PBJ: Bayesian analysis of the galaxy power spectrum and bispectrum

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Motivation: Stage-IV surveys

Mapping the Universe over unprecedented volumes $\rightarrow$ high precision measurements

Dark energy? Dark matter? Massive neutrinos?

- Need **fast** and **accurate** tools
- Robust validation on simulations/synthetic datavectors
- Modelling **systematics** is crucial

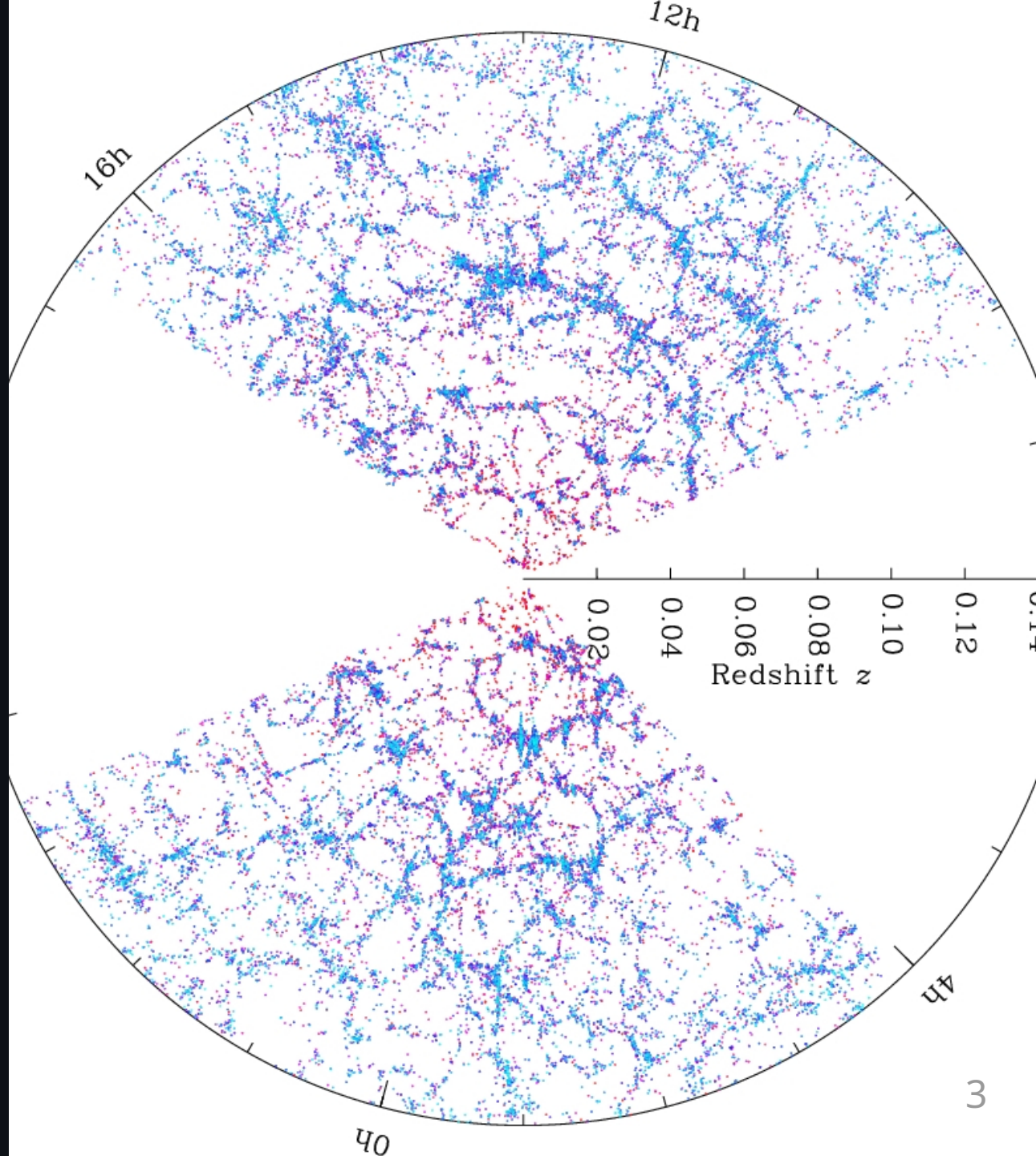
Galaxy clustering

Homogeneous distribution of overdensities

$\rightarrow$ gravity

$\rightarrow$ clustered distribution of galaxies

Galaxy distribution $\leftrightarrow$ cosmological model



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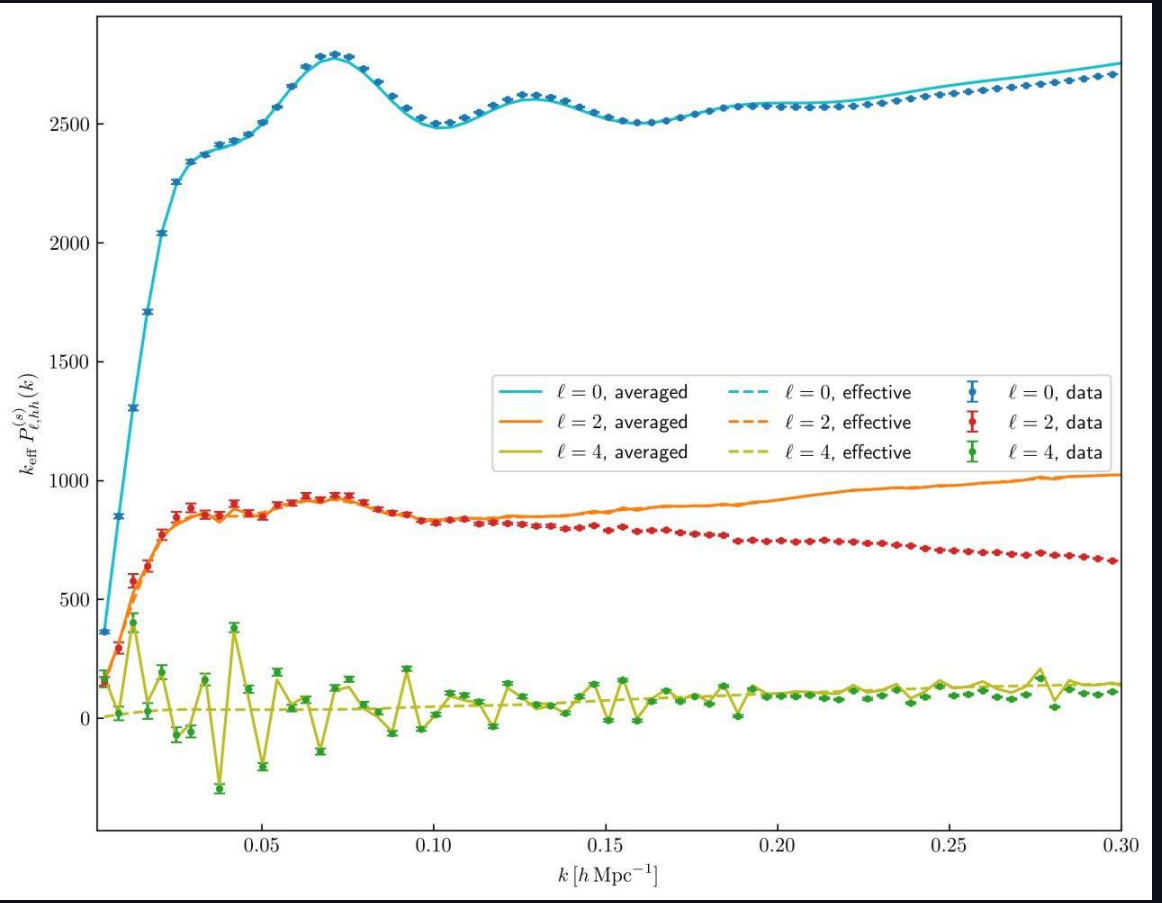


PBJ - Code overview

Joint likelihood pipeline for galaxy power spectrum + bispectrum

- EFT model for power spectrum $\rightarrow$ **ported to Euclid likelihood CLOE**
  - FastPT for fast loop corrections
  - Emulators for P_L (or Boltzmann solver)
  - wiggle-nowiggle decomposition for infra-red resummation
- Tree level bispectrum
  - expansion for fast Alcock-Paczinsky distortions
- Gaussian likelihood + corrections for noise in numerical covariance matrix

PBJ - Code overview

- Fully in python
- Extremely fast: P_{gg} evaluation in ~ 0.04s, B_{ggg} in ~ 0.1s
  - Euclid-like datavector: convergence in $\mathcal{O}(50)$ cpu hours
- Analytic marginalisation for nuisance parameters
- Option to run in fast mode when cosmology is fixed
- Several samplers: Metropolis-Hastings, affine invariant (`emcee`), nested (`ultranest`), ML powered (`pocomc`, `nautilus`)

PBJ - Code overview

Modular structure:

- **theory module**: implements computation of P_L, $P_{\rm NL}$, B_T, as well as several cosmological quantities (background evolution, growth functions, distance measurements)
- **likelihood module**: implements likelihoods functions and samplers
- **binning module**: implements binning strategies for observables
- **PBJ main module**: class to initialise all required quantities starting from the parameter file

PBJ - Code overview

Only needs three input files to run:

- parameter file (yaml file with path to data and run specifications)
- prior file (yaml file with prior distributions for parameters)
- minimal python script to run mcmc:

```
import PBJ
from tools.param_handler import read_file

init_dict = read_file("paramfile.yaml")

pbj = PBJ.pbj(init_dict)
pbj.initialise_full()

pbj.run_sampler(NmaxP=33.5, nsteps=20000, nwalker=200)
```

The EFT model

Anisotropic (redshift space) galaxy power spectrum:

$$P_{gg}(\vec{k}) = Z_1^2(\vec{k}) P_L(k) + 2 \int d^3q Z_2^2(\vec{q}, \vec{k}-\vec{q}) P_L(q) P_L(|\vec{k}-\vec{q}|) +$$

$$6 Z_1(\vec{k}) P_L(k) \int d^3q Z_3(\vec{k}, \vec{q}, -\vec{q}) P_L(q) +$$

$$\left[\tilde{c}_0 + \tilde{c}_2\ f\ \mu^2 + \tilde{c}_4\ f^2\ \mu^4\right] k^2 P_L(k) + c_{\nabla^4\delta}\ f^4\ \mu^4\ Z_1(\vec{k})\ k^4\ P_L(k) +$$

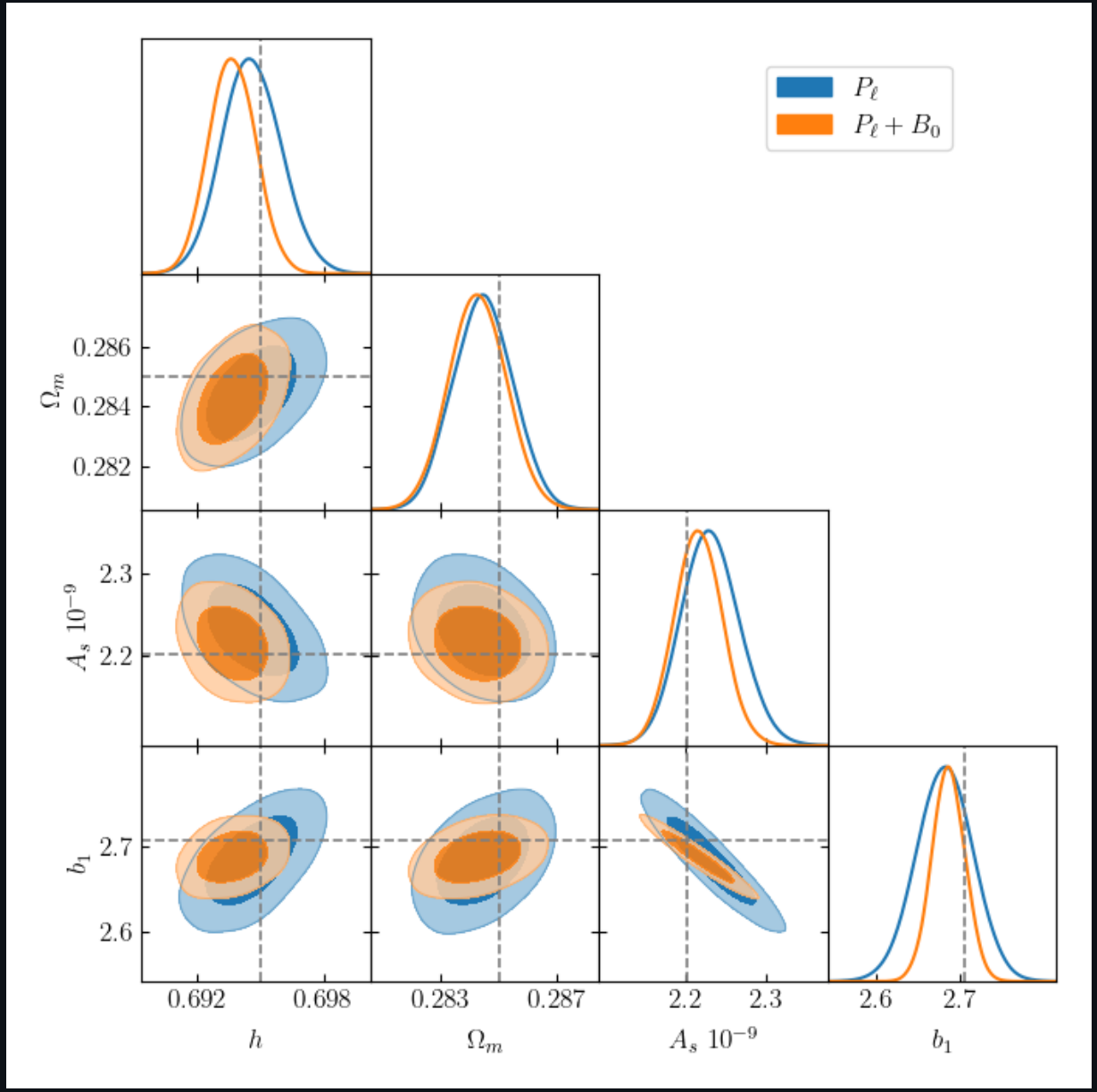
$$\frac{1}{\bar{n}} \left[(1+\alpha_P) + \epsilon_{0,k^2}\ k^2 + \epsilon_{2,k^2}\ k^2\ \mu^2\right]$$

Validation on simulations

Minerva dataset: 298 N-body simulations+10k Pinocchio mocks for covariance

$\Rightarrow \sim 1000\ (\mathrm{Gpc}/h)^3$ volume, extremely tight errorbars

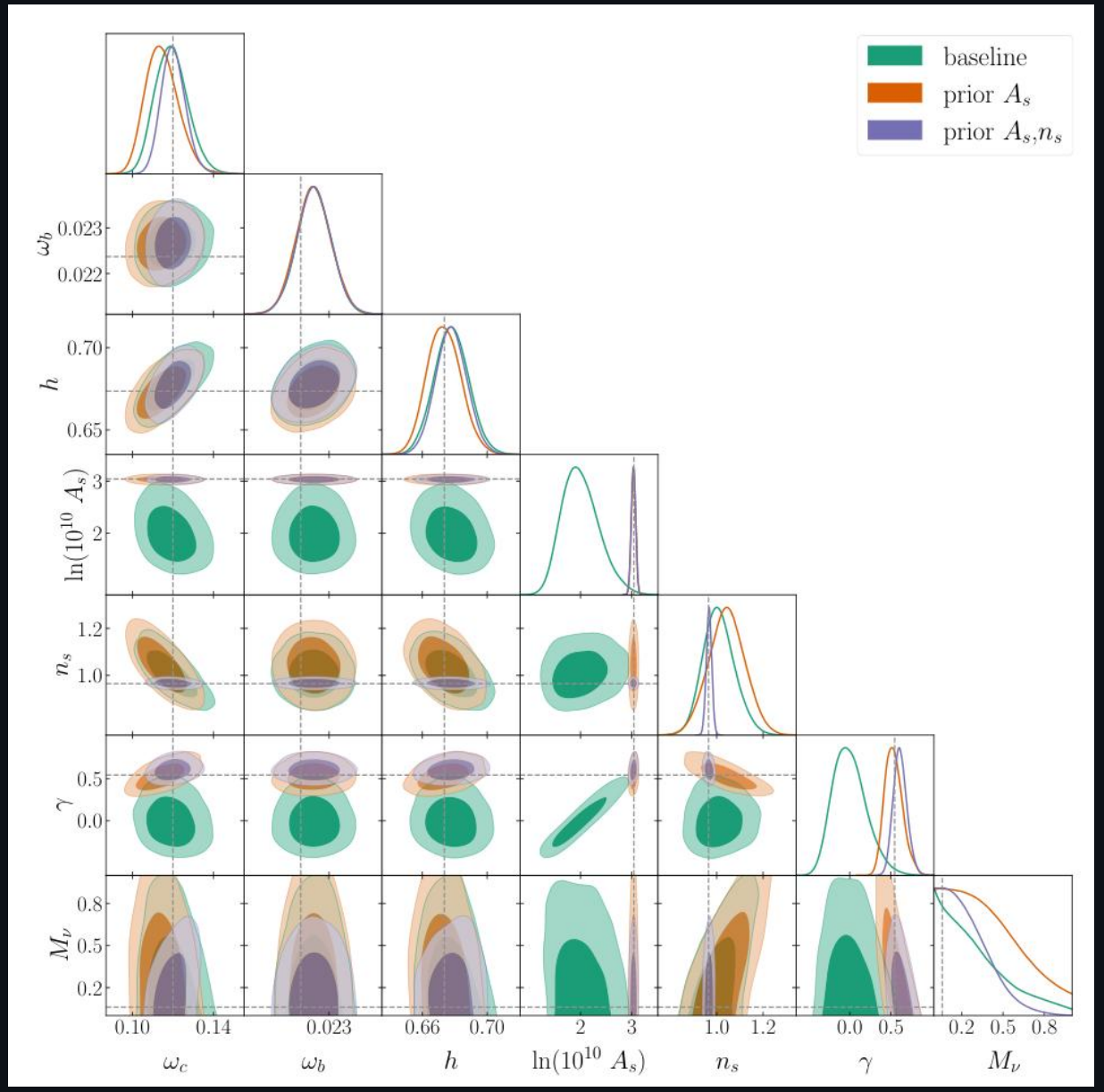
- validate bias relations to reduce parameter space
  - model selection tools
- inclusion of bispectrum improves constraints



BOSS analysis: growth index and massive neutrinos

CM+23, 2306.09275

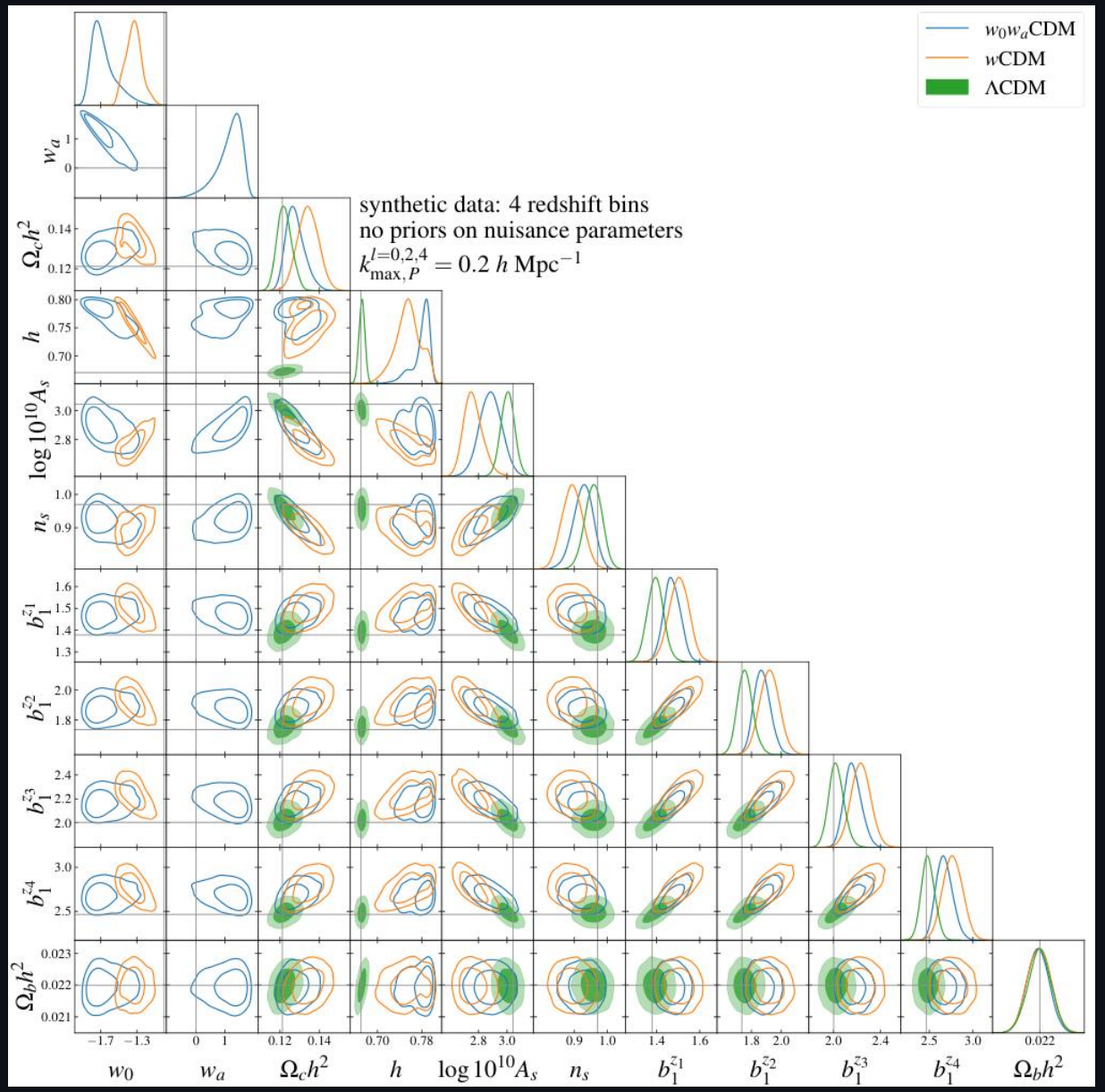
- constraints on γ + M_ν from full shape
- forecasts for Stage IV surveys
- profile likelihood to mitigate projections



Euclid

Currently used in several preparatory projects:

- modelling challenge Pezzotta+23 milestone 7
- Beyond ΛCDM models Bose+23 milestone 7
- IST:NL pre-launch KPs milestone 8?
- forecasts for SPV3 for P and P+B with w_0, w_a



Work in progress: future KPIs

- Window convolution (with Jacopo Salvalaggio) milestone 8? ✅
- Inclusion of post-reconstruction BAO (with Elena Sarpa) milestone 8? ✅
- Public code release milestone 8? 🟠
- Interlopers (with Matilde Barberi Squarotti) milestone 9? 🟠
- Massive neutrinos (with Emilio Bellini) milestone 9? 🟠