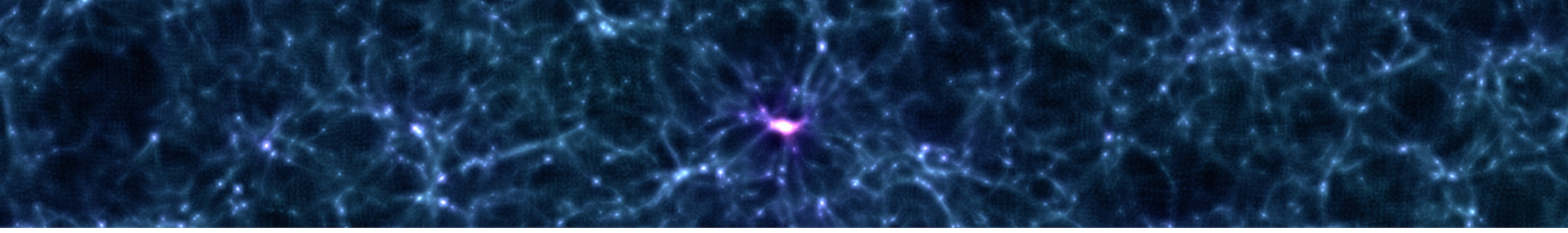


Matter Power Spectrum Covariance Matrix from the DEUS PUR ΛCDM simulations

Mass Resolution and non-Gaussian Errors

arxiv:1406.2713

Linda Blot

in collaboration with:
Pier Stefano Corasaniti, Jean-Michel Alimi, Vincent Reverdy, Yann Rasera

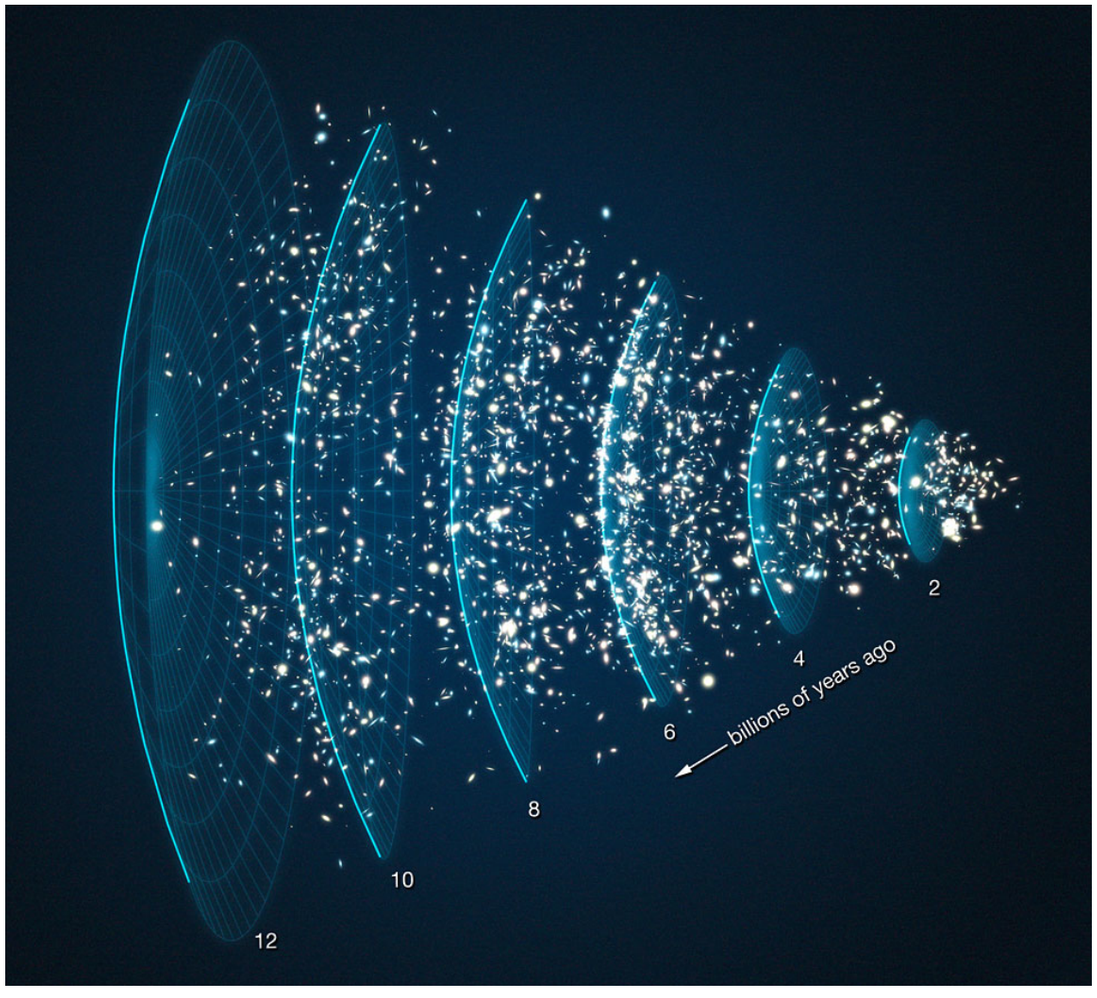
dépasser les frontières

Laboratoire de l'Univers et de ses Théories

Exploring Dark Energy Cosmic Structures

European Research Council
Established by the European Commission

LSS Surveys

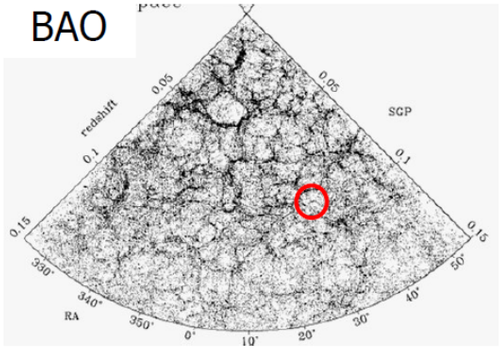


ESO/L. Calçada/ESO-GOODS team

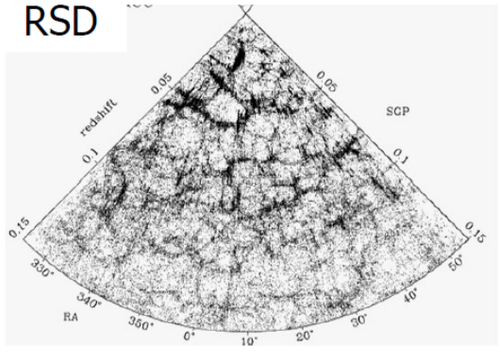
BAO, RSD and WL over 15,000 deg^2

50 million galaxies with redshifts

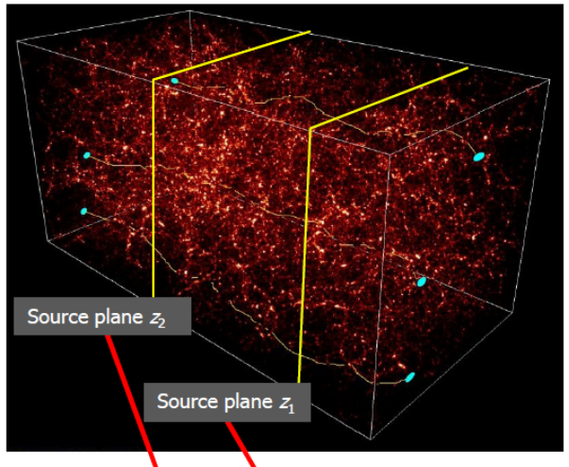
BAO

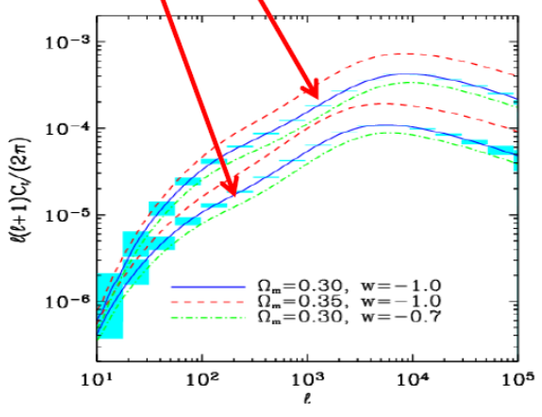


RSD



1.5 billion sources with shapes, 10 slices





EUCLID collaboration

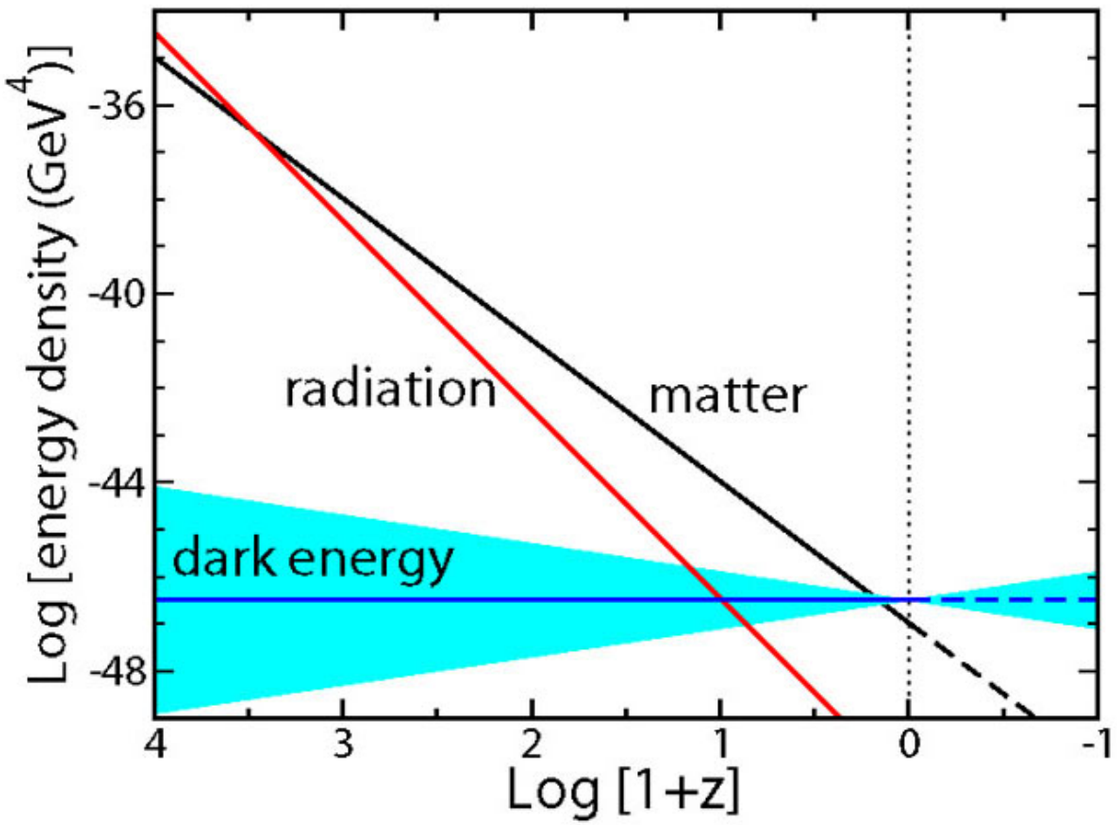
Claim: 1% accuracy on matter power spectrum over large range of scales

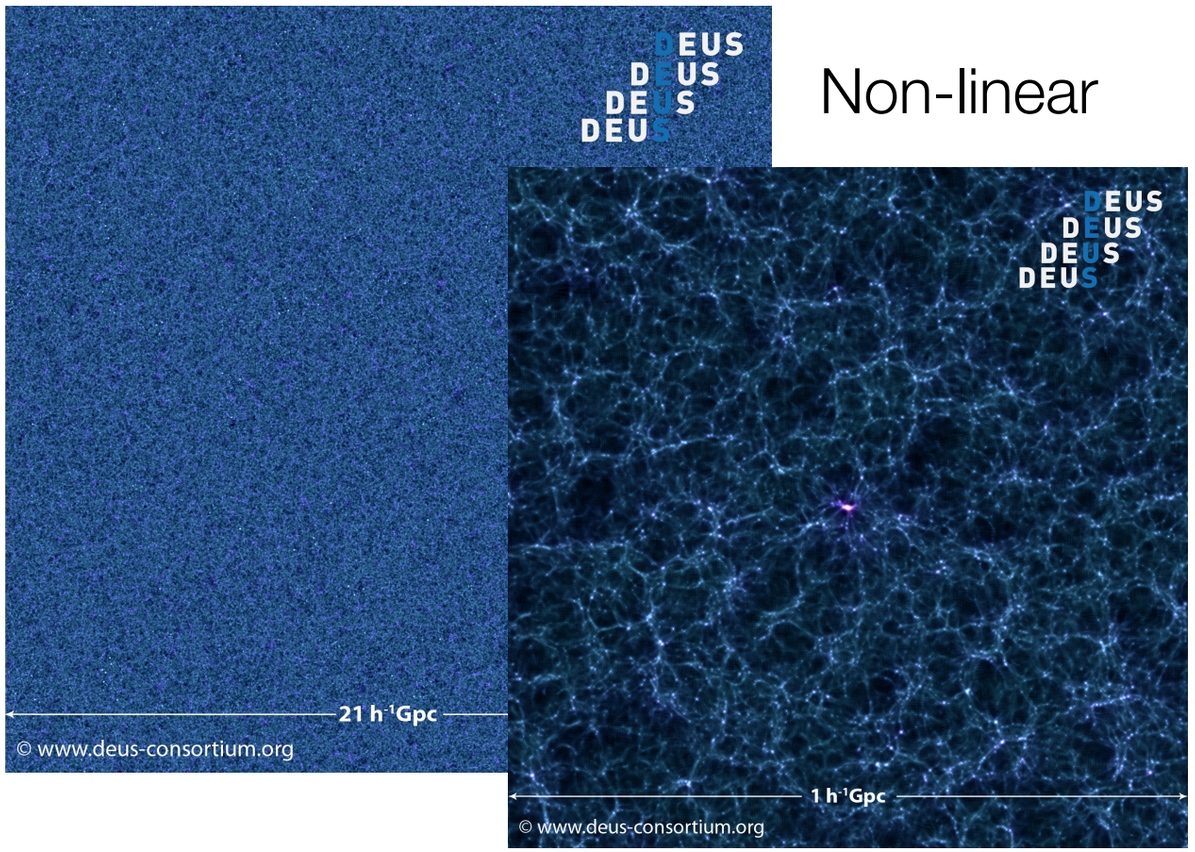
Competitive with CMB to constrain cosmological parameters values

LSS Surveys and Dark Energy

What is Dark Energy?

Dark Energy dominates at late times

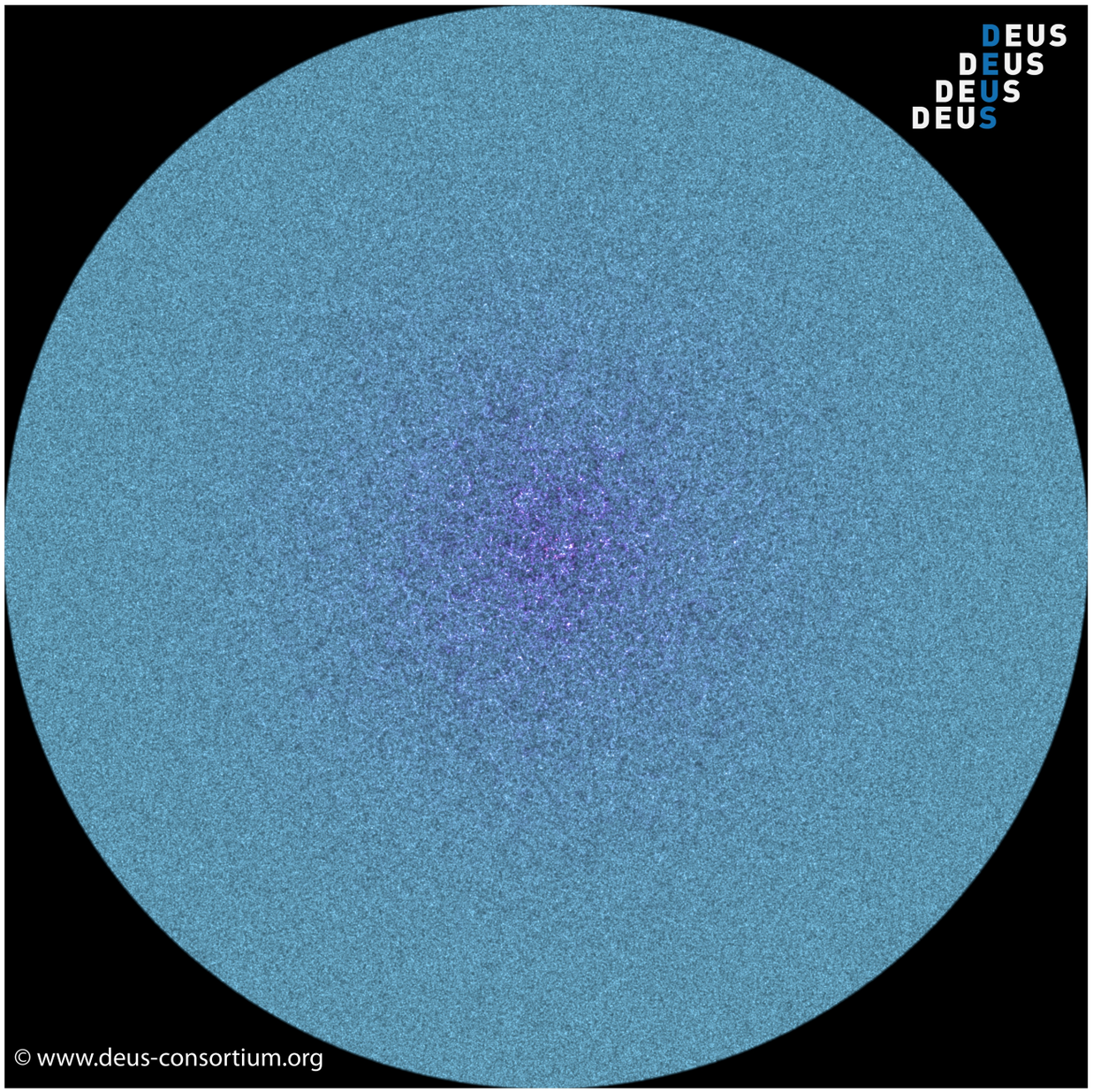




Non-linear

Need simulations to make accurate predictions

DEUS Full Universe Run



Alimi et al. 2012, arxiv:1206.2838

AMADEUS application:

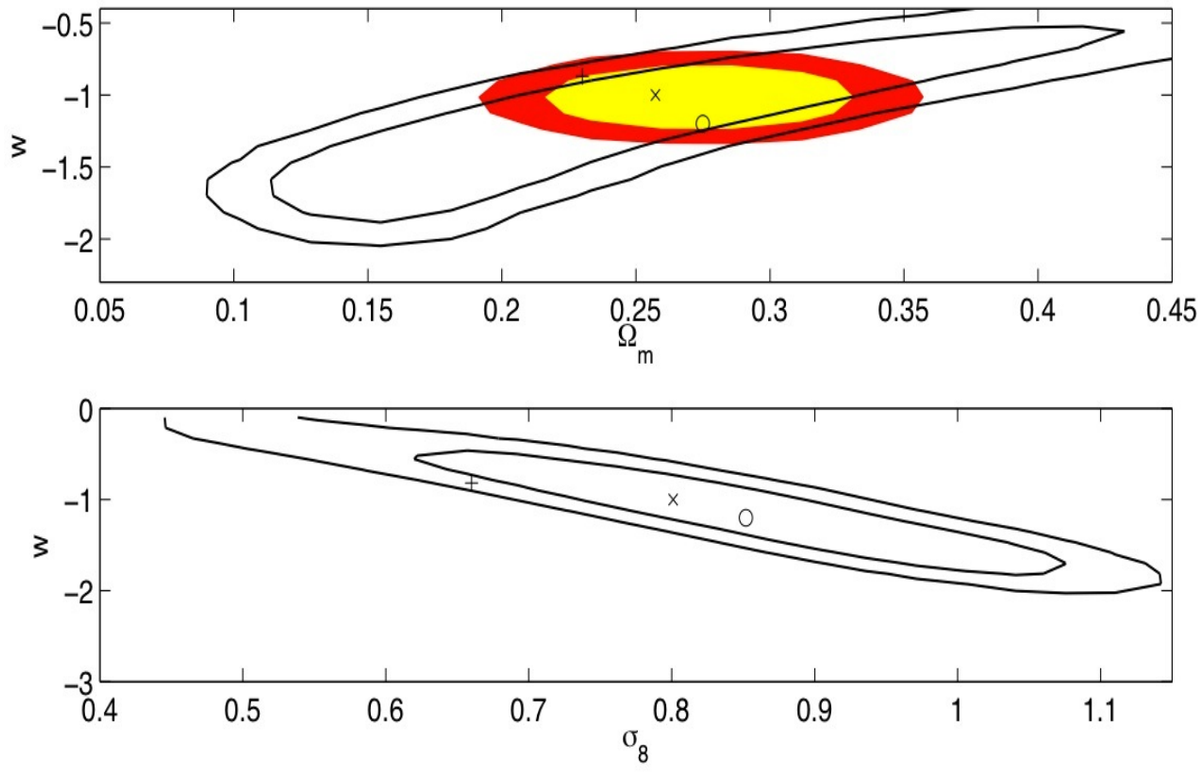
- IC: optimised version of MPGRAFIC (Prunet 2008)
- N-body: improved version of RAMSES (Teyssier 2002)
- Halo finder: PFOF (Roy et al. 2014)

Some numbers:

- 21 Gpc/h box-side
- 8192^3 particles
- 2 trillions AMR cells
- 5 million cpu hours on 76032 cores of the Curie Supercomputer at TGCC
- Resolves scales from the size of the horizon to the Milky Way size (40 kpc/h)

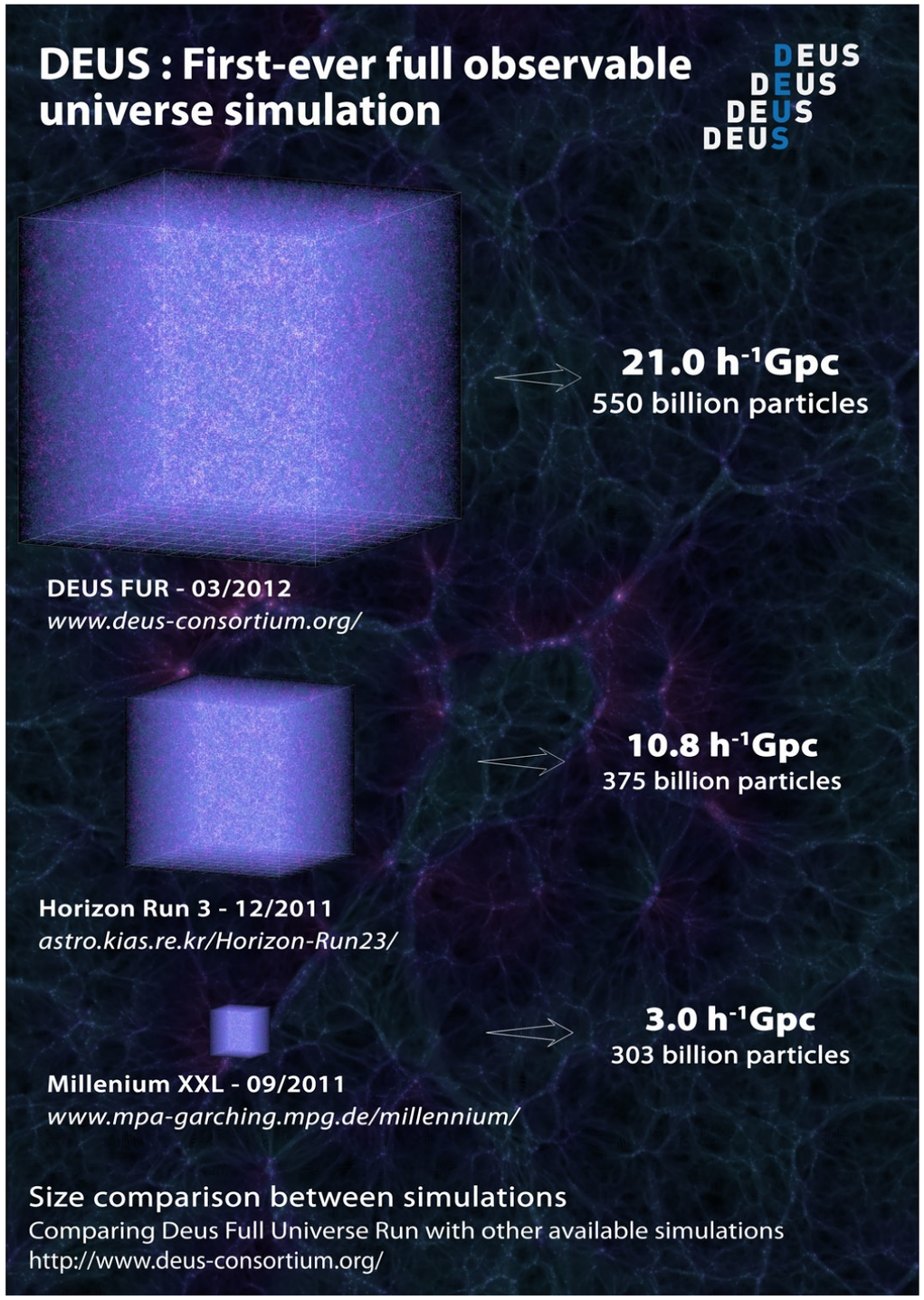
DEUS Full Universe Run

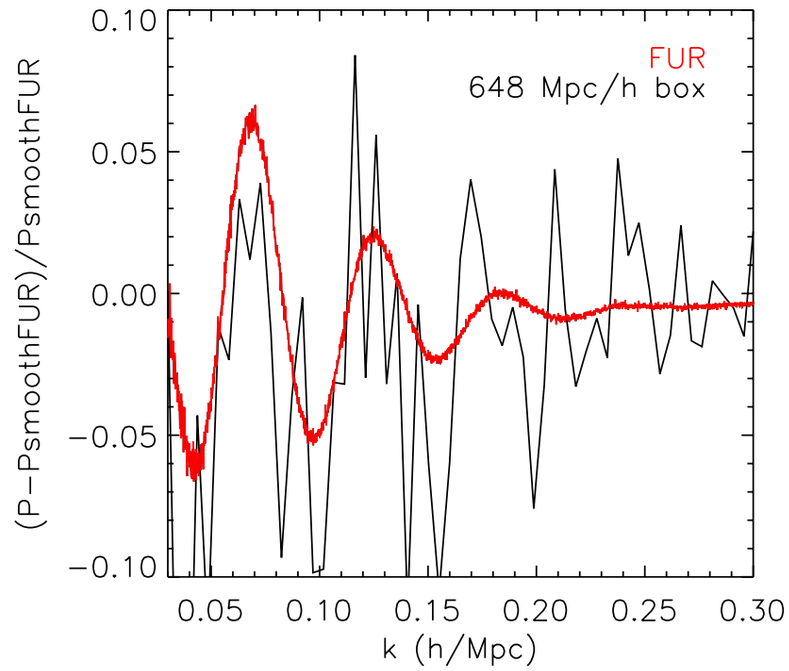
3 Dark Energy cosmologies:
WMAP-7 ΛCDM (x)
w=-0.87 Ratra-Peebles CDM (+)
w=-1.2 phantom fluid dark energy CDM (o)

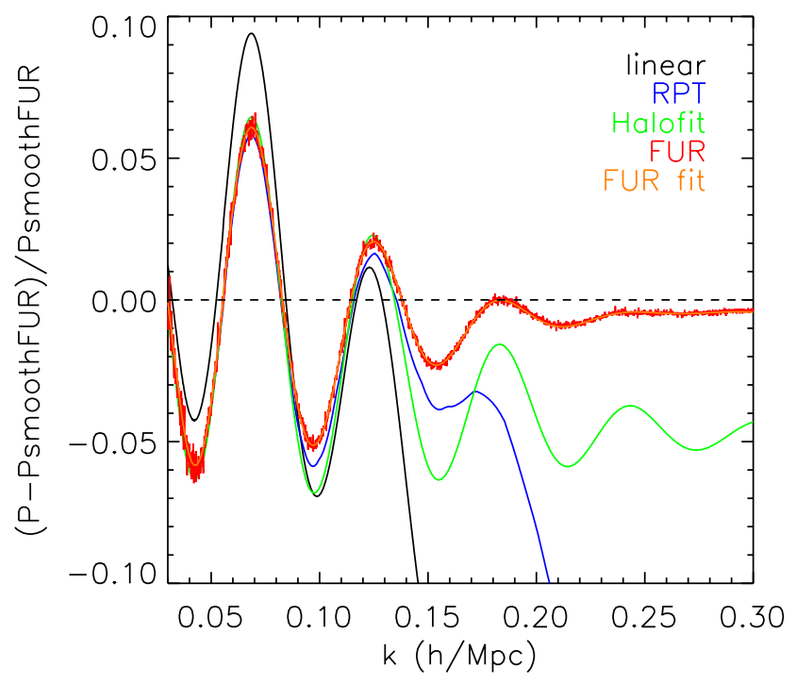


Black: WMAP-7
Color: SN Ia UNION

BAO from DEUS FUR



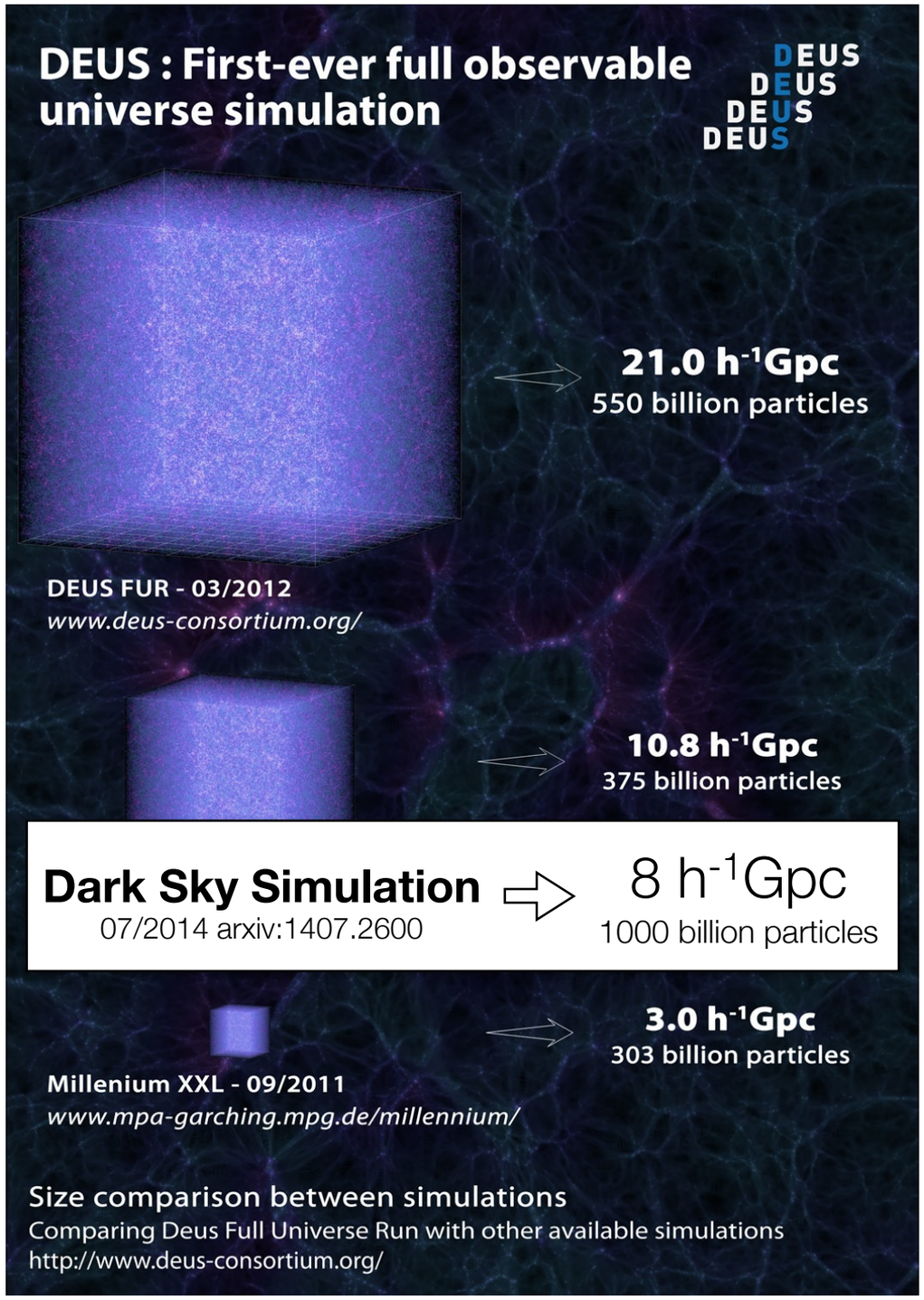


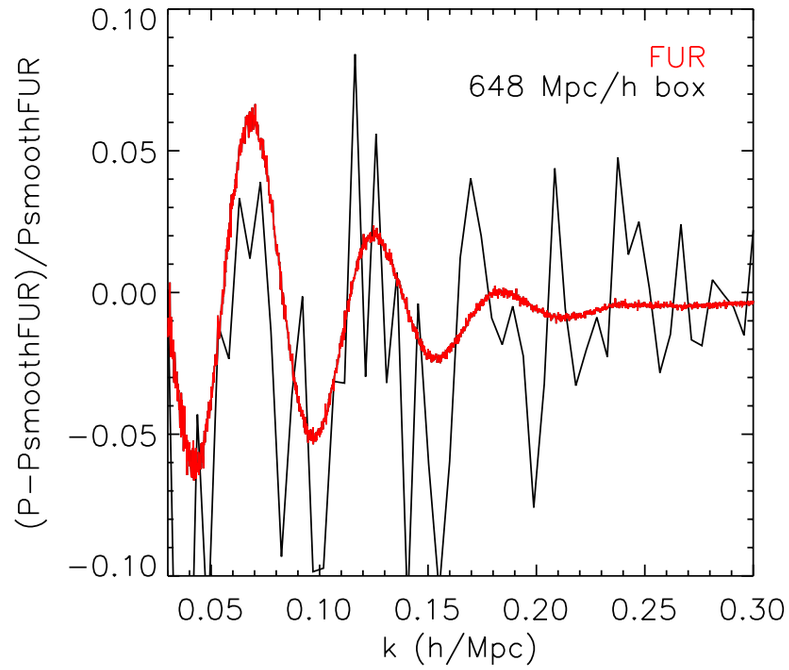


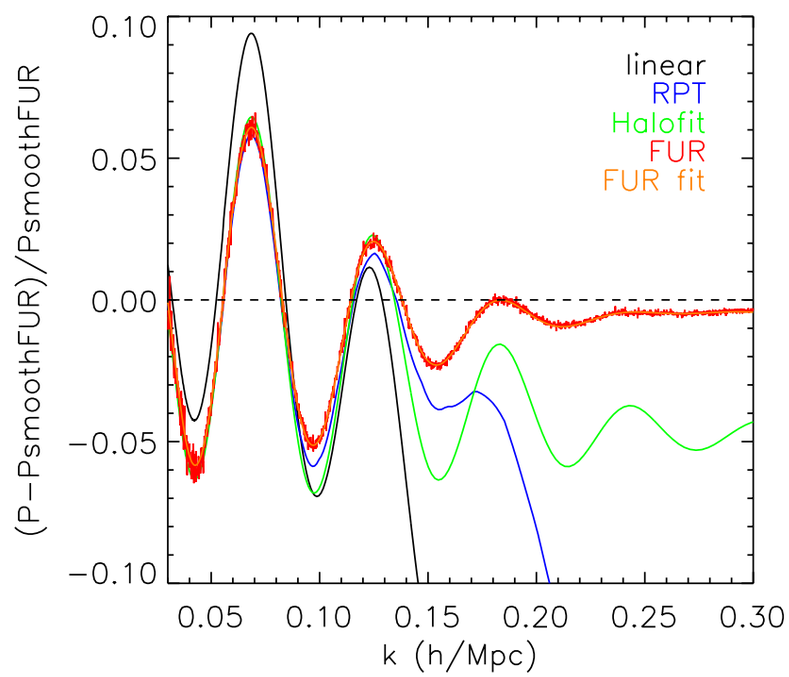
Sampling: $\Delta k = 2\pi / L_{box}$

Rasera et al. 2014 arxiv:1311.5662

BAO from DEUS FUR



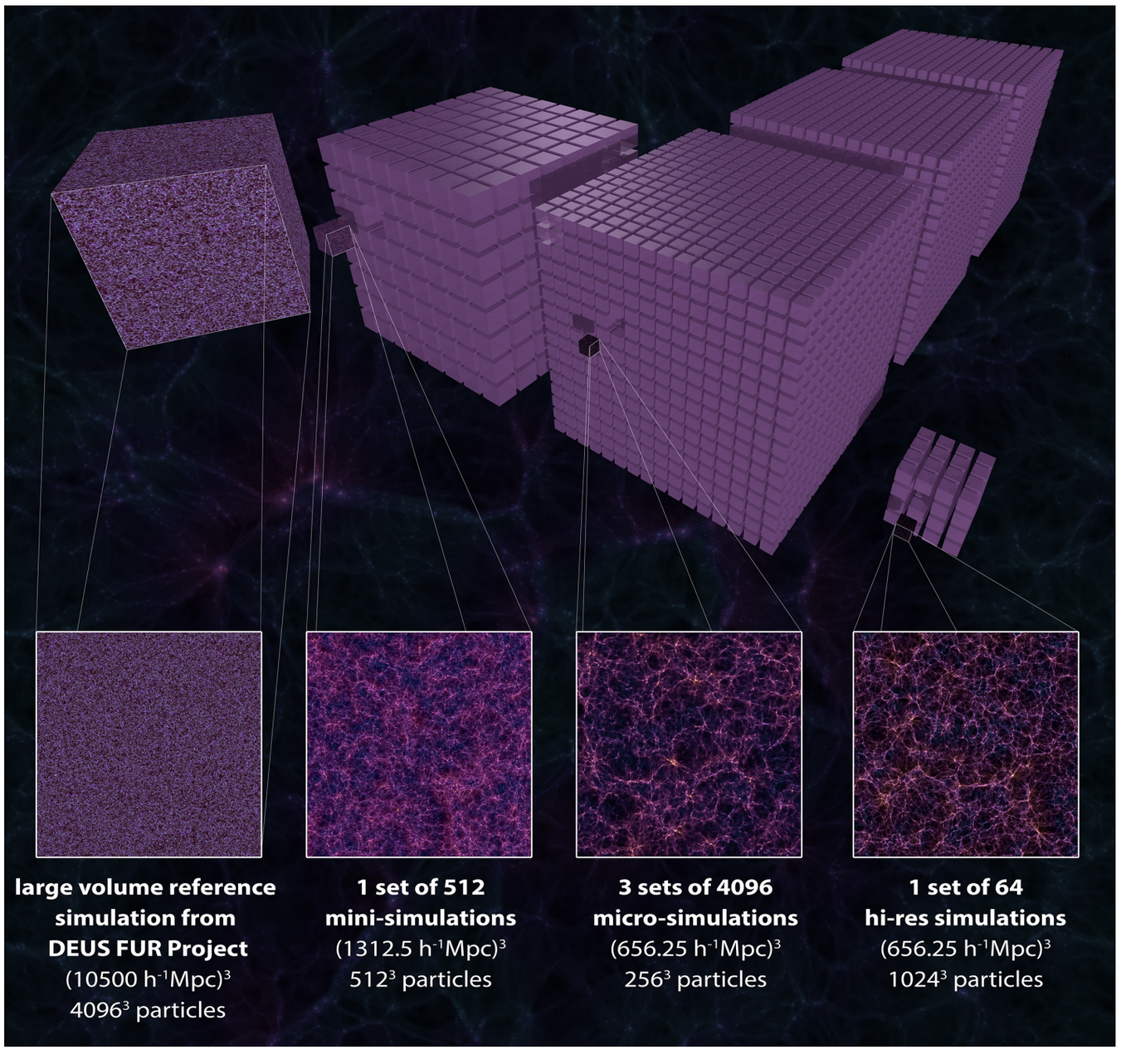




Sampling: $\Delta k = 2\pi / L_{box}$

Rasera et al. 2014 arxiv:1311.5662

DEUS Parallel Universe Runs

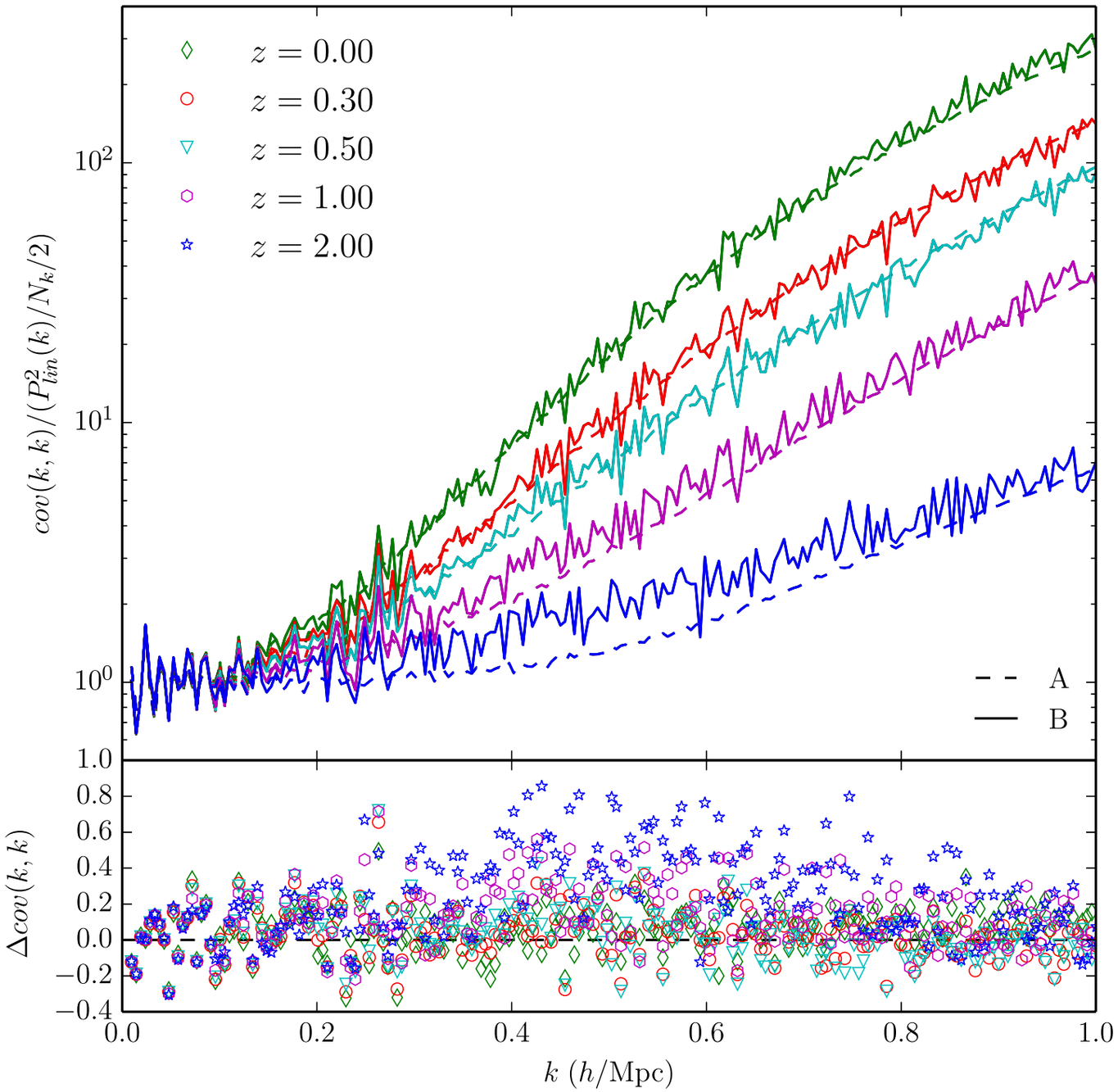


WMAP-7 ΛCDM

Set A: 12288 simulations
12 cpu hours/simulation on 32 cpus
Set B: 64+32=96 simulations
15k cpu hours/simulation on 512 cpus
Set C: 512 simulations
100 cpu hours/simulation on 32 cpus
Total: ~1.5M cpu hours on the ADA supercomputer at IDRIS

For comparison:
Takahashi et al. 2009
5000 PM simulations 1 Gpc/h 256^3 particles
Li et al. 2014b
3584 Tree-PM simulations 500 Mpc/h 256^3 particles

Matter Power Spectrum Variance

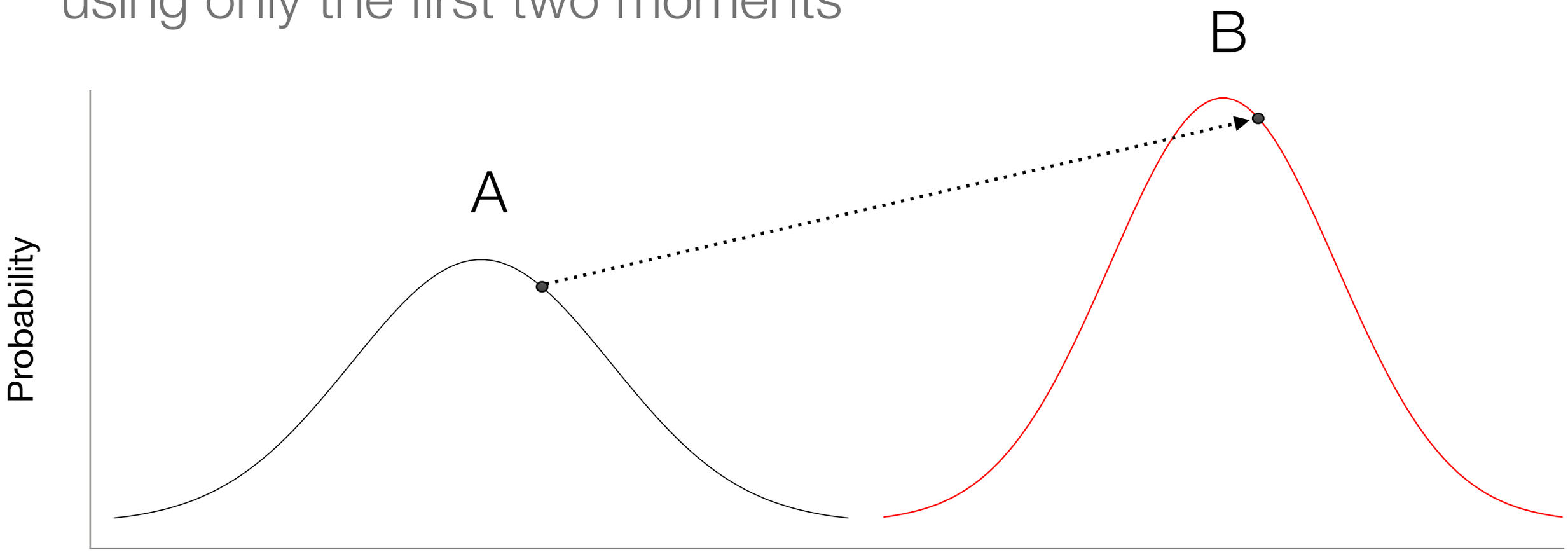


Blot et al. 2014, arxiv:1406.2713

$$\sigma^2 = \frac{1}{N_s - 1} \sum_{i=1}^{N_s} (P_i(k) - \bar{P}(k))^2$$

Mass Resolution Effect Correction

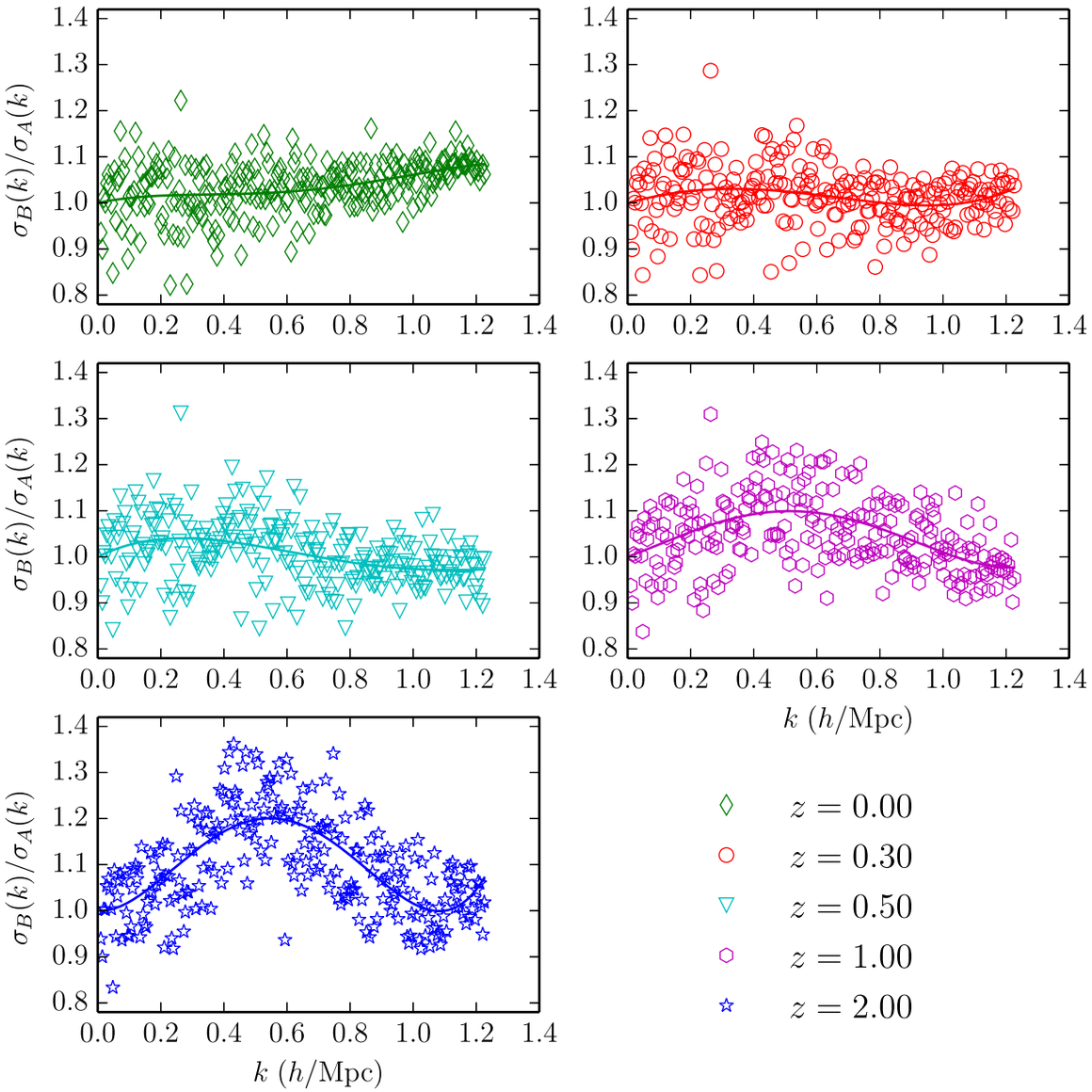
Map the spectrum from the PDF of set A into the one of set B using only the first two moments

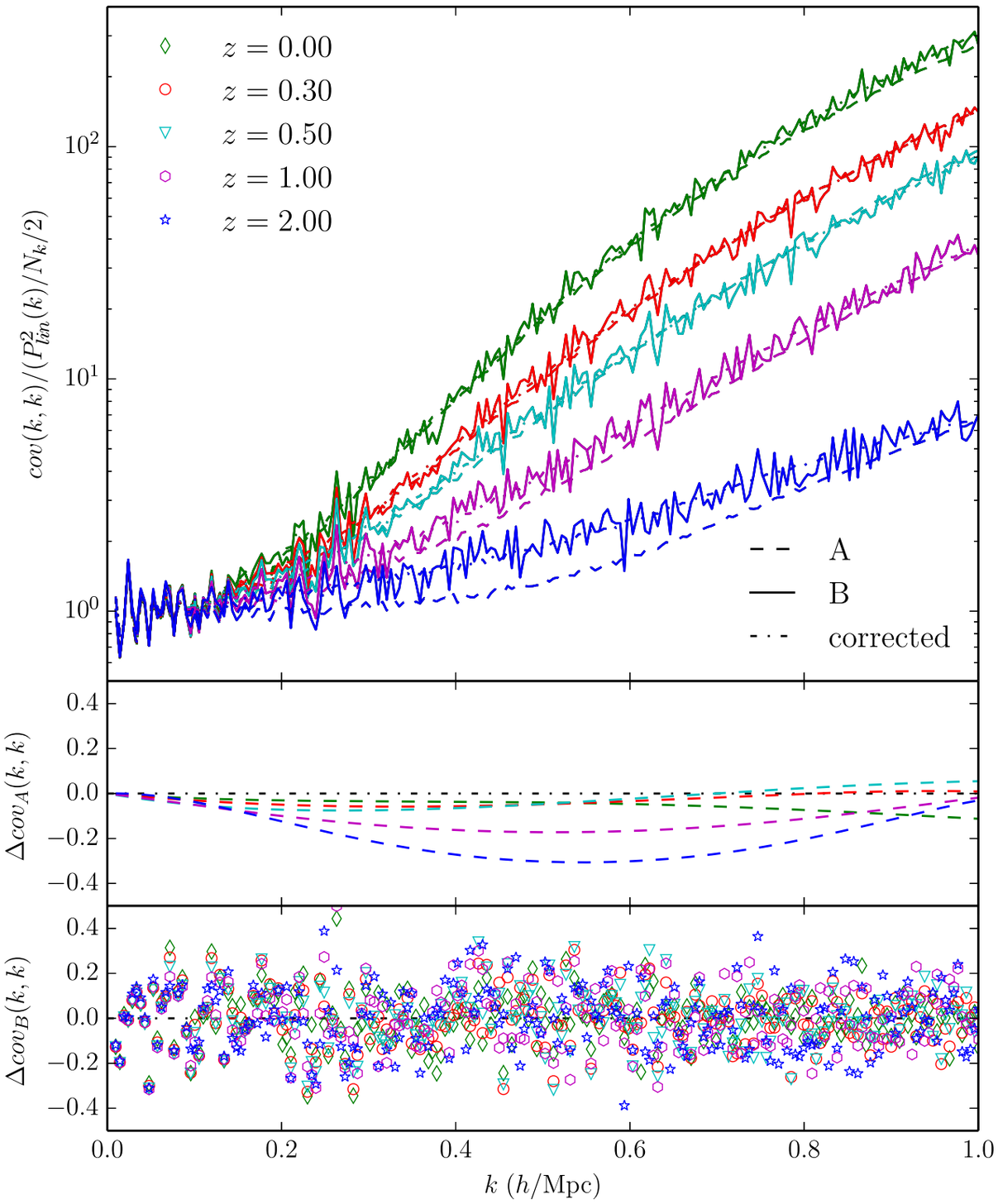


$$\hat{P}_A^{\mathrm{corr}}(k) = \left[\hat{P}_A(k) - \bar{P}_A(k)\right] \frac{\sigma_{\hat{P}_B}(k)}{\sigma_{\hat{P}_A}(k)} + \bar{P}_B(k)$$

Corrected Matter Power Spectrum Variance

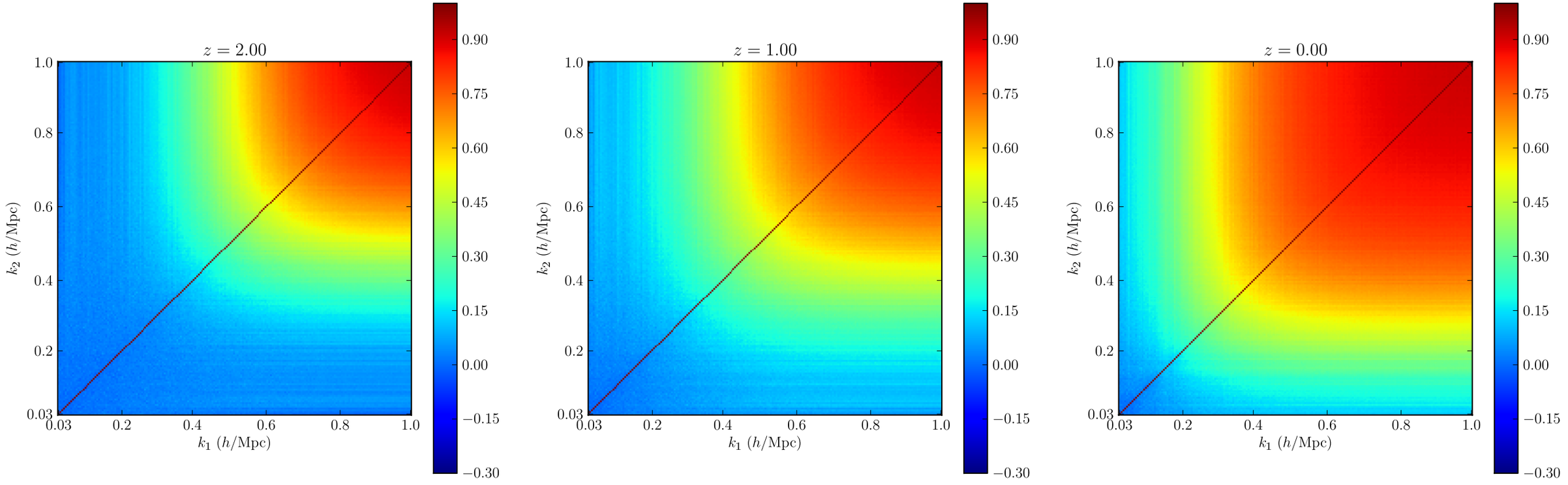
$$\hat{P}_A^{\rm corr}(k) = \left[\hat{P}_A(k) - \bar{P}_A(k)\right] \frac{\sigma_{\hat{P}_B}(k)}{\sigma_{\hat{P}_A}(k)} + \bar{P}_B(k)$$





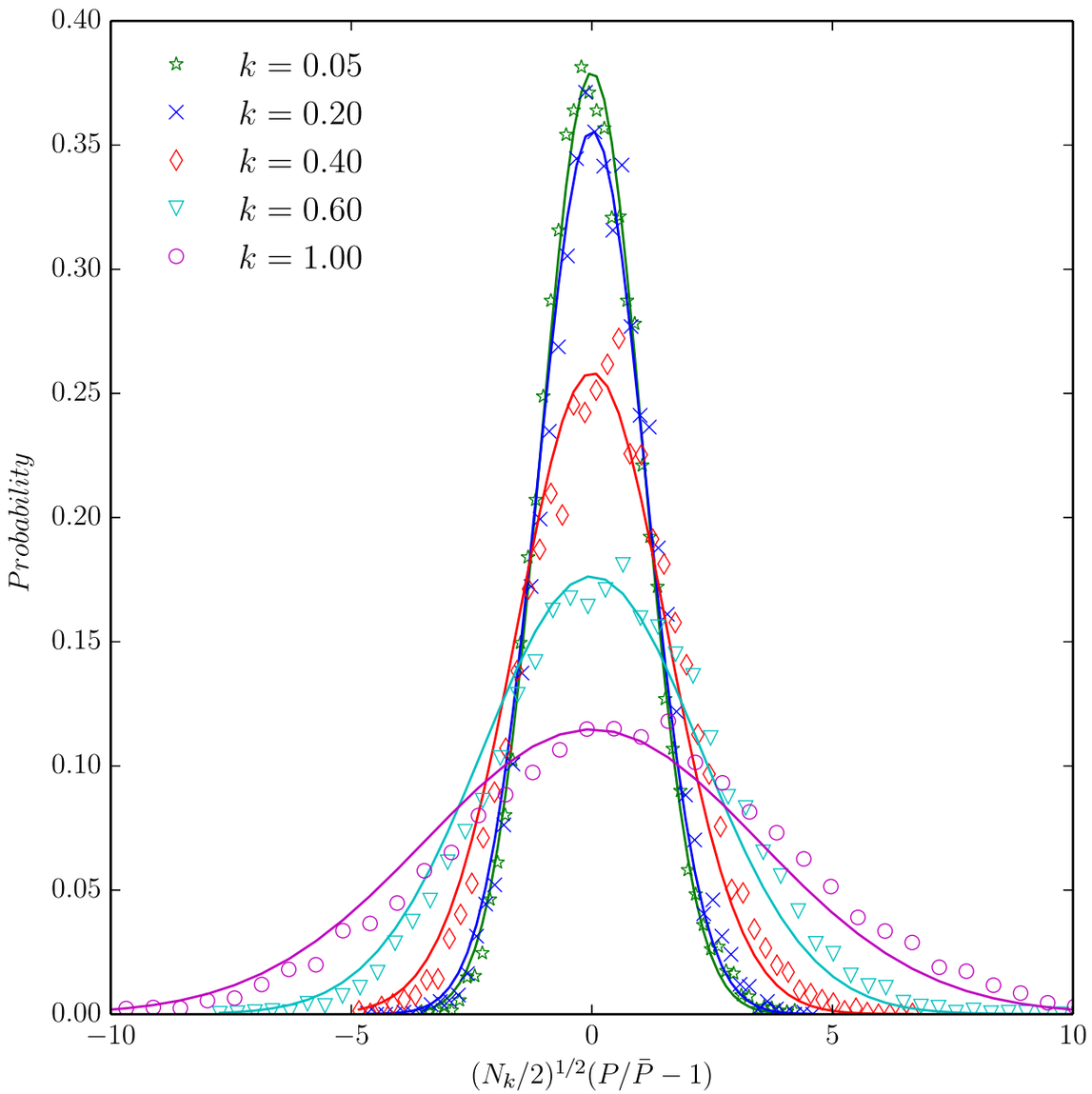
Correlation Matrix

$$r(k_1, k_2) = \frac{\mathrm{cov}(k_1, k_2)}{\sqrt{\mathrm{cov}(k_1, k_1)\,\mathrm{cov}(k_2, k_2)}}$$

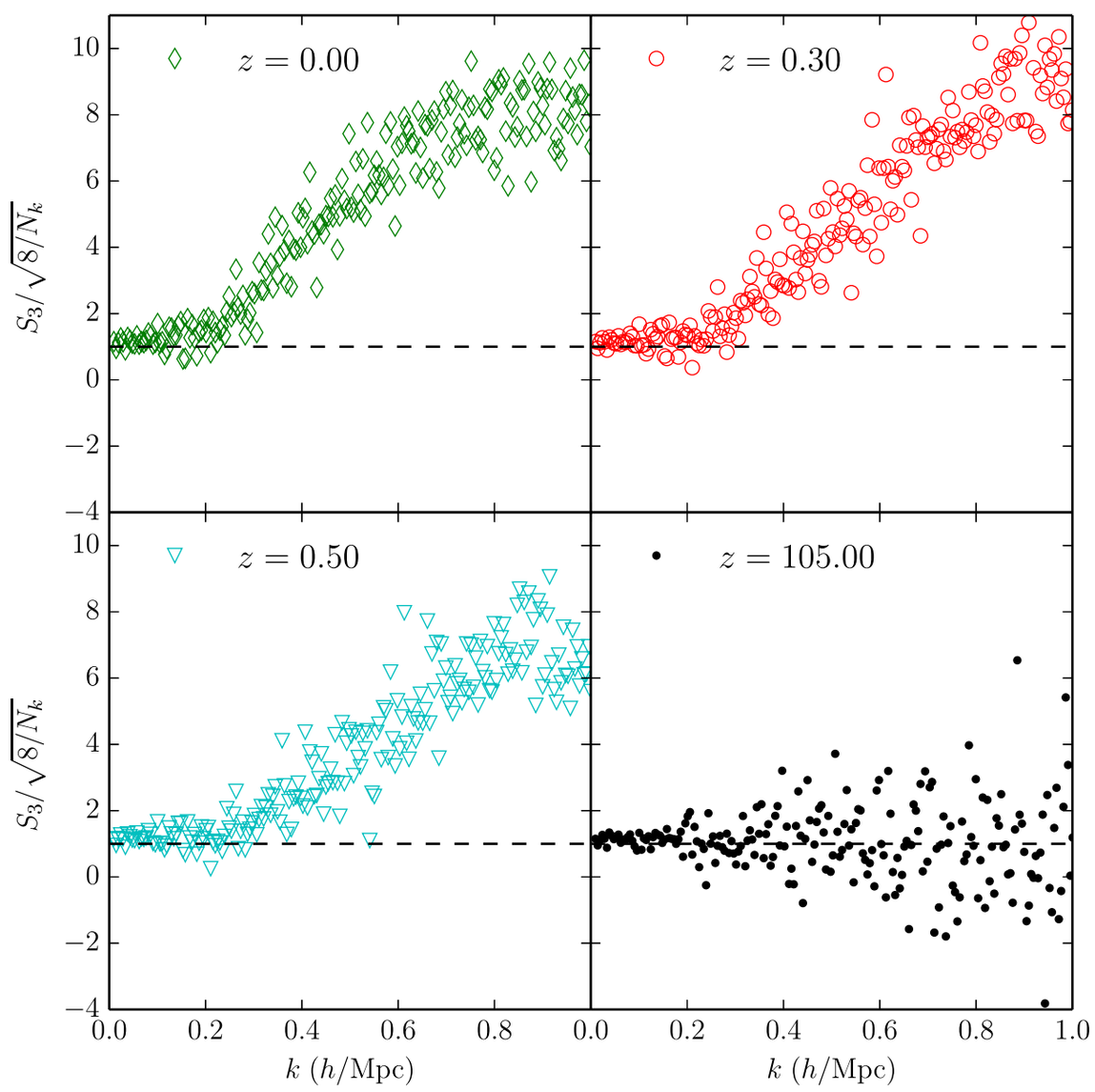


PDF of the Matter Power Spectrum

χ^2 distribution with N_k d.o.f. → Gaussian for $N_k >> 1$



Non-gaussian distribution



Skewness

Conclusions

- Simulations are not exempt from systematic uncertainties: mass resolution, finite volume

- Empirical method to correct for mass resolution effect

- Previous studies with less simulations found no evidences of PDF deviations from Gaussianity ➜ need very large number of simulations

- Non-Gaussianities play an important role from k~0.2 h/Mpc up

- Minor importance for BAO but need full PDF for smaller scales

Backup

Covariance matrices: from observations to constraints on cosmological parameters

Physical + statistical properties of the models -> differentiation of models in bayesian framework

Ideal world: full multivariate probability distribution of the data for all the models

If we assume multivariate Gaussian -> mean and covariance

Estimation of the covariance:

- internal: from the data themselves
- external: from simulations
- model: from the theoretical model

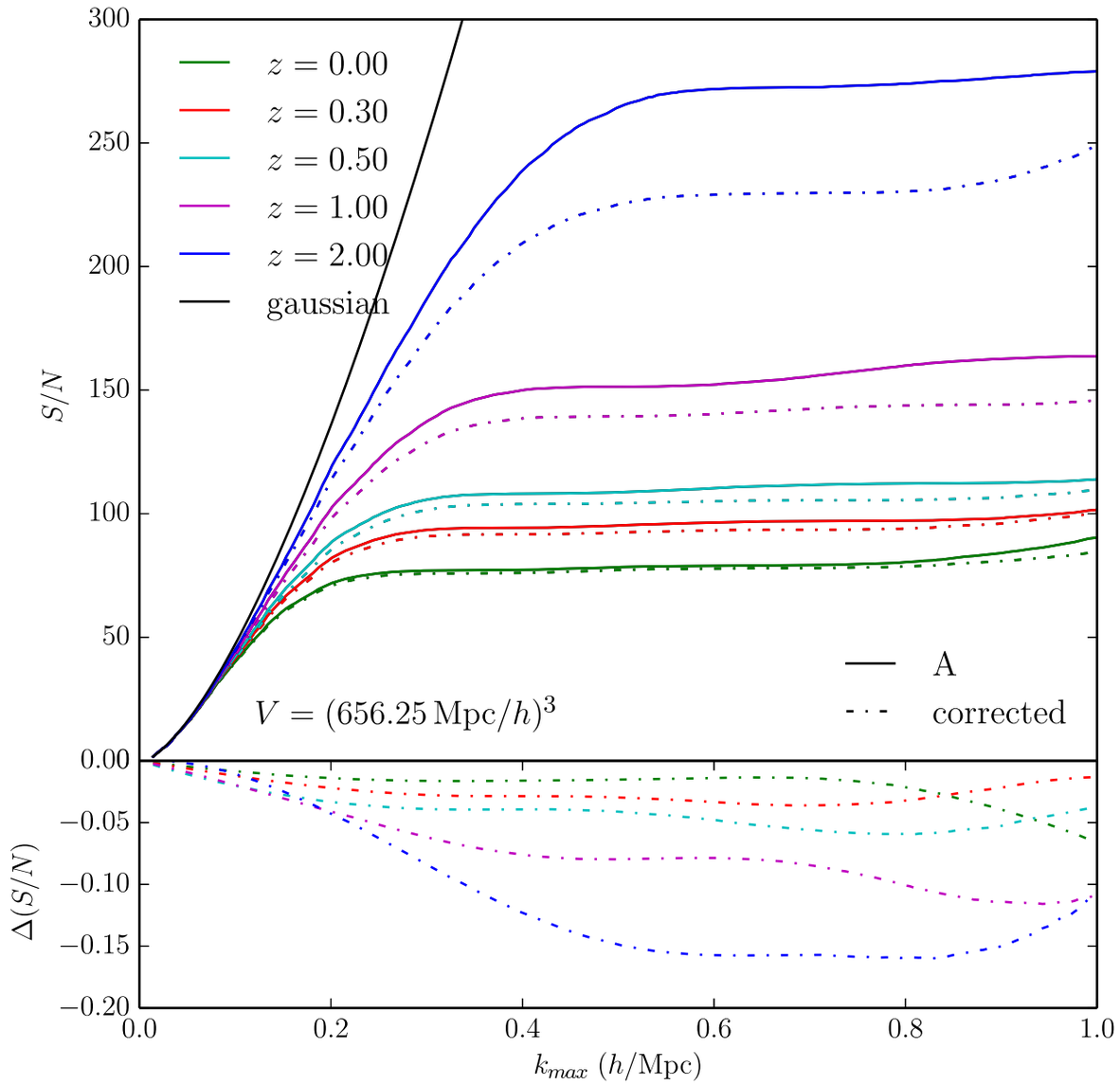
} Sample covariance

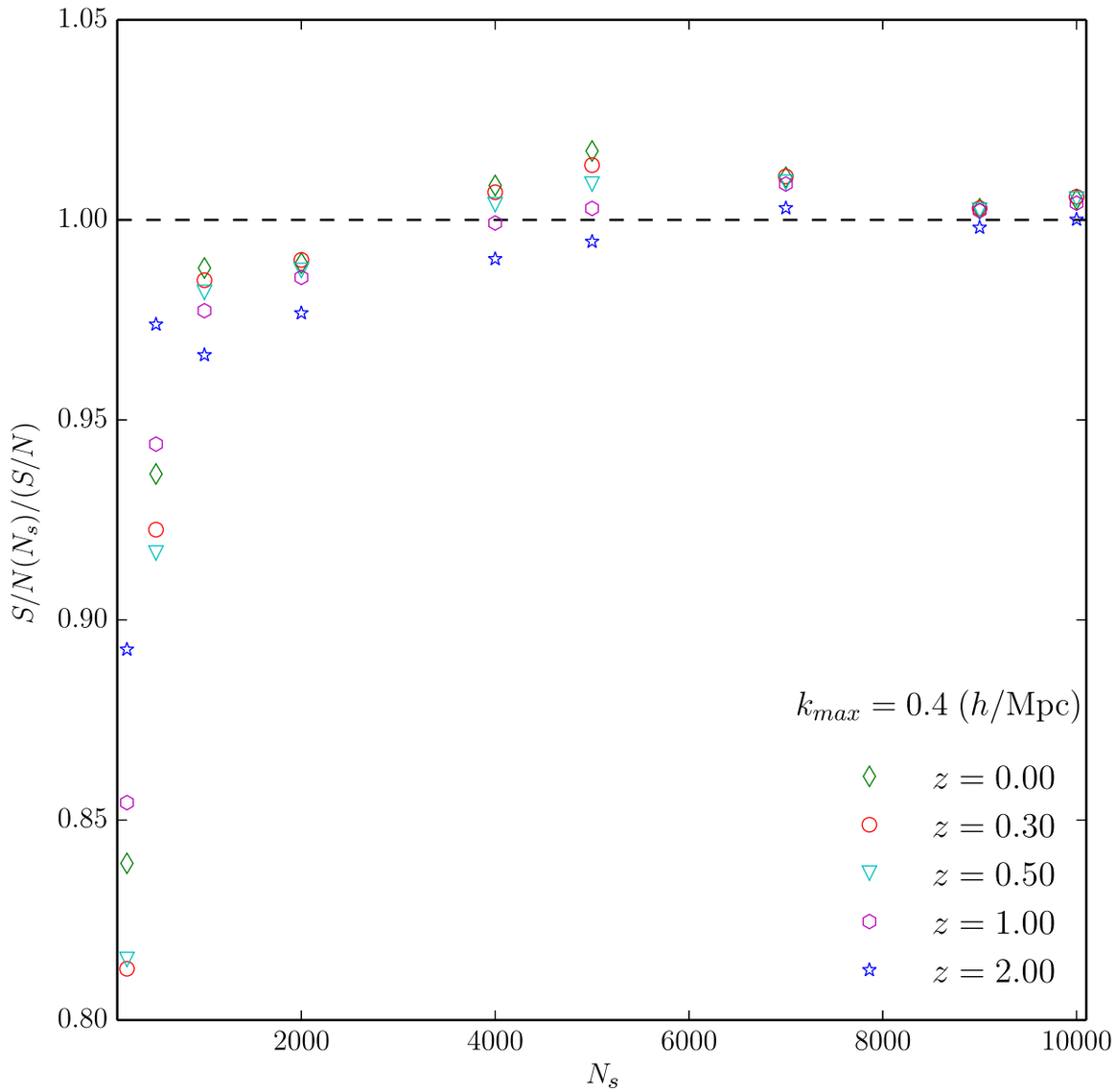
$$\widehat{\mathrm{cov}}(k_1, k_2) = \frac{1}{N_s - 1} \sum_{i=1}^{N_s} [\hat{P}_i(k_1) - \bar{P}(k_1)][\hat{P}_i(k_2) - \bar{P}(k_2)]$$

LSS: non-linear regime, bias + complicated data processing -> simulations

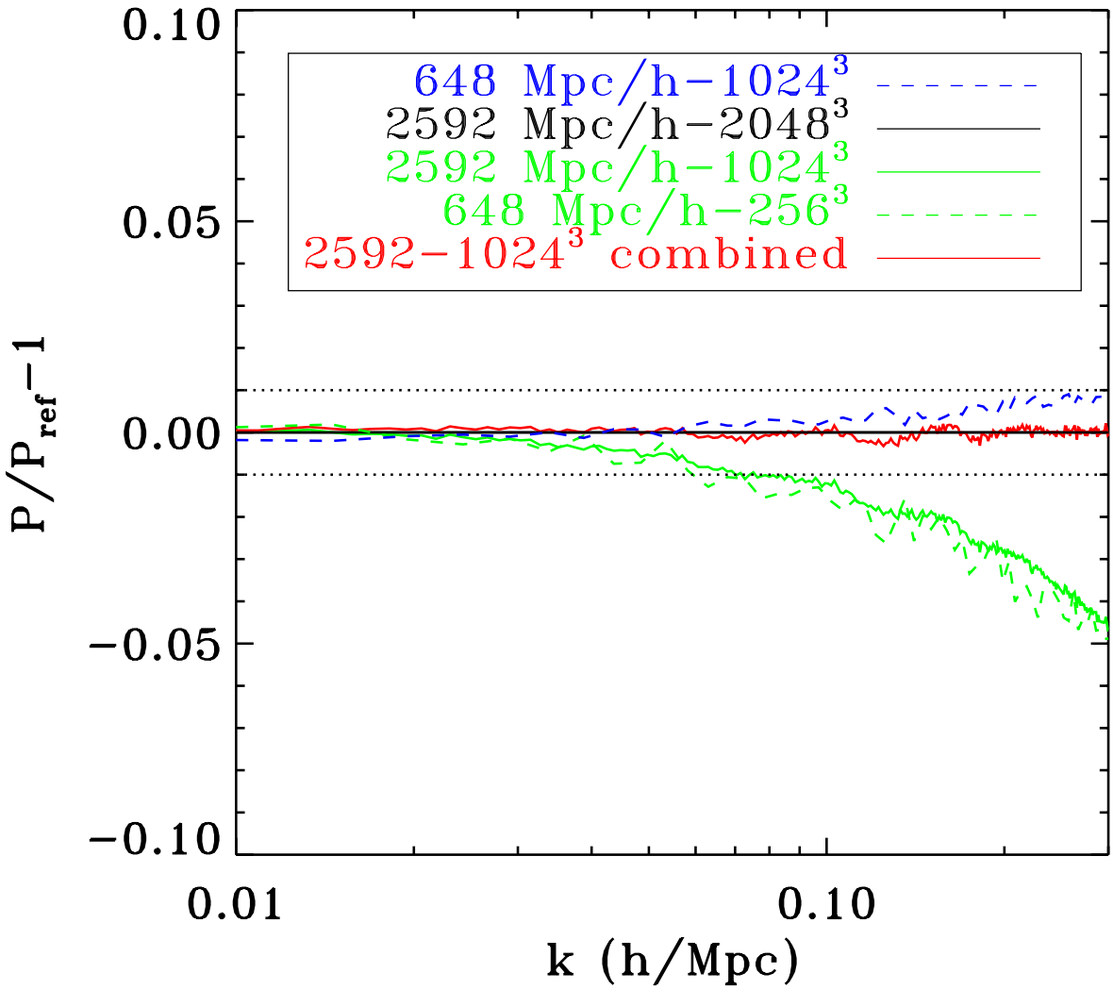
Signal to Noise

$$\left(\frac{S}{N}\right)^2 = \sum_{k_1,k_2<k_{\max}} P(k_1)\,\mathrm{cov}^{-1}(k_1,k_2)\,P(k_2)$$

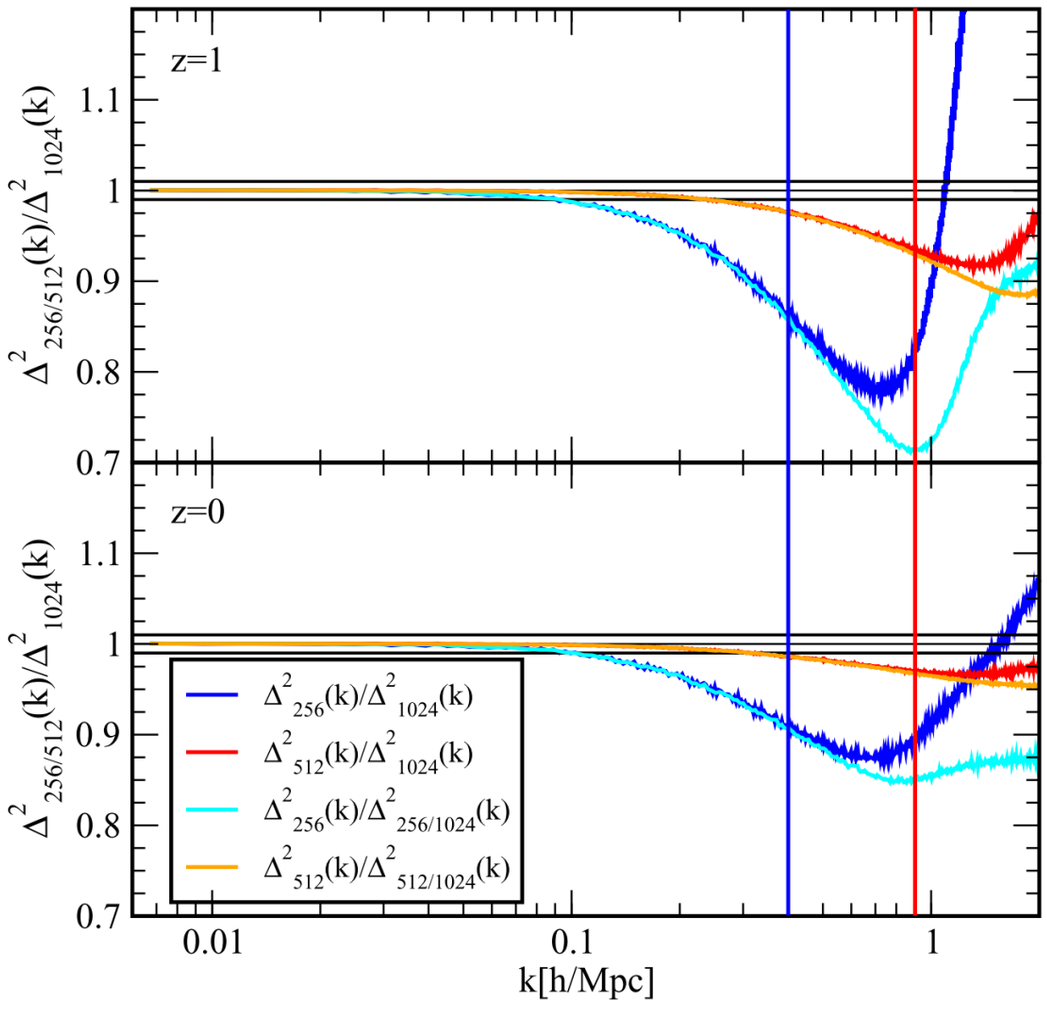




Mass Resolution Effect



Rasera et al. 2014



Heitmann et al. 2010