Constraints on dark interactions with the EFTofLSS and BOSS and a note on priors

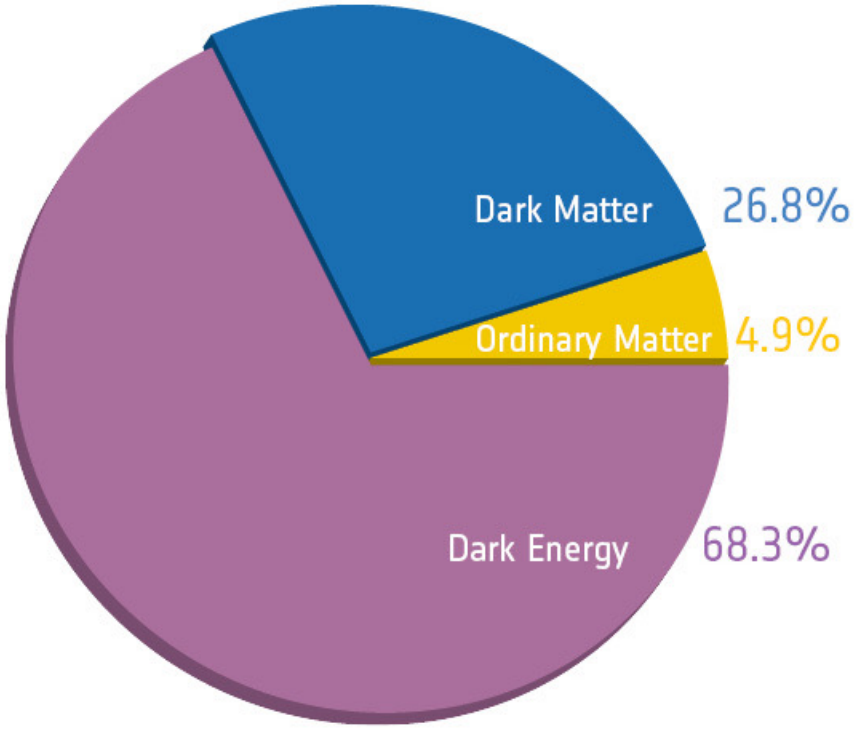
Pedro Carrilho

Based on **arXiv:2207.14784**
with
Chiara Moretti and Alkistis Pourtsidou

The troubles of the Universe

The composition of the Universe

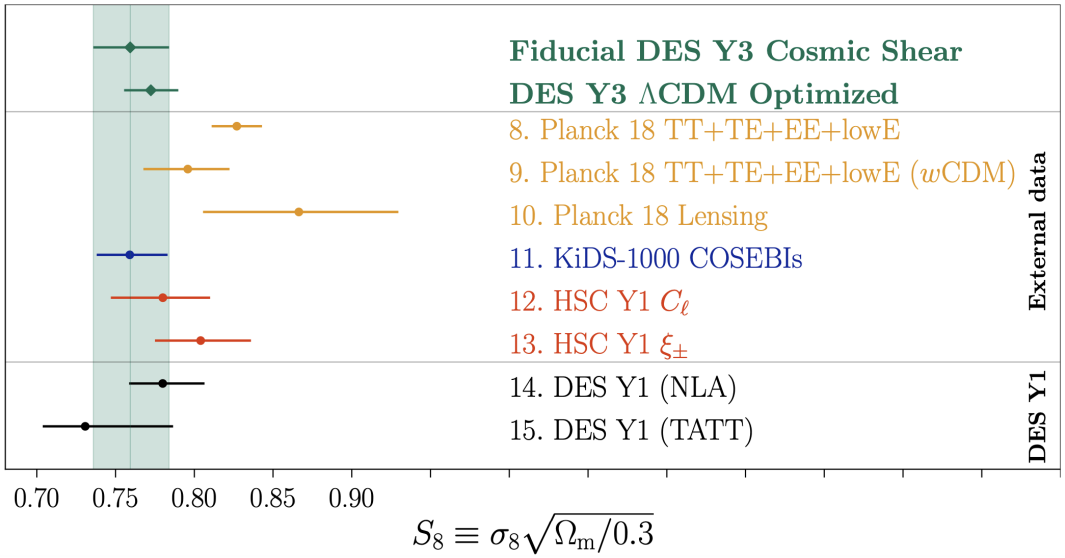
- We don’t know what causes acceleration
  - Best guess: Λ
- We know we need a non-baryonic cold component.
  - Best guess: **CDM**



This ΛCDM model has been quite successful, but cracks are appearing!

The troubles of the Universe

A possible crack in ΛCDM: $\boldsymbol{\sigma_8}$ tension



DES Y3, Secco et al 2021 (cropped)

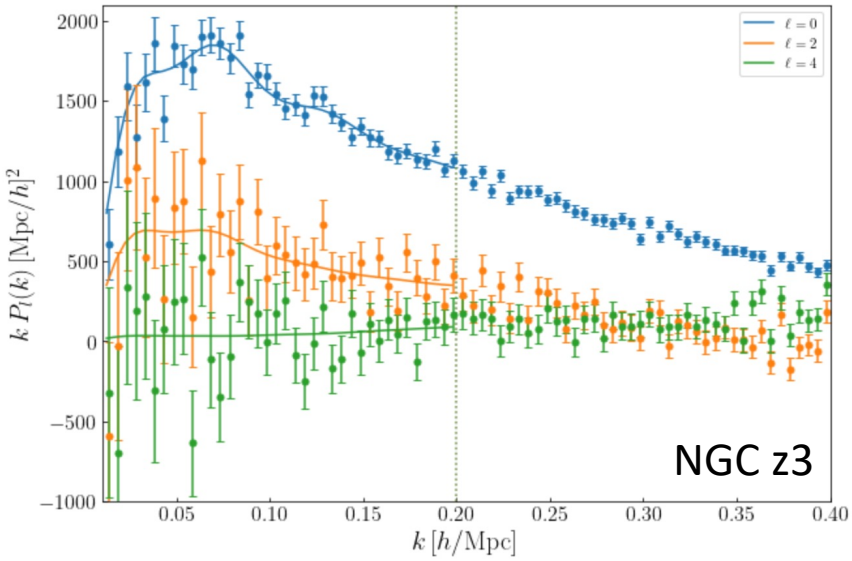
- Do other probes see a low amplitude?
- Could this be due to new physics in the dark sector?

Our work

- We perform a full shape analysis of **BOSS DR12 power spectrum** data
- We use an **EFTofLSS** model for the mildly nonlinear scales
- We perform likelihood analyses for 3 different dark energy models
  - ΛCDM, wCDM and **Dark Scattering** (wACDM)
- We evaluate the importance of **priors** on nuisance parameters

The data

- BOSS power spectrum multipoles, measured via a windowless estimator: [Philcox 2010]
  - Two redshift bins: $z_1 = 0.38$, $z_3 = 0.61$
  - Two skies: NGC and SGC
  - We use all multipoles up to $k_{max} = 0.2\ h/Mpc$
- Post-reconstruction BAO:
  - 6DF: $z = 0.106$
  - SDSS DR7 MGS: $z = 0.15$
  - BOSS DR12: $z_1 = 0.38$, $z_3 = 0.61$
  - eBOSS DR14 quasars/Lyα: $z = 2.334$
- BBN prior on baryon density:
  - $100\omega_b = 2.268 \pm 0.038$



- Some cases have 3σ Planck prior:
  - $\log 10^{10} A_s = 3.044 \pm 0.042$
  - $n_s = 0.9649 \pm 0.012$

Dark energy

- There are many models of dark energy. Here we study three:
  - Cosmological constant

$$\rho_{DE} \propto \Lambda = \text{const.}$$

  - Dynamical dark energy

$$w = \frac{p_{DE}}{\rho_{DE}} \neq -1$$

  - Interacting dark energy

$$DE \overset{E,p}{\longleftrightarrow} DM$$

Dark energy

Unless some principle forbids it, dark energy could interact

$$\nabla_\mu T^{\mu\nu}_{\rm DE} = Q^\nu, \quad \nabla_\mu T^{\mu\nu}_{\rm DM} = -Q^\nu$$

- Here, we focus on **momentum-exchange** only:

$$\boldsymbol{Q^\nu \perp u^\nu}$$

- **Feature:** interaction only affects the perturbations.

- We work with the **Dark Scattering** model [Simpson 2010]

$$\theta_{\rm DM}{}' + (\mathcal{H} + \boldsymbol{A\, a\, \rho_{DE}})\theta_{\rm DM} + \nabla^2\phi = 0 \qquad A \equiv (1+w)\frac{\sigma_D}{m_{\rm DM}}$$

- Interaction acts as **additional friction**, generating **scale-indep. growth**

Power spectrum modelling

- We use an EFTofLSS-based model: the so-called CLASS-PT model
  [Ivanov et al 2020, Chudaykin et al 2020]
  - Bias model

$$\delta_g = \boldsymbol{b_1}\delta_{cb} + \frac{\boldsymbol{b_2}}{2}\delta_{cb}^2 + \boldsymbol{b_{\mathcal{G}_2}}\mathcal{G}_2 + \boldsymbol{b_{\Gamma_3}}\Gamma_3 + \epsilon$$

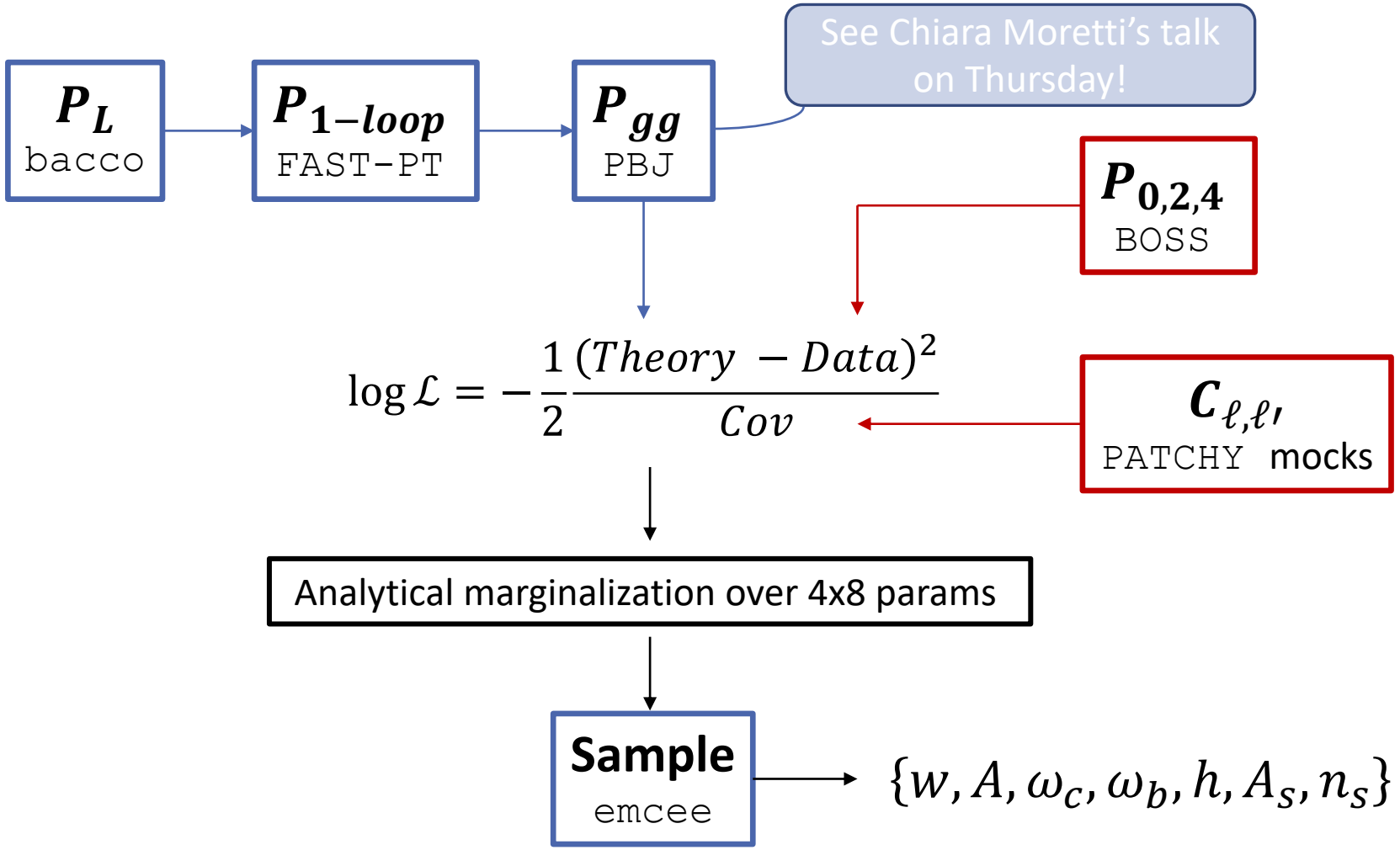
$$P_{\epsilon\epsilon} = \boldsymbol{N} + \boldsymbol{e_0}\, k^2 + \boldsymbol{e_2} k^2\mu^2$$

  - Counter-terms

$$P_{\rm ctr}(k,\mu) = -2\, k^2 P_L(k)[\boldsymbol{\tilde{c}_0} + \boldsymbol{\tilde{c}_2}\, f\mu^2 + \boldsymbol{\tilde{c}_4}\, f^2\mu^4] - \boldsymbol{c_{\nabla^4\delta}}\, f^4\, k^4\mu^4 P_{\rm Kais}(k,\mu)$$

  - Total of 11 nuisance parameters per redshift and sky cut (44 total)
  - **Priors** are set according to CLASS-PT/East Coast prescription (more later…)

Analysis set-up



Results - ΛCDM

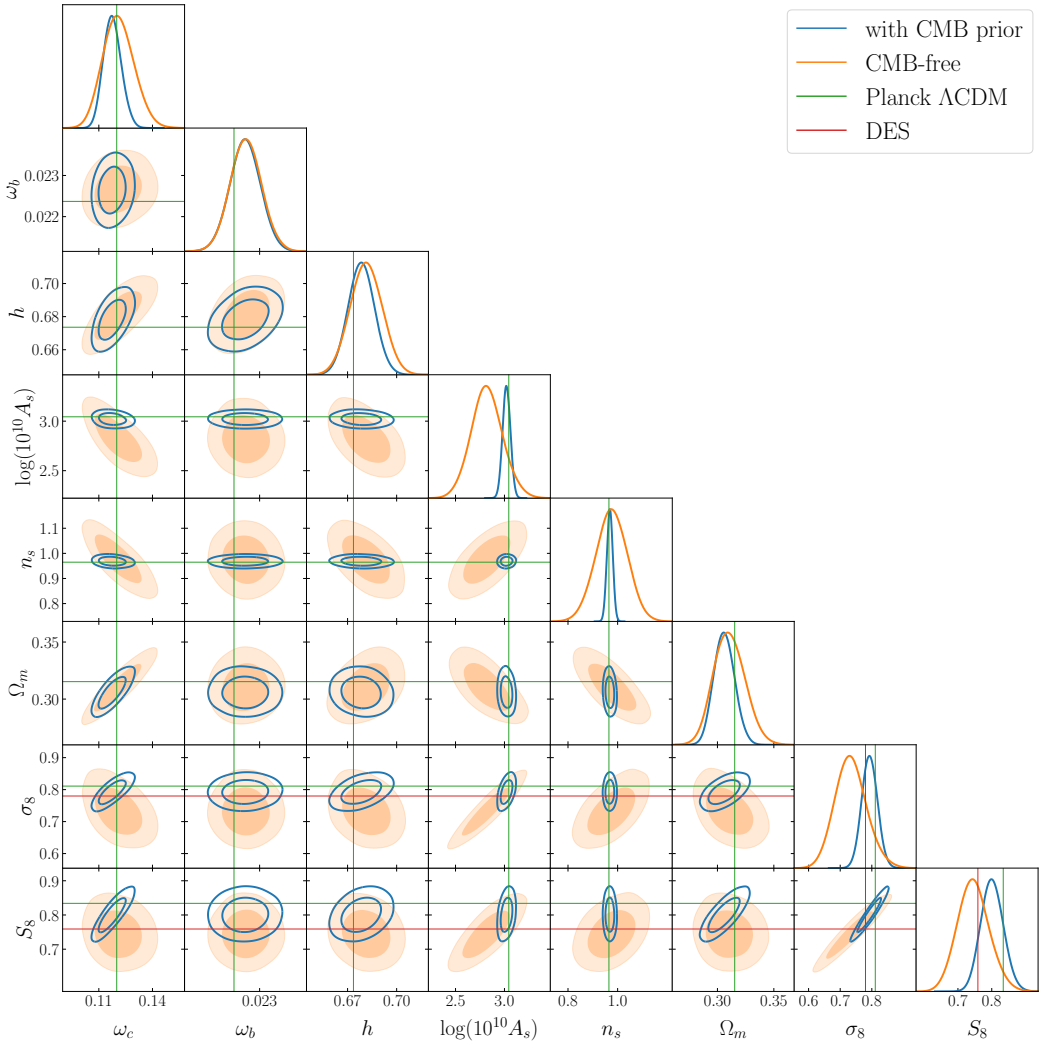
- CMB-free case
  - Low amplitude

$$\log 10^{10} A_s = 2.821 \pm 0.158$$

  - Otherwise agrees with Planck

$$h = 0.681 \pm 0.010$$

- CMB prior on A_s and n_s:
  - Full agreement with Planck



Results - wCDM

- CMB-free case
  - Lower amplitude

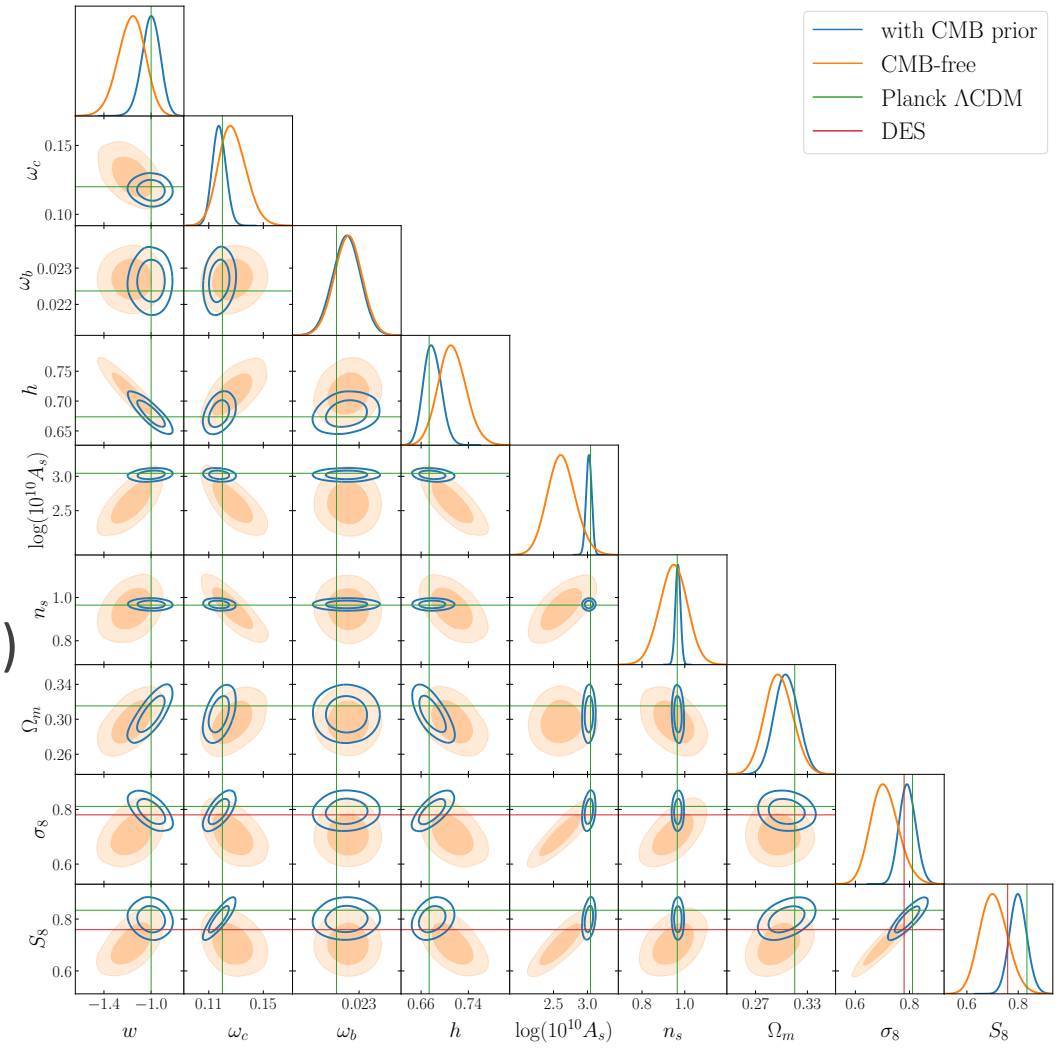
    $\log 10^{10} A_s = 2.62 \pm 0.21$

  - Preference for $w < -1$

    $w = -1.17 \pm 0.12$

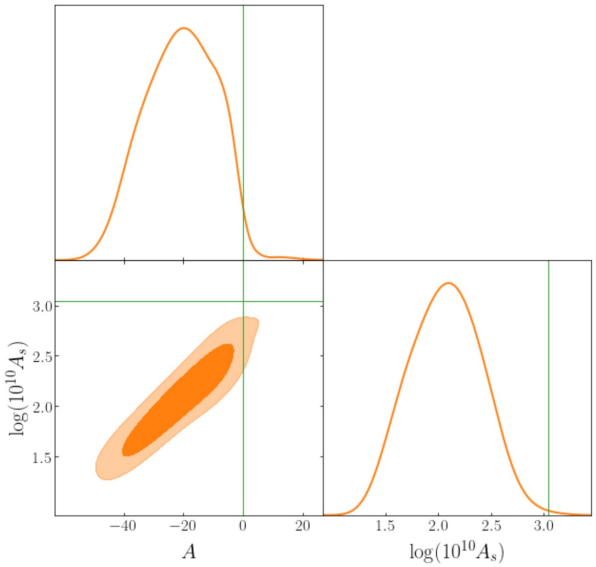
  - But large **degeneracies** (w, h, A_s)
- CMB prior on A_s and n_s:

  $w = -1.002^{+0.081}_{-0.073}$

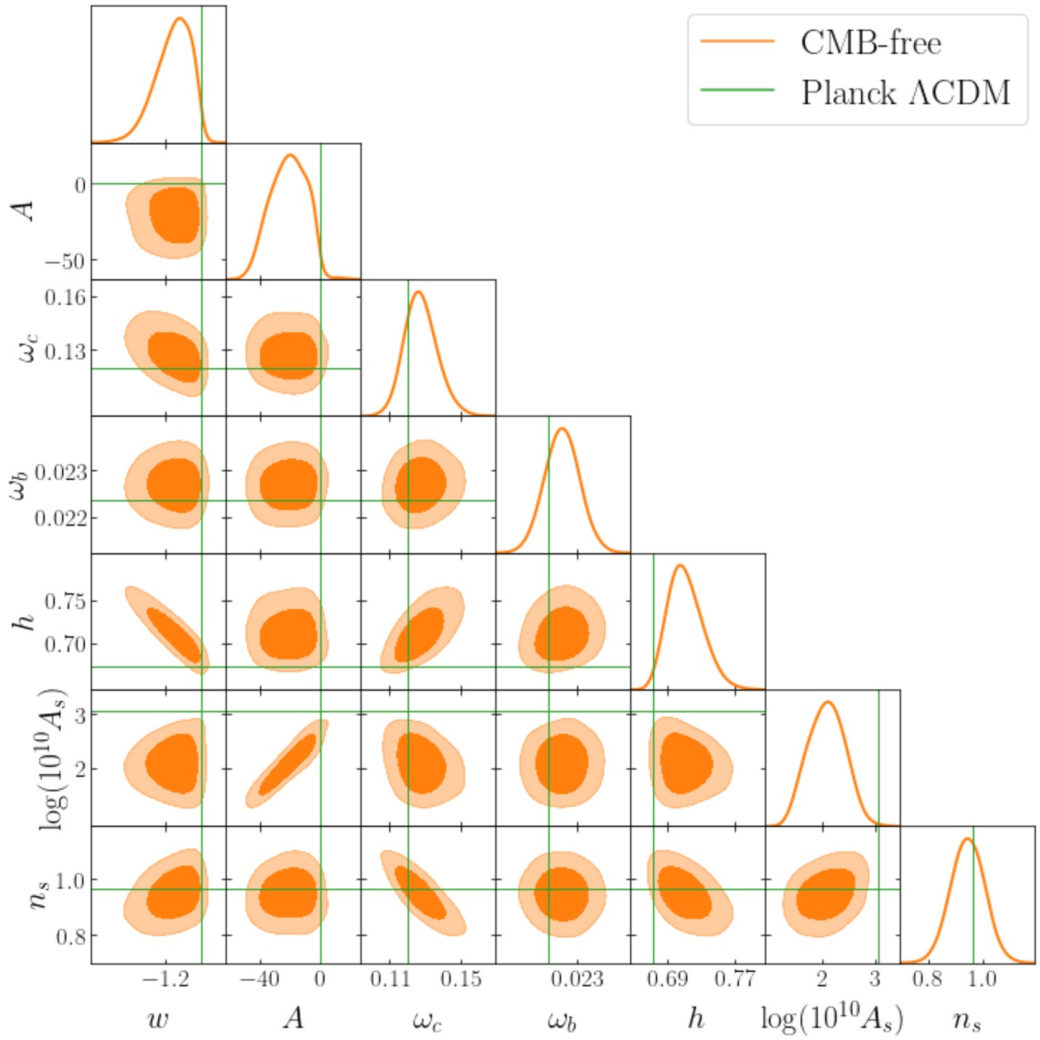


Results - wACDM

- CMB-free case
  - Interaction brings degeneracies
  - Strong degeneracy in A_s, A, b_1



  - Cannot constrain interaction



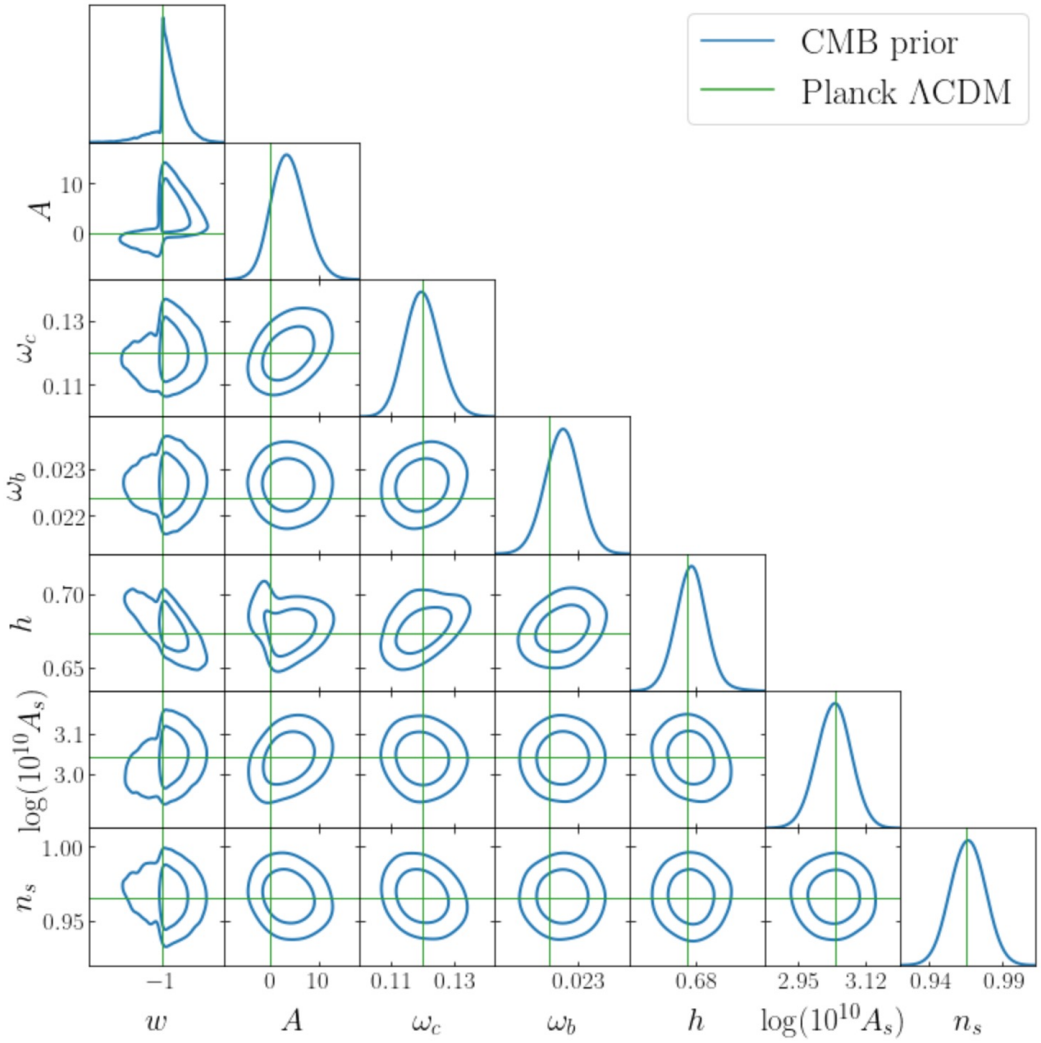
Results - wACDM

- CMB prior on A_s and n_s
  - Preference for $A > 0$ @ 1σ

$$w = -0.972^{+0.036}_{-0.029}$$

$$A = 3.9^{+3.2}_{-3.7}\ b/\mathrm{GeV}$$

  - Agreement with Planck



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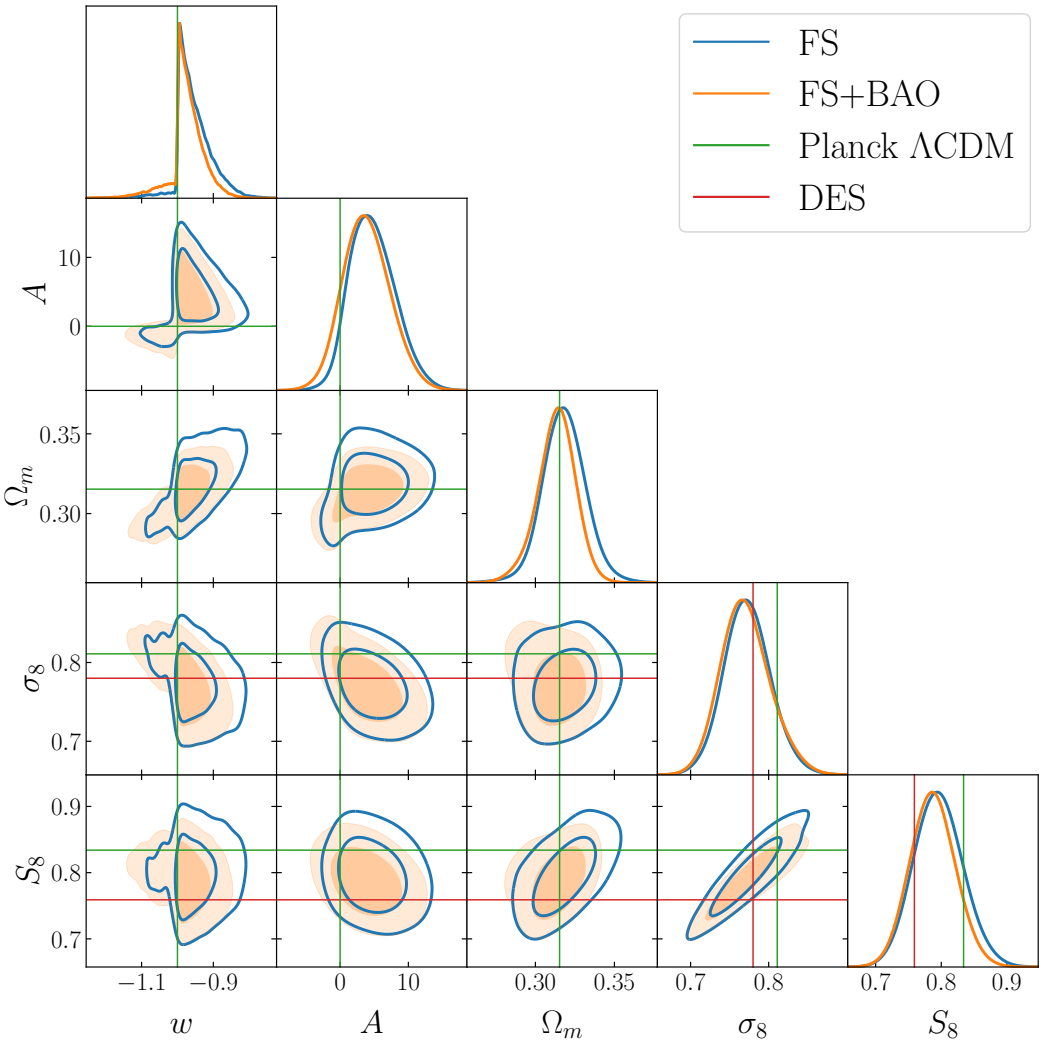
  - Agreement with Planck
  - Agreement with lensing σ_8
  - **Concordance restored!**



Dependence on priors

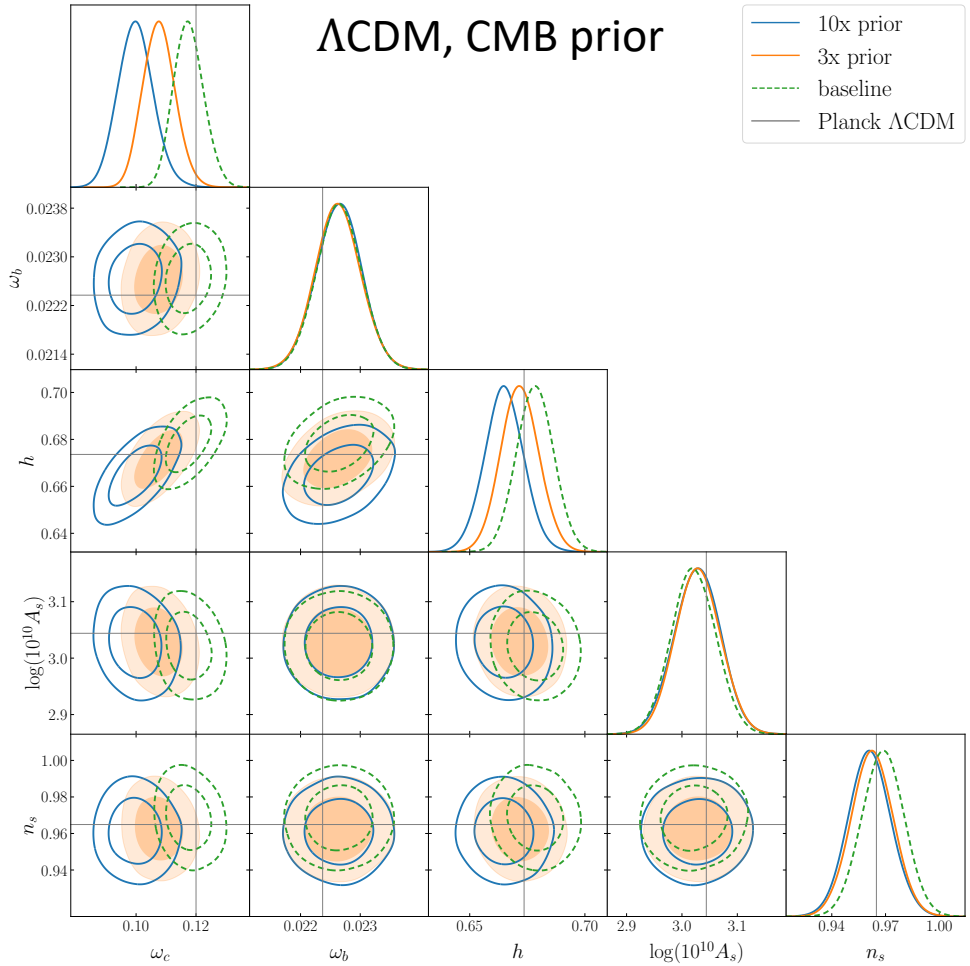
- The priors we used in all results so far are:

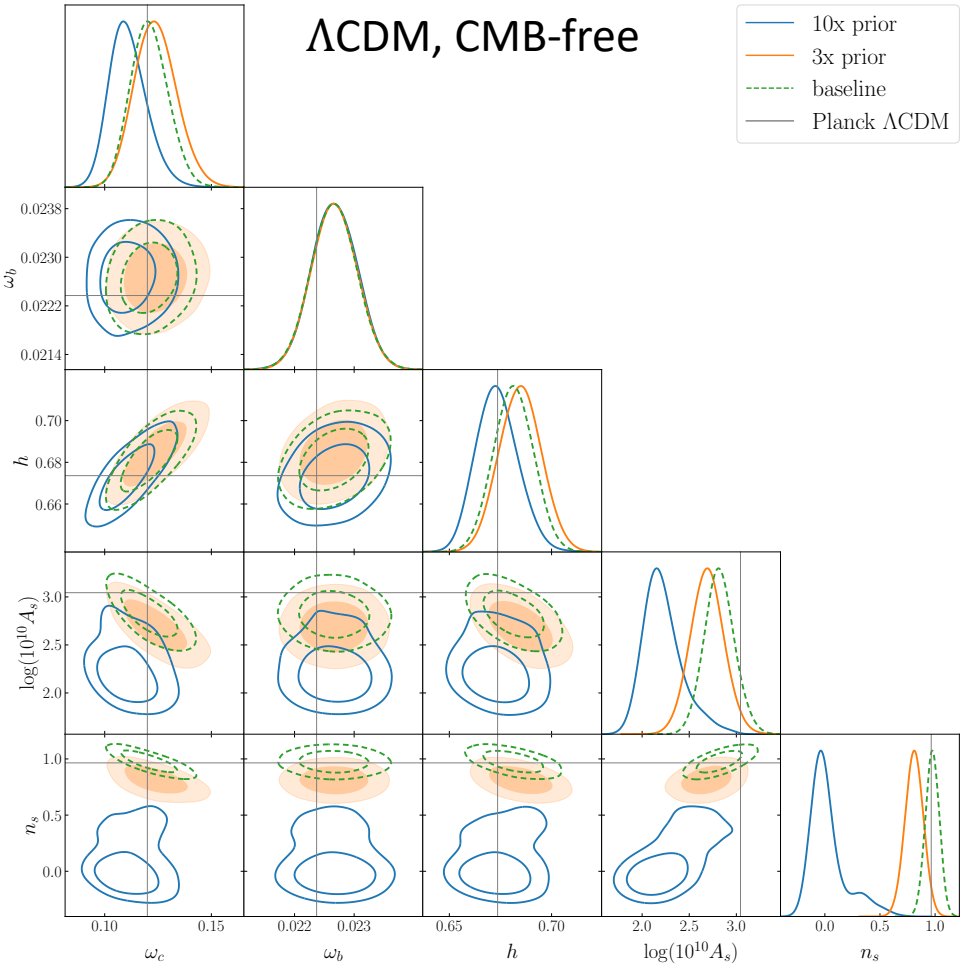
$$b_1 \sim \mathcal{U}(0,4)\,,\ b_2 \sim \mathcal{N}(0,1)\,,\ b_{\mathcal{G}_2} \sim \mathcal{N}(0,1)\,,\ b_{\Gamma_3} \sim \mathcal{N}\left(\frac{23}{42}(b_1-1),1\right)\,,$$
$$N \sim \mathcal{N}\left(\frac{1}{\bar{n}},\frac{2}{\bar{n}}\right)\,,\ e_0 \sim \mathcal{N}\left(0,\frac{2}{\bar{n}k_{\rm NL}^2}\right)\,,\ e_2 \sim \mathcal{N}\left(0,\frac{2}{\bar{n}k_{\rm NL}^2}\right)\,,\ \frac{c_0}{[{\rm Mpc}/h]^2} \sim \mathcal{N}(0,30)\,,$$
$$\frac{c_2}{[{\rm Mpc}/h]^2} \sim \mathcal{N}(30,30)\,,\ \frac{c_4}{[{\rm Mpc}/h]^2} \sim \mathcal{N}(0,30)\,,\ \frac{c_{\nabla^4\delta}}{[{\rm Mpc}/h]^4} \sim \mathcal{N}(500,500)\,,$$

- Are these priors informative?

- We tested it by broadening their std. deviations by $3\times$ and $10\times$.

Dependence on priors





Dependence on priors

- Priors are informative!
- Results for wACDM change:

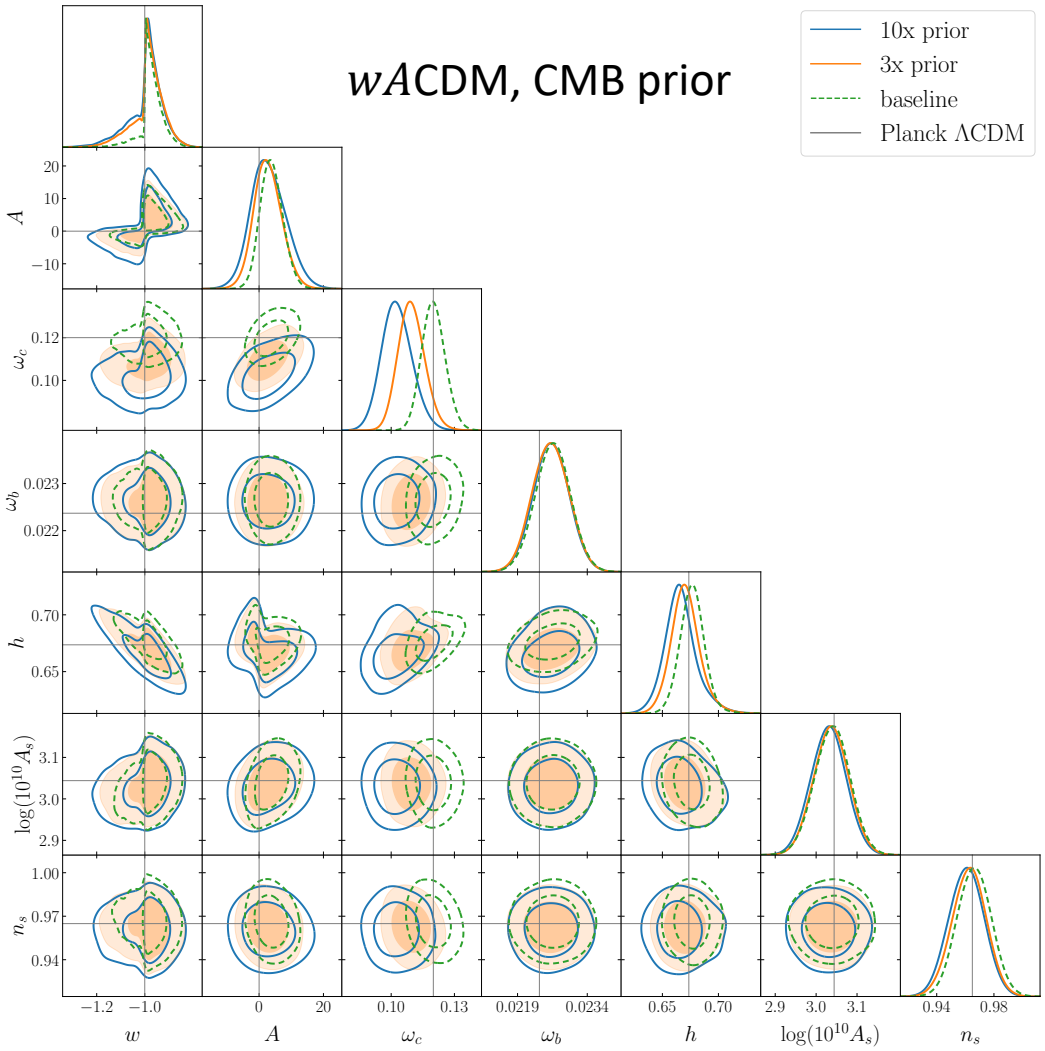
$$w = -0.972^{+0.036}_{-0.029}$$

$$A = 3.9^{+3.2}_{-3.7}\ b/\mathrm{GeV}$$

$$w = -0.985^{+0.081}_{-0.038}$$

3×:

$$A = 2.7^{+3.9}_{-4.5}\ b/\mathrm{GeV}$$



Summary

- We find low amplitudes in ΛCDM and wCDM;
- Concordance can be re-established within wACDM, and we find

$$w = -0.972^{+0.036}_{-0.029}\,, \quad A = 3.9^{+3.2}_{-3.7}\; b/\mathrm{GeV}\,;$$

- However, we see that **priors are informative** and change results!
- Prior issue needs to be addressed as it **could suggest fake signals**!
- Future work:
  - Adding the bispectrum (See M. Tsedrik et al, arxiv:2207.13011)
  - Joint analysis with lensing (ongoing with K. Carrion, arxiv:2111.13598)
  - Perform further tests of the importance of priors, also for stage IV

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