Predicting cosmic variance limited BAO with DEUS-FUR simulation: implication for the Euclid Survey

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Rasera et al. (arXiv:1311.5662)

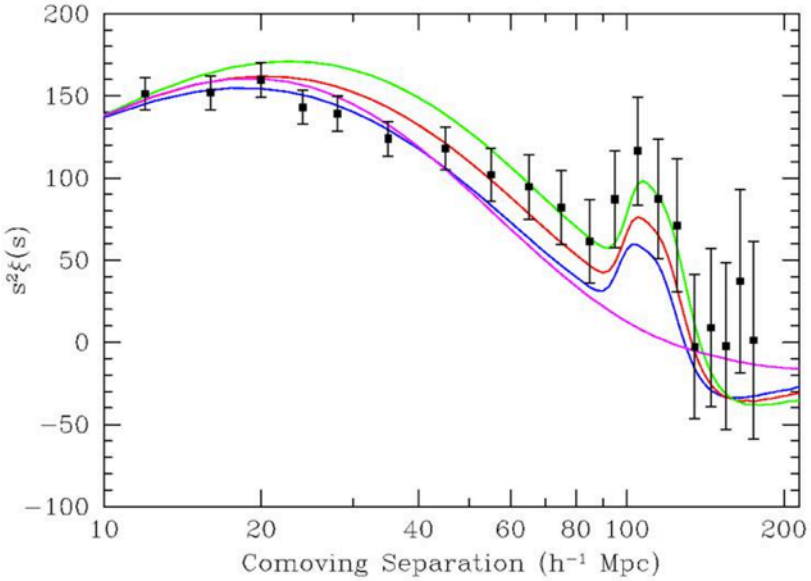
Baryon Acoustic Oscillations

Primeval Acoustic Waves

- Coupled Photon-Baryon Plasma (z > 1000)
- Sound Horizon Scale
- CMB Spectrum

Standard Ruler

- Bump in galaxy 2-pt
- $D_A(z)$ & $H(z)$



Eisenstein et al. 2005

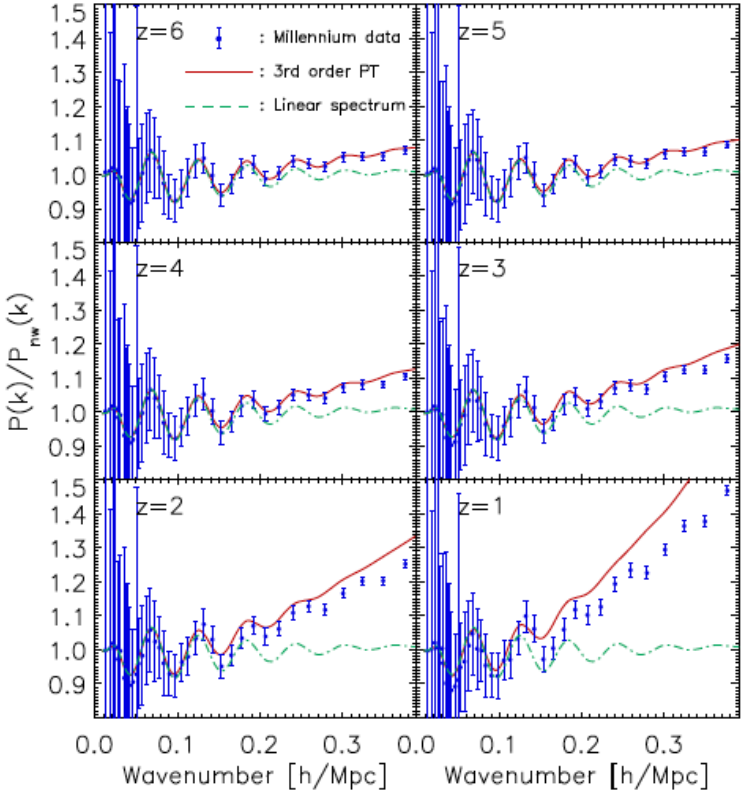
Resolving the BAO Scale

Large Dynamical Range

- ~100 Mpc/h quasi-linear scale at z < 1
- ~10 Mpc/h width

N-body Requirements

- Large Volume (> 1 Gpc)^3
- High Resolution (<10^{12} M_{sun})



Jeong and Komatsu 2008

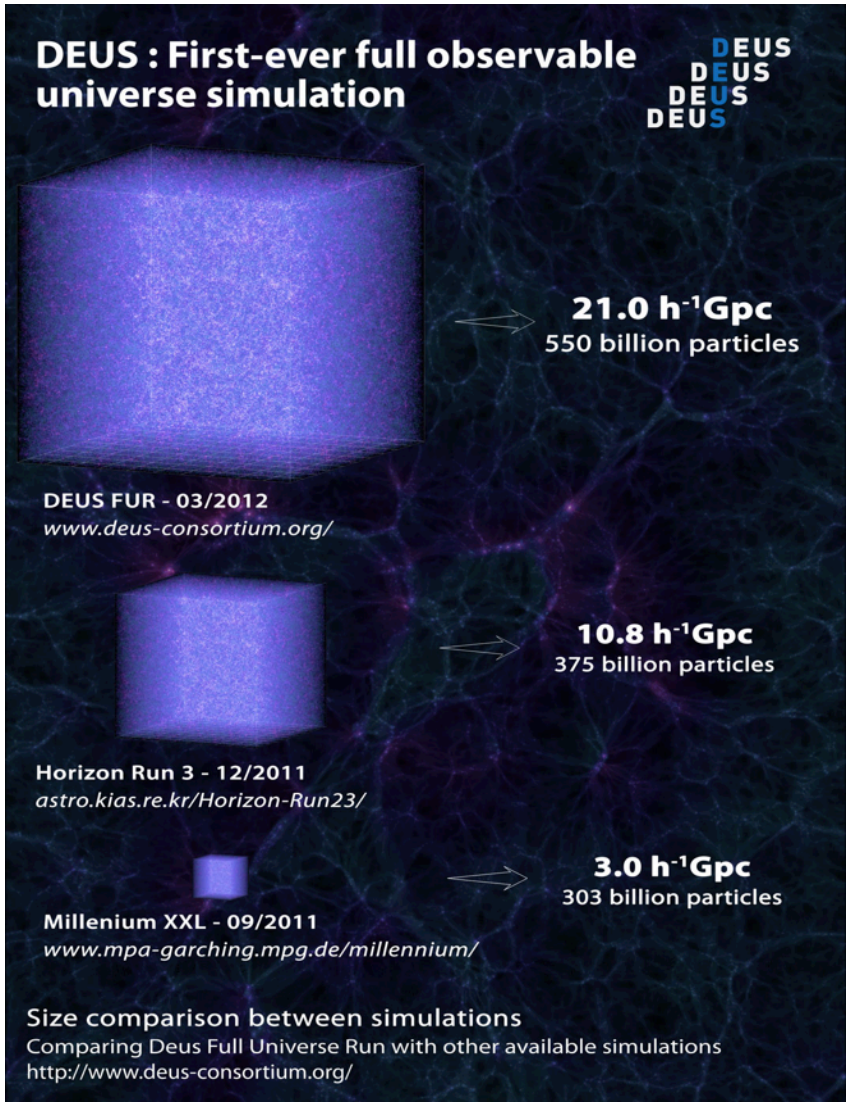
DEUS Full Universe Run

- L_{box} = 21 Gpc/h
- $N_p = 8192^3$
- $M_p = 10^{12}\ M_{sun}$
- Δ_x = 40 kpc/h
- 3 Models:

  LCDM-W7

  RPCDM-W7

  WCDM-W7

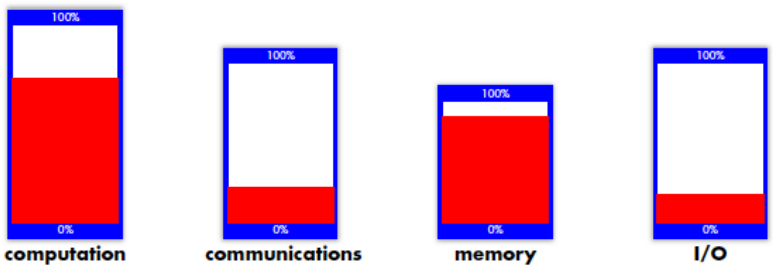


Grand Challenge Simulations

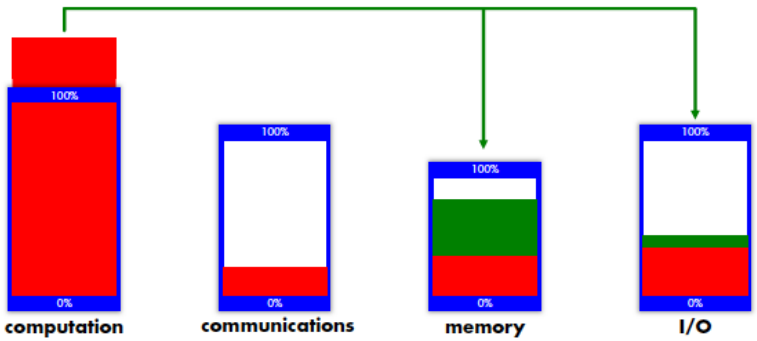
Code Architecture Performance

Simulation Requirements

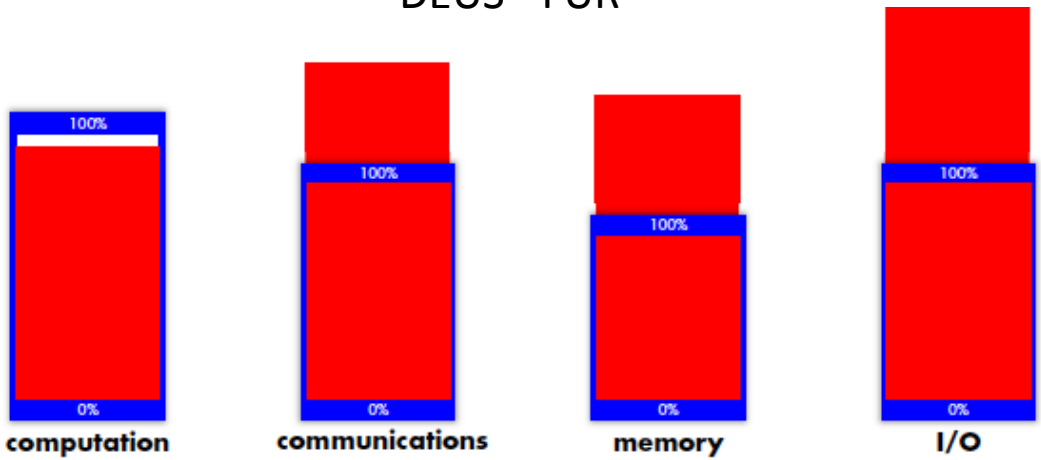
Standard

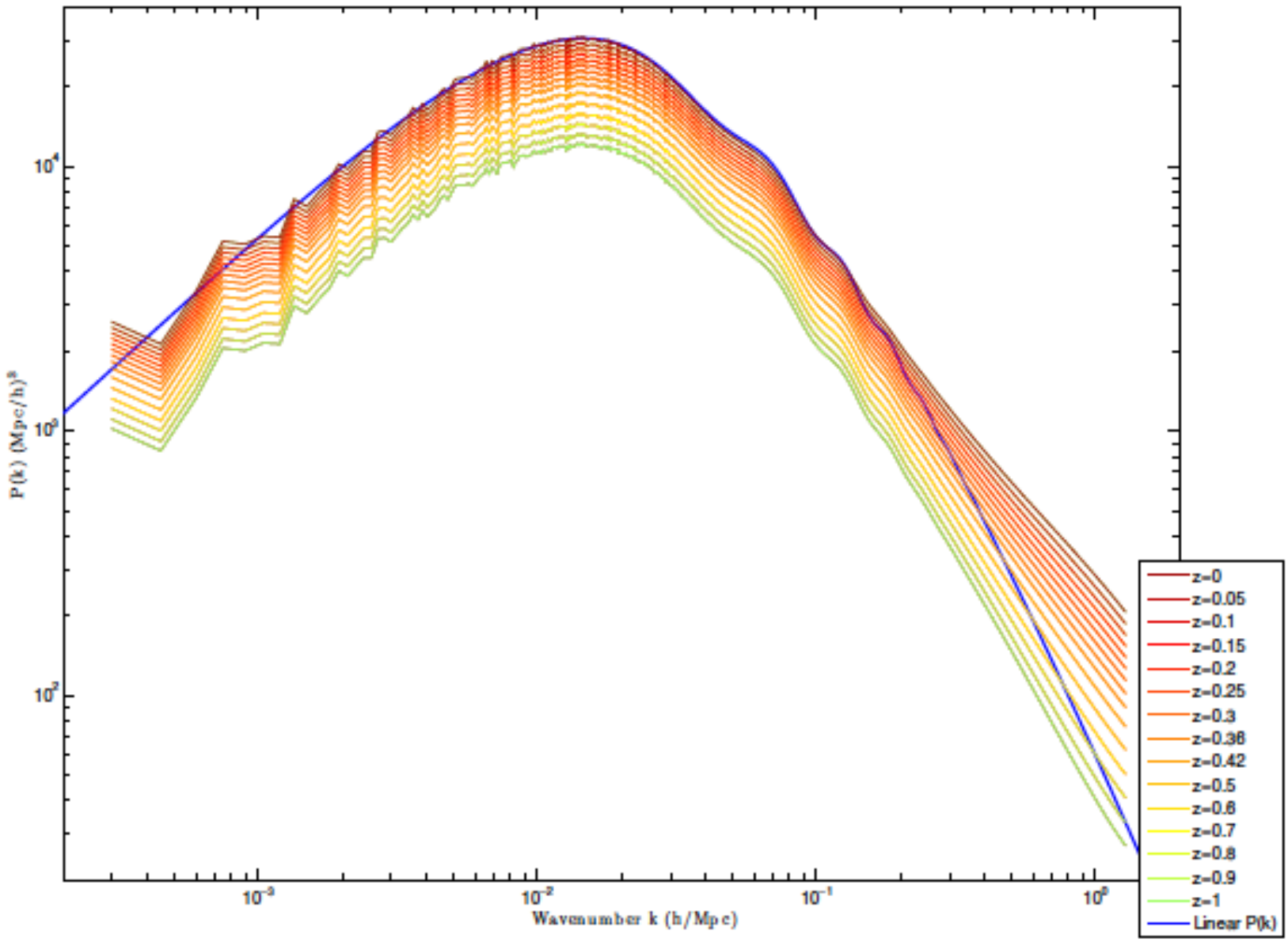


Easy Optimization



DEUS - FUR




P(k) (Mpc/h)³
Wavenumber k (h/Mpc)
z=0
z=0.05
z=0.1
z=0.15
z=0.2
z=0.25
z=0.3
z=0.36
z=0.42
z=0.5
z=0.6
z=0.7
z=0.8
z=0.9
z=1
Linear P(k)

Cosmic Variance Precision

Statistical Errors

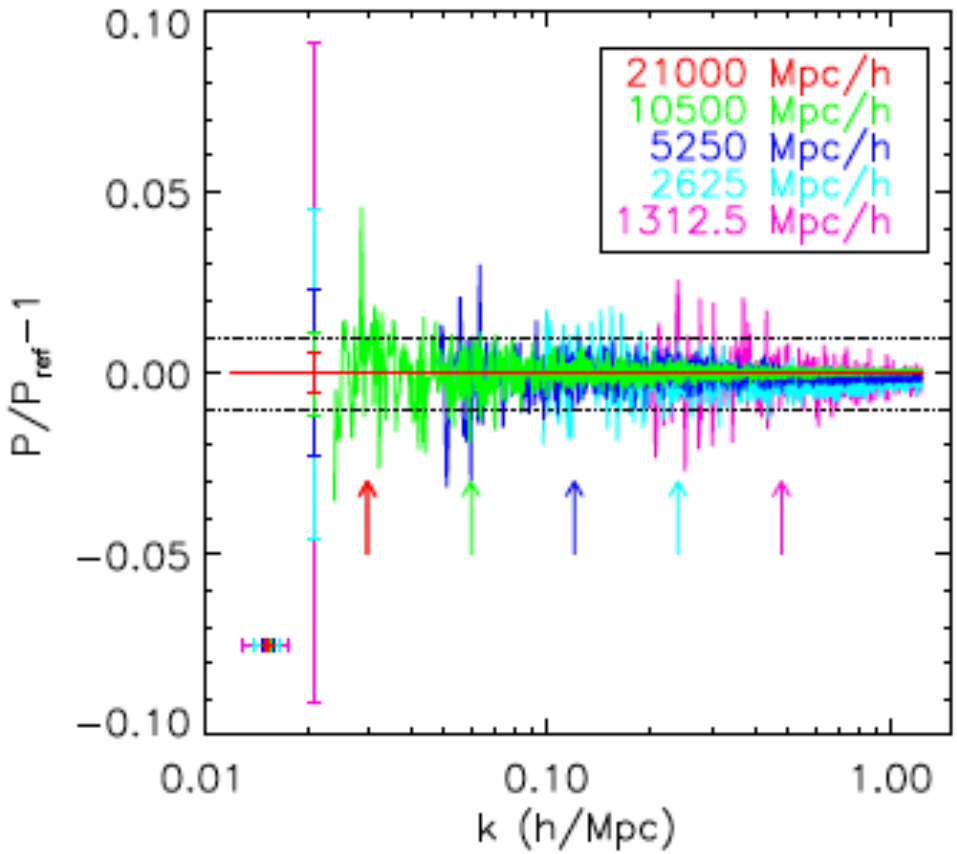
- RMS fluctuations

$$\sigma(k) = \sqrt{\frac{2}{N_k}}\left[P(k) + \frac{1}{N_p}\right]$$

$$\text{with} \quad N_k = \frac{4\pi k^2}{dk^2}$$

- Mode Sampling

$$dk = \frac{2\pi}{L_{box}}$$



We Need Accuracy!

Numerical Systematic Errors

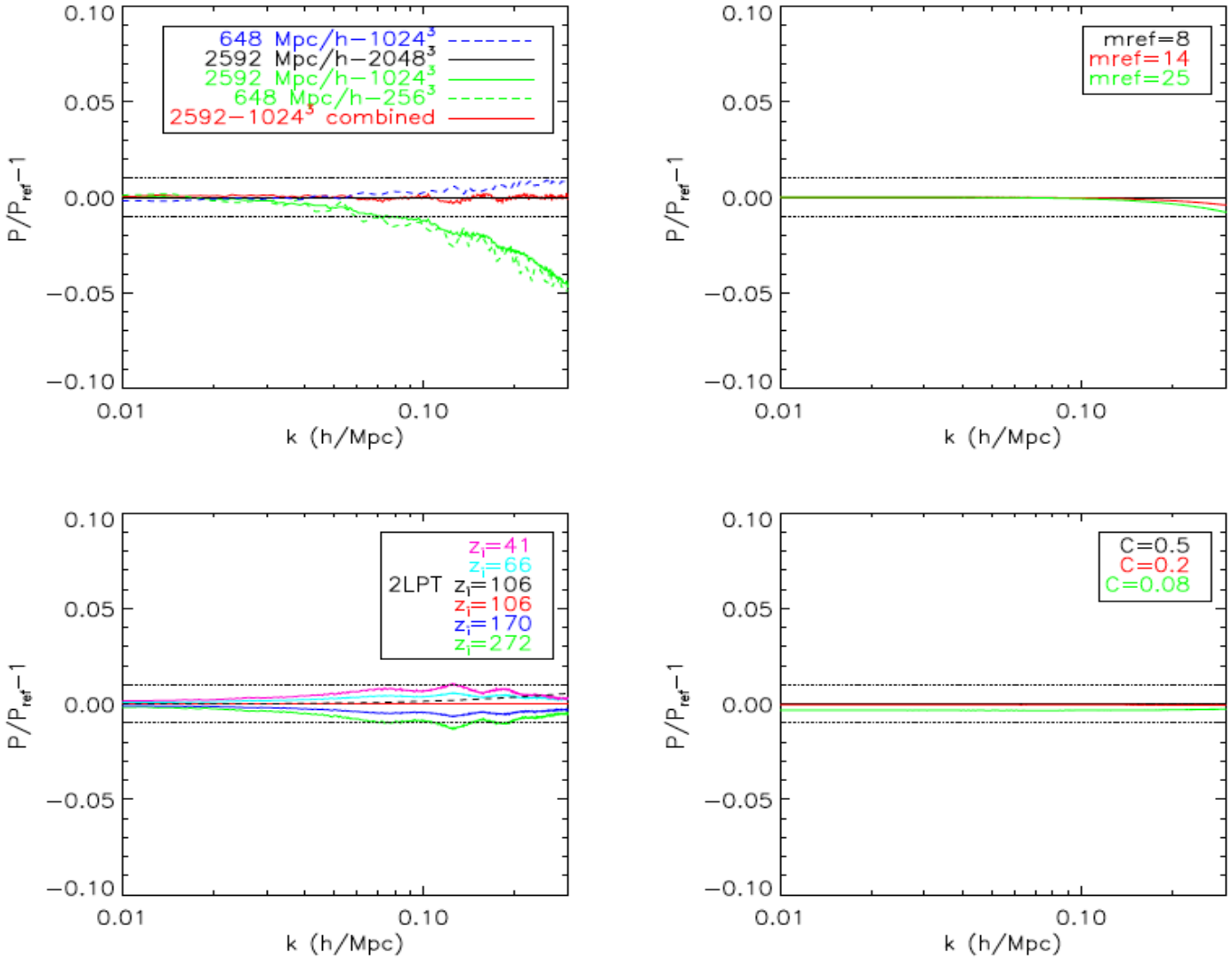
- Mass Resolution
- Refinement
- Initial Conditions
- Time Integration

Simulation Suite

L_{box}	n_x	m_{ref}	z_i	C_{dt}
10500	4096	14	106	0.2
5250	2048	14	106	0.2
2625	1024	14	106	0.2
1312	512	14	106	0.2
5250	2048	8	106	0.2
5250	2048	25	106	0.2
5250	2048	14	106	0.08
5250	2048	14	106	0.5
5250	2048	14	272	0.2
5250	2048	14	170	0.2

L_{box}	n_x	m_{ref}	z_i	C_{dt}
5250	2048	14	66	0.2
5250	2048	14	41	0.2
2592	2048	8	56	0.5
2592	1024	8	56	0.5
648	1024	8	93	0.5
648	512	8	93	0.5
648	256	8	93	0.5
2625	1024	14	106*	0.2
5250	2048	14	106**	0.2

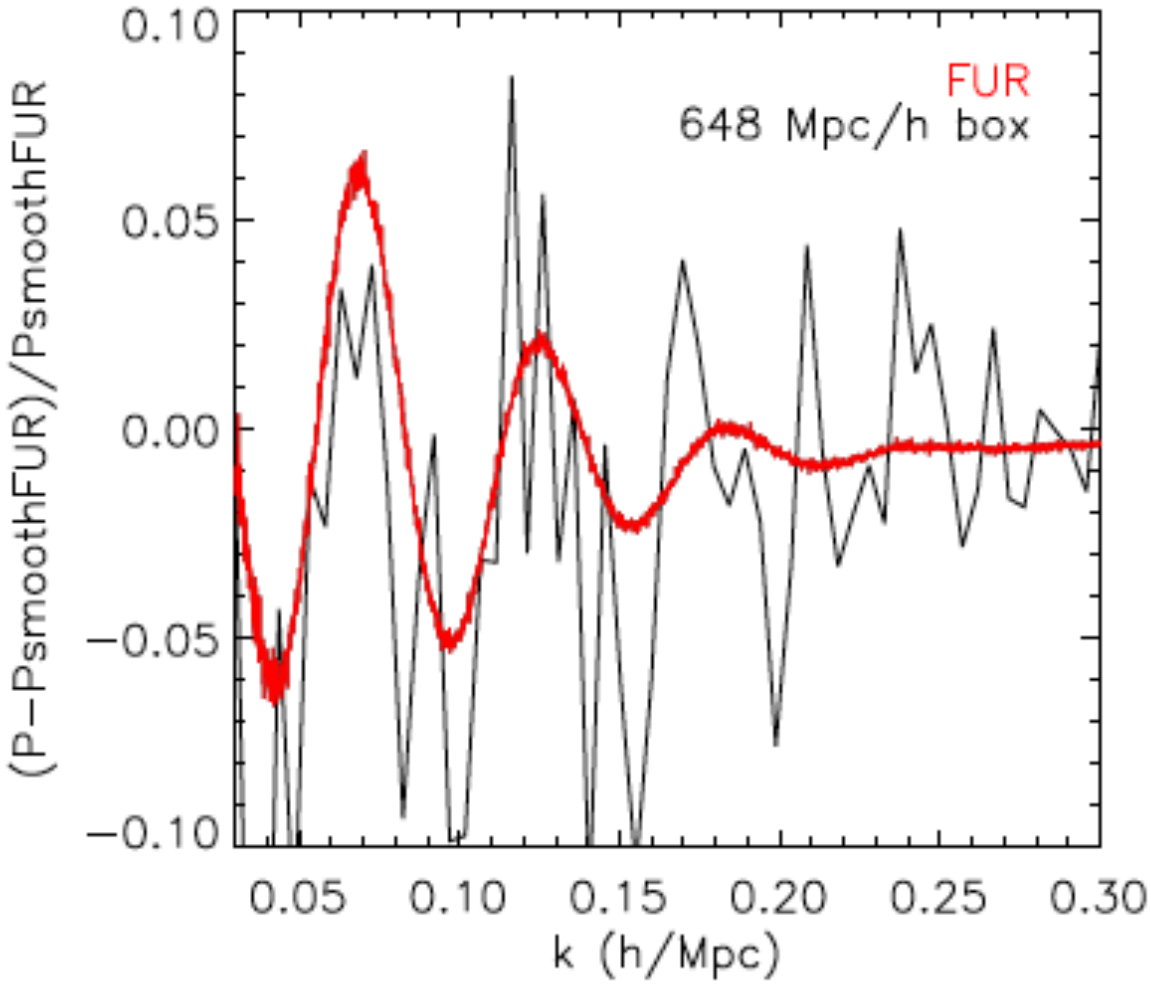
1% Accuracy Interval



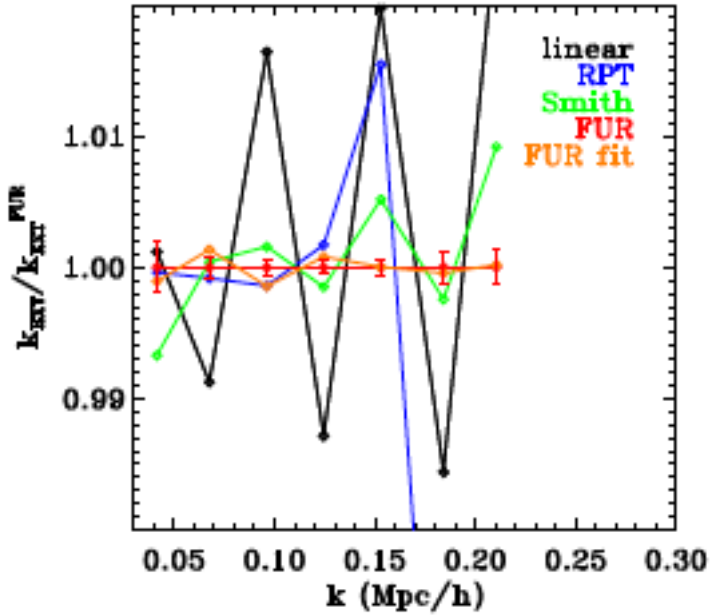
BAO Spectrum

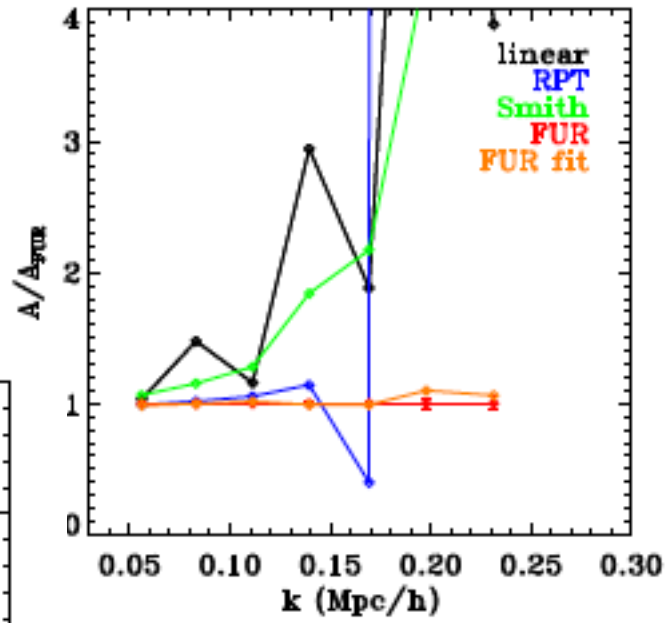
- $0.03 < k < 0.3$
- $P_{smooth}(k)$

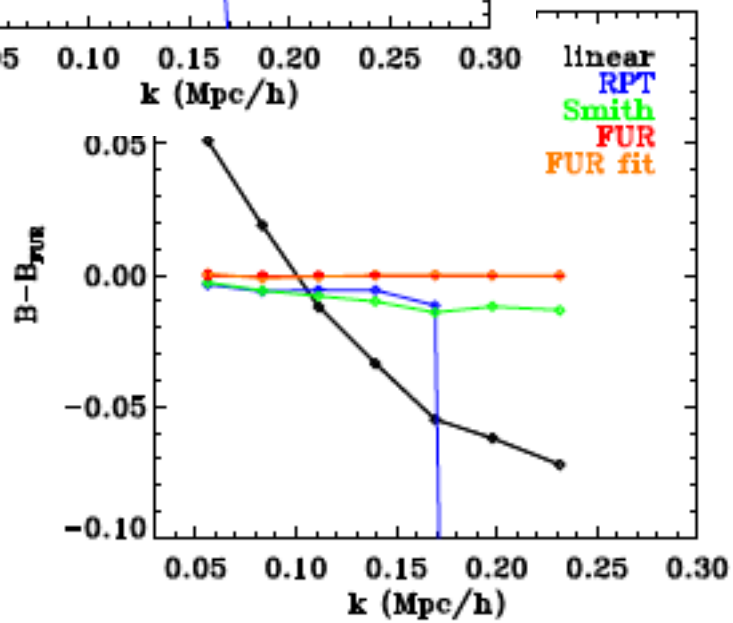
N-body evolved
Hu & Eisensten
wiggle-free Initial
Conditions



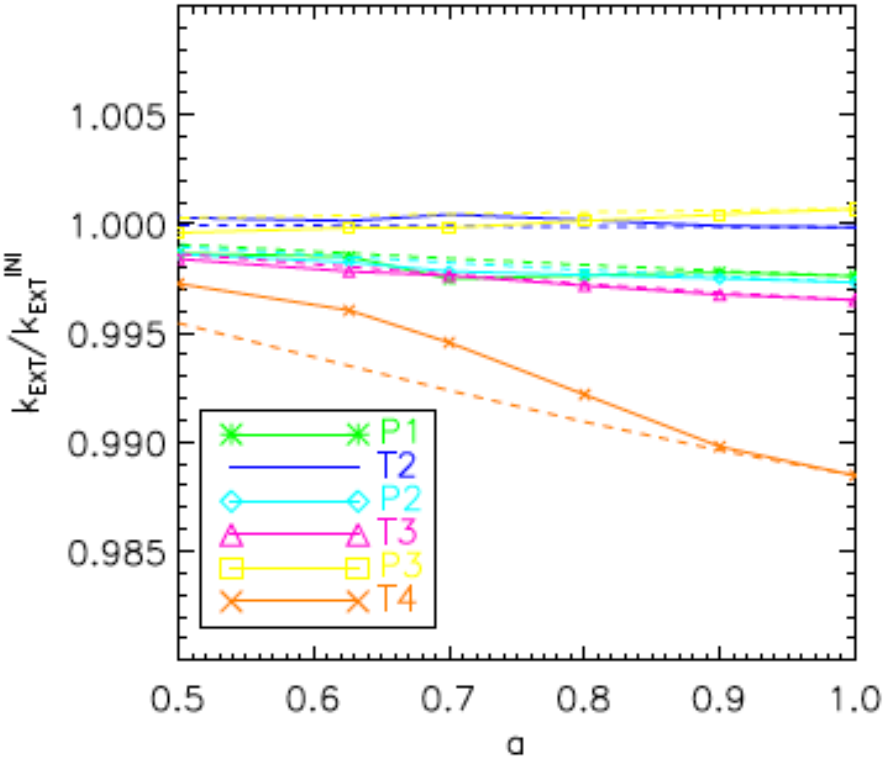
Shift, Damping and Coupling

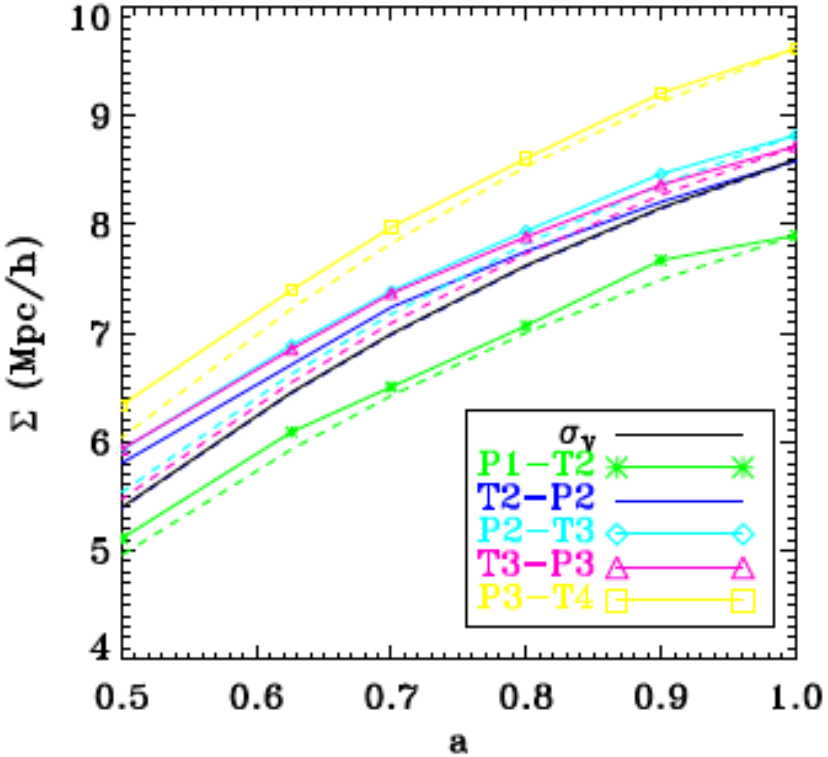






BAO Shift and Amplitude





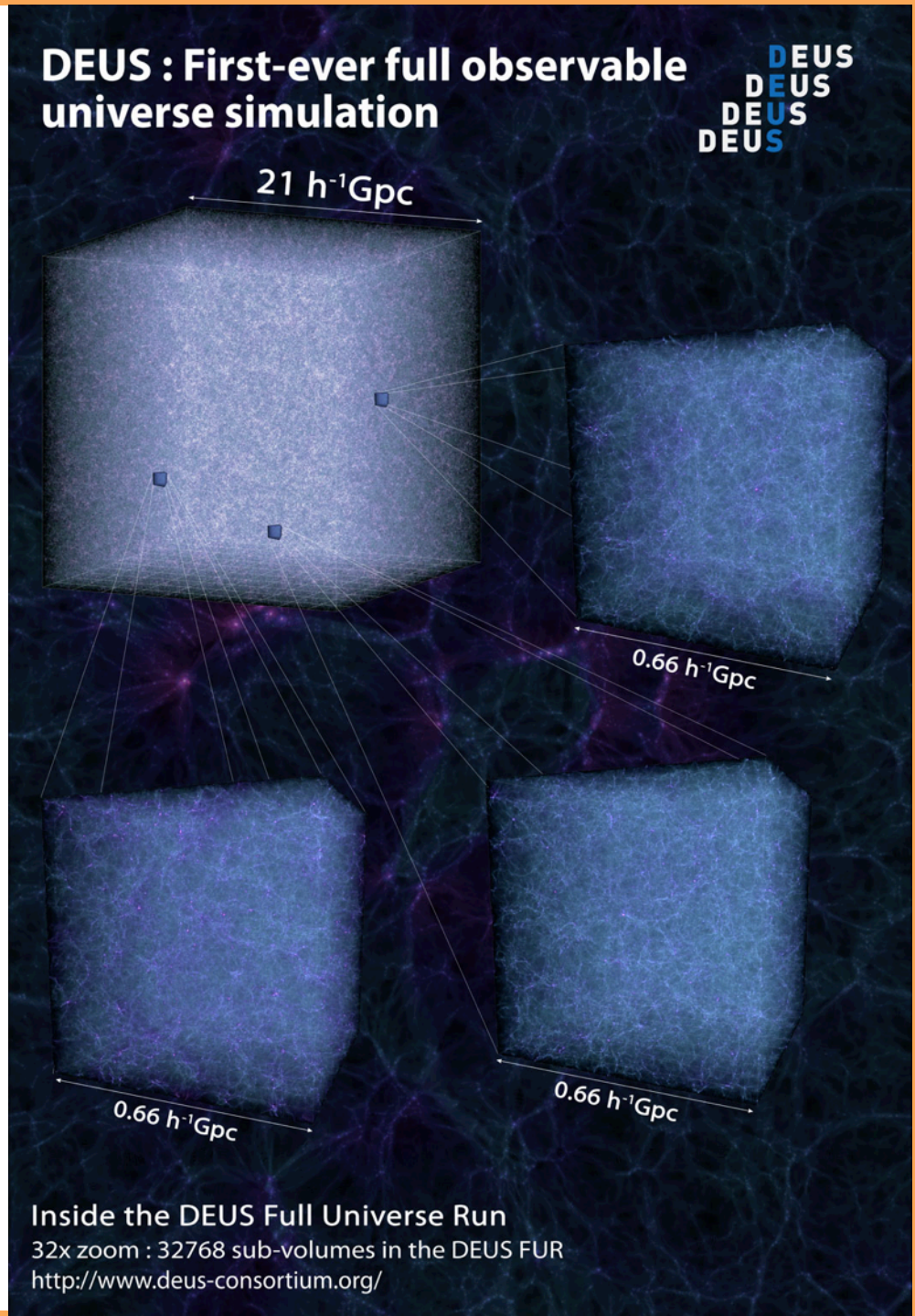
We nailed the mean, how about covariance?

DEUS-PUR

#-12288 Simulations
$N=256^3$ L=648 Mpc/h
$m_p \sim 10^{12} M_{sun}$

#-512 Simulations
$N=512^3$ L=1.3 Gpc/h
$m_p \sim 10^{12} M_{sun}$

#-128 Simulations
$N=1024^3$ L=648 Mpc/h
$m_p = 1.8 \times 10^{10} M_{sun}$

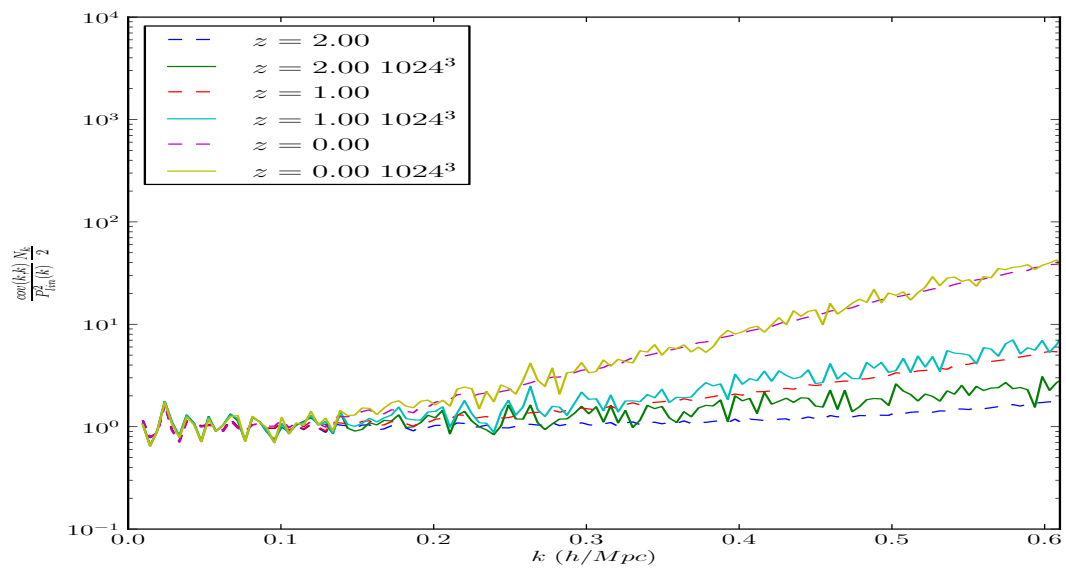


…work in progress

Covariance Matrix

$$\bar{P}(k) = \frac{1}{N_r}\sum_{i=1}^{N_r}\hat{P}_i(k) \qquad \mathrm{cov}(k_1,k_2) = \frac{1}{N_r - 1}\sum_{i=1}^{N_r}\left[\hat{P}_i(k_1) - \bar{P}(k_1)\right]\left[\hat{P}_i(k_2) - \bar{P}(k_2)\right]$$

- Mass resolution dependence
- S/N
- Parameter Estimation



Blot et al. (in preparation)

Conclusion

- Cosmic variance limited predictions and optimal mode sample
- Control of numerical systematics is crucial
- 1% accurate predictions are very challenging
- Covariance Matrix equally difficult

How to Improve

- To get 1% accuracy from BAO scale to k=5 h / Mpc

$N_p = 32768^3$

$L_{box} = 21$ Gpc / h

$M_p \sim 10^{10} M_{sun}$