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Limitations of Suppressed Variance Simulations

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ABSTRACT

Keywords: cosmology: —

1. INTRODUCTION

$$\delta(\boldsymbol{x}) = \frac{\rho(\boldsymbol{x}) - \bar{\rho}}{\bar{\rho}} \tag{1}$$

$$\delta(\boldsymbol{k}) = \frac{1}{(2\pi)^3} \int \mathrm{d}^3\boldsymbol{x} e^{-i\boldsymbol{k}\cdot\boldsymbol{x}} \delta(\boldsymbol{x}) = A e^{i\theta} \tag{2}$$

For Gaussian random field, θ is uniformly sampled from 0 to 2π and A is sampled from Rayleigh distribution:

$$p(A)\mathrm{d}A = \frac{A}{\sigma^2} e^{-A^2/2\sigma^2} \mathrm{d}A \tag{3}$$

where $\sigma^2 = V\ P(k)/(16\pi^3)$. The mean of this distribution is

$$\langle A \rangle = \int_0^\infty \frac{A^2}{\sigma^2} e^{-A^2/2\sigma^2} \mathrm{d}A = \sqrt{\frac{V\,P(k)}{32\pi^2}}. \tag{4}$$

Also,

$$\langle \delta(\boldsymbol{k})\delta^*(\boldsymbol{k}) \rangle = \langle A^2 \rangle = \int_0^\infty \frac{A^3}{\sigma^2} e^{-A^2/2\sigma^2} \mathrm{d}A = \frac{V\,P(k)}{(2\pi)^3}. \tag{5}$$

A paired Gaussian field is where you have two fields δ_1 and δ_2 where $\delta_2(k) = Ae^{i(\theta+\pi)} = -\delta_1(k)$.

A fixed field is when the amplitude is fixed,

$$A = \sqrt{\frac{V\ P(k)}{(2\pi)^3}}, \tag{6}$$

such that the power spectrum is the same.

Paired fixed is when you do both.

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2. THE QUIJOTE SIMULATION SUITE

We use a subset of simulations from the QUIJOTEsuite, a set of 43,000 N-body simulations that spans over 7000 cosmological models and contains, at a single redshift, over 8.5 trillion particles. The QUIJOTEsuite was designed to quantify the information content of cosmological observables and also to train machine learning algorithms. Hence, the suite includes enough realizations to accurately estimate the covariance matrices of high-dimensional observables such as the bispectrum as well as the derivatives of these observables with respect to cosmological parameters. For the derivatives, the suite includes sets of simulations run at different cosmologies where only one parameter is varied from the fiducial cosmology ($\Omega_{\rm m}$=0.3175, $\Omega_{\rm b}$=0.049, h=0.6711, n_s=0.9624, σ_8=0.834, and M_ν=0.0 eV). Along $\Omega_{\rm m}$, $\Omega_{\rm b}$, h, n_s, and σ_8, the fiducial cosmology is adjusted by either a small step above or below the fiducial value: $\{\Omega_{\rm m}^+, \Omega_{\rm m}^-, \Omega_{\rm b}^+, \Omega_{\rm b}^-, h^+, h^-, n_s^+, n_s^-, \sigma_8^+, \sigma_8^-\}$. Along M_ν, because $M_\nu \geq 0.0$ eV and the derivative of certain observable with respect to M_ν is noisy, QUIJOTEincludes sets of simulations for $\{M_\nu^+, M_\nu^{++}, M_\nu^{+++}\} = \{0.1, 0.2, 0.4 \text{ eV}\}$. At each of these 14 cosmologies, QUIJOTEincludes sets of standard N-body and suppressed variance simulations.

The initial conditions for all the simulations were generated at $z = 127$ using second-order perturbation theory for simulations with massless neutrinos ($M_\nu = 0.0$ eV) and the Zel'dovich approximation for massive neutrinos ($M_\nu > 0.0$ eV). The initial conditions with massive neutrinos take their scale-dependent growth factors/rates into account using the Zennaro et al. (2017) method, while for the massless neutrino case we use the traditional scale-independent rescaling.

From the initial conditions, the simulations follow the gravitational evolution of 512^3 dark matter particles, and 512^3 neutrino particles for massive neutrino models, to $z = 0$ using GADGET-III TreePM+SPH code (Springel 2005). Simulations with massive neutrinos are run using the "particle method", where neutrinos are described as a collisionless and pressureless fluid and therefore modeled as particles, same as CDM (Brandbyge et al. 2008; Viel et al. 2010). Halos are then identified using the Friends-of-Friends algorithm (FoF; Davis et al. 1985) with linking length $b = 0.2$ on the CDM + baryon distribution. We limit the halo catalogs to halos with masses above $M_{\rm lim} = 3.2 \times 10^{13} h^{-1} M_\odot$. For the fiducial cosmology, the halo catalogs have $\sim$156, 000 halos ($\bar{n} \sim 1.56 \times 10^{-4}\ h^3 \text{Gpc}^{-3}$) with $\bar{n}P_0(k = 0.1) \sim 3.23$. We refer readers to Villaescusa-Navarro et al. (in preparation) and Hahn et al. (2019) for further details on the QUIJOTEsimulations.

3. RESULTS

$$X_{{\rm pf},i} = \frac{1}{2}\big[X_{{\rm pf},i}^{(1)} + X_{{\rm pf},i}^{(2)}\big] \tag{7}$$

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APPENDIX

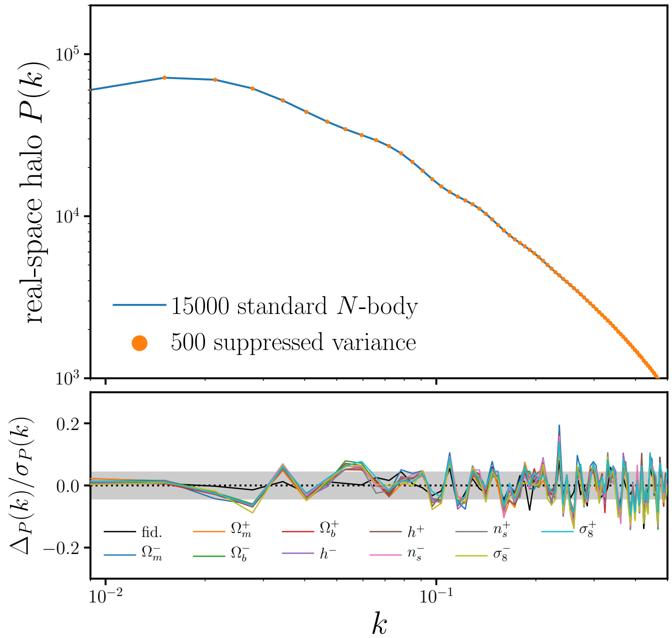


Figure 1. Comparison of the real-space power spectra of standard N-body simulations and suppressed variance simulations. We compare the average power spectrum monopole and quadrupole, $P_0(k)$ and $P_2(k)$ of 15,000 standard N-body simulations to the average P_0 and P_2 of 500 suppressed variance simulations at the fiducial cosmology (top panel).

REFERENCES

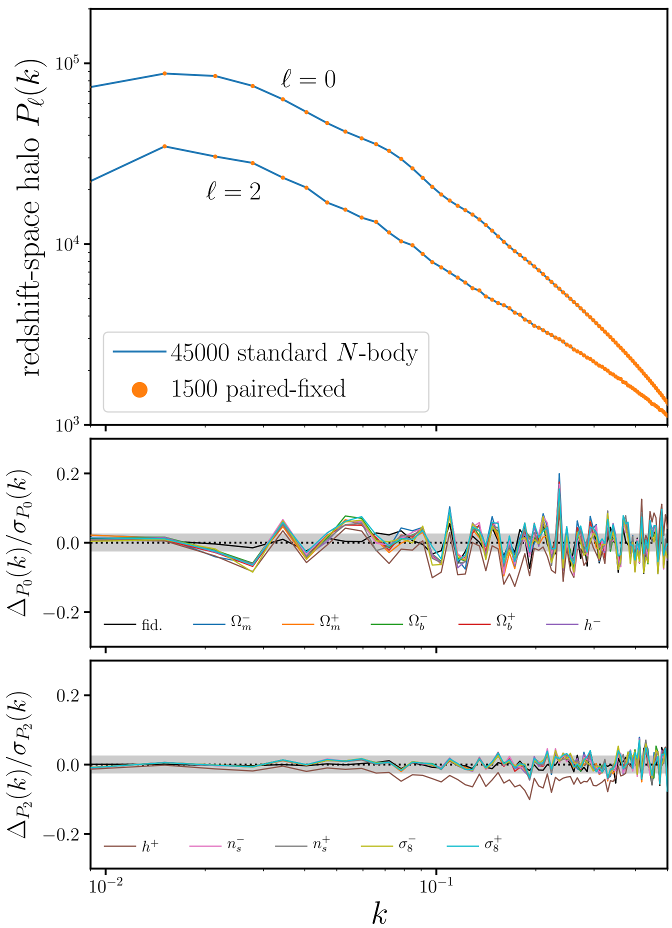
Brandbyge, J., Hannestad, S., Haugbølle, T., & Thomsen, B. 2008, Journal of Cosmology and Astro-Particle Physics, 08, 020

Davis, M., Efstathiou, G., Frenk, C. S., & White, S. D. M. 1985, The Astrophysical Journal, 292, 371

Springel, V. 2005, Monthly Notices of the Royal Astronomical Society, 364, 1105

Viel, M., Haehnelt, M. G., & Springel, V. 2010, Journal of Cosmology and Astro-Particle Physics, 06, 015

Zennaro, M., Bel, J., Villaescusa-Navarro, F., et al. 2017, Monthly Notices of the Royal Astronomical Society, 466, 3244



redshift-space halo $P_\ell(k)$
$\ell = 0$
$\ell = 2$
45000 standard N-body
1500 paired-fixed
$\Delta_{P_0}(k)/\sigma_{P_0}(k)$
fid.
Ω_m^-
Ω_m^+
Ω_b^-
Ω_b^+
h^-
$\Delta_{P_2}(k)/\sigma_{P_2}(k)$
h^+
n_s^-
n_s^+
σ_8^-
σ_8^+
k

Figure 2.

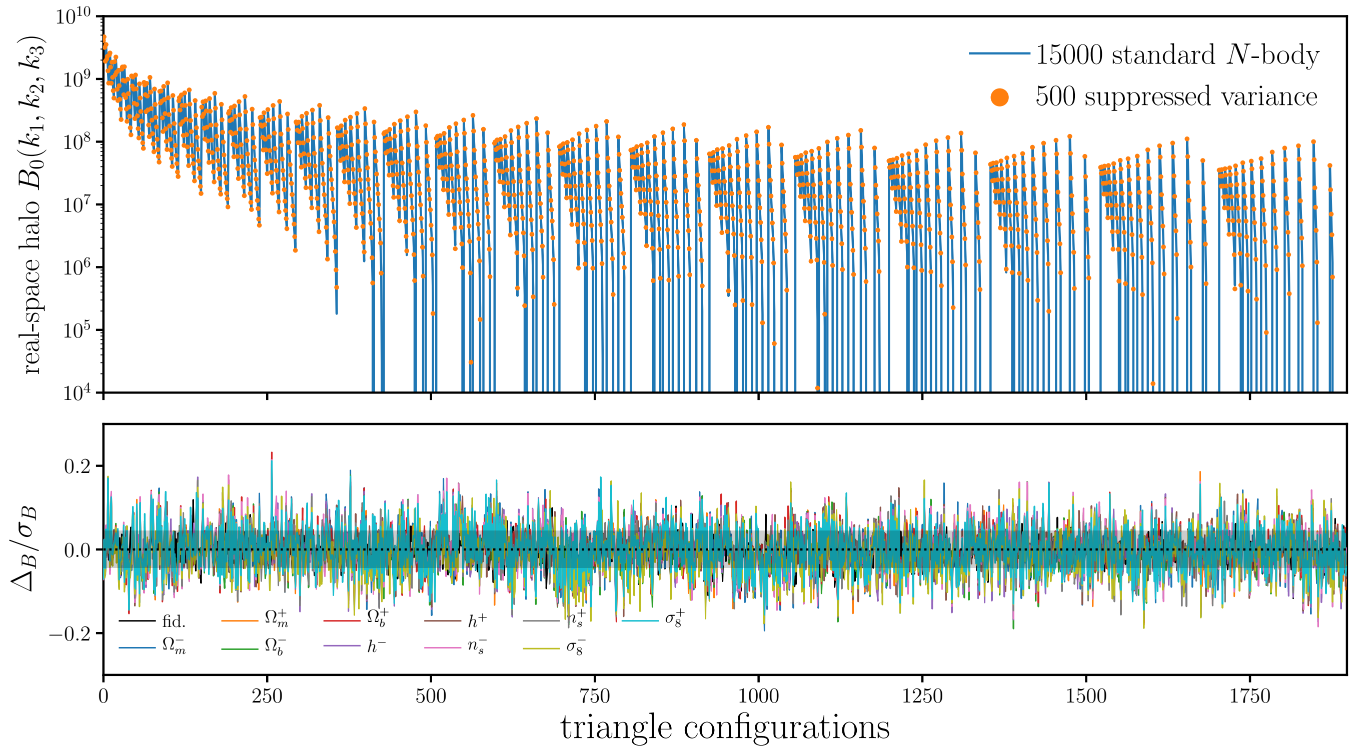


Figure 3.

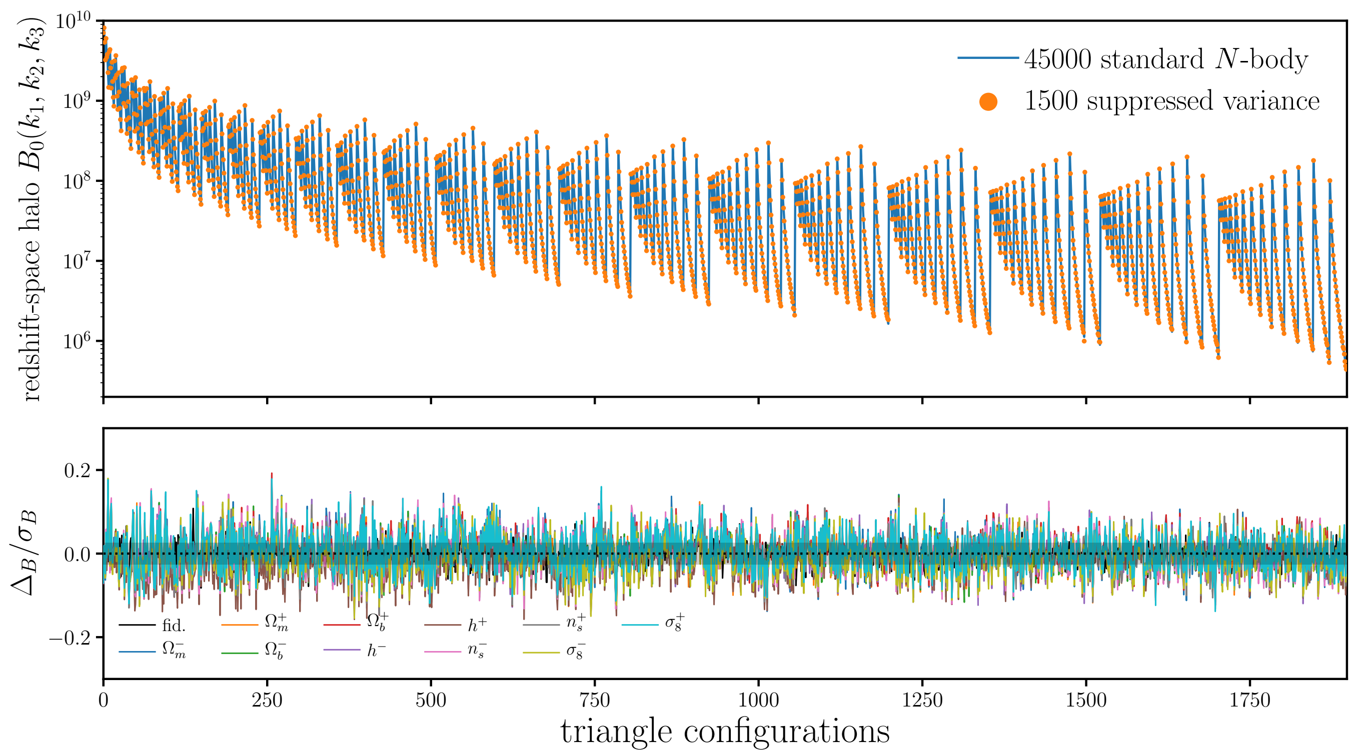


Figure 4.