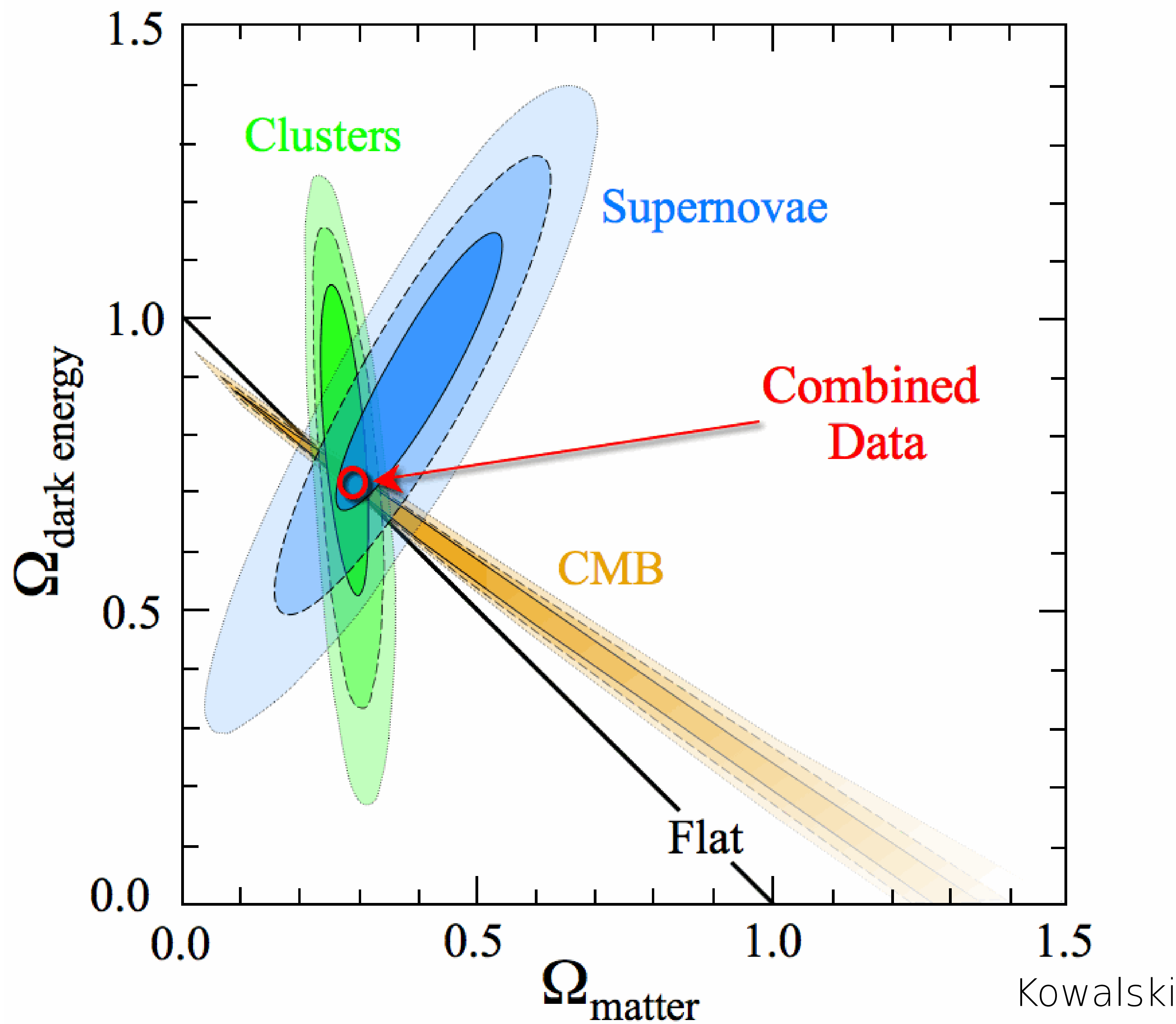
# Forecasting the joint analysis of Euclid and CMB experiments

Stéphane Ilić
(LERMA/APC)

in collaboration with the Euclid CMBX Science Working Group

Colloque national Action Dark Energy, 13/10/2021

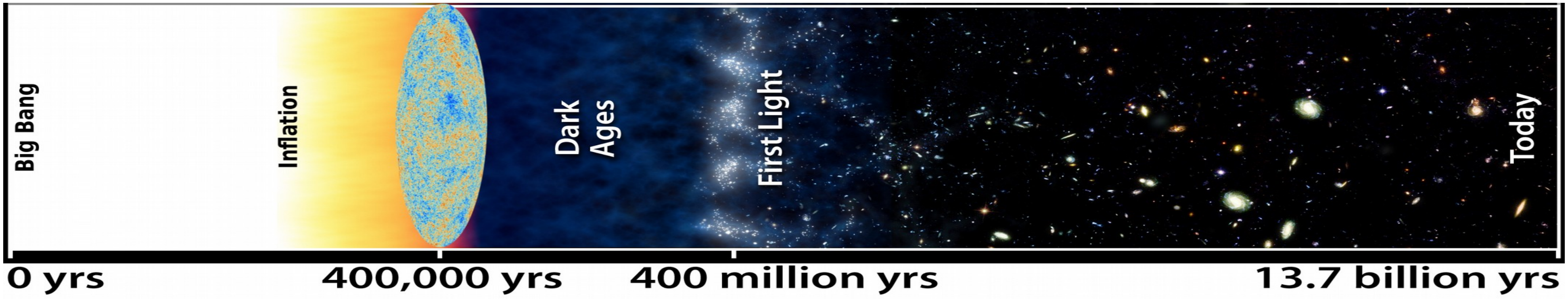
# Motivating the joint analysis of datasets




Kowalski et al. 2008

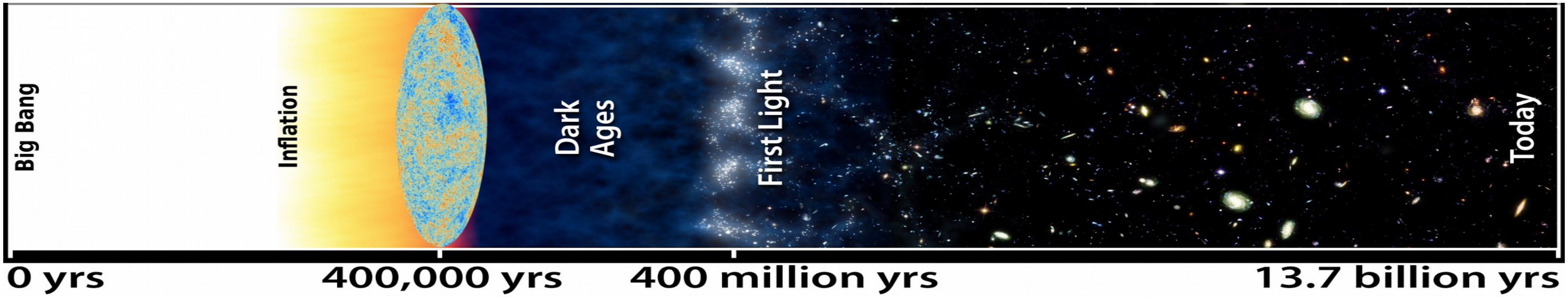
# Motivating the joint analysis of datasets

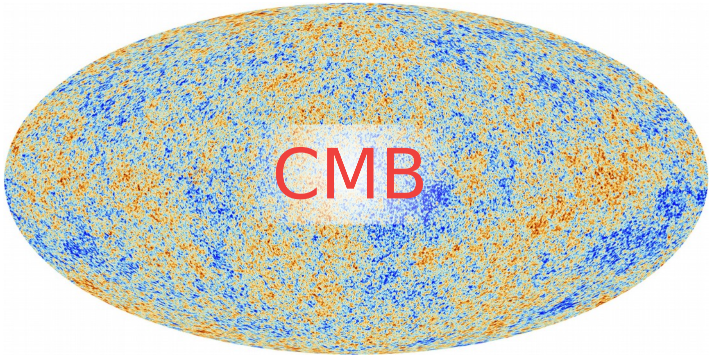
- Probes of different "sectors":
  - Background evolution: all standard rulers/candles
  - Perturbations: probes of structure growth
- Probes of different epochs:

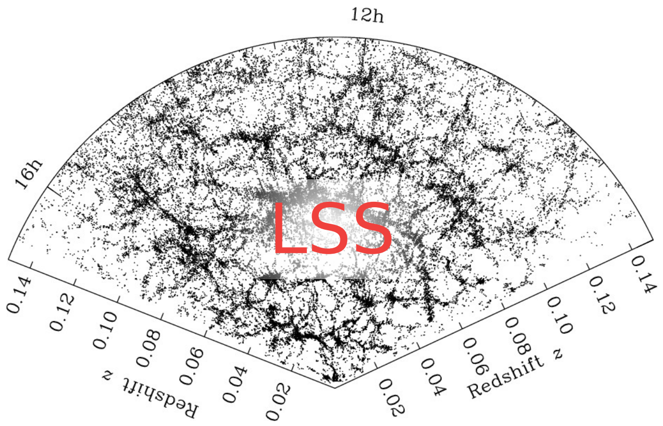


# Motivating the joint analysis of datasets

- Probes of different “sectors”:
    - Background evolution: all standard rulers/candles
    - Perturbations: probes of structure growth
- Probes of different epochs:

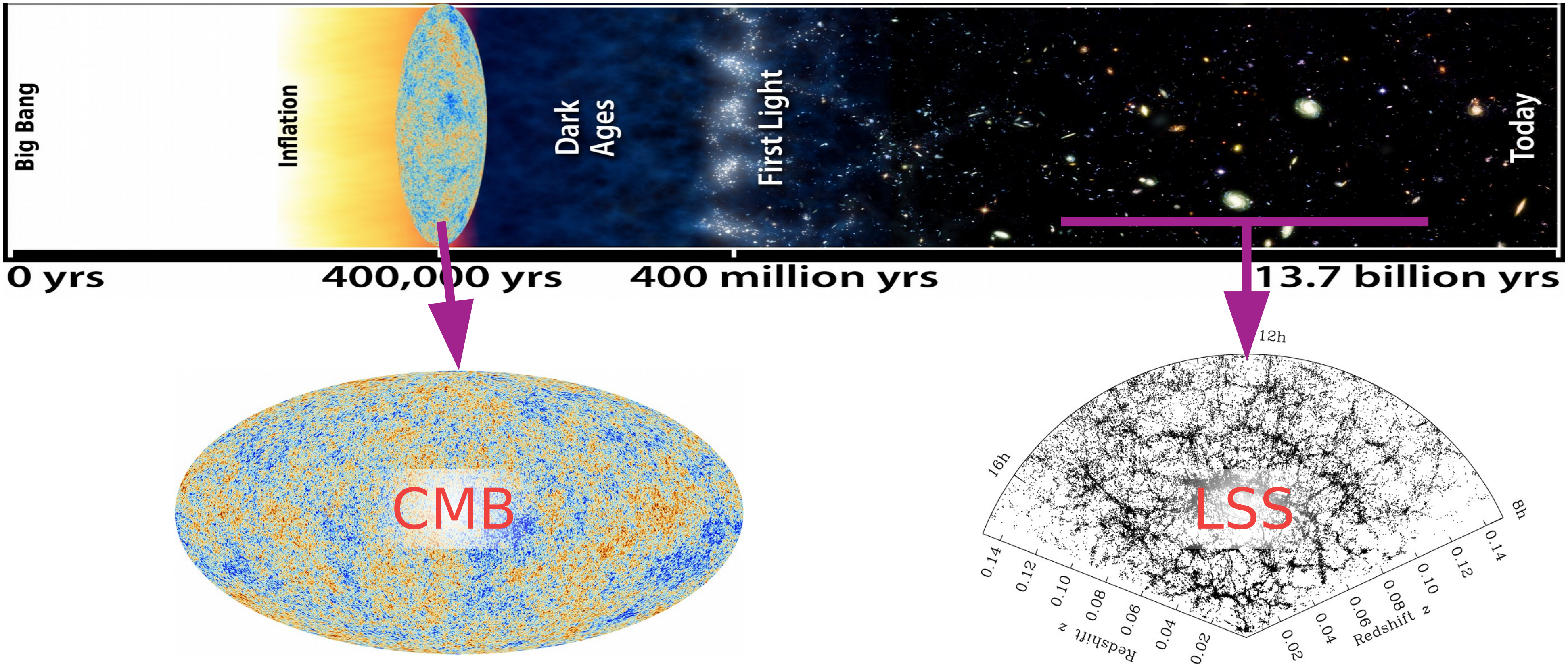


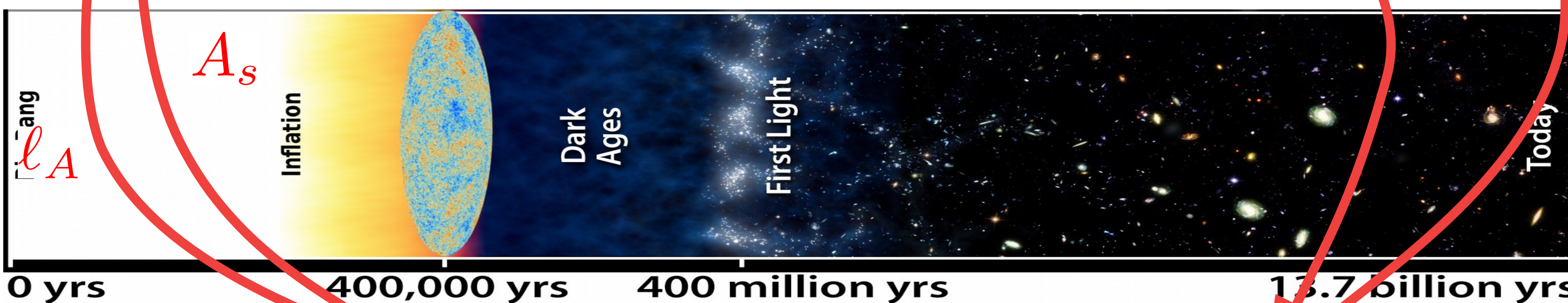
# Motivating the joint analysis of datasets

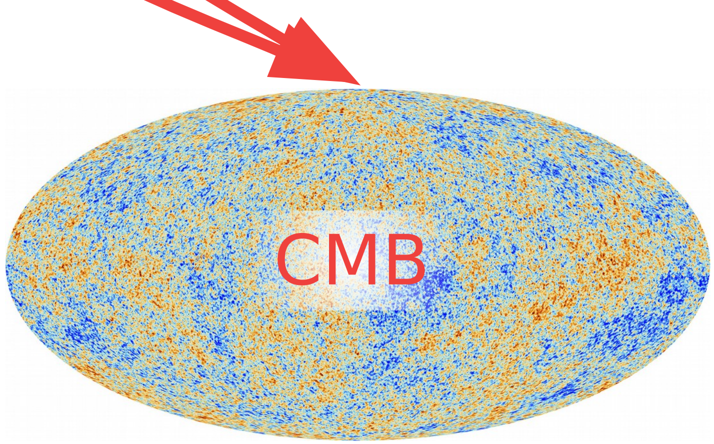
- Probes of different "sectors":
  - Background evolution: all standard rulers/candles
  - Perturbations: probes of structure growth
- Probes of different epochs:

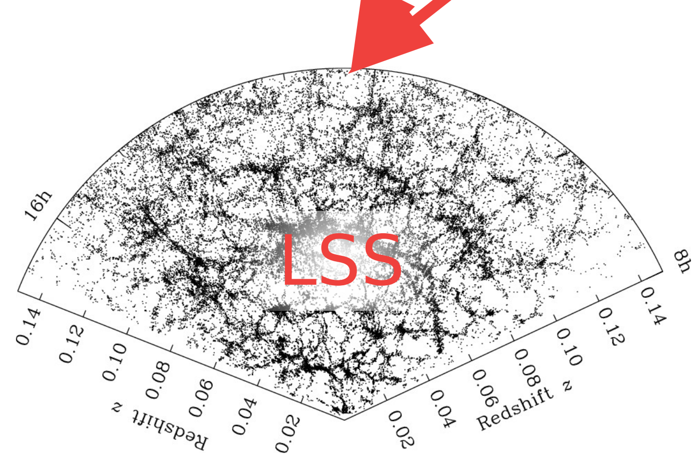


# Motivating the joint analysis of datasets

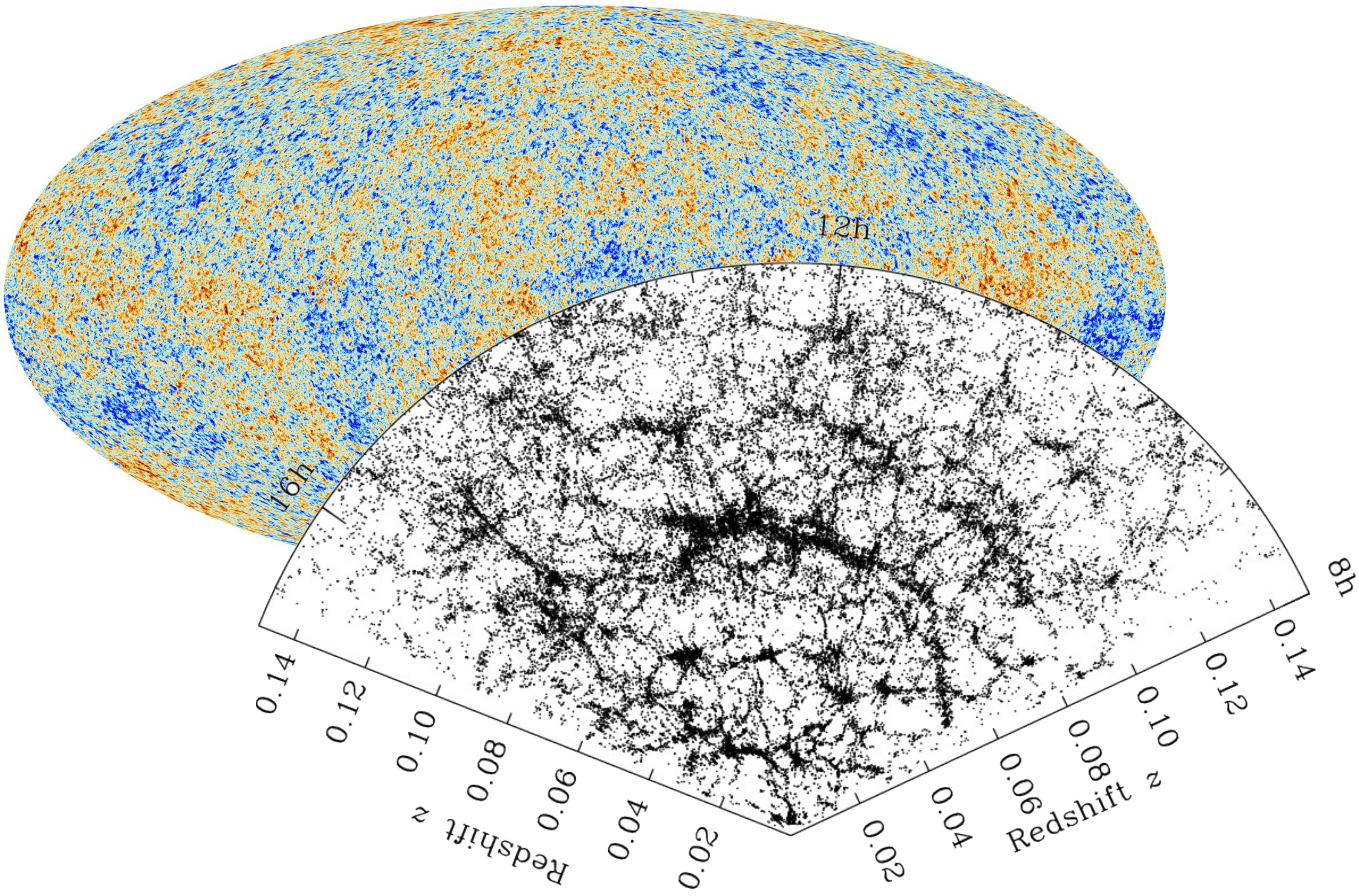
- Probes of different "sectors":
  - Background evolution: all standard rulers/candles
  - Perturbations: probes of structure growth
- Probes of different epochs:



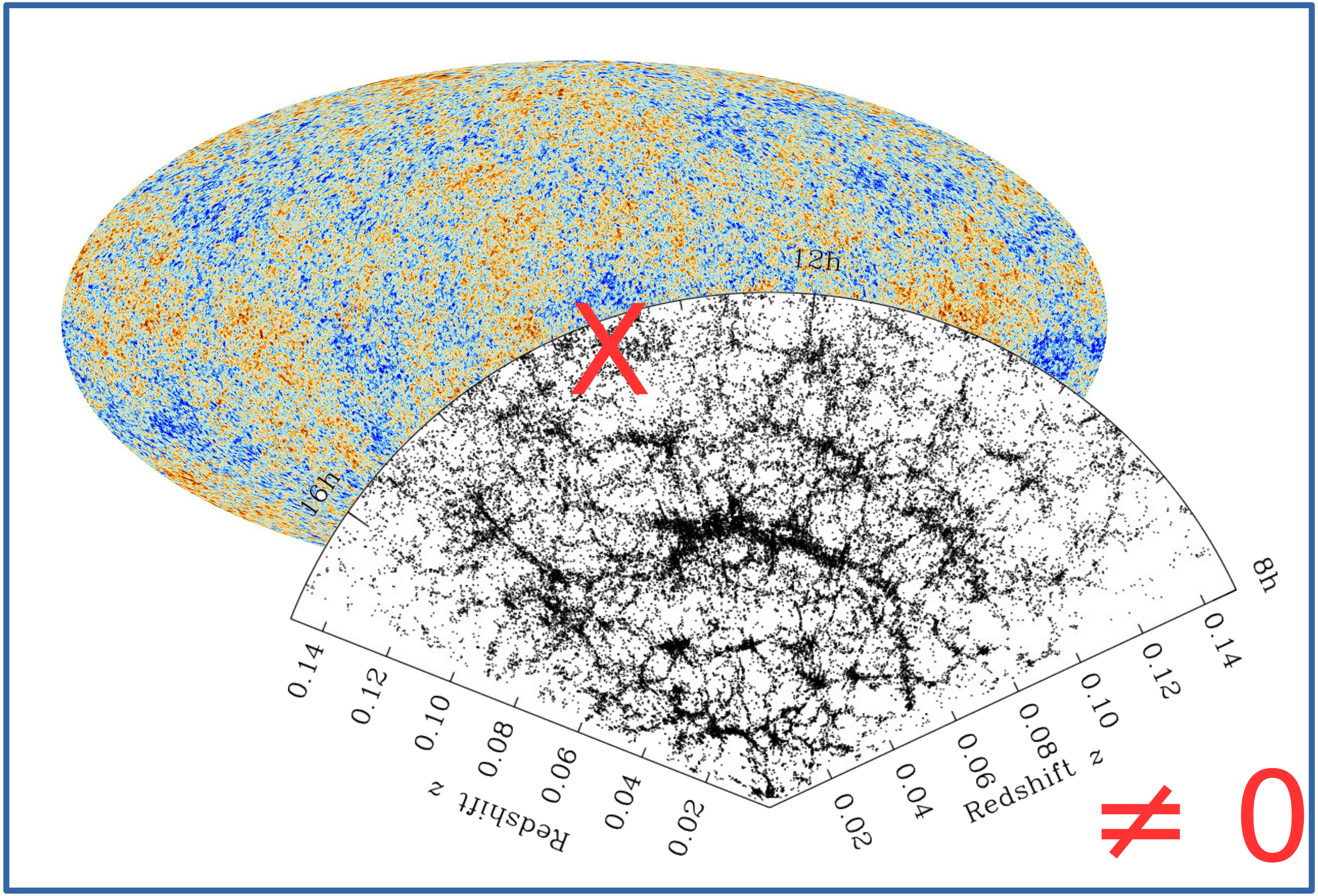



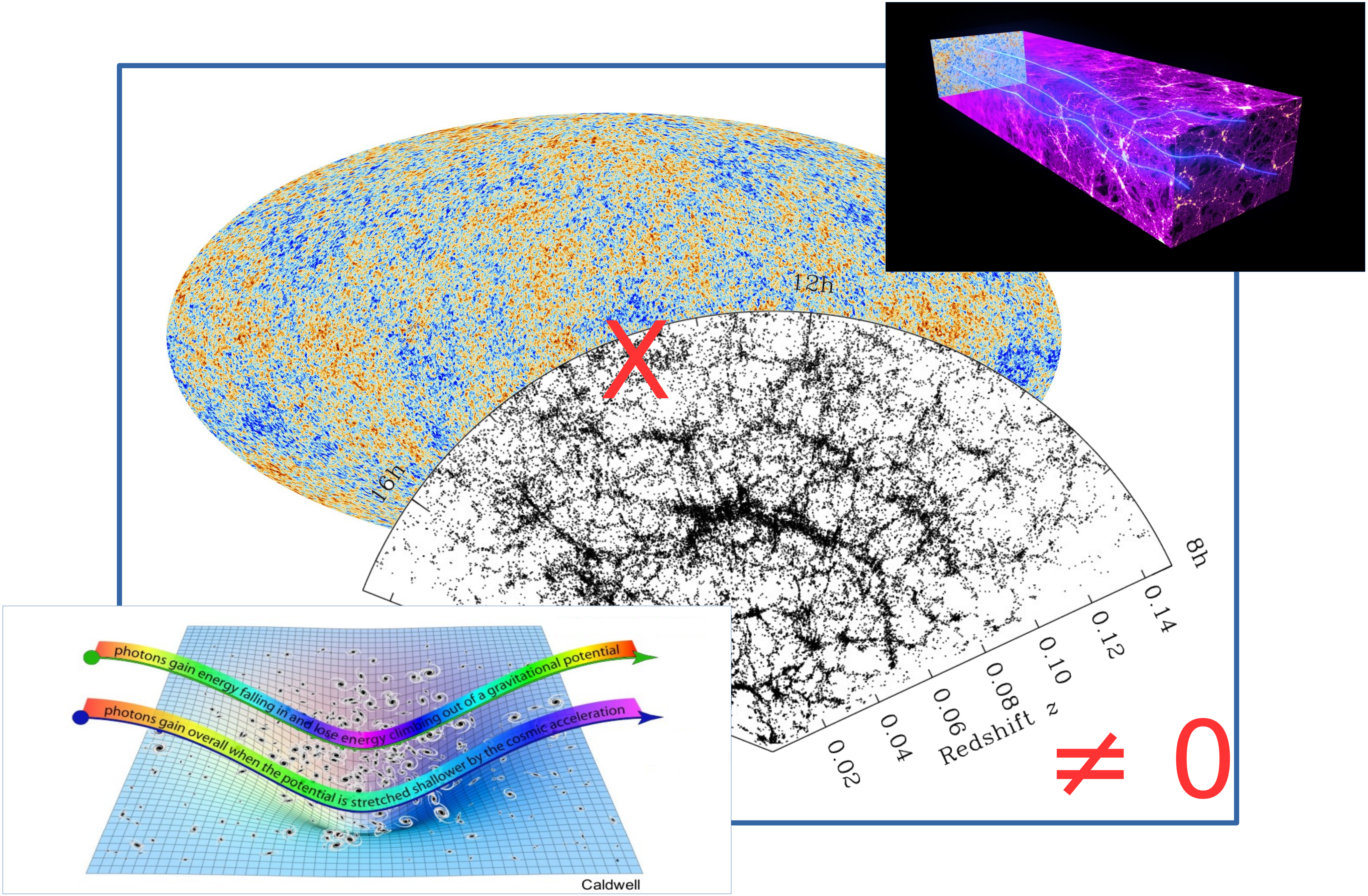
# CMB-LSS joint analysis



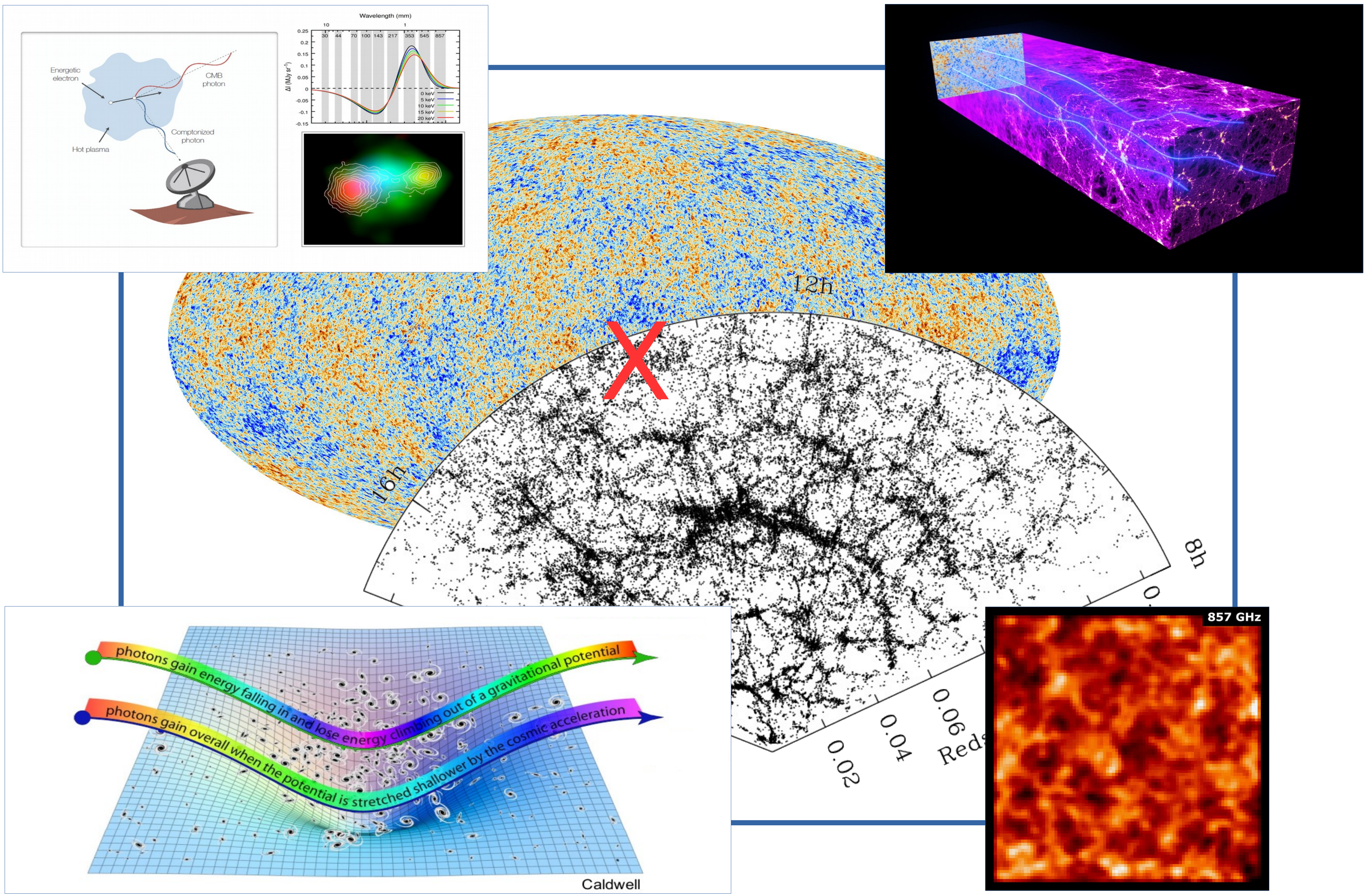
# CMB-LSS joint analysis



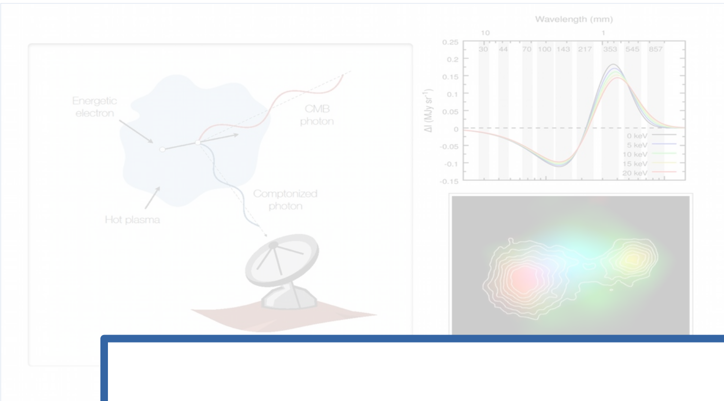
# CMB-LSS joint analysis



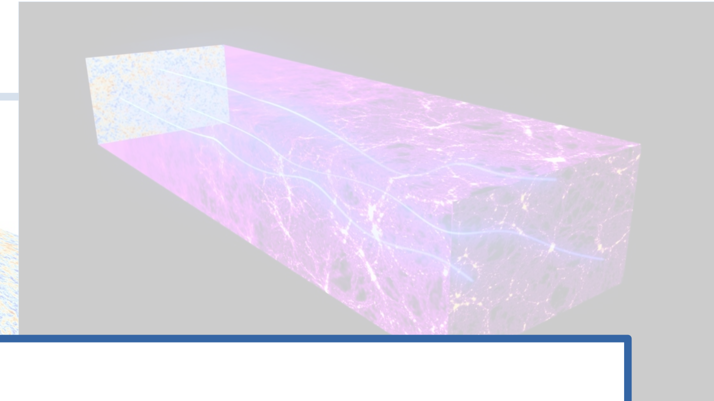
# CMB-LSS joint analysis



# CMB-LSS joint analysis







**<u>Euclid CMBX Science Working Group</u>**

Explore and prepare the joint analysis
of Euclid and CMB data

# The Euclid CMBX forecasts paper

arXiv:2106.08346

*Astronomy & Astrophysics* manuscript no. main
September 13, 2021



## *Euclid* preparation: XV. Forecasting cosmological constraints for the *Euclid* and CMB joint analysis

Euclid Collaboration: S. Ilić[1,2,3]⋆, N. Aghanim[4], C. Baccigalupi[5,6,7,8], J.R. Bermejo-Climent[9,10,11], G. Fabbian[12,114], L. Legrand[4,13], D. Paoletti[10,14], M. Ballardini[10,11,15], M. Archidiacono[16,17], M. Douspis[4], F. Finelli[10,11], K. Ganga[18], C. Hernández-Monteagudo[9,19,20], M. Lattanzi[21], D. Marinucci[22], M. Migliaccio[22,23], C. Carbone[24], S. Casas[25], M. Martinelli[26], I. Tutusaus[3,27,28], P. Natoli[21,29], P. Ntelis[30], L. Pagano[29], L. Wenzl[31], A. Gruppuso[10,14], T. Kitching[32], M. Langer[4], N. Mauri[14,33], L. Patrizii[14], A. Renzi[34,35], G. Sirri[14], L. Stanco[34], M. Tenti[14], P. Vielzeuf[5,6], F. Lacasa[4], G. Polenta[36], V. Yankelevich[37], A. Blanchard[3], Z. Sakr[3,38], A. Pourtsidou[39], S. Camera[40,41], V.F. Cardone[42,43], M. Kilbinger[25], M. Kunz[13], K. Markovic[44], V. Pettorino[25], A.G. Sánchez[45], D. Sapone[46], A. Amara[47], N. Auricchio[10], R. Bender[45,48], C. Bodendorf[45], D. Bonino[49], E. Branchini[43,50,51], M. Brescia[52], J. Brinchmann[53,54], V. Capobianco[49], J. Carretero[55], F.J. Castander[27,28], M. Castellano[43], S. Cavuoti[52,56,57], A. Cimatti[58,59], R. Cledassou[60,61], G. Congedo[62], C.J. Conselice[63], L. Conversi[64,65], Y. Copin[66], L. Corcione[49], A. Costille[67], M. Cropper[32], A. Da Silva[68,69], H. Degaudenzi[70], F. Dubath[70], C.A.J. Duncan[71], X. Dupac[65], S. Dusini[34], A. Ealet[66], S. Farrens[25], P. Fosalba[27,28], M. Frailis[8], E. Franceschi[10], P. Franzetti[24], M. Fumana[24], B. Garilli[24], W. Gillard[30], B. Gillis[62], C. Giocoli[72,73], A. Grazian[74], F. Grupp[45,48], L. Guzzo[16,17,75], S.V.H. Haugan[76], H. Hoekstra[77], W. Holmes[44], F. Hormuth[78,79], P. Hudelot[80], K. Jahnke[79], S. Kermiche[30], A. Kiessling[44], R. Kohley[65], B. Kubik[66], M. Kümmel[48], H. Kurki-Suonio[81], R. Laureijs[82], S. Ligori[49], P. B. Lilje[76], I. Lloro[83], O. Mansutti[8], O. Marggraf[84], F. Marulli[10,14,58], R. Massey[85], S. Maurogordato[86], M. Meneghetti[10,14,87], E. Merlin[43], G. Meylan[88], M. Moresco[10,58], B. Morin[25], L. Moscardini[10,11,58], E. Munari[8], S.M. Niemi[82], C. Padilla[55], S. Paltani[70], F. Pasian[8], K. Pedersen[89], W. Percival[90,91,92], S. Pires[25], M. Poncet[61], L. Popa[93], L. Pozzetti[10], F. Raison[45], R. Rebolo[9,19], J. Rhodes[44], M. Roncarelli[10,58], E. Rossetti[58], R. Saglia[45,48], R. Scaramella[42,43], P. Schneider[84], A. Secroun[30], G. Seidel[79], S. Serrano[27,28], C. Sirignano[34,35], J.L. Starck[25], P. Tallada-Crespí[94], A.N. Taylor[62], I. Tereno[68,95], R. Toledo-Moreo[96], F. Torradeflot[55,94], E.A. Valentijn[97], L. Valenziano[10,14], G.A. Verdoes Kleijn[97], Y. Wang[98], N. Welikala[62], J. Weller[45,48], G. Zamorani[10], J. Zoubian[30], E. Medinaceli[72], S. Mei[18], C. Rosset[18], F. Sureau[25], T. Vassallo[48], A. Zacchei[8], S. Andreon[75], A. Balaguera-Antolínez[9,19], M. Baldi[10,14,15], S. Bardelli[10], A. Biviano[5,8], S. Borgani[5,7,8,99], E. Bozzo[70], C. Burigana[11,29,100], R. Cabanac[3], A. Cappi[10,86], C.S. Carvalho[95], G. Castignani[58], C. Colodro-Conde[19], J. Coupon[70], H.M. Courtois[101], J. Cuby[67], S. de la Torre[67], D. Di Ferdinando[14], H. Dole[4], M. Farina[102], P.G. Ferreira[71], P. Flose-Reimberg[80], S. Galeotta[8], G. Gozaliasl[103,104], J. Graciá-Carpio[45], E. Keihanen[104], C.C. Kirkpatrick[81], V. Lindholm[104,105], G. Mainetti[106], D. Maino[16,17,24], N. Martinet[67], M. Maturi[107,108], R.B. Metcalf[10,15], G. Morgante[10], C. Neissner[55], J. Nightingale[85], A.A. Nucita[109,110], D. Potter[111], G. Riccio[52], E. Romelli[8], M. Schirmer[79], M. Schultheis[86], V. Scottez[80], R. Teyssier[111], A. Tramacere[70], J. Valiviita[105,112], M. Viel[5,6,7,8], L. Whittaker[63,113], E. Zucca[10]

*(Affiliations can be found after the references)*

**ABSTRACT**

The combination and cross-correlation of the upcoming *Euclid* data with cosmic microwave background (CMB) measurements is a source of great expectation since it will provide the largest lever arm of epochs, ranging from recombination to structure formation across the entire past light cone. In this work, we present forecasts for the joint analysis of *Euclid* and CMB data on the cosmological parameters of the standard cosmological model and some of its extensions. This work expands and complements the recently published forecasts based on *Euclid*-specific probes, namely galaxy clustering, weak lensing, and their cross-correlation. With some assumptions on the specifications of current and future CMB experiments, the predicted constraints are obtained from both a standard Fisher formalism and a posterior-fitting approach based on actual CMB data. Compared to a *Euclid*-only analysis, the addition of CMB data leads to a substantial impact on constraints for all cosmological parameters of the standard Λ-cold-dark-matter model, with improvements reaching up to a factor of ten. For the parameters of extended models, which include a redshift-dependent dark energy equation of state, non-zero curvature, and a phenomenological modification of gravity, improvements can be of the order of two to three, reaching higher than ten in some cases. The results highlight the crucial importance for cosmological constraints of the combination and cross-correlation of *Euclid* probes with CMB data.

**Key words.** Cosmology:large-scale structure of Universe, cosmic background radiation, Surveys, Methods: statistical

# Reference: InterScience Taskforce (IST:F) forecasts paper

arXiv:1910.09273

A&A 642, A191 (2020)
https://doi.org/10.1051/0004-6361/202038071


Astronomy & Astrophysics

## *Euclid* preparation

### VII. Forecast validation for *Euclid* cosmological probes

Euclid Collaboration*: A. Blanchard[1], S. Camera[2,3], C. Carbone[4,5,6], V. F. Cardone[7], S. Casas[8], S. Clesse[91,92], S. Ilić[1,9], M. Kilbinger[10,11], T. Kitching[12], M. Kunz[13], F. Lacasa[13], E. Linder[14], E. Majerotto[13], K. Markovič[15], M. Martinelli[16], V. Pettorino[8], A. Pourtsidou[17], Z. Sakr[1,18], A.G. Sánchez[19], D. Sapone[20], I. Tutusaus[1,21,22], S. Yahia-Cherif[1], V. Yankelevich[23], S. Andreon[24,25], H. Aussel[8,11], A. Balaguera-Antolínez[26,27], M. Baldi[28,29,30], S. Bardelli[28], R. Bender[19,31], A. Biviano[32], D. Bonino[33], A. Boucaud[34], E. Bozzo[35], E. Branchini[7,36,37], S. Brau-Nogue[1], M. Brescia[38], J. Brinchmann[39], C. Burigana[40,41,42], R. Cabanac[1], V. Capobianco[33], A. Cappi[28,43], J. Carretero[44], C. S. Carvalho[45], R. Casas[21,22], F. J. Castander[21,22], M. Castellano[7], S. Cavuoti[38,46,47], A. Cimatti[29,48], R. Cledassou[49], C. Colodro-Conde[27], G. Congedo[50], C. J. Conselice[51], L. Conversi[52], Y. Copin[53,54,55], L. Corcione[33], J. Coupon[35], H. M. Courtois[53,54,55], M. Cropper[12], A. Da Silva[56,57], S. de la Torre[58], D. Di Ferdinando[30], F. Dubath[35], F. Ducret[58], C. A. J. Duncan[59], X. Dupac[52], S. Dusini[60], G. Fabbian[61], M. Fabricius[19], S. Farrens[8], P. Fosalba[21,22], S. Fotopoulou[62], N. Fourmanoit[63], M. Frailis[32], E. Franceschi[28], P. Franzetti[6], M. Fumana[6], S. Galeotta[32], W. Gillard[63], B. Gillis[50], C. Giocoli[28,29,30], P. Gómez-Alvarez[52], J. Graciá-Carpio[19], F. Grupp[19,31], L. Guzzo[4,5,24,25], H. Hoekstra[64], F. Hormuth[65], H. Israel[31], K. Jahnke[66], E. Keihanen[67], S. Kermiche[63], C. C. Kirkpatrick[67], R. Kohley[52], B. Kubik[68], H. Kurki-Suonio[67], S. Ligori[33], P. B. Lilje[69], I. Lloro[21,22], D. Maino[4,5,6], E. Maiorano[70], O. Marggraf[23], N. Martinet[58], F. Marulli[28,29,30], R. Massey[71], E. Medinaceli[72], S. Mei[73,74], Y. Mellier[10,11], B. Metcalf[29], J. J. Metge[49], G. Meylan[75], M. Moresco[28,29], L. Moscardini[28,29,40], E. Munari[32], R. C. Nichol[15], S. Niemi[12], A. A. Nucita[76,77], C. Padilla[44], S. Paltani[35], F. Pasian[32], W. J. Percival[78,79,80], S. Pires[8], G. Polenta[81], M. Poncet[49], L. Pozzetti[28], G. D. Racca[82], F. Raison[19], A. Renzi[60], J. Rhodes[83], E. Romelli[32], M. Roncarelli[28,29], E. Rossetti[29], R. Saglia[19,31], P. Schneider[23], V. Scottez[11], A. Secroun[63], G. Sirri[30], L. Stanco[60], J.-L. Starck[8], F. Sureau[8], P. Tallada-Crespí[84], D. Tavagnacco[32], A. N. Taylor[50], M. Tenti[40], I. Tereno[45,56], R. Toledo-Moreo[85], F. Torradeflot[44], L. Valenziano[28,40], T. Vassallo[31], G. A. Verdoes Kleijn[86], M. Viel[32,87,88,89], Y. Wang[90], A. Zacchei[32], J. Zoubian[63], and E. Zucca[28]

*(Affiliations can be found after the references)*

Received 2 April 2020 / Accepted 15 July 2020

#### ABSTRACT

*Aims.* The *Euclid* space telescope will measure the shapes and redshifts of galaxies to reconstruct the expansion history of the Universe and the growth of cosmic structures. The estimation of the expected performance of the experiment, in terms of predicted constraints on cosmological parameters, has so far relied on various individual methodologies and numerical implementations, which were developed for different observational probes and for the combination thereof. In this paper we present validated forecasts, which combine both theoretical and observational ingredients for different cosmological probes. This work is presented to provide the community with reliable numerical codes and methods for *Euclid* cosmological forecasts.

*Methods.* We describe in detail the methods adopted for Fisher matrix forecasts, which were applied to galaxy clustering, weak lensing, and the combination thereof. We estimated the required accuracy for *Euclid* forecasts and outline a methodology for their development. We then compare and improve different numerical implementations, reaching uncertainties on the errors of cosmological parameters that are less than the required precision in all cases. Furthermore, we provide details on the validated implementations, some of which are made publicly available, in different programming languages, together with a reference training-set of input and output matrices for a set of specific models. These can be used by the reader to validate their own implementations if required.

*Results.* We present new cosmological forecasts for *Euclid*. We find that results depend on the specific cosmological model and remaining freedom in each setting, for example flat or non-flat spatial cosmologies, or different cuts at non-linear scales. The numerical implementations are now reliable for these settings. We present the results for an optimistic and a pessimistic choice for these types of settings. We demonstrate that the impact of cross-correlations is particularly relevant for models beyond a cosmological constant and may allow us to increase the dark energy figure of merit by at least a factor of three.

**Key words.** cosmology: observations – cosmological parameters – cosmology: theory

# Foreword

Objectives:

- Forecast the cosmological potential of the Euclid x CMB combined analysis
- Basis for the future of forecasts in Euclid and the development of the cosmological pipeline

# Recipe for Euclid x CMB forecasts

- Main ingredient : likelihood

$$\mathcal{L}(M|\mathcal{O})$$

# Recipe for Euclid x CMB forecasts

- Main ingredient : likelihood

$$\mathcal{L}(M|\mathcal{O})$$

1) Which model(s) ?

Same as chosen by IST:F

- Standard, 6-parameter ΛCDM
- Neutrinos : minimal non-zero $\sum m_\nu$
- w0/wa parametrisation and/or curvature
- MG model: “gamma”

# Recipe for Euclid x CMB forecasts

- Main ingredient : likelihood

$$\mathcal{L}(M|\mathcal{O})$$

**Issues for CMB :**
**choice of the parameter basis**

- $\theta$ versus $H_0$
- $A_s$ versus $\sigma_8$
- "Small" versus "big" omegas

+ gamma MG parameterisation

- MG model: "gamma"

# Recipe for Euclid x CMB forecasts

• Main ingr

## Final models (cf. IST)

- ΛCDM flat
- ΛCDM non-flat
- $w_0$, $w_a$ flat
- $w_0$, $w_a$ non-flat
- $w_0$, $w_a$ , gamma flat
- $w_0$, $w_a$ , gamma non-flat

**Table 1.** Parameter values of our fiducial cosmological model, both in the baseline ΛCDM case and in the considered extensions. Values are chosen to be identical to the ones in EC19. As mentioned in the text, it should be noted that for non-flat cosmological models, $\Omega_{\mathrm{DE},0}$ is also varied in conjunction with $\Omega_{\mathrm{K},0}$.

| Baseline | | | | | | | Extensions | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\Omega_{\mathrm{b},0}$ ($\omega_{\mathrm{b},0}$) | $\Omega_{\mathrm{m},0}$ ($\omega_{\mathrm{m},0}$) | $h$ | $n_{\mathrm{s}}$ | $\sigma_8$ | $\tau$ | $\sum m_\nu$ [eV] | $\Omega_{\mathrm{DE},0}$ | $w_0$ | $w_a$ | $\gamma$ |
| 0.05 (0.022445) | 0.32 (0.143648) | 0.67 | 0.96 | 0.816 | 0.058 | 0.06 | 0.68 | −1 | 0 | 0.55 |

# Recipe for Euclid x CMB forecasts

- Main ingredient : likelihood

$$\mathcal{L}(M|\mathcal{O})$$

2) Which observables ?

$$\mathcal{C}_\ell$$

- Euclid:
  - Photometric Galaxy Clustering
  - Weak Lensing
  - Spectroscopic Galaxy Clustering*

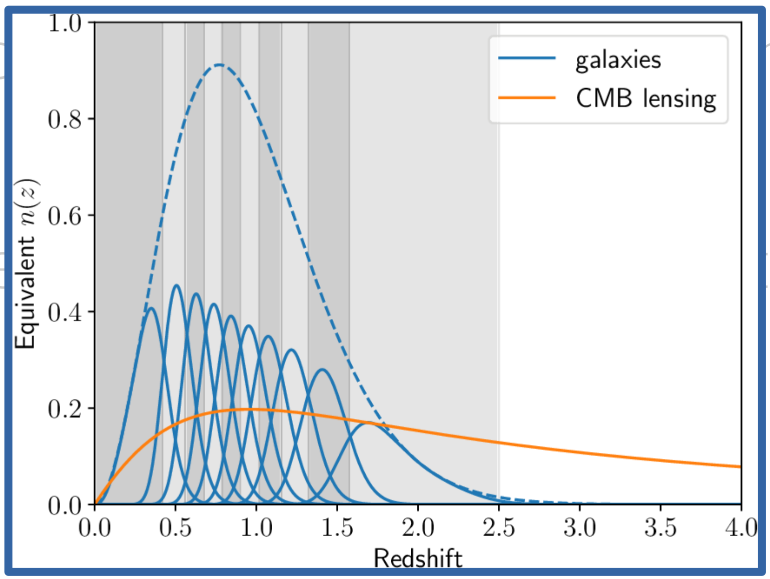
# Recipe for Euclid x CMB forecasts

- Main ingredient : likelihood

**Table 2.** Specifications for the *Euclid* photometric survey.

| | Parameter | *Euclid* |
|---|---|---|
| Survey area in the sky | $A_{\rm survey}$ | 15 000 deg$^2$ |
| Sky fraction | $f_{\rm sky}$ | 0.36 |
| Galaxy number density | $n_{\rm g}$ | 30 arcmin$^{-2}$ |
| Total intrinsic ellipticity dispersion | $\sigma_\epsilon$ | 0.30 |
| Minimum (measured) redshift | $z_{\rm min}$ | 0.001 |
| Maximum (measured) redshift | $z_{\rm max}$ | 0.9 (pessimistic), 2.5 (optimistic) |
| Number of redshift bins | $N_z$ | 5 (pessimistic), 10 (optimistic) |
| Minimum multipole (WL and GC) | $\ell_{\rm min}$ | 10 |
| Maximum multipole for WL | $\ell_{\rm max}$ | 1500 (pessimistic), 5000 (optimistic) |
| Maximum multipole for GC | $\ell_{\rm max}$ | 750 (pessimistic), 3000 (optimistic) |

- Euclid:
  - Pho... ...ing
  - We...
  - Spe... ...ering*



# Recipe for Euclid x CMB forecasts

- <u>Main ingredient : likelihood</u>

$$\mathcal{L}(M|\mathcal{O})$$

2) Which observables ?

$$\mathcal{C}_\ell$$

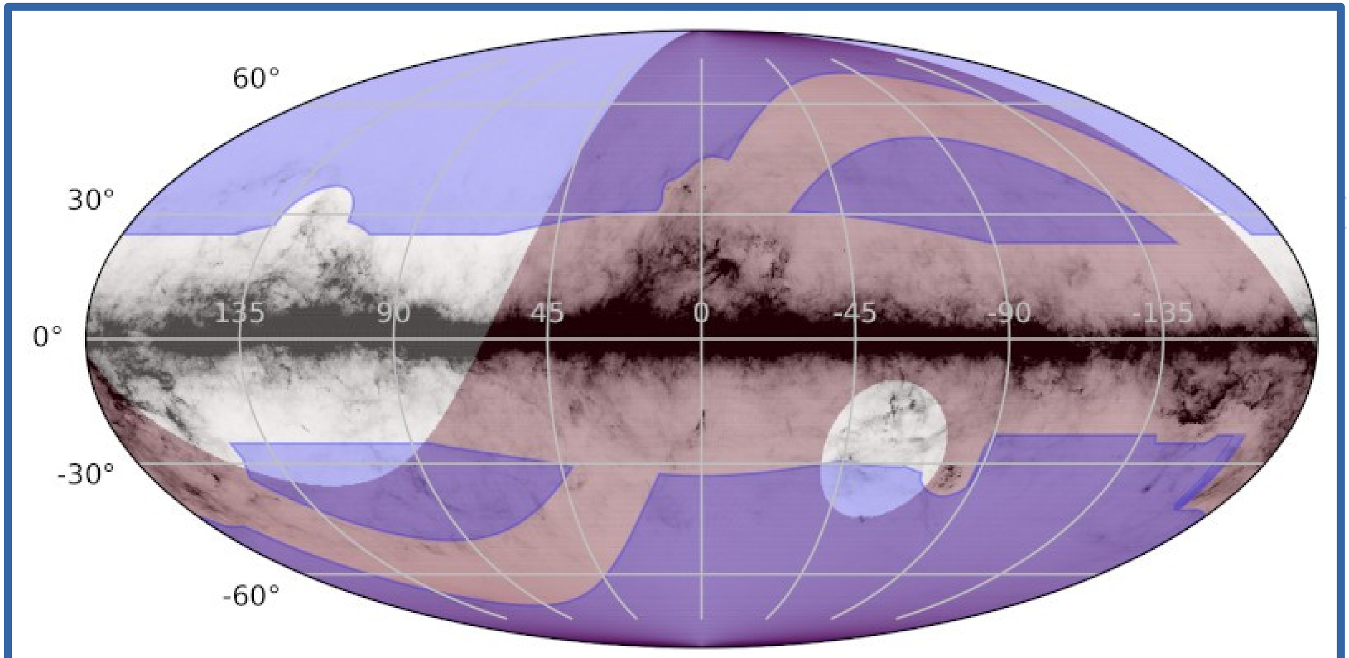
- <u>CMB</u>:
  - Temperature (T)
  - Polarization (E & ~~B~~)
  - CMB lensing (P)

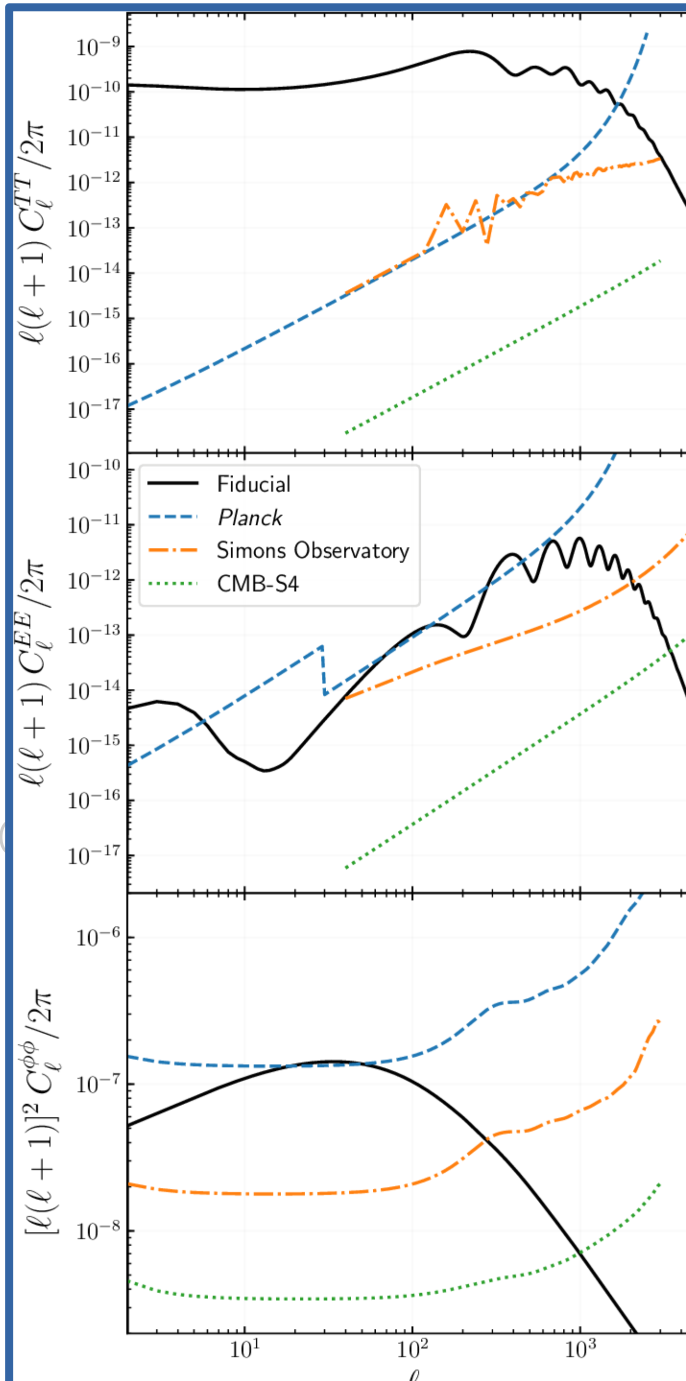
} contains secondary anisotropies

# Recipe for Euclid x CMB forecasts

• Main ingredient : likelihood

| | Parameter | *Planck* | Simons Observatory + *Planck* low-$\ell$ | CMB+Stage 4 + *Planck* low-$\ell$ |
|---|---|---|---|---|
| Sky fraction | $f_{\rm sky}$ | 0.7 | 0.4 | 0.4 |
| Beam FWHM | $\theta_{\rm FWHM}$ | 7 arcmin | 2 arcmin | 1 arcmin |
| Temperature noise | $\Delta T \equiv (w_{TT})^{-1/2}$ | 23 $\mu K$.arcmin | 3 $\mu K$.arcmin | 1 $\mu K$.arcmin |
| Polarization noise | $\Delta E \equiv (w_{EE})^{-1/2}$ | 42 $\mu K$.arcmin | $3\sqrt{2}$ $\mu K$.arcmin | $\sqrt{2}$ $\mu K$.arcmin |
| $TT$ multipole range | $[\ell_{TT,\rm min}, \ell_{TT,\rm max}]$ | $[2, 1500]$ | $[2, 3000]$ | $[2, 3000]$ |
| $TE$ multipole range | $[\ell_{TE,\rm min}, \ell_{TE,\rm max}]$ | $[2, 1500]$ | $[2, 3000]$ | $[2, 3000]$ |
| $EE$ multipole range | $[\ell_{EE,\rm min}, \ell_{EE,\rm max}]$ | $[2, 1500]$ | $[2, 5000]$ | $[2, 5000]$ |
| $\phi\phi$ multipole range | $[\ell_{\phi\phi,\rm min}, \ell_{\phi\phi,\rm max}]$ | $[8, 400]$ | $[2, 3000]$ | $[2, 3000]$ |
| $T\phi$ multipole range | $[\ell_{T\phi,\rm min}, \ell_{T\phi,\rm max}]$ | $[8, 400]$ | $[2, 3000]$ | $[2, 3000]$ |



# Observables considered

## Case n°0

| | T | E | B | P | D | L |
|---|---|---|---|---|---|---|
| T | tt | te | tb | tp | td | tl |
| | × | × | ×× | × | × | × |
| E | | ee | eb | ep | ed | el |
| | | × | ×× | × | × | × |
| B | | | bb | bp | bd | bl |
| | | | ×× | ×× | ×× | ×× |
| P | | | | pp | pd | pl |
| (CMB lens.) | | | | × | × | × |
| D | | | | | dd | dl |
| (Gal. Clus.) | | | | | ✔ | ✔ |
| L | | | | | | ll |
| (Weak Lens.) | | | | | | ✔ |

+ Gal. Clus. Spec.

Euclid only (=IST:F)

# Observables considered

## Case n°1

| | T | E | B | P | D | L |
|---|---|---|---|---|---|---|
| T | tt | te | tb | tp | td | tl |
| | ✗ | ✗ | ✗✗ | ✗ | ✗ | ✗ |
| E | | ee | eb | ep | ed | el |
| | | ✗ | ✗✗ | ✗ | ✗ | ✗ |
| B | | | bb | bp | bd | bl |
| | | | ✗✗ | ✗✗ | ✗✗ | ✗✗ |
| P | | | | pp | pd | pl |
| (CMB lens.) | | | | ✓ | ✓ | ✓ |
| D | | | | | dd | dl |
| (Gal. Clus.) | | | | | ✓ | ✓ |
| L | | | | | | ll |
| (Weak Lens.) | | | | | | ✓ |

+ Gal. Clus.
Spec.

All “matter” probes and
their cross-correlations

# Observables considered

## Case n°2

| | T | E | B | P | D | L |
|---|---|---|---|---|---|---|
| T | tt | te | tb | tp | td | tl |
| | ✔✔ | ✔✔ | ✗✗ | ✔✔ | ✔✔ | ✔✔ |
| E | | ee | eb | ep | ed | el |
| | | ✔✔ | ✗✗ | ✔✔ | ✔✔ | ✔✔ |
| B | | | bb | bp | bd | bl |
| | | | ✗✗ | ✗✗ | ✗✗ | ✗✗ |
| P | | | | pp | pd | pl |
| (CMB lens.) | | | | ✔ | ✔ | ✔ |
| D | | | | | dd | dl |
| (Gal. Clus.) | | | | | ✔ | ✔ |
| L | | | | | | ll |
| (Weak Lens.) | | | | | | ✔ |

+ Gal. Clus. Spec.

All CMB x Euclid probes & correlations

# Euclid x CMB forecasts in CMBX SWG

Code development & comparison effort :

- 4 teams involved (FR, IT, ES)
- **Coordinator (& participant) : S.I.**
- Collaboration with IST (validation)
- Tools : Slack & GitHub repo

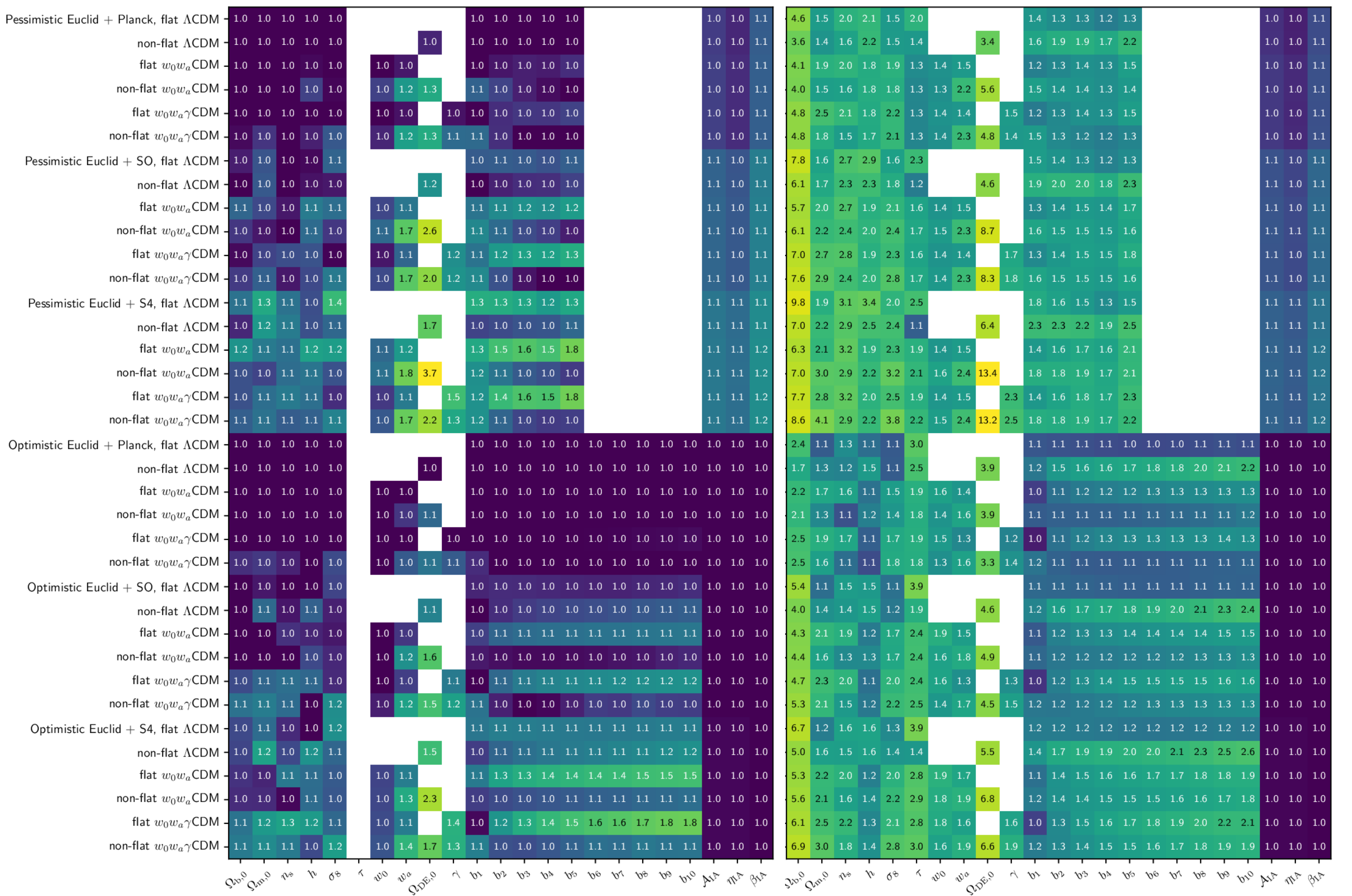
Results compiled in Euclid publication
(lead author/coordinator : S.I.)

# The results

- 2 “scientific cases”
- 6 cosmological models/scenarios
- 10 cosmological parameters
  + 8/13 nuisance parameters
- 2 sets of Euclid specifications
- 3 scenarios for CMB experiments

(+ forecasts based on real data via posterior fitting)

# The results



Pessimistic Euclid + Planck, flat ΛCDM
non-flat ΛCDM
flat $w_0w_a$CDM
non-flat $w_0w_a$CDM
flat $w_0w_a\gamma$CDM
non-flat $w_0w_a\gamma$CDM
Pessimistic Euclid + SO, flat ΛCDM
non-flat ΛCDM
flat $w_0w_a$CDM
non-flat $w_0w_a$CDM
flat $w_0w_a\gamma$CDM
non-flat $w_0w_a\gamma$CDM
Pessimistic Euclid + S4, flat ΛCDM
non-flat ΛCDM
flat $w_0w_a$CDM
non-flat $w_0w_a$CDM
flat $w_0w_a\gamma$CDM
non-flat $w_0w_a\gamma$CDM
Optimistic Euclid + Planck, flat ΛCDM
non-flat ΛCDM
flat $w_0w_a$CDM
non-flat $w_0w_a$CDM
flat $w_0w_a\gamma$CDM
non-flat $w_0w_a\gamma$CDM
Optimistic Euclid + SO, flat ΛCDM
non-flat ΛCDM
flat $w_0w_a$CDM
non-flat $w_0w_a$CDM
flat $w_0w_a\gamma$CDM
non-flat $w_0w_a\gamma$CDM
Optimistic Euclid + S4, flat ΛCDM
non-flat ΛCDM
flat $w_0w_a$CDM
non-flat $w_0w_a$CDM
flat $w_0w_a\gamma$CDM
non-flat $w_0w_a\gamma$CDM
$\Omega_{b,0}$ $\Omega_{m,0}$ $n_s$ $h$ $\sigma_8$ $\tau$ $w_0$ $w_a$ $\Omega_{DE,0}$ $\gamma$ $b_1$ $b_2$ $b_3$ $b_4$ $b_5$ $b_6$ $b_7$ $b_8$ $b_9$ $b_{10}$ $A_{IA}$ $\eta_{IA}$ $\beta_{IA}$

# The results: case n°0 to n°1

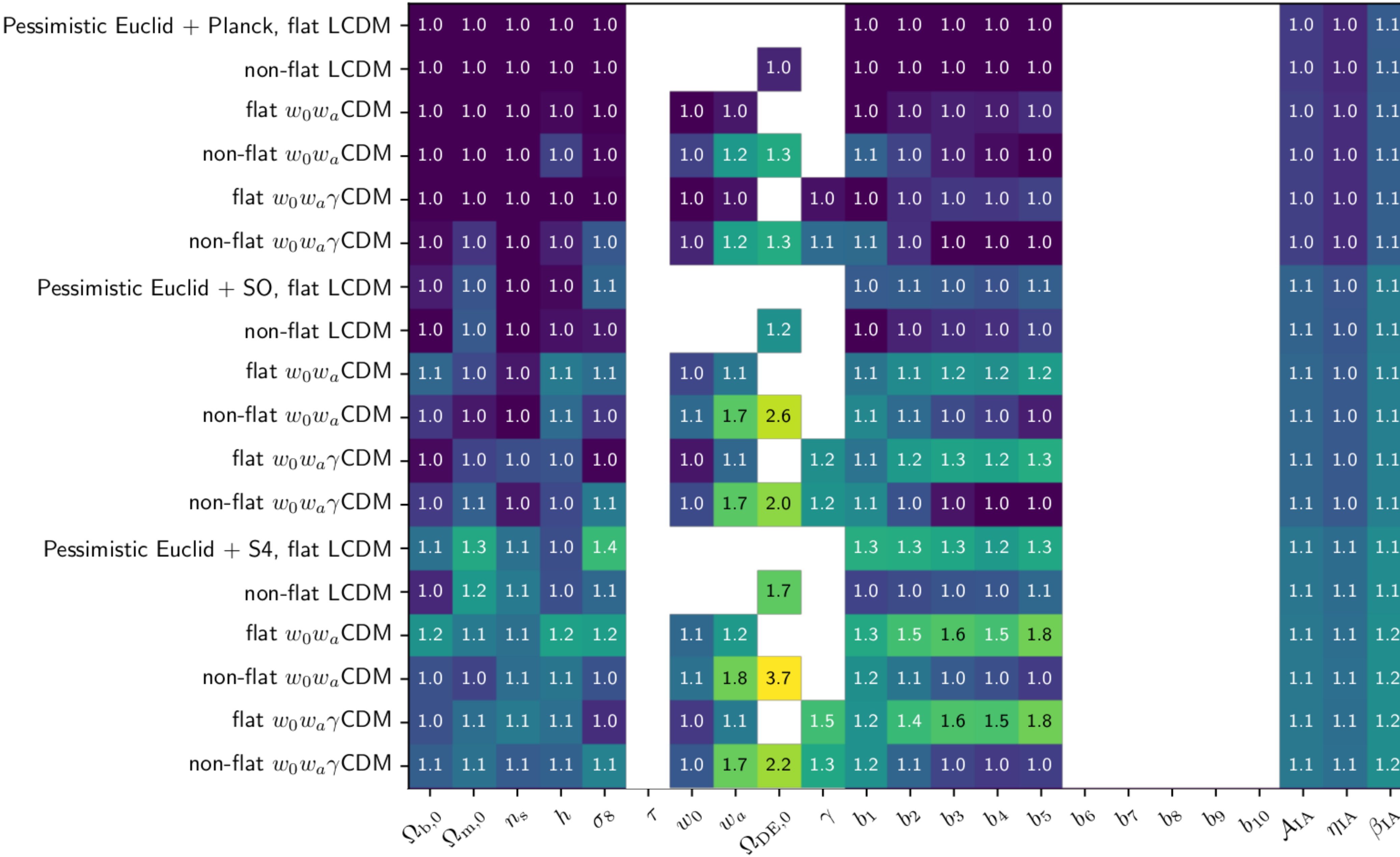
Euclid (GCp, WL, GCs) only

↓

Euclid (GCp, WL, GCs) x CMB phi

Improvement factors = $\sigma_{before} / \sigma_{after}$

# The results: case n°0 to n°1




Improvement factors = $\sigma_{before} / \sigma_{after}$

# The results: case n°0 to n°1 (cont.)

| | $\Omega_{b,0}$ | $\Omega_{m,0}$ | $n_s$ | $h$ | $\sigma_8$ | $\tau$ | $w_0$ | $w_a$ | $\Omega_{DE,0}$ | $\gamma$ | $b_1$ | $b_2$ | $b_3$ | $b_4$ | $b_5$ | $b_6$ | $b_7$ | $b_8$ | $b_9$ | $b_{10}$ | $A_{IA}$ | $\eta_{IA}$ | $\beta_{IA}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Optimistic Euclid + Planck, flat LCDM | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | | | | | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| non-flat LCDM | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | | | | 1.0 | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| flat $w_0w_a$CDM | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | | 1.0 | 1.0 | | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| non-flat $w_0w_a$CDM | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | | 1.0 | 1.0 | 1.1 | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| flat $w_0w_a\gamma$CDM | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | | 1.0 | 1.0 | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| non-flat $w_0w_a\gamma$CDM | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | | 1.0 | 1.0 | 1.1 | 1.1 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Optimistic Euclid + SO, flat LCDM | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | | | | | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| non-flat LCDM | 1.0 | 1.1 | 1.0 | 1.1 | 1.0 | | | | 1.1 | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.1 | 1.1 | 1.0 | 1.0 | 1.0 |
| flat $w_0w_a$CDM | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | | 1.0 | 1.0 | | | 1.0 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.0 | 1.0 | 1.0 |
| non-flat $w_0w_a$CDM | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | | 1.0 | 1.2 | 1.6 | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| flat $w_0w_a\gamma$CDM | 1.0 | 1.1 | 1.1 | 1.1 | 1.0 | | 1.0 | 1.0 | | 1.1 | 1.0 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.2 | 1.2 | 1.2 | 1.2 | 1.0 | 1.0 | 1.0 |
| non-flat $w_0w_a\gamma$CDM | 1.1 | 1.1 | 1.1 | 1.0 | 1.2 | | 1.0 | 1.2 | 1.5 | 1.2 | 1.1 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Optimistic Euclid + S4, flat LCDM | 1.0 | 1.1 | 1.0 | 1.0 | 1.2 | | | | | | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.0 | 1.0 | 1.0 |
| non-flat LCDM | 1.0 | 1.2 | 1.0 | 1.2 | 1.1 | | | | 1.5 | | 1.0 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.2 | 1.2 | 1.0 | 1.0 | 1.0 |
| flat $w_0w_a$CDM | 1.0 | 1.0 | 1.1 | 1.1 | 1.0 | | 1.0 | 1.1 | | | 1.1 | 1.3 | 1.3 | 1.4 | 1.4 | 1.4 | 1.4 | 1.5 | 1.5 | 1.5 | 1.0 | 1.0 | 1.0 |
| non-flat $w_0w_a$CDM | 1.0 | 1.0 | 1.0 | 1.1 | 1.0 | | 1.0 | 1.3 | 2.3 | | 1.0 | 1.0 | 1.0 | 1.0 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.0 | 1.0 | 1.0 |
| flat $w_0w_a\gamma$CDM | 1.1 | 1.2 | 1.3 | 1.2 | 1.1 | | 1.0 | 1.1 | | 1.4 | 1.0 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.6 | 1.7 | 1.8 | 1.8 | 1.0 | 1.0 | 1.0 |
| non-flat $w_0w_a\gamma$CDM | 1.1 | 1.1 | 1.1 | 1.0 | 1.2 | | 1.0 | 1.4 | 1.7 | 1.3 | 1.1 | 1.0 | 1.0 | 1.0 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.0 | 1.0 | 1.0 |

Improvement factors = $\sigma_{before} / \sigma_{after}$

# The results: case n°1 to n°2

Euclid (GCp, WL, GCs) x CMB phi

↓

Euclid (GCp, WL, GCs) x CMB T, E, phi

# The results: case n°1 to n°2

| | $\Omega_{b,0}$ | $\Omega_{m,0}$ | $n_s$ | $h$ | $\sigma_8$ | $\tau$ | $w_0$ | $w_a$ | $\Omega_{DE,0}$ | $\gamma$ | $b_1$ | $b_2$ | $b_3$ | $b_4$ | $b_5$ | $b_6$ | $b_7$ | $b_8$ | $b_9$ | $b_{10}$ | $A_{IA}$ | $\eta_{IA}$ | $\beta_{IA}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pessimistic Euclid + Planck, flat LCDM | 4.6 | 1.5 | 2.0 | 2.1 | 1.5 | 2.0 | | | | | 1.4 | 1.3 | 1.3 | 1.2 | 1.3 | | | | | | 1.0 | 1.0 | 1.0 |
| non-flat LCDM | 3.6 | 1.4 | 1.6 | 2.2 | 1.5 | 1.4 | | | 3.3 | | 1.6 | 1.8 | 1.9 | 1.7 | 2.1 | | | | | | 1.0 | 1.0 | 1.0 |
| flat $w_0 w_a$CDM | 4.0 | 1.9 | 2.0 | 1.8 | 1.9 | 1.3 | 1.4 | 1.4 | | | 1.2 | 1.2 | 1.3 | 1.3 | 1.5 | | | | | | 1.0 | 1.0 | 1.0 |
| non-flat $w_0 w_a$CDM | 3.9 | 1.5 | 1.6 | 1.8 | 1.8 | 1.3 | 1.3 | 1.9 | 4.3 | | 1.5 | 1.4 | 1.4 | 1.3 | 1.4 | | | | | | 1.0 | 1.0 | 1.0 |
| flat $w_0 w_a \gamma$CDM | 4.8 | 2.5 | 2.1 | 1.8 | 2.1 | 1.3 | 1.4 | 1.4 | | 1.5 | 1.2 | 1.2 | 1.3 | 1.3 | 1.5 | | | | | | 1.0 | 1.0 | 1.0 |
| non-flat $w_0 w_a \gamma$CDM | 4.8 | 1.8 | 1.5 | 1.7 | 2.0 | 1.3 | 1.3 | 1.8 | 3.6 | 1.4 | 1.4 | 1.3 | 1.2 | 1.2 | 1.2 | | | | | | 1.0 | 1.0 | 1.0 |
| Pessimistic Euclid + SO, flat LCDM | 7.7 | 1.5 | 2.6 | 2.9 | 1.5 | 2.3 | | | | | 1.4 | 1.3 | 1.3 | 1.2 | 1.2 | | | | | | 1.0 | 1.0 | 1.0 |
| non-flat LCDM | 6.0 | 1.7 | 2.3 | 2.3 | 1.8 | 1.2 | | | 3.9 | | 1.9 | 2.0 | 2.0 | 1.8 | 2.2 | | | | | | 1.0 | 1.0 | 1.0 |
| flat $w_0 w_a$CDM | 5.4 | 2.0 | 2.7 | 1.7 | 1.9 | 1.6 | 1.3 | 1.3 | | | 1.2 | 1.2 | 1.3 | 1.2 | 1.4 | | | | | | 1.0 | 1.0 | 1.0 |
| non-flat $w_0 w_a$CDM | 6.0 | 2.2 | 2.3 | 1.9 | 2.4 | 1.7 | 1.4 | 1.4 | 3.3 | | 1.5 | 1.4 | 1.5 | 1.4 | 1.6 | | | | | | 1.0 | 1.0 | 1.0 |
| flat $w_0 w_a \gamma$CDM | 6.9 | 2.6 | 2.7 | 1.8 | 2.3 | 1.6 | 1.4 | 1.3 | | 1.5 | 1.2 | 1.2 | 1.2 | 1.2 | 1.4 | | | | | | 1.0 | 1.0 | 1.0 |
| non-flat $w_0 w_a \gamma$CDM | 7.4 | 2.8 | 2.4 | 2.0 | 2.6 | 1.7 | 1.4 | 1.4 | 4.1 | 1.5 | 1.4 | 1.5 | 1.5 | 1.4 | 1.6 | | | | | | 1.0 | 1.0 | 1.0 |
| Pessimistic Euclid + S4, flat LCDM | 9.1 | 1.4 | 2.9 | 3.3 | 1.4 | 2.5 | | | | | 1.3 | 1.2 | 1.2 | 1.1 | 1.1 | | | | | | 1.0 | 1.0 | 1.0 |
| non-flat LCDM | 6.9 | 1.8 | 2.6 | 2.4 | 2.3 | 1.1 | | | 3.8 | | 2.2 | 2.2 | 2.1 | 1.8 | 2.3 | | | | | | 1.0 | 1.0 | 1.0 |
| flat $w_0 w_a$CDM | 5.3 | 1.9 | 3.0 | 1.6 | 1.9 | 1.9 | 1.3 | 1.2 | | | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | | | | | | 1.0 | 1.0 | 1.0 |
| non-flat $w_0 w_a$CDM | 6.7 | 2.9 | 2.7 | 2.0 | 3.1 | 2.1 | 1.5 | 1.3 | 3.6 | | 1.6 | 1.7 | 1.8 | 1.7 | 2.1 | | | | | | 1.0 | 1.0 | 1.0 |
| flat $w_0 w_a \gamma$CDM | 7.4 | 2.6 | 2.9 | 1.8 | 2.4 | 1.9 | 1.4 | 1.3 | | 1.5 | 1.2 | 1.1 | 1.2 | 1.1 | 1.3 | | | | | | 1.0 | 1.0 | 1.0 |
| non-flat $w_0 w_a \gamma$CDM | 8.2 | 3.8 | 2.8 | 2.1 | 3.4 | 2.2 | 1.5 | 1.4 | 6.0 | 1.9 | 1.6 | 1.7 | 1.8 | 1.7 | 2.1 | | | | | | 1.0 | 1.0 | 1.0 |

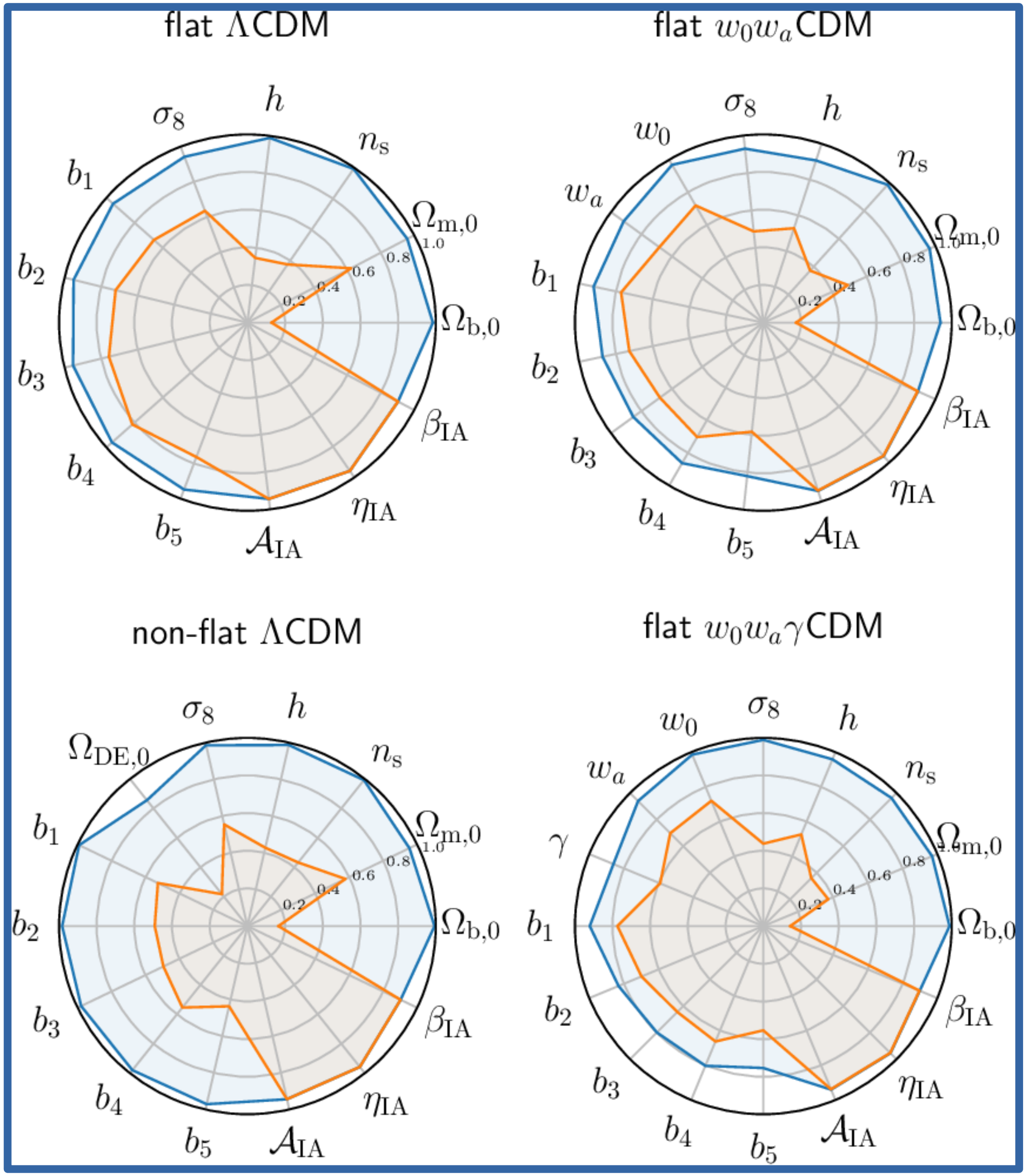
Improvement factors = $\sigma_{before} / \sigma_{after}$

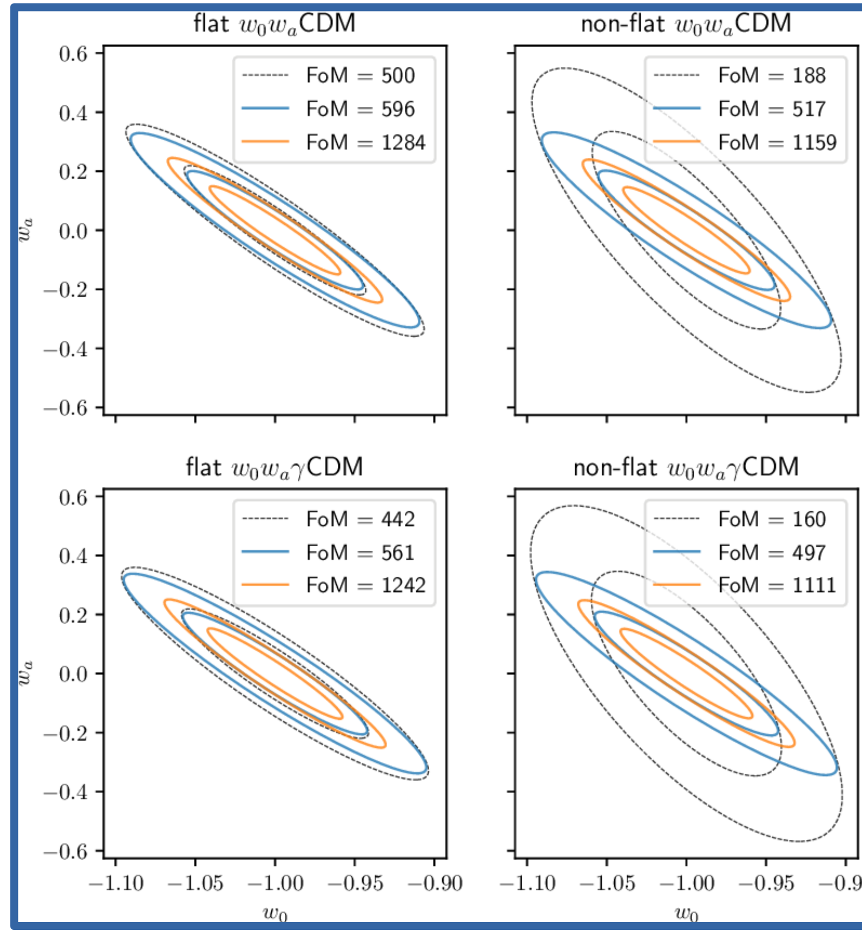
# The results: case n°1 to n°2 (cont.)

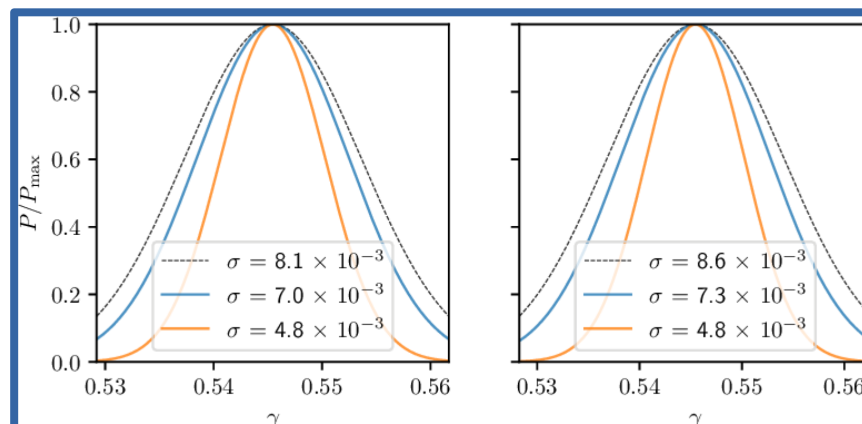
| | $\Omega_{b,0}$ | $\Omega_{m,0}$ | $n_s$ | $h$ | $\sigma_8$ | $\tau$ | $w_0$ | $w_a$ | $\Omega_{DE,0}$ | $\gamma$ | $b_1$ | $b_2$ | $b_3$ | $b_4$ | $b_5$ | $b_6$ | $b_7$ | $b_8$ | $b_9$ | $b_{10}$ | $A_{IA}$ | $\eta_{IA}$ | $\beta_{IA}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Optimistic Euclid + Planck, flat LCDM | 2.4 | 1.1 | 1.3 | 1.1 | 1.1 | 3.0 | | | | | 1.1 | 1.1 | 1.1 | 1.1 | 1.0 | 1.0 | 1.0 | 1.1 | 1.1 | 1.1 | 1.0 | 1.0 | 1.0 |
| non-flat LCDM | 1.7 | 1.3 | 1.2 | 1.5 | 1.1 | 2.5 | | | 3.9 | | 1.2 | 1.4 | 1.6 | 1.6 | 1.7 | 1.7 | 1.8 | 1.9 | 2.1 | 2.2 | 1.0 | 1.0 | 1.0 |
| flat $w_0 w_a$CDM | 2.2 | 1.7 | 1.6 | 1.1 | 1.5 | 1.9 | 1.6 | 1.4 | | | 1.0 | 1.1 | 1.2 | 1.2 | 1.2 | 1.2 | 1.3 | 1.3 | 1.3 | 1.3 | 1.0 | 1.0 | 1.0 |
| non-flat $w_0 w_a$CDM | 2.1 | 1.3 | 1.1 | 1.2 | 1.4 | 1.8 | 1.4 | 1.6 | 3.6 | | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.2 | 1.0 | 1.0 | 1.0 |
| flat $w_0 w_a \gamma$CDM | 2.4 | 1.9 | 1.7 | 1.1 | 1.7 | 1.9 | 1.5 | 1.3 | | 1.2 | 1.0 | 1.1 | 1.2 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.0 | 1.0 | 1.0 |
| non-flat $w_0 w_a \gamma$CDM | 2.5 | 1.5 | 1.1 | 1.1 | 1.7 | 1.8 | 1.3 | 1.5 | 3.1 | 1.3 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.0 | 1.0 | 1.0 |
| Optimistic Euclid + SO, flat LCDM | 5.3 | 1.1 | 1.5 | 1.5 | 1.1 | 3.9 | | | | | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.0 | 1.0 | 1.0 |
| non-flat LCDM | 4.0 | 1.3 | 1.4 | 1.5 | 1.2 | 1.9 | | | 4.1 | | 1.2 | 1.5 | 1.6 | 1.7 | 1.7 | 1.8 | 1.9 | 2.0 | 2.2 | 2.3 | 1.0 | 1.0 | 1.0 |
| flat $w_0 w_a$CDM | 4.3 | 2.1 | 1.8 | 1.2 | 1.7 | 2.4 | 1.8 | 1.5 | | | 1.0 | 1.2 | 1.2 | 1.2 | 1.3 | 1.3 | 1.3 | 1.3 | 1.4 | 1.4 | 1.0 | 1.0 | 1.0 |
| non-flat $w_0 w_a$CDM | 4.4 | 1.6 | 1.3 | 1.2 | 1.7 | 2.4 | 1.6 | 1.5 | 3.0 | | 1.1 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.3 | 1.3 | 1.0 | 1.0 | 1.0 |
| flat $w_0 w_a \gamma$CDM | 4.6 | 2.2 | 1.9 | 1.1 | 2.0 | 2.4 | 1.6 | 1.3 | | 1.2 | 1.0 | 1.1 | 1.2 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.4 | 1.3 | 1.0 | 1.0 | 1.0 |
| non-flat $w_0 w_a \gamma$CDM | 4.9 | 1.9 | 1.4 | 1.2 | 1.9 | 2.5 | 1.4 | 1.3 | 3.0 | 1.2 | 1.1 | 1.1 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.3 | 1.3 | 1.0 | 1.0 | 1.0 |
| Optimistic Euclid + S4, flat LCDM | 6.5 | 1.1 | 1.6 | 1.6 | 1.1 | 3.9 | | | | | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.0 | 1.0 | 1.0 |
| non-flat LCDM | 4.9 | 1.3 | 1.5 | 1.3 | 1.3 | 1.4 | | | 3.7 | | 1.4 | 1.6 | 1.7 | 1.7 | 1.8 | 1.8 | 1.9 | 2.0 | 2.2 | 2.2 | 1.0 | 1.0 | 1.0 |
| flat $w_0 w_a$CDM | 5.2 | 2.1 | 1.8 | 1.1 | 1.9 | 2.8 | 1.9 | 1.5 | | | 1.0 | 1.1 | 1.1 | 1.1 | 1.1 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.0 | 1.0 | 1.0 |
| non-flat $w_0 w_a$CDM | 5.5 | 2.1 | 1.6 | 1.3 | 2.1 | 2.9 | 1.8 | 1.5 | 3.0 | | 1.2 | 1.3 | 1.4 | 1.4 | 1.4 | 1.5 | 1.5 | 1.5 | 1.6 | 1.6 | 1.0 | 1.0 | 1.0 |
| flat $w_0 w_a \gamma$CDM | 5.6 | 2.1 | 1.7 | 1.0 | 2.0 | 2.8 | 1.7 | 1.4 | | 1.2 | 1.0 | 1.1 | 1.1 | 1.1 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.0 | 1.0 | 1.0 |
| non-flat $w_0 w_a \gamma$CDM | 6.3 | 2.6 | 1.7 | 1.3 | 2.3 | 3.0 | 1.5 | 1.4 | 3.9 | 1.4 | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.5 | 1.6 | 1.6 | 1.7 | 1.8 | 1.0 | 1.0 | 1.0 |

Improvement factors = $\sigma_{\text{before}} / \sigma_{\text{after}}$

# Focus: Pessimistic Euclid + SO



# Areas of improvement

- Galaxy dn/dz + photo-z uncertainties
- Galaxy bias scale dependence (esp. on non-linear scales)
- Correlations of all probes with GCs
- BAO reconstruction as additional probe
- Magnification bias and GR effects in GCp
- Non-Gaussian terms in covariances (e.g. SSC)

# Future perspectives

- Forecasting of extended models (incl. MG) (in collaboration with other SWGs, mostly TWG)
- More realistic forecasts (e.g. non-Gaussian covariance, masks, systematics, etc. + MCMC)
- Implement CMB in Euclid likelihood pipeline (in collaboration with IST:L)
- Additional Euclid x CMB probes (SZ, CIB, superstructures)

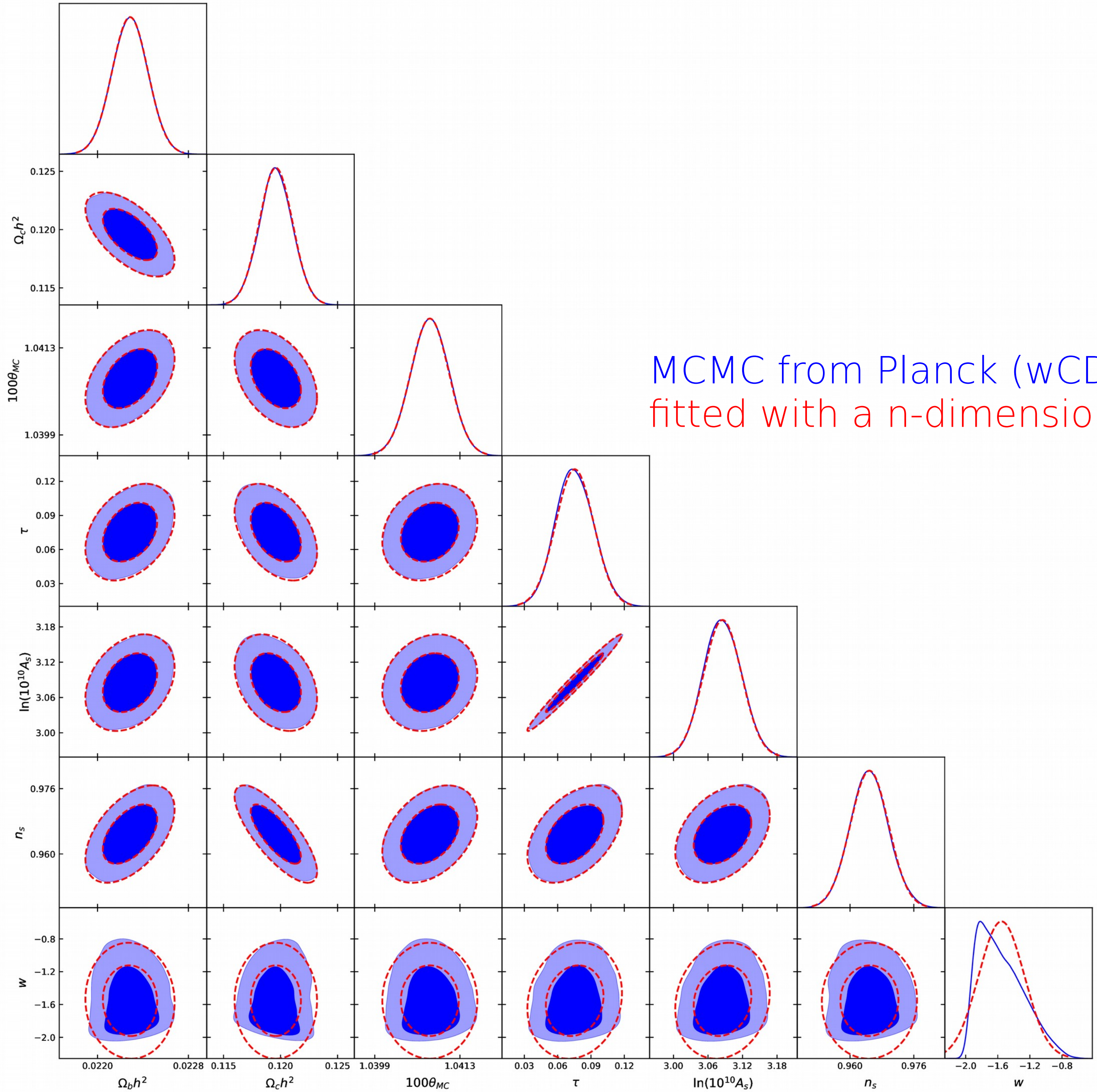
# The end

Thank you for
your attention !

# The end ?

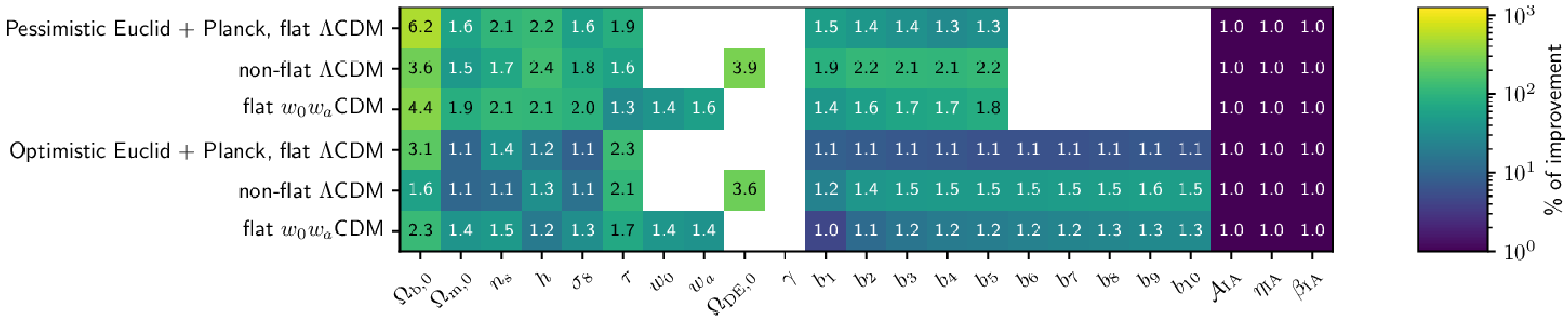
Extra slides
Posterior fit

# Fitting the posterior



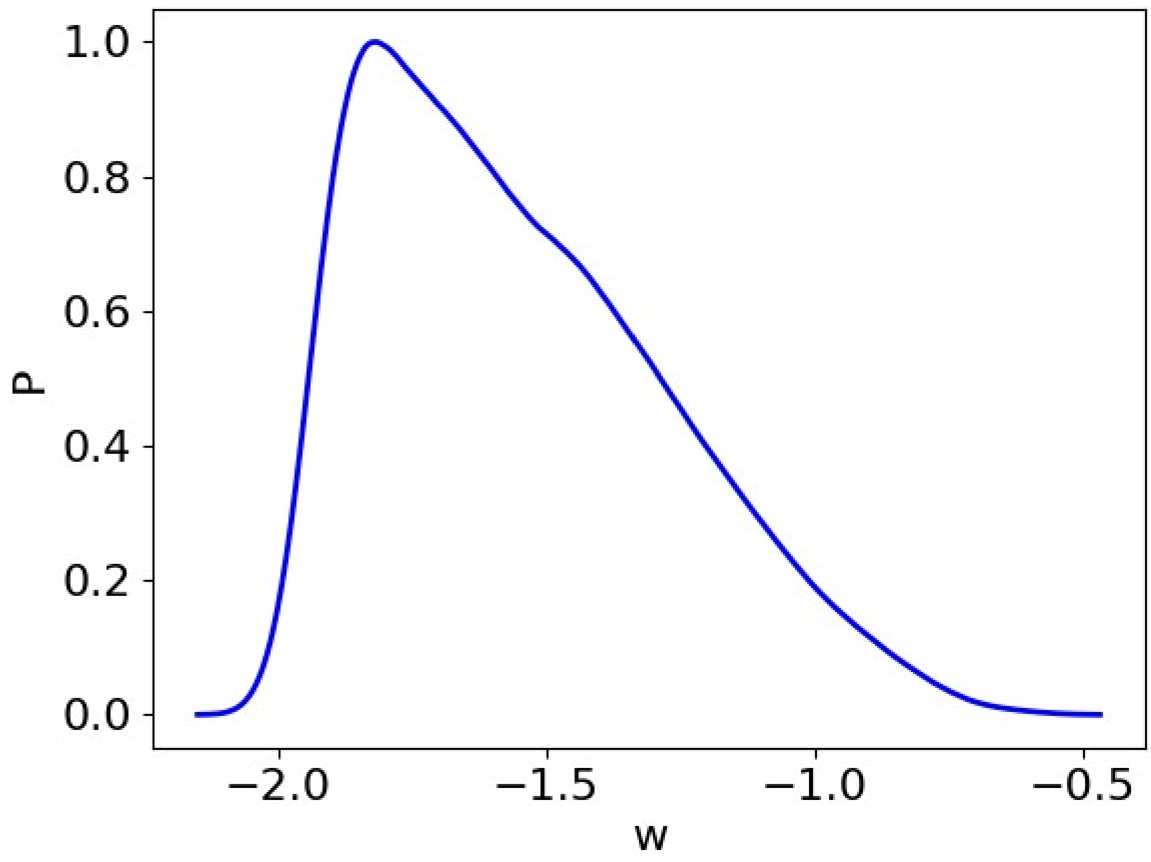

MCMC from Planck (wCDM)
fitted with a n-dimensional Gaussian

# Fitted Planck + Euclid



# Fitting the posterior

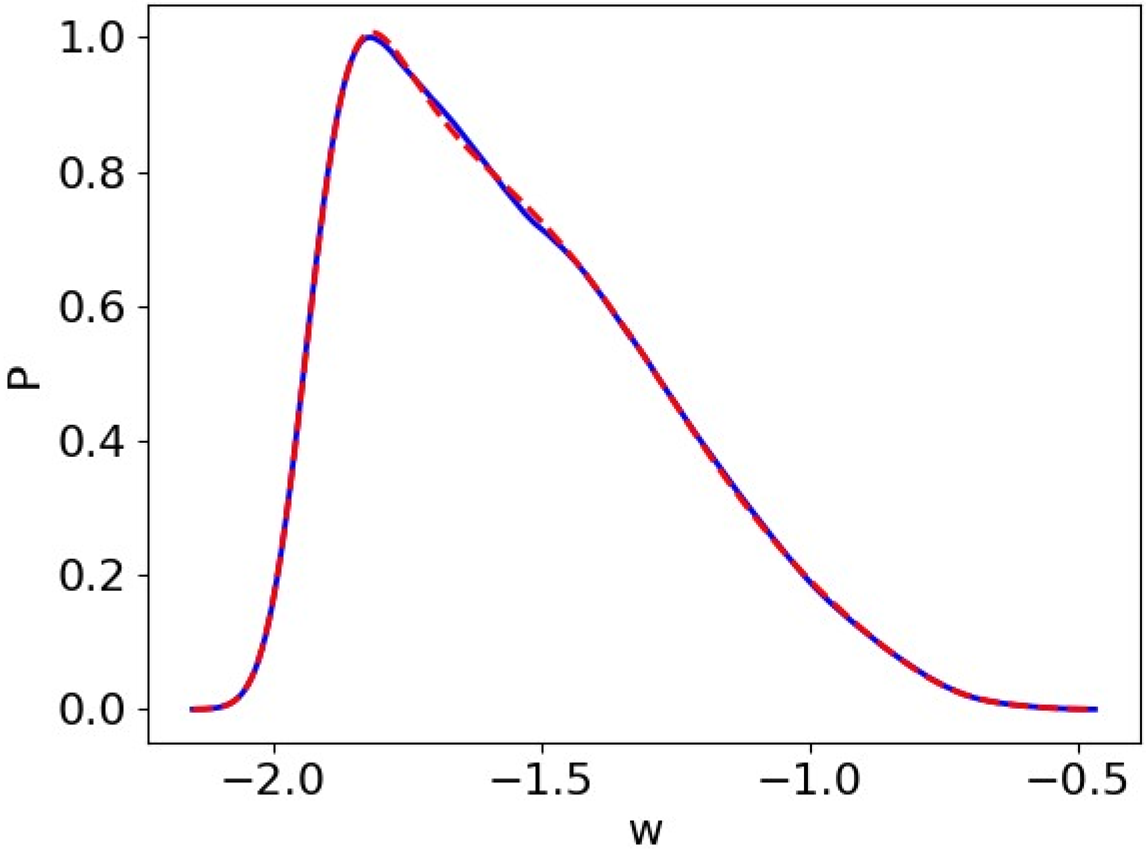
## Posterior from MCMC



# Fitting the posterior

Posterior from MCMC

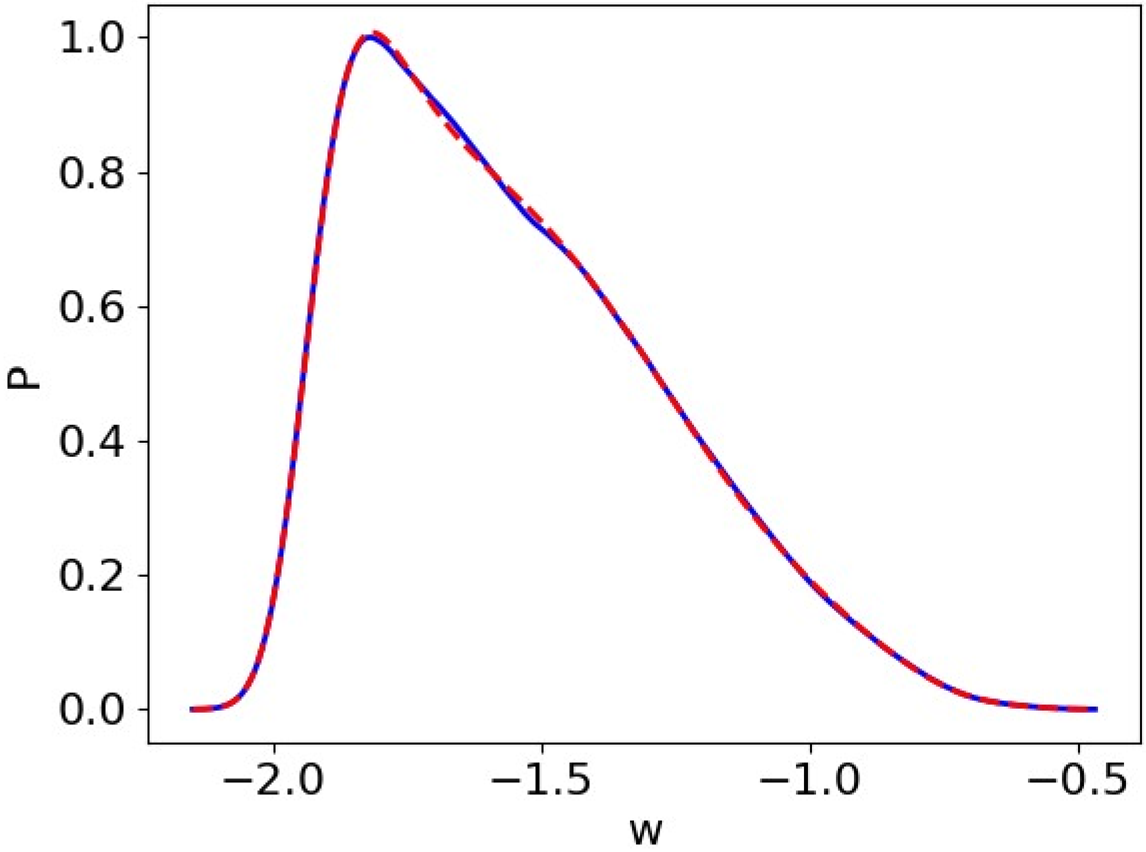
Gaussian fit, with smoothly varying mean and covariance



# Fitting the posterior

Posterior from MCMC

Gaussian fit, with smoothly varying mean and covariance

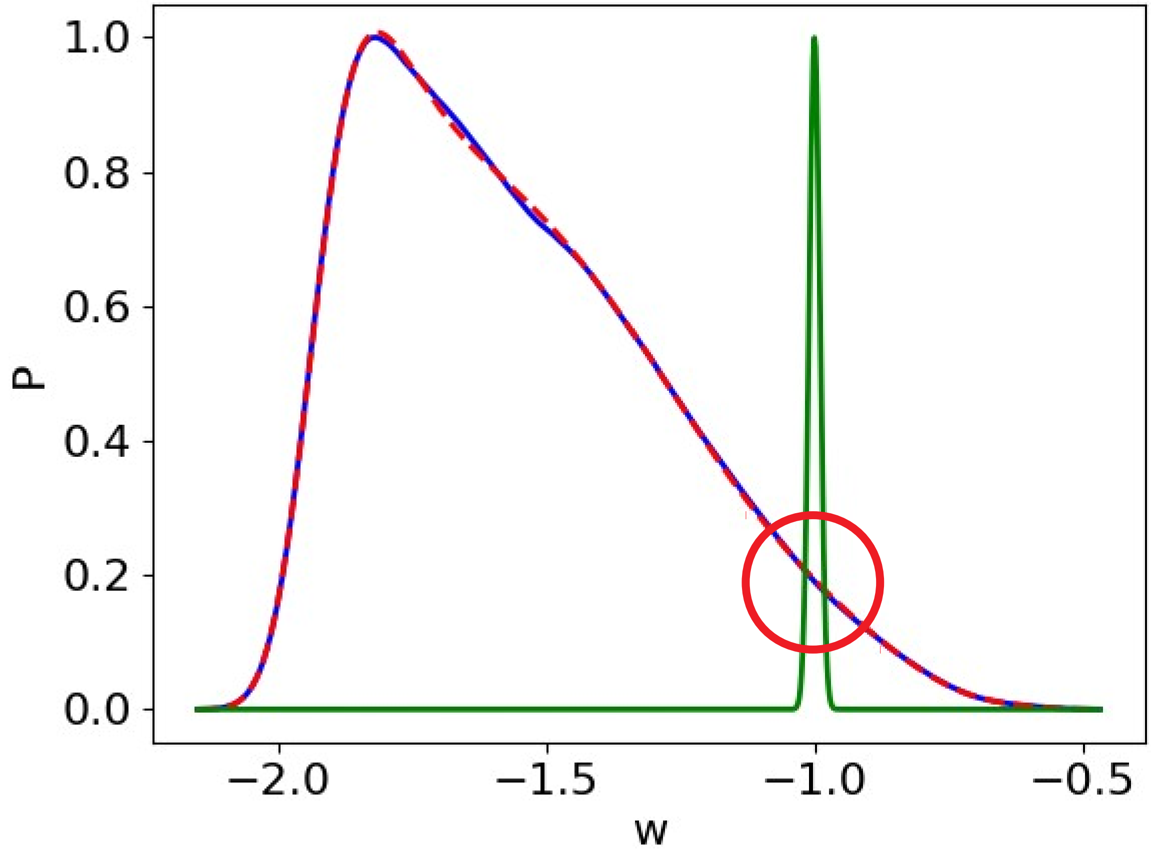



Either : MCMC with CMB fit + LSS Fisher

# Fitting the posterior

Posterior from MCMC

Gaussian fit, with smoothly varying mean and covariance




Typical next-gen LSS

Either : MCMC with CMB fit + LSS Fisher

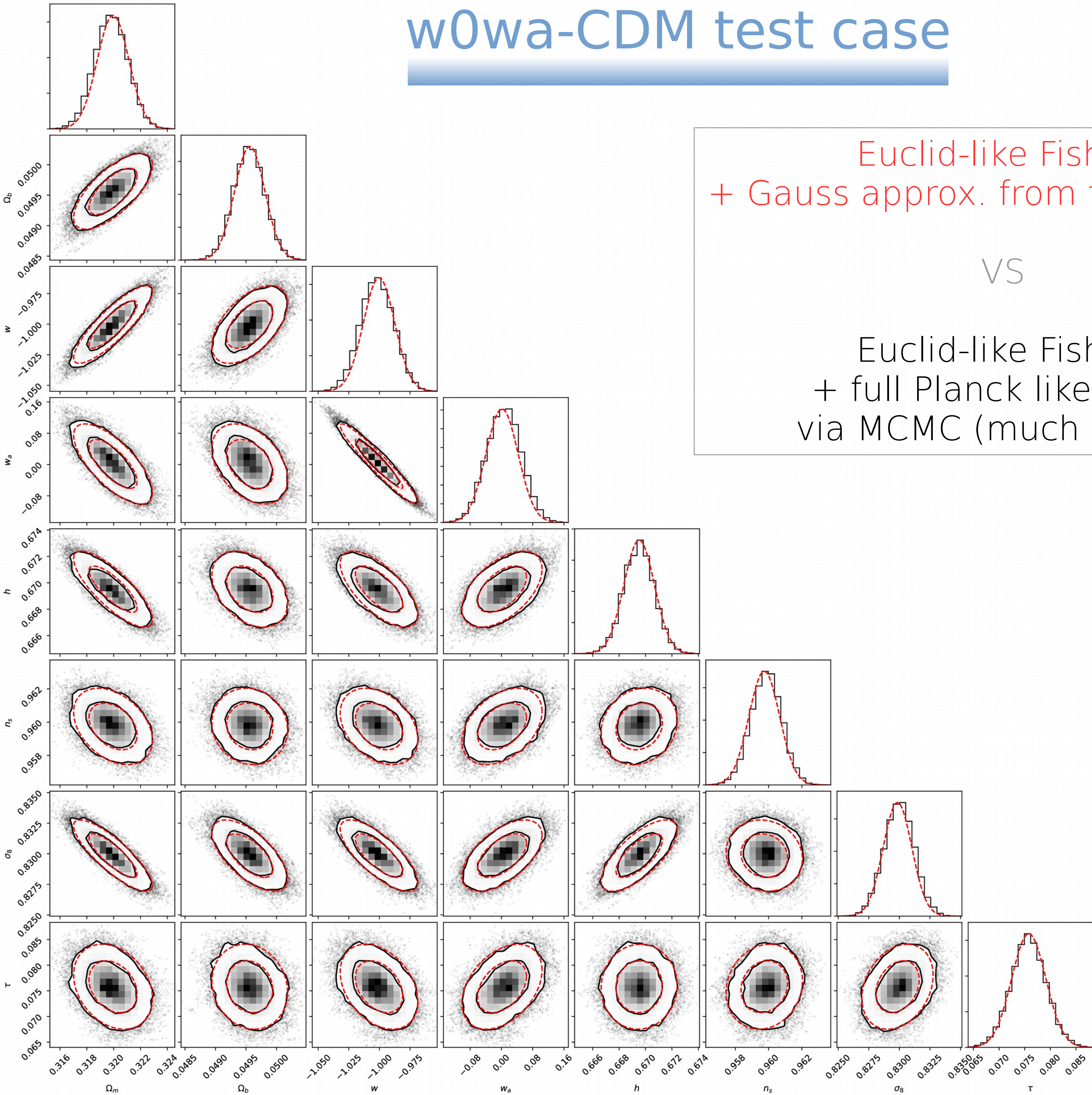
Or : Gauss. approx of CMB fit + LSS Fisher

# Fitting the posterior

$$F_{\theta+\xi} = F'_\theta + F'_\xi$$

$$\mu_{\theta+\xi} = (F_{\theta+\xi})^{-1}(F'_\theta \mu'_\theta + F'_\xi \mu'_\xi)$$

# w0wa-CDM test case

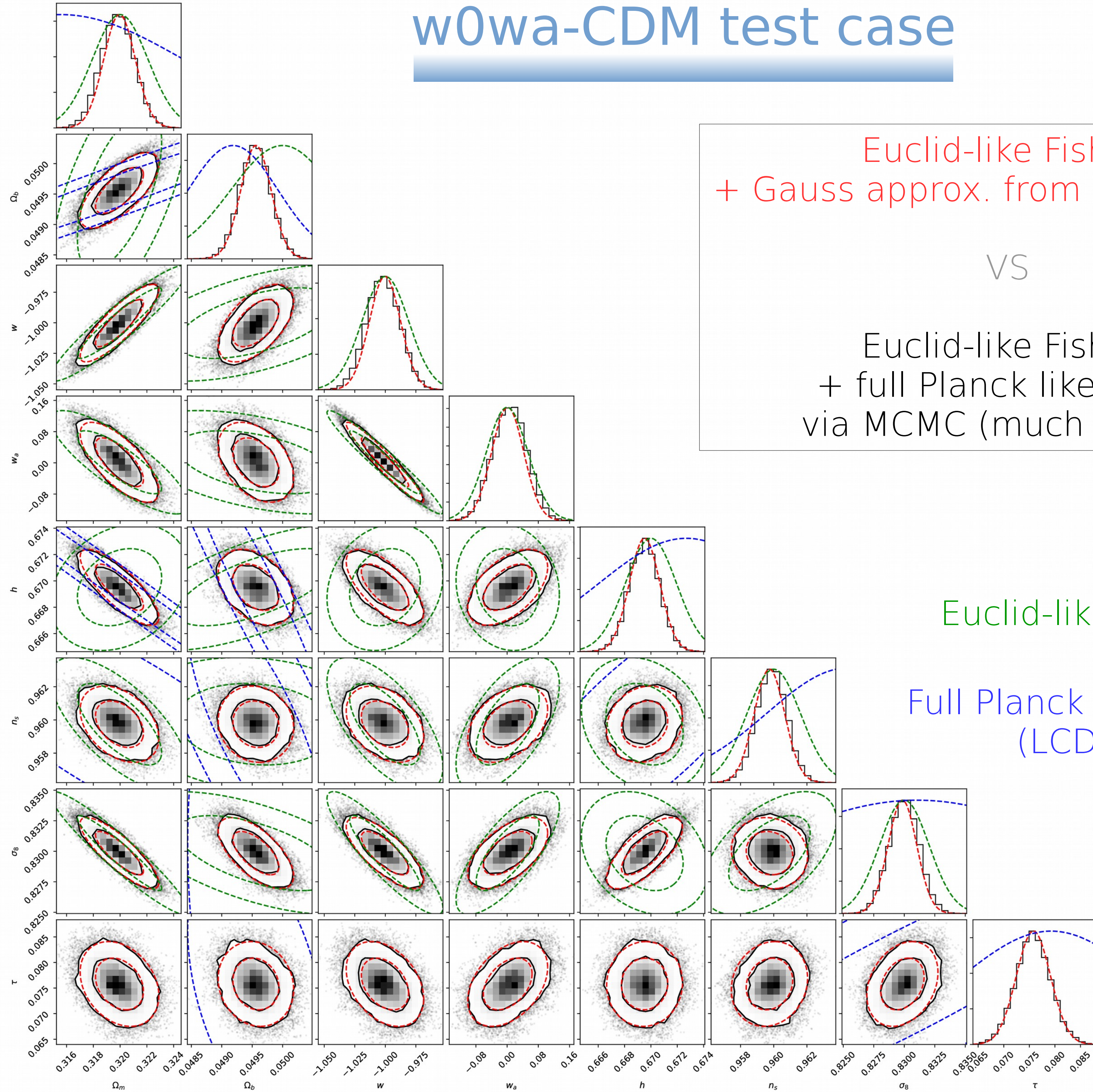



Euclid-like Fisher
+ Gauss approx. from fitted Planck

VS

Euclid-like Fisher
+ full Planck likelihood
via MCMC (much longer)

# w0wa-CDM test case




Euclid-like Fisher
+ Gauss approx. from fitted Planck

VS

Euclid-like Fisher
+ full Planck likelihood
via MCMC (much longer)

Euclid-like Fisher only

Full Planck likelihood only
(LCDM case)