

# Can blue-tilted primordial power spectrum save the small scale crisis in MW?

From the perspective of Zoom-In simulation for MW host size dark matter halo

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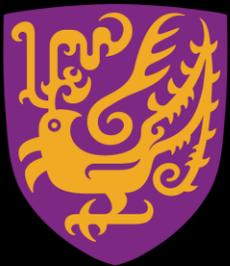
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Paper: Cosmological Zoom-In Simulations of Milky Way Host Size Dark Matter Halos with a Blue-Tilted Primordial Power Spectrum

<https://arxiv.org/abs/2412.16072> Under Review by PRD

Jianhao Wu(CUHK), Tsang Keung Chan(CUHK), Victor J. Forouhar Moreno(Leiden).



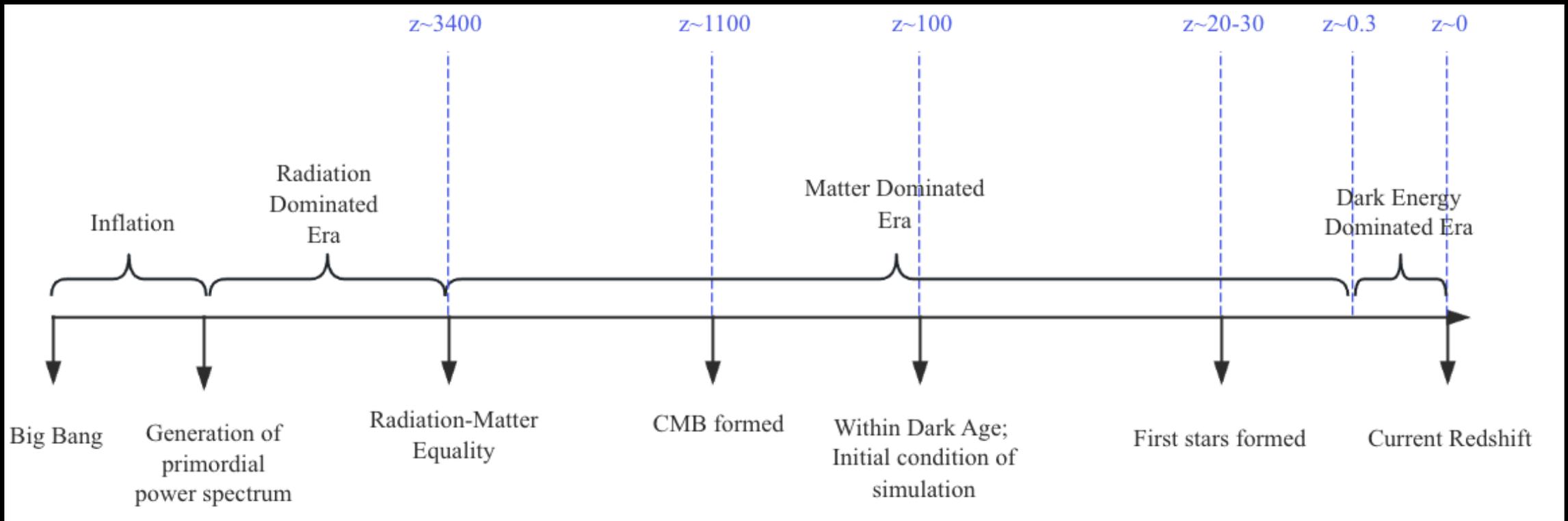
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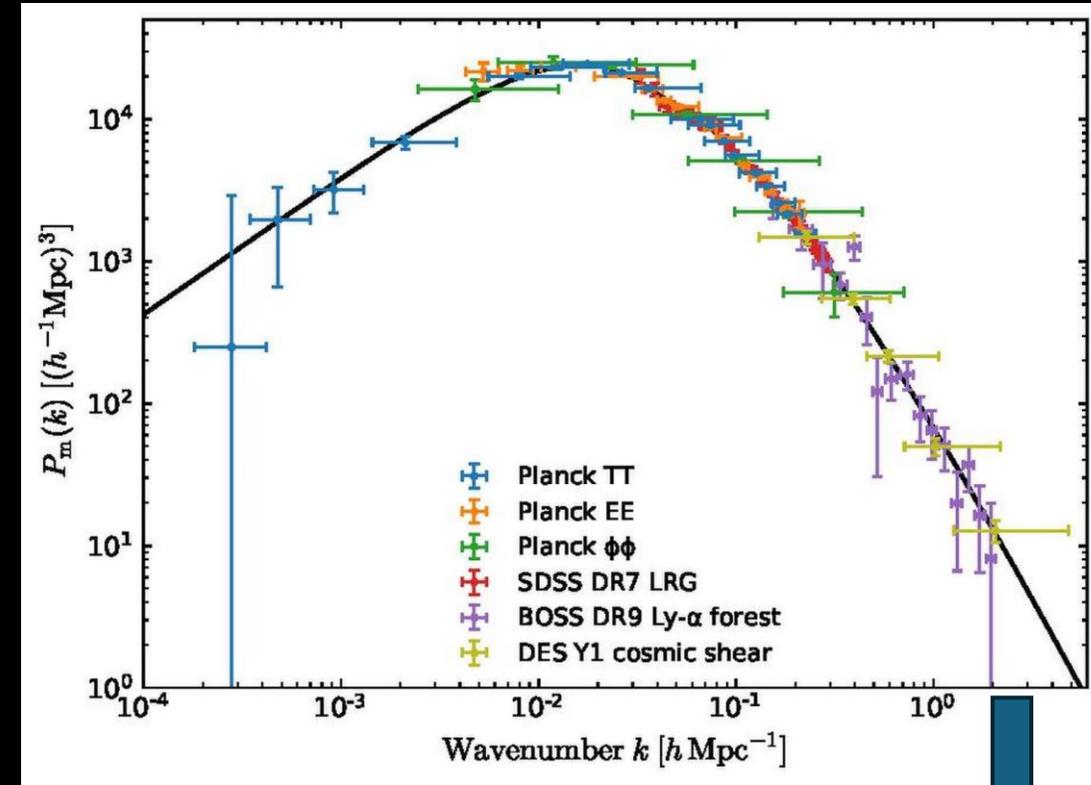
# Standard Cosmology Model

- The standard cosmology model consists of:
  - The single-field slow-roll inflationary model, which would generate a *power law* primordial power spectrum at very early universe
  - The LCDM model, which dominates the later evolution of the universe



# Uncertain at small scales

- Standard cosmology model has achieved great success during the past several decades, on *large scale of universe*
- However on *small scales* the primordial power spectrum is *loosely constrained*



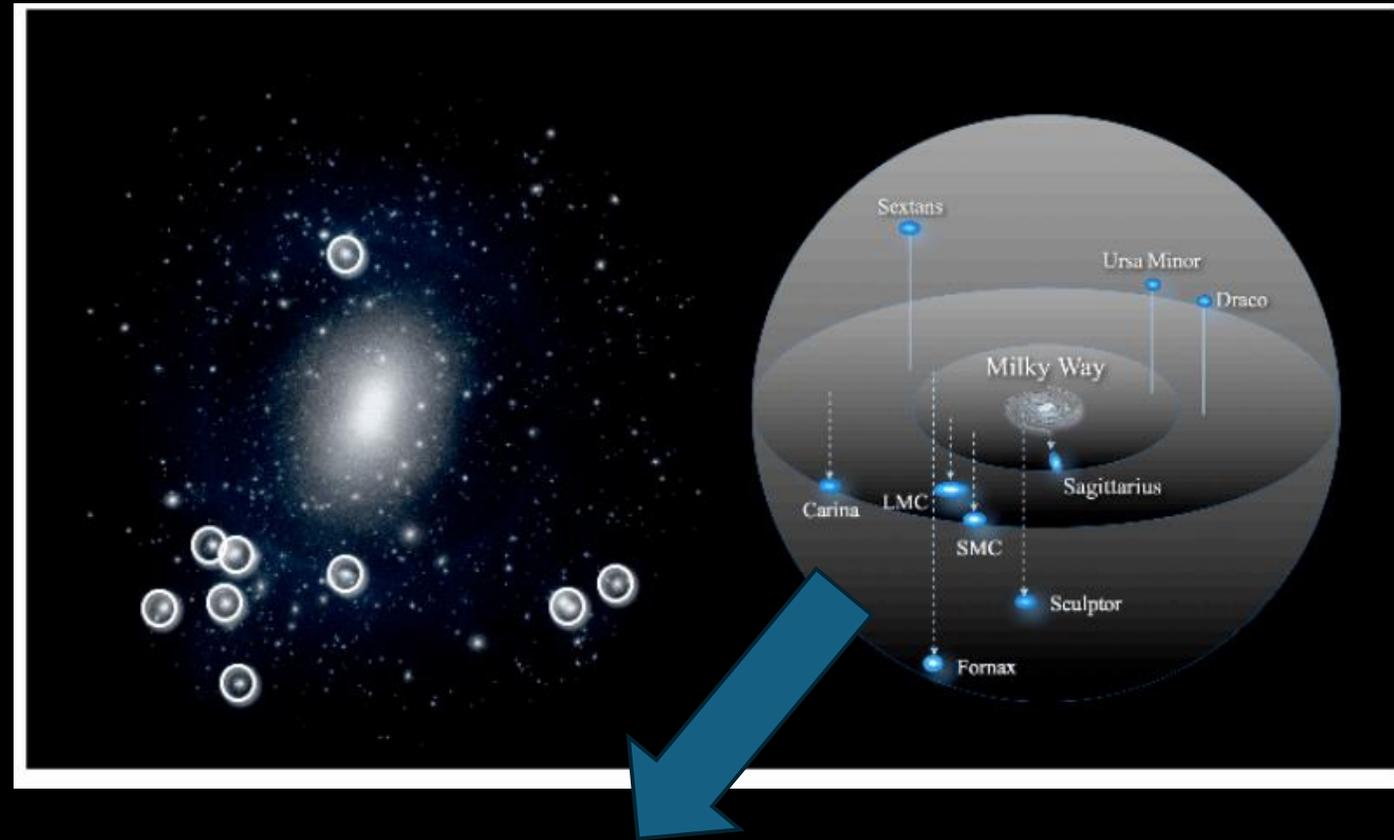
*MW host dark matter halo's size corresponds to  $\sim 2.5 h/\text{Mpc}$*

# A small-scale enhanced or suppressed?

- Besides, multiple observations are in favor of *a small scale enhanced* cosmological model:
  - JWST has observed early formation of massive galaxies (arxiv [2306.11993])
  - Even CDM model could not solve the “anomalous” flux ratio problem in strong lensing: a larger fraction mass of substructure is required (arxiv [0903.4559])
  - A too-many-satellite-galaxies problem appeared in nearby galaxy observation (arxiv [1711.06267] [2403.08717])

# MW satellite galaxies can help constrain small scale

A **satellite galaxy** is a smaller galaxy that orbits around a larger galaxy due to gravitational forces



Milky-Way has  $\gtrsim 50$  satellite galaxies!

# Change Power Law Primordial Power Spectrum -> Broken Power Law!

- Larger spectral index at small scale end (large  $k$ ), to give small scale enhancement!

*old model*

the growth factor. In the traditional single-field slow-roll inflation, the PPS follows the PL model:

$$P_i(k) \propto k^{n_s}, \quad (2)$$

with the spectral index  $n_s \sim 0.96$  (see [section III B 1](#)).

Ref. [23] gave the following formalism for the BT models:

*blue-tilted model*

$$P_i(k) \propto \begin{cases} k^{n_s}, & (\text{for } k \leq k_p), \\ k^{n_s} \cdot \left(\frac{k}{k_p}\right)^{m_s - n_s}, & (\text{for } k > k_p), \end{cases} \quad (3)$$

which is a broken power law modification of [Equation 2](#).

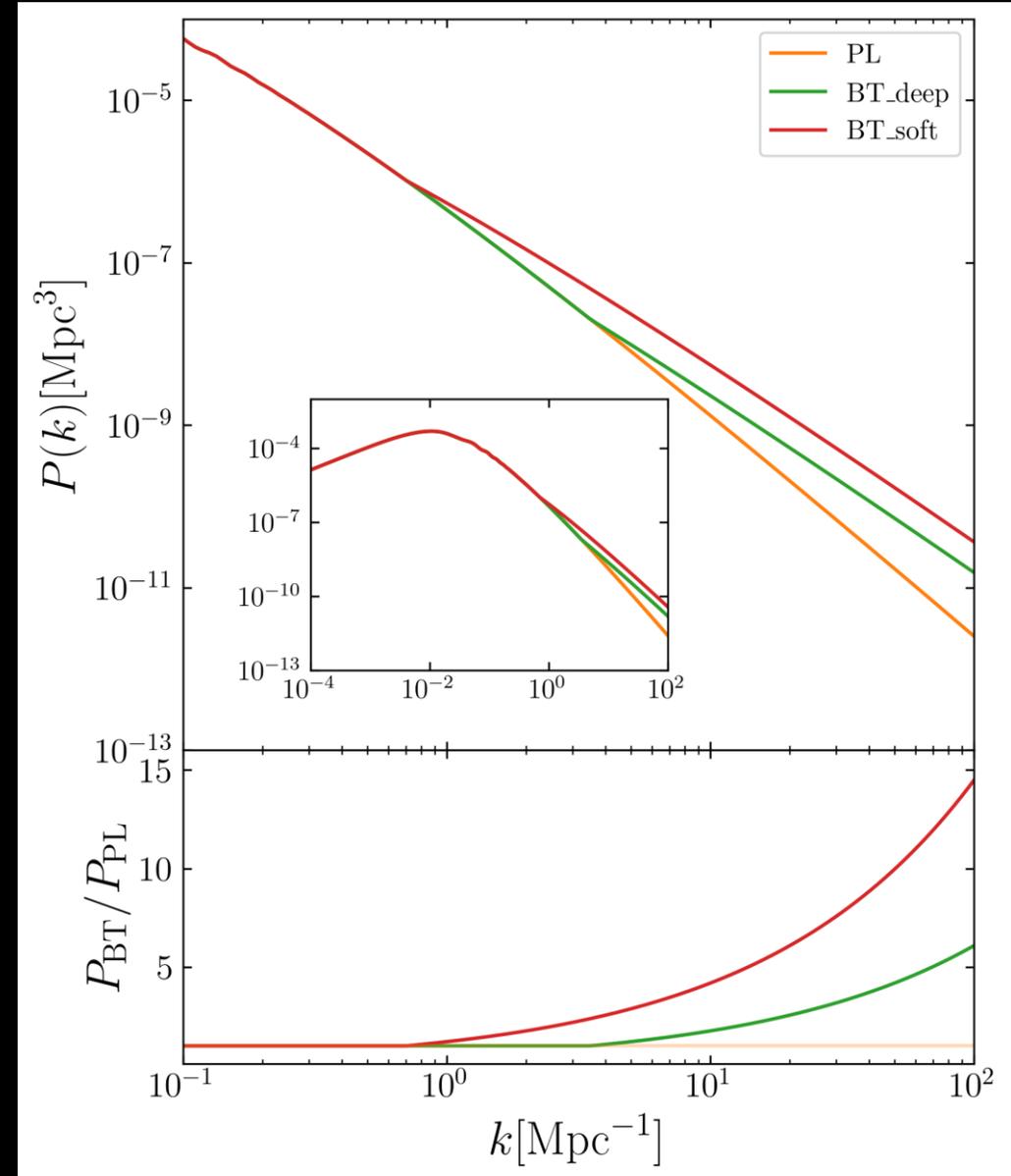
# Two blue-tilted models for instance

- We chose two sets of parameters for blue-tilted model (*BT model*), along with the standard model (power-law model aka *PL model* here)

Models	Related parameters
PL	Power Law Primordial Power Spectrum $n_s = 0.961$
BT_deep	$k_p = 3.51 \text{ Mpc}^{-1}$ $m_s = 1.5$
BT_soft	$k_p = 0.702 \text{ Mpc}^{-1}$ $m_s = 1.5$

**TABLE I.** The parameters of all the chosen models.  $k_p$  is the wave vector at which the BT PPS would deviate from the PL PPS.  $m_s$  is the enhanced spectral index for  $k > k_p$ , at the small scales. For other cosmological parameters, see [section III B 1](#).

[arxiv:2412.16072]



Broken point's scale corresponds to a cosmic structure mass scale

- $k_p$  should correspond to a mass scale for cosmic structure, only below which blue-tilted model could affect.
- How to get it?
  - wave number  $k_p \rightarrow$
  - wave length  $\lambda \rightarrow$
  - A sphere whose radius  $r_l = \frac{1}{2} \lambda$

$$M_l = \frac{4\pi}{3} r_l^3 \rho_m = \frac{\Omega_m H_0^2}{2G} r_l^3$$
$$= 1.71 \times 10^{11} \left( \frac{\Omega_m}{0.3} \right) \left( \frac{H_0}{70} \right)^2 \left( \frac{r_l}{1 \text{ Mpc}} \right)^3 M_\odot. \quad (4)$$

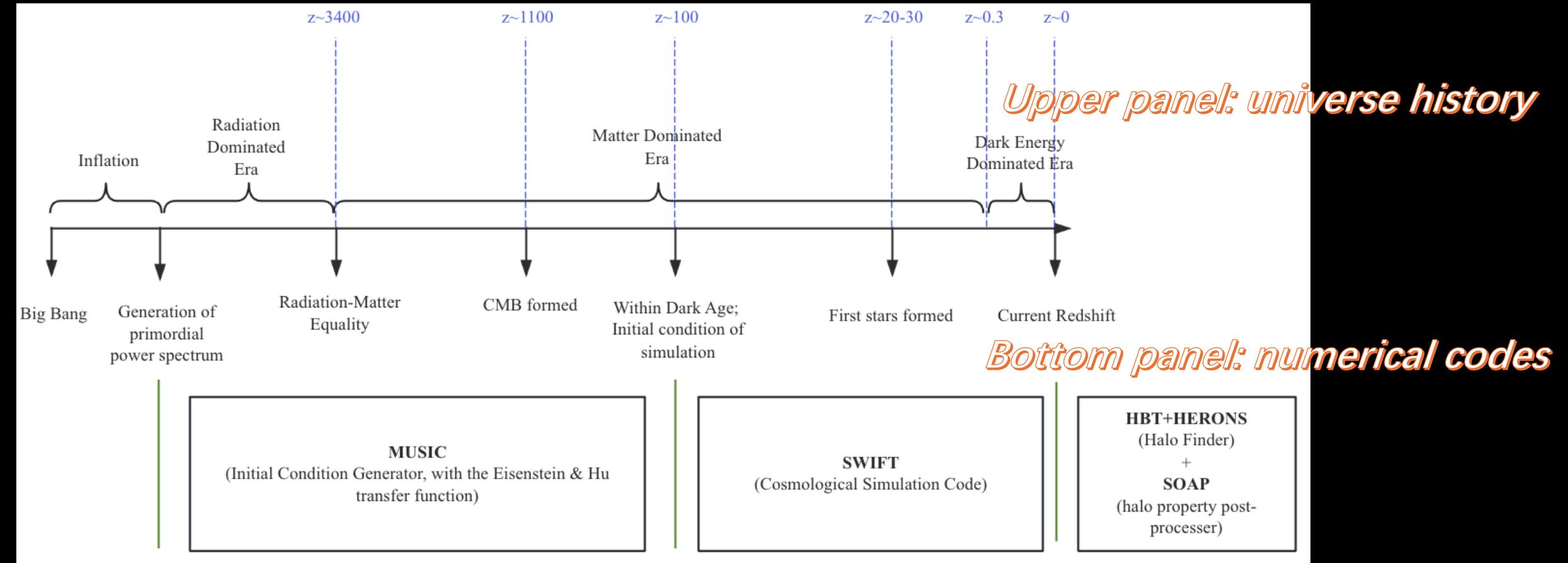
***For BT\_deep:  $1.1 \times 10^{11} M_\odot$***

***For BT\_soft:  $1.4 \times 10^{13} M_\odot$***

***Both could cover the mass scale  
for most dark matter subhalos  
in MW host ( $10^{12} M_\odot$ )!***

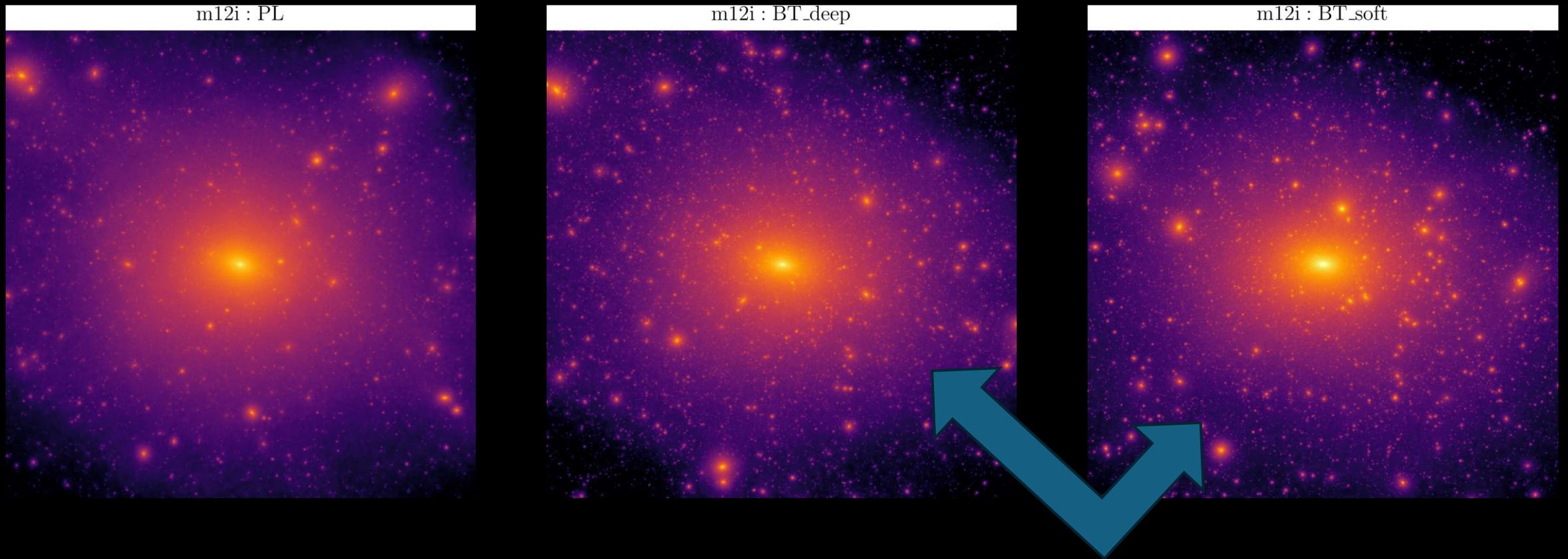
# Numerical pipeline we used

- After changing the primordial power spectrum, then use cosmological simulation to evolve to current redshift!



# Intuitive way: projection map showing more subhalos

- dark matter 2D projection map, with side length 400 kpc



***Both BT models give more subhalos than power-law!***

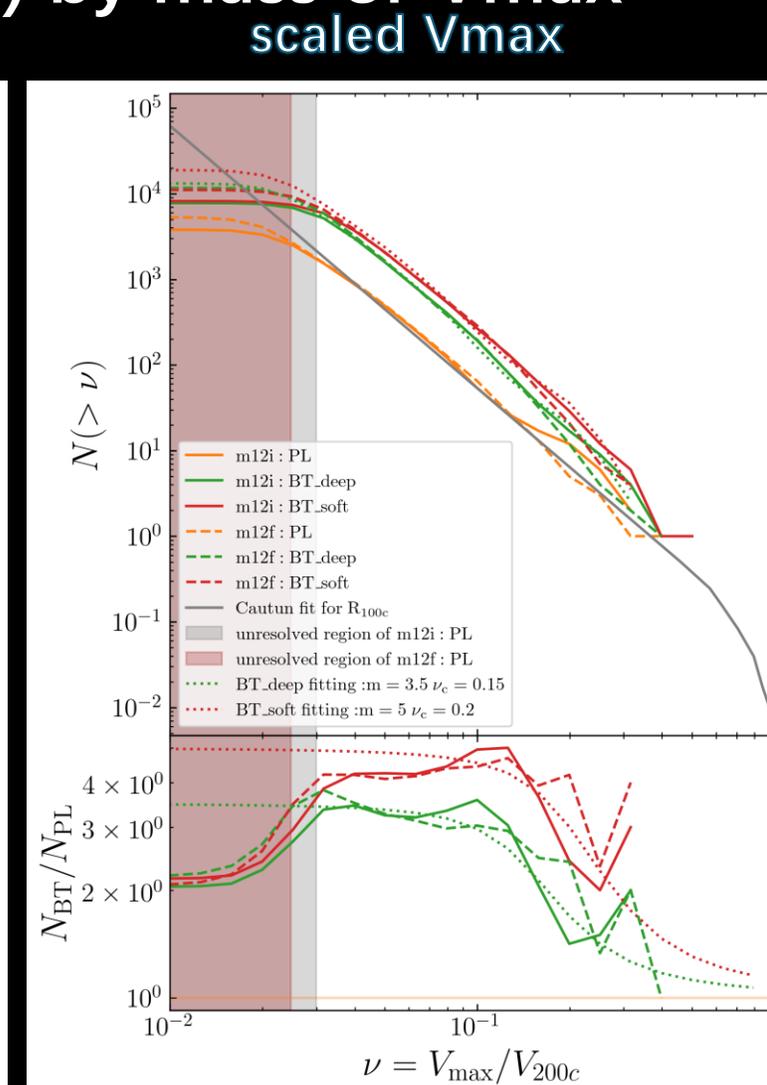
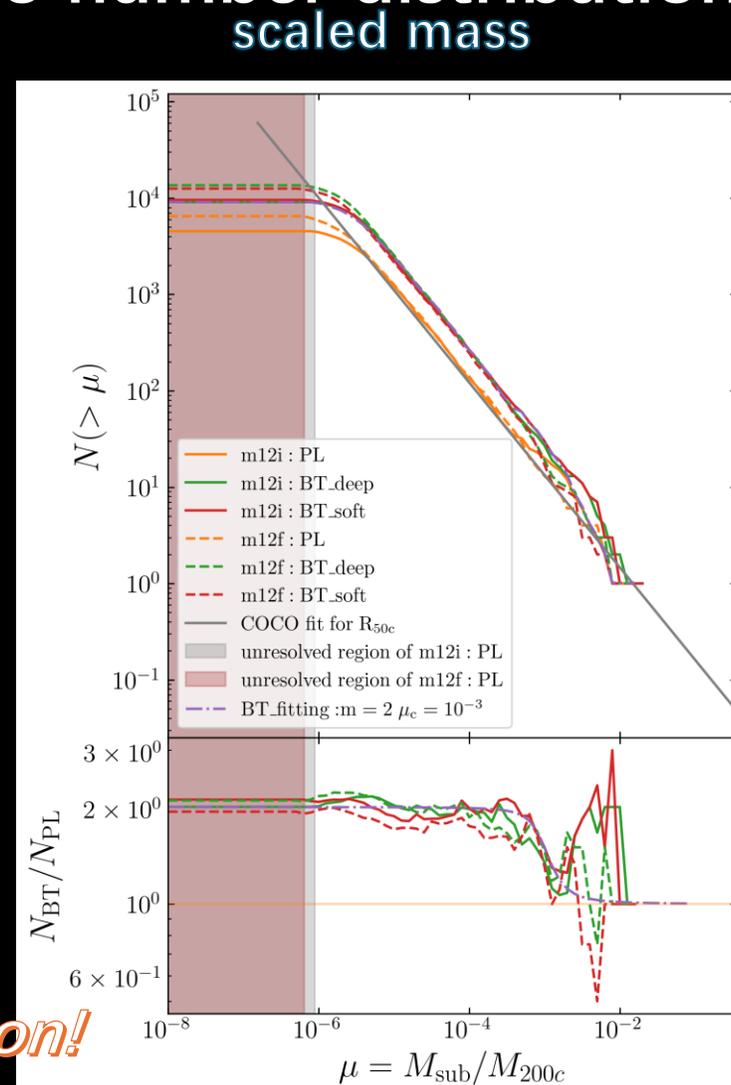
# In terms of mass and maximum circular velocity( $V_{\max}$ )

- subhalo function(aka subhalo number distribution) by mass or  $V_{\max}$ 
  - subhalo mass function could be enhanced by a factor of two at low mass end
  - subhalo  $V_{\max}$  function could be enhanced by more than 3 times at low  $V_{\max}$  end

Number of subhalos

Ratios between numbers

*The ratio for both functions, observes an inverse S shape function!*



# In terms of radial distance

- radial distance *from the center of main halo*

scaled radial distance

- At inner region of main halo, normalized number density nearly doubled

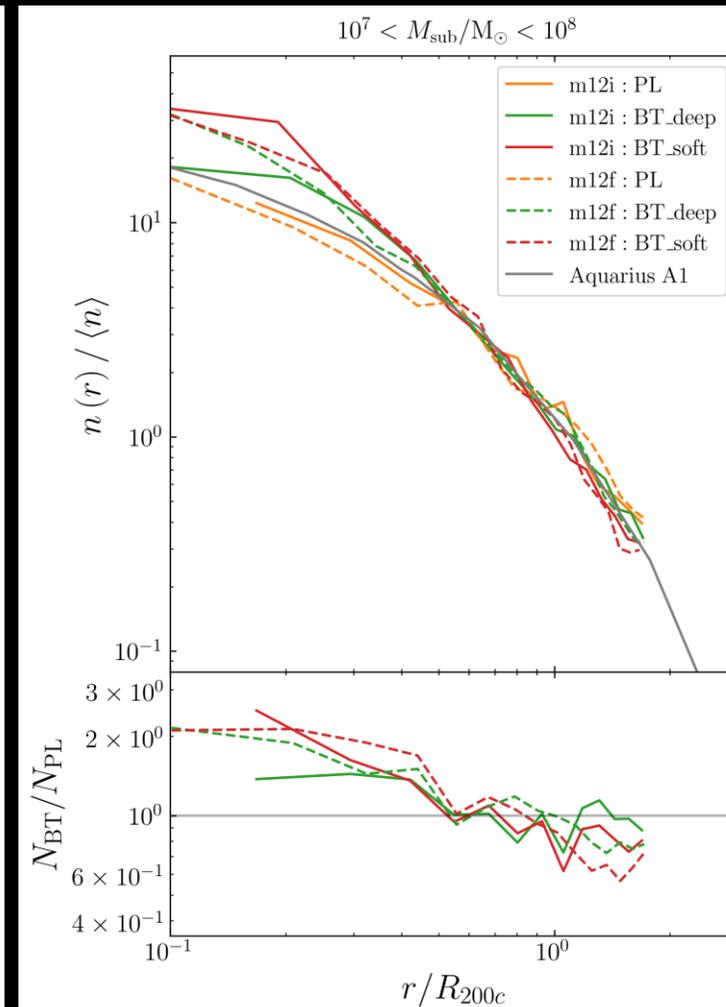
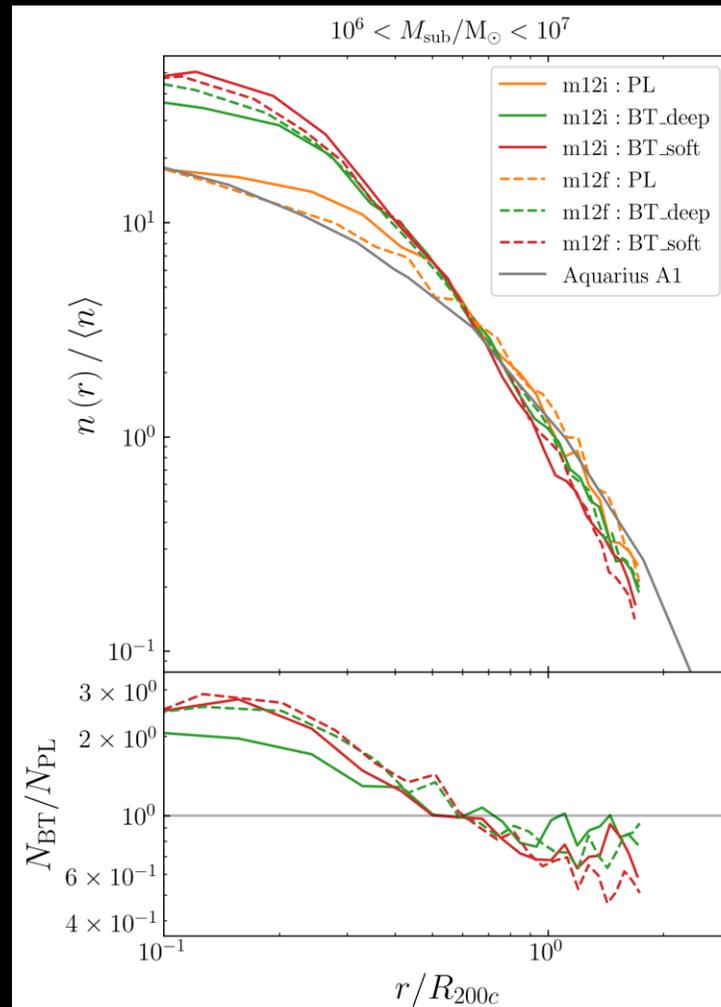
Normalized number density

Ratio(BT over PL)

*Grey lines are the same for different mass!*

*(Found by Aquarius simulation [arxiv0809.0898])*

scaled radial distance



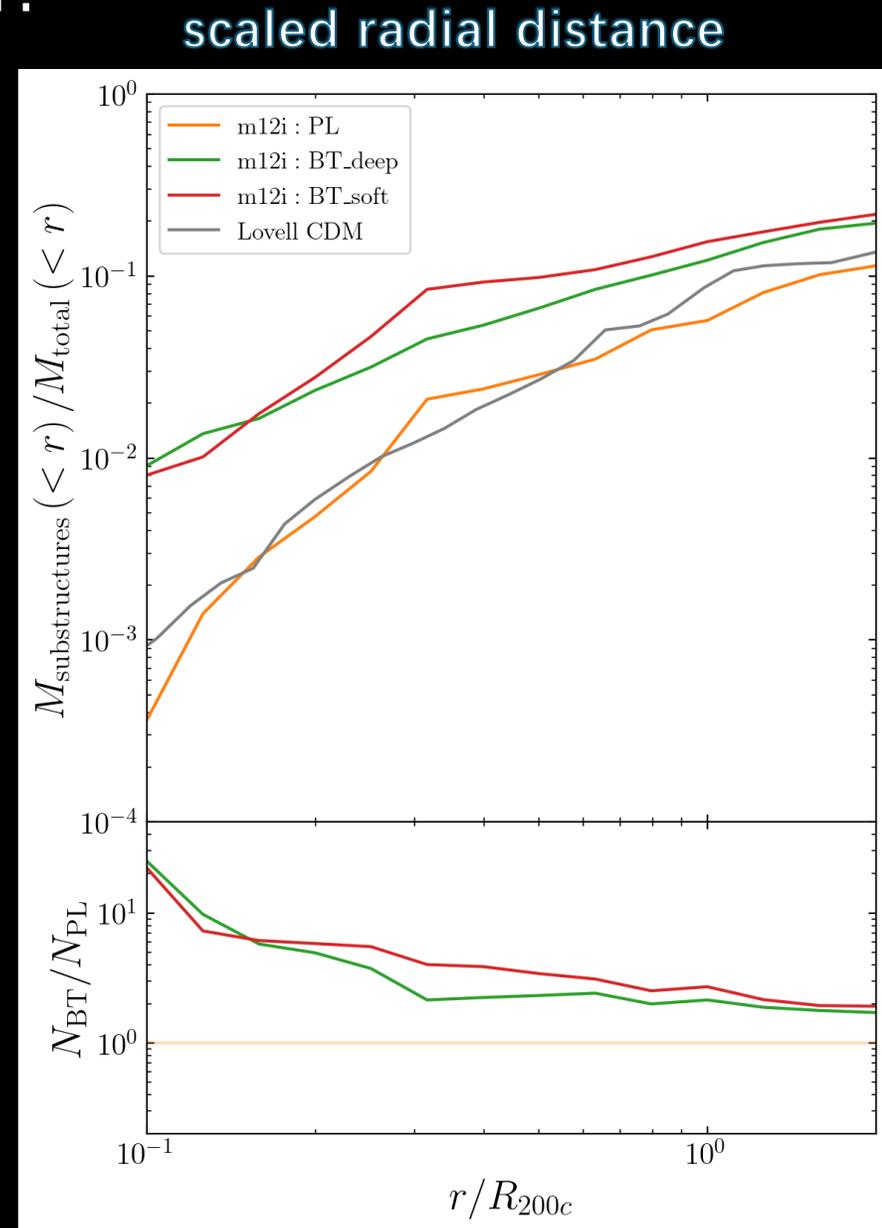
# Larger substructure mass fraction!

- substructure mass fraction:
  - Defined as *mass of particles belonging to substructures (within radius  $r$ ) / total mass (within radius  $r$ )*
  - CDMO simulation is insufficient to explain strong lensing result (arxiv [0903.4559])
  - Blue-tilted model could reach an order of magnitude enhancement compared to traditional model

Substructure  
Mass Fraction

Ratio(BT  
over PL)

[arxiv:2412.16072]



# Conclusion

- We use cosmological simulation to show that a small scale enhanced early universe model could indeed generate more substructure, potentially help to the small scale debate in cosmology:
  - More subhalos in terms of mass,  $V_{\max}$  and distance
  - Larger fraction of substructure mass
- Now we are working on a follow-up project of the first: introducing baryonic disk potential, and then use observed satellite galaxies to constrain the early universe cosmology.