

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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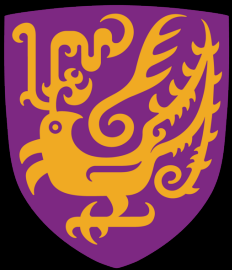
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Expanding the Boundaries of Dark Matter Halo, SJTU, 2025 May

Based on 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

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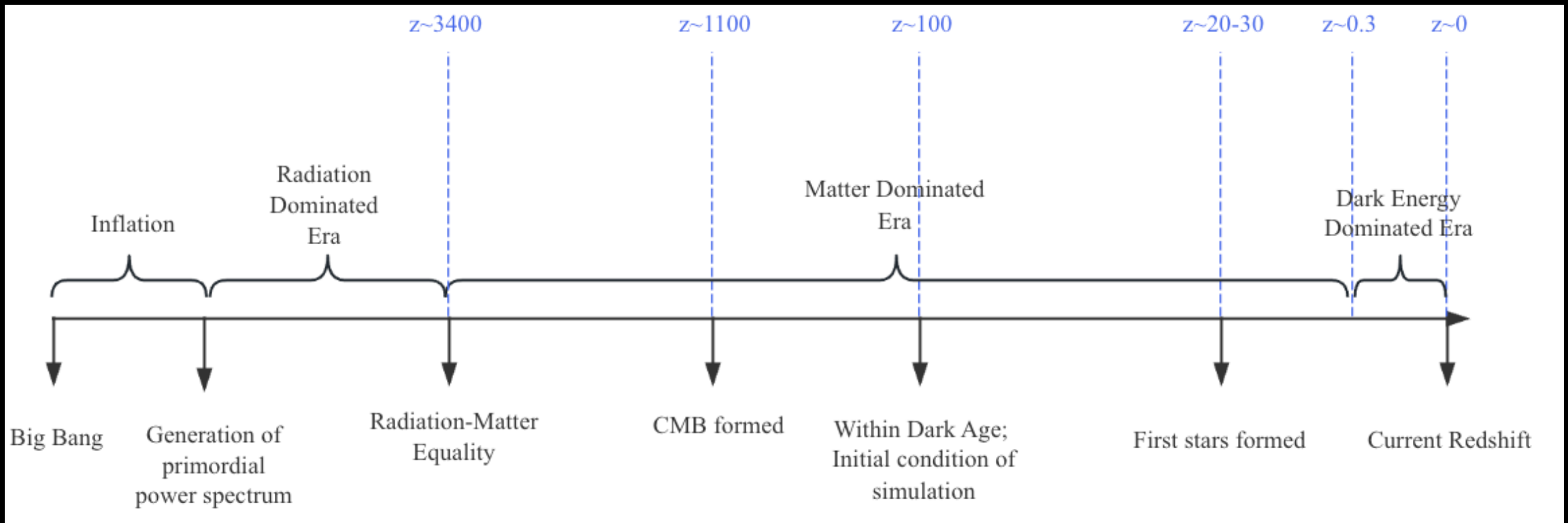


Universiteit
Leiden
Leiden Observatory

[arxiv:2412.16072]

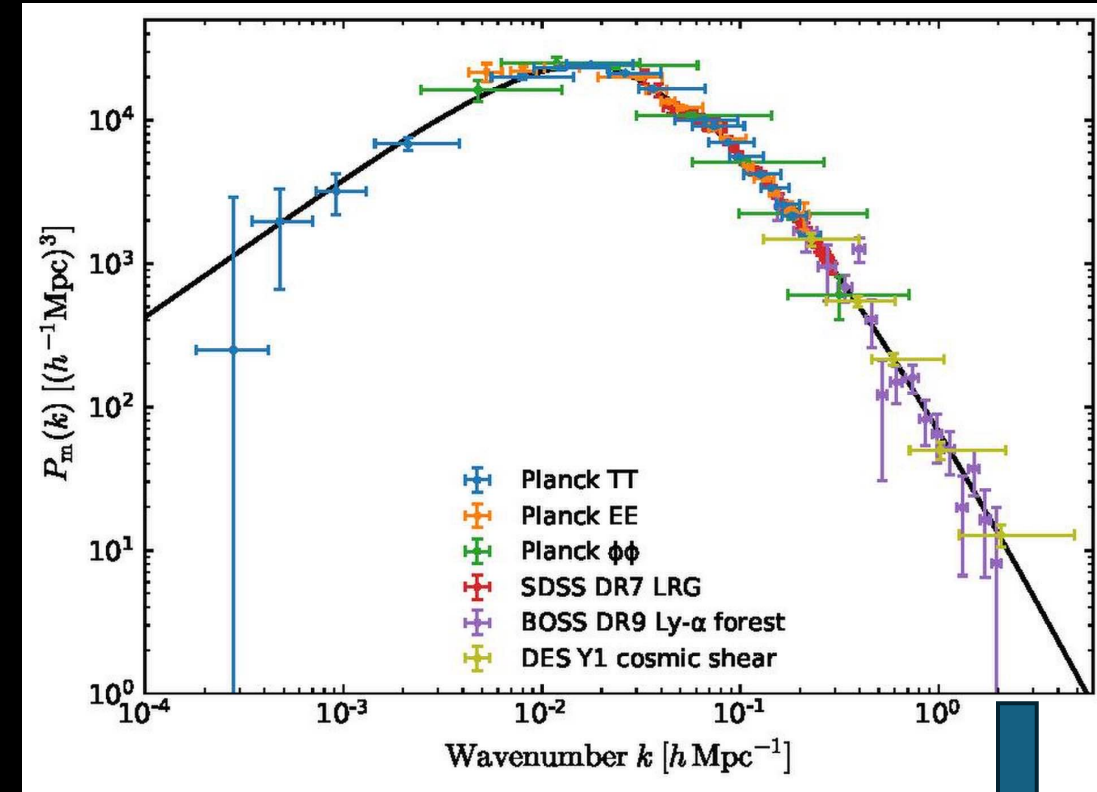
Standard Cosmology Model

- 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?

- There is *already paper* using a small scale enhanced primordial power spectrum to explain the *early formed massive galaxies in JWST*
- **Besides**, several **other** observations are in favor of *a small scale enhanced* cosmological model—we are trying to address them!
 - 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]) + *over-concentrated subhalo event* is detected (SDSSJ0946+1006, i.e. “Jack Pot” lensing event)
 - A *too-many-satellite-galaxies* problem appeared in nearby galaxy observation (arxiv [1711.06267] [2403.08717])

Change Power Law Primordial Power Spectrum \rightarrow 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

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

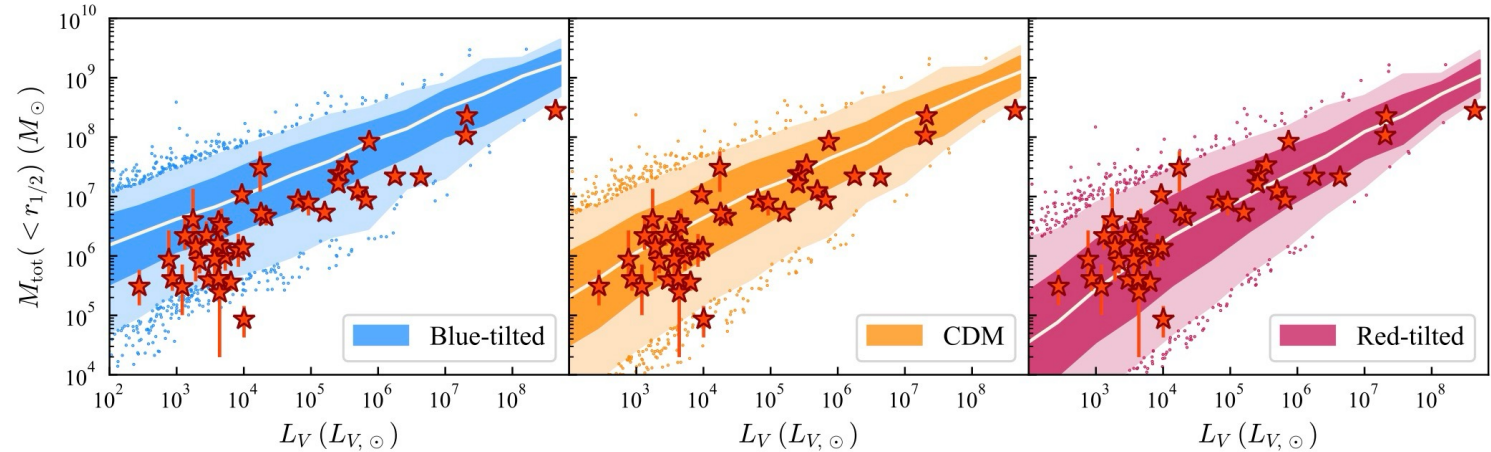
which is a broken power law modification of [Equation 2](#).

How to choose parameter sets?

Besides JWST, its hosting satellite galaxy's central density (concentration) could also constrain Primordial Power!

They assume:

*"the main effect of the change is on the **halo** concentration, while **galaxy** evolution is assumed to be unaffected."*



source: arxiv [2407.04198]

[arxiv:2412.16072]

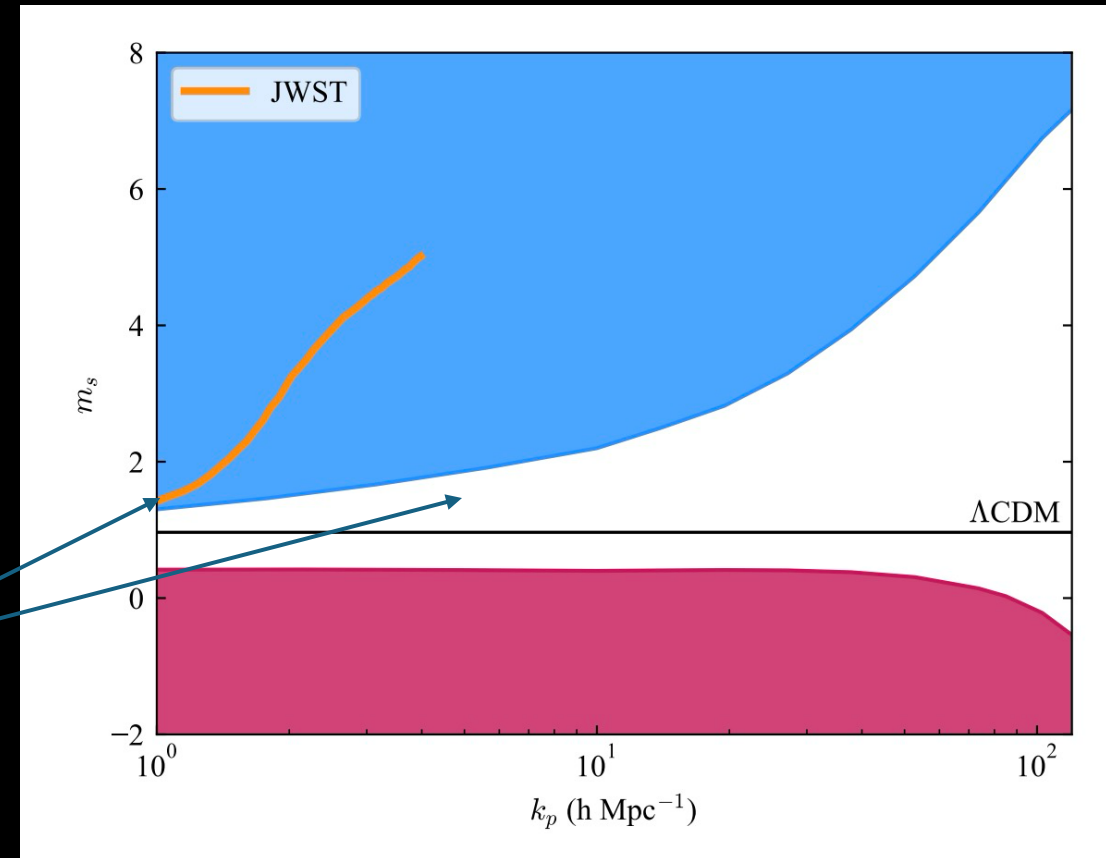
We chose two blue-tilted parameter sets within the allowable parameter space!

- One could ease the tension of high star formation rate brought by JWST, while another could not
- Both are within (or at least on the border of) parameter space :)

source: arxiv [2407.04198]

*Two BT models
we chose!*

[arxiv:2412.16072]



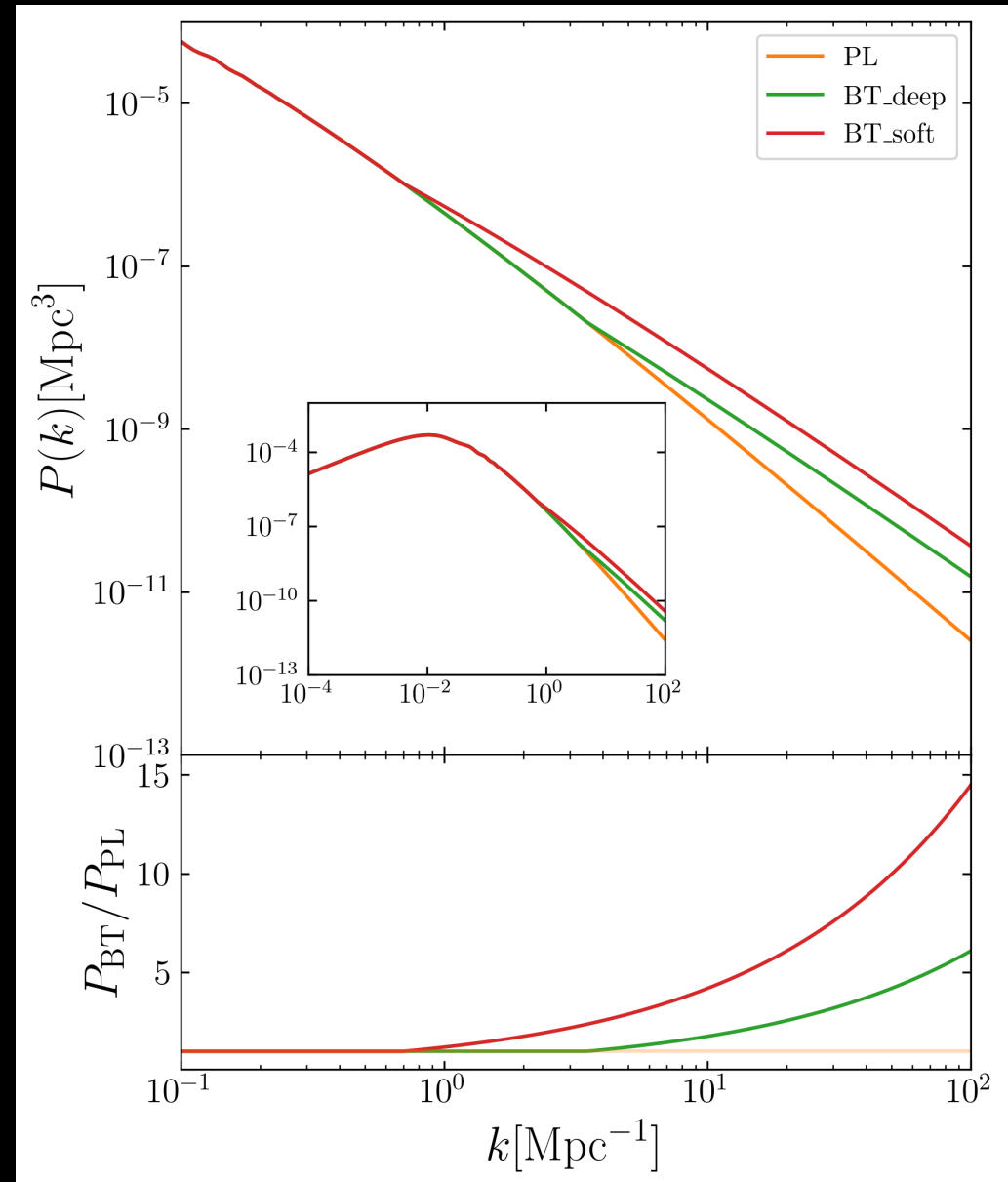
Two blue-tilted models

- 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 $r_l = \frac{1}{2} \lambda$

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

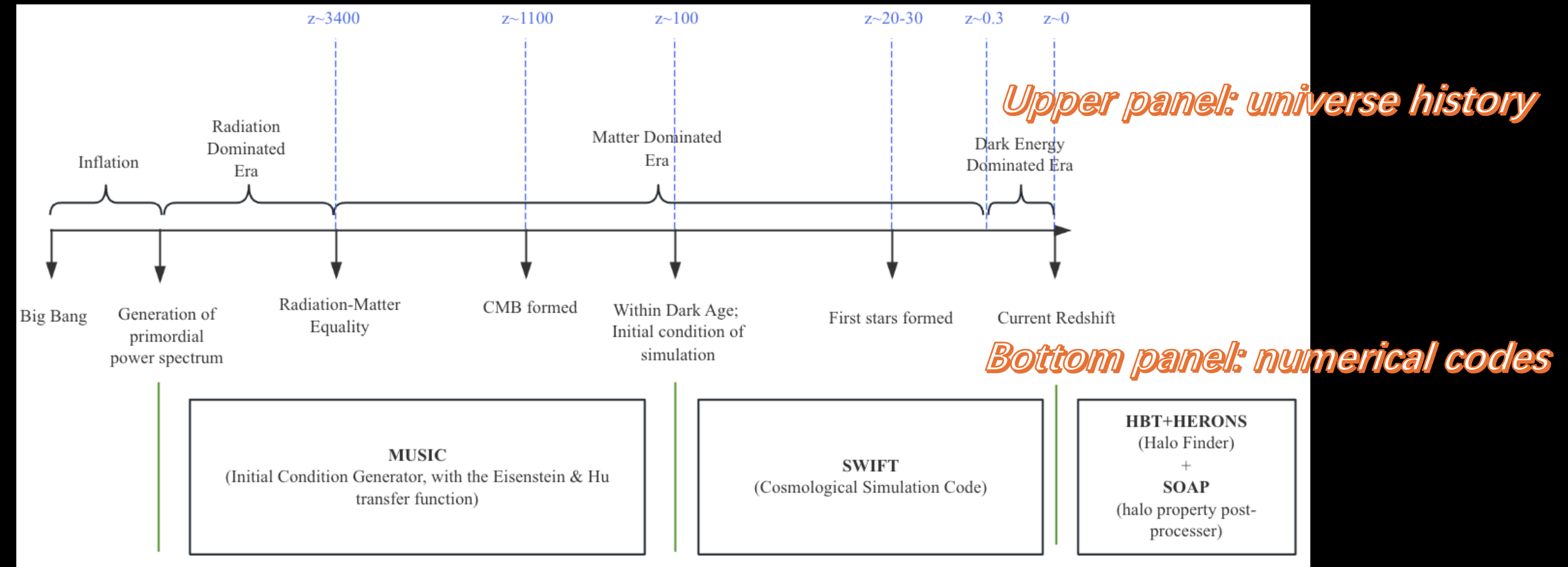
For BT_deep: $1.1 \times 10^{11} M_\odot$

For BT_soft: $1.4 \times 10^{13} M_\odot$

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

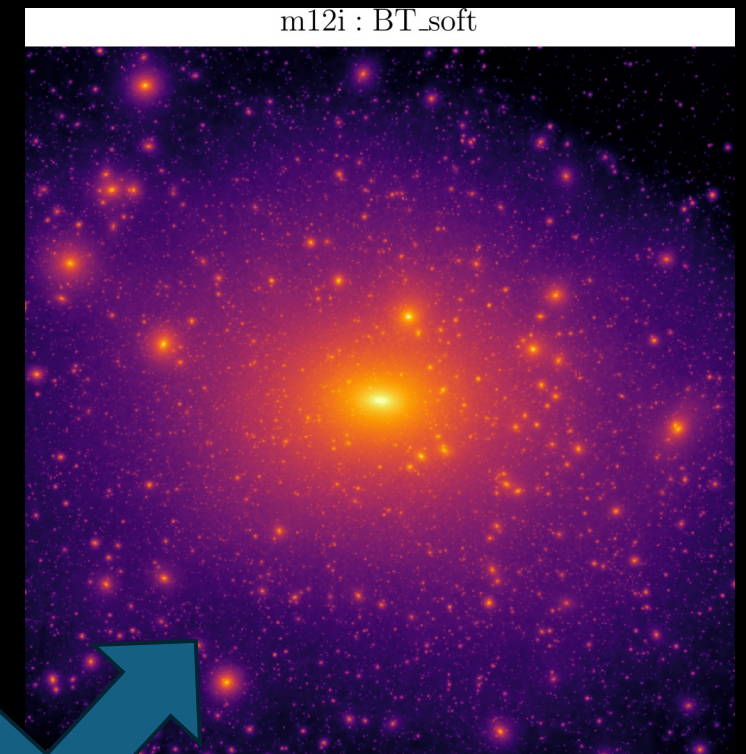
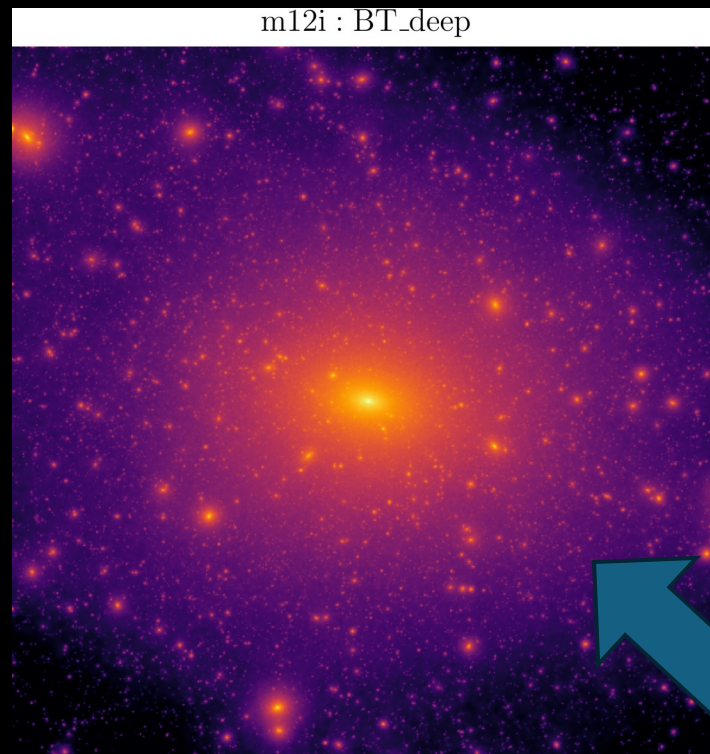
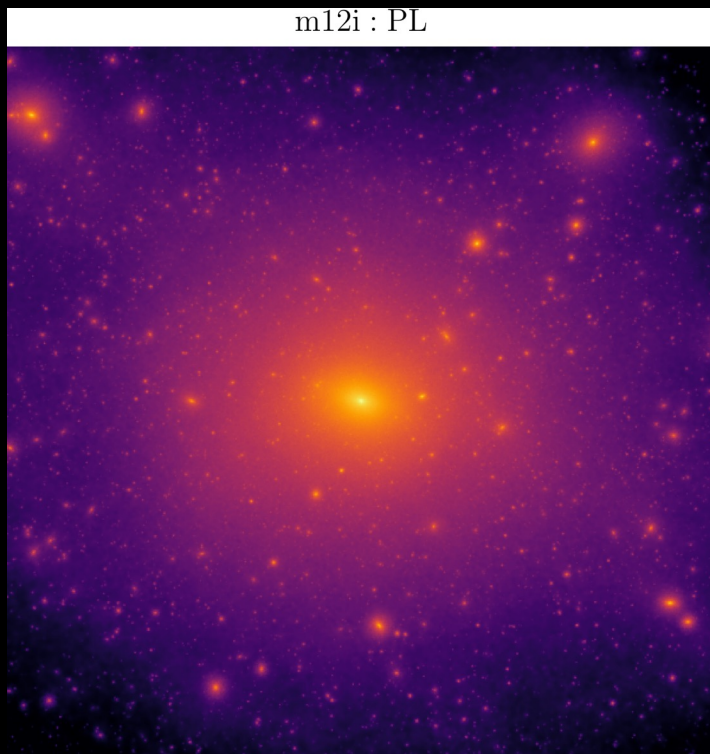
Numerical pipeline we used

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



Intuitive look: projection map

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



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

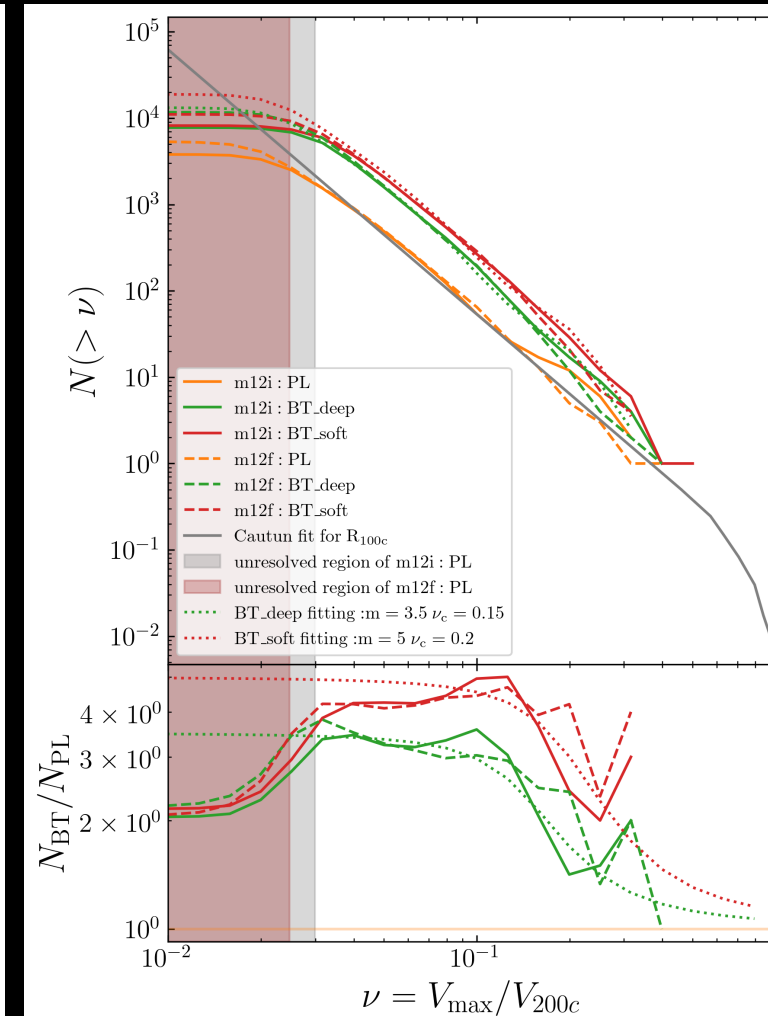
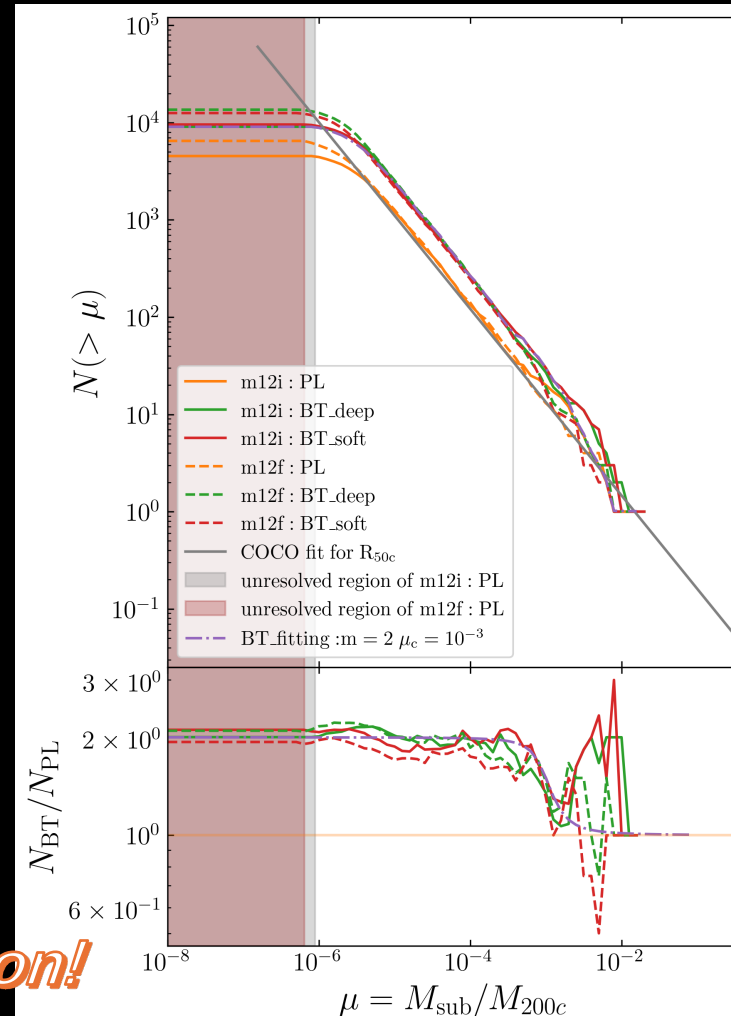
To help the Too-Many-Satellites (Mass/Vmax)

- subhalo function(aka subhalo number distribution) by mass or Vmax
 - subhalo mass function could be enhanced by a factor of two at low mass end
 - subhalo Vmax function could be enhanced by more than 3 times at low Vmax end

Number of
subhalos

Ratios
between
numbers

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



To help the Too-Many-Satellites (radial distance)

- radial distance *from the center of main halo*

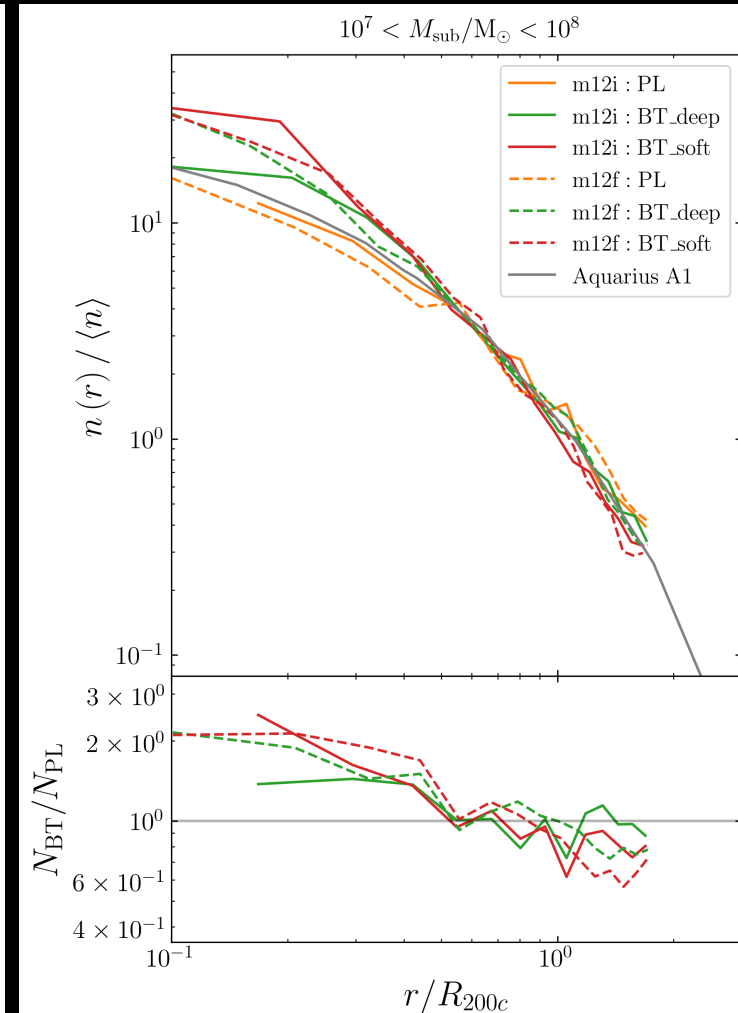
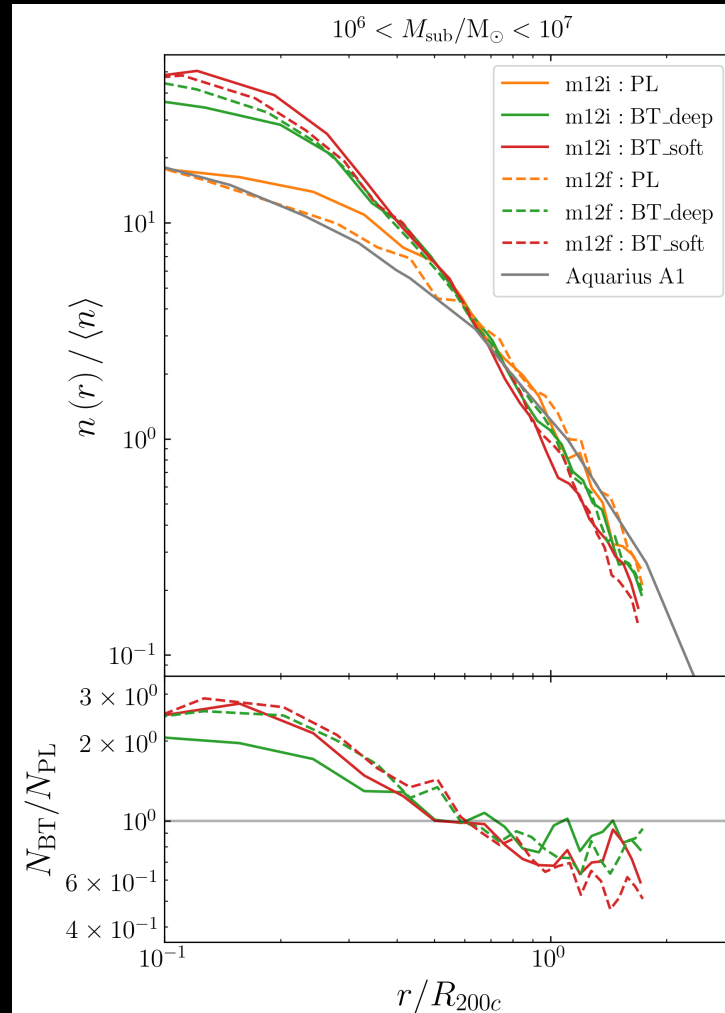
scaled radial distance

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

Normalized
number density

*Grey lines are the same for
different mass!*
*(Found by Aquarius simulation
[arxiv0809.0898])*

Ratio(BT
over PL)



To help Strong Lensing(larger substructure fraction)

- substructure mass fraction:

- Defined as *mass of particles belonging to substructures(within radius r)/total mass(within radius r)*

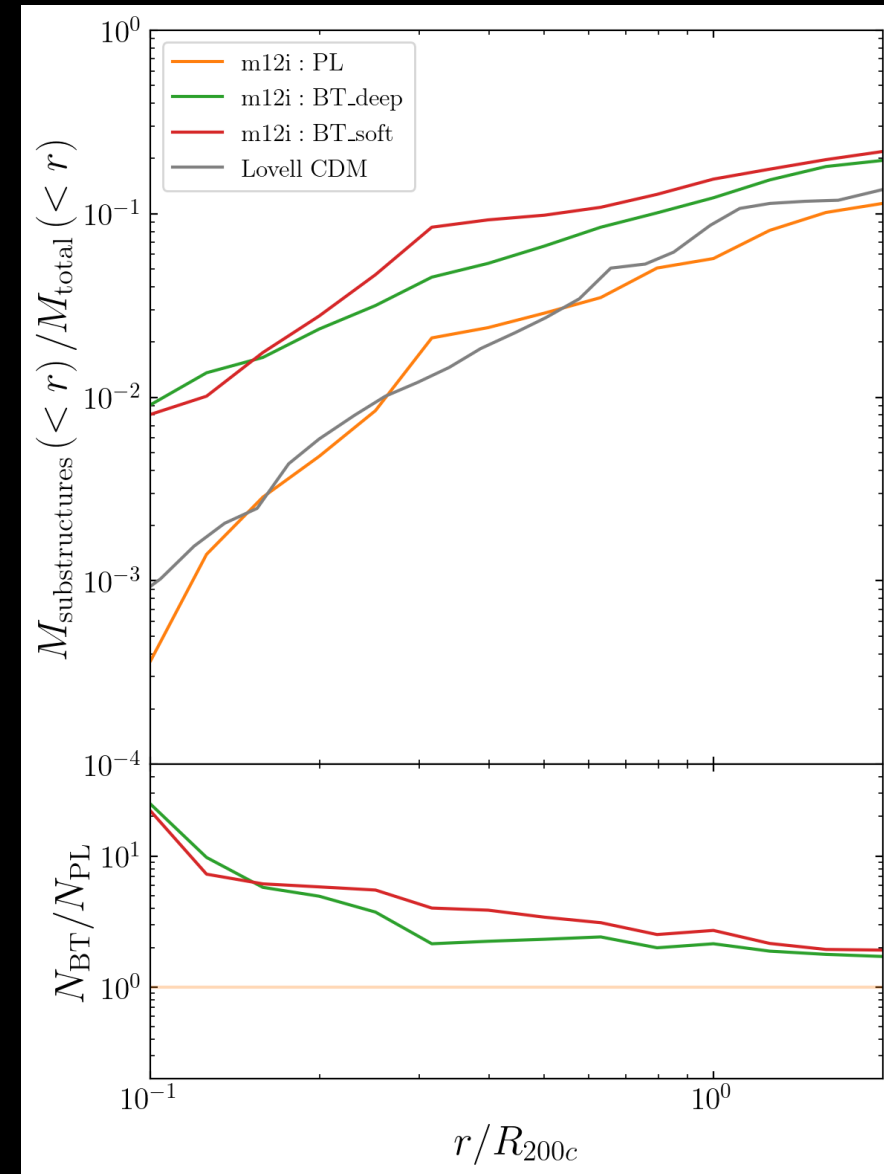
- CDMO simulation is insufficient to explain strong lensing result (arxiv [0903.4559])

Substructure
Mass Fraction

- Blue-tilted model could reach an order of magnitude enhancement compared to traditional model

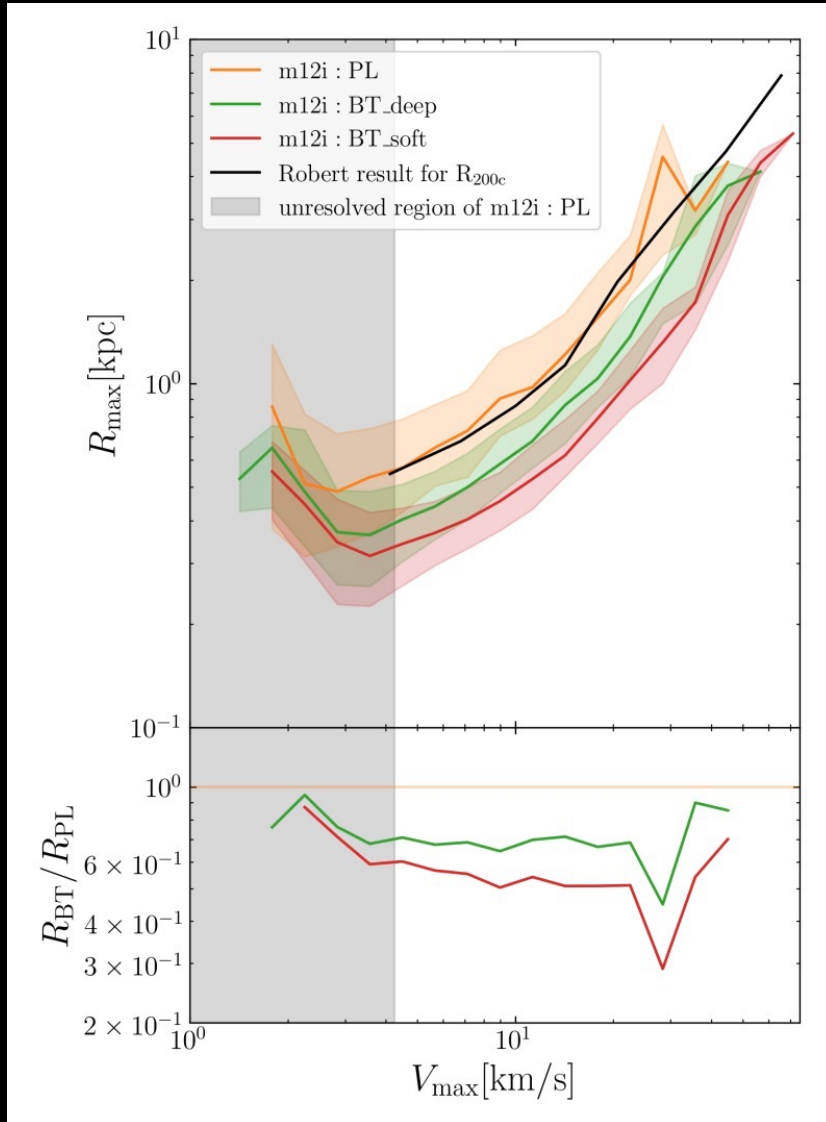
Ratio(BT
over PL)

[arxiv:2412.16072]



To help Strong Lensing (more concentrated subhalo)

Maximum circular velocity

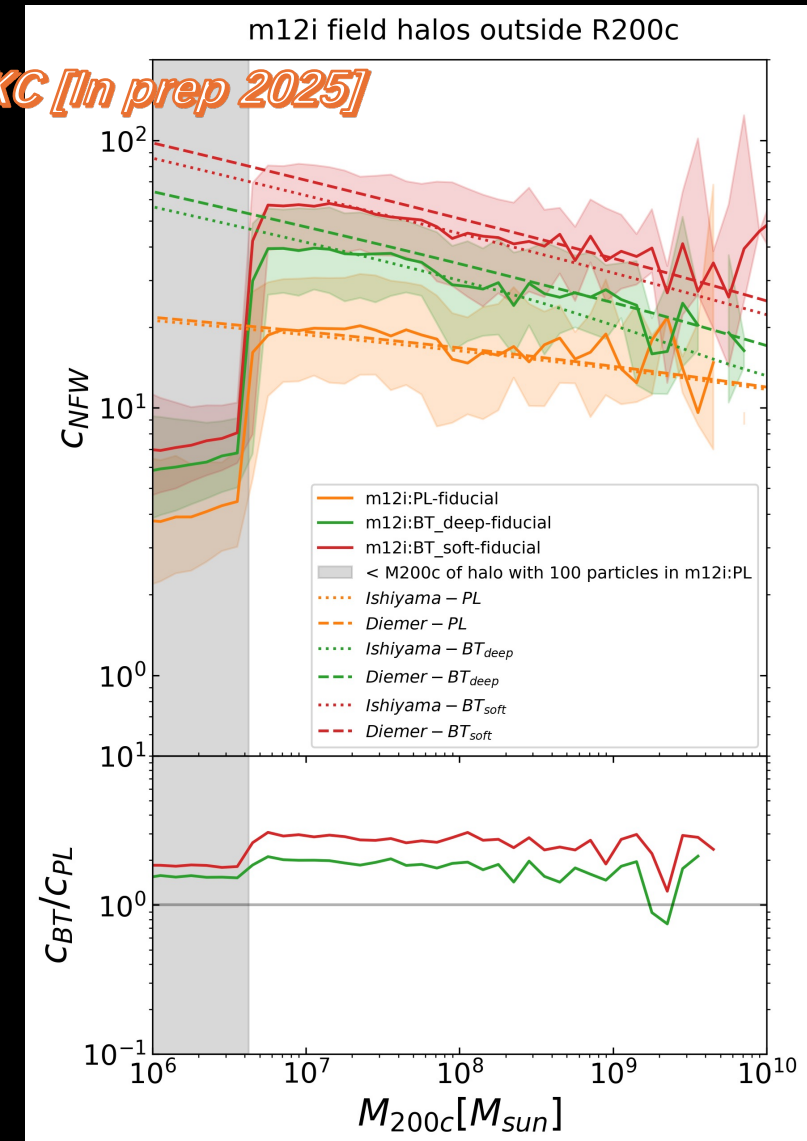


The median
Rmax/Cnfw
within one Vmax
bin

Ratio(BT
over PL)

[arxiv:2412.16072]

M200c



By-Product: Main halo becomes more concentrated
scaled radial distance

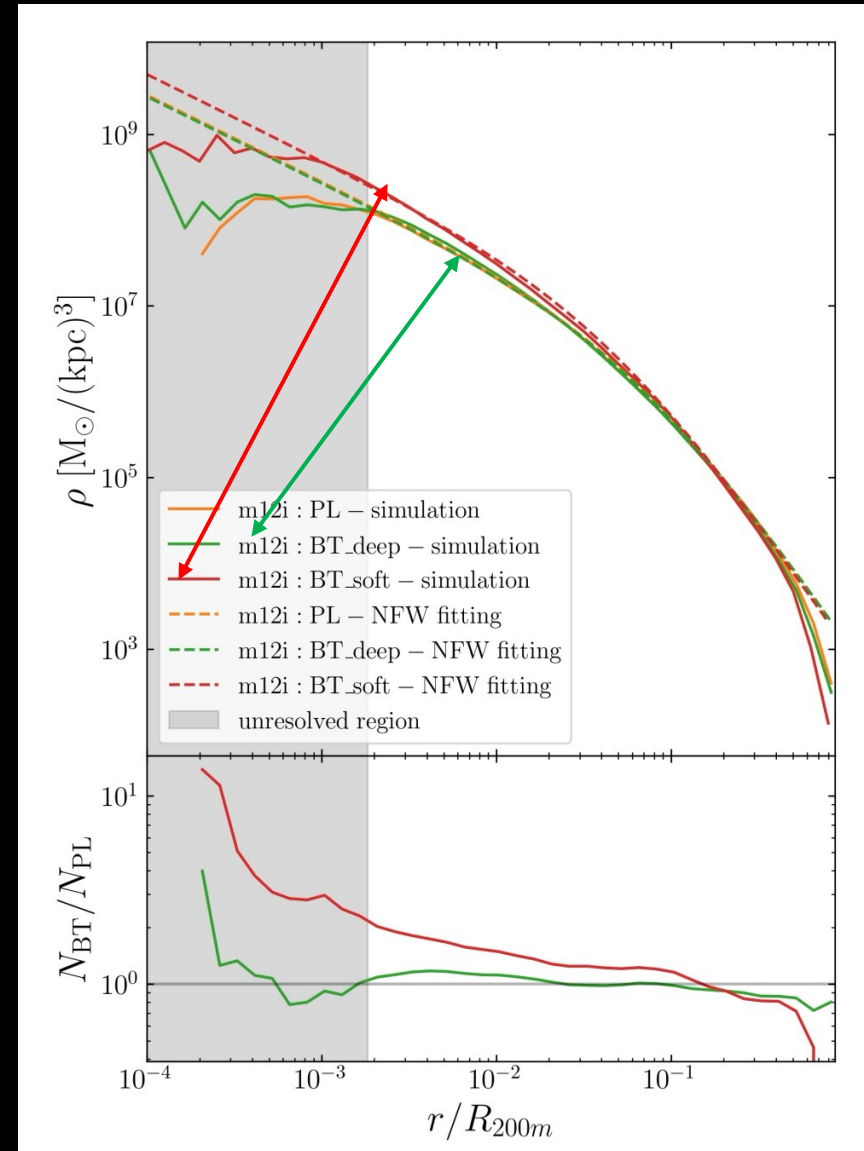
*But only in BT_soft, BT_deep is very close
to standard model!*

And That fits well with our prediction!

radial density

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 & More concentrated subhalo
- Currently working on follow-up projects: matching with satellites counts & strong lensing observation