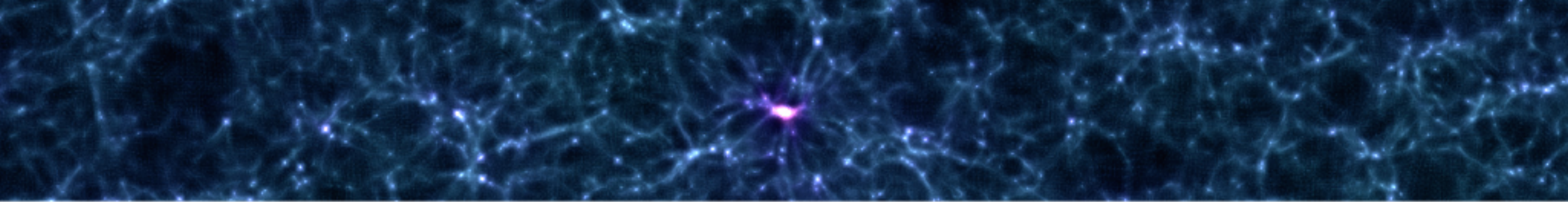

COSMOLOGICAL SIMULATIONS FOR PRECISION COSMOLOGY WITH LARGE GALAXY SURVEYS

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COSMOLOGICAL SIMULATIONS

- Non-linear regime of matter collapse
- Many applications in precision cosmology:
  - Prediction of observables
  - Covariance estimation
  - Mock galaxy catalogs
- Computational cost:
  - Number of simulations
  - Volume
  - Optimisation of codes

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PAIRED AND FIXED SIMULATIONS

- Suppress variance arising from mode sampling at large scales
- 2 simulations in which the initial Fourier modes
  - are exactly out of phase
  - their amplitudes are fixed to the ensemble average power spectrum

COSMOLOGICAL SIMULATIONS - INITIAL CONDITIONS

Gaussian field

$$\delta(\vec{x}) = \frac{1}{(2\pi)^3} \int d^3k \sqrt{P(k)} \lambda_{\vec{k}} e^{i\vec{k}\cdot\vec{x}}$$

$$\Pr(|\lambda(\vec{k})|, \theta) = \frac{|\lambda(\vec{k})|}{\pi} \exp(-|\lambda(\vec{k})|^2)$$

Independence condition

$$\langle \lambda_{\vec{k}_1} \lambda^*_{\vec{k}_2} \rangle = (2\pi)^3 \delta^3_D(\vec{k}_2 - \vec{k}_1)$$

Reality condition

$$\lambda^*_{\vec{k}} = \lambda_{-\vec{k}}$$

COSMOLOGICAL SIMULATIONS - FIXED INITIAL CONDITIONS

$$\delta(\vec{k}) = \sqrt{P(\vec{k})}\exp(i\theta)$$

Fixed amplitude

$$\Pr(|\lambda(\vec{k})|, \theta) = \frac{1}{2\pi}\delta_D(|\lambda(\vec{k})| - 1)$$

Independence condition

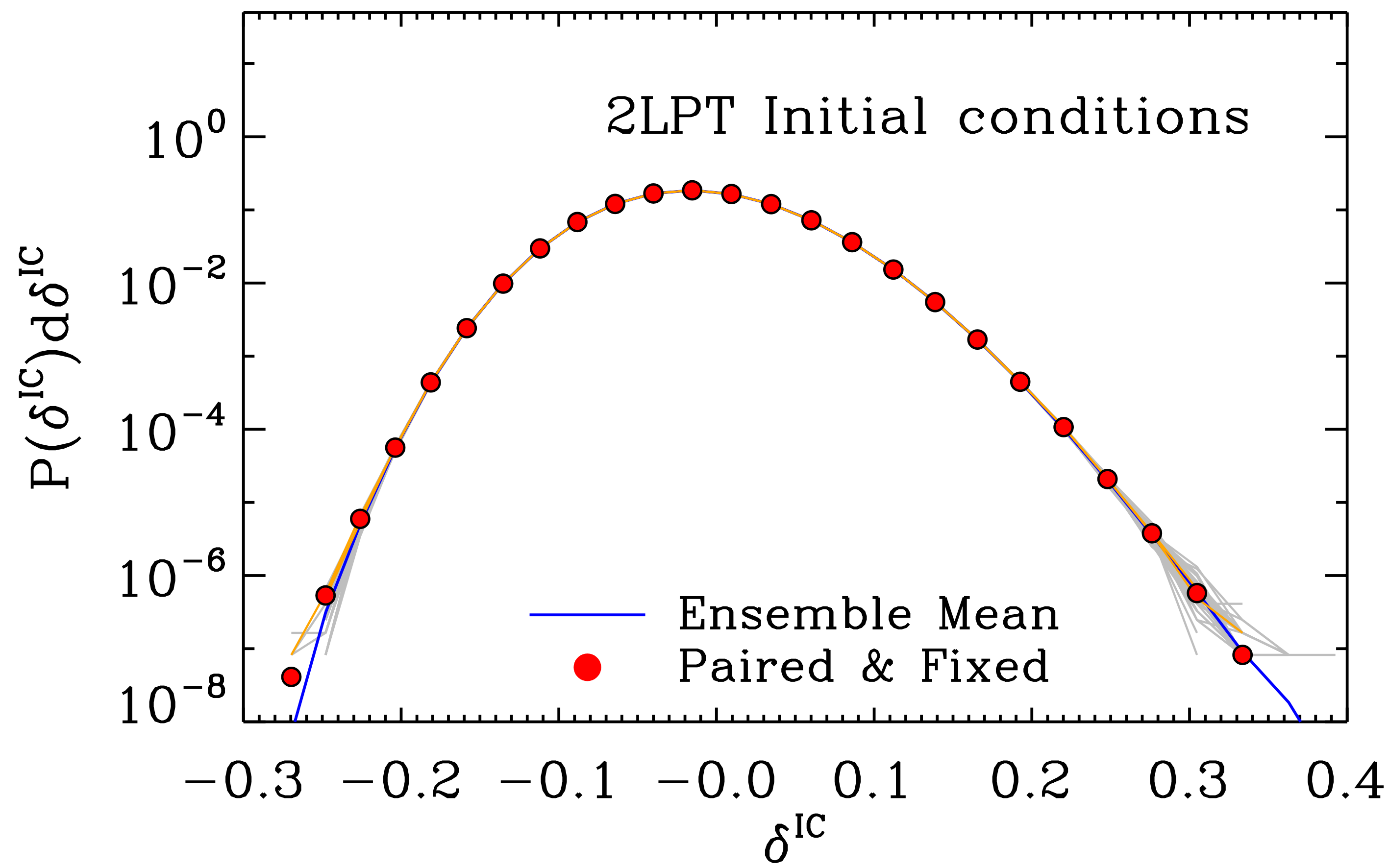
$$\langle \lambda_{\vec{k}_1} \lambda^*_{\vec{k}_2} \rangle = (2\pi)^3 \delta^3_D(\vec{k}_2 - \vec{k}_1)$$

Reality condition

$$\lambda^*_{\vec{k}} = \lambda_{-\vec{k}}$$

FIXED INITIAL CONDITIONS

- Destroy gaussianity of the density field
- In practice very small differences in the pdf

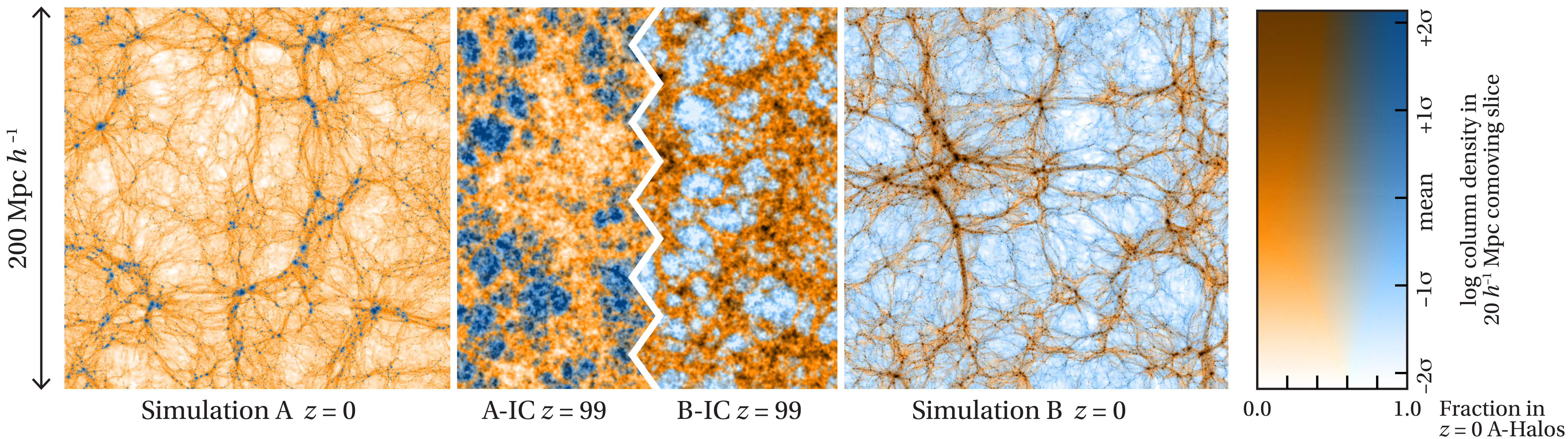


Angulo & Pontzen 2016

PAIRED INITIAL CONDITIONS

$$\delta(\vec{k}) = \sqrt{P(\vec{k})}\exp(i\theta)$$

$$\theta \rightarrow \theta + \pi$$



Pontzen et al. 2016

PAIRED INITIAL CONDITIONS

Pairing partially cancels sample variance

$$\tilde{P}(k) \simeq \frac{1}{N_k} \sum_{i \in S_k} \left(\delta^*_{i,L} \delta_{i,L} + G_{ijk} \left(\delta^*_{j,L} \delta^*_{k,L} \delta_{i,L} \right) + \text{c.c.} + \cdots \right)$$

since $\langle \tilde{P}(k) \rangle = P_L(k) + \cdots$

$$\tilde{P}(k)_{\text{corr},1} = \tilde{P}_{AA}(k) + P_L(k) - \tilde{P}_{LL}(k)$$

$\tilde{P}(k)_{\text{corr},1} - \langle \tilde{P}(k) \rangle$ is third order in δ

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since $\langle \tilde{P}(k) \rangle = P_L(k) + \cdots$

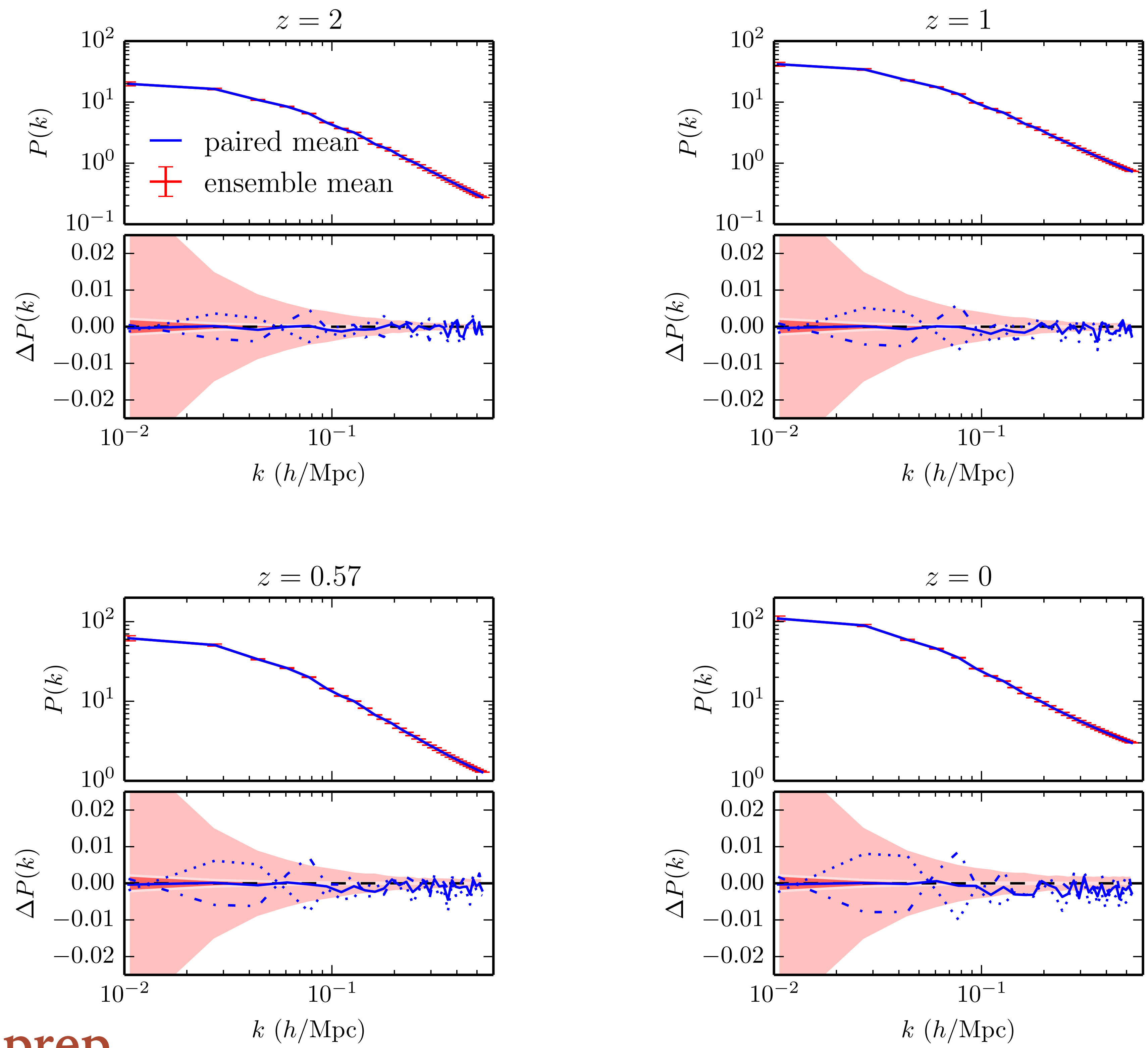
$$\tilde{P}(k)_{\text{corr},2} = \frac{1}{2} \left(\tilde{P}_{AA}(k) + \tilde{P}_{BB}(k) \right) + P_L(k) - \tilde{P}_{LL}(k)$$

$\tilde{P}(k)_{\text{corr},2} - \langle \tilde{P}(k) \rangle$ is fourth order in δ

MINERVA SIMULATIONS

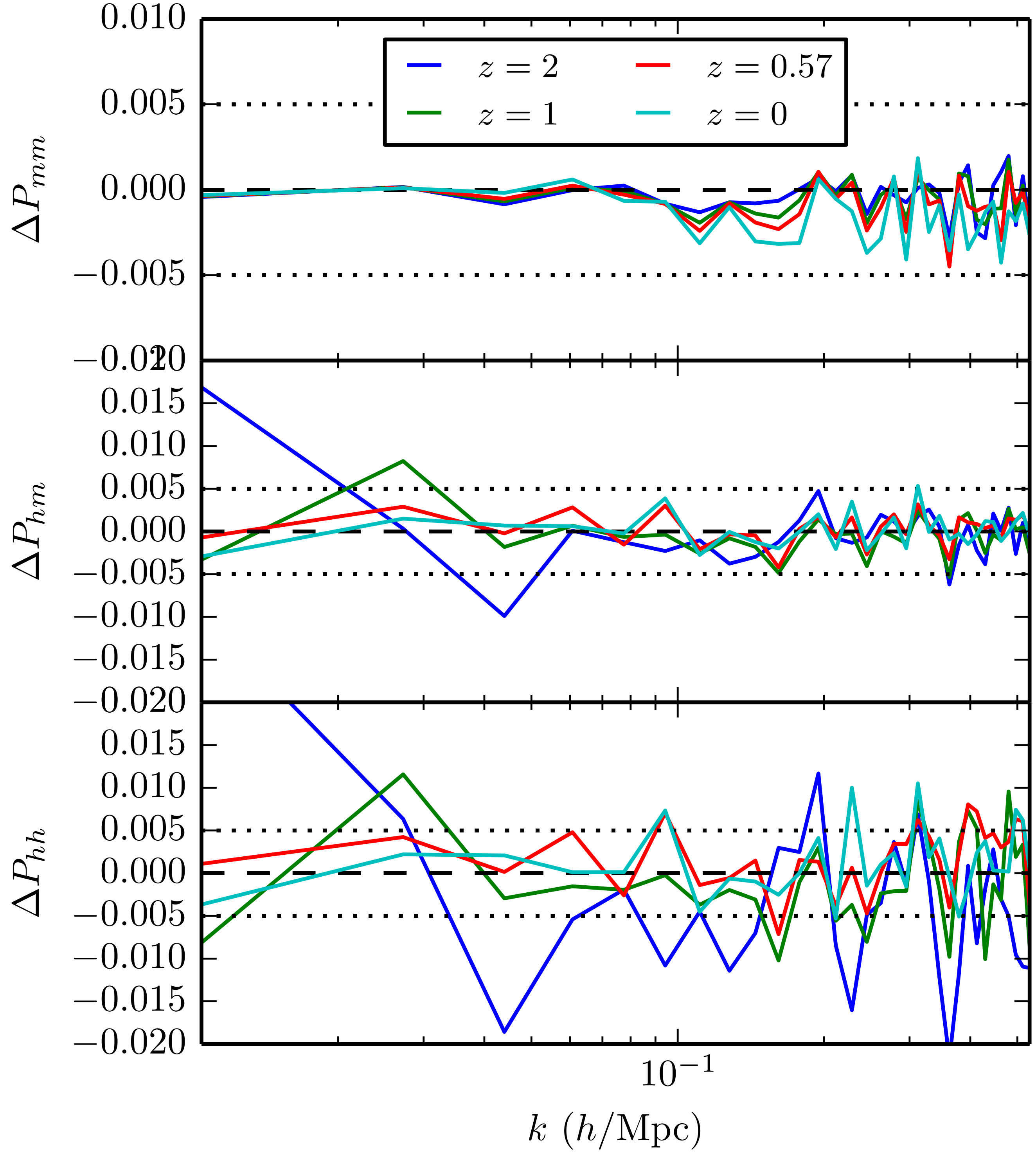
- 300 Gadget simulations
- 1000^3 particles 1500 Mpc/h box
- mass resolution: 2.67e11 $M_\odot$/h
- WMAP9 + BOSS DR9 cosmology (Sanchez et al. 2013)
- SUBFIND halos above 40 particles, i.e. 1.07e13 $M_\odot$/h

PAIRED AND FIXED SIMULATIONS – DARK MATTER



Blot et al. in prep.

PAIRED AND FIXED SIMULATIONS - HALOS



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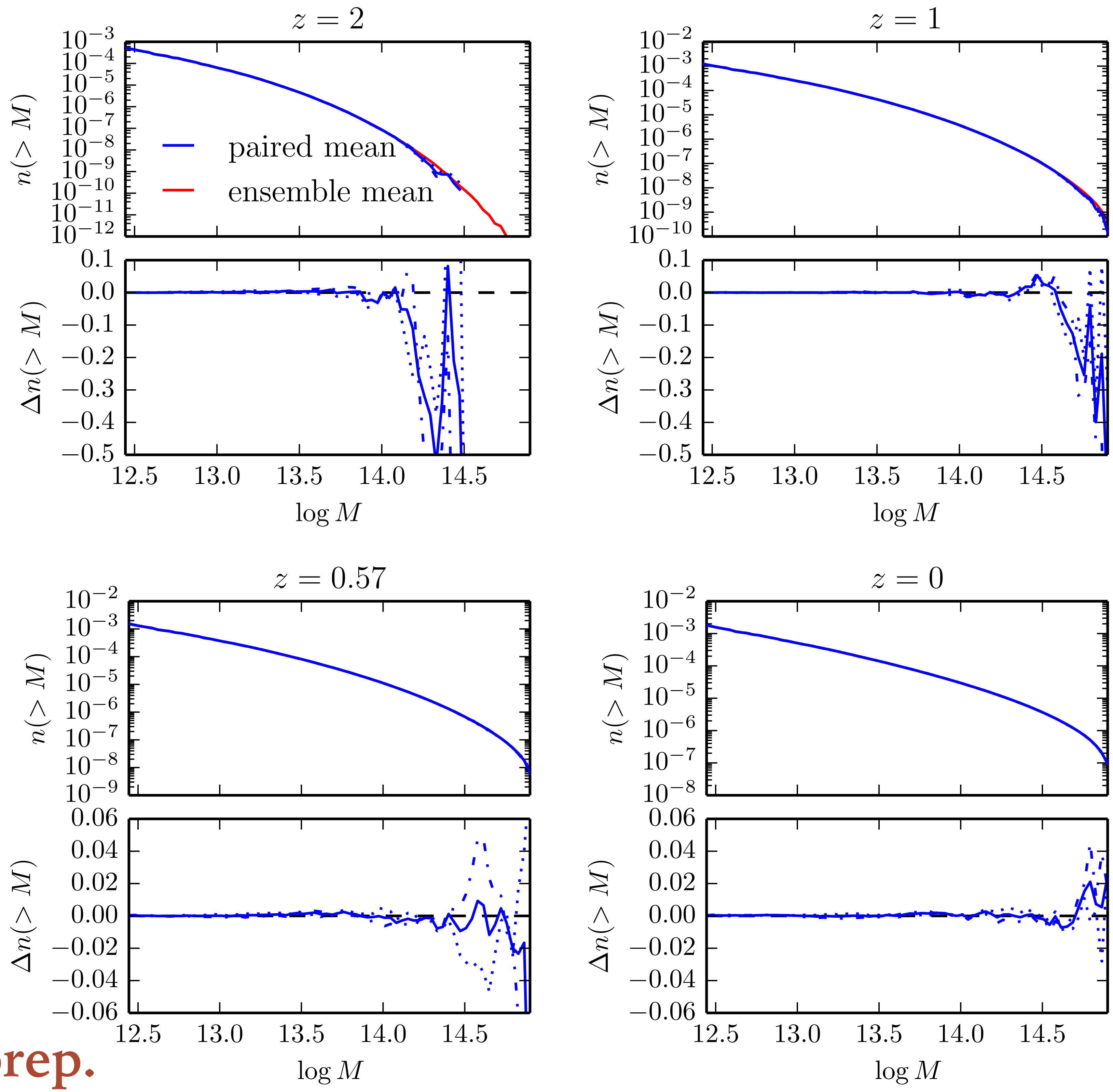

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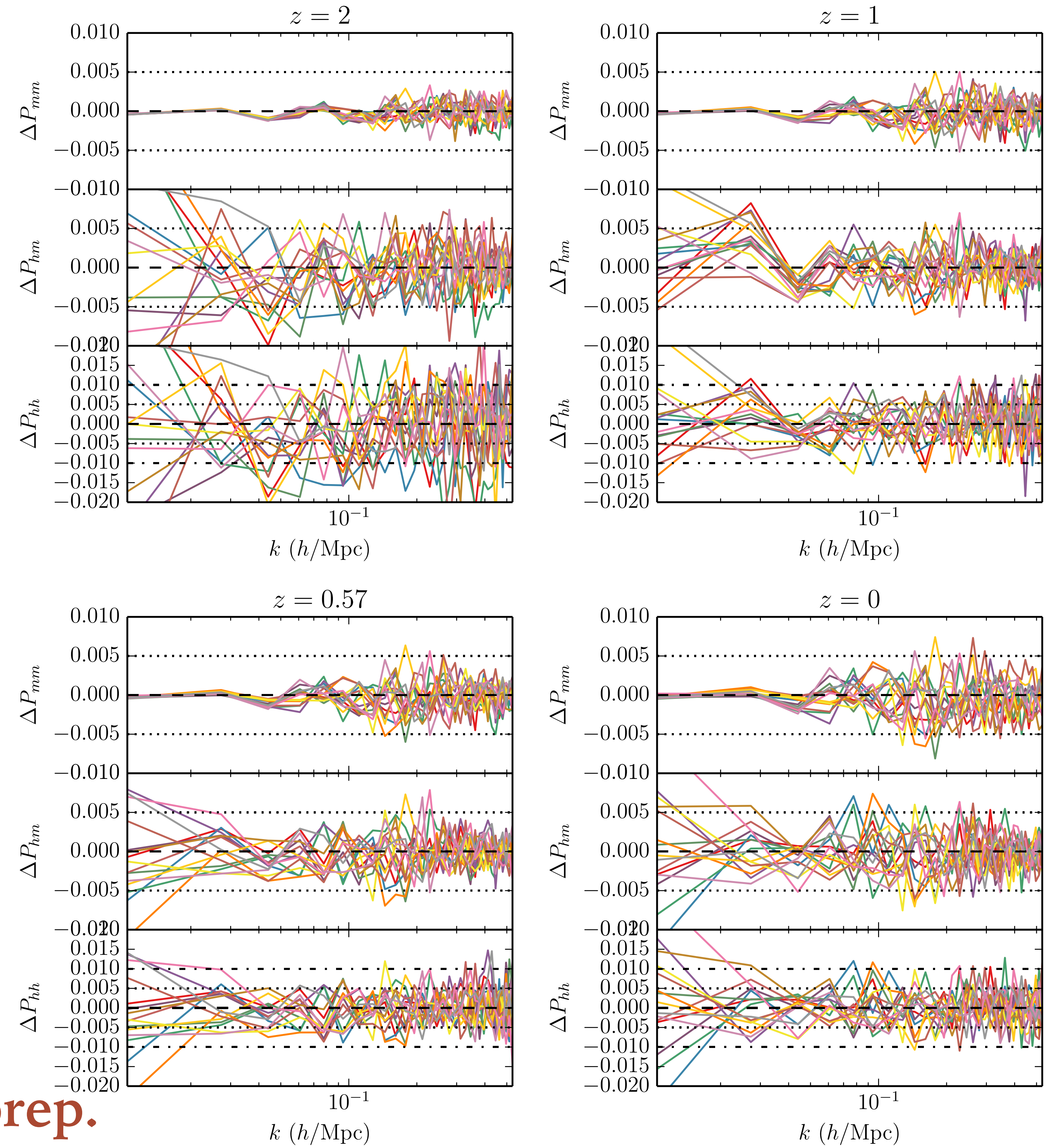

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PAIRED AND FIXED SIMULATIONS - ERROR

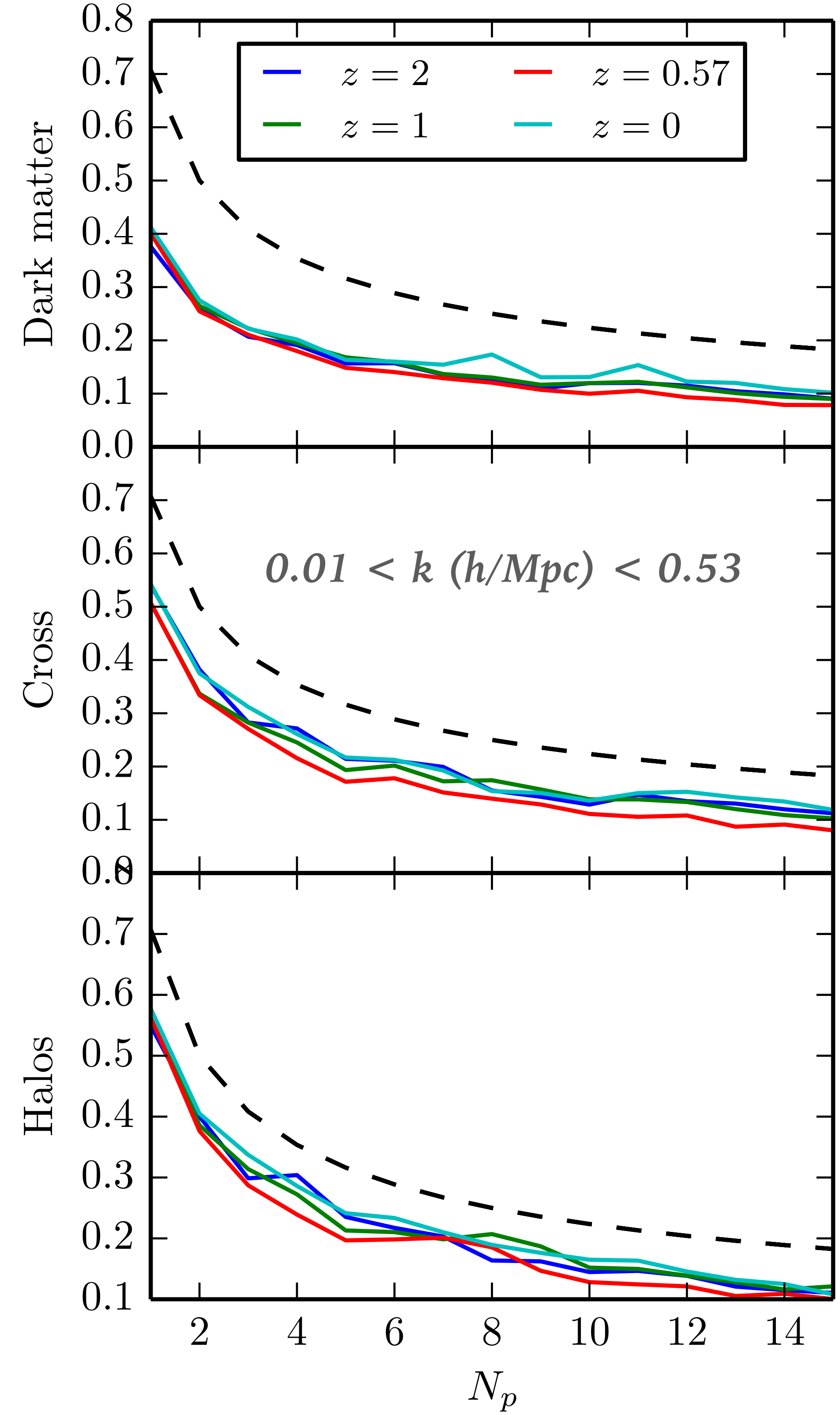
- Divide the 15 pairs in N_g groups of N_p pairs
- Variance averaged over k-range **Δ**

$$\sigma^2(N_p) = \frac{1}{N_{k_i}(N_g - 1)} \sum_{k_i \in \Delta} \sum_{j=1}^{N_g} (\bar{\hat{P}}_j(k_i) - \bar{P}(k_i))^2$$

- Relative error

$$\epsilon_{FP} = \sigma(N_p)/\sigma_{Min}$$

$$\epsilon = 1/\sqrt{2\,N_p}$$



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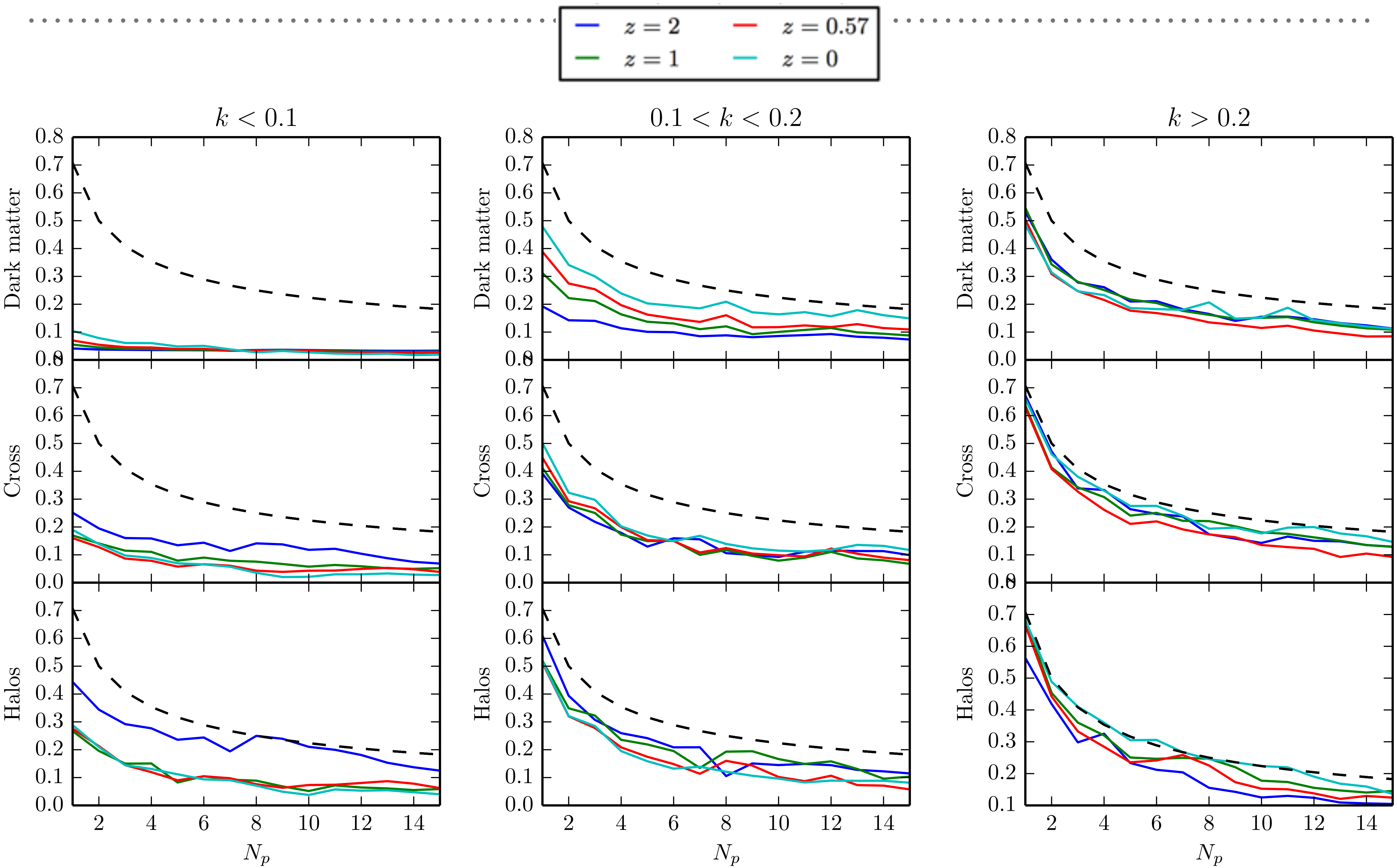

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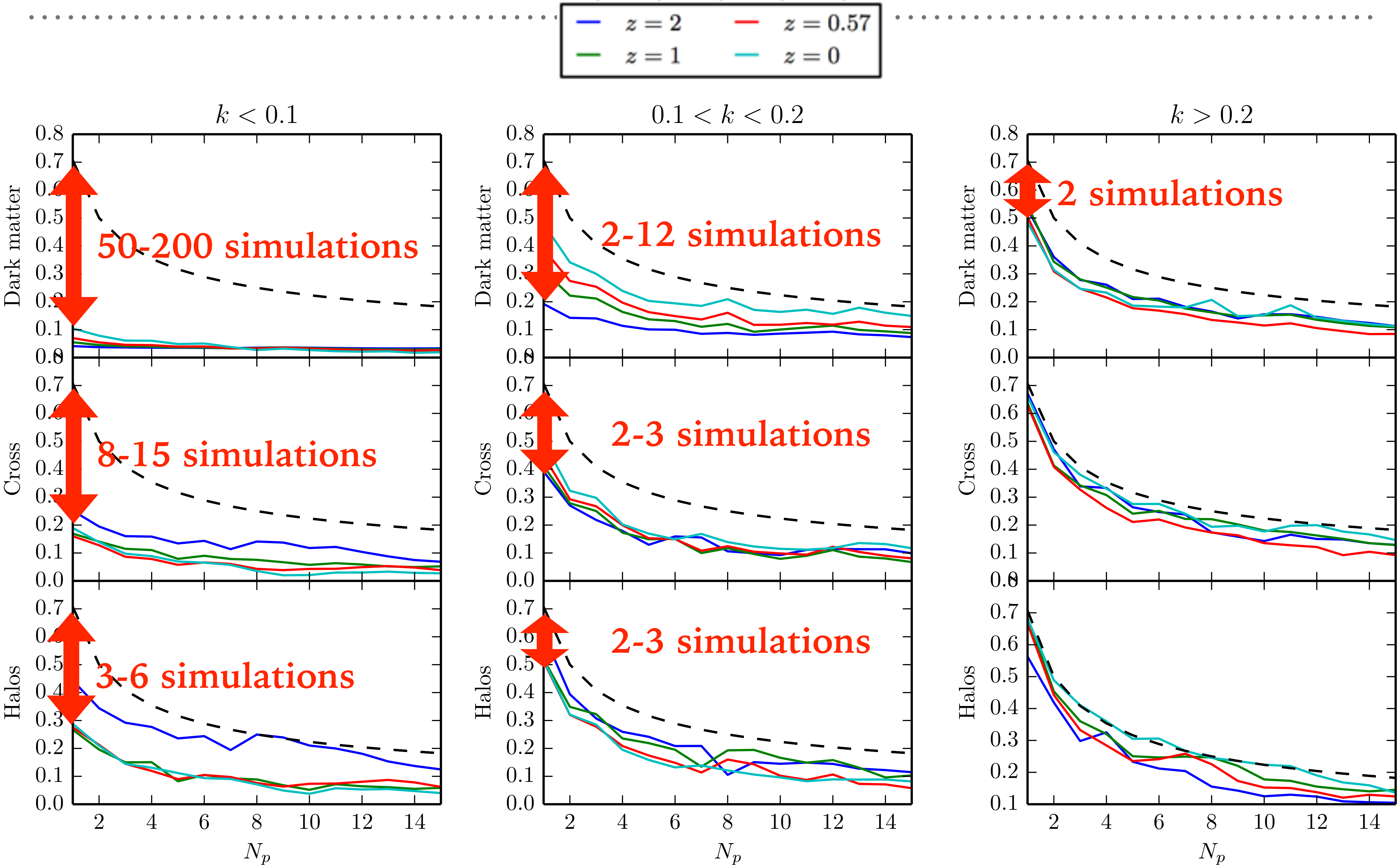

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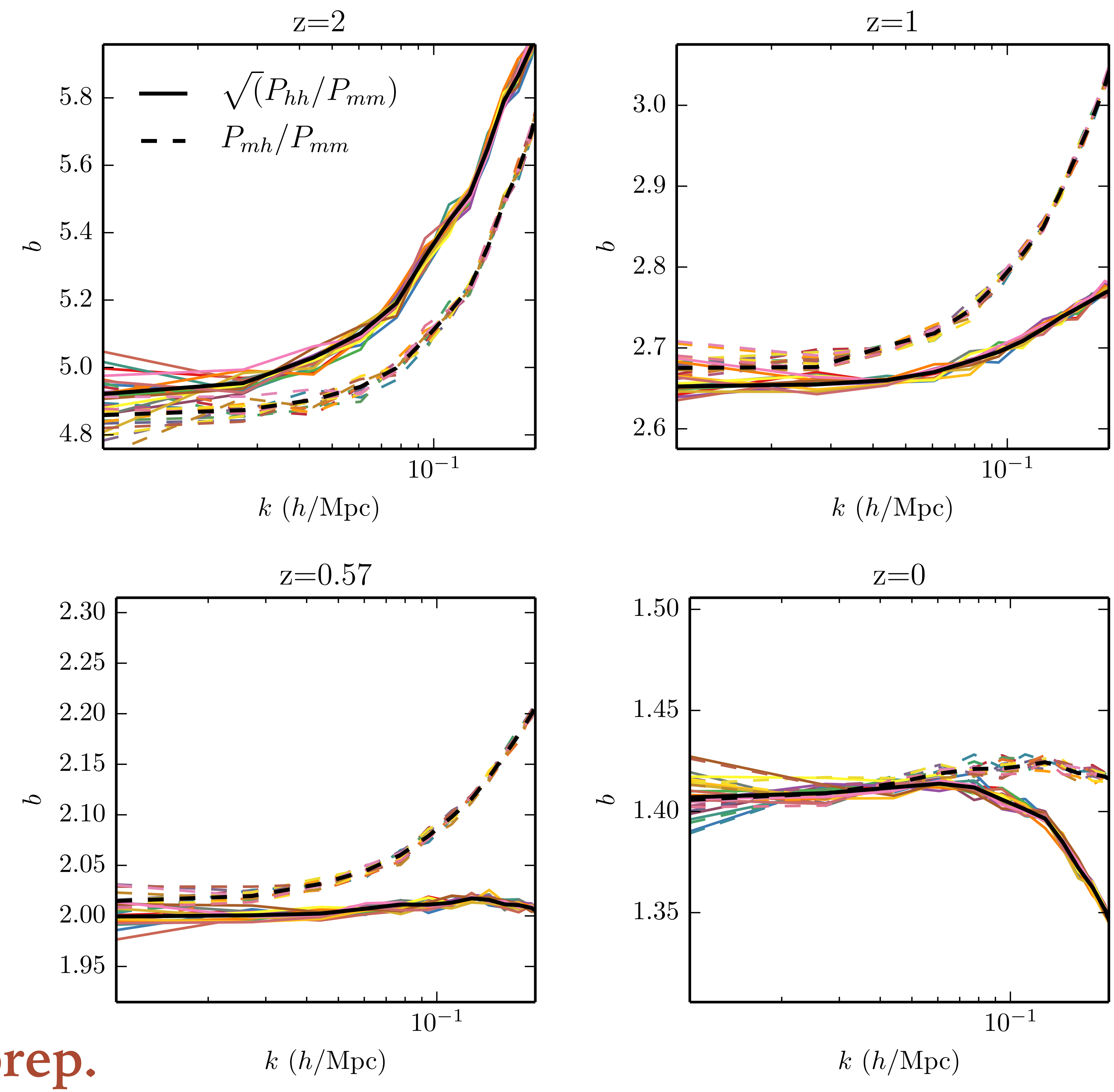
CONCLUSIONS AND FUTURE PROSPECTS

- Promising method to suppress large scale variance
- Understand source of noise in halos
- Galaxy power spectrum
- Show that method does not bias cosmological parameters

BACKUP

PAIRED AND FIXED SIMULATIONS - HALO BIAS



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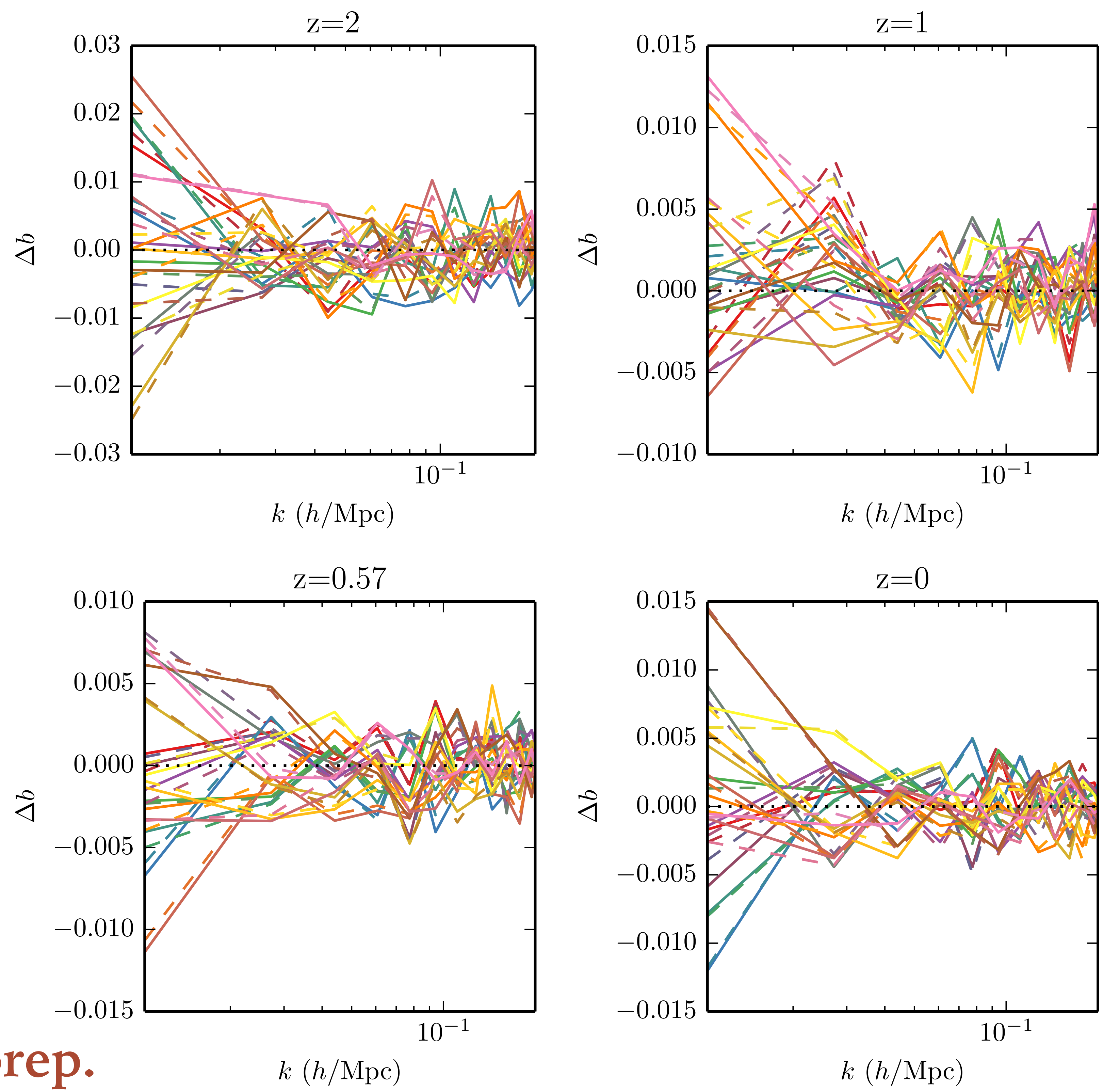

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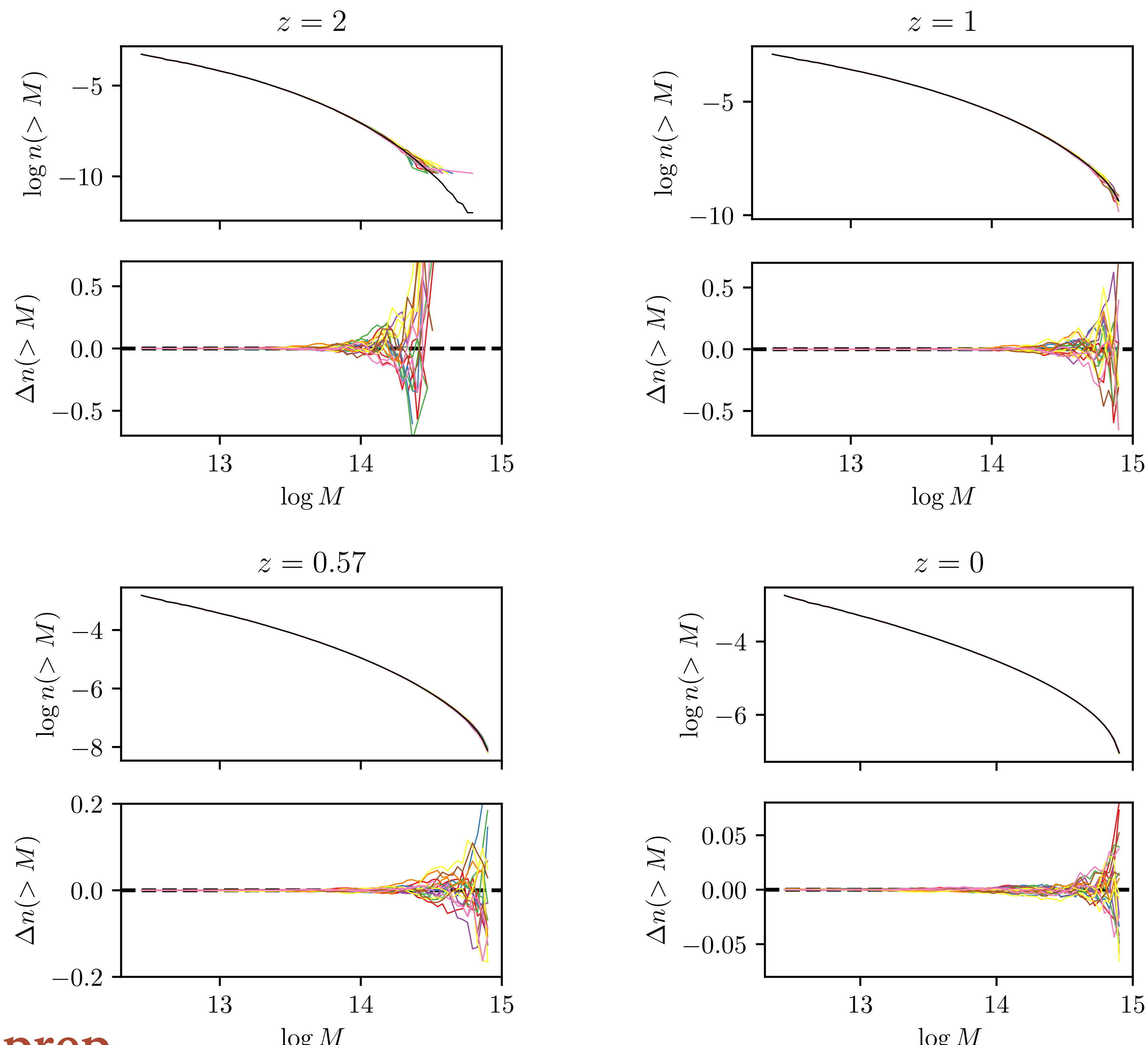
HALO MASS FUNCTION



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