More than the sum of its parts: joint analysis of LSS and CMB experiments

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Why do we combine data?

Why do we combine data?

$$\begin{tikzcd} \mathcal{L}(M|D) \arrow[d] \\ \mathcal{L}(\Theta|\mathcal{O}) \end{tikzcd}$$

$$\Theta \equiv \{\theta_1, \theta_2, \ldots\}$$

$$\mathcal{O} \equiv \{o_a, o_b, \ldots\}$$

Why do we combine data?

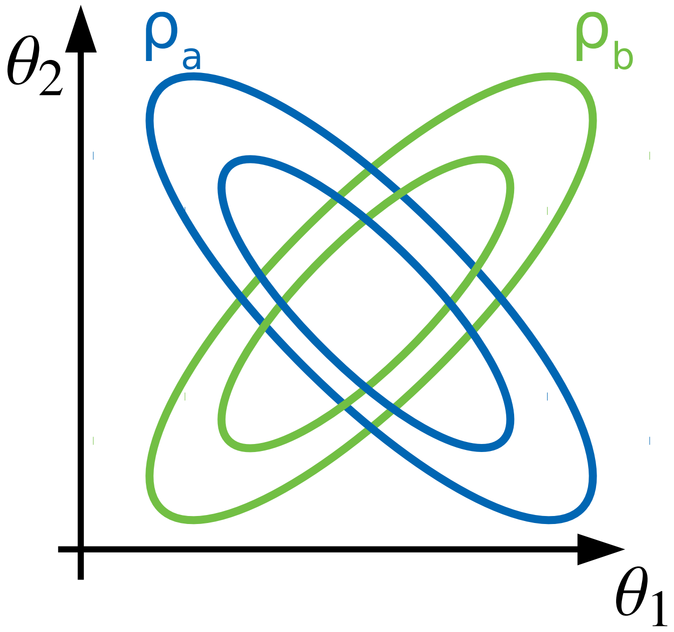
1) Beat the variance

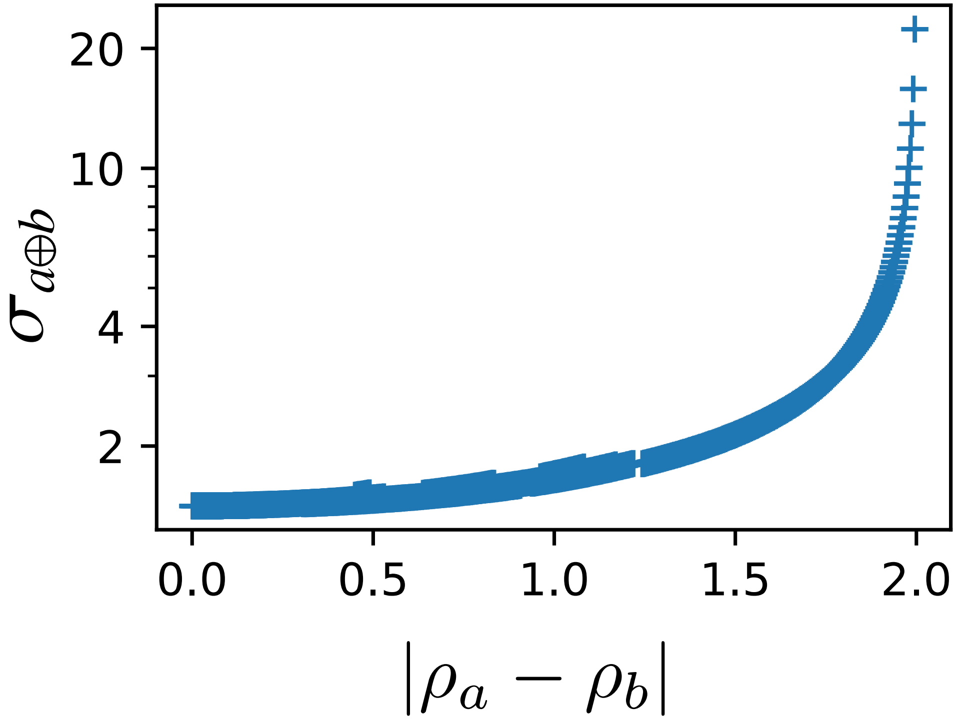
$$\sigma_x^2 \sim -\left.\frac{\partial^2 \ln \mathcal{L}(\theta|o_x)}{\partial\theta^2}\right|_{\theta=\theta_{\rm best}}$$

$$\sigma_{a\oplus b\oplus\ldots} = \left(\frac{1}{\sigma_a^2} + \frac{1}{\sigma_b^2} + \ldots\right)^{-1/2} \propto \frac{1}{\sqrt{N}}$$

Why do we combine data?

2) Break degeneracies





$$\sigma^2_{a\oplus b} = \frac{\rho_a^2 + \rho_b^2 - 2}{(\rho_a + \rho_b - 2)(\rho_a + \rho_b + 2)}$$

Why do we combine data?

3) Exploit cross-correlations

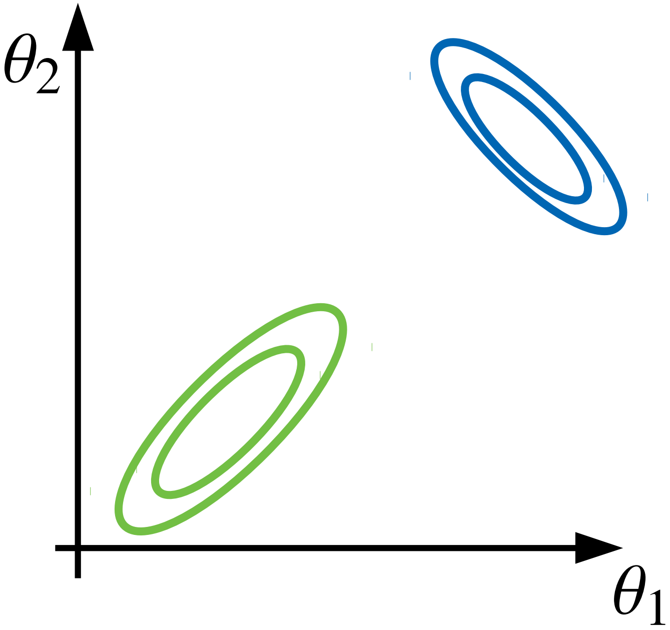
$$\sigma_x^2 \sim -\left.\frac{\partial^2 \ln \mathcal{L}(\theta|o_x)}{\partial\theta^2}\right|_{\theta=\theta_{\mathrm{best}}}$$

$$\mathcal{L}(\theta|\, o_a, o_b\,) \xrightarrow{\hspace{3cm}} \mathcal{L}(\theta|\, o_a, o_b, o_{a\otimes b}\,)$$

$$\sigma_{a\,\oplus\,b\,\oplus\,a\otimes b} \ll \sigma_{a\,\oplus\,b}$$

Why do we combine data?

4) Bring tensions to light



$$\Theta_a = \arg\max_{\Theta} \mathcal{L}(\Theta|o_a) \quad \neq \quad \Theta_b = \arg\max_{\Theta} \mathcal{L}(\Theta|o_b)$$

$$\frac{|\Theta_a - \Theta_b|}{\sigma_\Theta} \gg 1$$

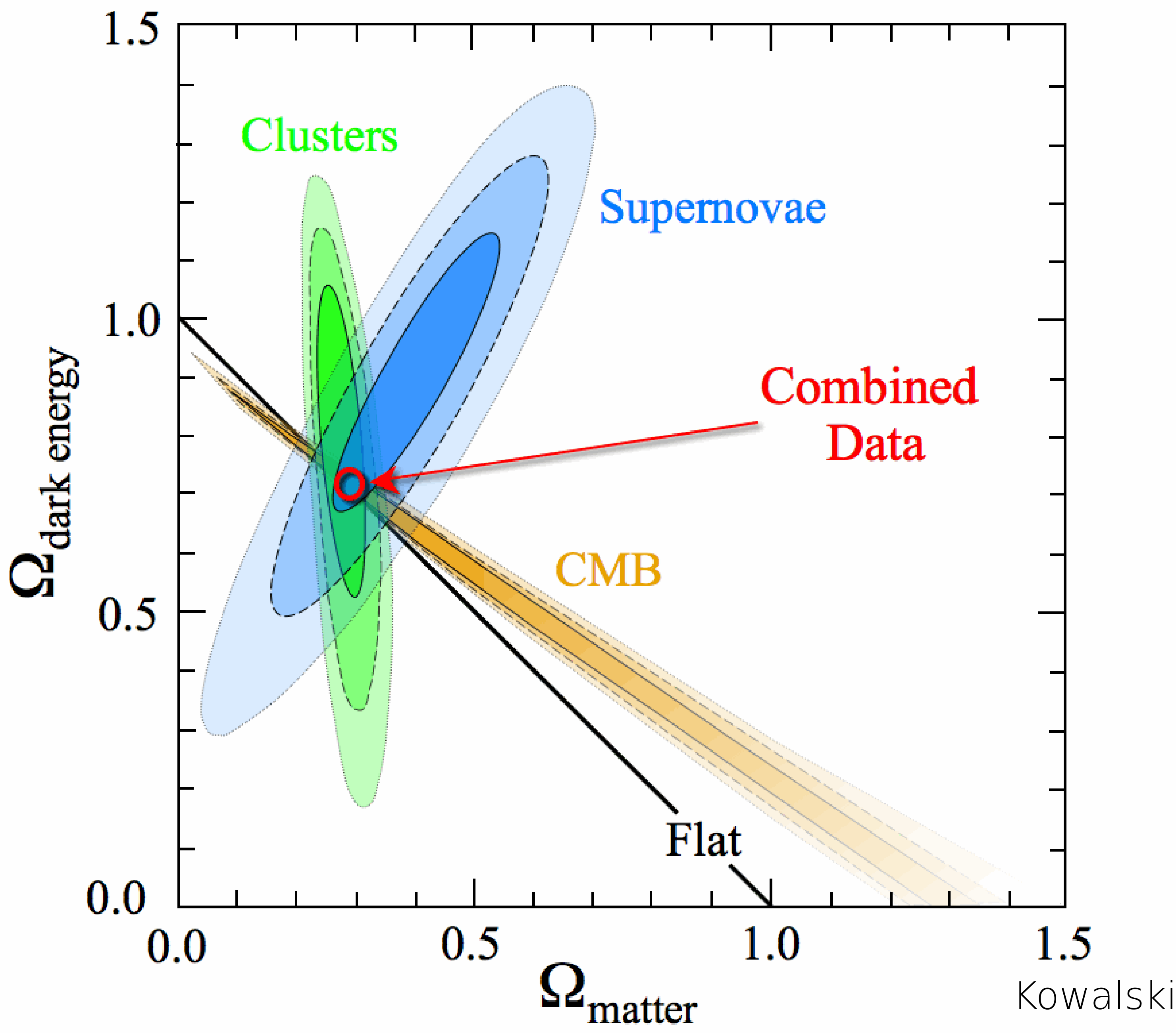
Why do we combine data?

5) Falsify models

$$\Theta_{\text{best}} = \arg\max_{\Theta} \mathcal{L}(\Theta|\mathcal{O})$$

$$\mathcal{L}(\Theta_{\text{best}}|o_x) \sim 0$$

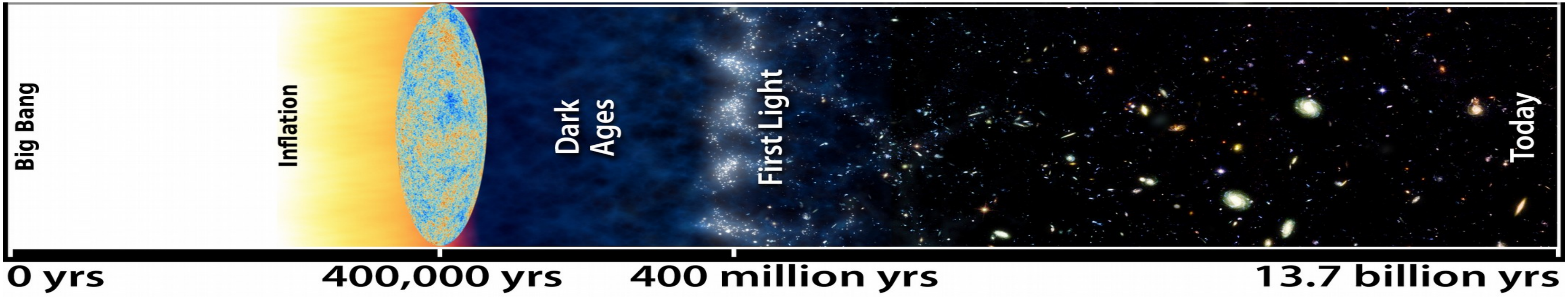
Motivating the joint analysis of datasets



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:



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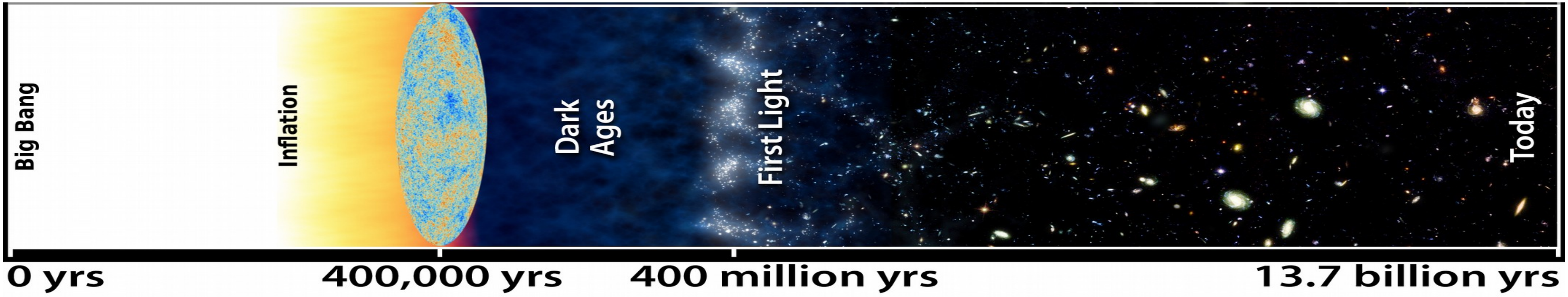

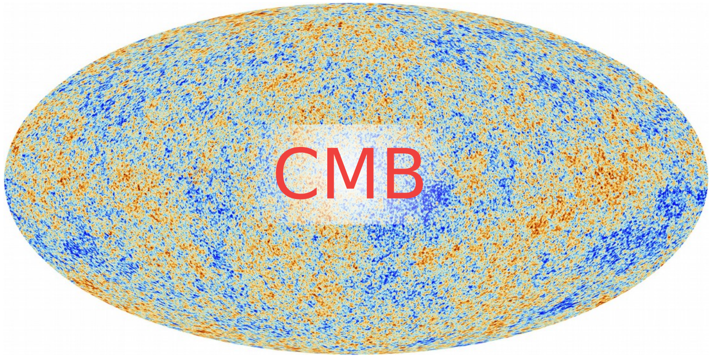

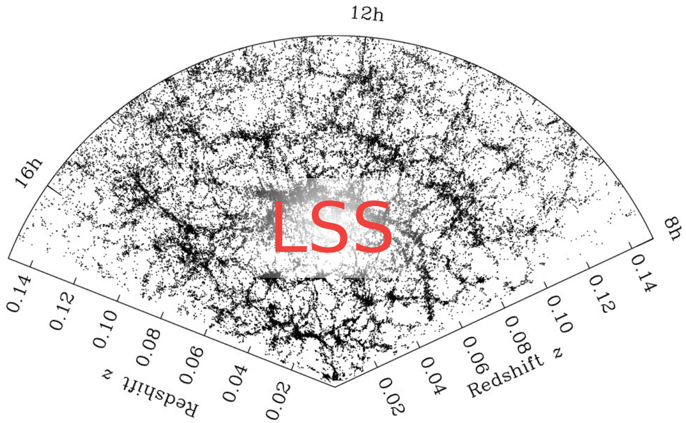

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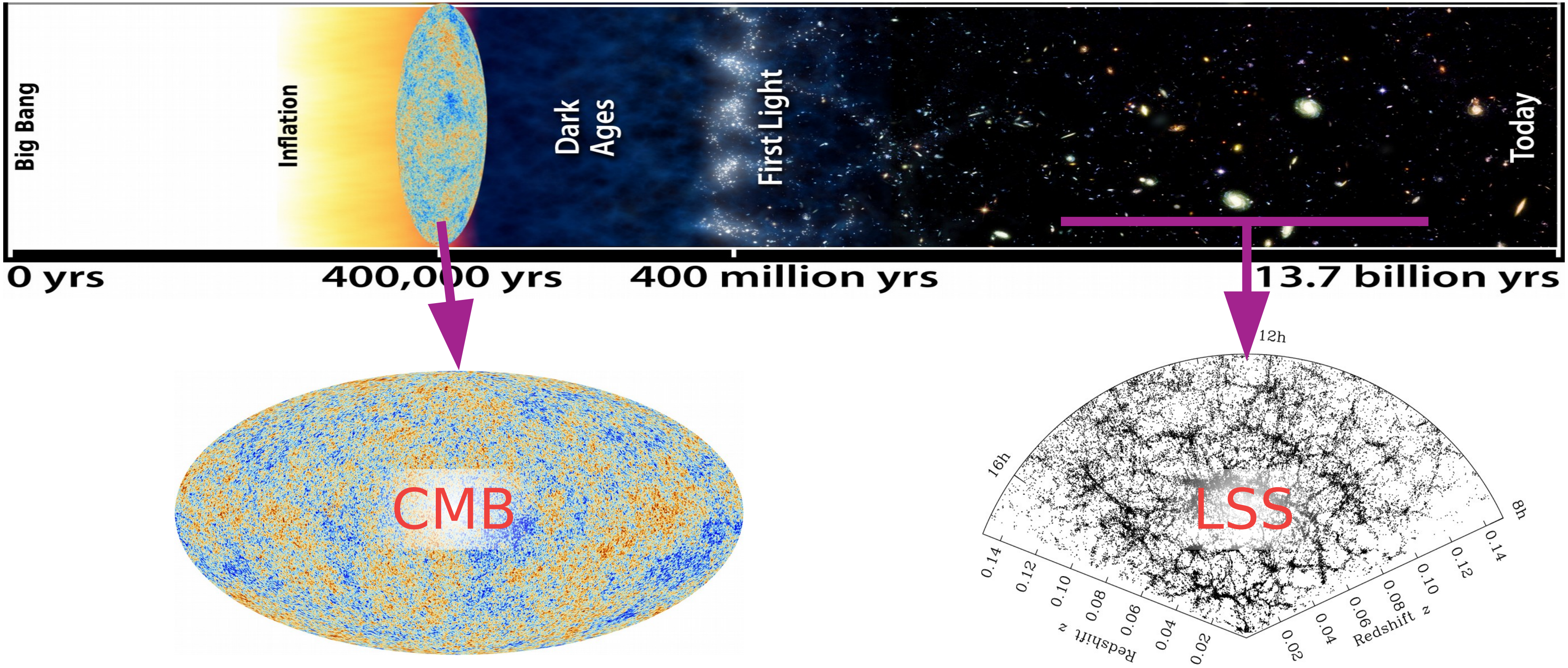

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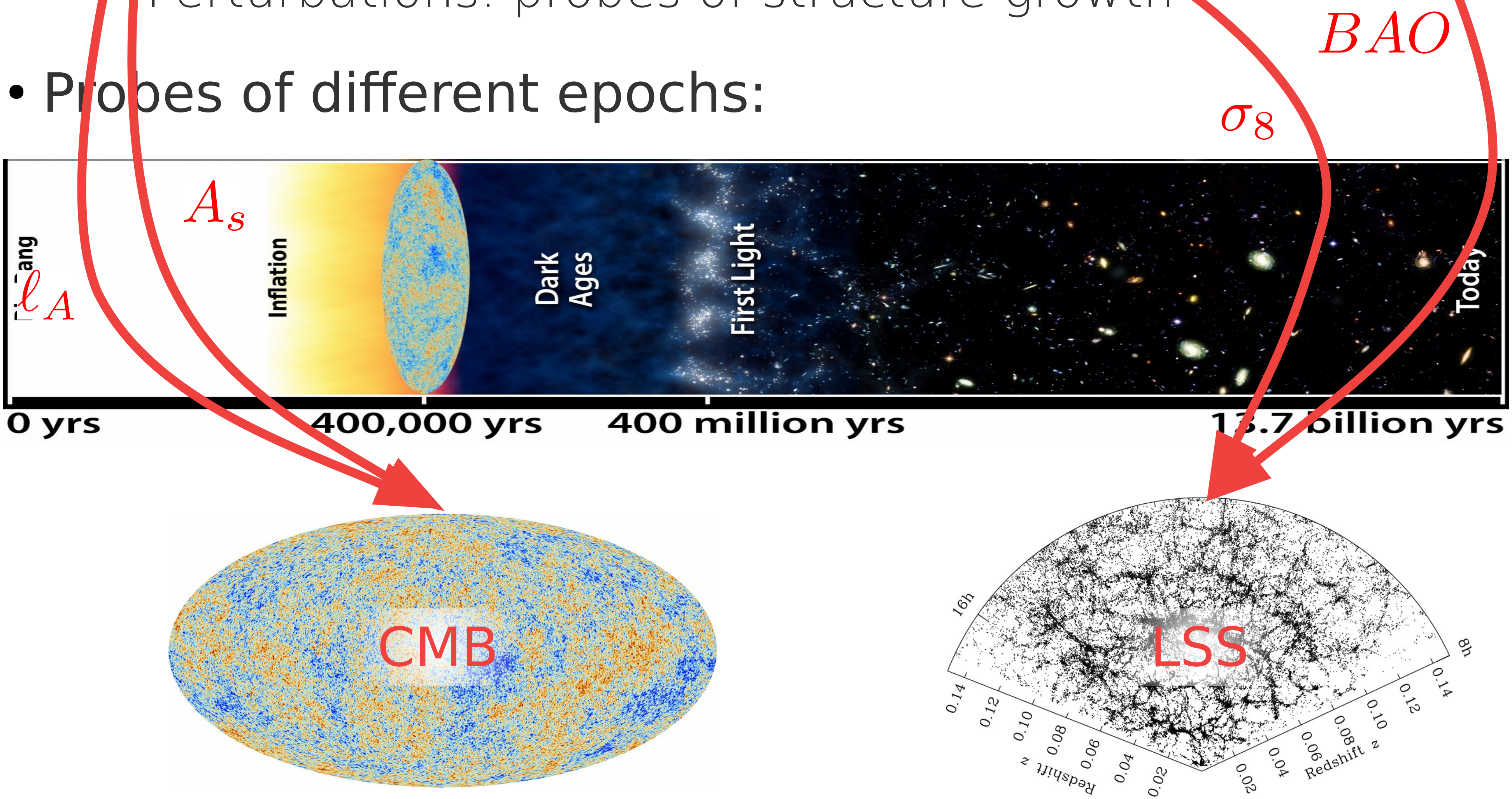
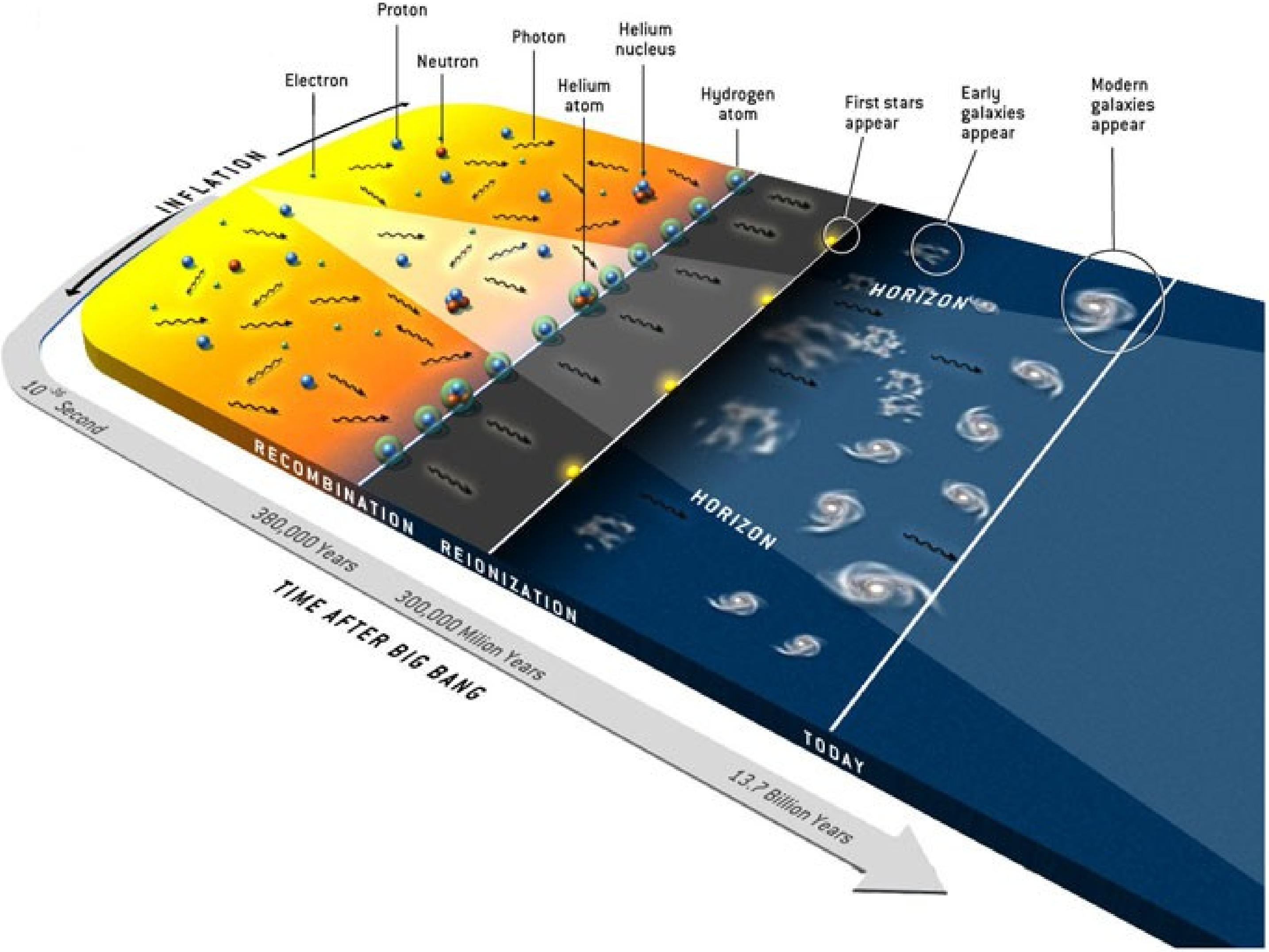


CMB-LSS joint analysis



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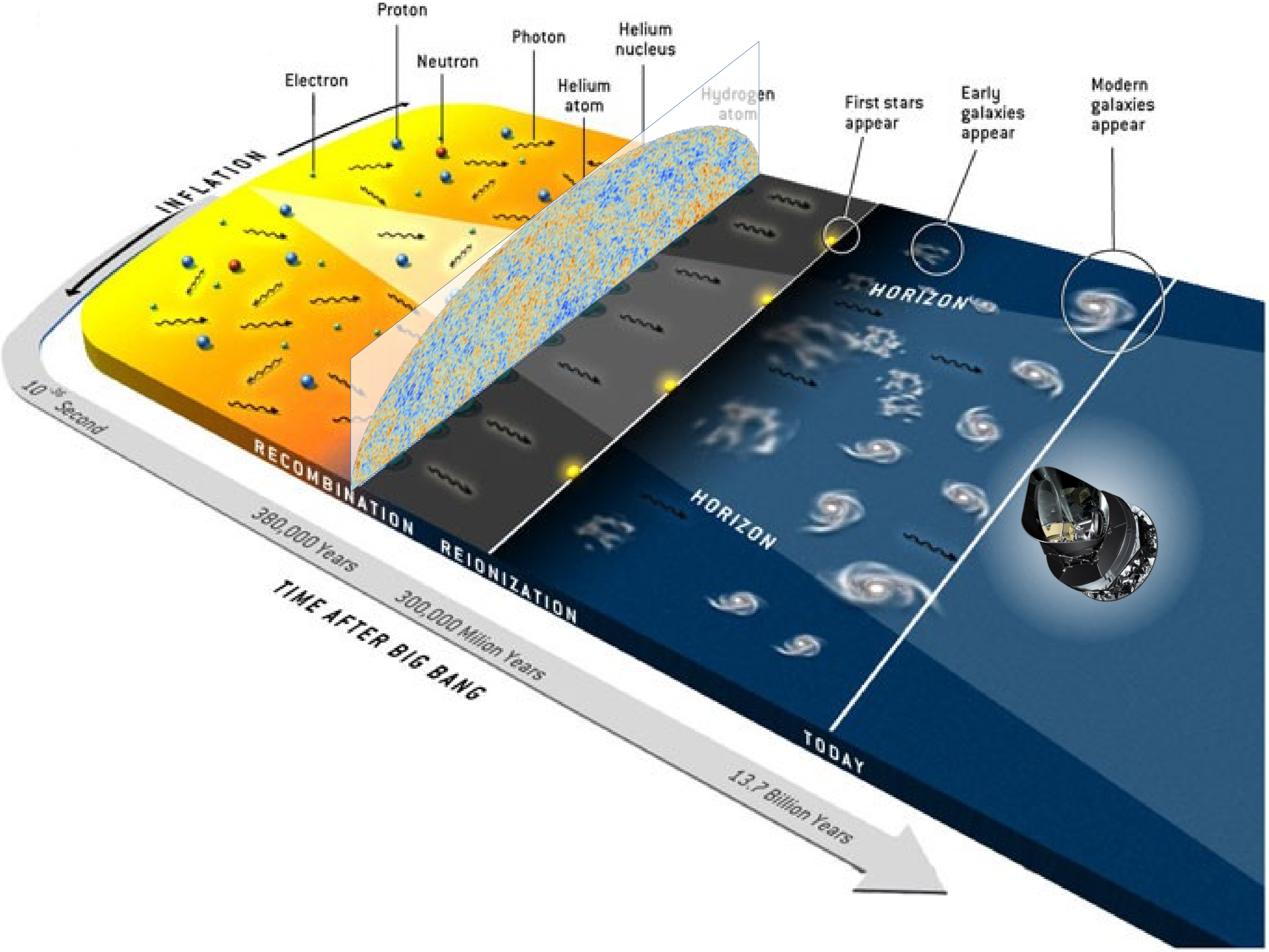

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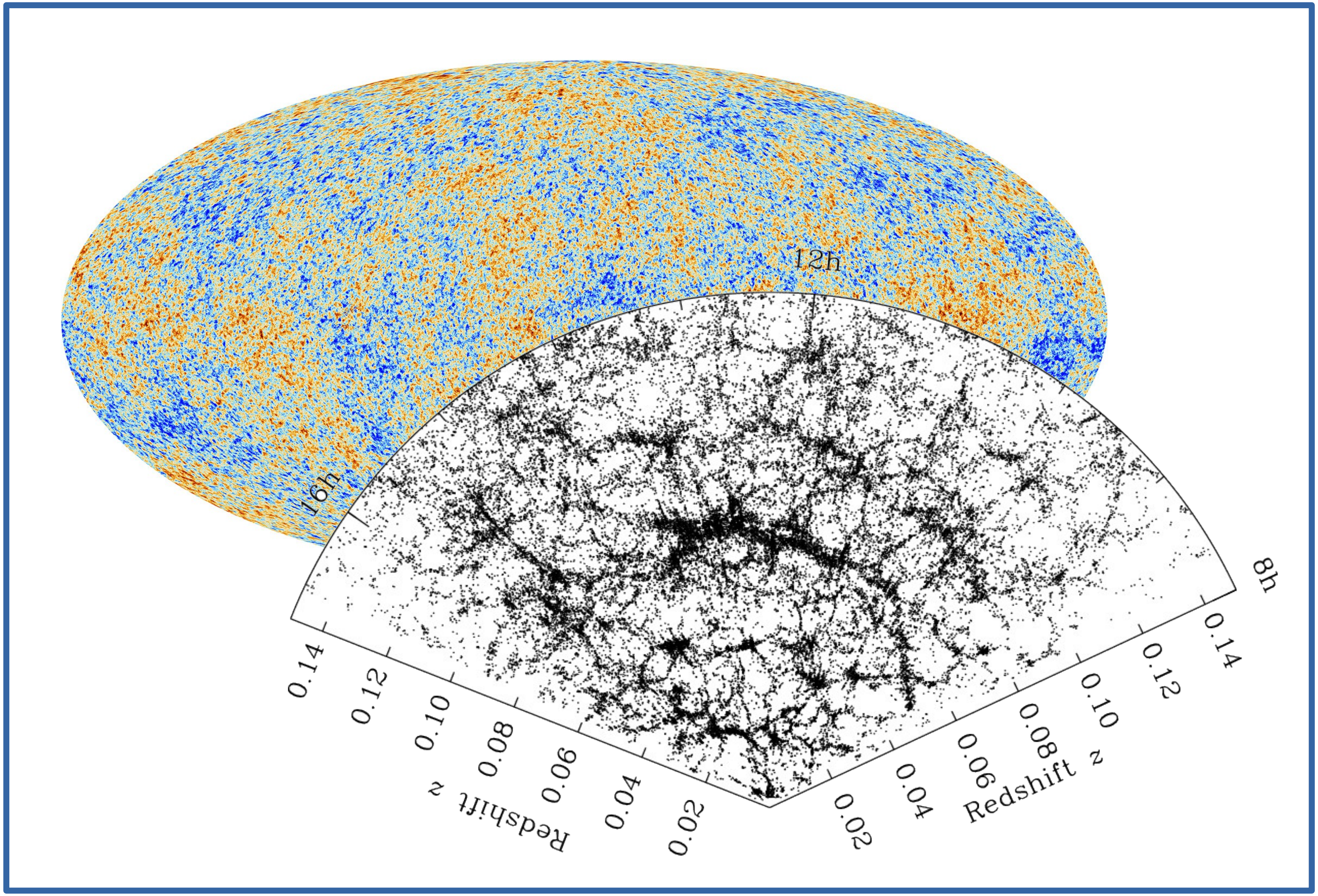

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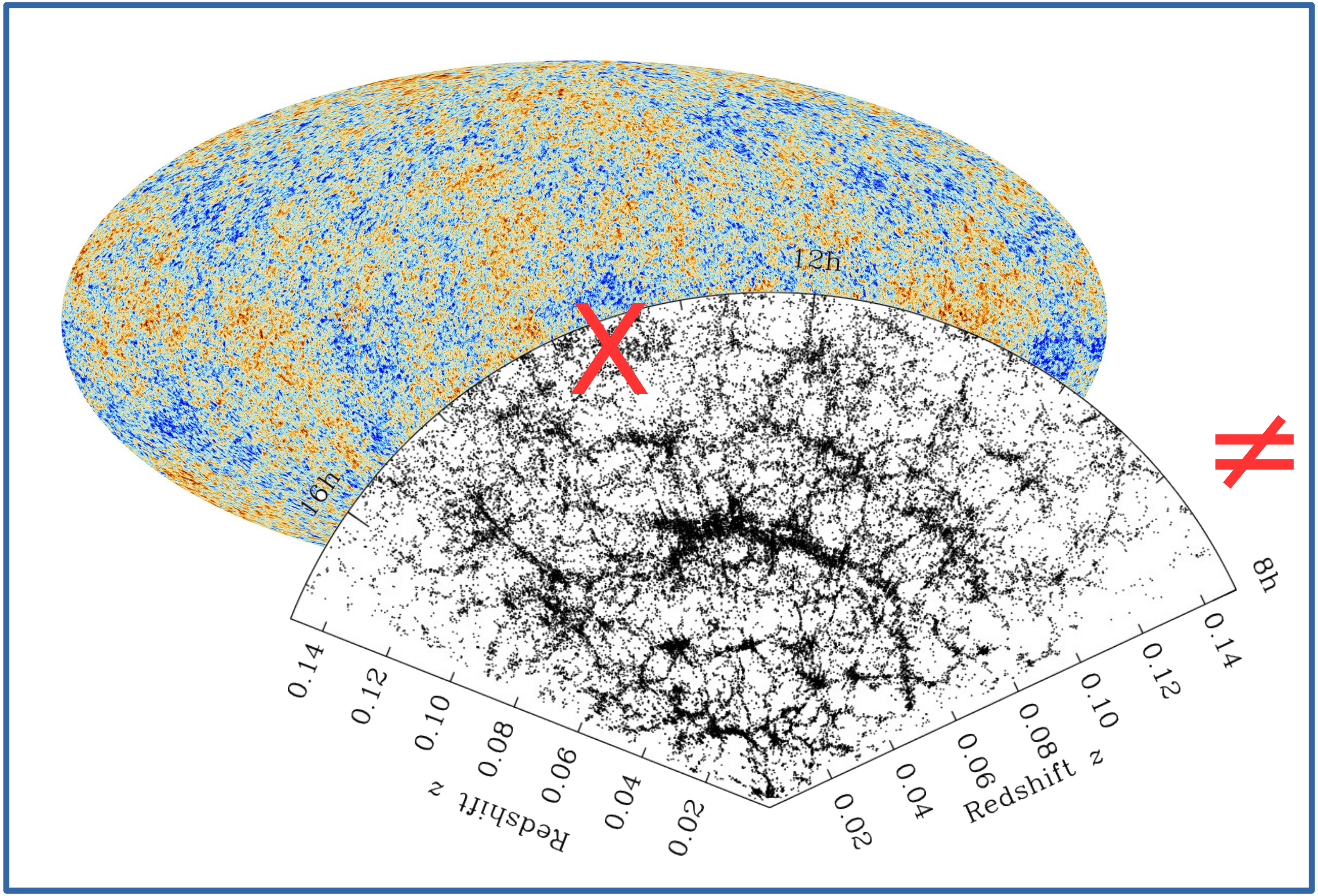
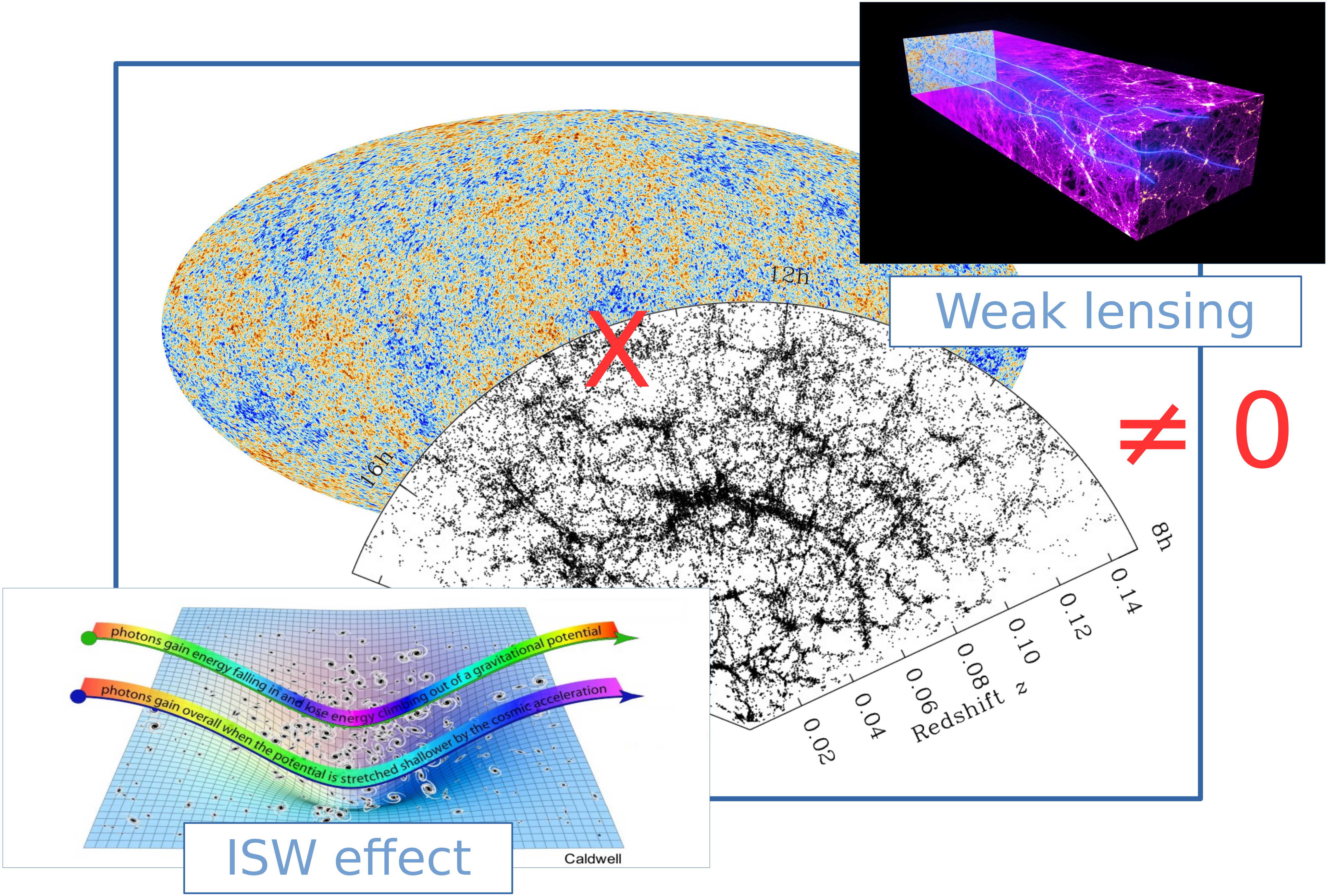


$\neq 0$

CMB-LSS joint analysis



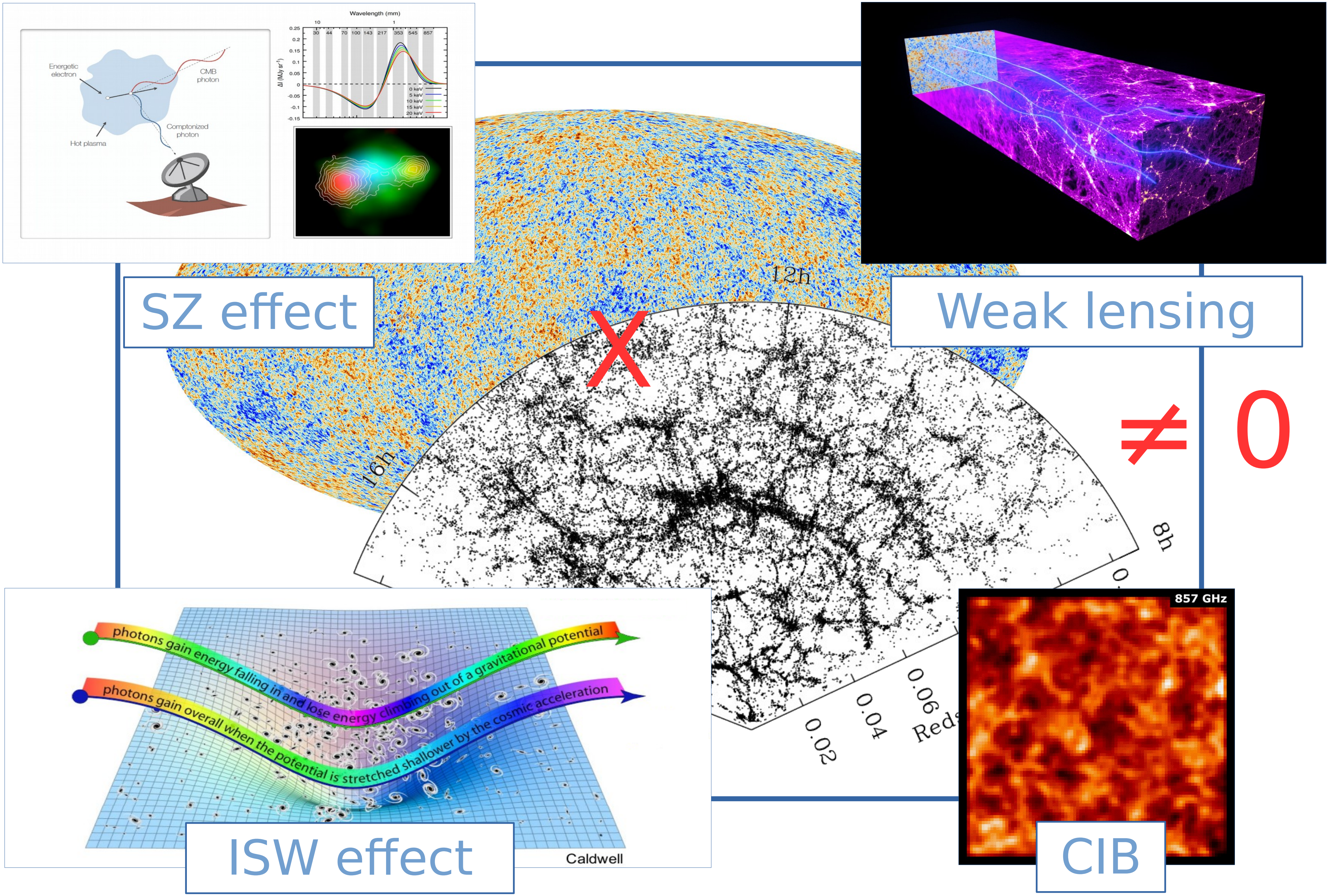
X

$\neq 0$

Weak lensing

ISW effect

CMB-LSS joint analysis



SZ effect

Weak lensing

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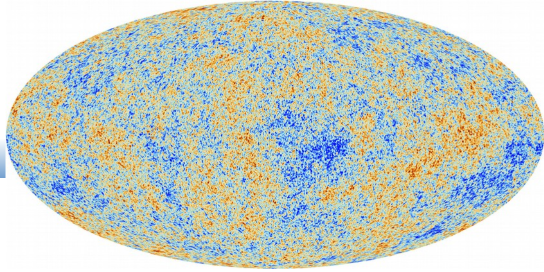
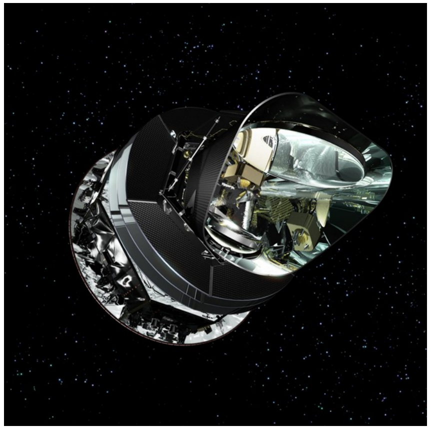
≠ 0

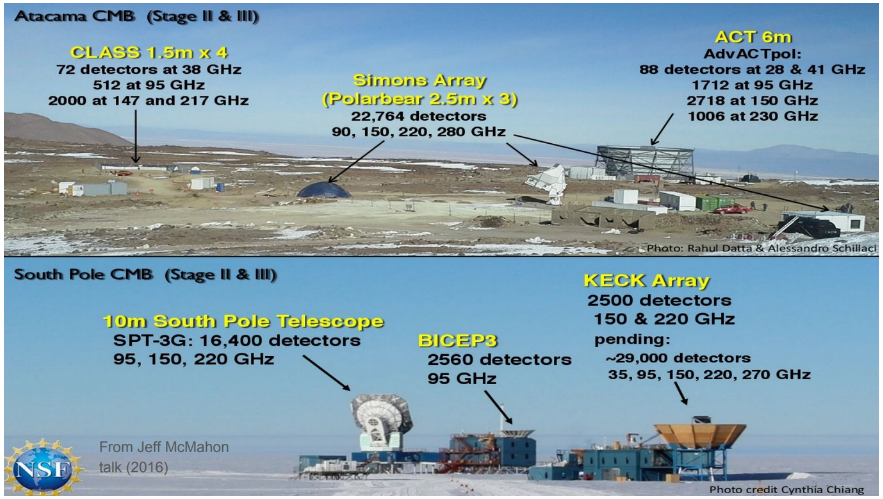
ISW effect

CIB

Current/upcoming CMB surveys







Atacama CMB (Stage II & III)

CLASS 1.5m x 4
72 detectors at 38 GHz
512 at 95 GHz
2000 at 147 and 217 GHz

Simons Array
(Polarbear 2.5m x 3)
22,764 detectors
90, 150, 220, 280 GHz

ACT 6m
AdvACTpol:
88 detectors at 28 & 41 GHz
1712 at 95 GHz
2718 at 150 GHz
1006 at 230 GHz

Photo: Rahul Datta & Alessandro Schillaci

South Pole CMB (Stage II & III)

10m South Pole Telescope
SPT-3G: 16,400 detectors
95, 150, 220 GHz

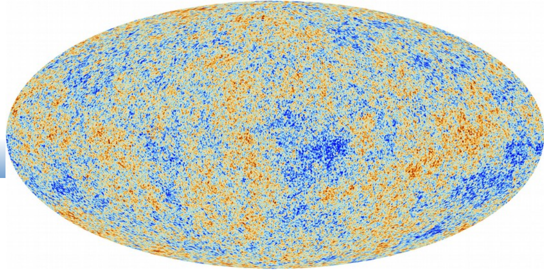
BICEP3
2560 detectors
95 GHz

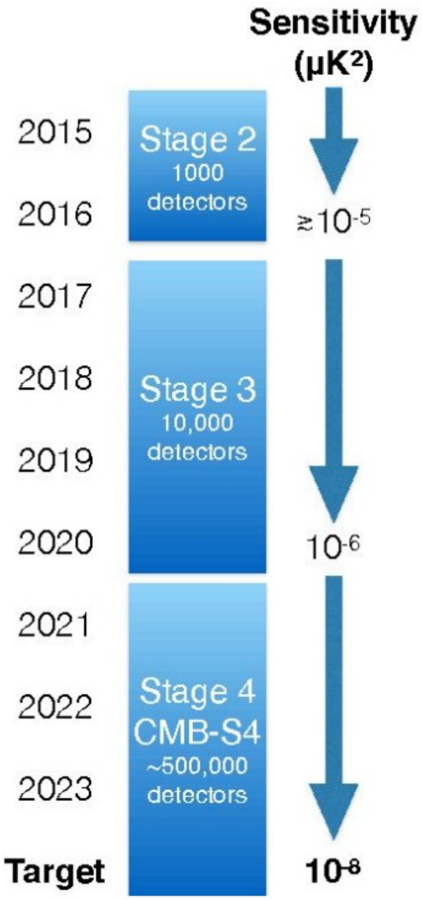
KECK Array
2500 detectors
150 & 220 GHz
pending:
~29,000 detectors
35, 95, 150, 220, 270 GHz

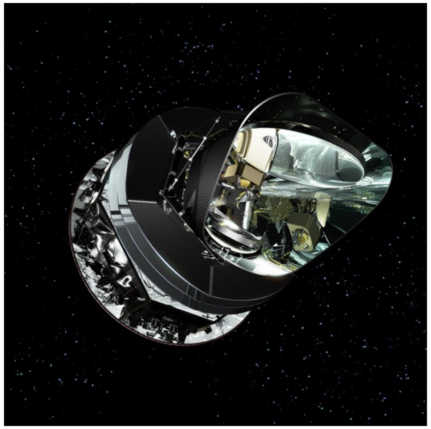
From Jeff McMahon talk (2016)

Photo credit Cynthia Chiang

Current/upcoming CMB surveys







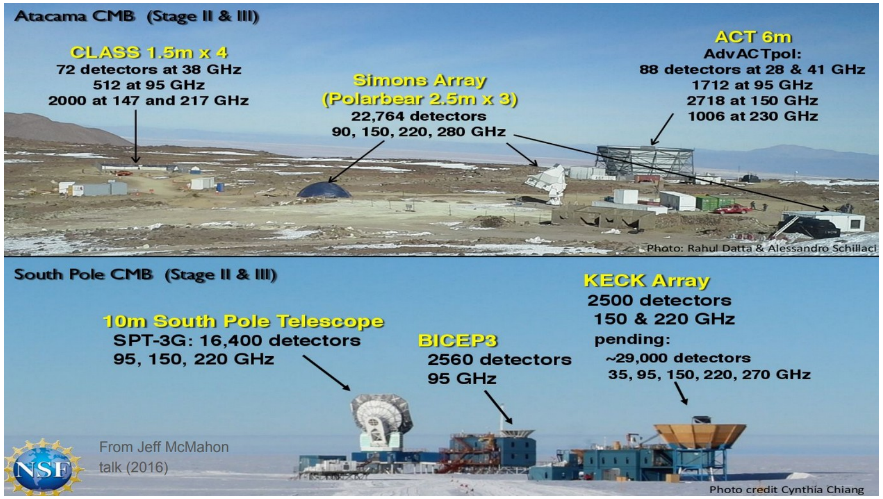


Photo: Rahul Datta & Alessandro Schillaci

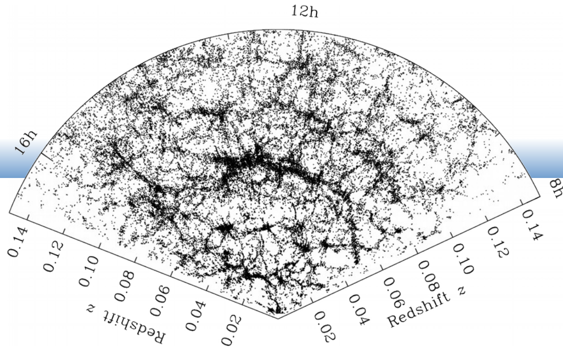
From Jeff McMahon talk (2016)

Photo credit Cynthia Chiang

<u>Future:</u>

- Simons Observatory
- LiteBIRD
- CMB Stage-4

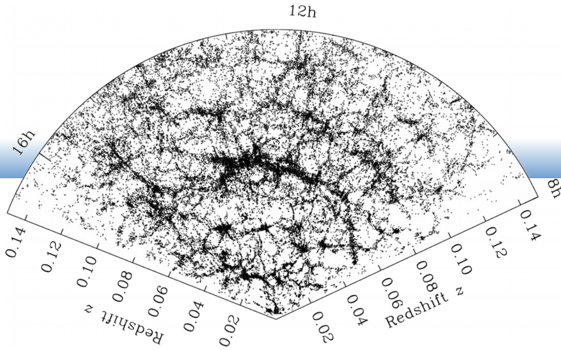
Current/upcoming LSS surveys



DETF classification:

- Stage II: SDSS, KiDS, …
- Stage III: DES, …
- Stage IV: DESI, LSST, Euclid

Current/upcoming LSS surveys



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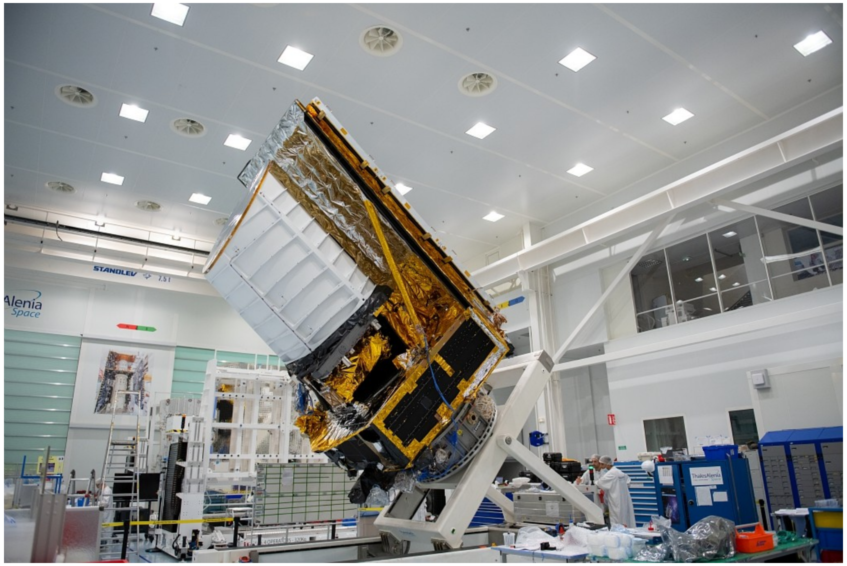
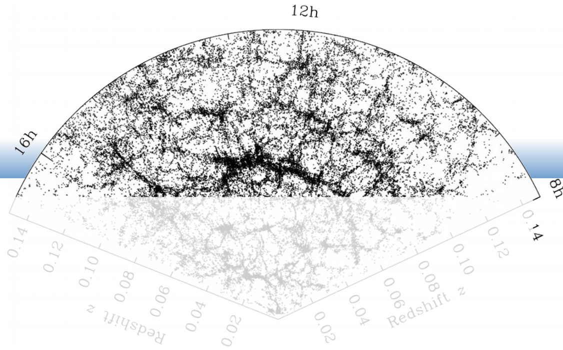
Slides from 12/2021!



Fact sheet:

- Orbit around L2
- ~6 years of mission
- Launch date (!): Feb. 5th 2023
- Q1 after 17 months, DR1 at 29
- VIS & NISP instruments
- ~15,000 sq. deg.
- Spectro + photo survey
- Gal. Clustering & Weak Lensing

Current/upcoming LSS surveys



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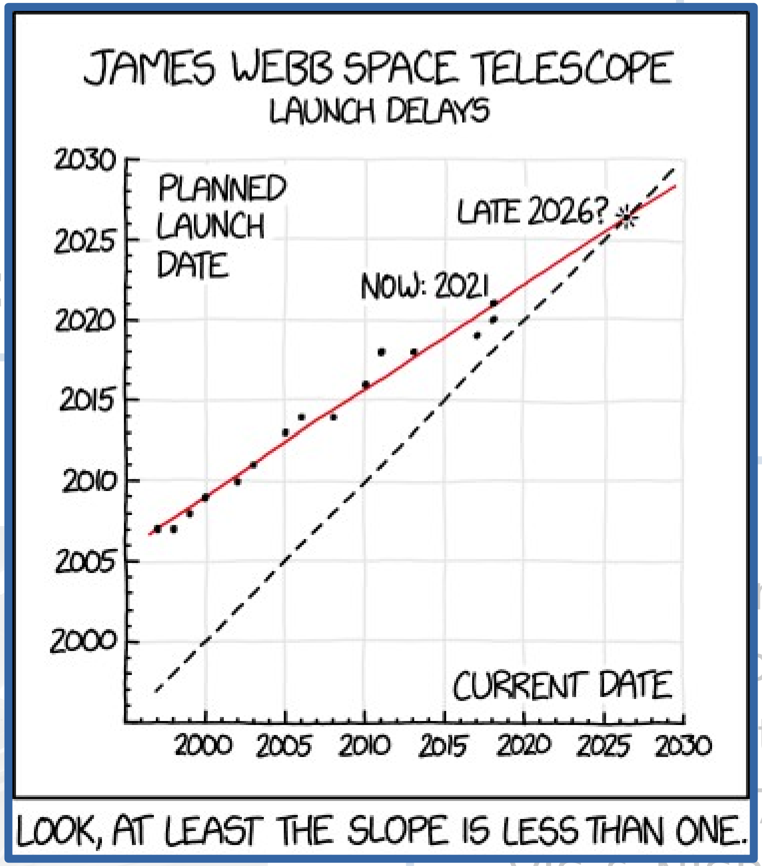

xkcd #2014 (July 2, 2018)

nd L2

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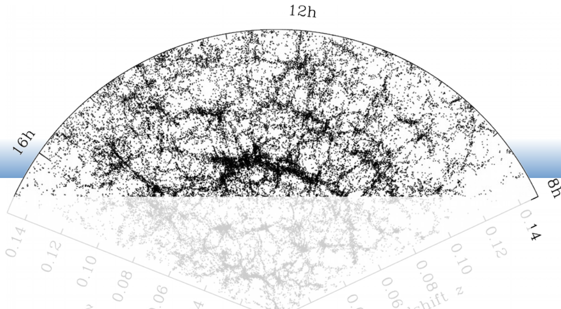

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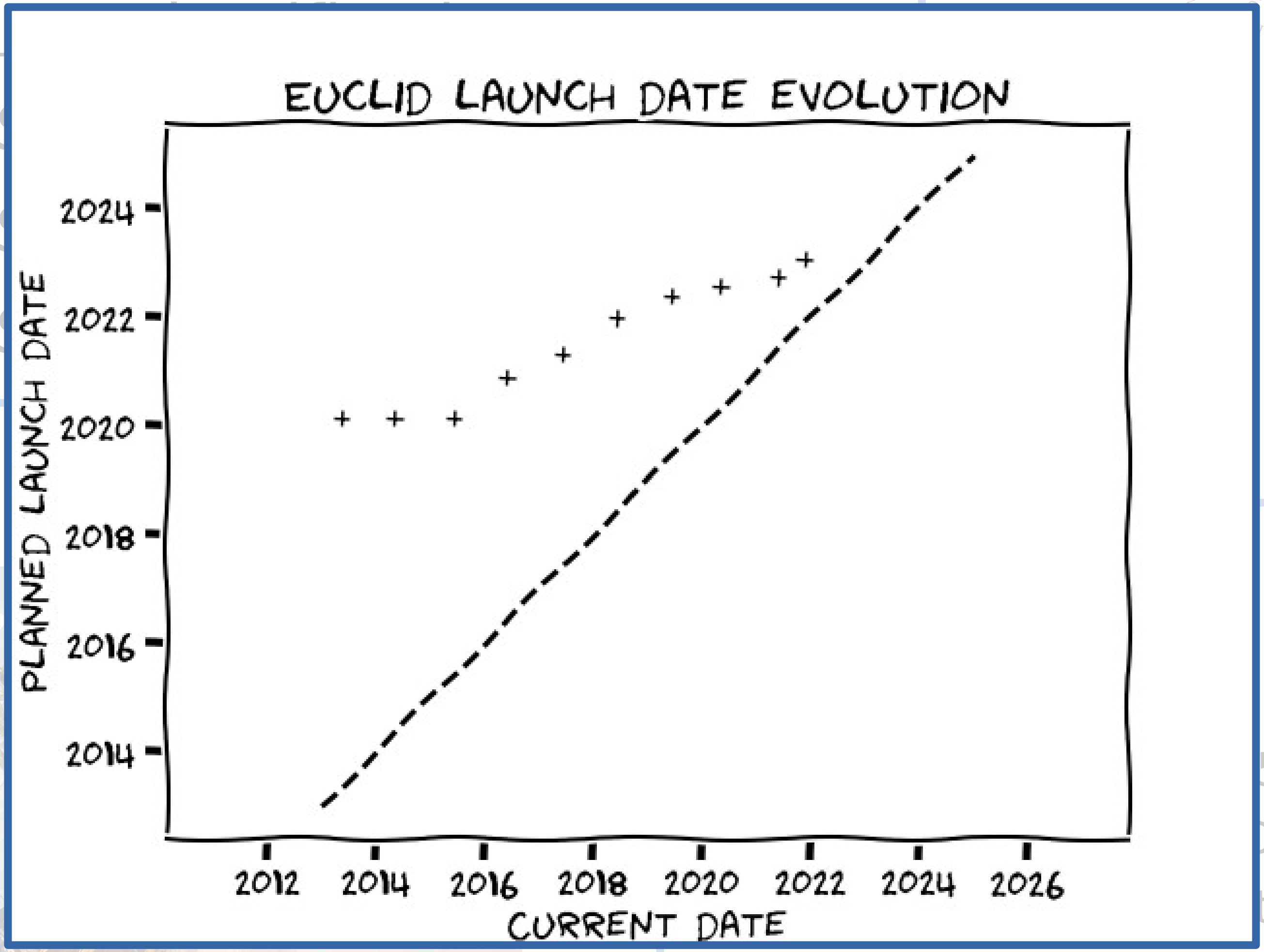

5th 2023

DR1 at 29

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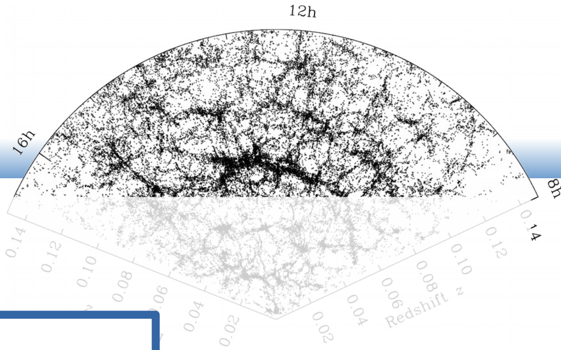

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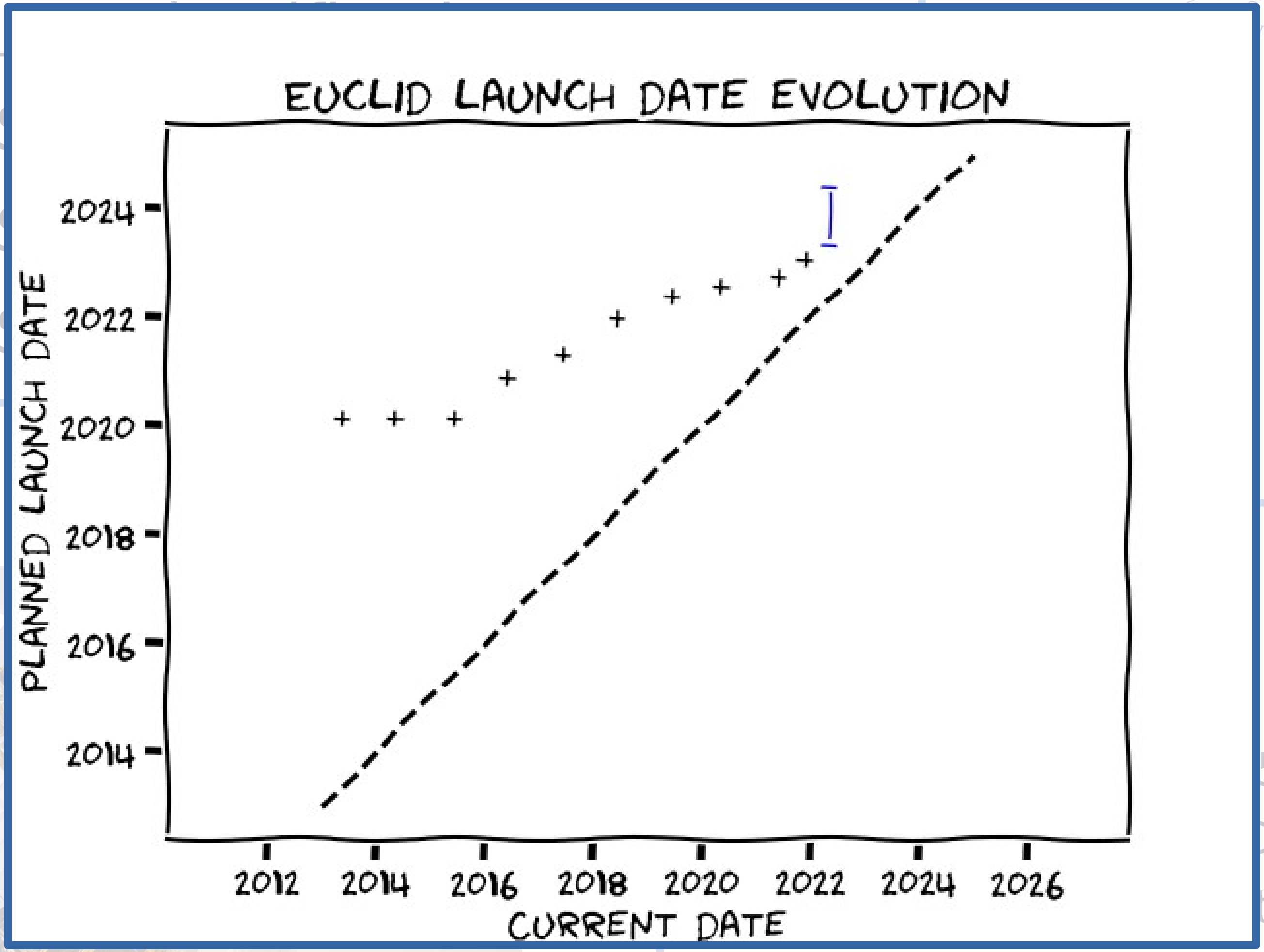

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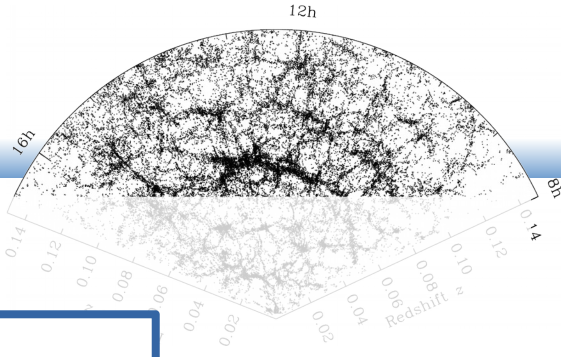

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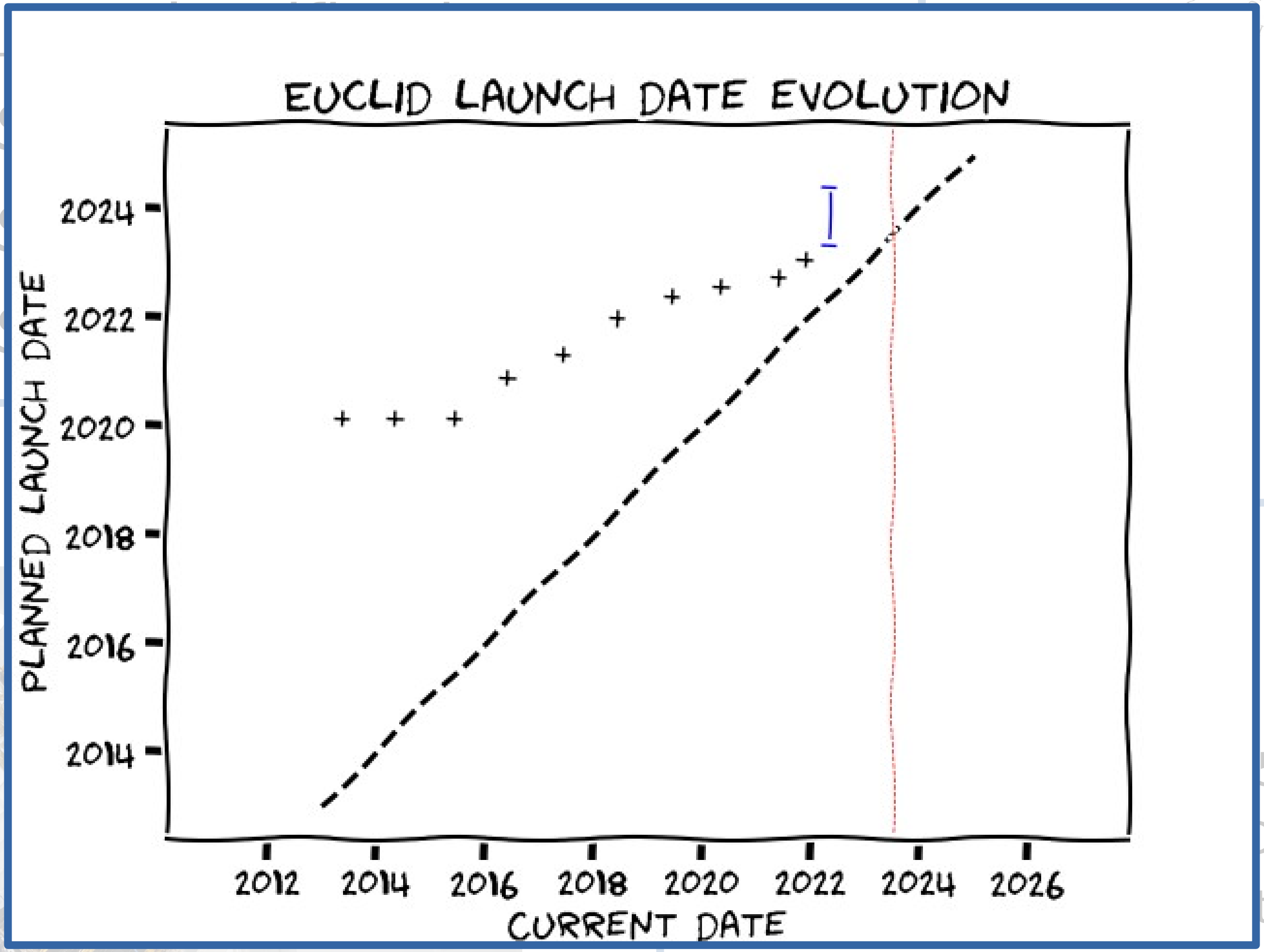

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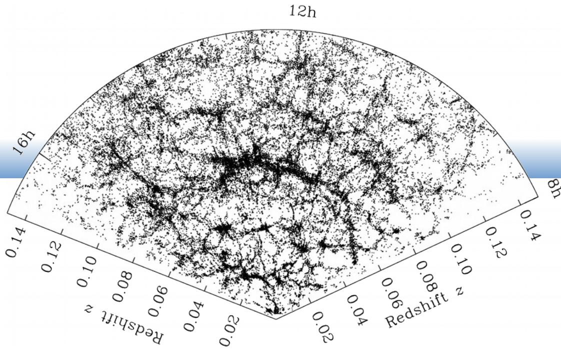

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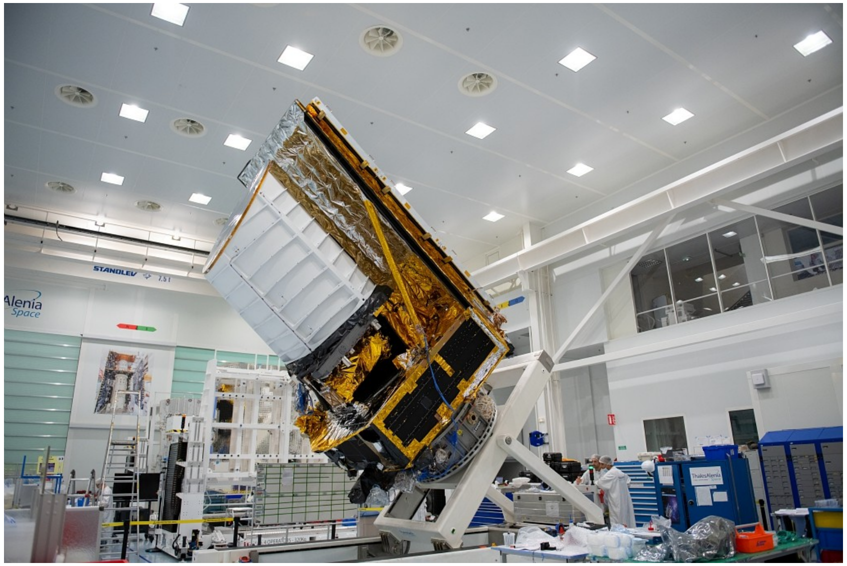

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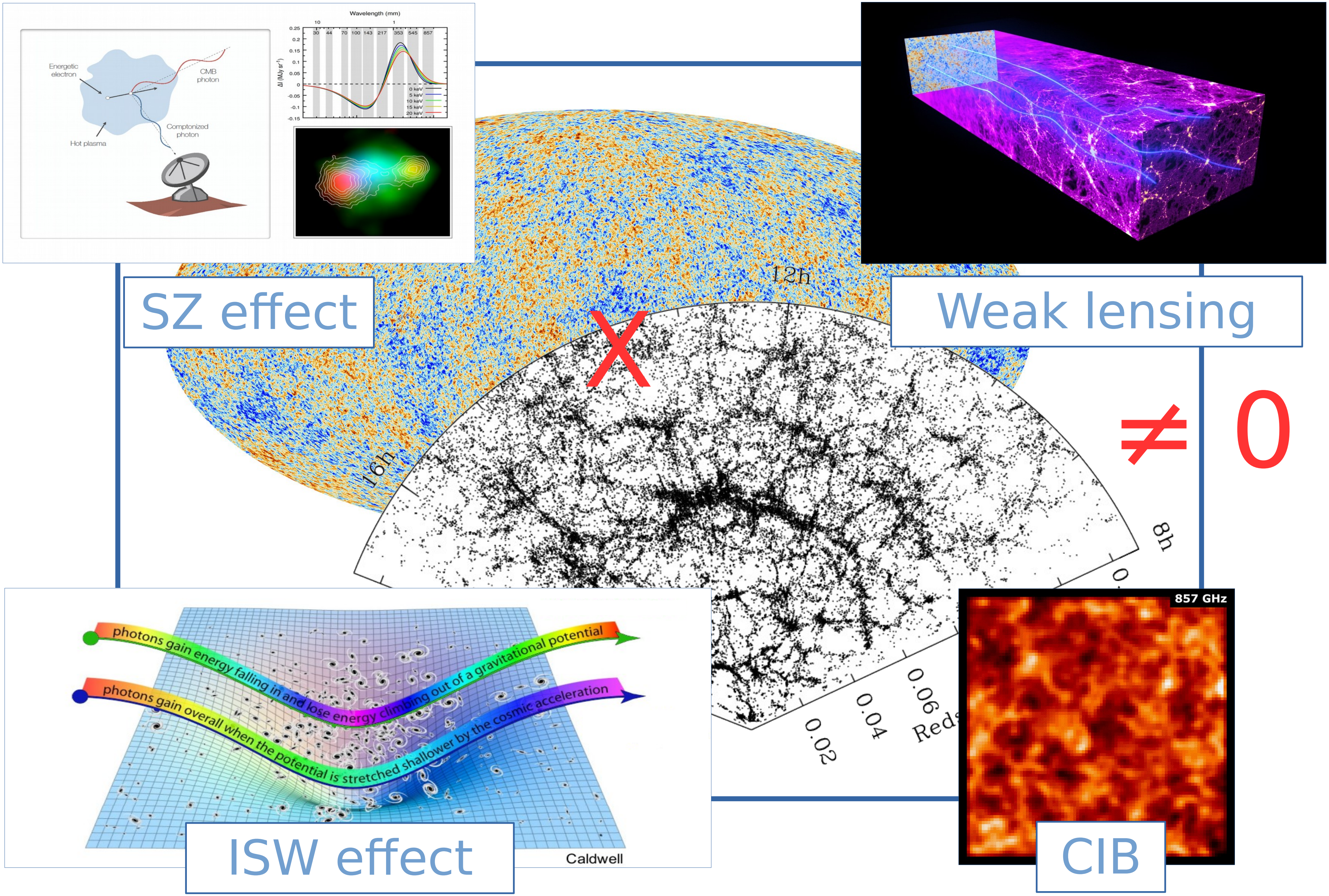

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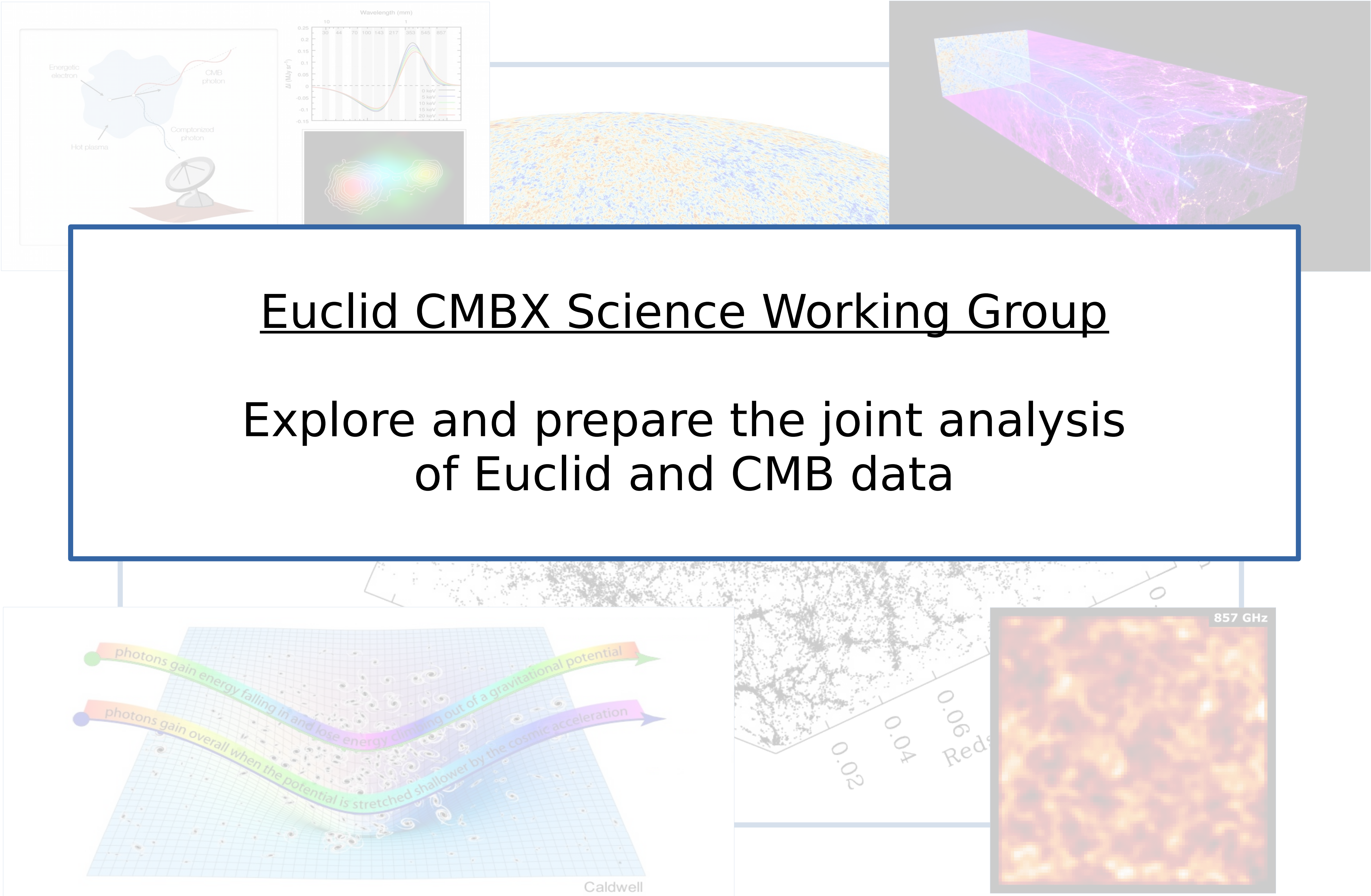
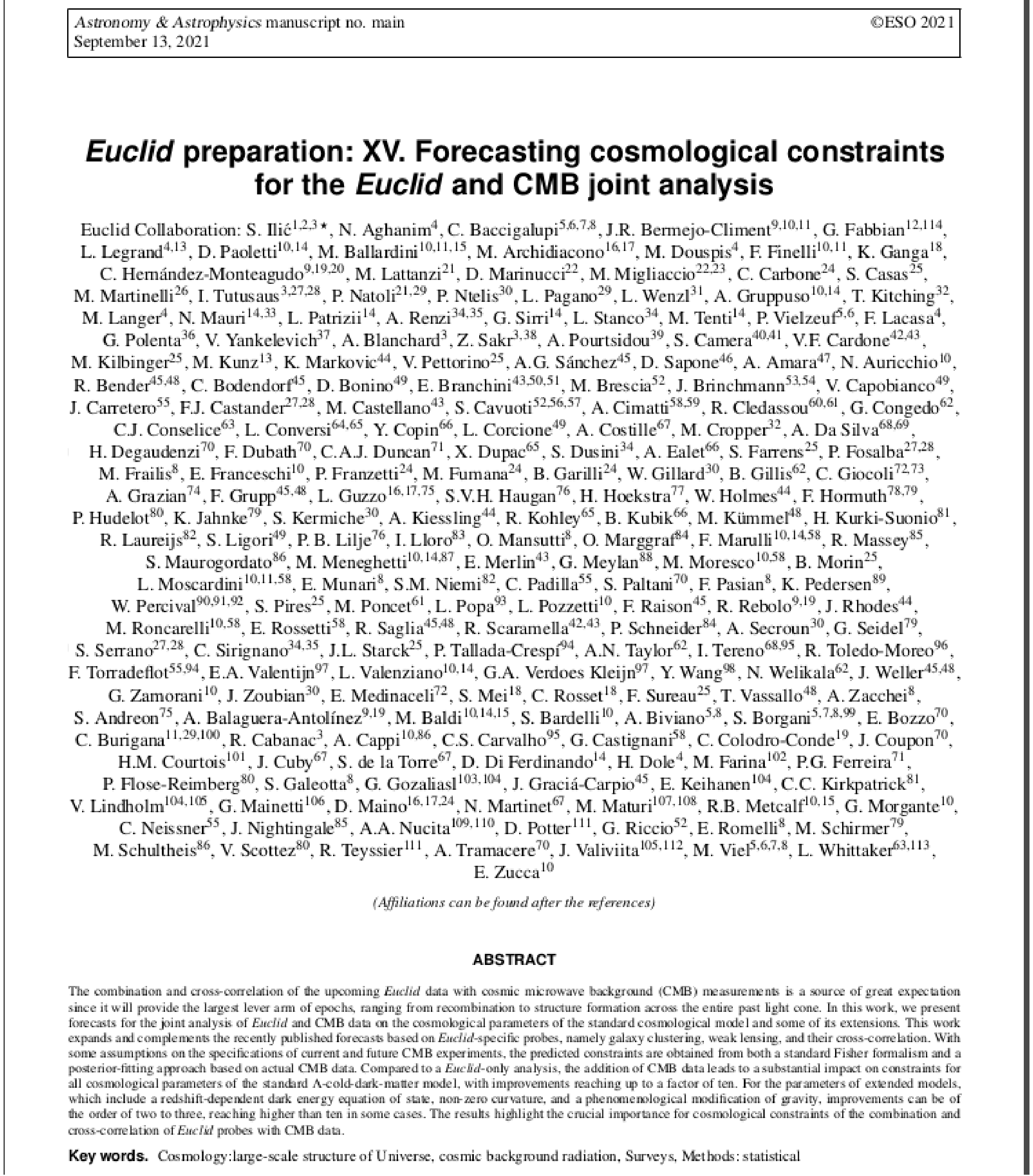


Euclid CMBX Science Working Group

Explore and prepare the joint analysis
of Euclid and CMB data

The Euclid CMBX forecasts paper

Ilic et al. 2021, A&A, arXiv:2106.08346



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

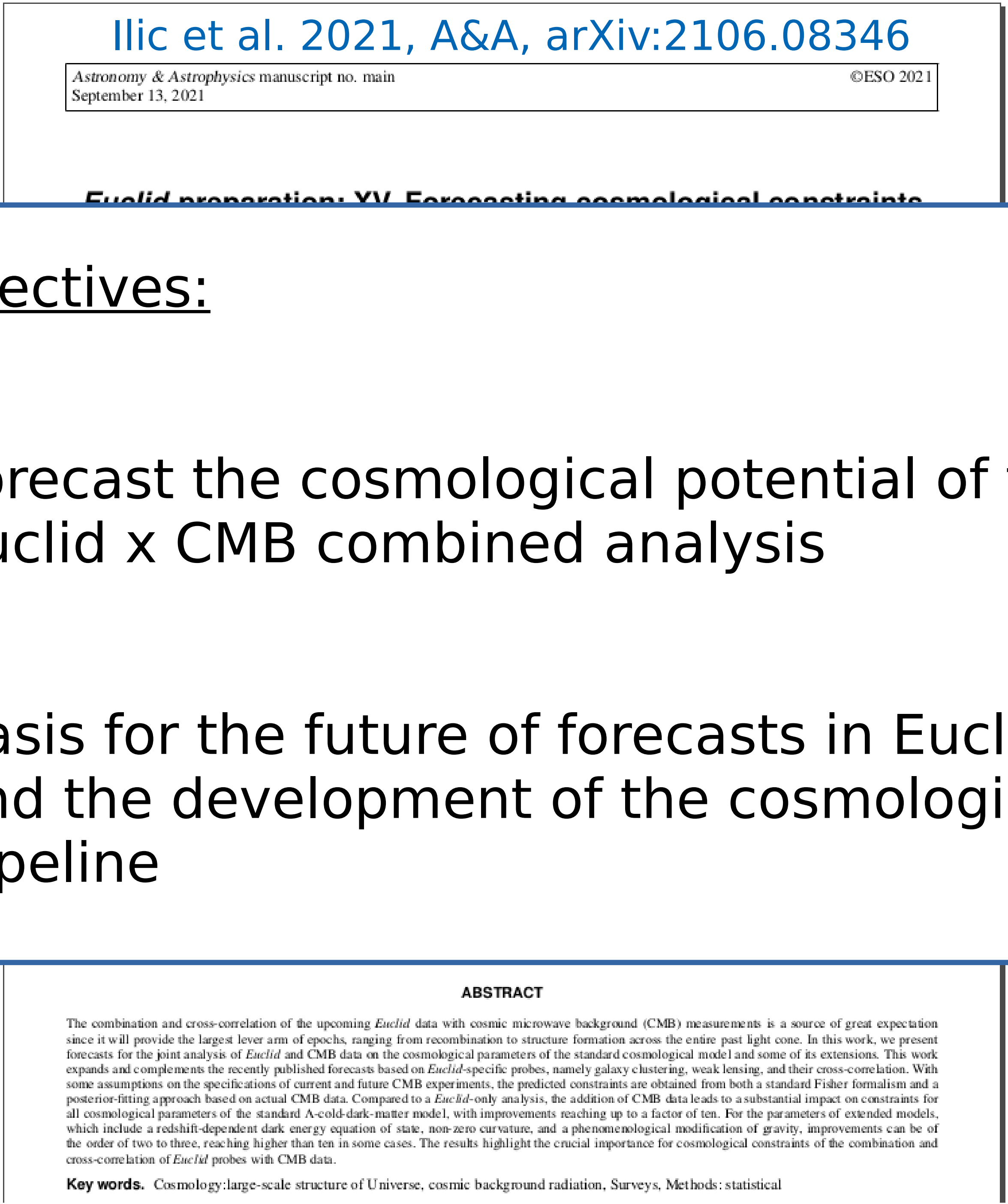
ABSTRACT

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

The Euclid CMBX forecasts paper

Ilic et al. 2021, A&A, arXiv:2106.08346



Astronomy & Astrophysics manuscript no. main
September 13, 2021

Euclid preparation: XV. Forecasting cosmological constraints

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

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

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(Affiliations can be found after the references)

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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

Recipe for Euclid x CMB forecasts

Fisher formalism/matrix

$$\mathsf{F}_{\alpha\beta} = -\left\langle \frac{\partial^2 \ln \mathcal{L}}{\partial\theta_\alpha \partial\theta_\beta} \right\rangle \Bigg|_{\theta_i=\theta_{i,\mathrm{fid}}} = \boxed{C}^{-1}$$

Forecasted errors on parameters

For observables with Gaussian pdf = $\mathcal{N}(\mu, \mathrm{C})$:

$$\mathsf{F}_{\alpha\beta} = \frac{1}{2}\,\mathrm{Tr}\left[\mathsf{C}^{-1}\frac{\partial \mathsf{C}}{\partial\theta_\alpha}\mathsf{C}^{-1}\frac{\partial \mathsf{C}}{\partial\theta_\beta}\right] + \frac{\partial \boldsymbol{\mu}^{\mathsf{T}}}{\partial\theta_\alpha}\mathsf{C}^{-1}\frac{\partial \boldsymbol{\mu}}{\partial\theta_\beta}$$

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

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

- C
- M
- V re
- MG model: “gamma”

Issues for CMB :
choice of the parameter basis

- θ versus H_0
- A_s versus σ_8
- “Small” versus “big” omegas

+ gamma MG parameterisation

Recipe for Euclid x CMB forecasts

- Main ingredient : likelihood

· G

· N

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

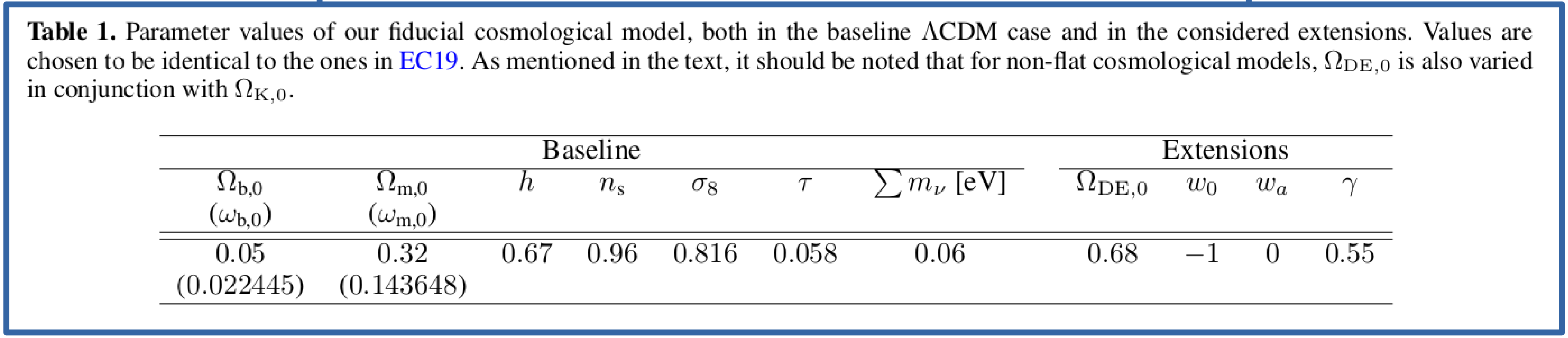


Table 1. Parameter values of our fiducial cosmological model, both in the baseline ΛCDM case and in the considered extensions. Values are chosen to be identical to the ones in EC19. As mentioned in the text, it should be noted that for non-flat cosmological models, $\Omega_{\rm DE,0}$ is also varied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

Baseline							Extensions			
$\Omega_{\rm b,0}$ ($\omega_{\rm b,0}$)	$\Omega_{\rm m,0}$ ($\omega_{\rm m,0}$)	h	$n_{\rm s}$	σ_8	τ	$\sum m_\nu$ [eV]	$\Omega_{\rm DE,0}$	w_0	w_a	γ
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

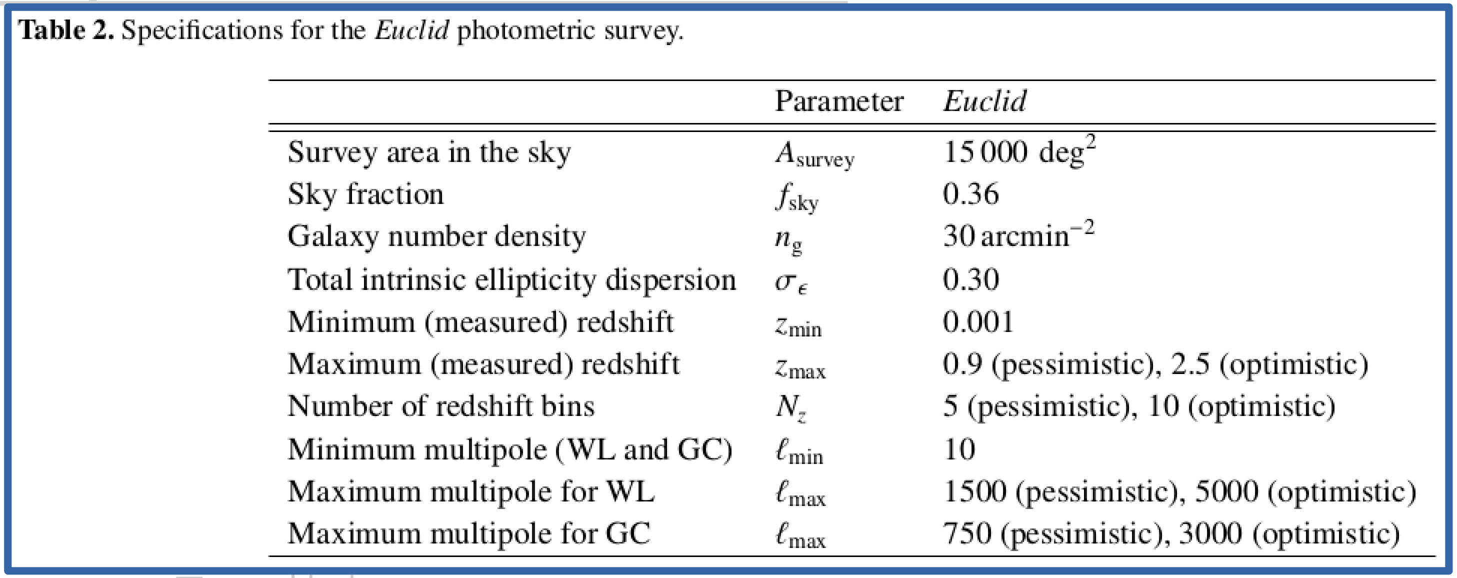


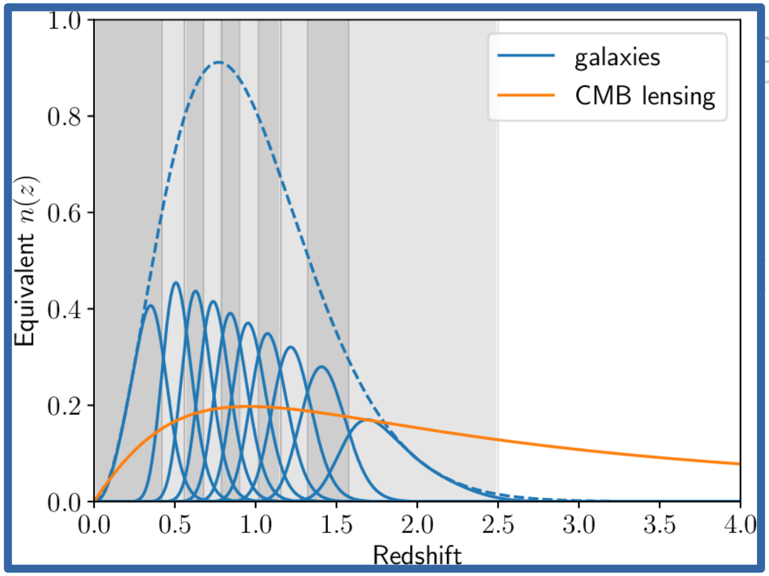
Table 2. Specifications for the *Euclid* photometric survey.

	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	σ_ϵ	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:

    - Galaxy Clustering

    - Galaxy



Nuisance parameters:

- 5/10 for (linear) bias
- 3 for intrinsic alignments model

Recipe for Euclid x CMB forecasts

- Main ingredient : likelihood

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

2) Which observables ?

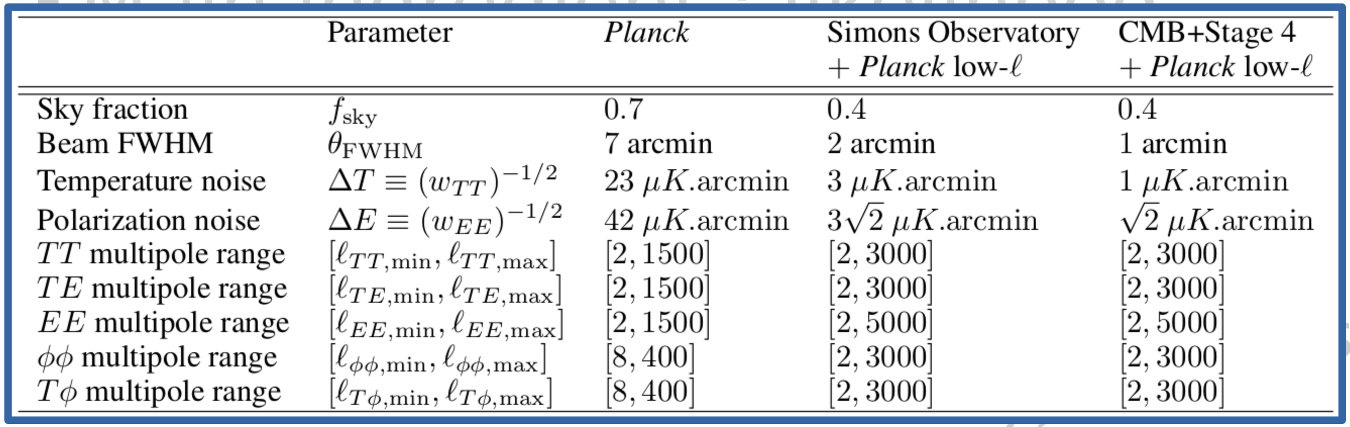
$$\mathcal{C}_\ell$$

- CMB:
  - Temperature (T)
  - Polarization (E & ~~B~~)
  - CMB lensing (P)

contains secondary anisotropies

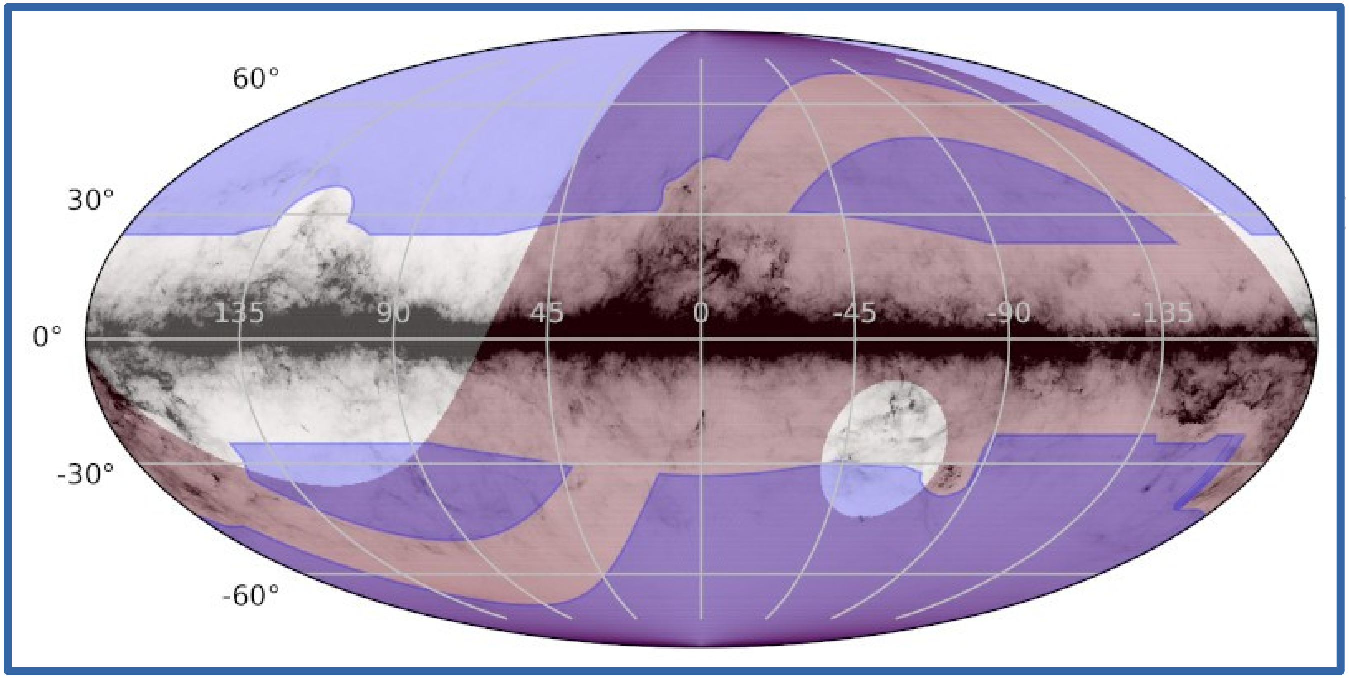
Recipe for Euclid x CMB forecasts

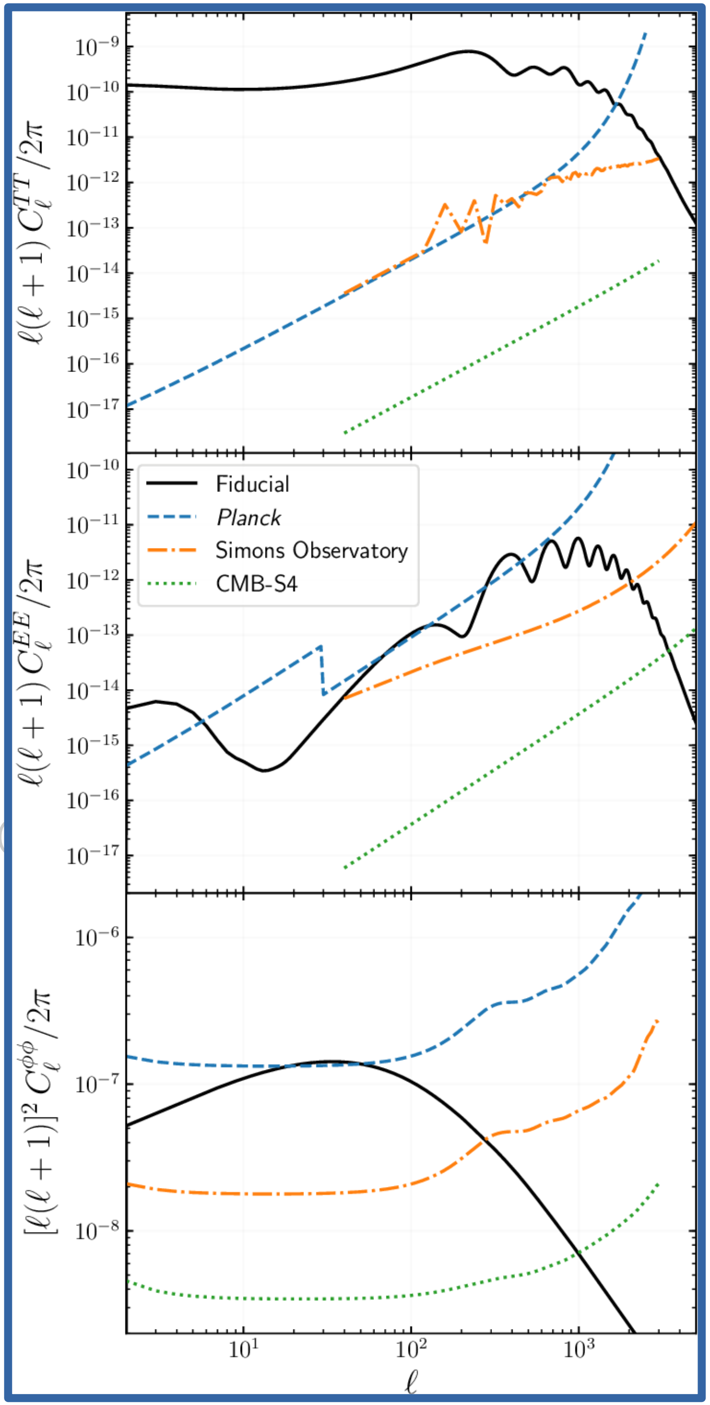
- Main ingredient : likelihood



	Parameter	*Planck*	Simons Observatory + *Planck* low-ℓ	CMB+Stage 4 + *Planck* low-ℓ
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	$[\ell_{T\phi,\rm min}, \ell_{T\phi,\rm max}]$	$[8, 400]$	$[2, 3000]$	$[2, 3000]$

C_ℓ





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)

For reference: case n°0

Euclid (GCp, WL, GCs) only

~0.3-4%

~0.1-2%

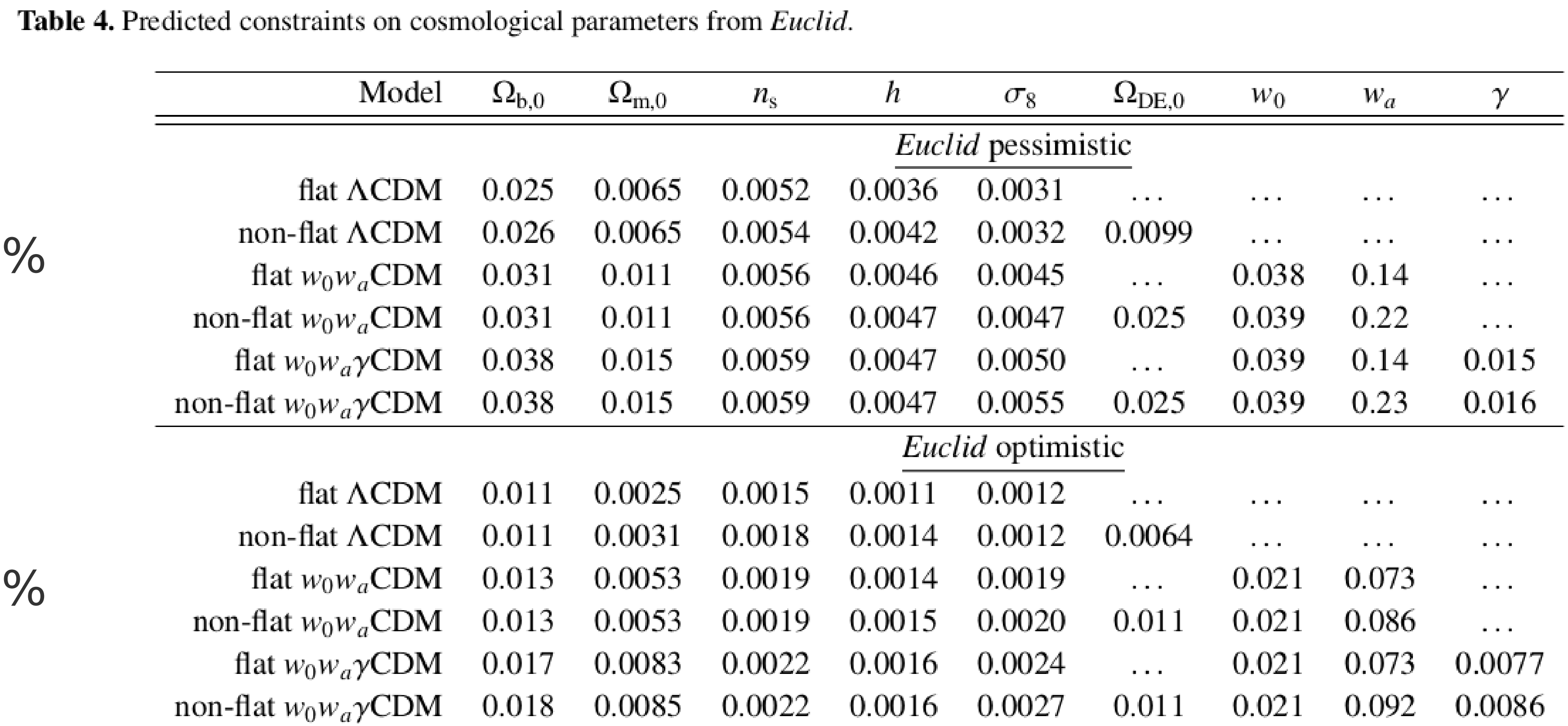


Table 4. Predicted constraints on cosmological parameters from *Euclid*.

Model	$\Omega_{\mathrm{b},0}$	$\Omega_{\mathrm{m},0}$	n_s	h	σ_8	$\Omega_{\mathrm{DE},0}$	w_0	w_a	γ
					Euclid pessimistic				
flat ΛCDM	0.025	0.0065	0.0052	0.0036	0.0031	...	...	...	...
non-flat ΛCDM	0.026	0.0065	0.0054	0.0042	0.0032	0.0099	...	...	...
flat w_0w_aCDM	0.031	0.011	0.0056	0.0046	0.0045	...	0.038	0.14	...
non-flat w_0w_aCDM	0.031	0.011	0.0056	0.0047	0.0047	0.025	0.039	0.22	...
flat $w_0w_a\gamma$CDM	0.038	0.015	0.0059	0.0047	0.0050	...	0.039	0.14	0.015
non-flat $w_0w_a\gamma$CDM	0.038	0.015	0.0059	0.0047	0.0055	0.025	0.039	0.23	0.016
					Euclid optimistic				
flat ΛCDM	0.011	0.0025	0.0015	0.0011	0.0012	...	...	...	...
non-flat ΛCDM	0.011	0.0031	0.0018	0.0014	0.0012	0.0064	...	...	...
flat w_0w_aCDM	0.013	0.0053	0.0019	0.0014	0.0019	...	0.021	0.073	...
non-flat w_0w_aCDM	0.013	0.0053	0.0019	0.0015	0.0020	0.011	0.021	0.086	...
flat $w_0w_a\gamma$CDM	0.017	0.0083	0.0022	0.0016	0.0024	...	0.021	0.073	0.0077
non-flat $w_0w_a\gamma$CDM	0.018	0.0085	0.0022	0.0016	0.0027	0.011	0.021	0.092	0.0086

The results: case n°0 to n°1

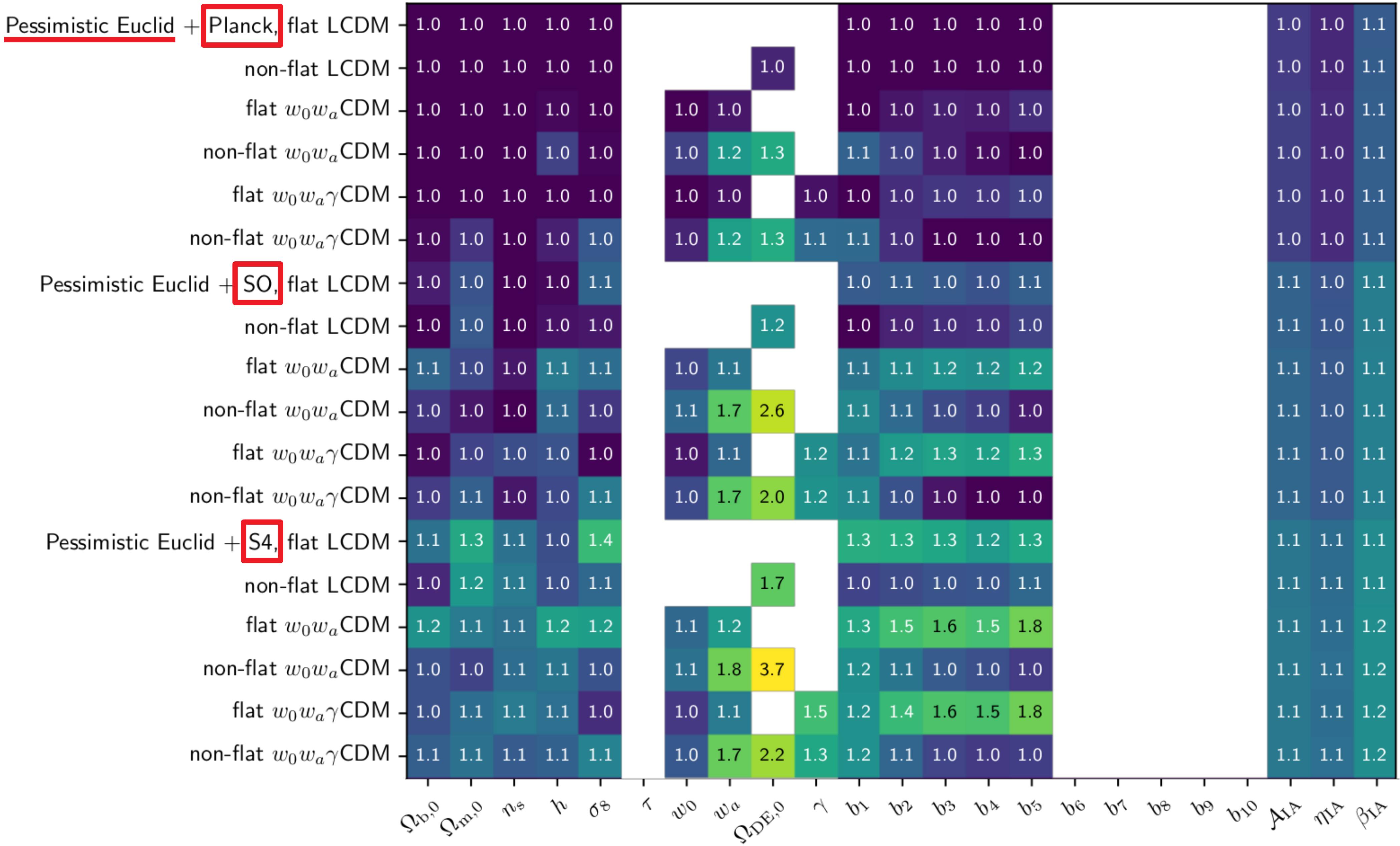
Euclid (GCp, WL, GCs) only

↓

Euclid (GCp, WL, GCs) x CMB phi

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

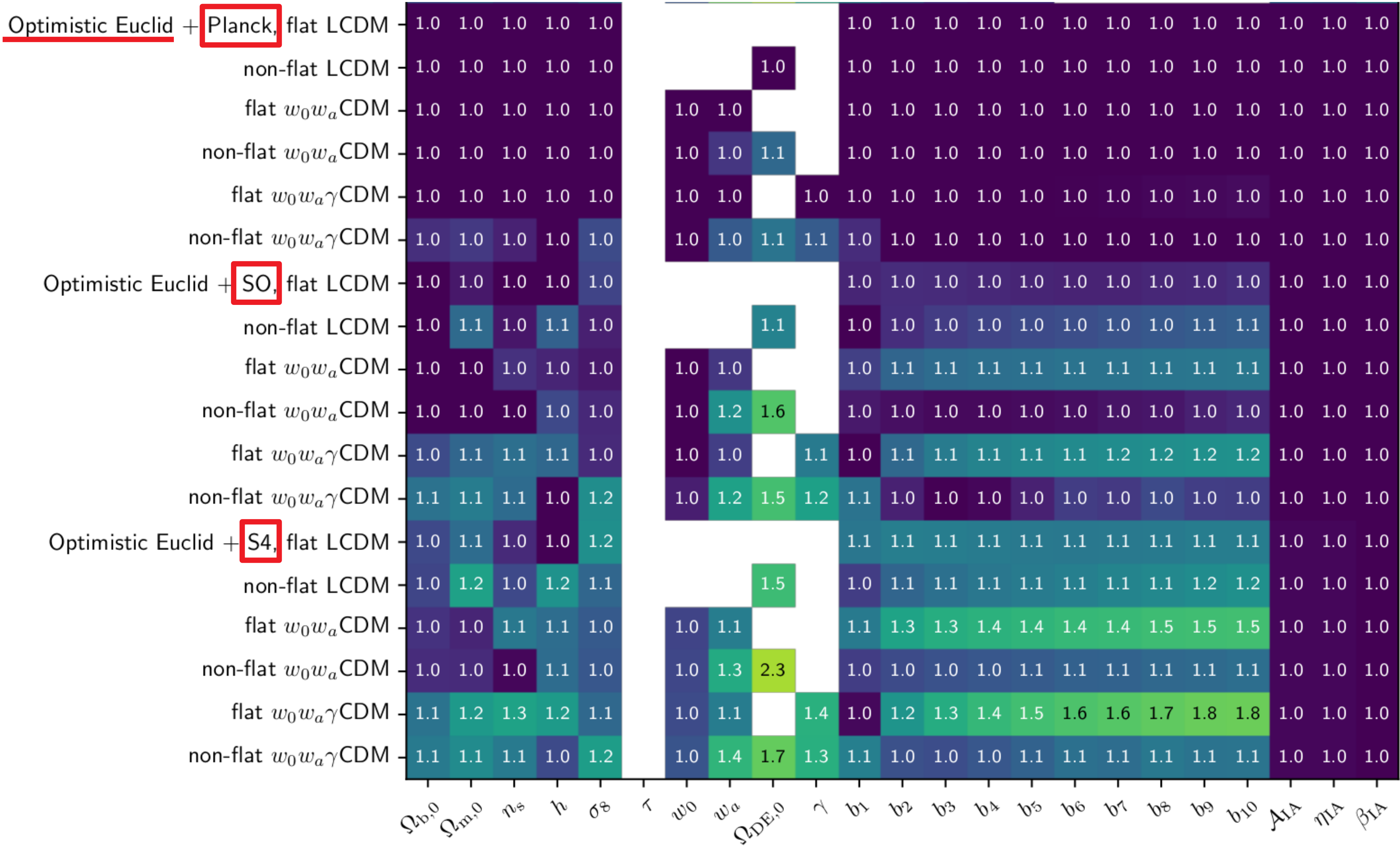
The results: case n°0 to n°1



	$\Omega_{b,0}$	$\Omega_{m,0}$	n_s	h	σ_8	τ	w_0	w_a	$\Omega_{DE,0}$	γ	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}	A_{IA}	η_{IA}	β_{IA}
Pessimistic 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	1.1
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	1.1
flat w_0w_aCDM	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	1.1
non-flat w_0w_aCDM	1.0	1.0	1.0	1.0	1.0		1.0	1.2	1.3		1.1	1.0	1.0	1.0	1.0						1.0	1.0	1.1
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	1.1
non-flat $w_0w_a\gamma$CDM	1.0	1.0	1.0	1.0	1.0		1.0	1.2	1.3	1.1	1.1	1.0	1.0	1.0	1.0						1.0	1.0	1.1
Pessimistic Euclid + SO, flat LCDM	1.0	1.0	1.0	1.0	1.1						1.0	1.1	1.0	1.0	1.1						1.1	1.0	1.1
non-flat LCDM	1.0	1.0	1.0	1.0	1.0				1.2		1.0	1.0	1.0	1.0	1.0						1.1	1.0	1.1
flat w_0w_aCDM	1.1	1.0	1.0	1.1	1.1		1.0	1.1			1.1	1.1	1.2	1.2	1.2						1.1	1.0	1.1
non-flat w_0w_aCDM	1.0	1.0	1.0	1.1	1.0		1.1	1.7	2.6		1.1	1.1	1.0	1.0	1.0						1.1	1.0	1.1
flat $w_0w_a\gamma$CDM	1.0	1.0	1.0	1.0	1.0		1.0	1.1		1.2	1.1	1.2	1.3	1.2	1.3						1.1	1.0	1.1
non-flat $w_0w_a\gamma$CDM	1.0	1.1	1.0	1.0	1.1		1.0	1.7	2.0	1.2	1.1	1.0	1.0	1.0	1.0						1.1	1.0	1.1
Pessimistic Euclid + S4, flat LCDM	1.1	1.3	1.1	1.0	1.4						1.3	1.3	1.3	1.2	1.3						1.1	1.1	1.1
non-flat LCDM	1.0	1.2	1.1	1.0	1.1				1.7		1.0	1.0	1.0	1.0	1.1						1.1	1.1	1.1
flat w_0w_aCDM	1.2	1.1	1.1	1.2	1.2		1.1	1.2			1.3	1.5	1.6	1.5	1.8						1.1	1.1	1.2
non-flat w_0w_aCDM	1.0	1.0	1.1	1.1	1.0		1.1	1.8	3.7		1.2	1.1	1.0	1.0	1.0						1.1	1.1	1.2
flat $w_0w_a\gamma$CDM	1.0	1.1	1.1	1.1	1.0		1.0	1.1		1.5	1.2	1.4	1.6	1.5	1.8						1.1	1.1	1.2
non-flat $w_0w_a\gamma$CDM	1.1	1.1	1.1	1.1	1.1		1.0	1.7	2.2	1.3	1.2	1.1	1.0	1.0	1.0						1.1	1.1	1.2

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

The results: case n°0 to n°1 (cont.)



	$\Omega_{b,0}$	$\Omega_{m,0}$	n_s	h	σ_8	τ	w_0	w_a	$\Omega_{DE,0}$	γ	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}	A_{IA}	η_{IA}	β_{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_aCDM	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_aCDM	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_aCDM	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_aCDM	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_aCDM	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_aCDM	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 = $\sigma_{\text{before}} / \sigma_{\text{after}}$

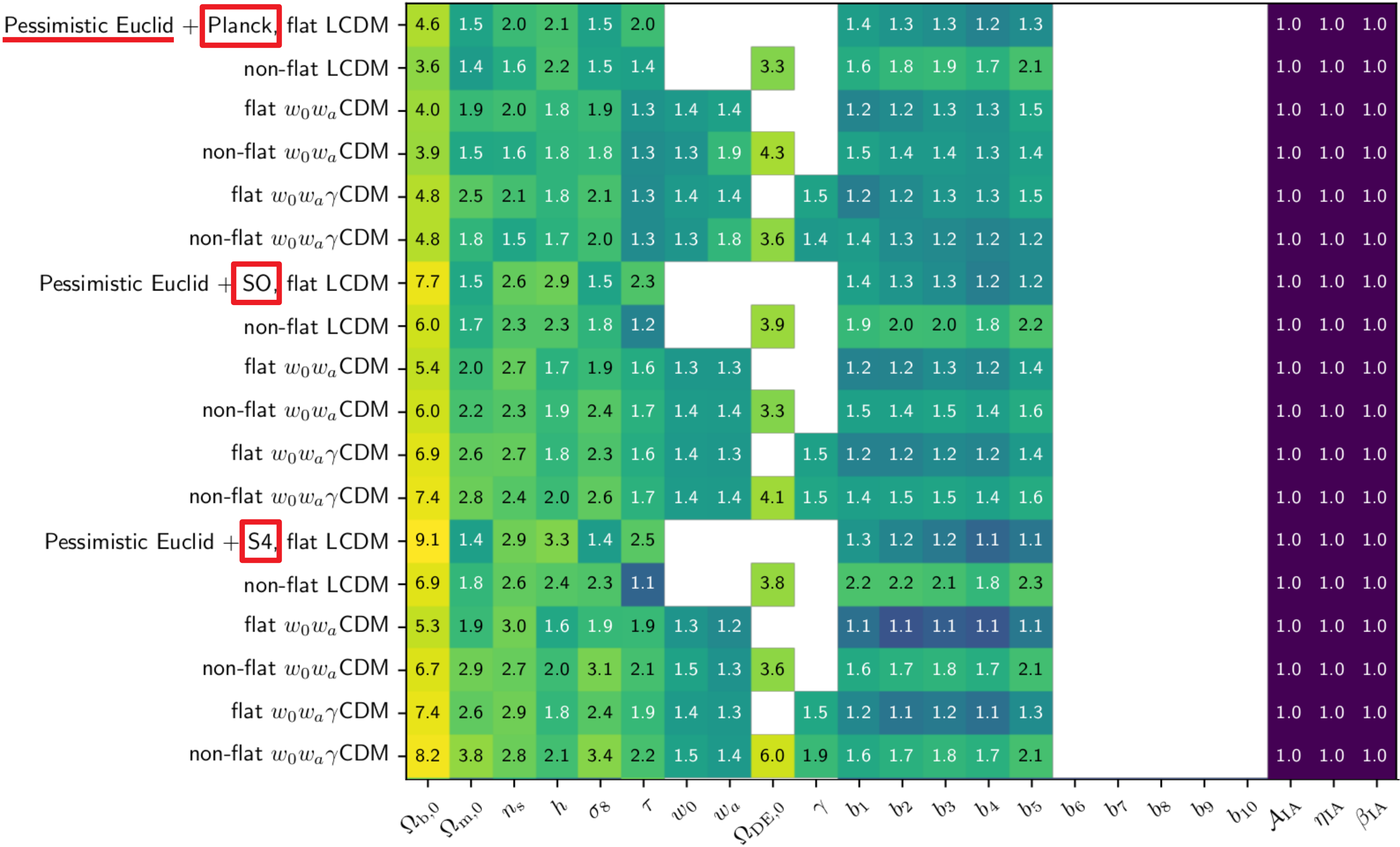
The results: case n°0 to n°2

Euclid (GCp, WL, GCs) only

↓

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

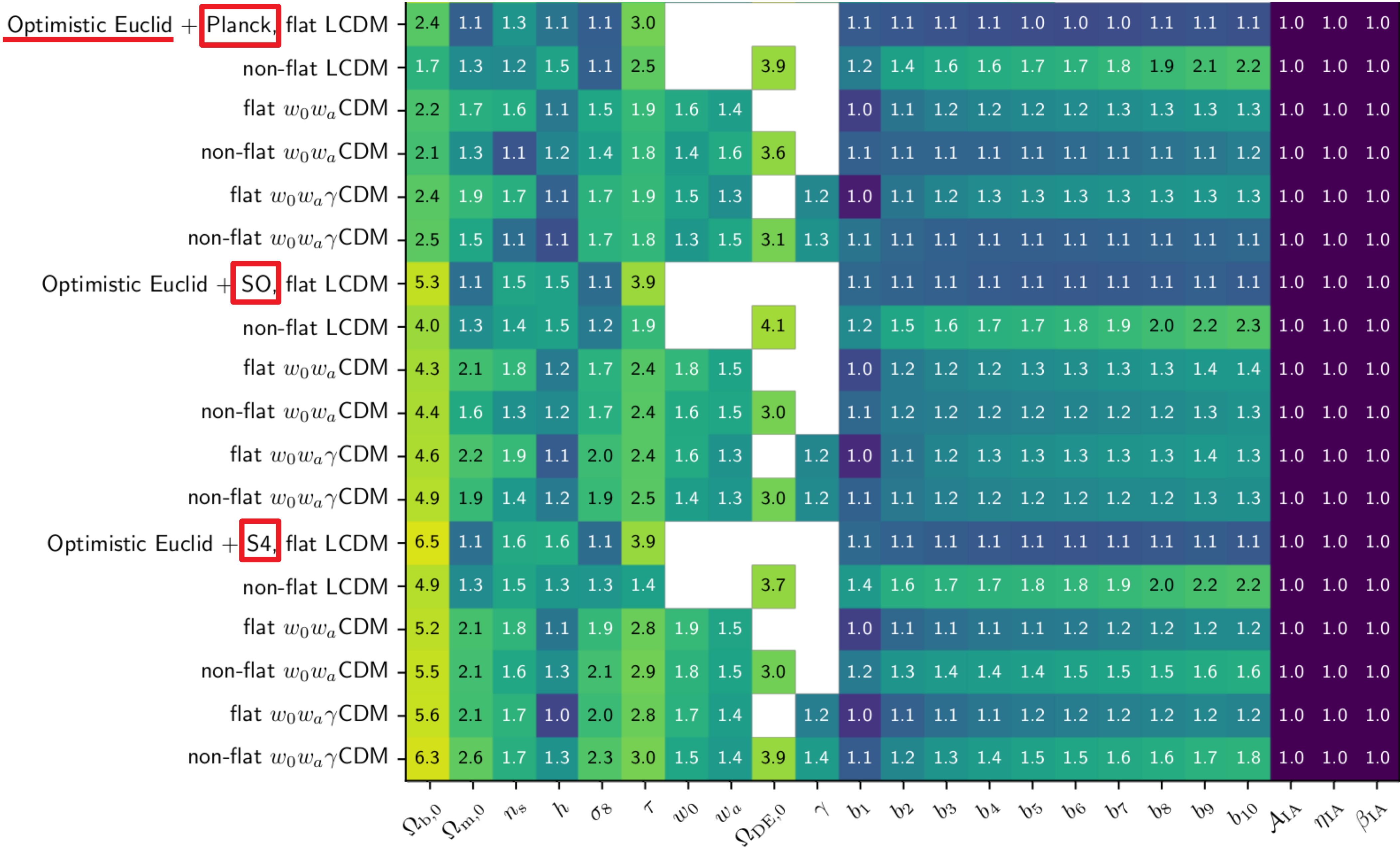
The results: case n°0 to n°2



	$\Omega_{b,0}$	$\Omega_{m,0}$	n_s	h	σ_8	τ	w_0	w_a	$\Omega_{DE,0}$	γ	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}	A_{IA}	η_{IA}	β_{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_0w_aCDM	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_0w_aCDM	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 $w_0w_a\gamma$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 $w_0w_a\gamma$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_0w_aCDM	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_0w_aCDM	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 $w_0w_a\gamma$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 $w_0w_a\gamma$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_0w_aCDM	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_0w_aCDM	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 $w_0w_a\gamma$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 $w_0w_a\gamma$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 = $\sigma_{\text{before}} / \sigma_{\text{after}}$

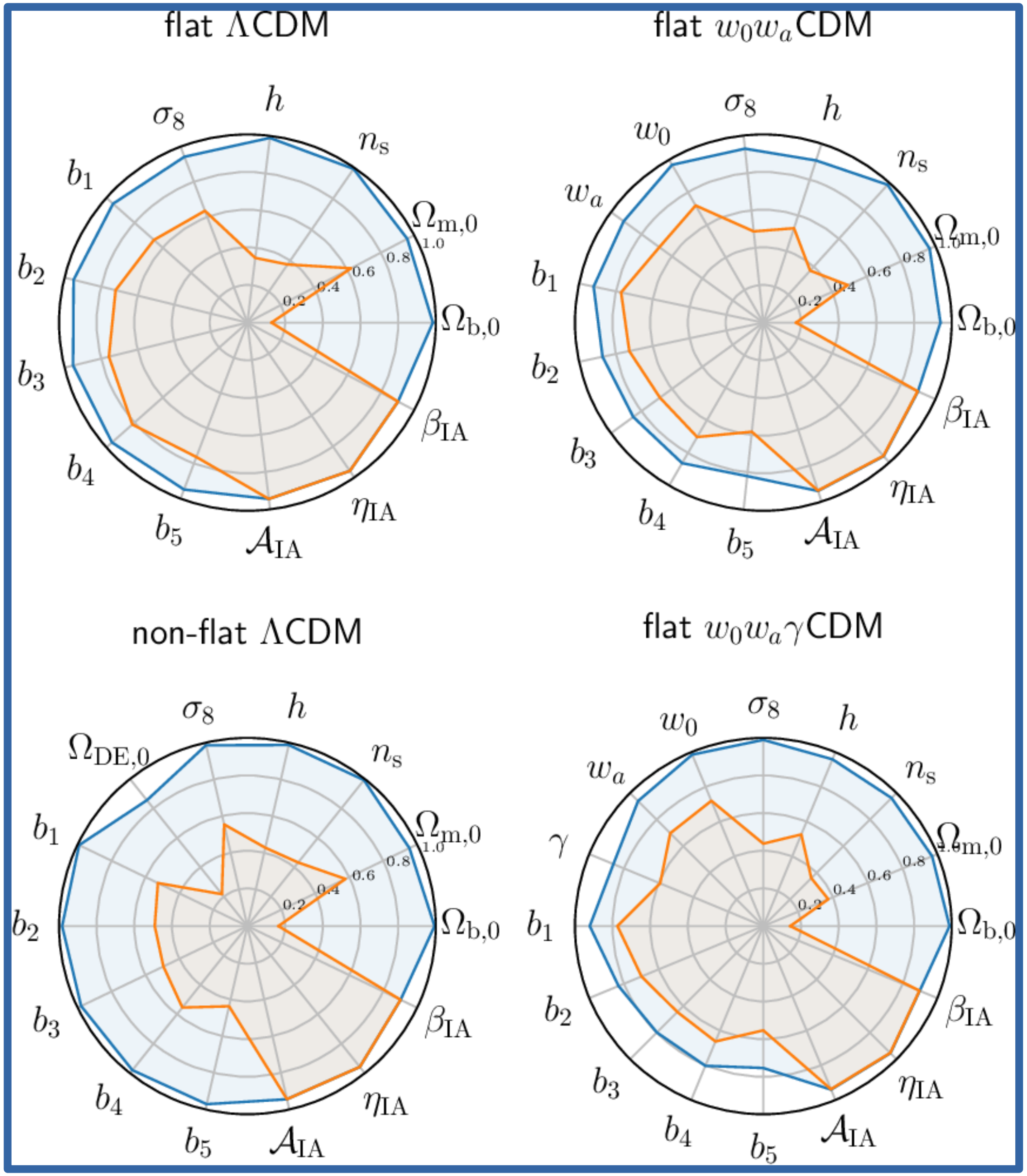
The results: case n°0 to n°2 (cont.)



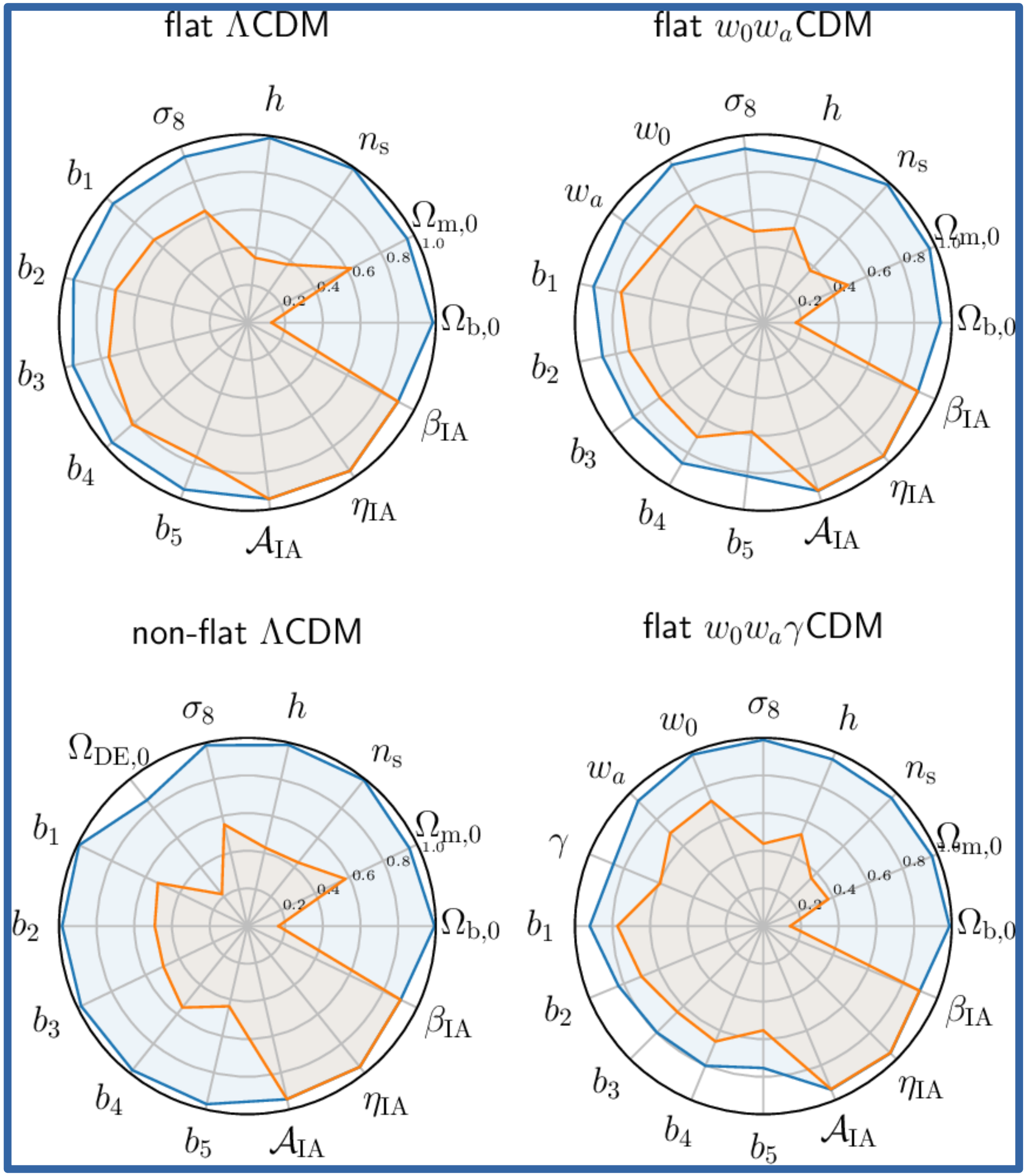
	$\Omega_{b,0}$	$\Omega_{m,0}$	n_s	h	σ_8	τ	w_0	w_a	$\Omega_{DE,0}$	γ	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}	A_{IA}	η_{IA}	β_{IA}
Optimistic Euclid + Planck, flat LCDM	2.4	1.1	1.3	1.1	1.1	3.0					1.1	1.1	1.1	1.1	1.0	1.0	1.0	1.1	1.1	1.1	1.0	1.0	1.0
non-flat LCDM	1.7	1.3	1.2	1.5	1.1	2.5			3.9		1.2	1.4	1.6	1.6	1.7	1.7	1.8	1.9	2.1	2.2	1.0	1.0	1.0
flat w_0w_aCDM	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_0w_aCDM	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 $w_0w_a\gamma$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 $w_0w_a\gamma$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_0w_aCDM	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_0w_aCDM	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 $w_0w_a\gamma$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 $w_0w_a\gamma$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_0w_aCDM	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_0w_aCDM	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 $w_0w_a\gamma$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 $w_0w_a\gamma$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

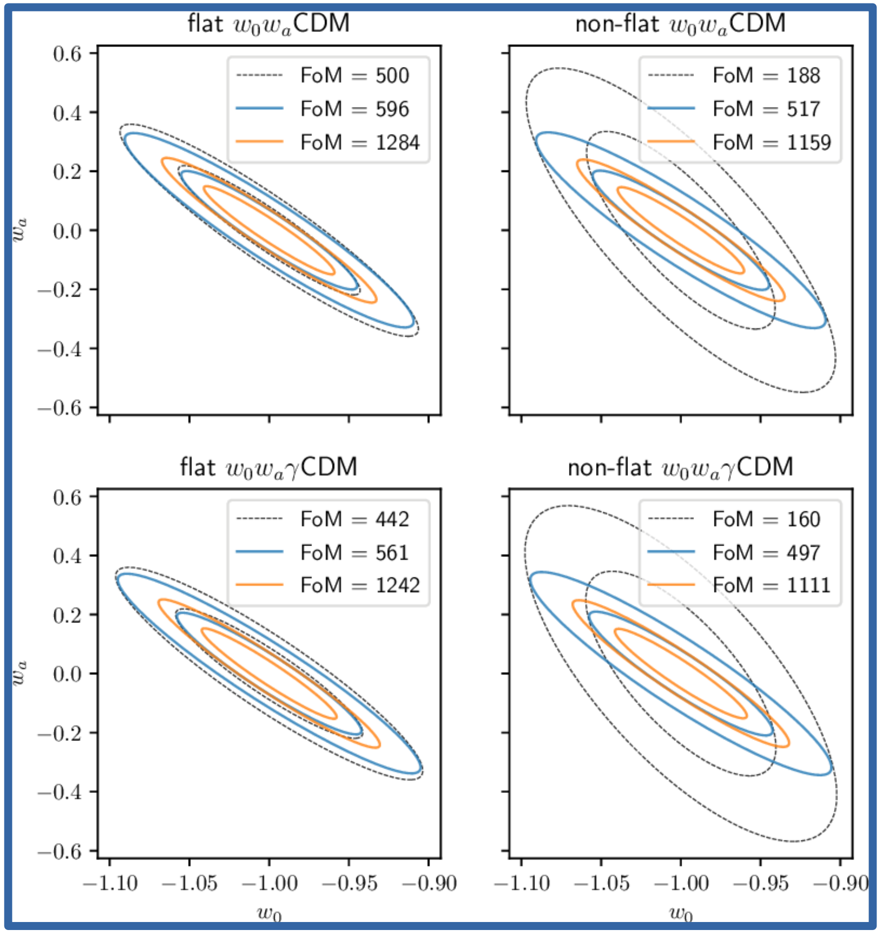
Improvement factors = $\sigma_{before} / \sigma_{after}$

Focus: Pessimistic Euclid + SO

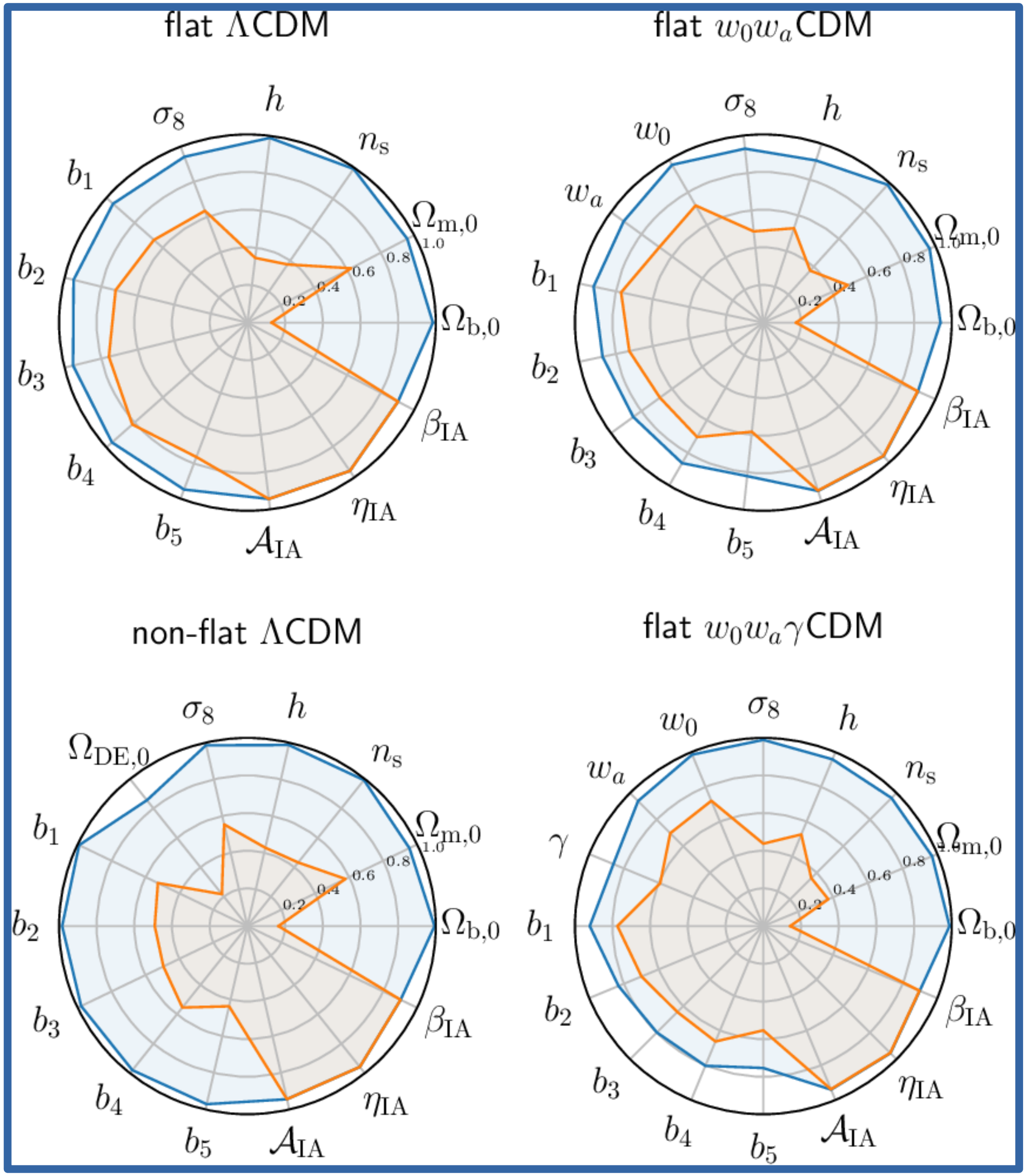


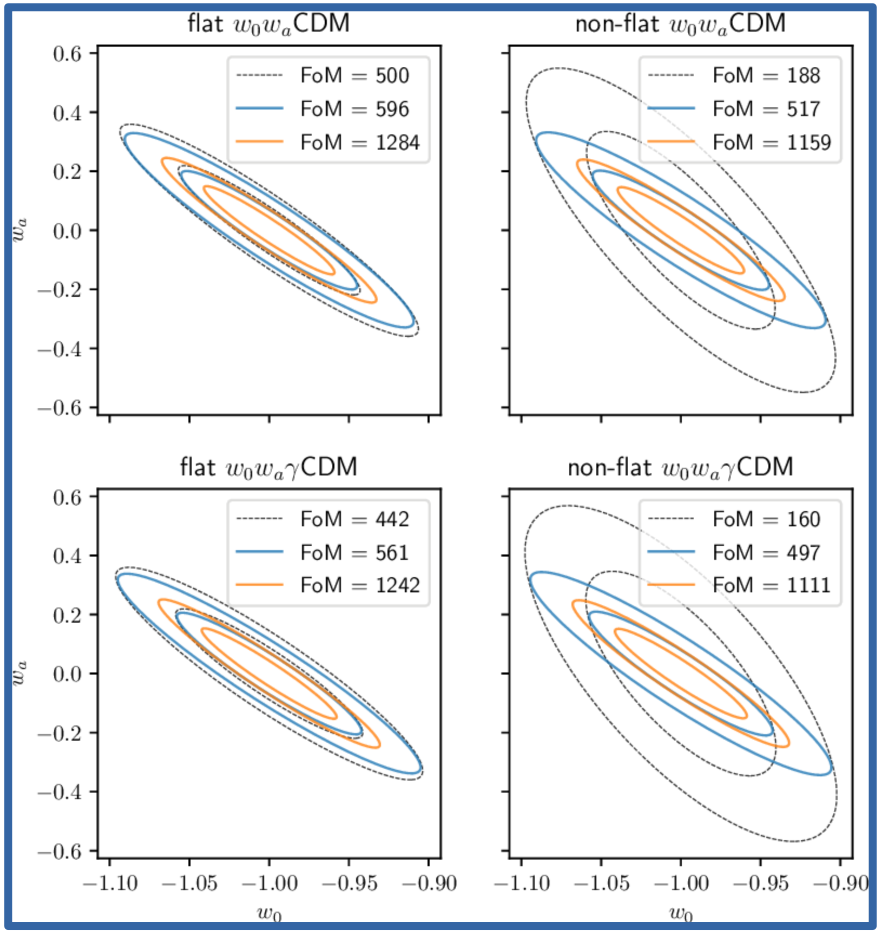
Focus: Pessimistic Euclid + SO

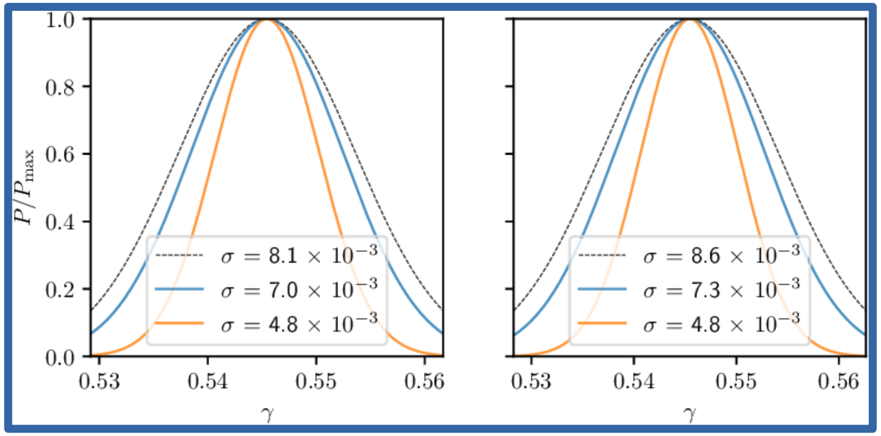




Focus: Pessimistic Euclid + SO

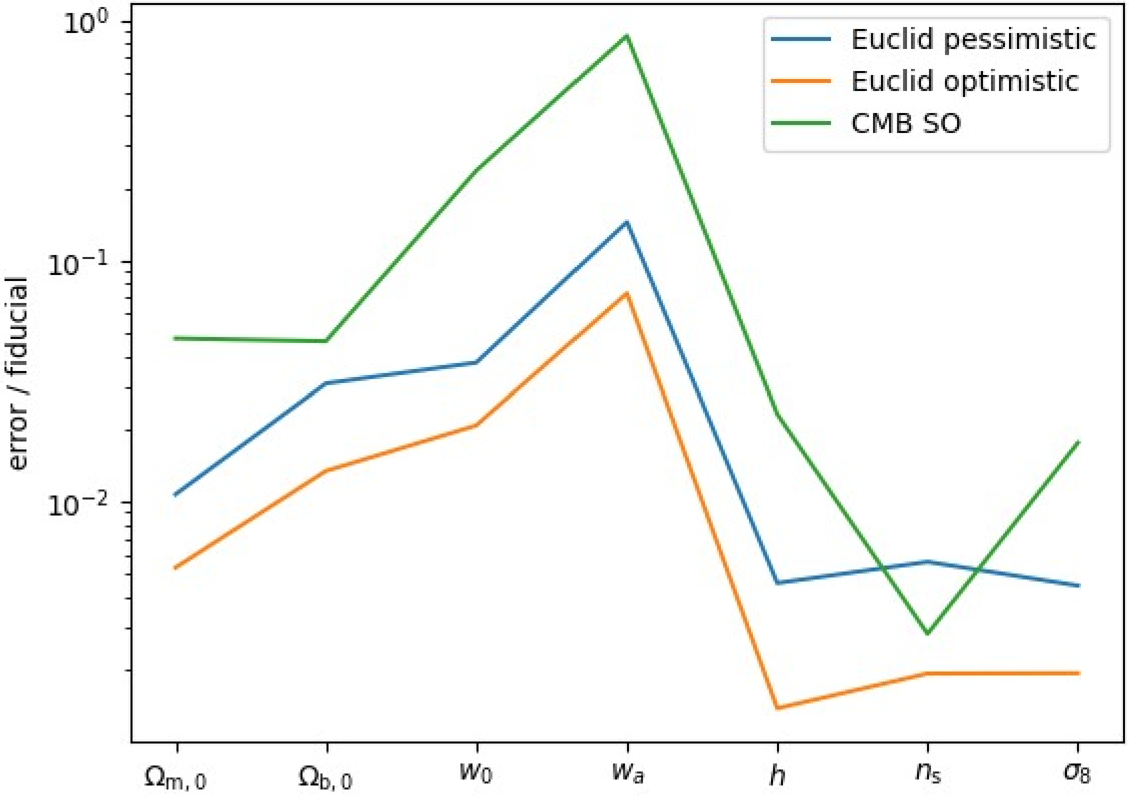






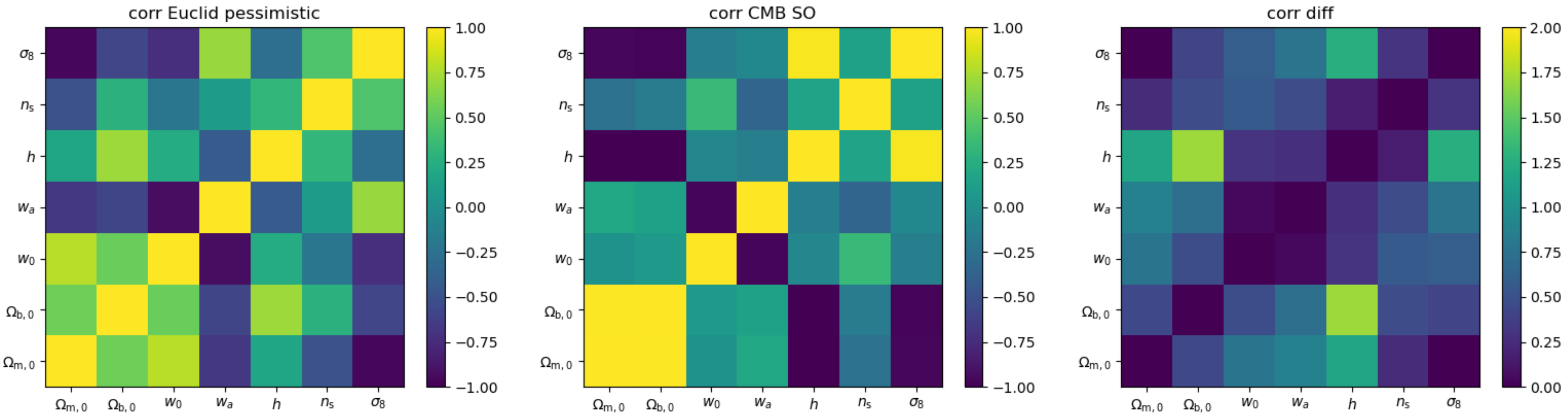
Focus: Pessimistic Euclid + SO

w_0, w_a flat

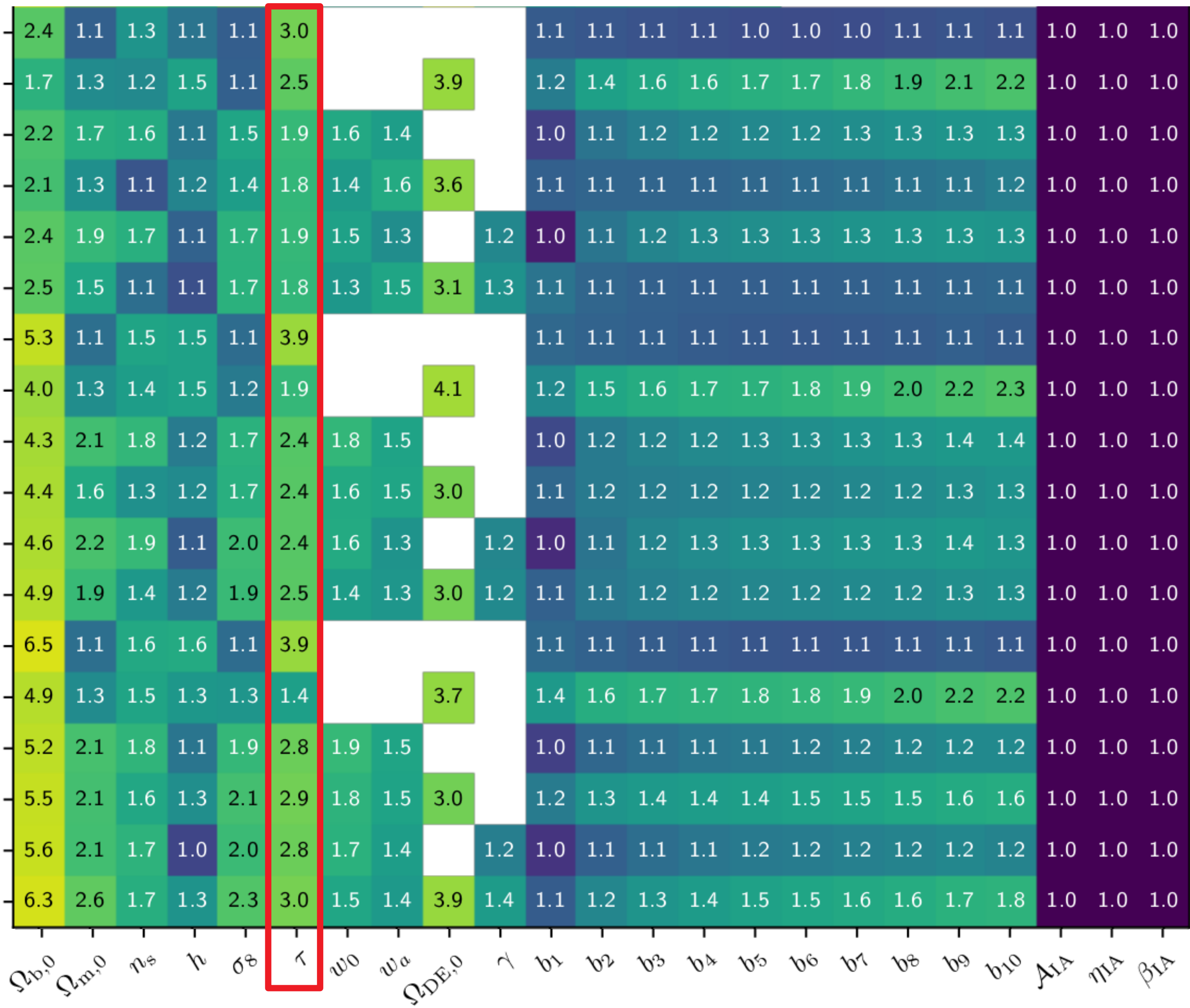


Focus: Pessimistic Euclid + SO

w_0, w_a flat



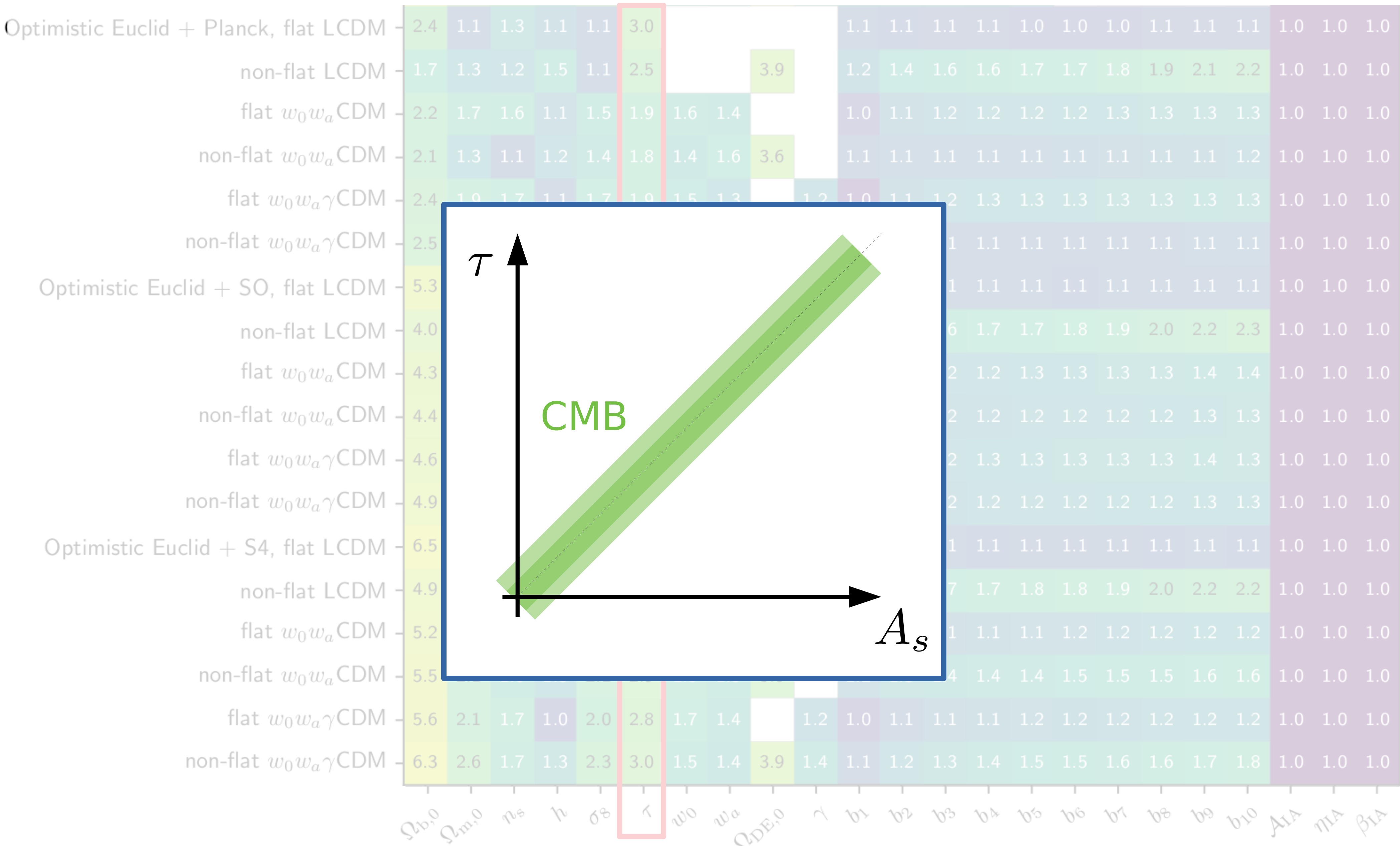
Focus: the tau parameter (case n°0 to 2)



	$\Omega_{b,0}$	$\Omega_{m,0}$	n_s	h	σ_8	τ	w_0	w_a	$\Omega_{DE,0}$	γ	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}	A_{IA}	η_{IA}	β_{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_0w_aCDM	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_0w_aCDM	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 $w_0w_a\gamma$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 $w_0w_a\gamma$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_0w_aCDM	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_0w_aCDM	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 $w_0w_a\gamma$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 $w_0w_a\gamma$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_0w_aCDM	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_0w_aCDM	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 $w_0w_a\gamma$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 $w_0w_a\gamma$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 = $\sigma_{before} / \sigma_{after}$

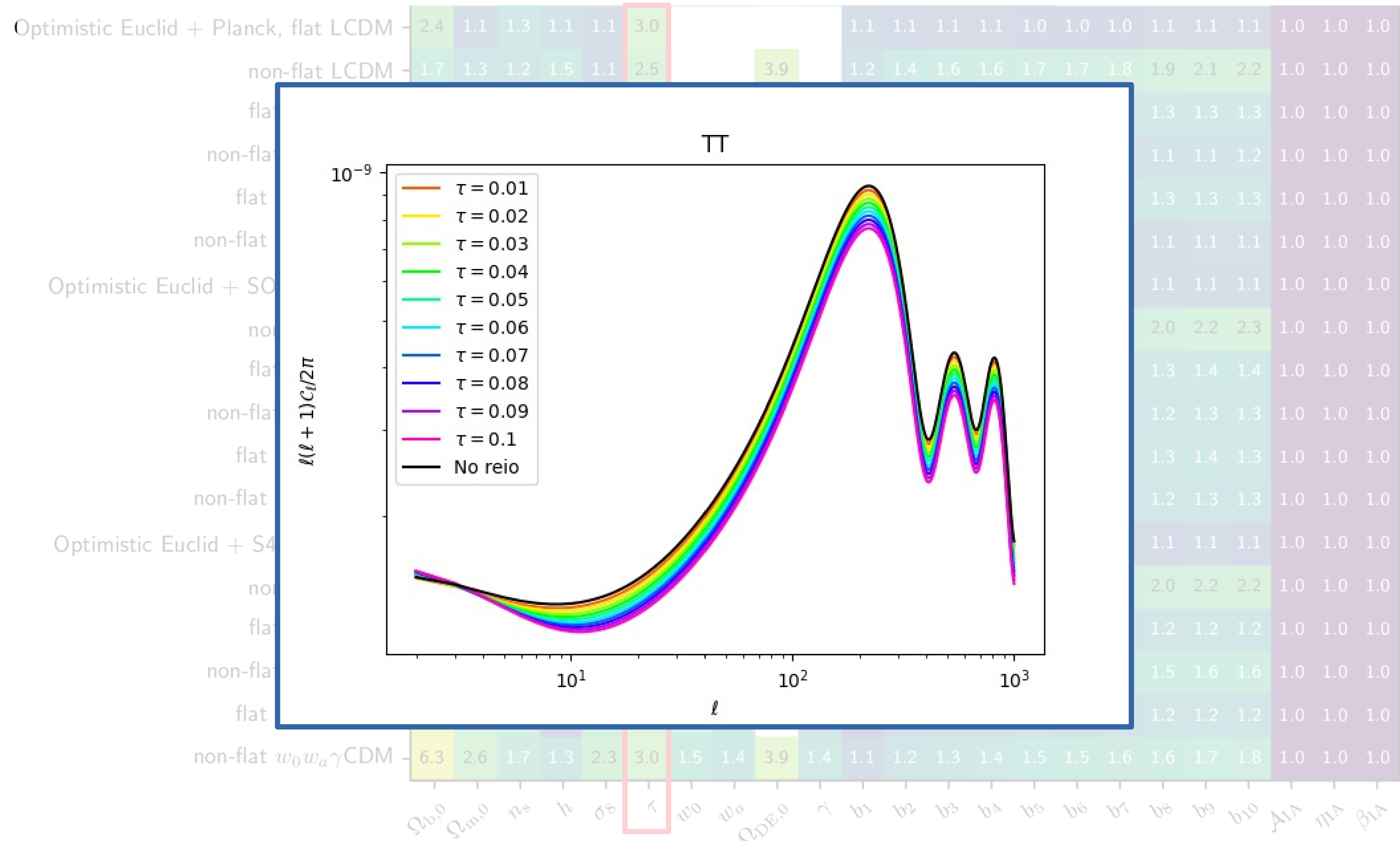
Focus: the tau parameter (case n°0 to 2)



	$\Omega_{b,0}$	$\Omega_{m,0}$	n_s	h	σ_8	τ	w_0	w_a	$\Omega_{DE,0}$	γ	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}	A_{IA}	η_{IA}	β_{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_0w_aCDM	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_0w_aCDM	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 $w_0w_a\gamma$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 $w_0w_a\gamma$CDM	2.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	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	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	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	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.7	1.7	1.8	1.9	2.0	2.2	2.3	1.0	1.0	1.0
flat w_0w_aCDM	4.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.2	1.3	1.3	1.3	1.3	1.4	1.4	1.0	1.0	1.0
non-flat w_0w_aCDM	4.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.0	1.0	1.0
flat $w_0w_a\gamma$CDM	4.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.0	1.0	1.0
non-flat $w_0w_a\gamma$CDM	4.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	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	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	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	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.7	1.8	1.8	1.9	2.0	2.2	2.2	1.0	1.0	1.0
flat w_0w_aCDM	5.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.0	1.0	1.0
non-flat w_0w_aCDM	5.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.4	1.4	1.5	1.5	1.5	1.6	1.6	1.0	1.0	1.0
flat $w_0w_a\gamma$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 $w_0w_a\gamma$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

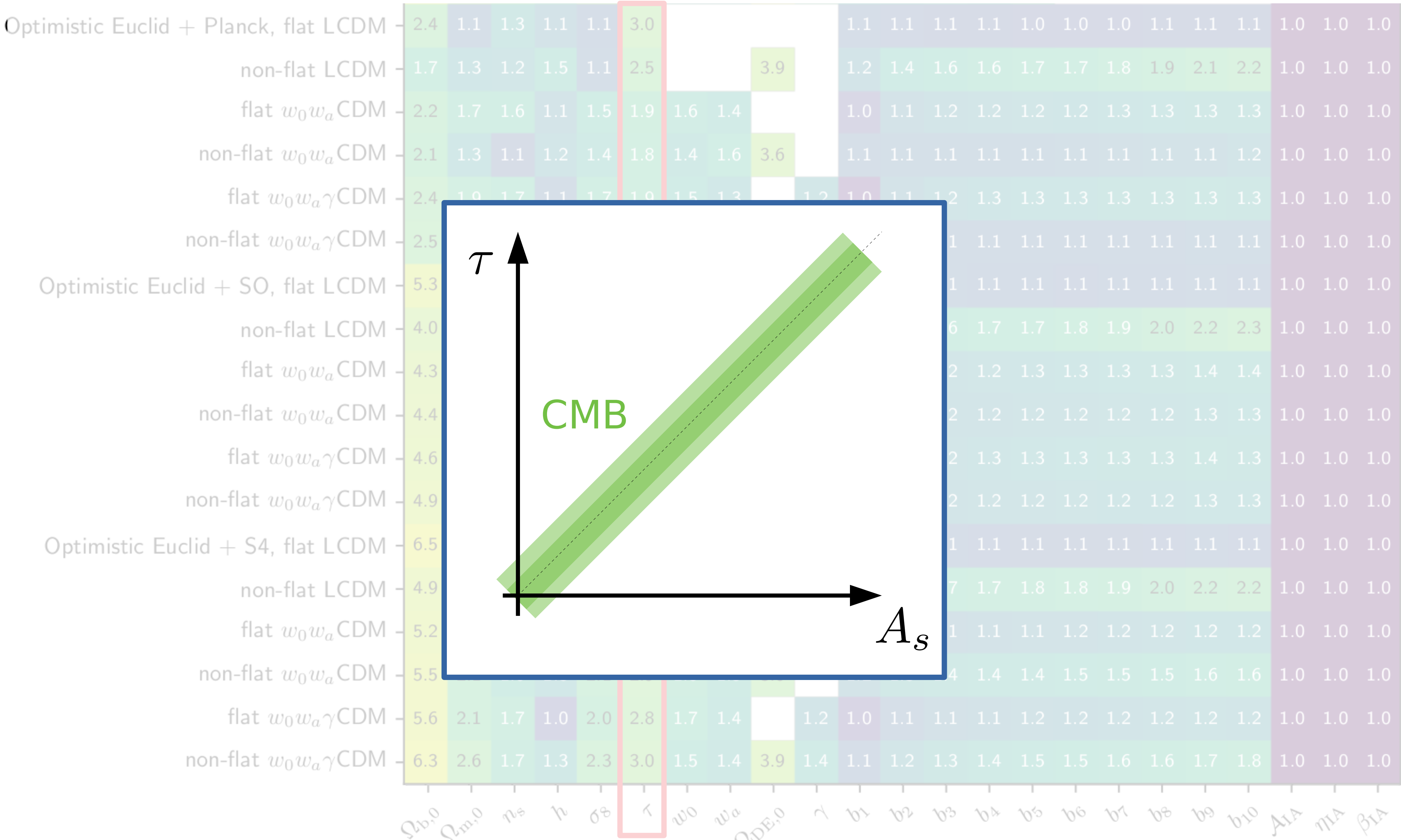
Improvement factors = σ_{before} / σ_{after}

Focus: the tau parameter (case n°0 to 2)



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

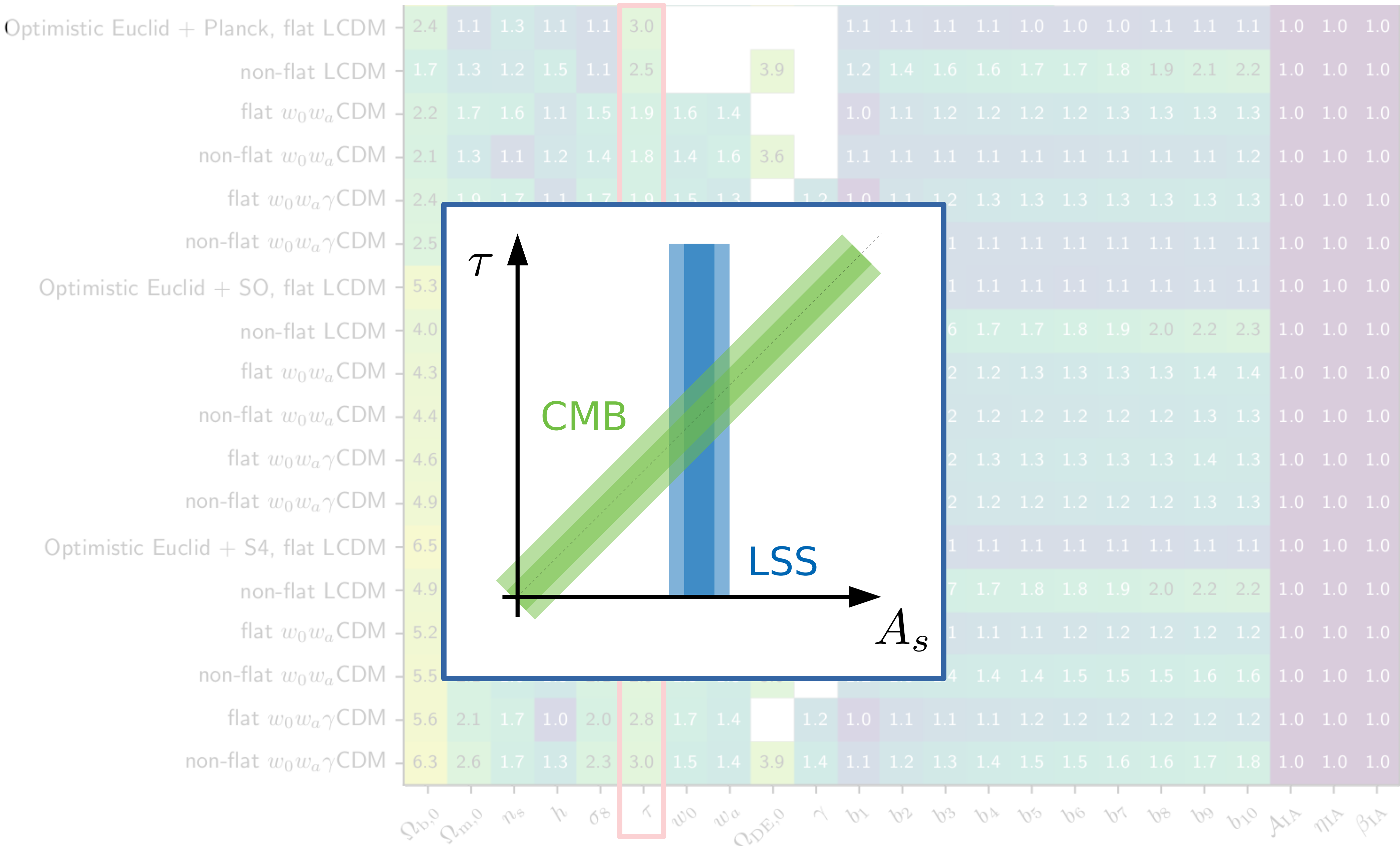
Focus: the tau parameter (case n°0 to 2)



	$\Omega_{b,0}$	$\Omega_{m,0}$	n_s	h	σ_8	τ	w_0	w_a	$\Omega_{DE,0}$	γ	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}	A_{IA}	η_{IA}	β_{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_0w_aCDM	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_0w_aCDM	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 $w_0w_a\gamma$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 $w_0w_a\gamma$CDM	2.5													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	1.1	1.1	1.1	1.1	1.1	1.1	1.0	1.0	1.0
non-flat LCDM	4.0													1.7	1.7	1.8	1.9	2.0	2.2	2.3	1.0	1.0	1.0
flat w_0w_aCDM	4.3													1.2	1.3	1.3	1.3	1.3	1.4	1.4	1.0	1.0	1.0
non-flat w_0w_aCDM	4.4													1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.0	1.0	1.0
flat $w_0w_a\gamma$CDM	4.6													1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.0	1.0	1.0
non-flat $w_0w_a\gamma$CDM	4.9													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	1.1	1.1	1.1	1.1	1.1	1.1	1.0	1.0	1.0
non-flat LCDM	4.9													1.7	1.8	1.8	1.9	2.0	2.2	2.2	1.0	1.0	1.0
flat w_0w_aCDM	5.2													1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.0	1.0	1.0
non-flat w_0w_aCDM	5.5													1.4	1.4	1.5	1.5	1.5	1.6	1.6	1.0	1.0	1.0
flat $w_0w_a\gamma$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 $w_0w_a\gamma$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: the tau parameter (case n°0 to 2)

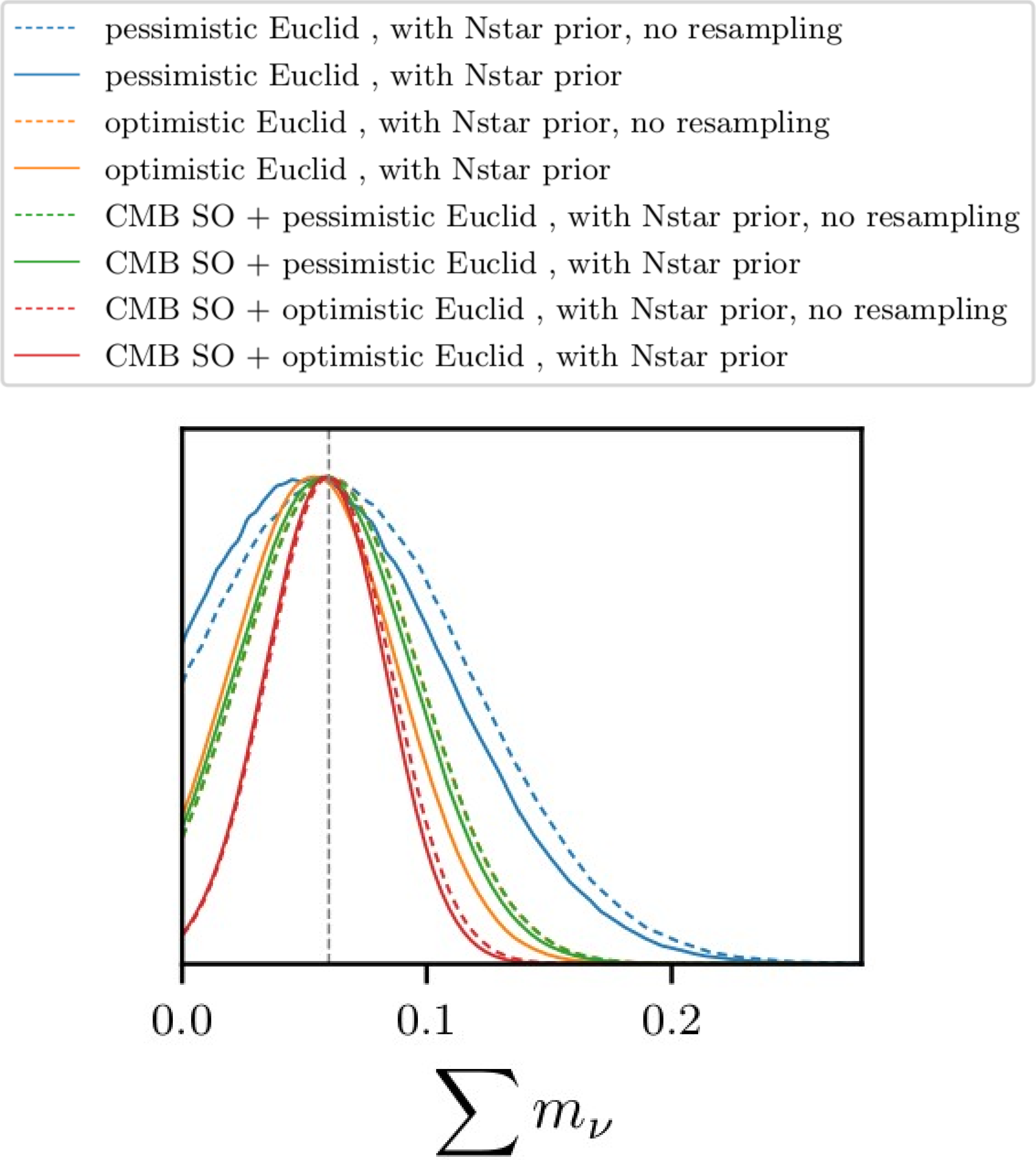


	$\Omega_{b,0}$	$\Omega_{m,0}$	n_s	h	σ_8	τ	w_0	w_a	$\Omega_{DE,0}$	γ	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}	A_{IA}	η_{IA}	β_{IA}
Optimistic Euclid + Planck, flat LCDM	2.4	1.1	1.3	1.1	1.1	3.0					1.1	1.1	1.1	1.1	1.0	1.0	1.0	1.1	1.1	1.1	1.0	1.0	1.0
non-flat LCDM	1.7	1.3	1.2	1.5	1.1	2.5			3.9		1.2	1.4	1.6	1.6	1.7	1.7	1.8	1.9	2.1	2.2	1.0	1.0	1.0
flat w_0w_aCDM	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_0w_aCDM	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 $w_0w_a\gamma$CDM	2.4													1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.0	1.0	1.0
non-flat $w_0w_a\gamma$CDM	2.5													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	1.1	1.1	1.1	1.1	1.1	1.1	1.0	1.0	1.0
non-flat LCDM	4.0													1.7	1.7	1.8	1.9	2.0	2.2	2.3	1.0	1.0	1.0
flat w_0w_aCDM	4.3													1.2	1.3	1.3	1.3	1.3	1.4	1.4	1.0	1.0	1.0
non-flat w_0w_aCDM	4.4													1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.0	1.0	1.0
flat $w_0w_a\gamma$CDM	4.6													1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.0	1.0	1.0
non-flat $w_0w_a\gamma$CDM	4.9													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	1.1	1.1	1.1	1.1	1.1	1.1	1.0	1.0	1.0
non-flat LCDM	4.9													1.7	1.8	1.8	1.9	2.0	2.2	2.2	1.0	1.0	1.0
flat w_0w_aCDM	5.2													1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.0	1.0	1.0
non-flat w_0w_aCDM	5.5													1.4	1.4	1.5	1.5	1.5	1.6	1.6	1.0	1.0	1.0
flat $w_0w_a\gamma$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 $w_0w_a\gamma$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 = $\sigma_{before} / \sigma_{after}$

Focus: sum of neutrino masses

Focus: sum of neutrino masses



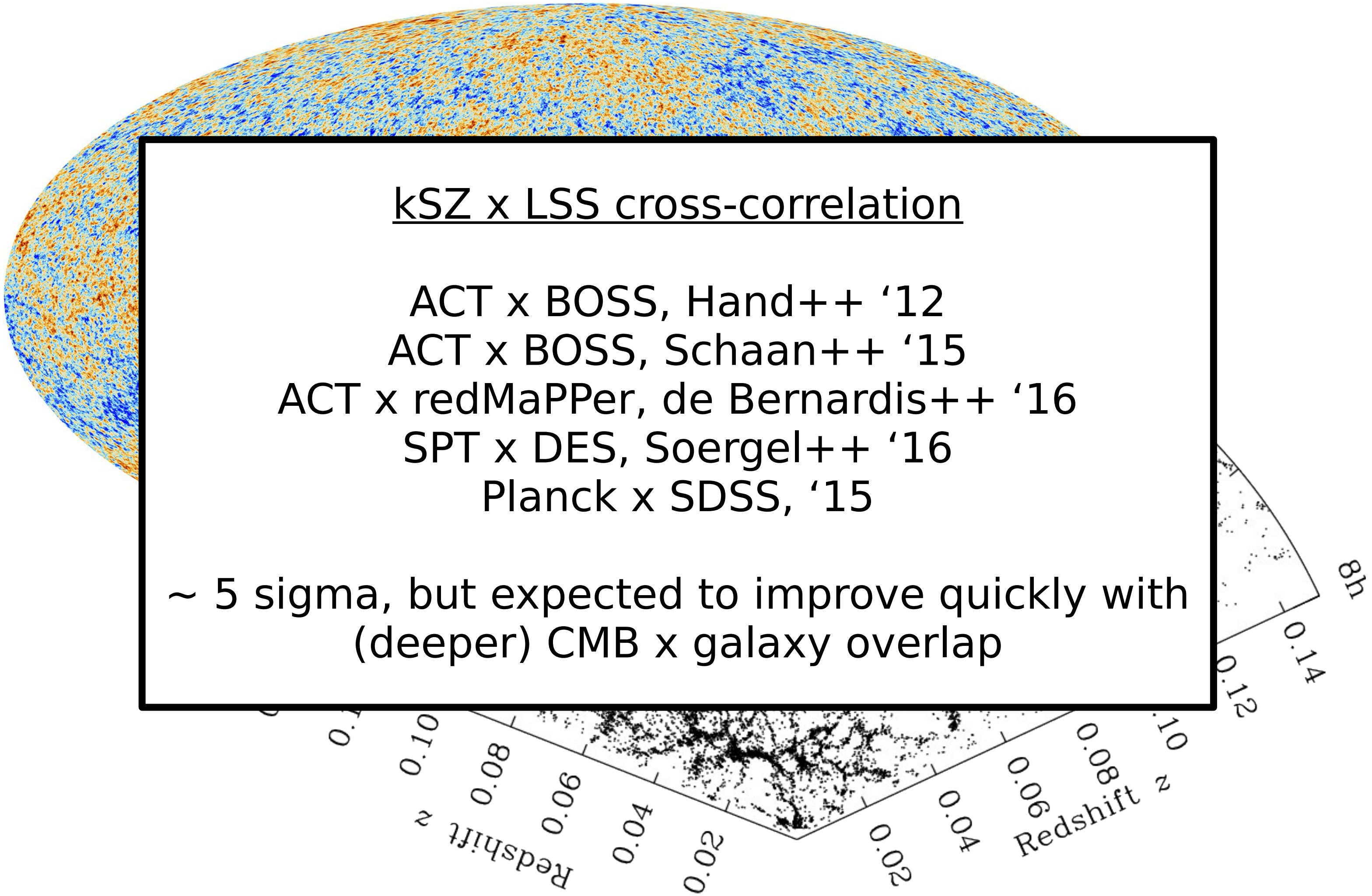
Areas of improvement

- 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)

kSZ x LSS



<u>kSZ x LSS cross-correlation</u>

ACT x BOSS, Hand++ ‘12
ACT x BOSS, Schaan++ ‘15
ACT x redMaPPer, de Bernardis++ ‘16
SPT x DES, Soergel++ ‘16
Planck x SDSS, ‘15

~ 5 sigma, but expected to improve quickly with (deeper) CMB x galaxy overlap

iSW: even with a low S/N...

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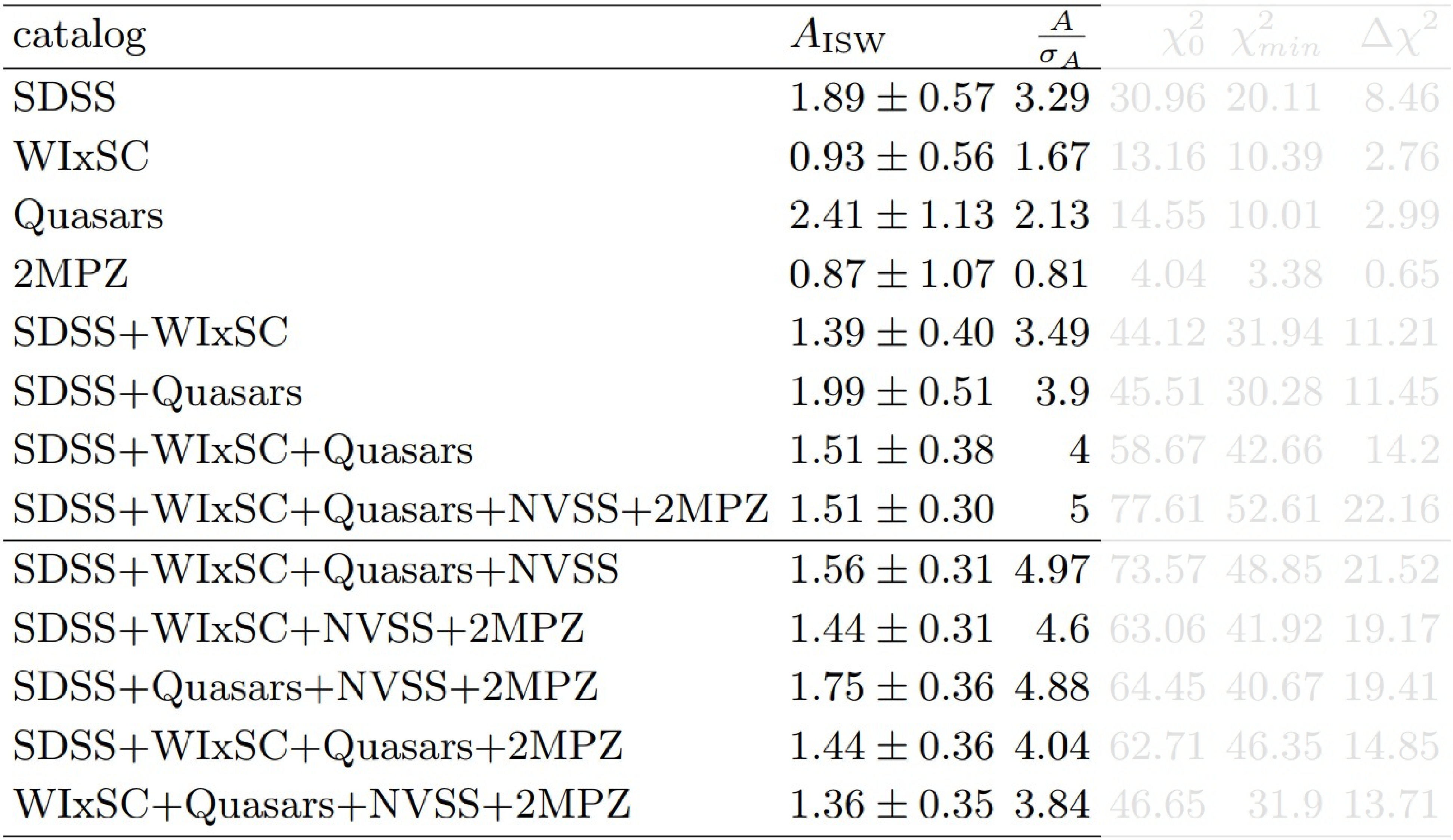
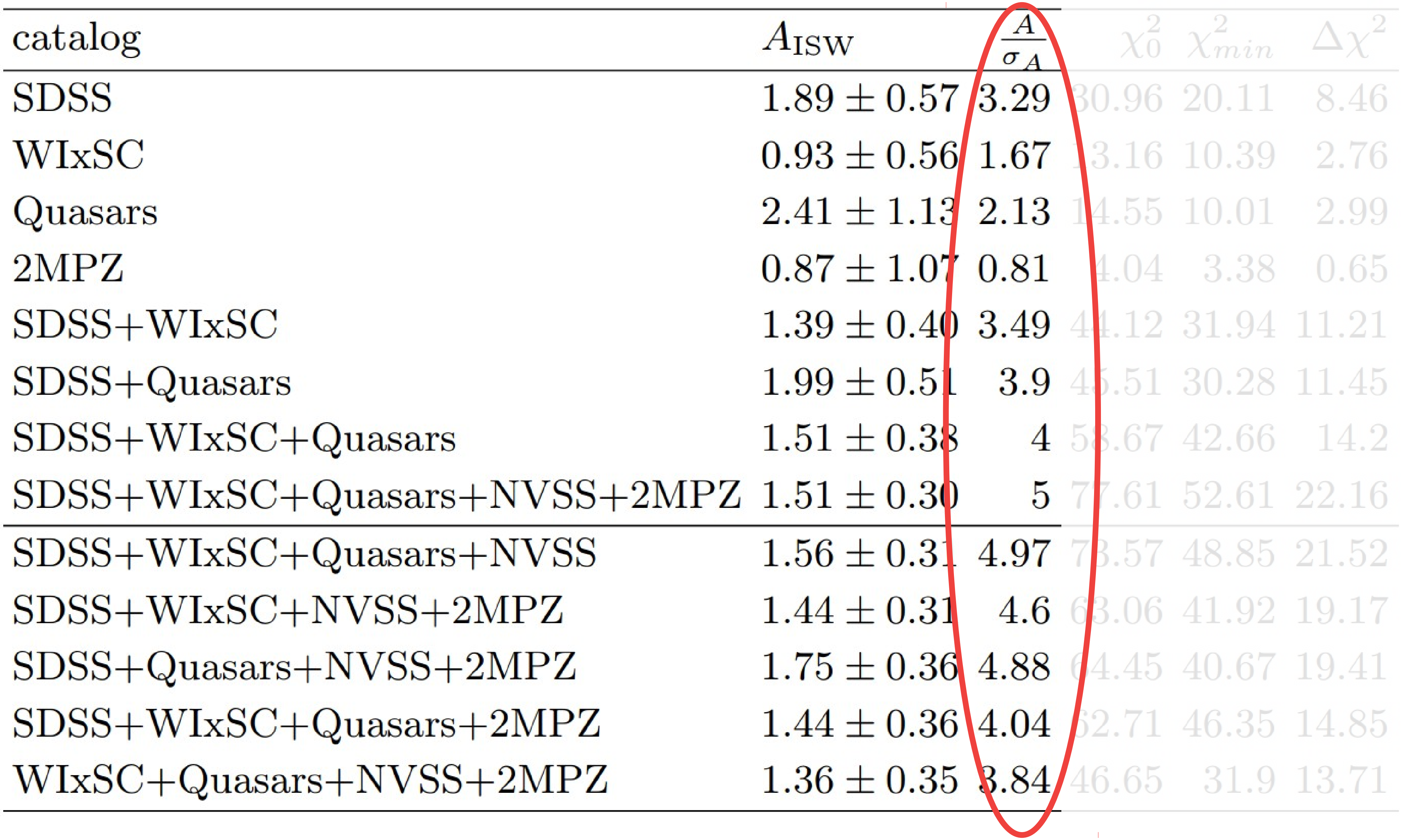


catalog	A_{ISW}	$\frac{A}{\sigma_A}$	χ_0^2	χ_{min}^2	$\Delta\chi^2$
SDSS	1.89 ± 0.57	3.29	30.96	20.11	8.46
WIxSC	0.93 ± 0.56	1.67	13.16	10.39	2.76
Quasars	2.41 ± 1.13	2.13	14.55	10.01	2.99
2MPZ	0.87 ± 1.07	0.81	4.04	3.38	0.65
SDSS+WIxSC	1.39 ± 0.40	3.49	44.12	31.94	11.21
SDSS+Quasars	1.99 ± 0.51	3.9	45.51	30.28	11.45
SDSS+WIxSC+Quasars	1.51 ± 0.38	4	58.67	42.66	14.2
SDSS+WIxSC+Quasars+NVSS+2MPZ	1.51 ± 0.30	5	77.61	52.61	22.16
SDSS+WIxSC+Quasars+NVSS	1.56 ± 0.31	4.97	73.57	48.85	21.52
SDSS+WIxSC+NVSS+2MPZ	1.44 ± 0.31	4.6	63.06	41.92	19.17
SDSS+Quasars+NVSS+2MPZ	1.75 ± 0.36	4.88	64.45	40.67	19.41
SDSS+WIxSC+Quasars+2MPZ	1.44 ± 0.36	4.04	62.71	46.35	14.85
WIxSC+Quasars+NVSS+2MPZ	1.36 ± 0.35	3.84	46.65	31.9	13.71

iSW: even with a low S/N...

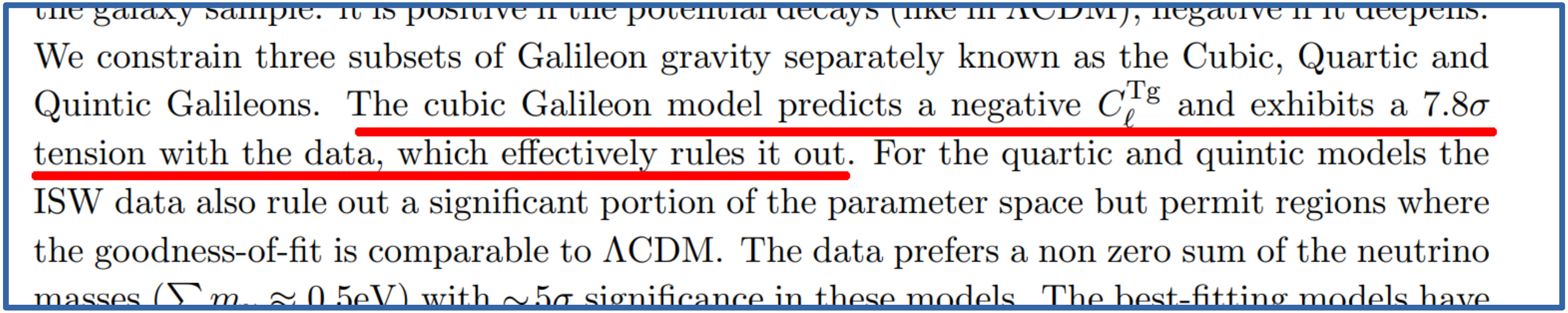
Stölzner et al. 2018



catalog	$A_{\rm ISW}$	$\frac{A}{\sigma_A}$	χ_0^2	χ_{min}^2	$\Delta\chi^2$
SDSS	1.89 ± 0.57	3.29	30.96	20.11	8.46
WIxSC	0.93 ± 0.56	1.67	13.16	10.39	2.76
Quasars	2.41 ± 1.13	2.13	14.55	10.01	2.99
2MPZ	0.87 ± 1.07	0.81	4.04	3.38	0.65
SDSS+WIxSC	1.39 ± 0.40	3.49	44.12	31.94	11.21
SDSS+Quasars	1.99 ± 0.51	3.9	45.51	30.28	11.45
SDSS+WIxSC+Quasars	1.51 ± 0.38	4	58.67	42.66	14.2
SDSS+WIxSC+Quasars+NVSS+2MPZ	1.51 ± 0.30	5	77.61	52.61	22.16
SDSS+WIxSC+Quasars+NVSS	1.56 ± 0.31	4.97	73.57	48.85	21.52
SDSS+WIxSC+NVSS+2MPZ	1.44 ± 0.31	4.6	63.06	41.92	19.17
SDSS+Quasars+NVSS+2MPZ	1.75 ± 0.36	4.88	64.45	40.67	19.41
SDSS+WIxSC+Quasars+2MPZ	1.44 ± 0.36	4.04	62.71	46.35	14.85
WIxSC+Quasars+NVSS+2MPZ	1.36 ± 0.35	3.84	46.65	31.9	13.71

...already stringent constraints on MG

From arXiv:1707.02263
Galileon Gravity in Light of ISW, CMB, BAO and H0 data

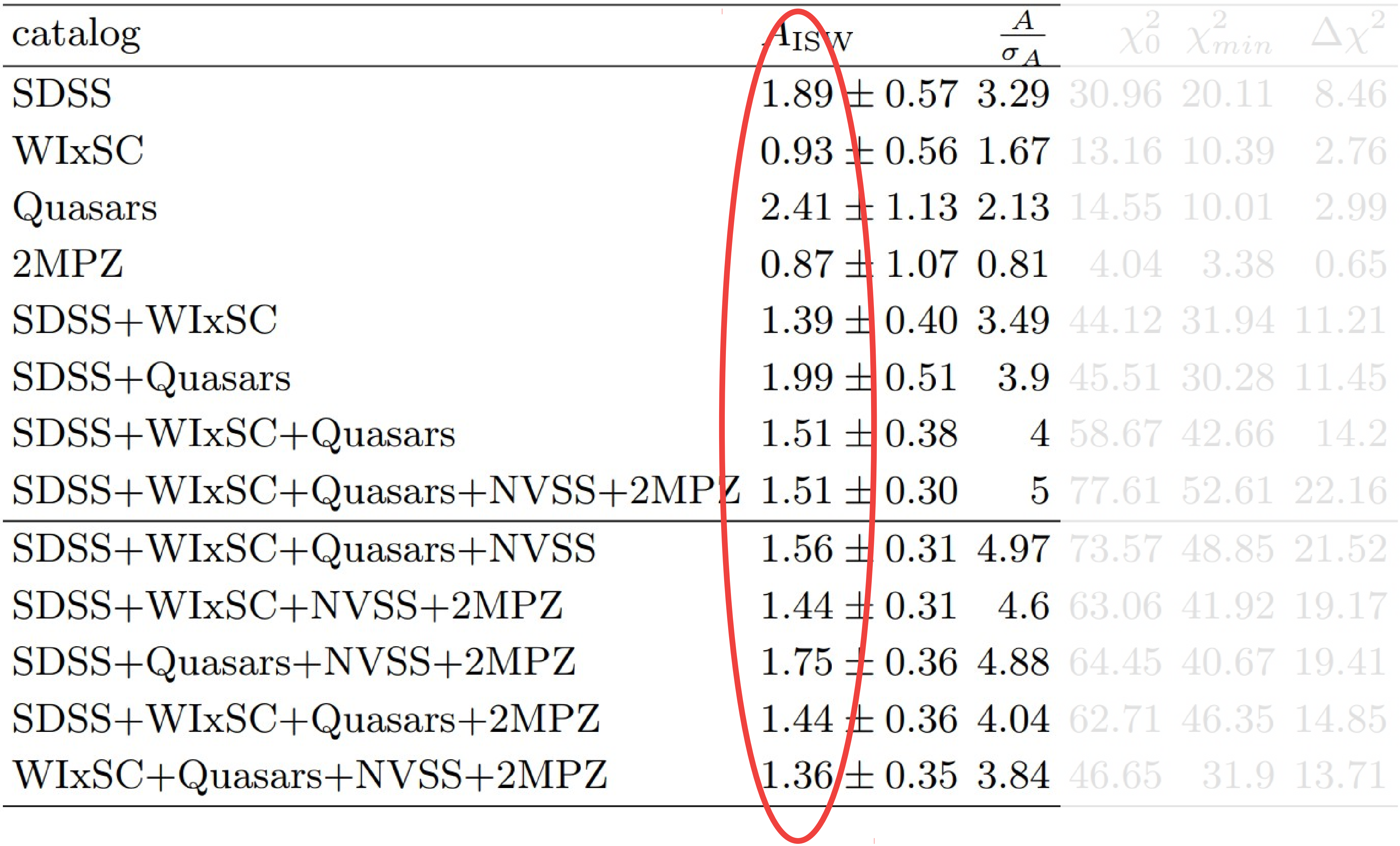


the galaxy sample. It is positive if the potential decays (like in ΛCDM), negative if it deepens. We constrain three subsets of Galileon gravity separately known as the Cubic, Quartic and Quintic Galileons. The cubic Galileon model predicts a negative C_ℓ^{Tg} and exhibits a 7.8σ tension with the data, which effectively rules it out. For the quartic and quintic models the ISW data also rule out a significant portion of the parameter space but permit regions where the goodness-of-fit is comparable to ΛCDM. The data prefers a non zero sum of the neutrino masses ($\sum m_\nu \approx 0.5$eV) with $\sim 5\sigma$ significance in these models. The best-fitting models have

...one month before GW170817 !

Beyond LCDM hints ?

Stölzner et al. 2018



catalog	A_{ISW}	$\frac{A}{\sigma_A}$	χ_0^2	χ_{min}^2	$\Delta\chi^2$
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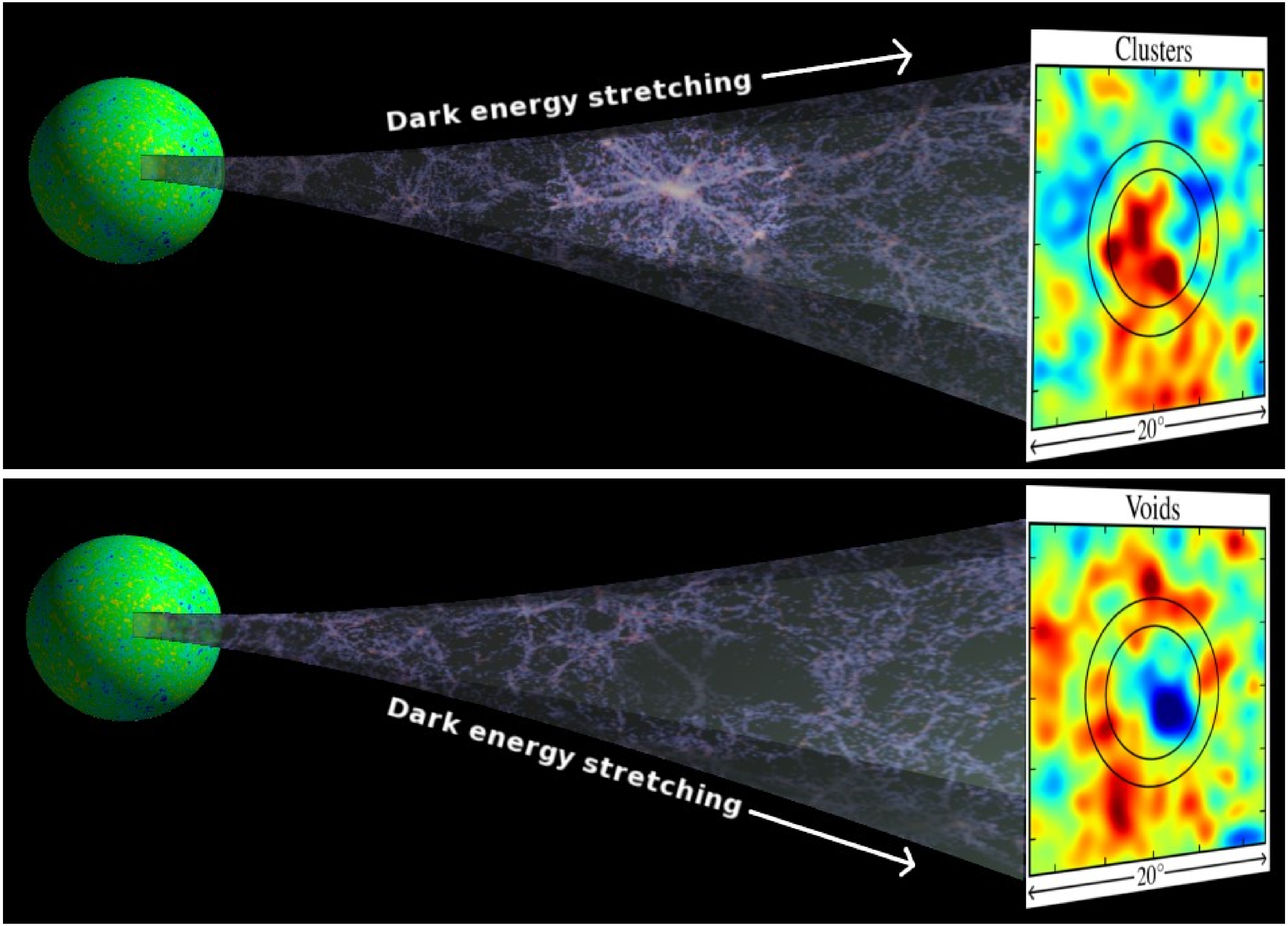
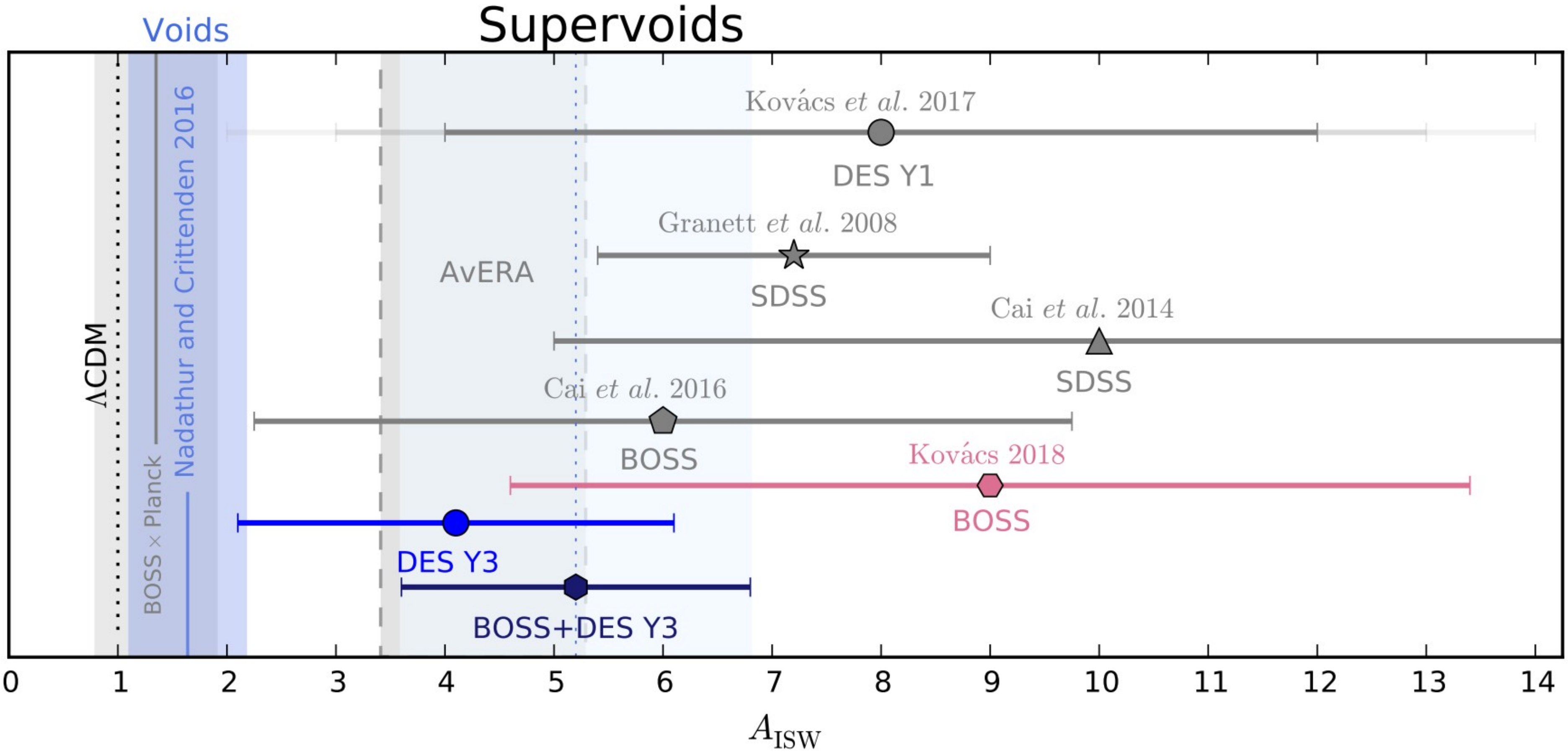
iSW effect of superstructures

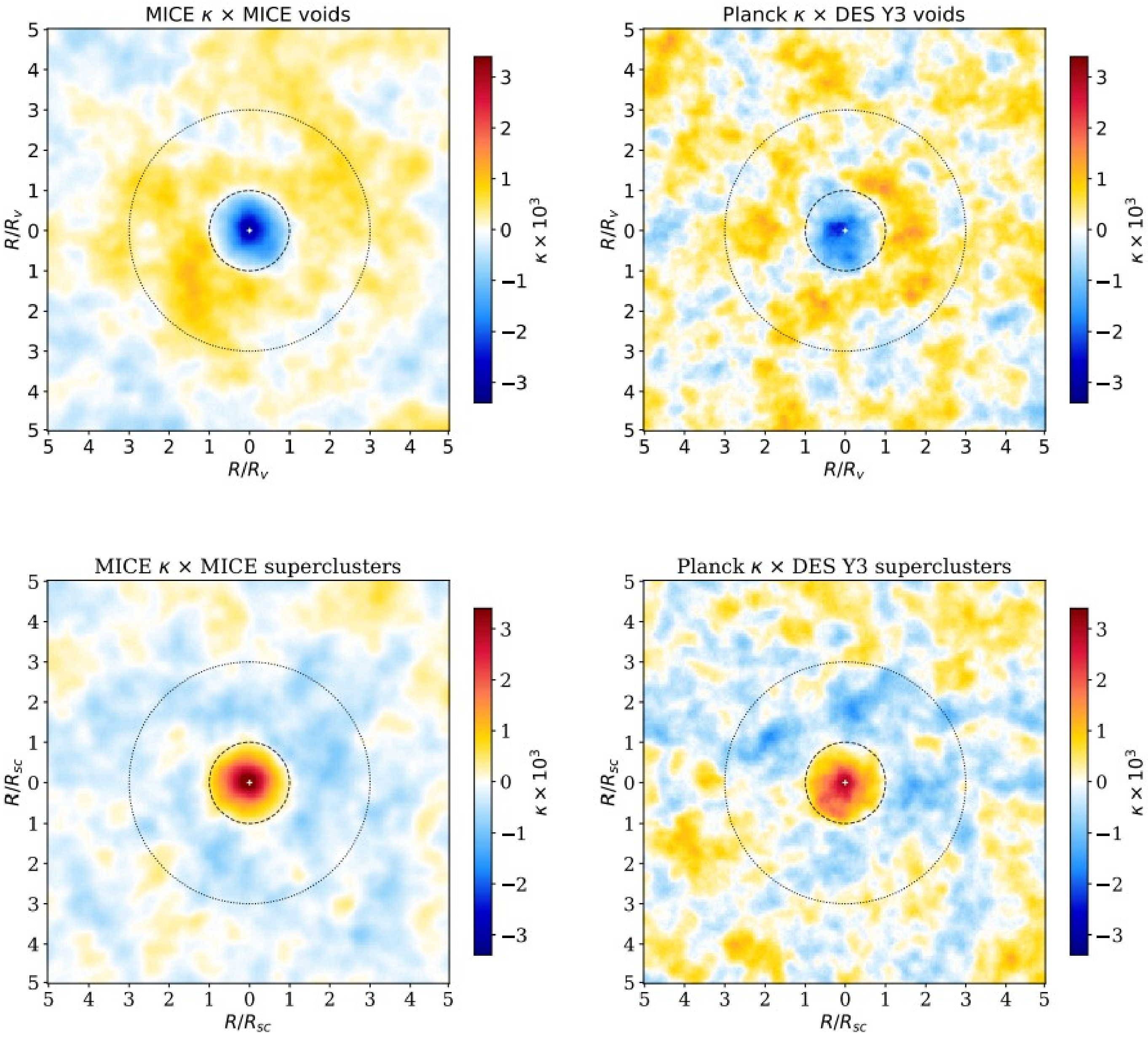


iSW effect of superstructures



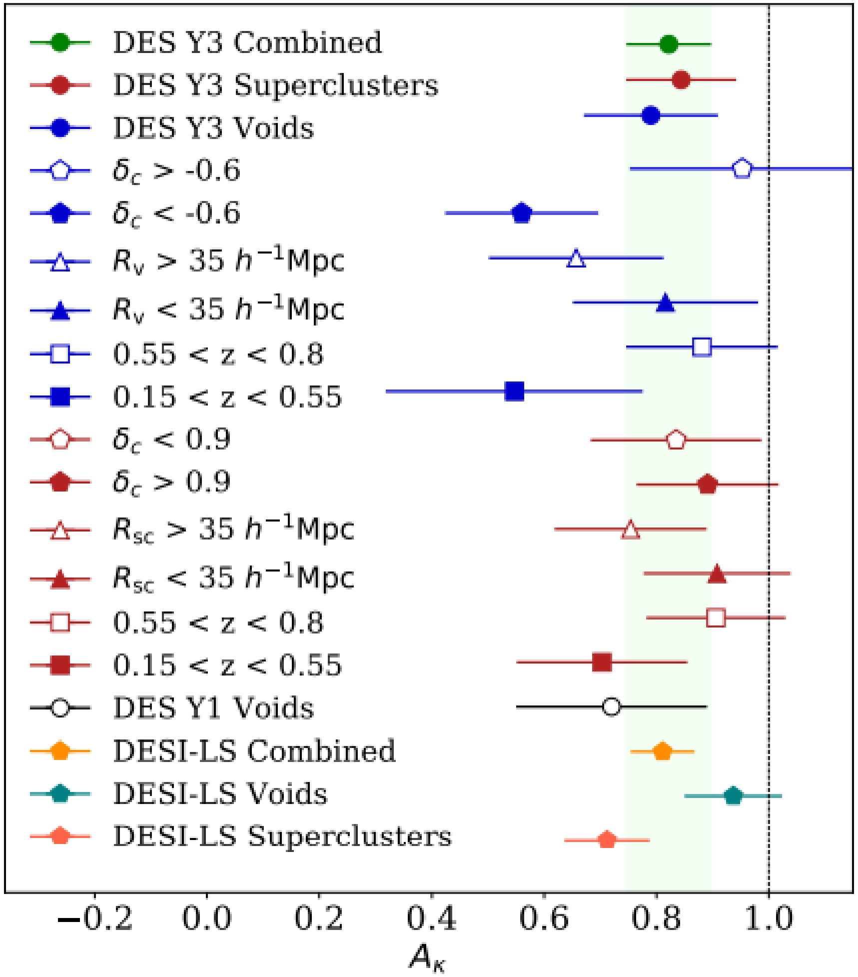
Kovács et al. 2019

Lensing effect of superstructures



Kovács et al. 2022

Lensing effect of superstructures



Kovács et al. 2022

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)

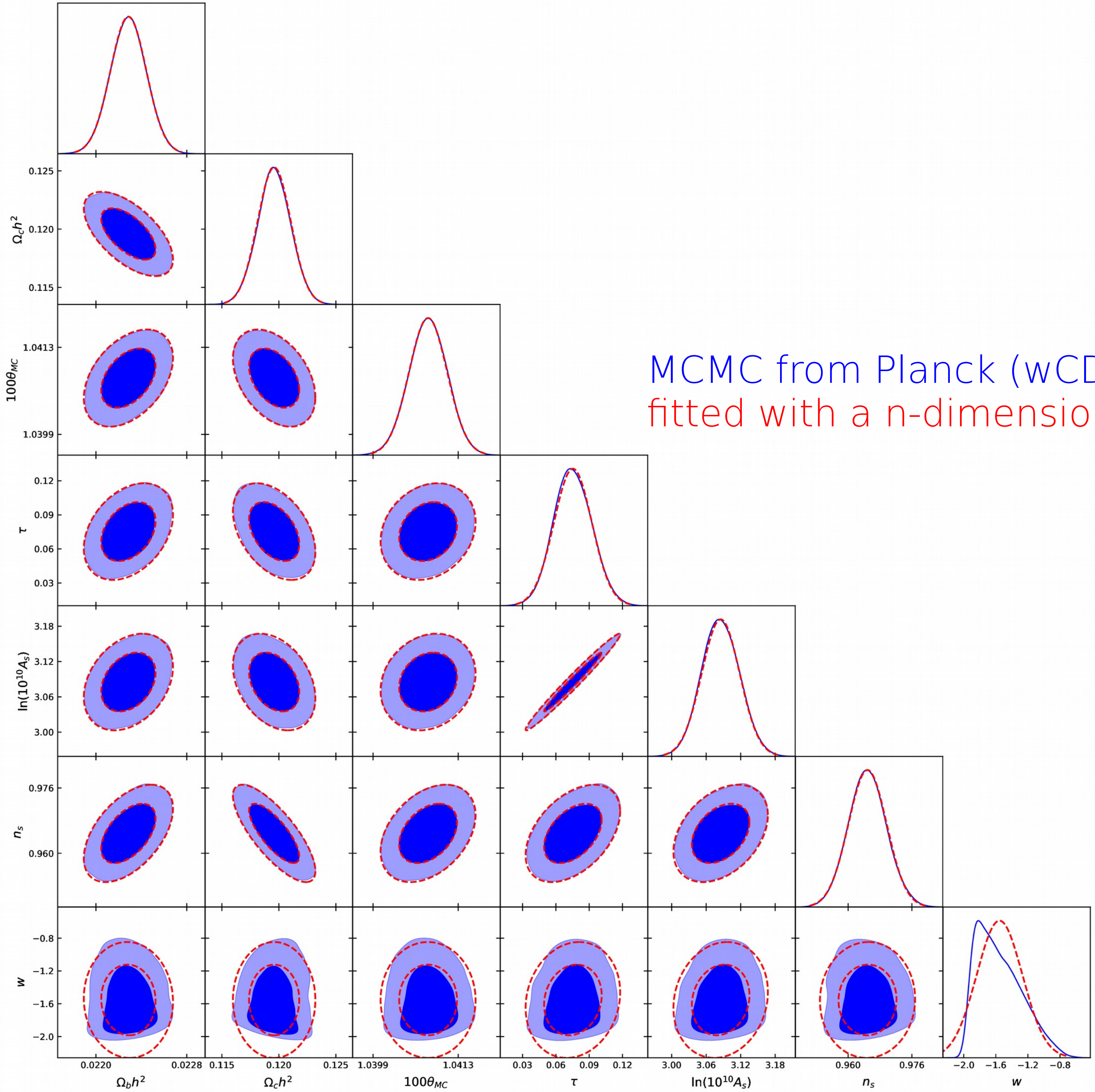
The end

Thank you for
your attention !

The end ?

Extra slides
Posterior fit

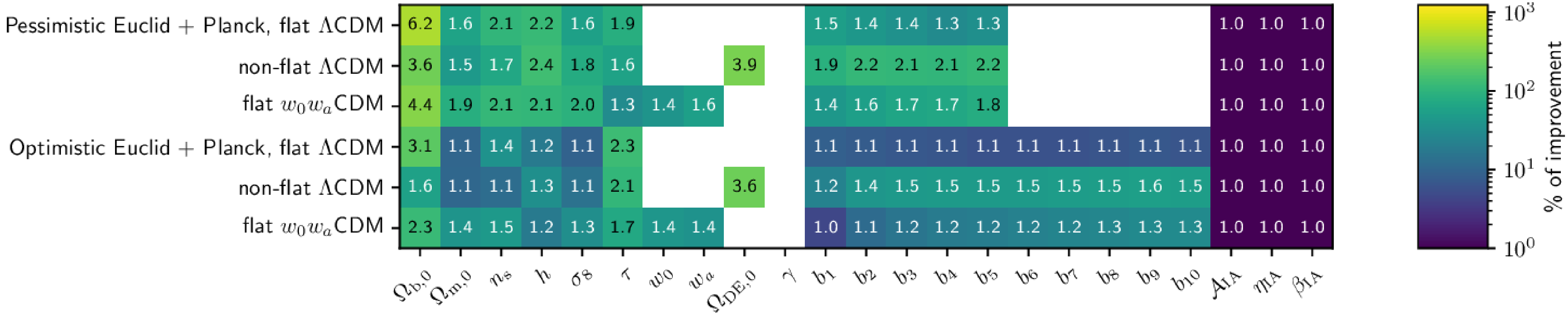
Fitting the posterior



MCMC from Planck (wCDM)

fitted with a n-dimensional Gaussian

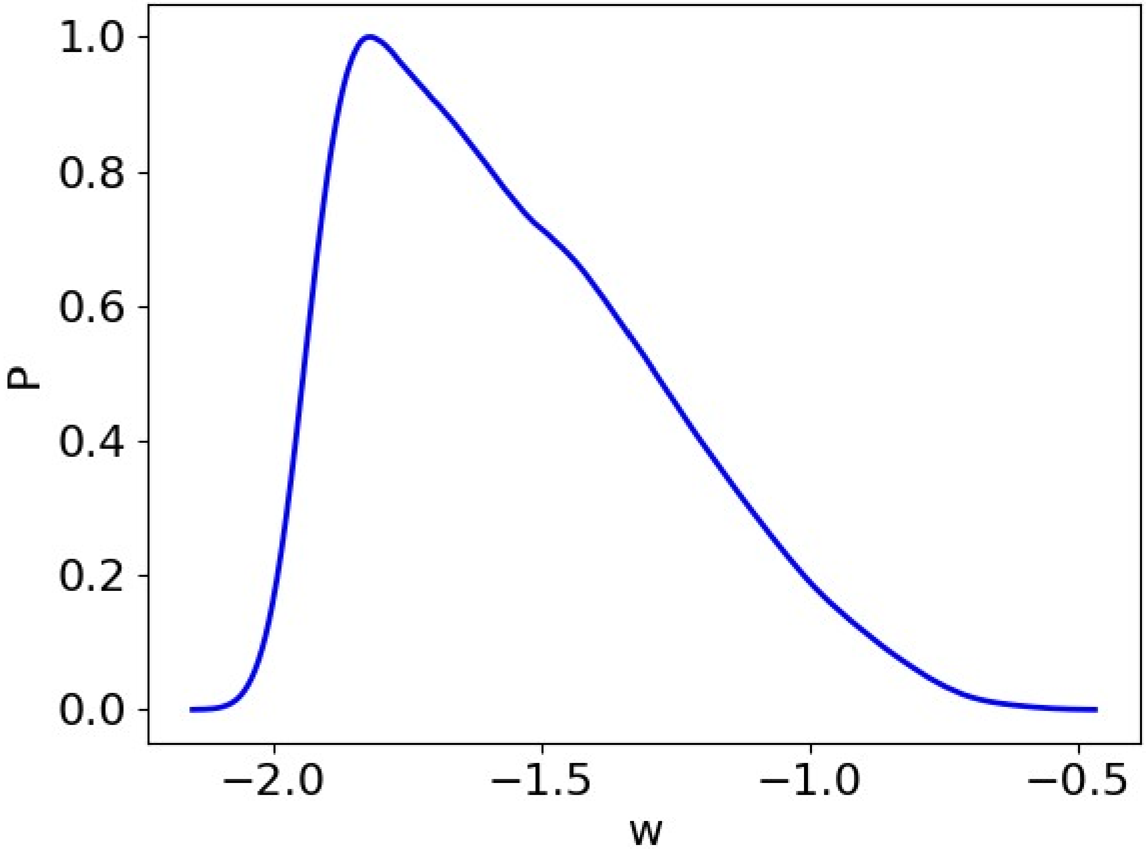
Fitted Planck + Euclid



	$\Omega_{\rm b,0}$	$\Omega_{\rm m,0}$	n_s	h	σ_8	τ	w_0	w_a	$\Omega_{\rm DE,0}$	γ	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}	$A_{\rm IA}$	$\eta_{\rm IA}$	$\beta_{\rm IA}$
Pessimistic Euclid + Planck, flat ΛCDM	6.2	1.6	2.1	2.2	1.6	1.9					1.5	1.4	1.4	1.3	1.3						1.0	1.0	1.0
non-flat ΛCDM	3.6	1.5	1.7	2.4	1.8	1.6			3.9		1.9	2.2	2.1	2.1	2.2						1.0	1.0	1.0
flat $w_0 w_a$CDM	4.4	1.9	2.1	2.1	2.0	1.3	1.4	1.6			1.4	1.6	1.7	1.7	1.8						1.0	1.0	1.0
Optimistic Euclid + Planck, flat ΛCDM	3.1	1.1	1.4	1.2	1.1	2.3					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
non-flat ΛCDM	1.6	1.1	1.1	1.3	1.1	2.1			3.6		1.2	1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.6	1.5	1.0	1.0	1.0
flat $w_0 w_a$CDM	2.3	1.4	1.5	1.2	1.3	1.7	1.4	1.4			1.0	1.1	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.0	1.0	1.0

Fitting the posterior

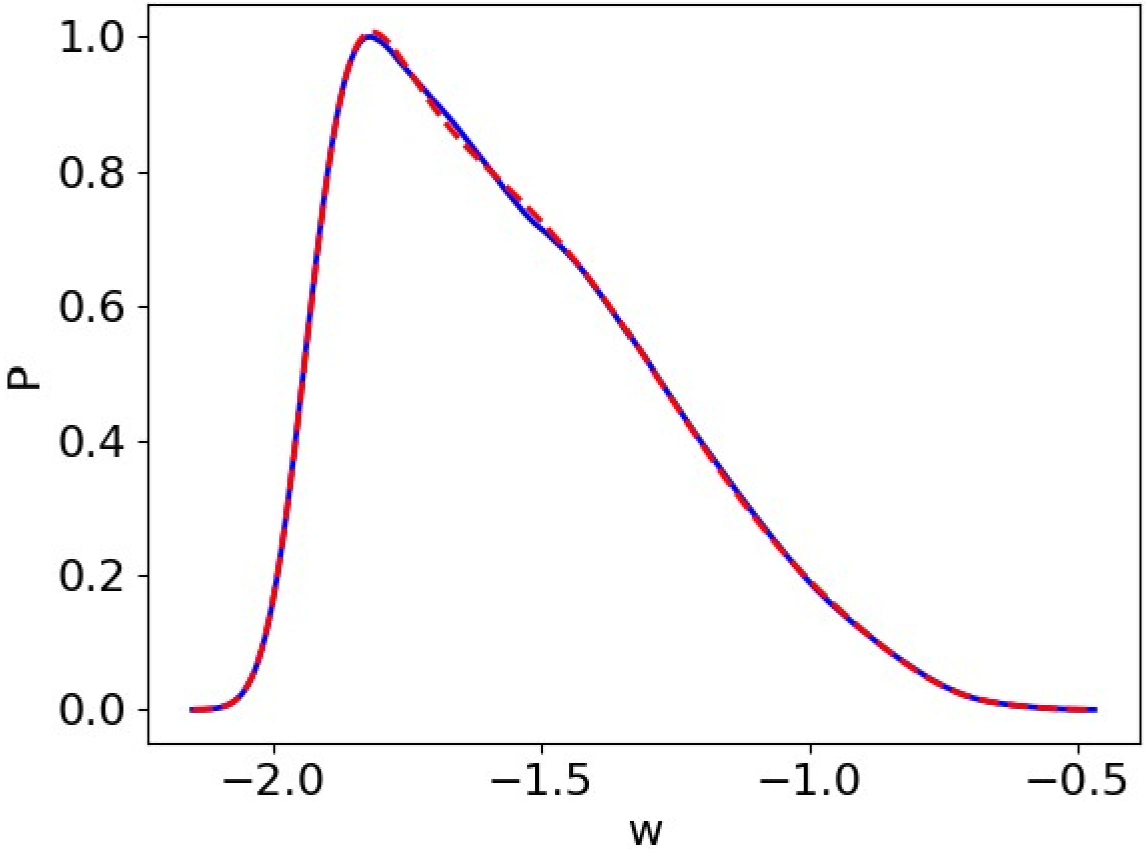
Posterior from MCMC



Fitting the posterior

Posterior from MCMC

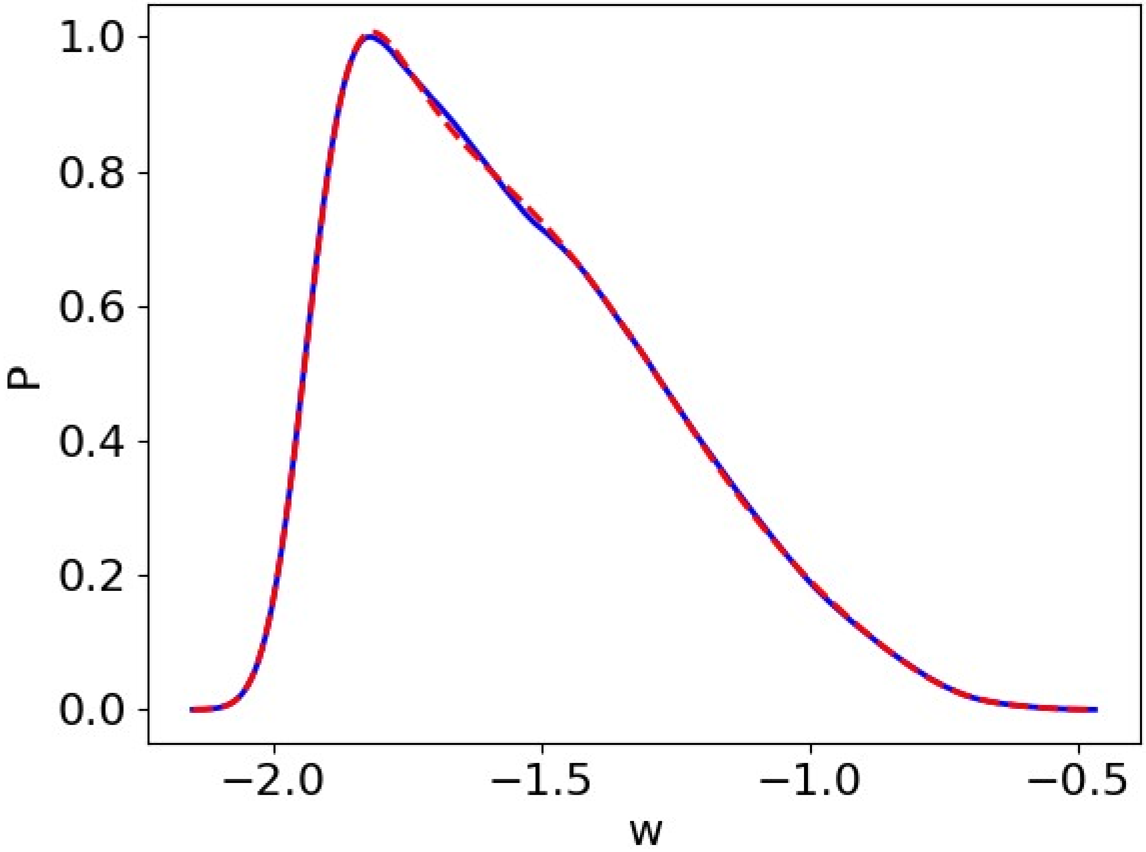
Gaussian fit, with smoothly varying mean and covariance



Fitting the posterior

Posterior from MCMC

Gaussian fit, with smoothly varying mean and covariance

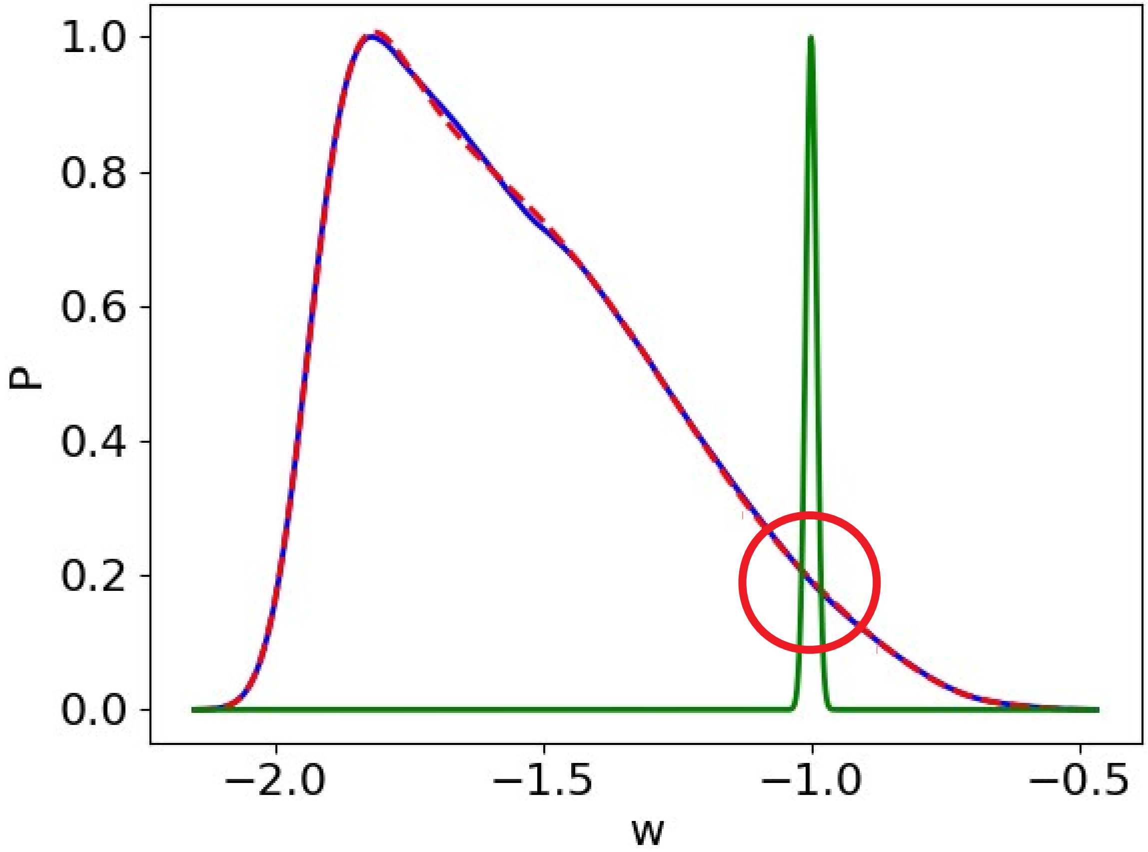


Either : MCMC with CMB fit + LSS Fisher

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

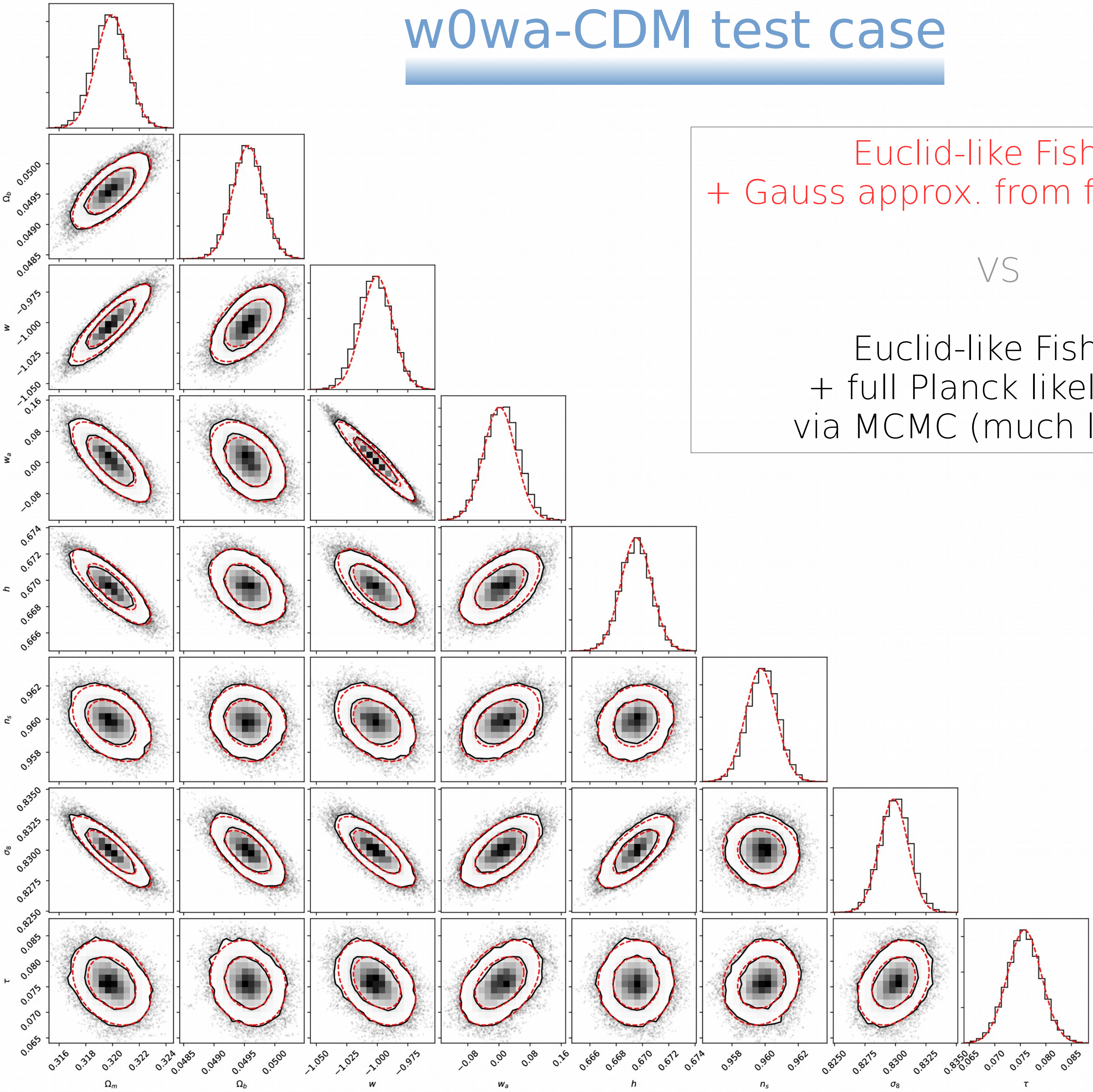
Or : Gauss. approx of CMB fit + LSS Fisher

Fitting the posterior

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

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

w0wa-CDM test case

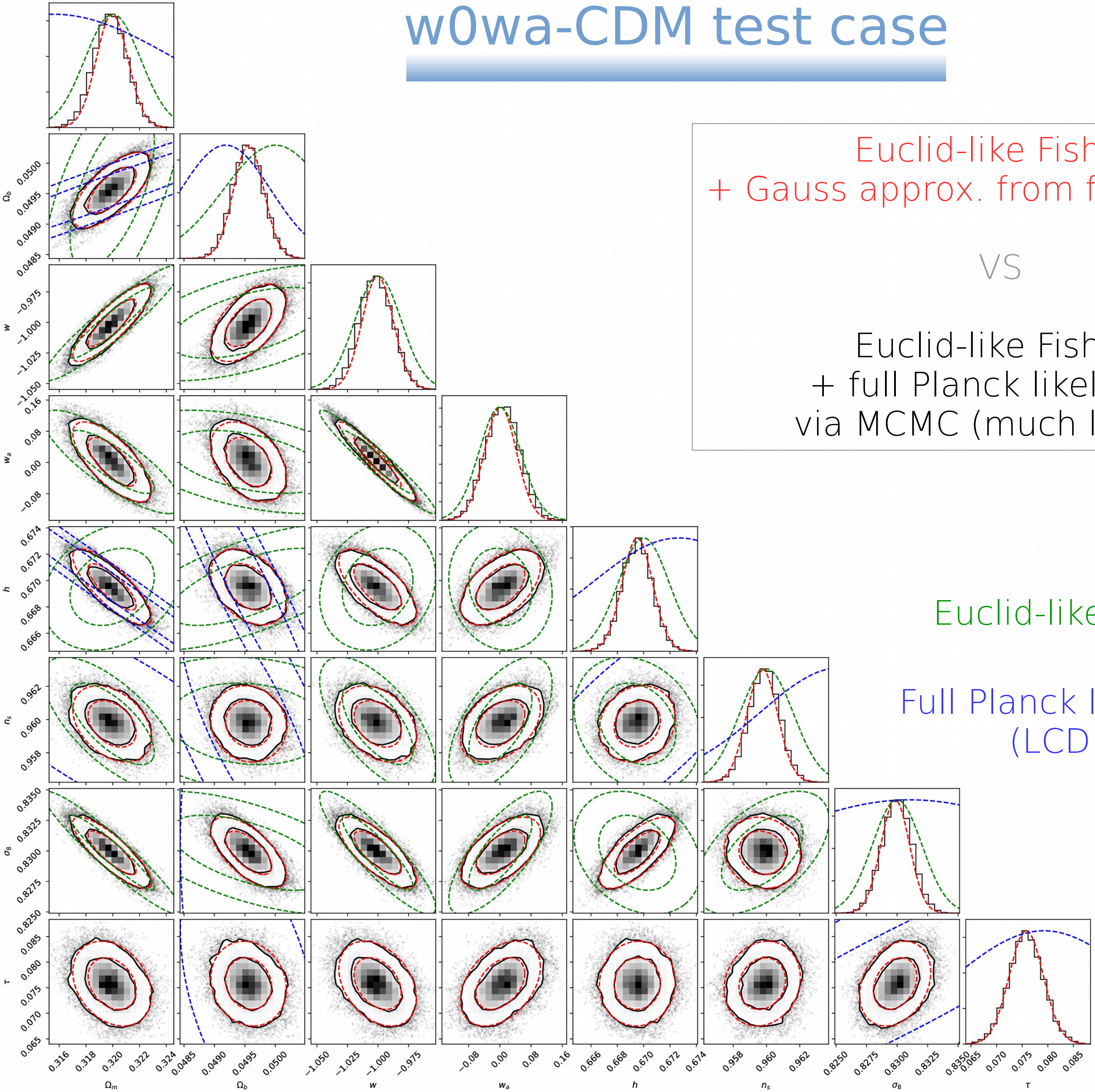


Euclid-like Fisher
+ Gauss approx. from fitted Planck

VS

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

w0wa-CDM test case



Euclid-like Fisher
+ Gauss approx. from fitted Planck

VS

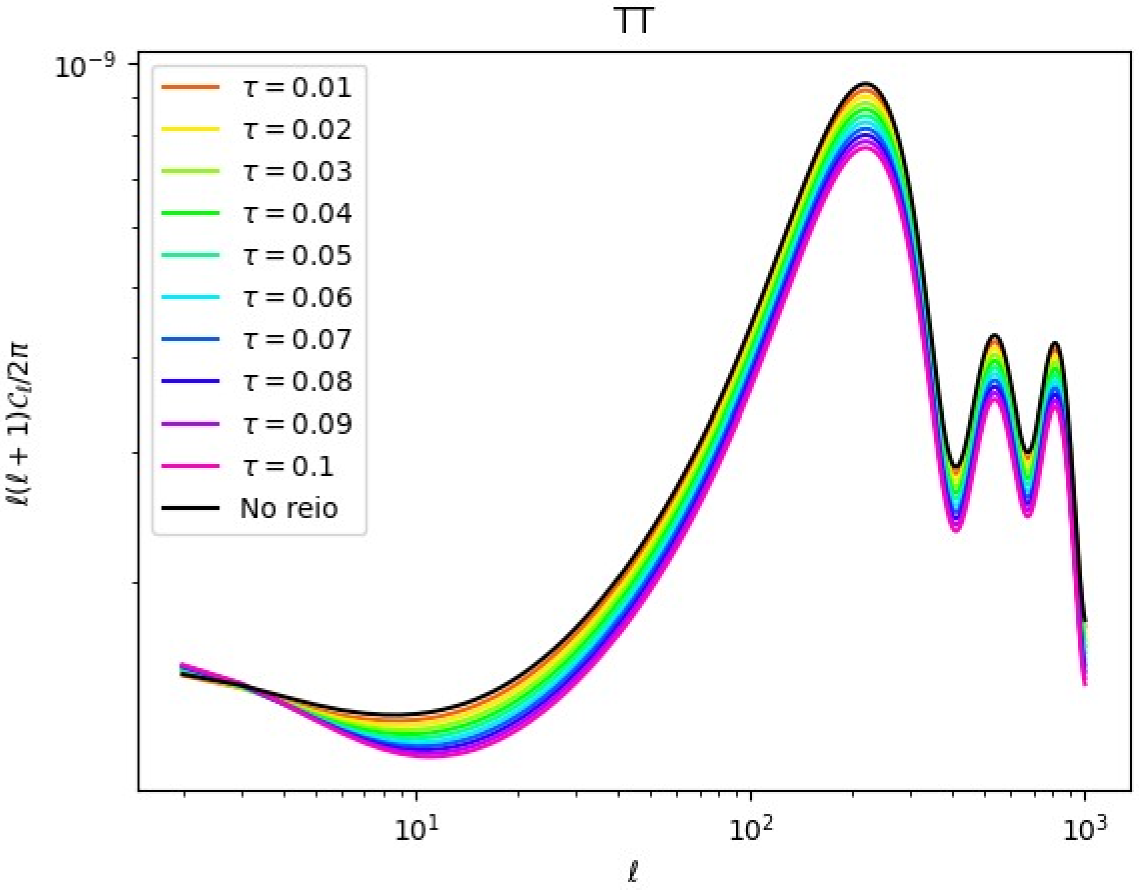
Euclid-like Fisher
+ full Planck likelihood
via MCMC (much longer)

Euclid-like Fisher only

Full Planck likelihood only
(LCDM case)

II) Reionisation & the CMB

Impact on CMB angular power spectra:



Rescaling A_s by $\exp(-2\tau)$