Linear growth in Gadget cosmology simulations

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Abstract

We compare the linear growth in Gadget-3 and MP-Gadget simulations to linear theory, reducing the perturbation amplitude by a factor of 100 in order to minimise non-linearities. In the case of having 2 fluids seeded with different intial power, the growth rate of each species is slightly inaccurate, with a deficiency in baryon power of 5% by $z = 3$.

Introduction

In anticipation of new cosmological spectroscopic surveys providing unprecedented numbers and resolution of spectra, the accuracy of current methods of generating theoretical data needs to be more closely understood. In particular, in the case of the Lyman-α forest, theoretical predictions are made by running cosmological hydrodynamical simulations whose systematics can be difficult to account for. The amplitude of the linear power spectrum at $z = 3$ was measured from the Lyman-α forest in BOSS[1] quasars to 10% accuracy in ref [1], and with the upcoming DESI survey[2] this error is expected to shrink by a factor of 3. Given this, it is necessary to understand the systematic errors in simulations at the 1% level. Such tests have been conducted in the case of simulations with only one particle type [3]. In this note we test the accuracy of a widely used family of codes that are derivatives of the TreePM code Gadget-2[4]. In order to verify the growth of structure in Gadget simulations, we run a test where the initial perturbation amplitude is set to 1% of the Planck value, and compare the power spectra in simulations to the predictions by linear theory. This is done in order to minimise non-linearities so that the simulation growth can be tested against theoretical predictions. We run this test in two codes that are descendents of Gadget-2: P-Gadget3 and MP-Gadget[2].

For the MP-Gadget sims, linear theory power spectra are calculated using classylss[3], and power spectra from simulations are generated using GenPK[4]. For Gadget-3, we use reps[5] as a wrapper for CAMB[6] and Pylians[7]. In Fig 1, we show results for DM-only simulations for two box sizes, $L = 300\mathrm{Mpc}/h$ and $L = 60\mathrm{Mpc}/h$. In Fig 2, we show the same plot for a simulation with CDM and baryon particles.

All simulations start at z = 99 and use the same cosmology. For the DM-only sims (Fig. 1), MP-Gadget sims have 512^3 particles, with Nmesh = 1024, and Gadget-3 sims have 256^3 particles with Nmesh = 512. For the simulations with two fluids (Fig. 2), we use 2×256^3 particles with Nmesh = 512 in all sims. In the MP-Gadget simulations, we have turned off hydrodynamical effects and star formation in order to replicate the physics that goes into linear theory as closely as possible. Crucially, the inital power spectra of the multiple species simulation is seeded according to the transfer function of each individual species, so the baryons and CDM particles have a different initial power. Historically, multiple fluid simulations have generally been run where the initial power in each species are both seeded with the same, total matter power. This approximation is valid if you are interested in the power spectrum at low redshift, i.e. ($z \lessapprox 1$), by which point linear theory predicts the power in the baryons and CDM have converged. However given that the Lyman-α forest probes a higher redshift range where the CDM and baryons still have different clustering, and the forest itself is affected by both

[1] http://cosmology.lbl.gov/BOSS/
[2] https://github.com/MP-Gadget/MP-Gadget
[3] https://github.com/nickhand/classylss
[4] https://github.com/sbird/GenPK
[5] https://github.com/matteozennaro/reps
[6] https://github.com/cmbant/CAMB
[7] https://github.com/franciscovillaescusa/Pylians

the baryon and CDM power, the approximation of seeding initial power spectra of both fluids with the total matter has a $> 1\%$ effect on the flux power spectra computed from simulations.

We find that the linear growth is accurate for simulations with DM-only, but when we introduce a second species with a different initial power, the structure growth in simulations no longer agrees with linear theory. In the final set of plots, we look at the effect of turning the Tree algorithm off on the growth of individual species, and find that the Tree significantly degrades the accuracy of the growth of individual species even on very large scales.

Power spectra ratios DM-Only

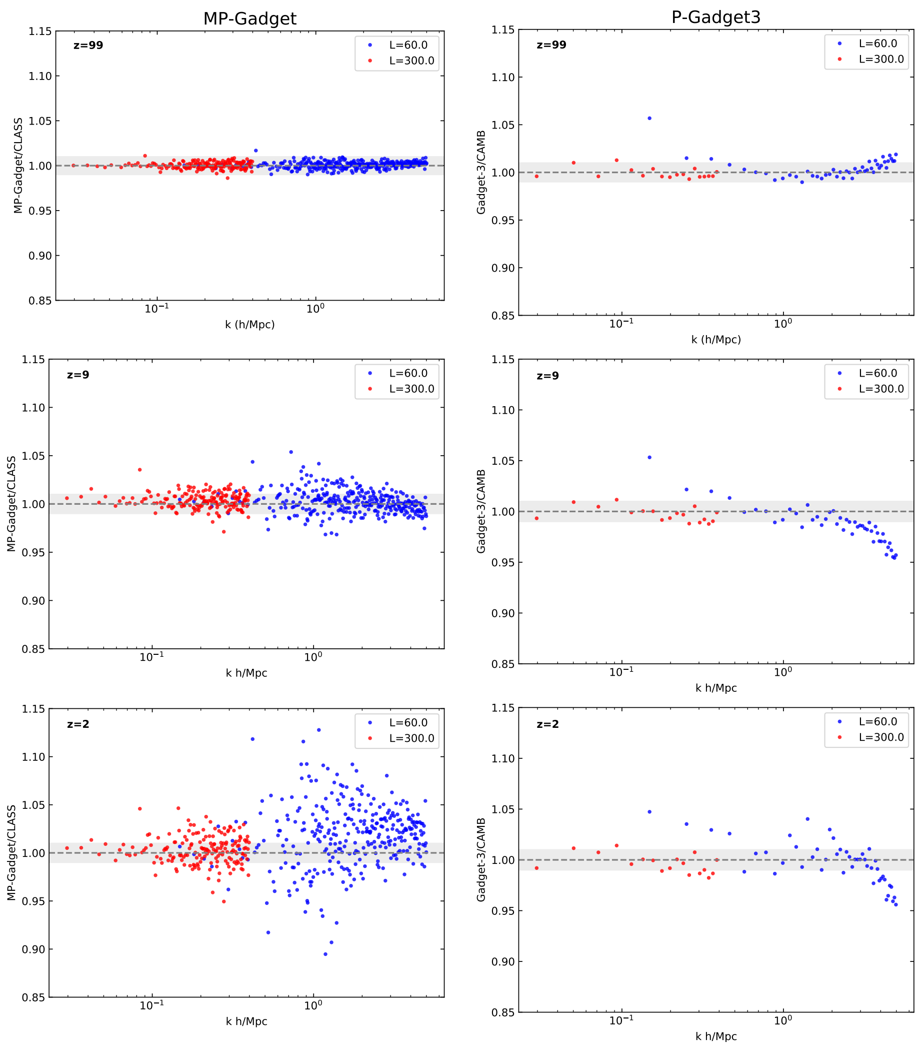

Figure 1: Left: MP-Gadget, 512^3 particle DM-only sim. Right: P-Gadget3, 256^3 particle DM-only sim. Shaded area represents the 1% error region, and we show results for $L = 300h/\mathrm{Mpc}$ and $L = 60h/\mathrm{Mpc}$ boxes to cover a larger range of k values. There is some scatter in the modes, but broadly the growth is accurate and in agreement with the predictions of linear theory. We note that in the P-Gadget3 simulations, there is an excess of power in the low-k modes of the small box. We think this is a binning issue caused by the fact that the k-bins in this power spectrum estimator are large, and around the BAO scale will have significant gradient across them.

Power spectra ratios for two particle species

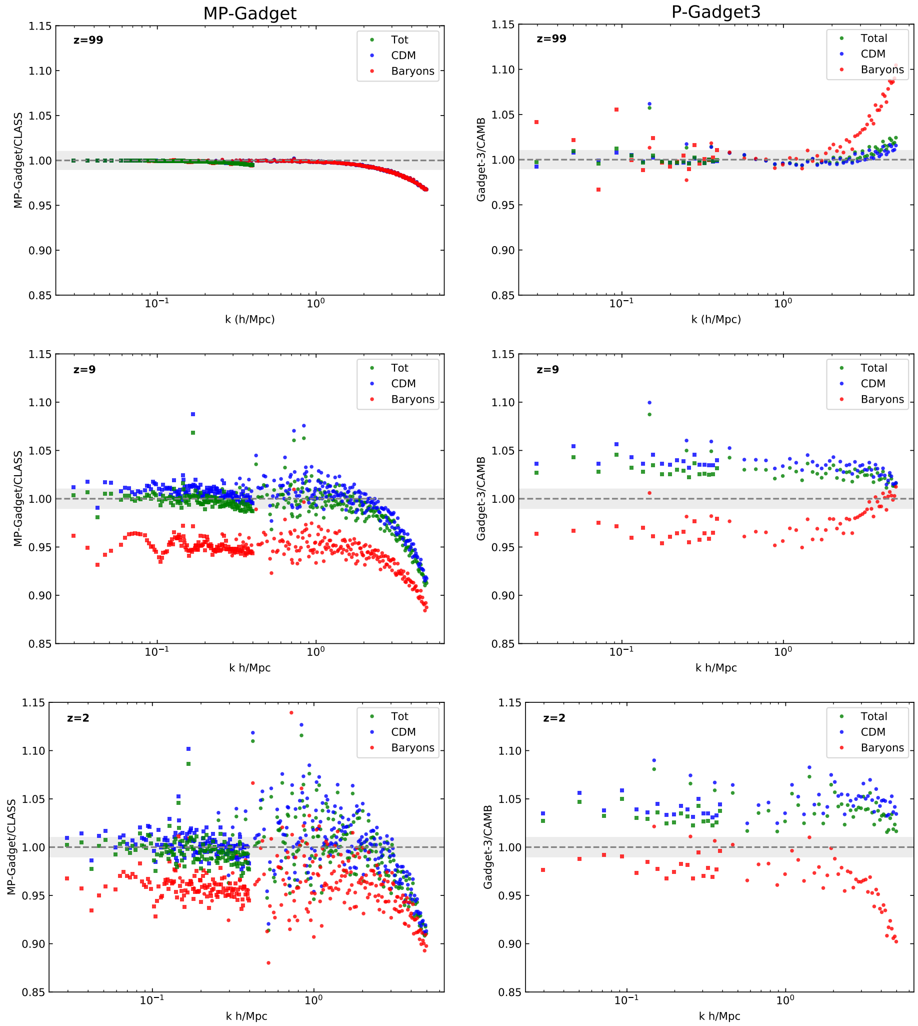

Figure 2: Same test but this time with DM and baryon particles, with MP-Gadget on left and P-Gadget3 on the right. Again we have used two box sizes, with $L = 300h/\mathrm{Mpc}$ shown in squares, and $L = 60h/\mathrm{Mpc}$ in circles. We plot the power in each simulation divided by the linear theory prediction for that individual species. For the case of multiple species, we see that the baryon power doesn't catch up to the CDM power as quickly as linear theory predicts. In MP-Gadget, the error in the baryon and CDM power approximately cancels out to give an accurate total matter, however in P-Gadget3, even the total growth is inaccurate with multiple species.

Effect of Tree in multiple species simulations

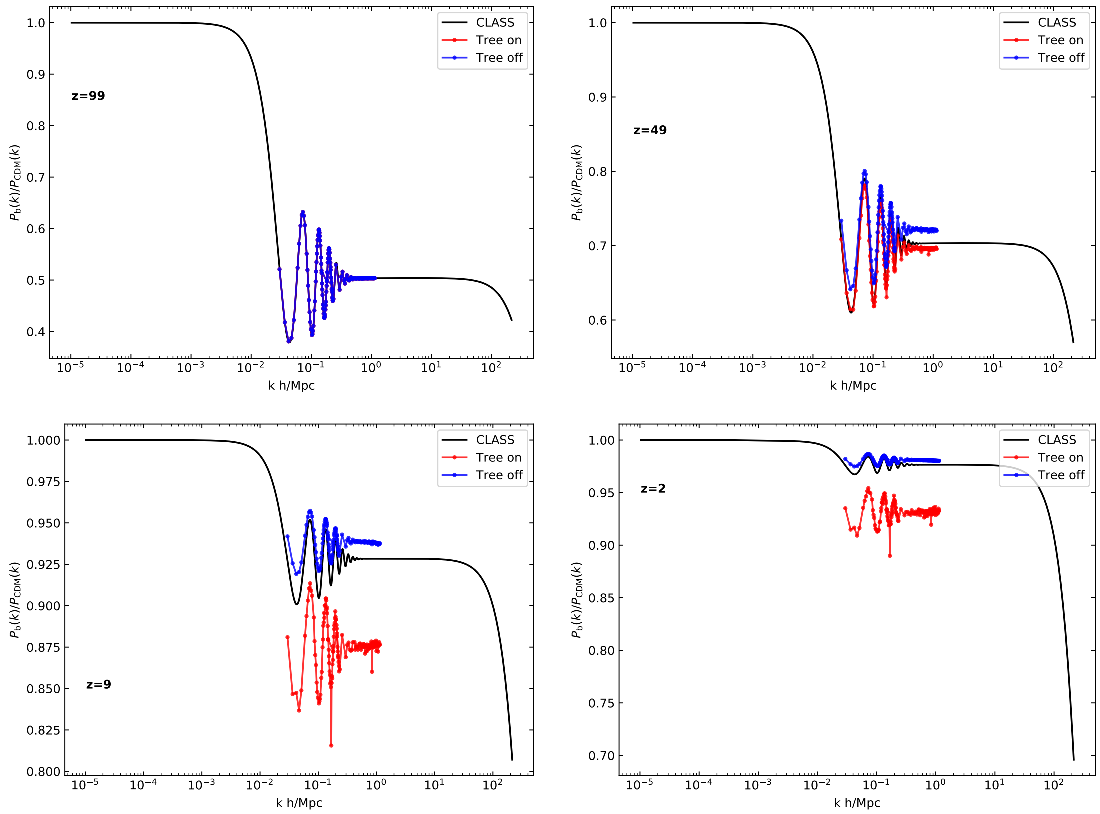

Figure 3: Effect of Tree on the ratios of the baryon and CDM power in MP-Gadget simulations. Turning on the Tree has a significant effect on the relative power in the two particle species, even on large scales.

Adaptive softenings

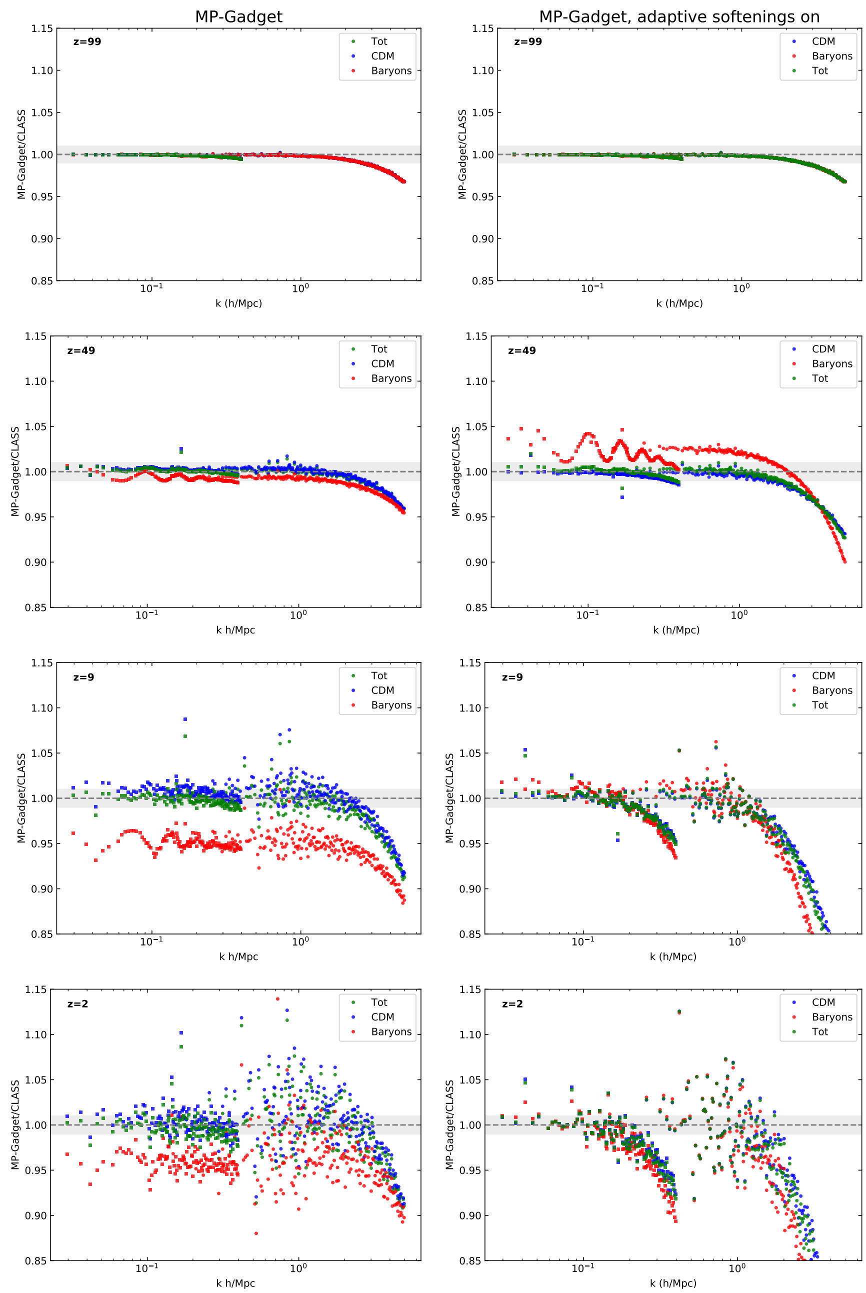

Figure 4: Effect of adaptive softening on 1% growth tests

References

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