Combining large-scale surveys and the CMB: the why and the how

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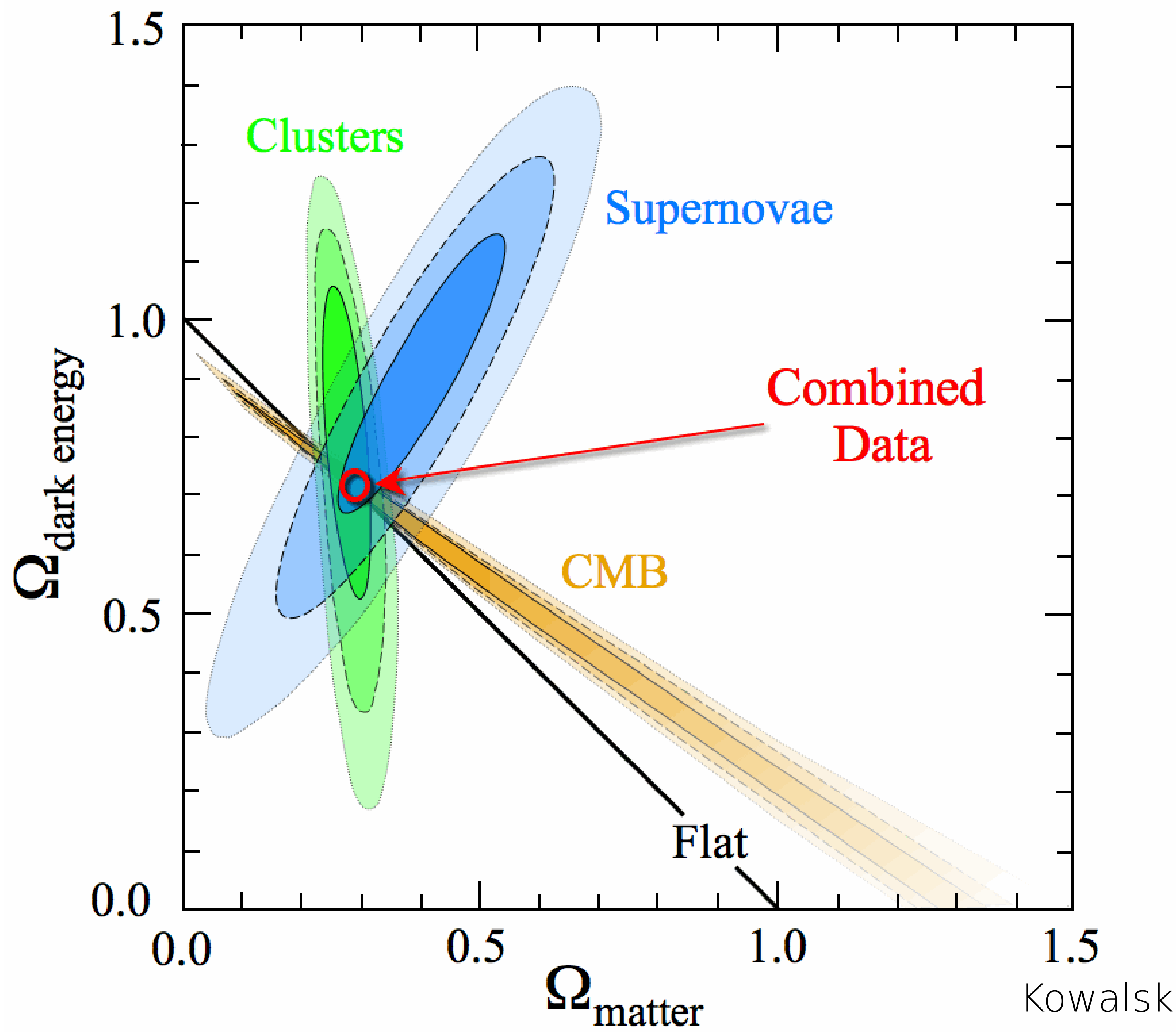
Colloque national Dark Energy @ IAP, 23/10/2018

Why we combine datasets



Kowalski et al. 2008

Which datasets to combine ?

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

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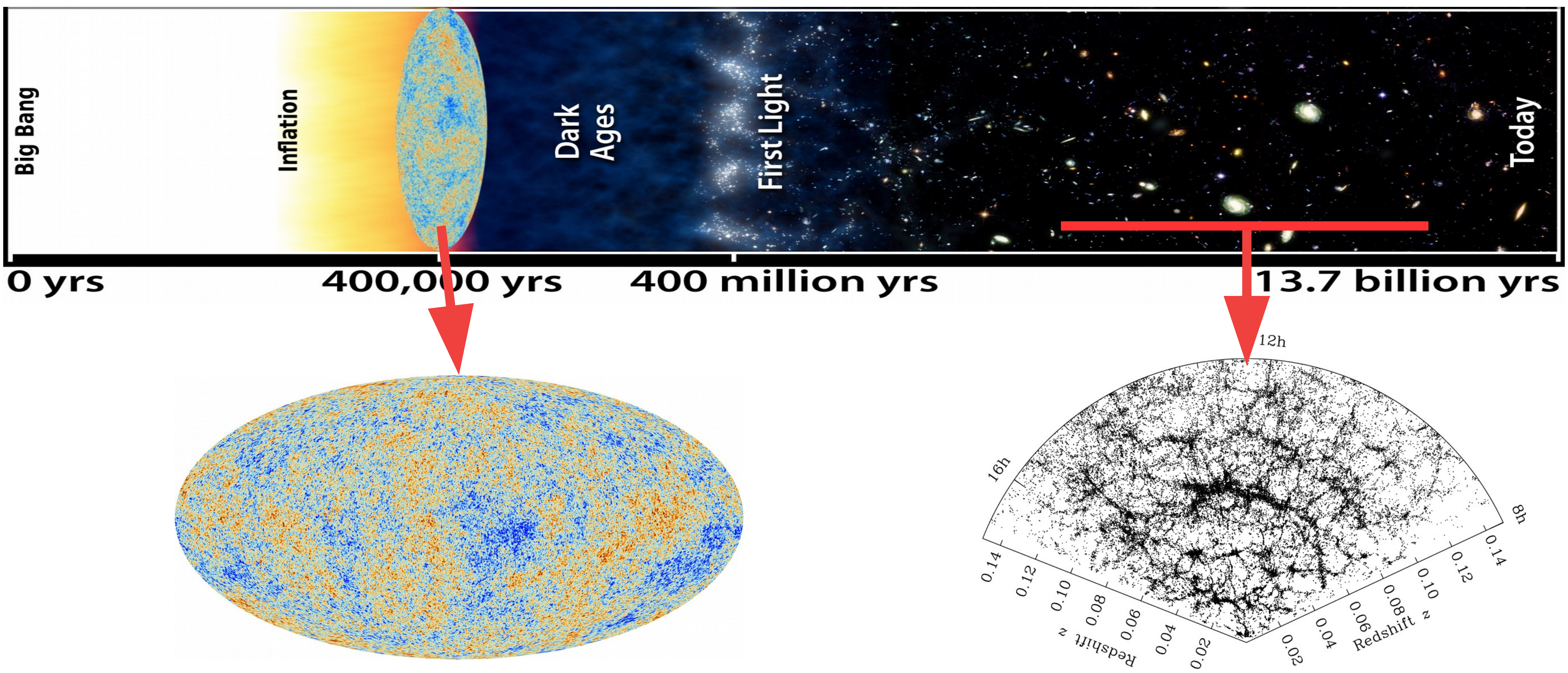
- Probes of different "sectors":
  - Background evolution: all standard rulers/candles
  - Perturbations: probes of structure growth
- Probes of different epochs:



Outline

I. Forecasting the CMB-LSS combination

How do we combine probes ?

Combining “existing” datasets

When analyzing data, fitting a model, running an MCMC,... :

$$\mathcal{L}_{\mathrm{probe1+probe2}} = \mathcal{L}_{\mathrm{probe1}} \times \mathcal{L}_{\mathrm{probe2}}$$

→ assumes “probe 1” and “probe 2” are uncorrelated

Combining "future" datasets

Fisher formalism :

- Approximates the posterior (~likelihood) as a Gaussian of the model parameters

$$\mathcal{L}(\mathbf{\Theta}) \propto \exp\left[-\frac{1}{2}(\mathbf{\Theta}-\mathbf{\Theta}_{\rm fid})^T \mathcal{F}\,(\mathbf{\Theta}-\mathbf{\Theta}_{\rm fid})\right]$$

- Fisher matrix :

$$\mathcal{F} = \begin{pmatrix} -\left.\frac{\partial^2 \ln \mathcal{L}}{\partial \theta_1^2}\right|_{\rm fid} & -\left.\frac{\partial^2 \ln \mathcal{L}}{\partial \theta_1 \partial \theta_2}\right|_{\rm fid} & \cdots \\ -\left.\frac{\partial^2 \ln \mathcal{L}}{\partial \theta_1 \partial \theta_2}\right|_{\rm fid} & -\left.\frac{\partial^2 \ln \mathcal{L}}{\partial \theta_2^2}\right|_{\rm fid} & \\ \vdots & & \ddots \end{pmatrix}$$

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Forecasted errors on parameters

- Then :

$$\mathcal{L}_{\rm probe1+probe2} = \mathcal{L}_{\rm probe1} \times \mathcal{L}_{\rm probe2}$$

is equivalent to $\mathcal{F}_{\rm probe1+probe2} = \mathcal{F}_{\rm probe1} + \mathcal{F}_{\rm probe2}$

Combining future & existing datasets ?

E.g. : Planck constraints + Euclid-like LSS forecasts

- LSS → Natural to use Fisher matrices
- CMB → Could use “Planck-like” Fisher,
  but Planck is already here !

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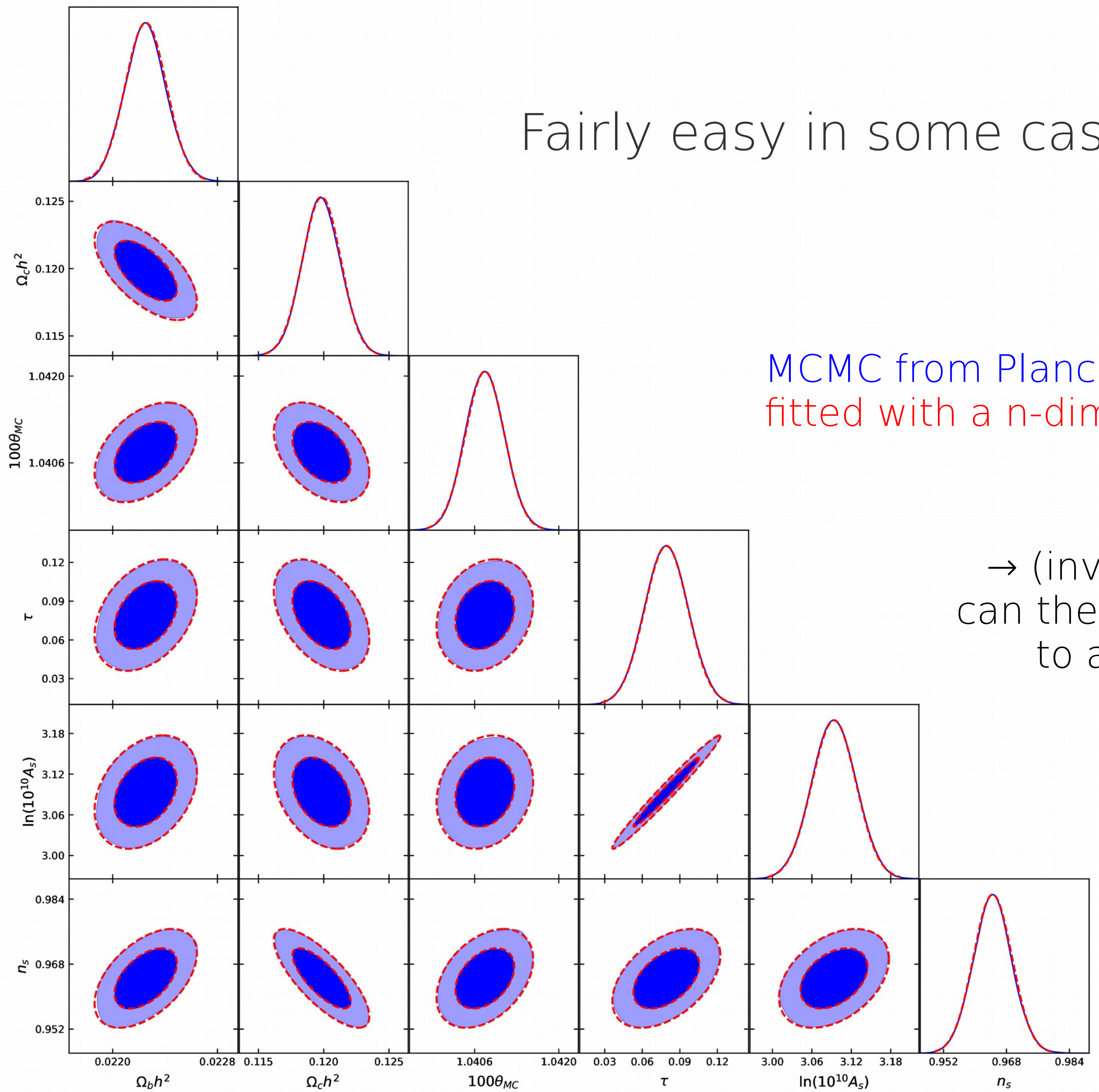
Ilić 2018 (in prep.):

- Produce a well-converged MCMC
- Perform an analytical fit of the posterior
- Combine it with any “classical” Fisher matrix

Fitting the posterior

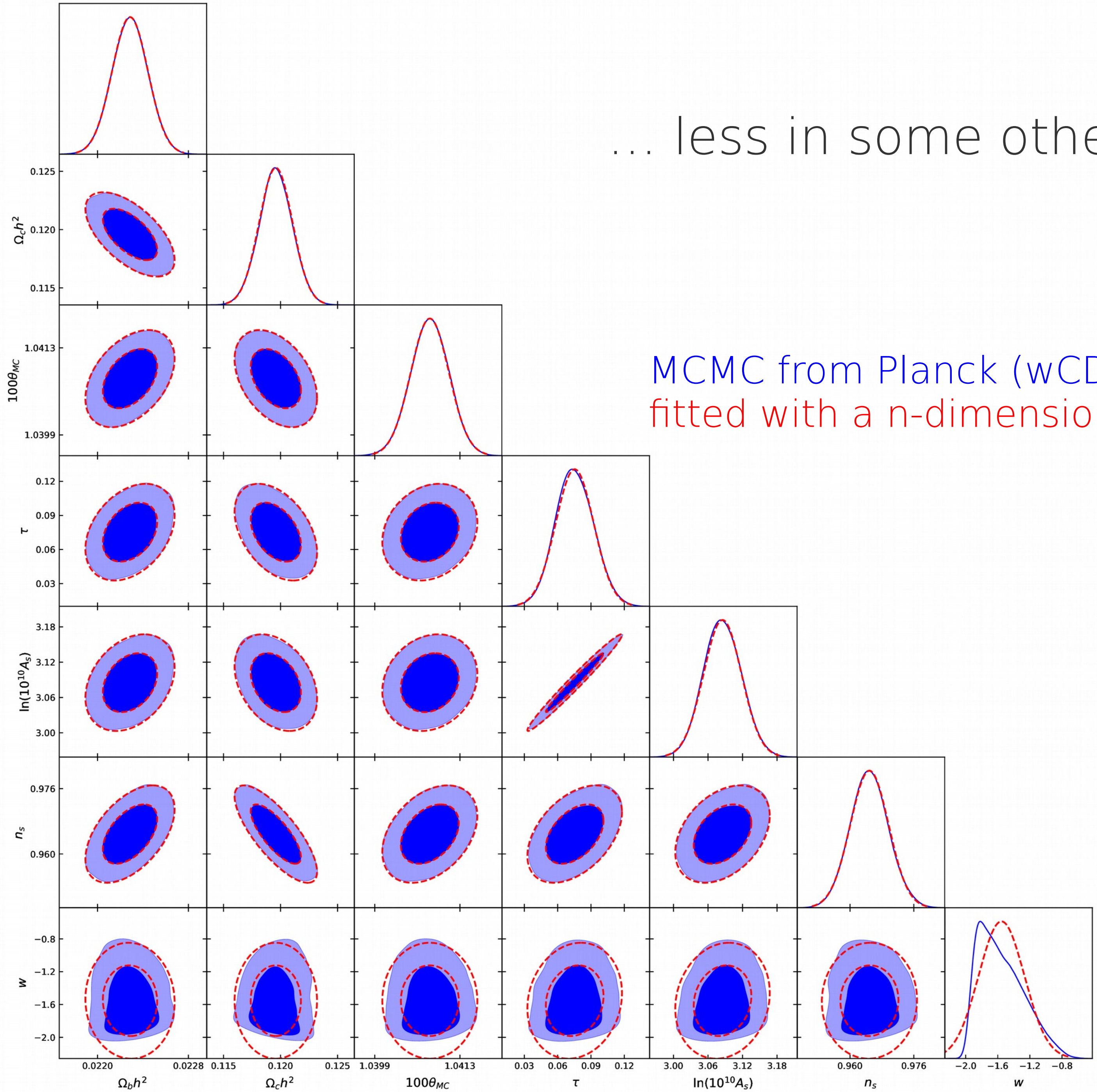


Fairly easy in some cases....

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

→ (inverse) covariance can then be simply added to a Fisher matrix

Fitting the posterior



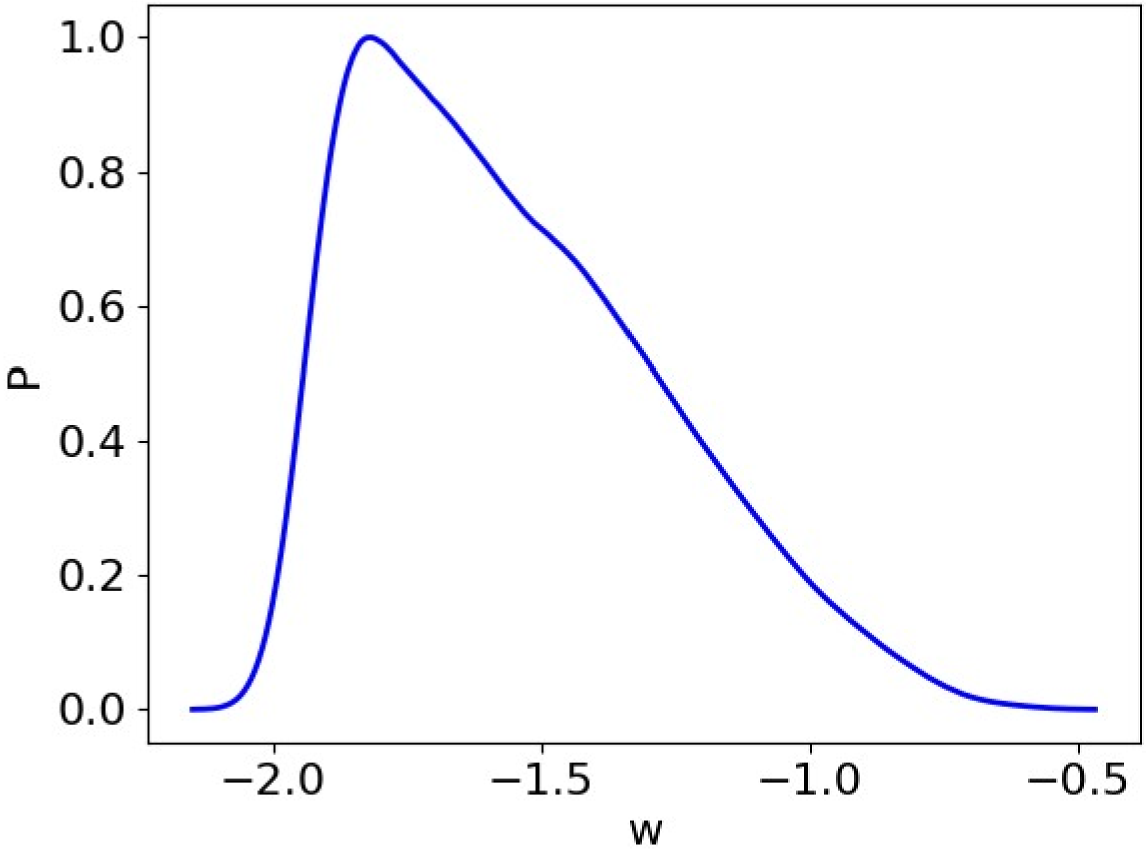
… less in some others

MCMC from Planck (wCDM)

fitted with a n-dimensional Gaussian

Fitting the posterior

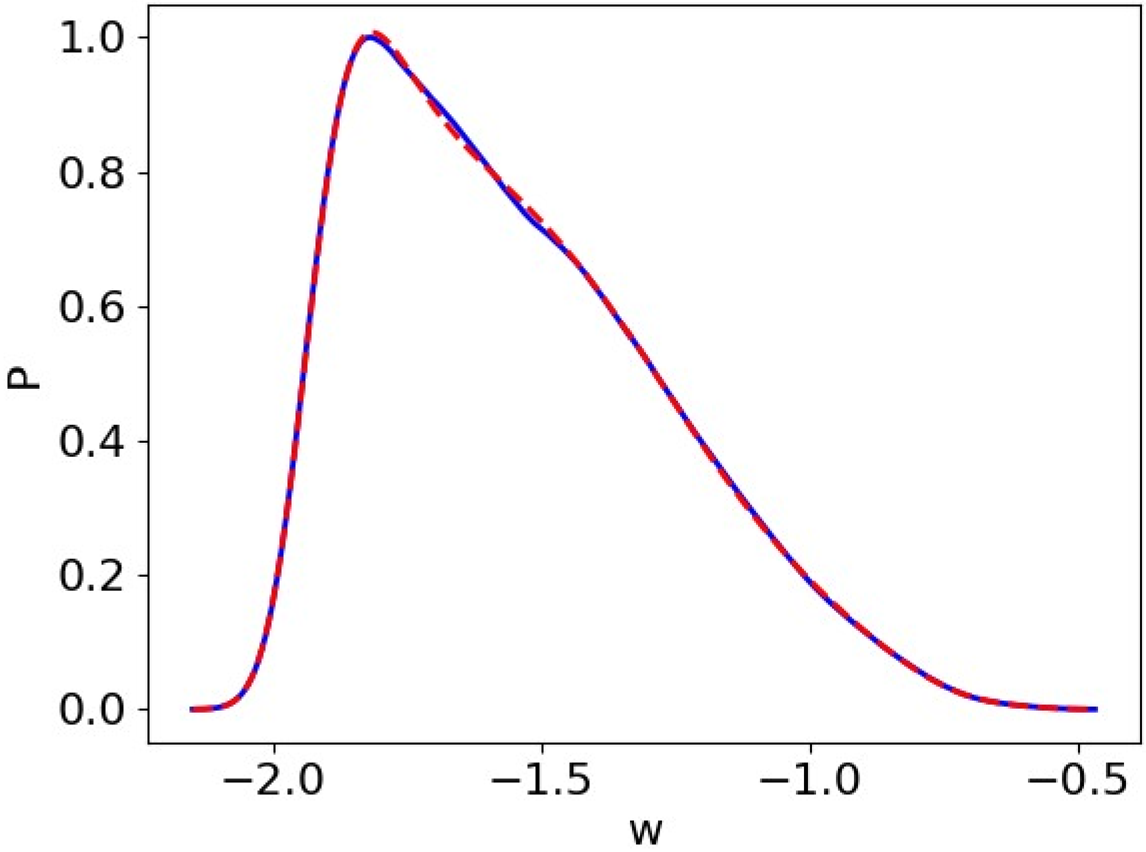
Posterior from MCMC



Fitting the posterior

Posterior from MCMC

Gaussian fit, with smoothly varying mean and covariance



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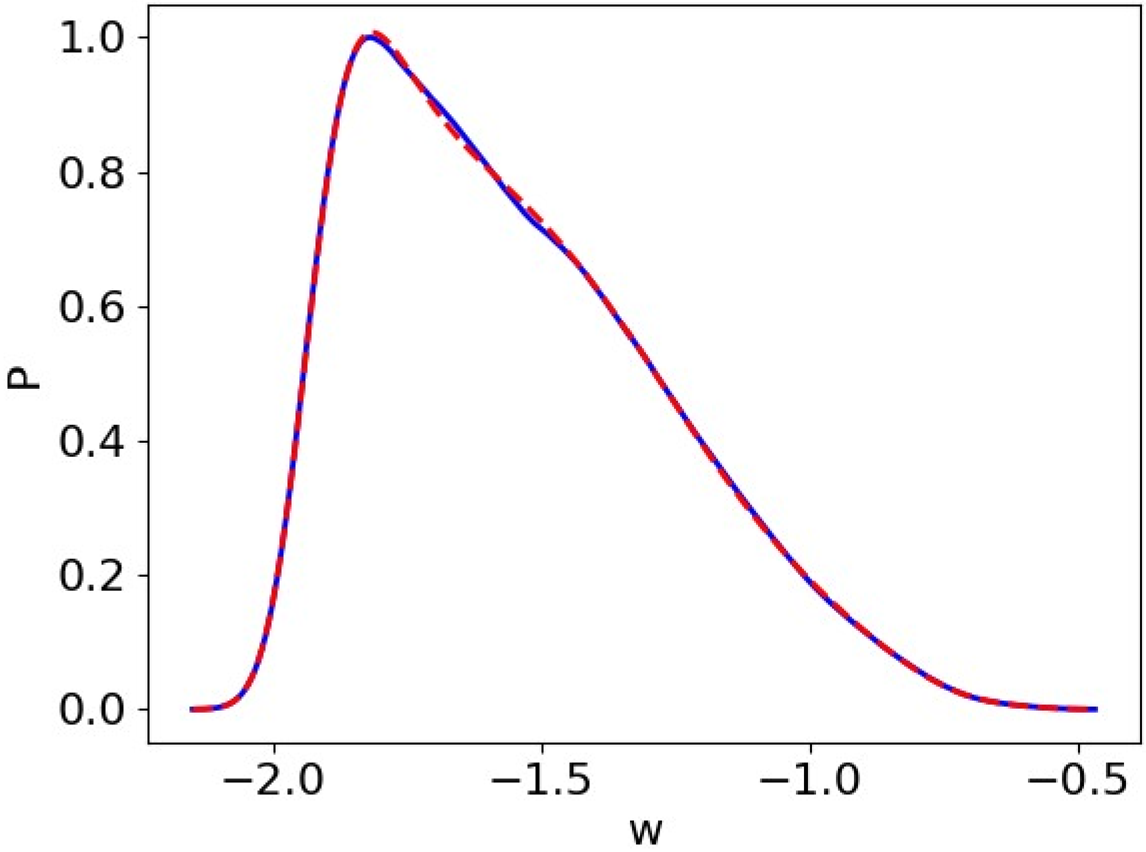
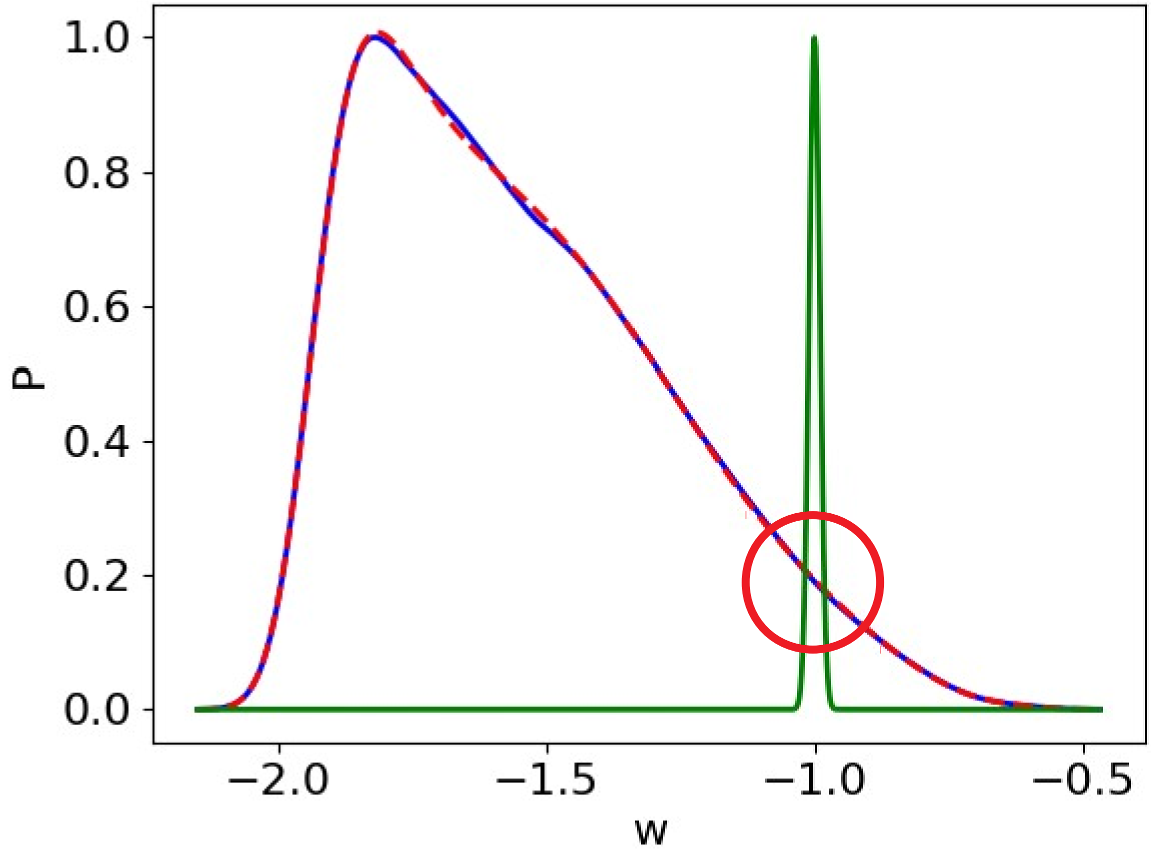


Either : MCMC with CMB fit + LSS Fisher (very quick)

Fitting the posterior

Posterior from MCMC

Gaussian fit, with smoothly varying mean and covariance

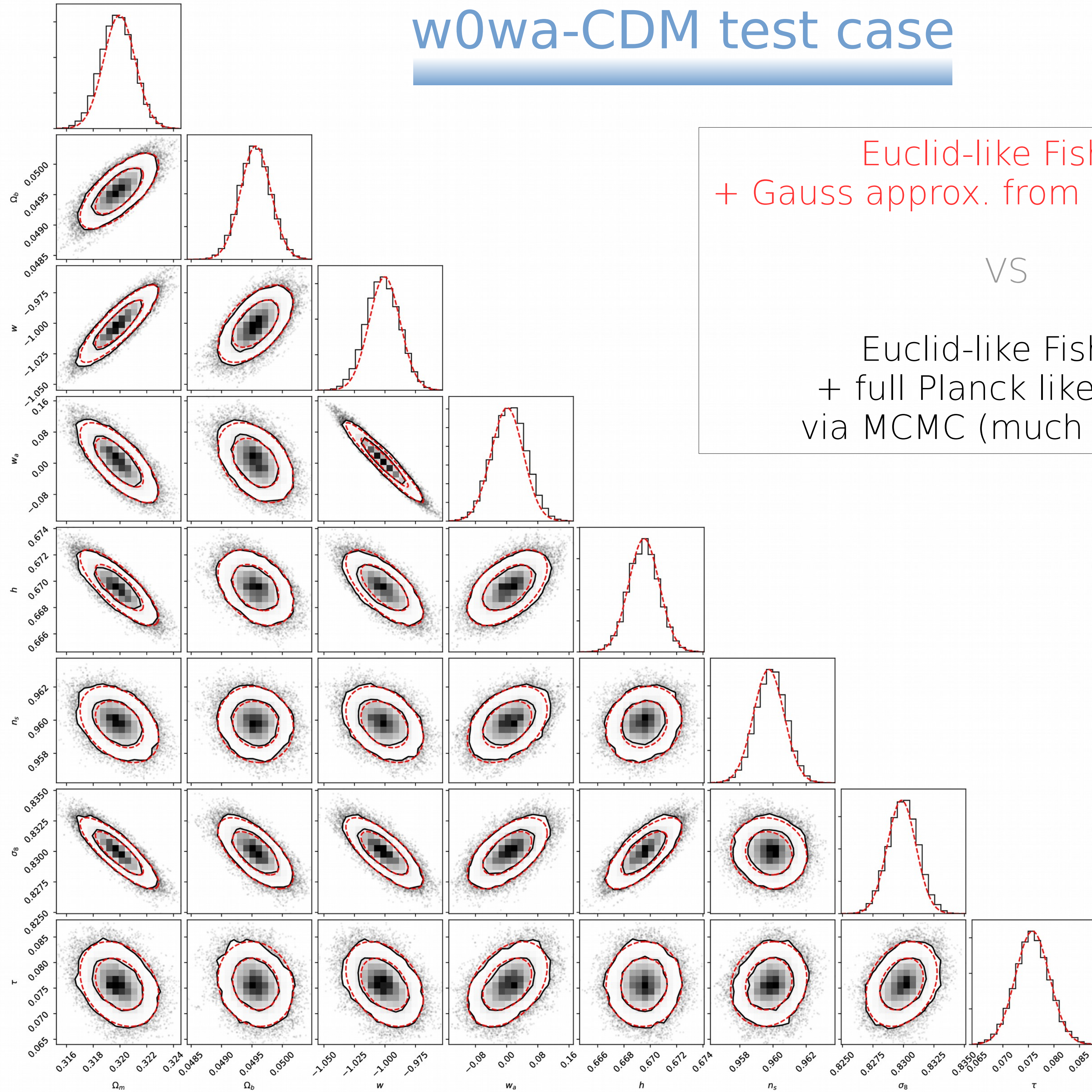


Typical next-gen LSS

Either : MCMC with CMB fit + LSS Fisher (very quick)

Or : Gauss. approx of CMB fit + LSS Fisher

w0wa-CDM test case

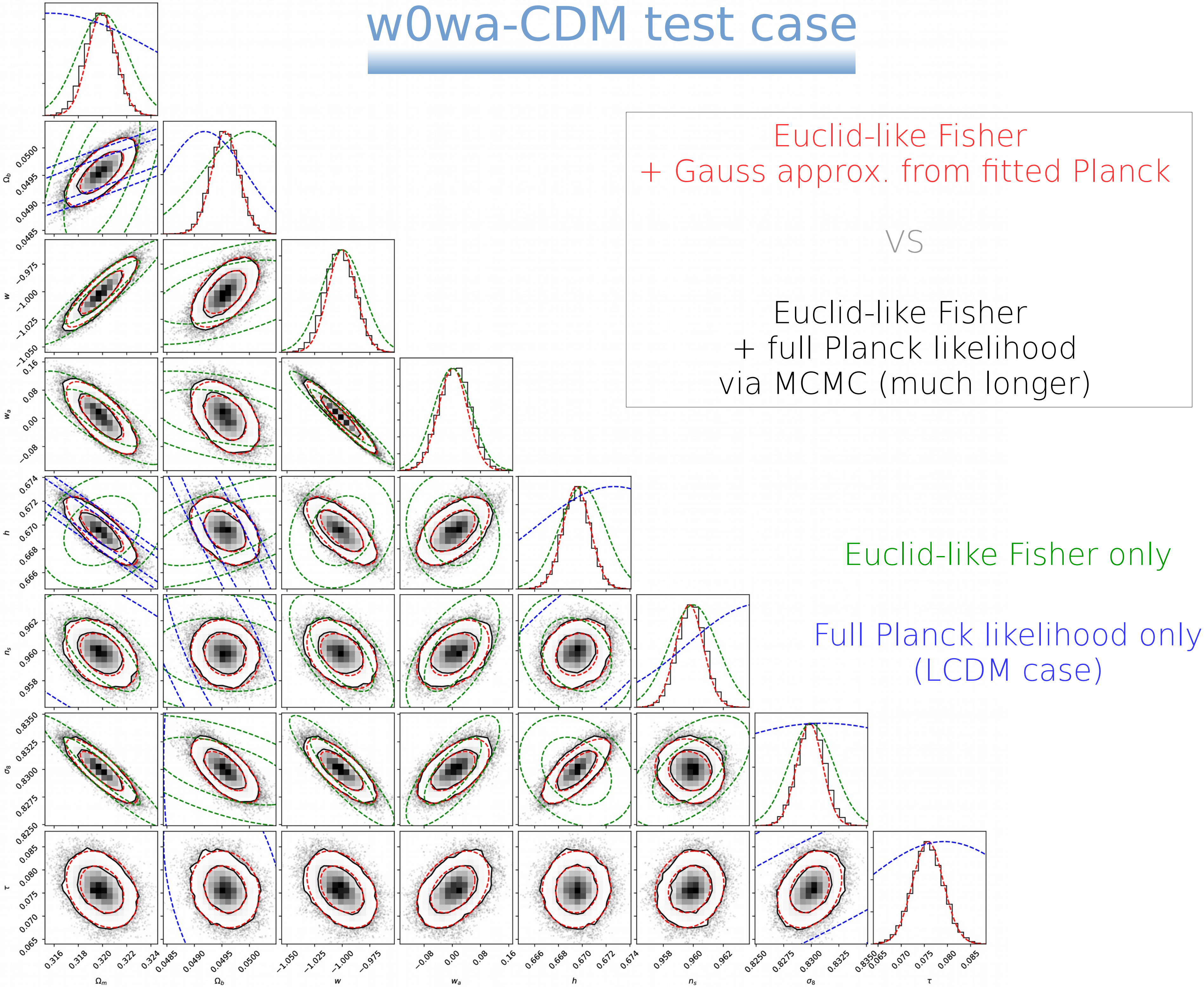


Euclid-like Fisher
+ Gauss approx. from fitted Planck

VS

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

w0wa-CDM test case

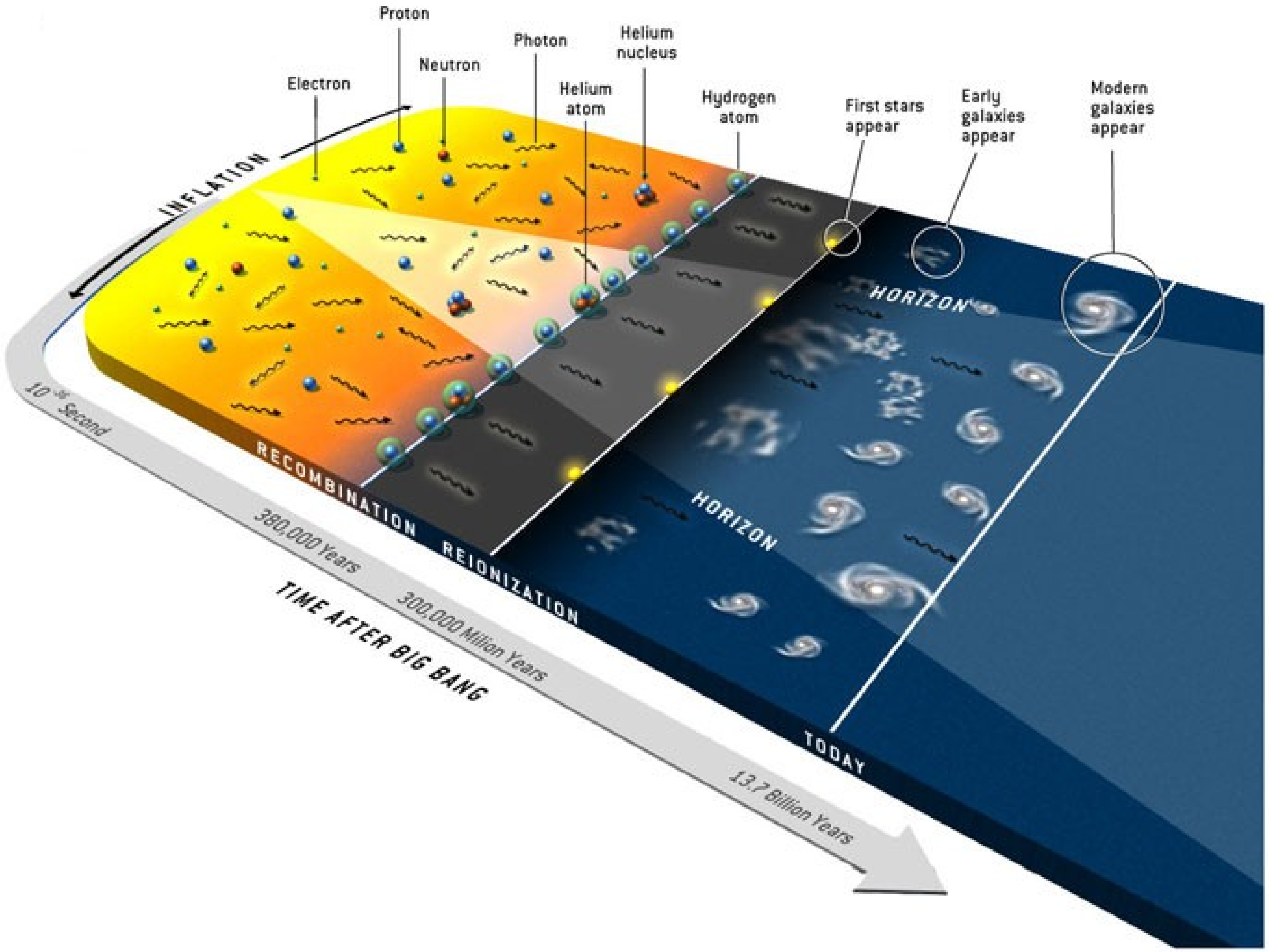


Outline

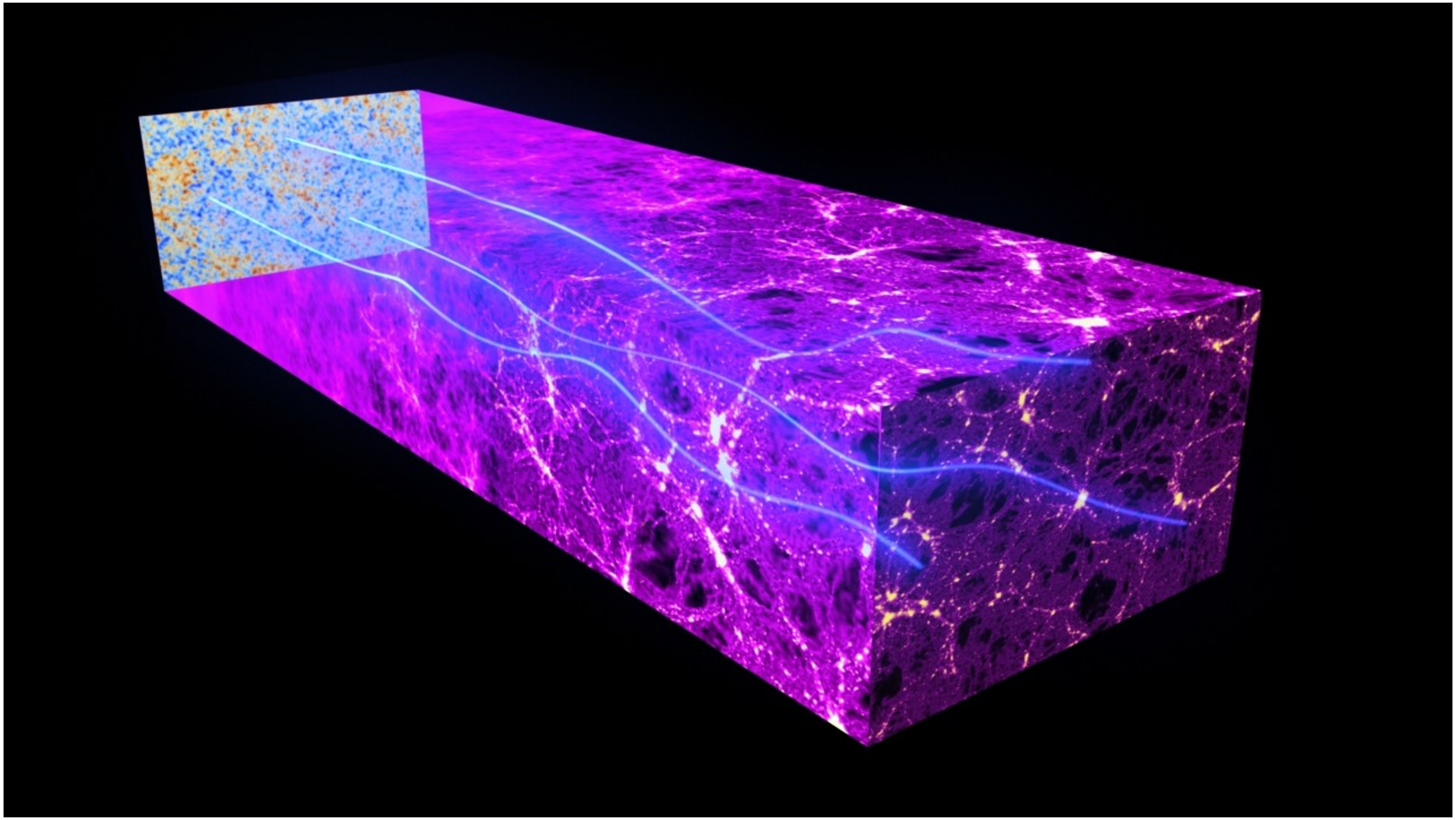
I. Forecasting the CMB-LSS combination

II. Forecasting the CMB-LSS correlation

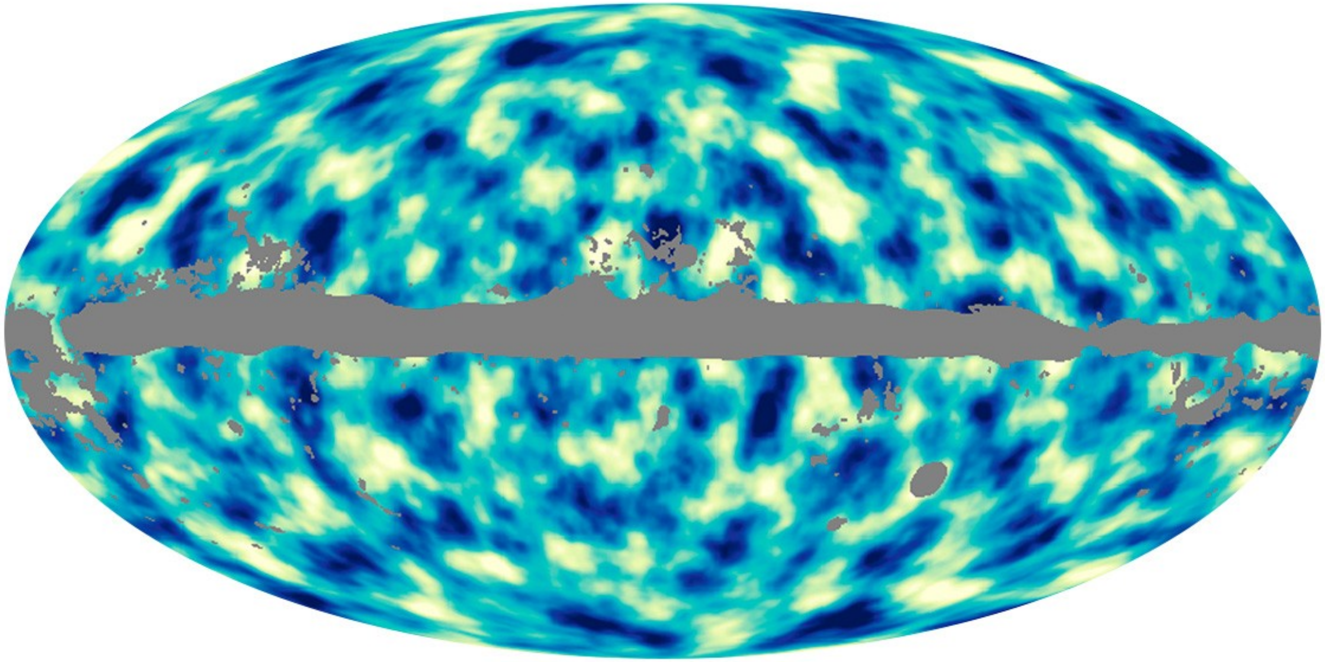
CMB-LSS cross-correlation



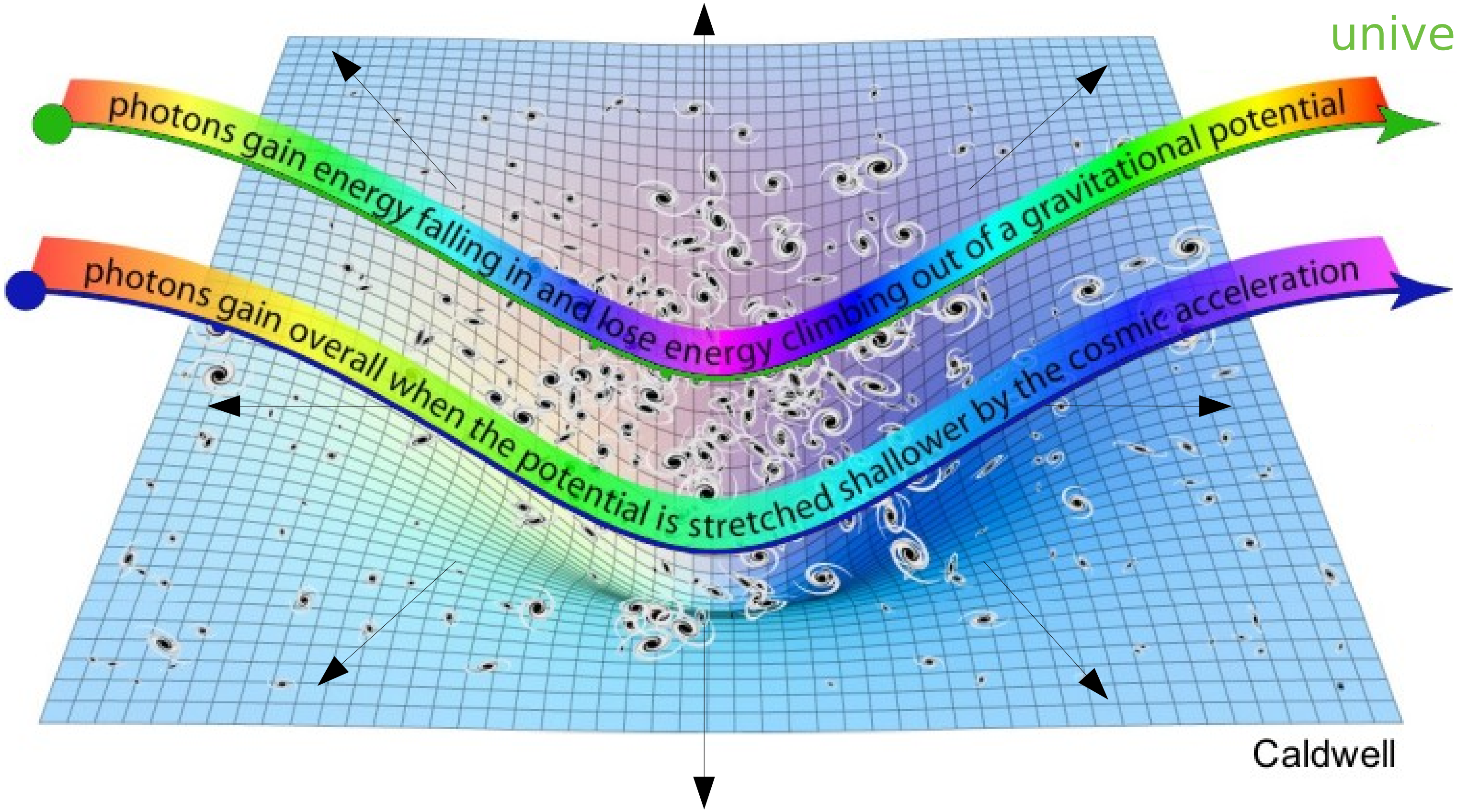
CMB-LSS cross-correlation



CMB-LSS cross-correlation



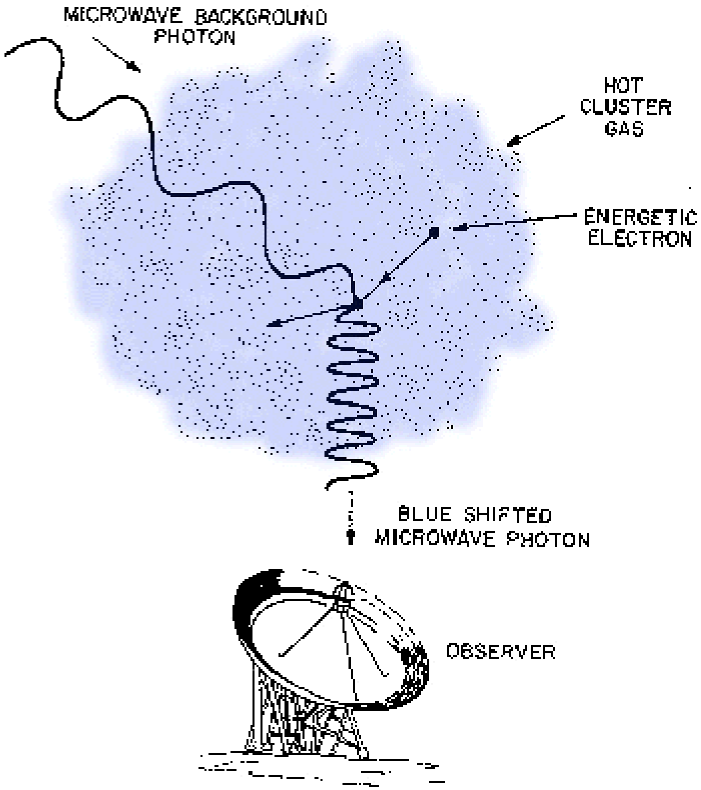
The integrated Sachs-Wolfe effect



In matter-dominated universe

In matter + dark energy universe

The Сюня́ев-Зельдо́вич effect



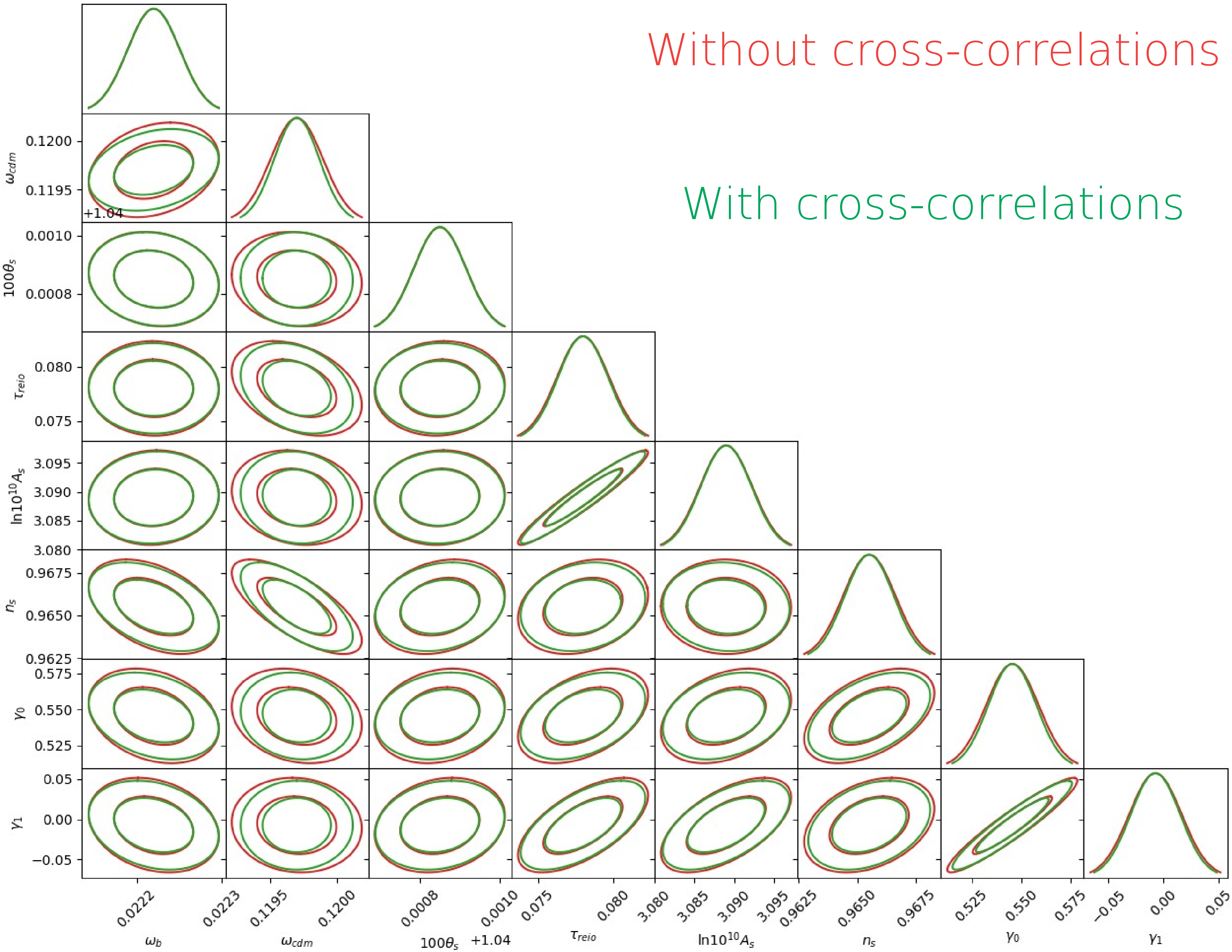
Test case for LSS x CMB via Fisher

- **Probes considered:**
  - Planck-like CMB: T, E, Φ
  - Euclid-like LSS: GC phot. (10 z-bins)

- **Model :** γ0-γ1-CDM ($f(a) = \Omega_m(a)^{\gamma_0 + \gamma_1 \ln a}$)

- **Two cases:**
  - All cross-correlations accounted for
  - Euclid-CMB correlations neglected (T-GC, Φ-GC)

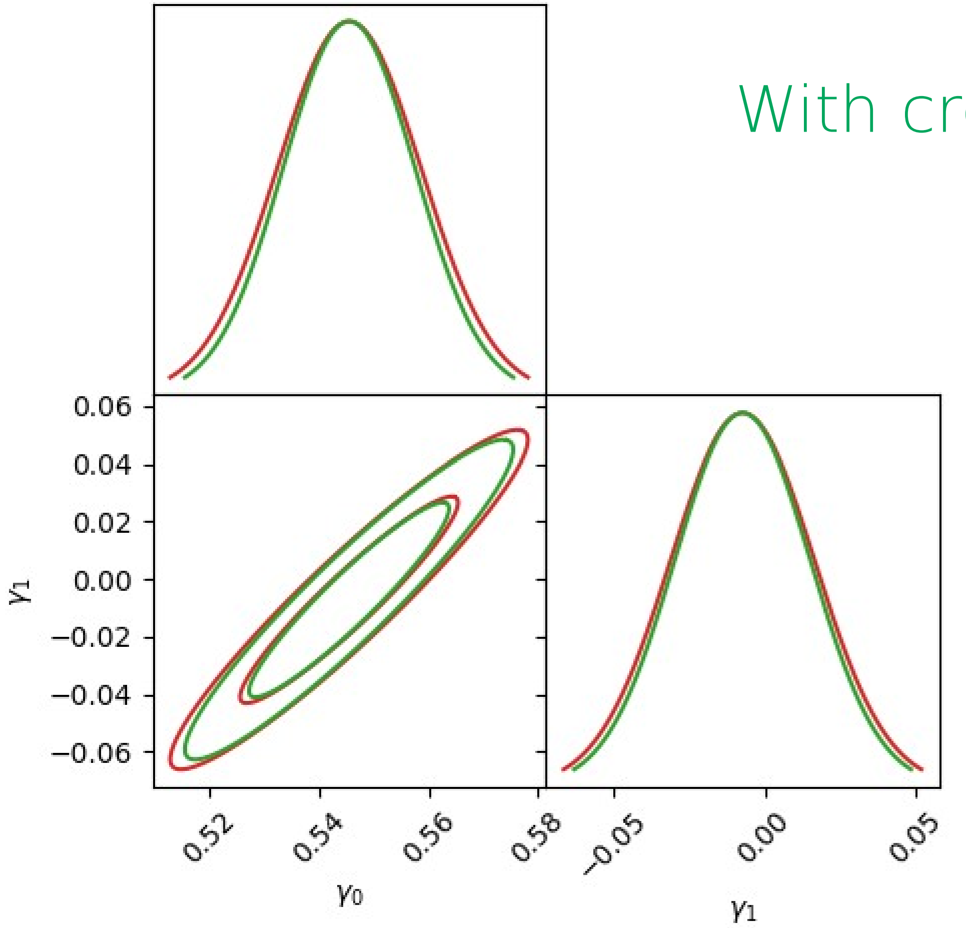
Test case for LSS x CMB



Test case for LSS x CMB

Without cross-correlations

With cross-correlations



Even with a low S/N...

Stölzner et al. 2018

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

...already stringent constraints

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

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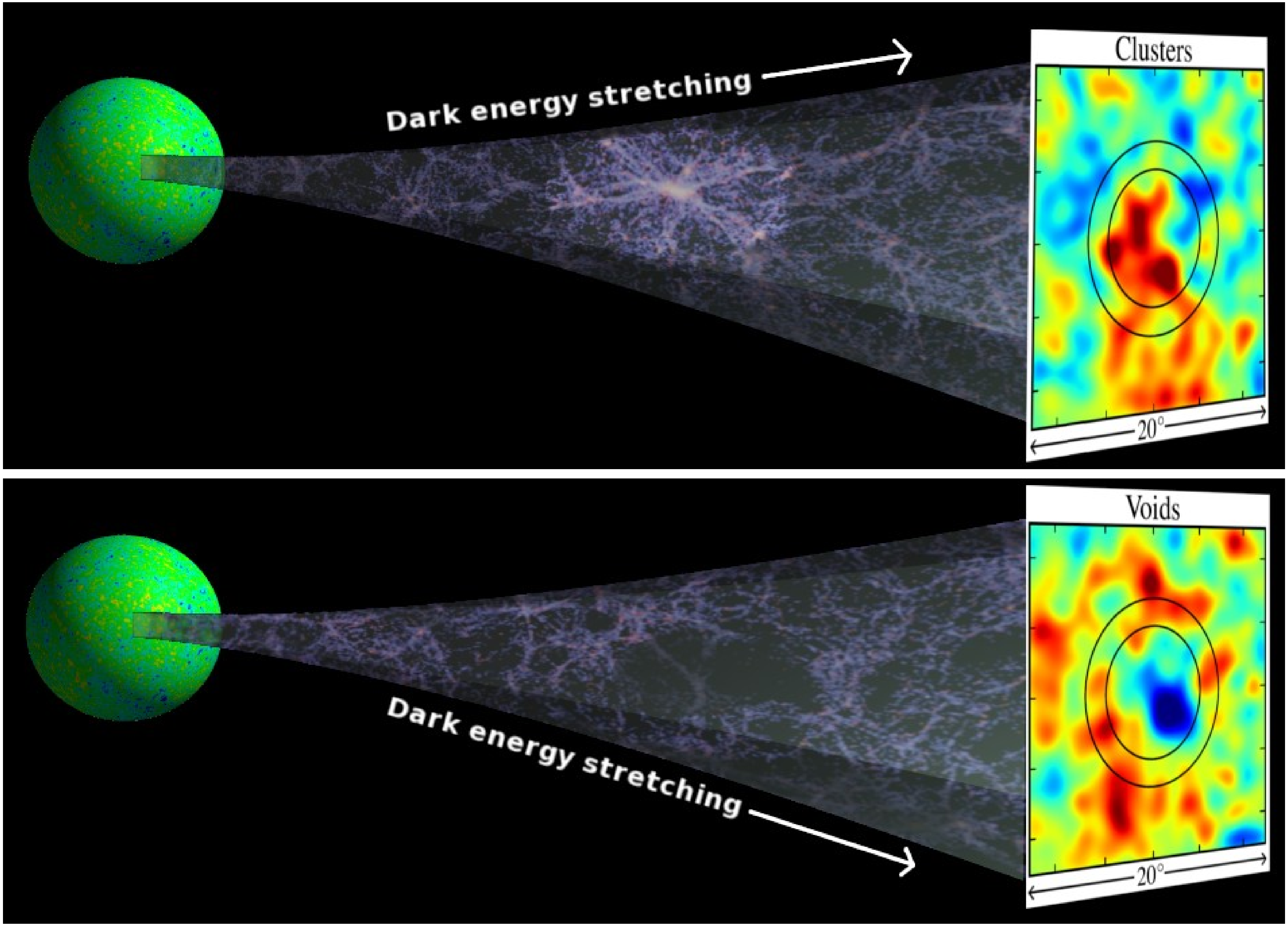
iSW effect of superstructures



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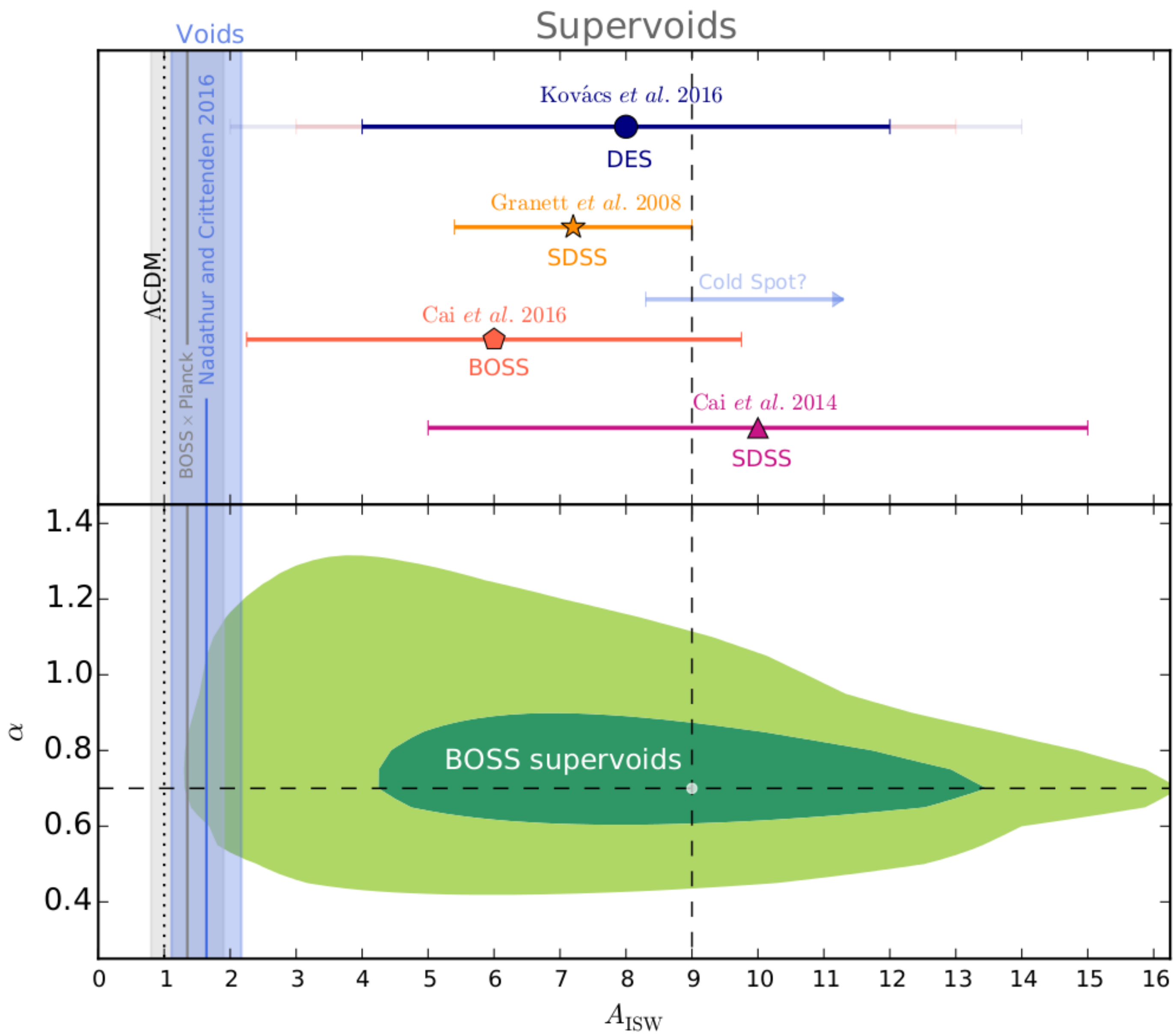

Kovács 2018

Thank you
for your attention !