Comparing cosmological snapshots made by AI assisted vs N-Body simulations

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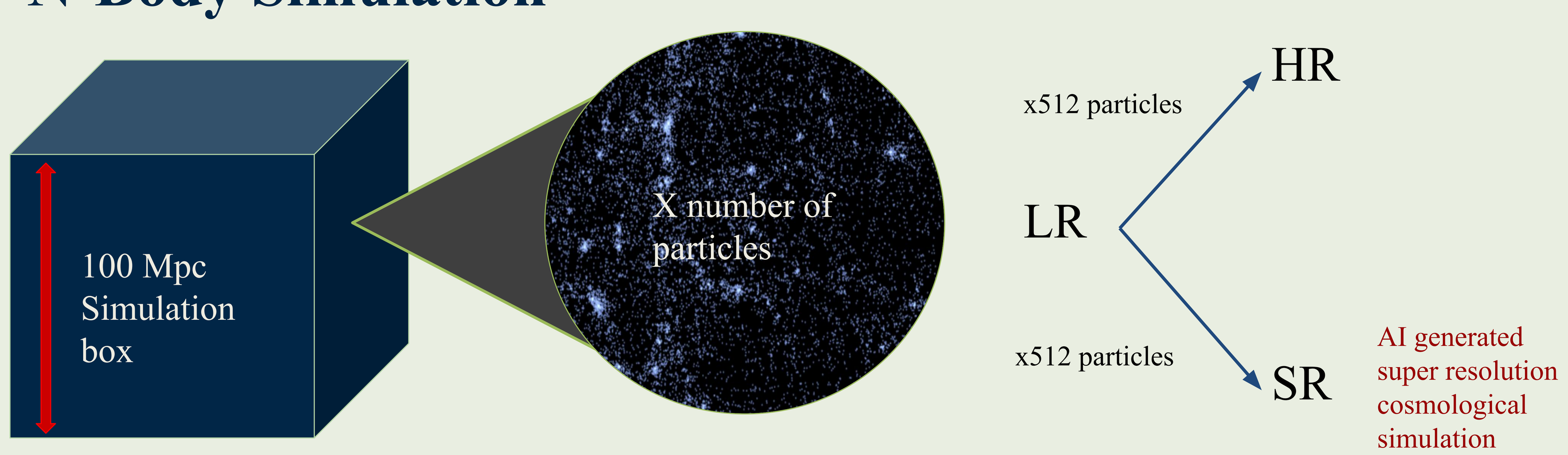
Introduction

Limited computational resources impose constraints on cosmological simulations of galaxy formation. To overcome this constraint, continuing research and advancement in Artificial Intelligence have been leveraged to make more computationally inexpensive simulations. Through Deep Learning- specifically by training neural networks on High-Resolution particle datasets made by N-Body We can effectively learn from high-resolution (HR) particle datasets and subsequently generate super-resolution (SR) versions of various low-resolution (LR) sets. Here we run a GAN with LR as the input noise and then compare the final SR and HR simulations. To provide a comprehensive understanding and a point of reference for our simulation, we compare AI-generated results with those obtained from a high-resolution (HR) simulation created using the N-body method. If they're similar, we can capitalize on the comparatively low computational effort to make LR cosmological N-body simulations and use AI to have the detail of an HR simulation by producing SR counterparts.

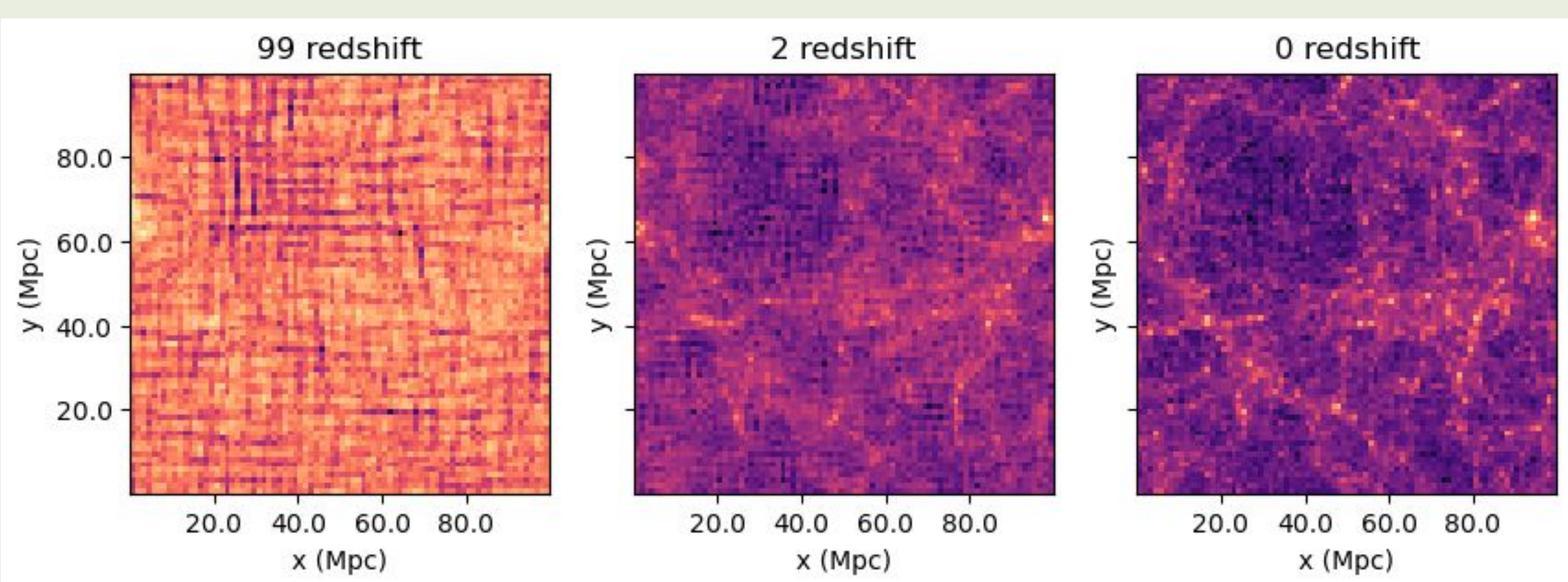
- ★ For this project we chose to use C-GAN or a Conditional Generative Adversarial Network.
- ★ We also only run simulations involving Dark Matter and Gravity.

N-Body Simulation



N-Body simulations are a numerical method of simulating a universe. The Simulation box with initial conditions is moved forward by gravity over some range of redshift. Low resolution consists of 64^3 particles and HR has 512 times more particles than LR. This is why it is computationally expensive to make HR simulations.

Note: It's important to remember that HR and SR have the same resolution and only differ by how they're generated.



Above is an LR simulation run from redshift 99 to 0. It shows a 2D slice that's about 2Mpc thick. This will be the input noise of our CGAN that will eventually create the SR simulation. We can see how galaxies grow under gravitational instability over time.

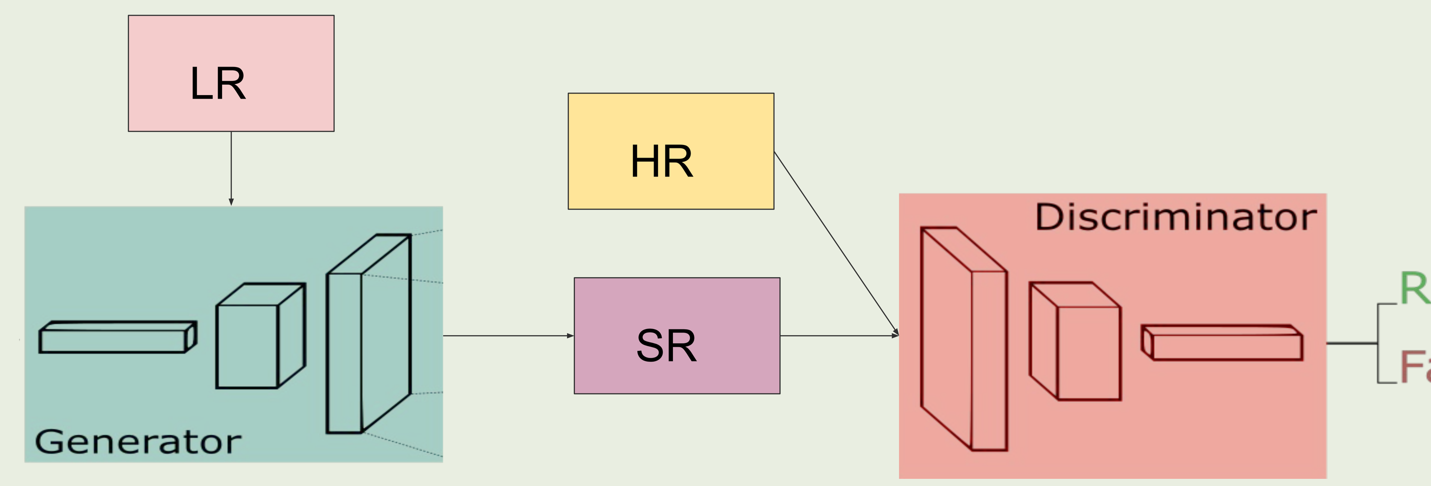
AI Assisted Simulation

The AI simulation aims to faithfully reproduce the statistical properties of the density field in the early universe with a finite number of point particles.

In summary it -

- Enhances LR by generating more particles
- Is trained on N-Body code
- Computationally inexpensive i.e 10,000 times faster
- Outputs same resolution as HR

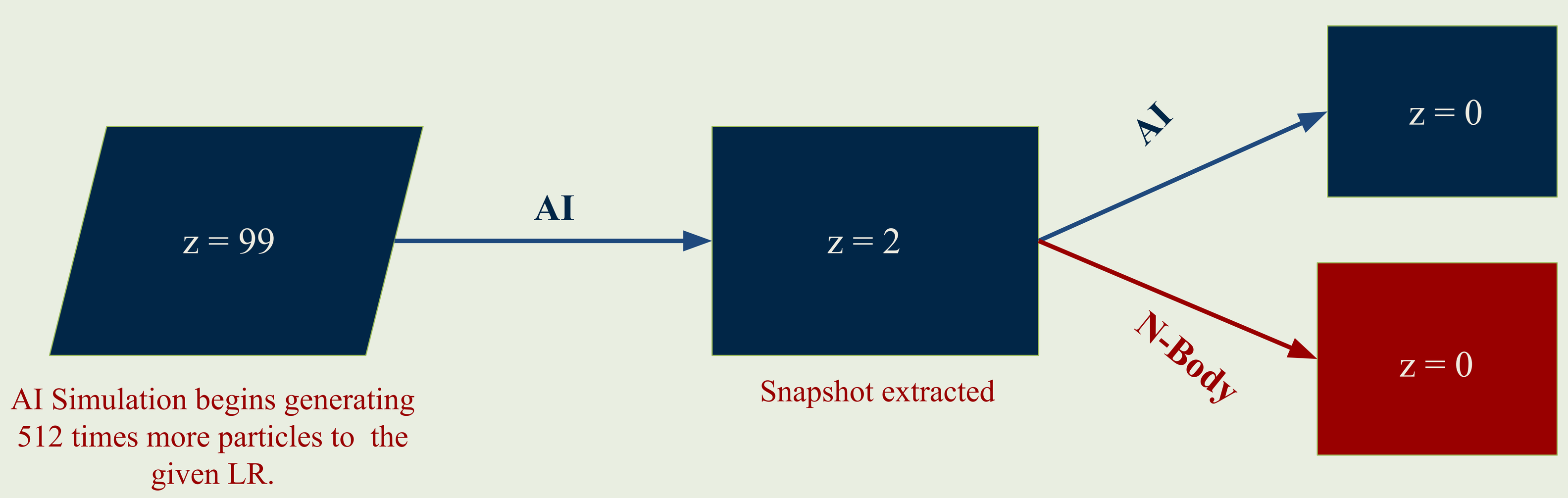
Conditional Generative Adversarial Networks (CGAN)



Conditional GANs work by running two networks against each other- a Generator and a Discriminator. The generator network generates candidates on the basis of the LR while the discriminator network evaluates them to be real or fake. They learn from each other. The generator is trained to make high quality "fakes" so the discriminator can't evaluate them as fake anymore. This is what the SR is- a "fake" HR.

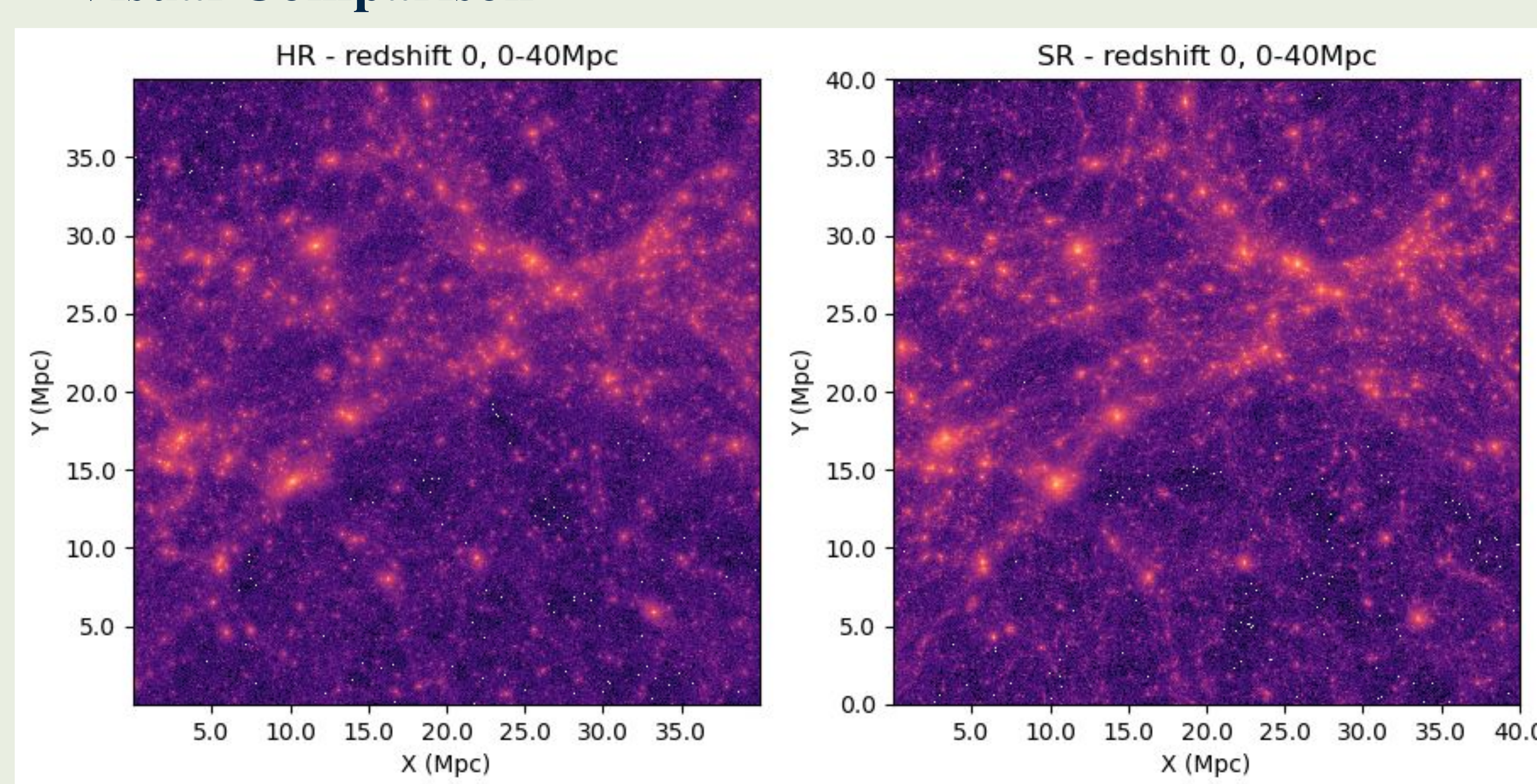
Methodology

Utilizing AI, we initiate a simulation spanning from redshift 99 to redshift 0. In this process, we extract a snapshot from Redshift 2 and subject it to N-Body evolution towards Redshift 0. Subsequently, we perform a comparative visual and statistical analysis between the resulting snapshots at redshift 0.



We repeat this process with the snapshot extracted at redshift 5 to further test how the snapshots vary when we test them with higher Redshifts.

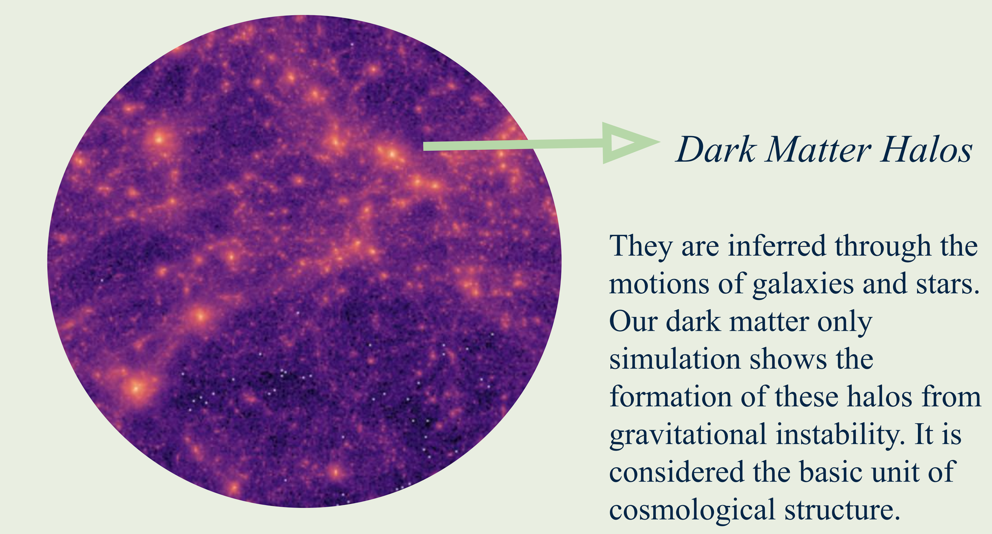
Visual Comparison



The simulation plots output a 100Mpc box. I zoomed into a particularly interesting section to compare the two simulations directly.

On average the number of halos or their masses may be the same but do they compare on a smaller scale? *Using a 40 x 40 Mpc section of the simulation we can see the two plots look nearly identical. These plots use a 2Mpc slice of the simulation cube. Notice both are high resolution compared to the previous plots - both have 512^3 particles.*

Understanding Halos

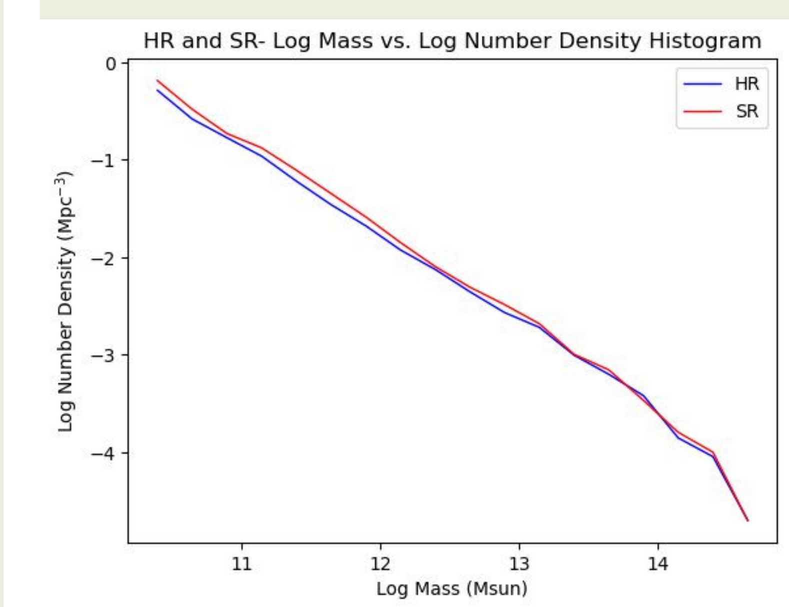


They are inferred through the motions of galaxies and stars. Our dark matter only simulation shows the formation of these halos from gravitational instability. It is considered the basic unit of cosmological structure.

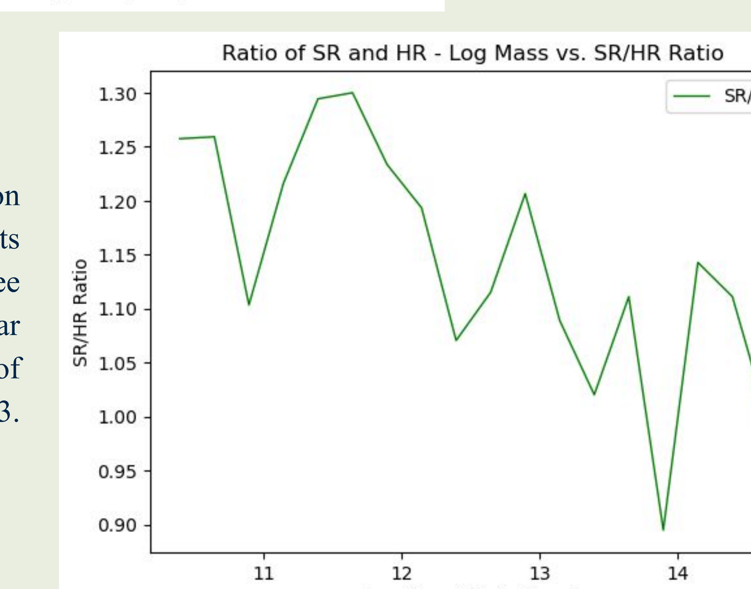
Each halo corresponds to a galaxy in the real universe. Therefore, we can compare two simulations by either mass or positions of our halos since they refer to galaxies.

Statistical Comparison

We compare the halo mass functions with a (100h−1Mpc)3 test set simulation, at z = 0. The mass function is defined as $\varphi \equiv dn/dlog10M\_h$



We find only small scale differences between the two. The HR and SR are able to correctly evolve most halos with higher mass.



The halo population match the HR results to a high degree since the ratio is near 1 with a deviation of 0.3.

Acknowledgements

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The simulations for training and testing is run with MP-Gadget (https://github. com/MP-Gadget/MP-Gadget).
Data and catalog analysis in this work is performed with open-source software nbodykit(Hand et al. 2018).