Fast generation of ensembles of cosmological N-body simulations via mode-resampling

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Motivation: power spectrum covariance

- Cosmological parameter estimation from surveys of LSS require knowledge of the nonlinear power spectrum covariance.
- Takahashi et al. (2009) use 5000 simulations to estimate the matter power spectrum covariance.
  - Nonlinearity of density field degrades S/N for power spectrum amplitude by $\sim 4$ (Neyrinck & Szapudi 2007, Rimes & Hamilton 2006)
  - PT or HM not accurate enough
- “Beat–coupling” requires independent mocks (Hamilton et al. 2006)
Adding large-scale perturbations
Peak–background split

Related work:
Little, Weinberg, Park (1991)
Tormen & Bertschinger (1996)
Cole (1997)

Two dominant effects of long-wavelength perturbations:

1. sub-volumes expanded or compressed (Zeldovich move)
2. sub-volumes gravitationally evolve with different effective background matter density (time-perturbation)

\[ D(a', \Omega_0) \approx D(a, \Omega_0(1 + \delta_L(x, a))) \]
Full algorithm for adding large-scale modes

1. Generate ICs with zero power for $k < k_{\text{thresh}}$.
2. Run N-body sim., saving snapshots at closely-spaced times and into the future.
3. Draw large–scale Fourier modes from Gaussian distribution.
4. Apply Zeldovich move evaluated at $z = 0$.
5. Use large–scale modes to calculate $x' \rightarrow \Omega'_m \rightarrow a'$.
6. Use saved snapshots to find particle positions at $a'$. 
Nonlinear power spectrum recovery

(a) SCDM

(b) $\Lambda$CDM
Power spectrum covariance estimates

\[ \text{var}(P(k)) = (2P_{\text{lin}}^2(k) N_k) \]

- \( k \ [h/\text{Mpc}] \)
- Computations:
  - Takahashi et al.
  - 20 simulations
  - 1 simulation
  - 20 sims., no resamp.

\( k: 0.025 \ [h/\text{Mpc}] \)

\( k: 0.125 \ [h/\text{Mpc}] \)

\( k: 0.225 \ [h/\text{Mpc}] \)

\( k: 0.325 \ [h/\text{Mpc}] \)
Covariance convergence rates

Extrapolating:
~ 385 of our simulations equivalent to 1000 “standard” simulations.
Conclusions

- Method to resample large-scale modes
  - Accurate nonlinear power spectrum
  - Introduce non-zero cross-covariance
- Improve convergence rate of power spectrum covariance estimates.
  - Useful for generating mocks for parameter estimation.
- Apply to rescaling simulations for new input parameters (following Angulo & White 2009)?
- Include dynamical effects from modes larger than the simulation box size?