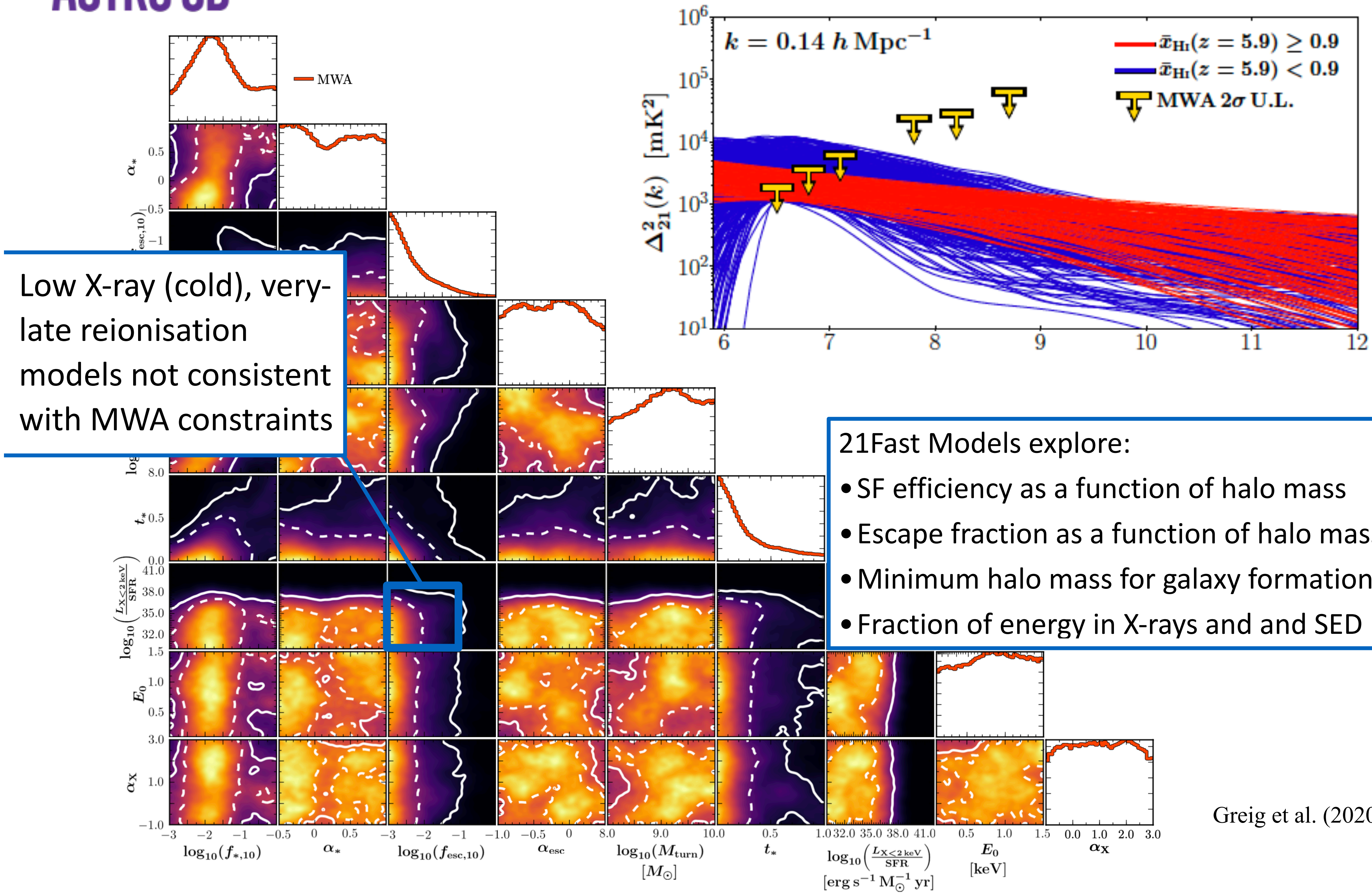
Constraints from the MWA limits

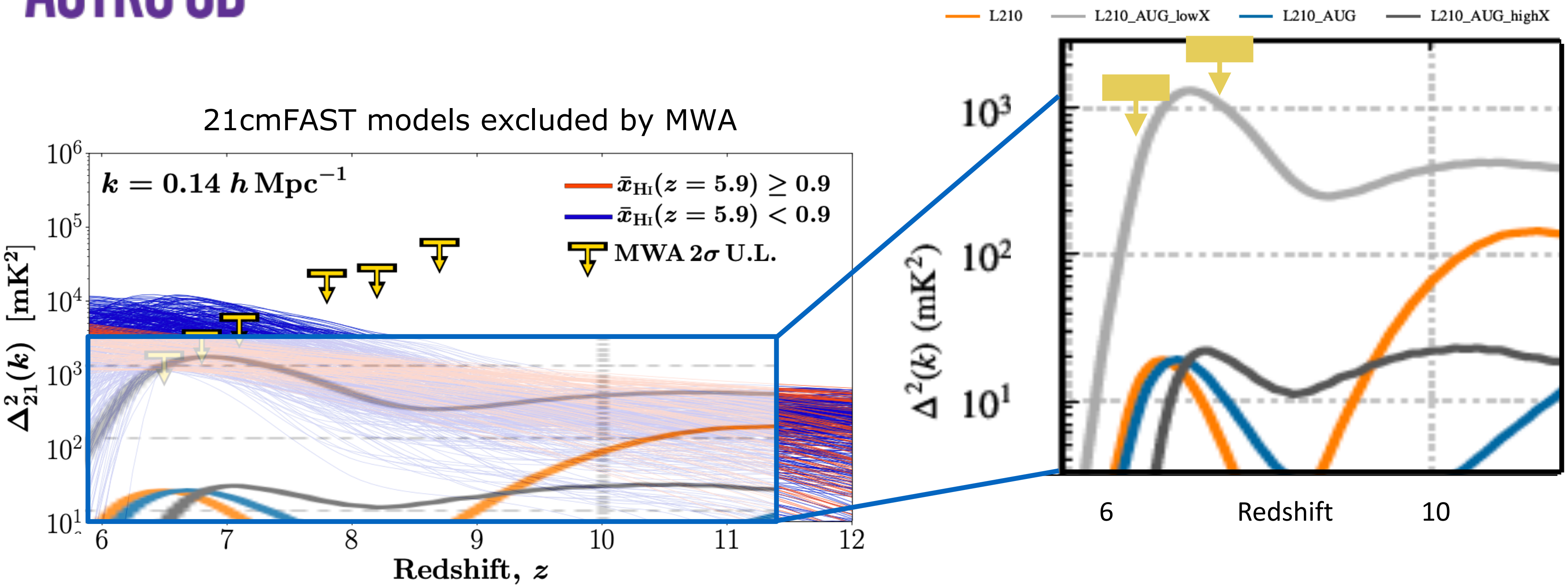


21Fast Models explore:

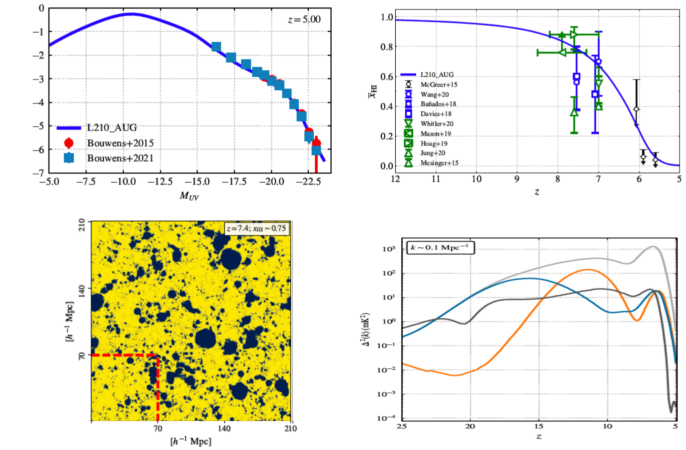
- SF efficiency as a function of halo mass
- Escape fraction as a function of halo mass
- Minimum halo mass for galaxy formation
- Fraction of energy in X-rays and and SED

Greig et al. (2020)

Constraints from the MWA limits



Galaxy formation model



- The MWA upper limits exclude a wide range of models plausible
- Some of these excluded models are on the border of what are physically “reasonable”

Balu et al. (2022)

Greig et al. (2022)

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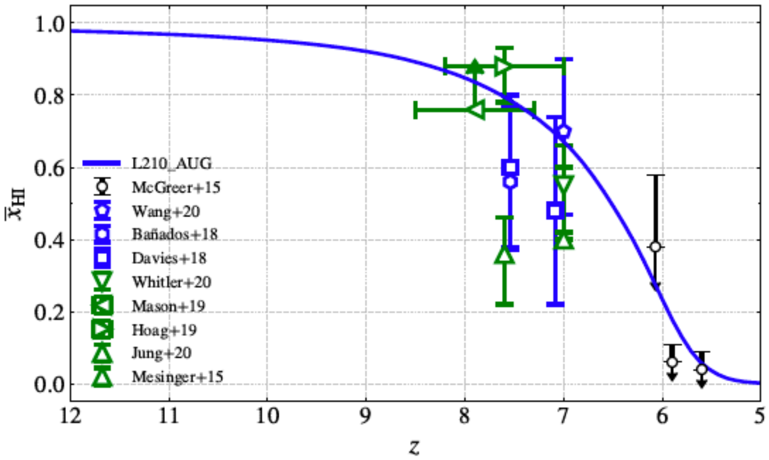
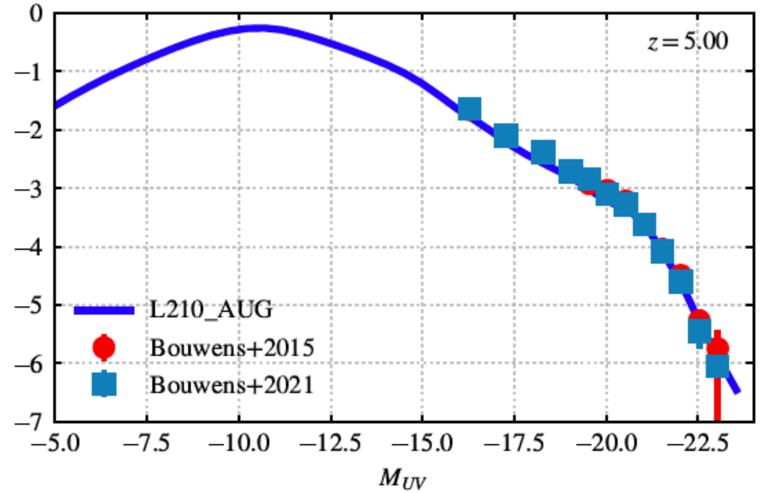
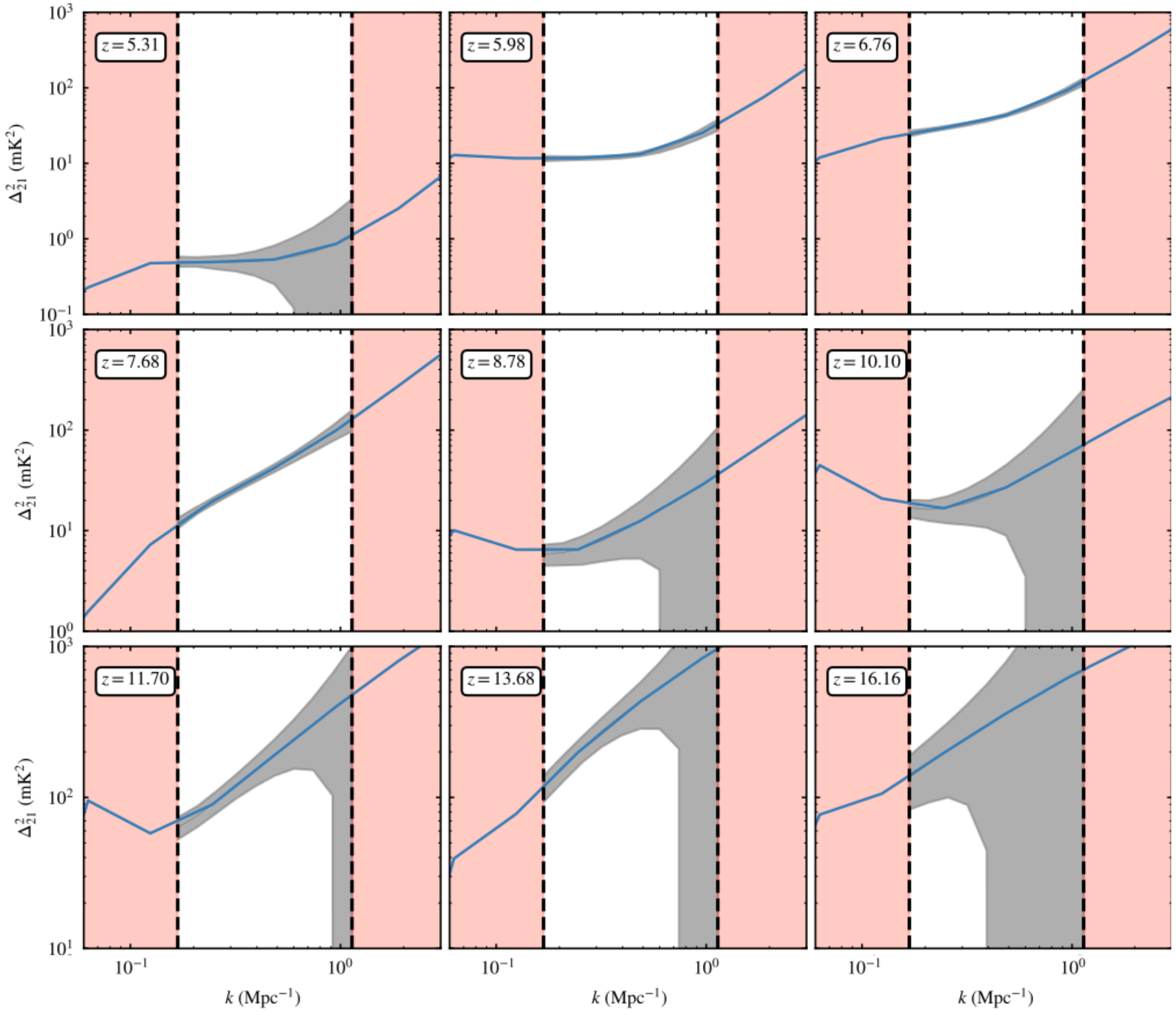
Forecast constraints for the SKA







- The SKA has the potential for high S/N measurements

Balu et al. (2023)

Forecast constraints for the SKA

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Balu et al. (2023)

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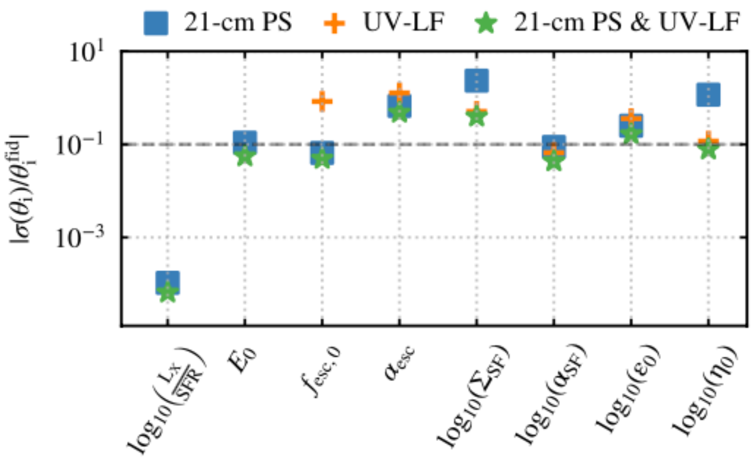

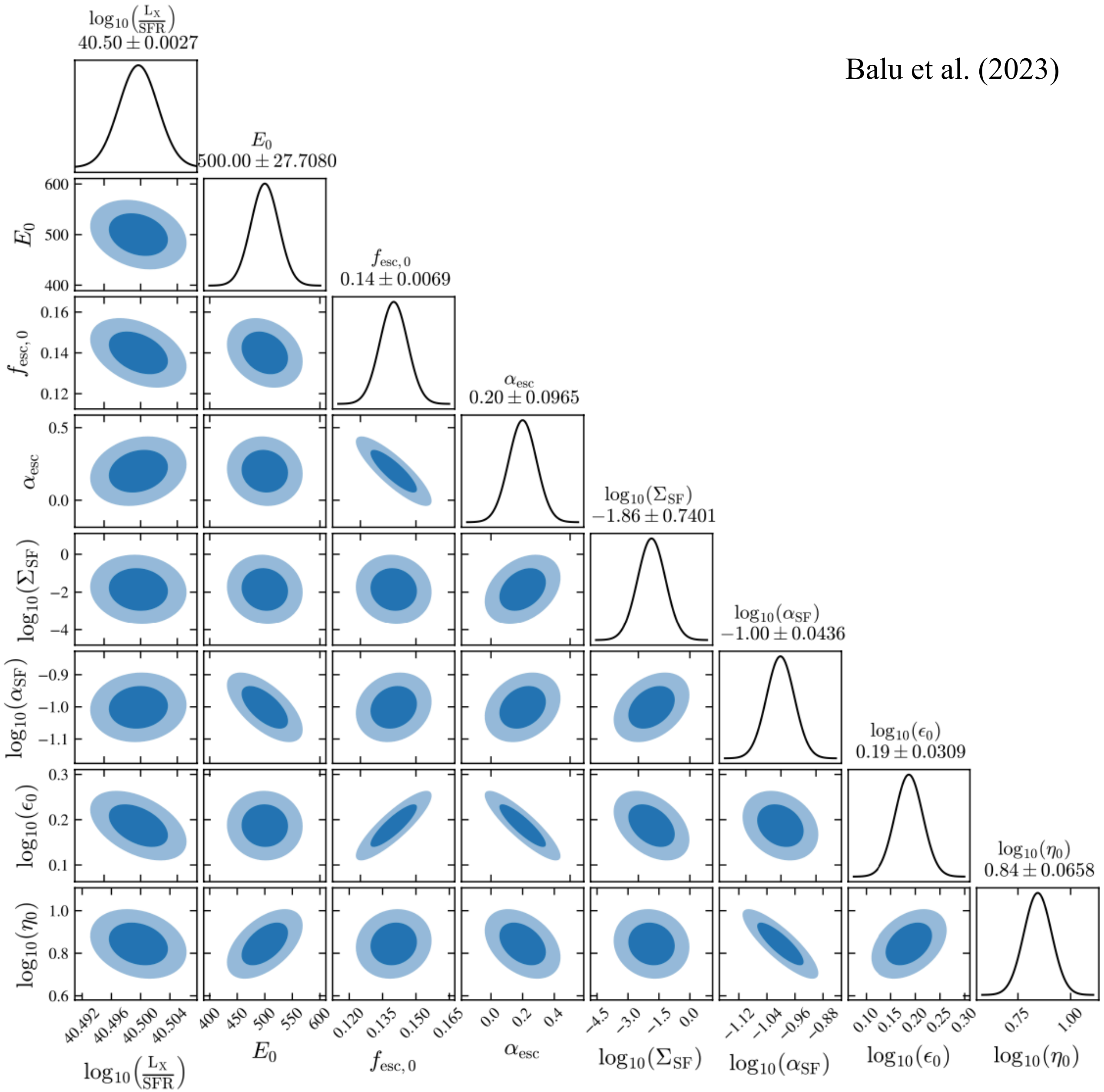

- The SKA has the potential to constraint star formation, SNe feedback and X-rays

Conclusions

ASTRO 3D

- Simulations of galaxy formation with reionisation show imprint in 21cm PS
- Astrophysics of reionisation beginning to be constrained by the MWA
- The SKA should be able to measure aspects of galaxy formation from 21cm PS

T1 First light: 2004