Primordial density and BAO reconstruction

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In this paper we introduce a new way to reconstruct BAO peaks in real space.

PACS numbers:

I. INTRODUCTION

The standard BAO reconstruction uses the negative Zel'dovich (linear) displacement to reverse the large-scale bulk flows [1]. The nonlinear density field is usually smoothed on the linear scale (~ 10 Mpc/h) to make the Zel'dovich approximation valid. Actually, the fully nonlinear displacement which describes the motion beyond the linear order (the Zel'dovich approximation) can be solved from the nonlinear density field. While the algorithm is complicated in the three spatial dimensions, it is quite simple in the 1D case, which is basically the ordering of mass elements. The 1D cosmological dynamics corresponds to the interaction of infinite sheets of matter where the force is independent of distance [2]. These sheets are moving in a Hubble flow relative to one another and the surface density in each sheet scales as a^{-2}. The simplified 1D dynamics provides an excellent means of understanding the structure formation and testing perturbation theories [2]. In this Letter, we solve the fully nonlinear displacement in 1D and present a new method to reconstruct the linear BAO information.

II. SIMULATIONS

To simulate the gravitational dynamics in 1D, we use the 1D particle-mesh (PM) code in Ref. [2]. The 1D simualtion we use involves 3×10^8 sheets with 3×10^8 PM elements in a 10^8 Mpc box. The initial condition is generated under the Zel'dovich approximation. Since the Zel'dovich approximation is exact up to shell crossing, we start the PM calculation at $z = 10$. In the analysis, we use the output at $z = 0$. We scale the initial density field by the linear growth factor to get the linear density field at $z = 0$.

III. RECONSTRUCTION ALGORITHM

The Lagrangian displacement $\Psi(q)$ fully describes the motion of mass elements. The Eulerian position x of a mass element is

$$x = q + \Psi(q), \tag{1}$$

where q is the initial Lagrangian position of this mass element. In the simulations, mass elements (sheets) are labeled by their initial Lagrangian coordinates. Once we know their Eulerian positions, the displacment field is obtained. Observationally, we only have the unlabelled Eulerian coordinates. The estimated displacement at the Lagrangian coordinate $q = iL/N$ is

$$s(q) = x_i - iL/N, \tag{2}$$

where we have ordered the sheet lables i from left to right, L is the box size, and N is the sheet number. If no shell crossing happens, the reconstructed displacement is exact up to a global shift. In the nonlinear regime once shell crossing occurs, the estimated displacement field is quite noisy on the scale L/N. To reduce stochasticities in the estimated displacement field, we can use the averaged displacement of n_p particles

$$s(q) = \frac{1}{n_p} \sum_{j=i}^{i+n_p-1} x_{i+j} - i n_p L/N, \tag{3}$$

where $q = i n_p L/N$ and j is the sheet label. Here i varies from 0 to N/n_p and j varies from 0 to N.

The derivative (actually the divergence) of $s(q)$ gives the reconstructed density field

$$\delta_r(q) = -\frac{\partial s(q)}{\partial q}, \tag{4}$$

i.e., the differential motion of mass elements. is this argument appropriate? shall we discuss more here? Reconstruction from the gridded density field can be implemented following the same principle, which we adopt in the following calculations.

IV. RESULTS

Figure 1 shows the linear, nonlinear and reconstructed power spectra, as well as the cross-corrlation power spectra. The correlation of the reconstruction density field δ_r with the linear density field δ_L is much better than that of the raw nonlinear density field δ. The wiggles in the reconstructed power spectrum are also much more transparent than the nonlinear power spectrum.

To convenienty quantify the linear information δ_L in the nonlinear density field δ, we decompose the nonlinear density field δ as

$$\delta(\boldsymbol{k}) = b(\boldsymbol{k})\delta_L(\boldsymbol{k}) + \delta_N(\boldsymbol{k}). \tag{5}$$

Here, $b\delta_L$ is completely correlated with the linear density field δ_L and $b = P_{\delta\delta_L}/P_{\delta_L}$. Nonlinear evolution drives b to drop from unity, reducing the linear signal. δ_N is generated in the nonlinear evolution and thus uncorrelated with the linear density field δ_L, further reducing $b\delta_L$ with

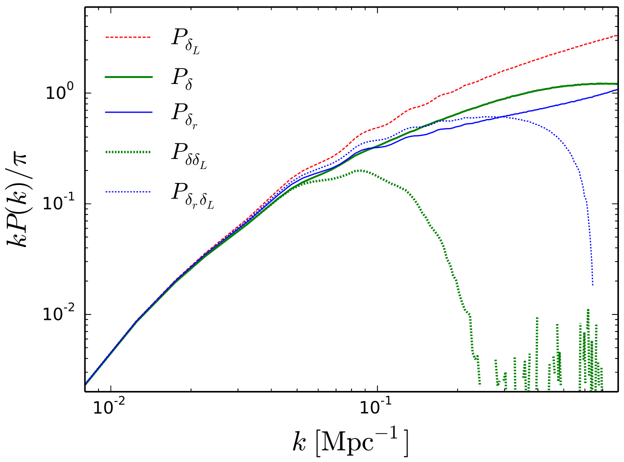

FIG. 1: The power spectra of the linear (dashed line), nonlinear (thick solid line), and reconstructed (thin solid line) fields. We also plot the nonlinear-linear (thick dotted line) and reconstructed-linear (thin dotted line) cross-correlation power spectra.

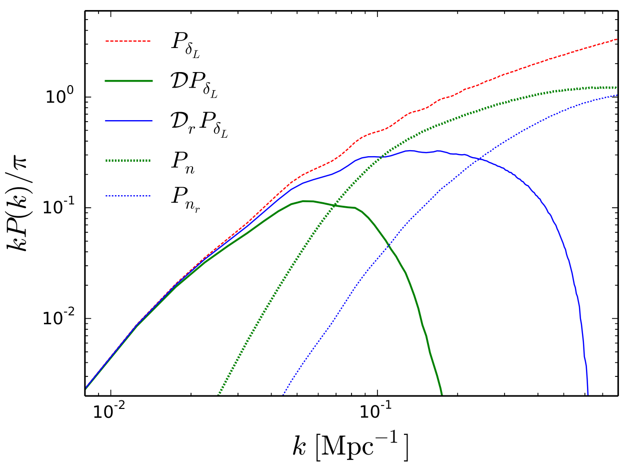

FIG. 2: The power spectra of the linear (dashed line), nonlinear (thick solid line), and reconstructed (thin solid line) fields. We also plot the nonlinear-linear (thick dotted line) and reconstructed-linear (thin dotted line) cross-correlation power spectra.

respect to δ. This part induces noises in the measurement of BAO. Hence we denote it with a subscript "N". Such decomposition helps to write the nonlinear power spectrum as

$$P_\delta(k) = \mathcal{D}(k)P_{\delta_L}(k) + P_{\delta_N}(k), \tag{6}$$

where $\mathcal{D} = b^2$ describes the damping of the linear power specturm. The reconstructed power spectrum P_{δ_r} can be describe in the same way. Here, $b(\boldsymbol{k})$ is often referred as the "propagator" and P_{δ_N} is usually called the mode-coupling term [3–5]. still to be modified

Figure 3 shows the damping functions for the raw and reconstructed fields. The nonlinear damping of the linear

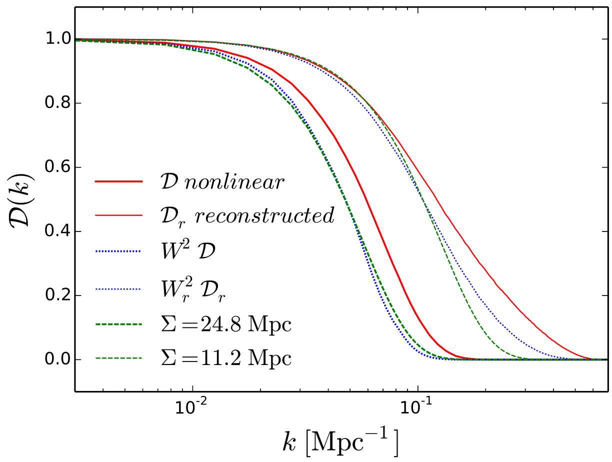

FIG. 3: The damping factors for the nonlinear (thin solid line) and reconstructed (thick solid line) fields. The Gaussian BAO damping models with $\Sigma = 20$ Mpc (thick dotted line) and $\Sigma = 10$ Mpc (thin dotted line).

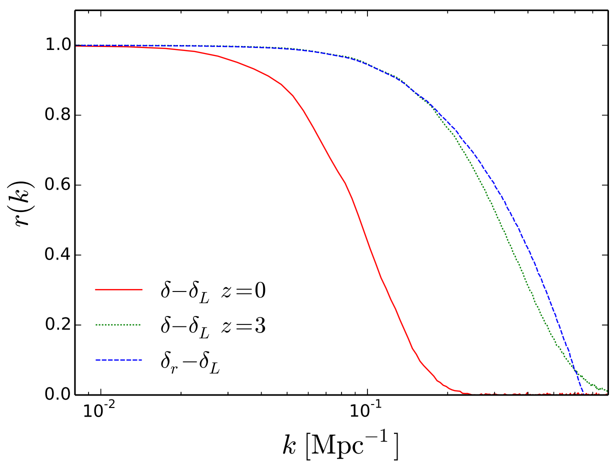

FIG. 4: The $\delta - \delta_L$ correlation coefficients at $z = 0$ (solid line) and $z = 3$ (dotted line), as well as the $\delta_r - \delta_L$ correlation coefficient (dashed line).

power spectrum is significantly reduced after reconstruction. We also overplot the best-fitting Gaussian BAO damping model,

$$\mathcal{D}(k) = \mathrm{e}^{-k^2\Sigma^2/2}, \tag{7}$$

with $\Sigma =$? Mpc and ? Mpc for the nonlinear and reconstructed fields. The new BAO reconstruction algorithm reduces the the nonlinear damping scale Σ by ?? per cent, i.e., a of ??. The damping factor is above 0.9 for $k \lesssim$? Mpc^{-1} indicating (almost) perfect reconstruction. how to best quantify the reduction of damping? However, the 100 per cent reconstruction, cancelling any nonlinear effects, is still unachievable, as some information has been irreversibly lost. (more discissions)

Reconstruction also reduces the noise term P_{δ_N}. To demonstrate this, in Fig. 4 we plot the cross-correltion

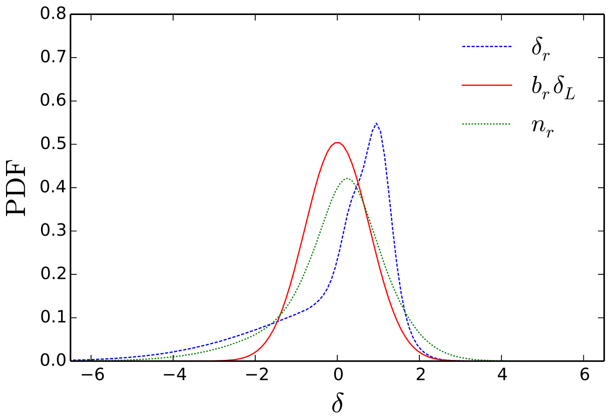

FIG. 5: The distribution functions.

coefficient

$$r(k) = \frac{P_{\delta\delta_L}(k)}{\sqrt{P_\delta(k)P_{\delta_L}(k)}} = \frac{1}{\sqrt{1+\eta(k)}}, \tag{8}$$

where $\eta = P_n/(\mathcal{D}P_{\delta_L})$ quantifies the relative amplitude of δ_N with respect to $b\delta_L$. The correlation of δ_r with δ_L is as good as that of δ at $z = 3$. how to quantify this better?

Distribution functions

V. DISCUSSIONS

The new method significantly improves the expansion rate measurement from BAO. (more discussions?)

This method can be generalized to the 3D case. We leave this to future work.

Comparision with and Implications for the standard BAO reconstruction: exact Lagrangian displacement, nonlinear displacement, which is easier to model.

If use the displacement solved in this paper for the standard BAO rec, we expect the performance will become much better but still not as good as our results.

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[1] D. J. Eisenstein, H.-J. Seo, E. Sirko, and D. N. Spergel, ApJ **664**, 675 (2007), astro-ph/0604362.
[2] M. McQuinn and M. White, J. Cosmology Astropart. Phys. **1**, 043 (2016), 1502.07389.
[3] M. Crocce and R. Scoccimarro, Phys. Rev. D **73**, 063520 (2006), astro-ph/0509419.
[4] M. Crocce and R. Scoccimarro, Phys. Rev. D **77**, 023533 (2008), 0704.2783.
[5] T. Matsubara, Phys. Rev. D **77**, 063530 (2008), 0711.2521.