

Title: Cosmology from current and future spectroscopic galaxy surveys

Speakers: Marco Simonovic

Series: Cosmology & Gravitation

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Abstract: Mapping of galaxy density fluctuations on large scales is one of the most important goals of observational cosmology in this decade. These observations can significantly improve our knowledge of the universe, its origins and composition. In this talk I will review some of the science goals of the ongoing and future spectroscopic galaxy surveys and explain how these goals can be met. In particular, I will focus on some recent progress in theoretical modelling of the nonlinear structure formation and show how it can be used to extract cosmology from observations of the cosmic web. As an example I will present several analyses from the publicly available Baryon Oscillation Spectroscopic Survey (BOSS) data and results for the standard Λ CDM model as well as several relevant extensions.

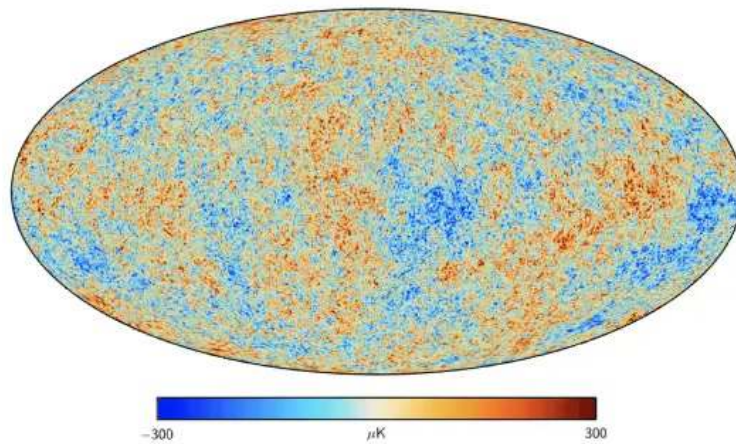
Cosmology from current and future spectroscopic galaxy surveys

Marko Simonović (CERN)

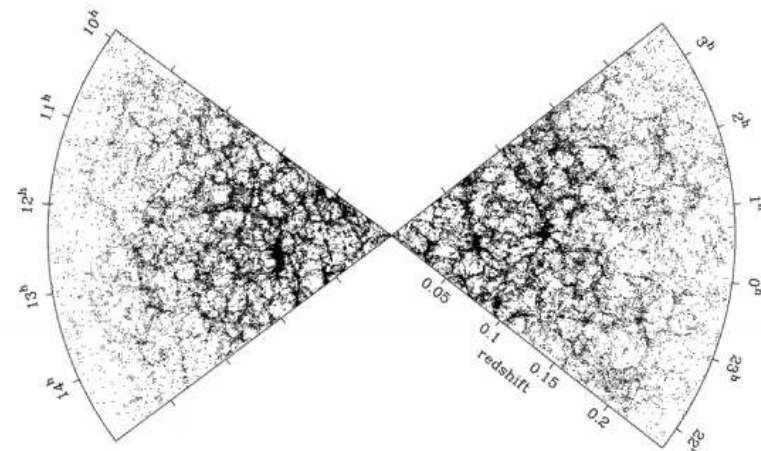
with Mikhail Ivanov, Oliver Philcox and Matias Zaldarriaga

PI cosmology seminar, October 2020

The promise of LSS



$N \sim 10^7$

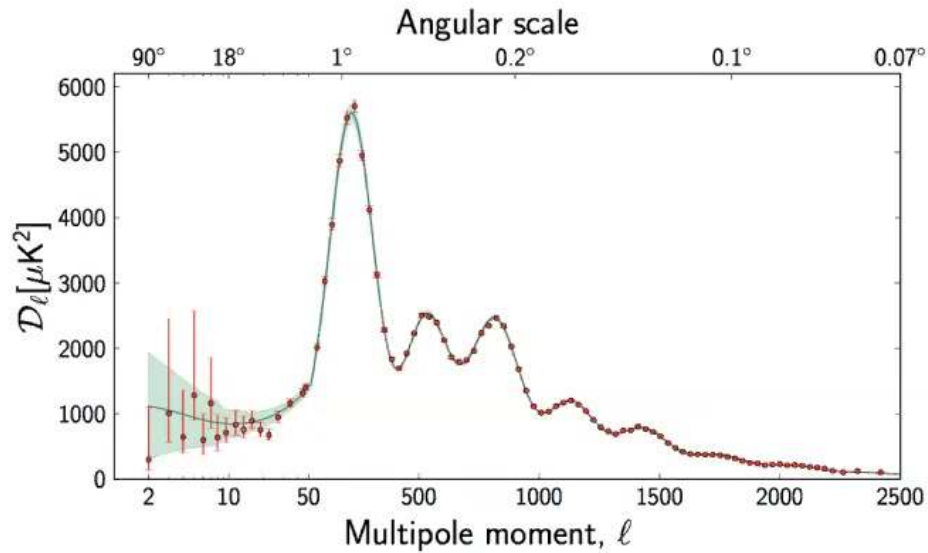


$N \sim 10^9$

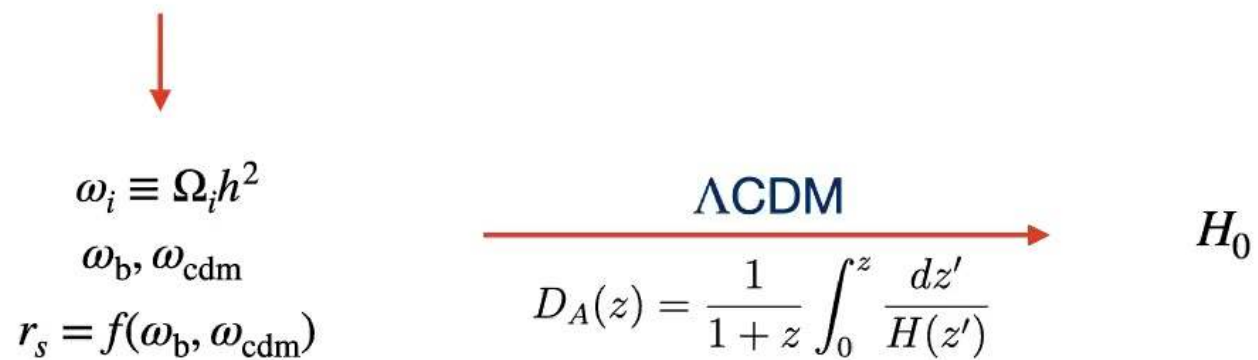
The major challenge — extract all available information from LSS

Inflation, PNG, early universe physics, new long-range forces, beyond Λ CDM...

Cosmology from CMB



Parameter	<i>Planck</i> alone
$\Omega_b h^2$	0.02237 ± 0.00015
$\Omega_c h^2$	0.1200 ± 0.0012
$100\theta_{MC}$	1.04092 ± 0.00031
τ	0.0544 ± 0.0073
$\ln(10^{10} A_s)$	3.044 ± 0.014
n_s	0.9649 ± 0.0042
H_0	67.36 ± 0.54

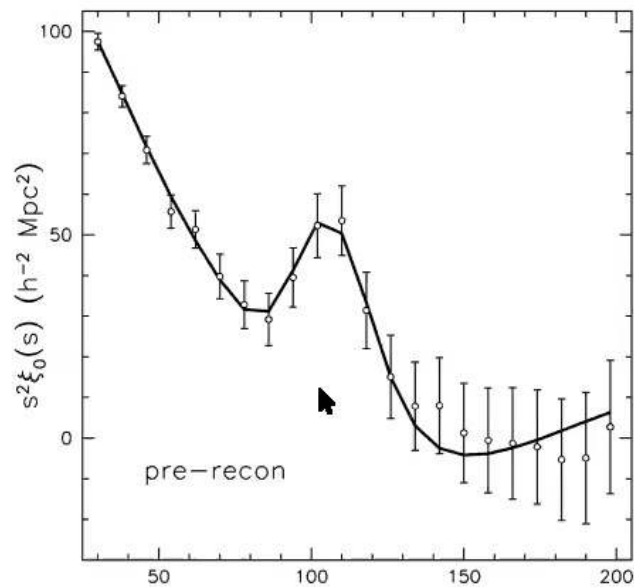


Cosmology from LSS

In LSS we observe the power spectrum or 2pf of galaxies

The simplest observable is the position of the BAO peak

Important in combination with CMB: Planck + BAO results



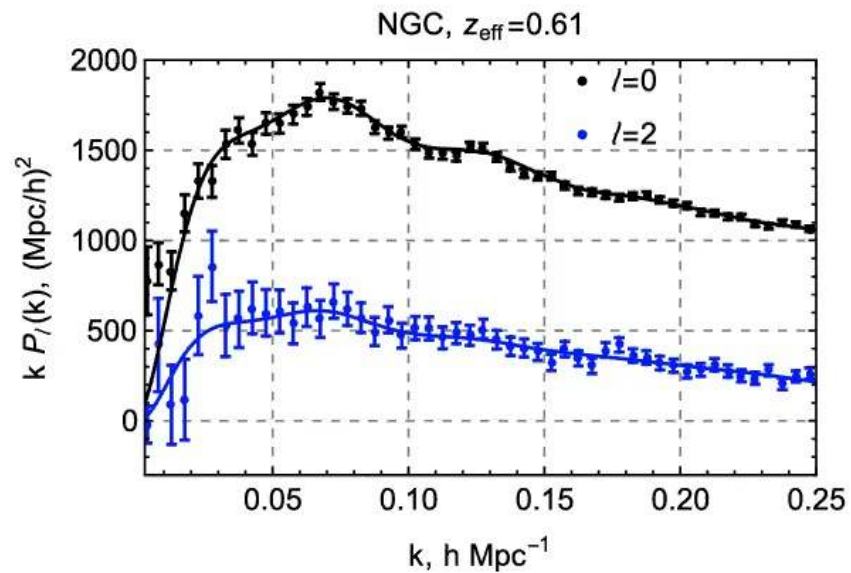
$$r_s = f(\omega_b, \omega_{\text{cdm}})$$

Cosmology from LSS

Additional information is in the amplitude of the power spectrum

$$P_g(k, \mu) = (b_1 + f\mu^2)^2 P_{\text{lin}}(k)$$

The amplitude of the quadrupole measures $f\sigma_8$



Cosmology from LSS

The BAO and $f\sigma_8$ can be constrained together: the standard FS analysis

Gil-Marín et. al. (2015)

Beutler et. al. (2016)

Grieb et. al. (2016)

One fixes the shape parameters using Planck and calculates the fixed template for the nonlinear power spectrum

In the MCMC chains, one varies only distances, $f\sigma_8$ and nuisance parameters

While this analysis uses the whole power spectrum, the shape is fixed!

This is very different from the CMB analysis

Cosmology from LSS

Why not varying all cosmological parameters?

- Planck has much better errors on the shape parameters
- More practical for MG/DE models

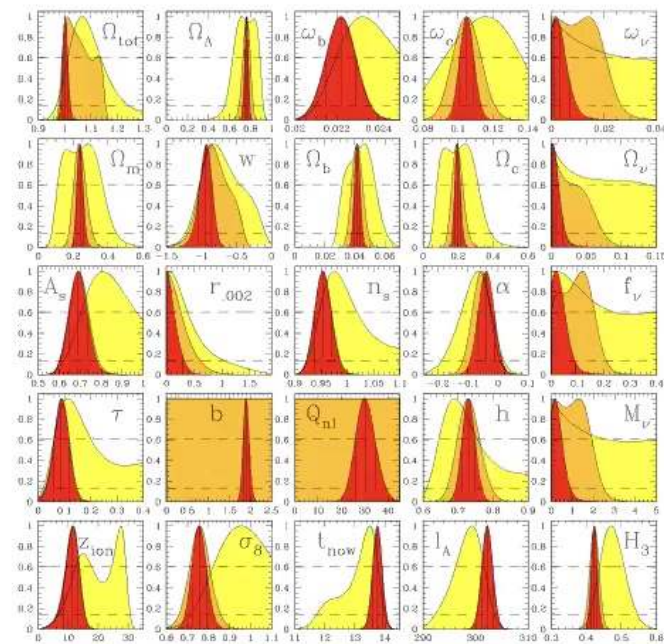
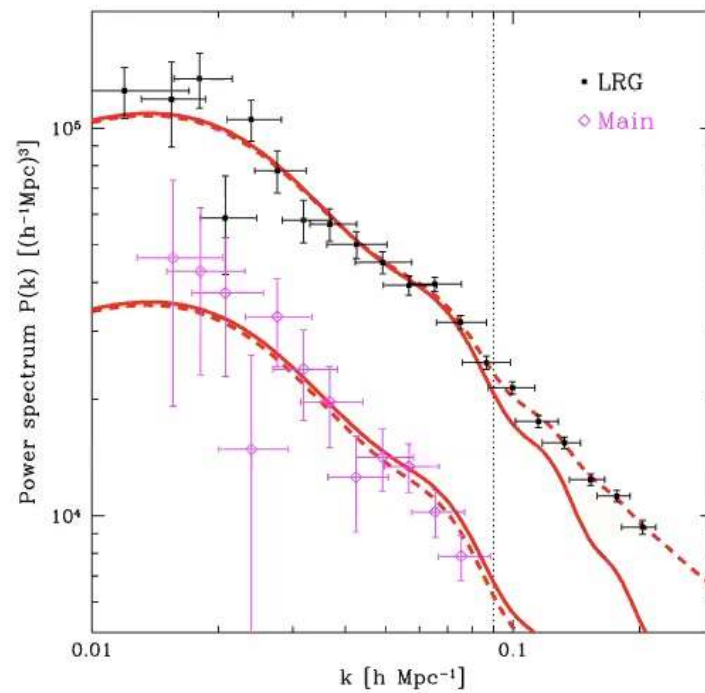
When $f\sigma_8$ + BAO FS analysis can fail?

- Extended early universe models, where Planck error bars increase
- If there are tensions in different cosmological data sets
- If Planck priors are not correct

Cosmology from LSS

Cosmology from LSS varying all cosmological parameters

Tegmark et al. (2006)



Cosmology from LSS

Reliable modeling of the nonlinear galaxy power spectrum

- EFT of LSS as a consistent PT approach to galaxy clustering
- “IR resummation”; the proper treatment of the spread of the BAO peak

Efficient evaluation of the nonlinear spectra to make MCMC analyses doable

- FFTLog method to solve loop integrals
MS, Baldauf, Zaldarriaga, Carrasco, Kollmeier (2017)
- CLASS-PT: nonlinear module that calculates all observables
Chudaykin, Ivanov, Philcox, MS (2020)

CLASS-PT and the BOSS likelihood code can be found here

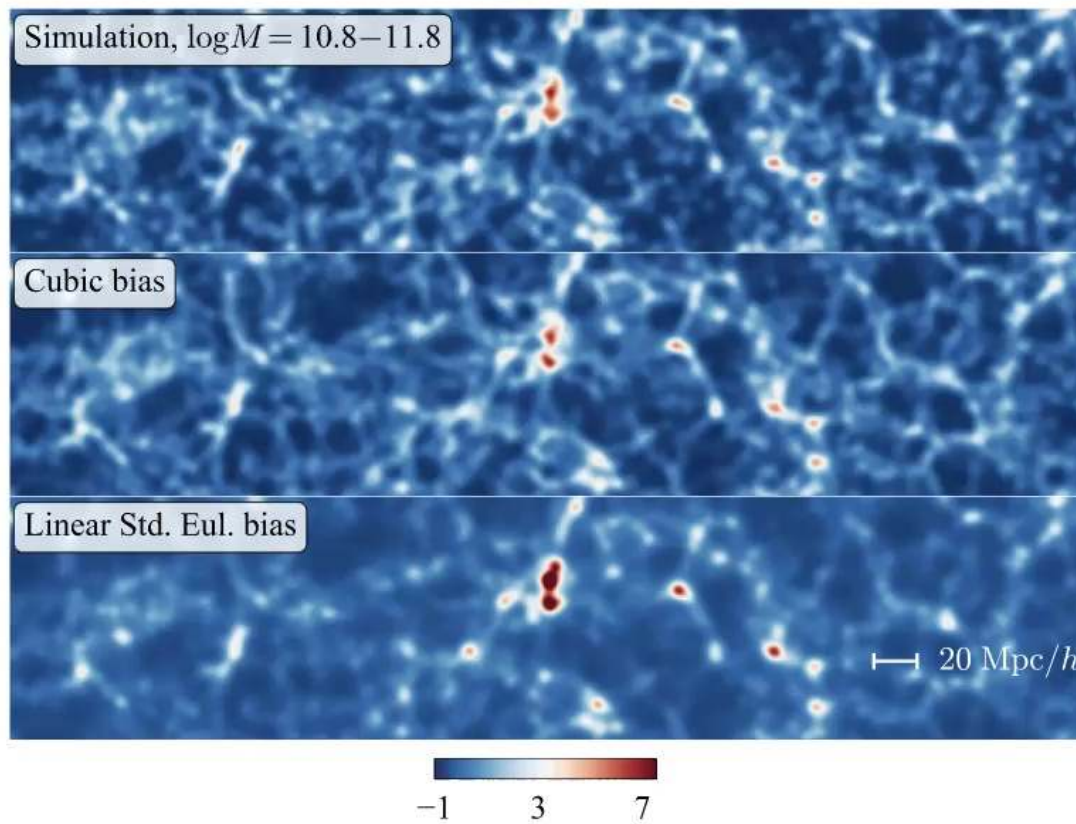
<https://github.com/Michalychforever/CLASS-PT>

https://github.com/Michalychforever/lss_montepython

Perturbation theory approach to LSS clustering

Schmittfull, MS, Assassi, Zaldarriaga (2018)

Biased tracers in real space



$$\delta_h(\mathbf{x})$$

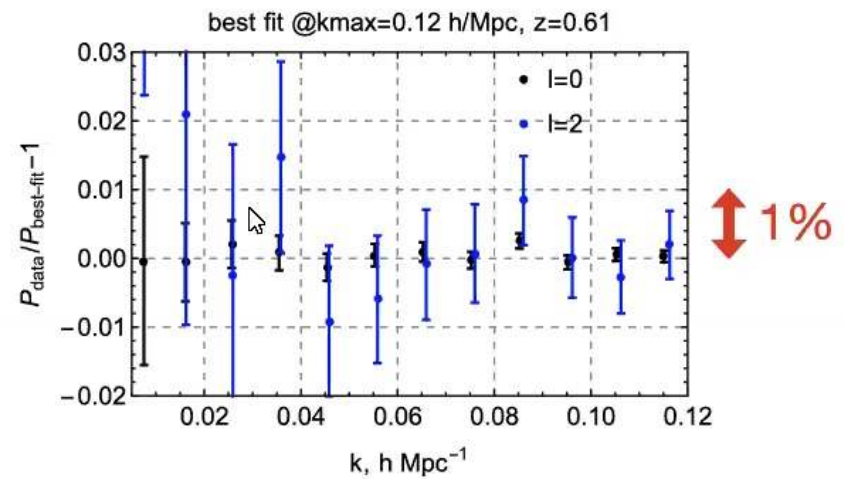
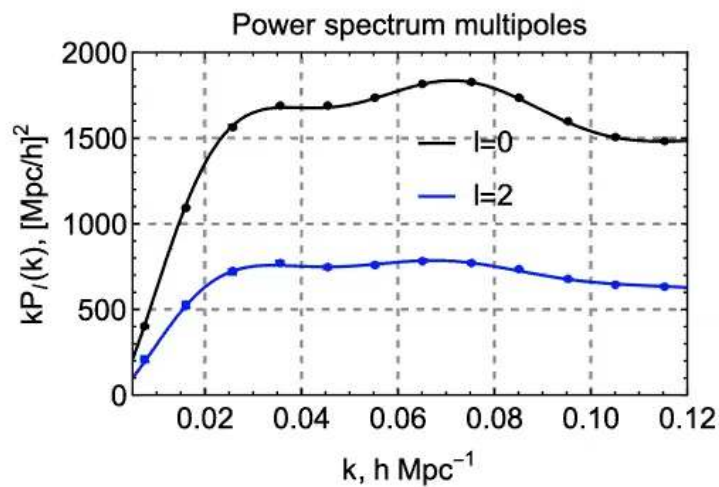
Linear bias with simulations

Perturbation theory approach to LSS clustering

PT Challenge: $V \sim 600 \text{ (Gpc/h)}^3$

(simulations: T. Nishimichi and M. Takada)

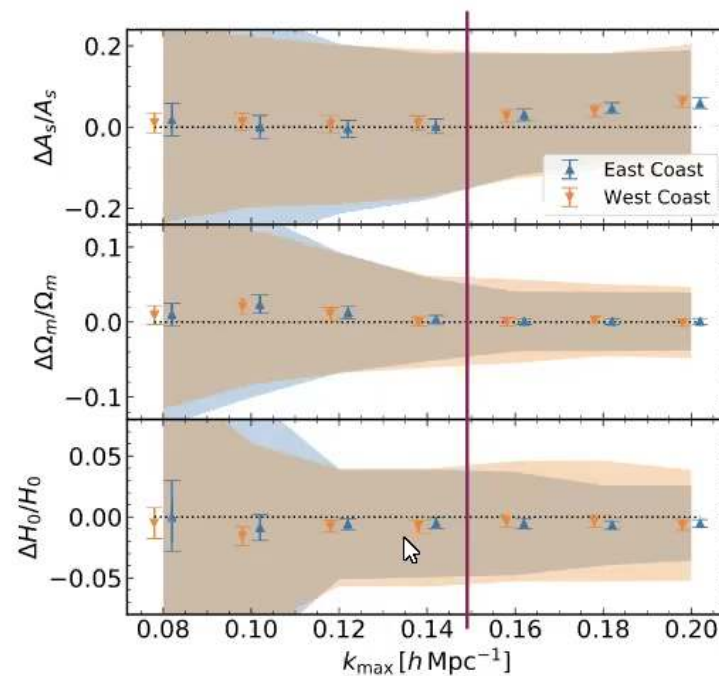
The challenge was blind, n_s and $\omega_b/\omega_{\text{cdm}}$ were known



Perturbation theory approach to LSS clustering

Nishimichi, D'Amico, Ivanov, Senatore, MS, Takada, Zaldarriaga, Zhang (2020)

Measured cosmological parameters were unbiased!



No significant biases given the BOSS volume

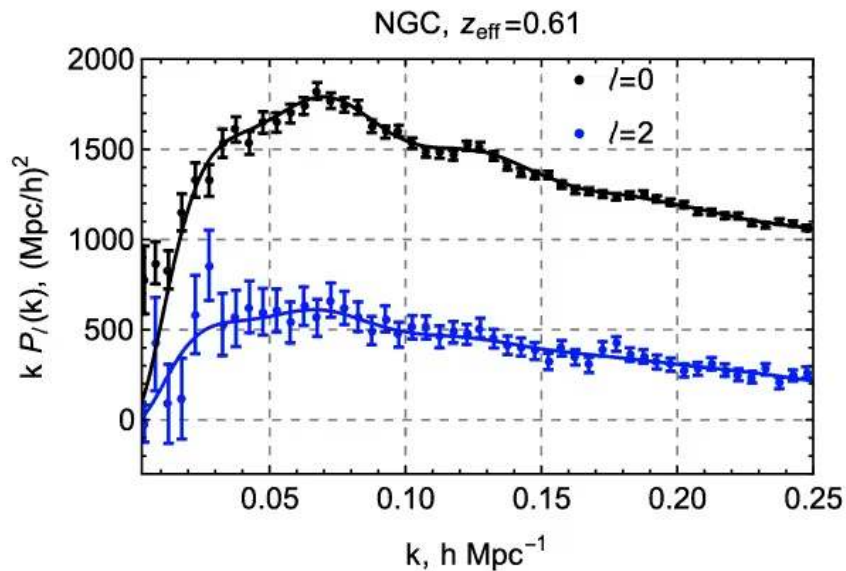
The same for nuisance parameters such as b_1 and derived parameters such as $H(z)$, σ_8 , f , D_A etc.

Perturbation theory approach to LSS clustering

Fit the monopole and quadrupole, vary all cosmological parameters

The only prior is the BBN prior on ω_b

Parameters: $(\omega_b, \omega_{\text{cdm}}, h, A^{1/2}, n_s, m_\nu) \times (b_1 A^{1/2}, b_2 A^{1/2}, b_{\mathcal{G}_2} A^{1/2}, P_{\text{shot}}, c_0^2, c_2^2, \tilde{c})$

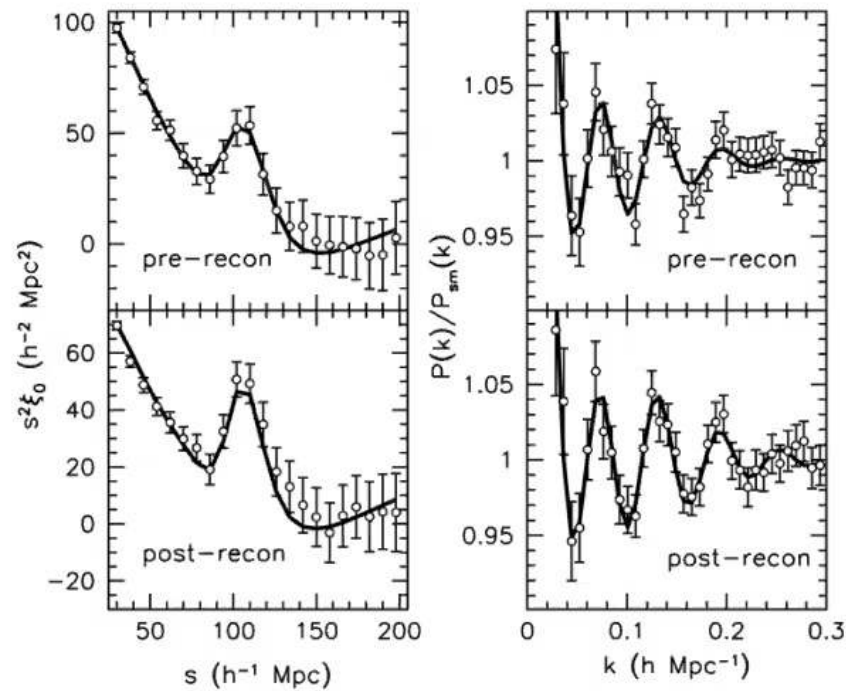


shape parameters
+
 H_0

Perturbation theory approach to LSS clustering

In addition, we can also exploit the BAO reconstruction

Sharper BAO wiggles improve measurement of H_0



Perturbation theory approach to LSS clustering

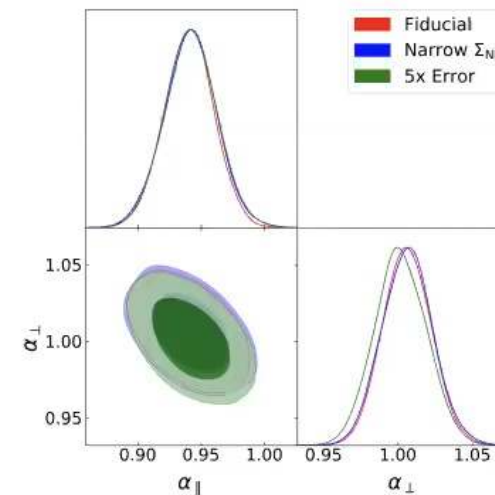
A new way to extract the BAO wiggles, using “theoretical error”

Philcox, Ivanov, MS, Zaldarriaga (2020)

Assign large *correlated* error bars to data points for the reconstructed power spectrum

Fit for the BAO template (Σ is a free parameter)

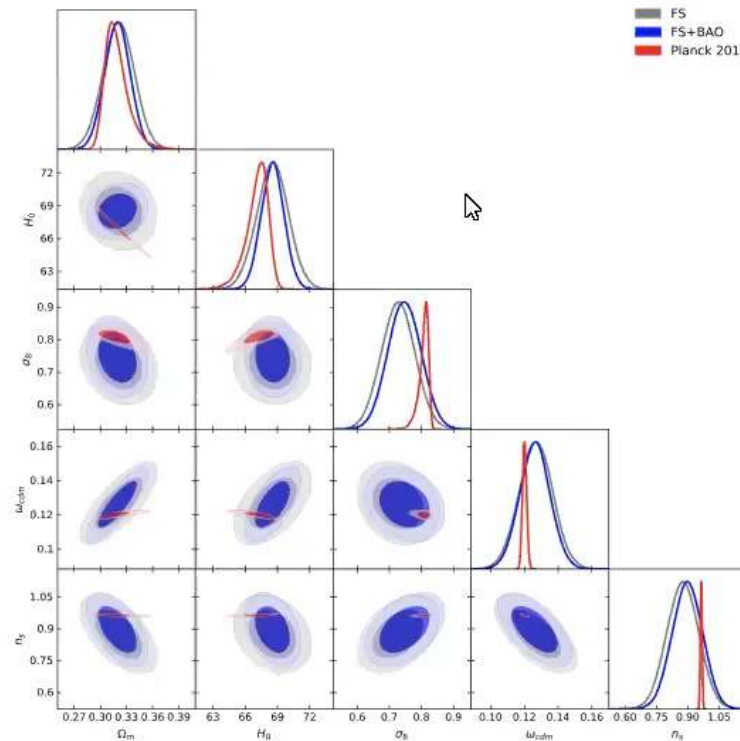
No broadband parameters



Final data vector: $\{P(k_i), \alpha_{\perp}, \alpha_{\parallel}\}$ with the appropriate covariance matrix

ΛCDM with BBN prior

Philcox, Ivanov, MS, Zaldarriaga (2020)



FS + BAO reconstruction

$$H_0 = (68.5 \pm 1.1) \text{ km/s/Mpc}$$

Similar results by:

d'Amico, Gleyzes, Kokron, Markovic, Senatore, Zhang, Beutler, Gil Marin (2019)

Tröster et al. (2019)

LCDM + m_ν + N_{eff} with BBN prior

Philcox, Ivanov, MS, Zaldarriaga (2020)

Constraints on neutrino mass change when FS is added

Planck + BAO: $m_\nu < 0.12$ eV

Planck + FS + BAO: $m_\nu < 0.16$ eV



due to somewhat lower σ_8

If we also the effective degrees of freedom to the fit

Planck + BAO: $N_{eff} = 2.99 \pm 0.17$

Planck + FS + BAO: $N_{eff} = 2.90 \pm 0.15$ ($H_0 = 67.0 \pm 1.0$)



Interesting in the context of H0 tension

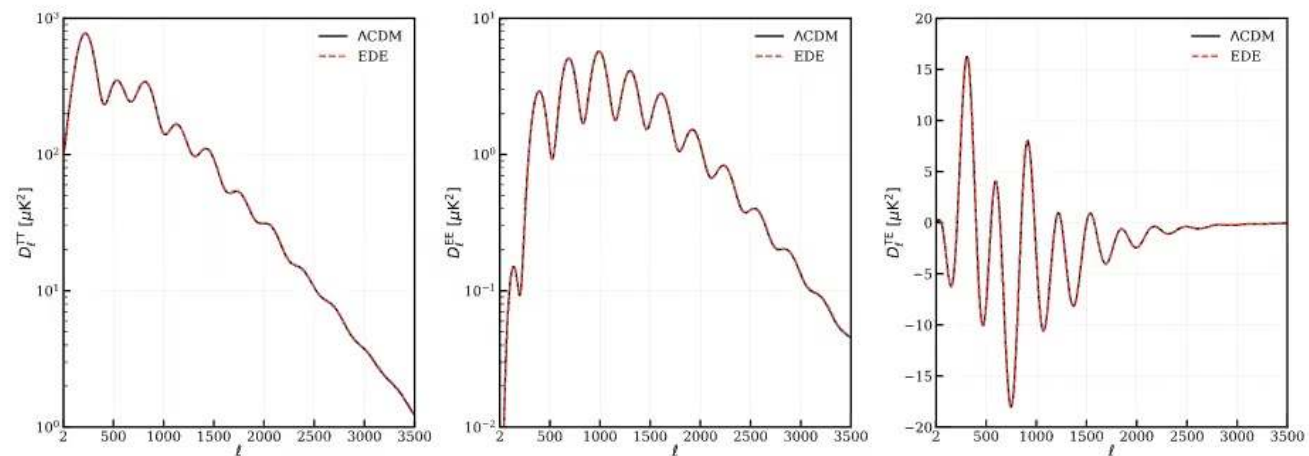
ΛCDM + EDE with BBN prior

EDE model tries to resolve the Hubble tension changing the early universe physics

Poulin, Smith, Karwal, Kamionkowski (2018)

O(5%) changes in the linear power spectrum are “invisible” in the CMB

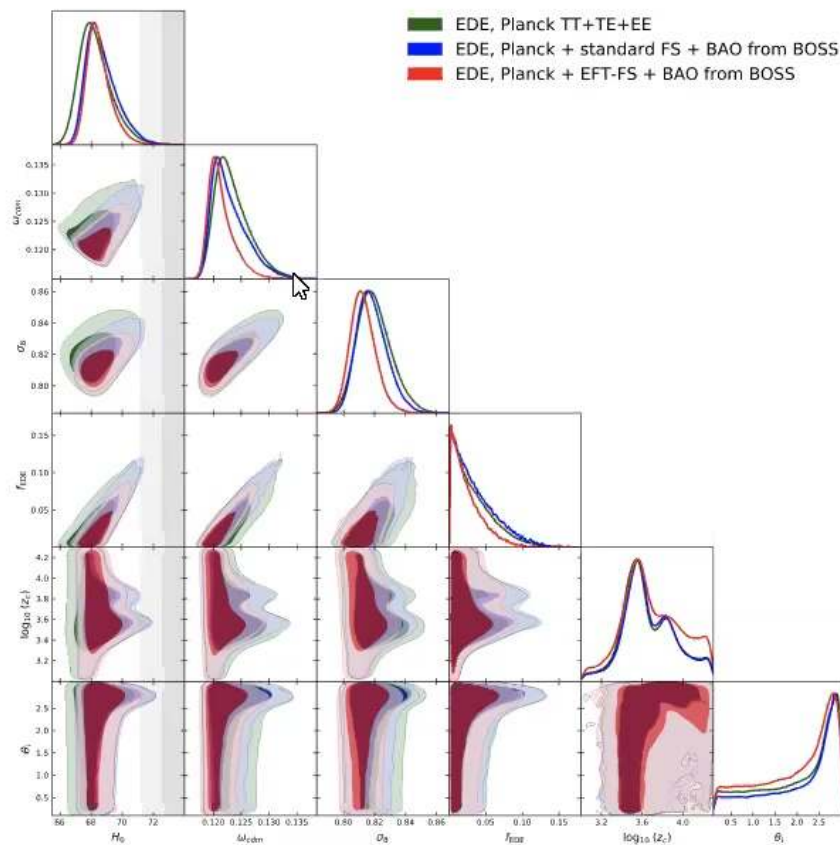
How about LSS?



ΛCDM + EDE with BBN prior

Ivanov et. al. (2020)

D'Amico et. al. (2020)



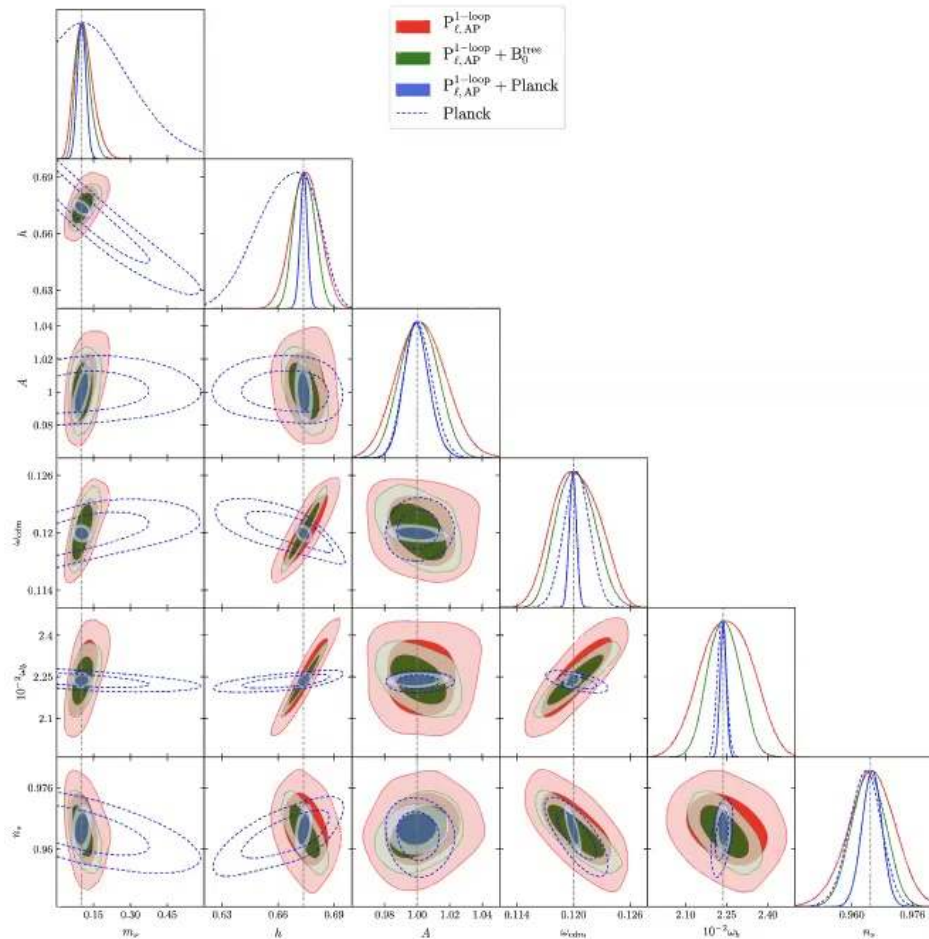
Improvement compared to the standard $f\sigma_8$ + BAO analysis

An example where the FS likelihood makes the difference

Future surveys

Chudaykin, Ivanov (2019)

Euclid/DESI-like survey



Euclid/DESI ~ Planck
some degeneracies broken

Future directions

Covariance matrices: analytic or mocks?

Data compression, particularly relevant for higher order statistics

Optimal estimator vs. FKP. Does it make a difference on large scales?

Can we get better priors on nuisance parameters?

How much does the bispectrum help?

Conclusions

Perturbation theory (EFTofLSS) works very well on large scales

It can be applied to galaxies in redshift space

CLASS-PT is a new tool that significantly simplifies evaluation of nonlinear spectra

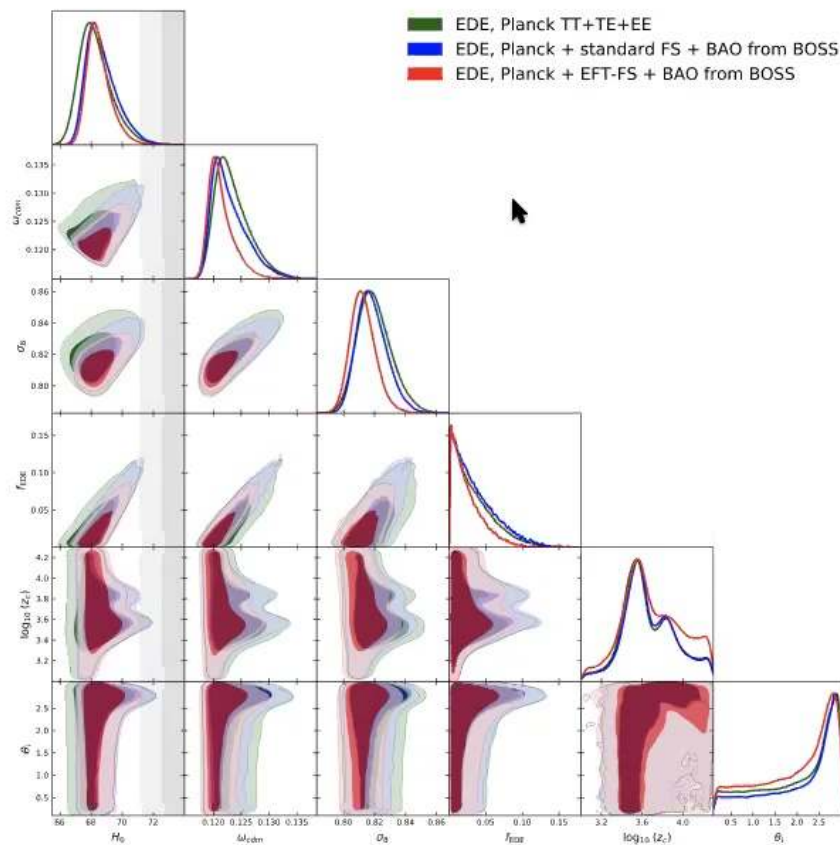
We can constrain cosmology (LCDM and extensions) from current data already

This will significantly improve in the future

ΛCDM + EDE with BBN prior

Ivanov et. al. (2020)

D'Amico et. al. (2020)



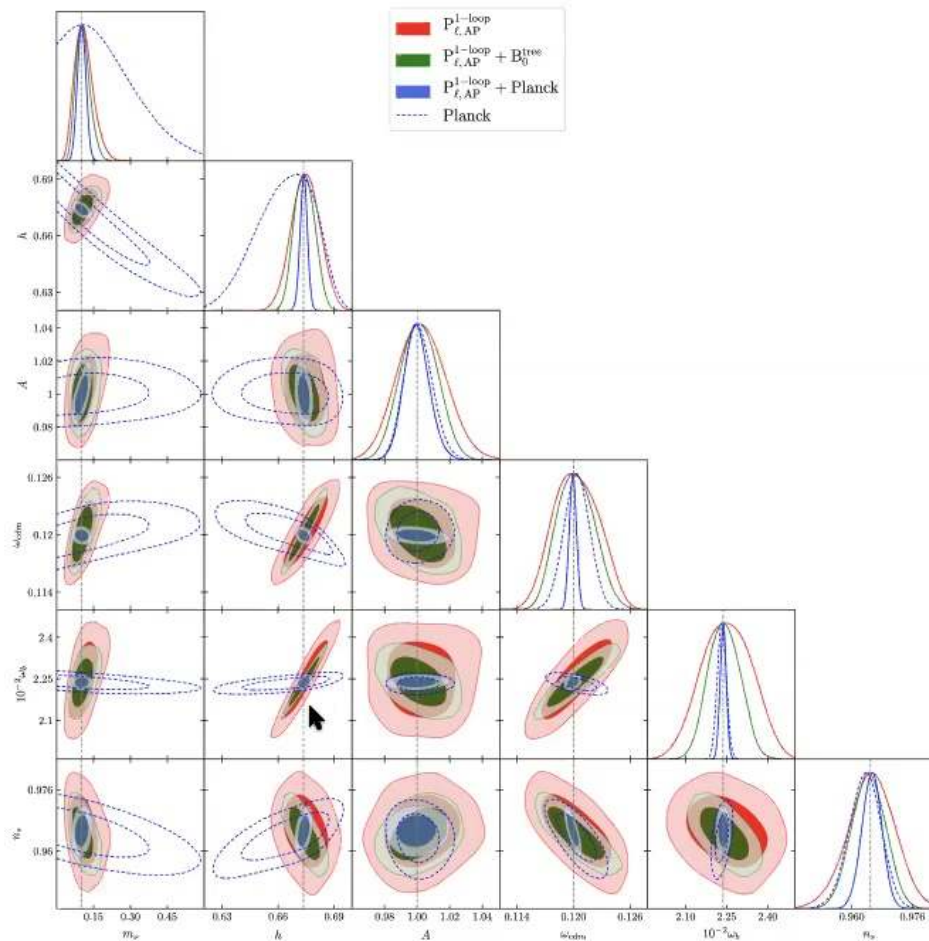
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