Precision cosmology with large-scale structure

Misha Ivanov (NYU)




O. Philcox A. Chudaykin M. Simonovic M. Zaldarriaga

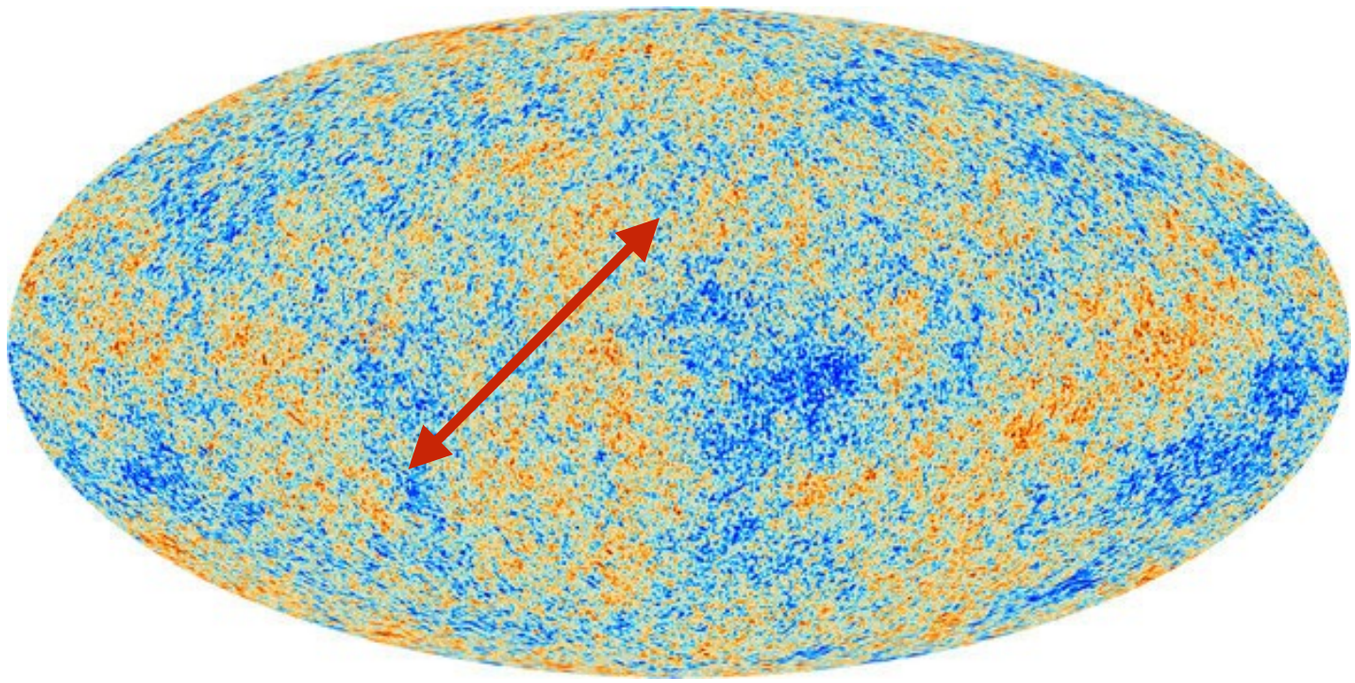
+ J. Wadekar, R. Scoccimarro,
+C. Hill, E. McDonough, M. Toomey, S. Alexander,
+ M. Takada, T. Nischimichi, L. Senatore,
P. Zhang, G. d'Amico

1907.06666,
1909.05277,
1912.08208,
2002.04035,
2003.08277,
2004.10607,
2006.11235, ++

Main goals

$$\mathcal{D}_\ell \sim \left(\frac{\delta T}{T}\right)^2$$

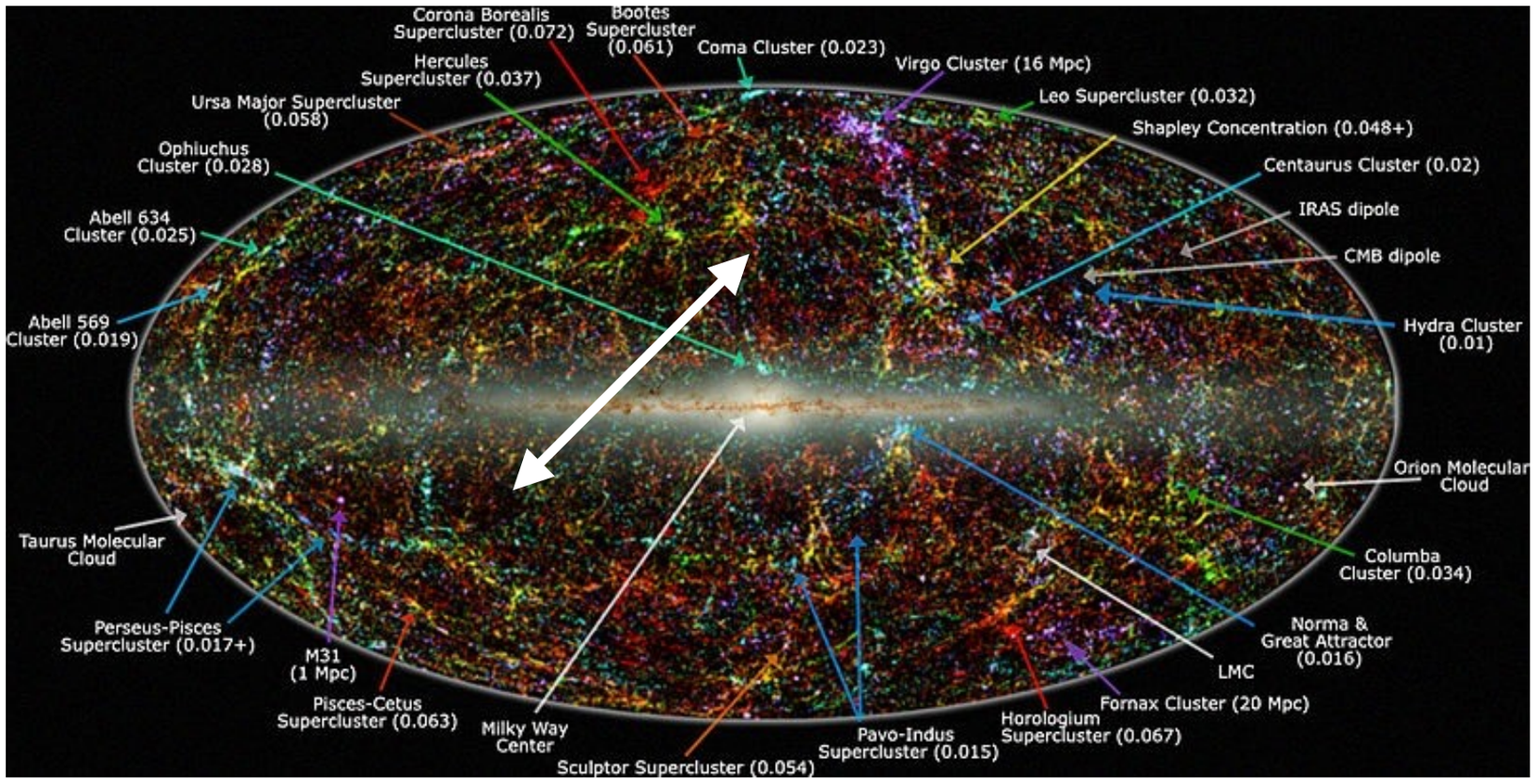
$$\ell \sim \frac{1}{\theta}$$



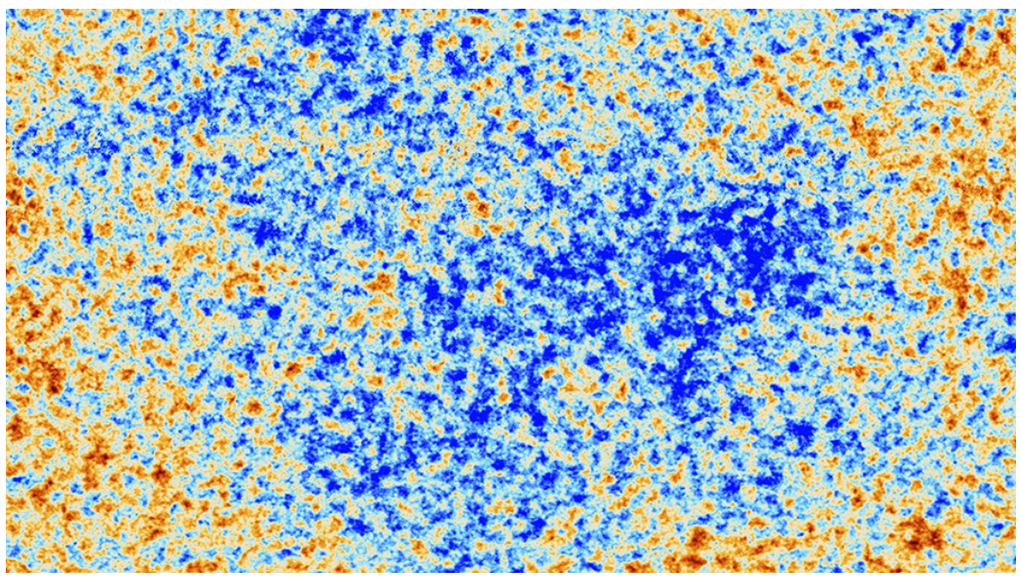
$$P(k) \sim \left(\frac{\delta\rho}{\rho}\right)^2$$

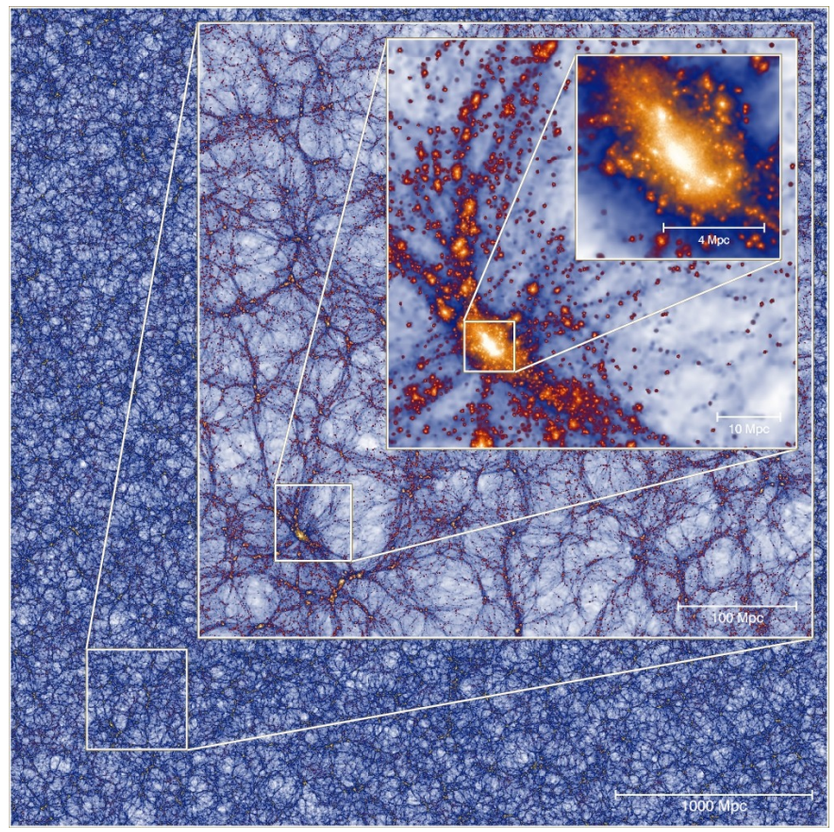
$$\delta \equiv \frac{\delta\rho}{\rho}$$

$$k = \frac{2\pi}{\lambda}$$



Non-Linearities come into play





Baumann, Nicolis, Senatore, Zaldarriaga 2012: effective field theory approach

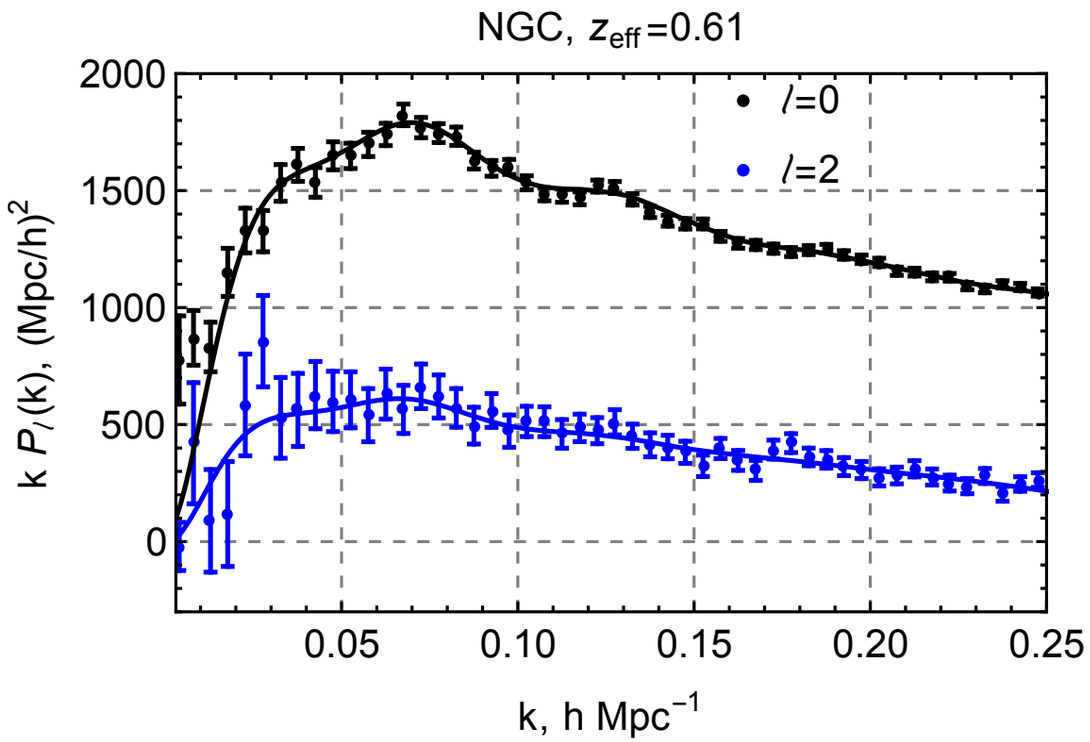
$$\delta_{\rm NL} = \delta_L + F_2\delta_L^2 + \ldots + \gamma\nabla^2\delta_L + \ldots$$

"counterterms"

should be treated as nuisance parameters

Our pipeline in a nutshell

I. Consistently recompute power spectrum as we vary cosmology (CMB style)
using the full non-linear model



II. MCMC analysis thanks to FFTLog

McEwen, Fang, Hirata, Blazek (2016)

III. `CLASS-PT` + Montepython

Schmittfull, Vlah, McDonald (2016)

Simonovic, Zaldarriaga et al. (2017)

1) User friendly & works out-of-the box
2) Easy scales with # of parameters
3) No hard coding !

2004.10607

https://github.com/Michalychforever/CLASS-PT

Applications of our pipeline

high-res. N-body mocks

BOSS data

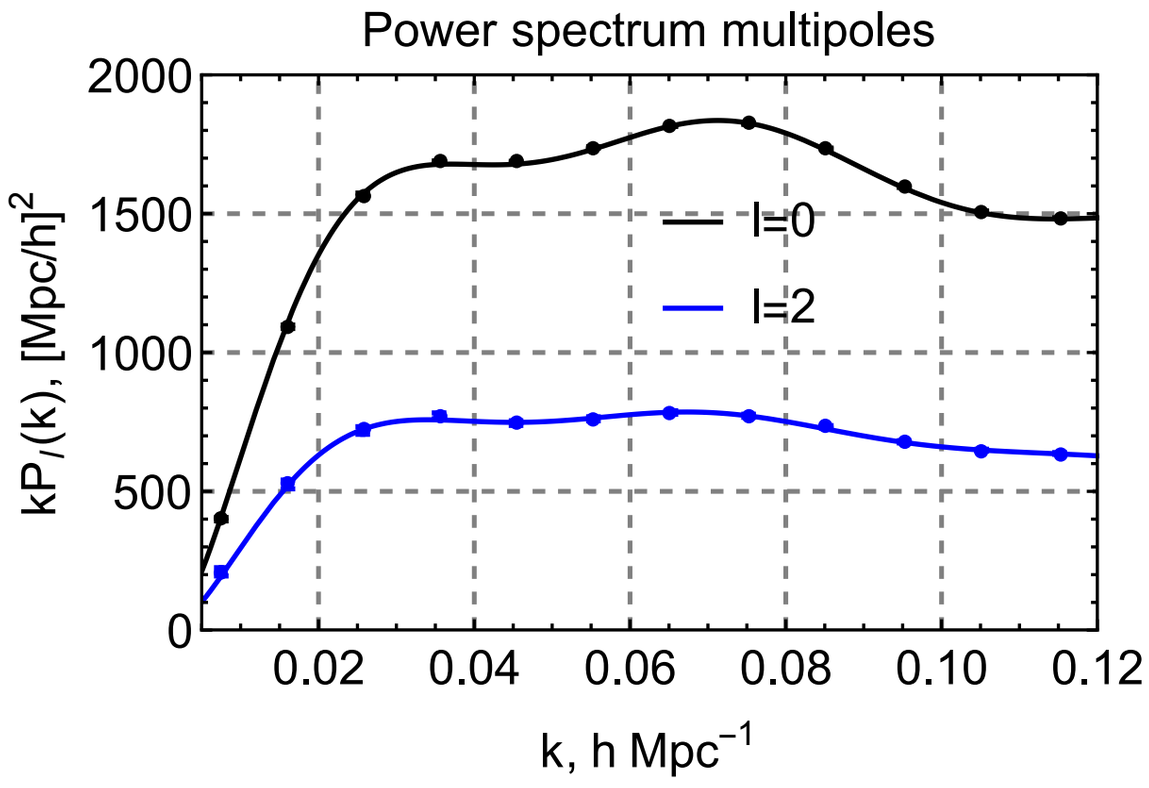
forecast for DESI/Euclid

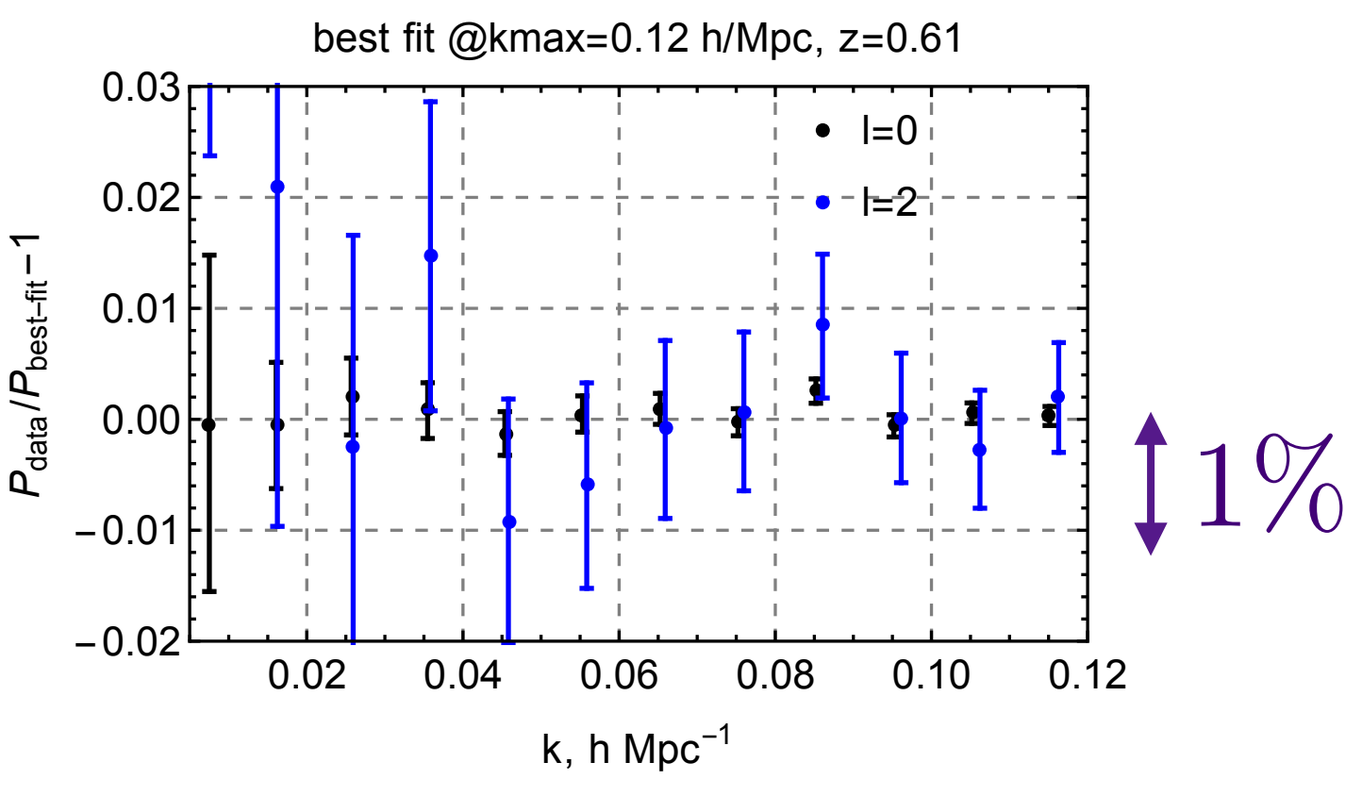
Results

Large N-body sims $\sim 600\ (\mathrm{Gpc}/h)^3$ =100x BOSS = 10x DESI

http://www-utap.phys.s.u-tokyo.ac.jp/~nishimichi/data/PTchallenge/

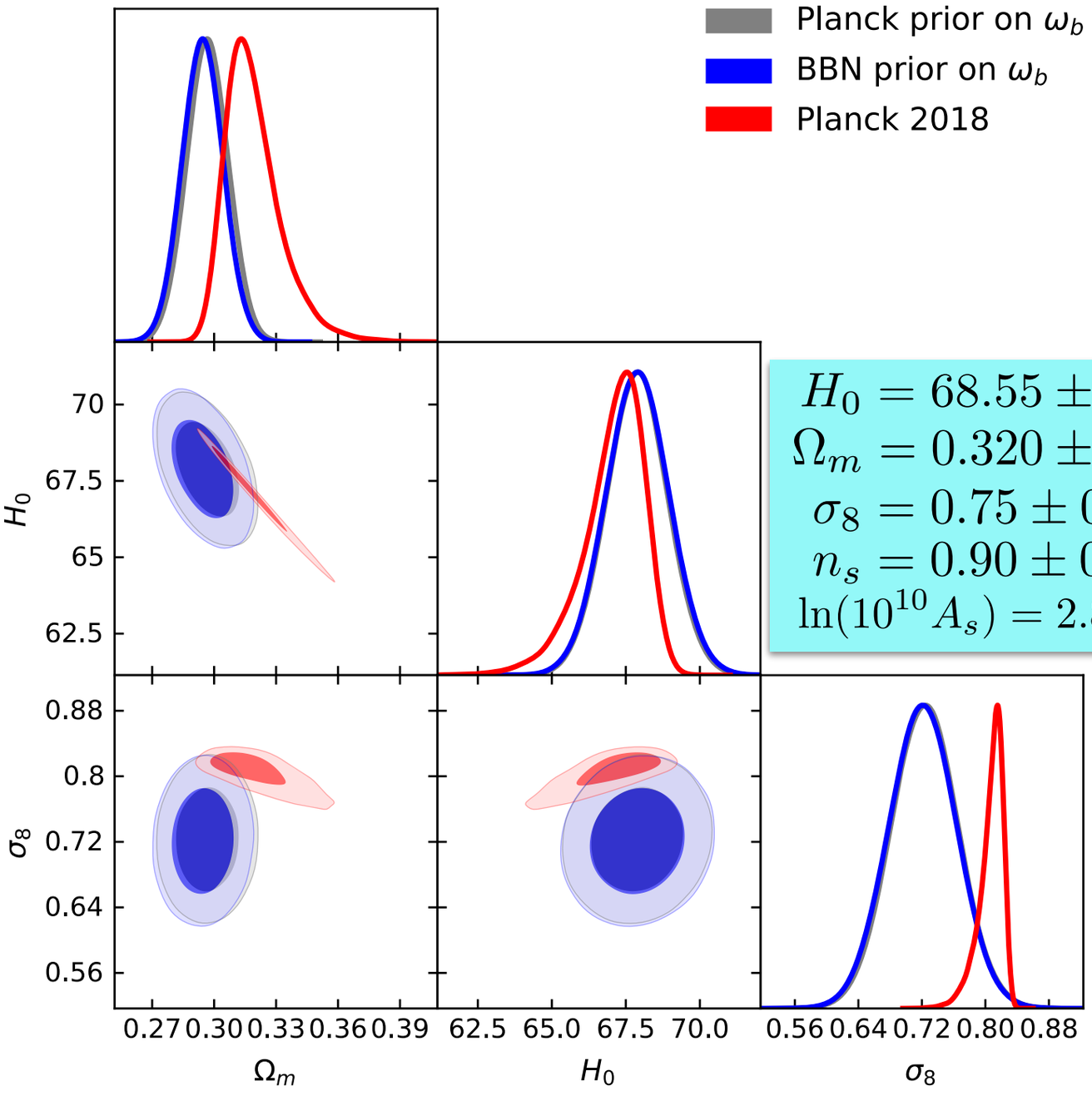
w/ M. Takada, T. Nishimichi



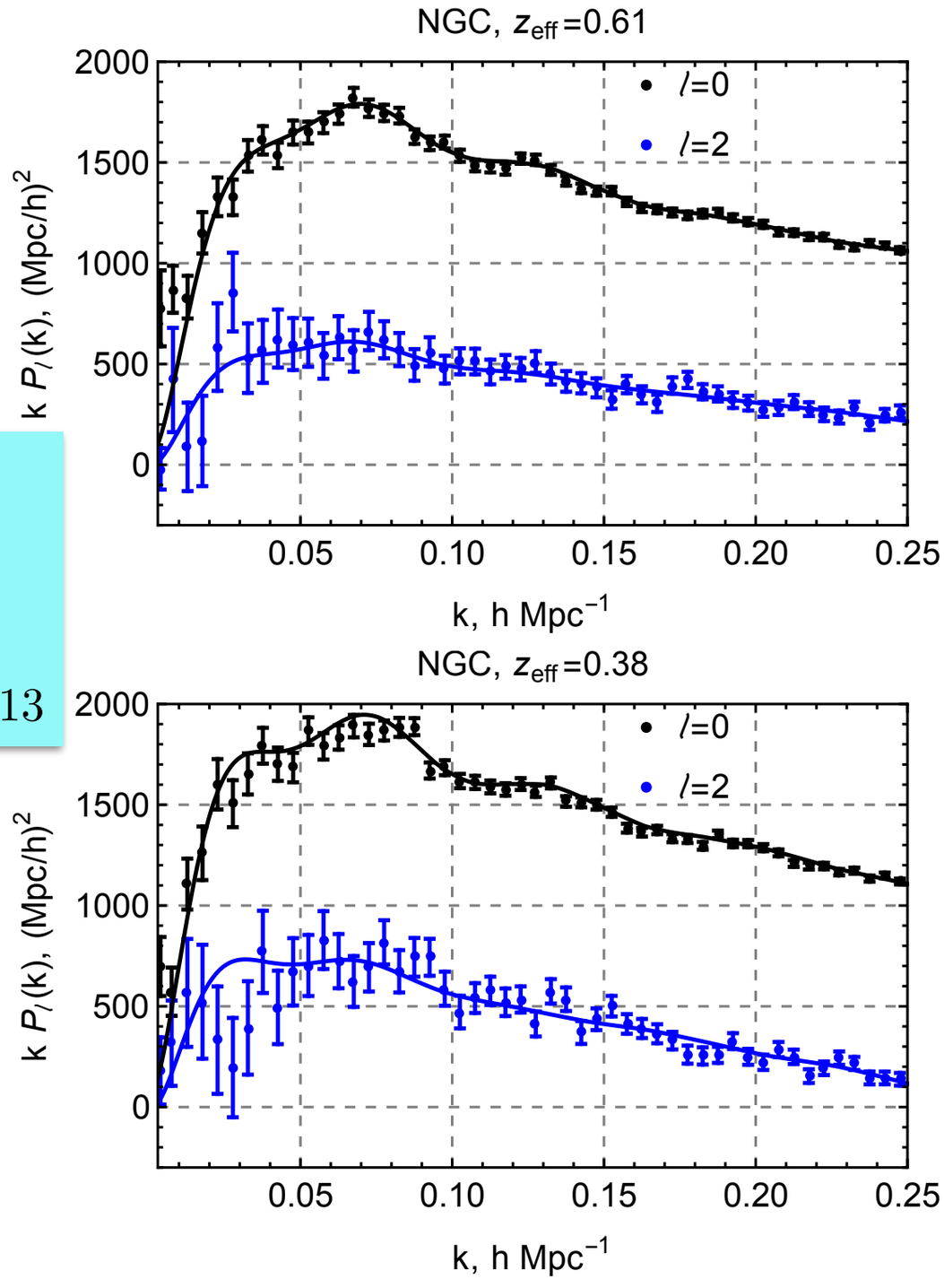


True cosmology recovered with ~0.1% accuracy

Reanalysis of the BOSS data (LCDM)



$$H_0 = 68.55 \pm 1.1$$
$$\Omega_m = 0.320 \pm 0.015$$
$$\sigma_8 = 0.75 \pm 0.05$$
$$n_s = 0.90 \pm 0.07$$
$$\ln(10^{10} A_s) = 2.82 \pm 0.13$$

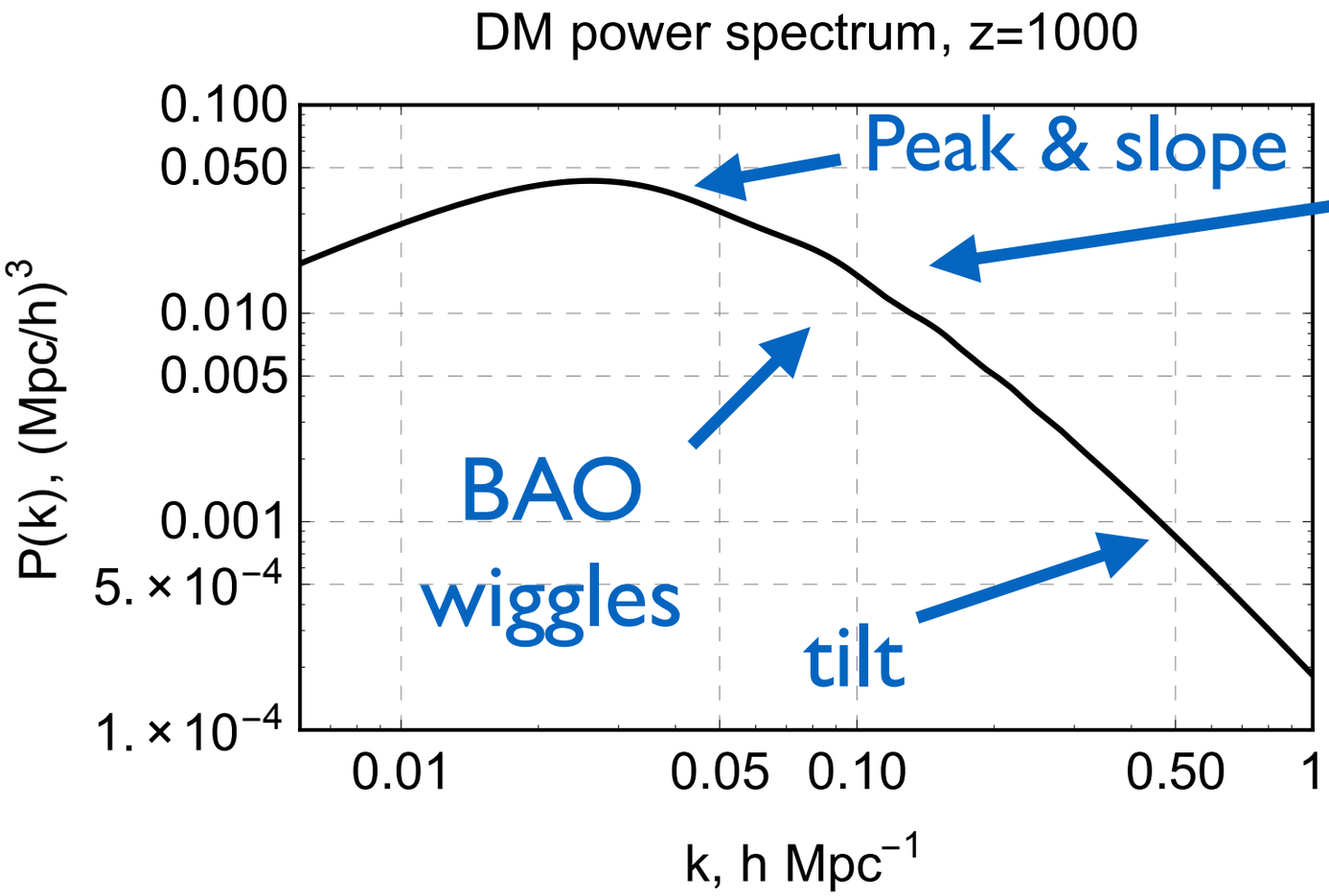


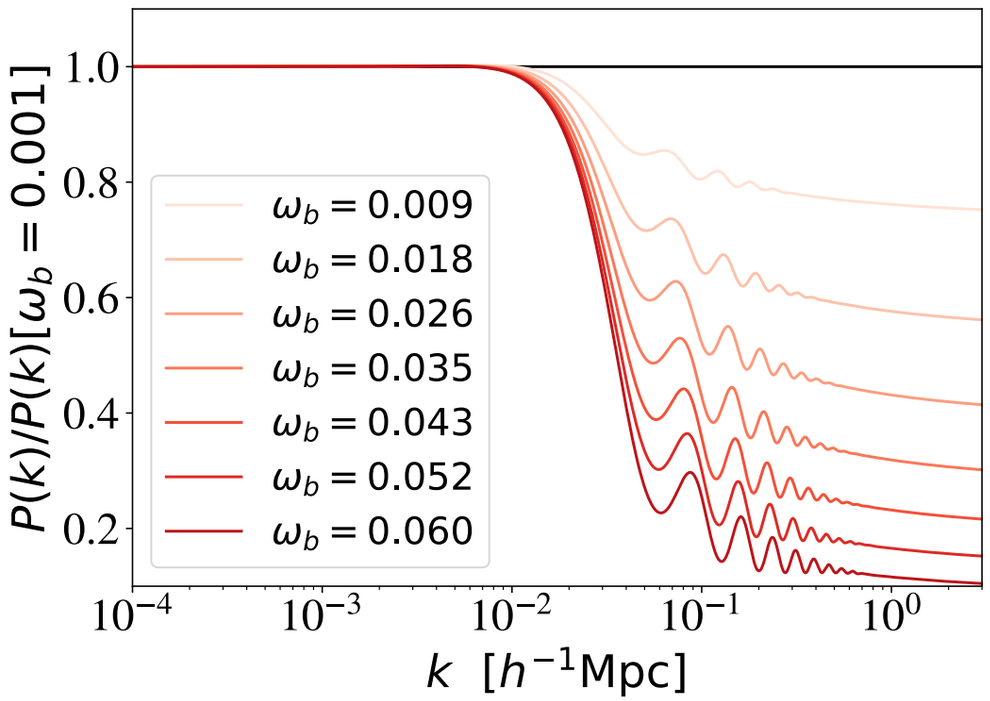
$z_{\rm eff} = 0.38,\ 0.61$ (SGC + NGC)

Nuisance params: $b_1, b_2, b_{\mathcal{G}_2}, P_{\rm shot} + c^{(0)}_{\nabla^2\delta}, c^{(2)}_{\nabla^2_z\delta}, c^{(0)+(2)}_{\nabla^4_z\delta}$

BBN prior on ob!

Information





- Shape $(\omega_b, \omega_{cdm}, n_s)$
- Distance $D_V \rightarrow H_0$

see Oliver Philcox's talk

- Amplitude $f\sigma_8 \rightarrow \sigma_8$

- AP effect $D_A, H \rightarrow$ nothing

Easy to include beyond-SM !

Combining with Planck: EDE

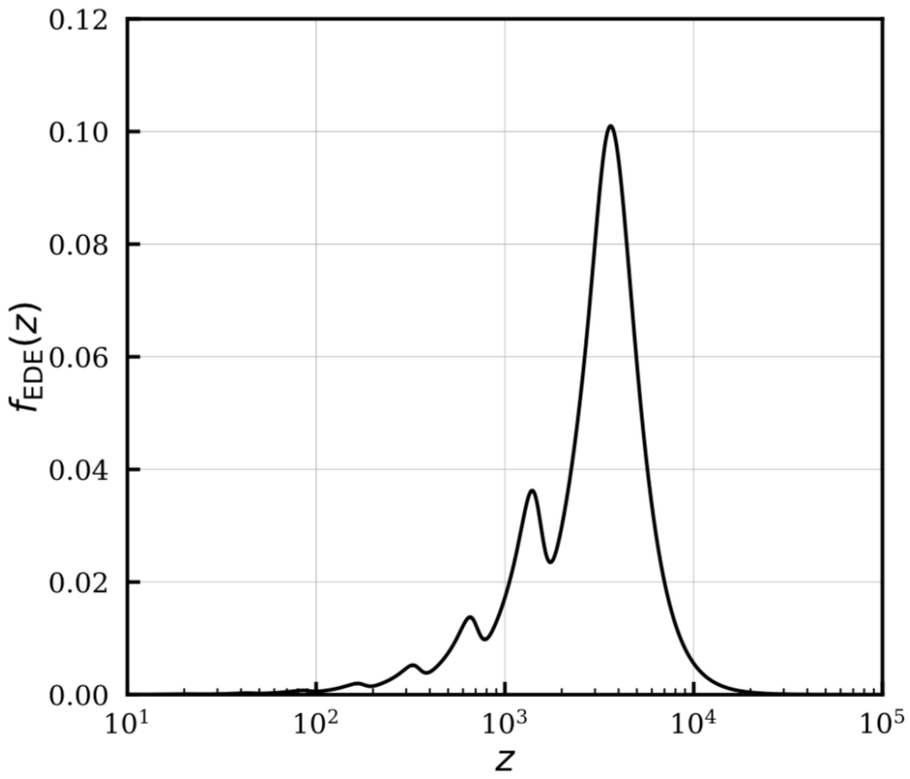
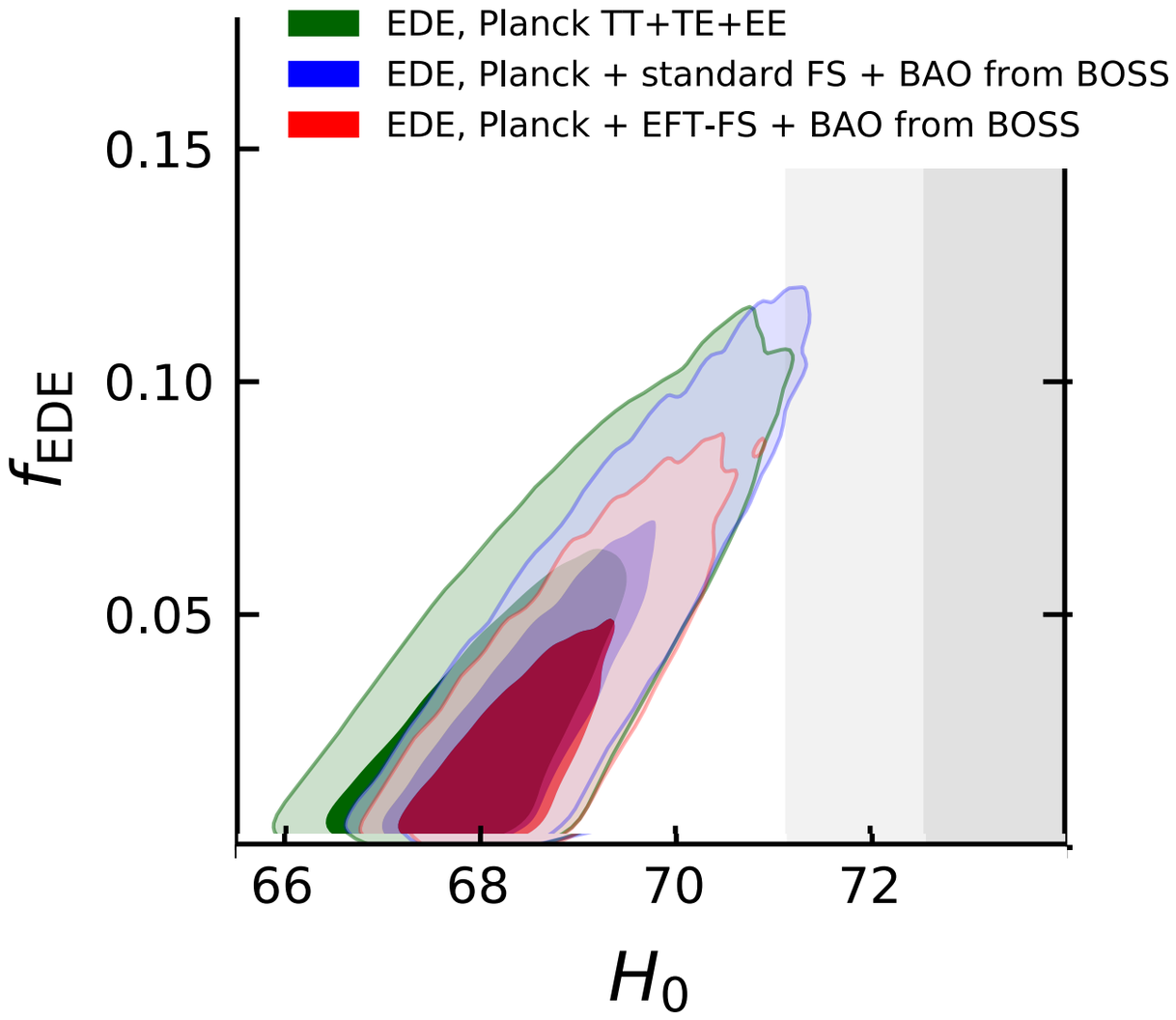


FIG. 1. Fraction of the cosmic energy density in the EDE field as a function of redshift, for the parameters in Eq. (7).

$$V = V_0 \left(1 - \cos(\phi/f)\right)^n \quad , \quad V_0 \equiv m^2 f^2 \, .$$

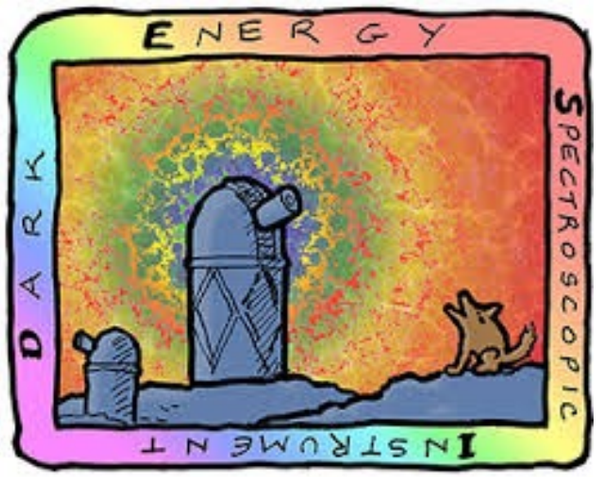


2006.11235

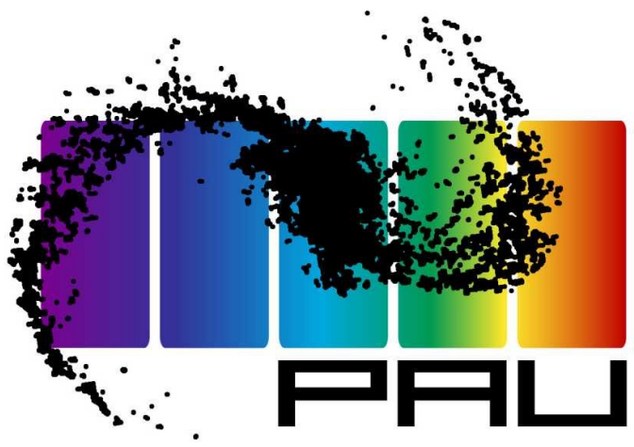
H0-resolving params. ruled out by FS

The future


euclid
consortium


ENERGY
SPECTROSCOPIC
INSTRUMENT
DARK


LSST
CORPORATION


PAU


SKA
SQUARE KILOMETRE ARRAY


NEW MISSION FROM NASA
SPHEREX

Forecast for Euclid/DESI - like survey

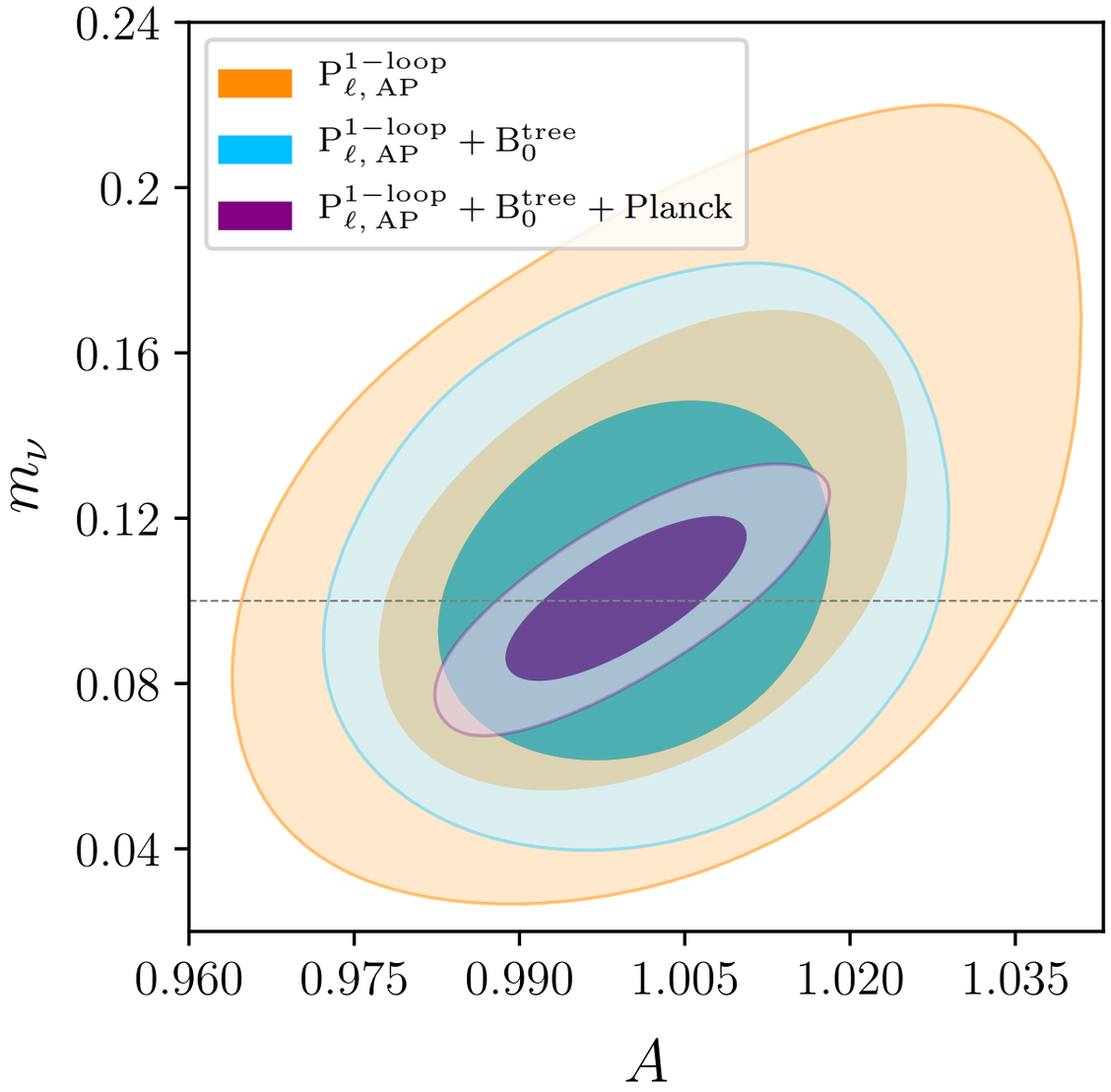
1907.06666 *w/ A. Chudaykin*

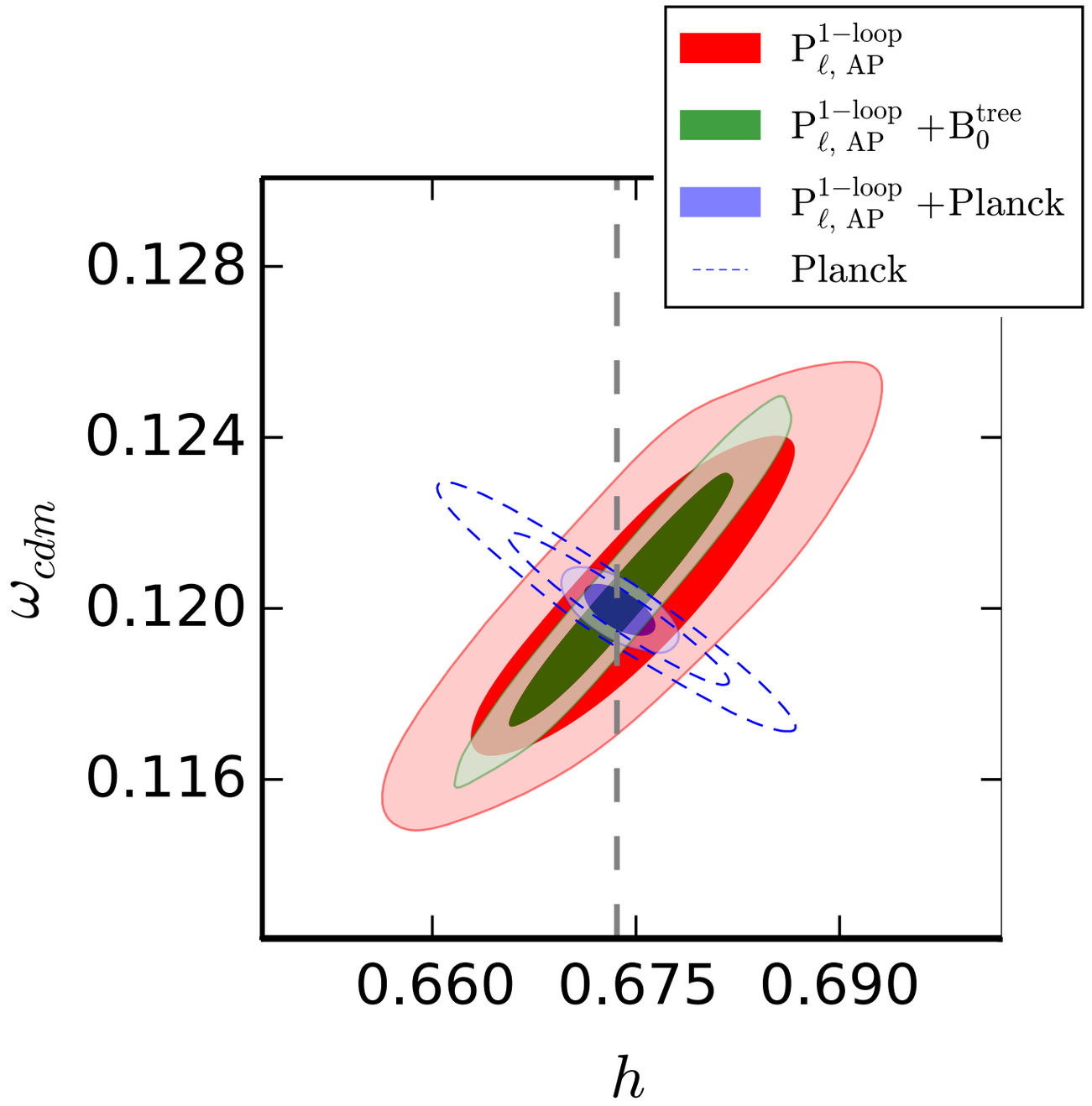
What if you gave me the data right now?

- ★ MCMC using the same pipeline w/ full non-linear model
- ★ Marginalize over all necessary nuisance params
- ★ Same data cuts as we use now

MCMC forecast for Euclid-like survey

$$\sigma(m_\nu) = 13 \text{ meV}$$





1907.06666 *w/ A. Chudaykin*

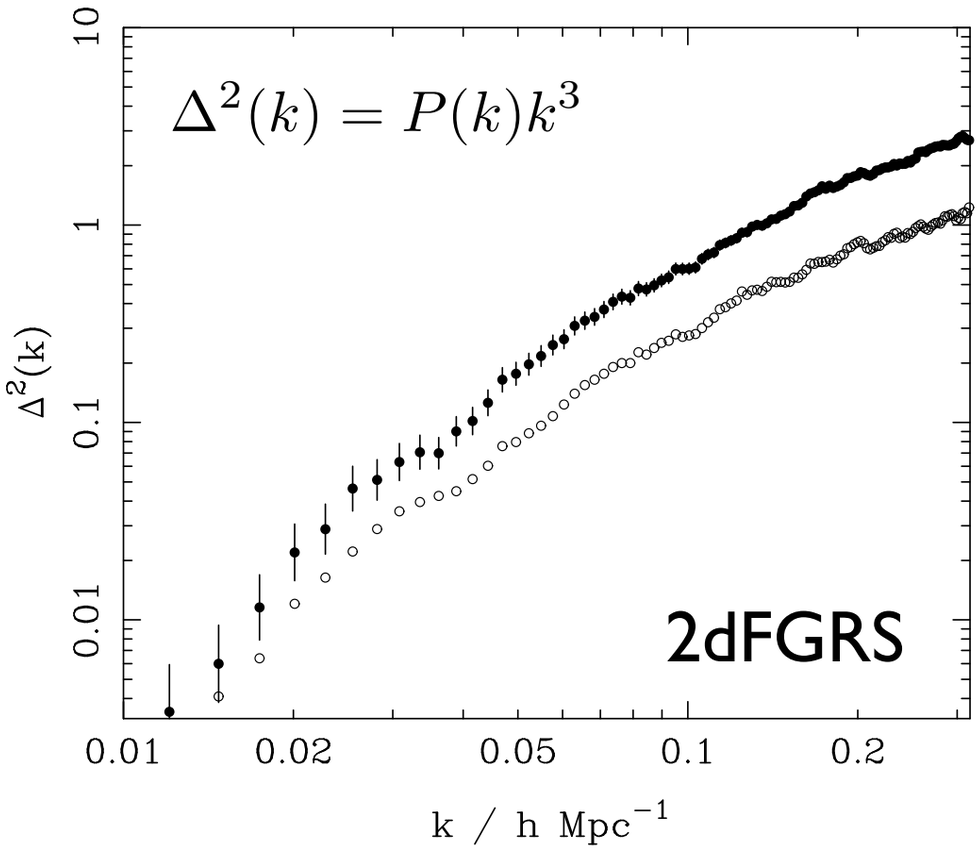
Summary

- LSS (full-shape) is a powerful probe
- PT is robust & precise, better than 0.1%
- BOSS rivals Planck for H0 and Omegam
- Cosmology similar or better than Planck with DESI/Euclid
- Detecting neutrino masses @5sigma

Ask me about the covariance matrices !

Thanks!

Bias and RSD

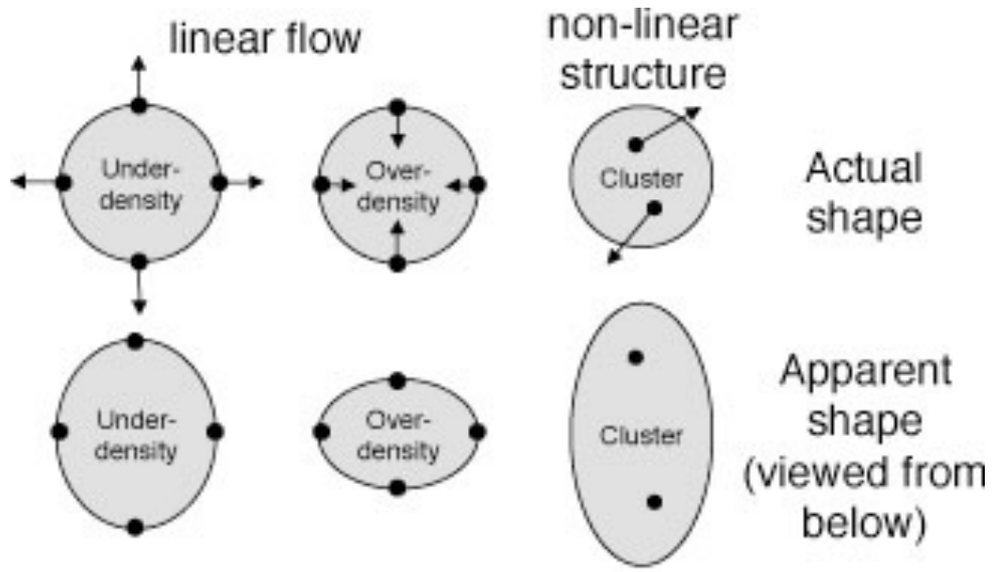


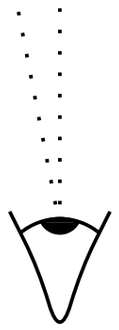
Red galaxies

blue galaxies

$$\delta_g = b_1 \delta_{dm}$$

$$v_{\rm obs} = Hr + v_{\rm pec}$$



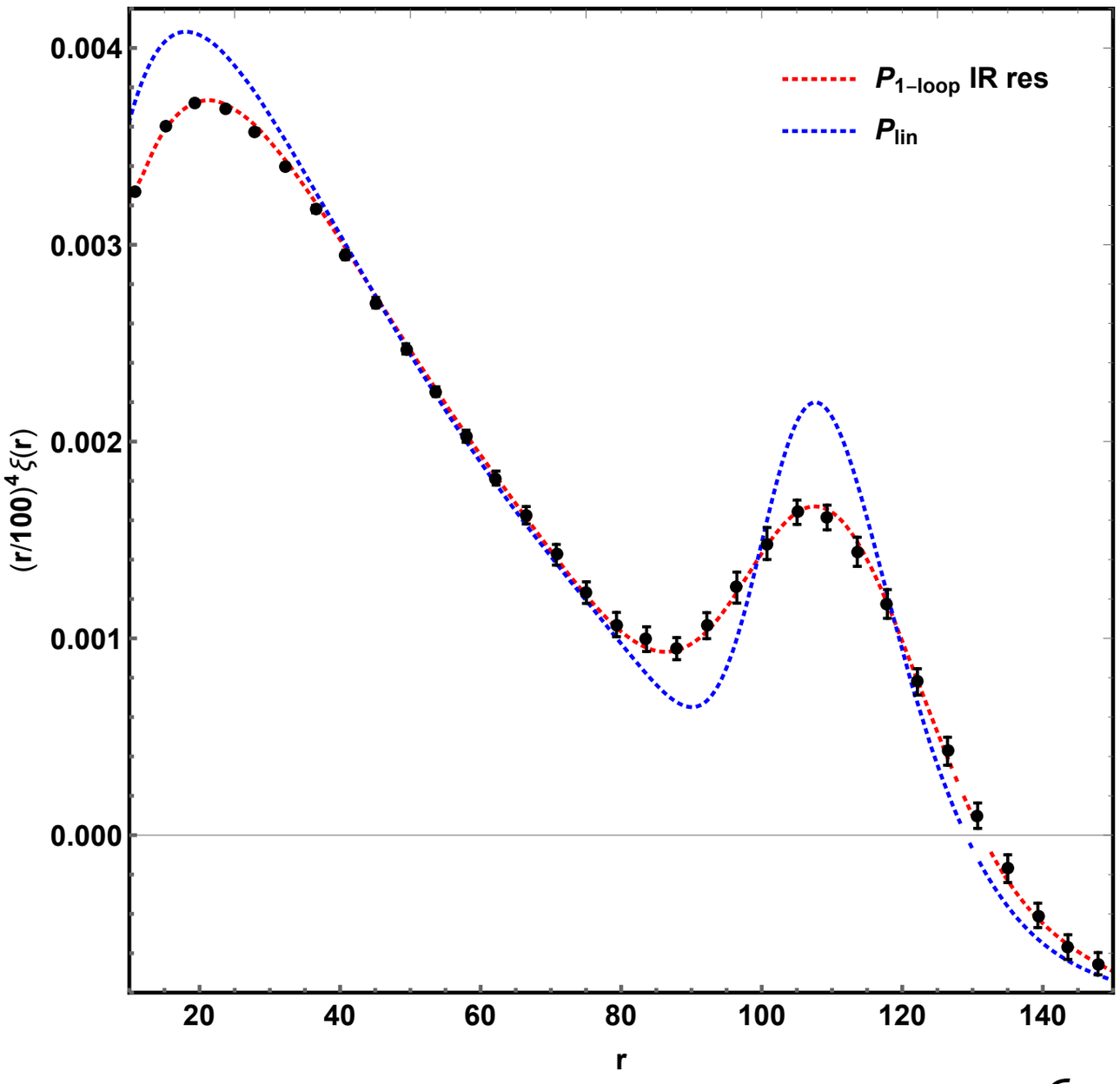


$$P_L^r(k, \cos(\mathbf{k}, \mathbf{n})) = \left(b_1 + \frac{d \ln D_+}{d \ln a} \cos^2(\mathbf{k}, \mathbf{n})\right)^2 P_L(k)$$

$$\delta_g = b_1 \delta_{dm} + \frac{b_2}{2} \delta_{dm}^2 + \frac{b_{\mathcal{G}_2}}{2} ((\partial_i \partial_j \Phi)^2 - (\Delta \Phi)^2) + \ldots$$

astro-ph/0309238

BAO and IR resummation



Measurements
by T. Baldauf

NO fitting parameters!

Same procedure for all tracers!

Crocce, Scoccimarro (2007)

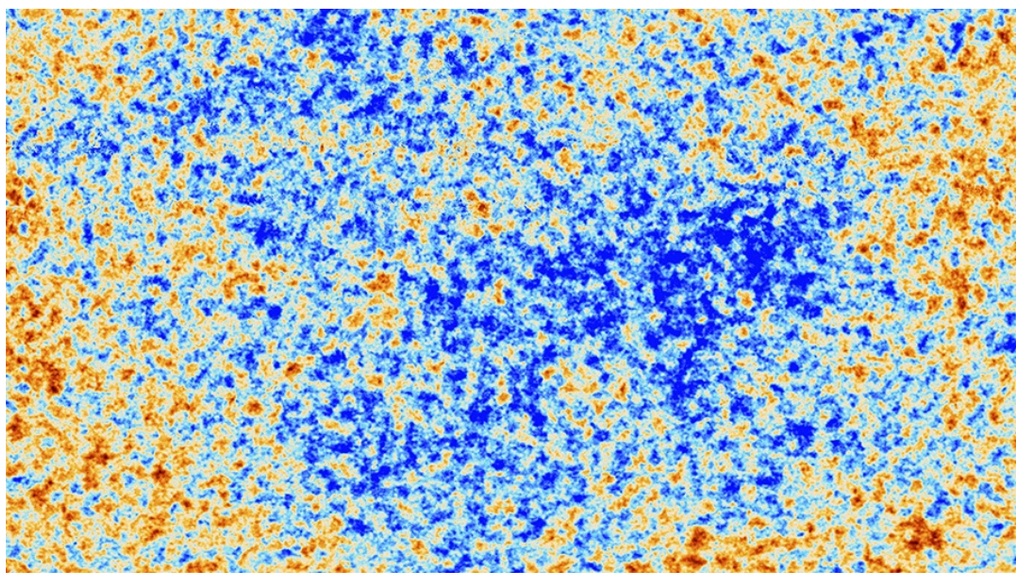
Senatore, Zaldarriaga (2014)

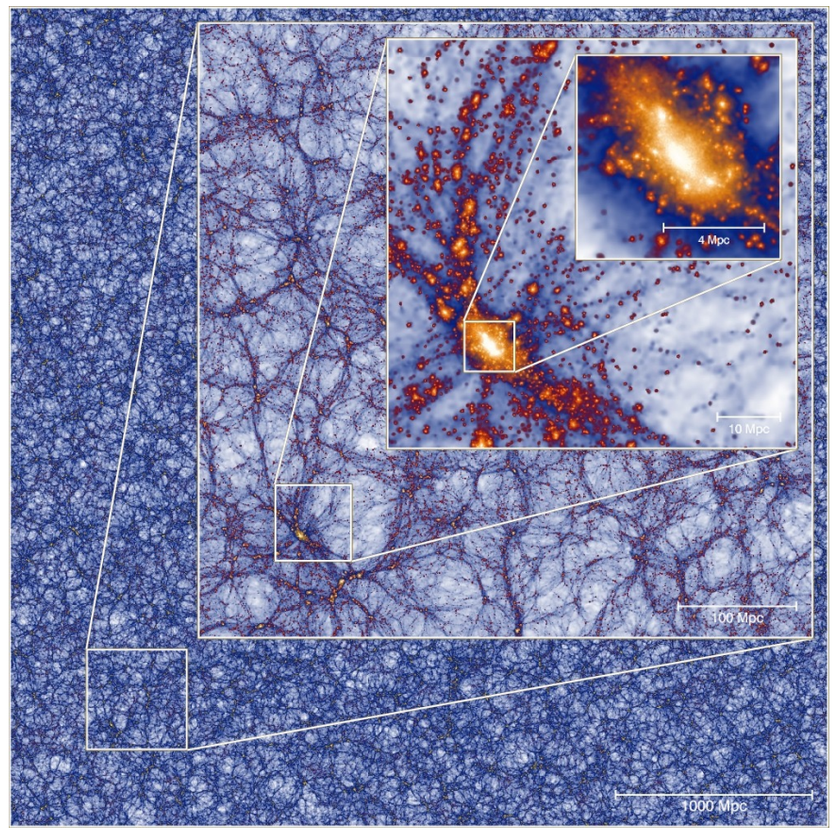
Baldauf, Mirbabayi, Simonovic, Zaldarriaga (2015)

Blas, Garny, MI, Sibiryakov (2016)

…

Non-Linearities come into play



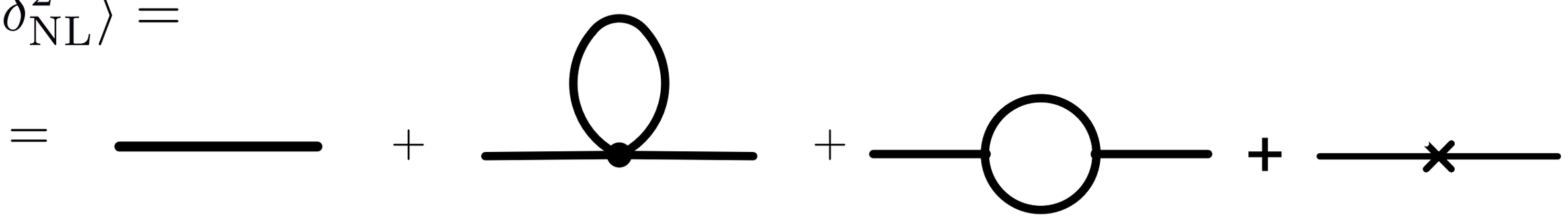


Baumann, Nicolis, Senatore, Zaldarriaga 2012: effective field theory approach

$$\delta_{\rm NL} = \delta_L + F_2\delta_L^2 + \ldots + \gamma\nabla^2\delta_L + \ldots$$

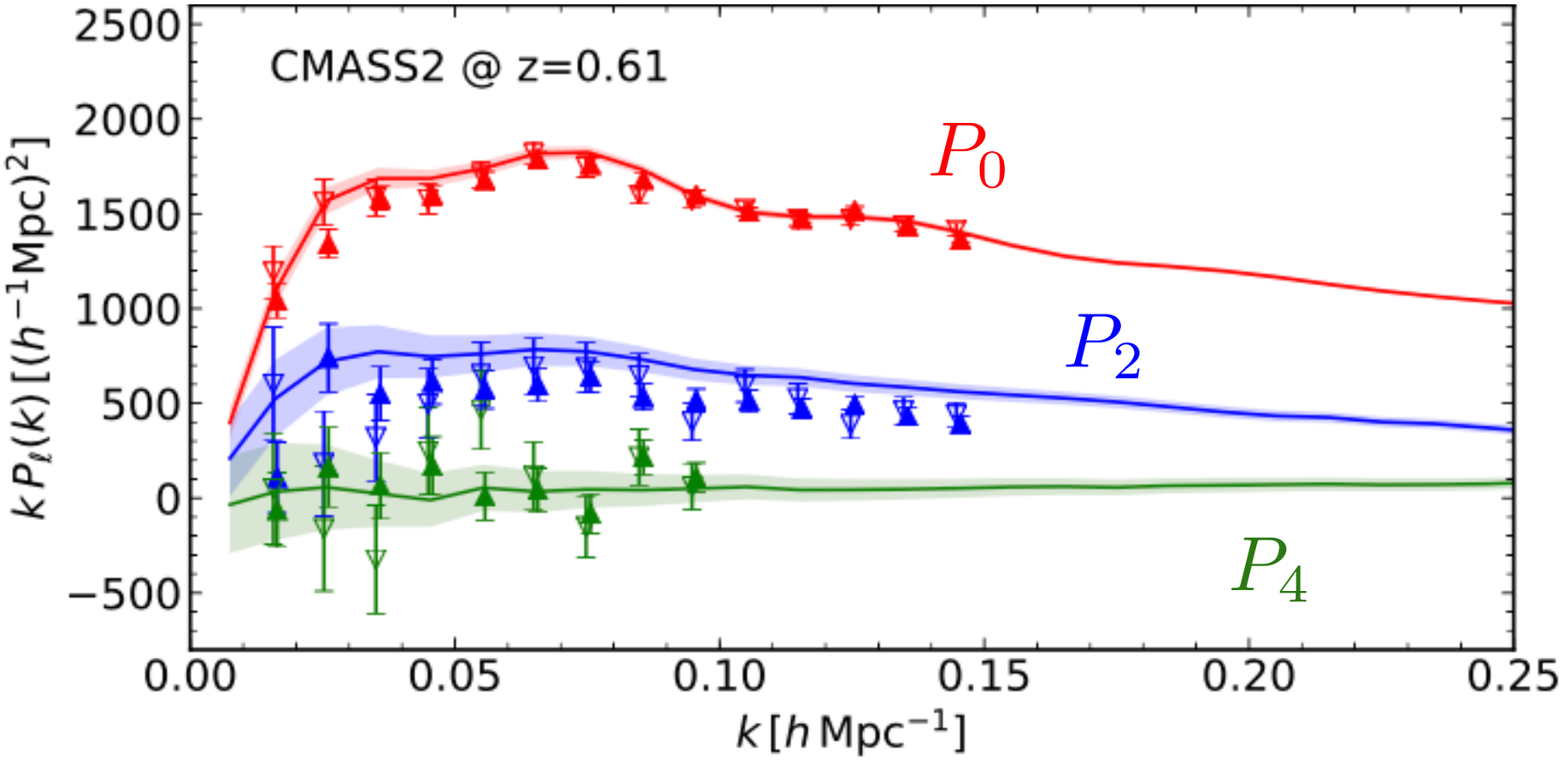
"counterterms"

$$\langle\delta^2_{\rm NL}\rangle =$$



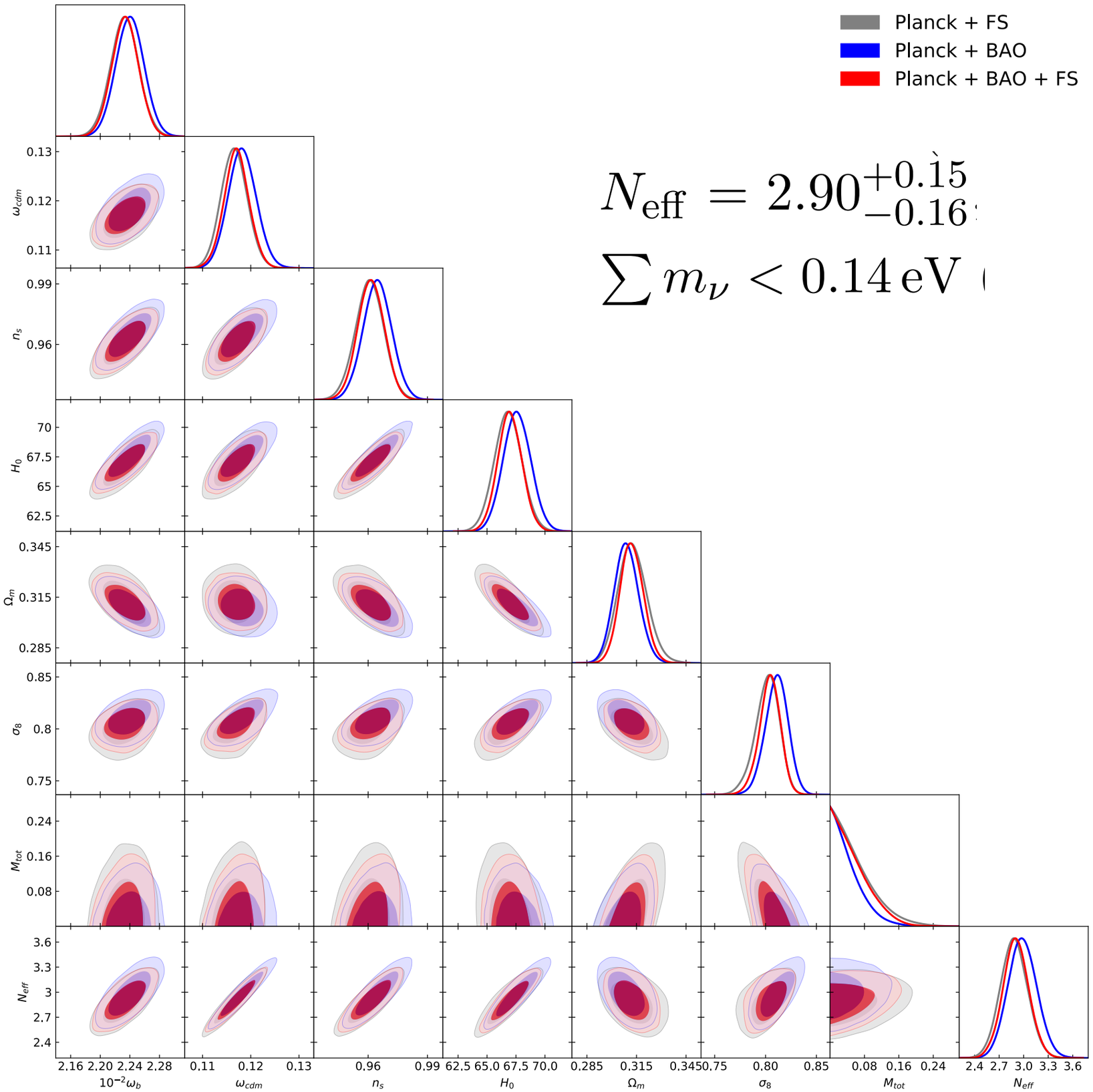
Blinded challenge

- ★ Large N-body sims $\sim 600\ (\mathrm{Gpc}/h)^3$
  =100x BOSS = 10x DESI
- ★ BOSS-like galaxies
- ★ 3 unknown parameters: (Ω_m, H_0, A_s)
- ★ Given: redshift space P(k)



2003.08277

Combining with Planck

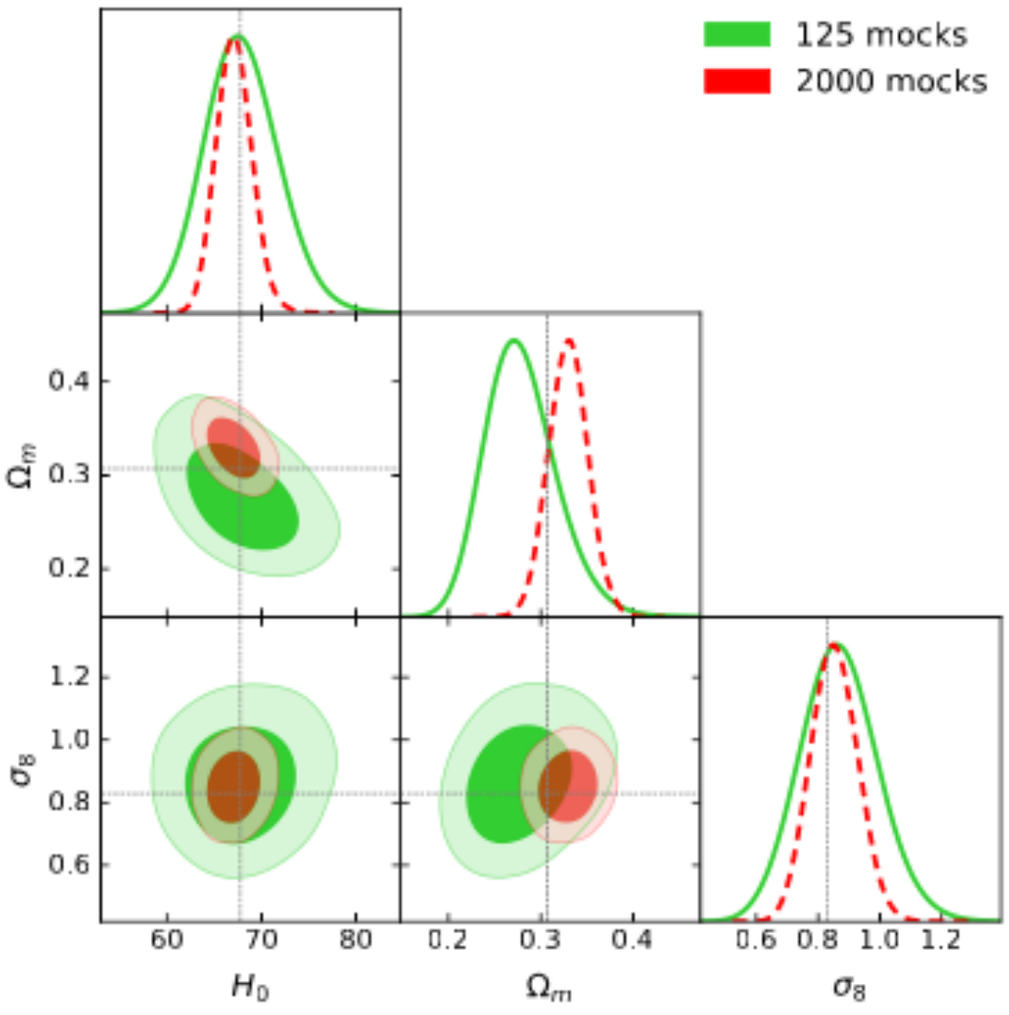


$$N_{\rm eff} = 2.90^{+0.\grave{1}5}_{-0.16}$$

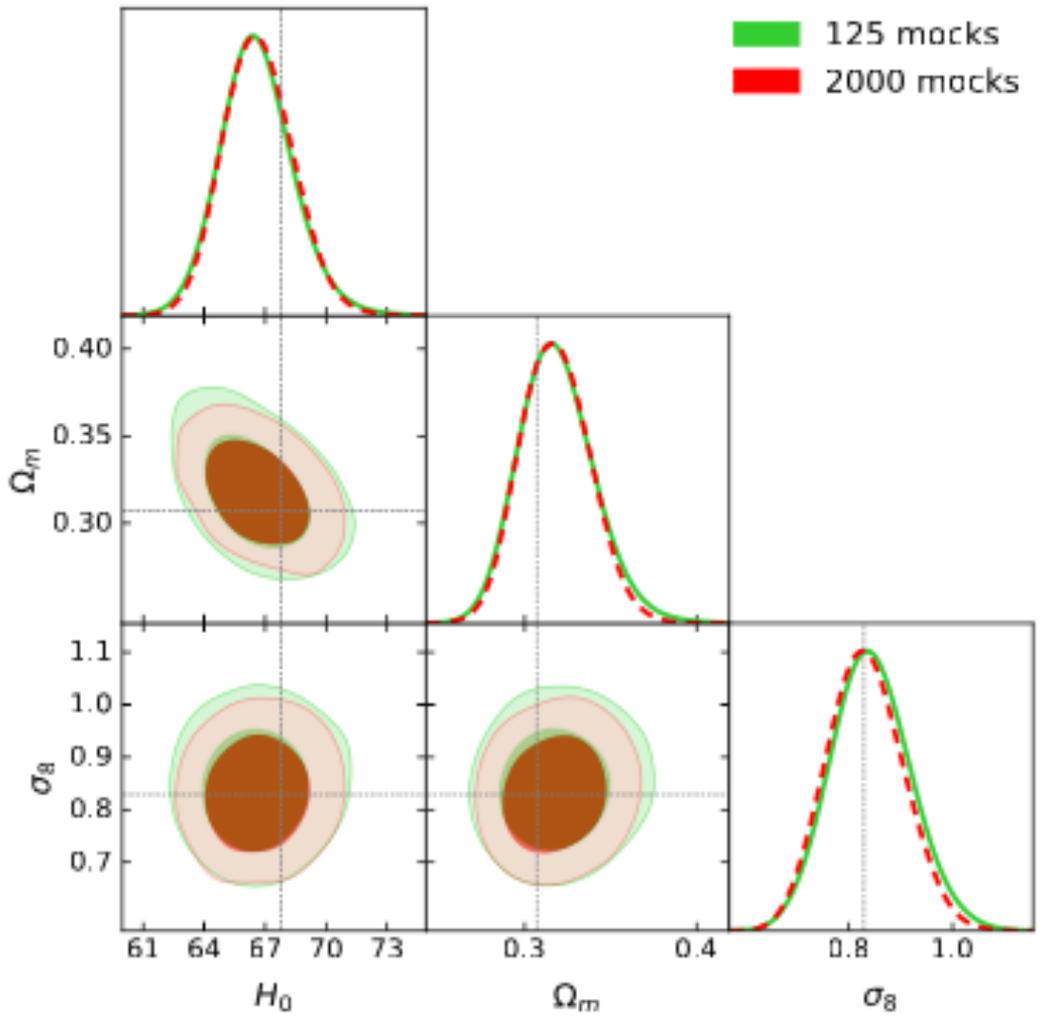
$$\sum m_\nu < 0.14\,{\rm eV}$$

Covariance matrices

★ Covariance matrices: accurate parameter estimation with few mocks or without them!



(a) 96-bin Power Spectrum

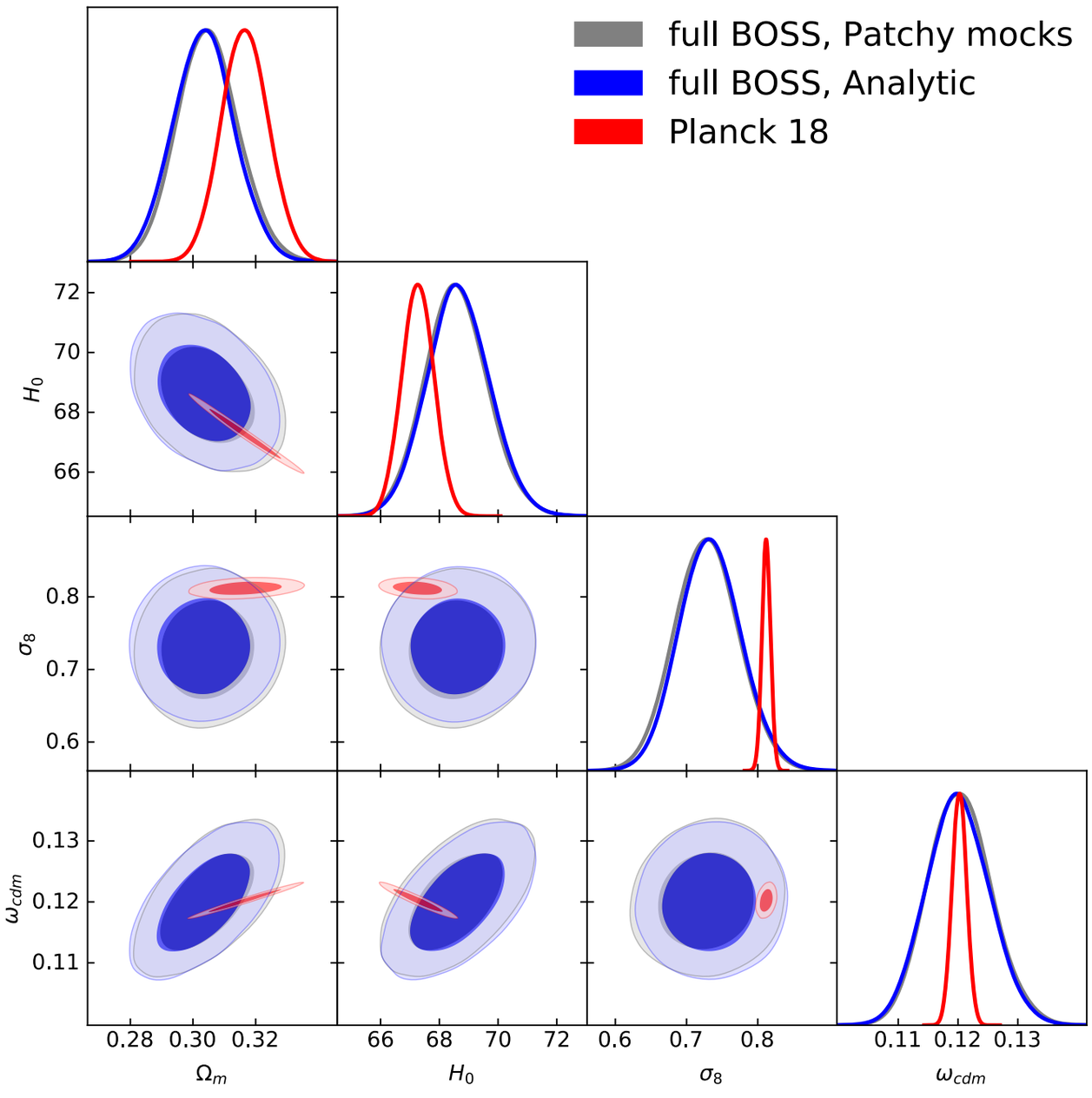


(c) 12 Subspace Coefficients

Philcox, MI, Zaldarriaga, Simonovic, Schmittfull

Covariance matrices

★ Covariance matrices: accurate parameter estimation with few mocks or without them!



PT covariances

Wadekar, Scoccimarro, 1910.02914

see Jay Wadekar's talk