We study the effect of noise in the density field, such as would arise from a finite number density of tracers, on reconstruction of the acoustic peak within the context of Lagrangian perturbation theory. Reconstruction performs better when the density field is determined from denser tracers, but the gains saturate at $n \sim 10^{-5} (\delta Mpc^{-1})^3$. For low density tracers it is best to use a large smoothing scale to define the shifts, but the optimum is very broad.

I. INTRODUCTION

Baryon acoustic oscillations (BAO) in the baryon-photon fluid provide a standard ruler to constrain the expansion of the Universe and have become an integral part of current and next-generation dark energy experiments [1]. These sound waves imprint an almost harmonic series of peaks in the power spectrum $P(k)$, corresponding to a feature in the correlation function $\xi(r)$ at $\sim 100$ Mpc, with width $\sim 10\%$ due to Silk damping [2–7]. Non-linear evolution leads to a damping of all broad band and mode-coupling features implicit in the linear power spectrum, $P_L$, (see below) and $\Sigma_{ss}^2 \equiv (1/2) (\Sigma_{ss}^2 + \Sigma_{dd}^2)$.

If we assume there is a contribution, $\delta_N$, from noise we find $\delta_{\text{recon}}$ is unchanged to lowest order. However the damping scale is modified. Following [15] we find

$$\Sigma_{ss}^2 \rightarrow \frac{1}{3\pi^2} \int dp \left[ P_L(p) + P_N(p) \right]$$

where $P_N$ is the power spectrum of $\delta_N$ and

$$\Sigma_{dd}^2 \rightarrow \frac{1}{3\pi^2} \int dp \left[ (1 - S(p))^2 P_L(p) + S^2(p) P_N(p) \right]$$

which reduce to the expressions of [15, 16] as $P_N \rightarrow 0$. For Poisson shot-noise we expect $P_N = b^2 n^{-1}$ for tracers with number density $n$ assuming linear bias $b$. These equations present the generalization of the treatment in [15, 16] to include shot-noise.

III. RESULTS

One method to forecast the effect of this noise on cosmological parameters constrained by BAO is to replace the Gaussian damping of Eq. (1) with Eq. (3) in the computation of the Fisher matrix for the acoustic scale $s$. For example, in spherical geometry [17]

$$\sigma_{\ln s}^{-2} = \frac{V_{\text{survey}}}{2} \int \frac{dk}{(2\pi)^3} \left[ \partial P/\partial \ln s \right]^2$$

with

$$P \propto D(k) \sin \frac{k s}{k s} e^{-k^2 \Sigma_{\text{Silk}}^2/2} + \ldots$$

where $\Sigma_{\text{Silk}}$ is the Silk damping scale and ... refers to terms independent of $s$ [17]. The effects of shot-noise show up in the increased damping of the higher harmonics of the signal.
FIG. 1: (Top) The damping scale at $z = 0$, $\Sigma_{\text{eff}}$, after reconstruction as a function of the number density of tracers, $\bar{n}$, assuming $b = 1$. The horizontal dot-dashed line indicates the Silk scale, or the intrinsic width of the acoustic peak, for our cosmology. (Bottom) As above but as a function of smoothing scale, $R$.

and the increase in the variance per $k$ mode (the denominator in Eq. 6).

However, almost as much intuition can be gained by approximating $D(k)$ as a Gaussian and asking how the effective damping depends on $P_N$. To this end we define an “effective” $\Sigma$ from the value of the damping at $k_{\text{fid}} = 0.2$ $h$ Mpc$^{-1}$.

Figure 1, top, shows how $\Sigma_{\text{eff}}(z = 0)$ depends on $\bar{n}$ for a $\Lambda$CDM model with $\Omega_m = 0.25$. Note that reconstruction improves for higher number density tracers, but the gains saturate above approximately $10^{-4}$ ($h$ Mpc$^{-1}$)$^3$. For lower number densities, it is advantageous to use a larger smoothing scale to define the shifted field, as expected. For comparison, without reconstruction the full non-linear smearing at $z = 0$ leads to $\Sigma \simeq 10 h^{-1}$Mpc, scaling as the growth factor to higher redshift. The horizontal dot-dashed line indicates the Silk scale, or the intrinsic width of the acoustic peak, for our cosmology — the observed width of the acoustic peak is the quadrature sum of $\Sigma_{\text{Silk}}$.

A different view is given in the lower panel of Figure 1, which shows how $\Sigma_{\text{eff}}(z = 0)$ depends on $R$ for different values of $\bar{n}$. Note the existence of an “optimal” smoothing scale, but that the minimum is extremely broad.

These results show that, within the context of Lagrangian perturbation theory, it is straightforward to understand the effects of noise in the density field on the efficacy of reconstruction. Reconstruction performs better when the density field is determined from denser tracers, but the gains saturate at $\bar{n} \sim 10^{-4}$ ($h$ Mpc$^{-1}$)$^3$. For low density tracers it is best to use a large smoothing scale to define the shifts, but the optimum is very broad.

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