Zoom-In Cosmological Simulation for a Small Scale Enhanced Primordial Power Spectrum

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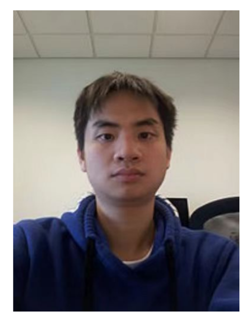

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1. Introduction

The standard cosmology model includes single-field slowroll inflation model which specifies the initial condition of the very early universe, and the lambda cold dark matter model which governs the later evolution of our universe. It has achieved great success in large scale over the past several decades. However, recent observational result has shown some of nearby galaxies have **too many satellite galaxies**[1], challenging the current standard cosmological model.

To address this too-many-satellites problem, we modify the traditional scale invariant primordial power spectrum by enhancing its small-scale power. Then we carried out several high resolution zoom-in simulation sets, to show the small scale enhanced effects including the statistical properties like the subhalo mass function, and the inner properties such as the subhalo radial density profile.

2. Theoretical Model

2.1 Blue tilted primordial power spectrum

Standard single-field slowroll inflationary model ([2, 3]) is believed to be the primordial power spectrum for the density perturbation generated during inflation:

$$P_i(k) \propto k^{n_s} \quad (1)$$

where n_s is close to 1 from CMB measurements.

To get enhancement in small scale structure, a *blue tilted* primordial power spectrum for the early universe density perturbation has been proposed([4], [5], [6]):

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

$$\propto k^{n_s} \cdot (\frac{k}{k_p})^{m_s - n_s} (k > k_p) \quad (3)$$

which could clearly show there is an additional factor $(\frac{k}{k_p})^{m_s - n_s}$ for the small scale modes. So we would require m_s to be larger than n_s to give an enhancement.

We chose the soft version model of blue tilted to compare with the traditional power law primordial power spectrum model. The parameters of models are shown in Table 1:

Model	Related parameters
PL	Standard Inflation, equivalent to $m_s = n_s$
BT_soft	$k_p = 0.702$ Mpc^{-1}, $m_s = 1.5$

Table 1: The parameters of chosen models.

The matter power spectrums for them are in Figure 1:

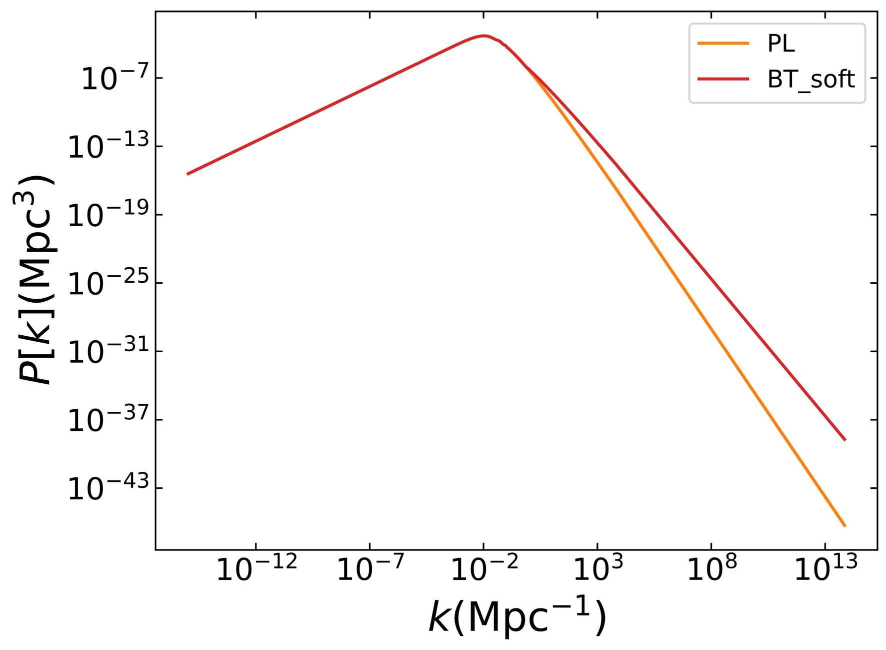


Figure 1: The power spectrum for matter density perturbation at z=1089.

3. Numerical Setup

The main simulation steps could be seen in Figure 5, where the corresponding cosmological stages are also shown:

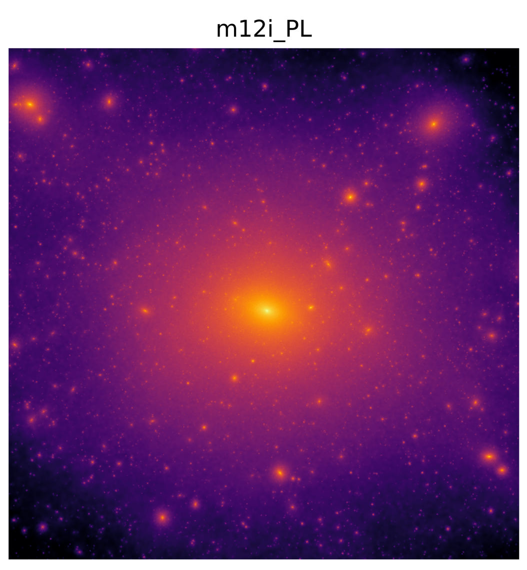
1. We use the public code MUSIC - *multi-scale cosmological initial conditions*([7]) which could help to fit with the CMB parameters, to generate the initial condition for our cosmological simulations. We also changed the source code making it capable of generating initial condition for blue tilted primordial power spectrum. To get a milky-way size halo, we check the publicly available FIRE-2[8] simulation dataset(https://flathub.flatironinstitute.org/fire) and adopt simulation set *m12i*'s configuration file.
2. We carry out zoom-in simulation using the publicly available cosmological simulation code SWIFT [9]. For N-body simulation, SWIFT uses Fast-Multipole-Method(FMM) at small scale, coupling with Particle Mesh Method at large scale to handle periodic volumes.

Besides, we also identify halos and subhalos from the cosmological snapshot by VELOCIraptor[10], a code based on the friends-of-friends (FOF) algorithm but using both the physical space and phase space information. Since we are doing zoom-in simulations, we have enabled the high resolution dark matter particle option.

4. Result

We perform cosmological dark matter only simulations with the traditional power law primordial power spectrum and the blue tilted primordial power spectrum.

We show more satellite galaxies from two ways: projection map and the subhalo mass function, both of which have suggested we could generate more satellite galaxies.



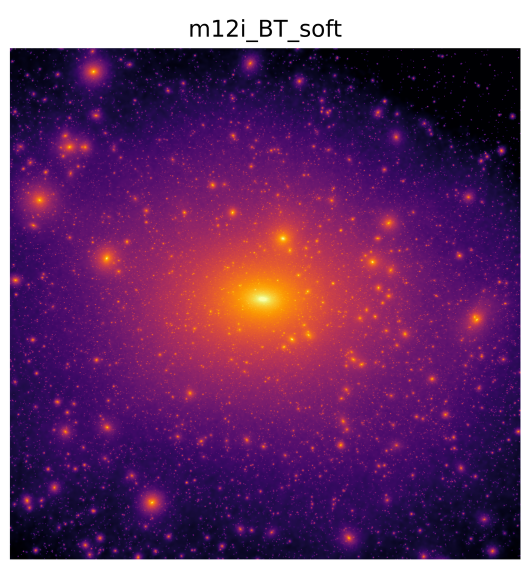


Figure 2: The comparison between dark matter mass projection maps with power law and blue tilted(soft) primordial power spectrum, for m12i in FIRE-2 simulation. Both images are square shape with side length to be 400 kpc, taking the position of main halo as the centre.

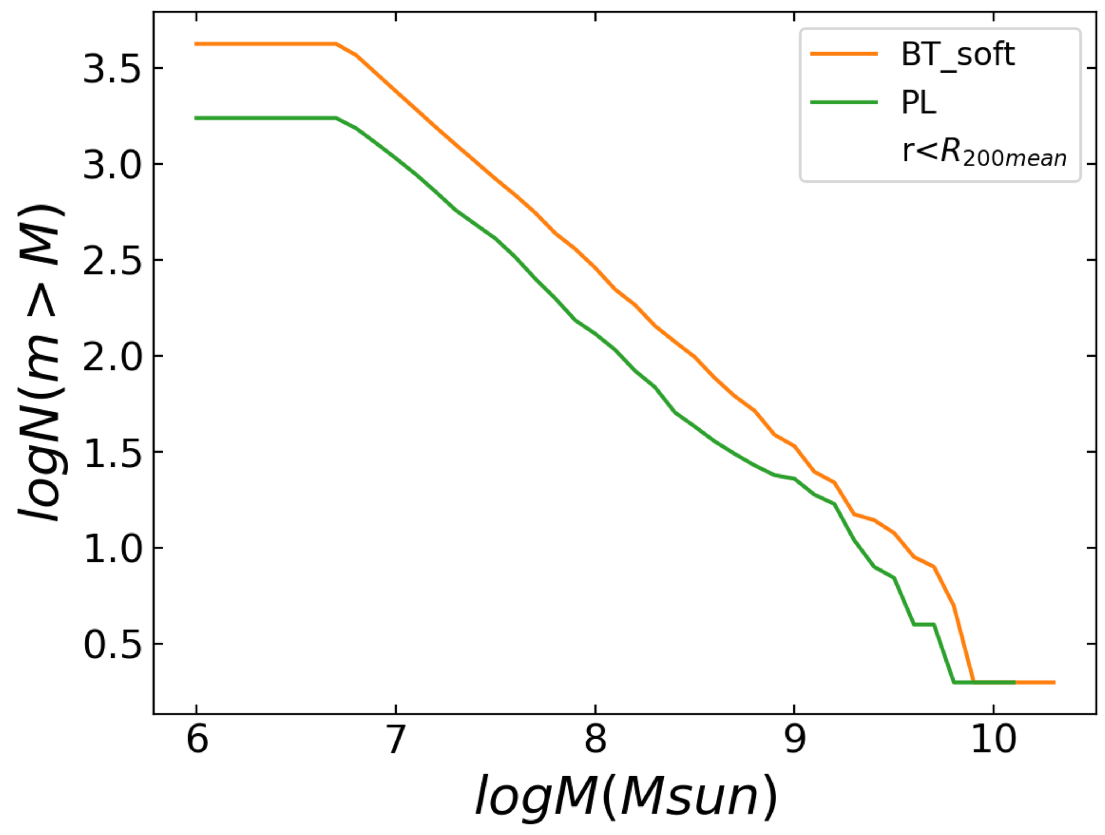


Figure 3: The subhalo mass function for m12i in two models

For the density profile of the main halo, blue tilted model could also bring higher concentration.

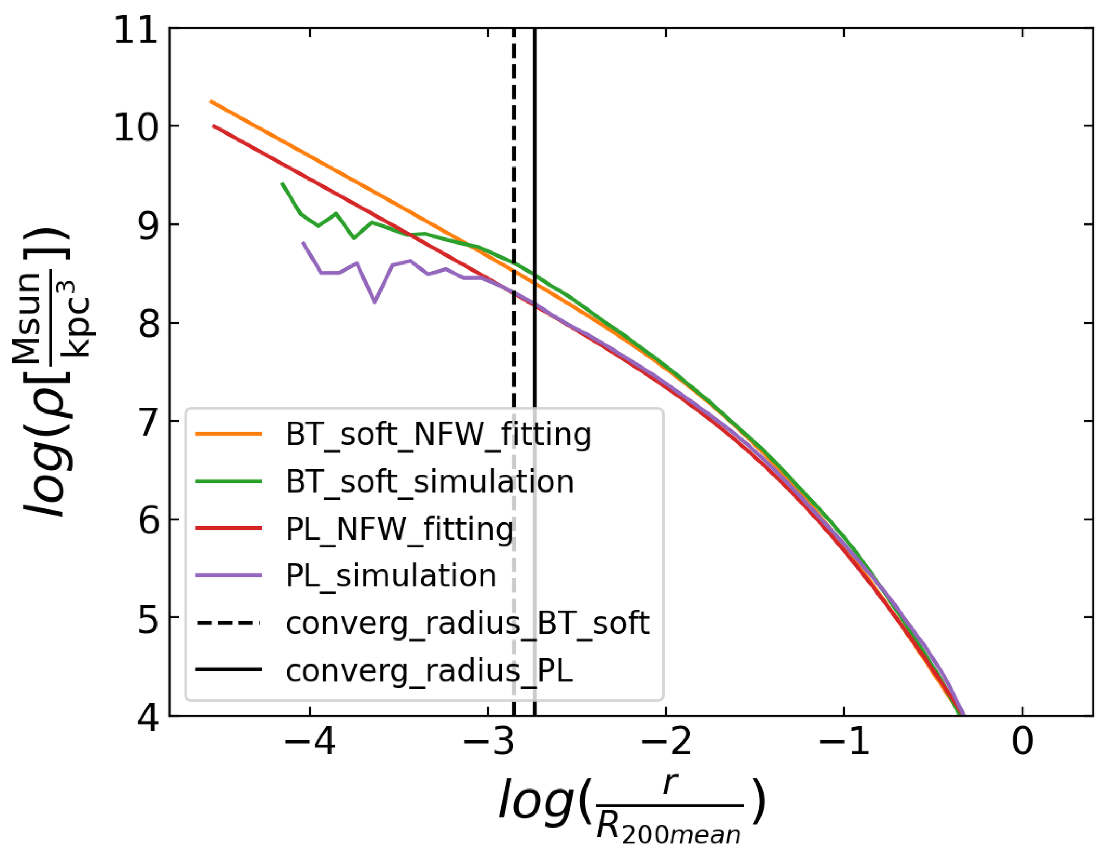


Figure 4: The density radial profile for the main halo of m12i in two models

5. Conclusion

Our preliminary result has shown that the blue tilted primordial power spectrum model could lead to more concentrated main halo and more subhalos. It may hopefully explain the too-many satellites in nearby galaxies.

Currently, we are running some additional simulations for 1e9 Msun size halo, 1e10 Msun size halo and other 1e12 Msun size halos. We are also doing simulations with other variations of blue tilted model like BT_deep model. We would compare our result with observations in the future.

6. ACKNOWLEDGEMENT

The research in this paper made use of the SWIFT open-source simulation code (http://www.swiftsim.com, [9]) version 1.0.0.

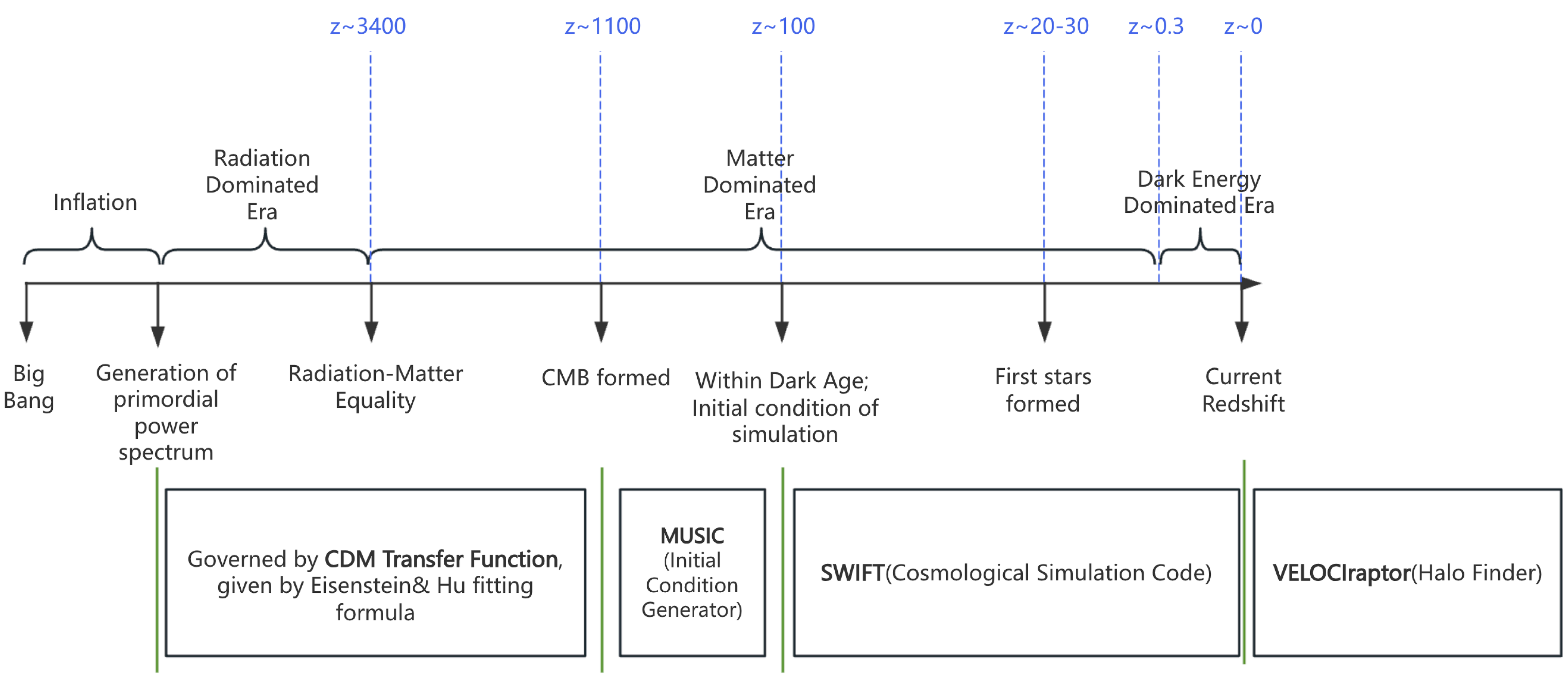


Figure 5: The conceptual flow and the corresponding cosmological history.

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