Reconstruction of Baryon Acoustic Oscillations in 1+1 Dimensions

(Dated: August 14, 2016)

In this paper we introduce a new way to reconstruct BAO peaks in real space.
title 0: Reconstructing the Primordial Density Field in 1+1 Dimensions
title 1: Reconstruction of BAO Peaks in 1+1 Dimensions
title 2: Baryon Acoustic Oscillations Reconstruction in 1+1 Dimensions.
title 2: BAO Reconstruction in 1+1 Dimensions.

PACS numbers:

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.

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 our 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 $z = 0$.

Reconstruction algorithm.—The nonlinear Lagrangian displacement can be solved easily in 1D by the ordering of mass elements.

(1) Solve the displacement $\Psi(q)$ field by ordering of the mass elements.

(2) Take the differential derivative of $\Psi(q)$ to get the reconstructed density field $\delta_r(\boldsymbol{q}) = -\nabla_{\boldsymbol{q}}\Psi(\boldsymbol{q})$. $\delta_r(\boldsymbol{q}) = -\partial\Psi(q)/\partial q$.

To solve the displacement field, we combine grids to get two fields with five PM elements per grid and ten PM elements per grid, respectively.

Reconstruction from the gridded density field can be implemented following the same principle, which we adopt in the following calculations to be updated

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 raw nonlinear power spectrum.

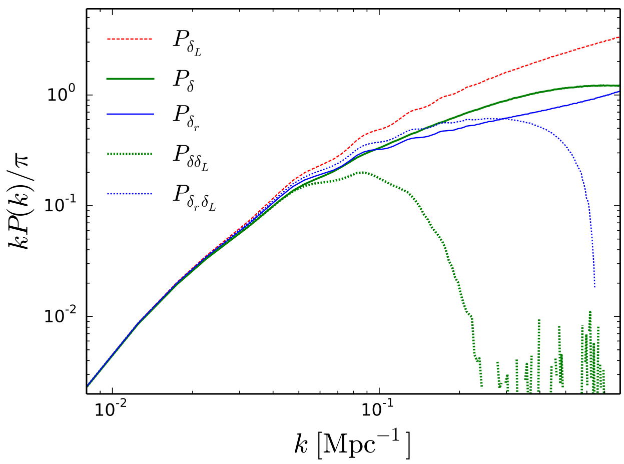

FIG. 1: The power spectra of the linear (dashed line), nonlinear (thick solid line), and reconstructed (thin solid line) fields. We also plot the nonlinear-linear (thick dotted line) and reconstructed-linear (thin dotted line) cross-correlation power spectra.

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

$$\delta(\boldsymbol{k}) = b(\boldsymbol{k})\delta_L(\boldsymbol{k}) + \delta_N(\boldsymbol{k}). \tag{1}$$

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 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

$$P_\delta(k) = \mathcal{D}(k)P_{\delta_L}(k) + P_{\delta_N}(k), \tag{2}$$

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 $n(\boldsymbol{k})$ is usually called the mode-coupling term [3–5]. still to be modified

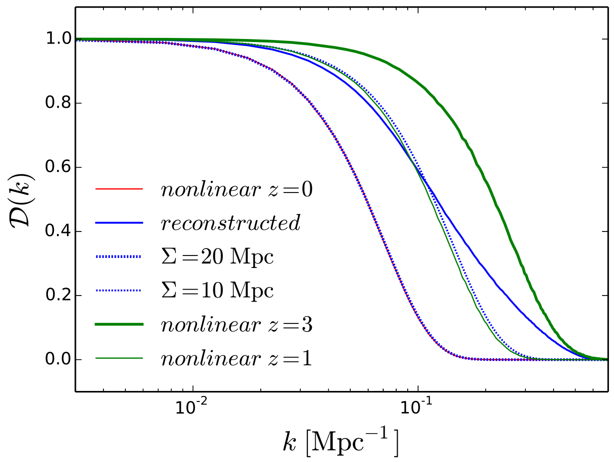

FIG. 2: The damping factors for the nonlinear (thin solid line) and reconstructed (thick solid line) fields. The Gaussian BAO damping models with $\Sigma = 20$ Mpc (thick dotted line) and $\Sigma = 10$ Mpc (thin dotted line).

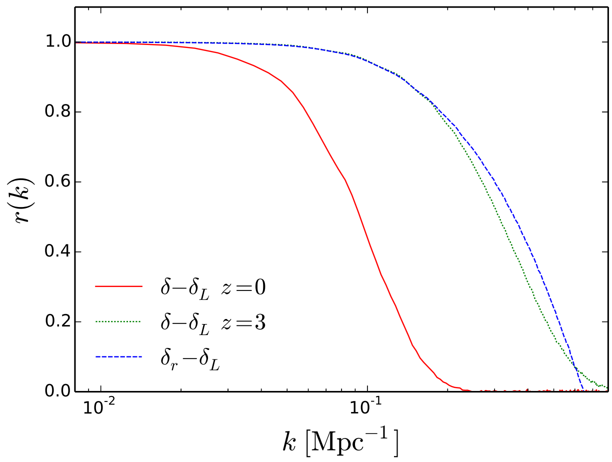

FIG. 3: The $\delta - \delta_L$ correlation coefficients at $z = 0$ (solid line) and $z = 3$ (dotted line), as well as the $\delta_r - \delta_L$ correlation coefficient (dashed line).

Figure 2 shows the damping functions for the raw and reconstructed fields. The nonlinear damping of the linear power spectrum is significantly reduced after reconstruction. We also overplot the best-fitting Gaussian BAO damping model,

$$\mathcal{D}(k) = \mathrm{e}^{-k^2\Sigma^2/2}, \tag{3}$$

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. 3 we plot the cross-correltion coefficient

$$r(k) = \frac{P_{\delta\delta_L}(k)}{\sqrt{P_\delta(k)P_{\delta_L}(k)}} = \frac{1}{\sqrt{1+\eta(k)}}, \tag{4}$$

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

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.

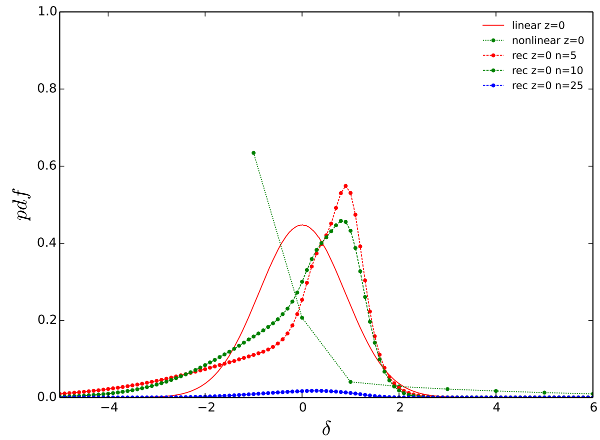

FIG. 4: The distribution functions.

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.

We acknowledge the support of the Chinese MoST 863 program under Grant No. 2012AA121701, the CAS Science Strategic Priority Research Program XDB09000000, the NSFC under Grant No. 11373030, IAS at Tsinghua University, and NSERC. The Dunlap Institute is funded through an endowment established by the David Dunlap family and the University of Toronto. Research at the Perimeter Institute is supported by the Government of Canada through Industry Canada and by the Province of Ontario through the Ministry of Research & Innovation.

[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.