UNIVERSITÉ DE GENÈVE

SWISS COSMOLOGY DAYS 2025
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# Reconstructing the Dark Energy Density in Light of DESI BAO Observations

Is it possible to **measure DE/MG** in a **truly model-independent** way, **without assuming** any functional form for the **time evolution** of the DE/MG functions?

# Model-Independent Reconstruction of Gravity

**Covariant Theory**

$S[g_{\mu\nu}, \phi]$
+initial cond.

$G_i(X,\phi)\Big|_{i=2,3,4,5}$

$\phi'(\tau_0),\ \phi(\tau_0)$

**Effective Description**

Expansion $w(\tau)$
Kineticity $\alpha_K(\tau)$
Braiding $\alpha_B(\tau)$
$M_p$ running $\alpha_M(\tau)$
Tensor speed $\alpha_T(\tau)$

**Predictions**

$H(z)$
$C_\ell^{ij}$
$P(k,z)$
$\dots$

**MG Description**

$\mu(z,k)$
$\Sigma(z,k)$
$[\gamma(z,k))]$

OBSERVATIONS

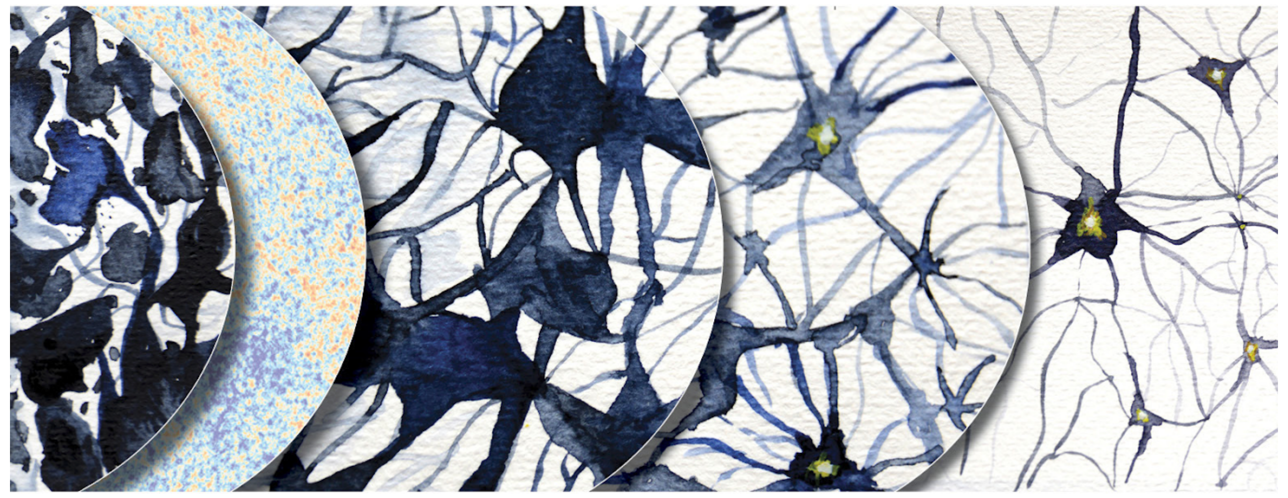

Image by E. Bellini

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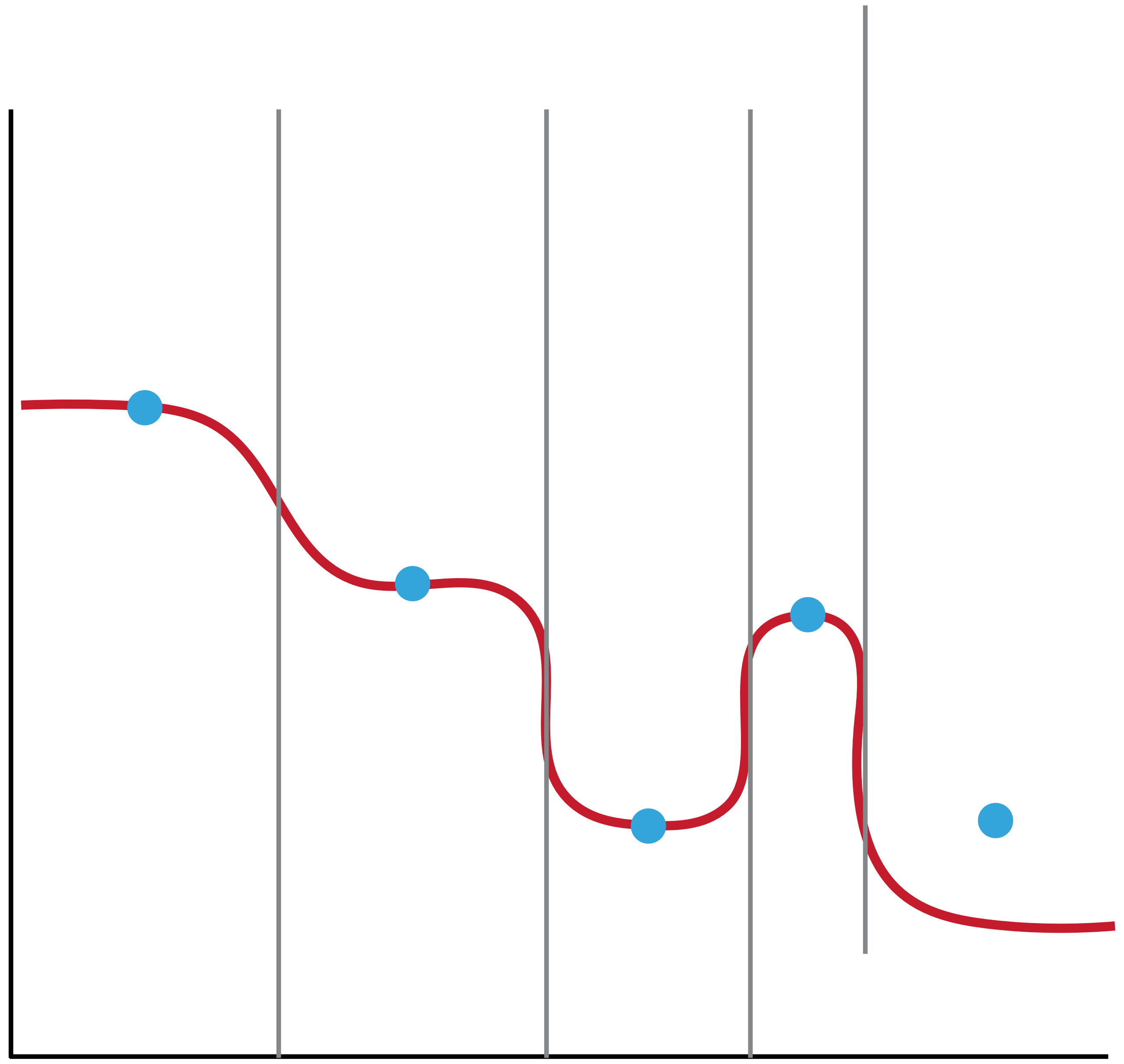


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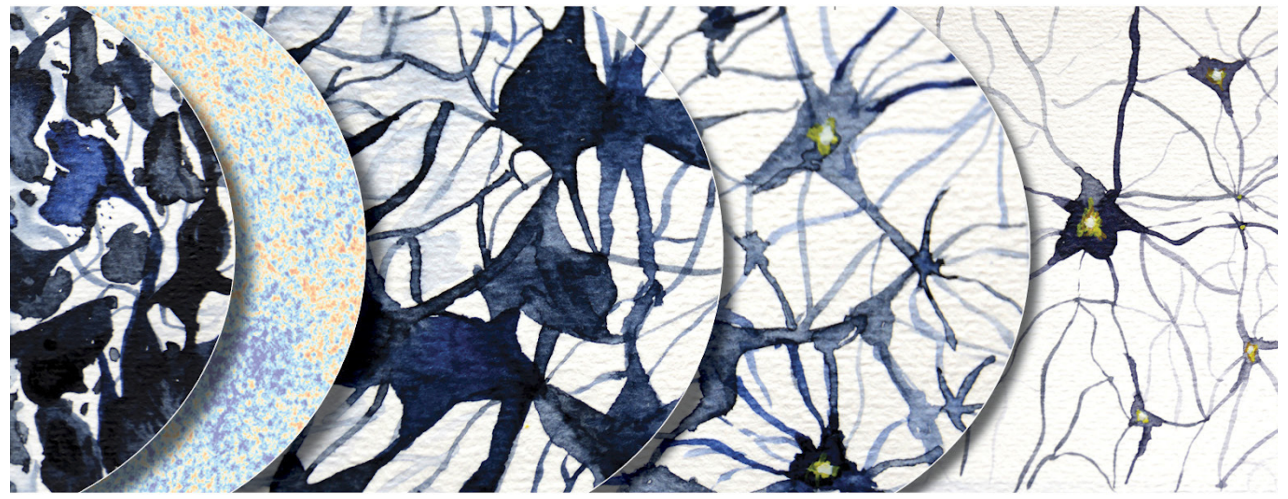

# Background Reconstruction With DESI

GOAL → reconstruct the **DE density parameter** evolution with the recent **DESI BAO** measurements






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University of Geneva

Emilio Bellini
SISSA - IFPU

Miguel Zumalacárregui
Max Planck - Potsdam

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Martin Kunz
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$$\Omega_{\mathrm{X}}(z) = \Omega_{\Lambda}(z)\,[1 + \Delta\Omega_{\mathrm{X}}(z)]$$

with $\Omega_{\Lambda}(z) = \rho_{\Lambda}/\rho_{\mathrm{cr}}(z)$ and keeping fixed $\Delta\Omega_{\mathrm{X}}(0) = 0$

↓

**Natural cubic spline**

to ensure good behaving derivatives

- Follow the approach from DESI, investigating the role of supernovae data
- We anchor $\Omega_{\mathrm{X}}(z)$ to be constant at high redshifts

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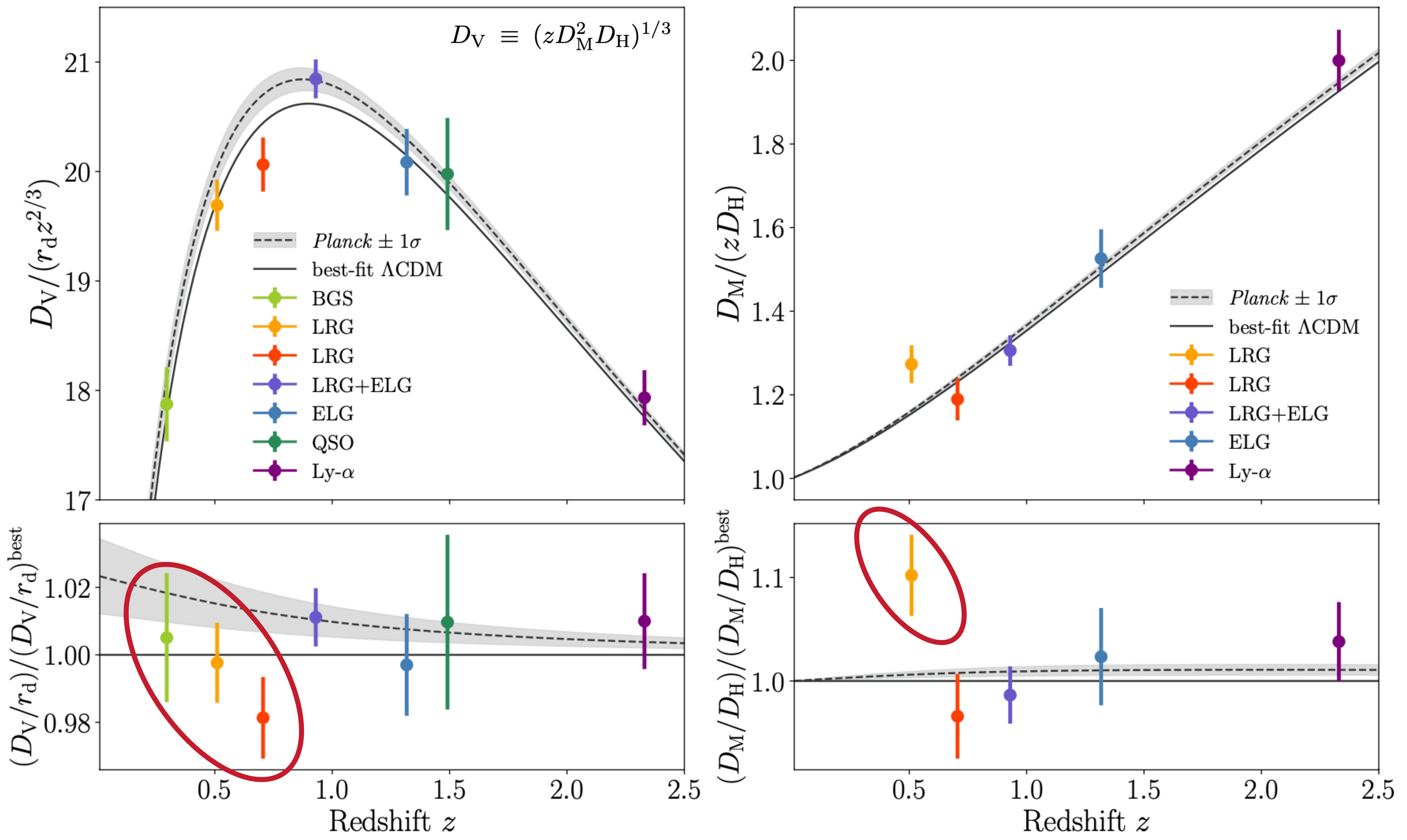
Based on arXiv:2503.13198

# The DR1 DESI Measurements

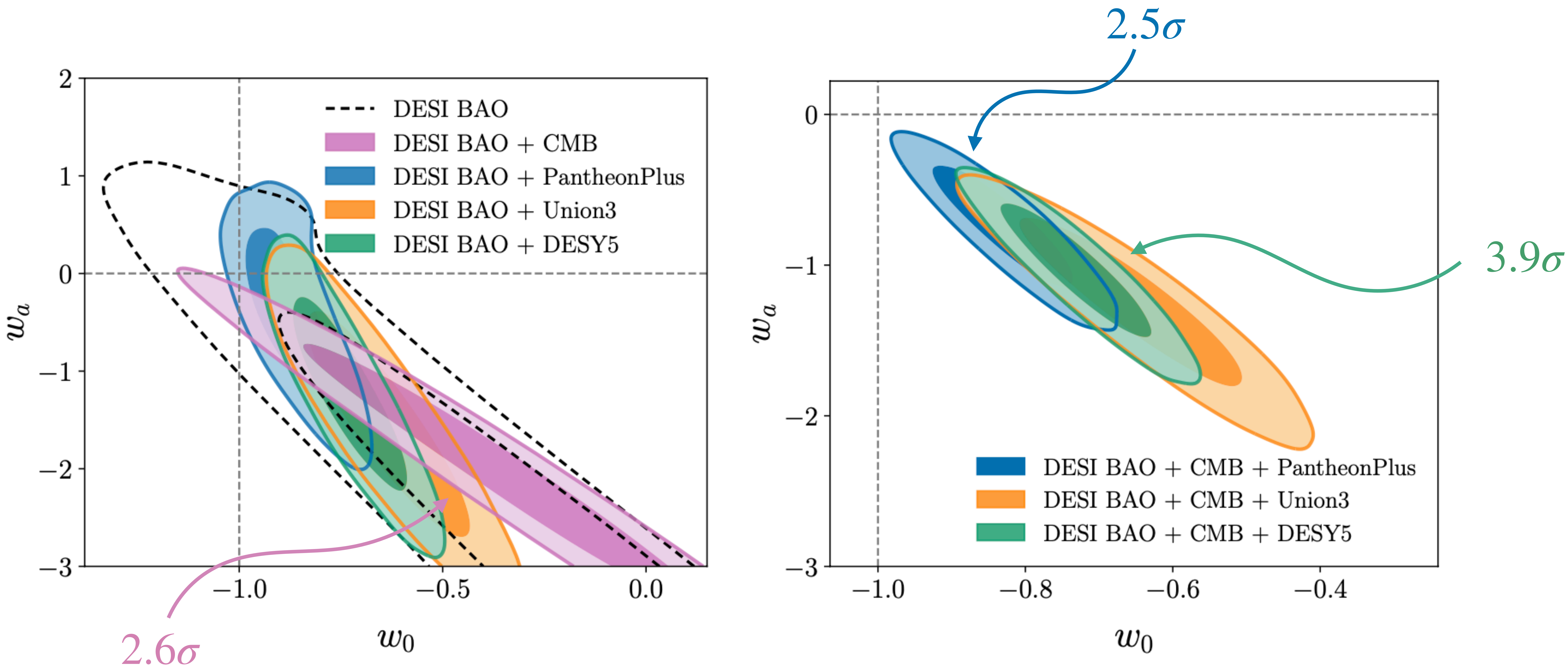



- 7 redshifts
- 5 measurements of $D_M$ and $D_H$
- 2 measurements of $D_V$
- One anomalous measurement at $z = 0.51$ (in $F_{AP}$)

*DESI collaboration VI (2024)*

# Evolving DE Equation of State






$$w(a) = w_0 + w_a(1 - a)$$

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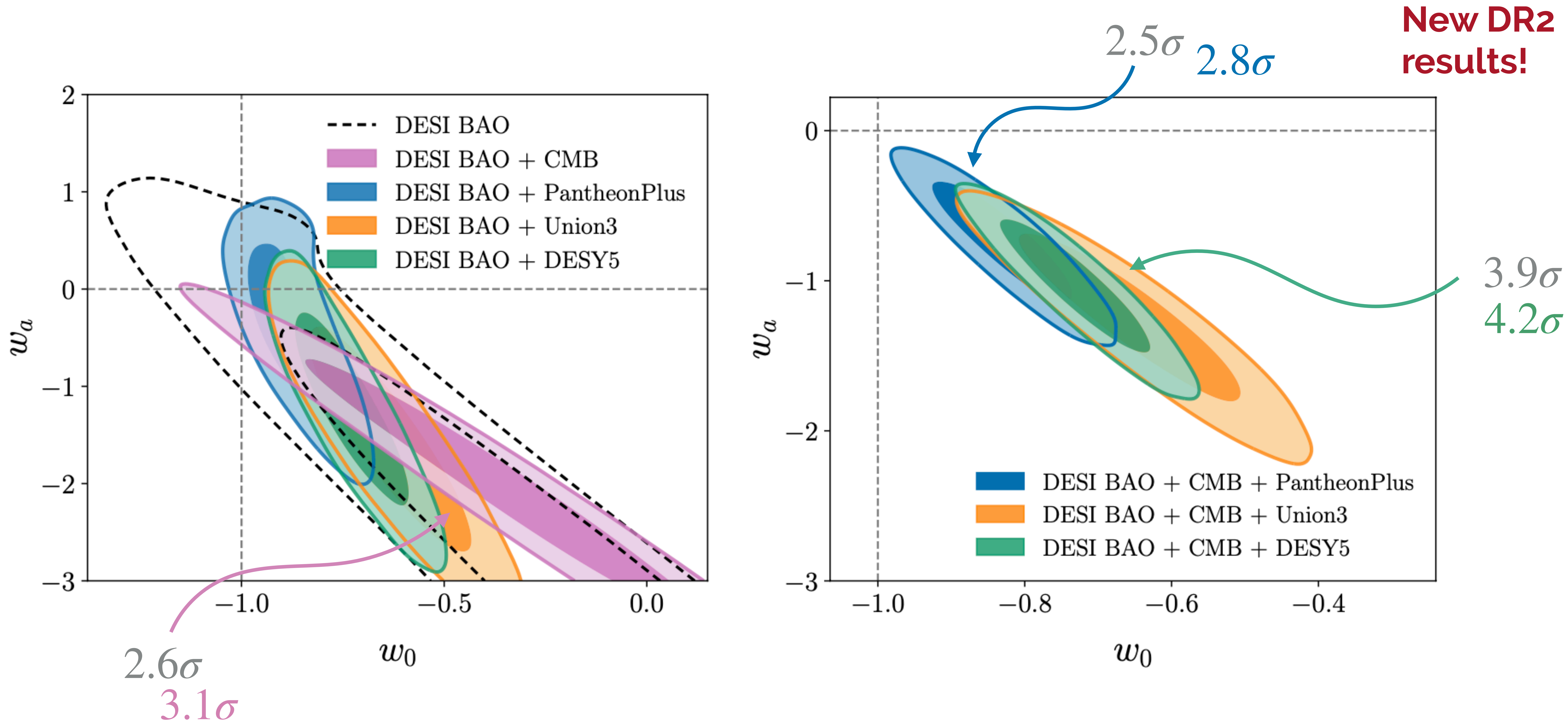


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# Our Background Parametrization

$$\Omega_X(z) = \Omega_\Lambda(z)\,[1 + \Delta\Omega_X(z)] \longrightarrow z_{bin} = \{0.3, 0.51, 0.71, 0.93, 1.32, 1.49, 2.33, 4\}$$

ANCHOR

## ANALYSIS SET UP

- MCMC analysis
- Implement likelihood functions in CosmoSIS
- Planck 2018 TT,TE,EE, lowE, lensing
- ACT lensing
- Supernovae from Pantheon+ and DESY5

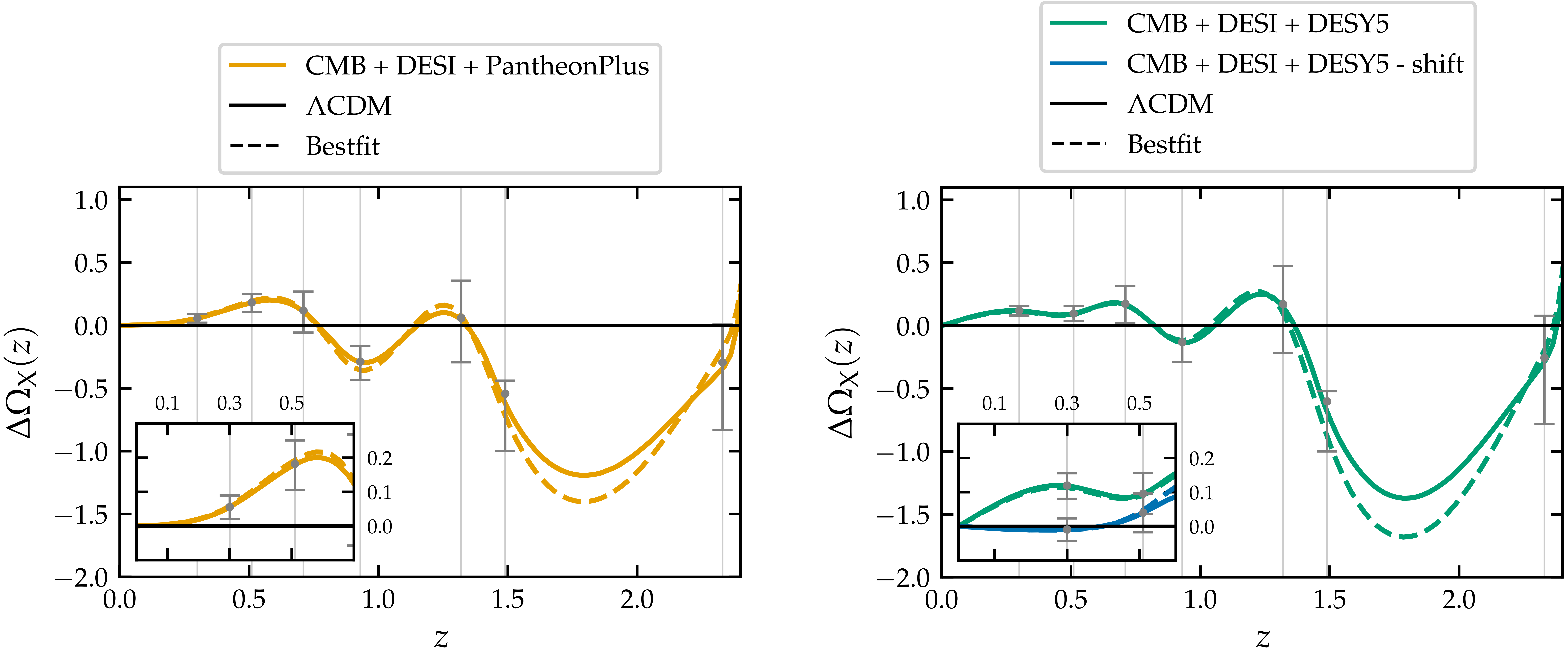
## DESI + SNe

- Varying $\{\Omega_m, H_0, \omega_b\}$ + 8 $\Omega_X(z)$
- Planck prior on $r_d$

## Planck + DESI + SNe

- Varying $\{\Omega_b h^2, \Omega_c h^2, \tau, \theta_{MC}, A_s, n_s\}$ + 8 $\Omega_X(z)$
- Planck and ACT likelihoods

# Reconstructed DE Density

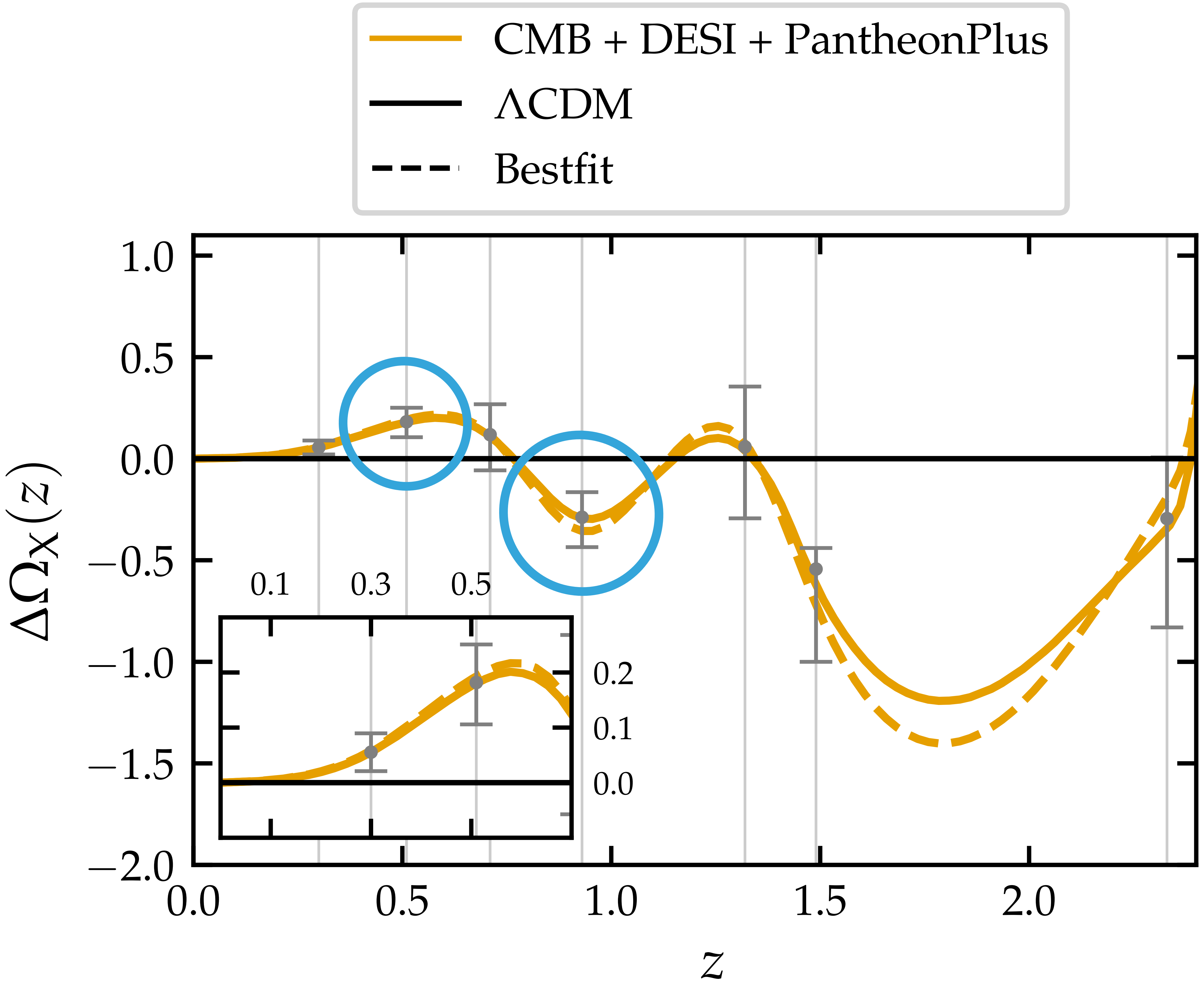



1.33σ

2.42σ

# Reconstructed DE Density



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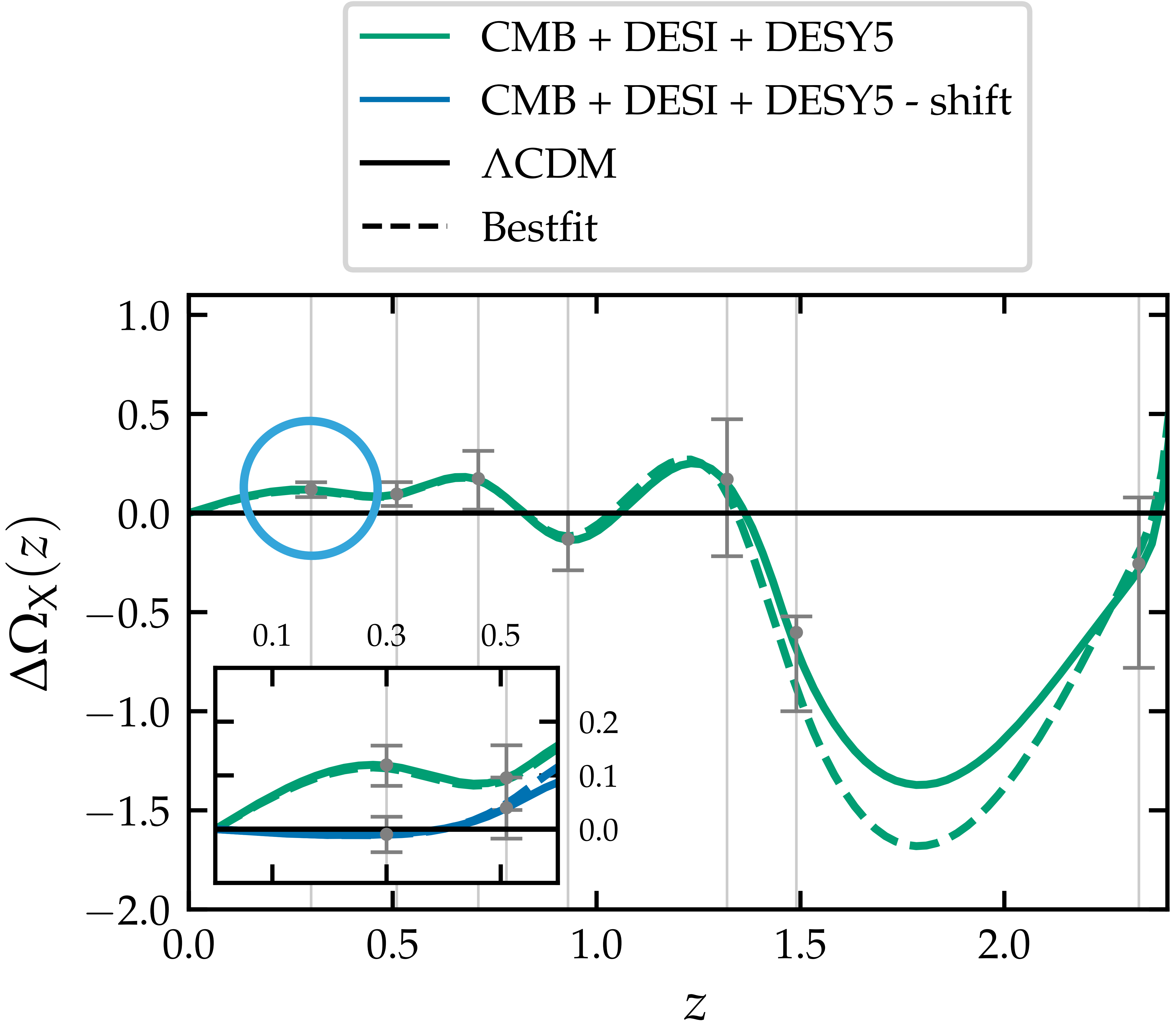


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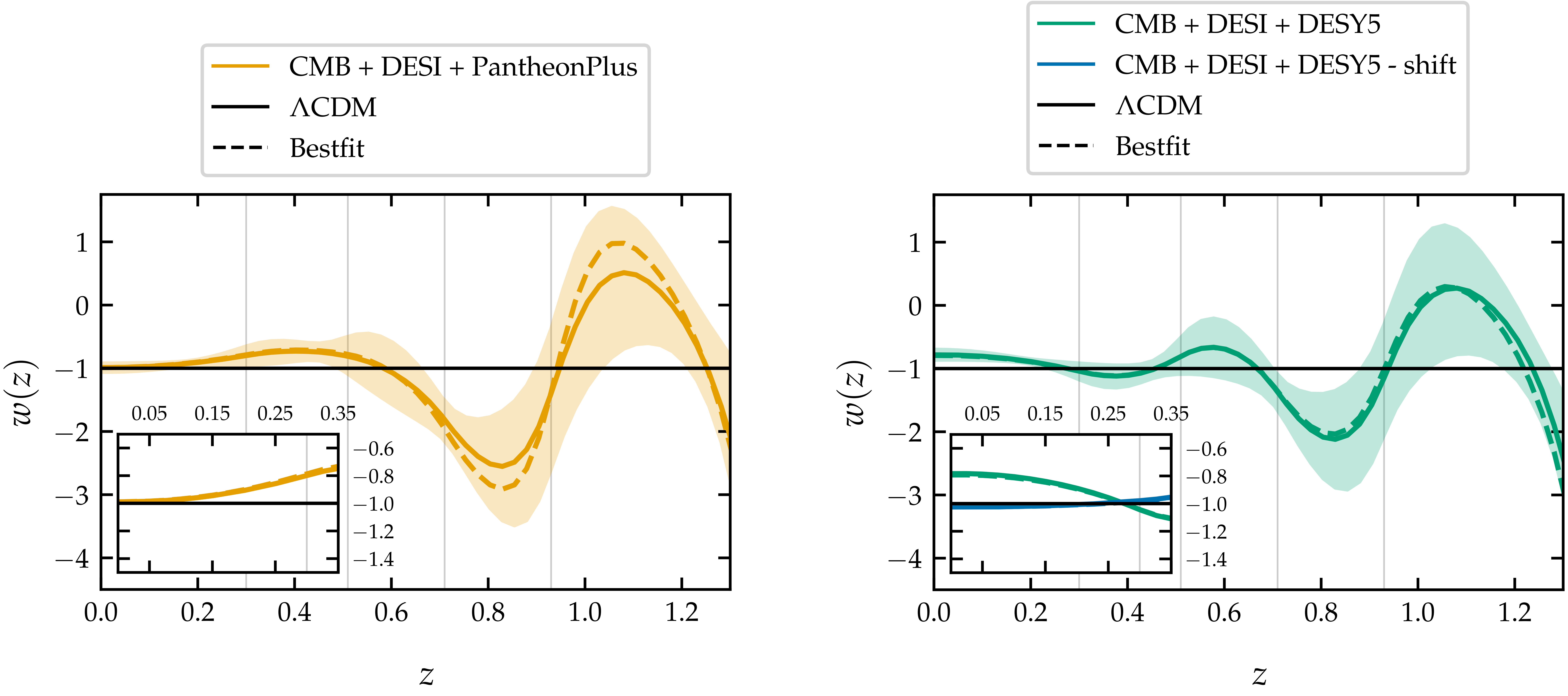

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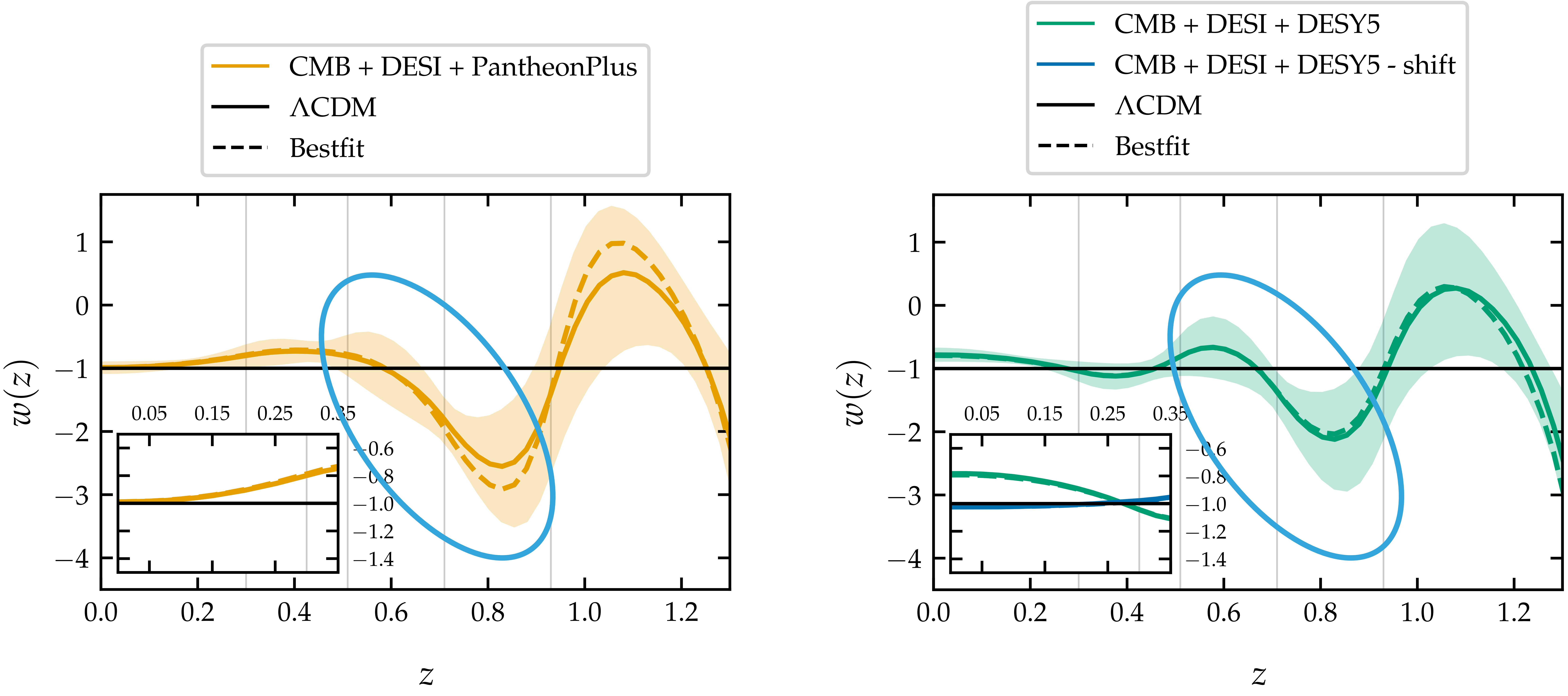
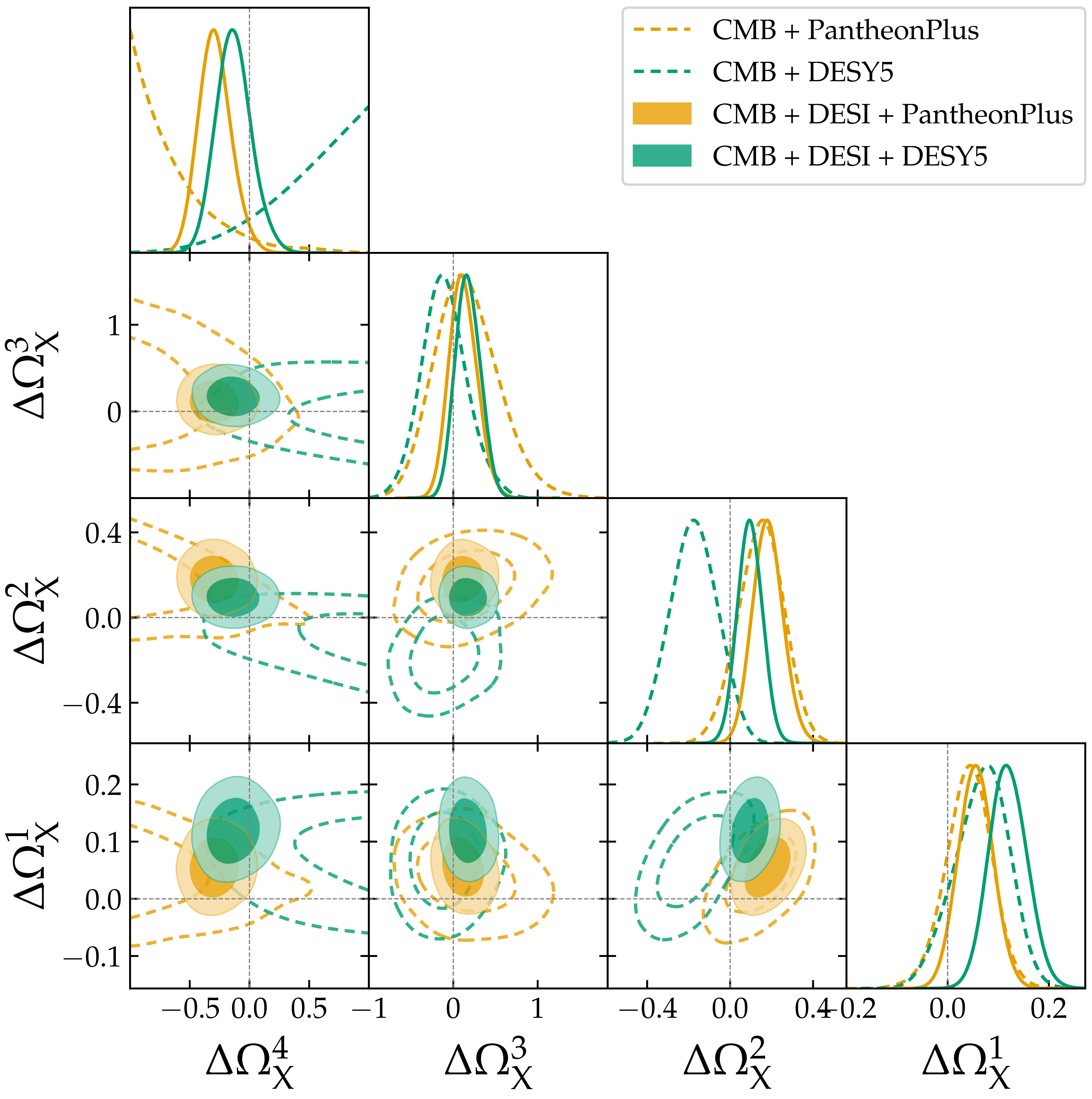
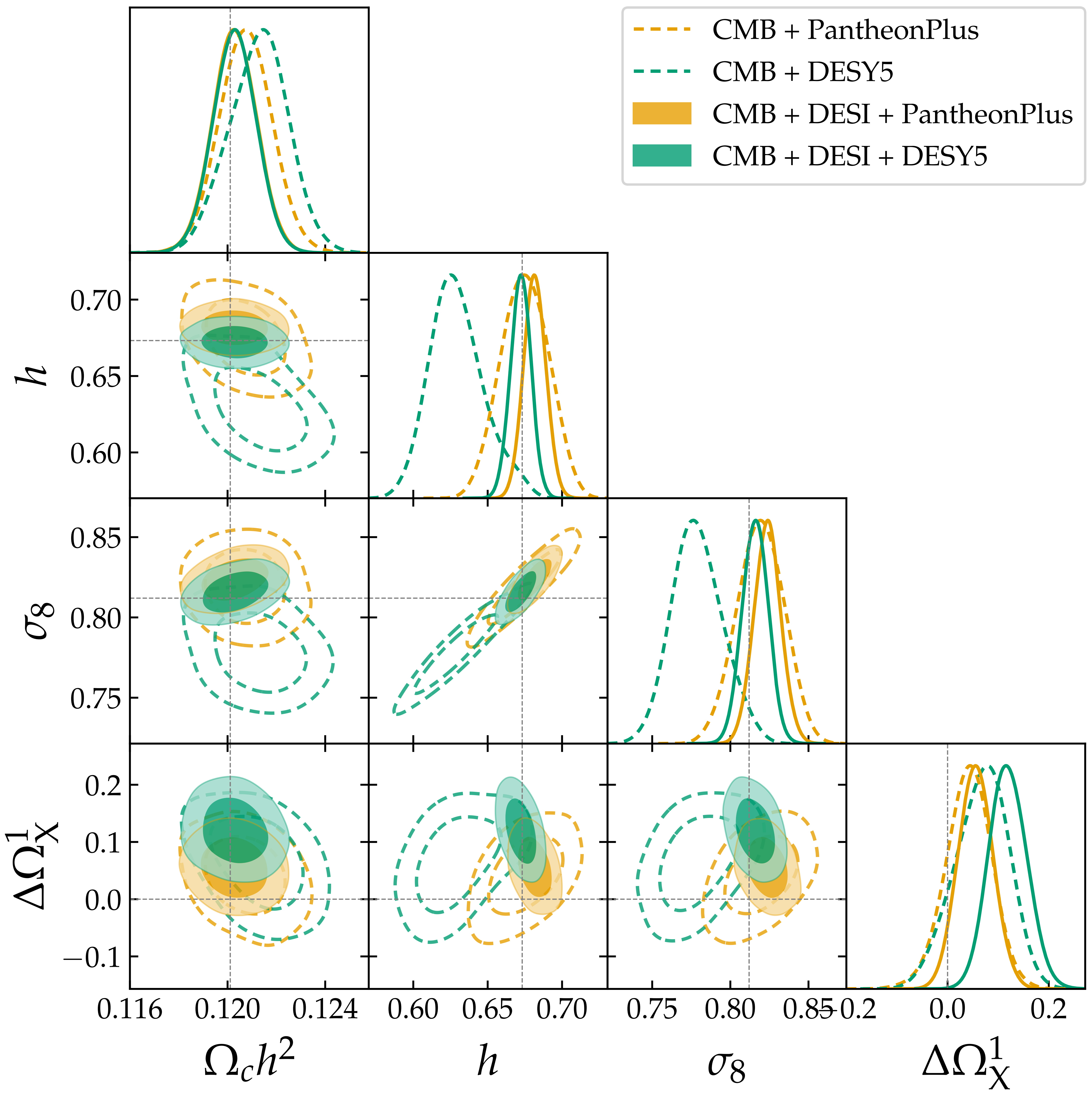


# Constraints on the Model Parameters



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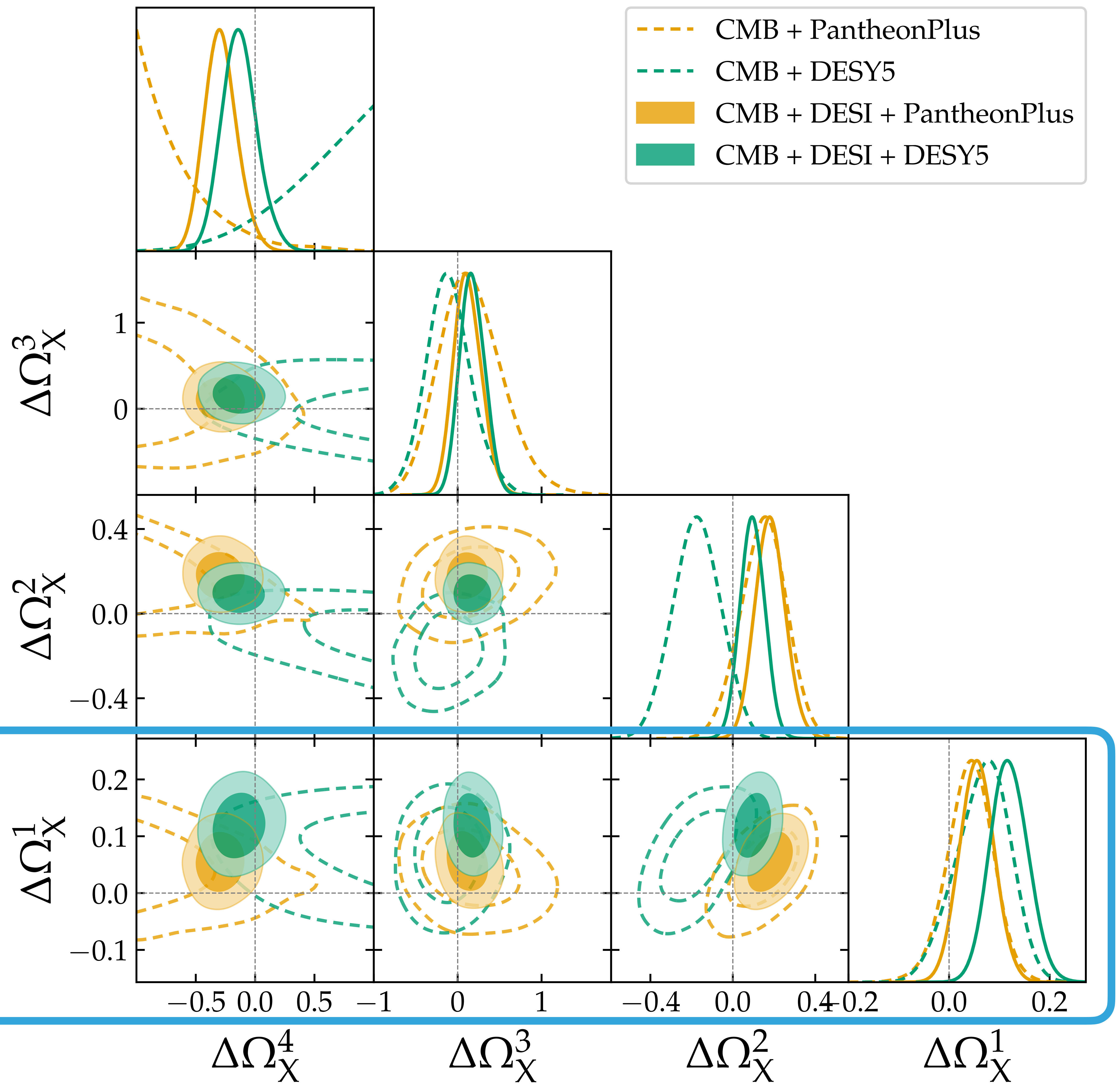


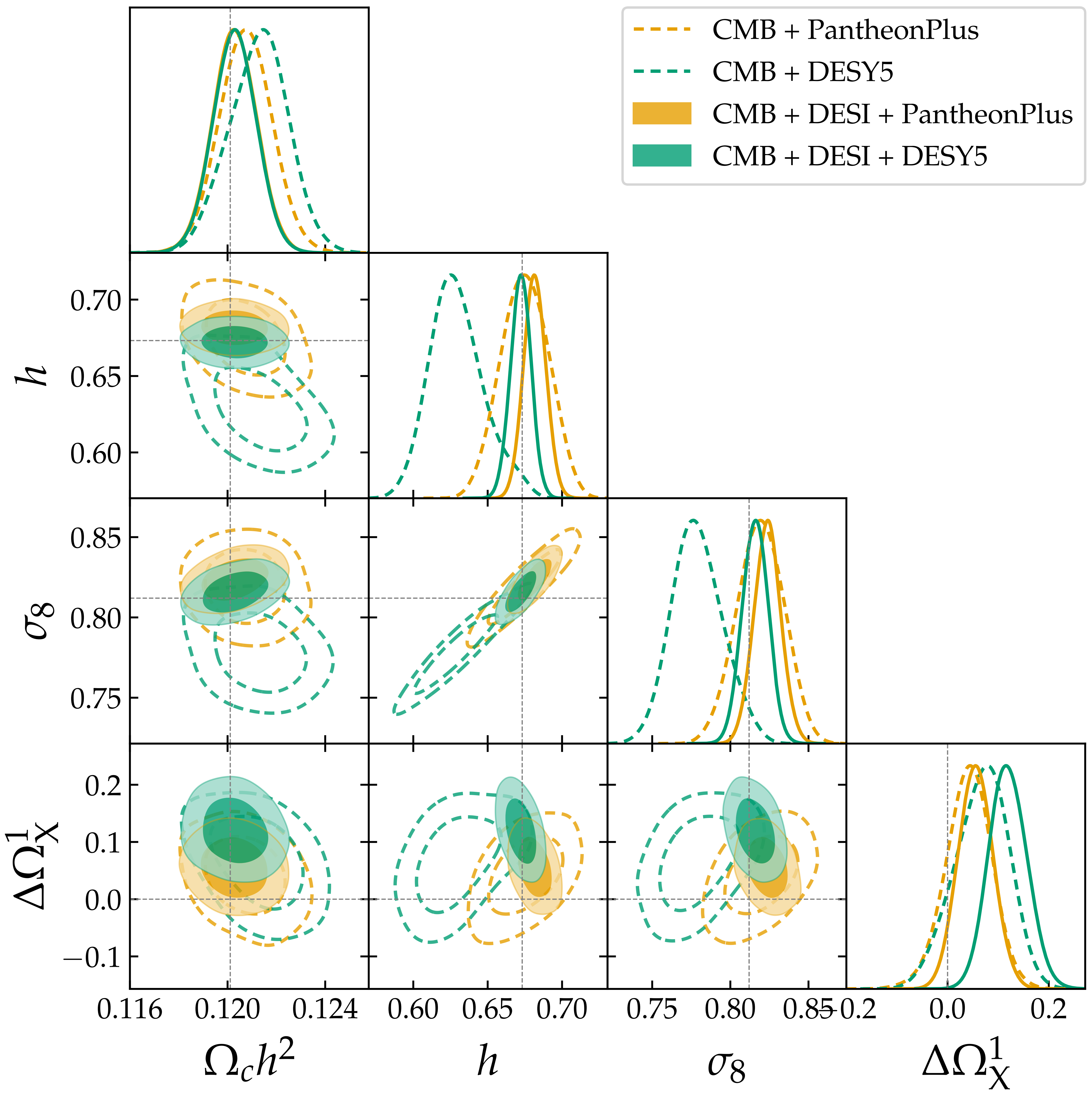

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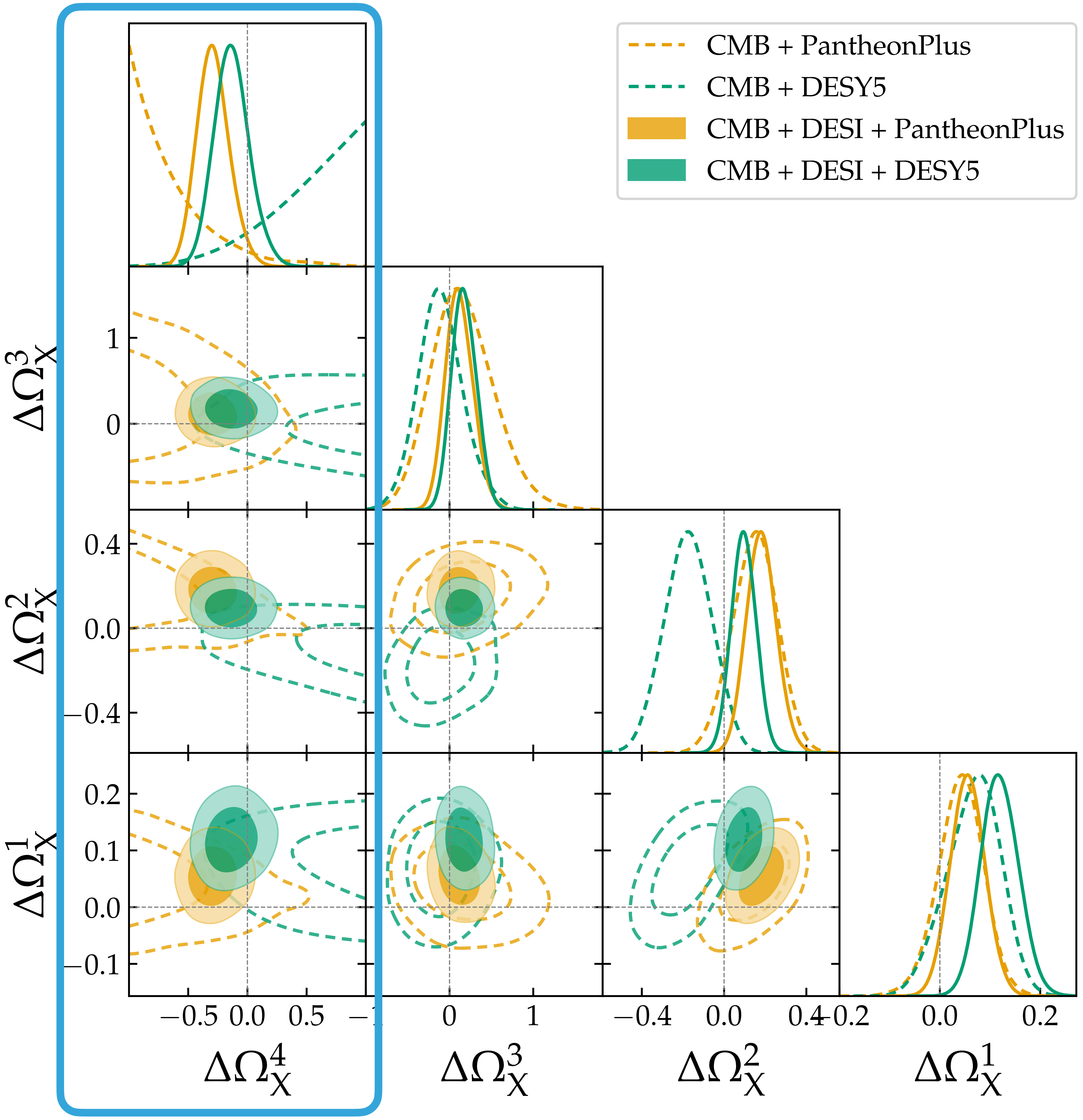


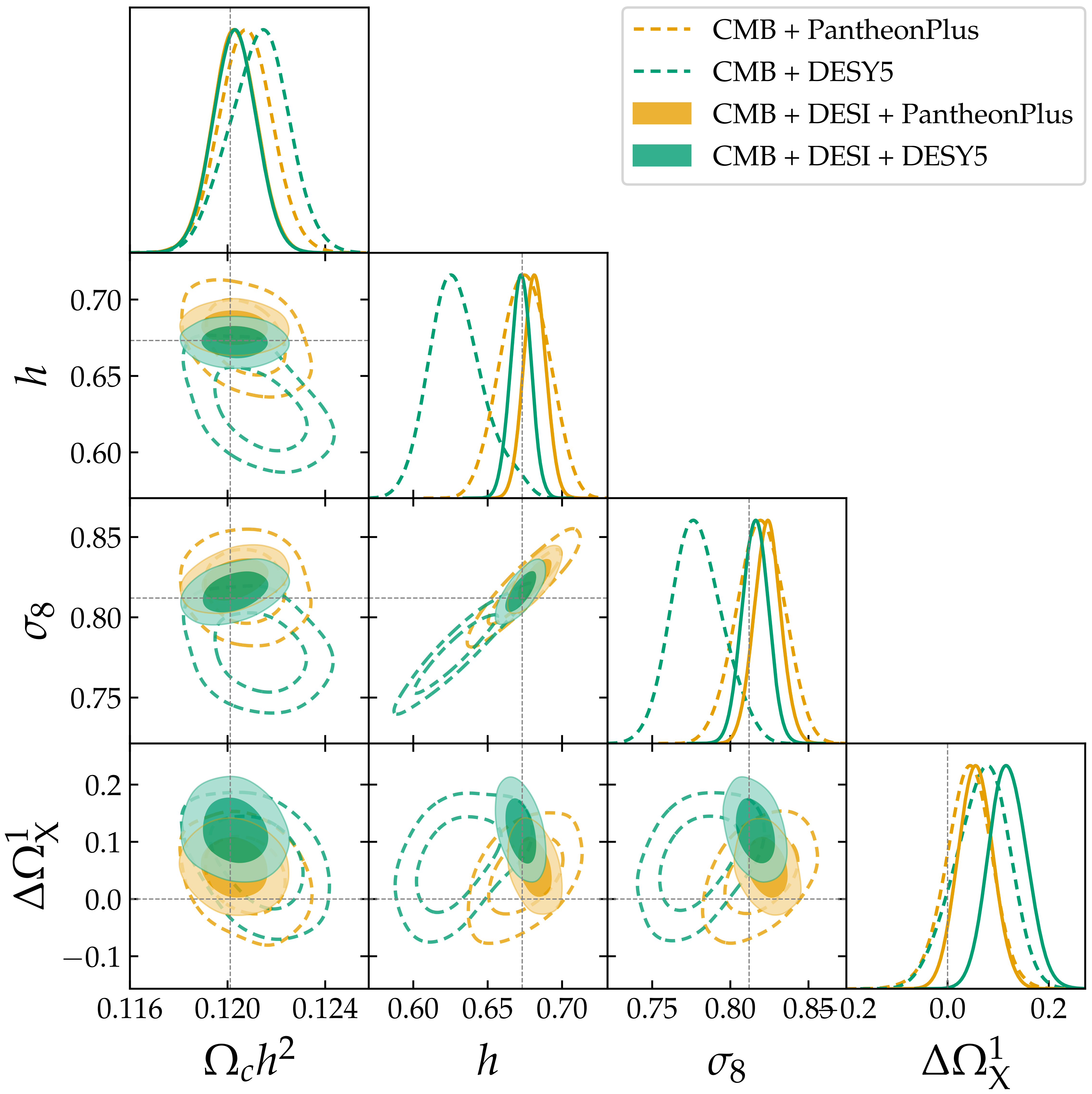

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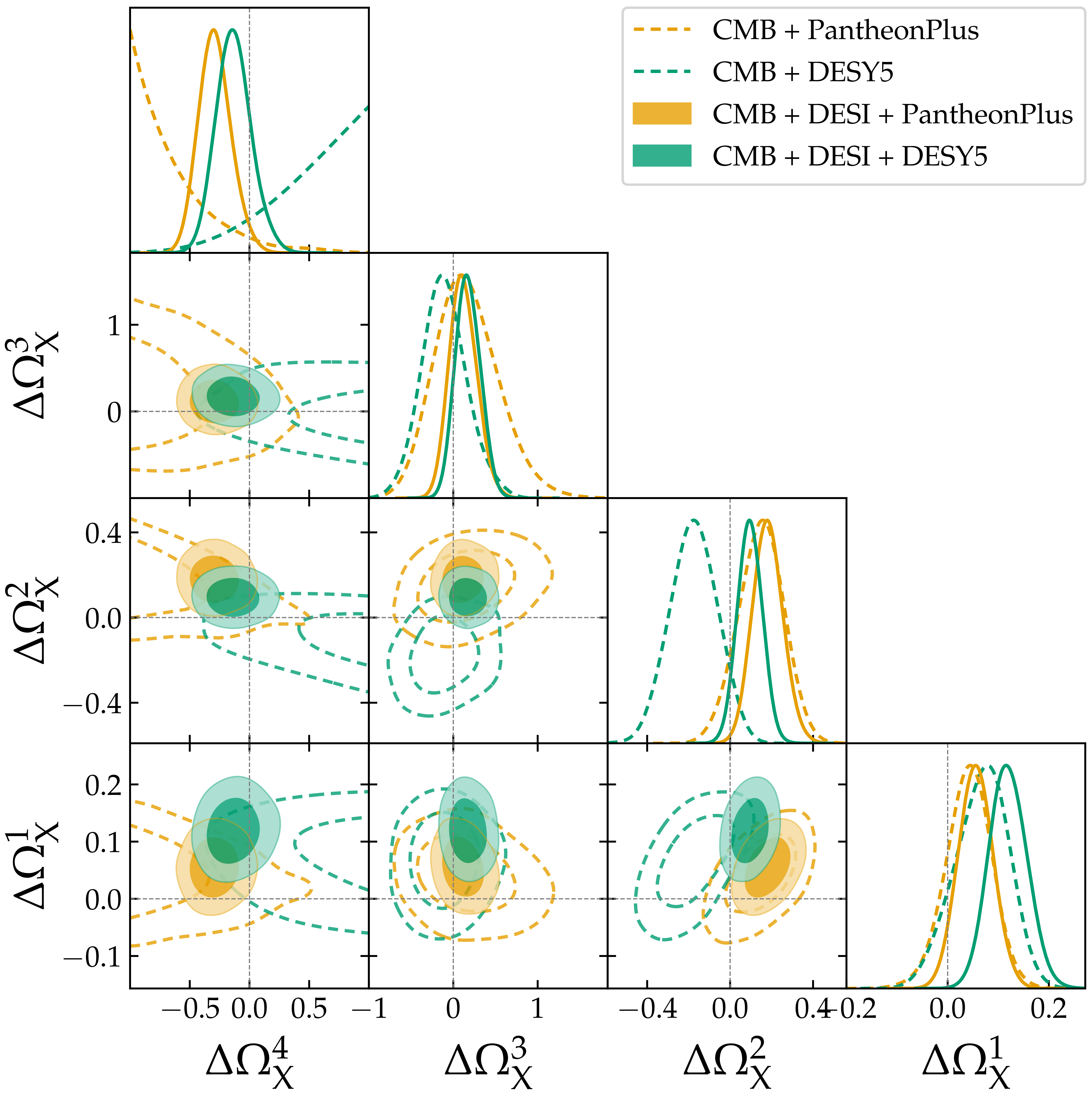


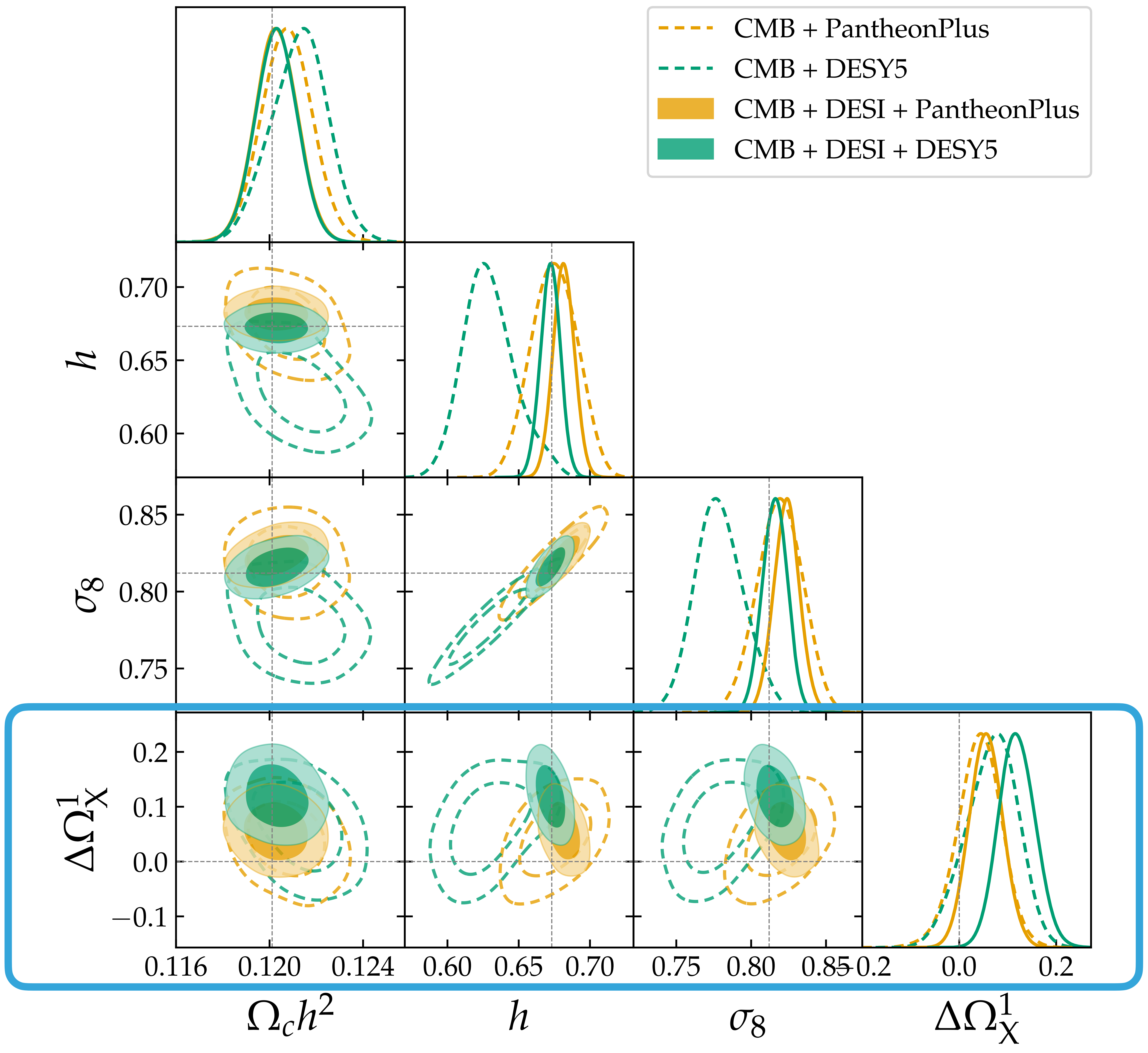

# Conclusions and Outlook

- We **validate** our **new pipeline** finding **results compatible** with the ones obtained from other widely tested codes
- Our results are qualitatively **in agreement with the DESI DR1 analysis**. Although milder, we find yet further **evidence** for a **non-standard DE background behaviour**
- With our pipeline we are able to **appreciate more redshift-dependent features**
- The reconstructed equation of state **crosses the phantom divide** in all the cases we consider
- The **significance** of the deviation is **highest** when using **DESY5 observations** combined with CMB and DESI data ($2.42\sigma$, **driven** by the **constraints in the lowest node**)

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➡ Impact of the number of nodes

➡ Possible overfitting: implementing smoothing techniques

➡ Update with DESI DR2 results

# Model-Independent Reconstruction of Gravity

## A MODEL-INDEPENDENT OBSERVABLE FOR LENSING?

$$\textbf{Lensing} \quad \propto \quad \Psi_W = (\Phi + \Psi)/2 \quad \propto \quad D_1(z)\,\Omega_m(z) \quad \propto \quad J(z)$$

Galaxy-galaxy lensing angular power spectrum

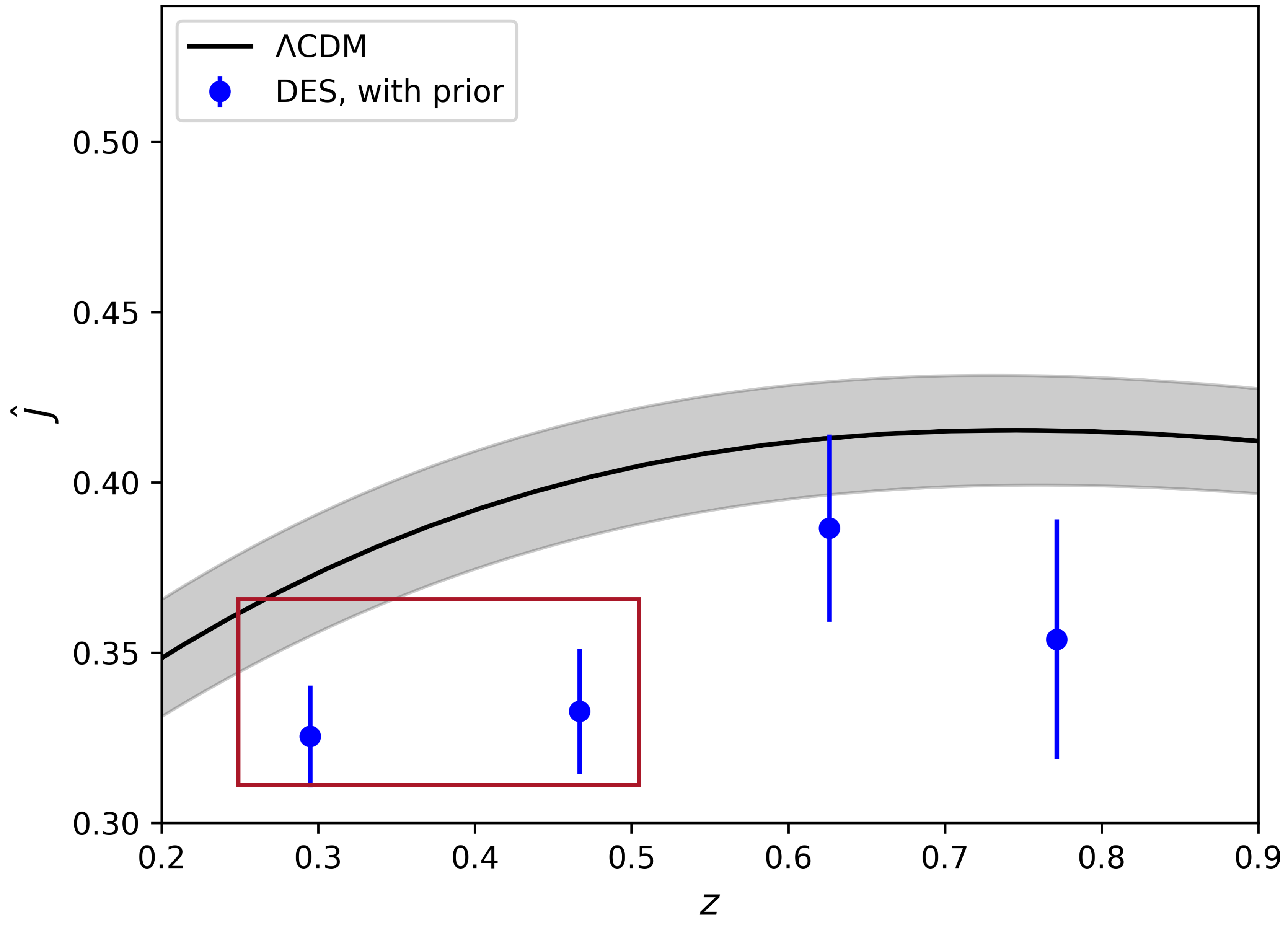
$$C_\ell^{\Delta\kappa}(z_i, z_j) = \frac{3}{2}\int \mathrm{d}z\, n_i(z)\mathscr{H}^2(z)\hat{b}_i(z)\hat{J}(z)B\left(k_\ell, \chi\right)\frac{P_{\delta\delta}^{\mathrm{lin}}\left(k_\ell, z_*\right)}{\sigma_8^2(z_*)}\int \mathrm{d}z' n_j(z')\frac{\chi'(z') - \chi(z)}{\chi(z)\chi'(z')}$$

with

$$\hat{J}(z) \equiv \frac{J(z)\sigma_8(z)}{D_1(z)}$$

$$\hat{b}_i(z) \equiv b_i(z)\sigma_8(z)$$

## CONSTRAINTS ON $\hat{J}$ FROM LSS DATA

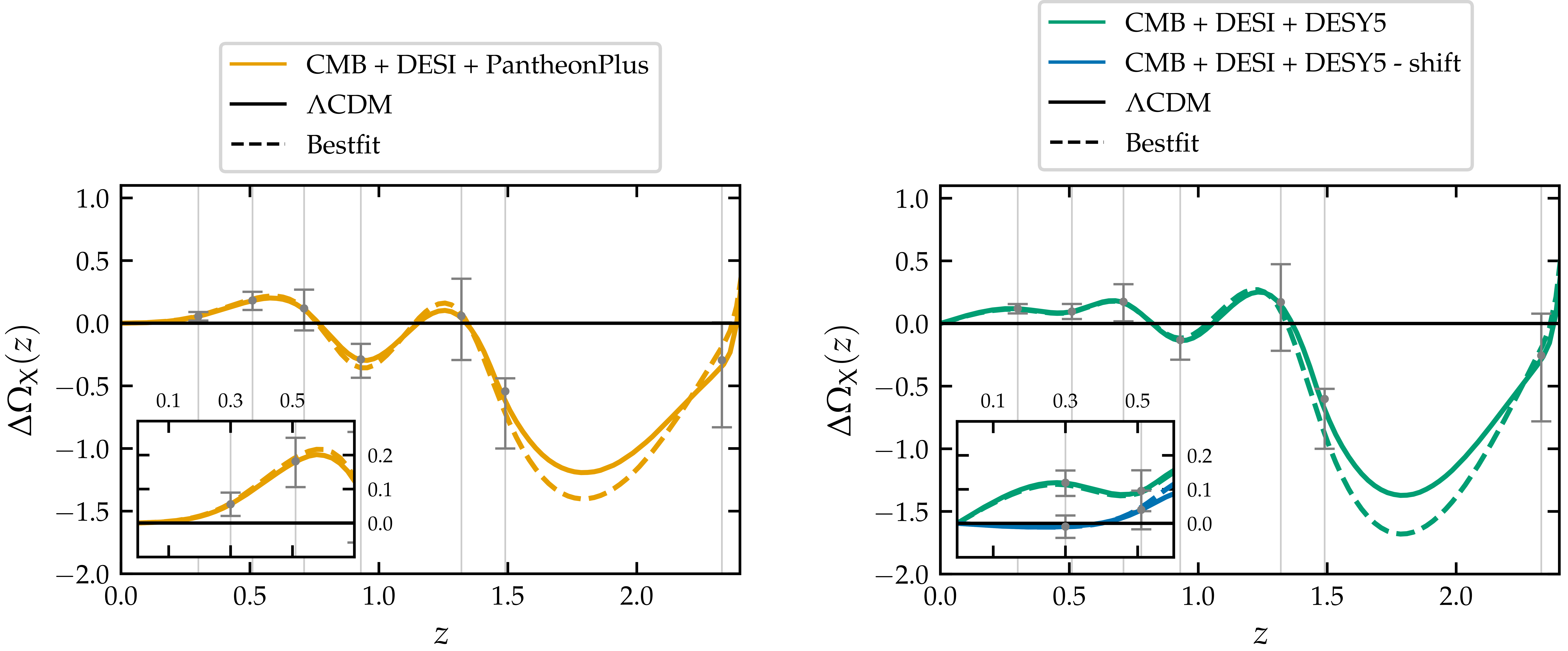



Constraints on $\hat{J}$ in **4 redshift bins** of DES data:

- $5 - 10\ \%$ constraints on $\hat{J}$
- $2.8\sigma$ tension with ΛCDM at $z = 0.47$

I. **Tutusaus**, C. **Bonvin** & N. **Grimm**, arXiv:2312.06434

We are working or **measuring** $\hat{J}$ from **Euclid's Flagship** simulation, in preparation for **Euclid DR1**.



CMB + DESI + PantheonPlus
ΛCDM
Bestfit
CMB + DESI + DESY5
CMB + DESI + DESY5 - shift
ΛCDM
Bestfit
$\Delta\Omega_X(z)$
$z$


Thank you!