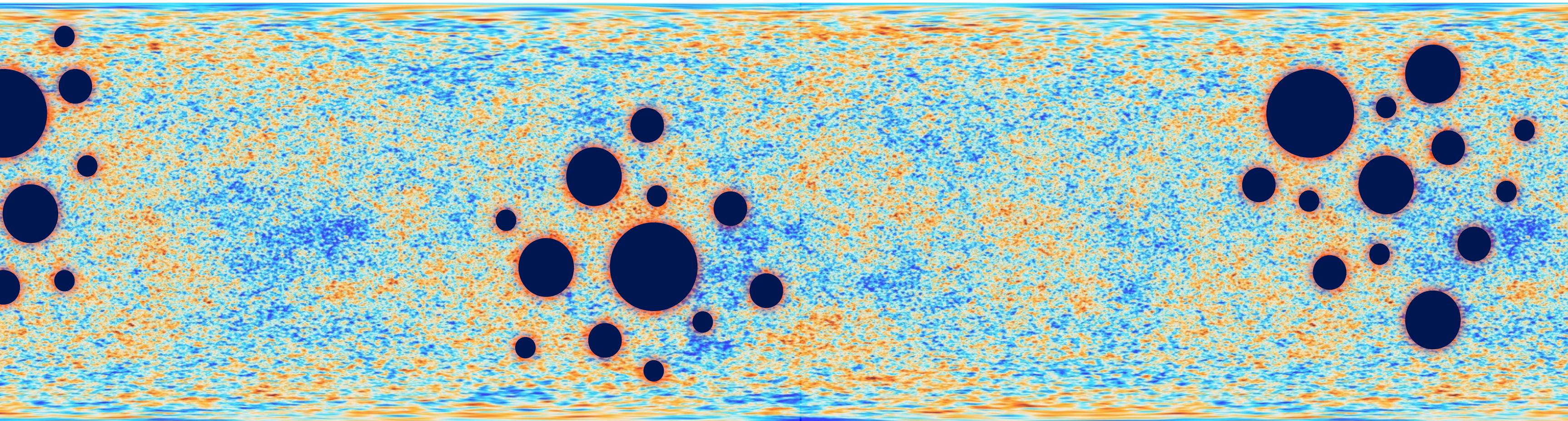


Probing the primordial power spectrum with dark matter minihalos and the CMB



Guillermo Franco Abellán



GRAPPA 
GRavitation AstroParticle Physics Amsterdam

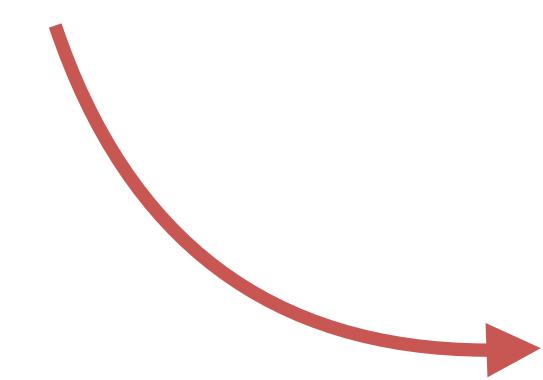
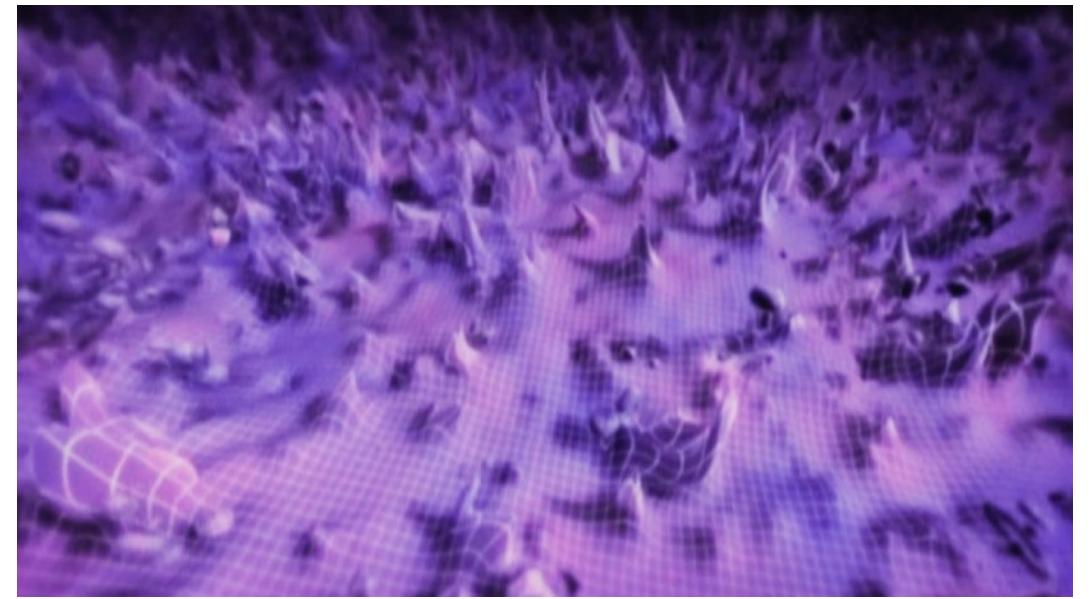
Based on: [arXiv:2304.02996](https://arxiv.org/abs/2304.02996)
with [Gaétan Facchinetti \(ULB\)](#)

PONT - 03/05/2023

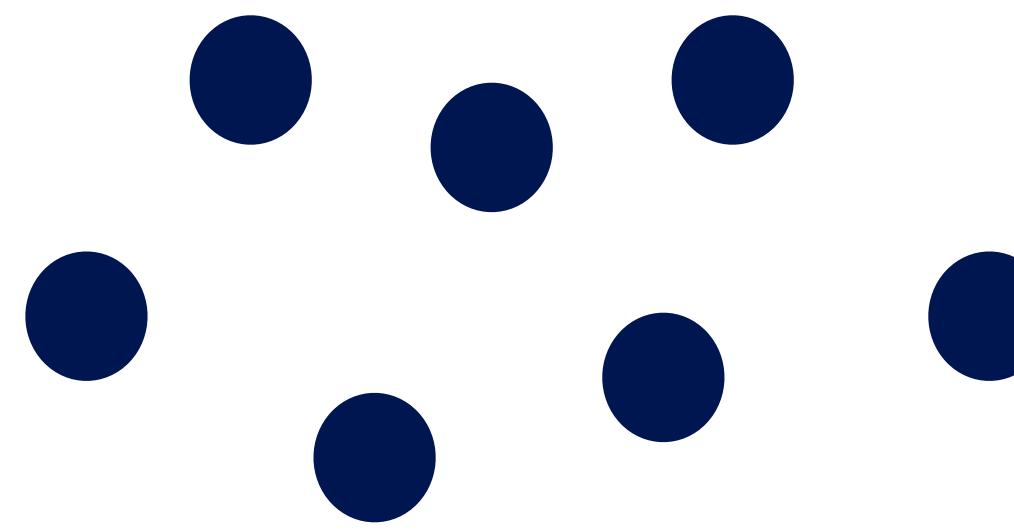
Primordial fluctuations



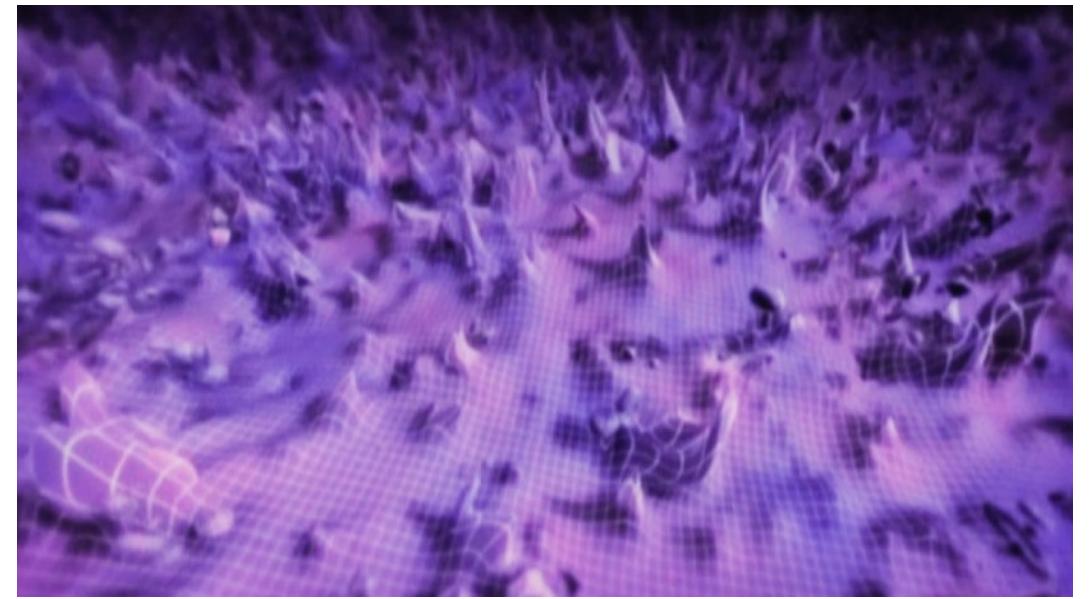
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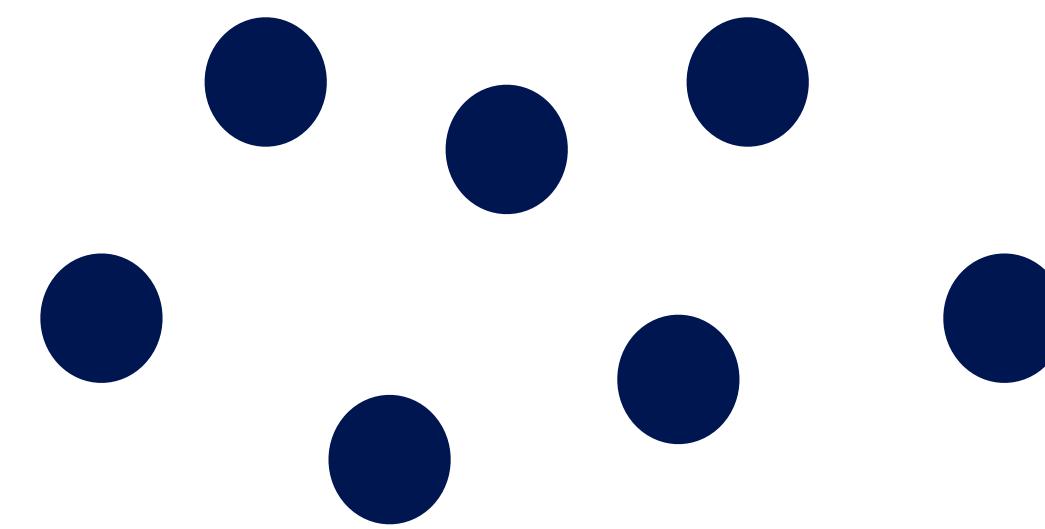
Halo collapse ($z \sim 30 - 100$)



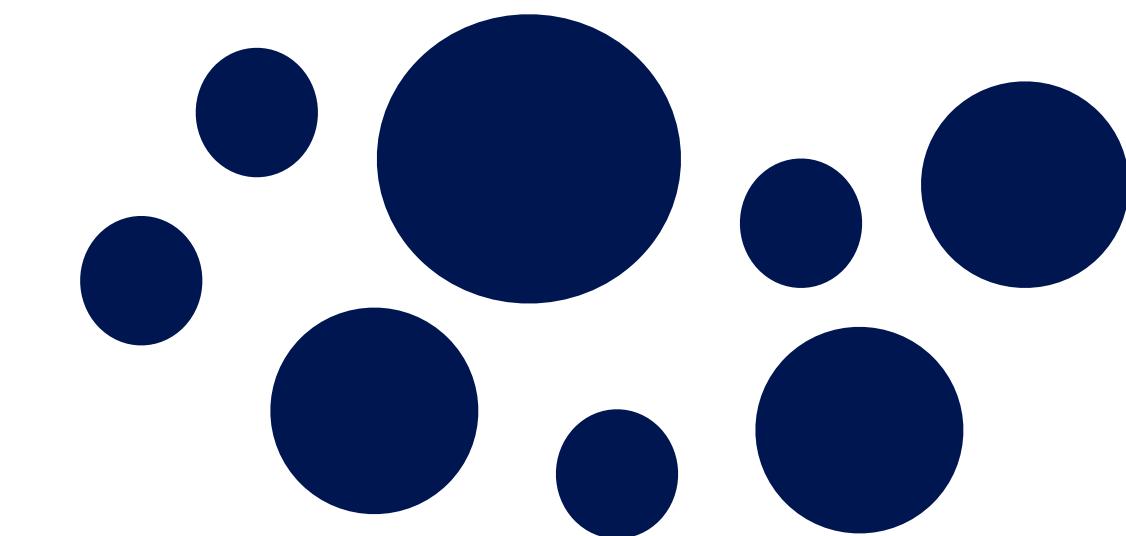
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Hierarchical growth



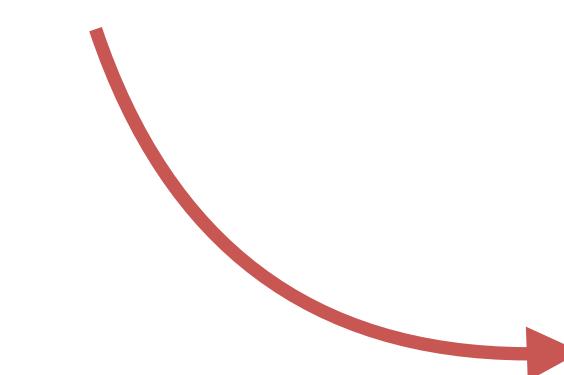
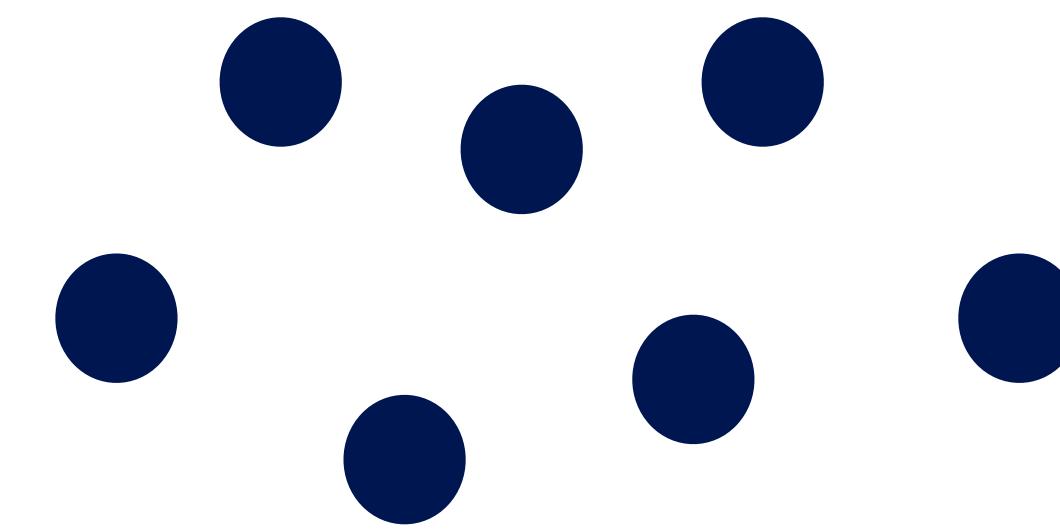
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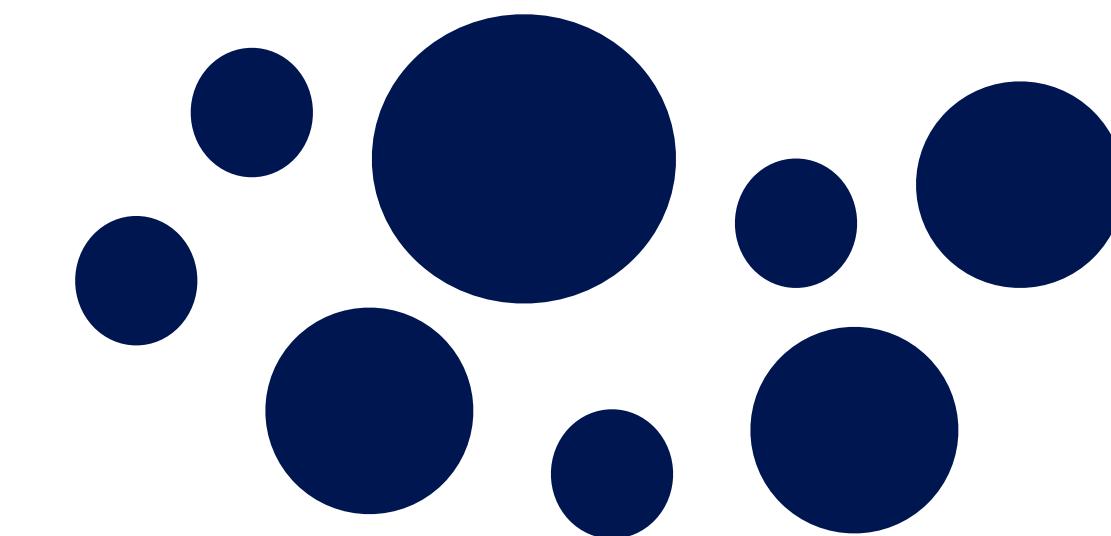
Primordial power spectrum

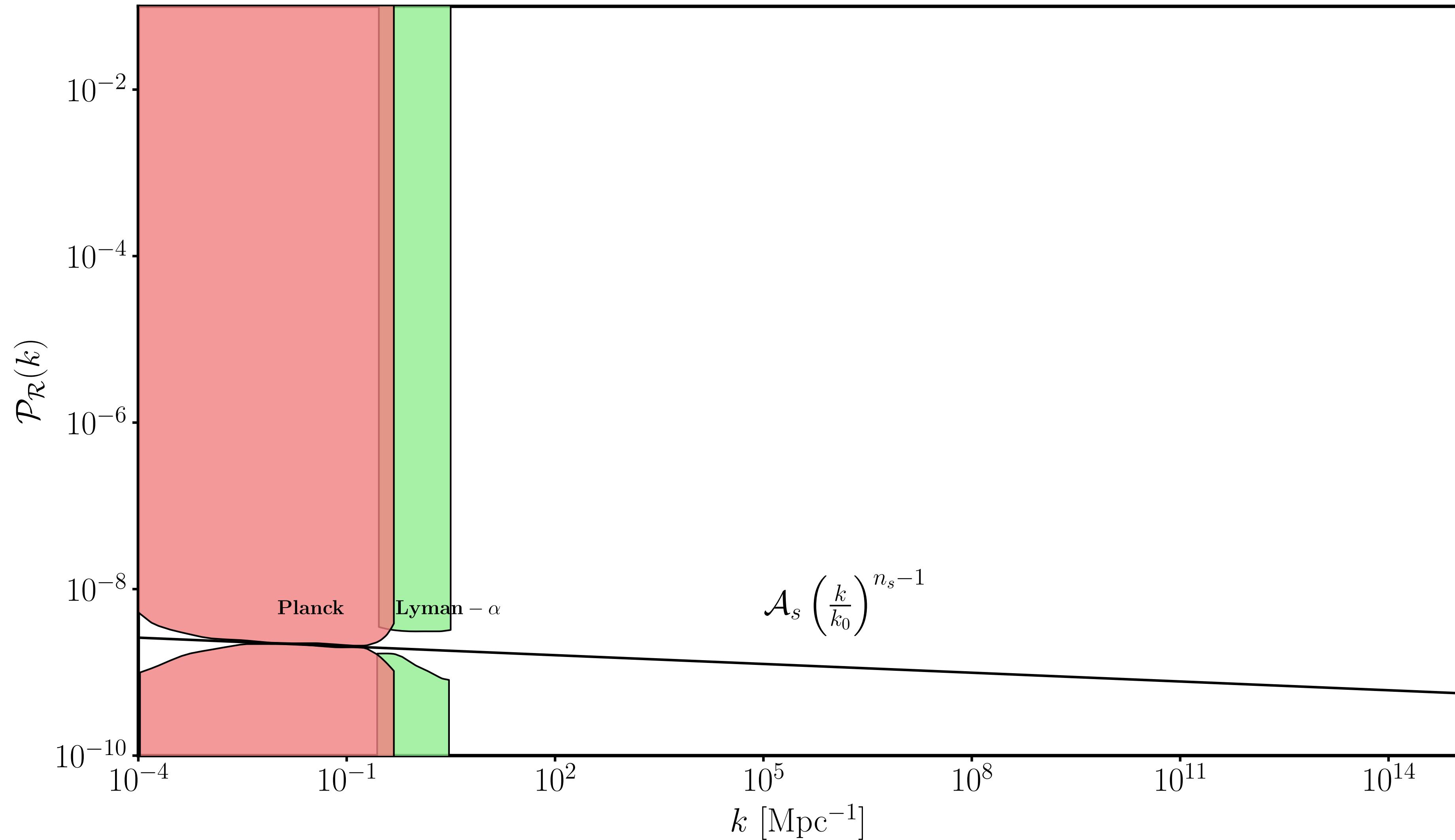
$$\mathcal{P}_{\mathcal{R}}(k)$$

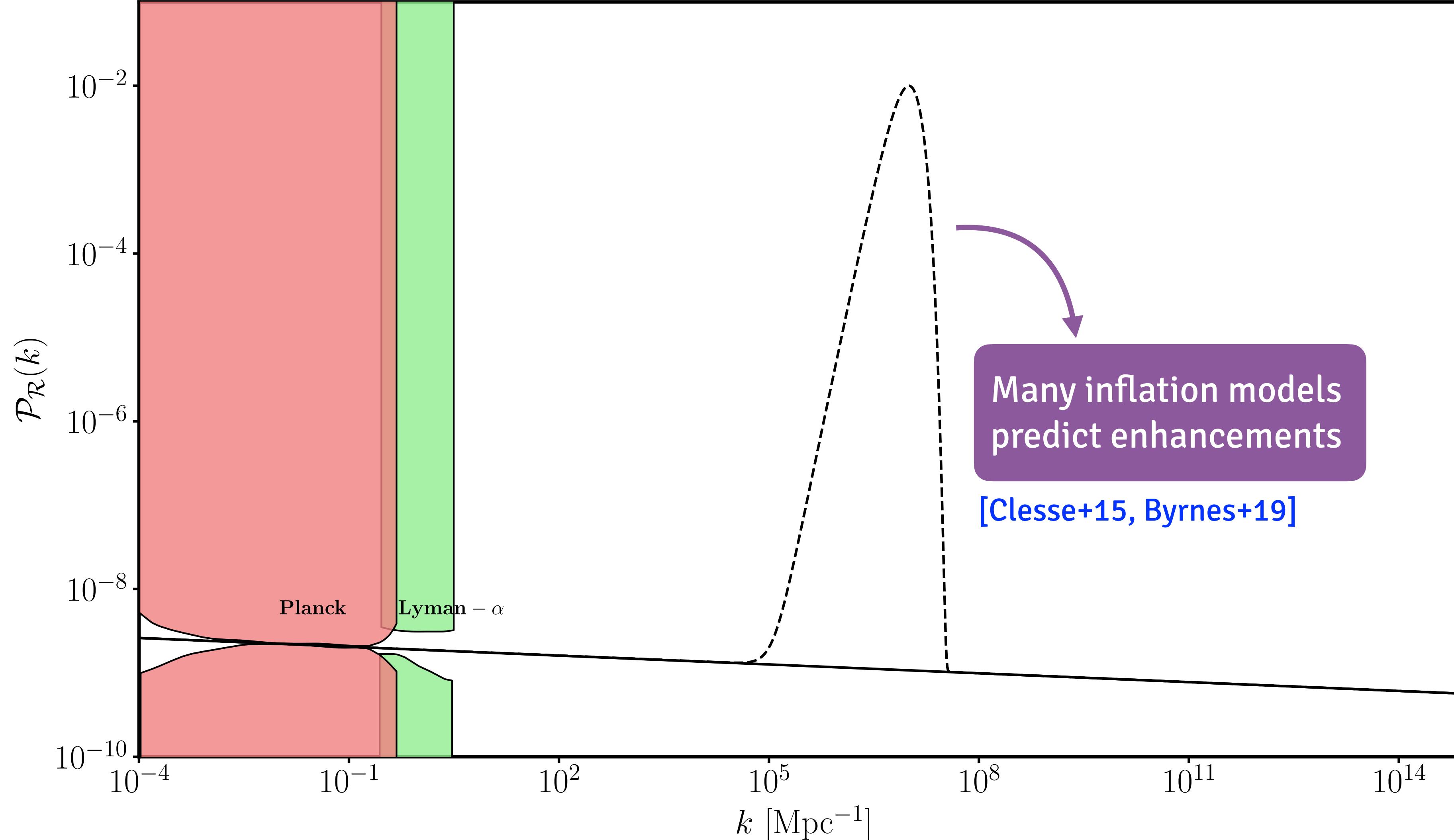
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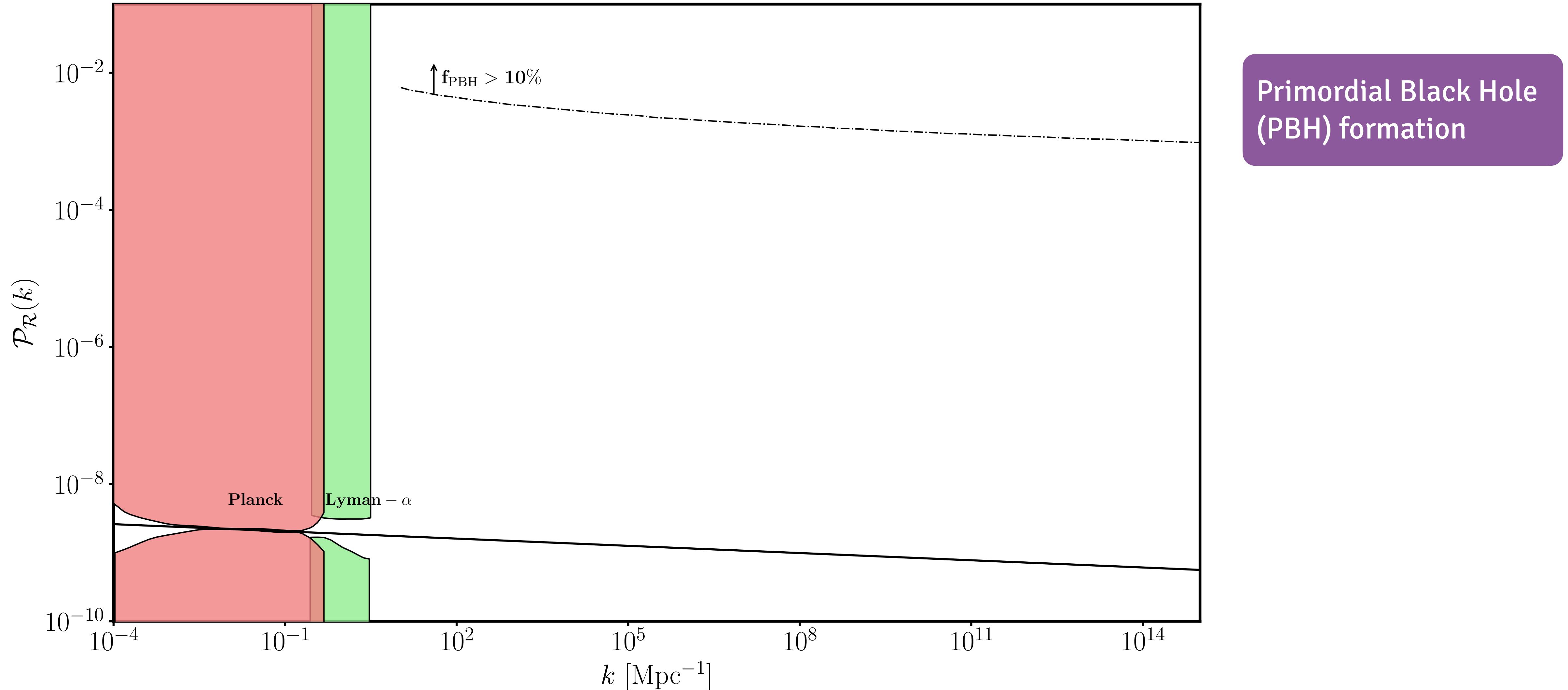


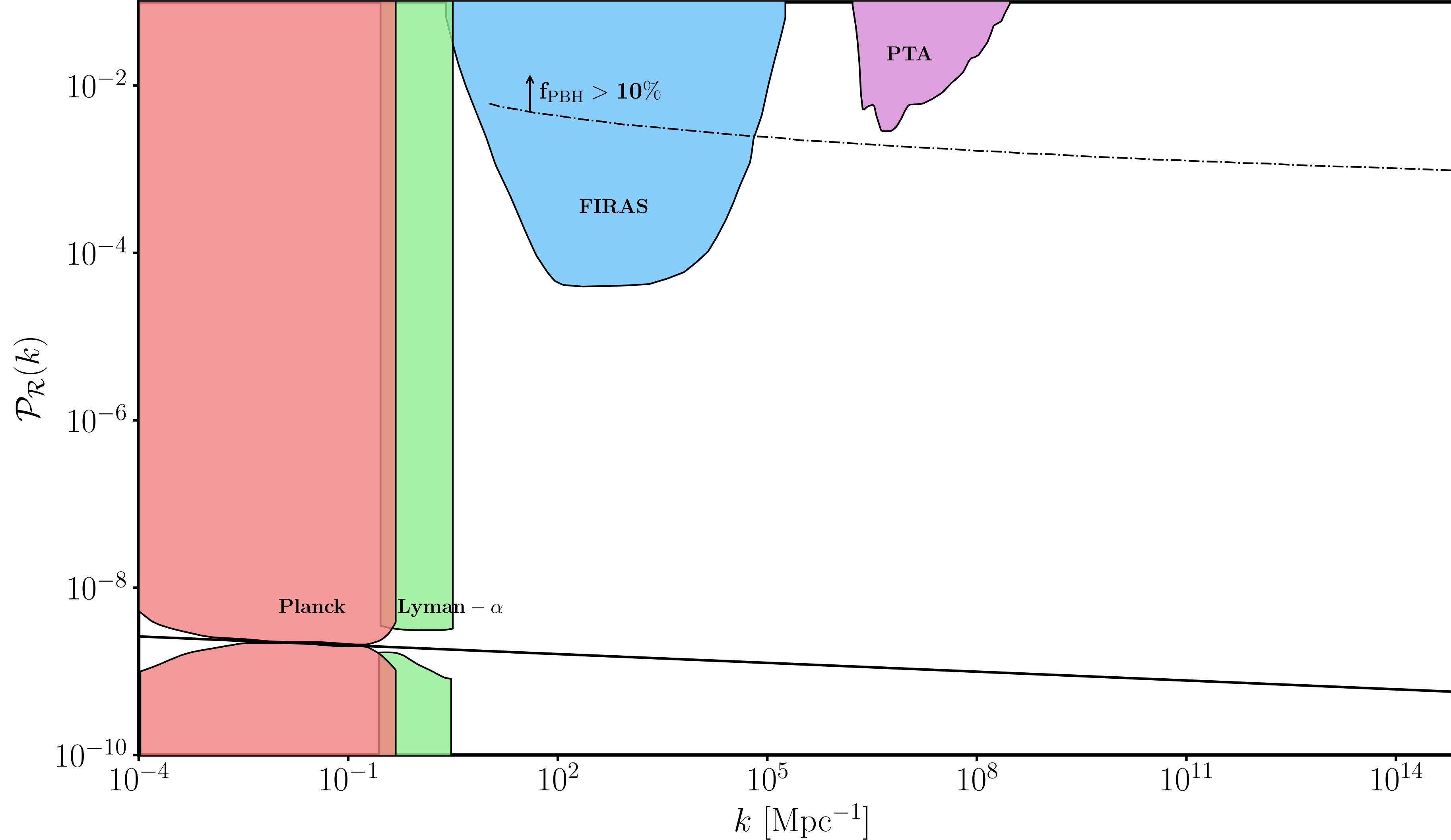
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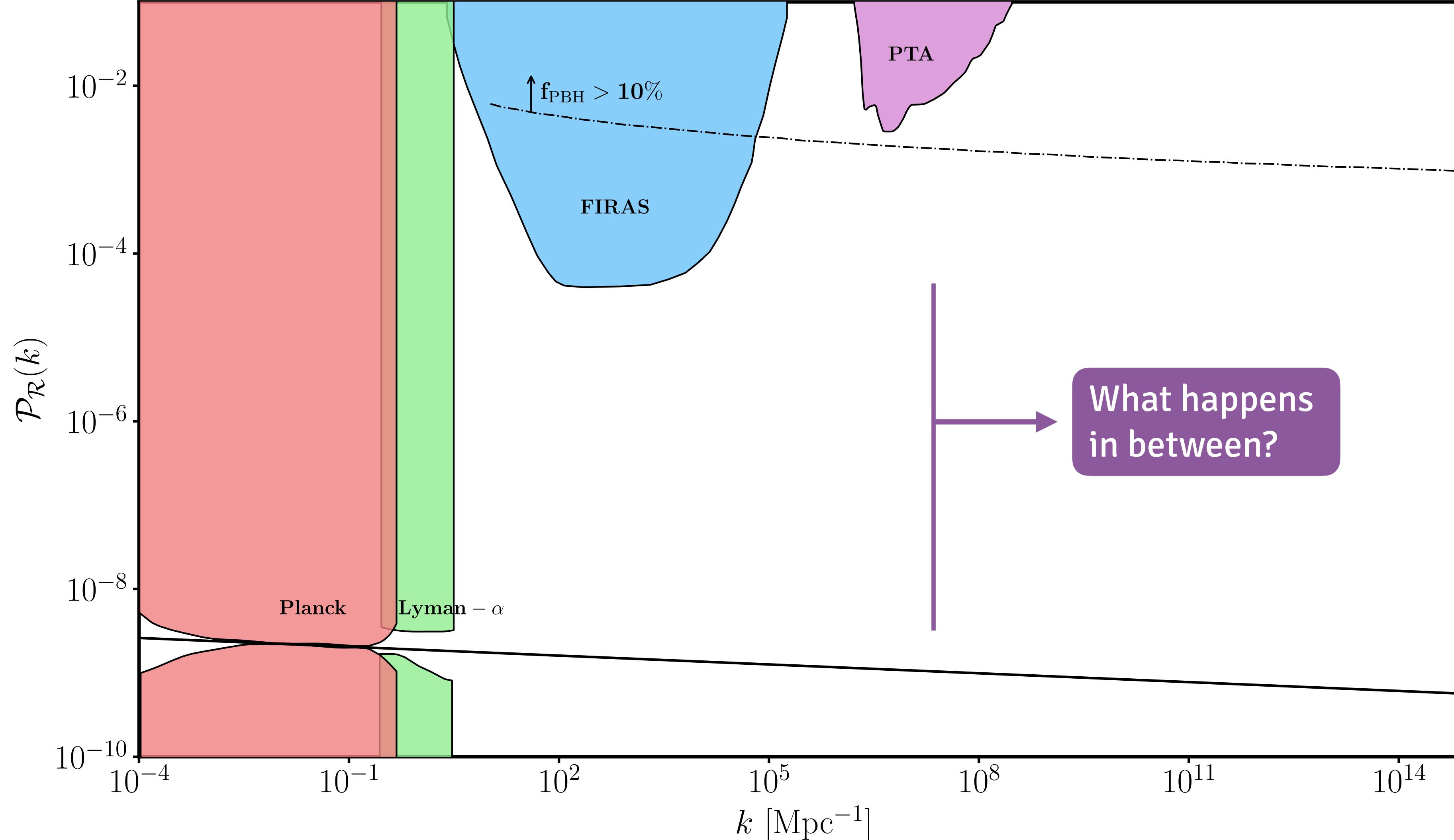




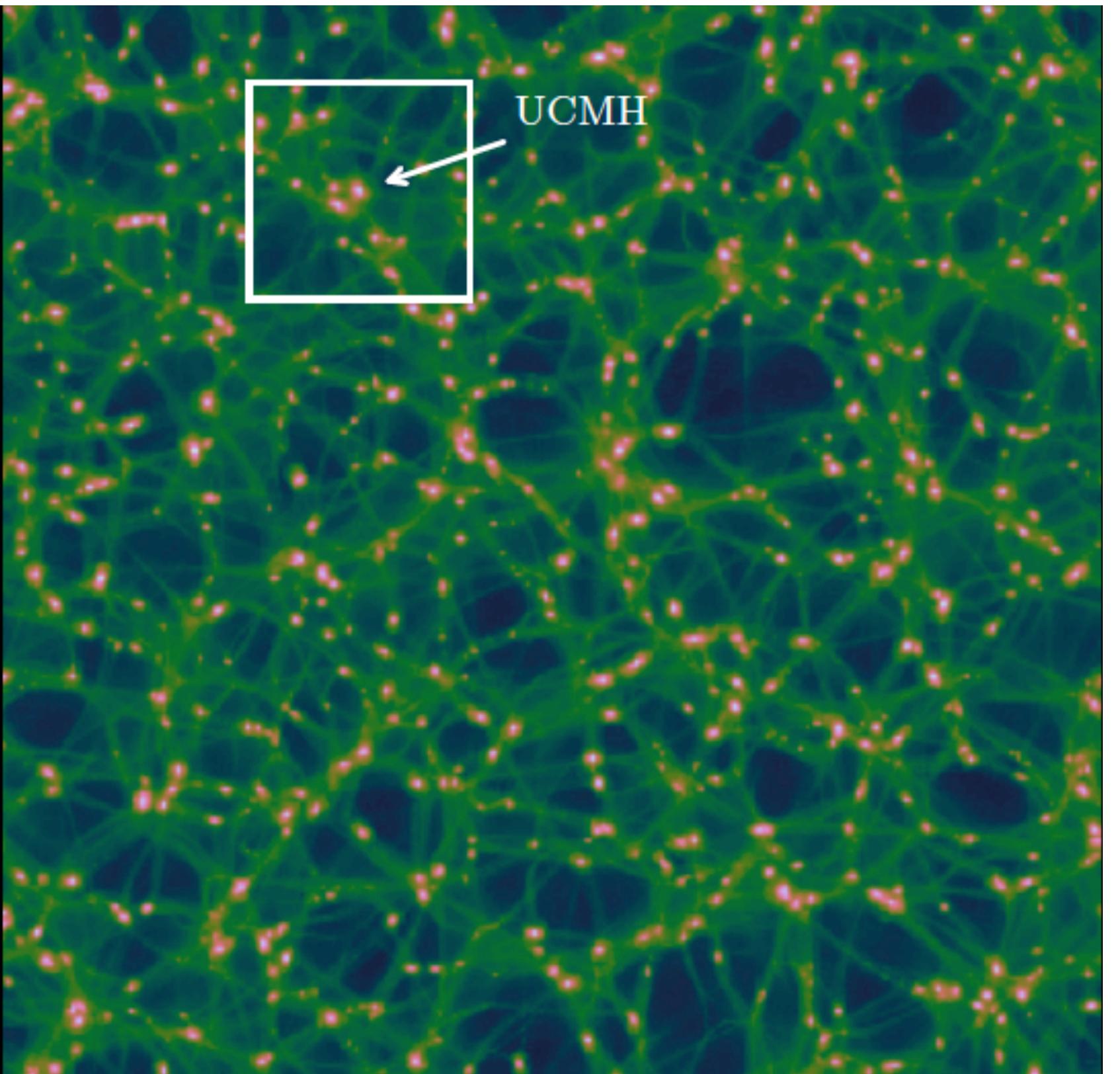






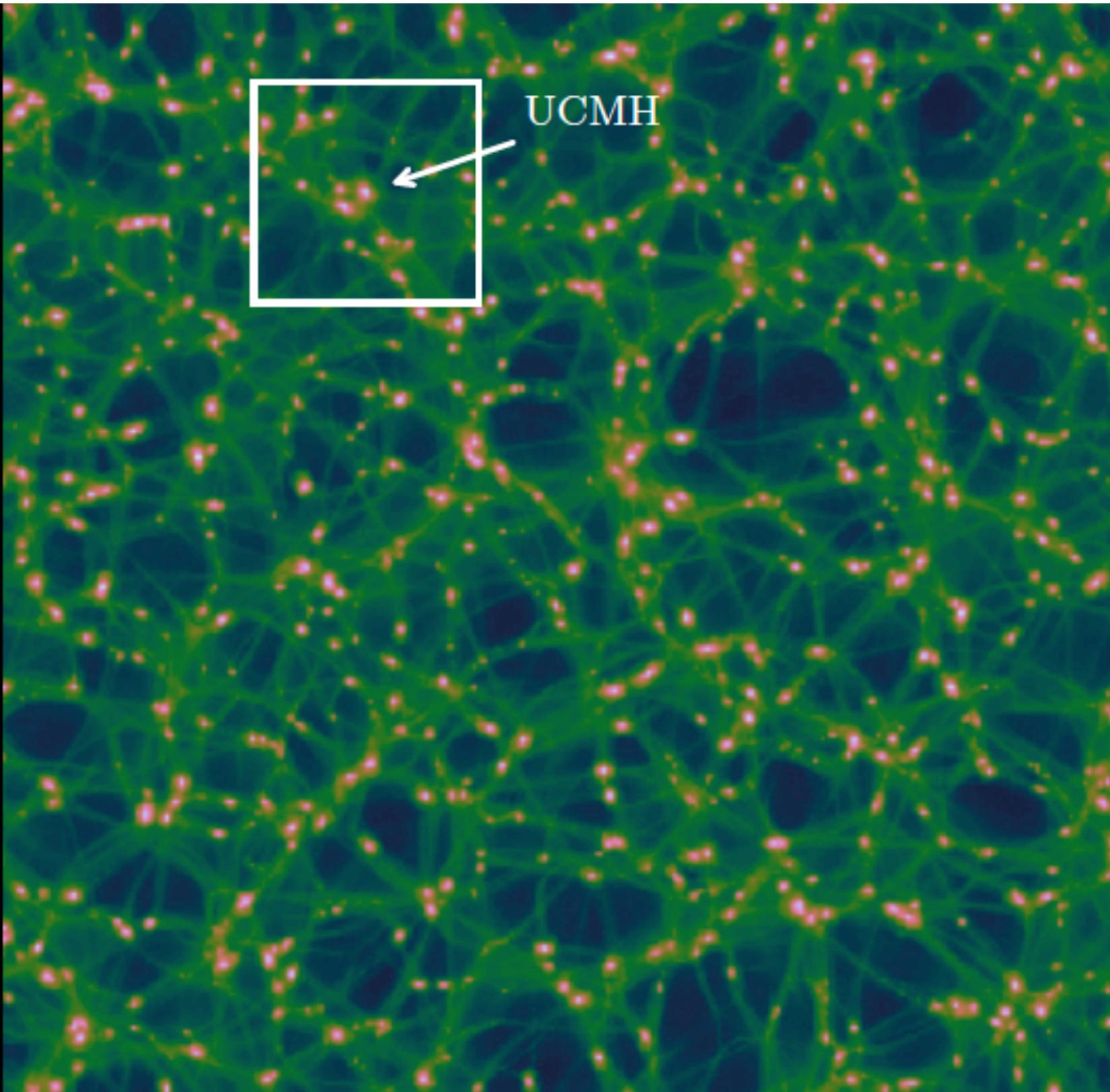


Moderate enhancements can produce
Ultra Compact Mini Halos (UCMHs)



[Delos+18]

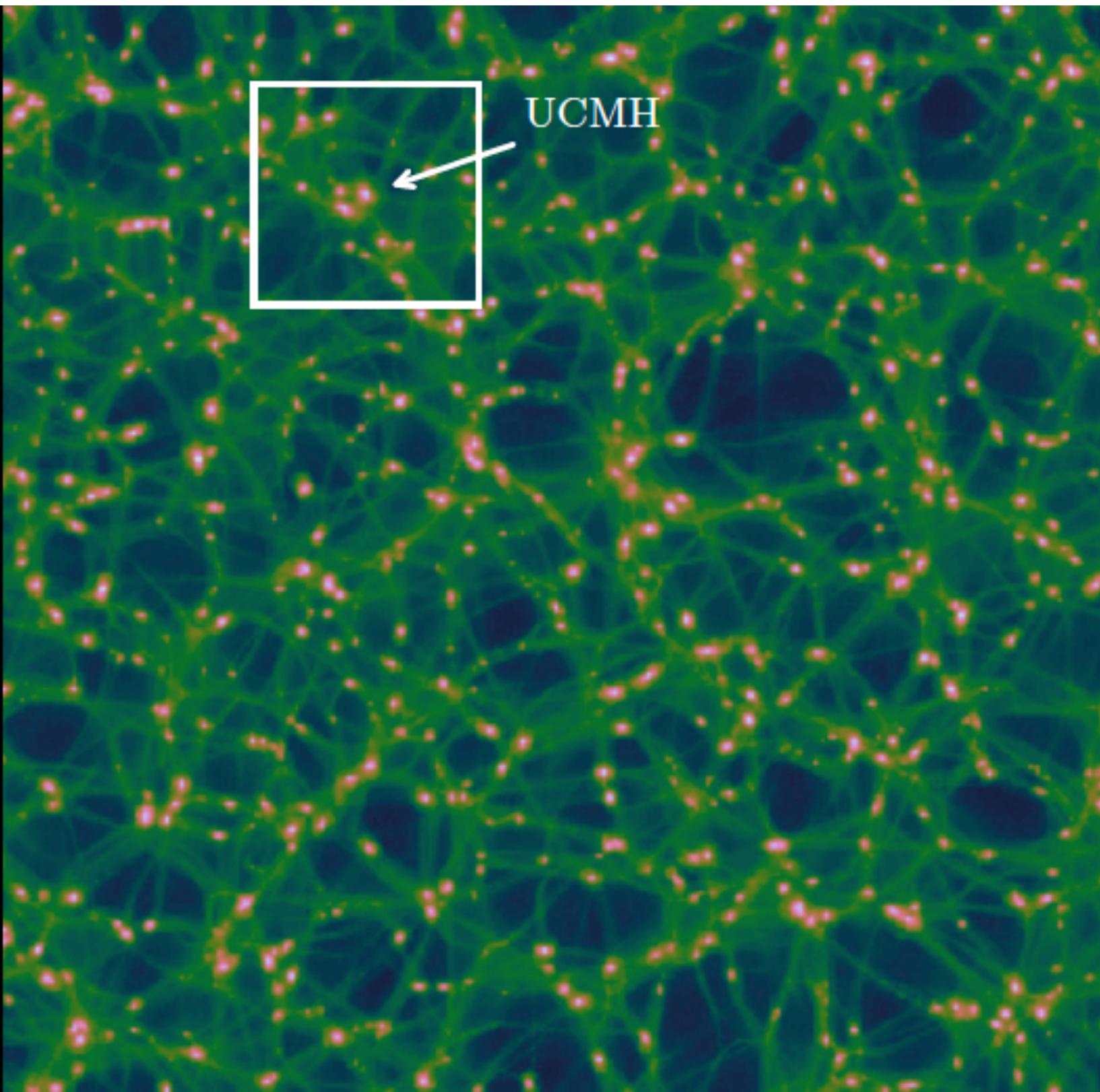
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Much earlier collapse ($z \sim 10^2 - 10^3$)

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Moderate enhancements can produce
Ultra Compact Mini Halos (UCMHS)



■ Much earlier collapse ($z \sim 10^2 - 10^3$)

■ Potentially much stronger constraints
on the small-scale $\mathcal{P}_{\mathcal{R}}(k)$ than PBHs

[Delos+18]

The presence of minihalos has been probed by various methods

- γ -ray fluxes [Bringmann+11, Delos+18]
- CMB anisotropies [Kawasaki+21]
- 21cm signal [Yang+16, Furugori+20]
- Microlensing [Erickcek+12]
- Free-free emission [Abe+21]

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If dark matter (DM) self-annihilates, minihalos can significantly **boost the DM annihilation signal**, leaving an imprint on the CMB

Deposited energy into the plasma per volume and time (**no halos**)

$$\frac{dE}{dVdt} \Big|_{\text{DM}} (z) = \langle \rho_{\text{DM}}^0 \rangle^2 (1+z)^6 p_{\text{ann}}$$

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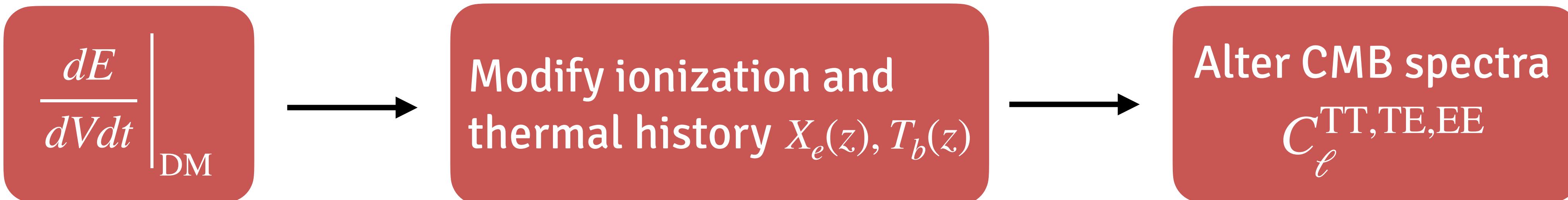
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In presence of halos, deposited energy is modified as

$$\frac{dE}{dVdt} \Big|_{\text{DM}}(z) = (1 + B(z)) \langle \rho_{\text{DM}}^0 \rangle^2 (1 + z)^6 p_{\text{ann}}$$

where $B(z) \equiv \frac{\langle \rho_{\text{DM}}^2 \rangle}{\langle \rho_{\text{DM}} \rangle^2} - 1$ is the **cosmological boost factor**

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How do we compute $B(z)$?

In the framework of the halo model

$$B(z) = \frac{1}{\langle \rho_m^0 \rangle} \int M \frac{dn(M|z)}{dM} B_h(z_f(M), z) dM$$

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Depends on $\mathcal{P}_{\mathcal{R}}(k)$

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1-halo boost
Depends on density profile $\rho_h(r)$

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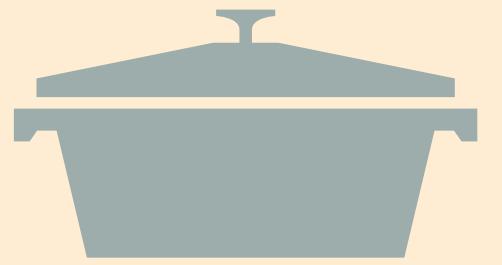
- New formalism (based on ext. Press-Schechter) to account for a **mixed population of halos** with different profiles
(expected to arise as a result of accretion and mergers)

NFW: $\rho_h(r) \propto r^{-1}$

UCMHs: $\rho_h(r) \propto r^{-3/2}$

[Delos+17]

RECIPE



to get the constraints

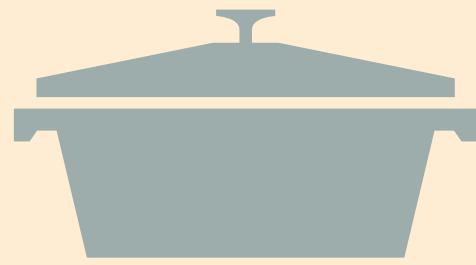
Ingredients

■ Modified version of ExoCLASS
[Stocker+18]

■ Planck legacy data

Instructions

RECIPE



to get the constraints

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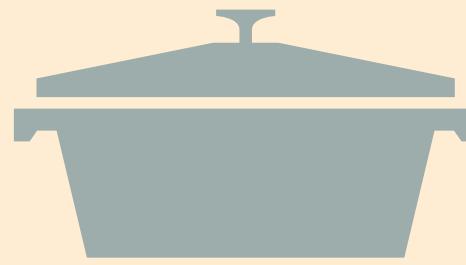
Planck legacy data

Instructions

1. Consider a **spike** at large k

$$\mathcal{P}_{\mathcal{R}}(k) = \mathcal{A}_s \left(\frac{k}{k_0} \right)^{n_s - 1} + \mathcal{A}_* k_* \delta(k - k_*)$$

RECIPE



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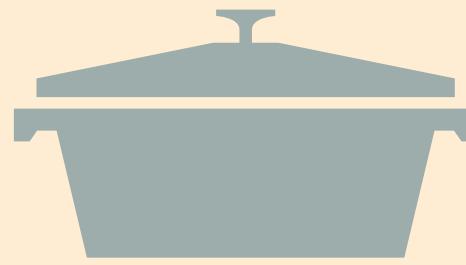
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2. Compute **boost factor** and the **DM annihil. signal** in the CMB (ExoCLASS)

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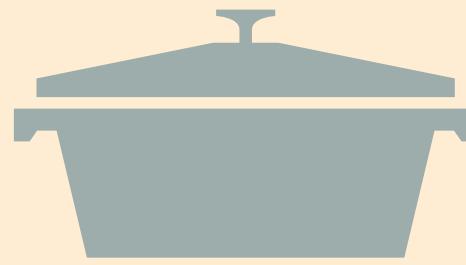
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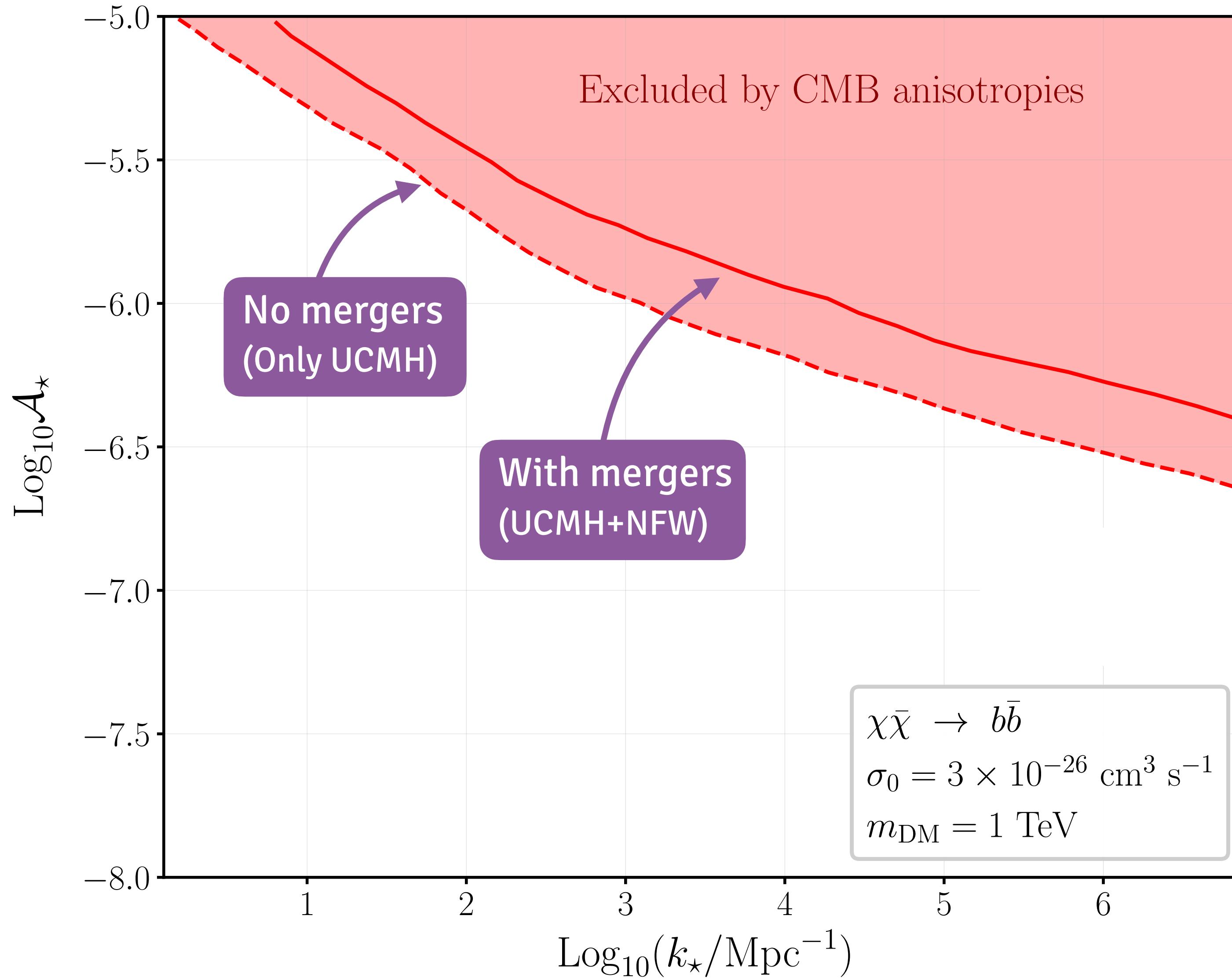
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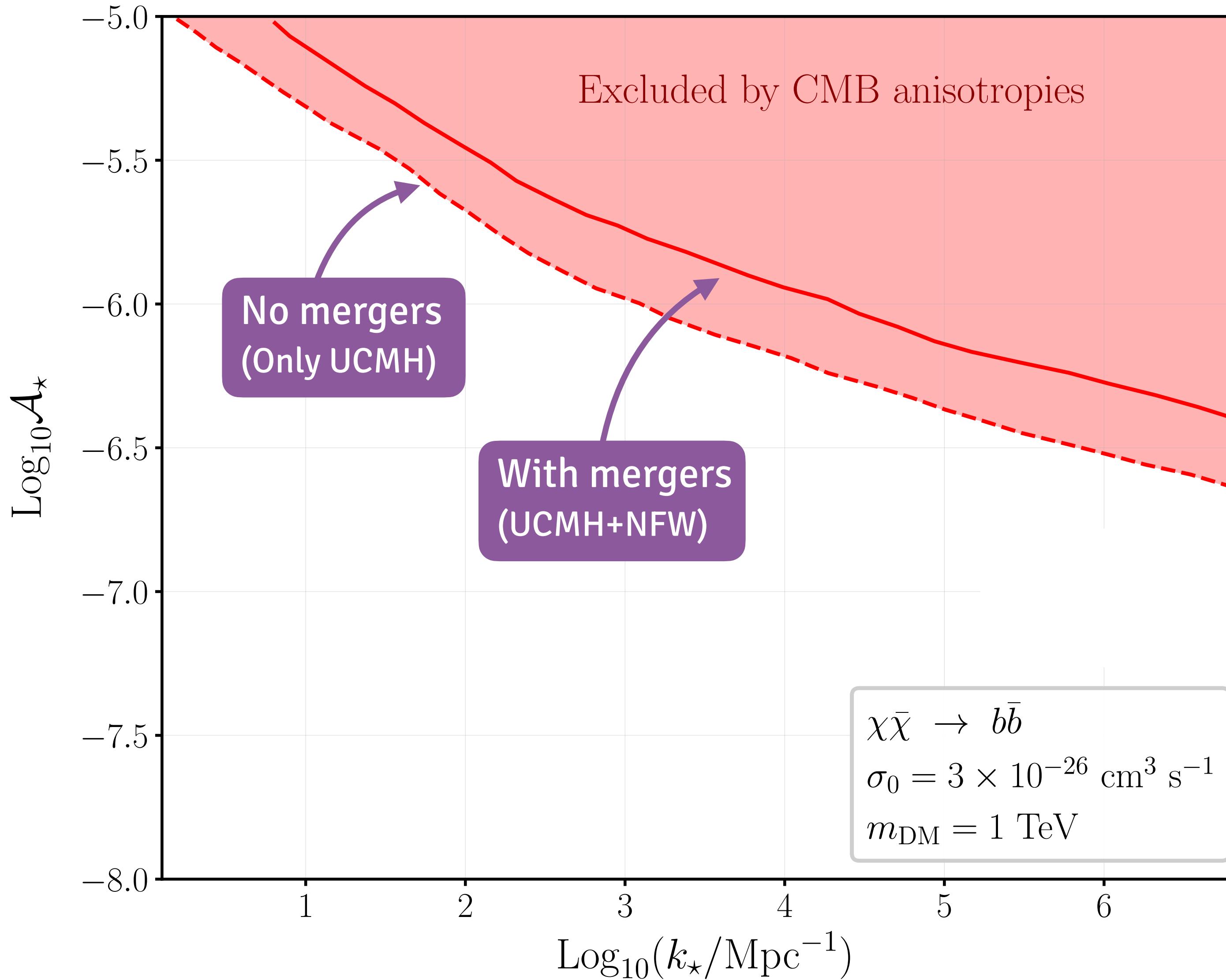
3. Compare prediction against Planck data

4. Obtain constraints on \mathcal{A}_* vs. k_*
(for a fiducial param. $p_{\text{ann}} \propto \langle \sigma v \rangle / m_{\text{DM}}$)

RESULTS

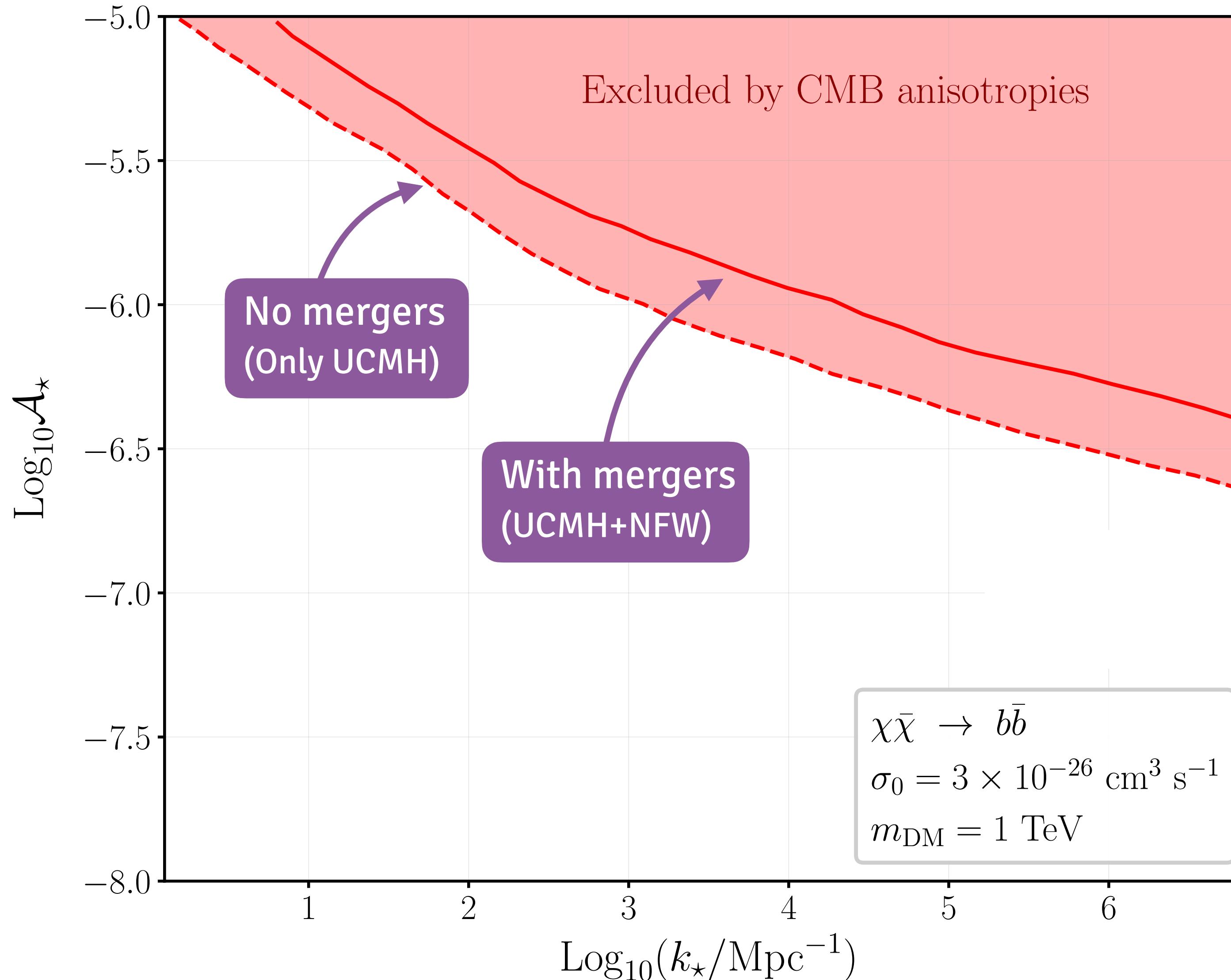


RESULTS



Accounting for **mergers** leads
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Expected to be much more relevant for **low-z probes** (e.g. 21 cm)

RESULTS

So far, we only looked at
s-wave DM annihilations

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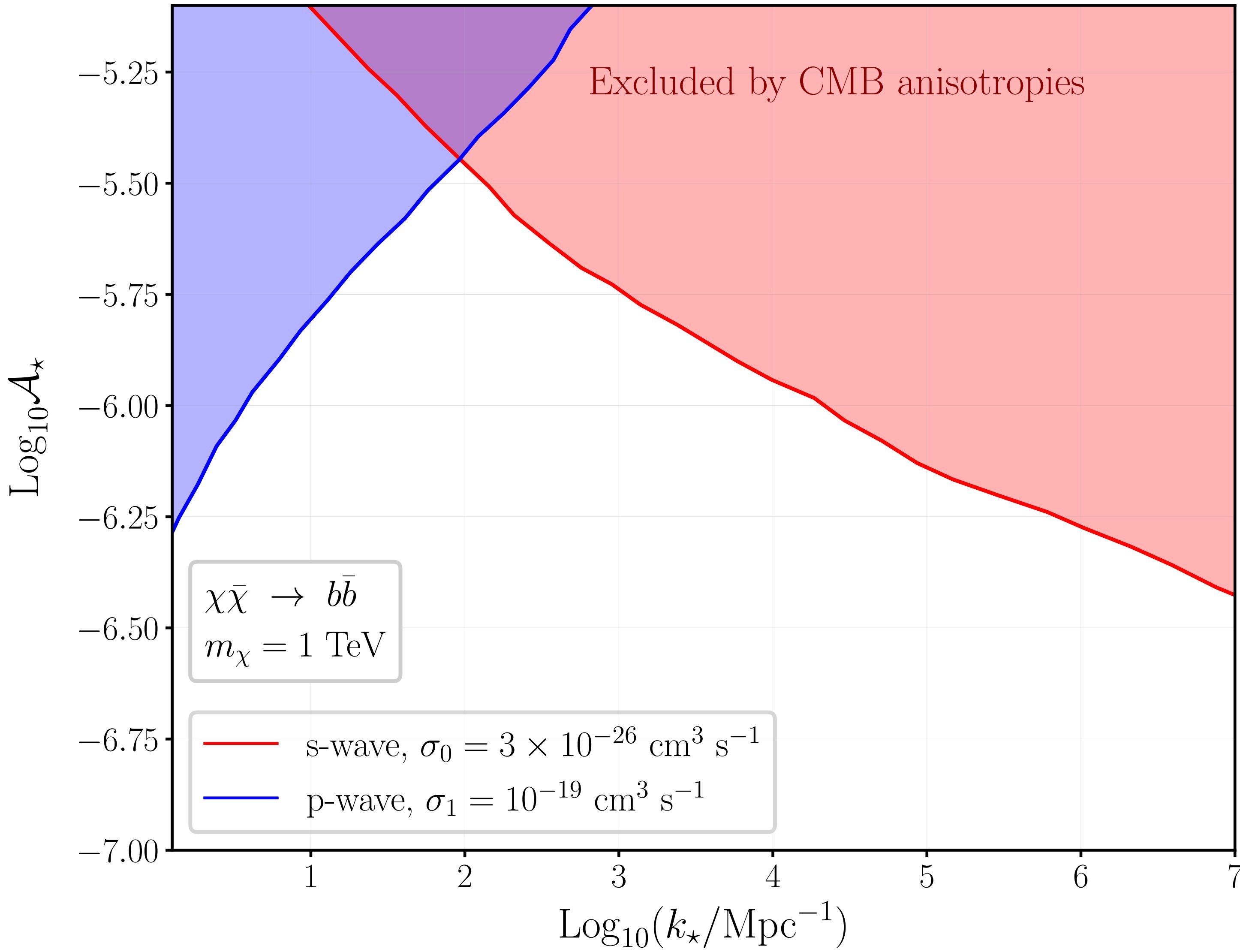
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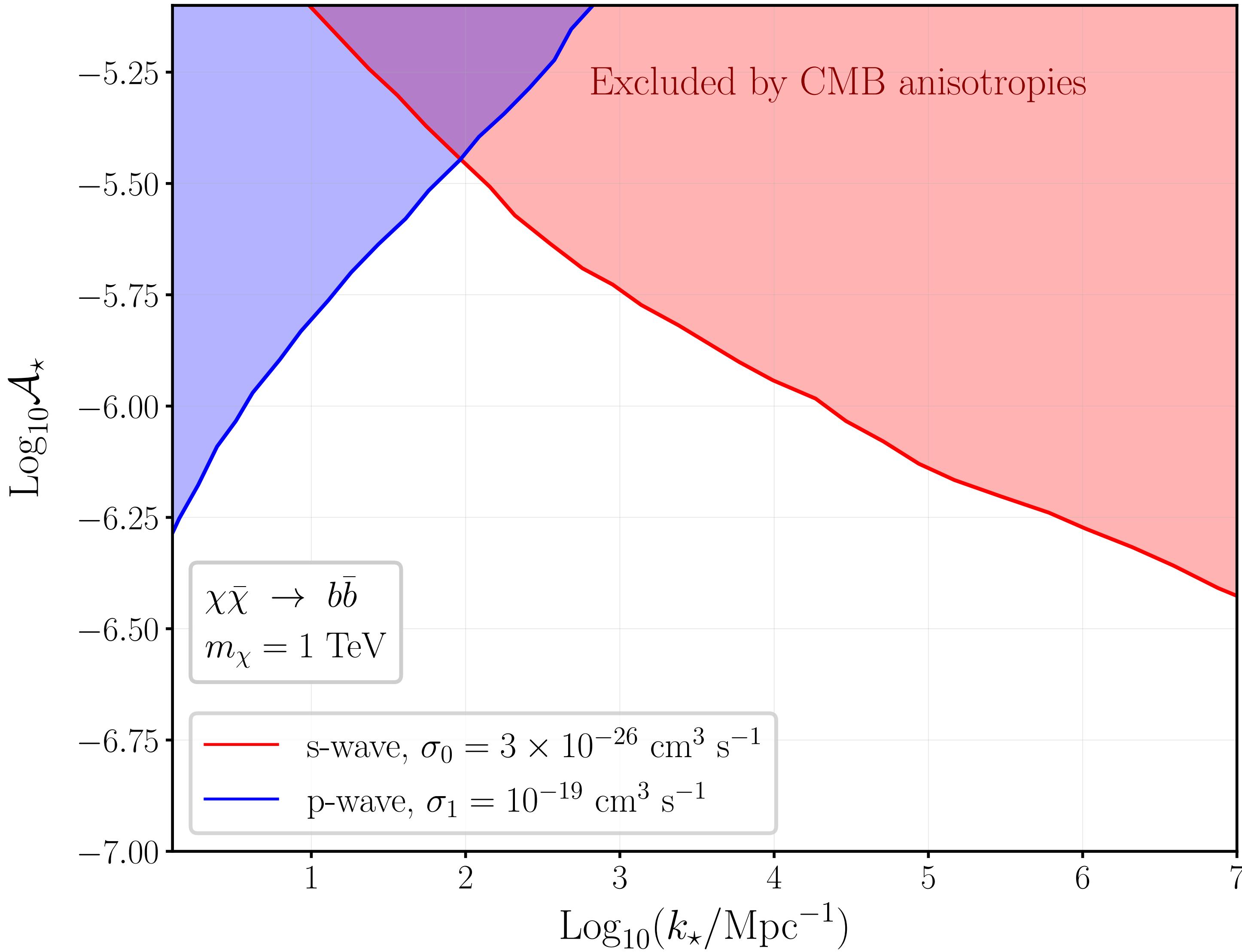
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- First calculation of p-wave boost factor in presence of UCMHs

RESULTS

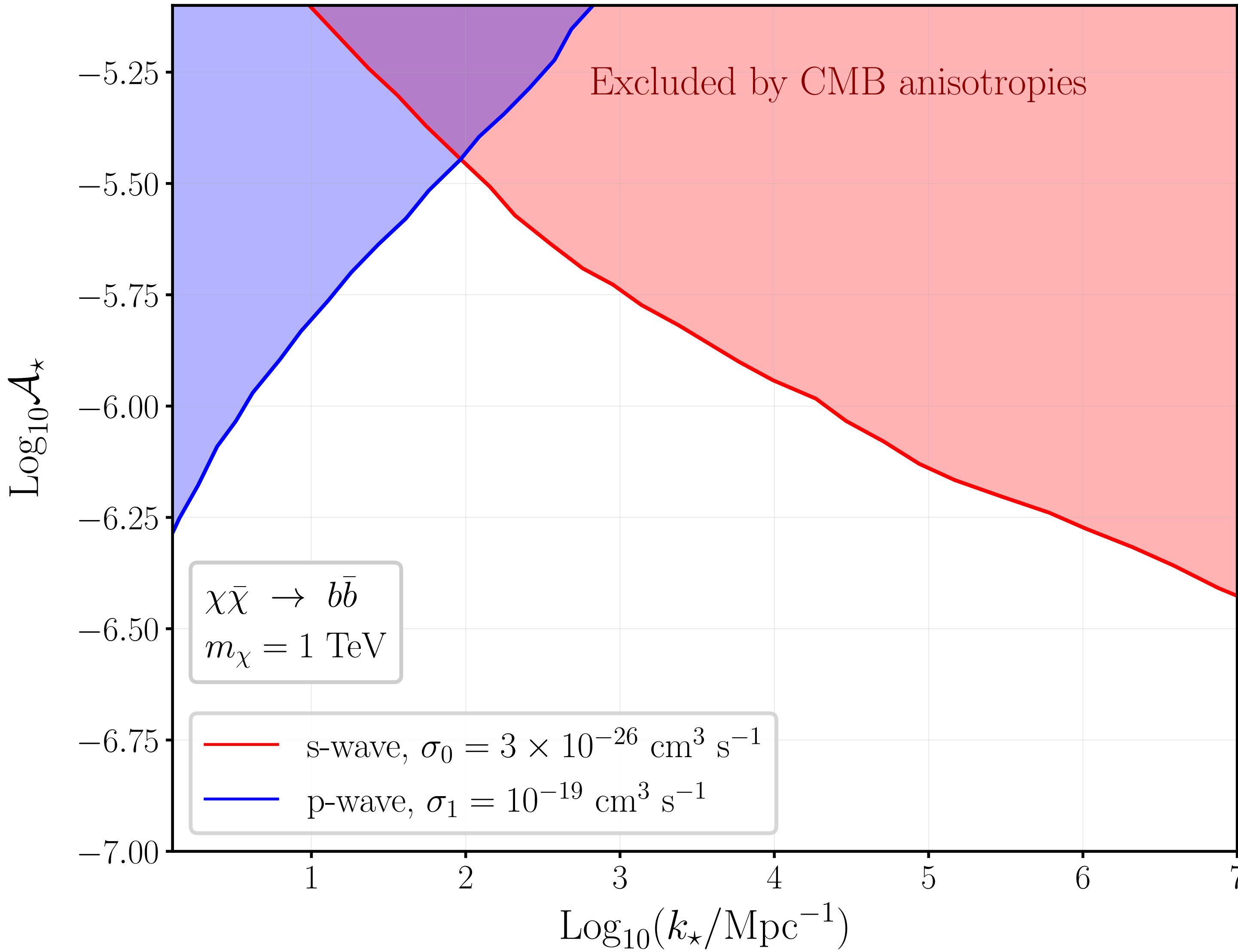


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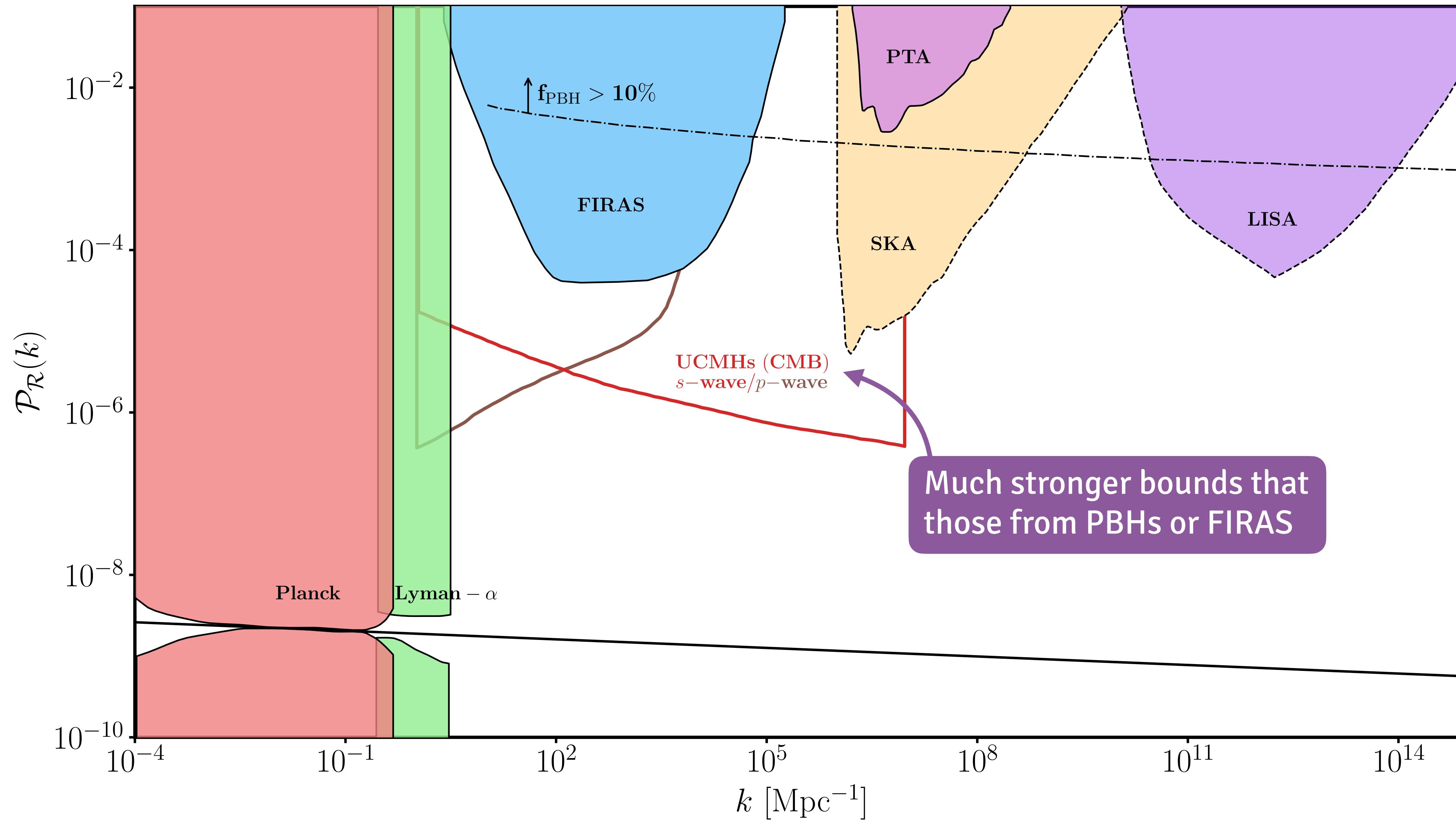
**p-wave constraints are
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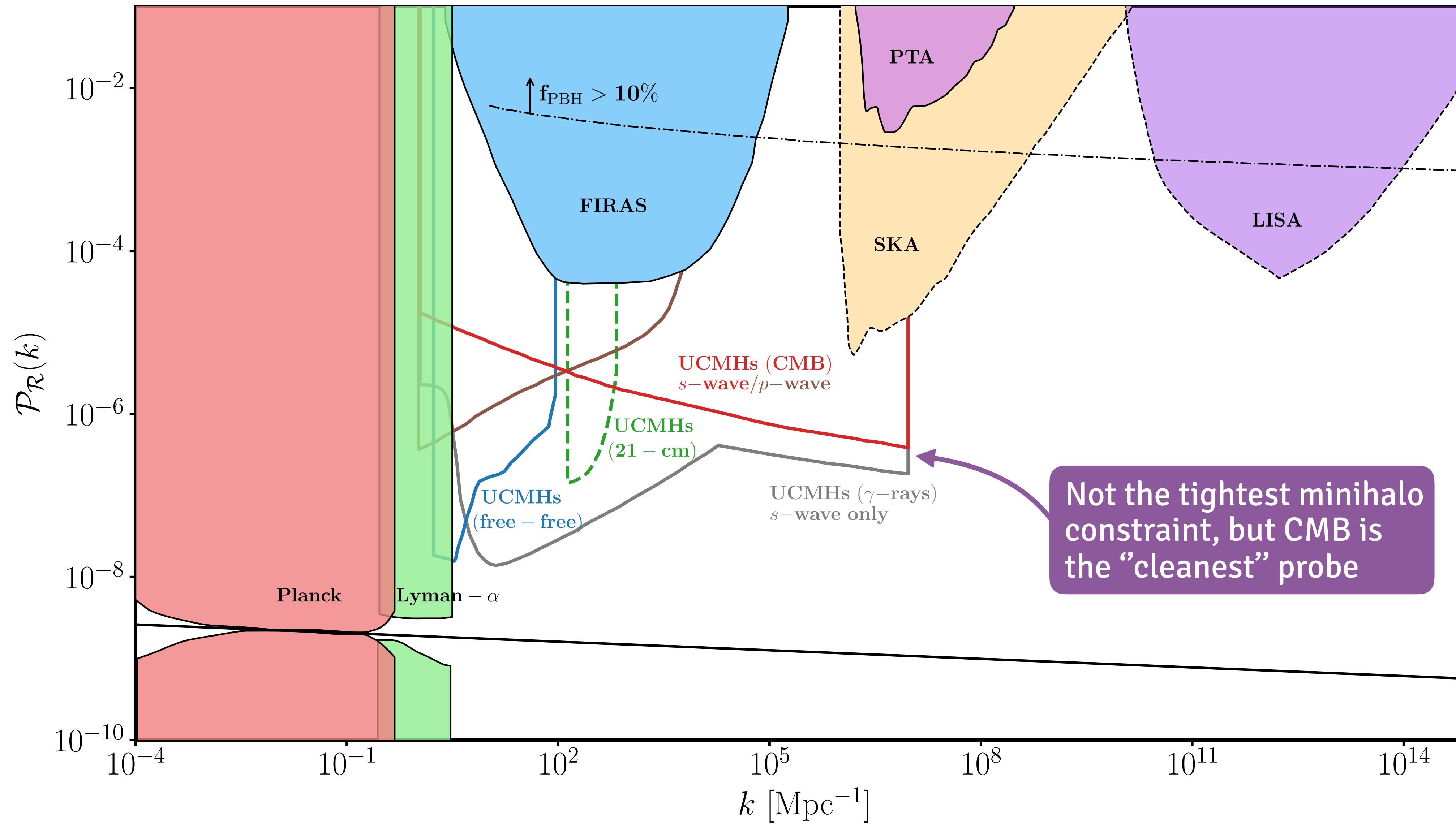


- p-wave constraints are competitive at small k
- Relevant for models that predict vanishing s-wave terms

RESULTS



RESULTS



Conclusions and prospects

- Robust CMB bounds on small-scale $\mathcal{P}_{\mathcal{R}}(k)$ using both s-wave and p-wave DM annihil. in minihalos

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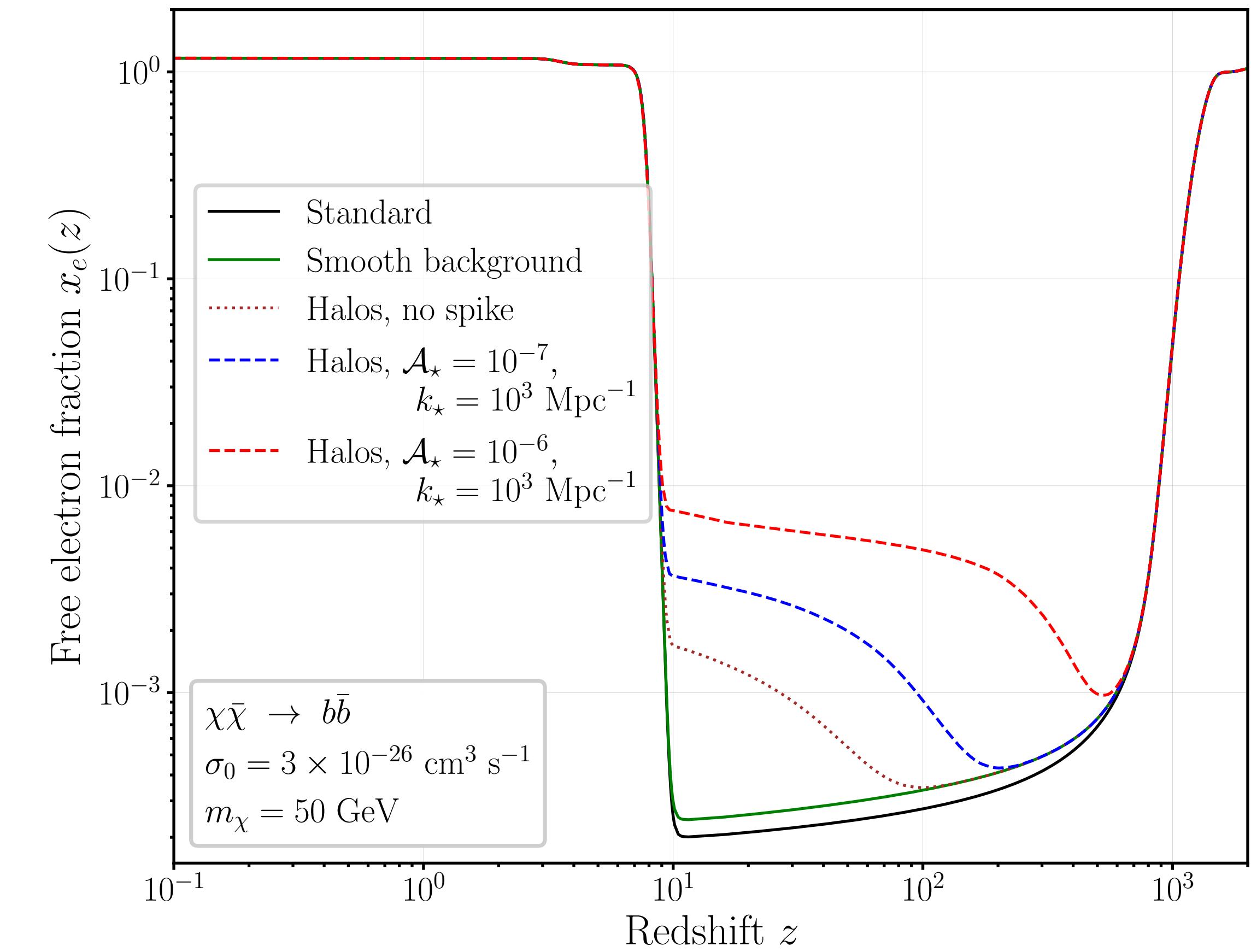
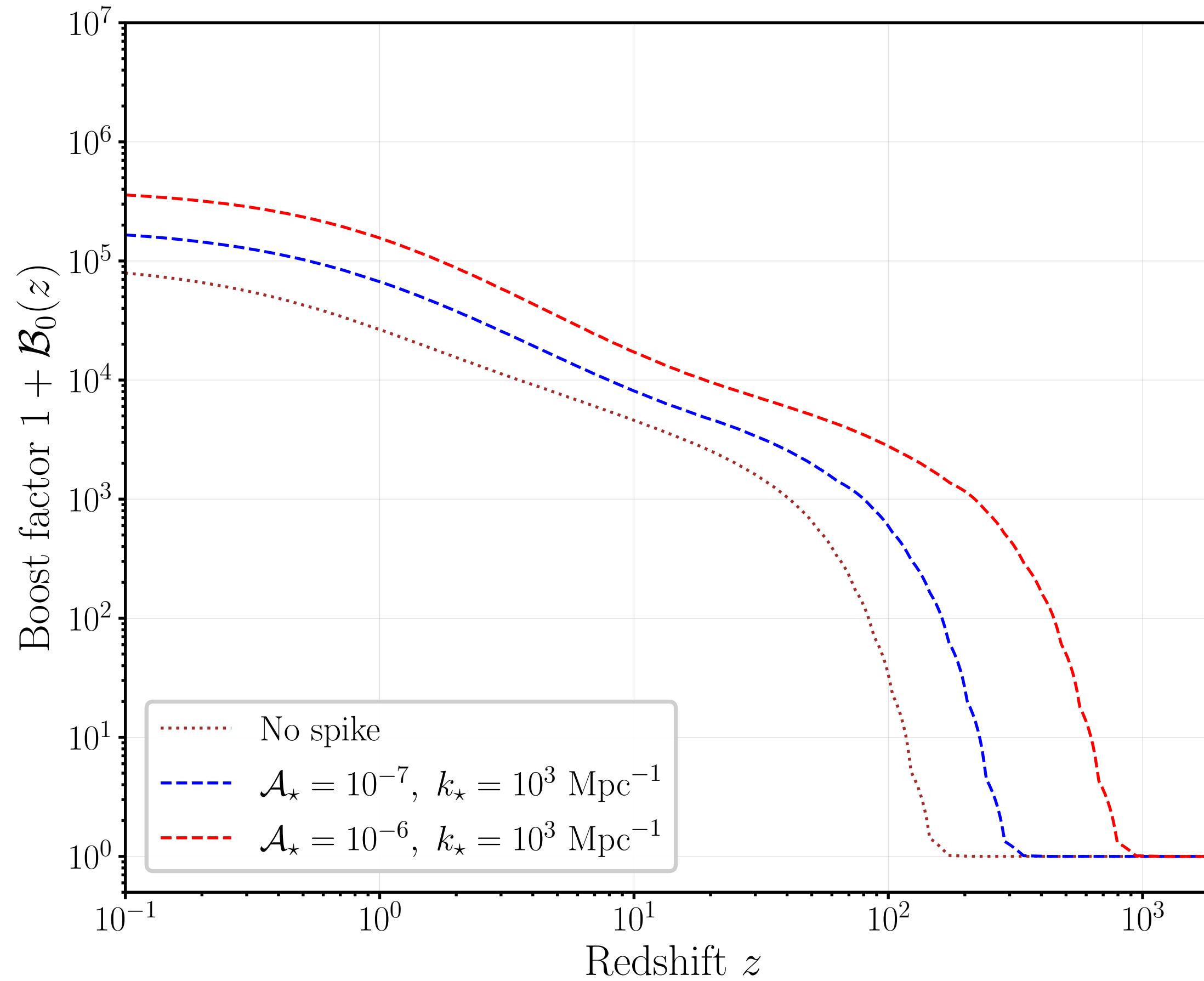
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THANKS FOR
YOUR ATTENTION

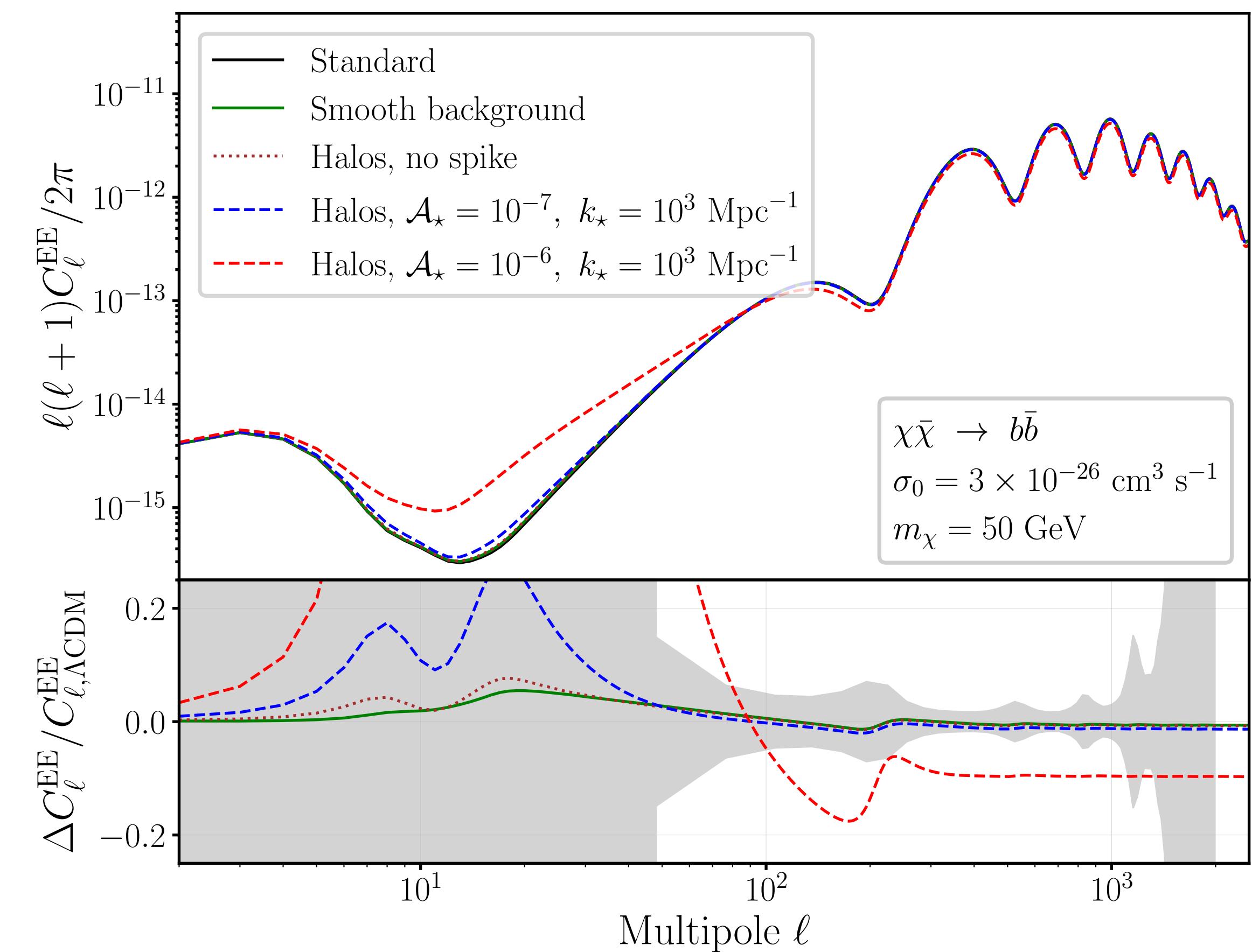
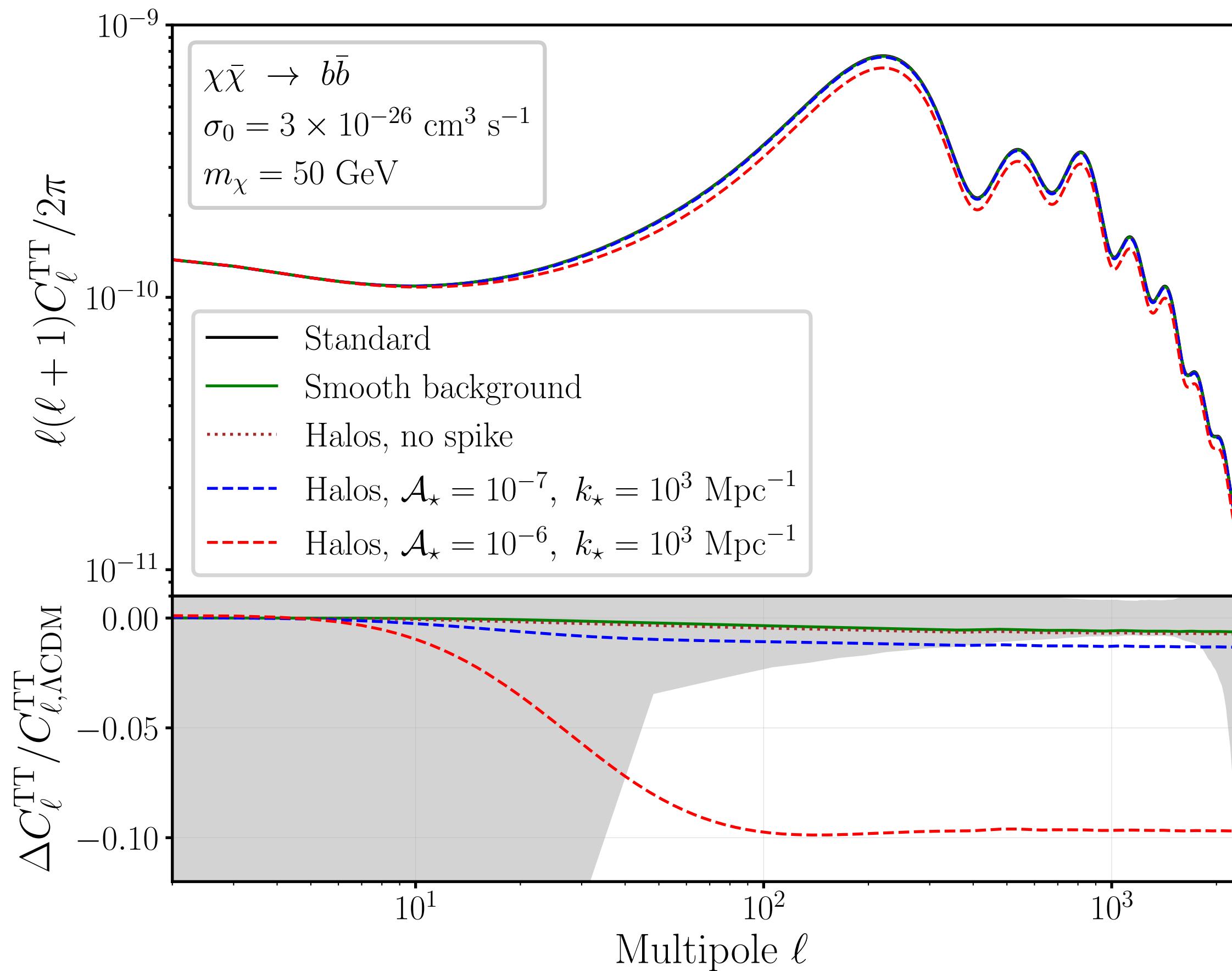
g.francoabellan@uva.nl

BACK-UP

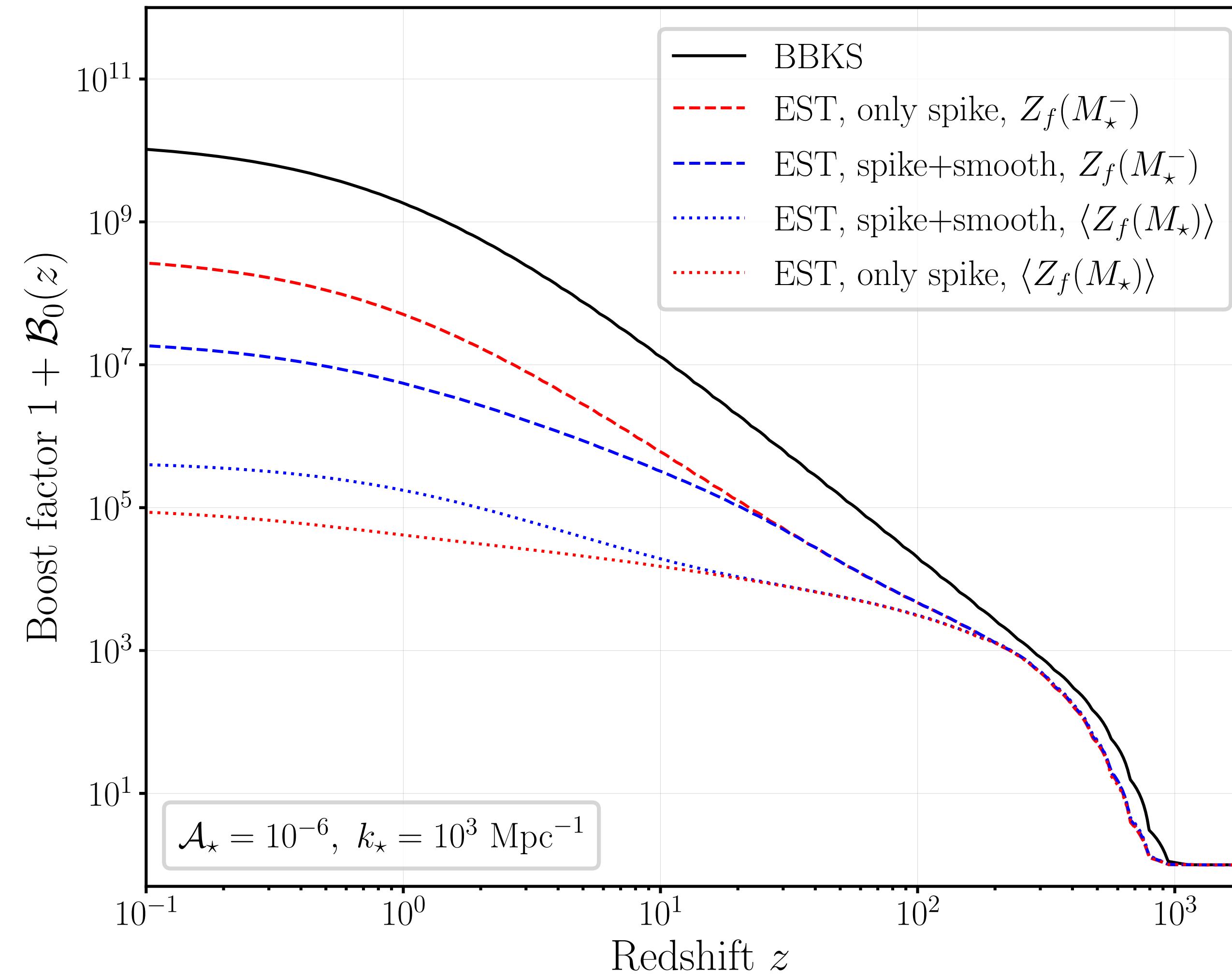
Impact of UCMHs on ionisation history



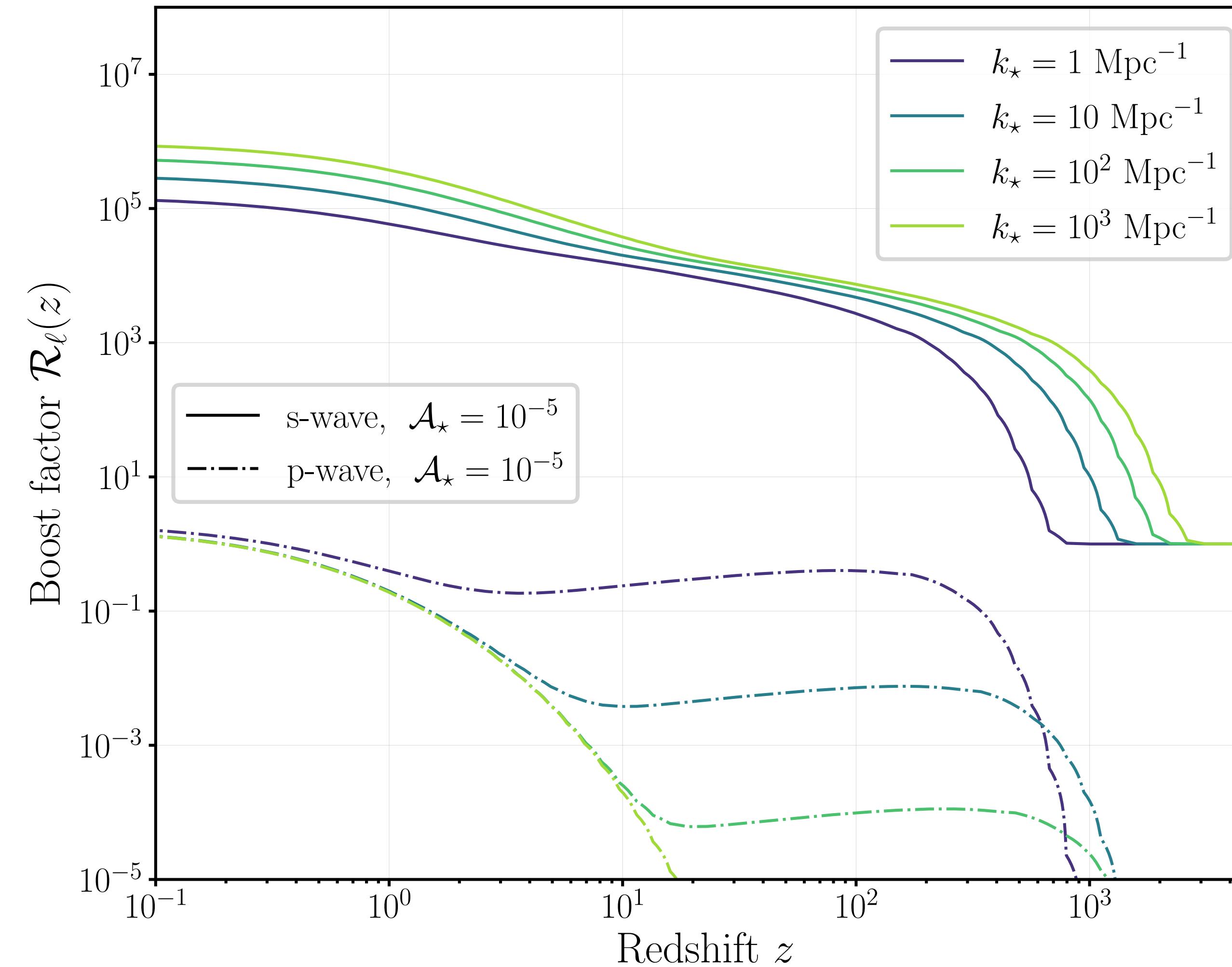
Impact of UCMHs on CMB anisotropy spectra



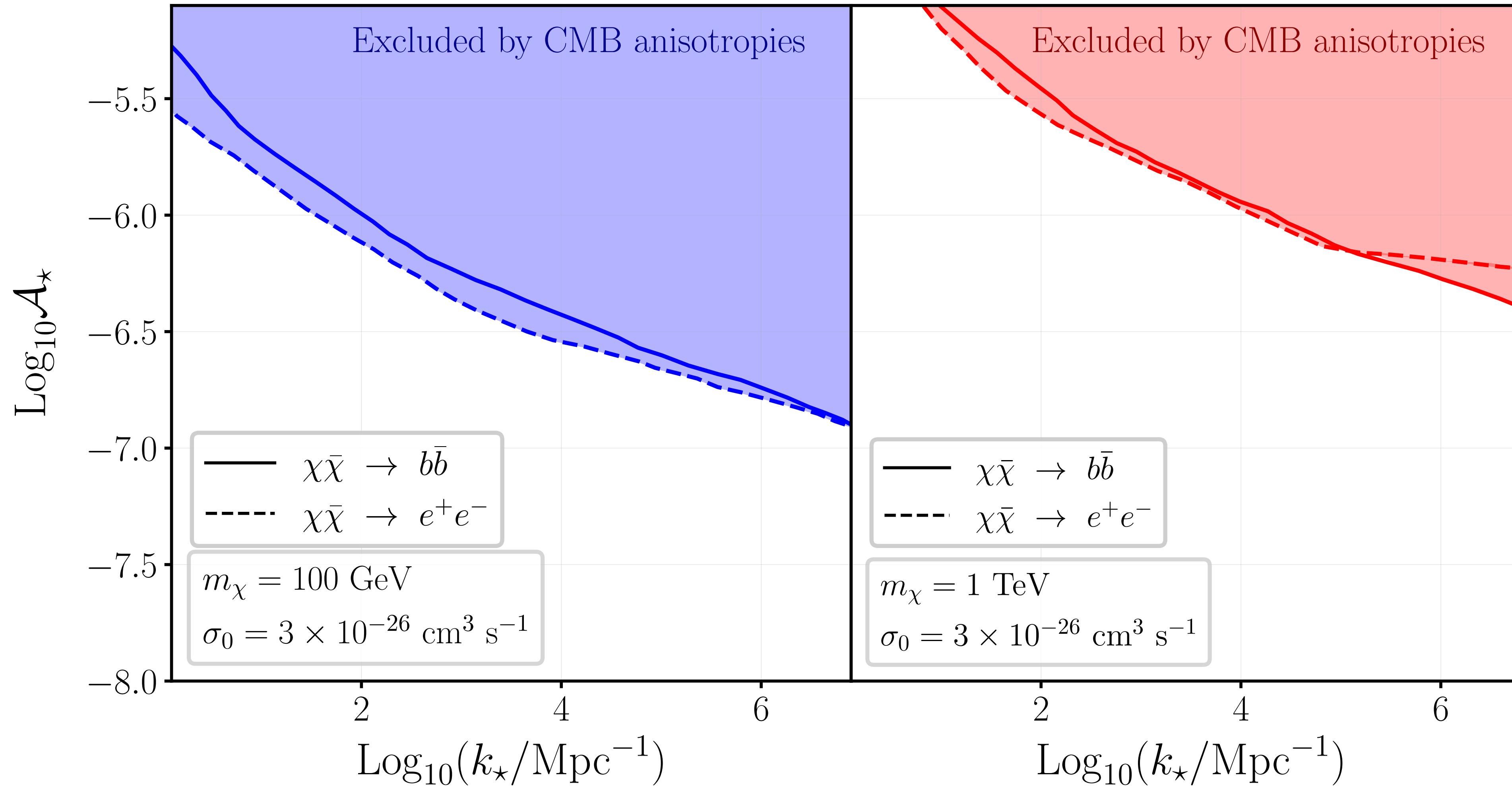
Boost factor: comparison between formalisms



Boost factor: s-wave vs. p-wave



Constraints for different DM masses and annihil. channels



Prior range for the amplitude and location of the spike

$$0 \leq \text{Log}_{10}(k_{\star}/\text{Mpc}^{-1}) \leq 7$$

Typical value for the free-streaming scale of WIMPs

$$-8 \leq \text{Log}_{10}\mathcal{A}_{\star} \leq -4$$

Larger amplitudes may lead to **PBH formation** or minihalo formation during the radiation era

