Shedding new light on the first billion years of the Universe

Can we see Pop III stars and mini-halos during the Epoch of Reionization?

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DRAGONS

Dark-ages, Reionization And Galaxy-formation Observable Numerical Simulation

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Maybe if we use the

21cm global signal from Cosmic Dawn

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21cm signal from Cosmic Dawn

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The role of Pop III stars and early black holes in the 21-cm signal from Cosmic Dawn

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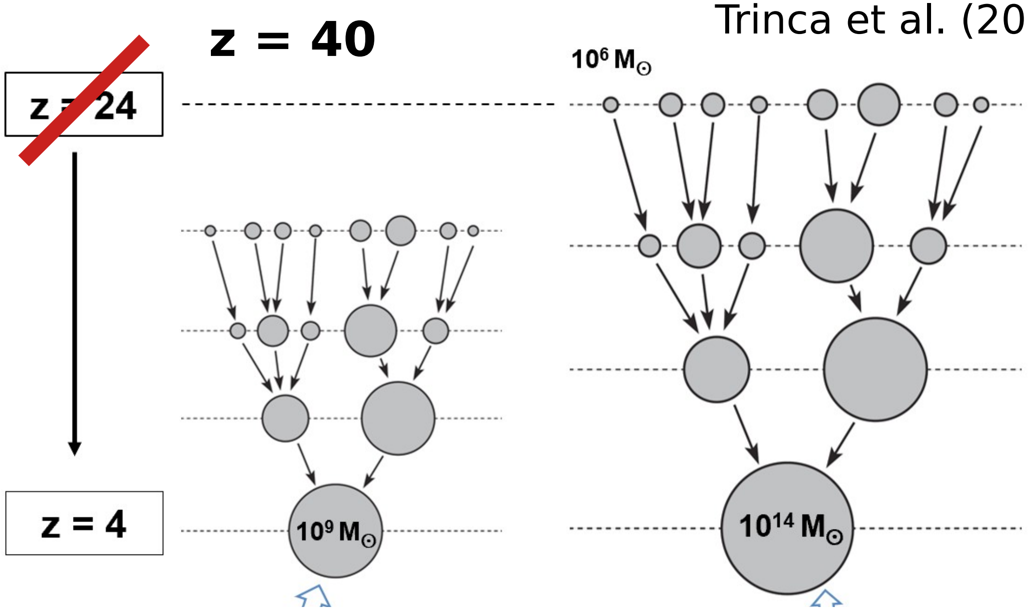
ABSTRACT

Modeling the 21-cm global signal from the Cosmic Dawn is challenging due to the many poorly constrained physical processes that come into play. We address this problem using the semi-analytical code 'Cosmic Archaeology Tool' (CAT). CAT follows the evolution of dark matter haloes tracking their merger history and provides an ab initio description of their baryonic evolution, starting from the formation of the first (Pop III) stars and black holes (BHs) in mini-haloes at $z > 20$. The model is anchored to observations of galaxies and AGN at $z < 6$ and predicts a reionization history consistent with constraints. In this work, we compute the evolution of the mean global 21-cm signal between $4 \leq z \leq 40$ based on the rate of formation and emission properties of stars and accreting BHs. We obtain an absorption profile with a maximum depth $\delta T_b = -95$ mK at $z \sim 26.5$ (54 MHz). This feature is quickly suppressed turning into an emission signal at $z = 20$ due to the contribution of accreting BHs that efficiently heat the intergalactic medium (IGM) at $z < 27$. The high-z absorption feature is caused by the early coupling between the spin and kinetic temperature of the IGM induced by Pop III star formation episodes in mini-haloes. Once we account for an additional radio background from early BHs, we are able to reproduce the timing and the depth of the EDGES signal only if we consider a smaller X-ray background from accreting BHs, but not the shape.

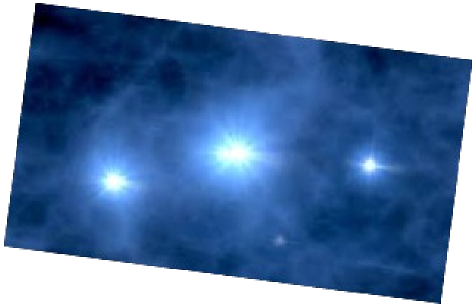
Key words: quasars: supermassive black holes – galaxies: high-redshift – cosmology – dark ages, reionization, first stars.

Cosmic Archaeology Tool (CAT)

Trinca et al. (2022)

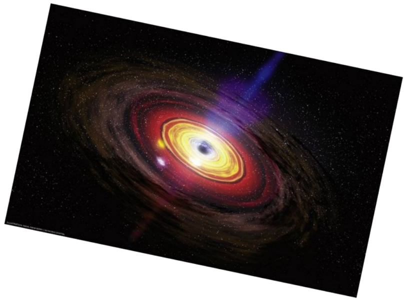


- Semi-analytical model based on the well tested **GameteQSOdust** *(Valiante et al. 2011,2012, 2016, Sassano et al. 2021)*
- Reconstruct the evolution of a statistical sample of the **galaxy population** over the first billion years of cosmic history
- $M\,halo \in [\mathbf{10^6}, \mathbf{10^{14}}]\,\mathbf{M_{sun}}$



Pop III stars

Pop II stars



Early accreting BHs

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Cosmic Archaeology Tool (CAT)

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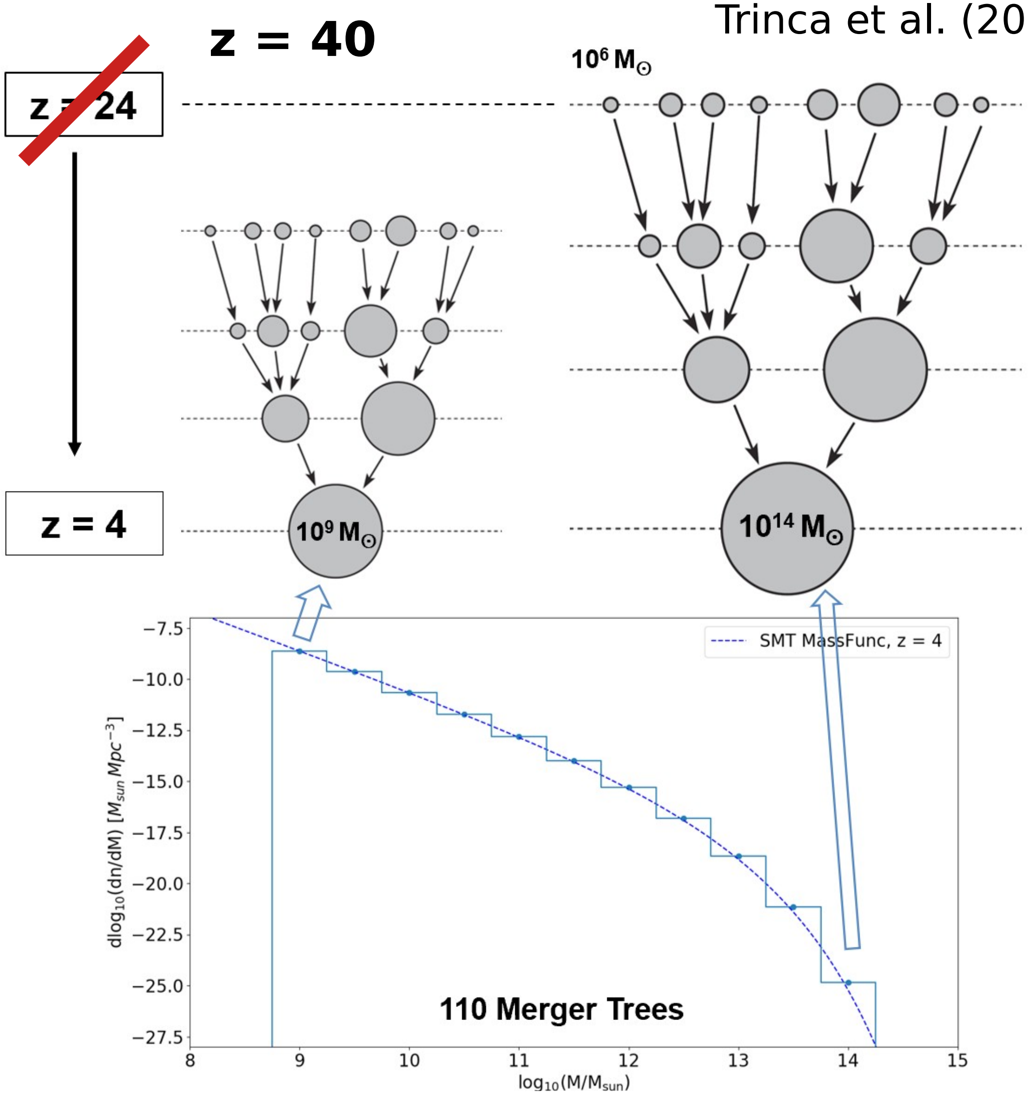

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- Reconstruct the evolution of a **statistical sample** of the **galaxy population** over the first billion years of cosmic history
- $M_{halo} \in [10^6, 10^{14}] M_{sun}$

To retrieve the global history of the Universe, weight halo merger trees with the halo mass function.

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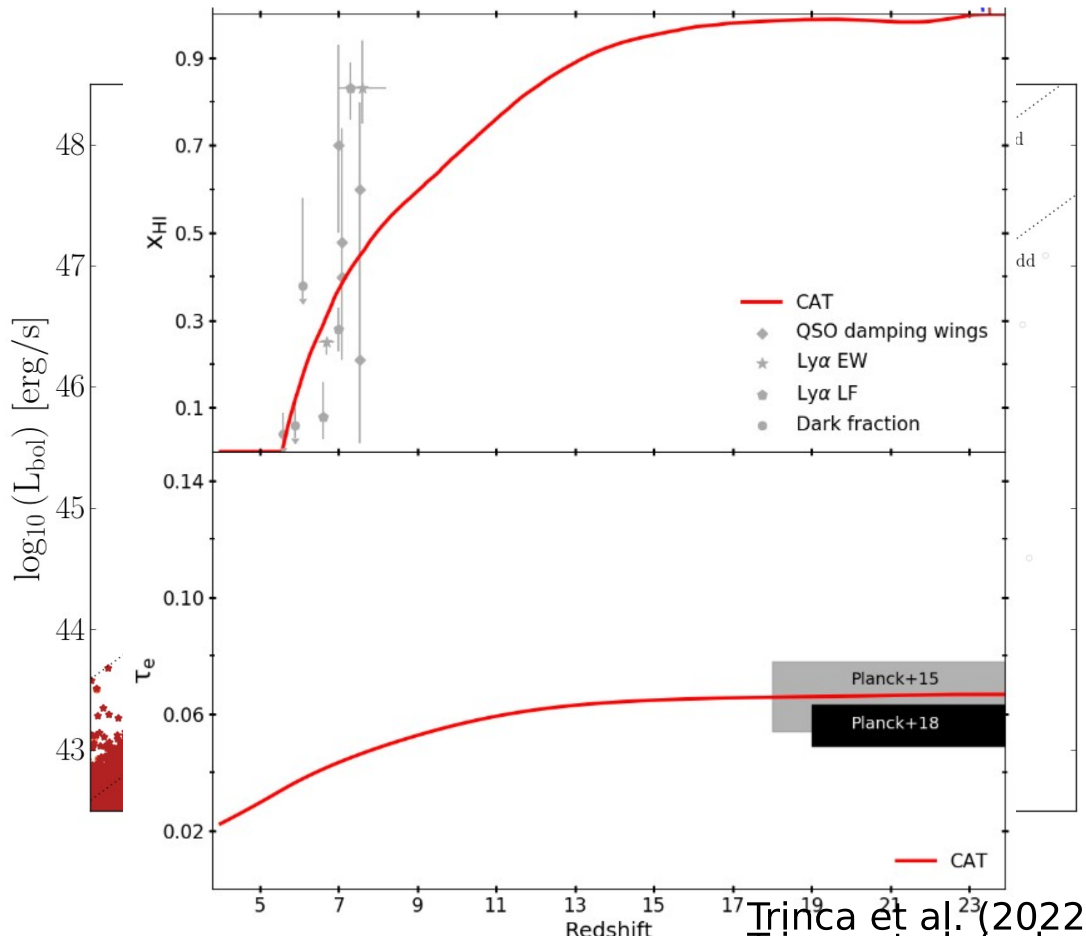
Model Calibration

The model is calibrated to reproduce at the same time:

- **Cosmic Star Formation history.**
- **Properties of high-z quasars.**
- **Reionization histories**



Trinca et al. (2022)
Trinca et al. (subm)

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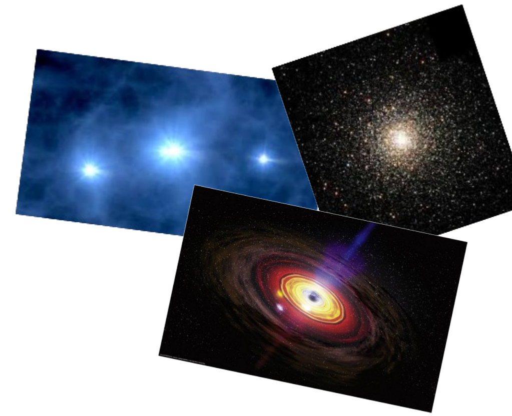
21cm signal with CAT

$$\delta T_{\rm b} = 27\, x_{\rm HI}(1+\delta)\left(\frac{\Omega_{\rm b}h^2}{0.023}\right)\left(\frac{0.15}{\Omega_{\rm m}h^2}\frac{1+z}{10}\right)^{1/2} \times \left(\frac{T_{\rm S}-T_\gamma}{T_{\rm S}}\right)\,{\rm mK},$$

$$T_{\rm S}^{-1} = \frac{T_\gamma^{-1} + x_\alpha T_{\rm c}^{-1} + x_{\rm c} T_{\rm K}^{-1}}{1 + x_\alpha + x_{\rm c}}$$



UV ionizing photons ($x_{\rm HI}$)

Radio photons (other than CMB) (T_γ)

Lyman-α photons (x_α)

X-ray photons (+ other effects) ($T_{\rm K}$)

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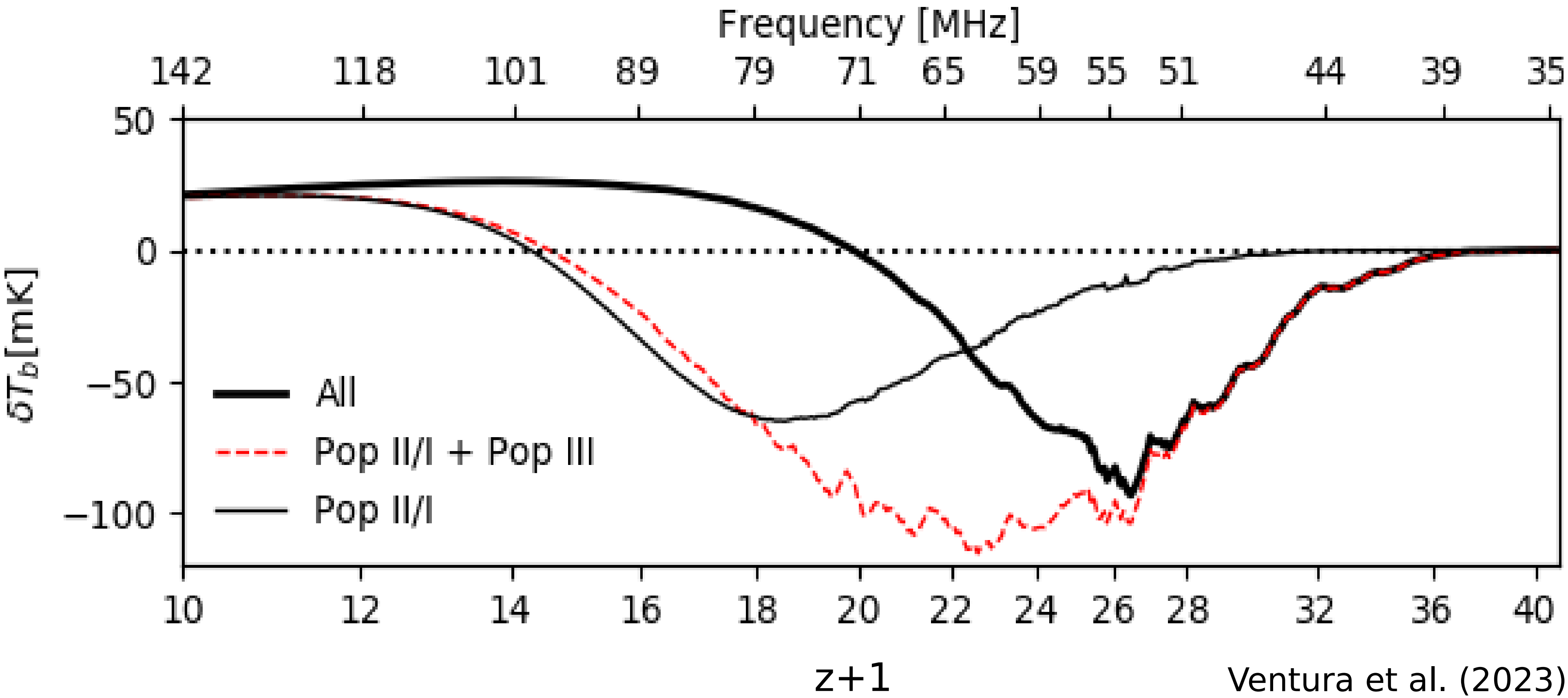
Anatomy of the signal



Ventura et al. (2023)

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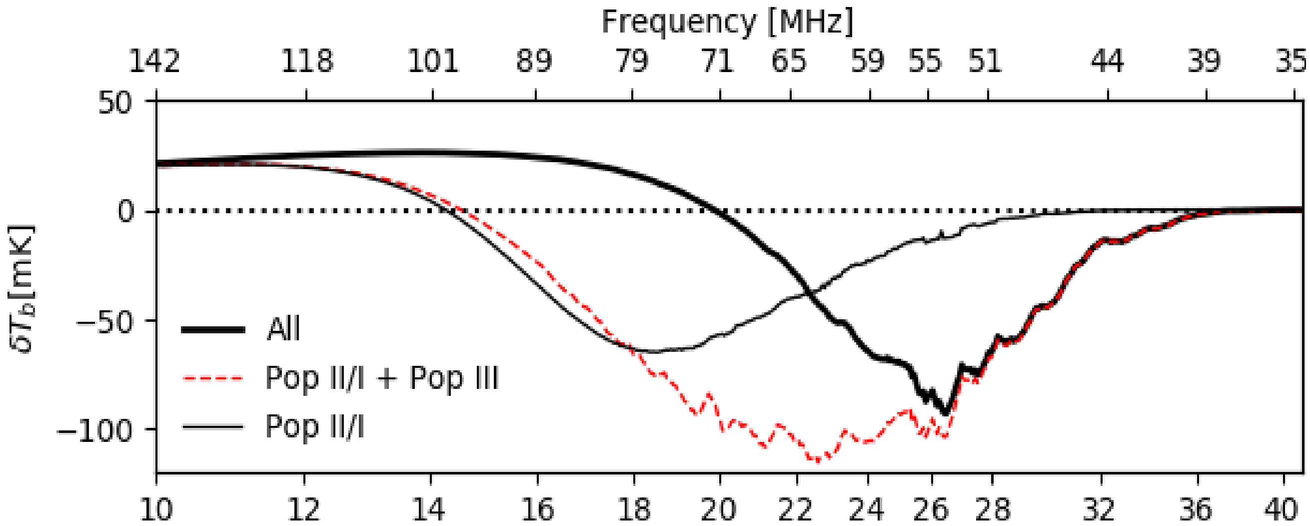
Impact of different sources



z+1 Ventura et al. (2023)

Pop II stars: Main contribution to both heating and Lyman-alpha coupling

→ “Classic” shape of the 21cm signal: strong absorption and shallow emission.

Pop III stars: Introduce an earlier and stronger Lyman-alpha coupling

→ Absorption at lower frequencies and deeper.

Accreting BHs: Introduce an earlier and stronger X-ray heating

→ Signal in absorption is suppressed faster.

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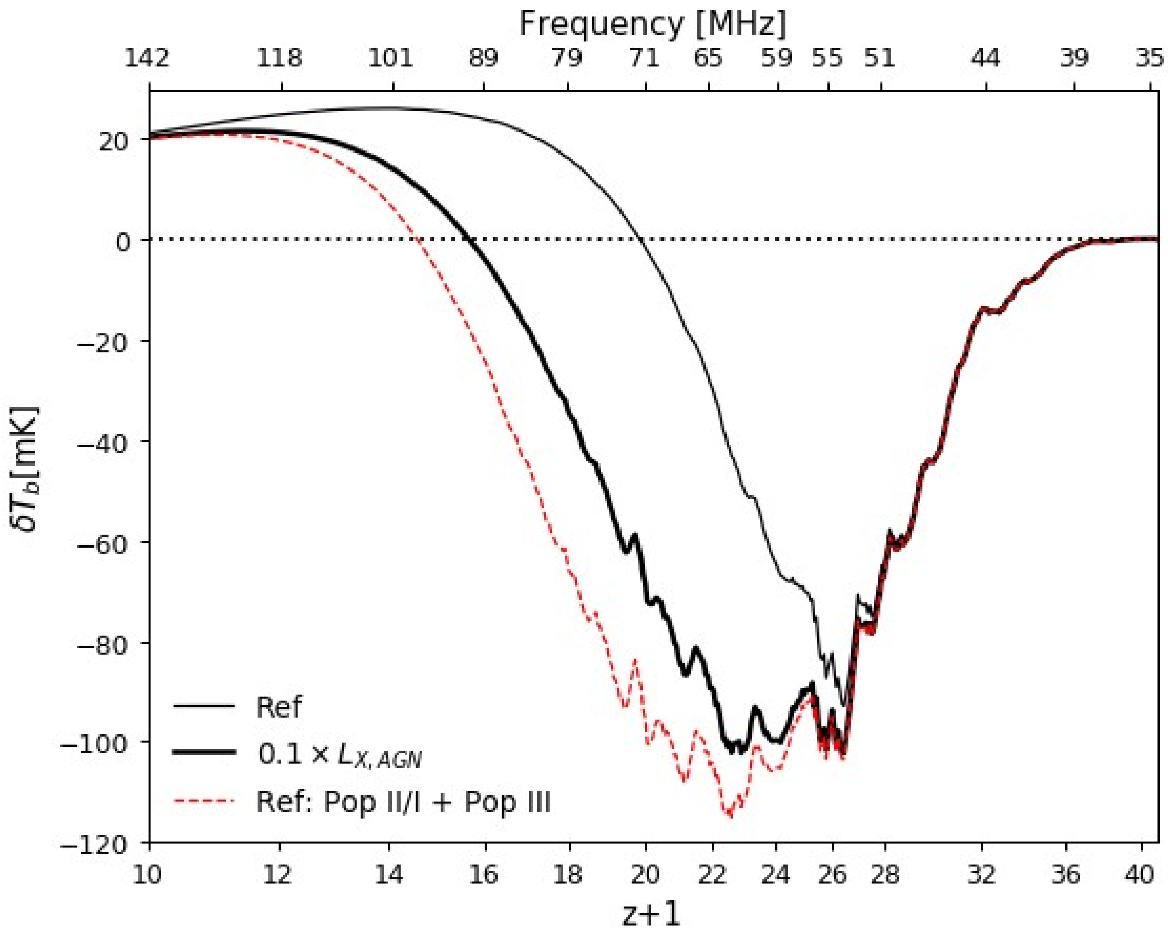
Accreting BHs

$L_{X,AGN} = L_{bol} / K_X$

$$K_{X,0.5-2keV} = c_1 \left(\frac{L_{bol}}{10^{10} L_\odot} \right)^{k_1} + c_2 \left(\frac{L_{bol}}{10^{10} L_\odot} \right)^{k_2},$$

Parameters calibrated at low z!



Impact of accreting BHs is still visible!

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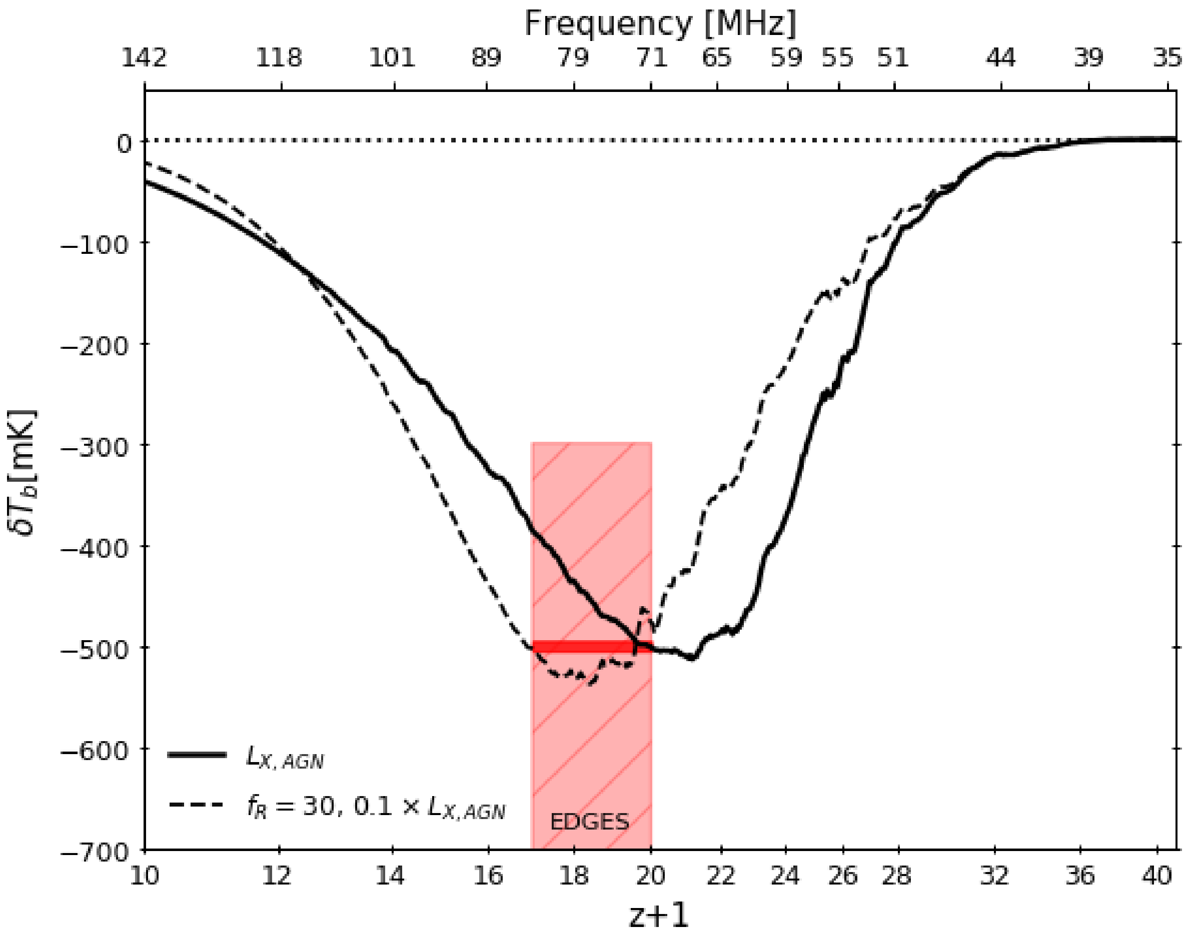
Additional Radio background

Early accreting BHs might emit in the radio band strongly enough to modify T_{rad}

More likely mechanism for BHs that are accreting at least 1% of their f_{edd}



Ventura et al. (2023)

Radio emissivity → ρ_{BH}, f_R

EDGES is rejected at 95.3% confidence level by recent observations of SARAS3
Singh et al. (2022)

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Conclusions

- **Each class of sources leaves a unique imprint on the 21cm global signal.**
- **With CAT we are able to compute their contribution to the main radiative backgrounds in a self-consistent way.**
- **Pop III stars introduce an earlier Lyman-α coupling shifting the deepest absorption of $\Delta z \approx 4$.**
- **Early accreting BHs heat up the IGM faster suppressing the absorption signal at $z > 16$.**

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Thank you!

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