Simulating the end of Cosmic Reionisation

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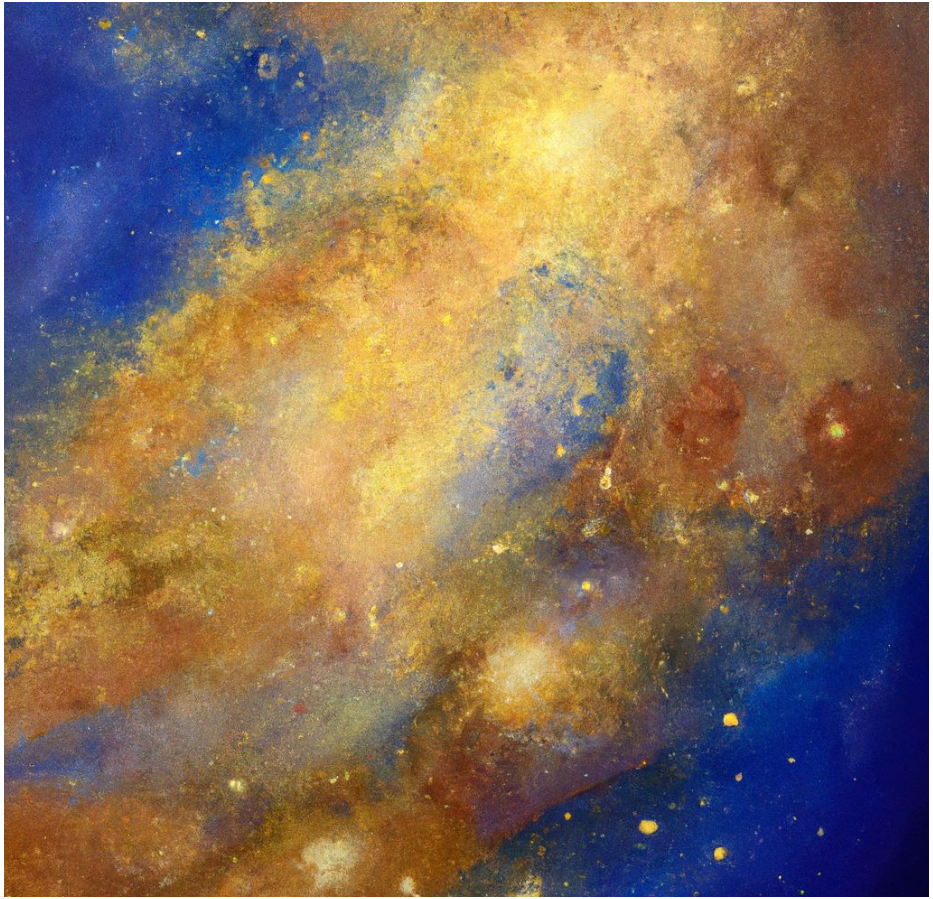
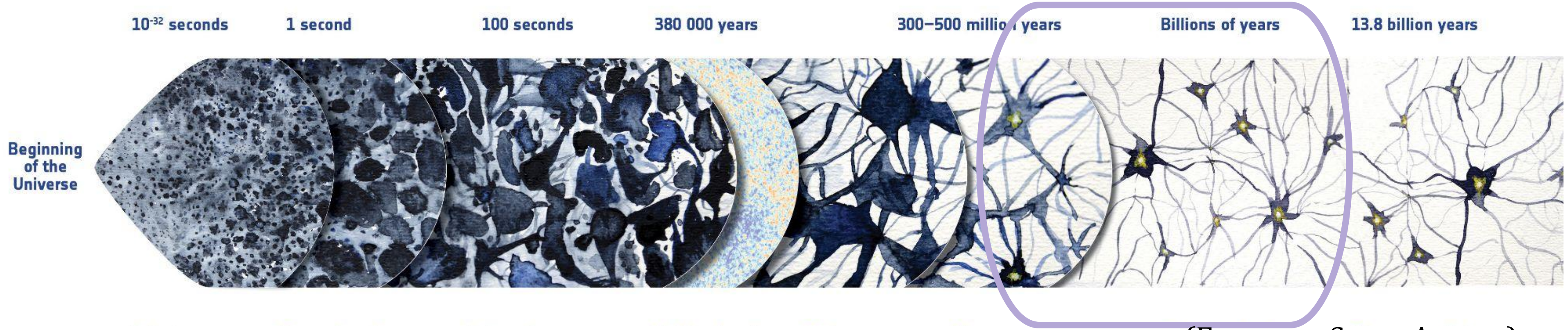


Reionisation: A Brief Introduction

During the cosmic dark ages, the Universe primarily consists of **neutral hydrogen** (HI), **which emits radiation via the 21-cm line**.

The first sources will ionise the neutral hydrogen around them, **masking away the 21-cm signal**.

The Epoch of Reionisation (EoR) spans astrophysical & cosmological scales.
It contains ionisation and density information.



(European Space Agency)

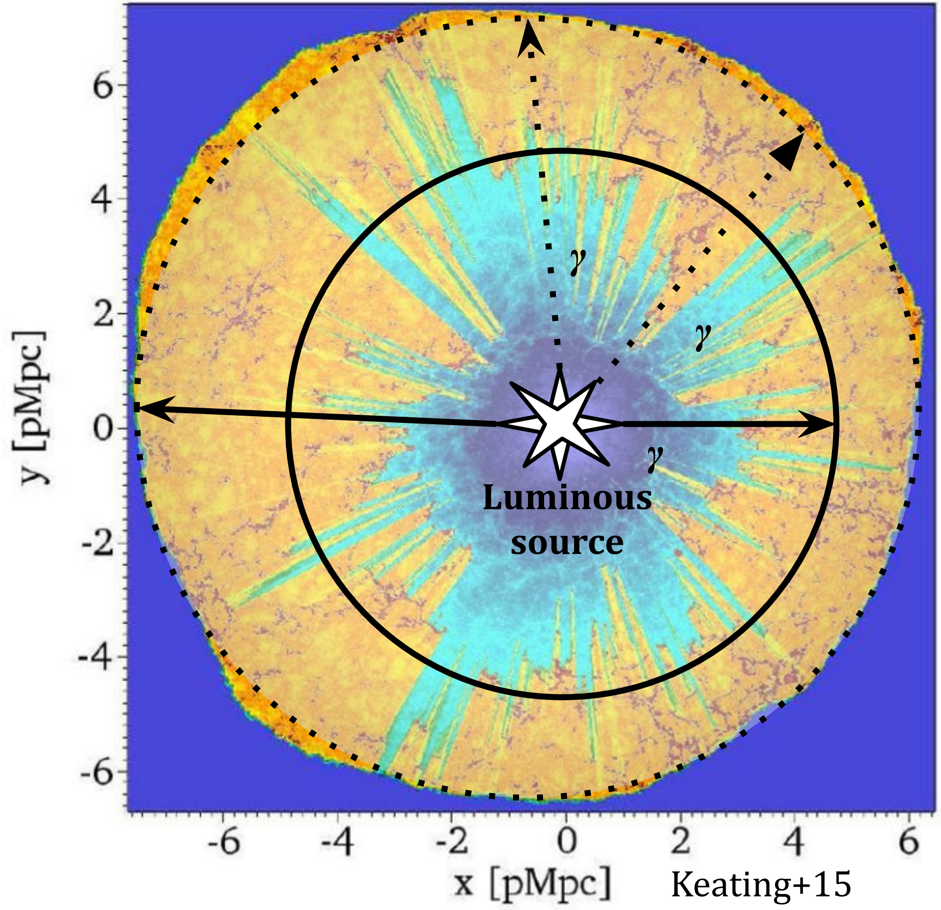
Modelling the MFP Effect is hard

Mean free path (**MFP**): distance to which an ionising photon (E ~13.6 eV/ 912 Å) travels in the presence of an absorption fraction of ~$e^{-\tau}$ for τ =1.

Can be limited by

A. large neutral islands,

B. absorption due to residual neutral gas in the ionized IGM.



Keating+15

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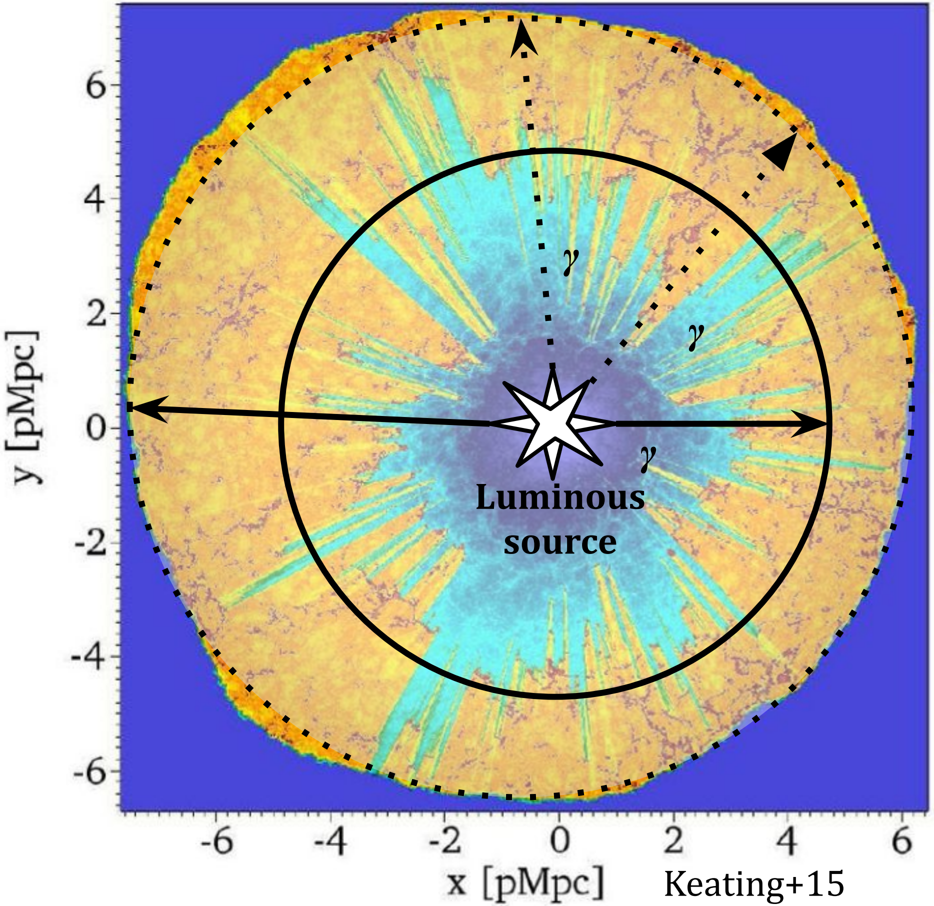
Modelling the MFP Effect is diverse

Investigate the MFP effect by comparing 3 sets of two C^2 - Ray simulations Mellema+06 of box size $244h^{-1}$cMpc

1. **hard**: **hard barrier** λ_{mfp} = 20 cMpc (≈ 2.9 pMpc at z = 6),

2. **soft**: **evolving gradual absorption barrier** $\tau \approx 2$ at λ_{mfp} from Worseck+14 fit,

3. **clumpy**: global clumping factor of **C = 2** (ie. higher recombinations rates in ionised regions).



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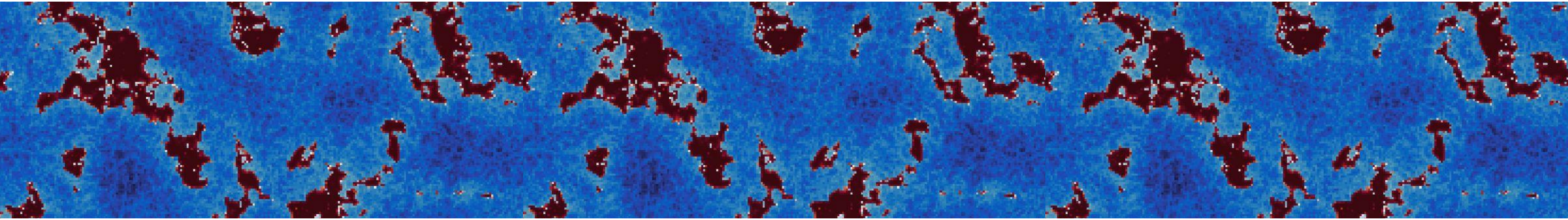
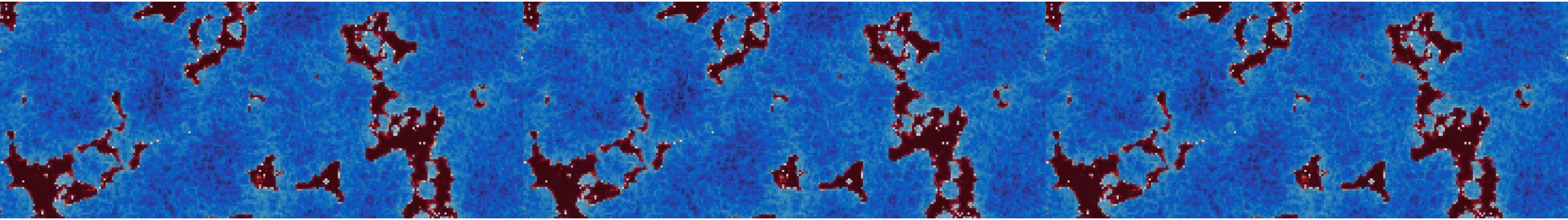
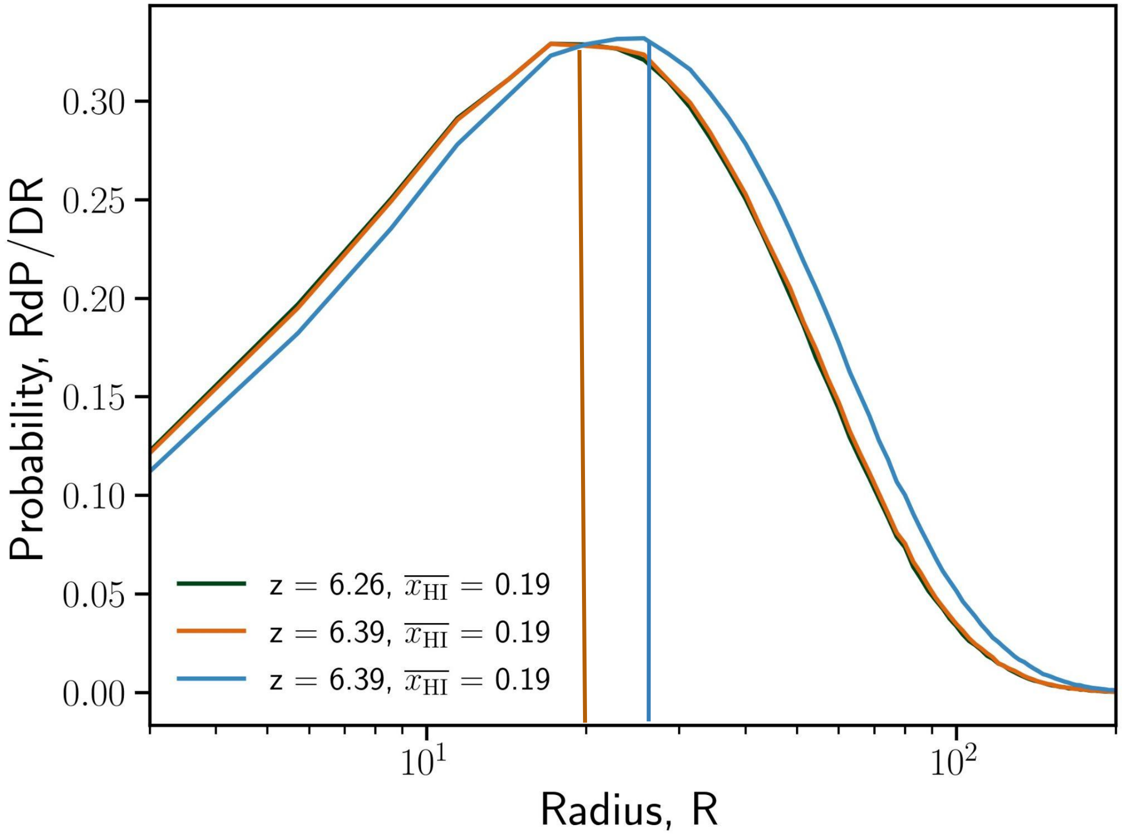


HI Island Statistics



Small effect on the HI Islands

hard, **soft**, **clumpy**



Similar distribution of HI islands peak ~ 25 cMpc.

Hard model R_{peak} evolves slower.

Clumpy model has slightly larger HI islands.

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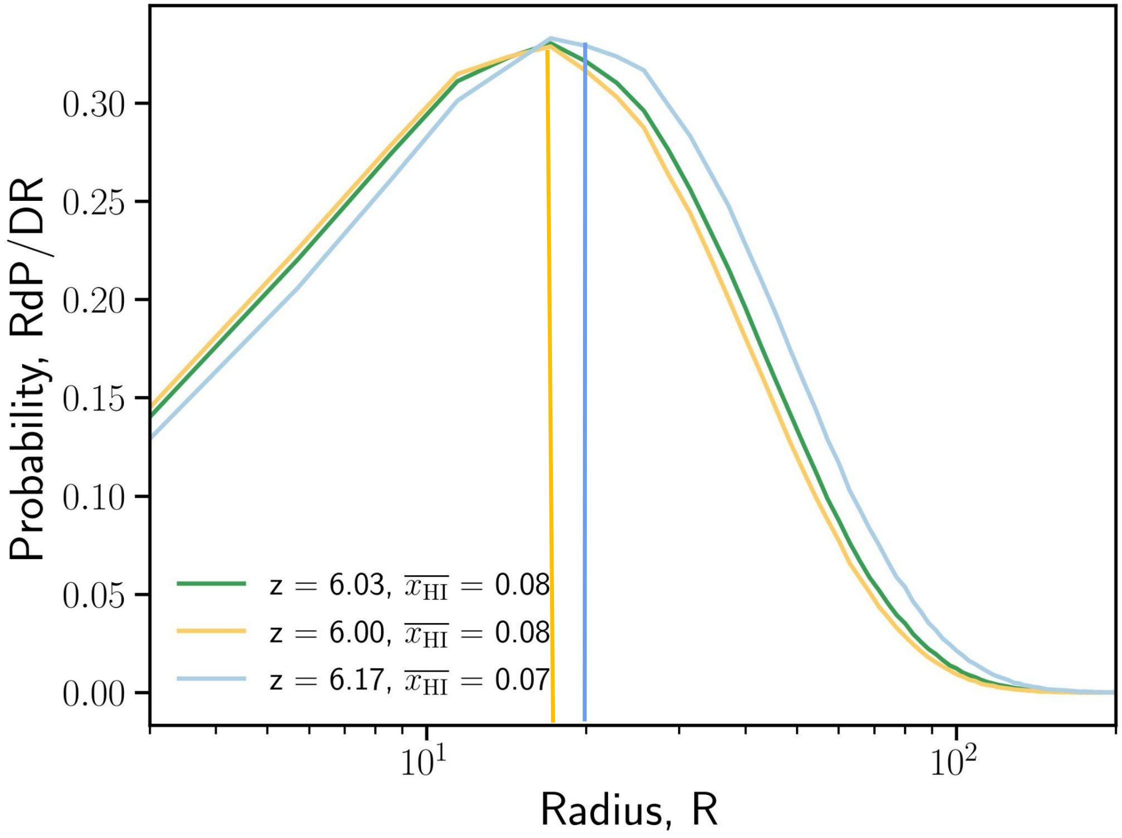
Small Effect on the HI Islands



HI islands in barrier models evaporate slower.

Clumpy HI islands are re-ionsed faster due to **no** MFP barrier.

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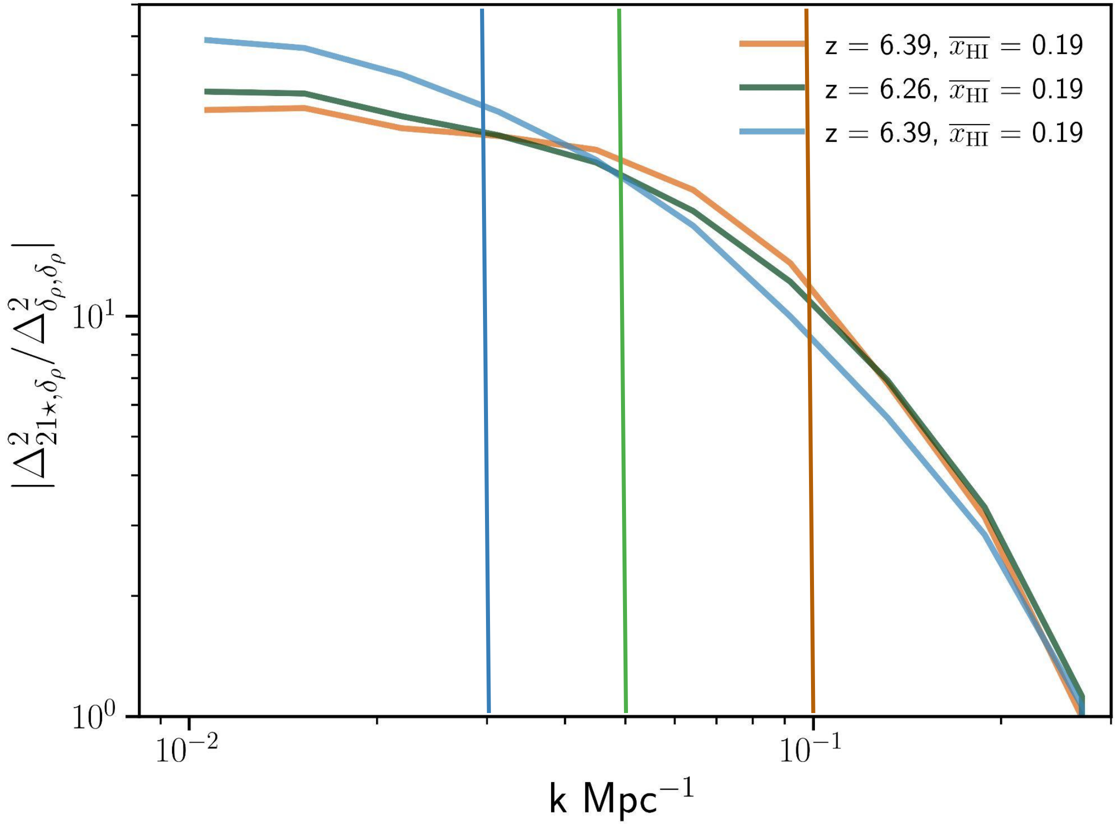
Effect on the 21-cm Bias

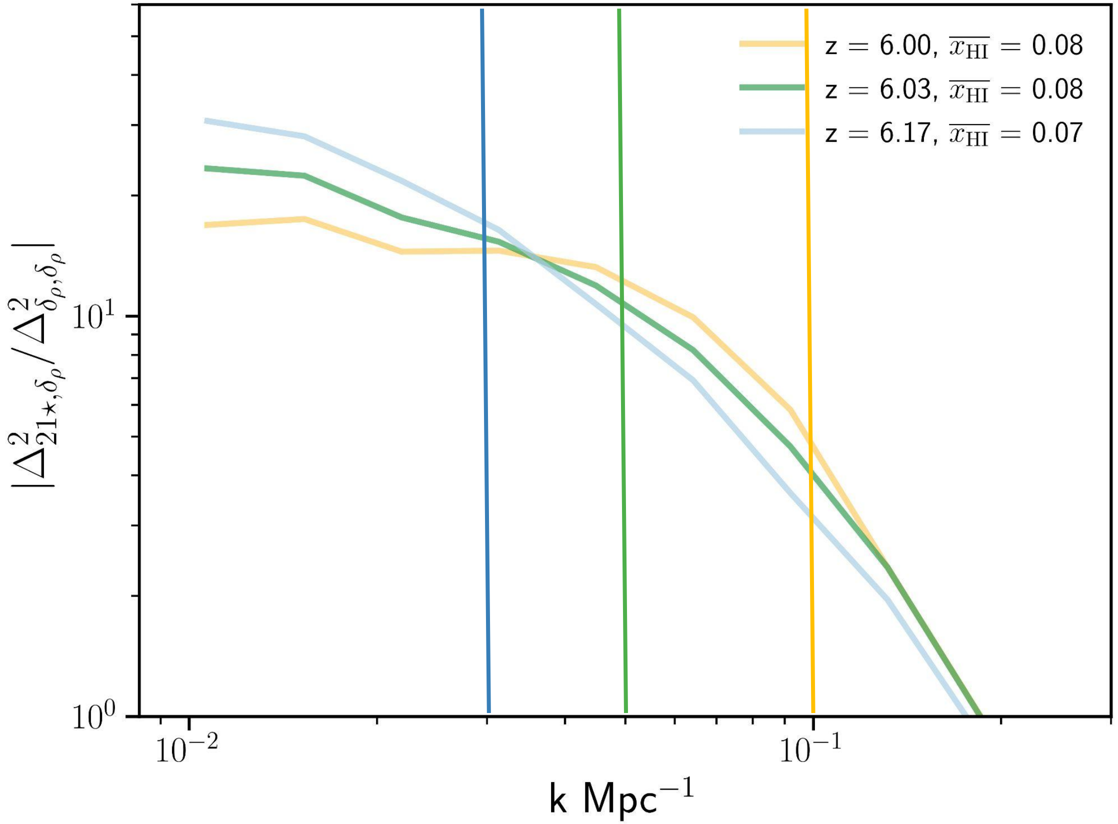


Scale-independent part of the bias depends on $k \approx 2.0/\lambda_{mfp}$ Georgiev+22.

For the **hard** model λ_{mfp} = 20 cMpc, $k \approx 0.1$ Mpc^{-1}.

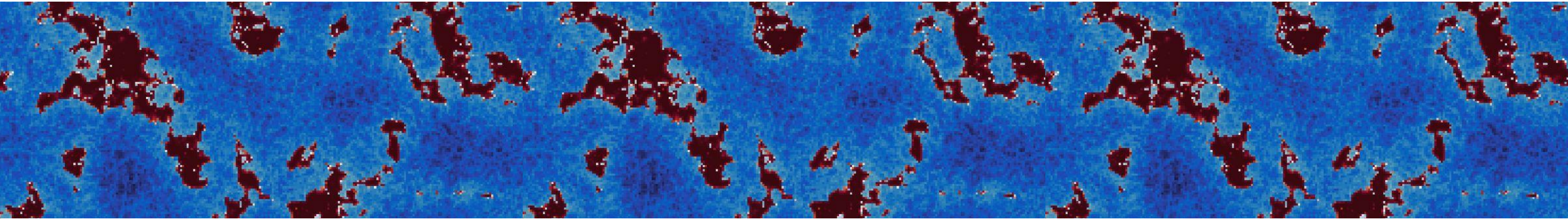
Feature **is smoother** for the **soft** model $\lambda_{mfp} \sim 40$ cMpc, $k \approx 0.05$ Mpc^{-1}.

Effect on the 21-cm Bias

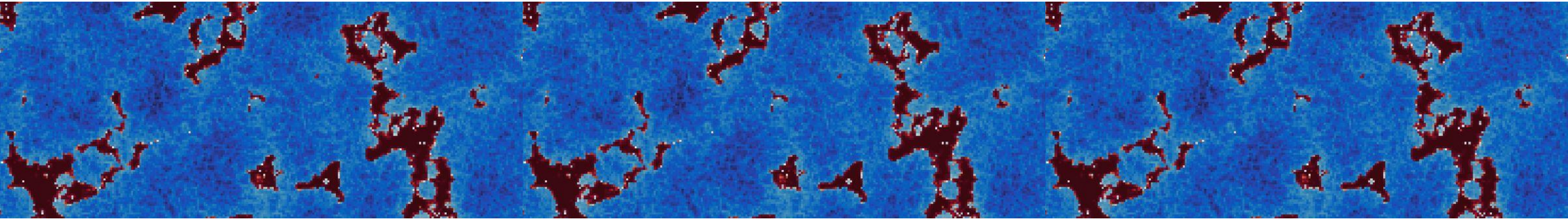


Hard model feature remains fixed.

Soft & **clumpy** model features evolve.



Residual HI Statistics



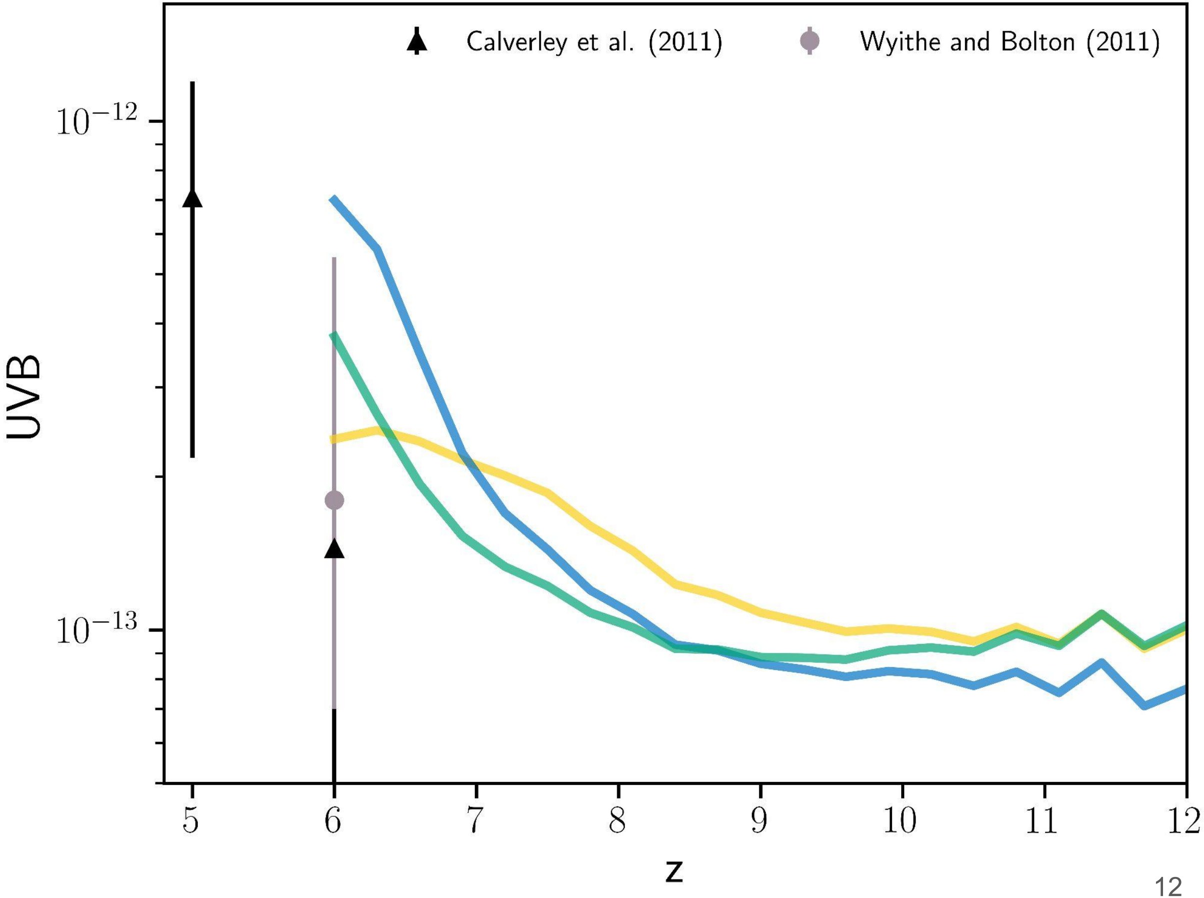
Effect regulates the UVB

hard, **soft**, **clumpy**

MFP regulates the UVB amplitude.

Clumpy & **soft** models evolve consistently with high-res hydrodynamic simulations.

Hard models **feature asymptotes** due to the MFP model.



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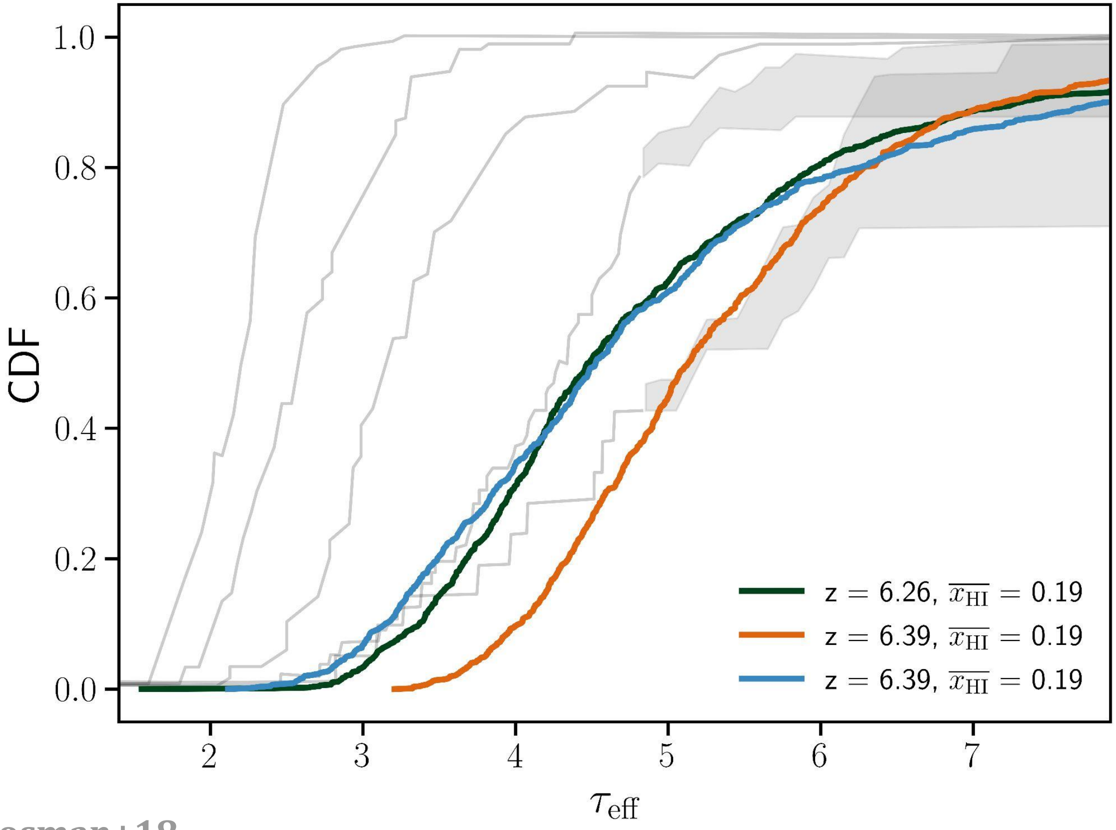
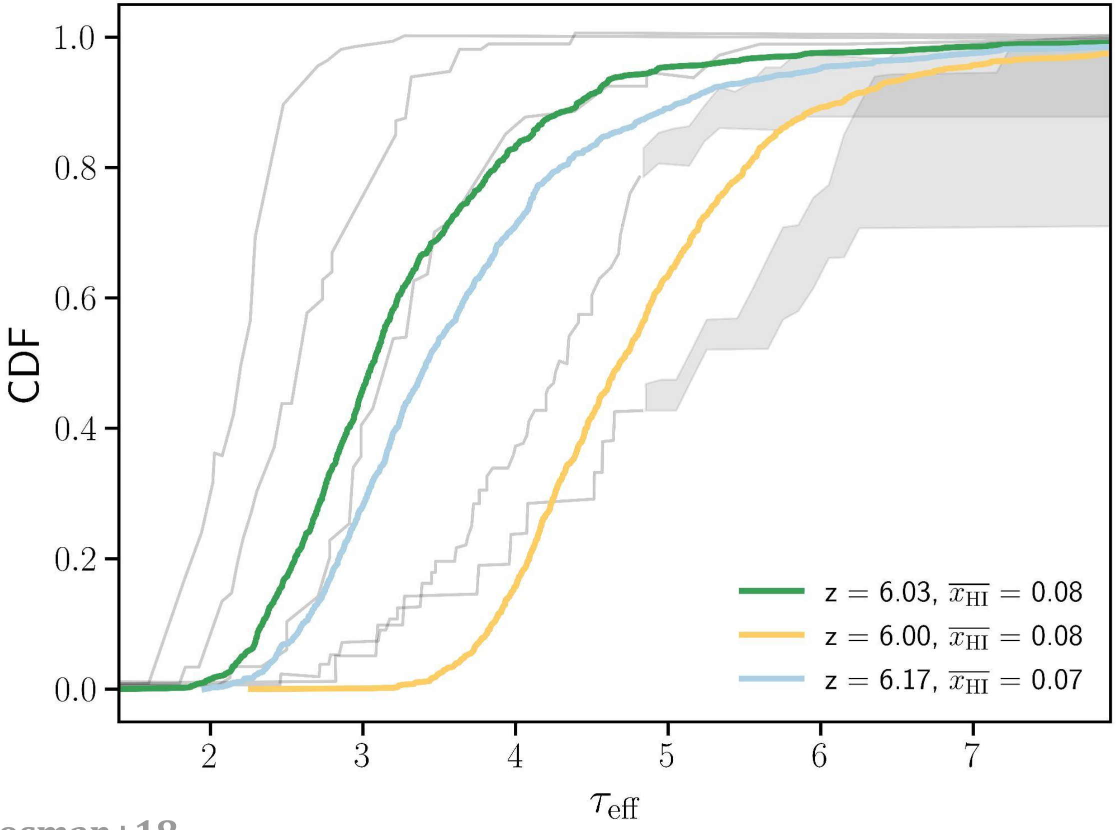
Effect on the Lyα opacity



Bosman+18

Hard model cannot reproduce the Lyα tail. The wing of the CDF is attributed to the HI regions.

Effect on the Lyα opacity



Bosman+18

Hard model cannot reproduce the Lyα tail. The wing of the CDF is now omitted.

Soft and **clumpy** models are more consistent with a reionised universe.

Conclusions & Summary

1. The last stages of reionisation are difficult to model but contain a wealth of information about neutral hydrogen in the IGM.
2. This information is imprinted in the 21-cm bias.
3. UVB is regulated by the MFP implementation.
4. This effect is also observed in the Laα transmission.

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