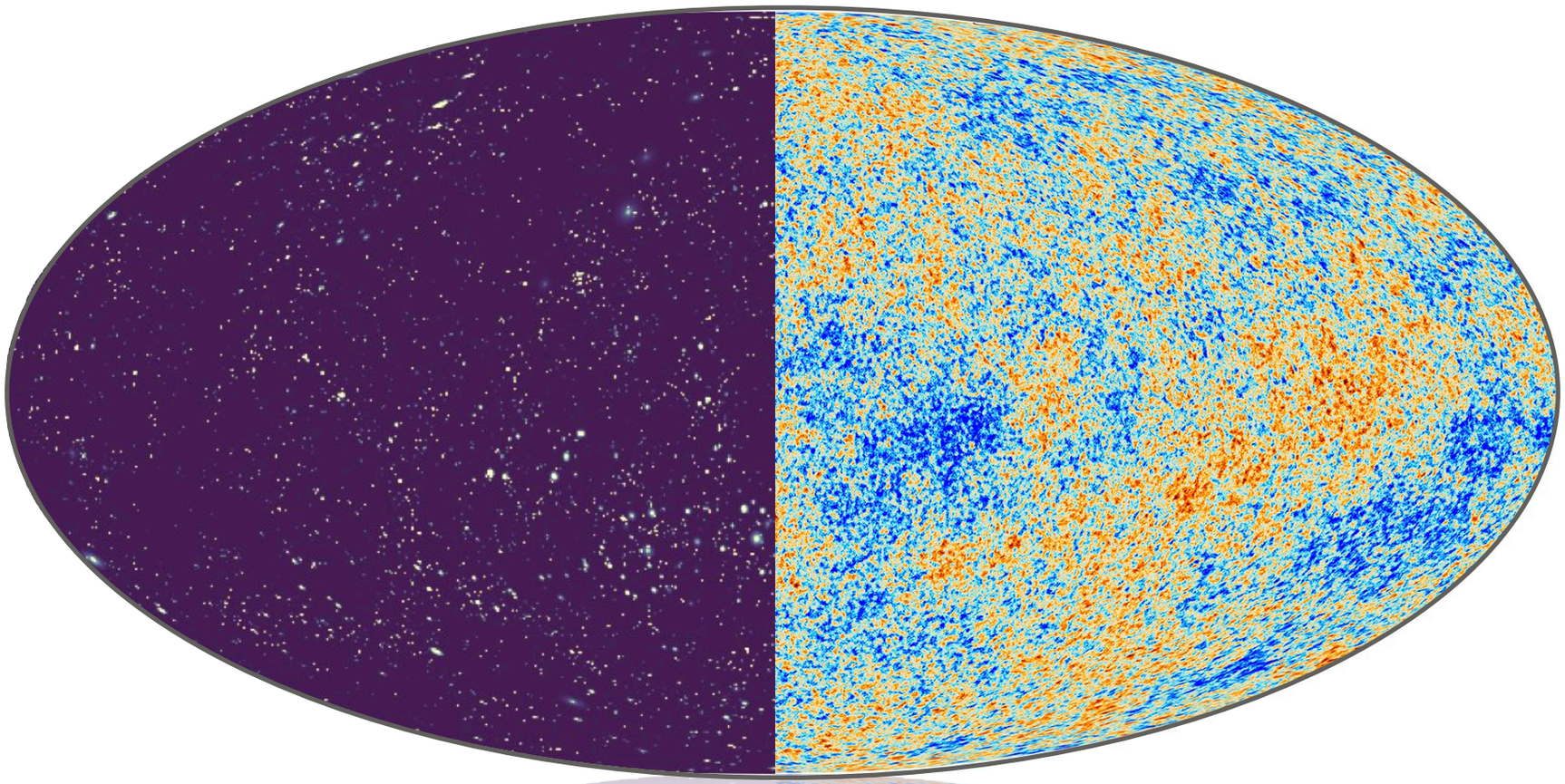

Non-Linear Fuzzy Dark Matter Modelling with Extended LPT

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UNIVERSITY OF TORONTO

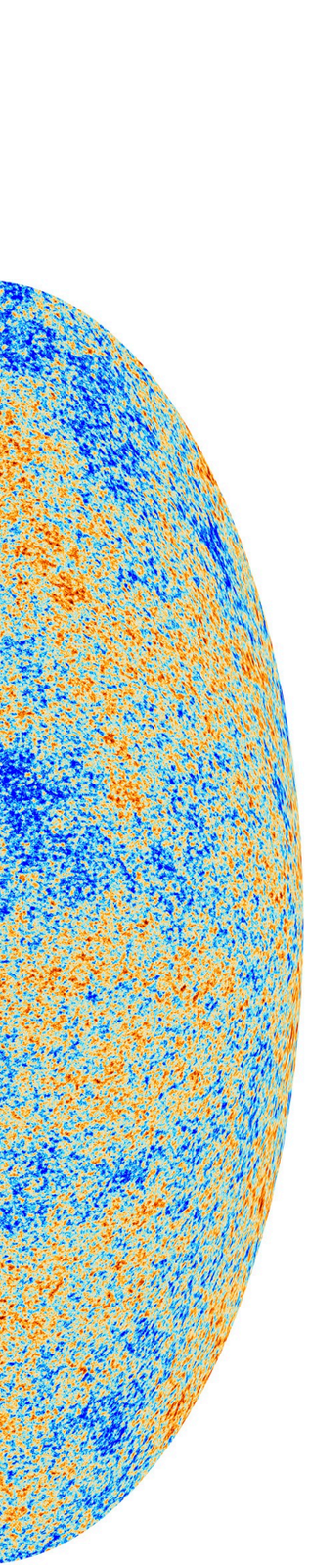
Fuzzy Dark Matter (FDM)

- Ultra-light boson: $10^{-26}\ \mathrm{eV} \lesssim m \lesssim 10^{-21}\ \mathrm{eV}$

- Scale-dependent sound speed: $c_s^2 = \dfrac{\hbar^2 k^2}{4m^2 a^2}$

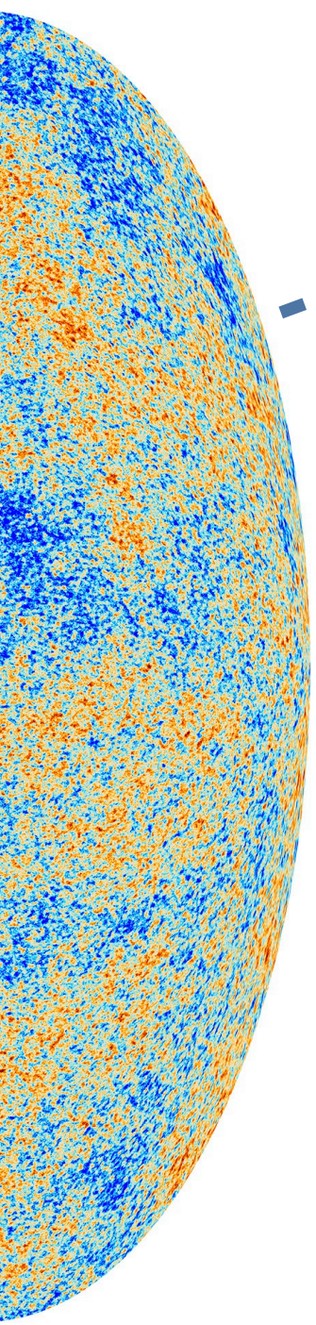
- Jeans scale: $k_J = 66.5 a^{1/4} \left(\dfrac{\Omega_{\mathrm{FDM}} h^2}{0.12} \right)^{1/4} \left(\dfrac{m}{10^{-22}\ \mathrm{eV}} \right)^{1/2} \mathrm{Mpc}^{-1}$

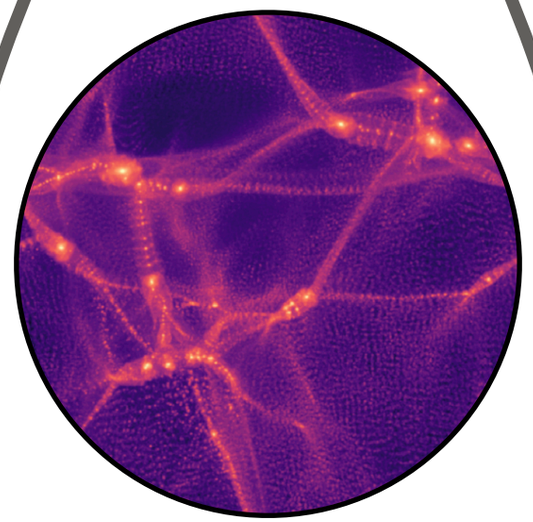
Marsh (1510.07633)



$$P_{matter}(k,z)$$

$$C_l^{\kappa\kappa}$$



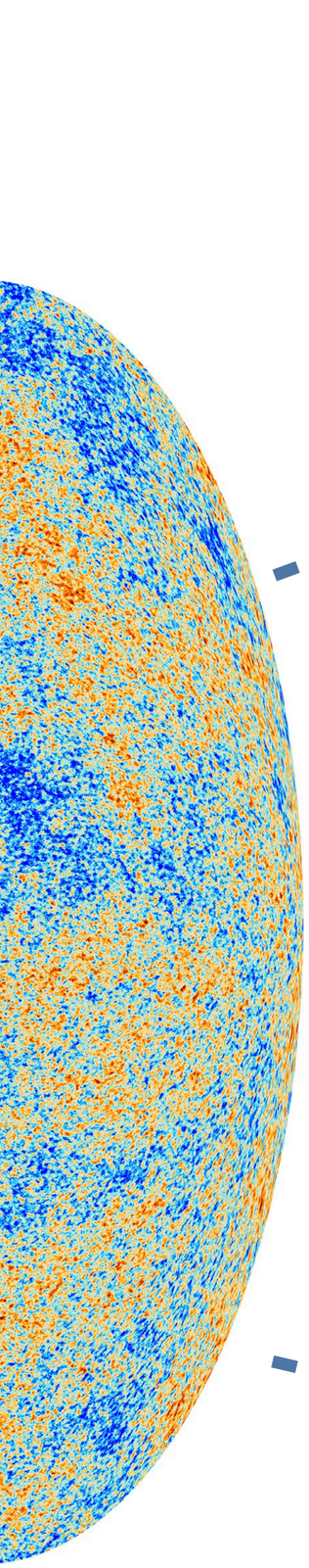


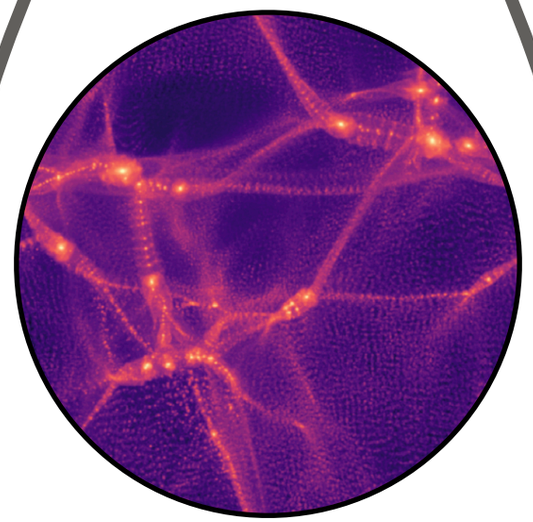
$P_{matter}(k,z)$

N-Body
(AX-Gadget,
Modified AREPO, etc.)

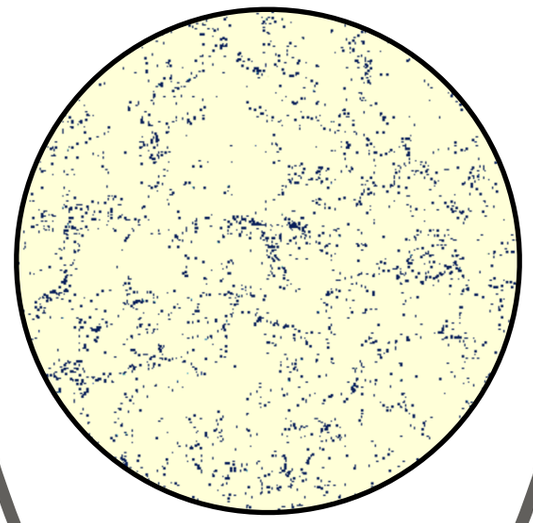
$C_l^{\kappa\kappa}$

Nori et al. (1801.08144)





$P_{matter}(k,z)$



N-Body
(AX-Gadget, Modified AREPO, etc.)

$C_l^{\kappa\kappa}$

LPT
(*Peak-Patch, Pinocchio, COLA, etc.*)

Nori et al. (1801.08144)

Why Modified LPT

1. Non-linear CMB lensing from LSS

2. Low computational cost

3. Large simulation volume

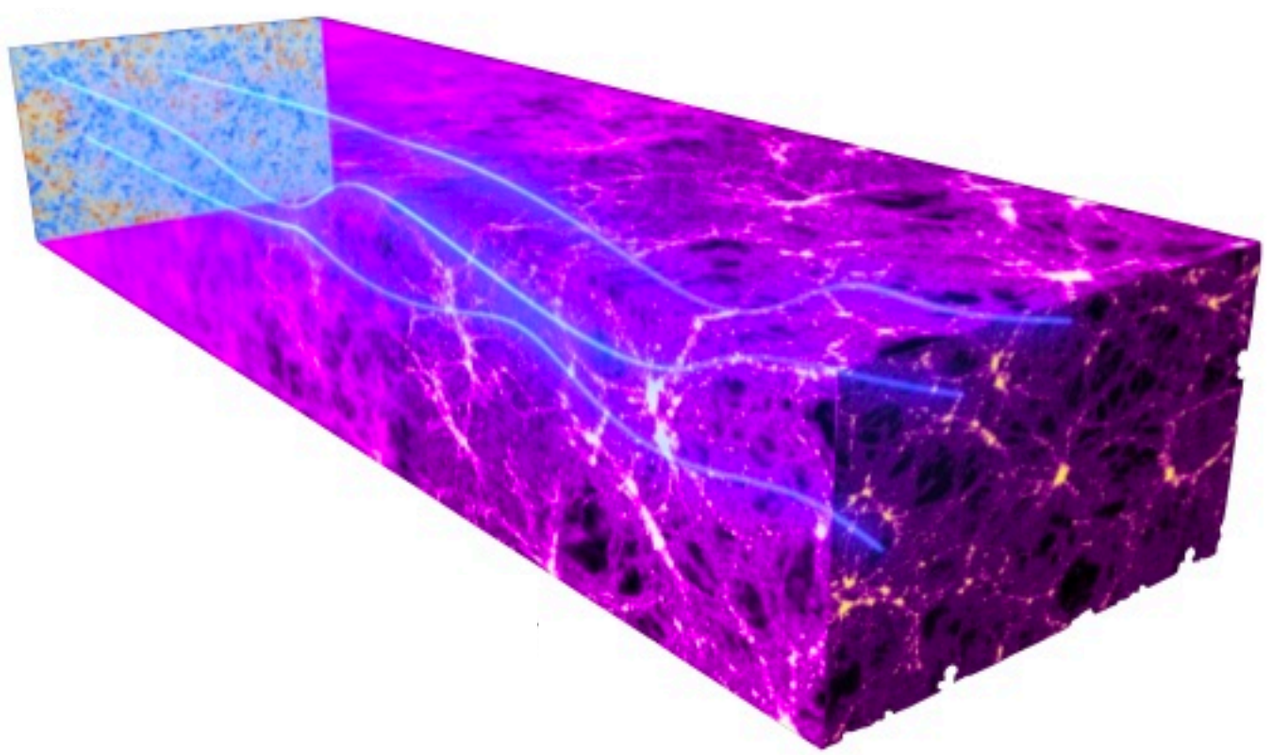
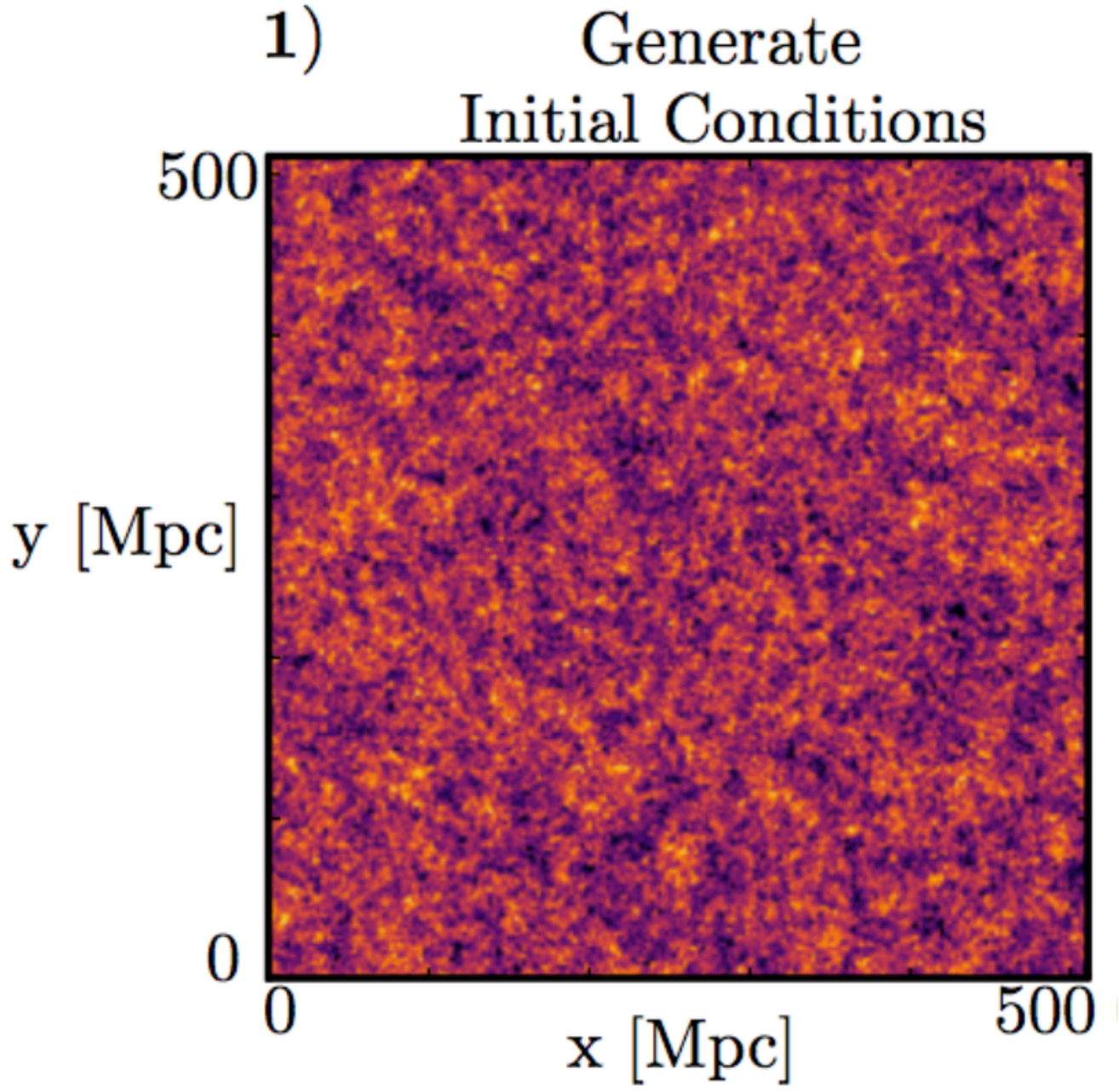


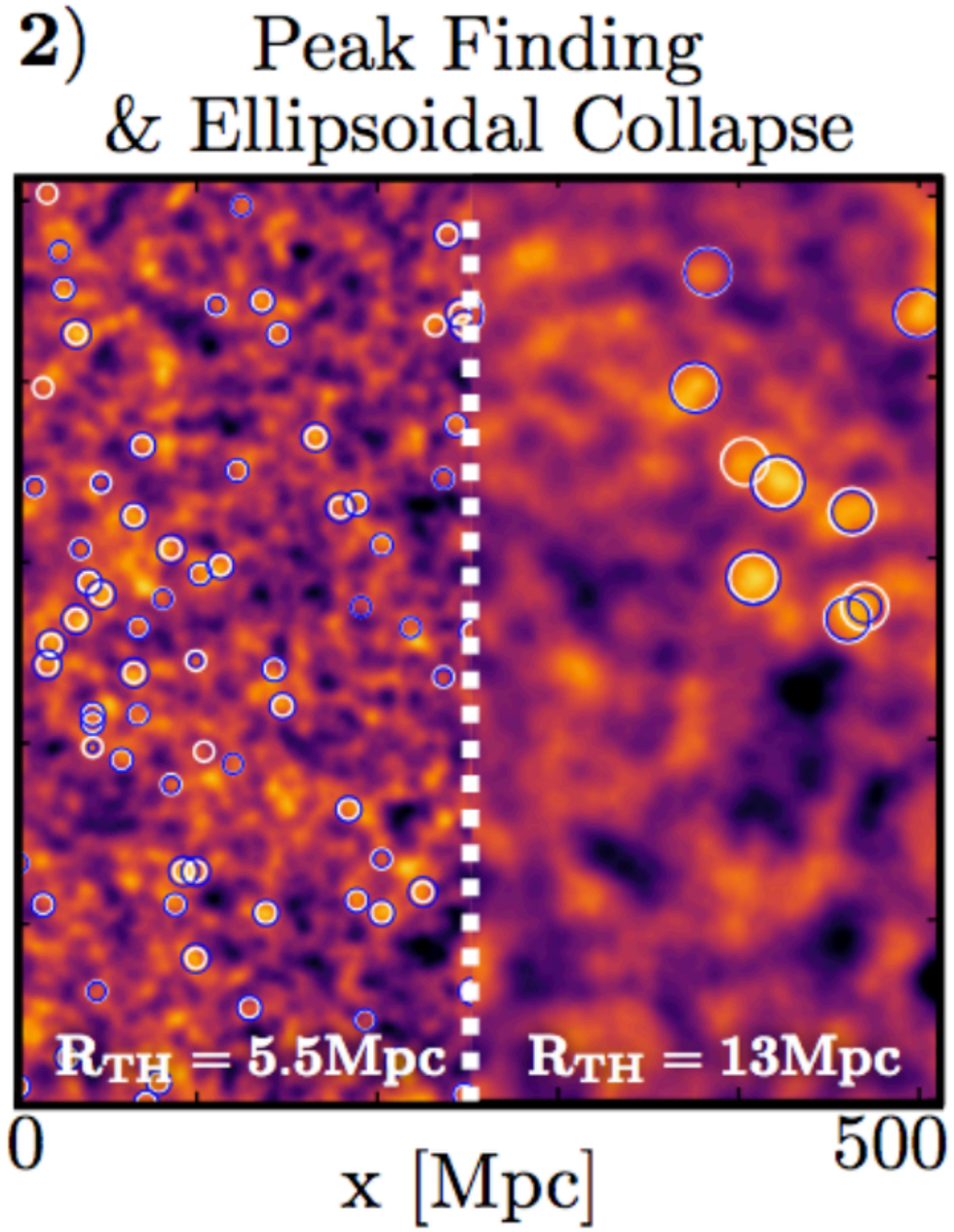
Image: ESA

Peak-Patch Method



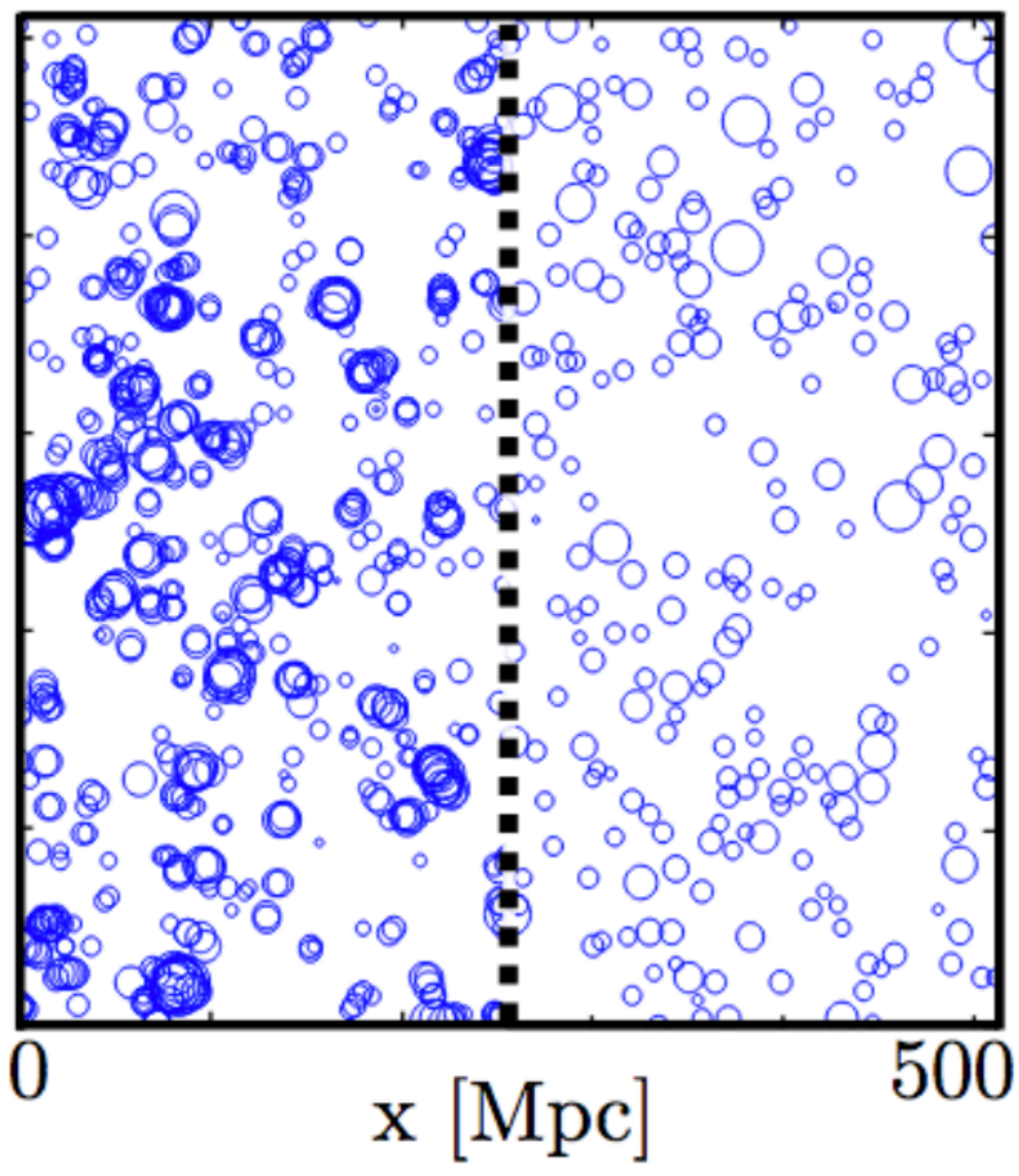
Stein et al. (1810.07727)

Peak-Patch Method



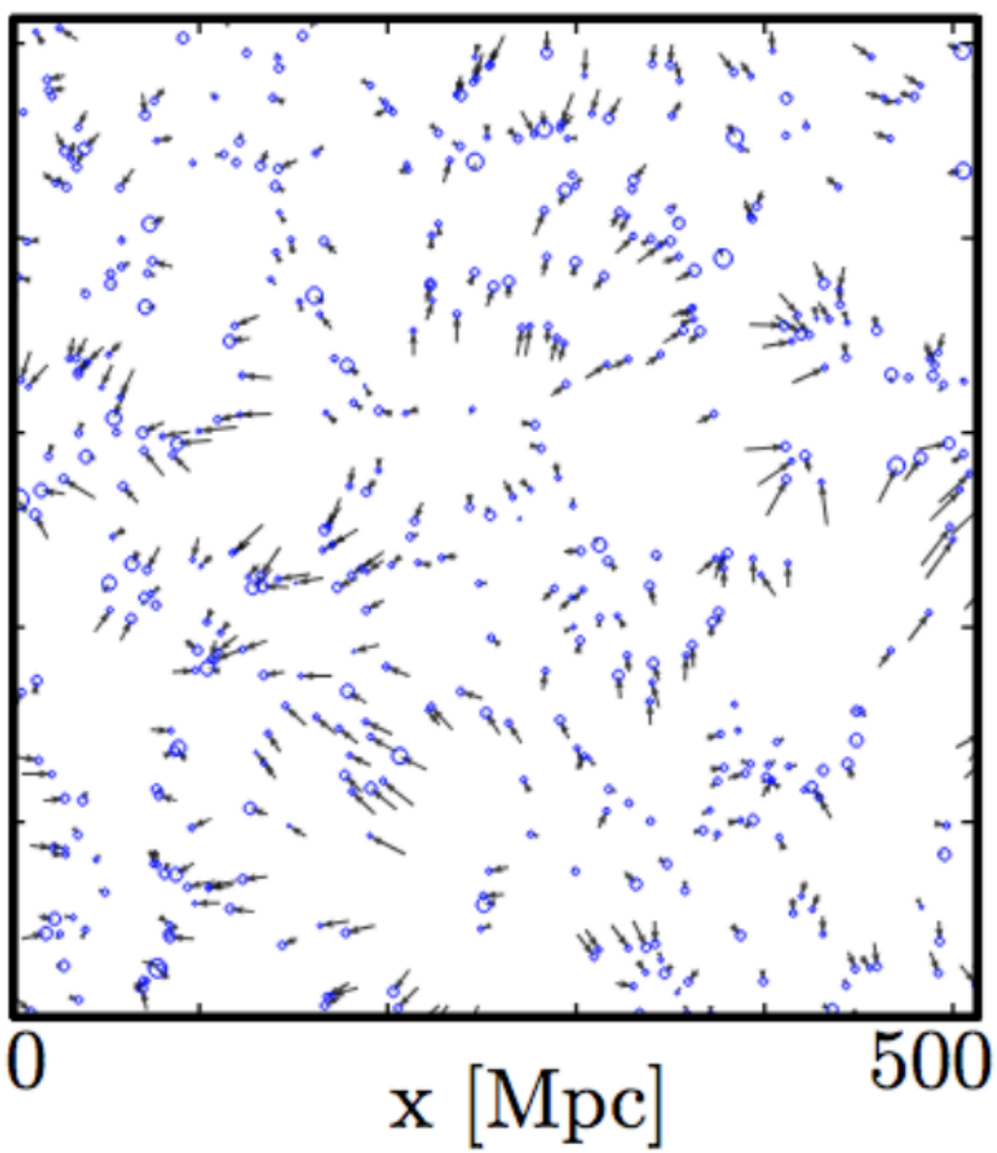
Stein et al. (1810.07727)

Peak-Patch Method



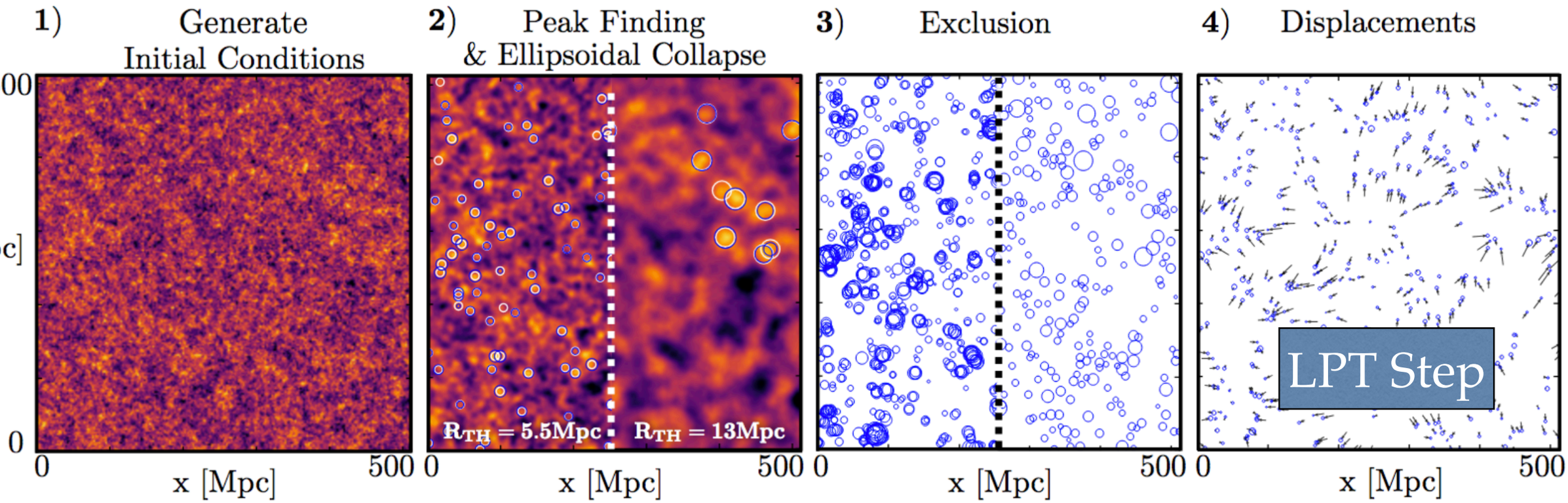
Stein et al. (1810.07727)

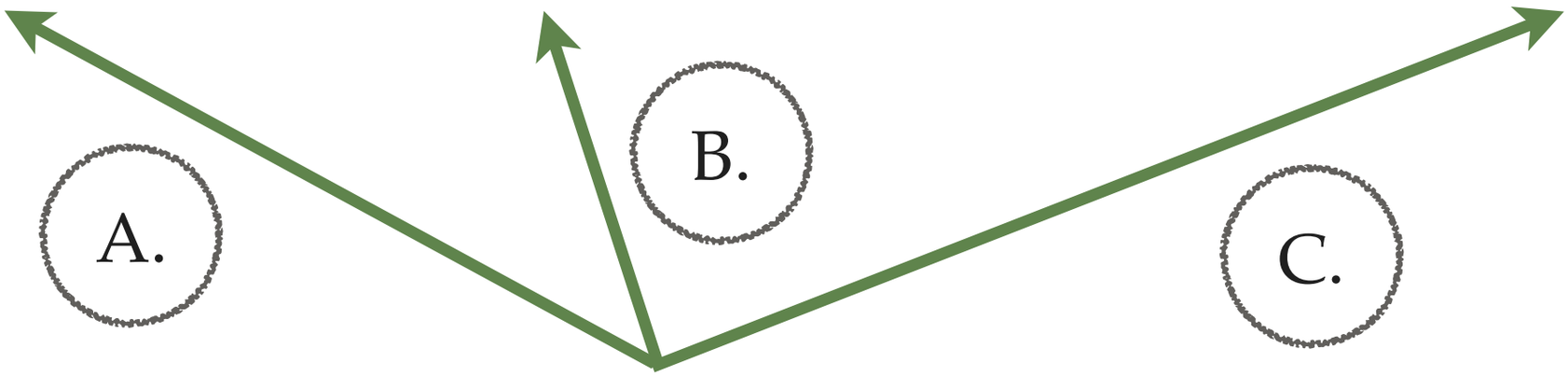
Peak-Patch Method



Stein et al. (1810.07727)

Peak-Patch Method Modifications

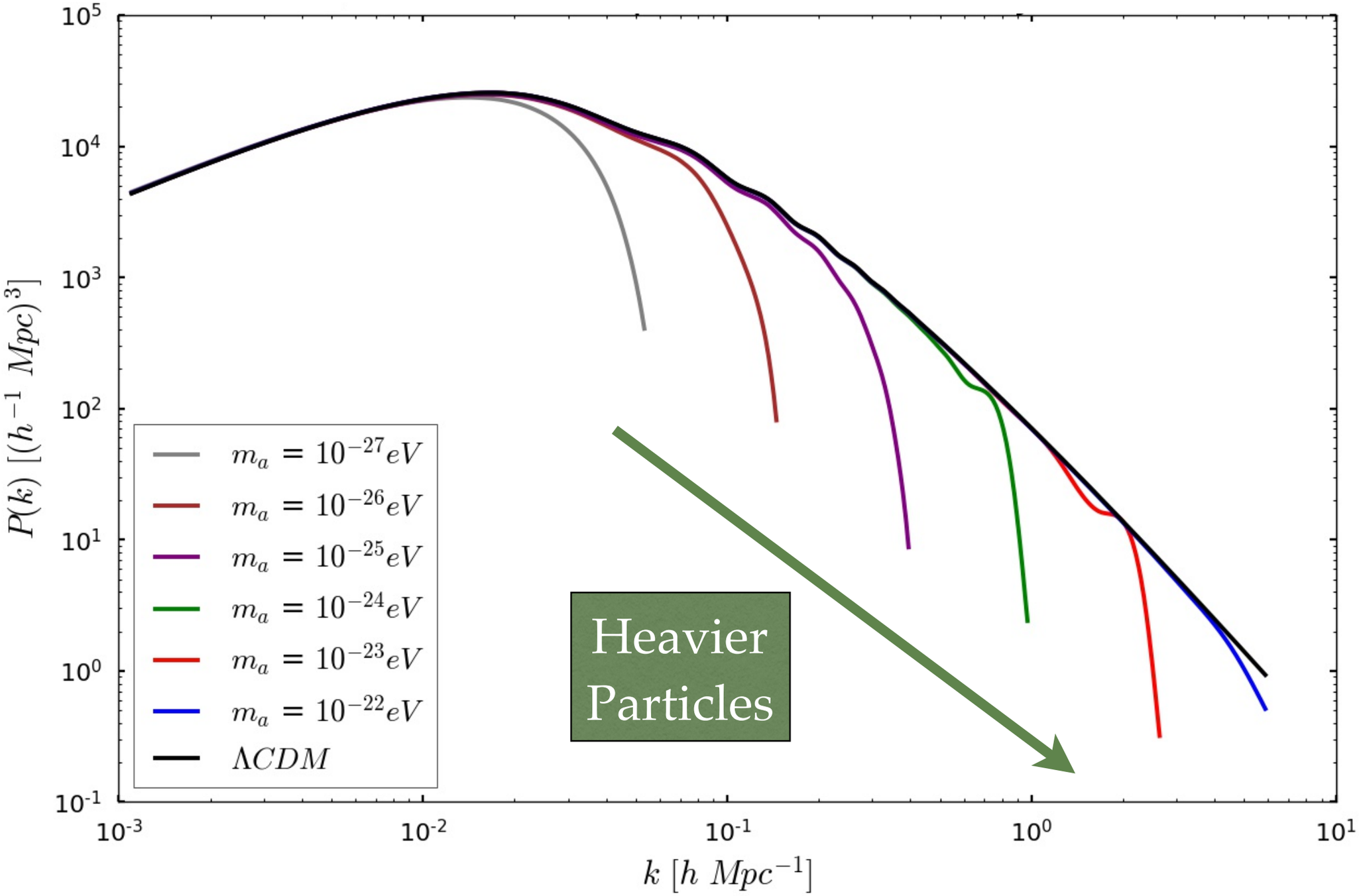




FDM-Modified Steps

Stein et al. (1810.07727)

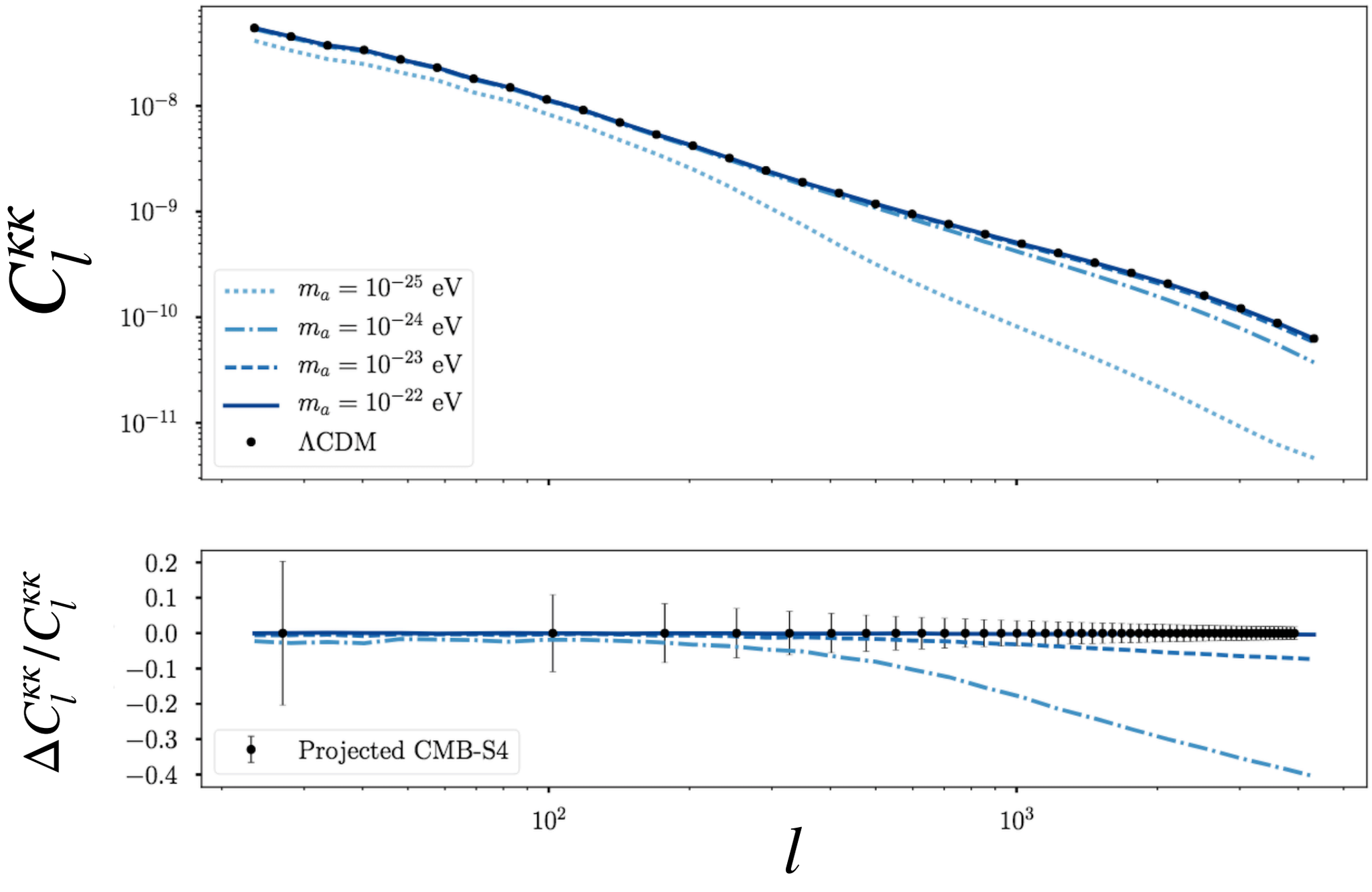
A. Initial Conditions



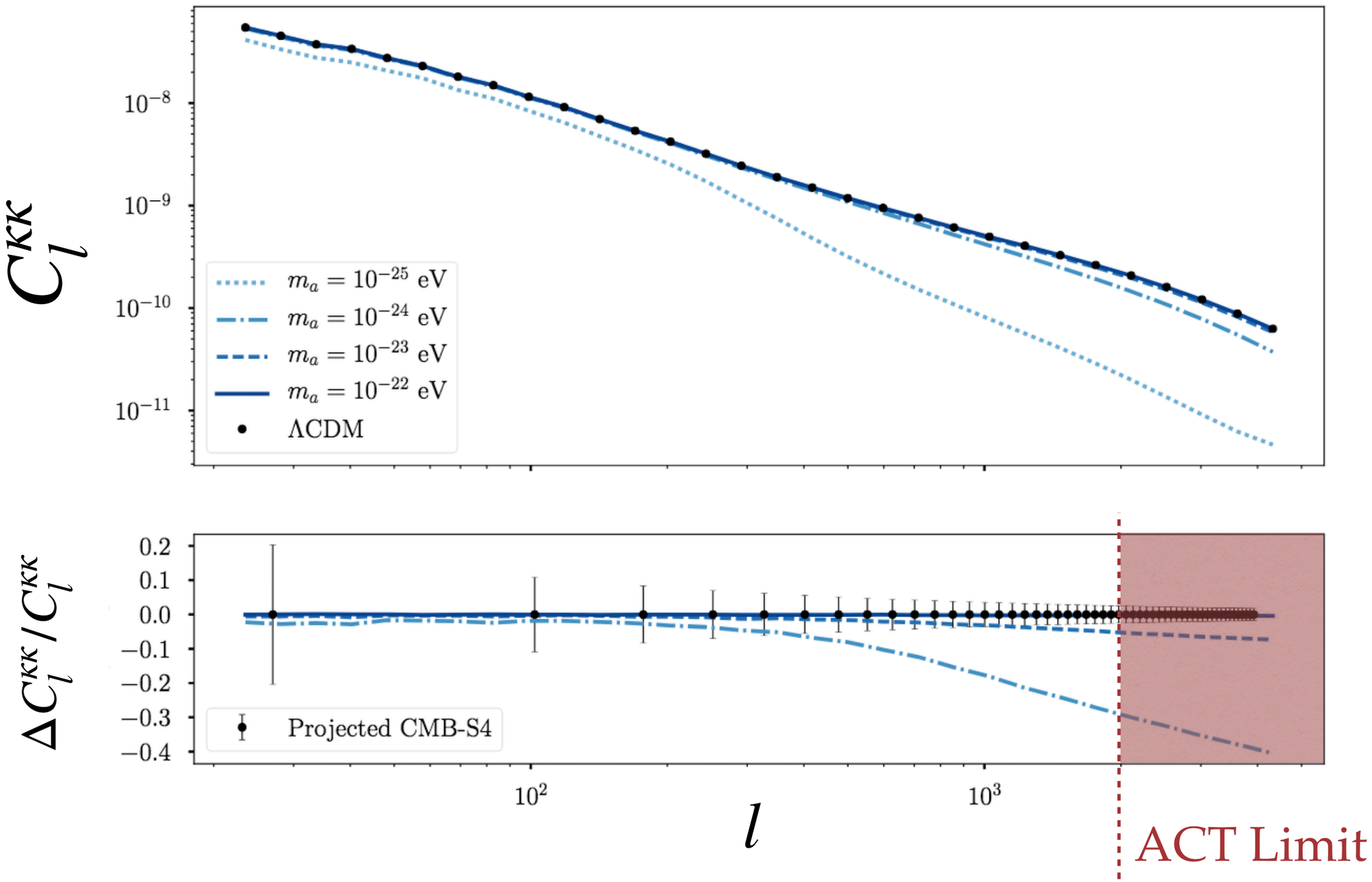
Computed with AxionCAMB (1607.08208)

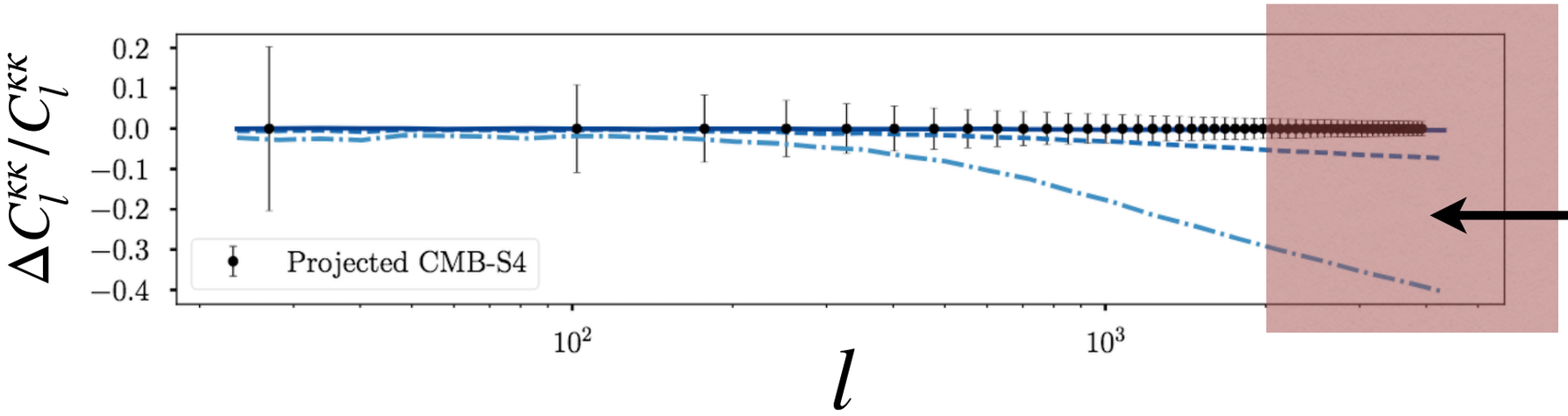
Lensing Constraints

$$C_l^{\psi} \approx \int_0^{\chi} \chi' d\chi' P_{\Psi}(l/\chi'; \eta_0 - \chi') \left(\frac{\chi - \chi'}{\chi \chi'} \right)^2$$

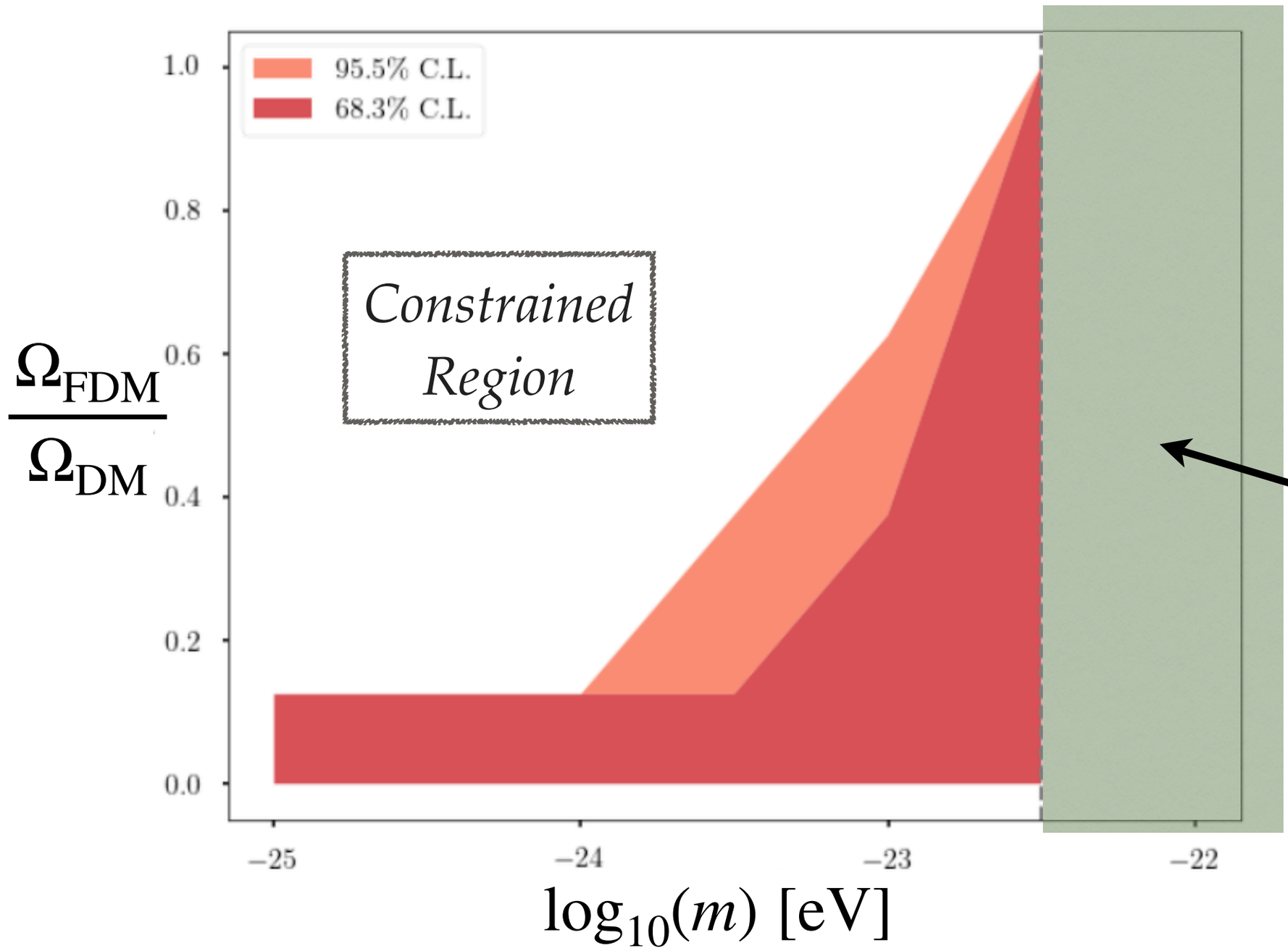


Lensing Constraints





Observationally Unexplored



Computationally Accessible

C. LPT Displacements

$$\mathbf{x} = \mathbf{q} + \mathbf{\Psi}$$

$\mathbf{\Psi}$: Displacement

$\mathbf{x}$: Final Position

$\mathbf{q}$: Initial Position

$$\mathbf{\Psi} \approx \mathbf{\Psi}^{(1)} + \mathbf{\Psi}^{(2)}$$

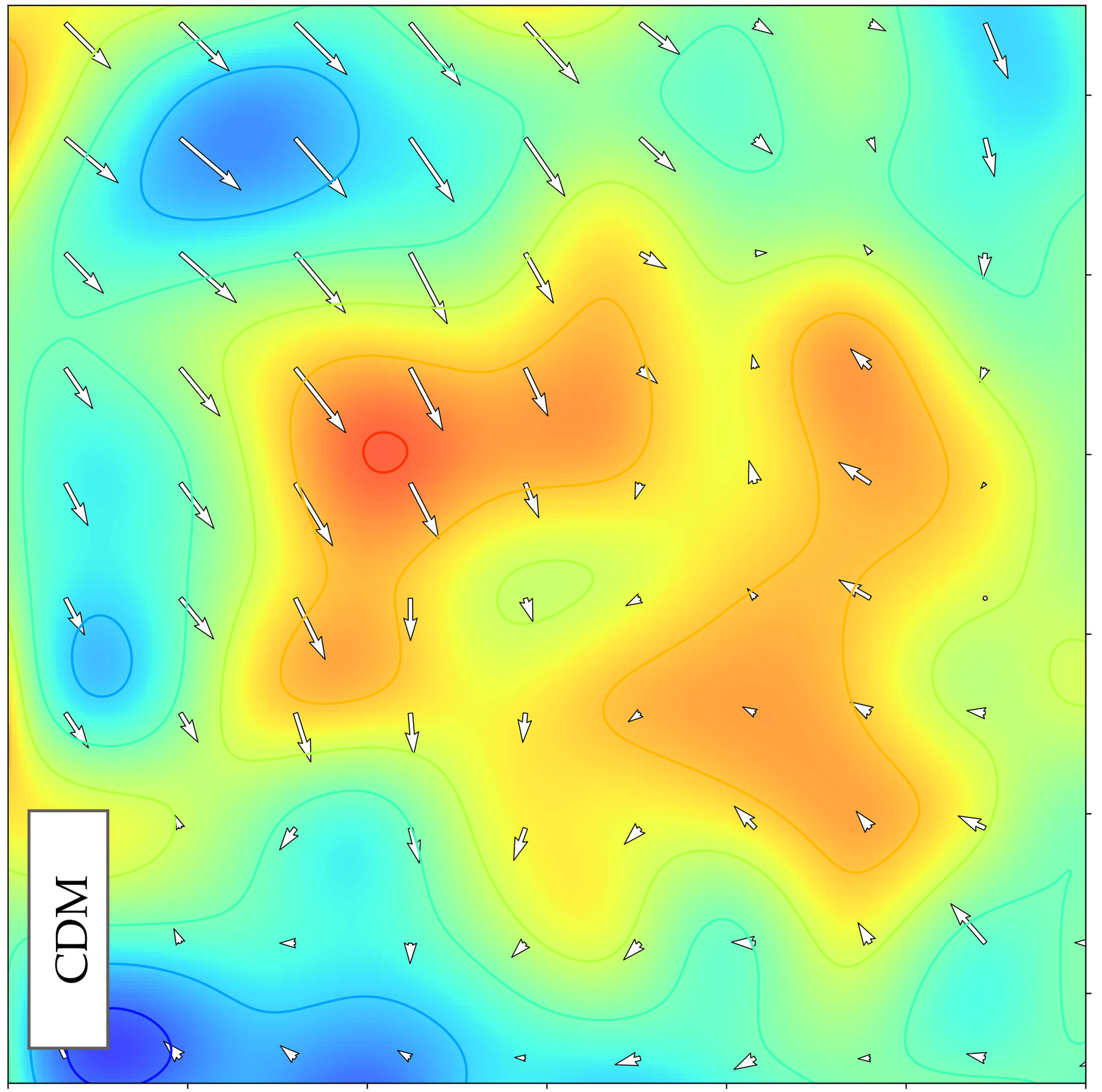
$\mathbf{\Psi}^{(1)}$: Linear

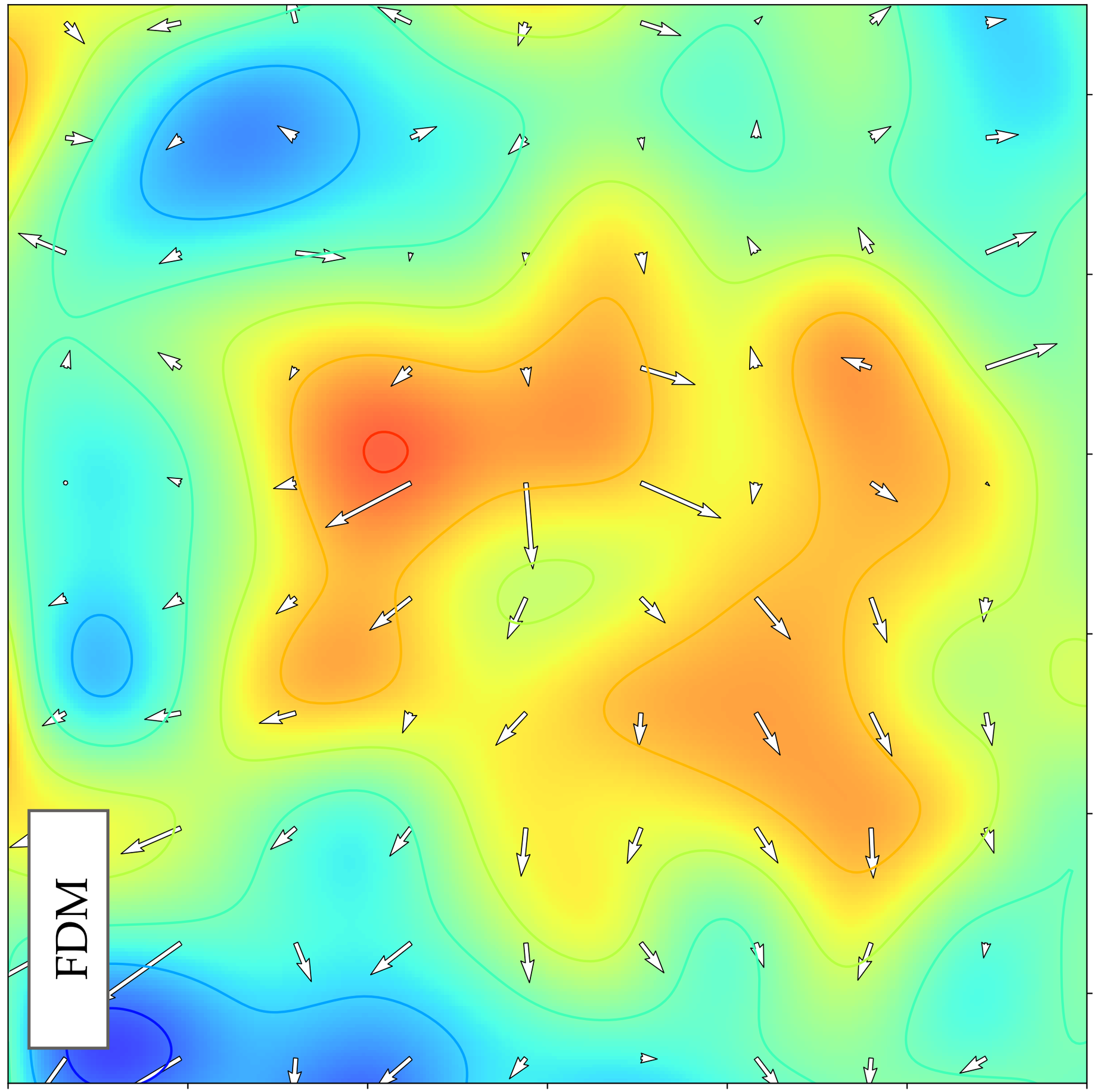
$\mathbf{\Psi}^{(2)}$: Quadratic

$$\nabla_{\mathbf{x}} \cdot \left(\frac{d^2\mathbf{\Psi}}{d\tau^2} + 2\frac{\dot{a}}{a}\frac{d\mathbf{\Psi}}{d\tau} \right) = -4\pi G\bar{\rho}\delta(\mathbf{x}) - \underbrace{\frac{c_s^2}{a^2}\nabla_{\mathbf{x}}^2\delta(\mathbf{x})}$$

c_s: Axion Sound Speed

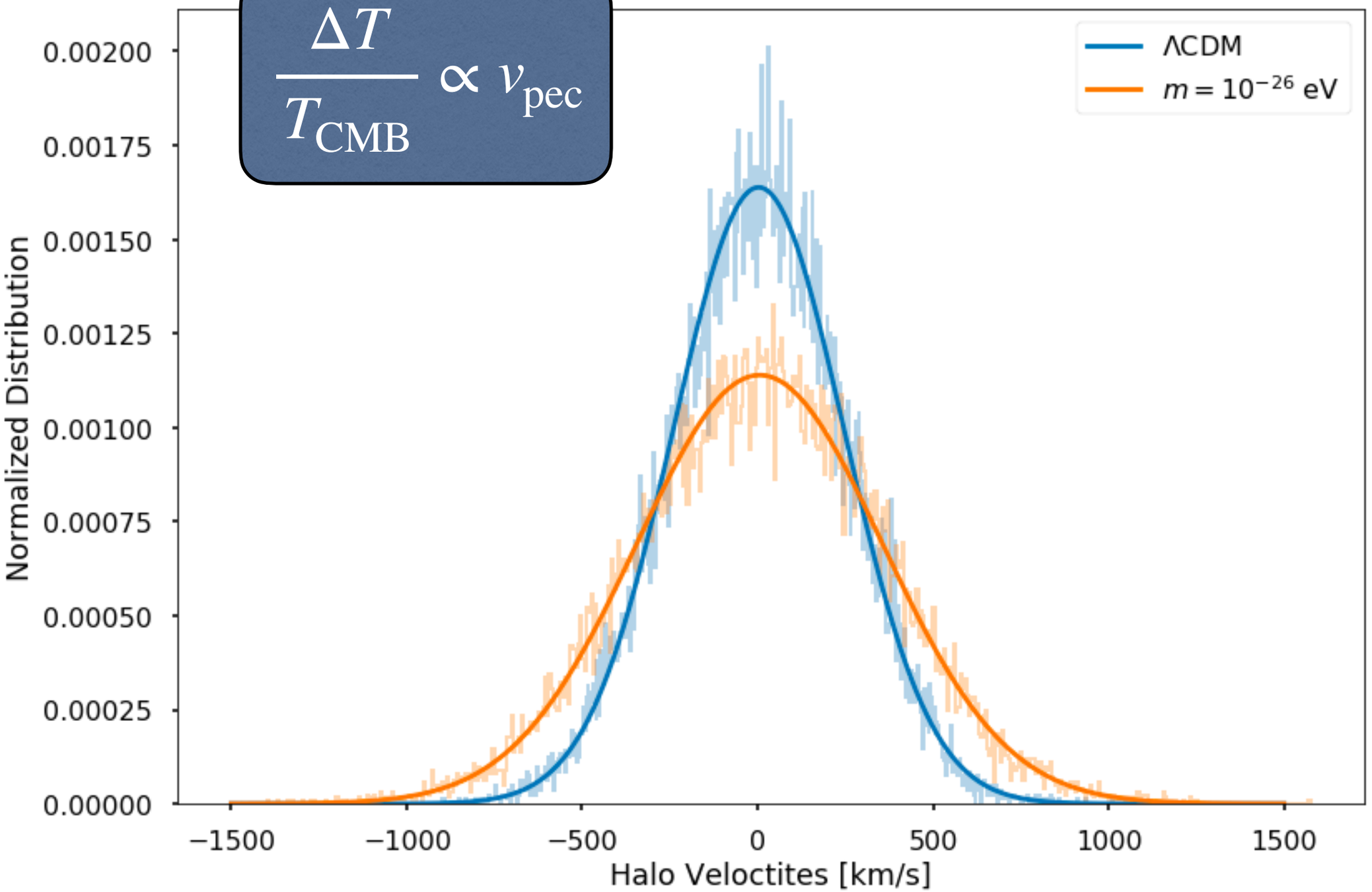
$\frac{c_s^2}{a^2}\nabla_{\mathbf{x}}^2\delta(\mathbf{x})$: Fuzzy DM Term


CDM
1 Mpc
Overdensity $\delta(\mathbf{x})$


Overdensity $\delta(\mathbf{x})$
FDM
1 Mpc

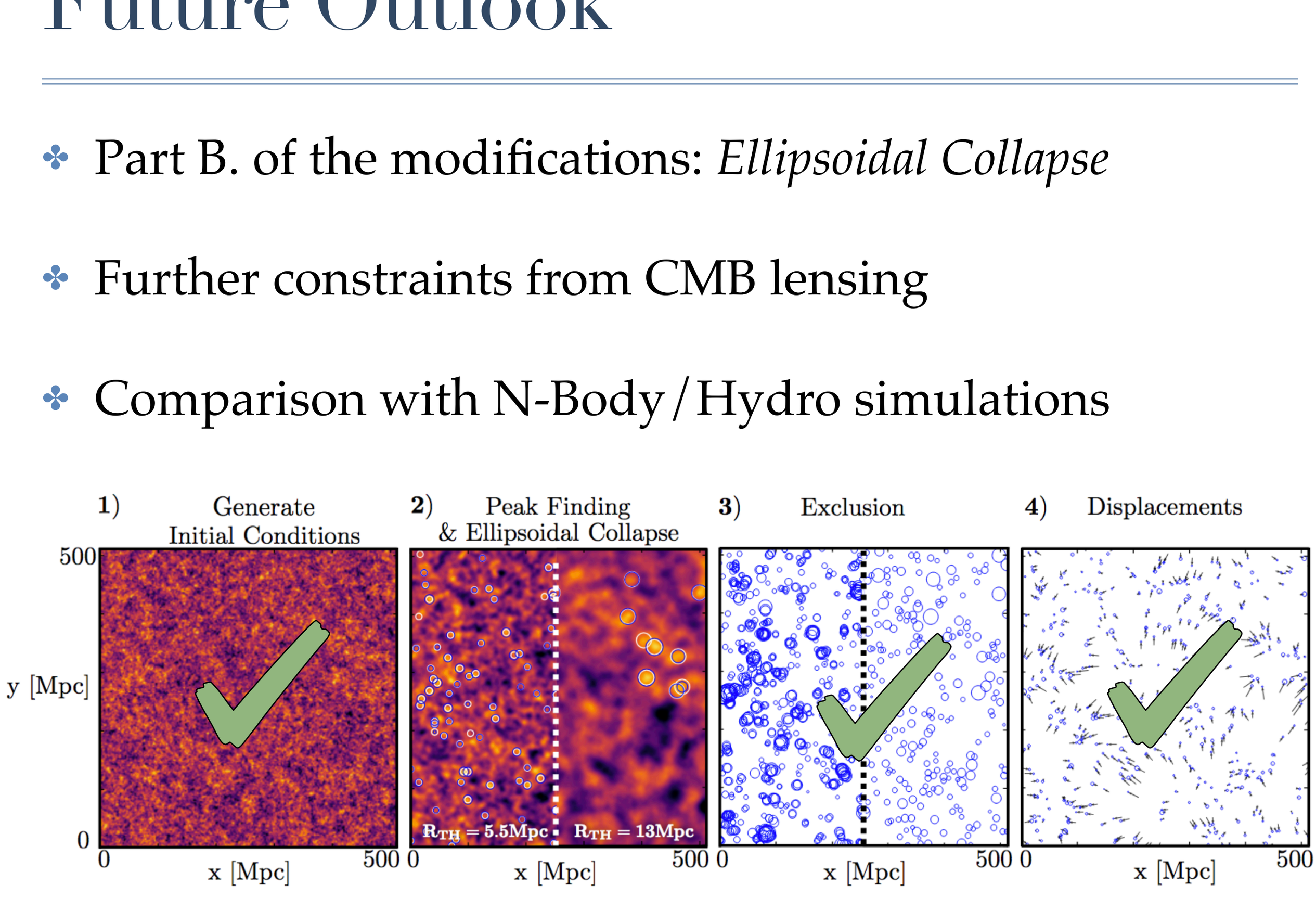
kSZ Contribution

$$\frac{\Delta T}{T_{\mathrm{CMB}}} \propto v_{\mathrm{pec}}$$



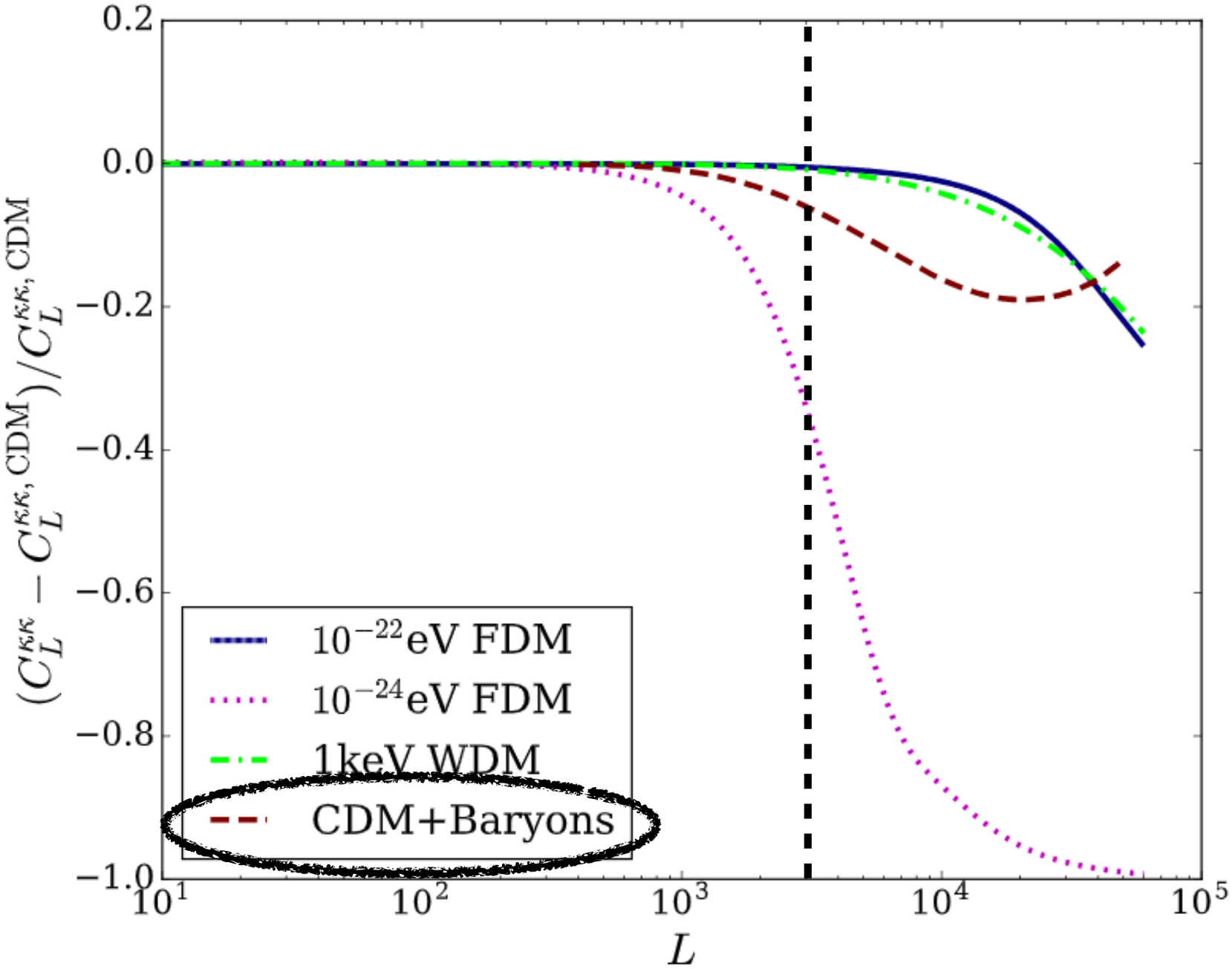
Future Outlook

- Part B. of the modifications: *Ellipsoidal Collapse*
- Further constraints from CMB lensing
- Comparison with N-Body / Hydro simulations



Thank you!

Baryon-Dominated Suppression

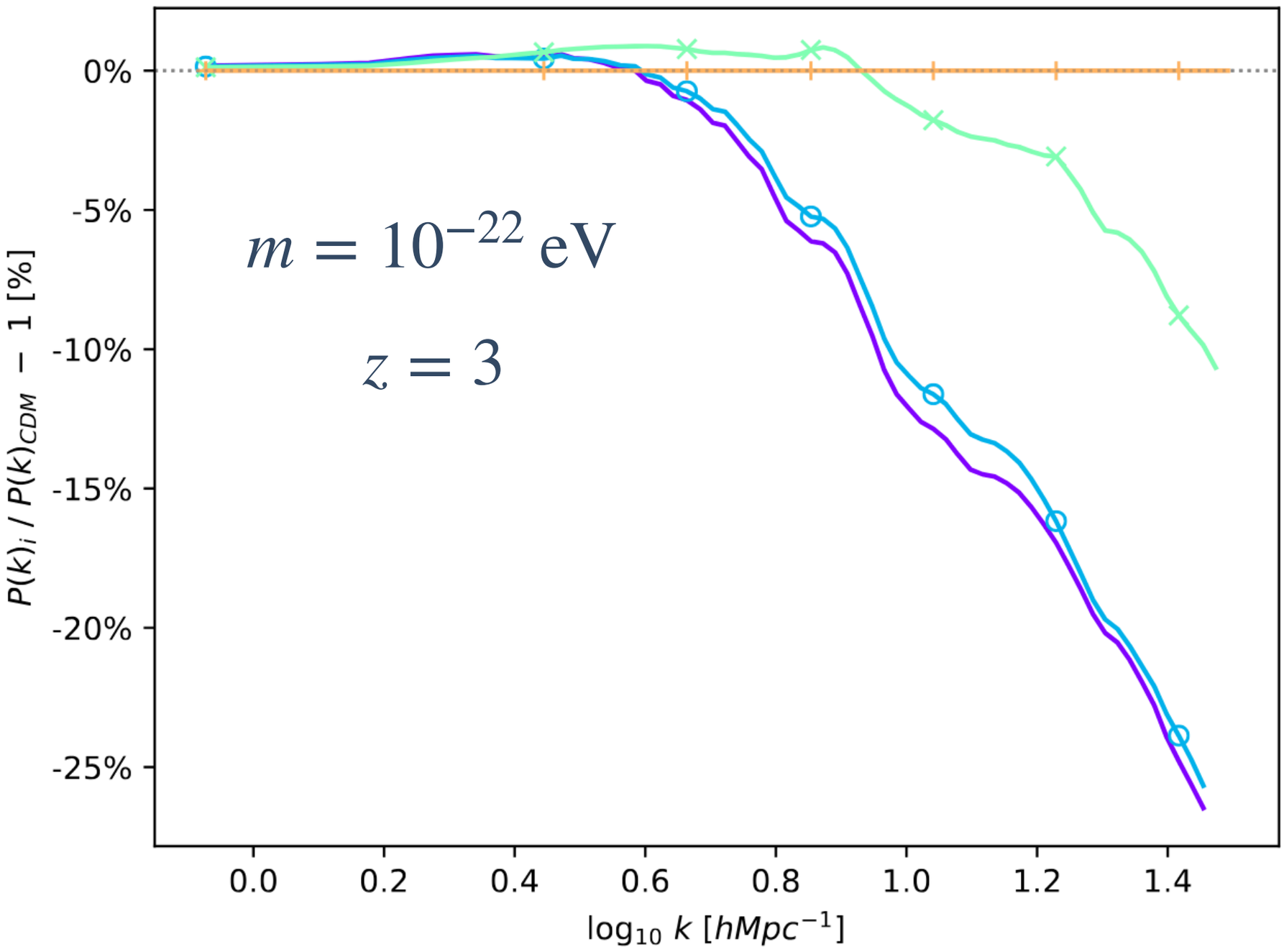


$L \approx 3000$

Nguyễn et al. (1710.03747)

Dynamical Effects (QP)

N-Body (AX-GADGET)



Adding Pressure

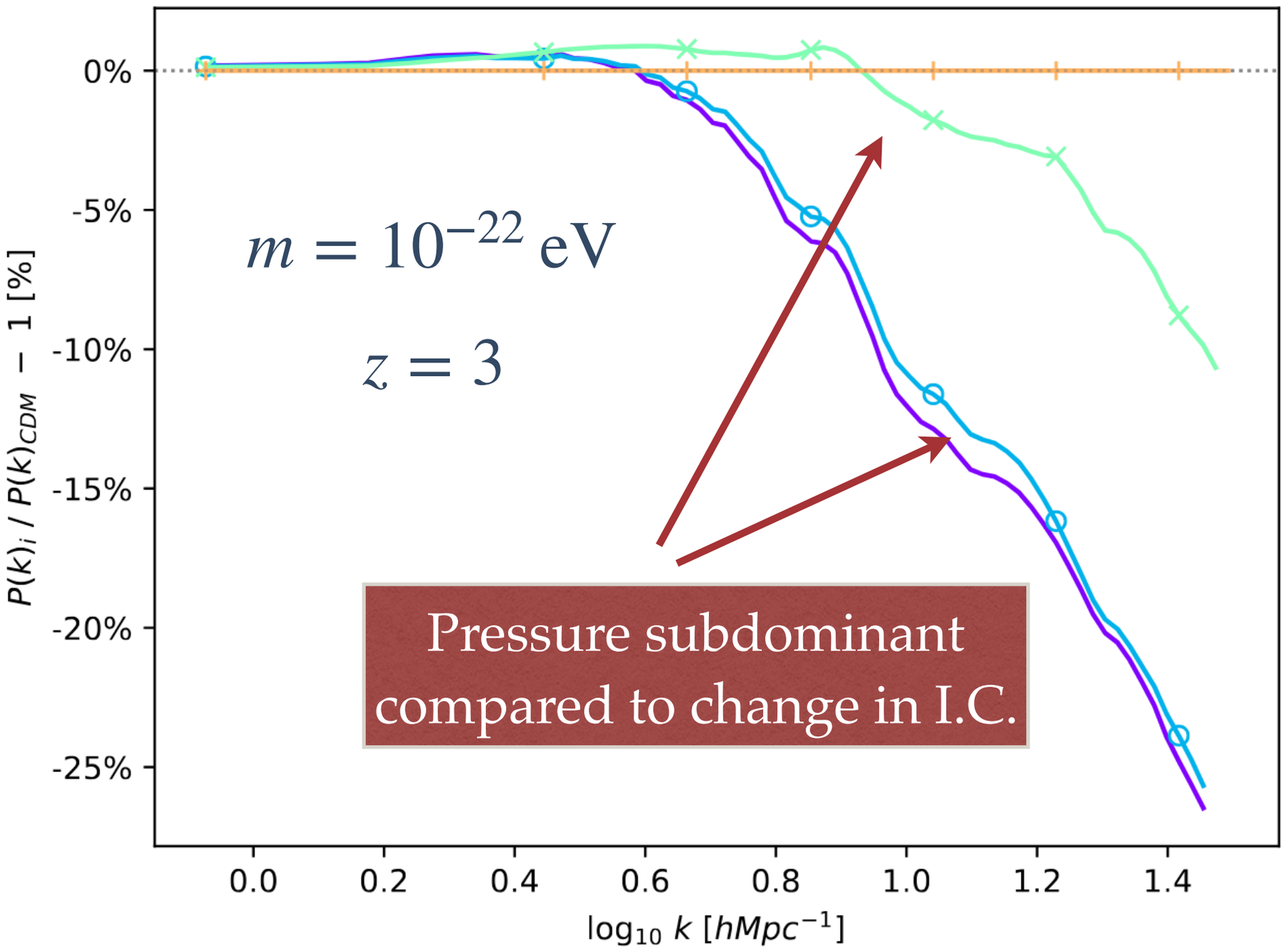
Changing I.C.

Both

Nori et al. (2018)

Dynamical Effects (QP)

N-Body (AX-GADGET)



Adding Pressure

Changing I.C.

Both

Nori et al. (2018)