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Abstract

Eisenstein et al. 2007

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Chapter 1

Introduction

1.1 Cosmological Context

Introduce the context of Modern Cosmology

1.2 The Cosmic Microwave Background

Introduce the CMB and talk about the starting point. E.g. very smooth initial field with some anisotropies that will be locked in the matter distribution.

Introduce BAOs.

1.3 Large Scale Structure and Galaxy Surveys

Introduce the Structure of the Universe today and the tools used to study it.

Talk about the detection of the BAO in the galaxy distribution and its smearing due to collapse.

1.4 The Missing Link (Reconstruction)

Motivate our desire to link the two and talk about the problems we have (Dark Ages)

Motivate the desire to reconstruct the BAO feature

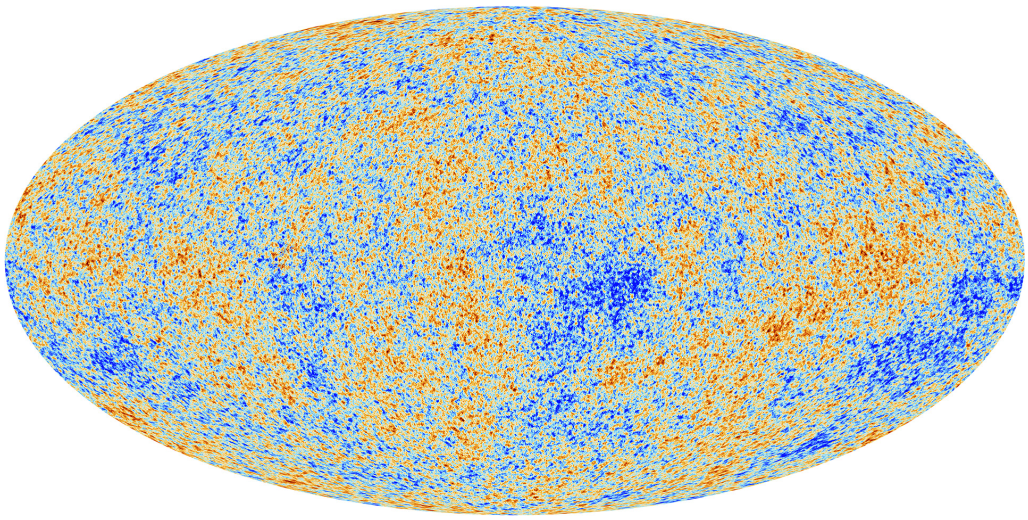


Figure 1.1: Map of the Cosmic Microwave Background aquired by the Planck Space Telescope (ref).

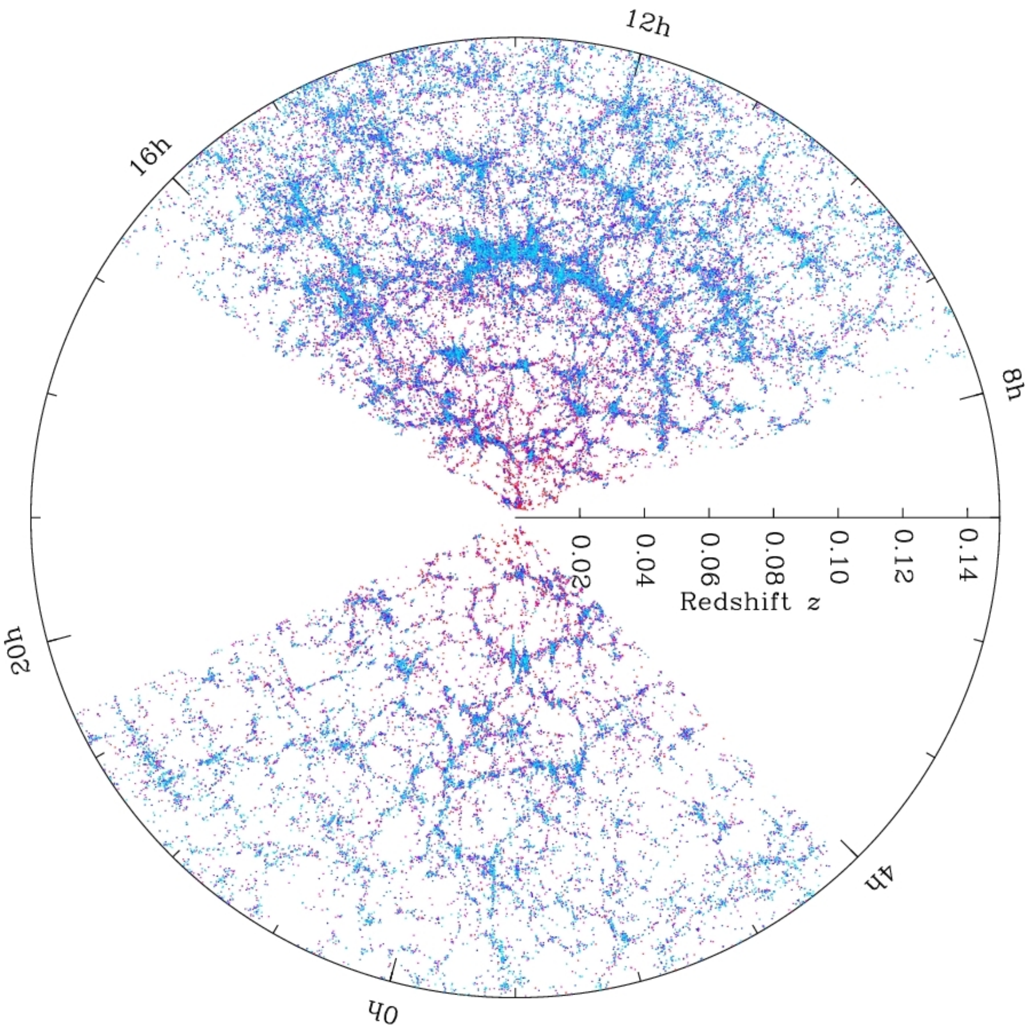


Figure 1.2: Galaxy map from the Sloan Digital Sky Survey.

Chapter 2

The Growth of Structure

2.1 Perturbation Theory

Give a brief introduction to the use of Perturbation theory to study the evolution of structure. Present advatages and shortcomings

This could be merged with the next section.

2.2 Linear vs Non-Linear Collapse

Talk about the Linear regime of collapse versus the non-linear regime. Present the difficulty of constructing analytical models of non-linear collapse. Motivate our use of simulations as well as our desire to get back to the linear regime for reconstruction.

Add images of the velocity field here

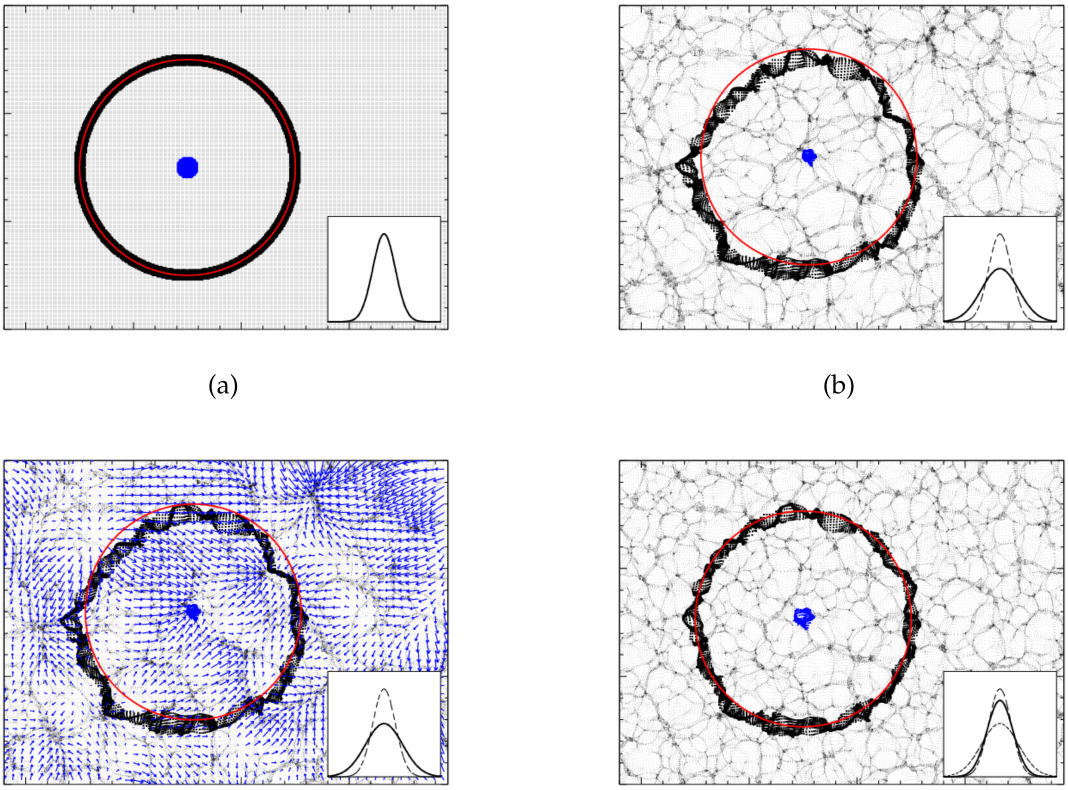
2.3 The Zeldovich Approximation

Introduce the theory of the Zeldovich Approximation and motivate its use (+ background).

2.4 Reconstruction (BAO)

Finally link everything with an overview of Reconstruction techniques and how our work fits into the modern context.

Showcase the BAO reconstruction.



(a) (b)

(c) (d)

Figure 2.1: An illustration taken from Padmanabhan et al. 2012, showing how the acoustic scale is distorted by non-linear effects and then reconstructed. (a) In the early Universe, the density field was very smooth. The acoustic feature is marked with a ring of radius $150Mpc$, and the distance between the centroid (blue point) and the radially distributed black points is represented by a Gaussian. (b) In the late Universe, non-linear effects move the points on the acoustic scale from their original positions (still represented by the red circle). This can be seen as a broadening of the radial distribution (dashed line is the original). The evolution here was modelled using the Zel'dovich approximation. (c) The Lagrangian displacement field (blue arrows) is calculated. The concept behind reconstruction techniques is to estimate the displacement field in order to move the particles back to their original position. The field was smoothed using a Gaussian filter. (d) The particles were moved back along the displacement field, and a clear improvement can be seen. The solid line marks the reconstructed radial distribution, the dashed line represents the primordial distribution, and the dotted line is the late time distribution before reconstruction. In this case the reconstruction is not perfect because of the Gaussian filter, which was used to mimic a real scenario. Note that this was done just for illustration purposes, and actual reconstruction methods are more complex.

Chapter 3

Methods

3.1 Cosmological Simulations

Introduce simulations and motivate their use. Present the simulations we used and the analysis tools e.g. Pynbody

First density slices here.

3.2 The Power Spectrum

Introduce the power spectrum and motivate its use.

Could put an image with a Power Spectrum and present a few of the features.

This could be moved to the Growth of Structure chapter, depending on how much detail I want to go into there.

3.3 Calculating the Power Spectrum of a Simulation

Talk about how we obtain the power spectrum (GenPk) and give more detail about the interface between Pynbody and GenPk

Chapter 4

Perfect Reconstruction

The section names here are just temporary.

4.1 Method

Present how we did the perfect reconstruction

The first step in understanding the evolution of the universe is to look at the theoretical limits we encounter when trying to reconstruct it. As a field is defined at every point in space, any attempt at representing it with data is inherently imperfect. We would have to measure the density field at every point in the Universe in order to obtain all the information it contains. This fact already implies that no data driven reconstruction will ever succeed at perfectly recovering the primordial density field (unless we manage to make an infinity of measurements).

To show this unavoidable loss of information we performed a 'perfect' reconstruction. We have access to multiple snapshots at various redshifts in our simulations, including the initial positions of all particles (at $z = 99$). Therefore, we used this information to reconstruct the density field. We first calculated the density field at various redshifts in the interval $z = 0 - 9$. The field was calculated at the particle positions instead of being calculated on a regular grid. This is because we want the particles to carry the density field when we move them. After that, all the particles were moved to their initial positions at $z = 99$.

The density field is carried by the particles to $z = 99$. As the particle distribution was almost perfectly uniform at the beginning, the density field will also be very uniform. However, this procedure also creates an interesting side effect. At late time, most particles tend to be clumped together. Therefore, when measuring the density field at the particle positions, we will mostly get very high values. These values don't change when moving the particles, so the final field will also have very high values, but this time distributed on an almost uniform grid. This results in an apparent increase in the total mass of the simulation. As this increase is just a result of the way we represent the density field, it needs to be accounted for when analysing the results. The total mass of the simulation should be conserved.

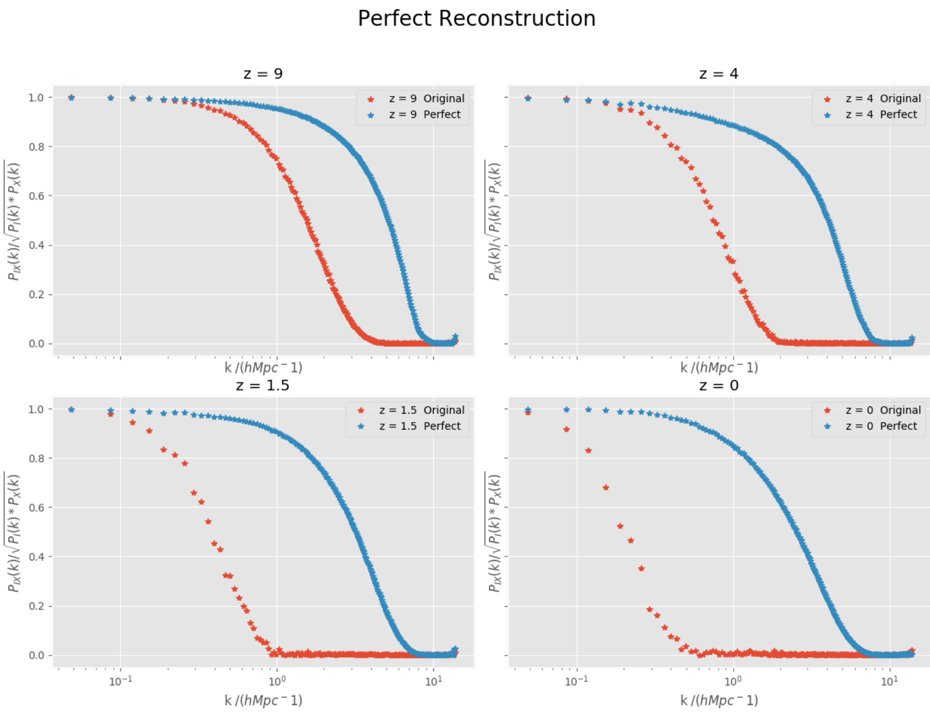


Figure 4.1: Comparison between the original and perfect reconstruction cross-Spectra at different redshifts.

4.2 Results

Show some density slices of the results, and talk about the effects that pop up (e.g. the increase in total mass). Show Power Spectra

4.3 Analysis

Present Cross-Spectra and talk about how well this worked and the weird effect around z=4.

Sim A: $(200Mpc)^3$, 512^3 Particles
Sim B: $(200Mpc)^3$, 256^3 Particles
Sim C: $(100Mpc)^3$, 256^3 Particles

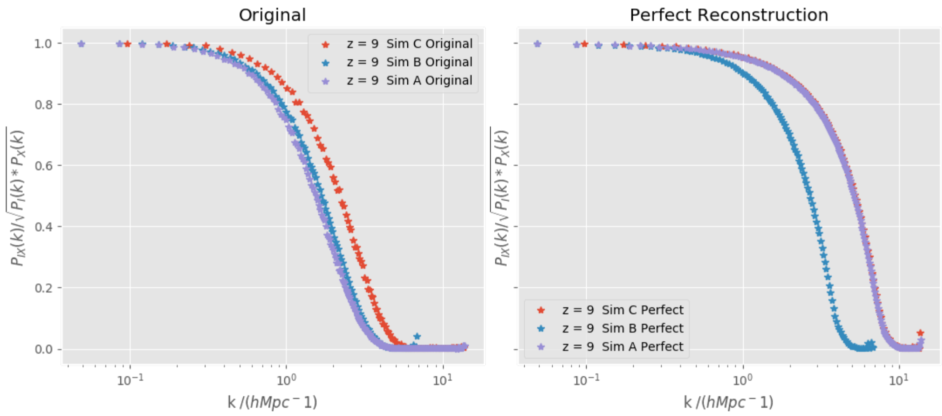


Figure 4.2: Comparison between different simulations of the original and the reconstructed correlation.

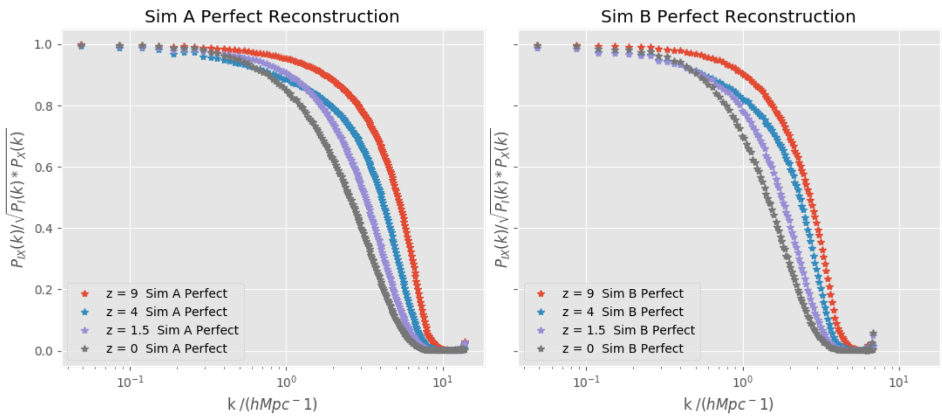


Figure 4.3: Perfect Reconstruction from different redshifts in Sim A and Sim B

Chapter 5

Realistic Reconstructions

5.1 The velocity field

Introduce our use of the velocity field to do the reconstruction. Present method of obtaining this in practice and the problems encountered.

5.2 Getting back to the linear regime

Talk about how we try to get back to the linear regime. Introduce different ways of avergaing the velocities

5.3 Results

Present our results -¿ Density Slices and Cross Spectra.

5.4 Analysis

Talk about the results for different averaging methods and Bin Sizes.

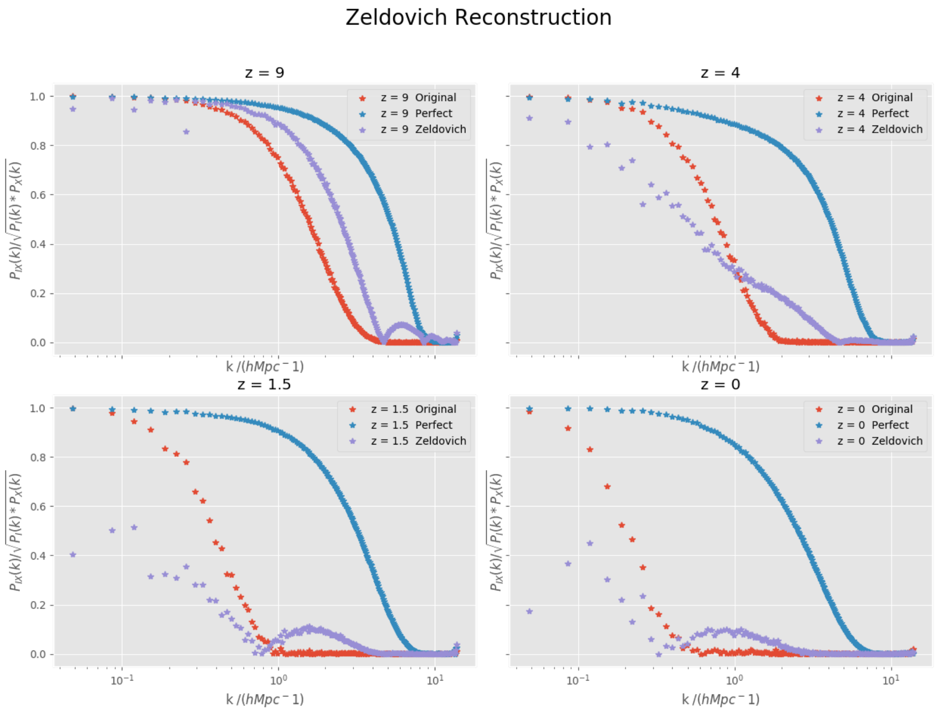


Figure 5.1: Reconstructed by applying the Zeldovich Offset directly to the particles for different redshifts.

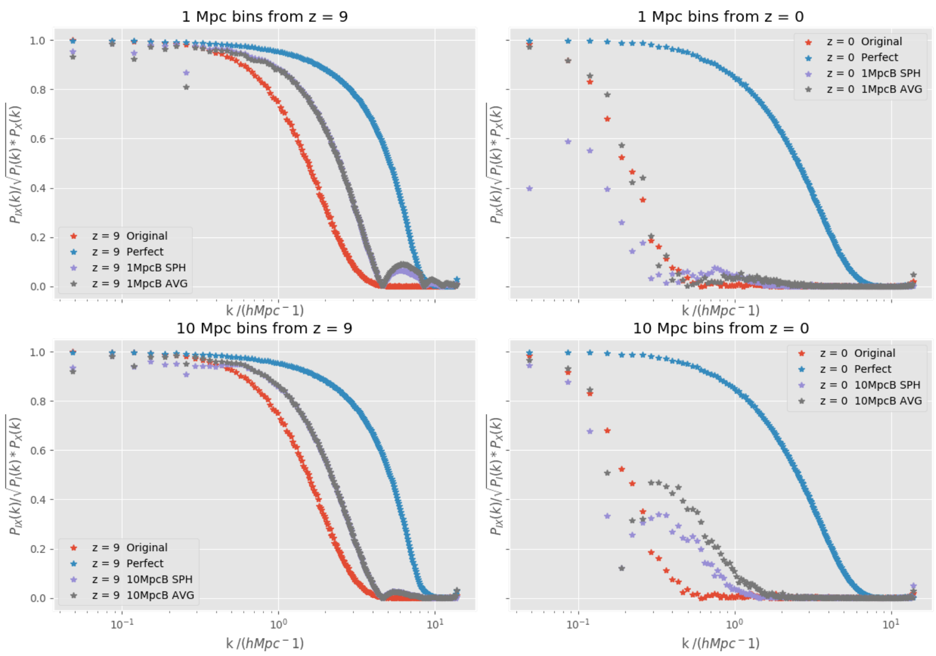


Figure 5.2: Cross spectra of realistic reconstructions from redshift 9 and 0, using 1 Mpc and 10 Mpc bins to average velocities. There are two averaging methods used: AVG - average of all particles in each bin, SPH - A point estimate of the velocity at the center of the bin.

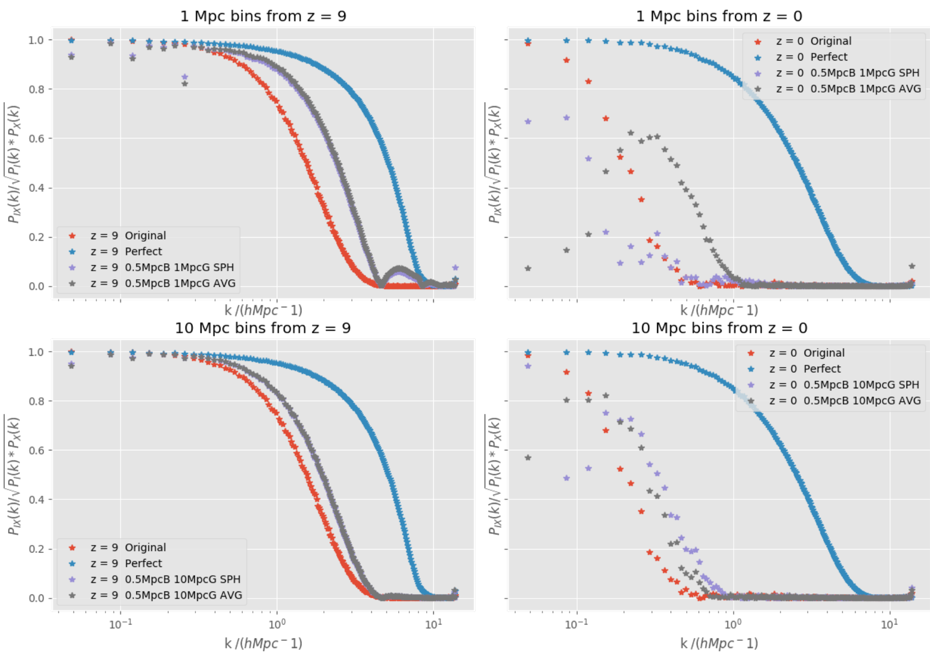


Figure 5.3: Cross spectra of realistic reconstructions from redshift 9 and 0, using 1 Mpc and 10 Mpc bins to smooth velocities. In this case the average was taken across 0.5 Mpc bins (using the two methods presented above), and then a Gaussian Filter with standard deviation of 1 Mpc and 10 Mpc respectively was applied.

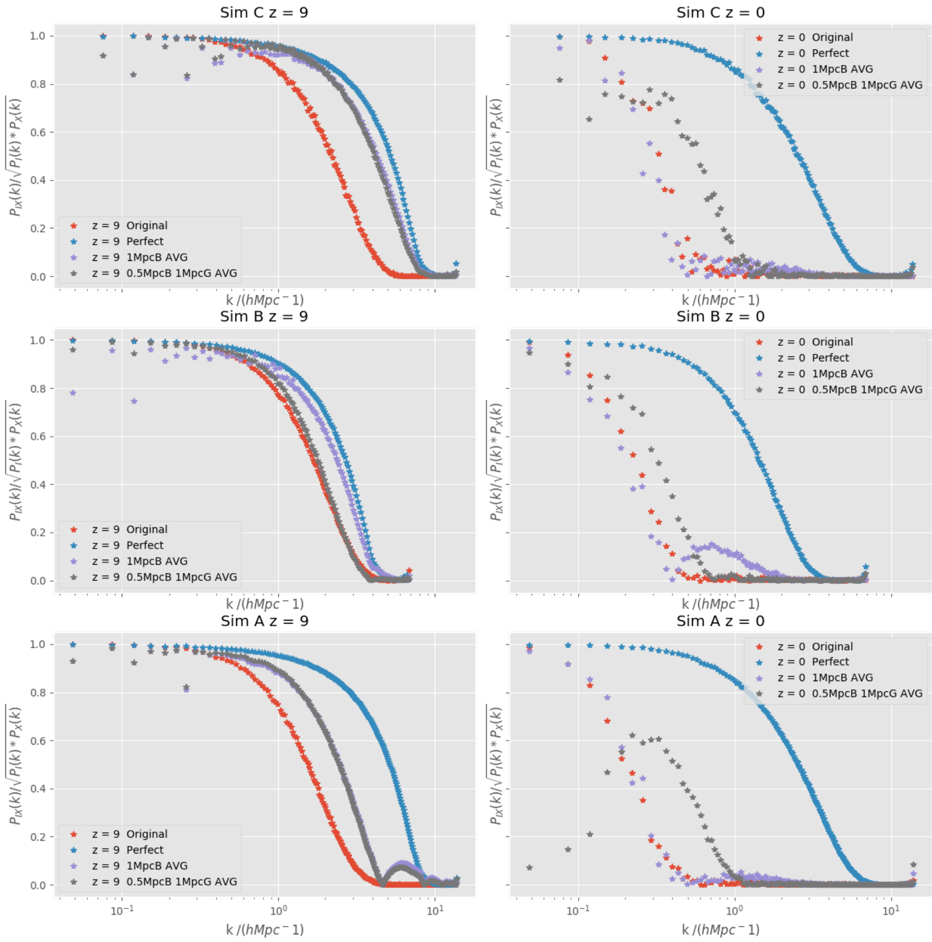


Figure 5.4: Cross spectra of realistic reconstructions from redshift 9 and 0 across the 3 simulations. Velocities were averaged over 1 Mpc scales using normal averaging of all the particles in each bin.

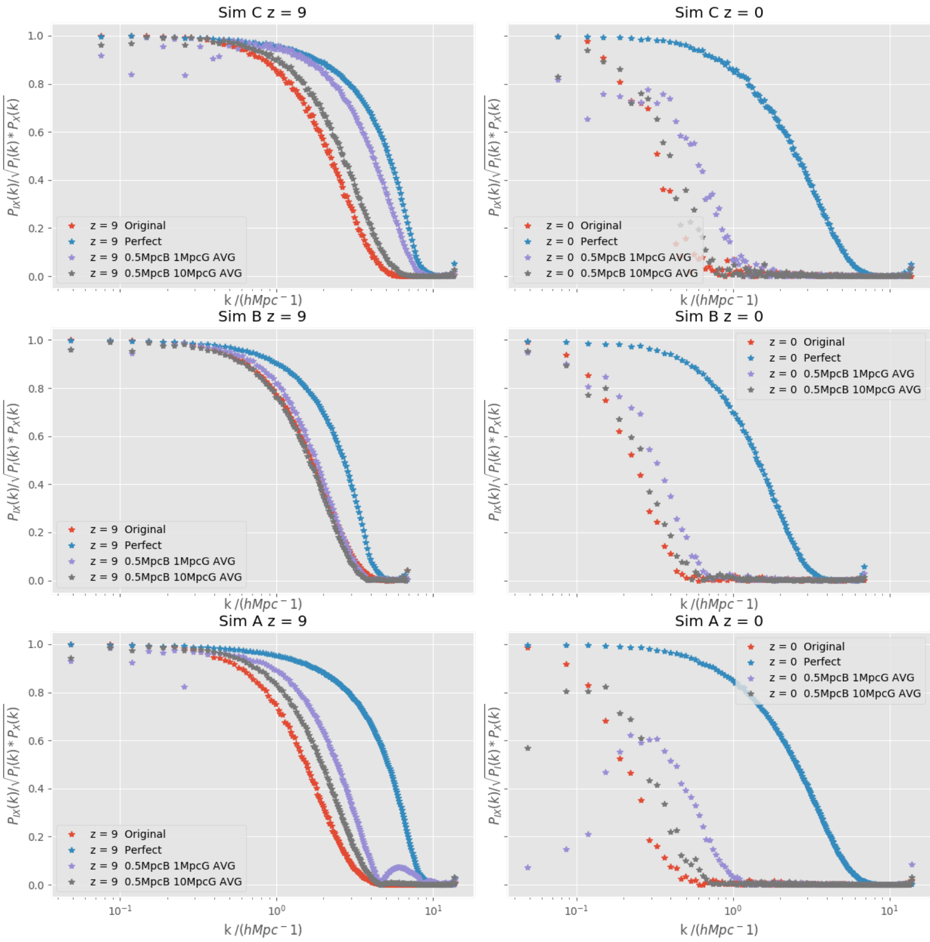


Figure 5.5: Cross spectra of realistic reconstructions from redshift 9 and 0 across the 3 simulations. Velocities were averaged over 1 Mpc and 10 Mpc scales using normal averaging of all the particles in each bin.

Chapter 6

Conclusions

6.1 Information loss

Talk about the inevitable information loss and the big discrepancy between the perfect and realistic reconstructions.

6.2 Future Work

Talk about the problems encountered and Future Work.

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Eisenstein, D. J. et al. (2007). "Improving Cosmological Distance Measurements by Reconstruction of the Baryon Acoustic Peak". In: ApJ 664, pp. 675–679. DOI: 10.1086/518712. eprint: astro-ph/0604362.

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