Cosmological parameters from current and future redshift surveys

Misha Ivanov (NYU)

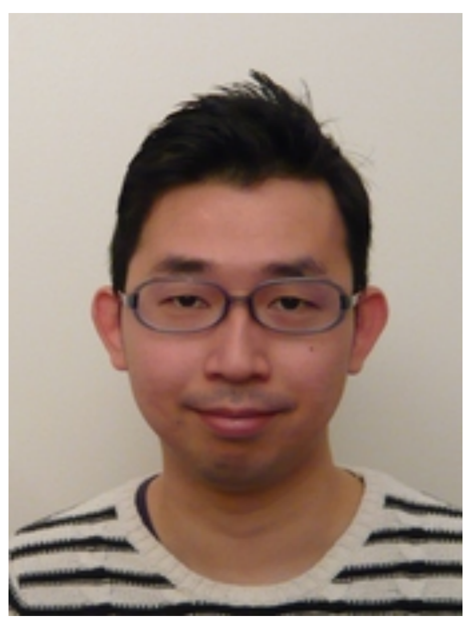
O. Philcox

M. Simonovic

M. Zaldarriaga

A. Chudaykin

M. Takada



T. Nischimichi

+Y. Ali-Haimoud, J. Lesgourgues, C. Hill, E. McDonough, M. Toomey, S. Alexander, L. Senatore, P. Zhang, G. d'Amico

H0 or T0 tension ?

$$T_{0,\mathrm{FIRAS}} = (2.72548 \pm 0.00057)\ \mathrm{K}$$

What if we don't use it?

w Y. Ali-Haimoud, J. Lesgourgues, 2005.10656

Controversy in the literature:

Planck,1502.01589 ++

large impact (!)

no constraints (?)

T0 is only a cosmic clock

it has nothing to do with recombination !

$$\varpi_i \equiv \frac{\omega_i}{T_0^3}, \qquad i = b, c.$$

$$T_* \approx 2970 \left(\frac{\varpi_m\,\mathrm{K}^3}{7.06\times10^{-3}}\right)^{0.0105} \left(\frac{\varpi_b\,\mathrm{K}^3}{1.1\times10^{-3}}\right)^{-0.028} \mathrm{K}\,.$$

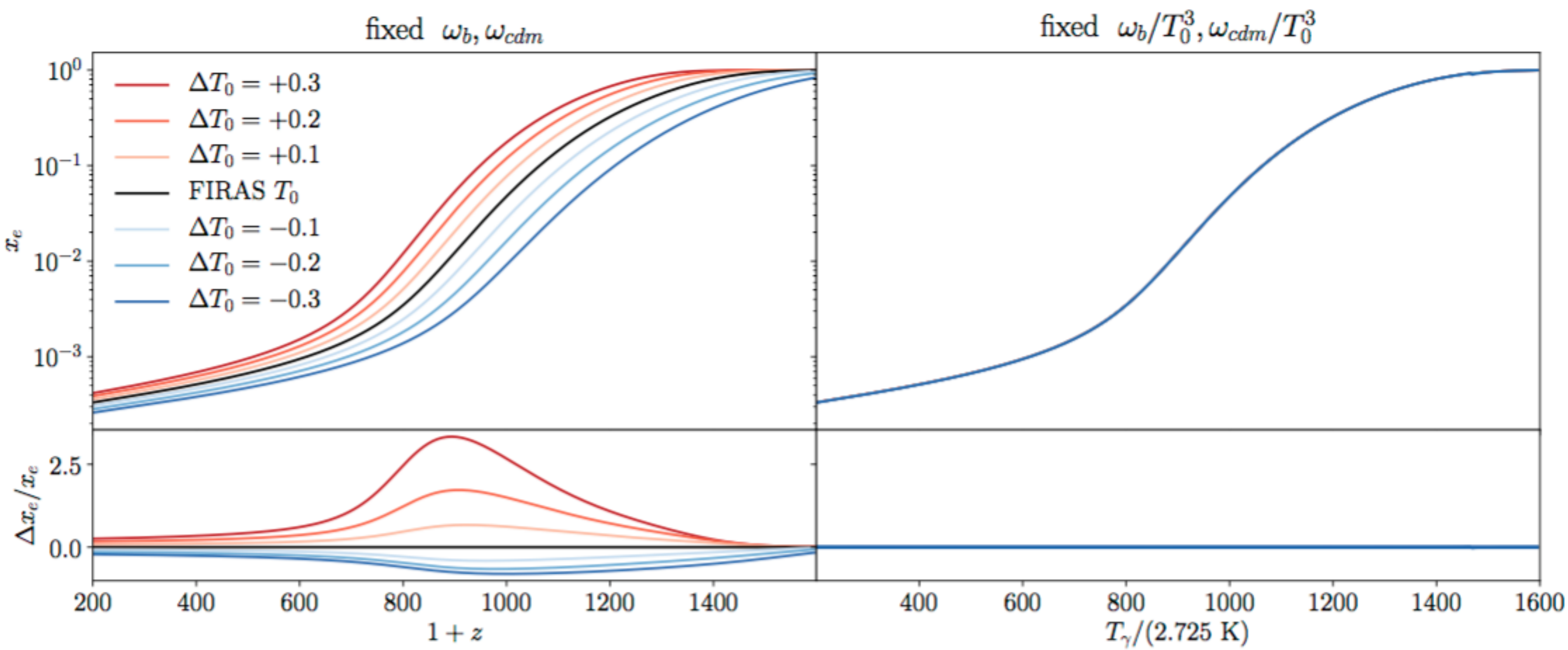
H0 or T0 tension ?

Observer-dependent

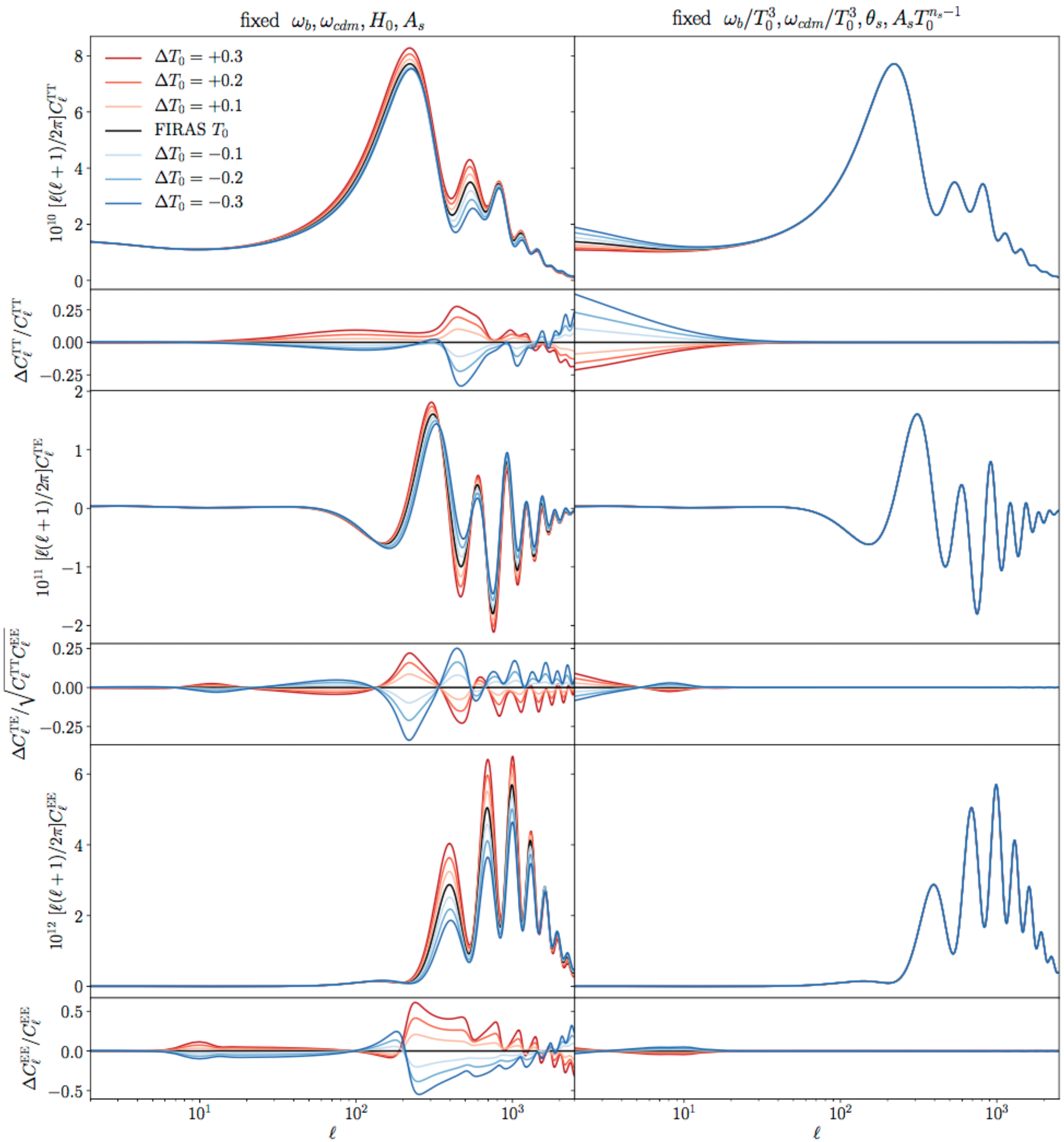
$$H_0, T_0, \omega_m\ (\Omega_m h^2), \omega_b\ (\Omega_b h^2)$$

Observer-independent

$$\Lambda, \omega_m/T_0^3, \omega_b/T_0^3$$



H0 or T0 tension ?



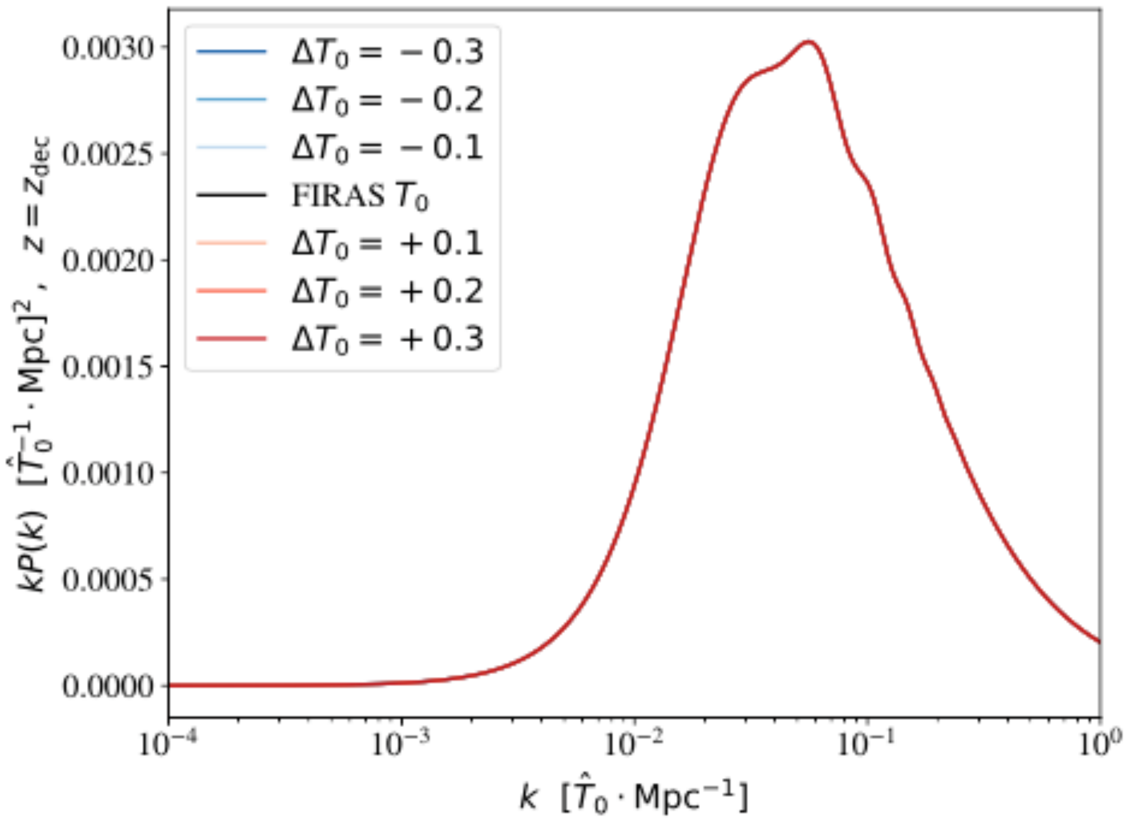
$$\theta_s \simeq \text{const}$$

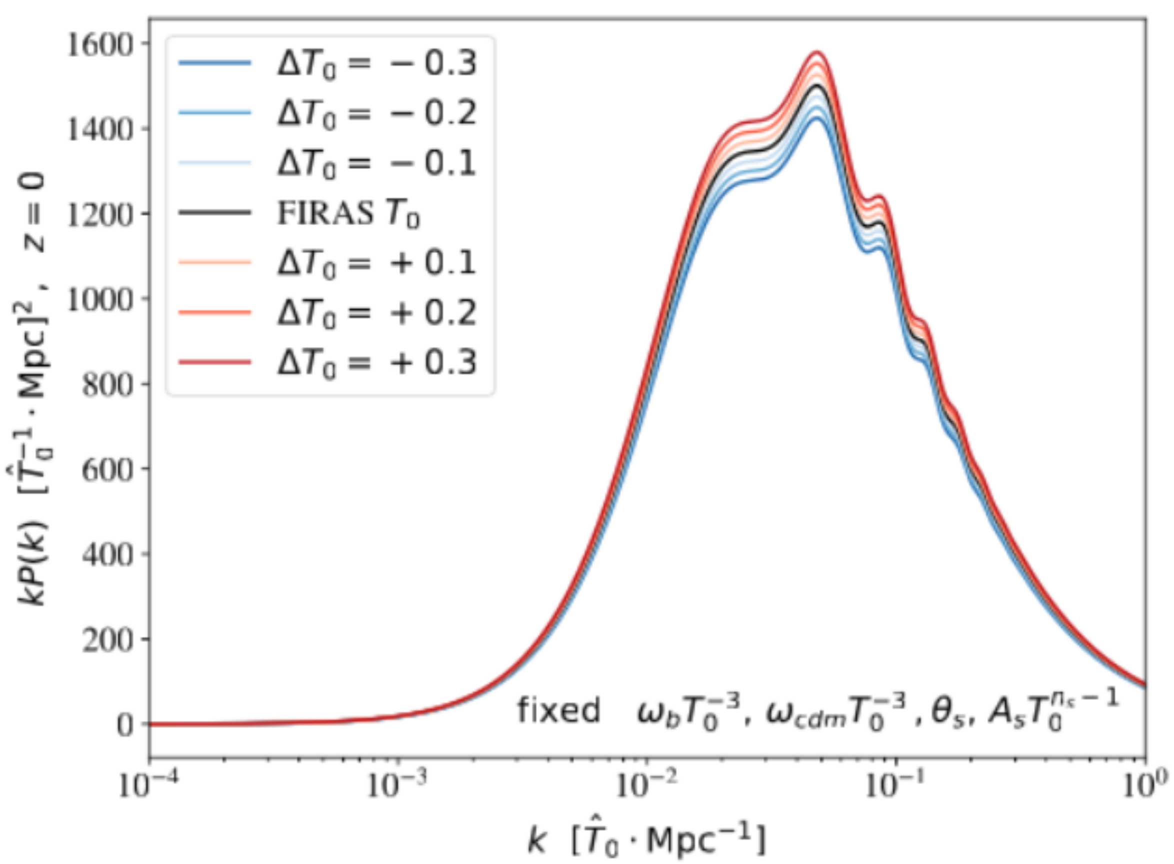
$$\theta_s = \frac{r_d}{D_A(z_*)}$$

$$\left.\frac{\partial \ln D_A}{\partial \ln T_0}\right|_{\text{Planck}} \approx -0.22\,, \quad \left.\frac{\partial \ln D_A}{\partial \ln h}\right|_{\text{Planck}} \approx -0.19$$

$$T_0 H_0^{1.2} \simeq \text{const}$$

H0 or T0 tension ?





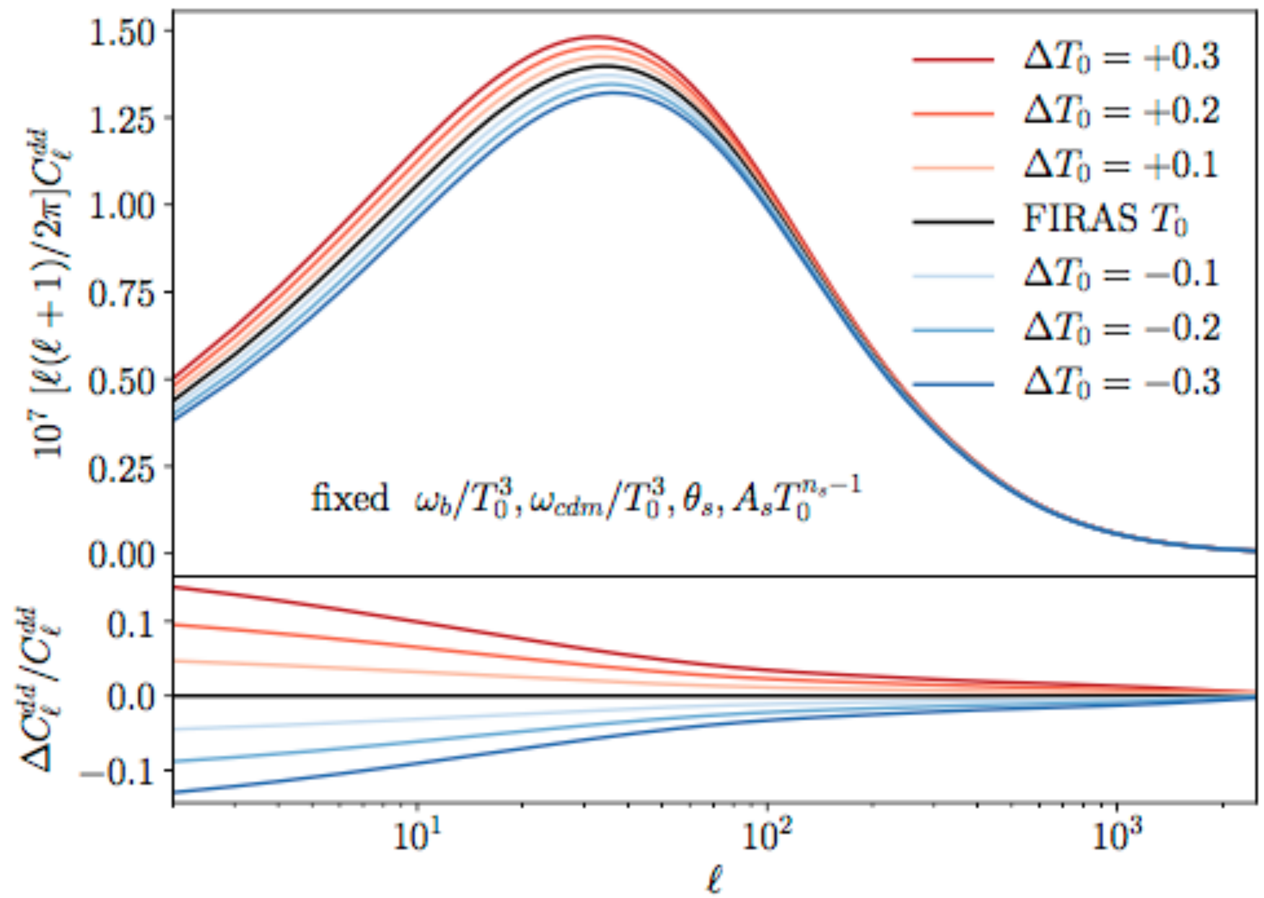
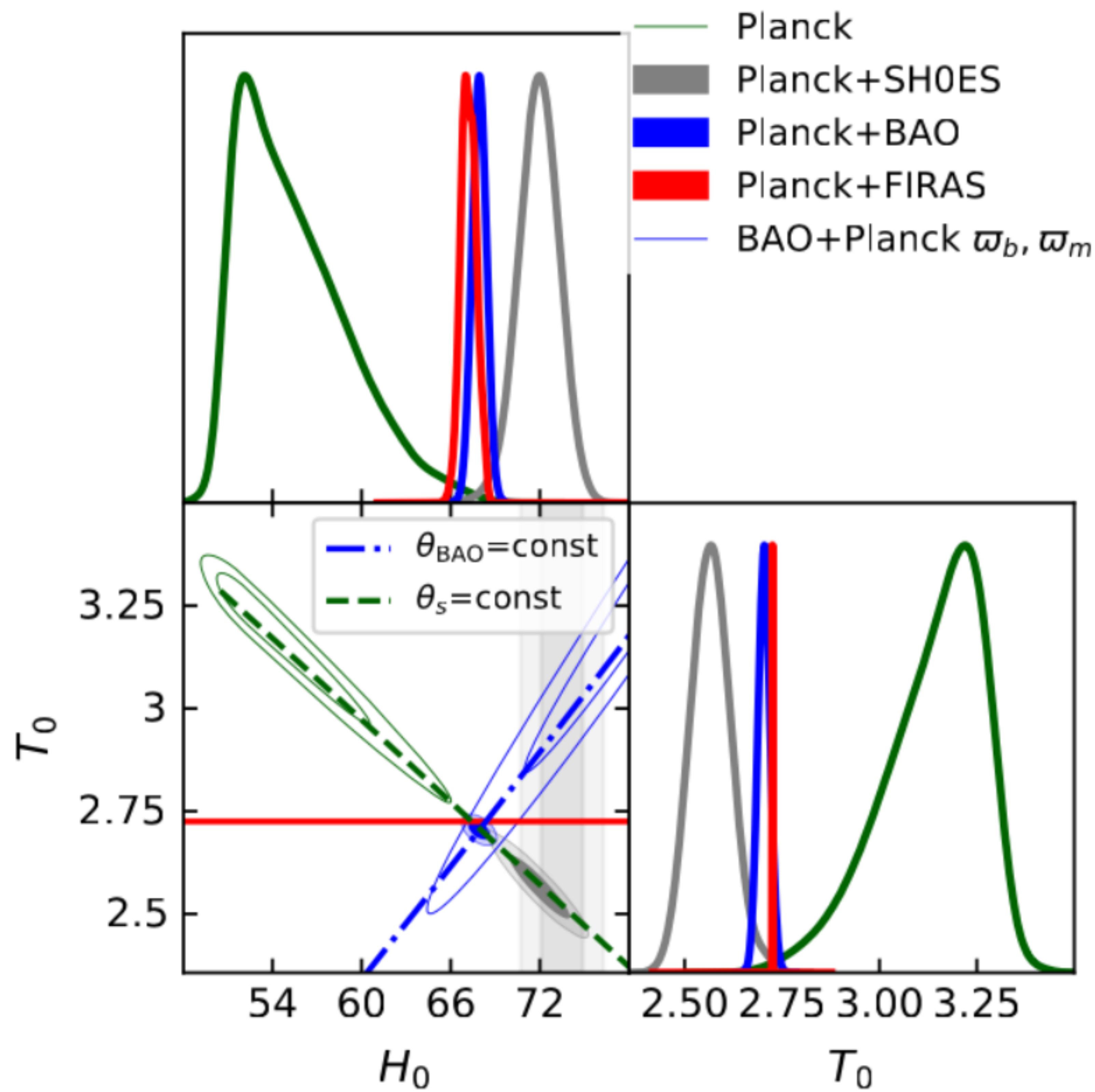


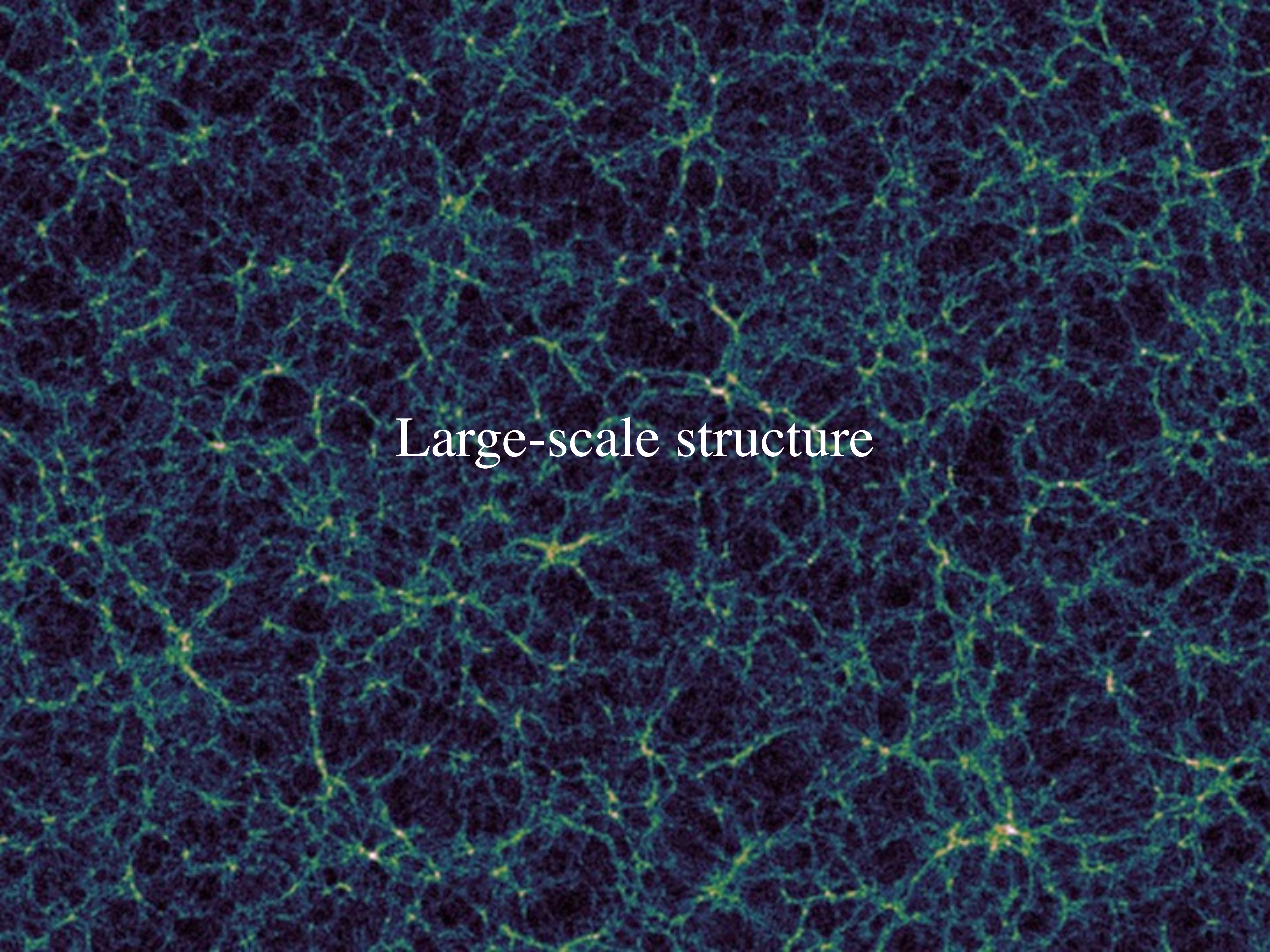
FIG. 4. Power spectrum of the lensing deflection angle as a function of T_0, for fixed $\omega_b/T_0^3, \omega_c/T_0^3, \theta_s$ and $A_s T_0^{n_s-1}$. Note that this power spectrum is computed entirely within the Limber approximation for simplicity.

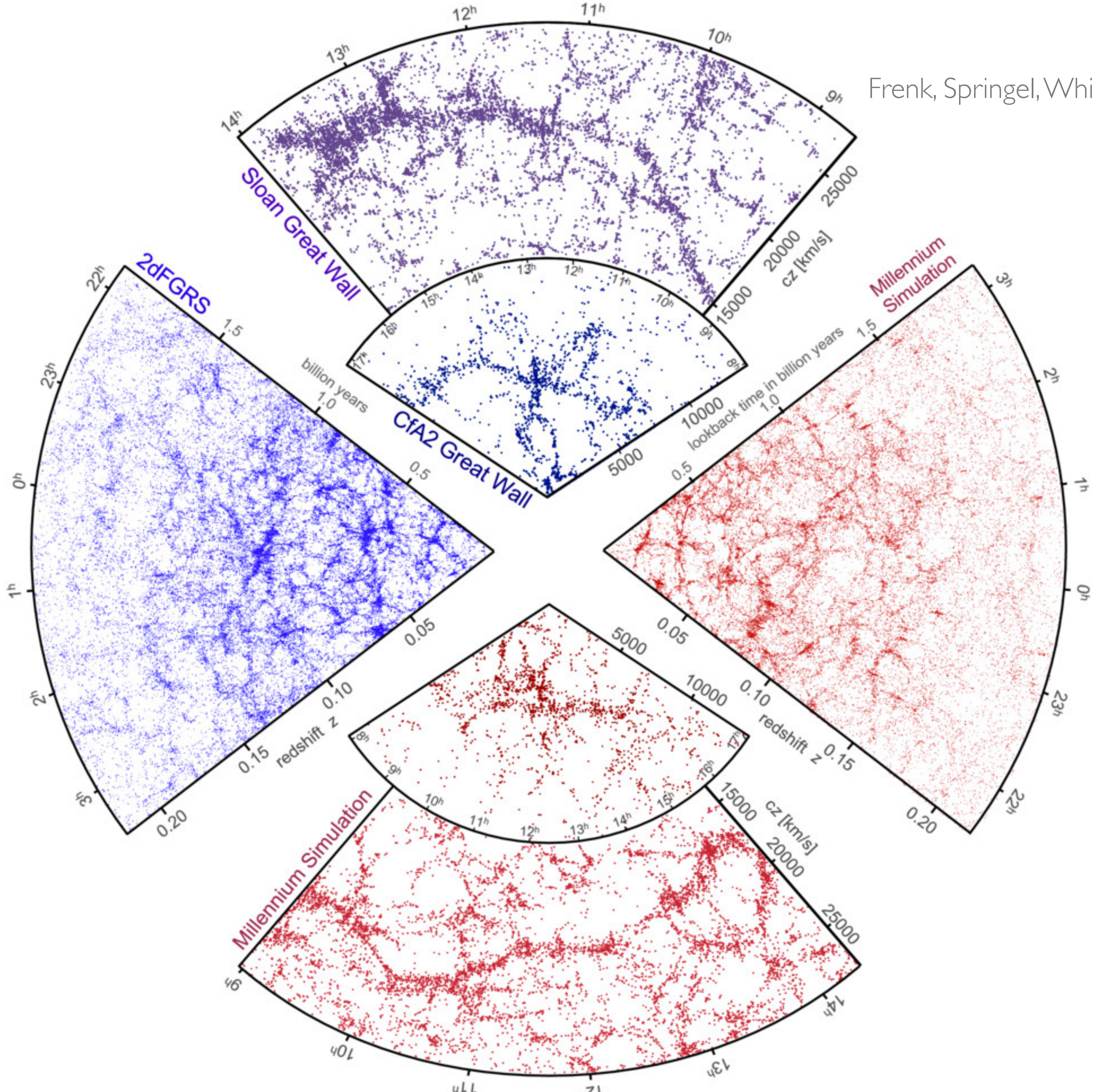
H0 or T0 tension ?



soon in v2!

Large-scale structure



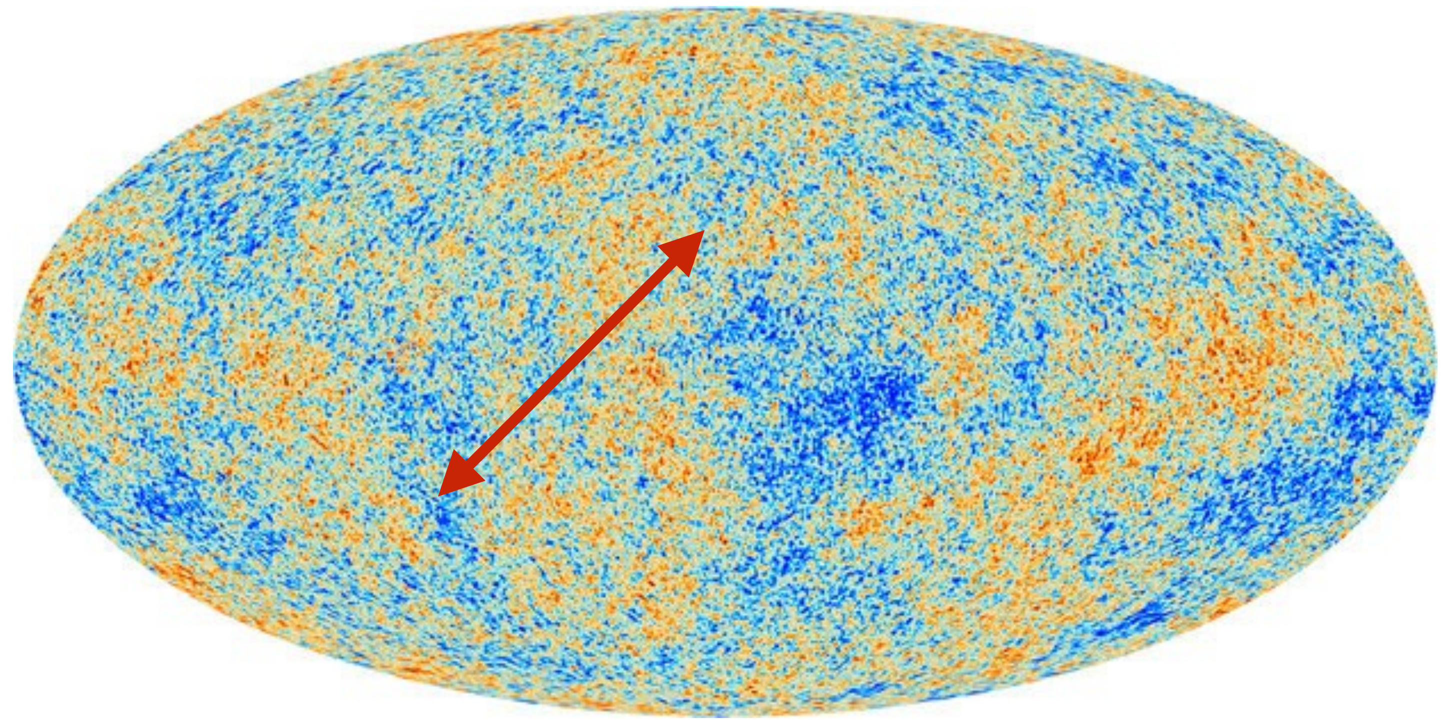


Frenk, Springel, White 06

Main goals

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

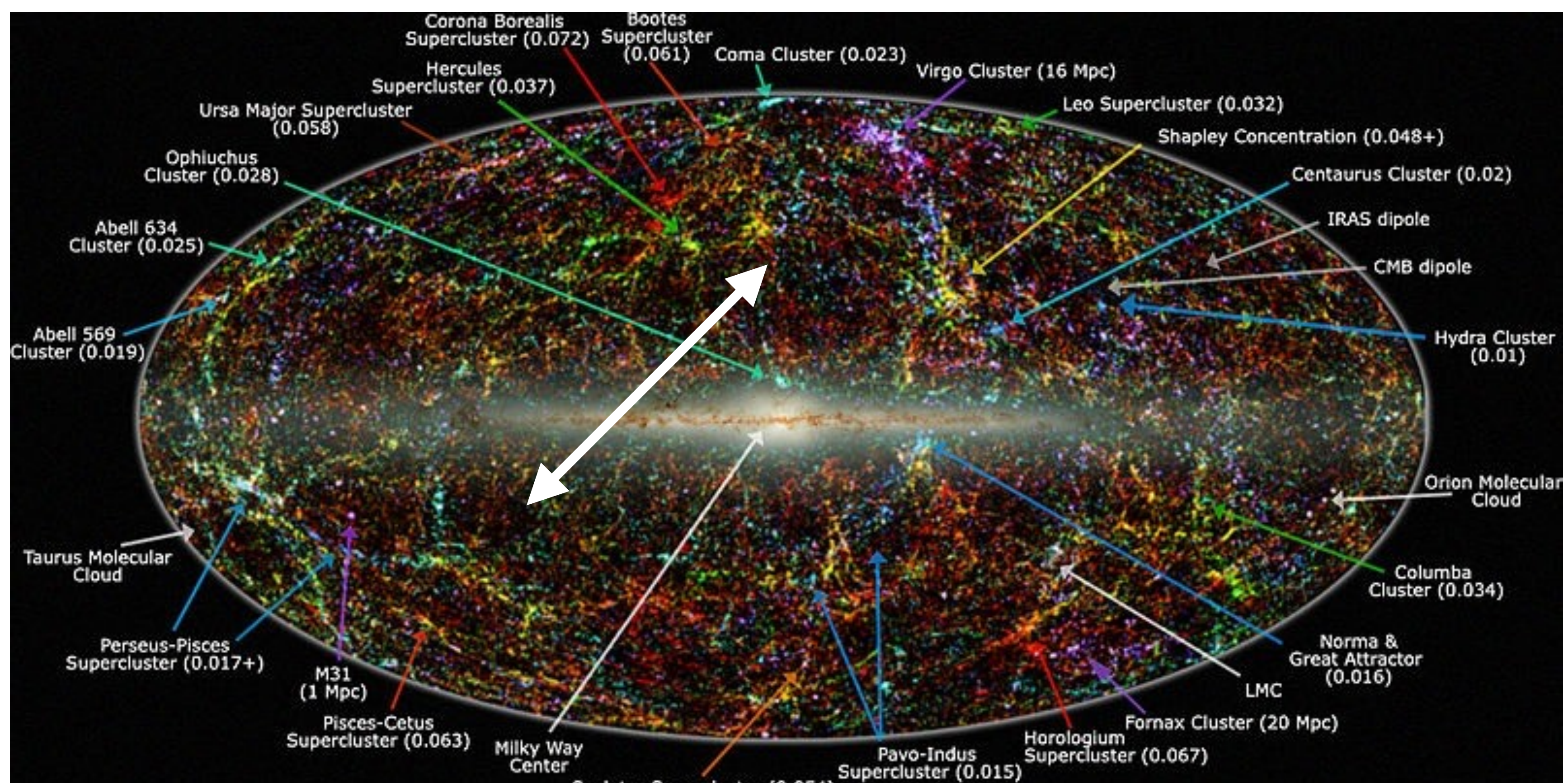
$$\ell \sim \frac{1}{\theta}$$



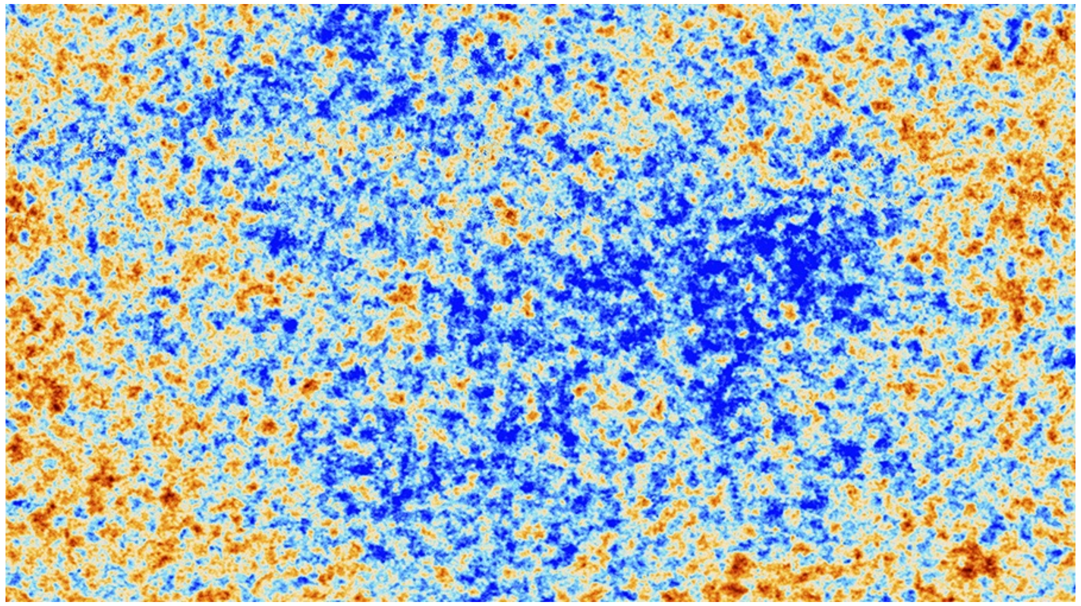
$$P(k) \sim \left(\frac{\delta \rho}{\rho}\right)^2$$

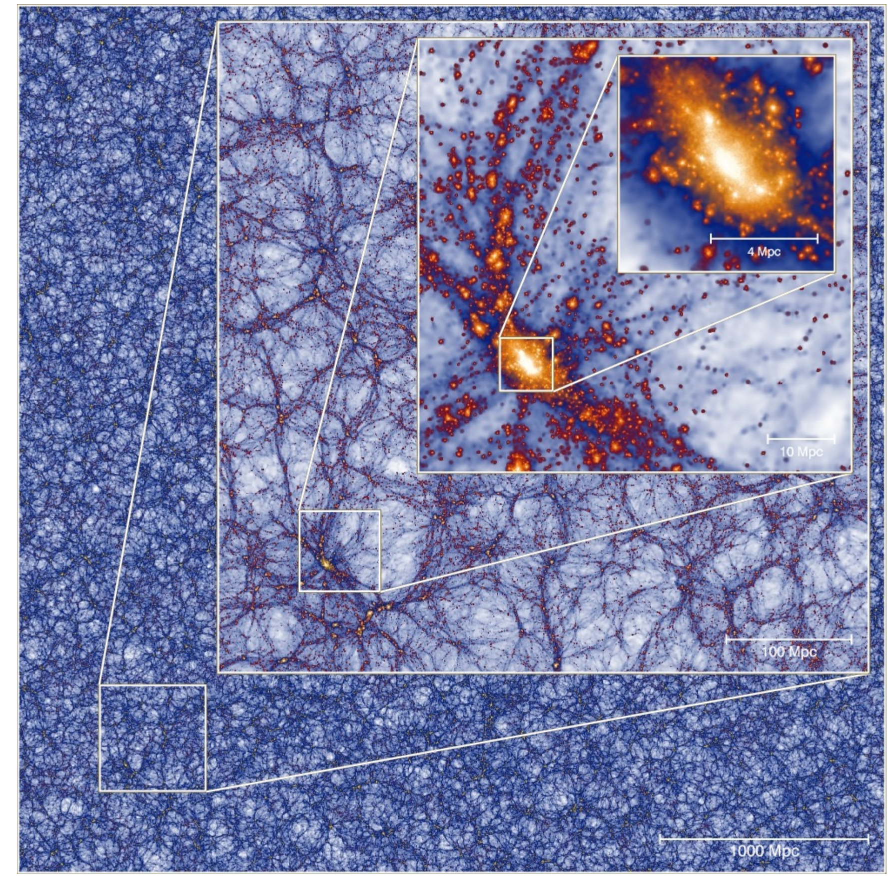
$$\delta \equiv \frac{\delta \rho}{\rho}$$

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



Non-Linearity comes into play



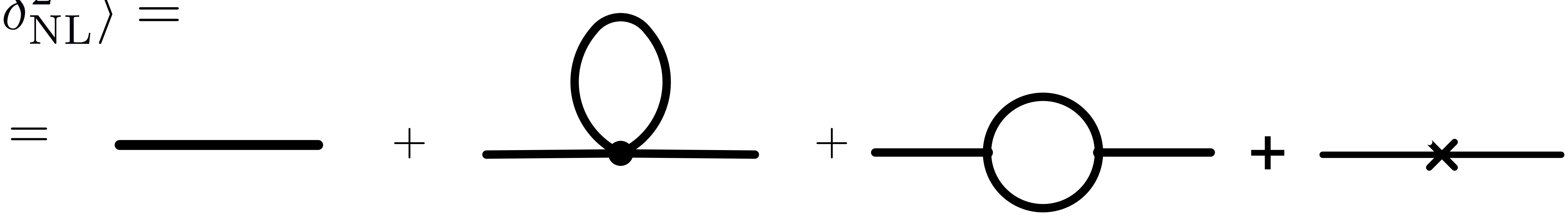


Baumann, Nicolis, Senatore, Zaldarriaga 2012: effective field theory approach

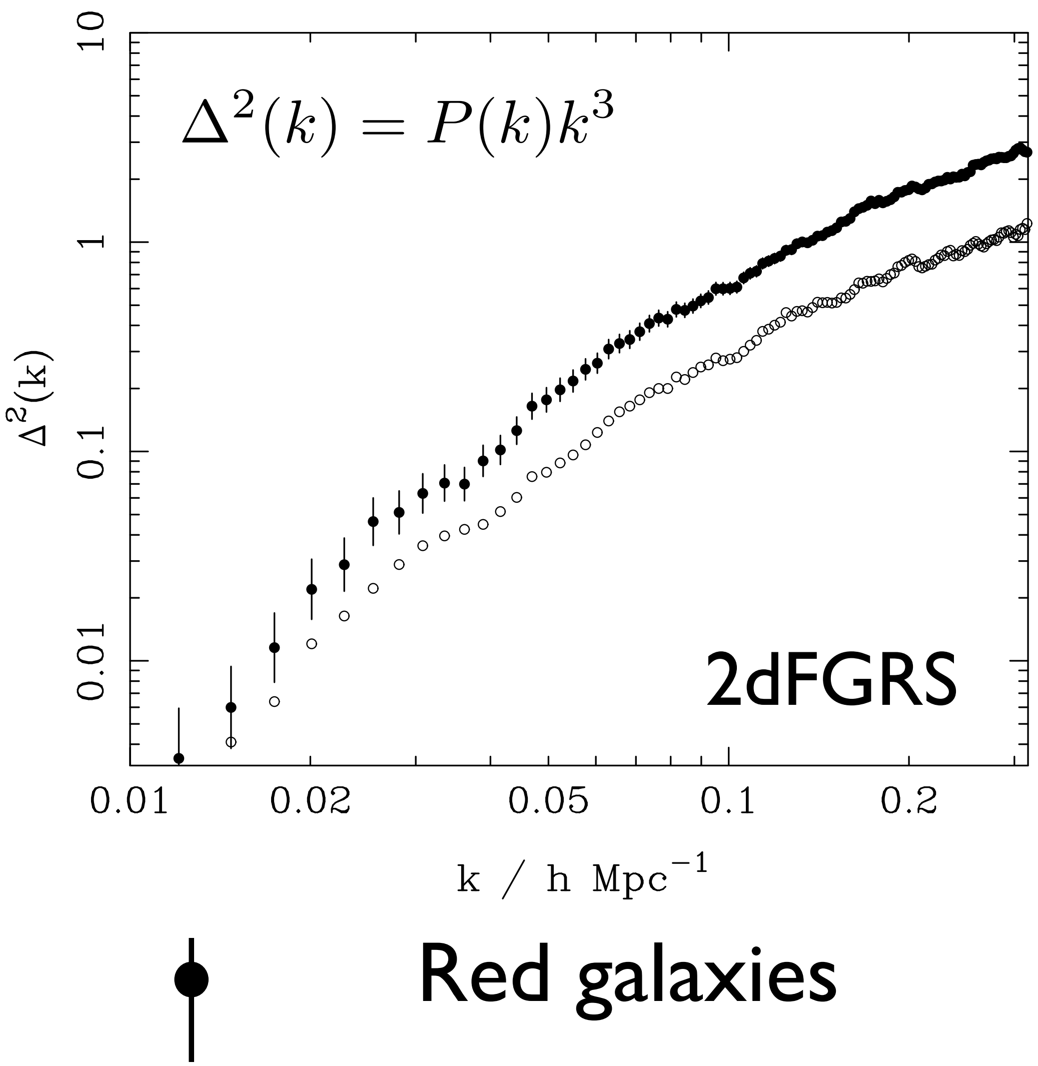
$$\delta_{\rm NL} = \delta_L + F_2 \delta_L^2 + \ldots + \gamma \nabla^2 \delta_L + \ldots$$

"counterterms"

$$\langle \delta_{\rm NL}^2 \rangle =$$

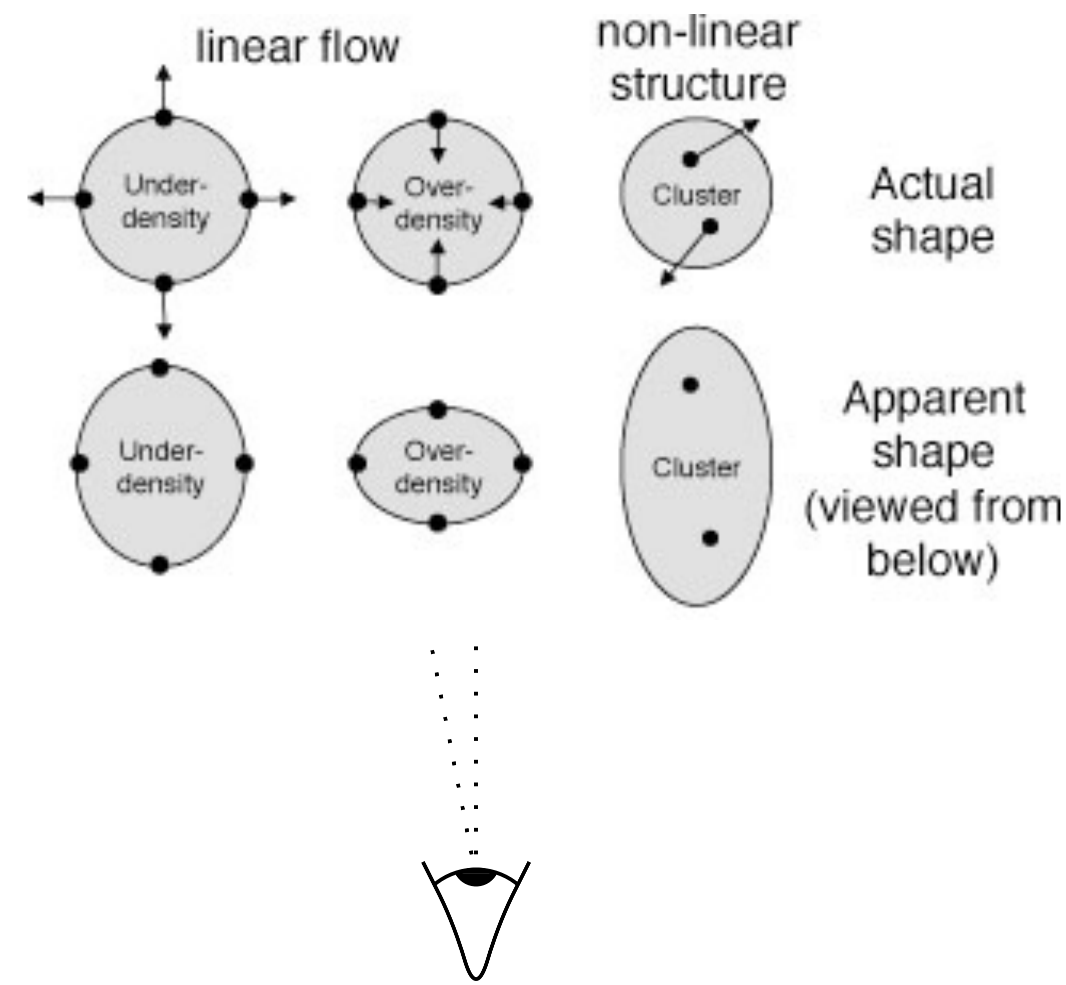


Bias and RSD



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

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

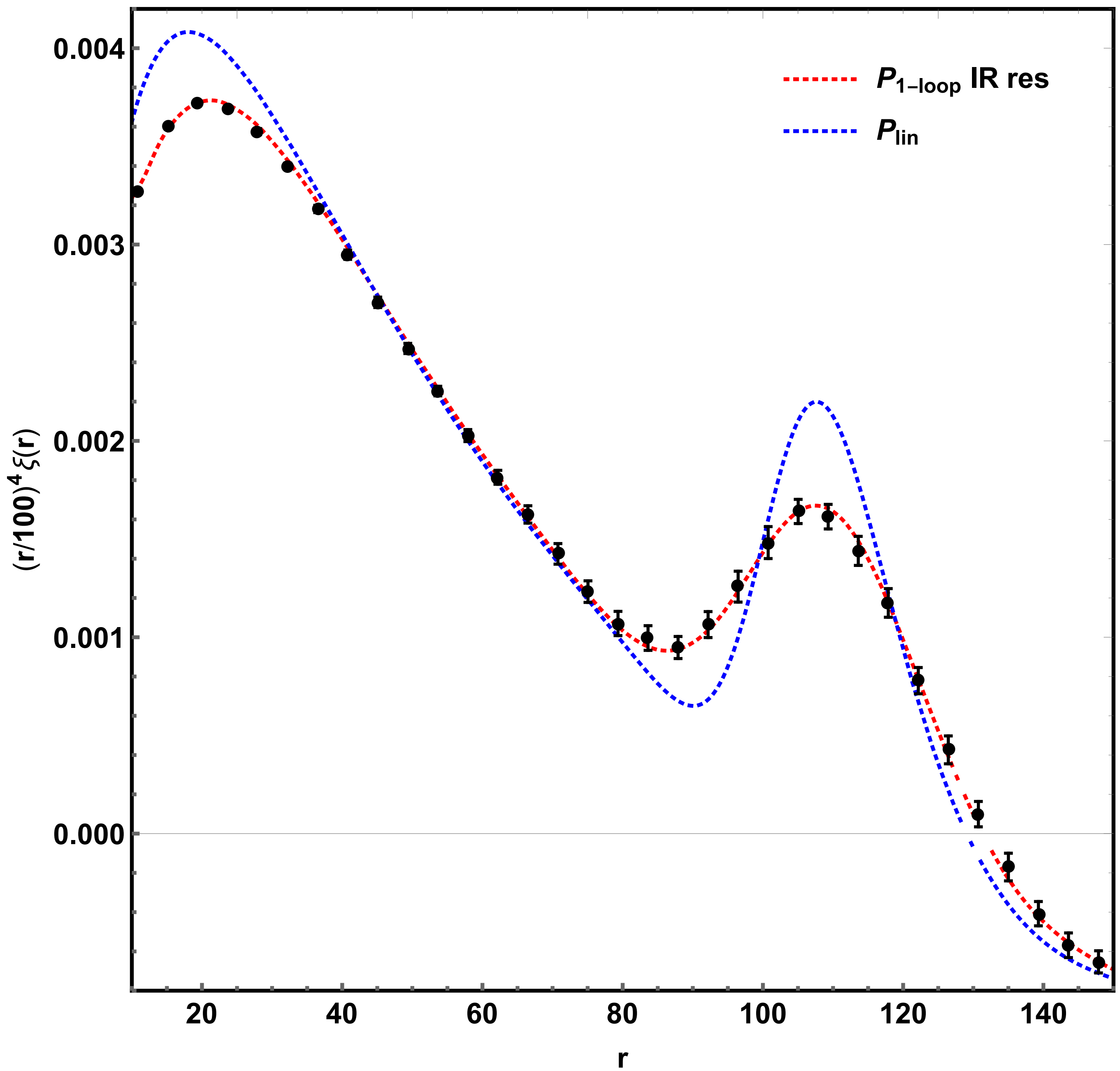


$$P_L^r(k, \cos(\mathbf{k}, \mathbf{n})) = \left(b_1 + \frac{d \ln D_+}{d \ln a} \cos^2(\mathbf{k}, \mathbf{n})\right)^2 P_L(k)$$

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

astro-ph/0309238

BAO and IR resummation



Measurements by T. Baldauf

NO fitting parameters!

Same procedure for all tracers!

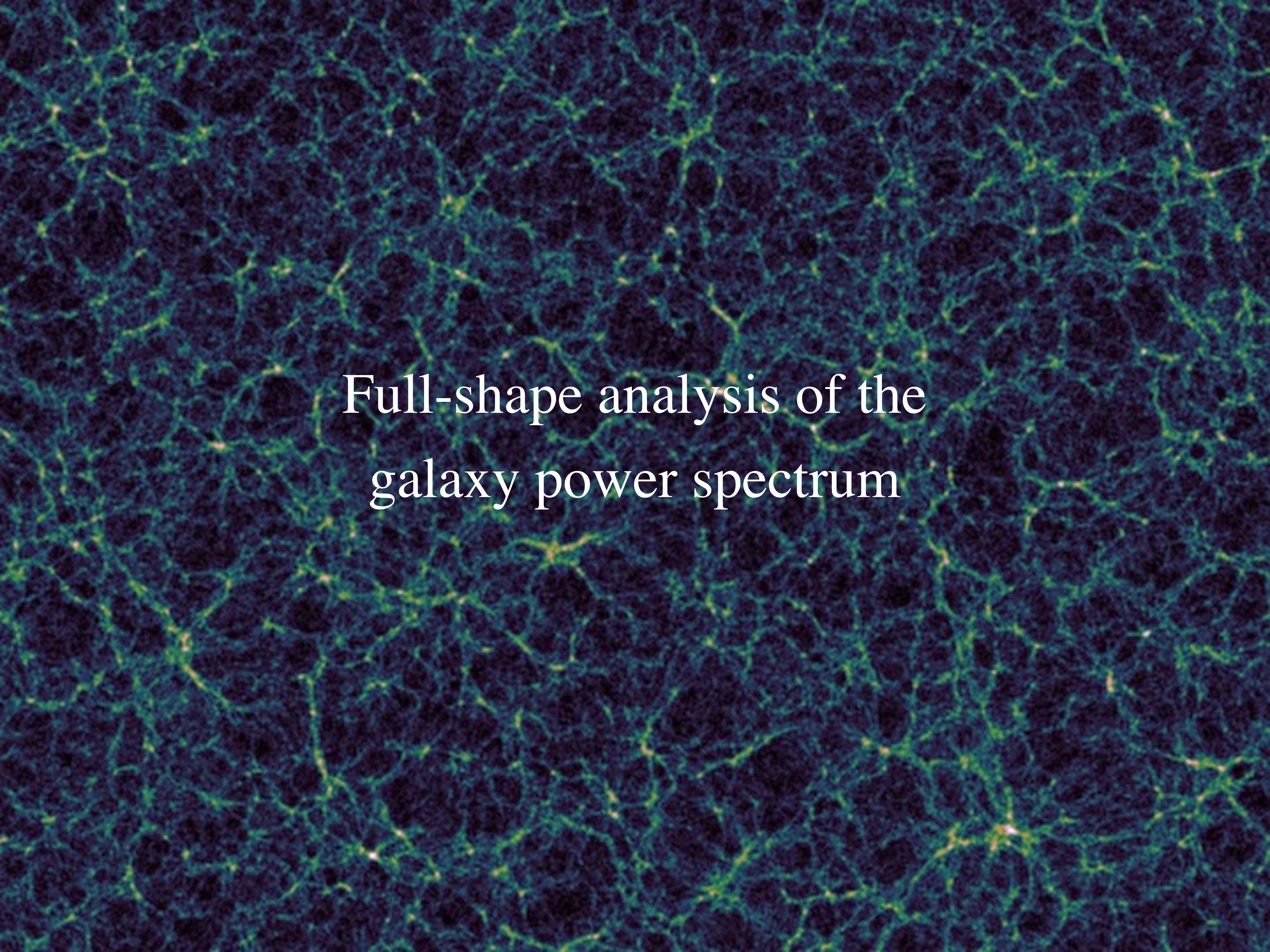
Crocce, Scoccimarro (2007)

Senatore, Zaldarriaga (2014)

Baldauf, Mirbabayi, Simonovic, Zaldarriaga (2015)

Blas, Garny, MI, Sibiryakov (2016)

…



Full-shape analysis of the galaxy power spectrum

Motivation

- Non-linear PT is settled down and can be readily applied to data
- Discoveries are around the corner

Our pipeline in a nutshell

0. Consistently recompute power spectrum as we vary cosmology (CMB style)

I. Non-linear model based on PT

Lifshitz (1946) + …

Baumann, Nicolis, Senatore, Zaldarriaga (2012)

counterterms, IR-resummation

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

II. MCMC analysis thanks to FFTLog

III. `CLASS-PT` + Montepython

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

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

Applications of our pipeline

high-res. N-body mocks

BOSS data

forecast for DESI/Euclid

Blinded challenge

arXiv.org > astro-ph > arXiv:2003.08277

Search...

Help | Advanced

Astrophysics > Cosmology and Nongalactic Astrophysics

Blinded challenge for precision cosmology with large-scale structure: results from effective field theory for the redshift-space galaxy power spectrum

Takahiro Nishimichi, Guido D'Amico, Mikhail M. Ivanov, Leonardo Senatore, Marko Simonović, Masahiro Takada, Matias Zaldarriaga, Pierre Zhang

(Submitted on 18 Mar 2020)

An accurate theoretical template for the galaxy power spectrum is a key for the success of ongoing and future spectroscopic surveys. We examine to what extent the Effective Field Theory of Large Scale Structure is able to provide such a template and correctly estimate cosmological parameters. To that end, we initiate a blinded challenge to infer cosmological parameters from the redshift-space power spectrum of high-resolution mock catalogs mimicking the BOSS galaxy sample but covering a hundred times larger cumulative volume. This gigantic simulation volume allows us to separate systematic bias due to theoretical modeling from the statistical error due to sample variance. The challenge task was to measure three unknown input parameters used in the simulation: the Hubble constant, the matter density fraction, and the clustering amplitude. We present analyses done by two independent teams, who have fitted the mock simulation data generated by yet another independent group. This allows us to avoid any confirmation bias by analyzers and pin down possible tuning of the specific EFT implementations. Both independent teams have recovered the true values of the input parameters within sub-percent statistical errors corresponding to the total simulation volume.

Comments: 23 pages, 12 figures, participation in the challenge welcome, mock data available at this https URL
Subjects: **Cosmology and Nongalactic Astrophysics (astro-ph.CO)**
Report number: YITP-20-25, INR-TH-2020-009, CERN-TH-2020-040, IPMU20-0025
Cite as: arXiv:2003.08277 [astro-ph.CO]
(or arXiv:2003.08277v1 [astro-ph.CO] for this version)

Multipole moment data for PT challenges

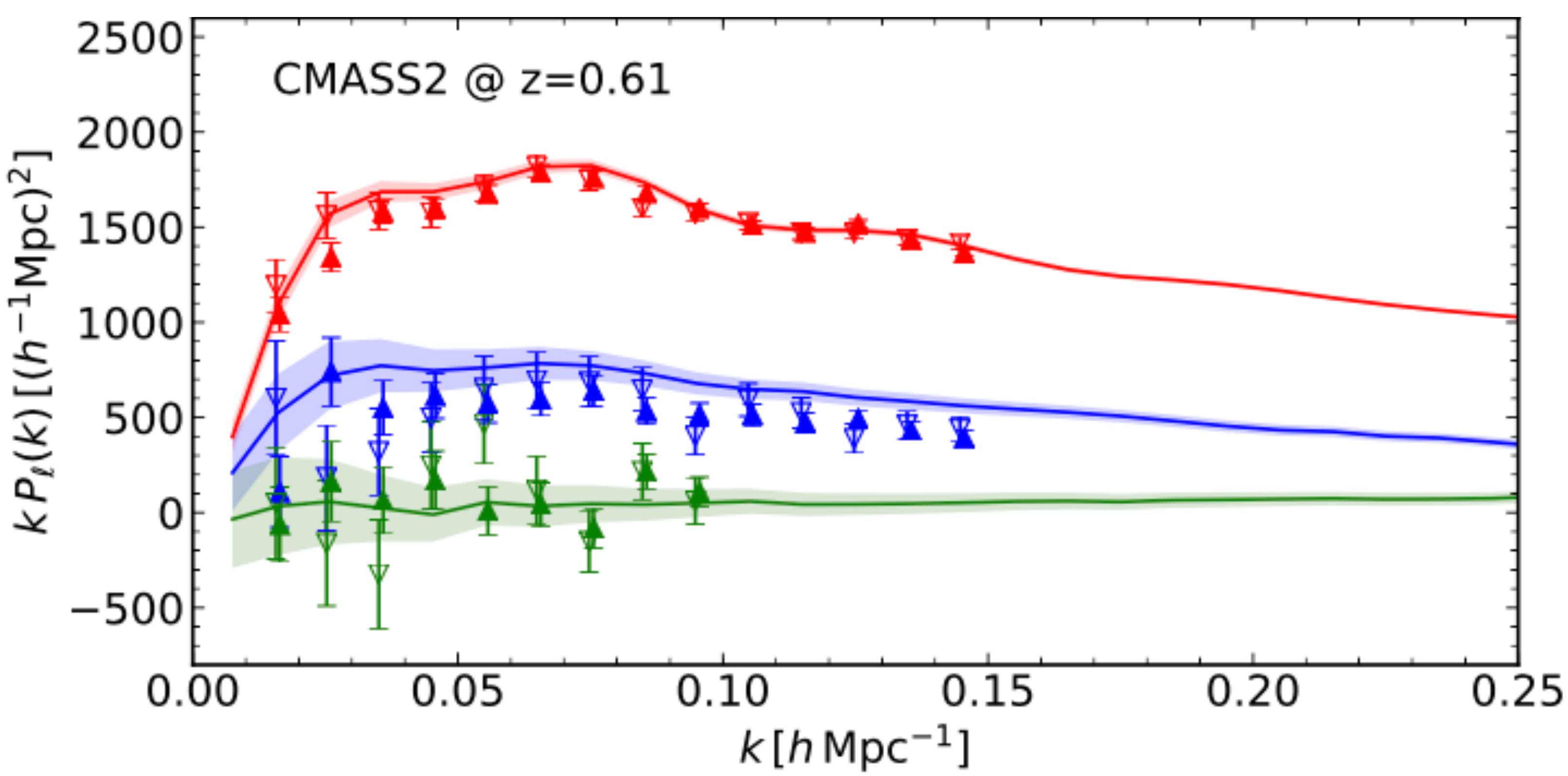
Overview

I provide multipole moments of the redshift-space power spectrum measured from mock galaxies created on this webpage.

- Simulations are done in periodic comoving cubes with the side length of 3840Mpc/h with 3072^3 particles.
- I assume a flat Lambda-CDM cosmology. Omega_nu is set to be zero.
- I do not tell you the 3 cosmological parameters Om, H0 and sigma8 (or As @ k0 = 0.05[1/Mpc]).
- These 3 parameters are drawn randomly around the Planck cosmology.
- Other parameters are set to Planck 2018 (fb = Ob/Om = 0.1571, ns=0.9649).
- To be precise, I provide the parameter file for CAMB which is used to compute the linear power spectrum, with the parameters relevant to the challenge erased. You can download it from here.
- I assume a flat Lambda-CDM cosmology with Om=0.3 to simulate the Alcock-Paczynski effect: the simulation cube is artificially distorted according to the ratio of the

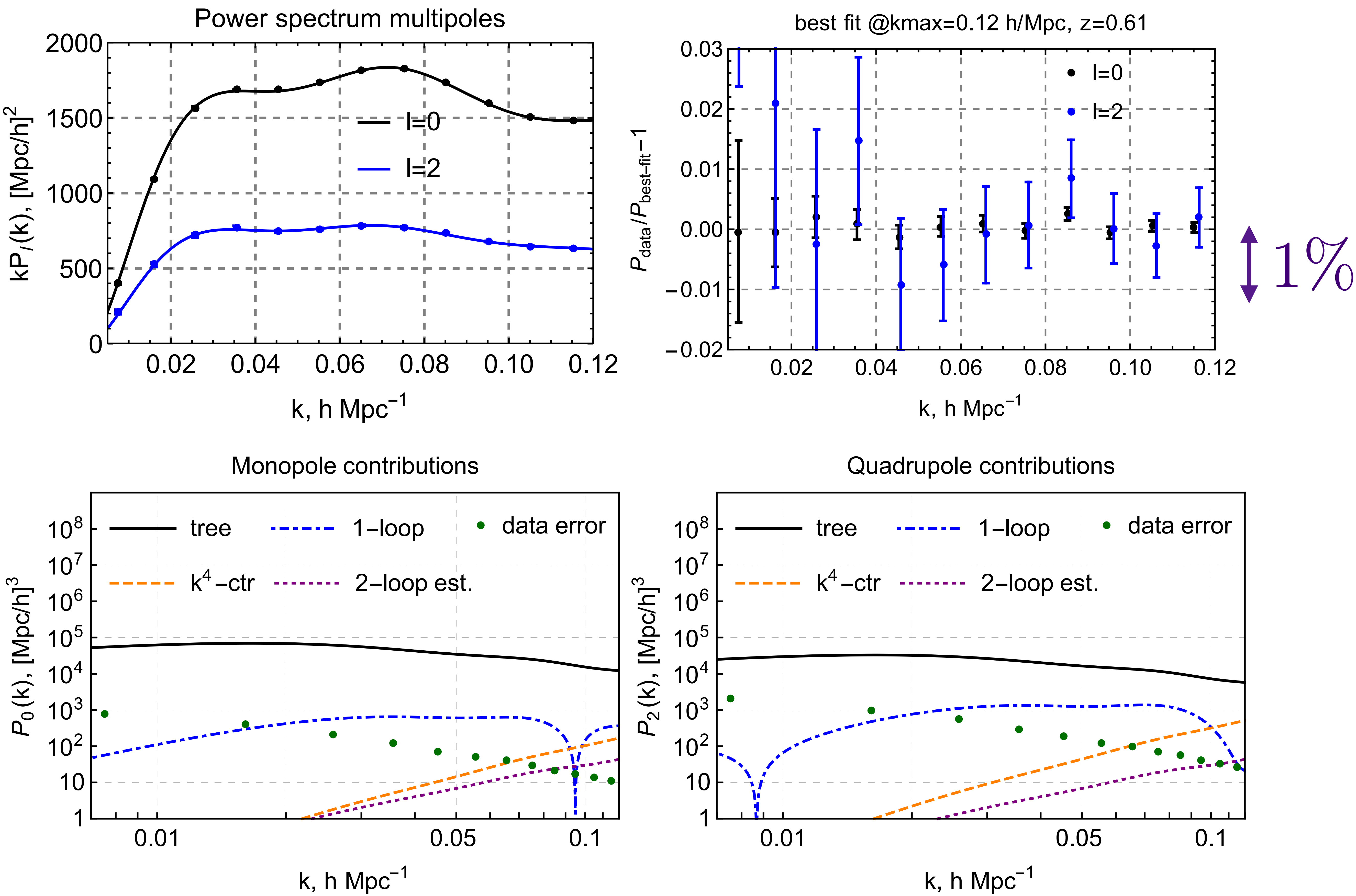
Blinded challenge

- Large N-body sims
- 10 boxes, ~60 (Gpc/h)^3 each $\sim 600\ (\mathrm{Gpc}/h)^3$
- HOD BOSS-like galaxies
- 3 unknown parameters: (Ω_m, H_0, A_s)
- Given: redshift space P(k)



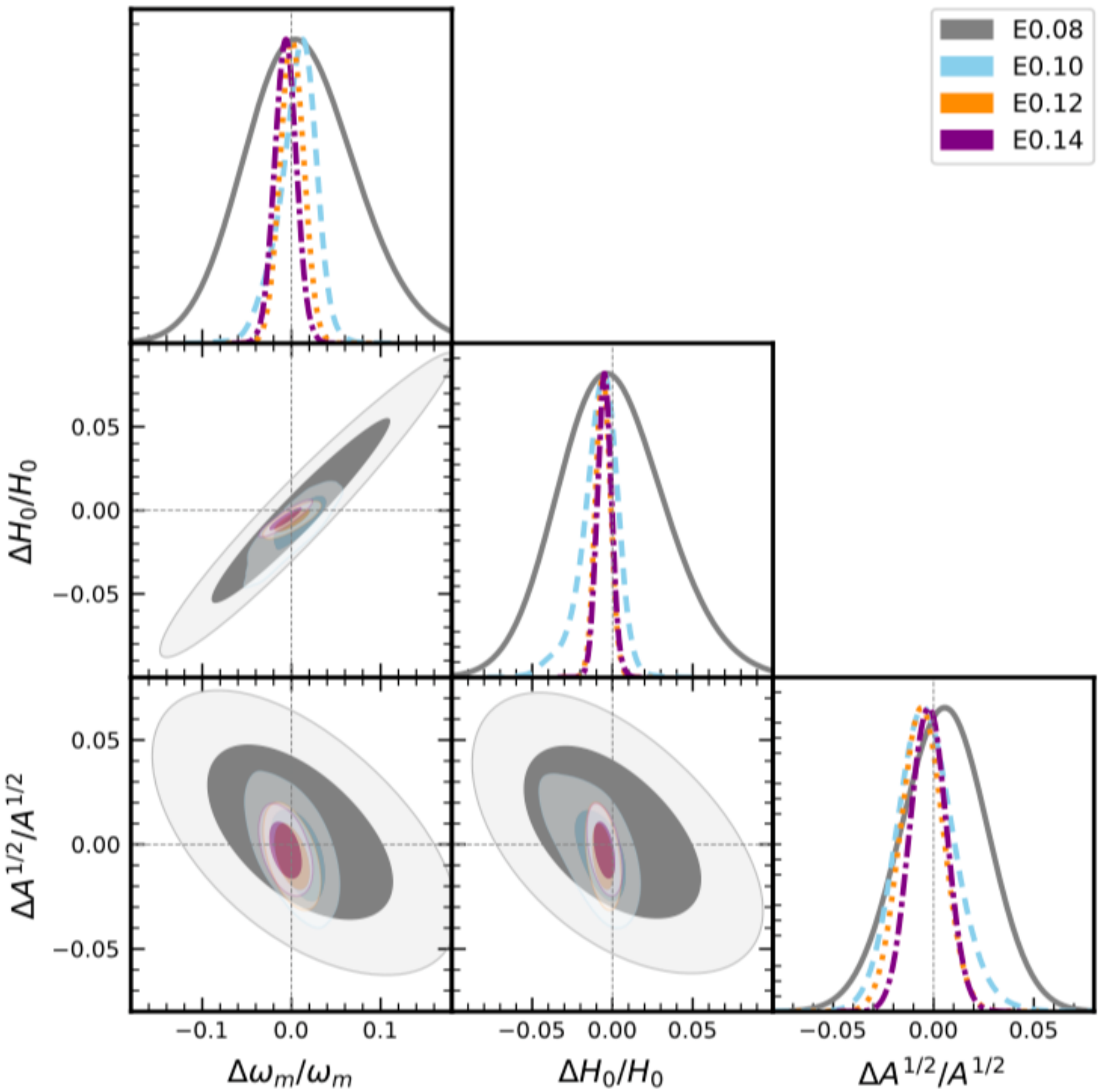
2003.08277

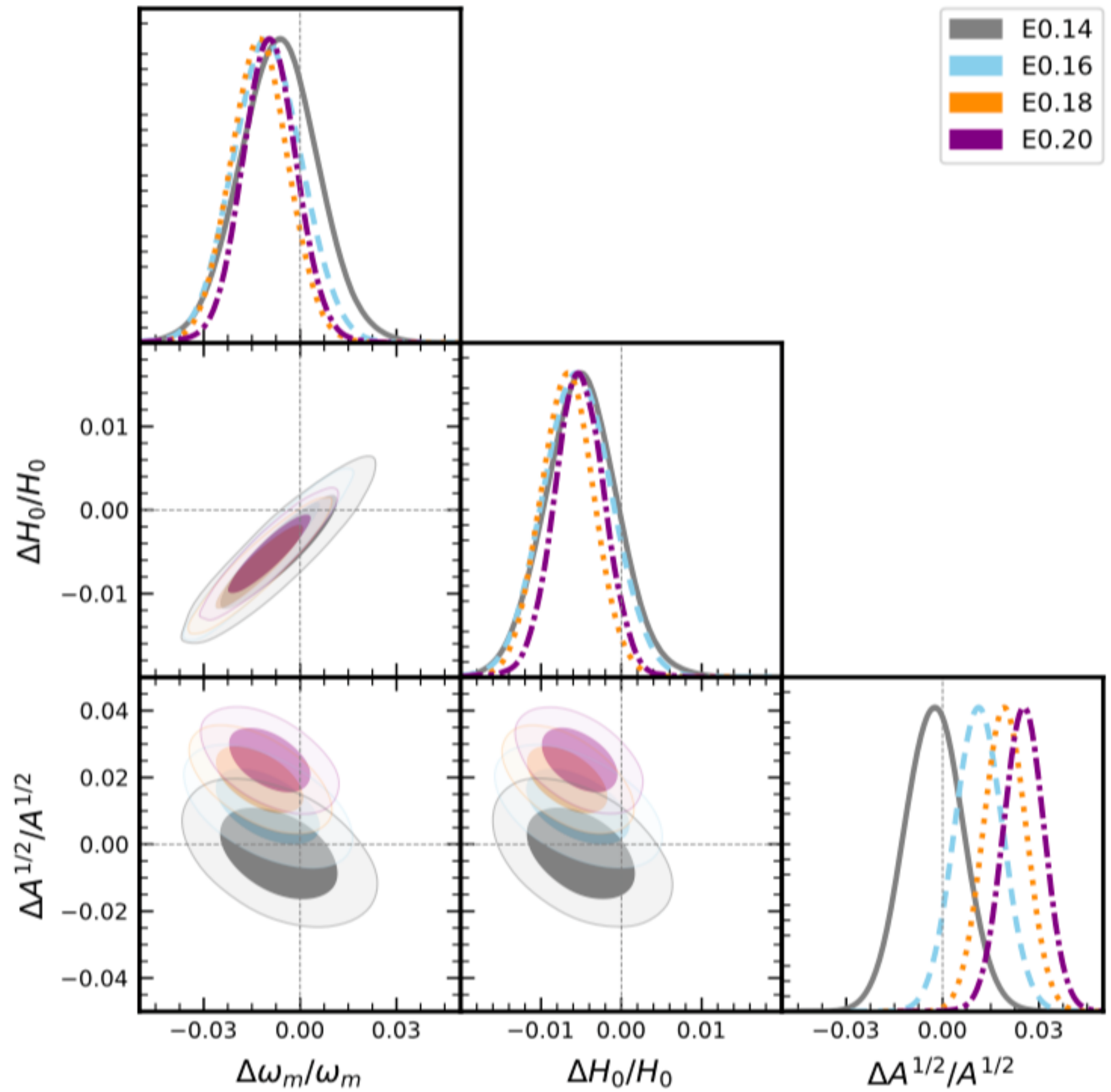
Results



Power spectrum multipoles
$kP_l(k)$, $[\mathrm{Mpc}/h]^2$
k, h Mpc^{-1}
l=0
l=2
best fit @kmax=0.12 h/Mpc, z=0.61
$P_{\mathrm{data}}/P_{\mathrm{best\text{-}fit}}-1$
1%
Monopole contributions
$P_0(k)$, $[\mathrm{Mpc}/h]^3$
Quadrupole contributions
$P_2(k)$, $[\mathrm{Mpc}/h]^3$
tree
1−loop
data error
k^4−ctr
2−loop est.

Results

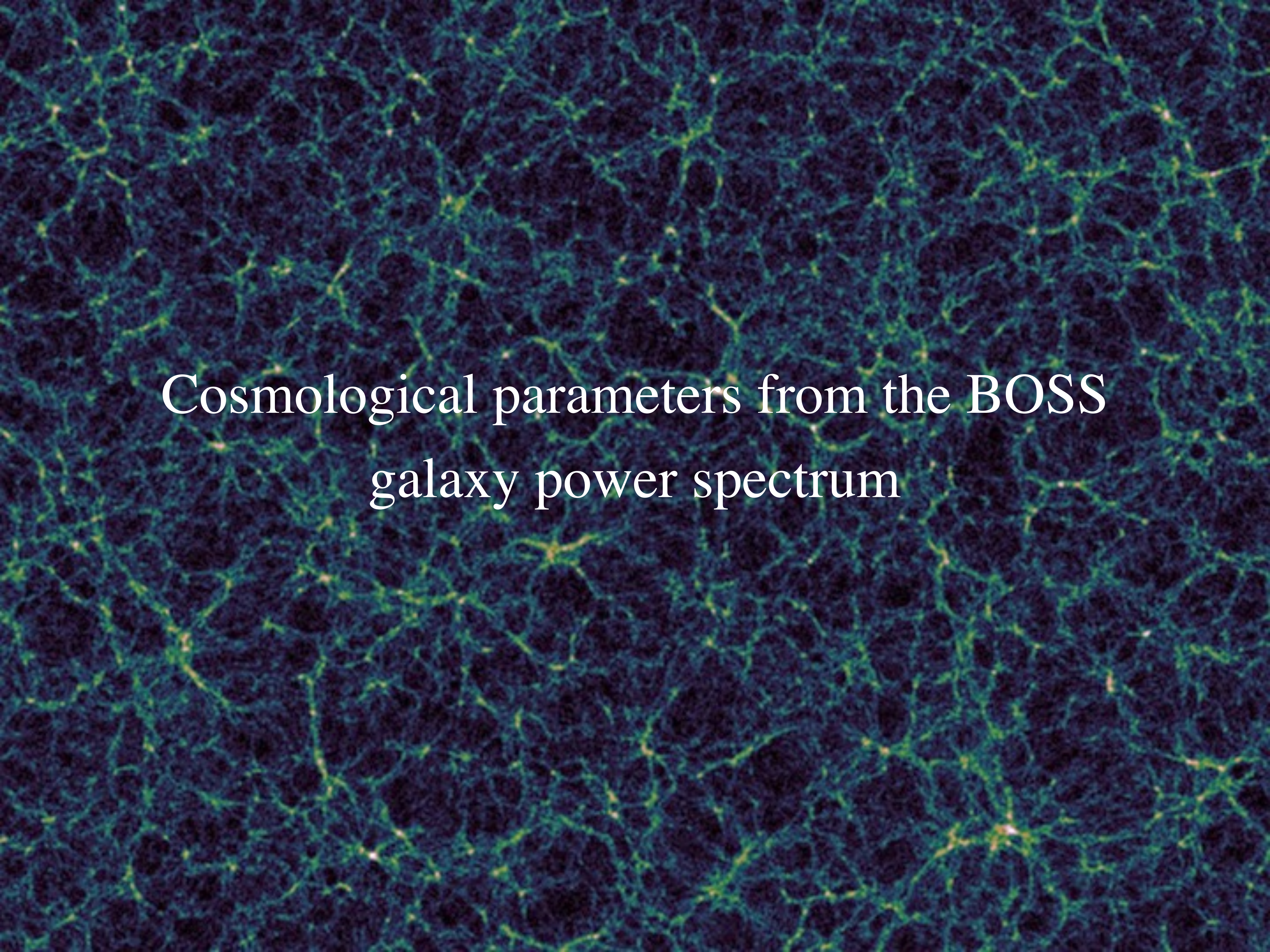




$\sim 600\ (\mathrm{Gpc}/h)^3$

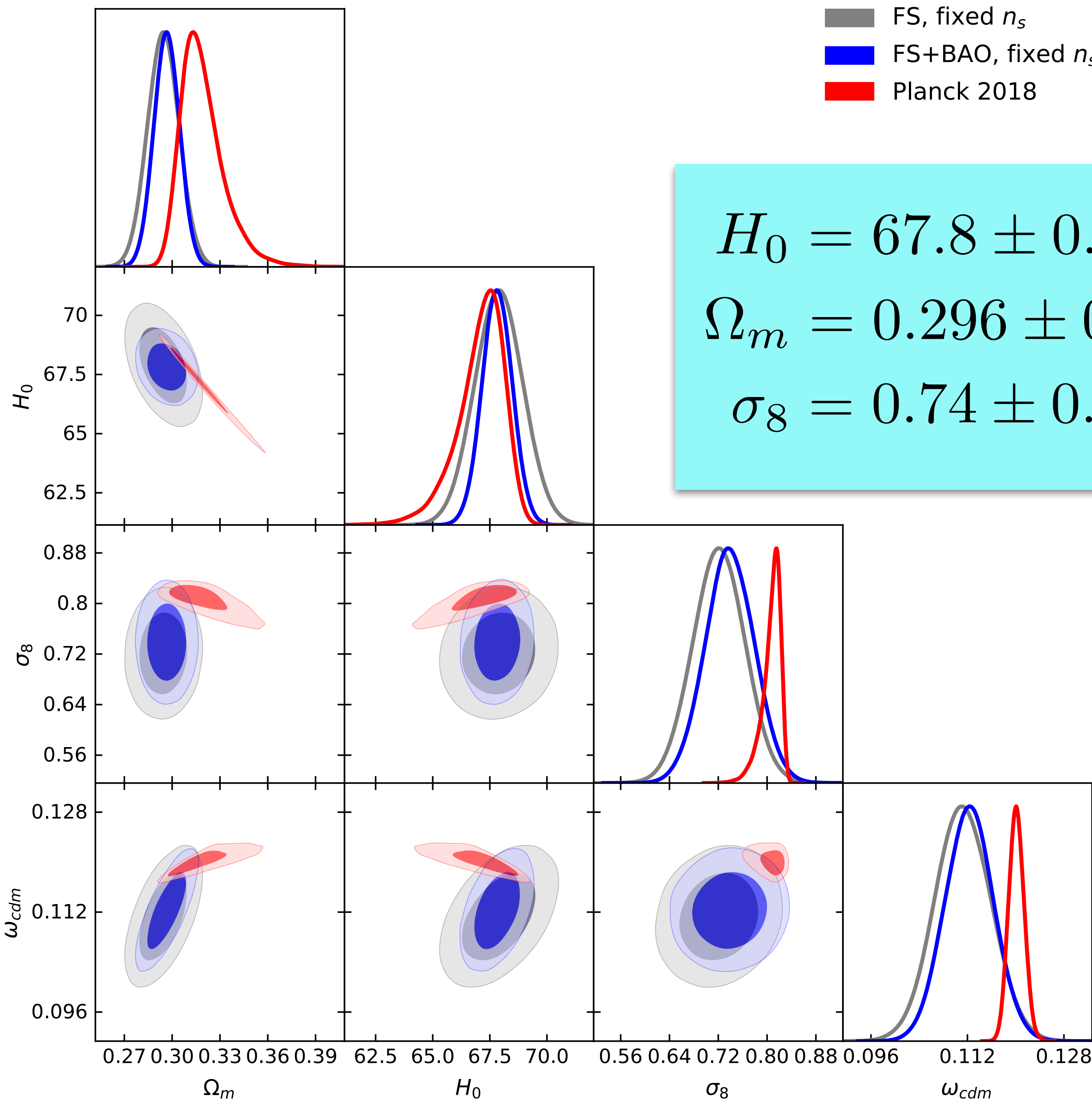
$$A \equiv \frac{A_s}{A_{s,\,\mathrm{Planck}}}$$

Sign of bias

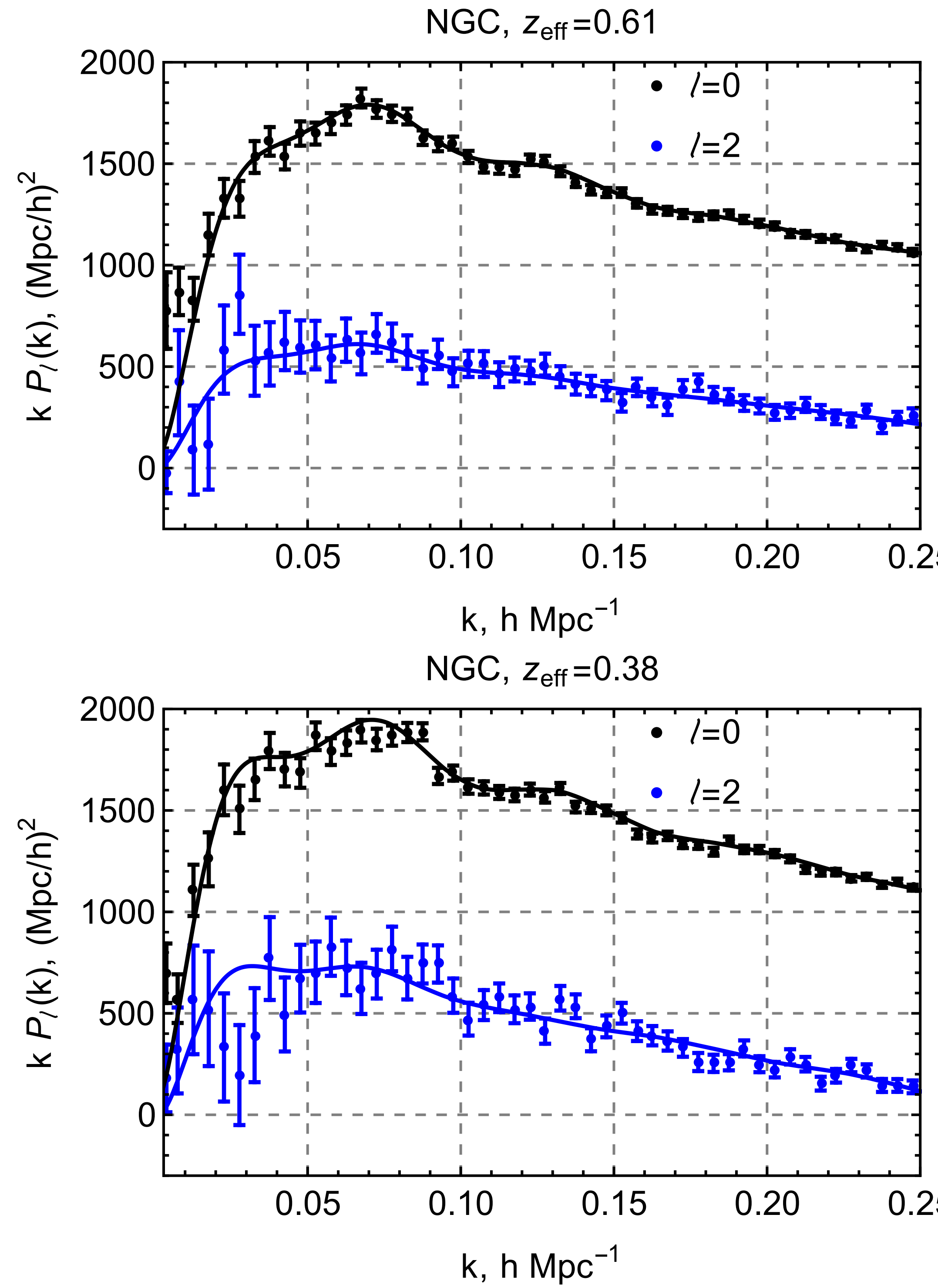


Cosmological parameters from the BOSS galaxy power spectrum

Reanalysis of BOSS data



$$H_0 = 67.8 \pm 0.7$$
$$\Omega_m = 0.296 \pm 0.008$$
$$\sigma_8 = 0.74 \pm 0.4$$



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

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

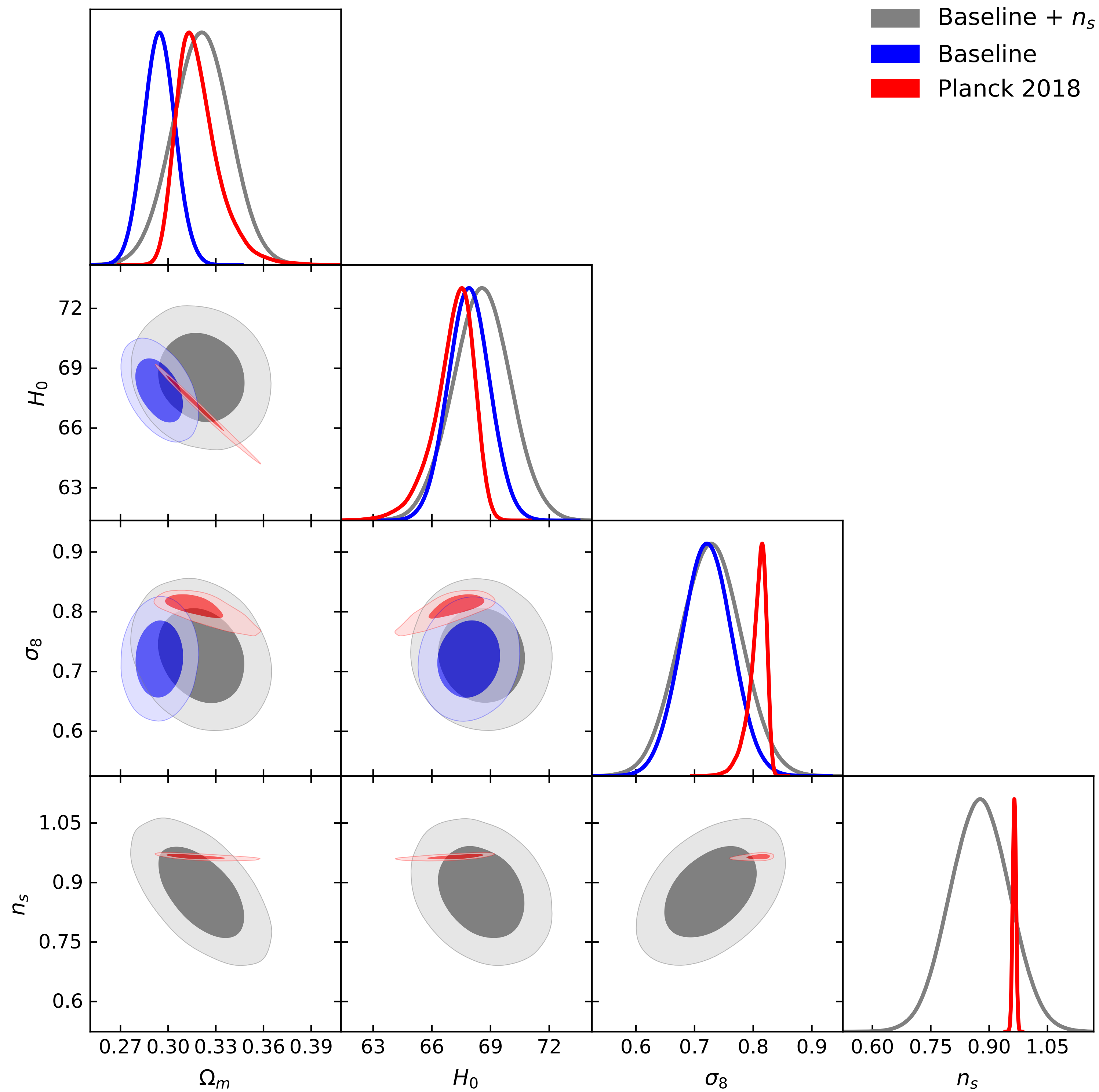
Assumptions

- ★ Standard Model of particles (w/ neutrinos)
- ★ + CDM + C.C.
- ★ CMB monopole temperature $T_0 \;=\; 2.7255 \pm 0.0006\,\mathrm{K}$
- ★ Simple initial power spectrum $\mathcal{P}_\zeta \propto A_s k^{n_s - 1}$
- ★ Optional: prior on baryon density

$$\omega_b = 0.02268 \pm 0.00038 \qquad (\omega_b\text{–BBN prior})$$

$$\omega_b = 0.02237 \pm 0.00015 \qquad (\omega_b\text{–CMB prior})$$

Full likelihood

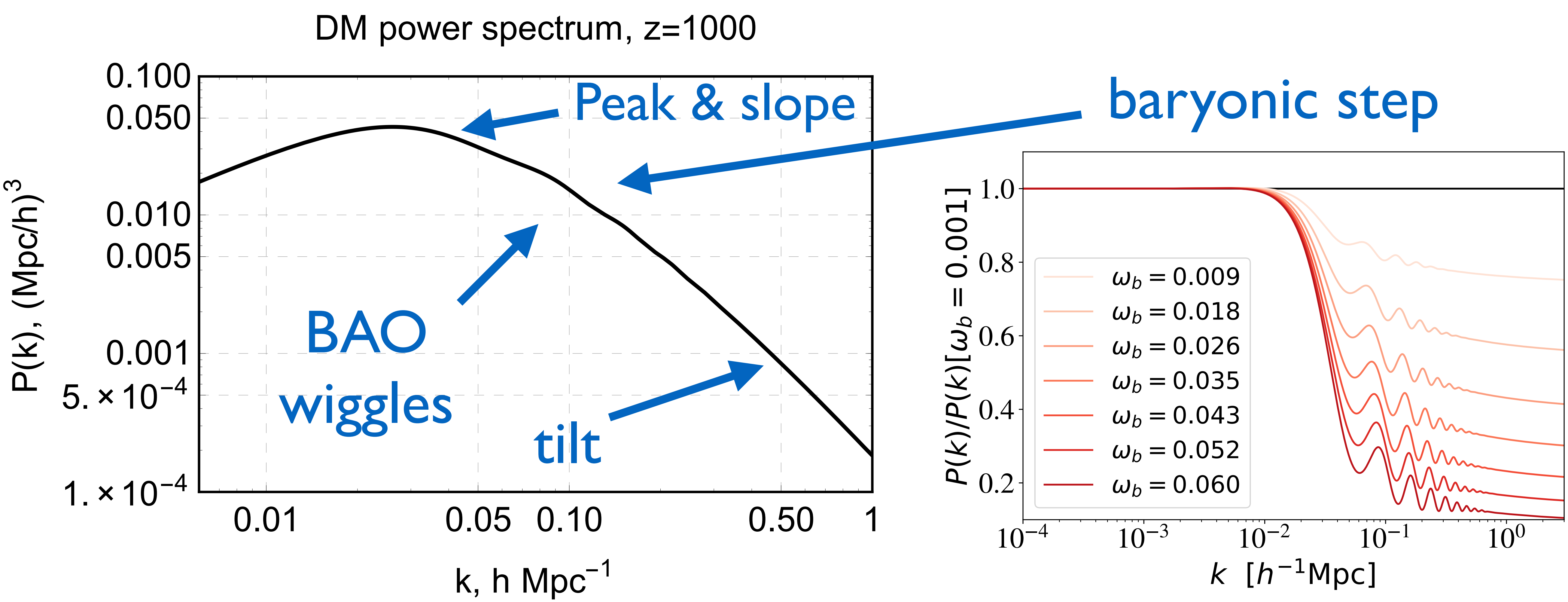


BBN ω_b	best-fit	mean $\pm 1\sigma$
ω_{cdm}	0.1267	0.1268 ± 0.0099
H_0	68.61	68.55 ± 1.47
n_s	0.874	0.876 ± 0.076
σ_8	0.724	0.728 ± 0.052
Ω_m	0.320	0.321 ± 0.018

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

★ DE & inflation confirmed

Information

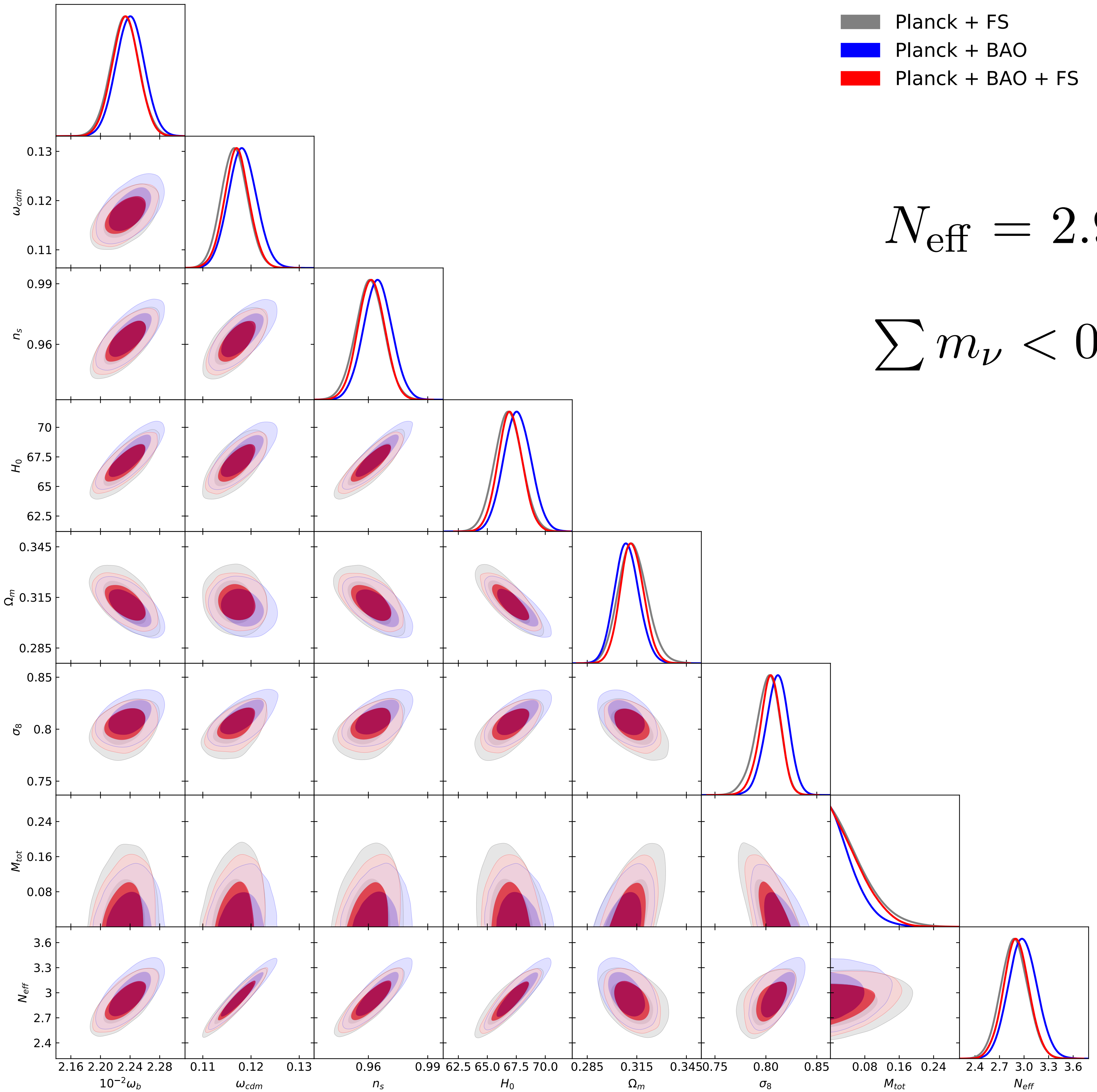


- Shape $(\omega_b, \omega_{cdm}, n_s)$
- Distance $D_V \to H_0$
- Amplitude $f\sigma_8 \to \sigma_8$

AP effect $D_A, H \to \text{nothing}$

Numerical evaluation of equation (7) shows that $\Delta z/(z\Delta\theta)$ is not a powerful estimator of q_0 in the $\Lambda = 0$ case—there is only 11% variation of $\Delta z/(z\Delta\theta)$ between $q_0 = 0$ and $q_0 = 1$ at $z = 2$.

Combining with Planck



$$N_{\rm eff} = 2.90^{+0.15}_{-0.16}$$

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

Combining with Planck: EDE

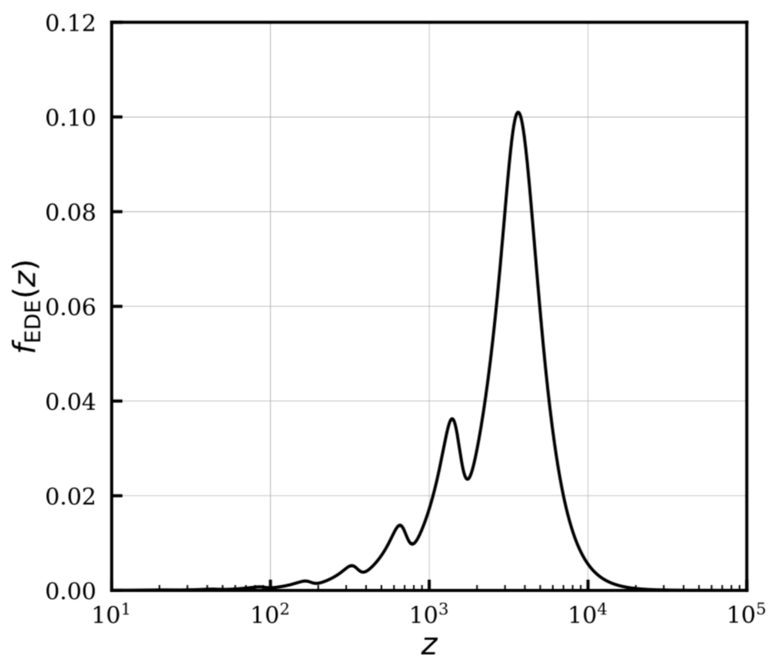
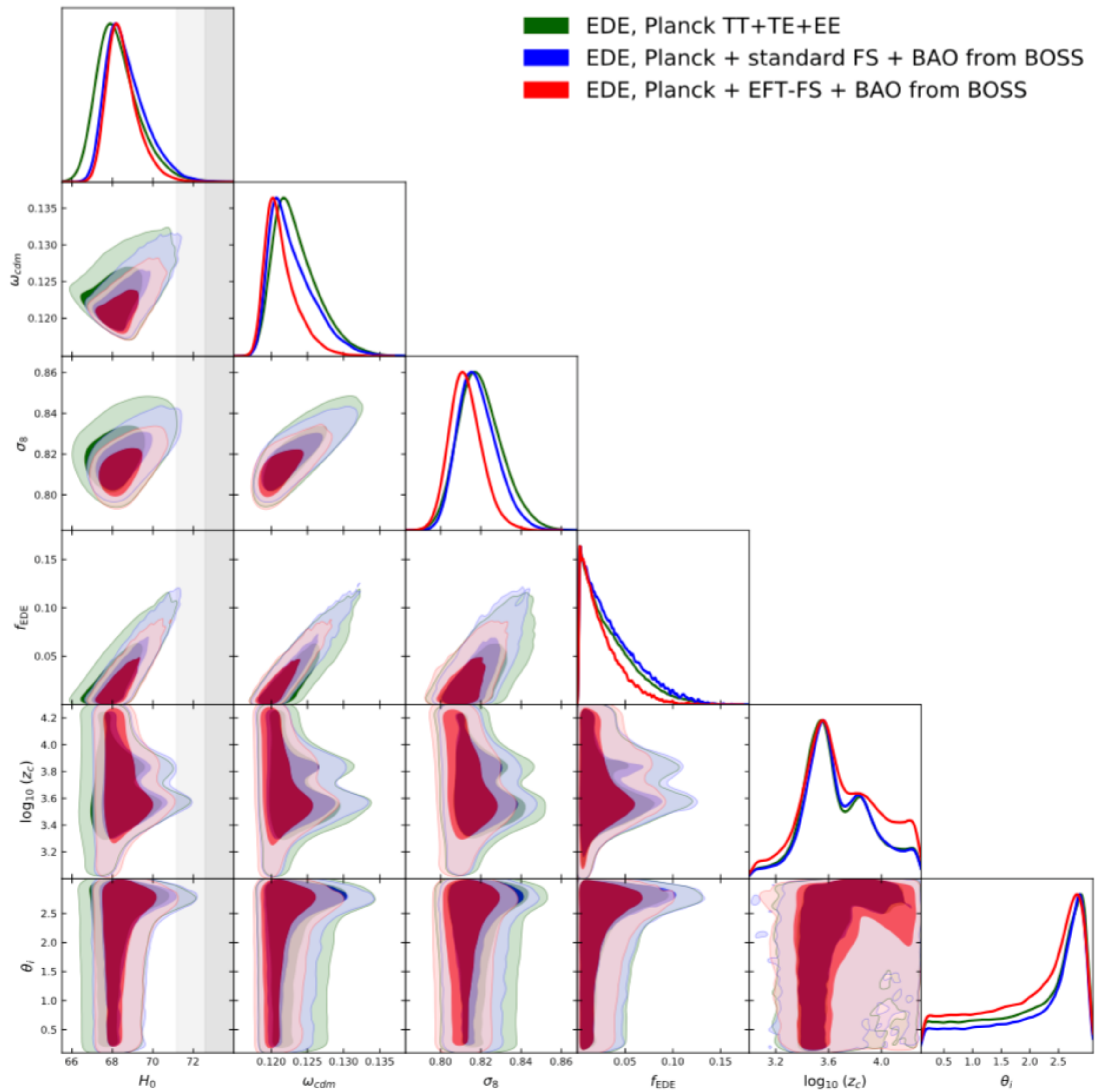


FIG. 1. Fraction of the cosmic energy density in the EDE field as a function of redshift, for the parameters in Eq. (7).

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



The future

euclid
consortium

ENERGY
DARK
SPECTROSCOPIC
INSTRUMENT

LSST
CORPORATION

PAU

SKA
SQUARE KILOMETRE ARRAY

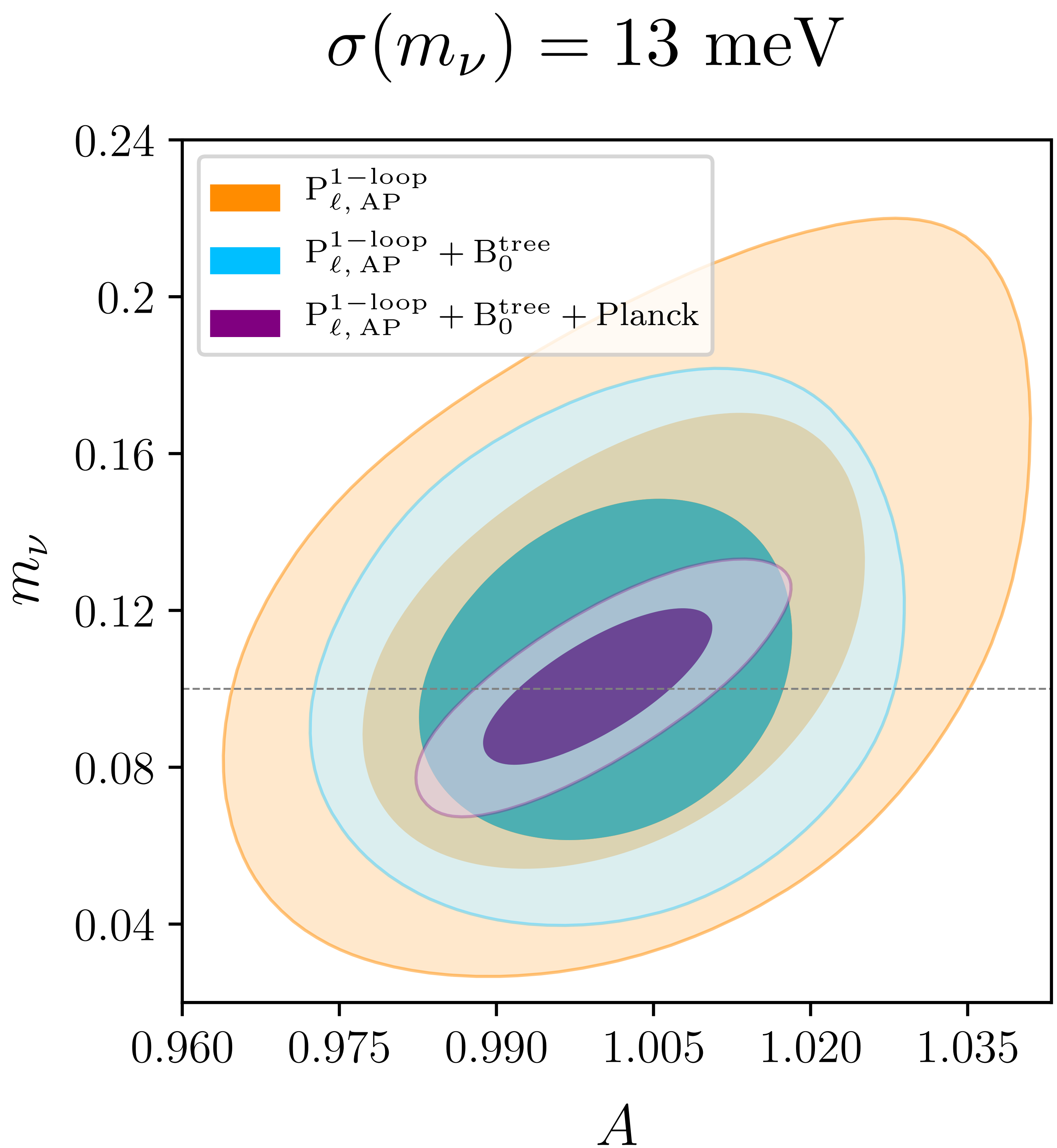
Forecast for Euclid/DESI - like survey

1907.06666 *w/ A. Chudaykin*

What if you gave me the data right now?

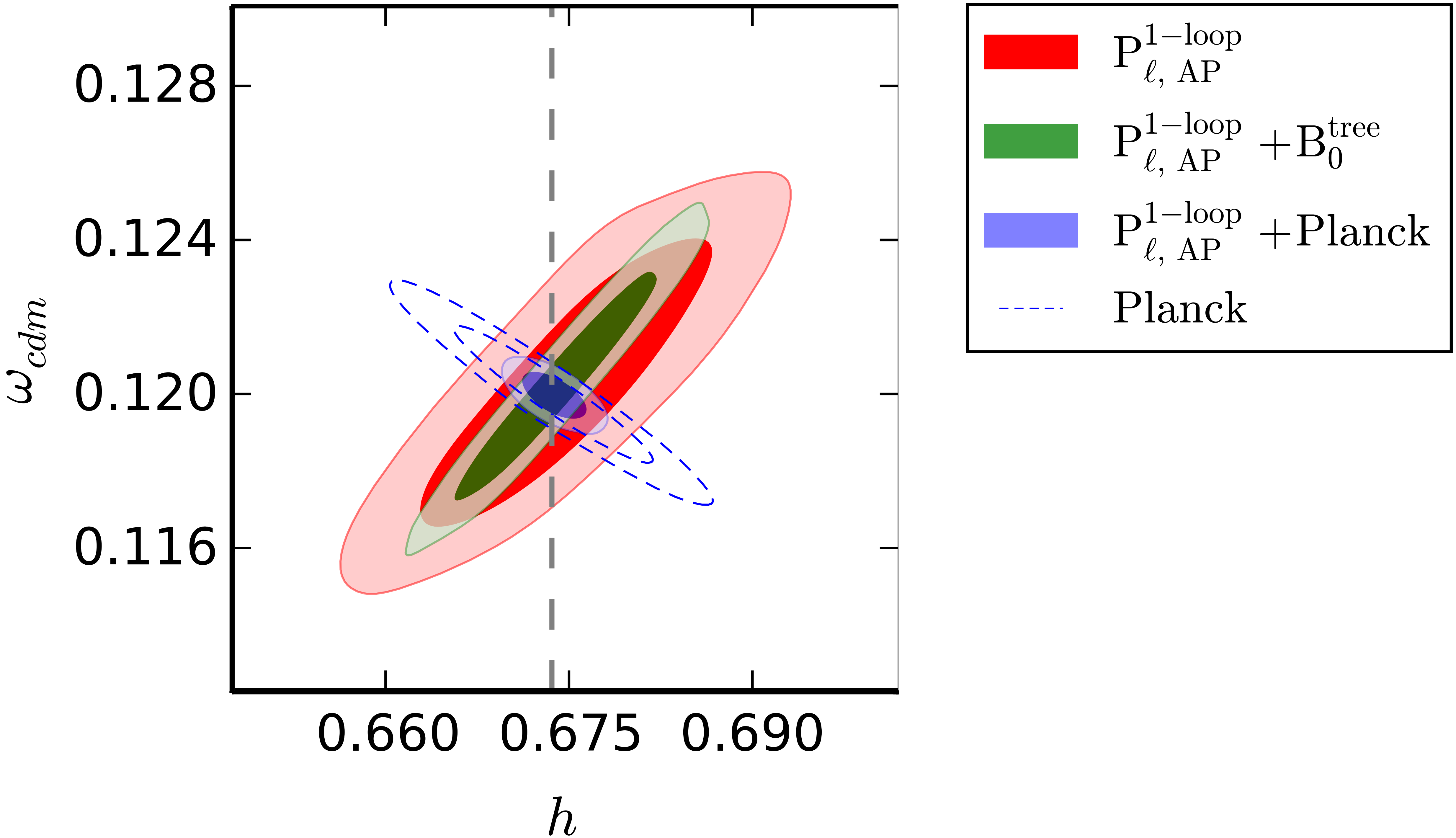
- ★ MCMC using the same pipeline w/ full non-linear model
- ★ Keep agnostic about bias and other nuisance prms.
- ★ Marginalize over other systematics, e.g. fiber collisions
- ★ Same data cuts as we use now

MCMC forecast for Euclid-like survey



1907.06666 *w/ A. Chudaykin*

MCMC forecast for Euclid-like survey



1907.06666 *w/ A. Chudaykin*

Other topic I didn't have time to discuss

- ★ Non-perturbative PDF of the counts in cells
- ★ Covariance matrices: accurate parameter estimation with few mocks or without them!
- ★ Extending modeling to short scales with Q0

Summary

PT is precise, better than 0.1%

PT is robust: unbiased recovery of cosmology

BOSS rivals Planck for H0 and Omegam

Cosmology similar or better than Planck with DESI/Euclid

Detecting neutrino masses @5sigma

Thanks!