The power of probe combination: joint analysis of CMB and LSS data

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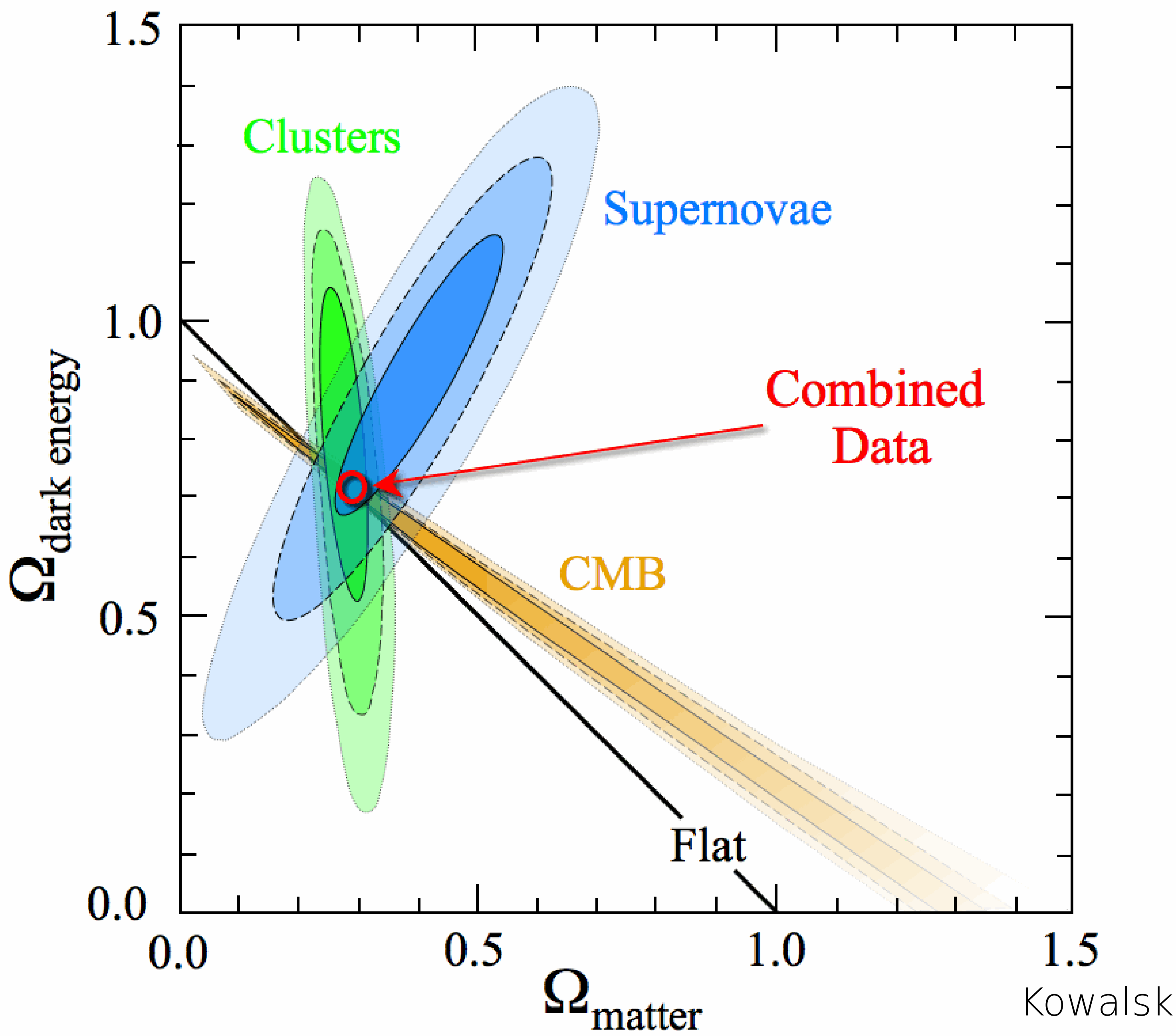
Action nationale Dark Energy – Atelier Sondes @ Paris, 12/06/2019

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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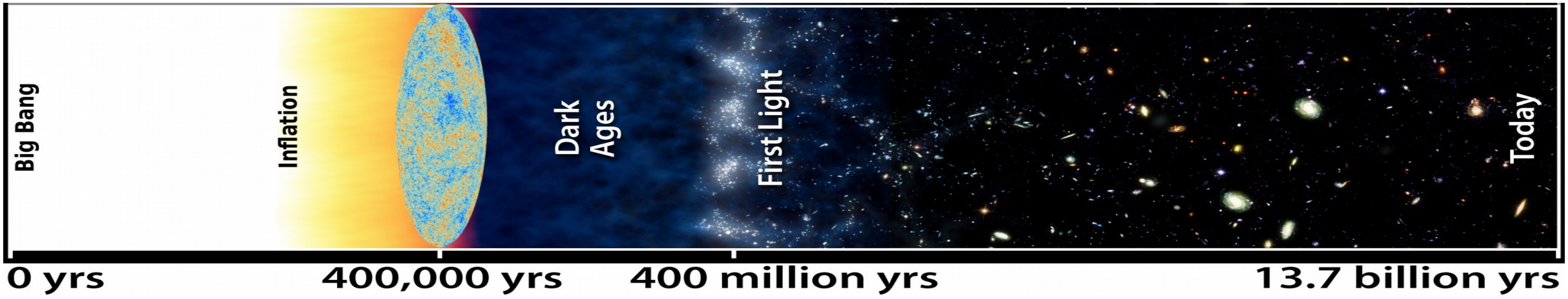

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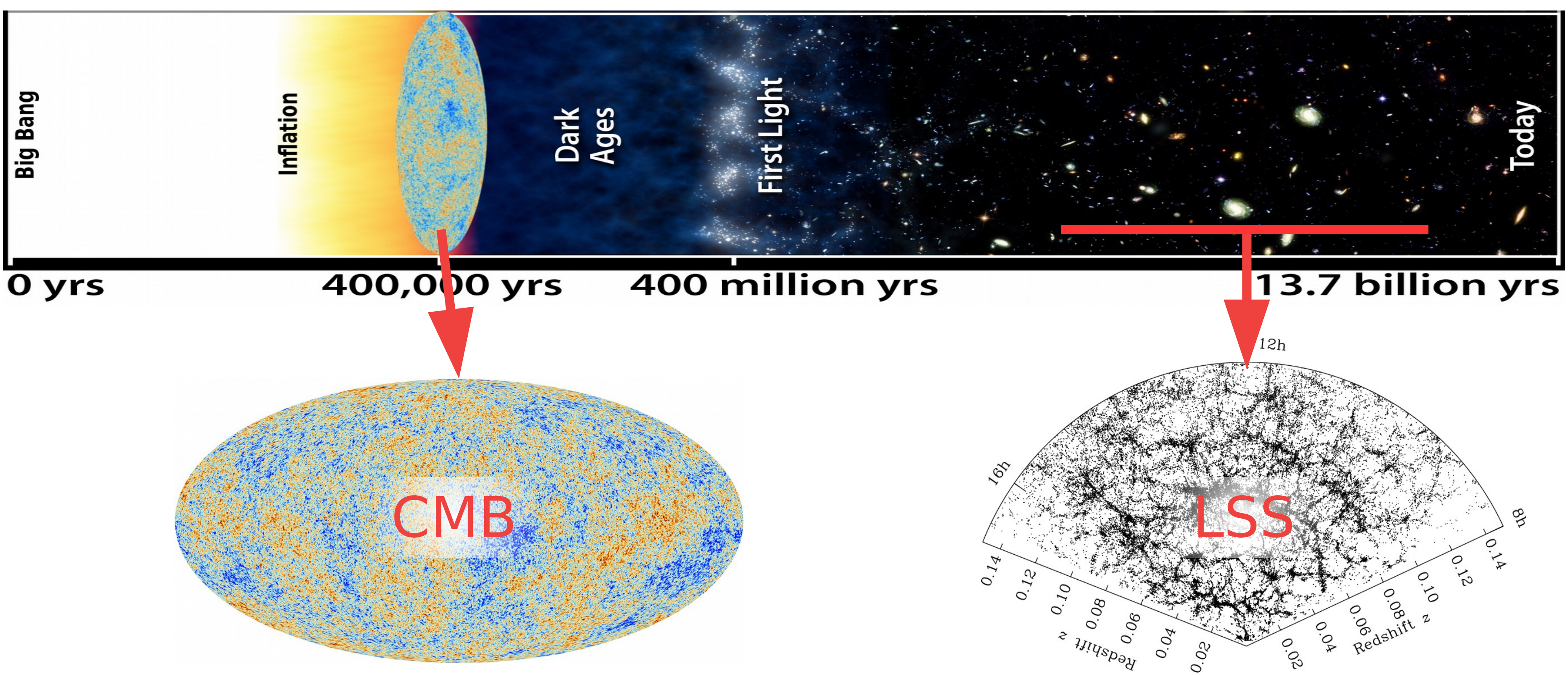

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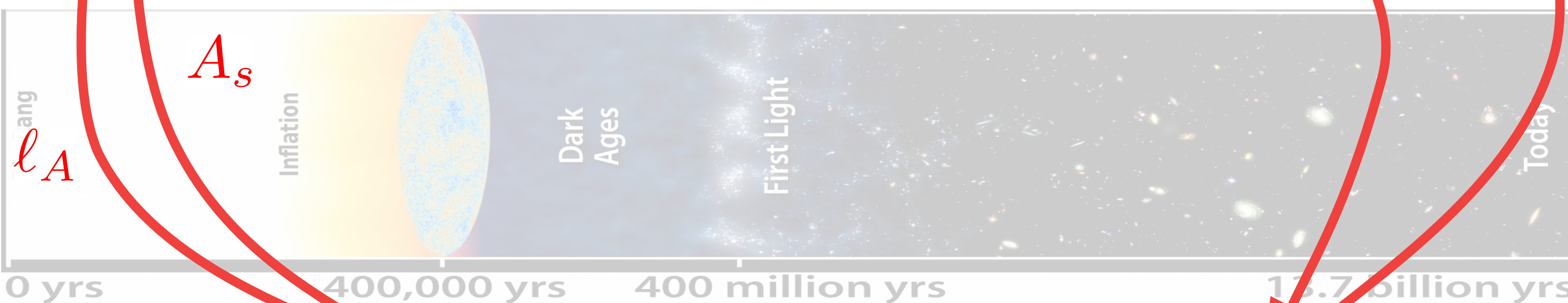

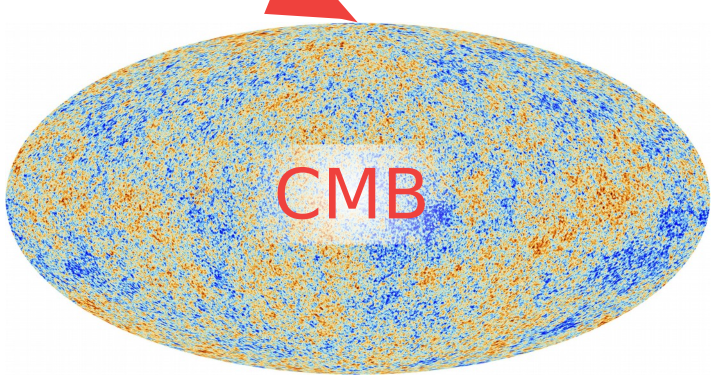

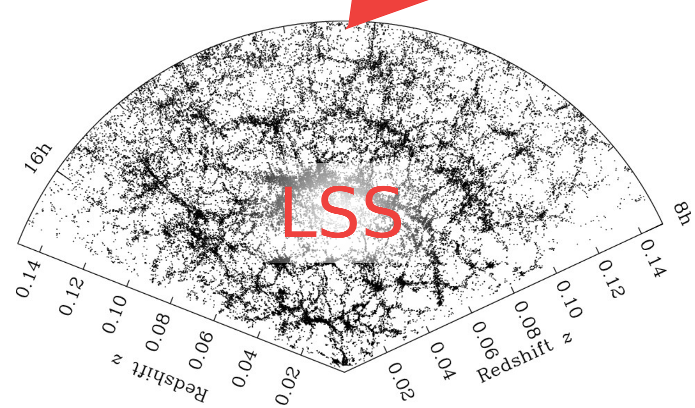

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<u>Euclid CMBX Science Working Group</u>

Explore and prepare the joint analysis
of Euclid and CMB data

Outline

I. Forecasting the CMB-LSS combination

How to combine probes

- All the info of a given probe :

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

- At "first order", when performing forecasts, fits, MCMC, etc :

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

...assuming "probe 1" and "probe 2" are uncorrelated

Forecasting constraints

Fisher formalism :

- For a given likelihood $\mathcal{L}(M|\mathcal{O}_{bs})$, in a certain model (with fiducial parameters)
- Approximate posterior (~likelihood) as Gaussian fct of model parameters $\boldsymbol{\Theta}$

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

- 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 :

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

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

Combining future & existing datasets ?

“Adding” Planck constraints to Euclid forecasts :

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

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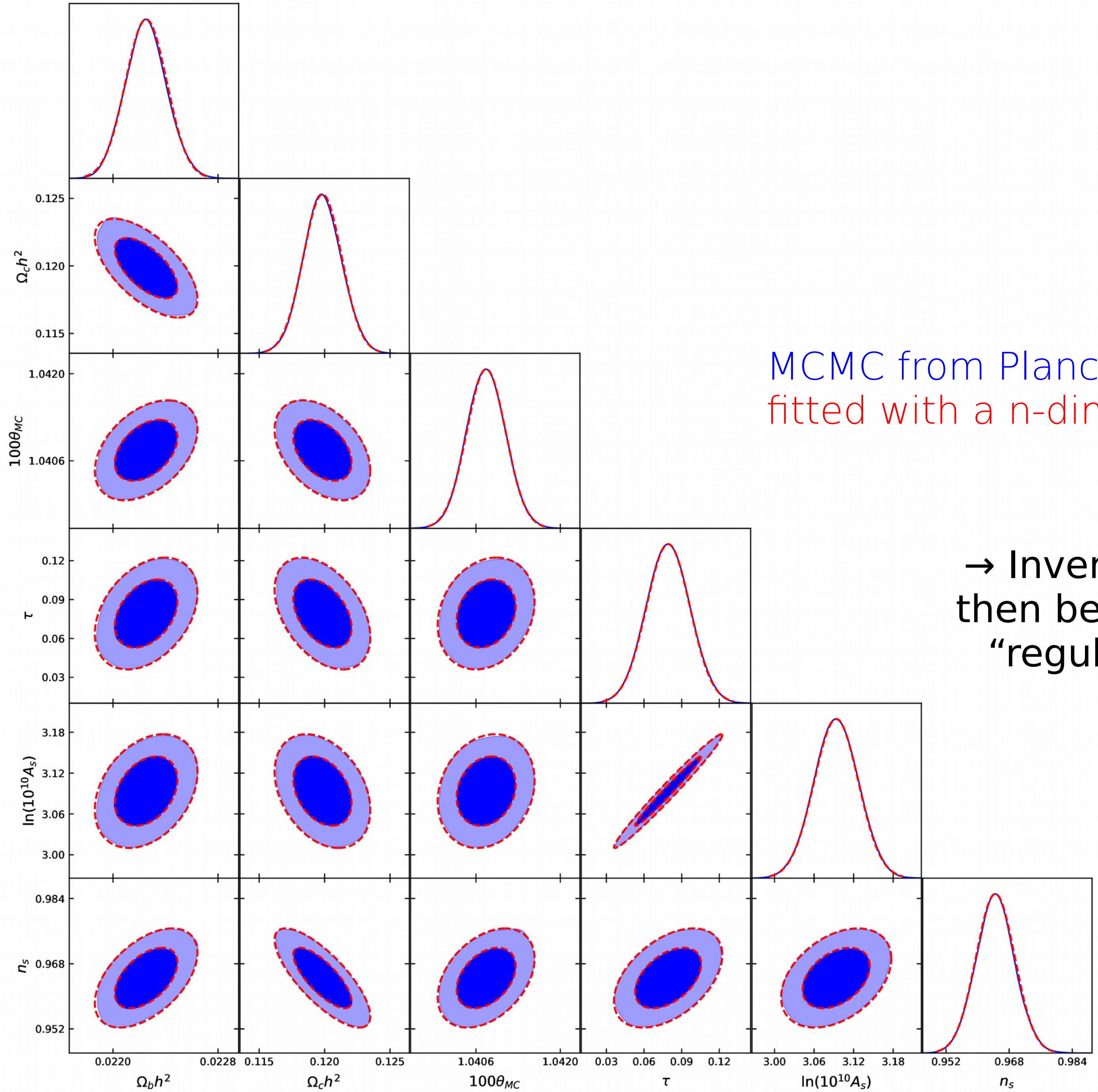
<u>Alternative approach :</u>

Fitting the Planck posterior

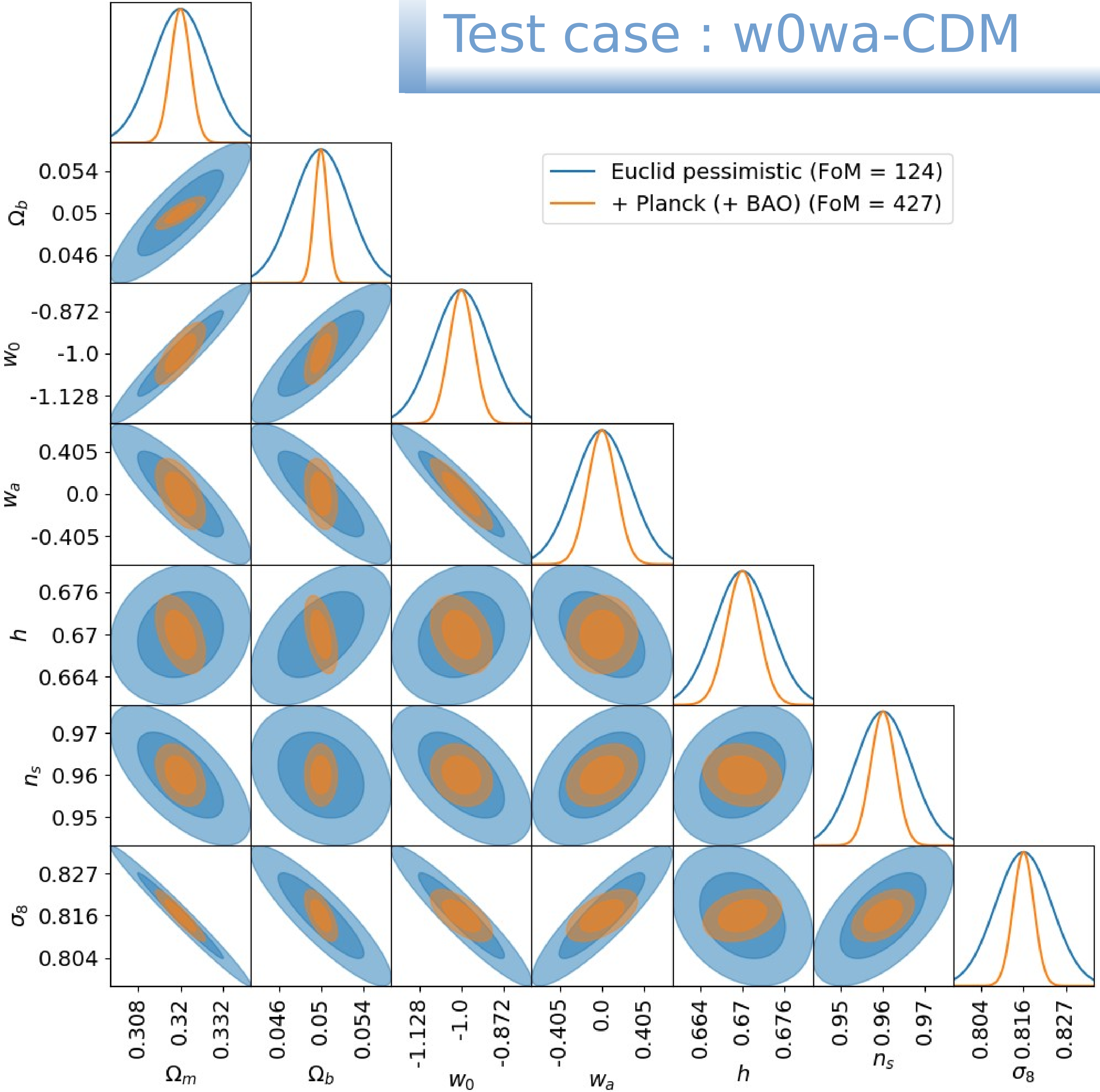
Posterior fitting



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

→ Inverse covariance can then be simply added to a "regular" Fisher matrix

Test case : w0wa-CDM



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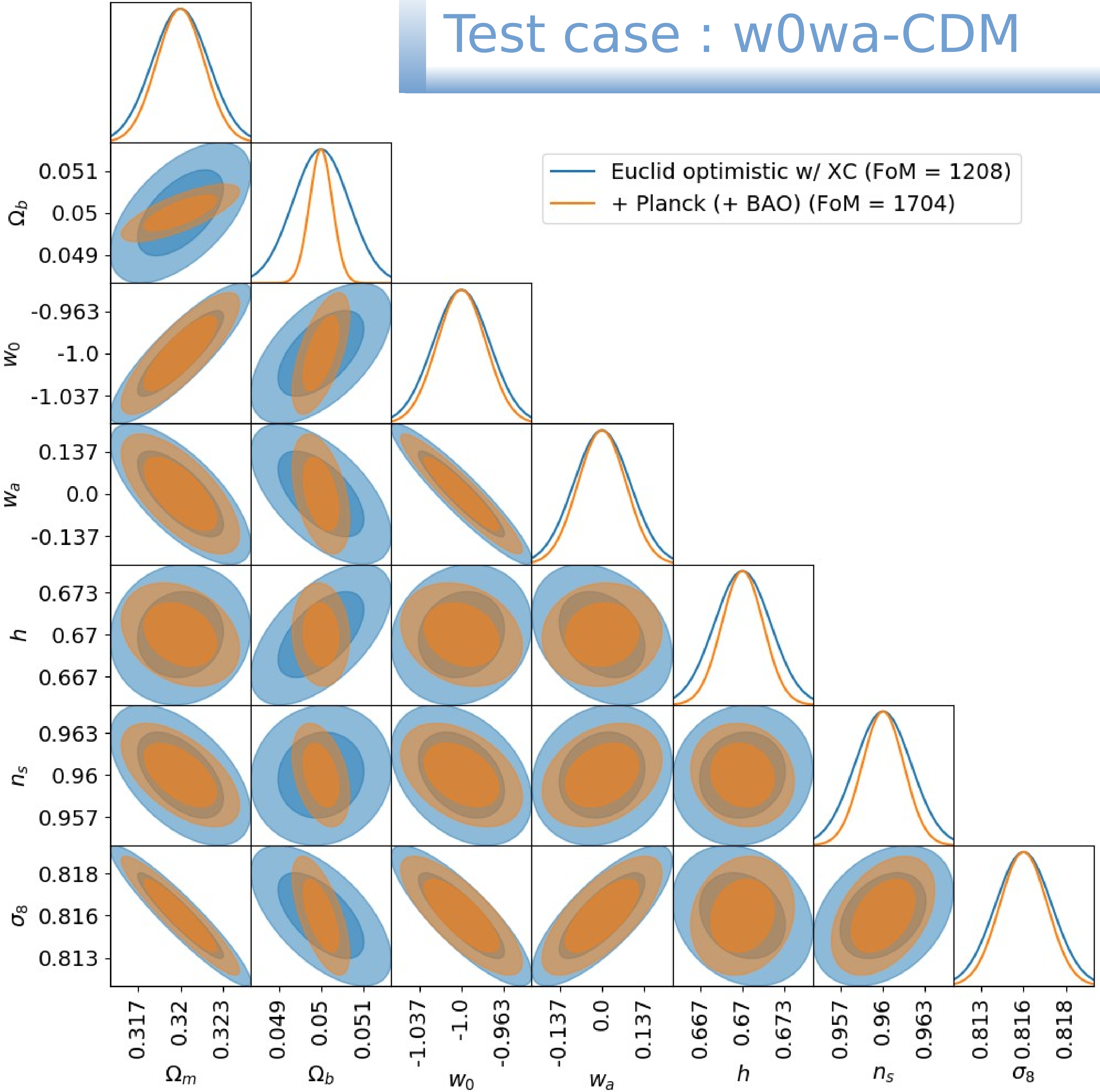

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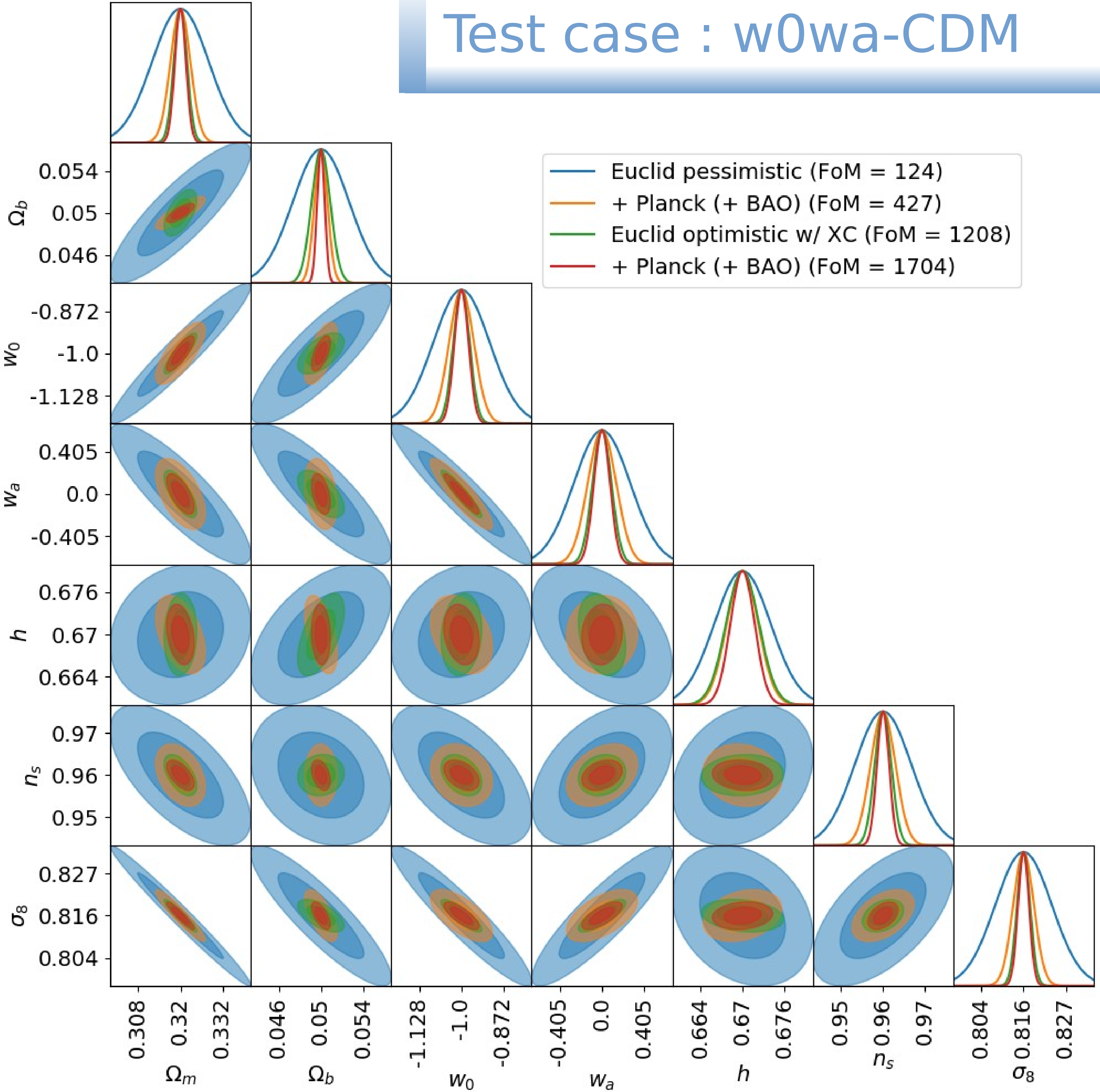

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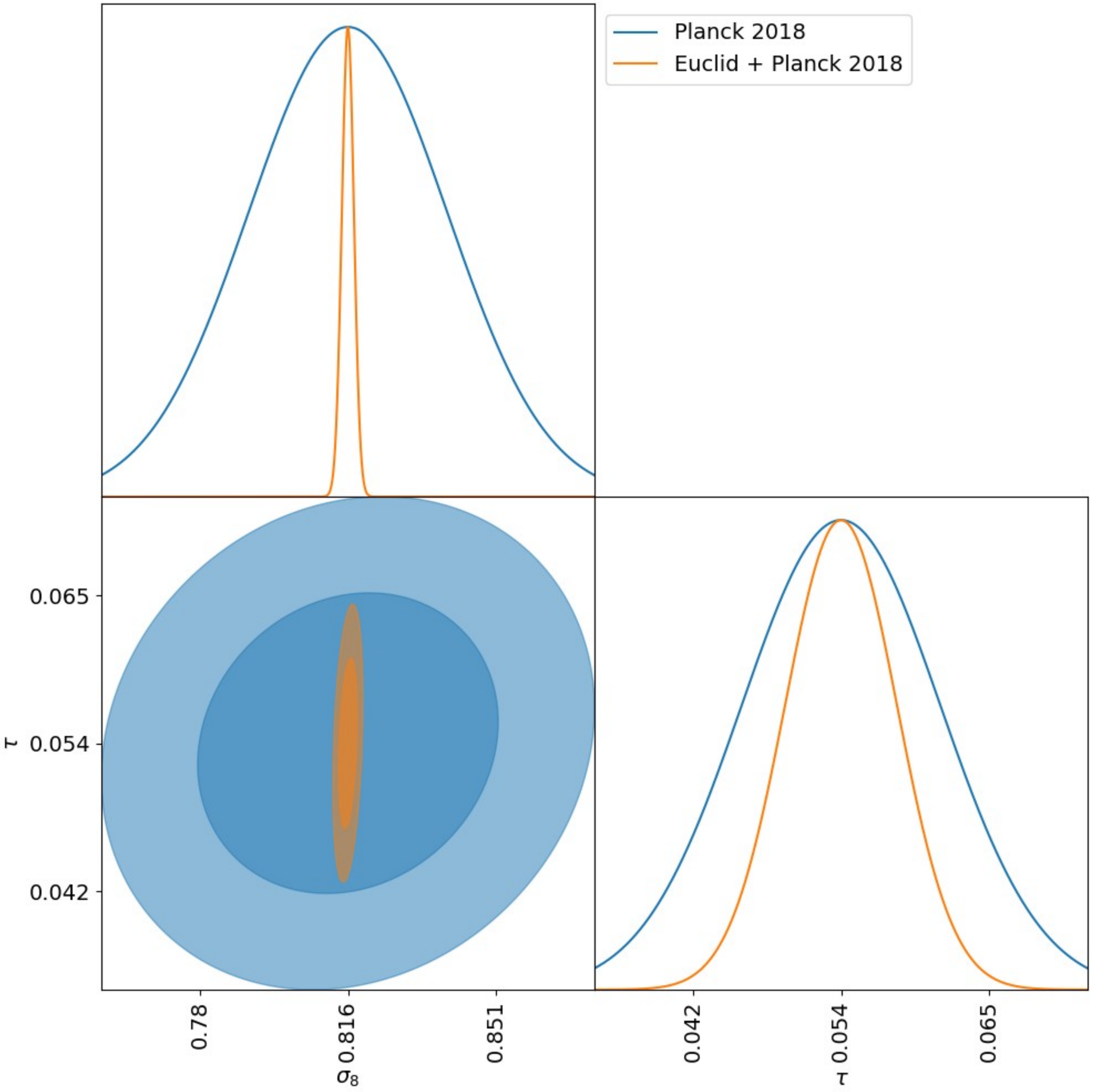
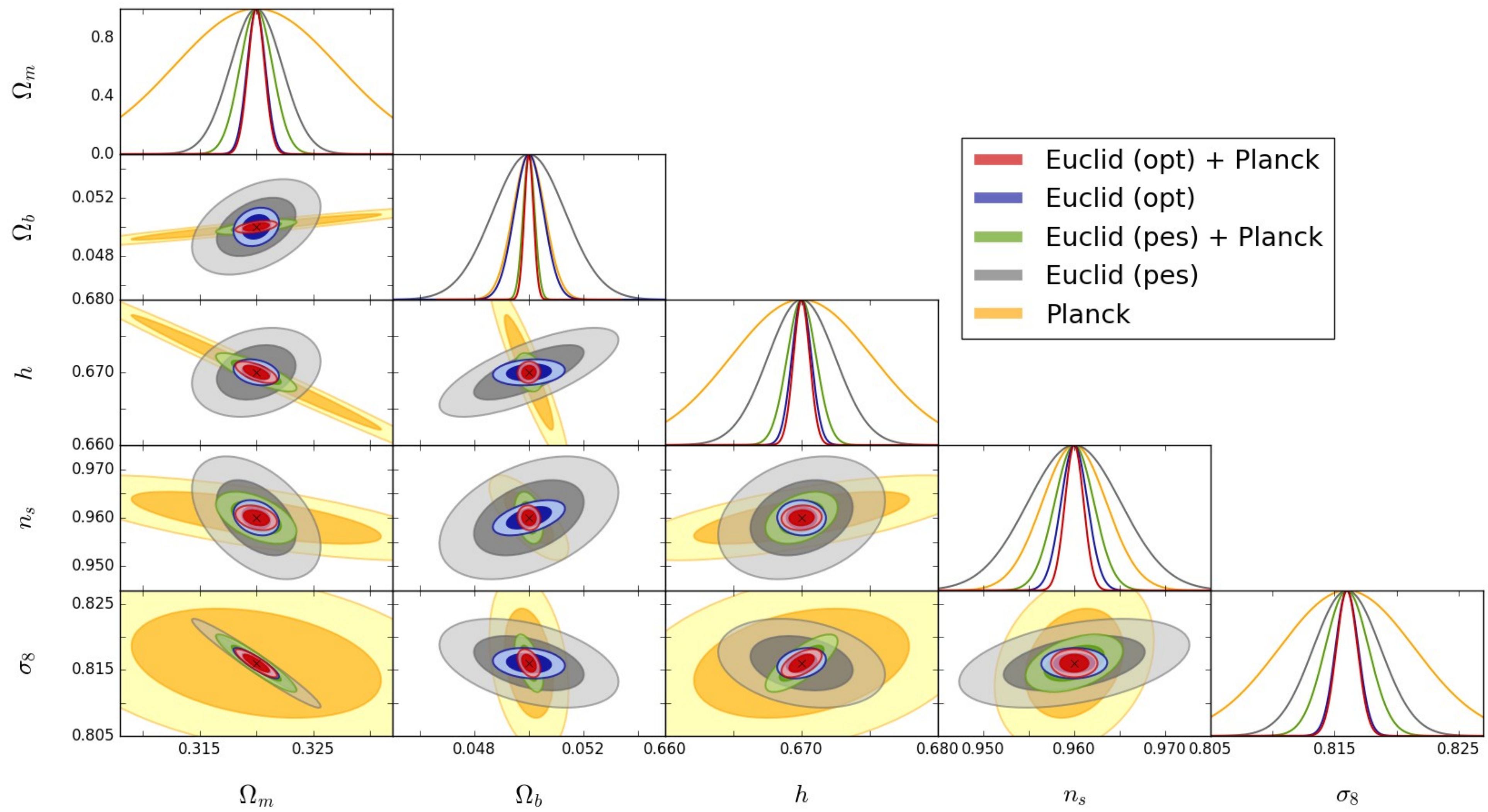


"Traditional" Fisher analysis



Courtesy of
J. Bermejo-Climent

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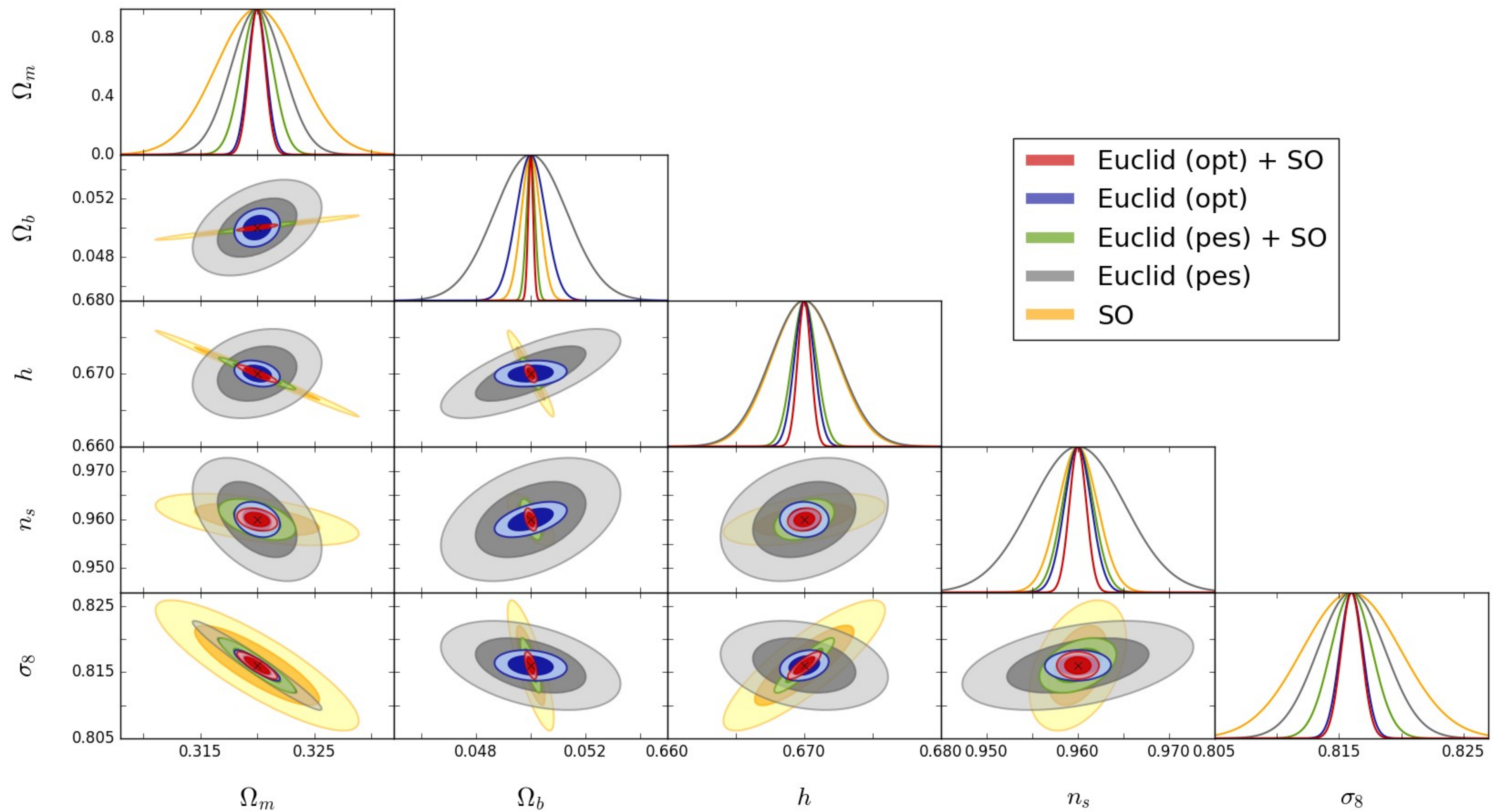

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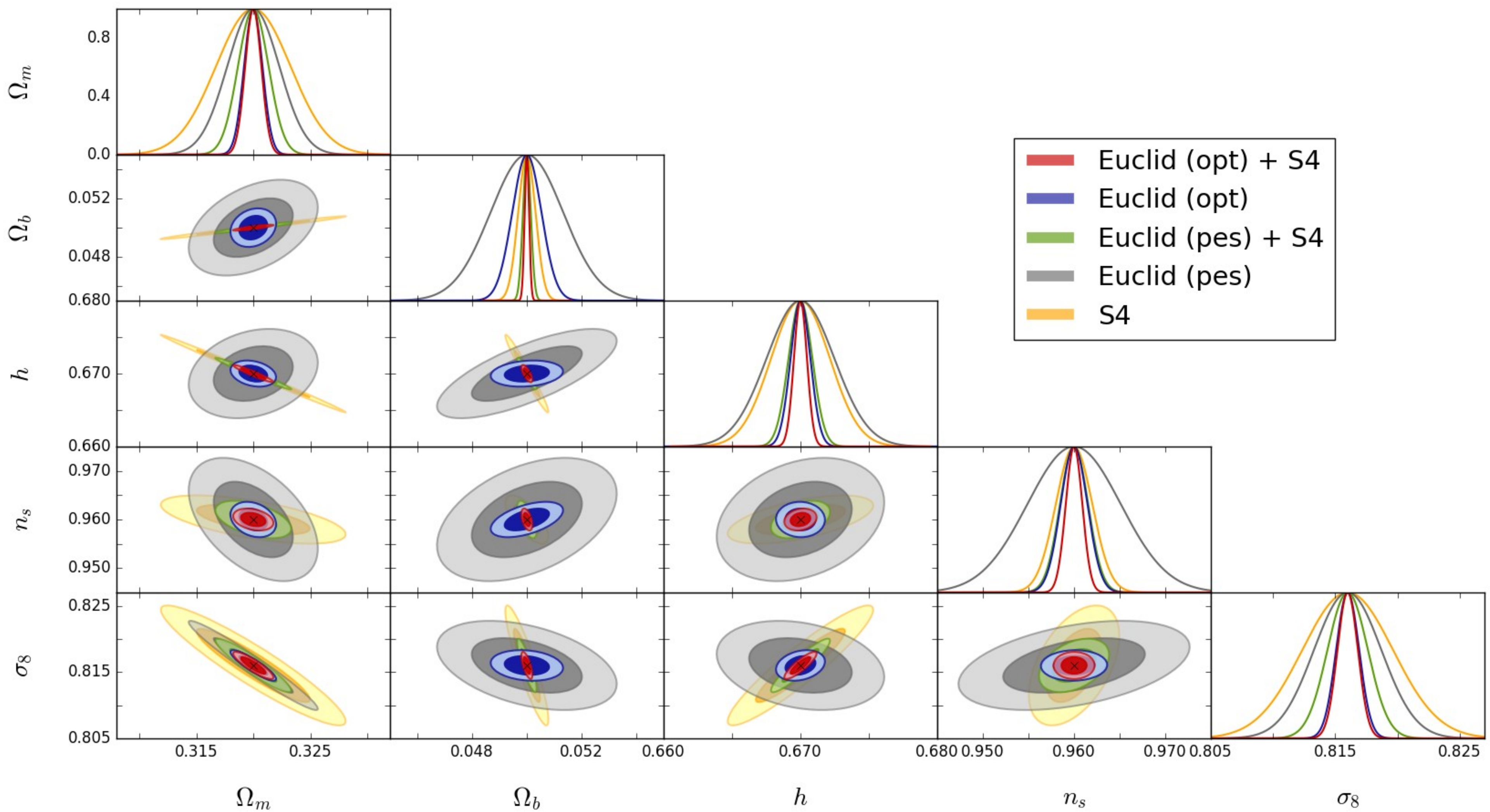

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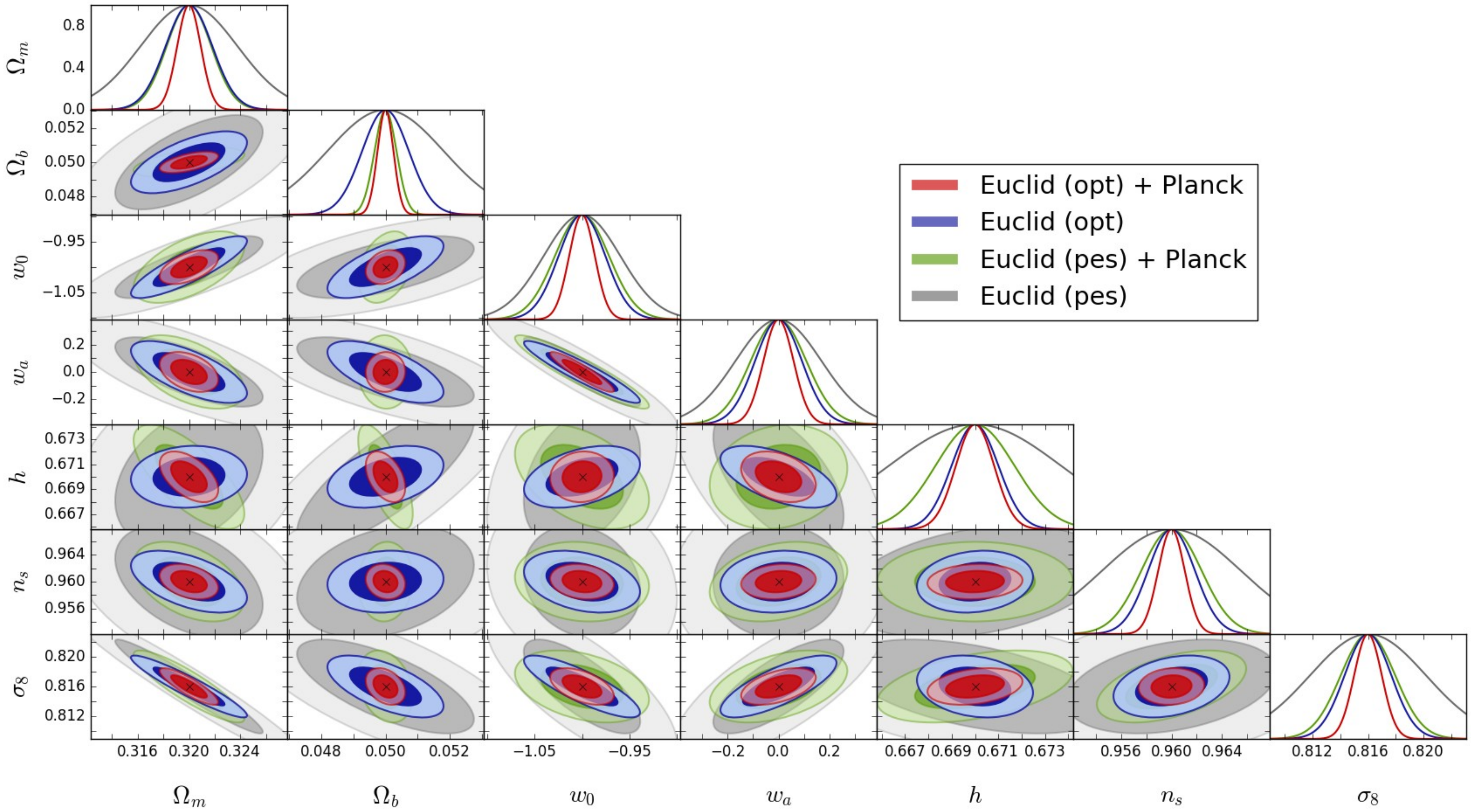

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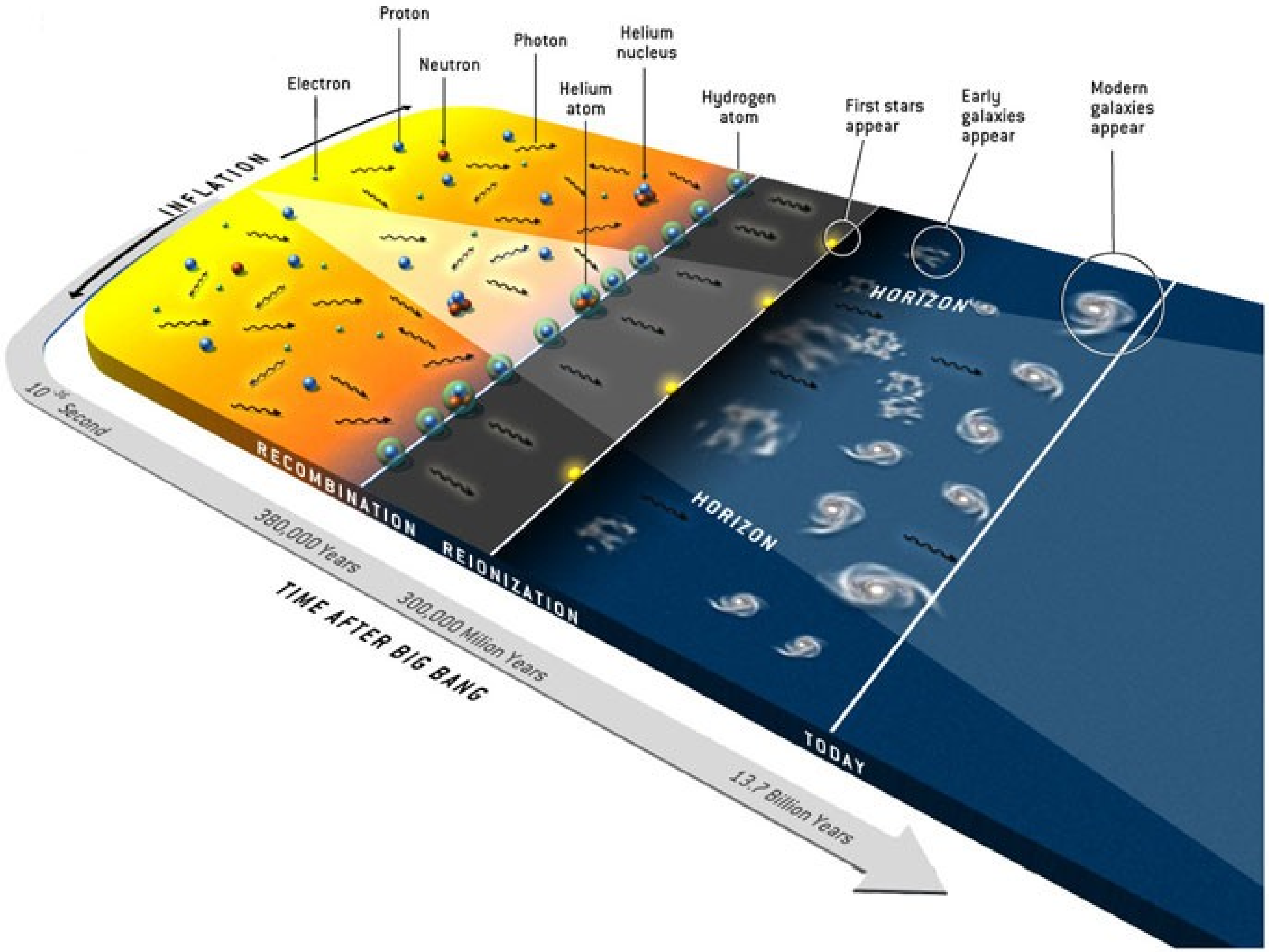
Outline

I. Forecasting the CMB-LSS combination

II. Full CMB-LSS joint analysis

CMB-LSS cross-correlation



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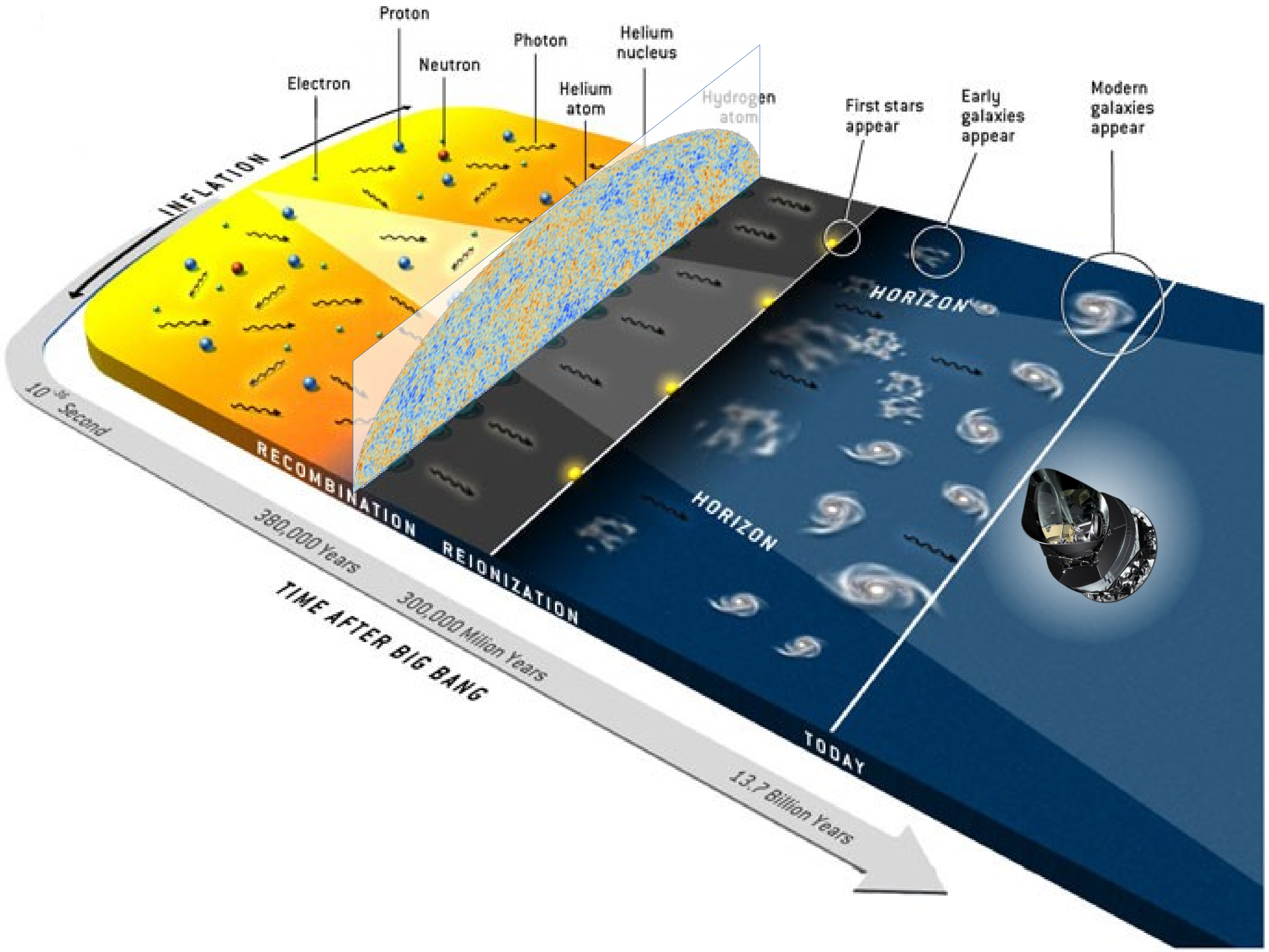

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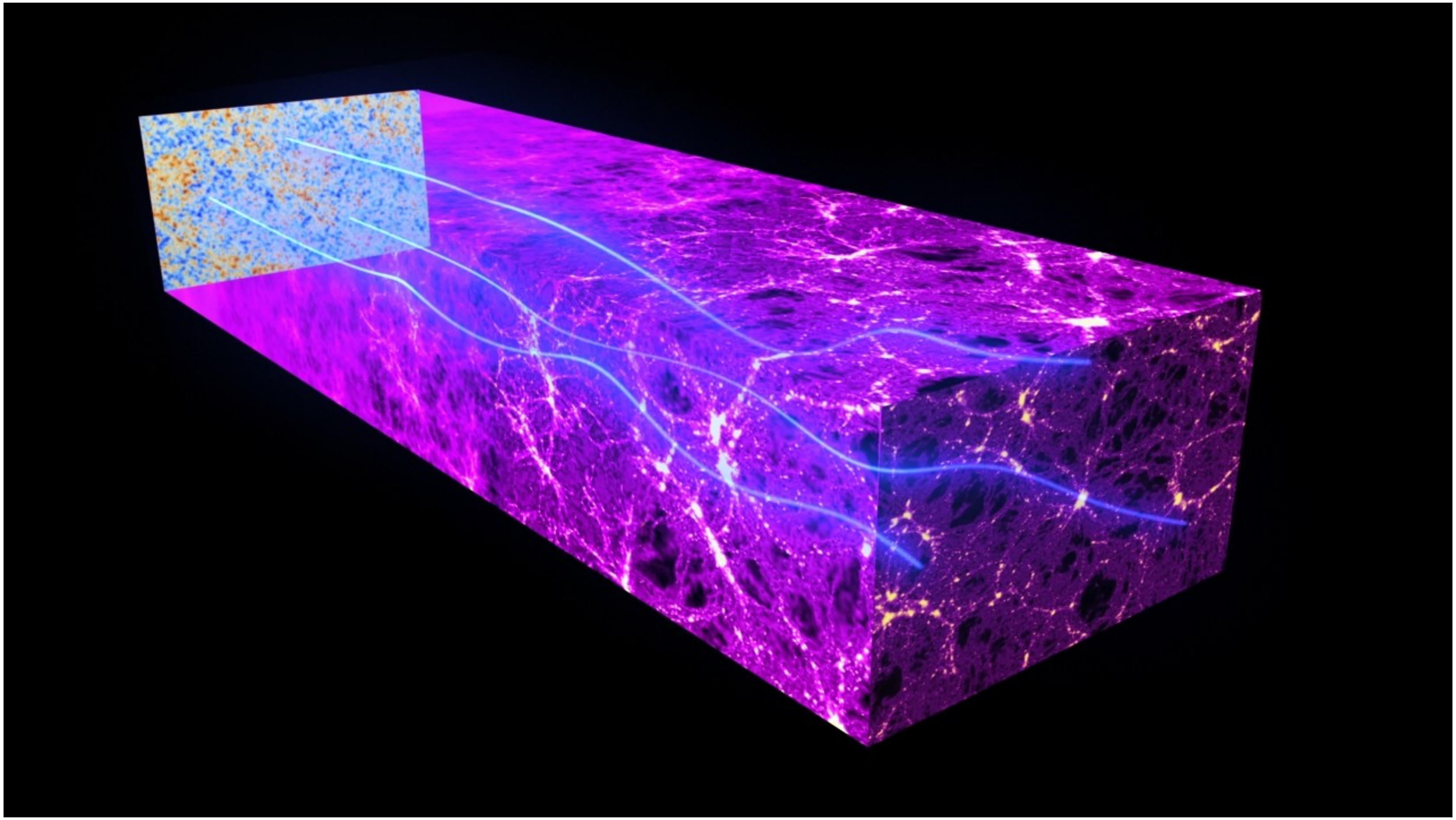

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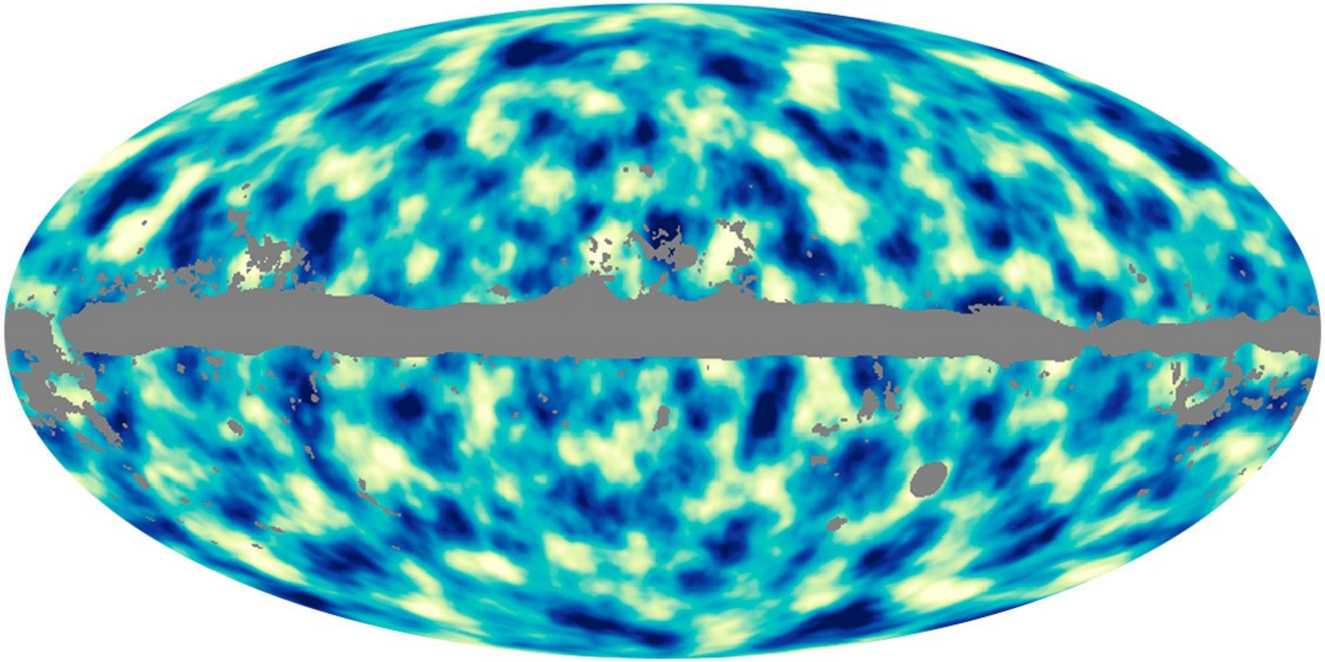
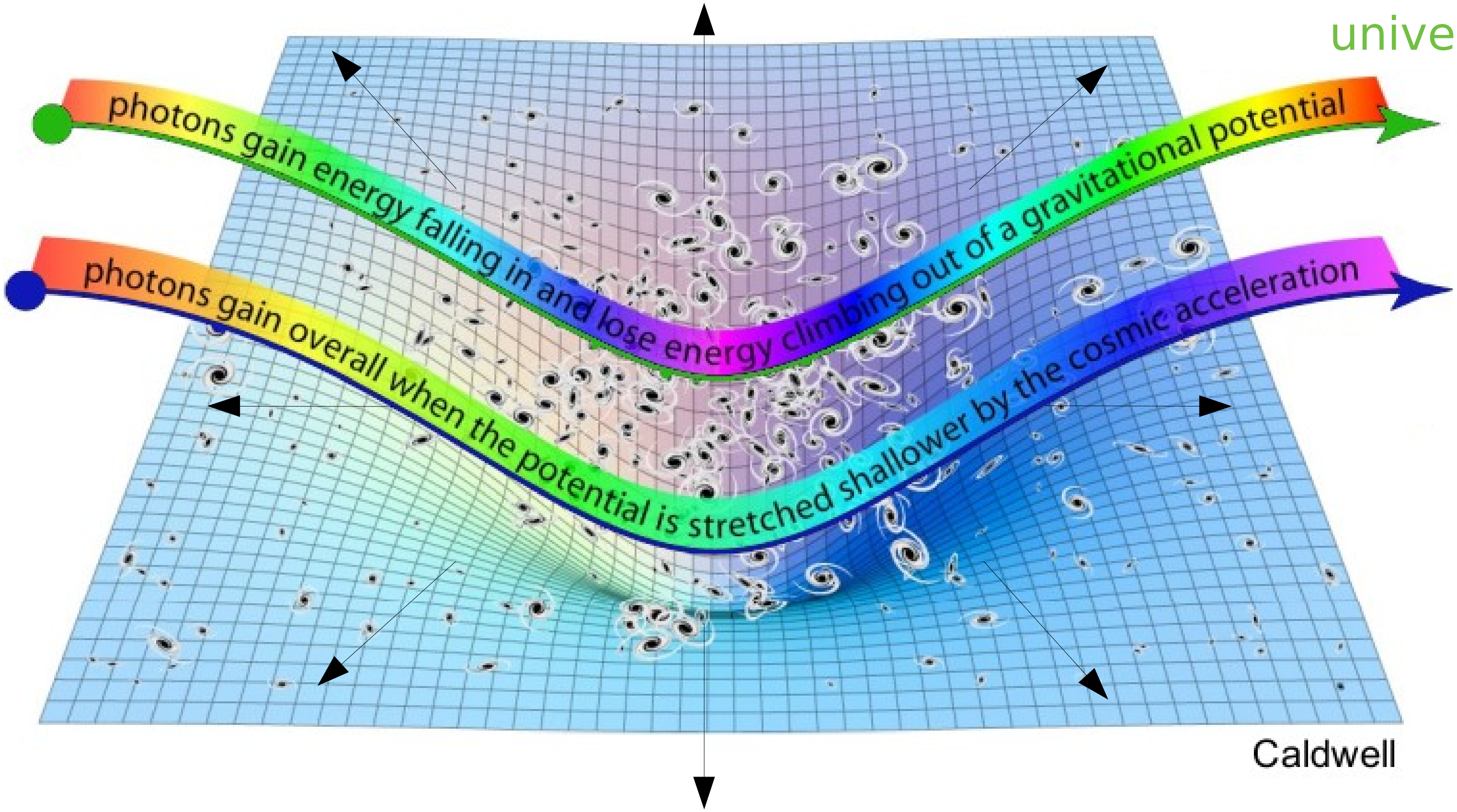


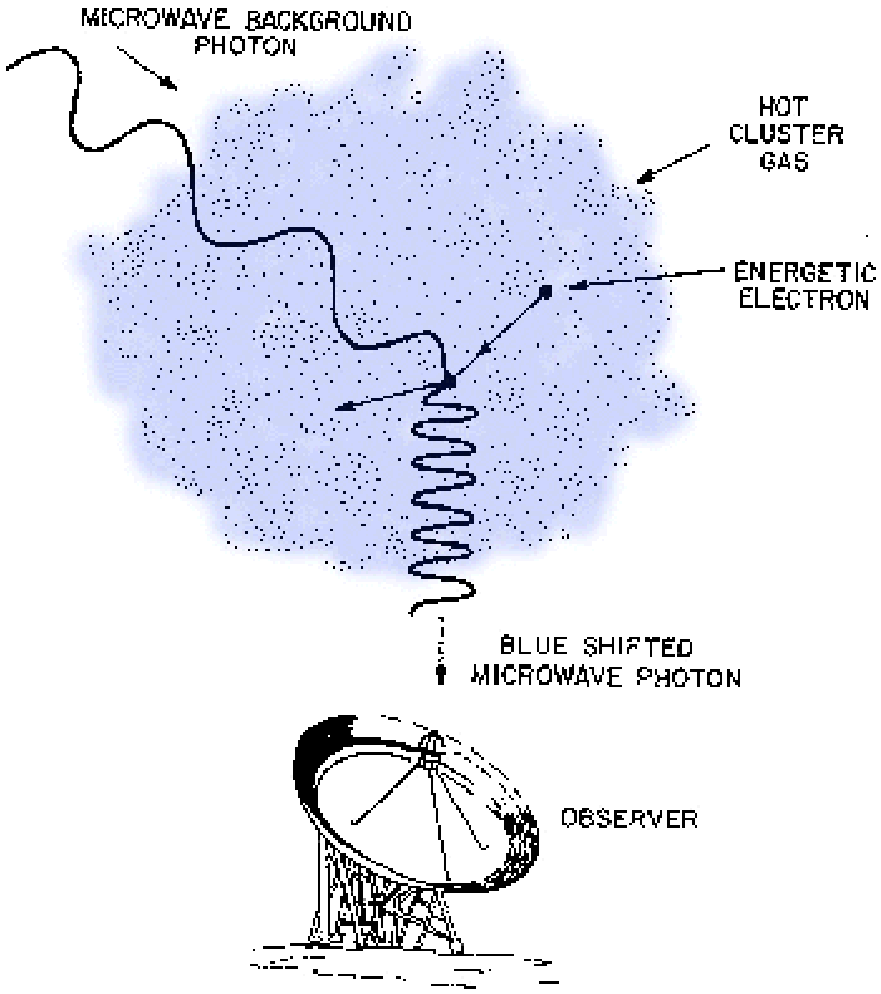
The integrated Sachs-Wolfe effect



In matter-dominated universe

In matter + dark energy universe

The Сюня́ев-Зельдо́вич effect



LSS x CMB joint analysis

Which observables ?

- LSS:
  - Photometric Galaxy Clustering
  - Weak Lensing
  - (Spectroscopic Galaxy Clustering)
  - (Secondary LSS probes)

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  - Temperature
  - Polarization (E & B)
  - CMB lensing

} contains secondary anisotropies (Temperature, Polarization)

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Exploit all auto- and Cross-correlations
(in SH space)

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  - Polarization (E & B)
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Outline

I. Forecasting the CMB-LSS combination

II. Full CMB-LSS joint analysis

III. Closing thoughts : current state-of-the-art

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

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 ?

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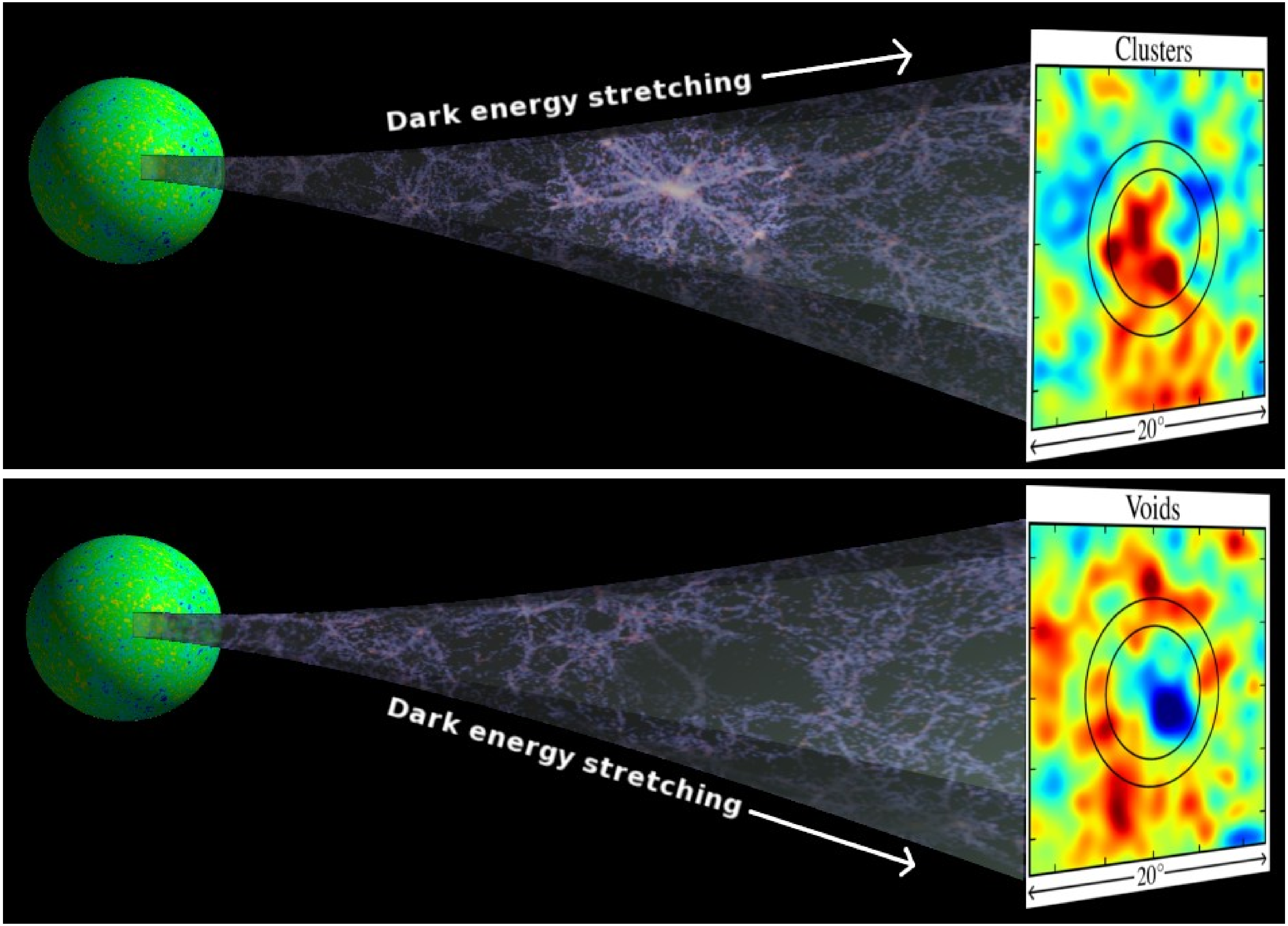
iSW effect of superstructures



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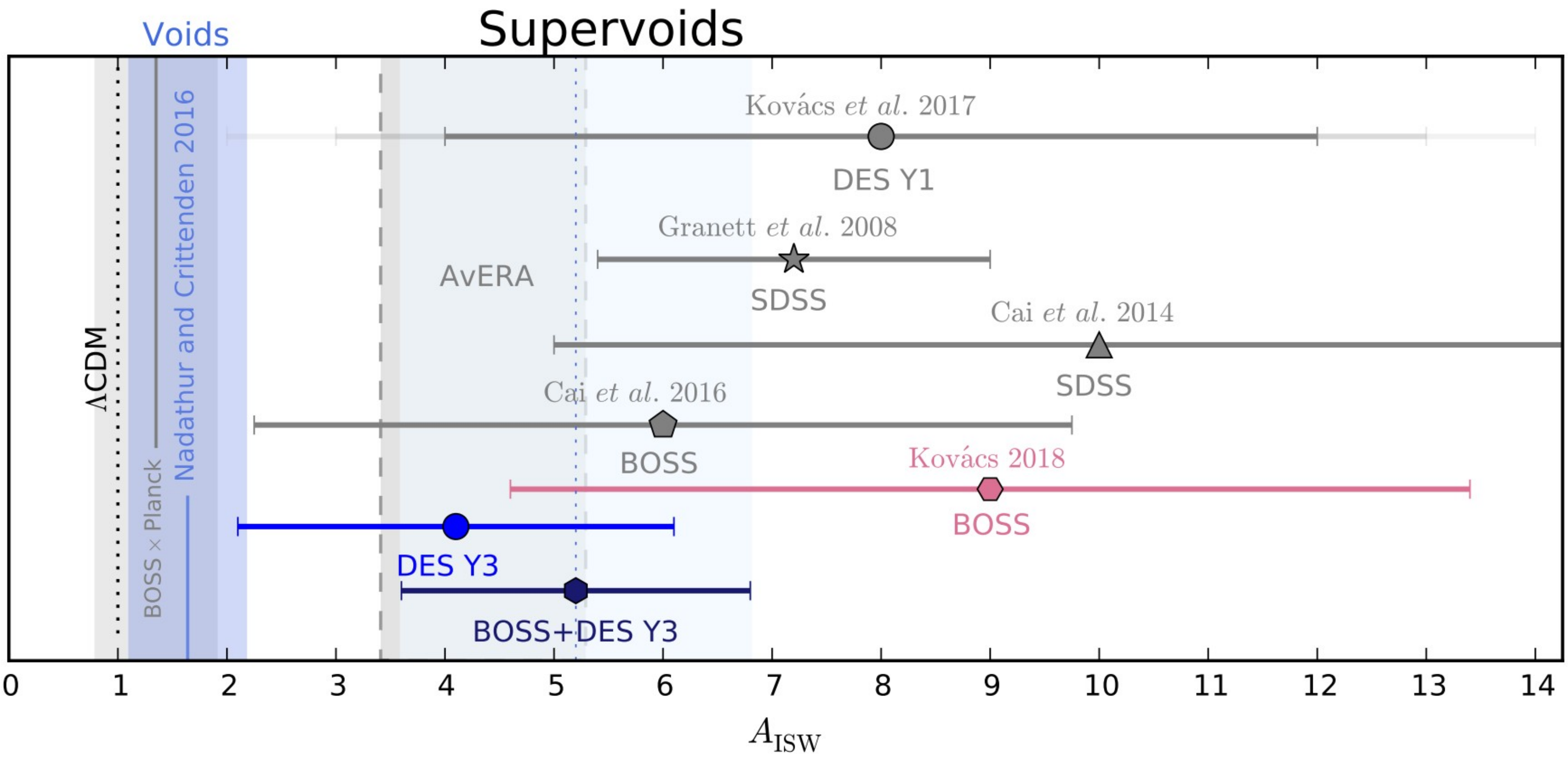

Kovács et al. 2019

Thank you
for your attention !