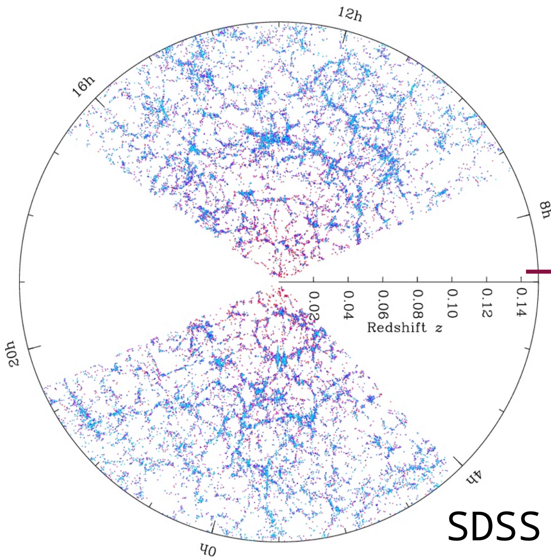
Cosmology with galaxy clustering

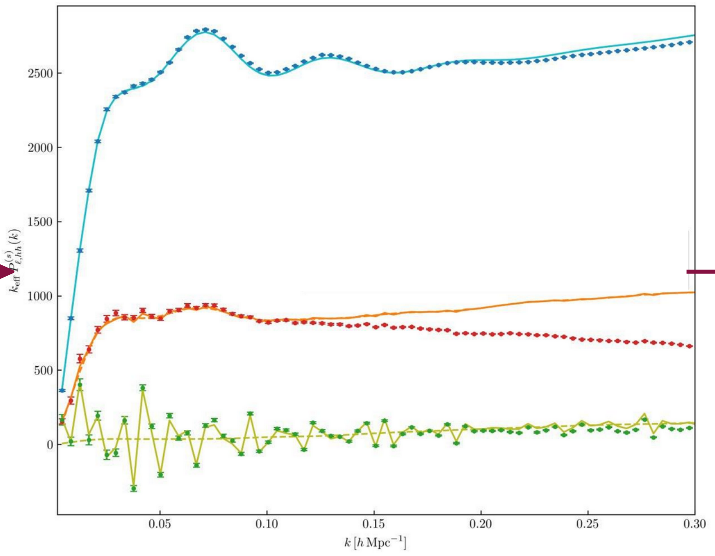
A joint analysis of the power spectrum and bispectrum

Chiara Moretti

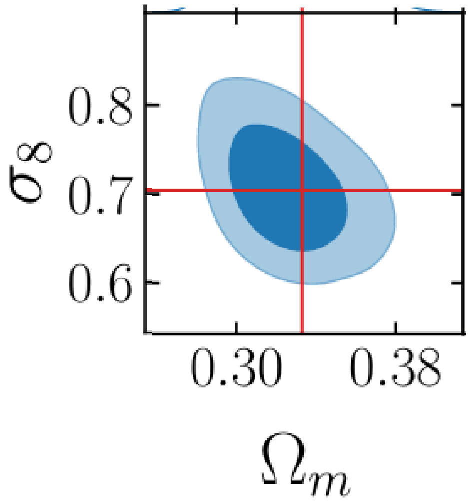
From galaxy surveys to cosmology



Galaxy distribution

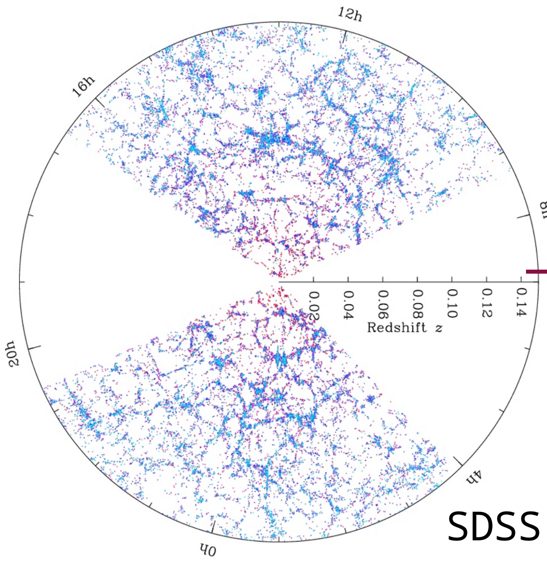


Power spectrum multipoles

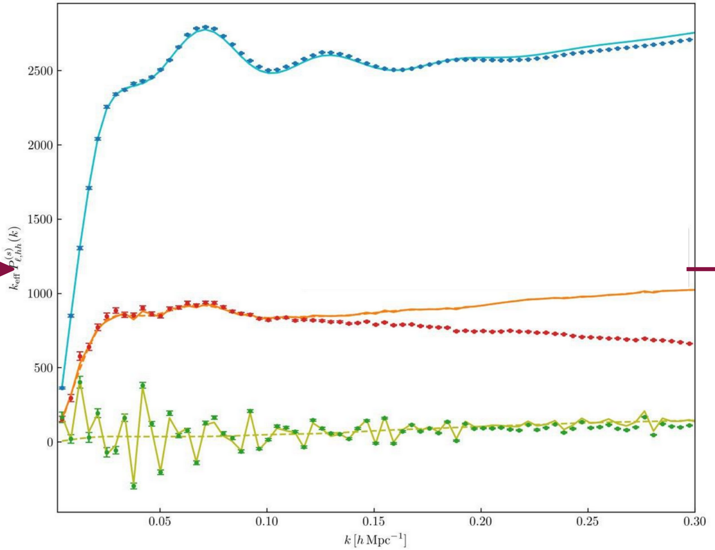


Cosmological parameters

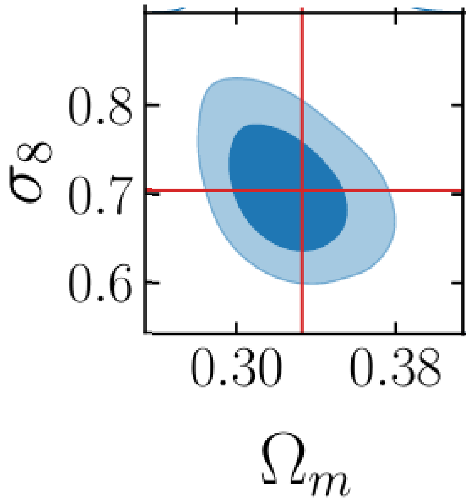
From galaxy surveys to cosmology



Galaxy distribution



Power spectrum multipoles



Cosmological parameters

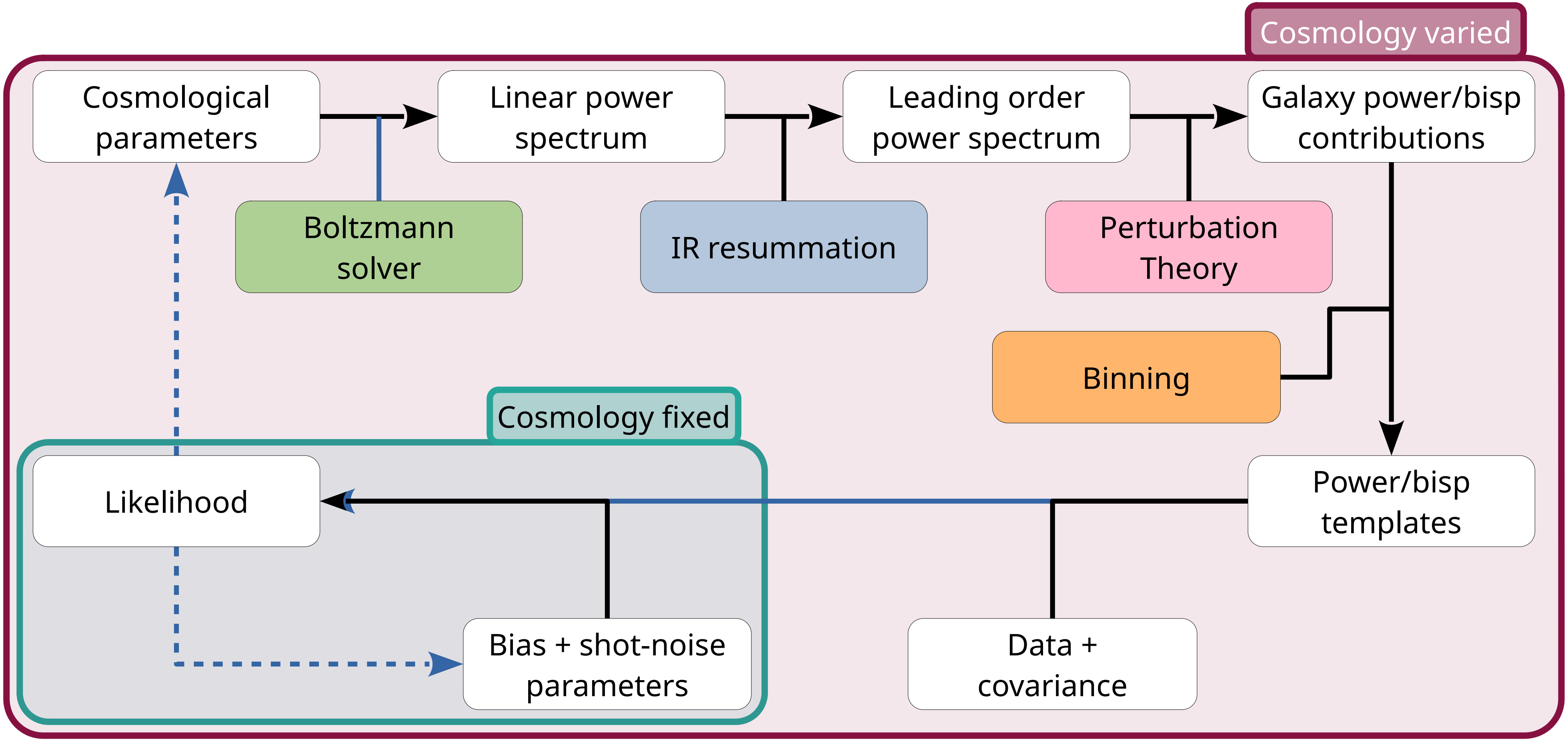
Accurate & fast theoretical model → Likelihood analysis

PBJ: Power spectrum & Bispectrum Joint analysis

- 1-loop power spectrum + tree-level bispectrum with non-linear galaxy bias (all in Python)
- IR-resummation routine (w – nw split)
- samplers: emcee (affine invariant & Metropolis-Hastings), Multinest (nested sampling)
- Binning effects
- Different likelihood functions for noise in the covariance matrix

CM, F. Rizzo, K. Pardede, A. Oddo, E. Sefusatti, A. Eggemeier, C. Porciani
[1908.01774] [2108.03204] [2204.13628]

PBJ: Power spectrum & Bispectrum Joint analysis



Theoretical model – power spectrum

- EFTofLSS model (1loop + counterterms)
- Non-linear bias expansion
- Infra-red resummation routine (Eisenstein-Hu P_{smooth})
- FastPT → model evaluation (28 loop integrals!) in ~30 ms

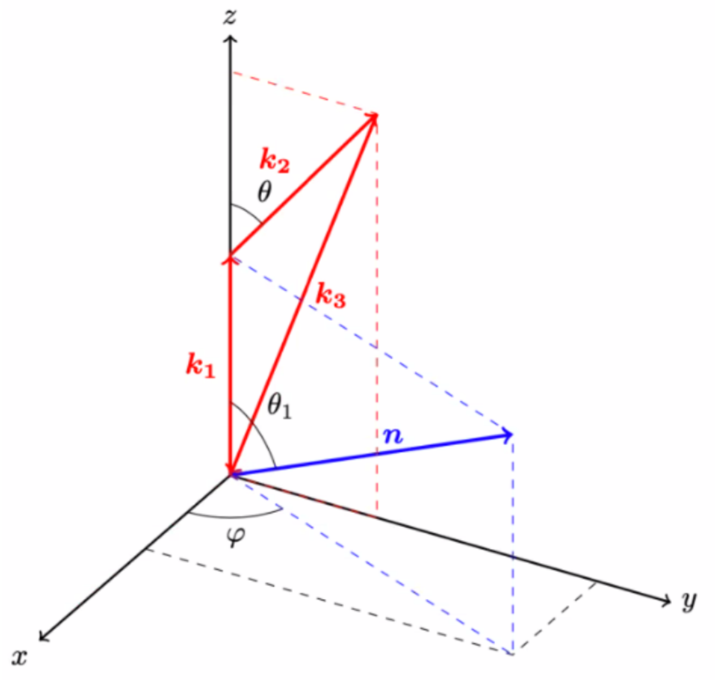
$$P_{gg}(\mathbf{k}) = Z_1^2(\mathbf{k})P_L(k) + 2\int \mathrm{d}^3\mathbf{q}\;\left[Z_2(\mathbf{q},\mathbf{k}-\mathbf{q})\right]^2 P_L(q)P_L(|\mathbf{k}-\mathbf{q}|)$$
$$+ 6Z_1(\mathbf{k})P_L(k)\int \mathrm{d}^3\mathbf{q}\; Z_3(\mathbf{k},\mathbf{q},-\mathbf{q})P_L(q) + P_{\text{ctr}}(\mathbf{k}) + P_{\text{noise}}(\mathbf{k})$$

Nuisance parameters

$b_1,\ b_2,\ b_{\gamma 2},\ b_{\Gamma 3},$	bias
$\alpha_P,\ \epsilon_{1,k^2},\ \epsilon_{2,k^2},$	noise
$c_0,\ c_2,\ c_4,\ c_{k^4}$	EFT counterterms

Theoretical model – bispectrum

- Tree-level model
- Bias parameters: $b_1, \; b_2, \; b_{\gamma_2}, \; \alpha_1, \; \alpha_2, \; \alpha_3$
- Higher order multipoles
- Model evaluation in ~0.1 s



$$B_s(\vec{k}_1, \vec{k}_2, \hat{n}) = 2Z_1(\vec{k}_1)Z_1(\vec{k}_2)Z_2(\vec{k}_1, \vec{k}_2)P_L(k_1)P_L(k_2)$$

$$B_{stoch}(k_1, \vec{k}_2, \hat{n}) = \frac{1}{\bar{n}}\left[(1+\alpha_1)b_1 + (1+\alpha_3)f\mu^2\right] Z_1(\vec{k}_1)P_L(k_1) + \frac{1+\alpha_2}{\bar{n}^2}$$

Theoretical model – bispectrum

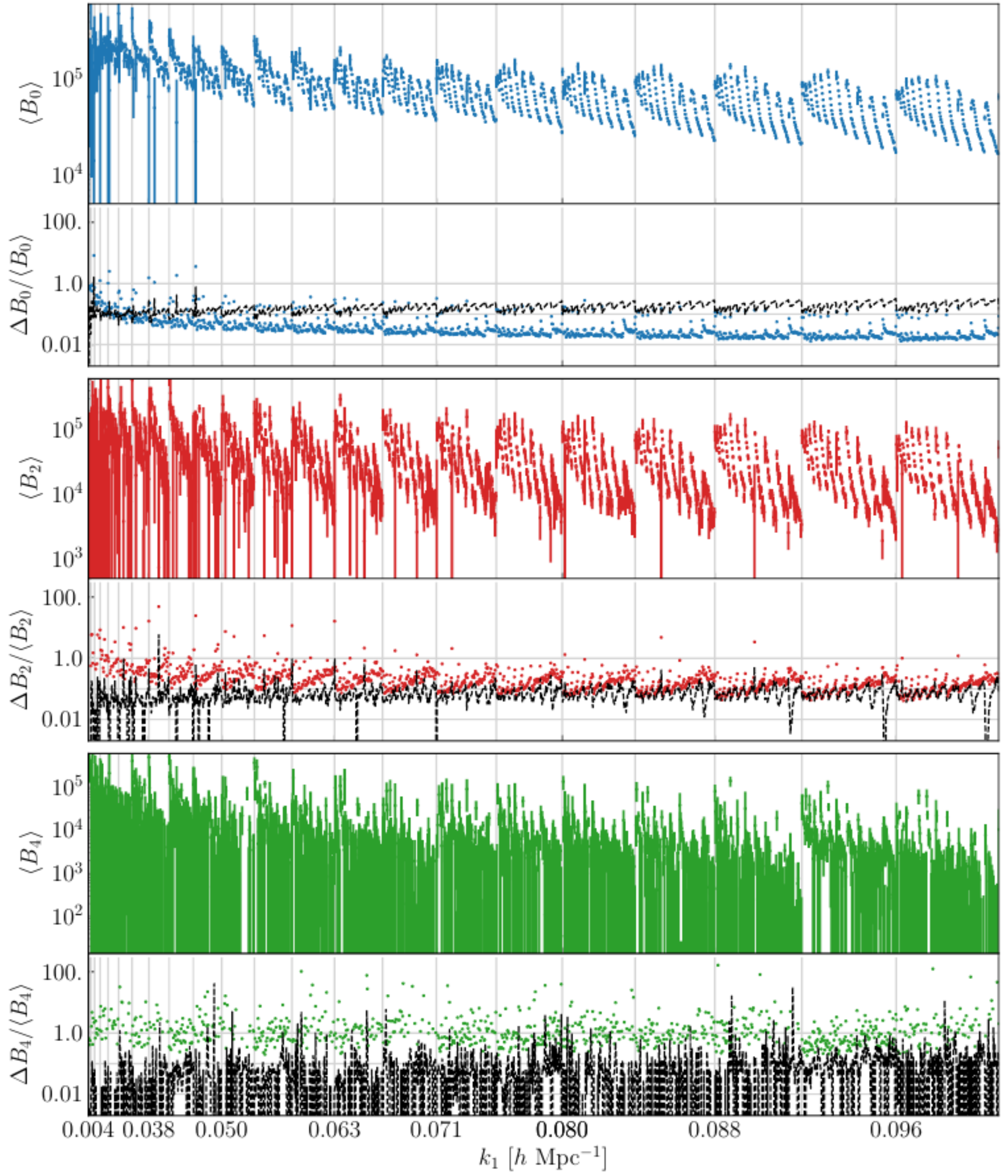
Alcock-Paczynski: expansion around $\alpha_\parallel \approx 1$ and $\alpha_\perp \approx 1$:

$$B_\ell(k_1,k_2,k_3) = \frac{2\ell+1}{\alpha_\perp^4 \alpha_\parallel^2} \sum_{n_1,n_2} \int_{-1}^{1} \frac{\mathrm{d}\mu_1}{2} \int_0^{2\pi} \frac{\mathrm{d}\varphi}{2\pi} \mathcal{L}_\ell(\mu_1) \mu_1^{n_1} \mu_2^{n_2} B_{n_1,n_2}(k_1,k_2,k_3) \times$$
$$\Big\{ 1 + \left[n_1(\mu_1^2 - 1) + n_2(\mu_2^2 - 1) \right] (F-1) +$$
$$\sum_{i=1}^{3} \left[1 - \alpha_\perp + (\alpha_\perp - \alpha_\parallel)\mu_i^2 \right] \frac{\partial \ln B_{n_1,n_2}}{\partial \ln k_i}(k_1,k_2,k_3) \Big\}$$

→ we can factor out the dependence on $\alpha_\parallel, \alpha_\perp$ and treat them as bias parameters

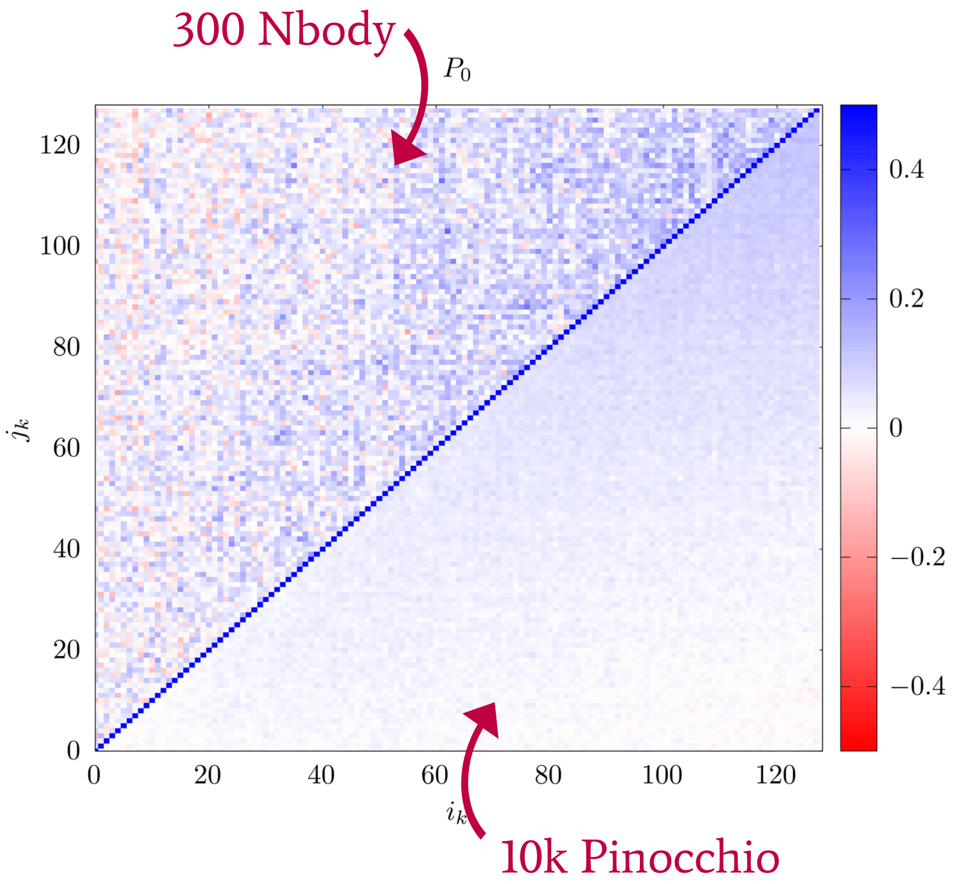
Validation dataset

- 300 DM-only N-body simulations (Minerva), ΛCDM cosmology
- L=1500 Mpc/h → $V_{tot} \approx 1000$ Gpc³/h³



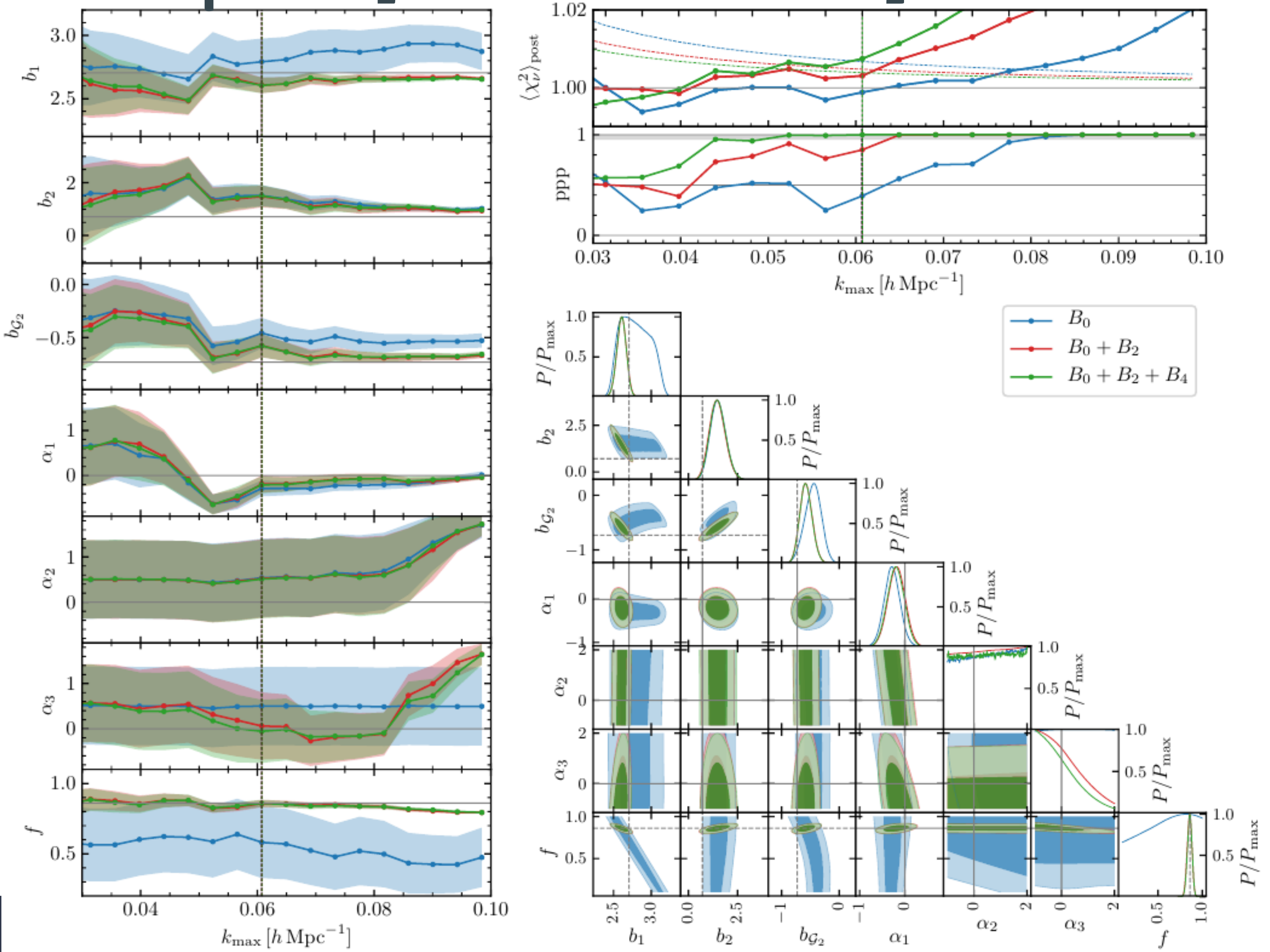
Validation dataset

- 300 DM-only N-body simulations (Minerva), ΛCDM cosmology
- L=1500 Mpc/h → $V_{tot} \approxeq 1000$ Gpc³/h³
- Covariance from 10000 Pinocchio mocks



Bispectrum in redshift space [Rizzo,CM+ 2204.13628]

- Higher order multipoles



Bispectrum in redshift space [Rizzo,CM+ 2204.13628]

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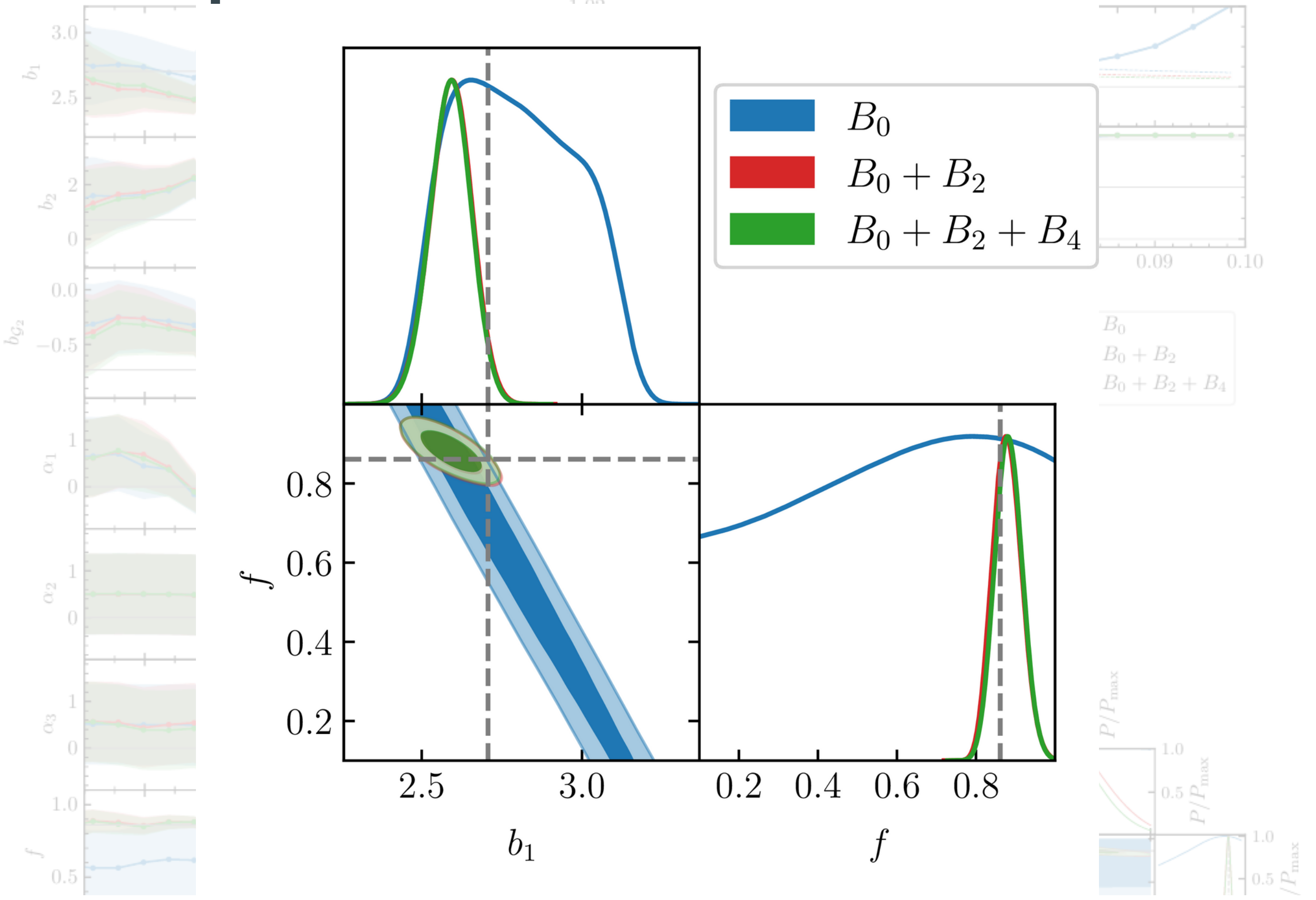
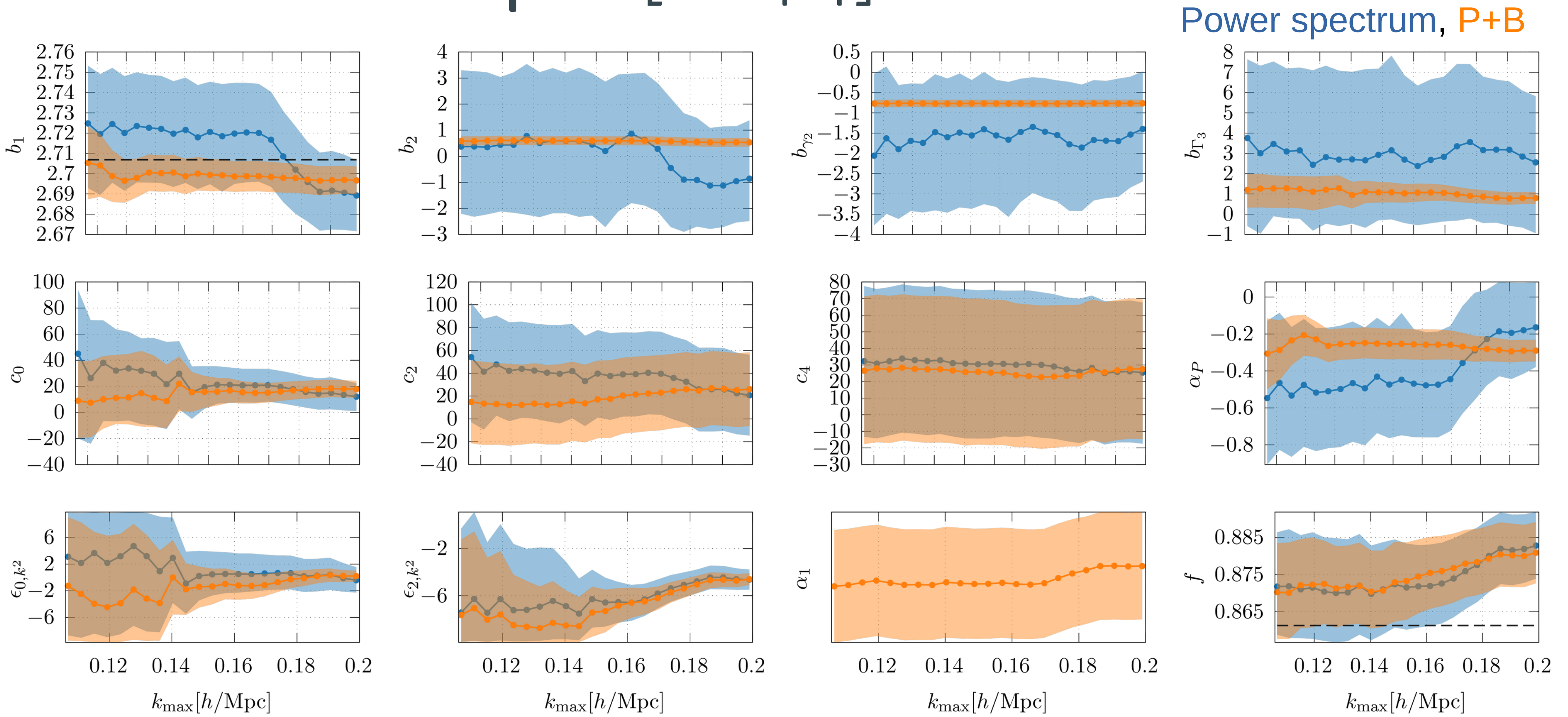


Bispectrum in redshift space [Rizzo,CM+ 2204.13628]

- Higher order multipoles
- Model selection (selecting minimal model & test bias relations)
- Different scale cuts for the multipoles, covariance approximation, binning effects

P+B in redshift space [CM+ in prep]

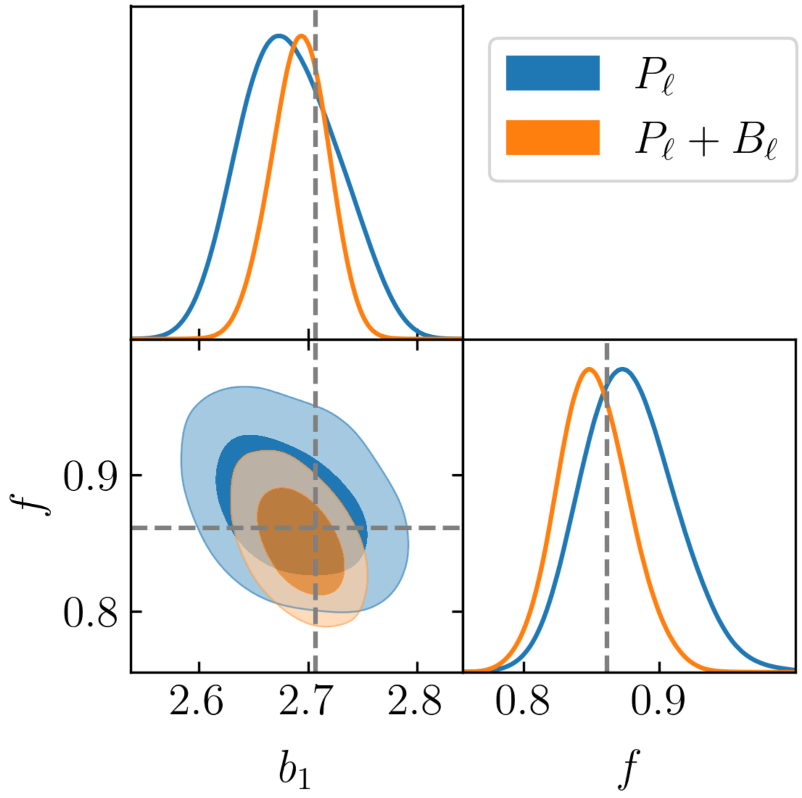


P+B in redshift space [CM+ in prep]

Rescale the covariance to ~10 Gpc^3/h^3

(match first redshift bin of Euclid)

→ adding B0,B2 improves constraints on f-b1



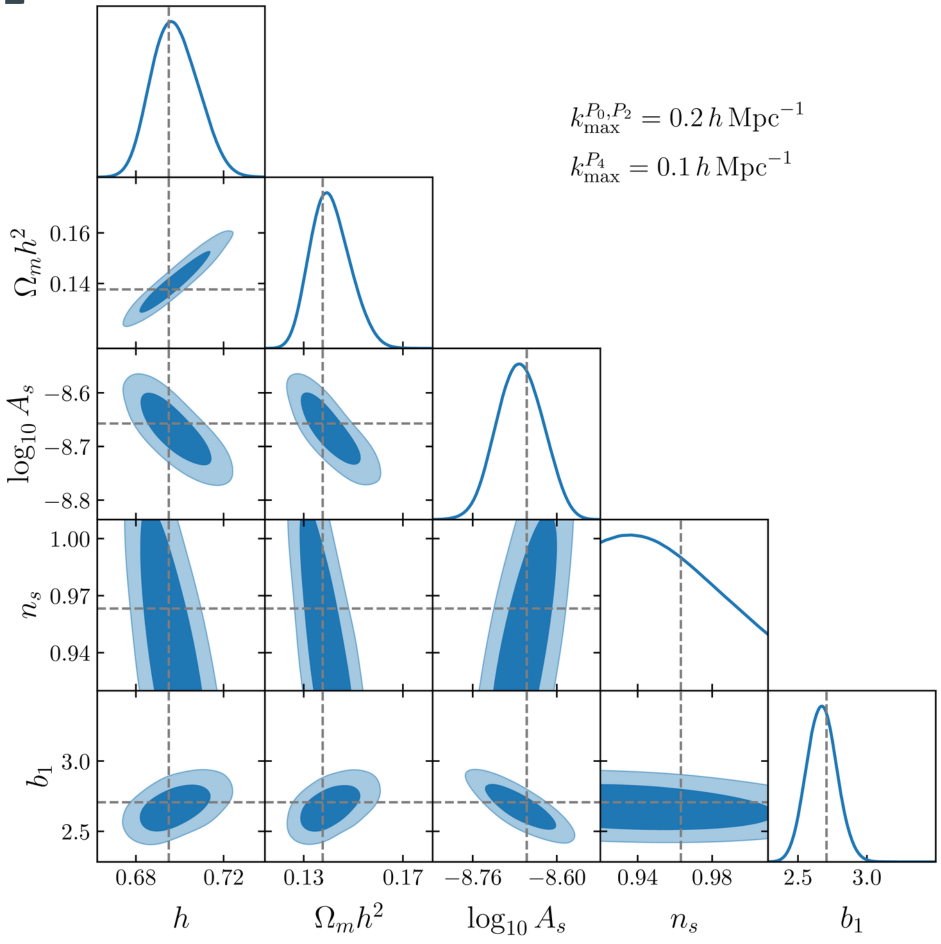
P+B in redshift space [CM+ in prep]

Rescale the covariance to ~10 Gpc³/h³

(match first redshift bin of Euclid)

→ adding B0,B2 improves constraints on f-b1

→ cosmological parameters (covariance rescaled to match Euclid redshift bin):



Beyond LCDM

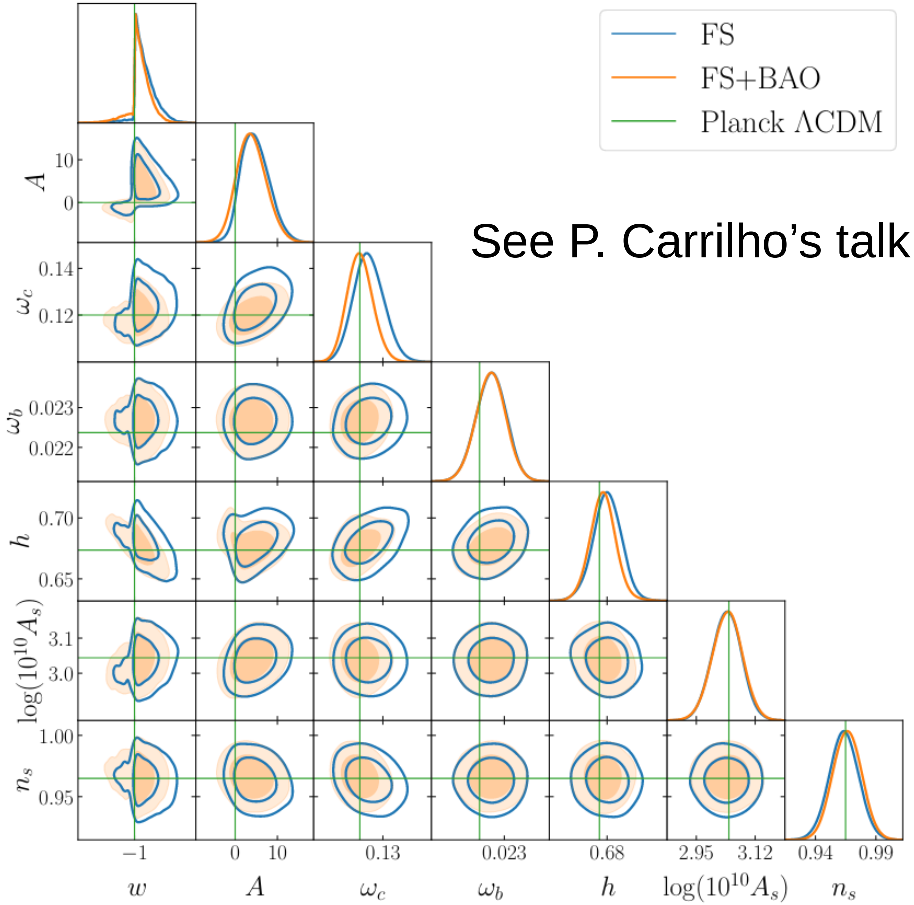
With P. Carrilho, M. Tsedrik, A. Pourtsidou
2207.14784, 2207.13011

- Interacting DE model: elastic scattering with momentum transfer [Simpson+10, Pourtsidou+13]
- Rescale P_L with appropriate growth factor
- 2 additional parameters: w, A
- Validation on simulations [2106.13163] + BOSS analysis [Carrilho,CM+] + inclusion of bispectrum [Tsedrik,CM+]

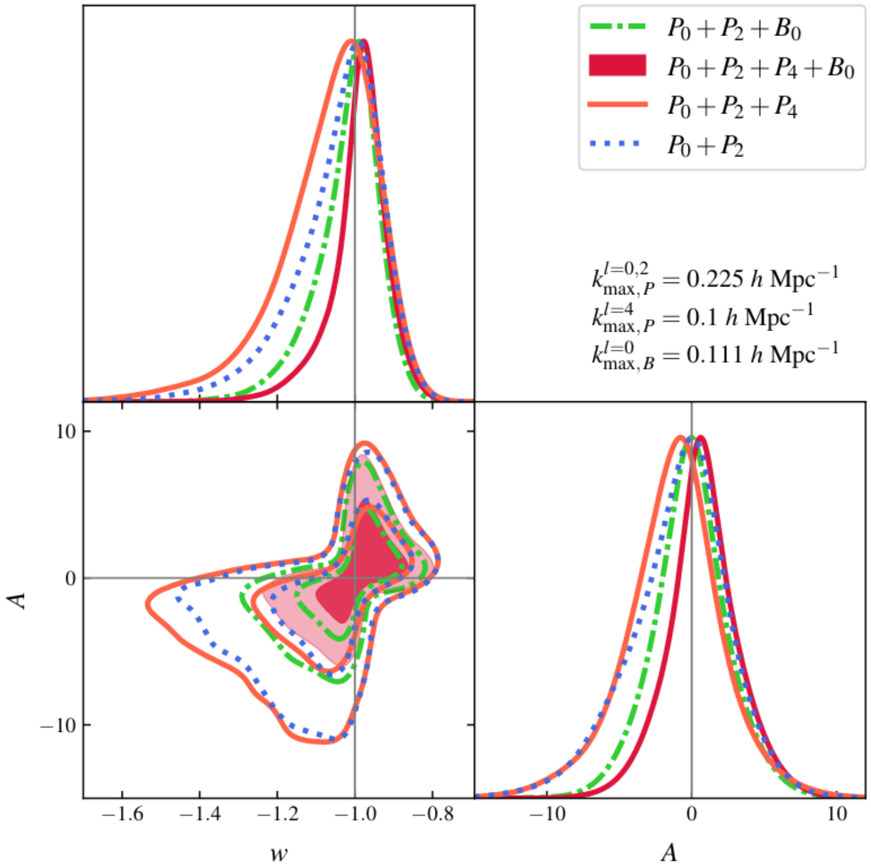
See P. Carrilho's talk

Beyond LCDM

With P. Carrilho, M. Tsedrik, A. Pourtsidou
2207.14784, 2207.13011



See P. Carrilho's talk

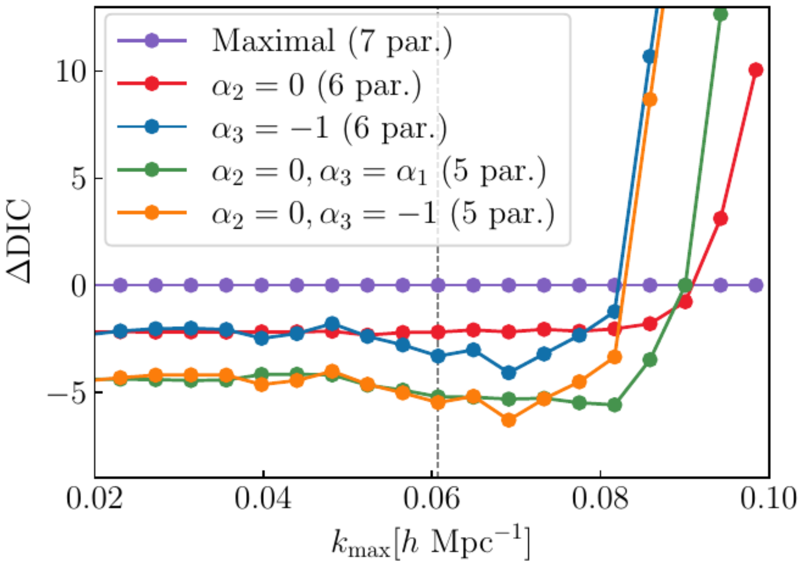


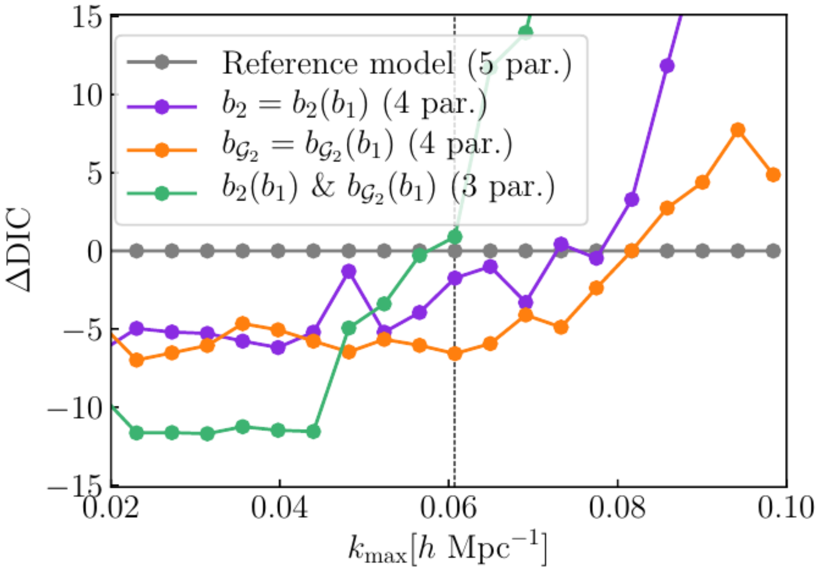
Summary & conclusion

- Pipeline for the power spectrum + bispectrum joint analysis of biased tracers
  → soon to be public!
- 1-loop power spectrum + tree-level bispectrum
- Validation on large set of sim → robust test of theoretical model
  [Oddo+20,21; Pardede+22; Rizzo,CM+ 2204.13628; CM+ in prep]
- Validation and forecasts for Euclid + ported to official likelihood code
- Beyond-LCDM: IDE constraints from BOSS [Carrilho,CM+ 2207.14784],
  inclusion of bispectrum [Tsedrik,CM+ 2207.13011]

Bispectrum in redshift space [Rizzo,CM 2204.13628]

- Higher order multipoles
- Model selection





P+B in redshift space [CM+ in prep]