Constraining High-z radio clustering and 21-cm signature of radio galaxies at cosmic dawn

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EDGES signal and Non-standard models

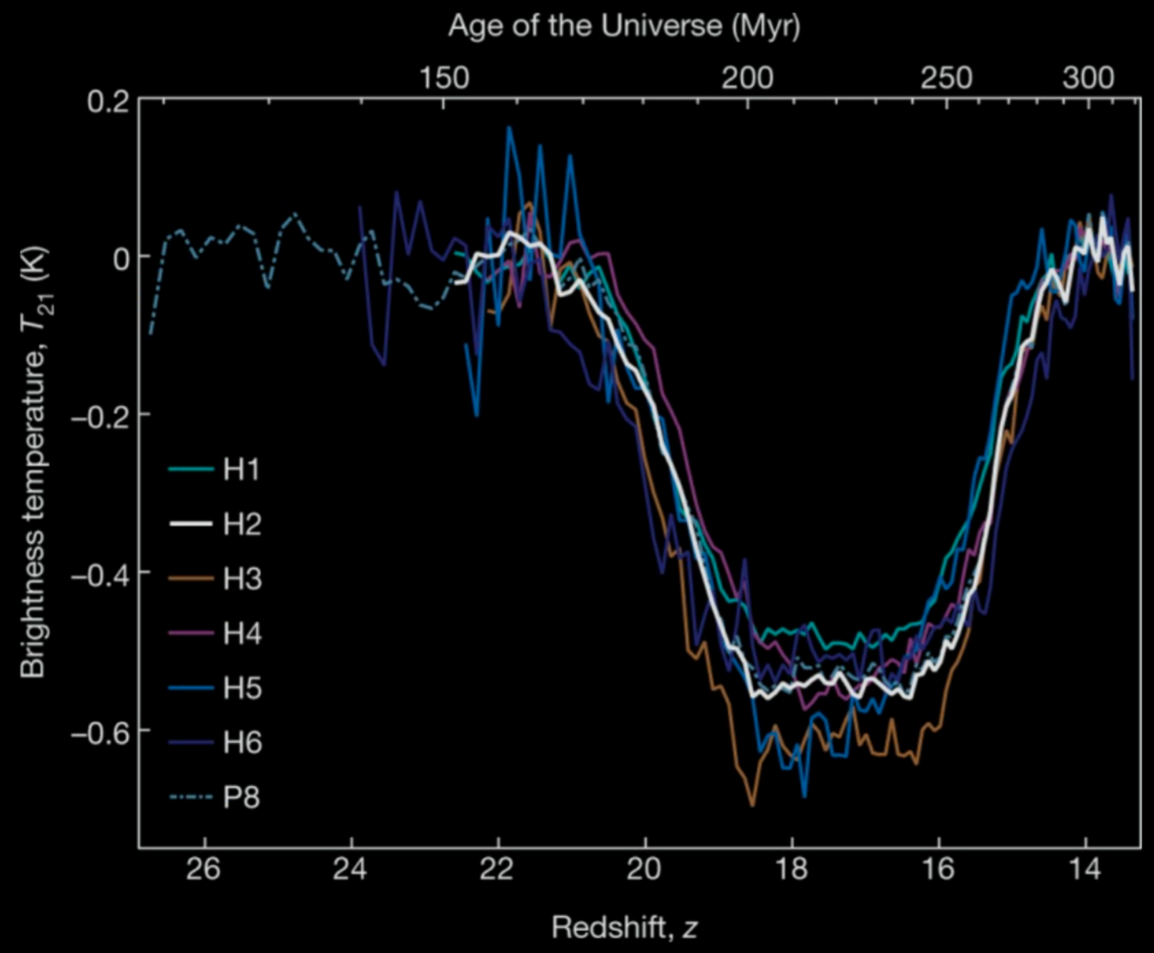
$$T_{21} \propto \left(\frac{T_S - T_{CMB}}{T_S} \right)$$

$T_S < T_{S,expected}$

Coupling of gas to DM ?

$T_{CMB} > T_{CMB,expected}$

Excess radio background over CMB ?



Bowman et al. (2018)

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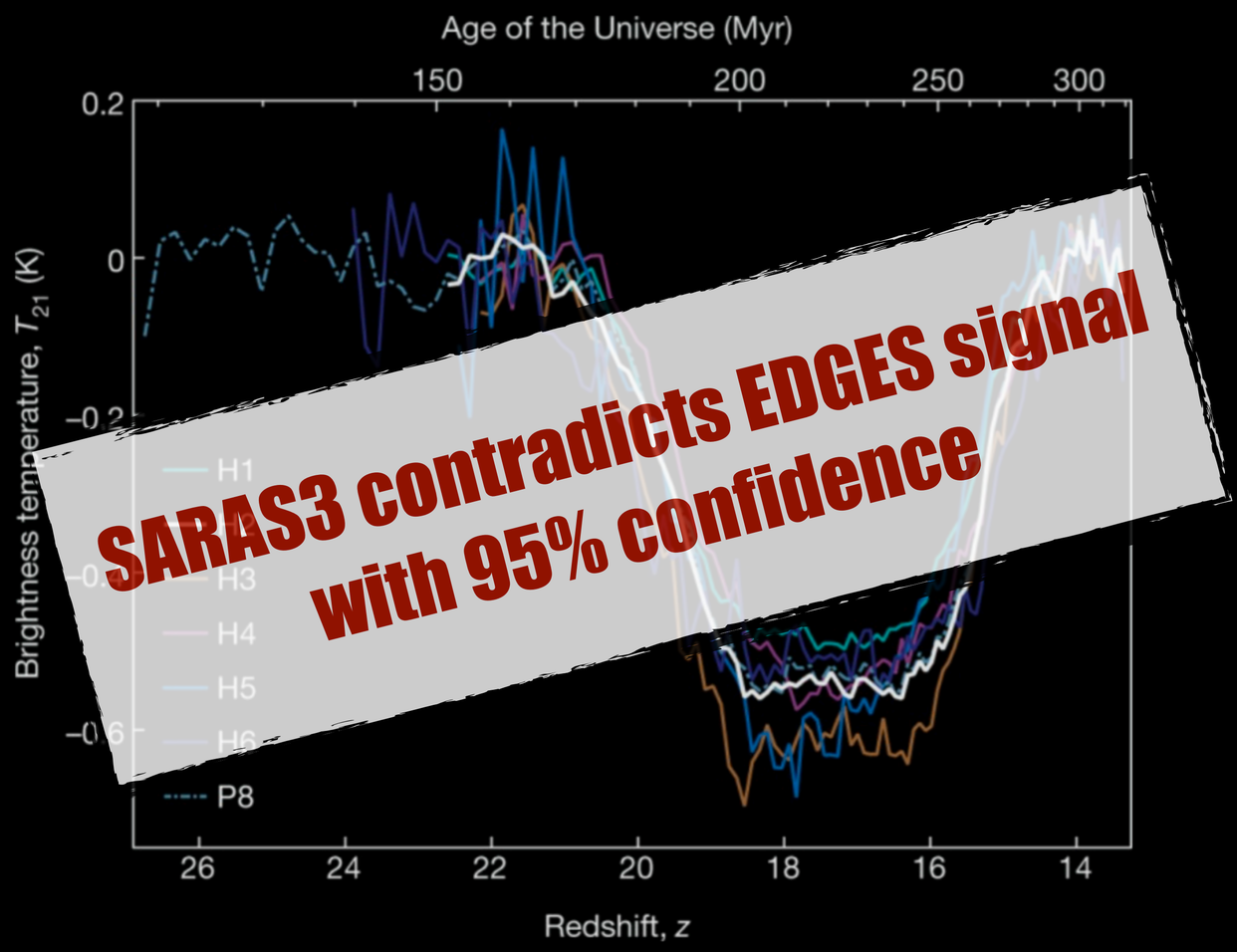

Bowman et al. (2018)

Observed excess radio background

Evidence of excess radio background:

Detected by ARCADE-2	Fixsen et al. (2011)
Confirmed by LWA-1	Dowell & Taylor (2018)

The observed excess radio could be explained by extragalactic sources

The effect of radio fluctuations on 21-cm signal

The effect of inhomogeneous radio background on the 21-cm signal

Reis et al. (2020)

Approximation: Isotropically-averaged radio intensity

The effect of radio fluctuations on 21-cm signal

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Reis et al. (2020)

Approximation:

Isotropically-averaged radio intensity

Accurate in the limit of many radio sources

LoS effect of radio background from galaxies

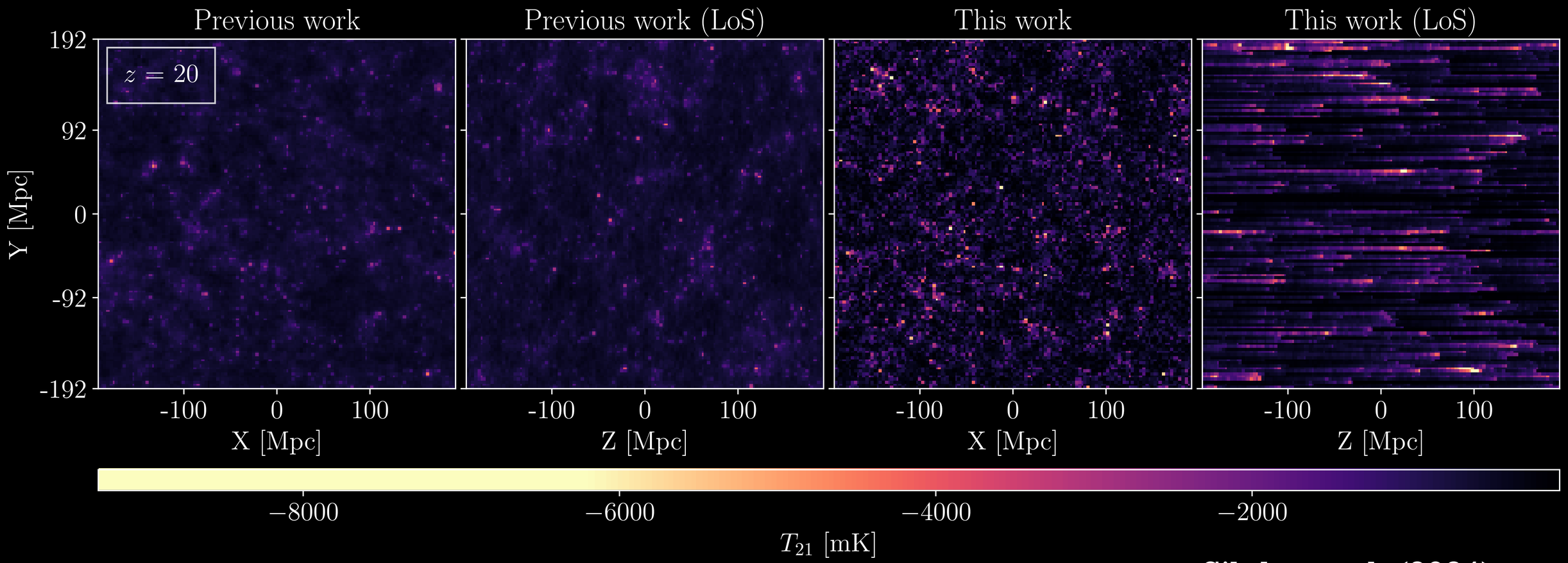
Full calculation :

$$T_{21} = \frac{T_S - \left(T_{R,\mathrm{los}} + T_{\mathrm{CMB}}\right)}{1+z}\left(1 - e^{-\tau_{21}}\right)$$

$T_{\mathrm{R,los}}$ is the brightness temperature of the radio background from sources lying behind the pixel along our LoS

The effect of radio intensity from background radio emitting galaxies that lie behind the cloud along our LoS

LoS effect of radio background from galaxies



Sikder et al. (2024)

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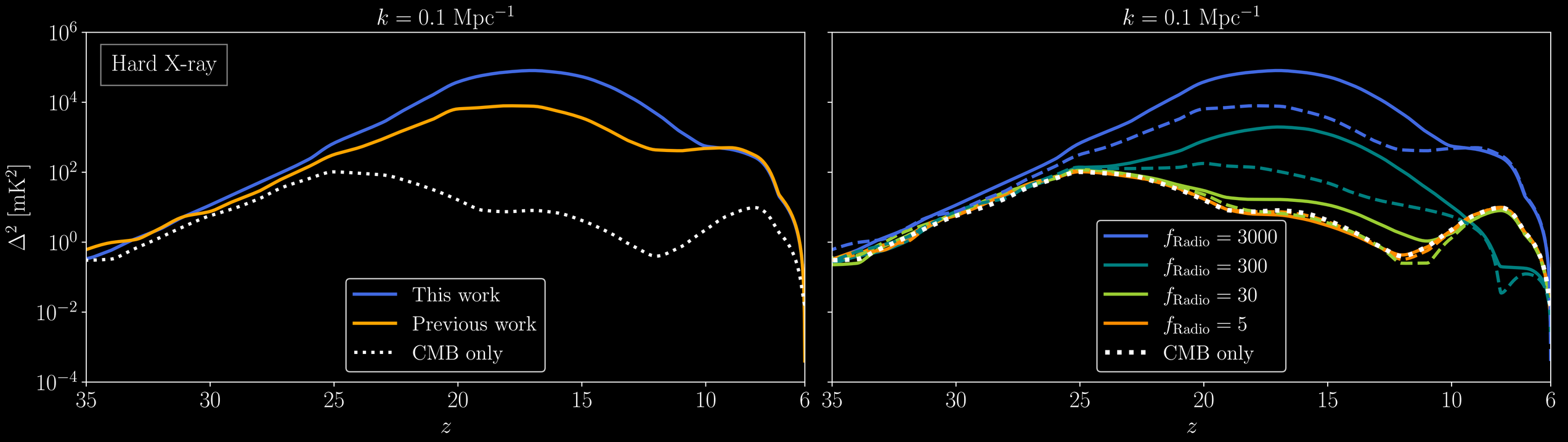

Enhancement in 21-cm power spectrum during cosmic dawn

Sikder et al. (2024)

Radio background: Mean level and clustering

$$T_{21}^{\mathrm{Full}} = \frac{\left(T_{R,\mathrm{los}} + T_{\mathrm{CMB}}\right) e^{-\tau_{21}} + T_S\left(1 - e^{-\tau_{21}}\right) - T_{\mathrm{CMB}}}{1+z}$$

$\tau_{21} = 0$ term :

$$T_{21}^{\tau=0} = \frac{T_{\mathrm{R,los}}}{1+z}$$

Independent of 21-cm absorption or emission

Strongly dominates the overall background

Radio background: Mean level and clustering

Maximum radio background from unresolved sources:

$$T_{\rm excess} = T_{\rm arcade} - T_{\rm counts}$$

Holder (2014)

$$f_{\rm Radio}^{\rm mean}(z) = \frac{T_{\rm excess}(z)}{\langle T_{21}^{f_{\rm Radio}=1}(z)\rangle}$$

$\langle T_{21}^{f_{\rm Radio}=1}(z)\rangle$ is the mean brightness temperature from the radio background at the redshifted wavelength of 21-cm radiation, in a simulation with $f_{\rm Radio} = 1$

Radio background: Mean level and clustering

CMB anisotropy searches using VLA and ATCA → Upper limits on the CRB clustering

Two sets of observational data:

1. 8.7 GHz from ATCA
2. 4.86 GHz from VLA

Subrahmanyan et al. (2000)
Fomalont et al. (1988)

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Observed upper limits on clustering **&** Dimensionless angular fluctuations of the excess radio background

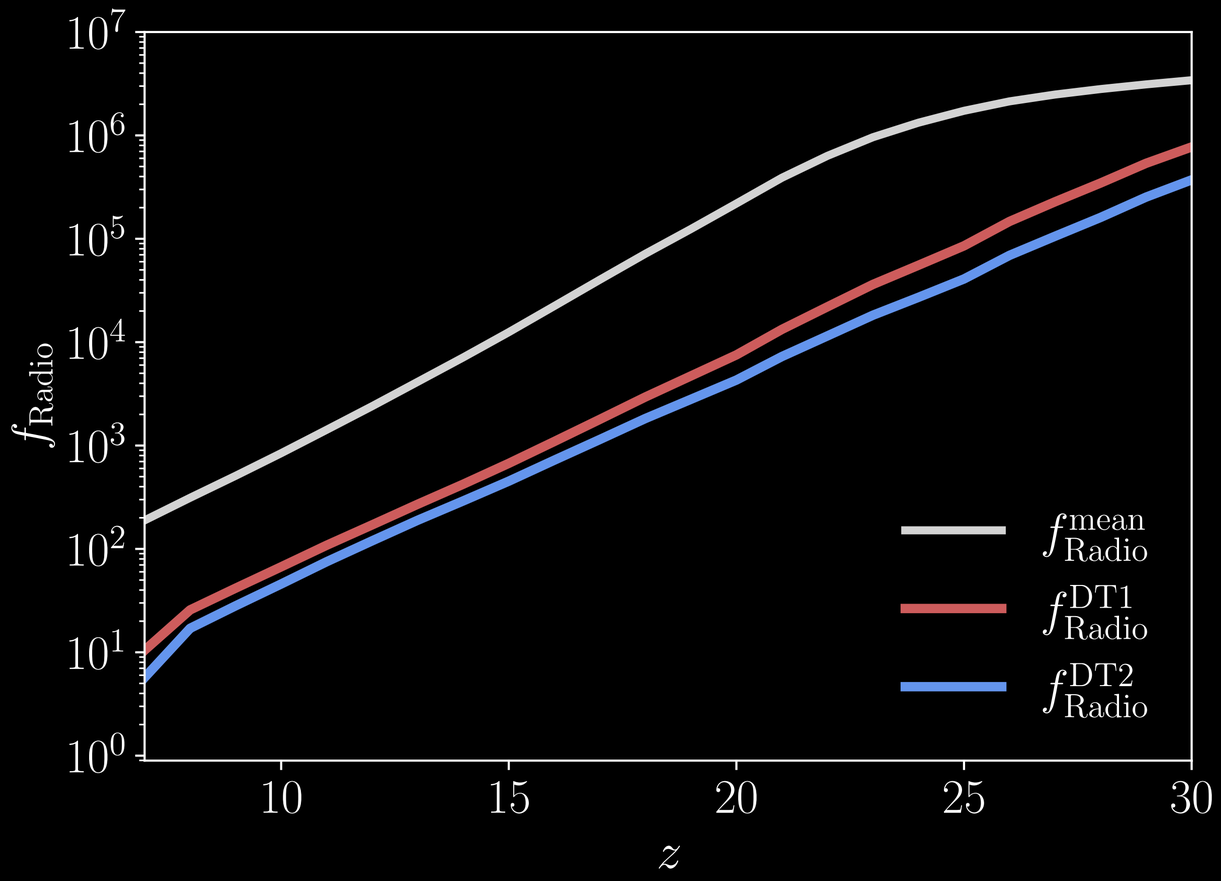
→ **Upper limits on f_{Radio}**

Radio background: Mean level and clustering

$f_{\rm Radio}^{\rm mean}$: upper limit from ARCADE-2

$f_{\rm Radio}^{\rm DT1}$: upper limit from ATCA

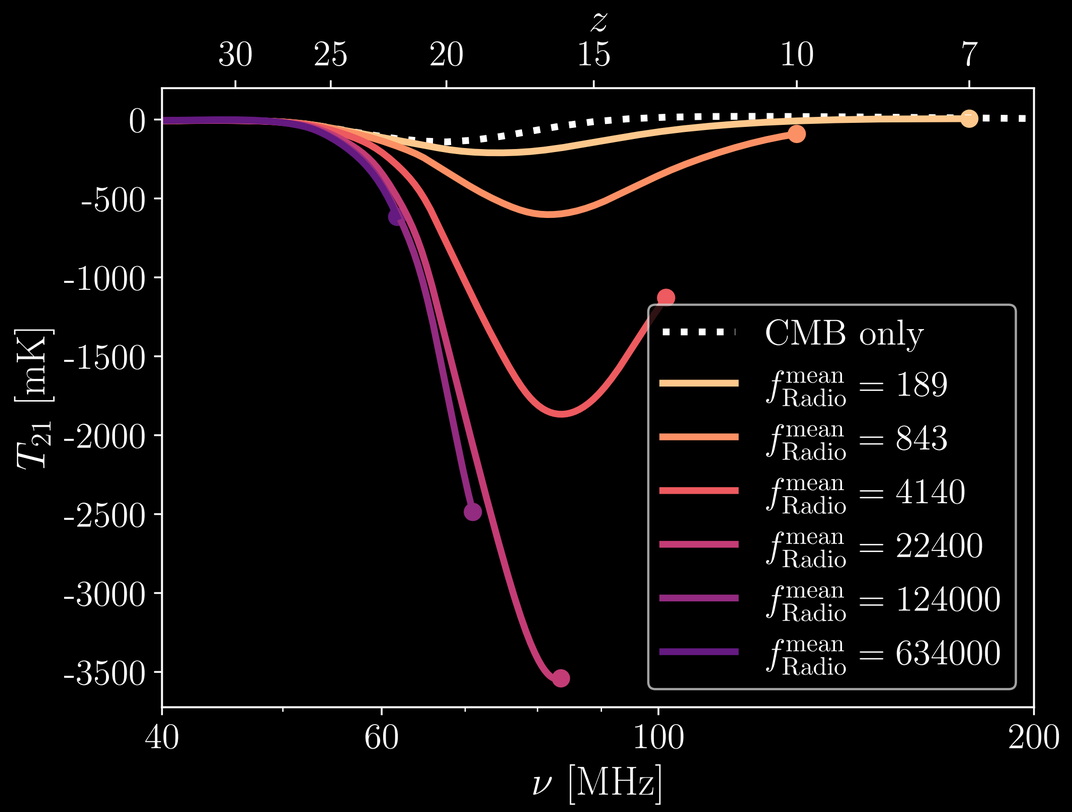
$f_{\rm Radio}^{\rm DT2}$: upper limit from VLA



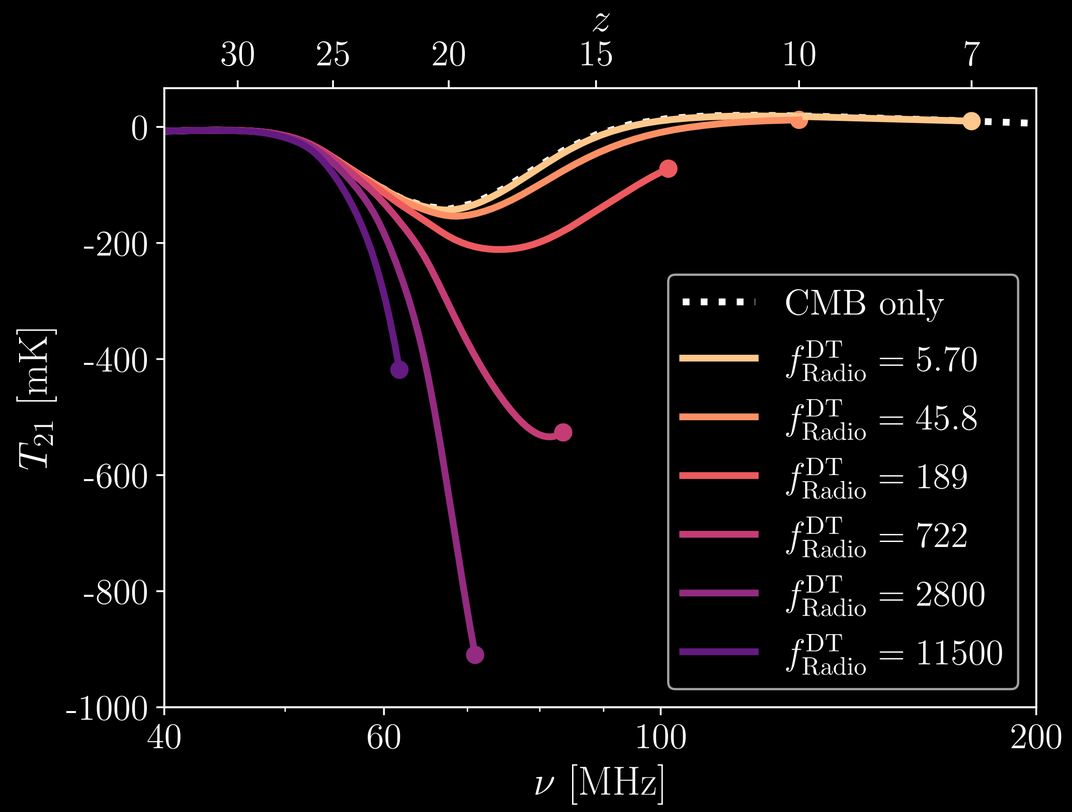
Sikder +, ApJL (accepted)

Consequences for the 21-cm signal

Mean radio background



Radio clustering



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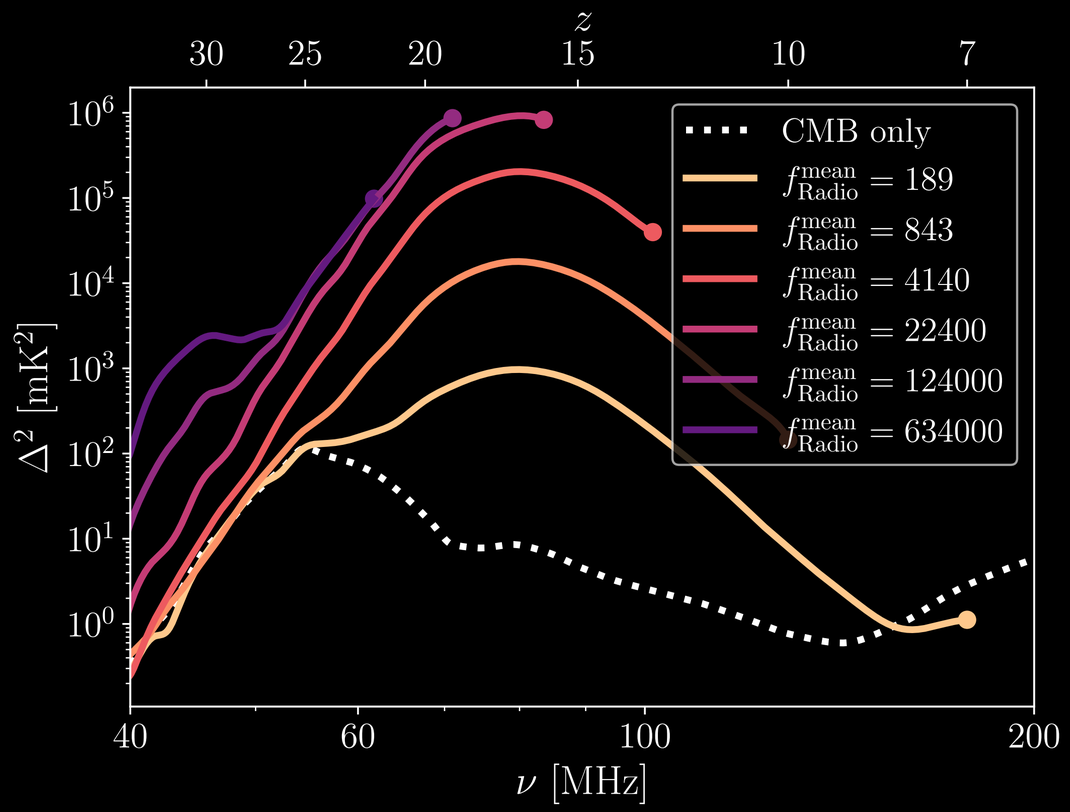

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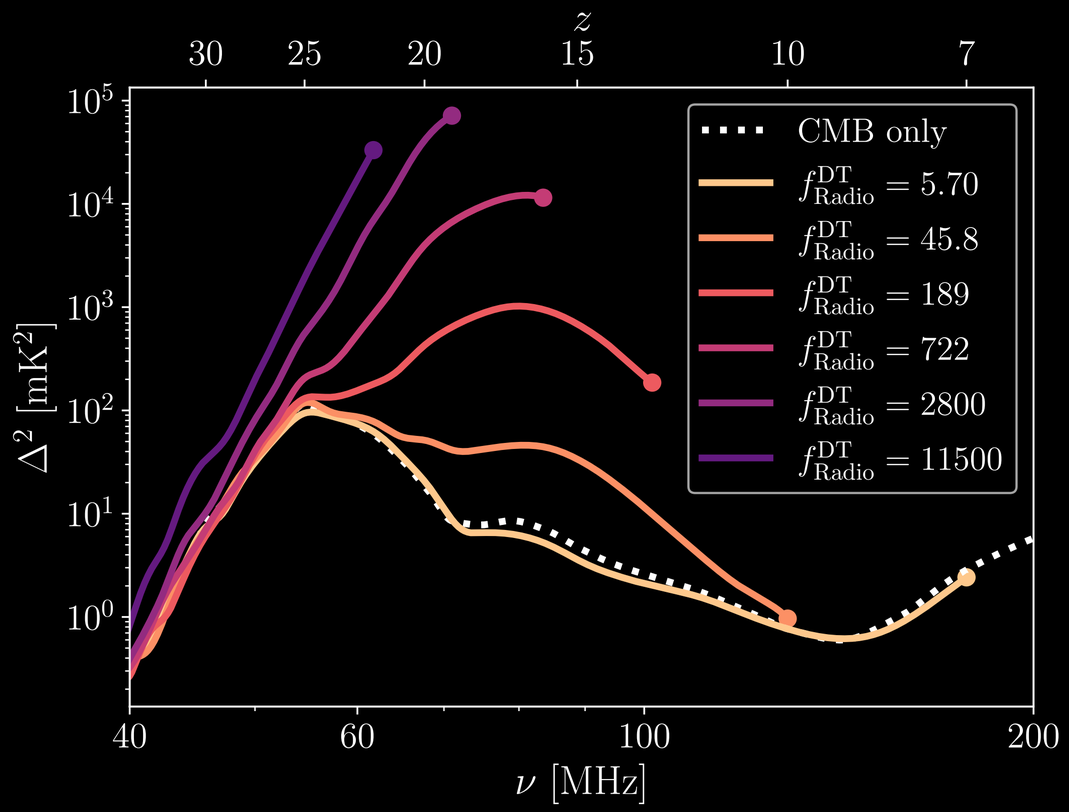

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Summary

- New constraints on astrophysical models of high-redshift galaxies with a high efficiency of radio emission.
- Observational constraints on the overall intensity of cosmic radio background as well as its clustering.
- The clustering constraints on the radio efficiency is stronger than those from the overall background intensity.
- Include the constraints from radio clustering when considering current and upcoming 21-cm experiments.