Guido D'Amico

UNIVERSITÀ DI PARMA

INFN Istituto Nazionale di Fisica Nucleare

The EFTofLSS: Successes and next moves

Based on several works with L. Senatore, P. Zhang, Y. Donath, M. Lewandowski, et al.

PyBird: *PYthon code for Biased tracers In ReDshift space*

PyOwl: *PyBird, but nightly*

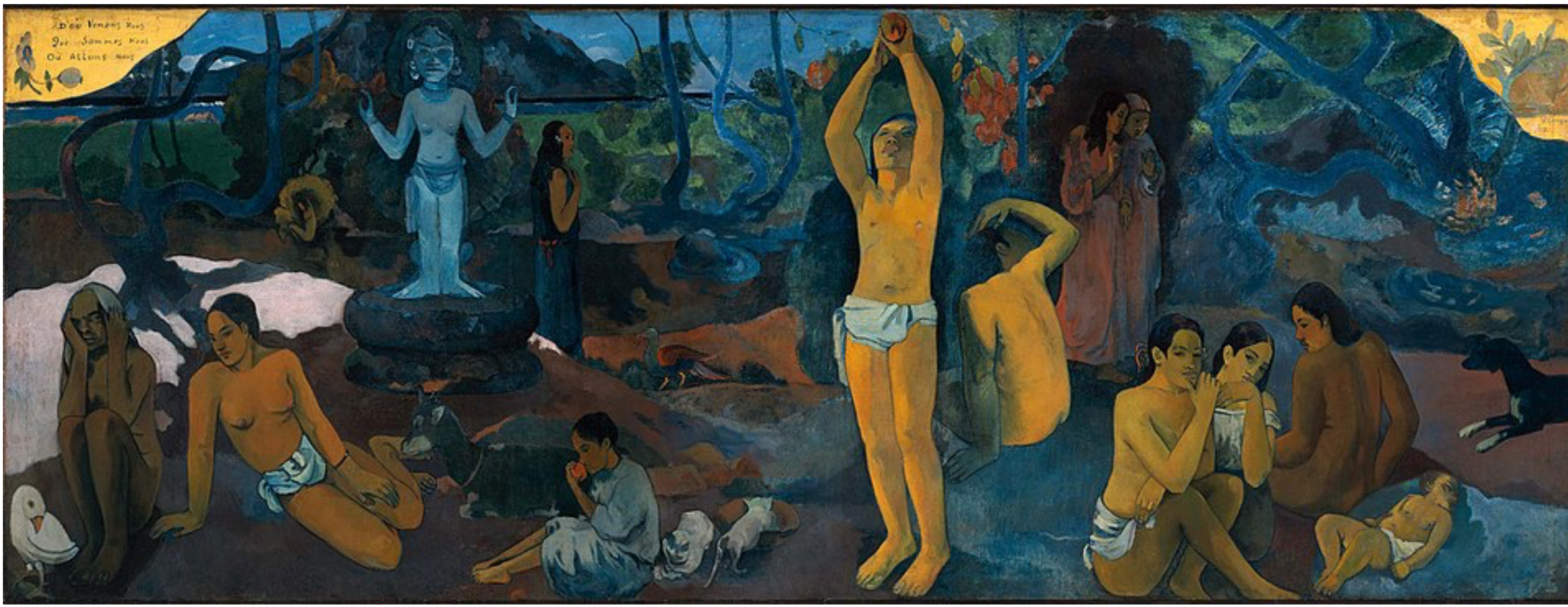
PyFowl: *PYthon code For Observables in Weak Lensing*

New Physics from Galaxy Clustering at GGI, Florence, 2025/9/29

D'où venons-nous ?

Que sommes-nous ?

Où allons-nous ?



Gauguin 1898

What is this for?

- We are getting a wealth of LSS data (DESI, Euclid, Spherex…) What's the end goal of the experimental effort?

- Understanding the universe! Practically, this means measuring known and detecting unknown physics across a wide range of energy scales (neutrino masses, PNG, dynamical DE, light mediators, relics, ?)

- As with any experimental information, we struggle for
  - Precision: more volume, more galaxies, more time
  - Accuracy: less and less systematics, and a reliable interpretation of the data

- EFTofLSS gives us just that – analytical understanding in terms of a description of the system based on good old effective theory

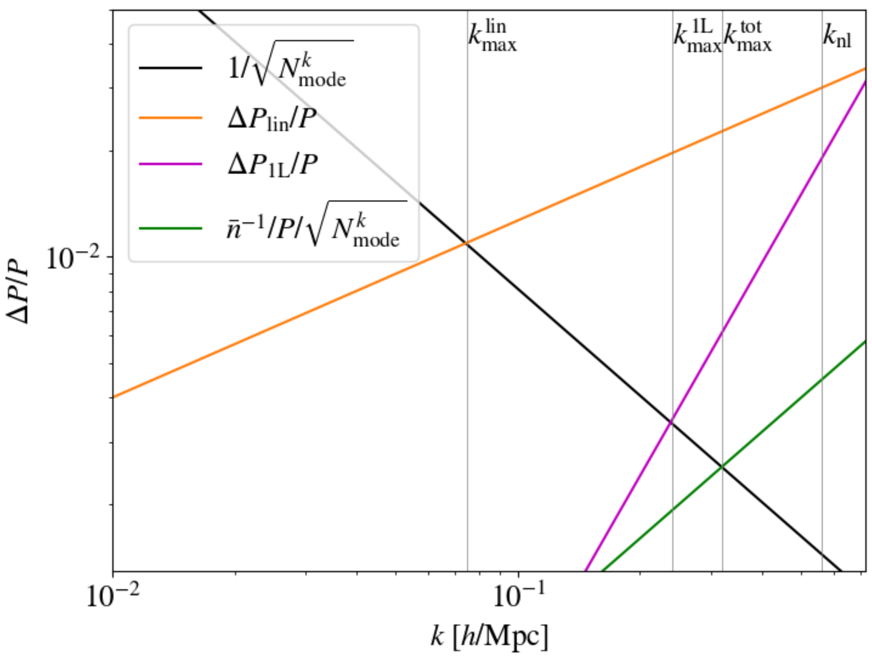
The EFTofLSS, in a nutshell

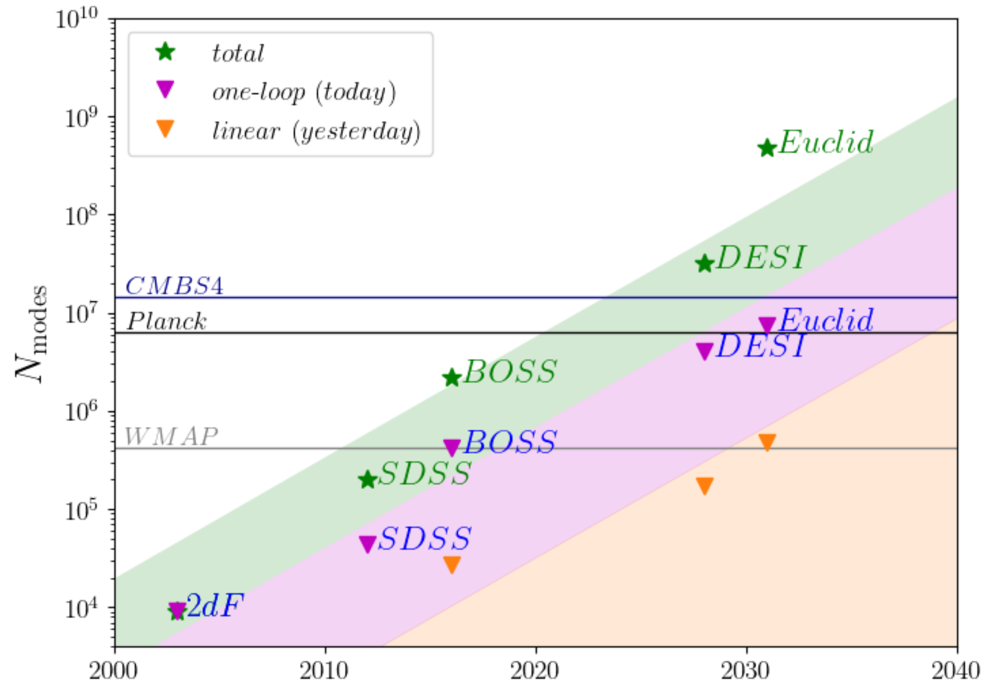
- Basic dofs and symmetries: CDM smoothed density and momentum (or displacement), translations, rotations, diffs
- Physical cutoff(s) of the theory: $k_{\rm NL}, k_{\rm R}$
- Expansion parameter(s): basically $k/k_{\rm NL}$, k/k_R
- Do perturbation theory, where possible. Renormalise unknown effects of small scales. Resum non-perturbative effects. Congratulations, you have (unobservable) CDM!
- Add biasing scheme, go to redshift space, do projection integrals, to get to specific observables. Now you can build a likelihood!
- Estimate the scale cuts.
- Add eventual known systematics.
- Do the data analysis, report the results

Why the pain?

$$N_{\rm modes}({\rm CMB}) \sim \ell_{\rm max}^2$$

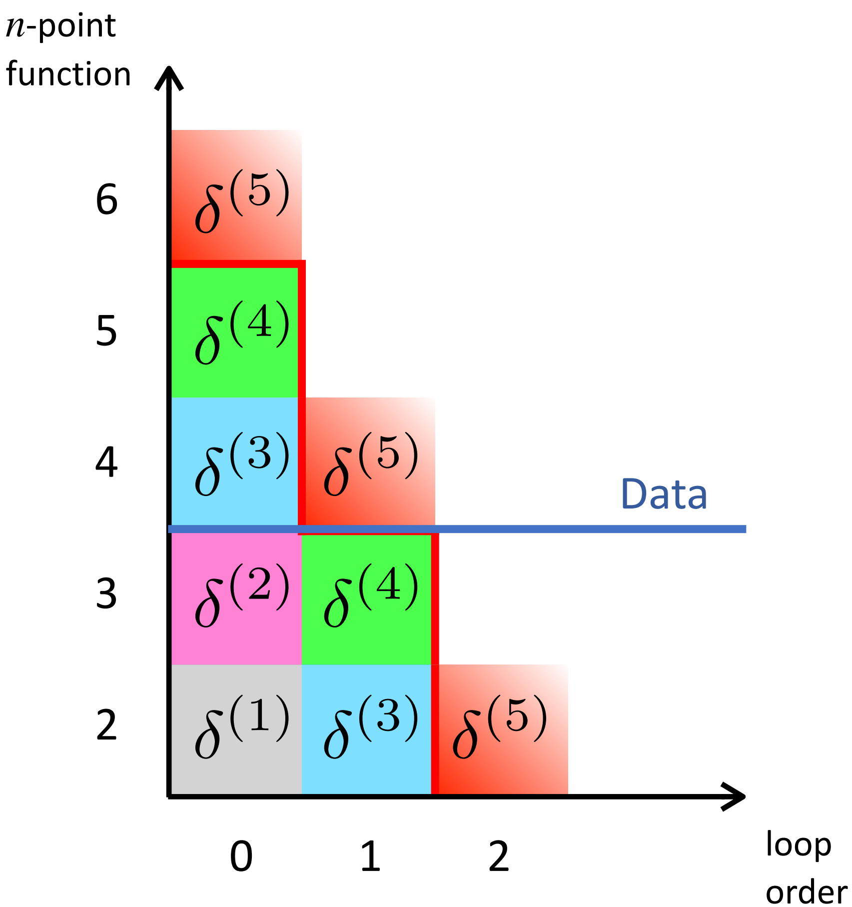
$$N_{\rm modes}({\rm LSS}) \sim V_{\rm survey} k_{\rm max}^3$$





Credit: P. Zhang

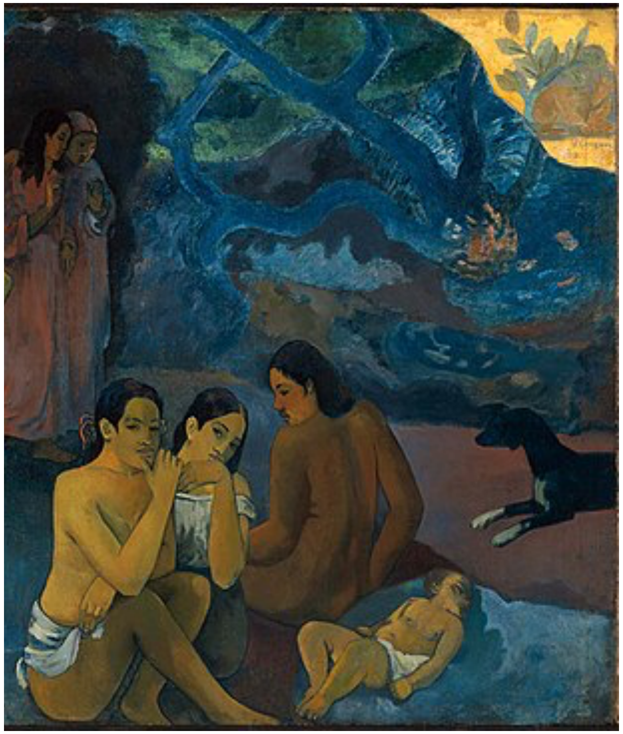
What have we computed?



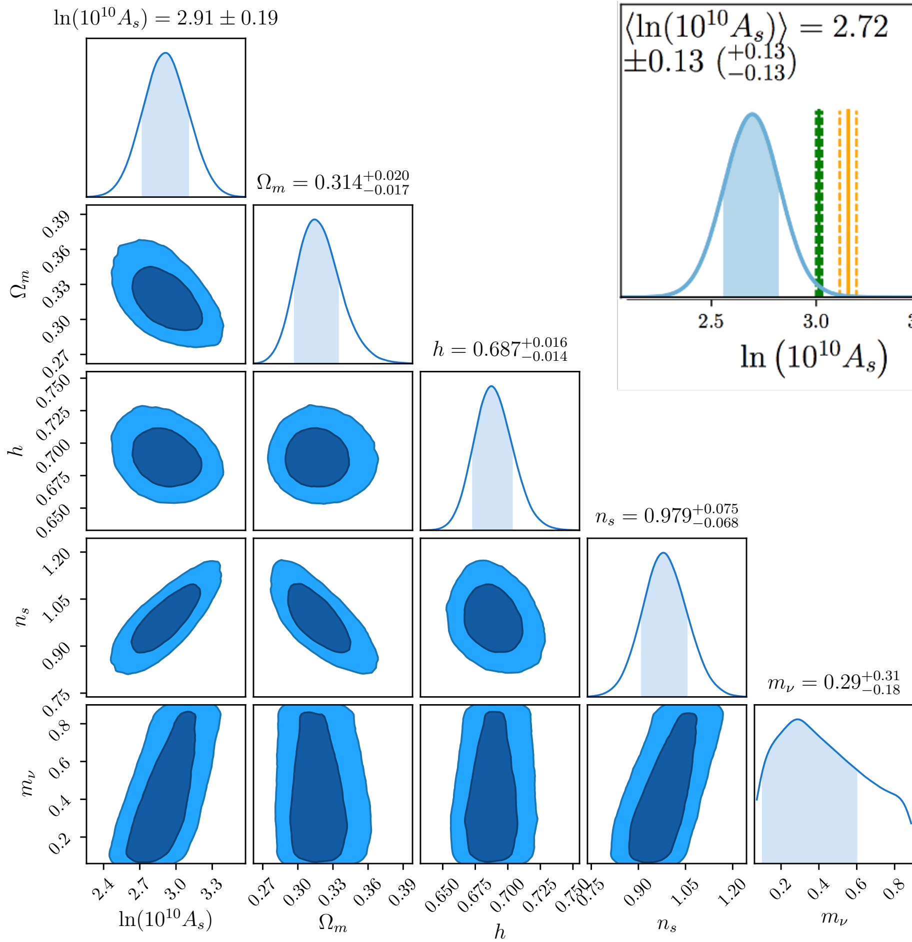
	Bias	**Ren.**	**RSD**
$\delta^{(3)}$	✓	✓	✓
$\delta^{(4)}$	✓	✓	✓
$\delta^{(5)}$	✓	✓	✗

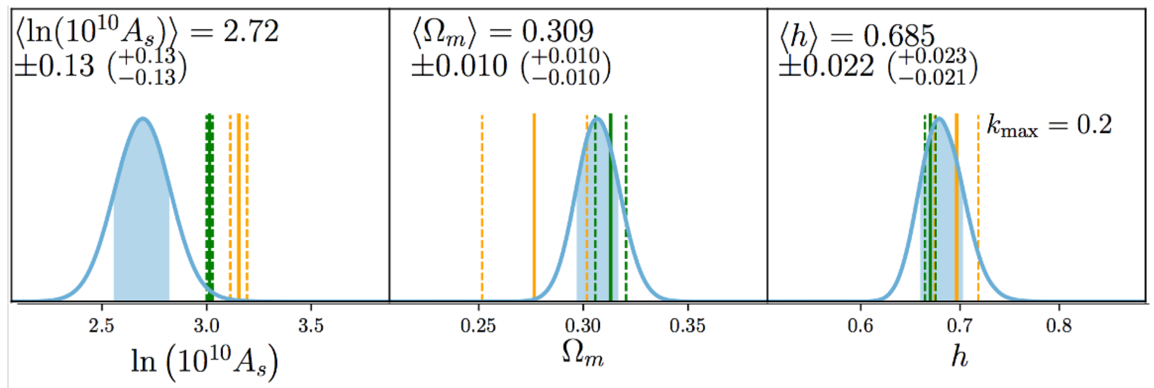
Credit: P. Zhang

D'où venons-nous ?



The story: 1-loop 2-point function



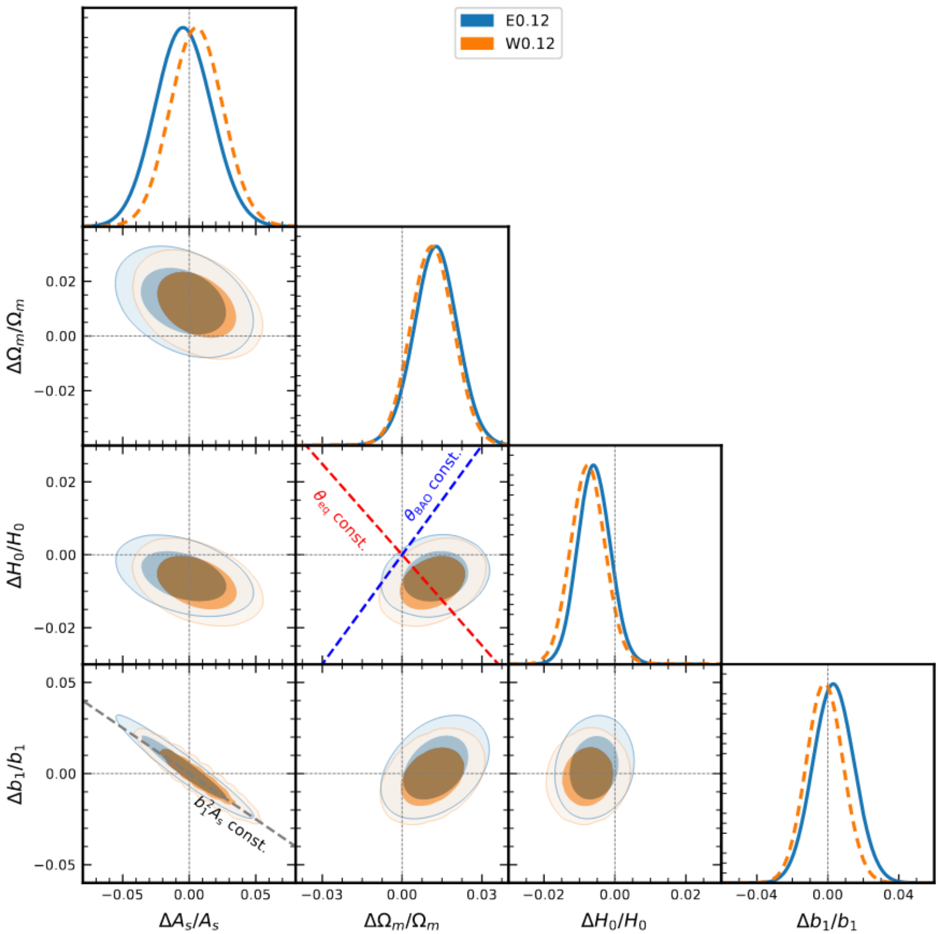


- Start from 1-loop power spectrum
- Many validations, conservative scale-cut, agreement with Planck
- Still some confusions (low A_s)
- Overall, looks like a good job. Will the full-shape become the new standard analysis?

D'Amico, Gleyzes, Kokron, Markovic, Senatore, Zhang, Beutler, Gil-Marin 2019

Colas, D'Amico, Senatore, Zhang 2020

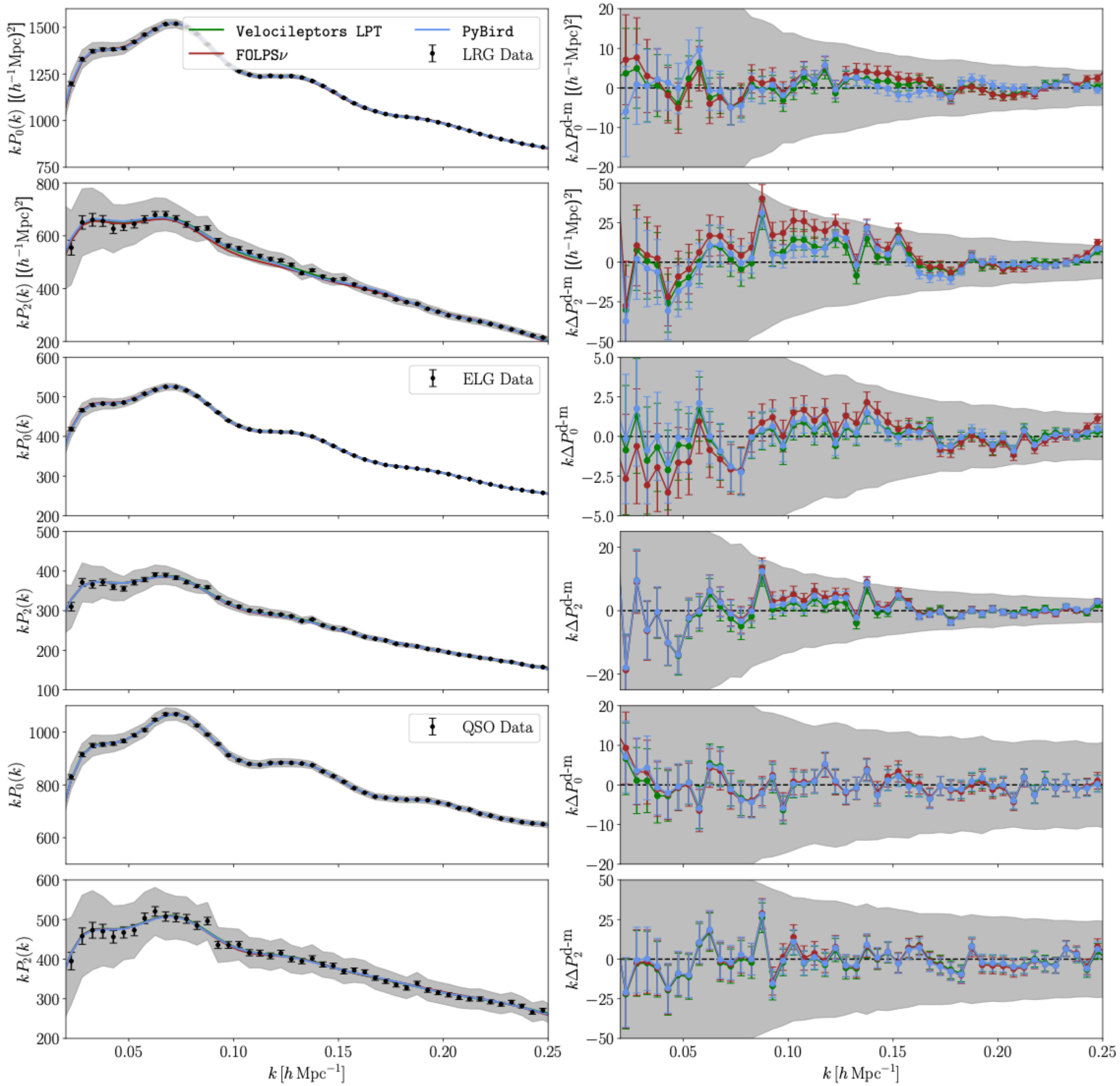
The blinded PT-challenge



Nishimichi, D'Amico, Ivanov, Senatore, Simonovic, Takada, Zaldarriaga, Zhang 2020
Chen, Vlah, Castorina, White 2021

- Total volume: $566\,(h^{-1}\mathrm{Gpc})^3$, ~100 times BOSS
- 2 independent blind analyses, on 3 cosmological parameters: we agreed between us and with the truth!
- This helped establish the reliability of the method
- Now many codes available: PyBird (and PyBird-Jax), CLASS-PT, Velocileptors, Class-OneLoop, PBJ

DESI validation



Maus et al. 2024

The scale-cut problem

- Crucial issue: where to stop the fit?
  Usual tradeoff between *accuracy* and *precision*: smaller scales have smaller errors, but perturbative approach starts to fail
- Important observation: effective field theories set their own scale cut, given a required precision

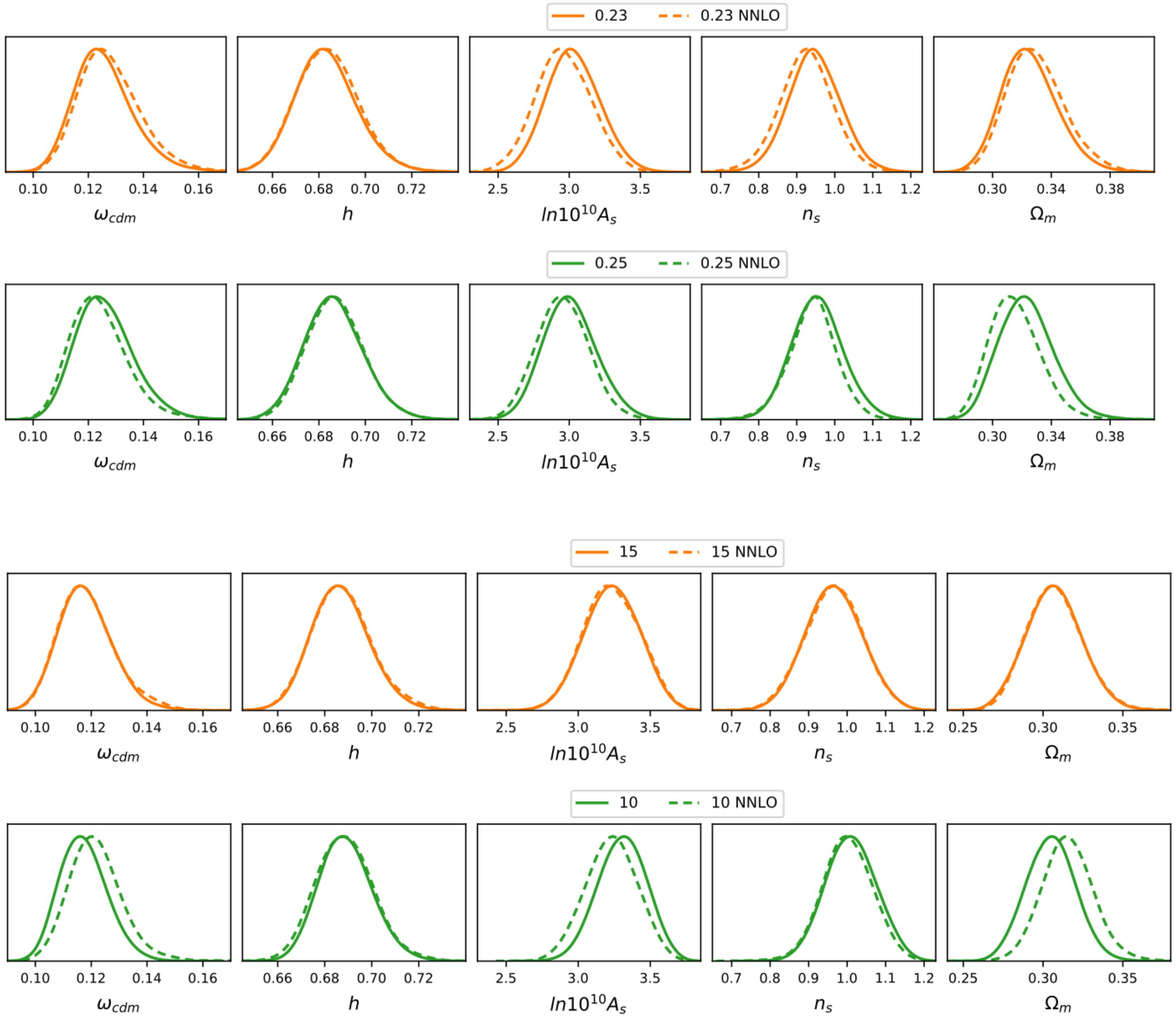
- The theory is a controlled approximate description of reality.
  - If we compute up to order n, we are making a (theoretical) error of order $\Delta^{(n+1)}$
  - Data have an error σ_{data}. We choose how much accurate we want to be (30%? 10%? 1%?).
    Then, let's require $\Delta^{(n+1)} < \alpha\sigma_{\text{data}}$

- NNLO estimate are more or less reliable. For the power spectrum

$$P_{2L}^{\mu=0}(k) \sim c_e \frac{k^2}{k_M^2} P_{1L}^{\mu=0}(k) \qquad\qquad P_{2L}(k,\mu) \sim b_1\left(c_{r,4} b_1 + c_{r,6}\mu^2\right)\mu^4 \frac{k^4}{k_R^4} P_{11}(k)$$

- Of course, we can also use simulations (if they are reliable)

The scale-cut problem



$$\sigma_{\rm sys} < \frac{1}{3}\sigma_{\rm data}$$

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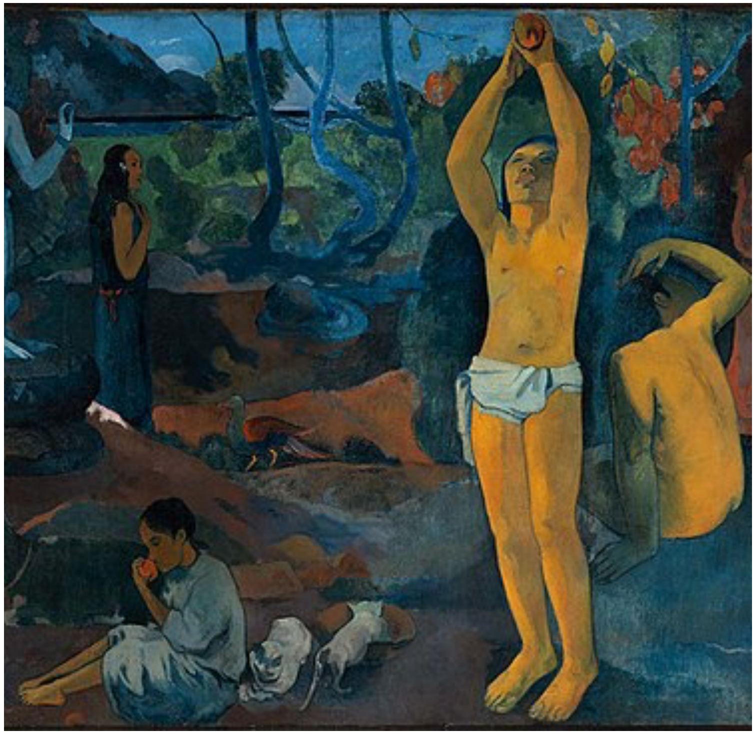
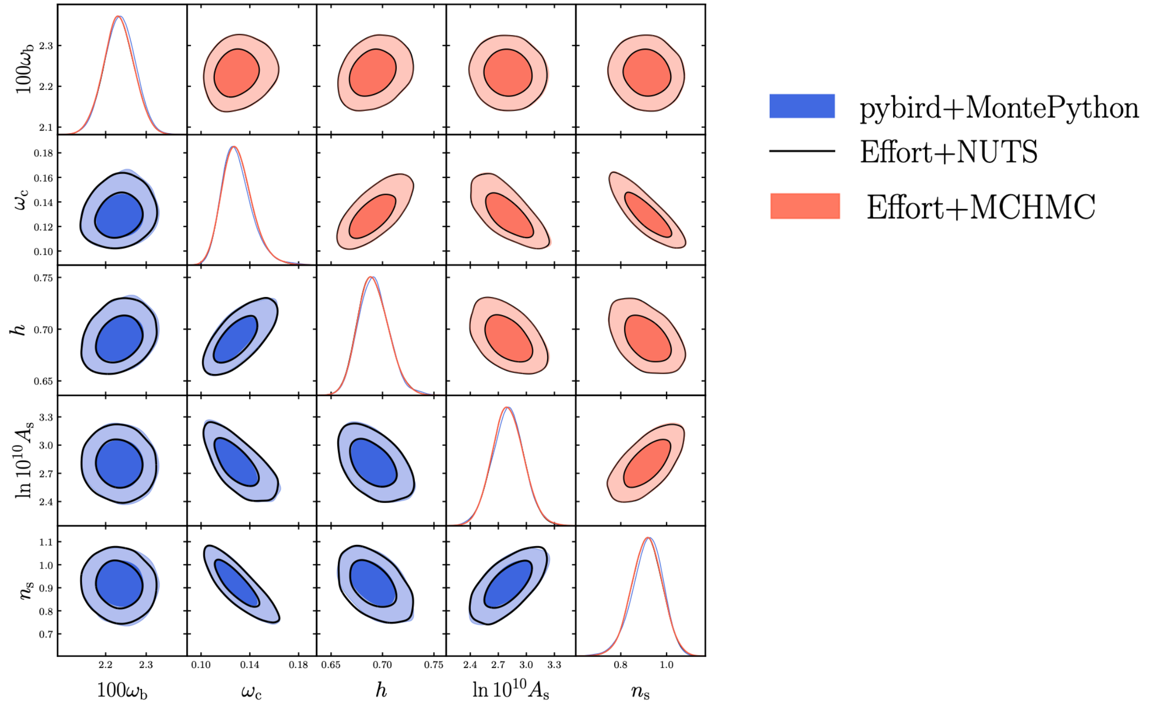
Zhang, GDA, Senatore, Zhao, Cai 2021

Que sommes-nous ?



Towards differentiable cosmology: Effort.jl

- Would be really nice to be super fast and use analytical gradients: easy minimisation, likelihood profile, use of HMC
- Possible solution: emulate the theory, in a smart way
  For 2-pt very easy. One can afford to build a slower, more precise EFT code, since the NN is trained only once.
  Each evaluation takes $\sim O(100\,\mu\text{sec})$ ($15\,\mu$sec without AP)



Bonici, GDA, Bel, Carbone 2025
Reeves, Zhang, Zheng 2025

Beyond 2-pt: the 1-loop bispectrum in LSS

- Lots of work to develop the pipeline for 1-loop bispectrum
  - Biased tracers to 4th order in perturbations
  - Redshift distortions up to 4th order
  - Counterterms up to 2nd order
  - Efficient way of computing loop integrals
  - Generalization to non-Gaussian initial conditions

GDA, Lewandowski, Senatore, Zhang (2022)
GDA, Donath, Lewandowski, Senatore, Zhang (2022a, 2022b)
Philcox, Ivanov, Cabass, Simonovic, Zaldarriaga (2022a, 2022b, 2022c)
Bakx, Ivanov, Philcox, Vlah (2025)

Theory Model

- Perturbation theory up to 4th order: 11 bias parameters

$$P_{11}^{r,h}[b_1]\ ,\quad P_{13}^{r,h}[b_1,b_3,b_8]\ ,\quad P_{22}^{r,h}[b_1,b_2,b_5]\ ,\quad B_{321}^{r,h,(I)}[b_1,b_2,b_3,b_5,b_6,b_8,b_{10}]\ ,$$
$$B_{211}^{r,h}[b_1,b_2,b_5]\ ,\quad B_{321}^{r,h,(II)}[b_1,b_2,b_3,b_5,b_8]\ ,\quad B_{411}^{r,h}[b_1,\dots,b_{11}]\ ,\quad B_{222}^{r,h}[b_1,b_2,b_5]$$

- Stochastic and counterterms up to 2nd order: 30 parameters

$$P_{13}^{r,h,ct}[b_1,c_1^h,c_1^\pi,c_1^{\pi v},c_3^{\pi v}]\ ,\quad P_{22}^{r,h,\epsilon}[c_1^{\rm St},c_2^{\rm St},c_3^{\rm St}]\ ,$$
$$B_{321}^{r,h,(II),ct}[b_1,b_2,b_5,c_1^h,c_1^\pi,c_1^{\pi v},c_3^{\pi v}]\ ,\quad B_{321}^{r,h,(I),\epsilon}[b_1,c_1^{\rm St},c_2^{\rm St},\{c_i^{\rm St}\}_{i=4,\dots,13}]\ ,$$
$$B_{411}^{r,h,ct}[b_1,\{c_i^h\}_{i=1,\dots,5},c_1^\pi,c_5^\pi,\{c_j^{\pi v}\}_{j=1,\dots,7}]\ ,\quad B_{222}^{r,h,\epsilon}[c_1^{(222)},c_2^{(222)},c_5^{(222)}]$$

Observational effects

- Window: use approximation (on linear term) from Gil-Marin et al. (2014)

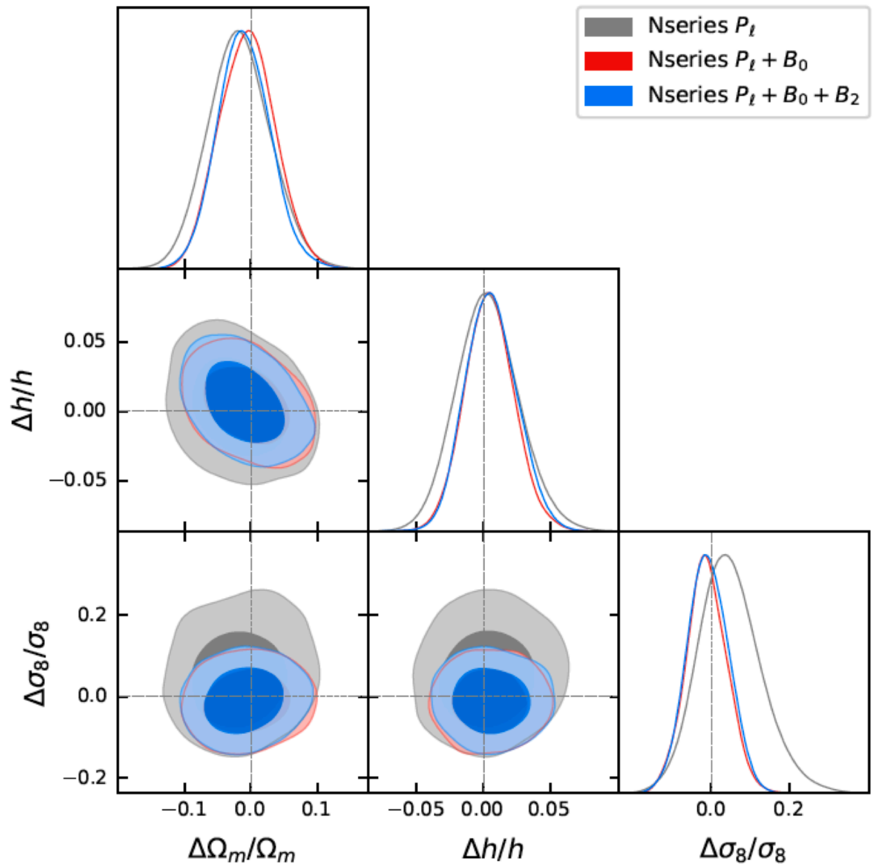
$$B_{211}^{r,h} = 2K_1^{r,h}(\vec{k}_1;\hat{z})K_1^{r,h}(\vec{k}_2;\hat{z})K_2^{r,h}(\vec{k}_1,\vec{k}_2;\hat{z})[W*P_{11}](\vec{k}_1)[W*P_{11}](\vec{k}_2) + \ 2\text{ perms.}\ ,$$

$$[W*P_{11}](\vec{k}) = \int \frac{\mathrm{d}^3k'}{(2\pi)^3} W(\vec{k}-\vec{k}')P_{11}(\vec{k}')$$

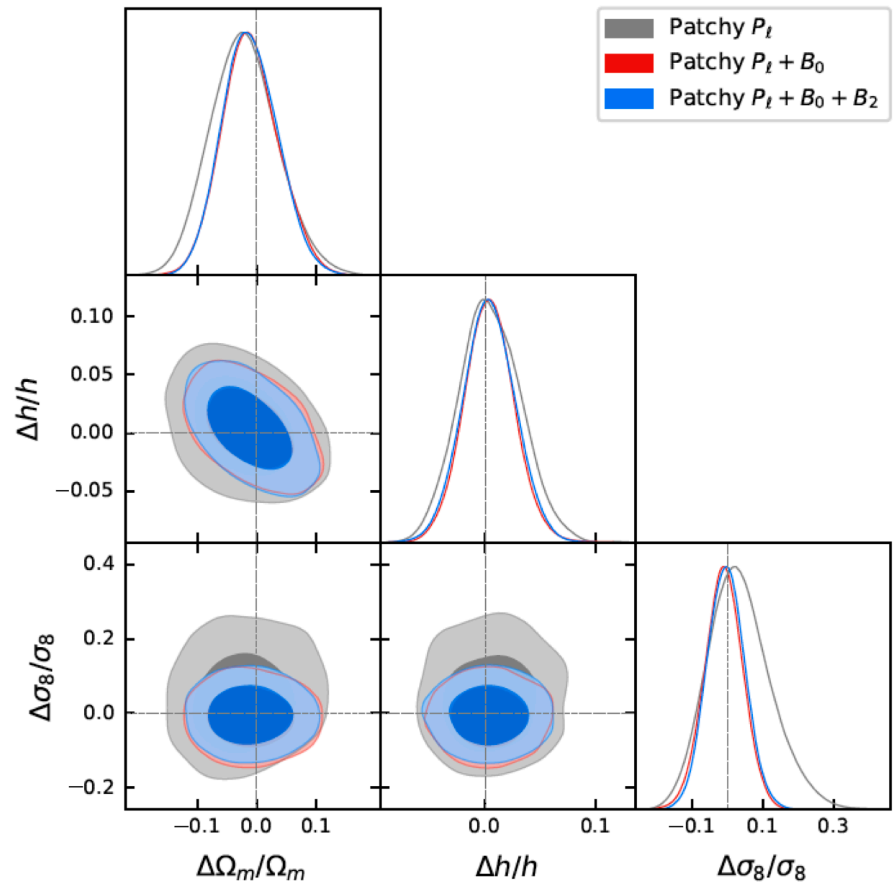
- Binning effect: it is performed (together with AP) exactly on the linear part, loop terms are small
- Effect of approximations are small

$\Delta_{\rm shift}/\sigma_{\rm stat}$	Ω_m	h	σ_8
$P_\ell + B_0$: base - w/ NNLO	-0.03	-0.09	-0.03
$P_\ell + B_0$: base - w/o B_0 window	0.11	-0.05	0.01
$P_\ell + B_0 + B_2$: base - w/o B_0, B_2 window	0.51	0.09	0.02

Theoretical error



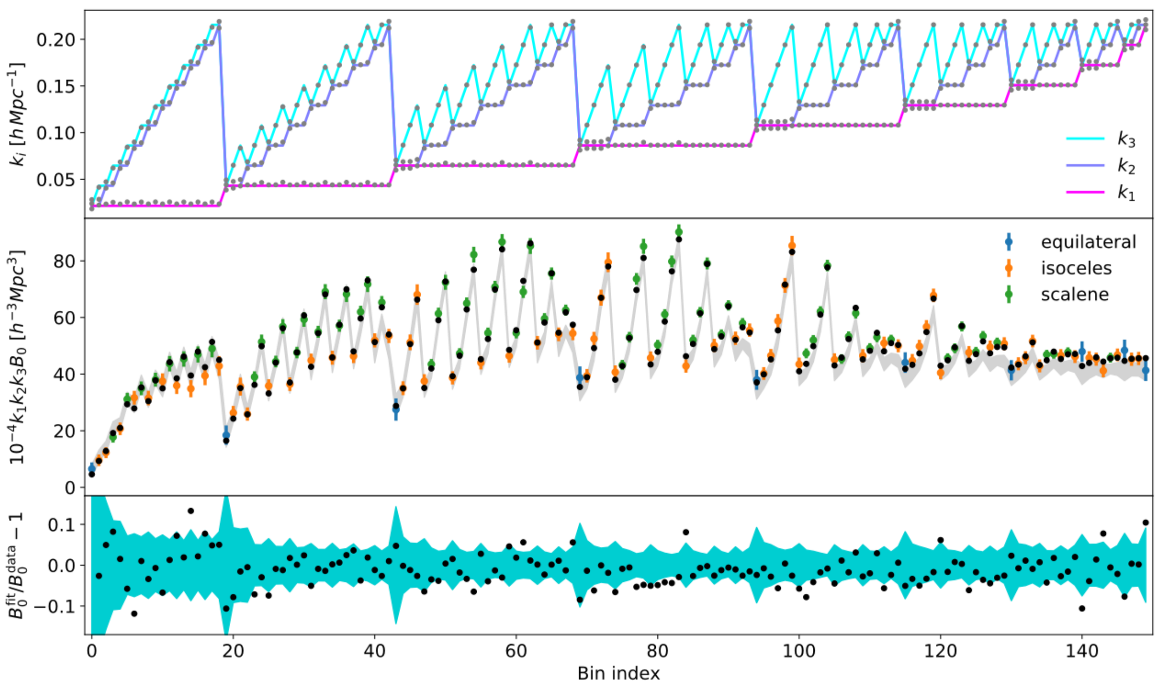
Nseries: 80 x BOSS volume

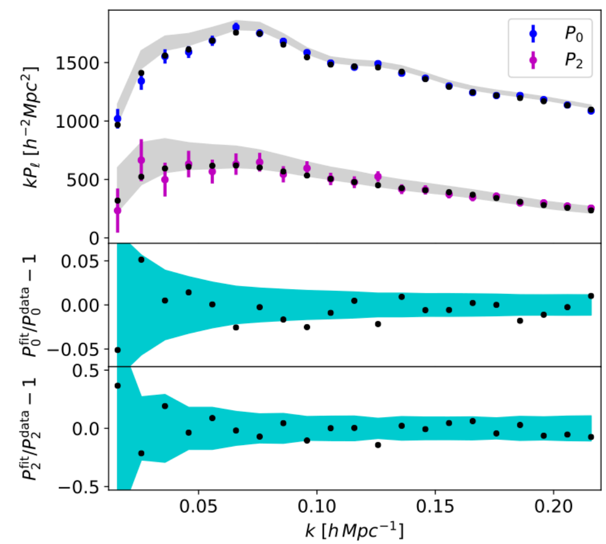


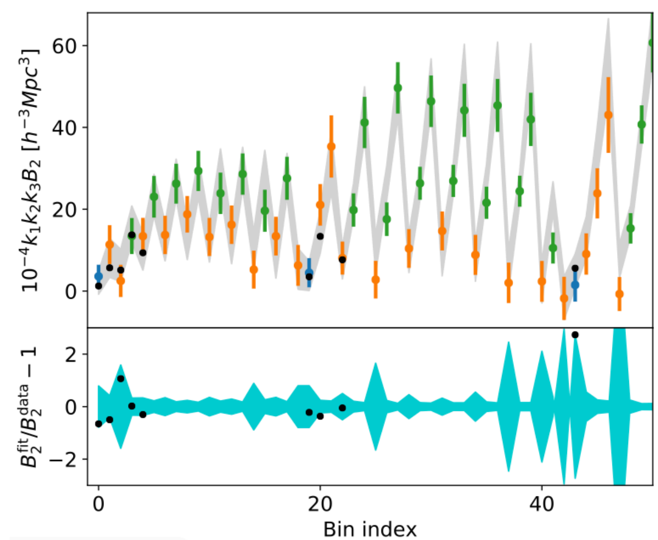
Patchy mocks: 2000 x BOSS volume

Fit with BOSS-volume covariance, safely within $\sigma_{data}/3$!

Best fit





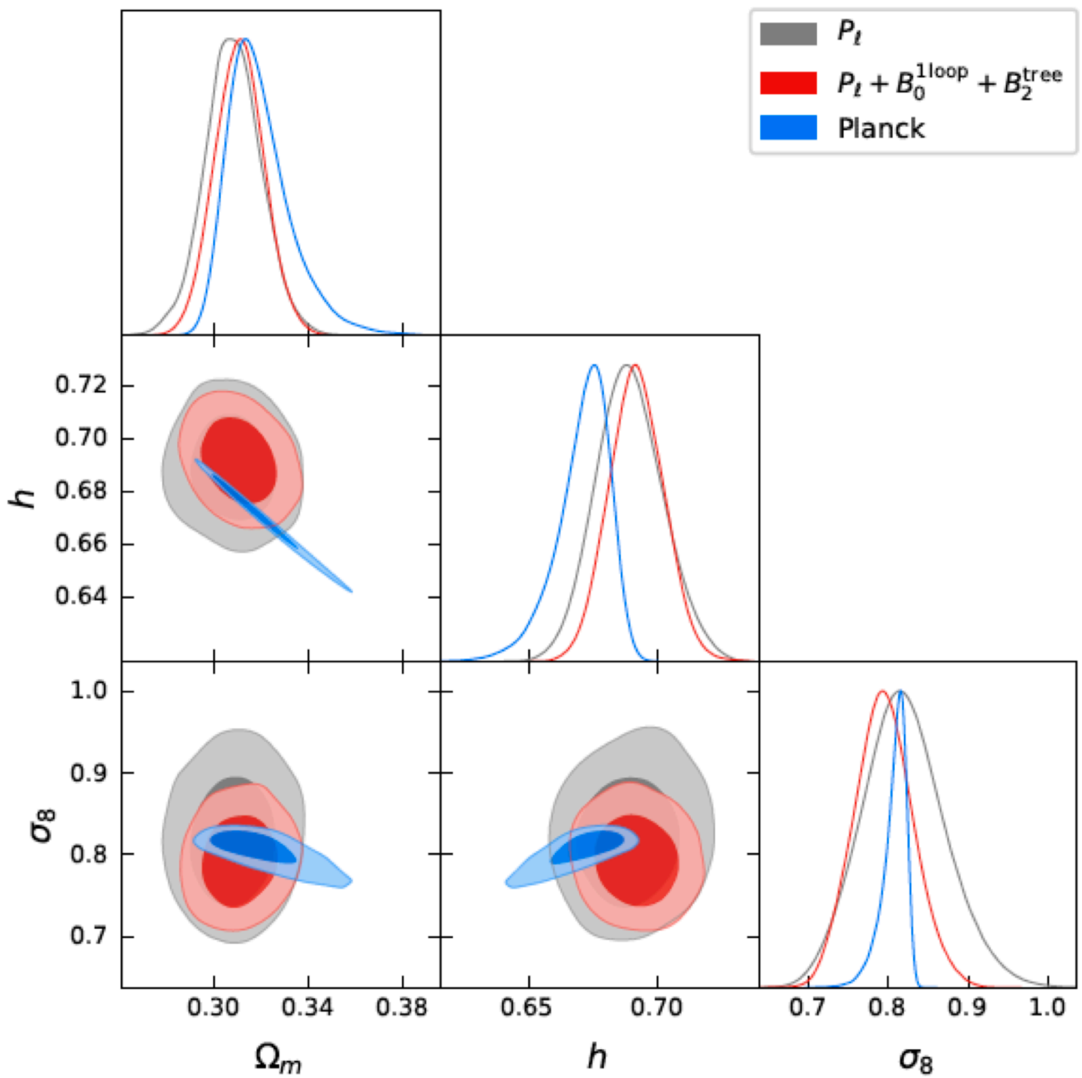


B_0 up to $k_{max} = 0.23\ h/Mpc$

B_2 tree-level, up to $k_{max} = 0.08\ h/Mpc$

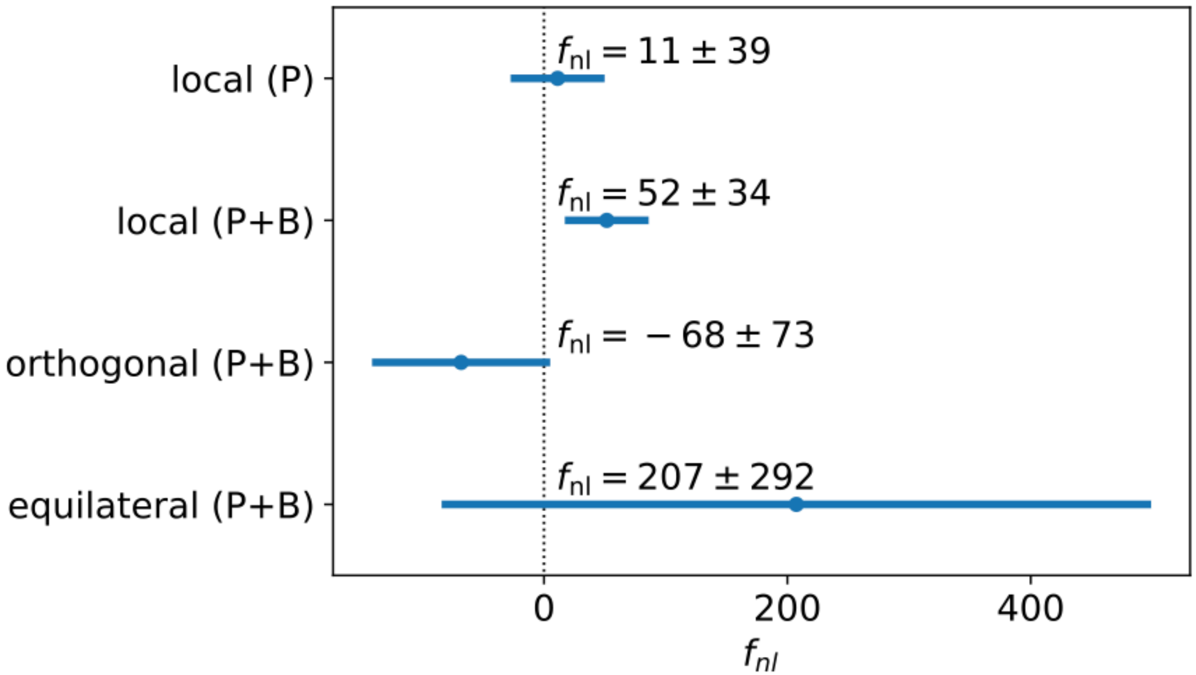
Binned in triangles of $12\ k_f \sim 0.02\ h/Mpc$

Results



- Improvements of
  13% on Ω_m
  18% on h
  30% on σ_8
- Agreement with Planck

And with PNG!



	BOSS	WMAP	Planck
$f_{\rm NL}^{\rm equil.}$	207 ± 292	51 ± 136	-26 ± 47
$f_{\rm NL}^{\rm orth.}$	-68 ± 73	-245 ± 100	-38 ± 24
$f_{\rm NL}^{\rm loc.}$	52 ± 34	37.2 ± 19.9	-0.9 ± 5.1

Not only spectroscopy in the sky

- Photometric surveys will also be important now — e.g., for Euclid lensing is as important as clustering

- Why can't we apply the EFTofLSS to 3x2pt analysis? Turns out that, with a ~~bit~~ lot of effort, we can. Look also at DESxDESI 2x2pt (Chen et al. 2024)

- Some peculiarities can be dealt with in an EFT-like way: baryonic effects and intrinsic alignments. Systematics are what they are, hopefully improvements in the future

- Main practical challenges: determine the scale cuts, and keep the number of free parameters under control

GDA, Refregier, Senatore, Zhang *2510.XXXXX*

Projection integrals

$$w^i(\theta) = \int \frac{\mathrm{d}l\, l}{2\pi} J_0(l\theta) \frac{2}{\pi} \int \mathrm{d}k\, k^2 \int \mathrm{d}\chi_1 \int \mathrm{d}\chi_2 f^i_{\delta_g}(\chi_1) f^j_{\delta_g}(\chi_2) P_{gg}\left(k, z(\chi_1), z(\chi_2)\right)$$

$$\gamma^{ij}_{\mathrm{t}}(\theta) = \int \frac{\mathrm{d}l\, l}{2\pi} J_2(l\theta) \frac{2}{\pi} \int \mathrm{d}k\, k^2 \int \mathrm{d}\chi_1 \int \mathrm{d}\chi_2 f^i_{\delta_g}(\chi_1) f^j_{\kappa}(\chi_2) P_{gm}\left(k, z(\chi_1), z(\chi_2)\right)$$

$$\xi^{ij}_{+}(\theta) = \int \frac{\mathrm{d}l\, l}{2\pi} J_0(l\theta) \int \mathrm{d}\chi \frac{f^i_\kappa(\chi) f^j_\kappa(\chi)}{\chi^2} P_{mm}\left(\frac{l}{\chi}; z(\chi)\right)$$

$$\xi^{ij}_{-}(\theta) = \int \frac{\mathrm{d}l\, l}{2\pi} J_4(l\theta) \int \mathrm{d}\chi \frac{f^i_\kappa(\chi) f^j_\kappa(\chi)}{\chi^2} P_{mm}\left(\frac{l}{\chi}; z(\chi)\right)$$

Modeling choices

- In general, we use unequal-time PS at linear level; and Limber approximation, so equal-time PS, at loop level
- RSD and magnification term are linear, in Limber approx.
- P_{mm}

$$P_{mm,\mathrm{lin}}(k, z_1, z_2) = D(z_1)D(z_2)P_{11}(k)$$

$$P_{mm,1\mathrm{L}}(k, z) = D^4(z)\left(P_{22}(k) + P_{13}(k)\right) + 2c_s(z)^2 D^2(z)P_{11}(k)\frac{k^2}{k_{\mathrm{NL}}^2}$$

- P_{gg}

$$P_{gg,\mathrm{lin}}(k, z_1, z_2) = D(z_1)D(z_2)b_1(z_1)b_1(z_2)P_{11}(k)$$

$$P_{gg,1\mathrm{L}}(k, z) = D^4(z)\left(P_{gg,22}(k; b_1, c_2) + P_{gg,13}(k; b_1, b_3)\right) + 2D^2(z)b_1(z)c_{gg}(z)P_{11}(k)\frac{k^2}{k_{\mathrm{M}}^2}$$

- P_{gm}

$$P_{gm,\mathrm{lin}}(k, z_1, z_2) = D(z_1)D(z_2)b_1(z_1)P_{11}(k)$$

$$P_{gm,1\mathrm{L}}(k, z) = D^4(z)\left(P_{gm,22}(k; b_1, c_2) + P_{gm,13}(k; b_1, b_3)\right) + 2c_{gs}(z)D^2(z)P_{11}(k)\frac{k^2}{k_{\mathrm{M}}^2}$$

Intrinsic alignments

- Shear modifies the shape of lensed galaxies. But these have intrinsic ellipticity, whose distribution is correlated with LSS

- And shear is inferred from observed ellipticity of background galaxies: thus, intrinsic alignment term $\gamma_{ab}(\hat{n}) \to \gamma_{ab}(\hat{n}) + \gamma_{ab}^{IA}(\hat{n})$

- Can be computed in EFT, and in fact it has:
  Vlah, Chisari, Schmidt 2019; Chen, Kokron 2023

- DES-Y3 uses TATT model (Blazek et al. 2019); we use the simpler NLA model, used in Y1 (Hirata, Seljak 2004)

$$f_\kappa^j(z) \to f_\kappa^j(z) - A \left(\frac{1+z}{1+z_0}\right)^\alpha \frac{C_1 \rho_{m,0}}{D(z)} \frac{n^j_{source}(z)}{\bar{n}^j_s} \frac{dz}{d\chi}$$

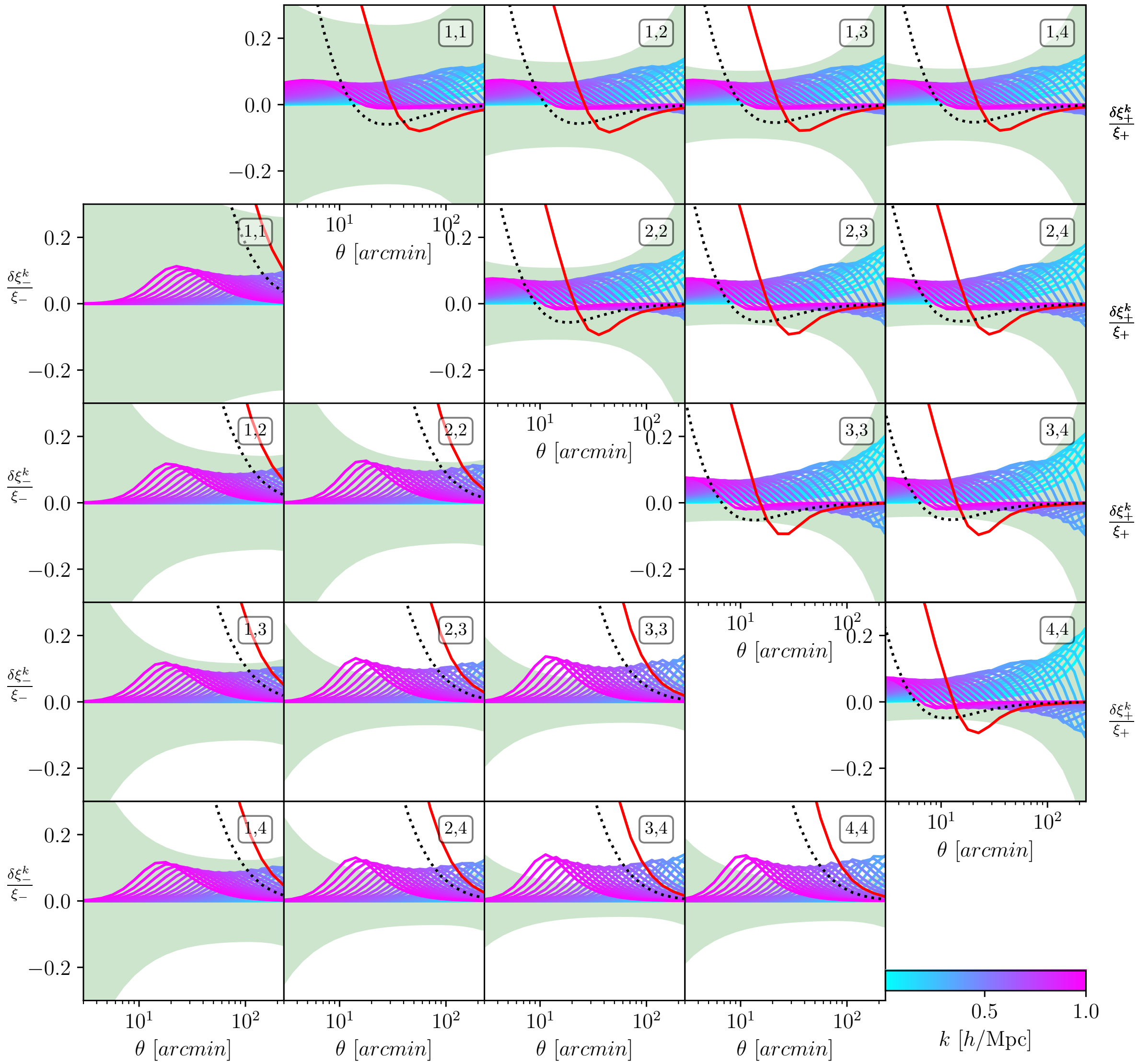
Integral over unknown bias functions

- Standard EFTofLSS expressions for the P_{mm} , P_{gm} , P_{gg}, but we have integrals over parameters with unknown time dependence!
- Assume parameter is almost constant over the bin, so each redshift bin combination now has its own parameters, e.g.

$$\xi^{ij}_{+/-}(\theta) \supset 2\frac{c^{ij}_{+/-}}{k^2_{\rm NL}} \int \frac{{\rm d}l\, l}{2\pi} J_{0/4}(l\theta) \int {\rm d}\chi \frac{f^i_\kappa(\chi) f^j_\kappa(\chi)}{\chi^2} D^2_+(z) P_{11}\left(\frac{l}{\chi}\right) \frac{l^2}{\chi^2} \, .$$

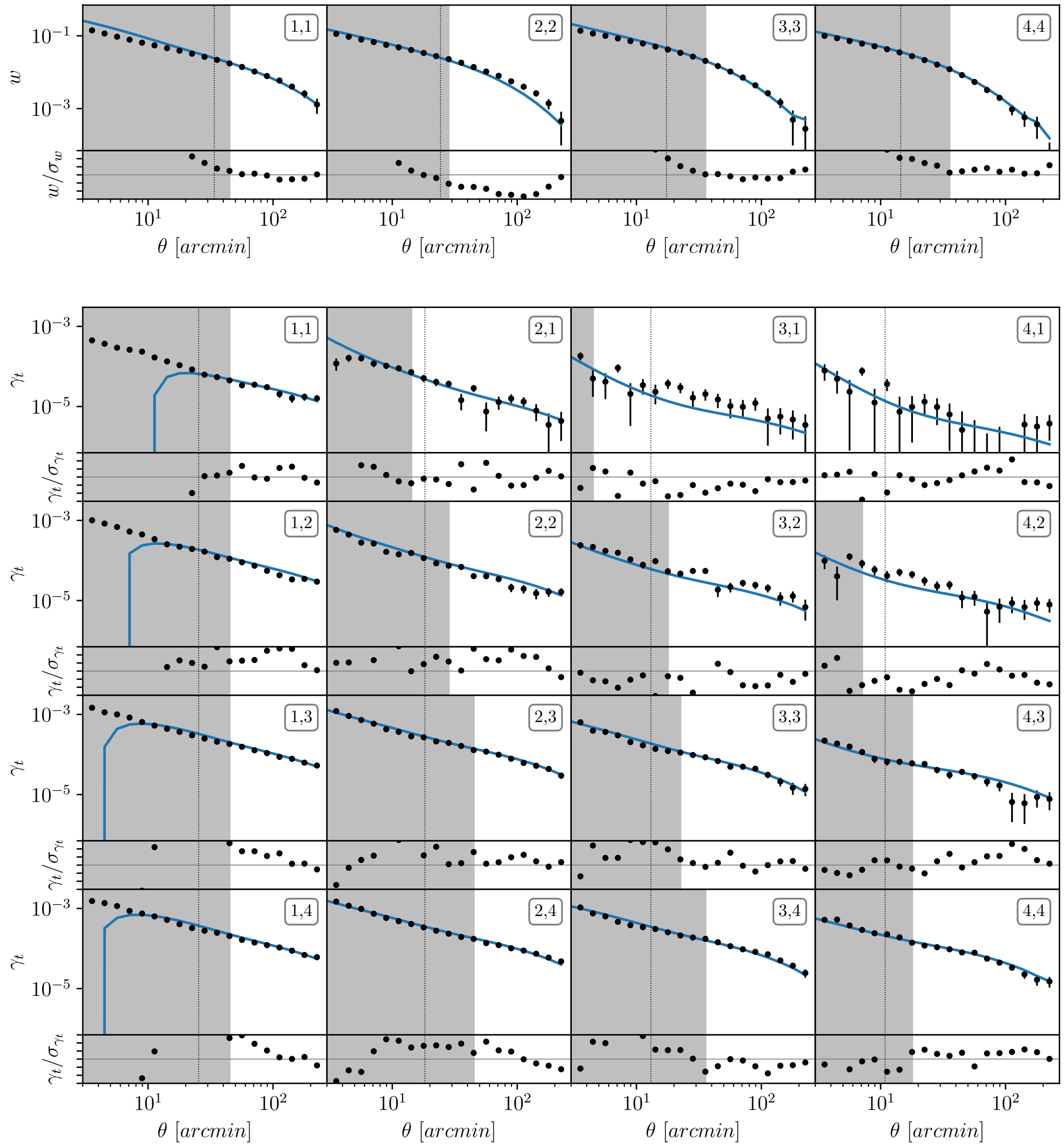
- How to reduce their impact? Simple, we correlate them! After all, their time dependence is smooth and of order Hubble.

Scale cuts: NNLO and UV sensitivity

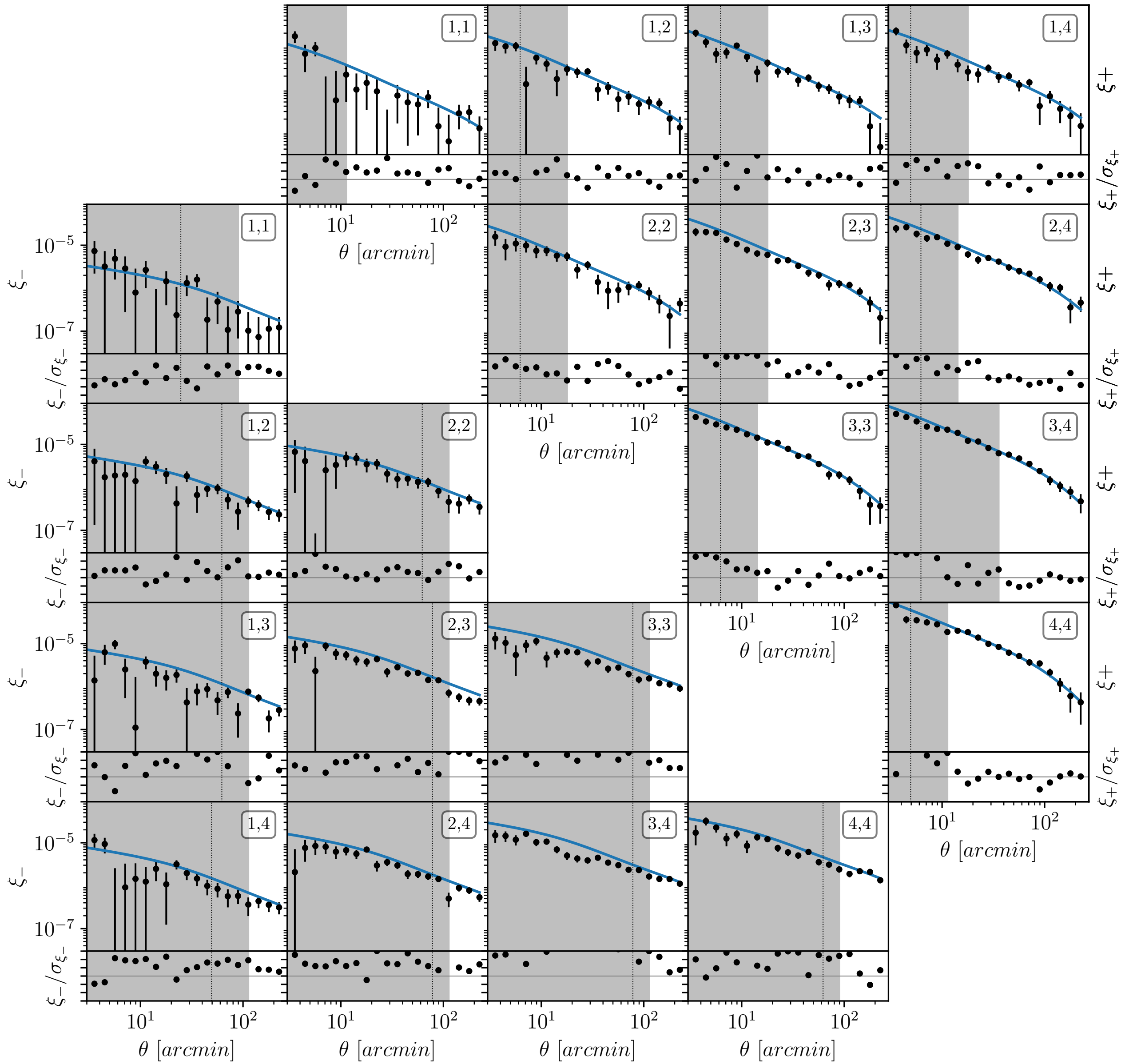


Results on Buzzard simulations

DES Y3 data and best-fit



DES Y3 data and best-fit



A new measurement of H_0

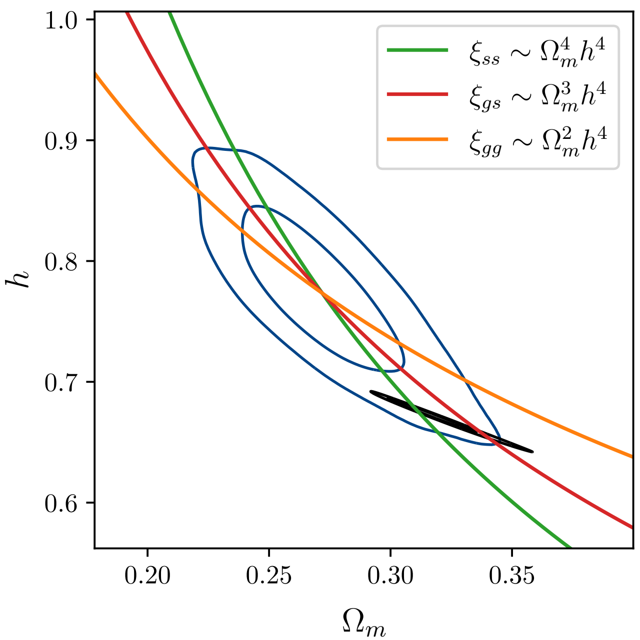
$$k_{\rm eq} = H_0 \frac{\sqrt{2}\Omega_m}{\sqrt{\Omega_r}} \simeq 0.073\,\Omega_m h^2\,{\rm Mpc}^{-1}$$

- Scale very small: but it enters the amplitude of power spectrum

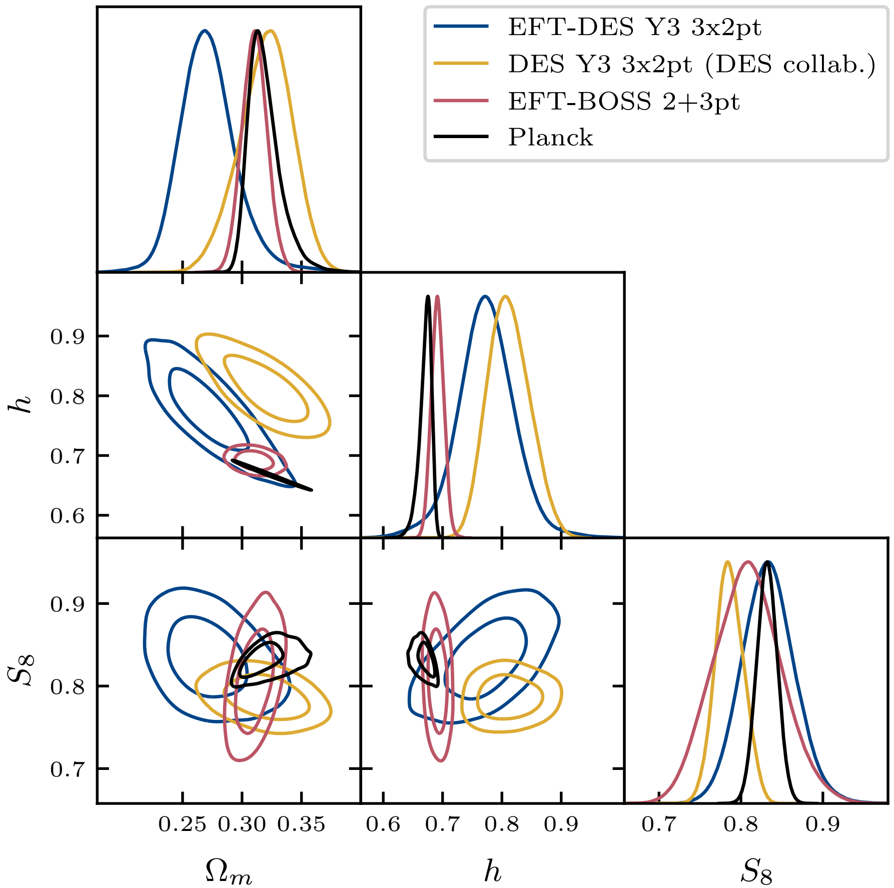
$$P_{lin}(k,z) \approx D(z)^2\,A_s \left(\frac{k}{k_*}\right)^{n_s-1} k(\Omega_m H_0^2)^{-2} \left(\frac{k_{\rm eq}}{k}\right)^4 \log\left(\frac{k}{k_{\rm eq}}\right)^2$$

- This gives, for the scales of interest
$P_{lin}(k,z) \propto D(z)^2\,A_s(\Omega_m h^2)^2\,k^\nu$

- In fact, considering the lensing kernels, you can roughly predict the degeneracy Ω_m-h !



Flagship results



- We have larger errors than the official analysis. This is due to larger number of parameters and different scale cuts.
- But, we agree better with Planck and BOSS, especially in Ω_m-h
- Full posterior agreement at 1.7σ with BOSS and 2.3σ with Planck. Official analysis discrepant at 4.9σ with Planck.
- Reasonable precision on Ω_m, S_8, not competitive on h.
- But, independent h measurement! It basically comes from $k_{\rm eq}$

Where do we stand?

- Power spectrum at one loop: settled.
  - Several codes agreeing, and official analysis of DESI/Euclid
  - Window function, real space $\xi(r)$, addition of BAO, all done
  - Full EFT pipeline: self-consistent determination of $k_{\rm max}$ and analytical covariance available (Wadekar, Scoccimarro 2019)
  - Prior on biases: reasonable perturbative prior, possible to include small-scale information

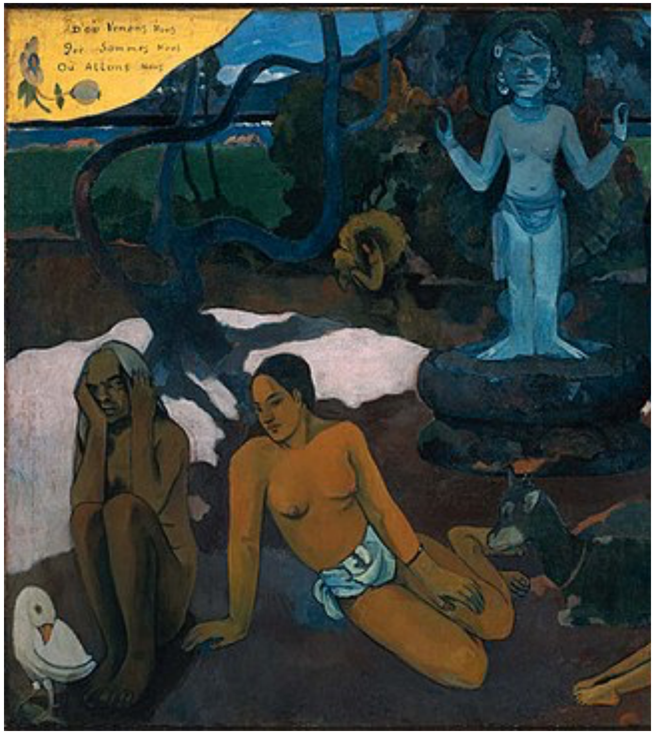
Where do we stand?

- Bispectrum at one loop: almost done
  - Done: one loop expression (twice), efficient implementation (twice), $k_{\max}$ determination
  - Done: study of IR resummation (Chen, Vlah, White, 2024)
  - Missing: a practical treatment of the survey mask
  - Missing: full analytical covariance. If too many triangles, can use mocks and compression, and approximate covariance available (Salvalaggio et al, 2024)
  - Not an official analysis yet, but soon

Where do we stand?

- 3x2pt: in progress
  - Definitely doable, needs more studying
  - Main difficulties (data side): systematics, and their modelling
  - Main difficulties (theory side)
    - Lots of parameters: can we reliably use some information on bias evolution?
    - Shear-shear: N-body are a good UV theory here, with 1-loop matter PS we stop early. Can do hybrid approach?
    - Does new physics show up at all? Which new physics can we probe by photometry?

Où allons-nous ?



A note on priors

- In Bayesian analysis, data update our belief on the model and its parameters. Must start from a probability measure on parameters. *There is no "uninformative prior"*.
- And what if data are not precise enough?

The status of LSS EFT analysis: two manifestly equivalent implementations of the manifestly correct theory on manifestly the same data produce manifestly different results. #cosmology

Priors on counterterms? The encarnation of the devil on Earth.

A note on priors

- What priors on EFT parameters?
  We know they have to be perturbative correction, but not much more: except for a few, we center them at 0 with $\sigma=2$.
- Other choices are possible, as long as they cover the physically allowed region, but EFT parametrization stays the same.
  ''West Coast'' and ''East Coast'' parameters are a *linear transformation of each other.* Prior choice is, however, different.
- Maximum likelihood points are unchanged. But credible intervals can shift due to projection.
- What should you put in the abstract on your paper?

$$\mathbb{E}_{\mathcal{P}}[\lambda_{\alpha_1}\ldots\lambda_{\alpha_n}] = Z^{-1}\int \mathcal{M}(\boldsymbol{\lambda})d^k\boldsymbol{\lambda}\ \lambda_{\alpha_1}\ldots\lambda_{\alpha_n}\ \mathcal{P}(\boldsymbol{\lambda})$$

Simon, Zhang, Poulin, Smith (2022)
Carrilho, Moretti, Pourtsidou (2022)
Reeves, Zhang, Zheng (2025)

Fixing phase space issues

- Our solution, for bispectrum: adjusting the prior, measuring the effect on synthetic data fit to our data

$$\ln \mathcal{M} = -48 \left(\frac{b_1}{2}\right) + 32 \left(\frac{\Omega_m}{0.31}\right) + 48 \left(\frac{h}{0.68}\right)$$

$\sigma_{\rm proj}/\sigma_{\rm stat}$	Ω_m	h	σ_8	ω_{cdm}
1 sky, $\sim 100\, V_{\rm 1sky}$	-0.1	-0.14	-0.21	-0.2
1 sky, $V_{\rm 1sky}$, adjust.	0.13	0.06	0.04	0.15
4 skies, $V_{\rm 4skies}$, adjust.	0.1	0.	-0.05	0.07

- On 3x2pt, similar thing:

$$\log \mathcal{M} = -55\, \omega_{cdm} - 9\, b_1$$

You are doing a morally wrong thing!

What to do?

- Just wait. Sooner or later data will just not care about the priors?

- Perturbativity prior

$$\mathcal{P}_P = \frac{1}{2N^P_{\text{bins}}} \sum_{i\in \text{bins}_P} \left(\frac{P^h_{\text{1-loop}}(k_i)}{\sigma^{\text{P.P.}}_P(k_i)} \right)^2 \qquad \mathcal{P}_B = \frac{1}{2N^B_{\text{bins}}} \sum_{i\in \text{bins}_B} \left(\frac{B^h_{\text{1-loop}}(k^i_1, k^i_2, k^i_3)}{\sigma^{\text{P.P.}}_B(k^i_1, k^i_2, k^i_3)} \right)^2$$

$$\sigma^{\text{P.P.}}_P(k) \sim S^P(k) P^{k_{\max}}_{\text{1-loop}} \,, \qquad \sigma^{\text{P.P.}}_B(k_1, k_2, k_3) \sim S^B(k_1, k_2, k_3) B^{k_{\max}}_{\text{1-loop}}$$

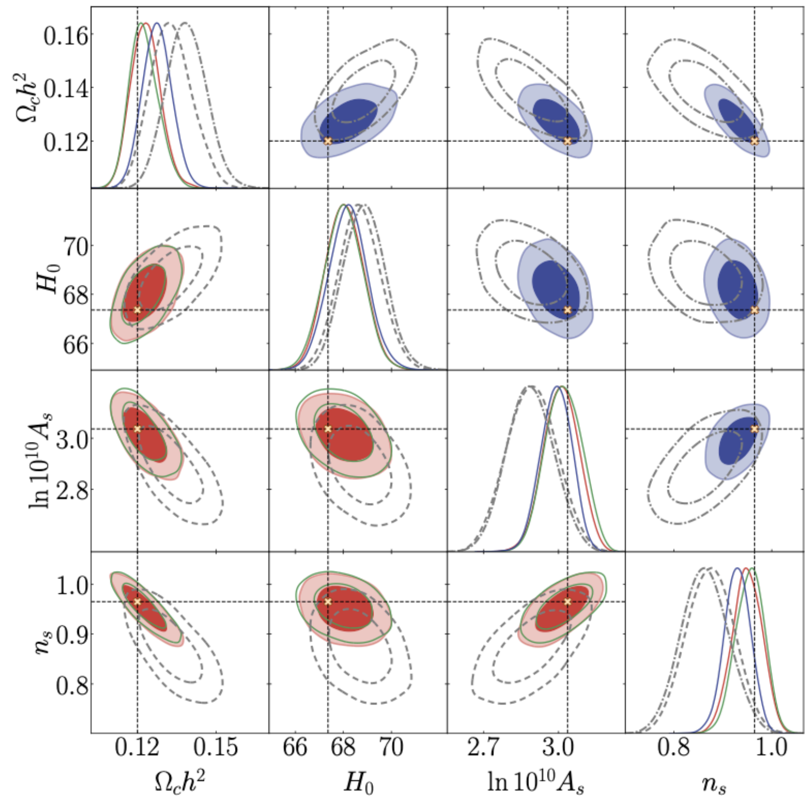
$$S^P_{\text{1-loop}}(k) \sim b_1^2 P_{11}(k) \left(\frac{k}{k_{\text{NL}}} \right)^{3+n(k)} \qquad S^B_{\text{1-loop}}(k_1, k_2, k_3) \sim B^h_{211}(k_1, k_2, k_3) \sum_{i=1}^{3} \left(\frac{k_i}{k_{\text{NL}}} \right)^{3+n(k_i)}$$

Bragança, Donath, Senatore, Zheng (2023)
GDA, Lewandowski, Senatore, Zhang (2025)

- Get some controlled UV information.
  We used some old fitting formulas from simulations.
  Now, the idea is to do a dedicated search. As a first step, fitting HOD.
  But have to marginalise over them.

Small-scale information

- Can we get the best of both worlds?
- Simple, but effective, attempt: translate HOD priors into EFT (Zhang, Bonici, GDA, et al. 2024; see also Ivanov et al. 2024)
- Interesting more general direction: Hybrid SBI (Modi, Philcox 2024; Zhang, Modi, Philcox 2025)
- Can galaxies be reliably simulated? In other words, can we claim detection of new physics based on small-scale information?



Where do we go now, technically?

- Higher loops?
  - 2-loop power spectrum requires 5th order. Several works on it, soon it will be done.
    Integrals are complicated, but not an issue, really.
    Determination of $k_{\rm max}$ easy.
  - But, will it be useful? Depending on the tracer and the data noise, it can be. Also, could construct $\mu \to 0$ variable and practically reach 0.5

Where do we go now, technically?

- Higher point functions / field-level?
  - Today could include up to tree-level 5-pt, though additional 4 biases.
  - But at least tree-level trispectrum has no more biases than 1-loop bispectrum.
  - Measurement and analysis seems daunting.
  - Field-level model and measurements simple. But, how about the likelihood?
  - But forward model super useful to help with standard analysis.

Getting new physics

- ΛCDM very well studied (and boring).
  Cosmology's before LHC moment

Known new physics

- Neutrinos exist, they are light: must measure their mass, and we have surprises
- Inflationary dynamics is not free fields: need to push for primordial non-Gaussianities, not only local but single-field

Under the lamppost physics

- Dynamical dark energy: may or may not exist, no scalar field models solve the CC problem. Super interesting to look for, but must go beyond w_0-w_a
- CDM, only billiard balls? No.
  Here a question of scales (and naturalness): LSS exquisite probe for ultralights!

Getting new physics

- Can we just claim that
  "Something is rotten in the state of νΛCDM"?
- First time that we can use precise data at vastly different times, if not complementary length scales: CMB at z=1100, LSS at z=0.3-2, also SN, Ly-α, what else in the future?
- Could expose anomalies and tensions. Need some parametrisation though.
- LSS boostrap: Impose symmetries, and parametrize the kernels with basic building blocks. Can match to specific models

$$G_2(\vec{k}_1,\vec{k}_2) = 2\beta(\vec{k}_1,\vec{k}_2) + d_1^{(2)}\,\gamma(\vec{k}_1,\vec{k}_2)$$

$$G_3(\vec{k}_1,\vec{k}_2,\vec{k}_3) = 2\,\beta(\vec{k}_1,\vec{k}_2)\beta(\vec{k}_{12},\vec{k}_3) + d_5^{(3)}\gamma(\vec{k}_1,\vec{k}_2)\gamma(\vec{k}_{12},\vec{k}_3) - 2\,\left(d_{10}^{(3)} - h\right)\gamma(\vec{k}_1,\vec{k}_2)\beta(\vec{k}_{12},\vec{k}_3)$$
$$+ 2(d_1^{(2)} + 2\,d_{10}^{(3)} - h)\beta(\vec{k}_1,\vec{k}_2)\gamma(\vec{k}_{12},\vec{k}_3) + d_{10}^{(3)}\gamma(\vec{k}_1,\vec{k}_2)\alpha_a(\vec{k}_{12},\vec{k}_3) + \text{cyc.}$$

Fujita, Vlah (2020)
GDA, Marinucci, Pietroni, Vernizzi (2021)
Taule et al. (2024)
Marinucci, Pardede, Pietroni (2024)

Getting new physics

- Want to be more general? For instance, capture scale dependence
- Maybe we can use machine learning (agnostic parametrizations) Already applied with success in particle physics

$$n(x|\vec{w}) = n(x|R)e^{f(x;\vec{w})}$$

$$t(\mathcal{D}) = -2\text{Min}_{\vec{w}}[N(\vec{w}) - N(R) - \sum_{x\in\mathcal{D}} f(x;\vec{w})]$$

D’Agnolo, Wulzer 2018

End of the beginning or beginning of the end?

- EFTofLSS has been successful, stays strong in the wake of AI.
  1-loop power spectrum, 1-loop bispectrum, 3x2pt.
  What is next for it?
- Maybe more technical developments.
  Higher loops? Field level analysis?
- Other observables? Ly-α, 21cm?
- Should we become friends with the machine?
  Power analyses semianalytically with EFT forward model.
  Controlled inclusion of small-scale information.
- Getting new physics
  Must push for known physics, get tight constraints.
  Solid modelling of beyond-standard models.
  And surprises? Model-agnostic assessment of new physics.

Thank you!