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DESI Part 2: Cosmological Implication of DR1&DR2 measurements

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On behalf of the DESI Collaboration

Swiss Cosmology Days 2025,
ETH Zurich

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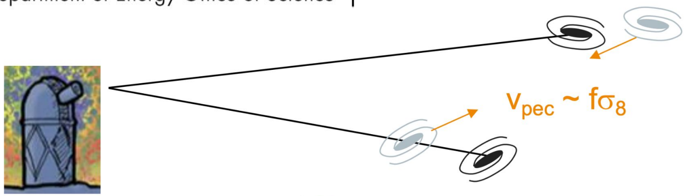
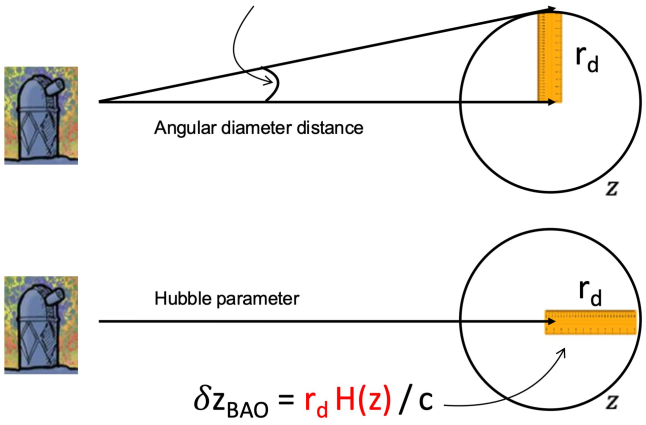
Full-shape & BAO in a Nutshell

$\theta_{BAO} = r_d / D_M(z)$



$z_{obs} = z_{cosmo} + z_{pec}$

Peculiar velocities ⟹ redshift-space distortion (RSD)



$\delta z_{BAO} = r_d\, H(z) / c$

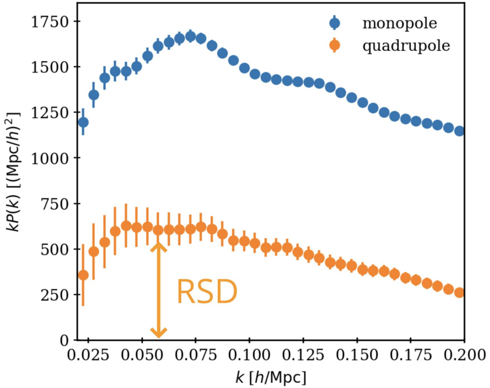
Full-Shape

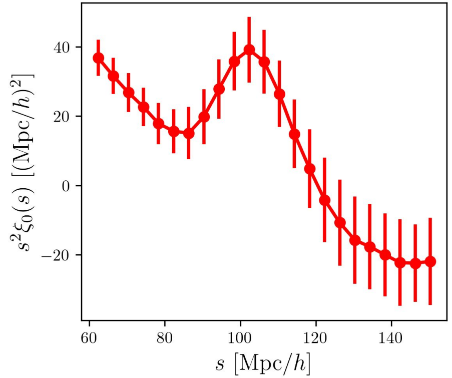
→ Growth of structure (σ_8, S_8)

→ Test of General Relativity (f)

BAO

→ Expansion (Dark Matter, Dark Energy)





Full-shape DR1: Modified Gravity

FLRW: $$ds^2 = a(\tau)^2[-(1+2\Psi)d\tau^2 + (1-2\Phi)\delta_{ij}dx^i dx^j]$$

At late times:

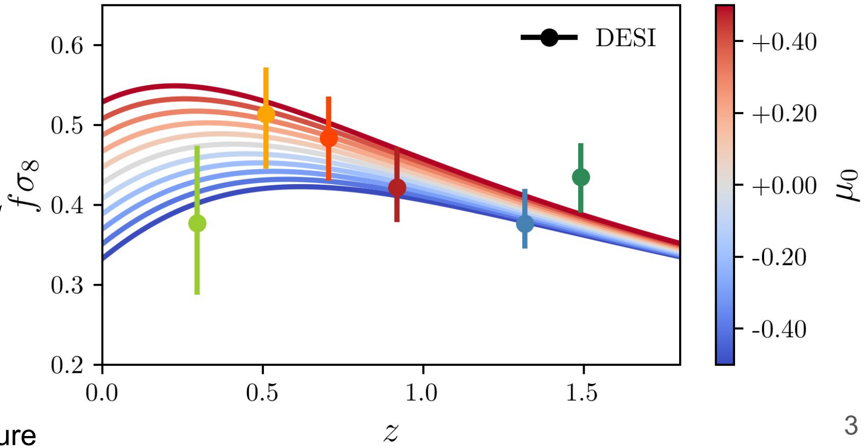
$$\left.\begin{aligned} k^2\Psi &= -4\pi G a^2 \mu(a,k)\Sigma_i \rho_i \Delta_i \\ k^2(\Phi+\Psi) &= -8\pi G a^2 \Sigma(a,k)\Sigma_i \rho_i \Delta_i \end{aligned}\right\}$$

In GR: $\mu(a,k) = \Sigma(a,k) = 1$

Choose the following time dependence:

$$\mu(a) = 1 + \frac{\Omega_\Lambda(a)}{\Omega_\Lambda}\mu_0$$

$$\Sigma(a) = 1 + \frac{\Omega_\Lambda(a)}{\Omega_\Lambda}\Sigma_0$$



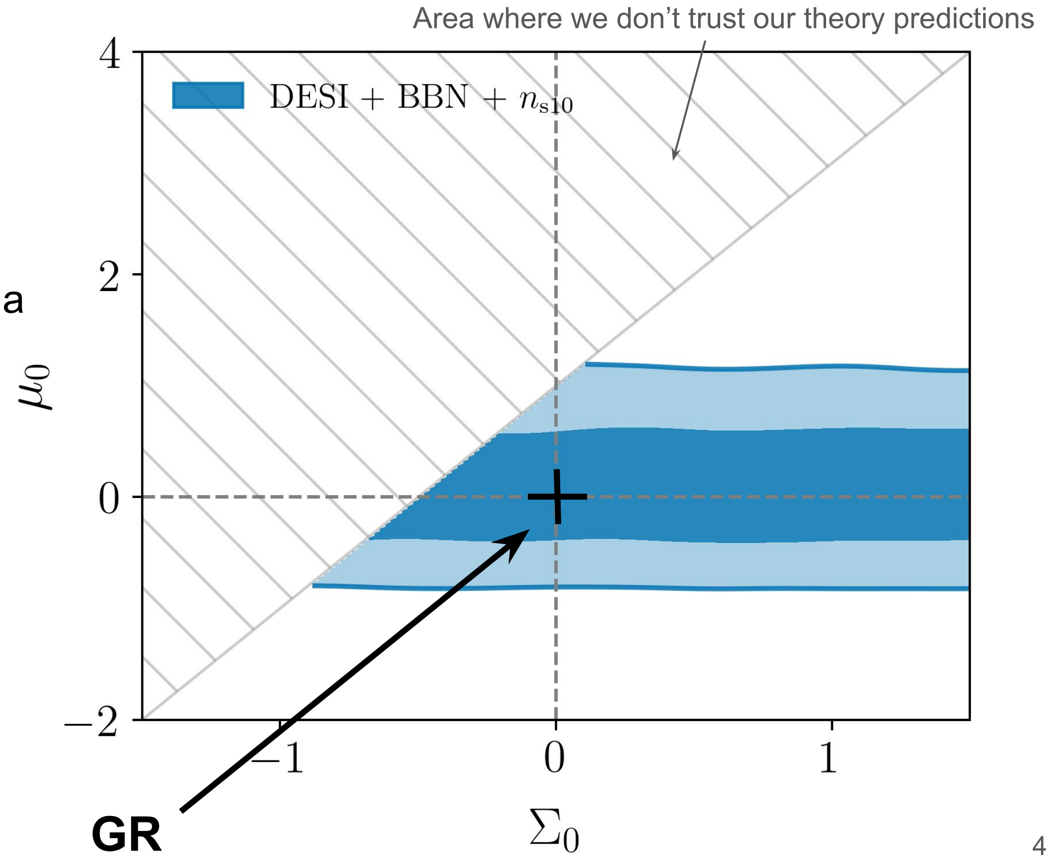
Growth rate of structure

Full-shape DR1: Modified Gravity

$$k^2\Psi = -4\pi G a^2 \mu(a,k)\Sigma_i \rho_i \Delta_i$$

Describes the motion of massive particles in a gravitational field
→ can be directly constrained by DESI

$$\mu_0 = 0.11^{+0.45}_{-0.54}$$



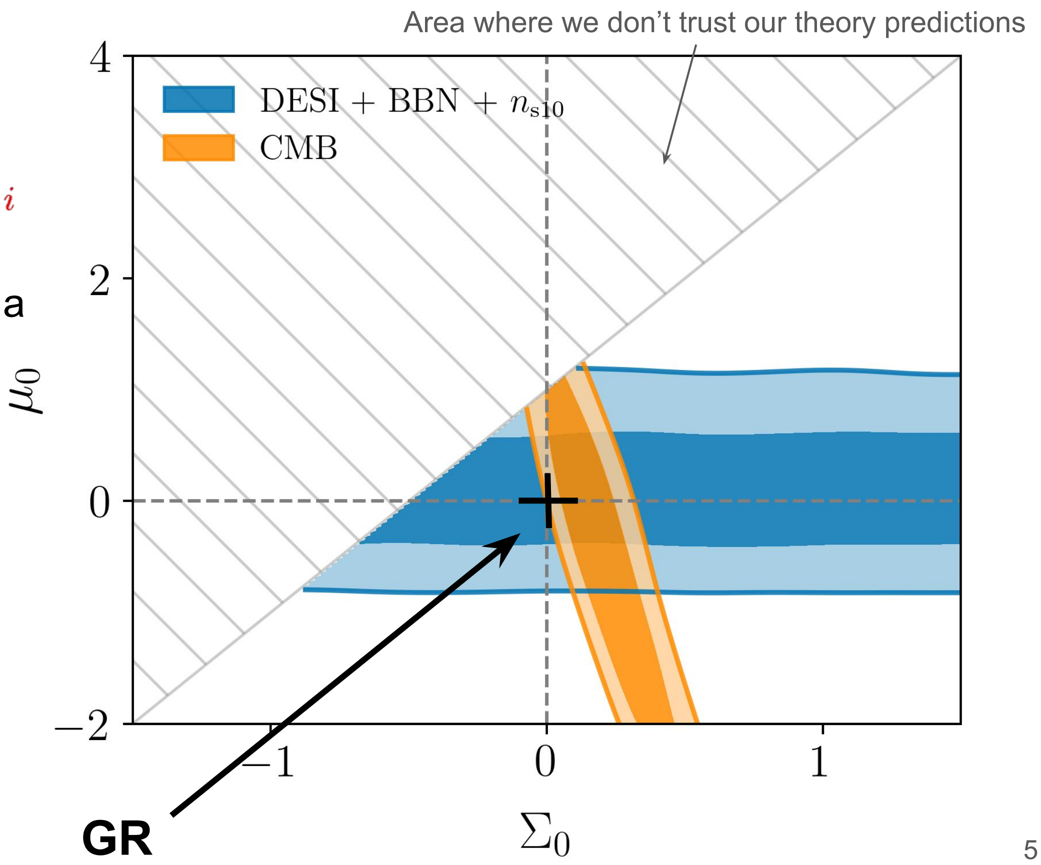
Full-shape DR1: Modified Gravity

$$k^2(\Phi + \Psi) = -8\pi G a^2 \Sigma(a,k) \Sigma_i \rho_i \Delta_i$$

Describes the motion of massless particles in a gravitational field
→ can be constrained by lensing and ISW

$$\Sigma_0 = 0.25^{+0.12}_{-0.18}$$

Slight departure from GR related to CMB lensing anomaly



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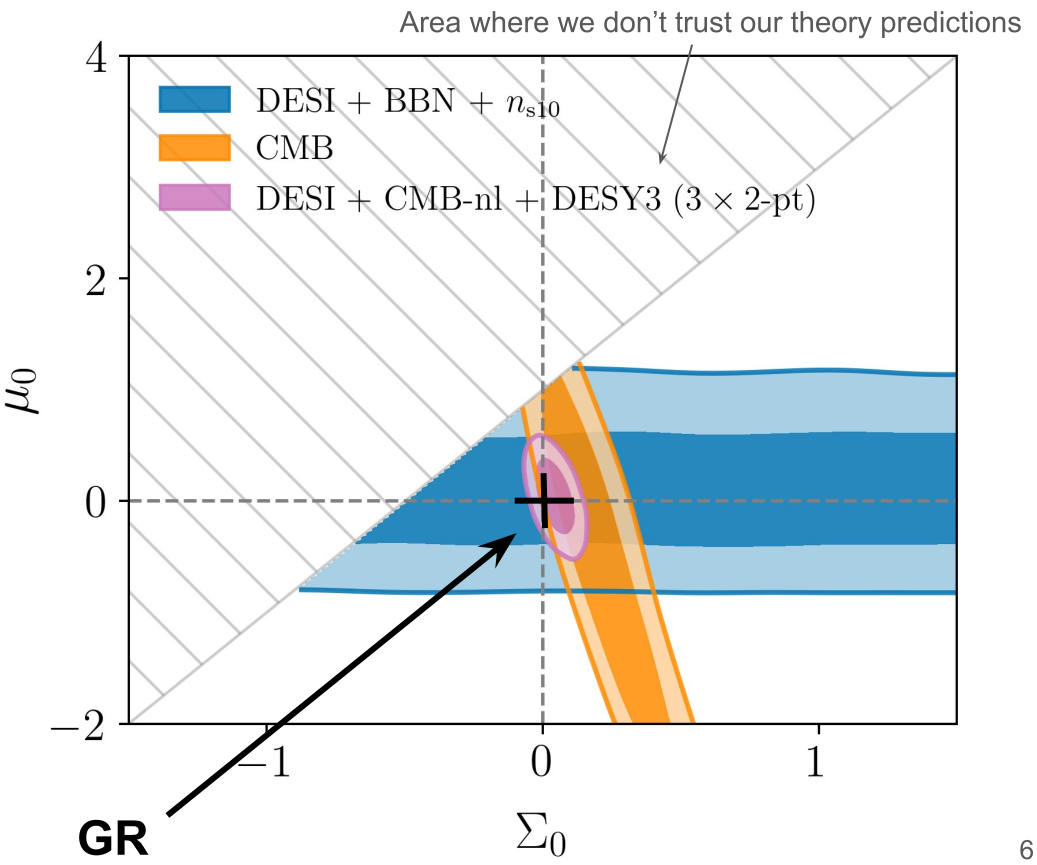
Full-shape DR1: Modified Gravity

Combination of clustering and lensing:

$$\mu_0 = 0.04 \pm 0.22$$
$$\Sigma_0 = 0.044 \pm 0.047$$

DESI +CMB-nl+ DESY3

Suggest consistency with GR



BAO: From DR1 to DR2

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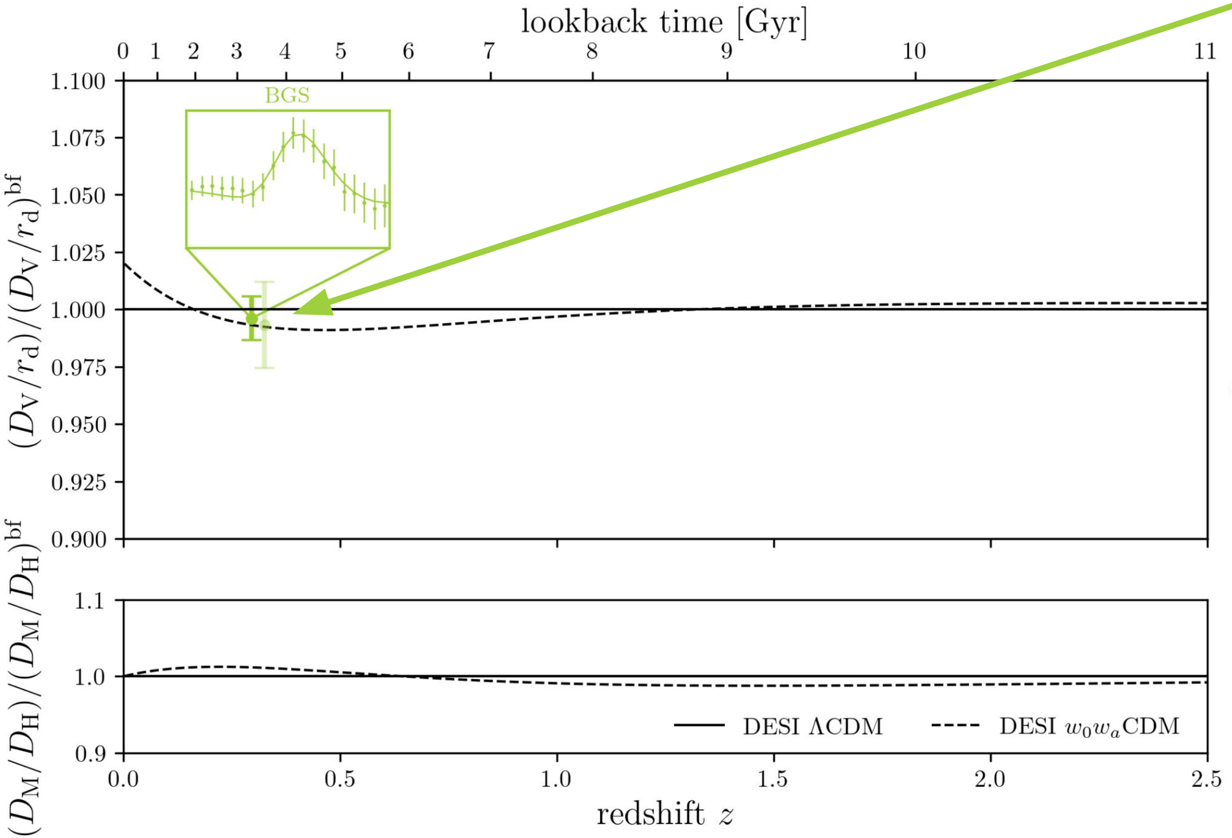
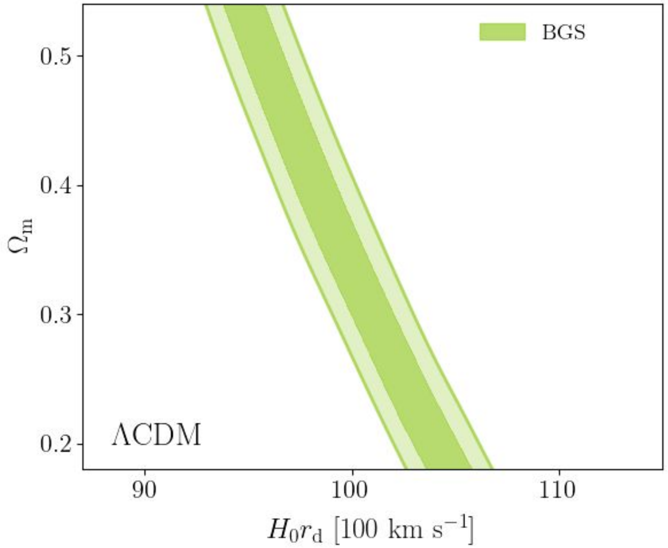
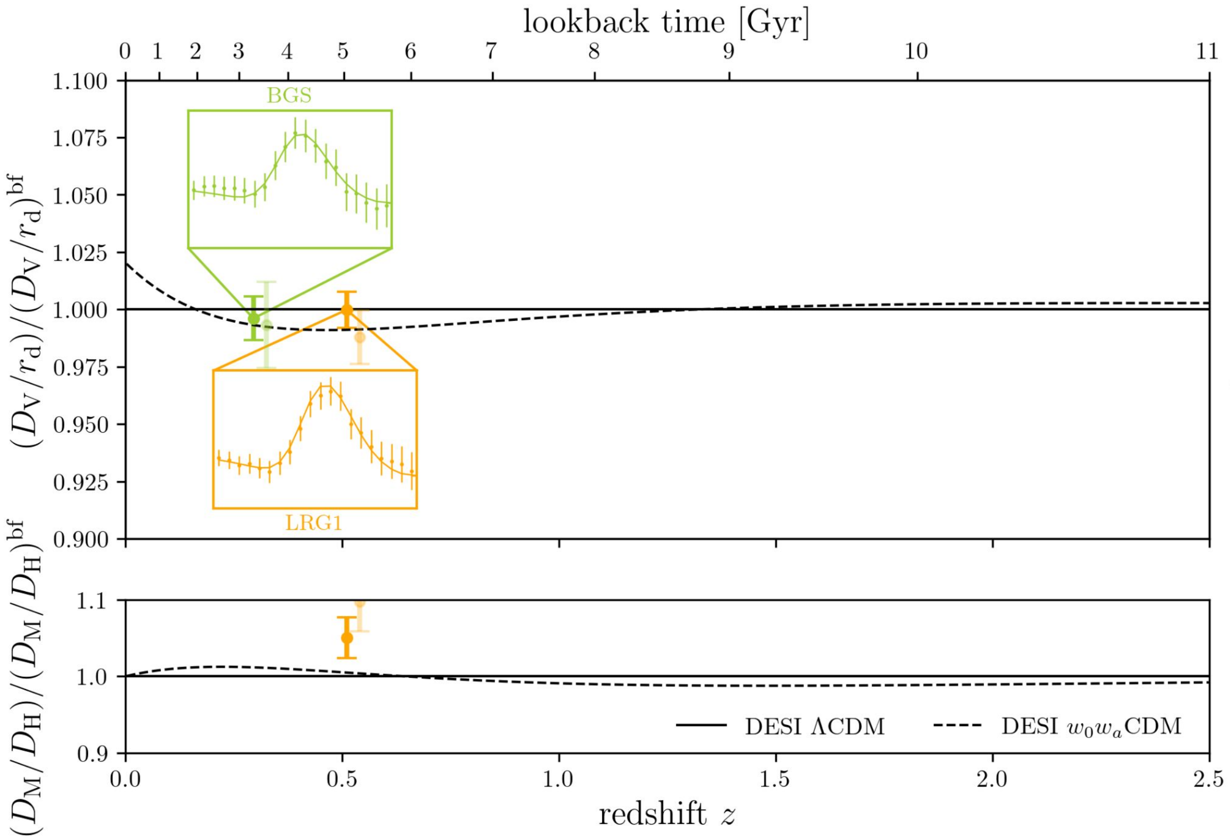
Only isotropic BAO fit

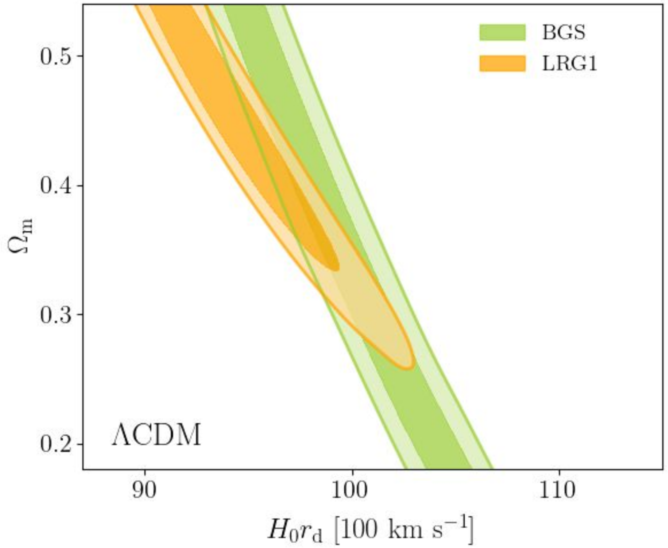




bf: DESI + CMB + DESY5

BAO: From DR1 to DR2

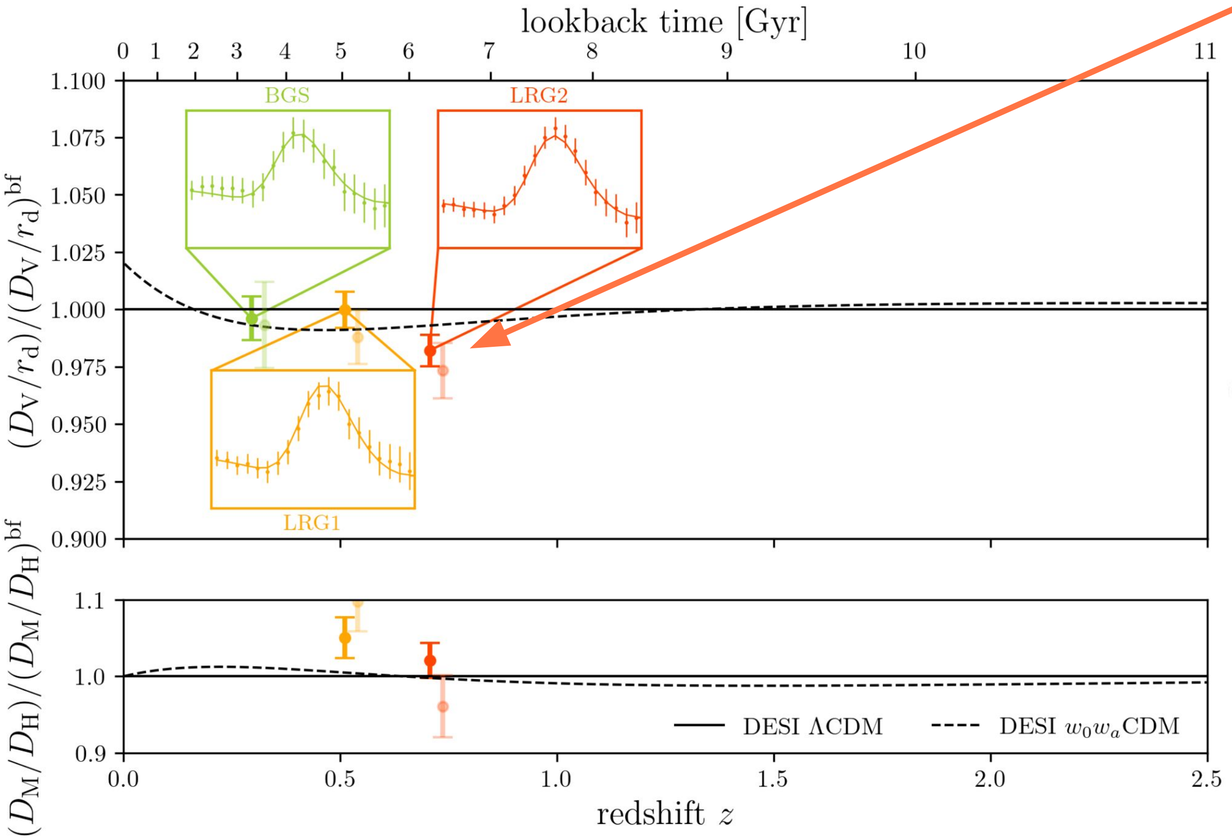




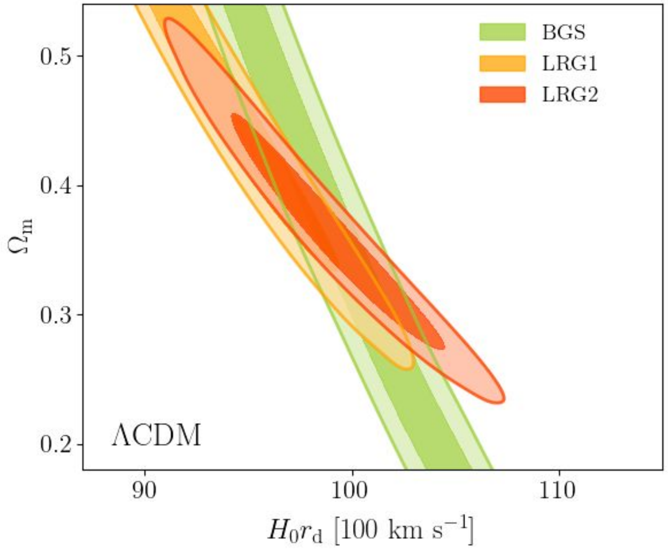
bf: DESI + CMB + DESY5

BAO: From DR1 to DR2

Tension with SDSS is reduced to 2.6σ



bf: DESI + CMB + DESY5



BAO: From DR1 to DR2

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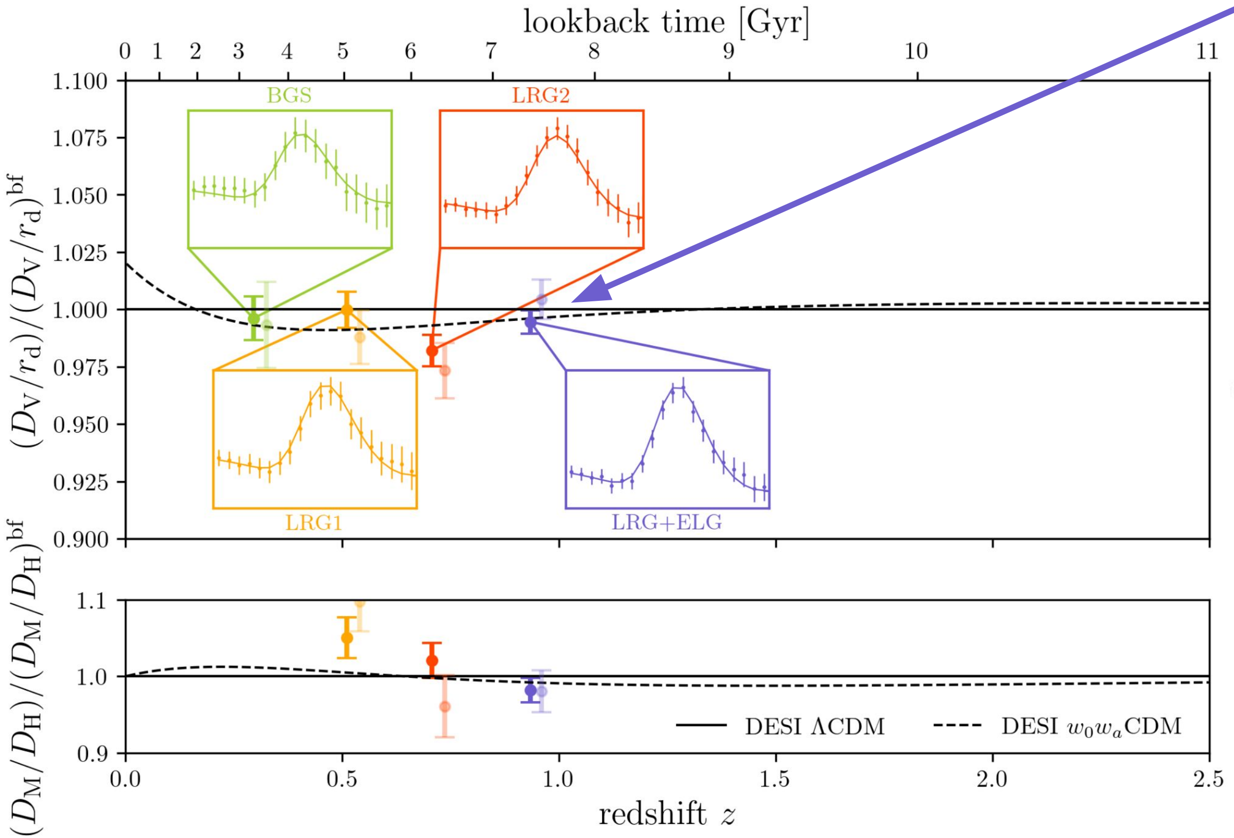
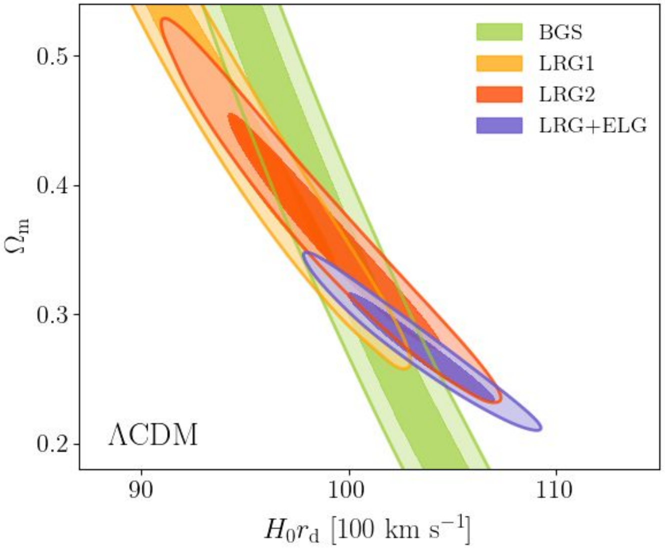
Combination of LRG3 and ELG, yielding our tightest BAO measurement





bf: DESI + CMB + DESY5

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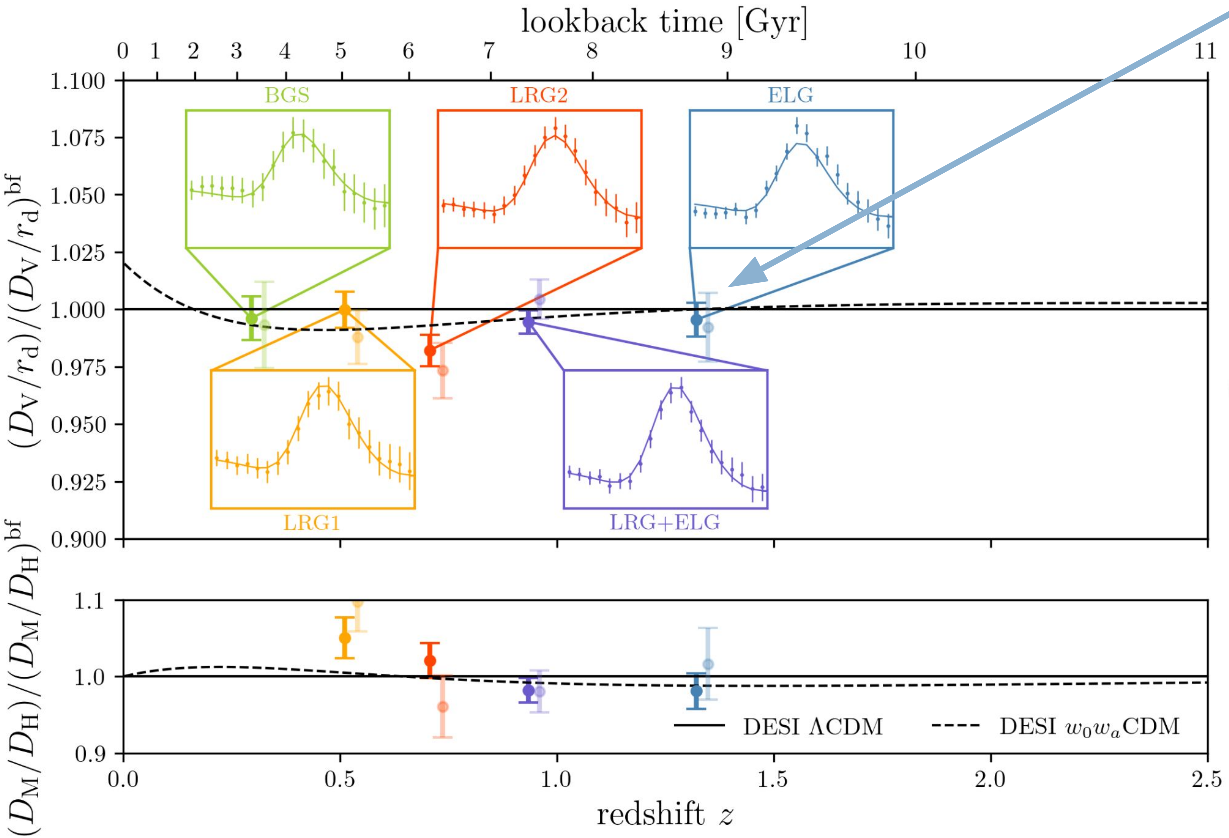
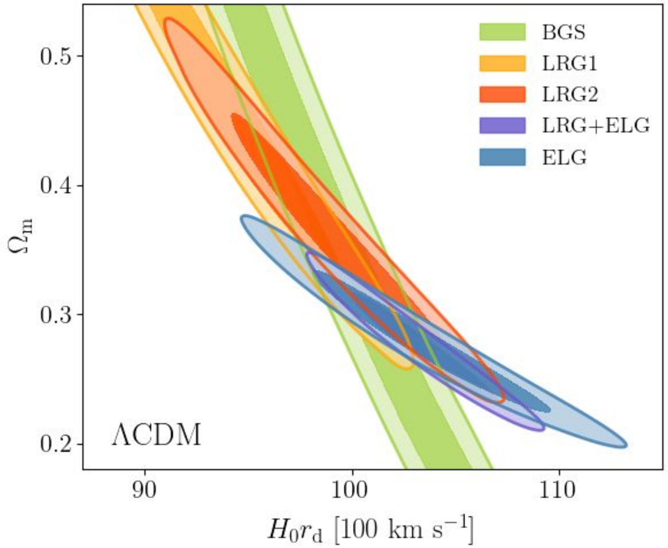
BAO: From DR1 to DR2

Error bars are reduced by a factor of two





bf: DESI + CMB + DESY5

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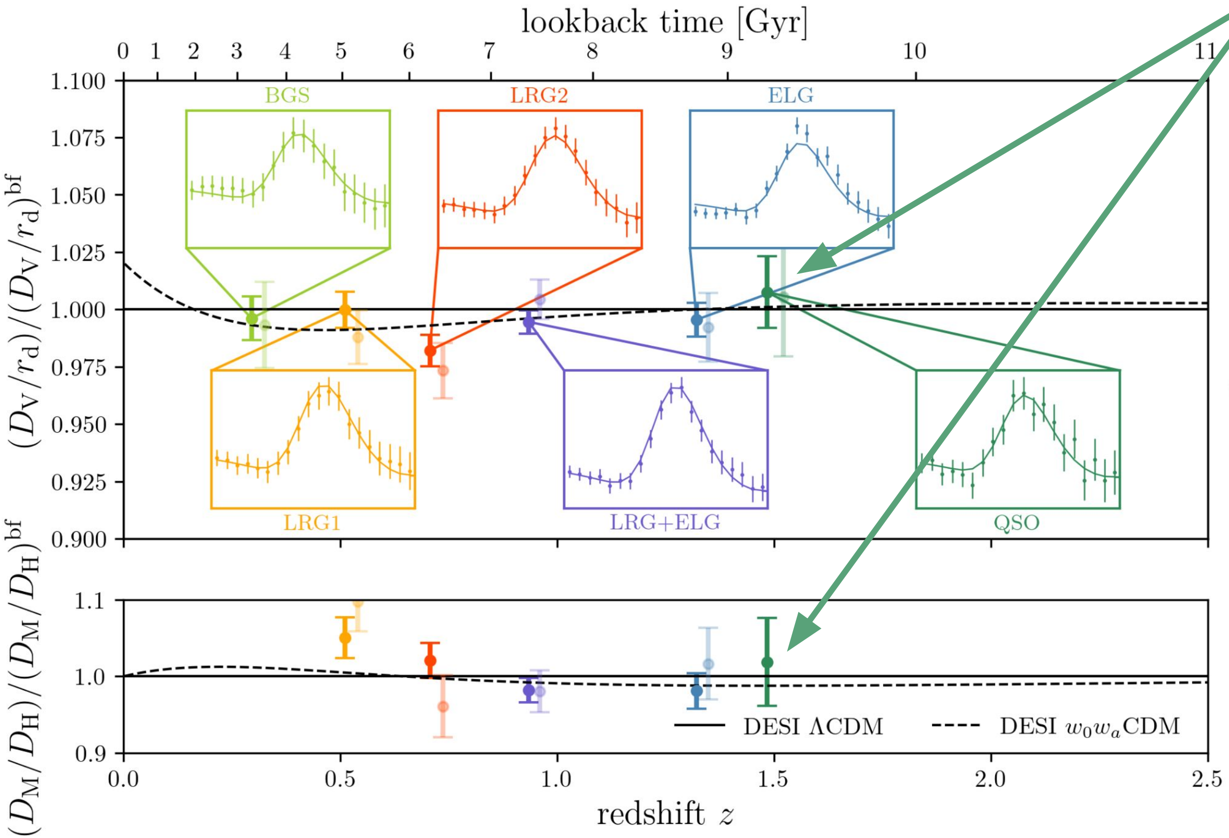
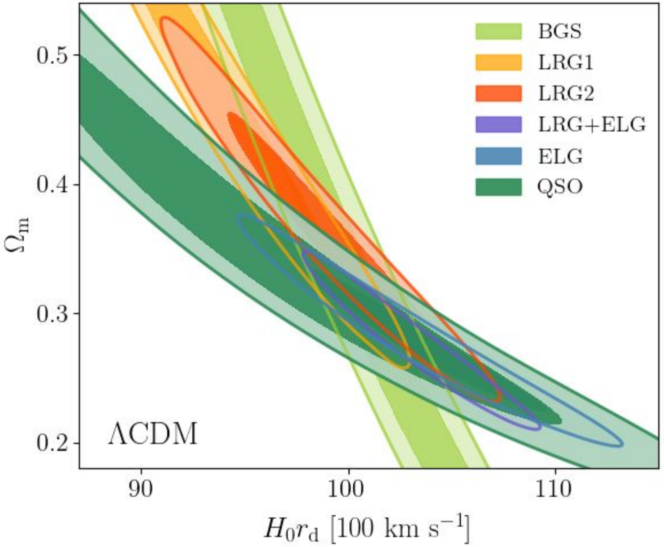
BAO: From DR1 to DR2

New 2D BAO fits for QSO





bf: DESI + CMB + DESY5

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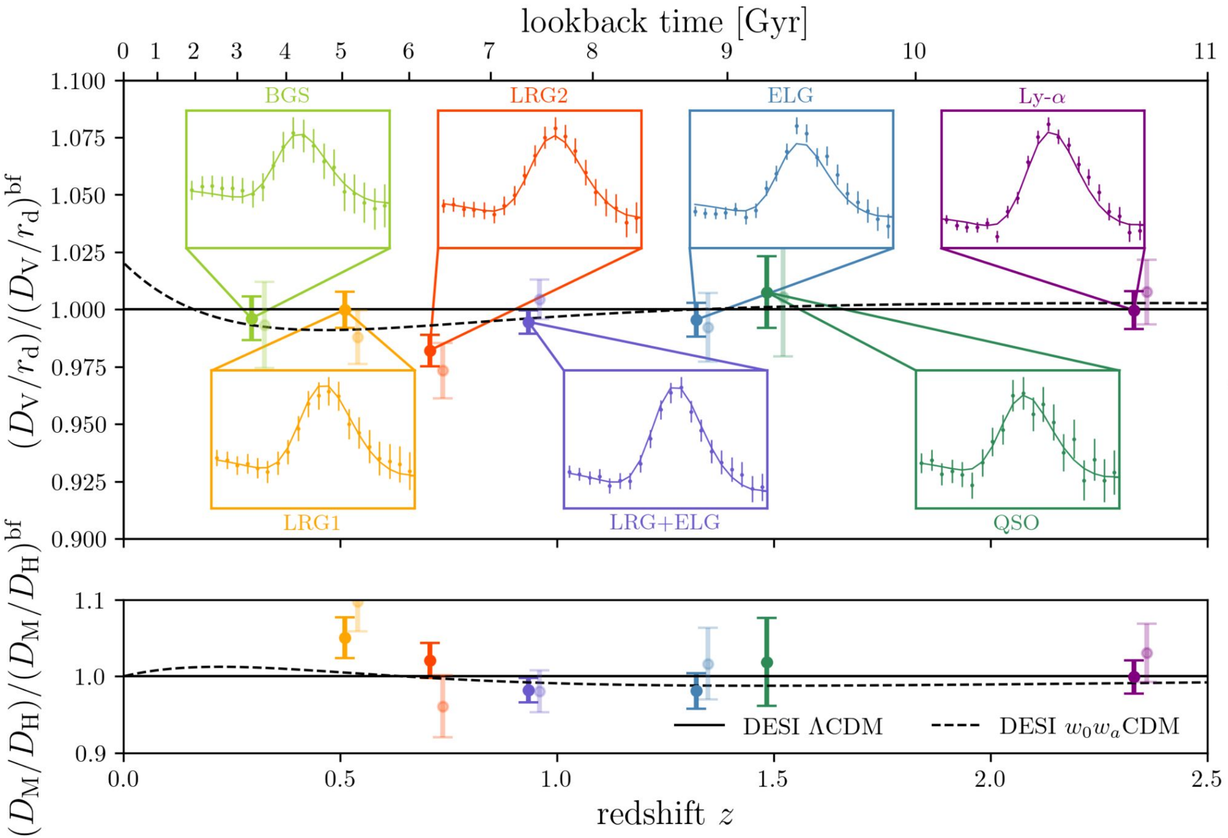
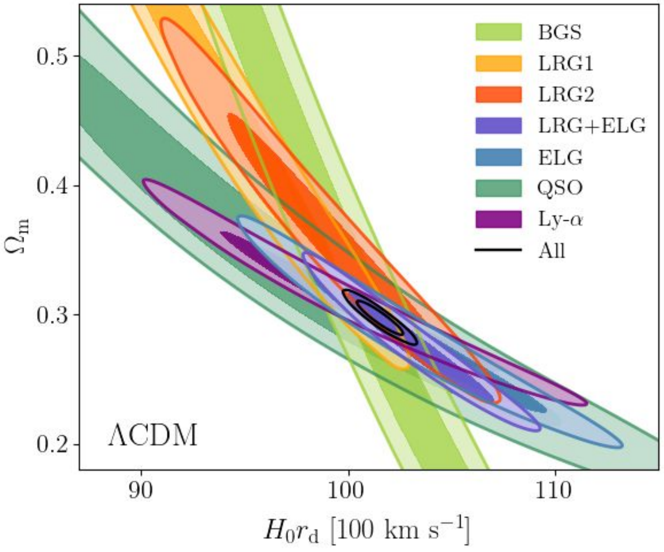
BAO: From DR1 to DR2

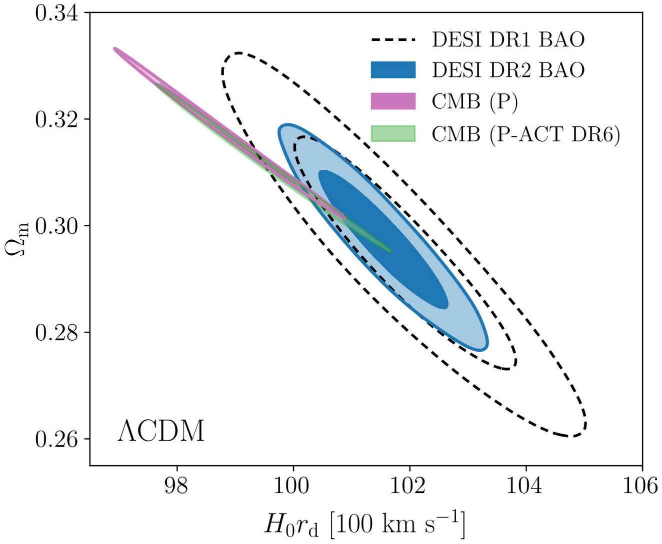


bf: DESI + CMB + DESY5

Agreement & complementarity between tracers



BAO: From DR1 to DR2



$$\text{DESI DR2} \begin{cases} \Omega_m & = 0.2975 \pm 0.0086 \\ h r_\mathrm{d} & = (101.54 \pm 0.73)\ \mathrm{Mpc} \end{cases}$$

DR1 → DR2: 40% improvement in precision on Ω_m and hr_d

On the consistency between CMB (including the new ACT results) and DESI, see arXiv:2504.18464

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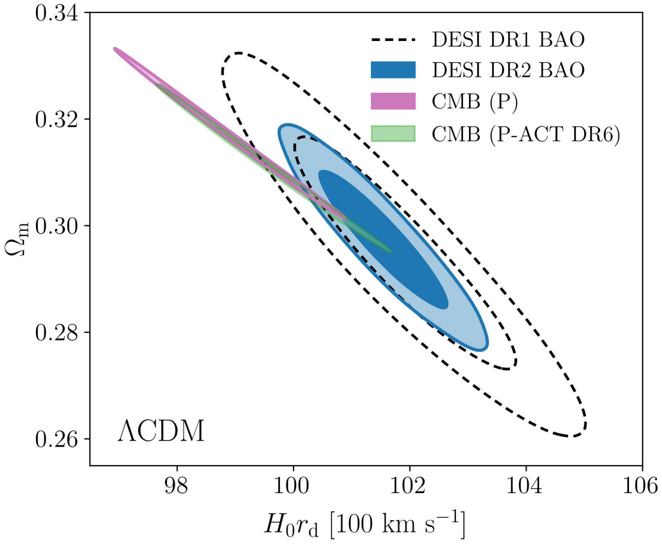
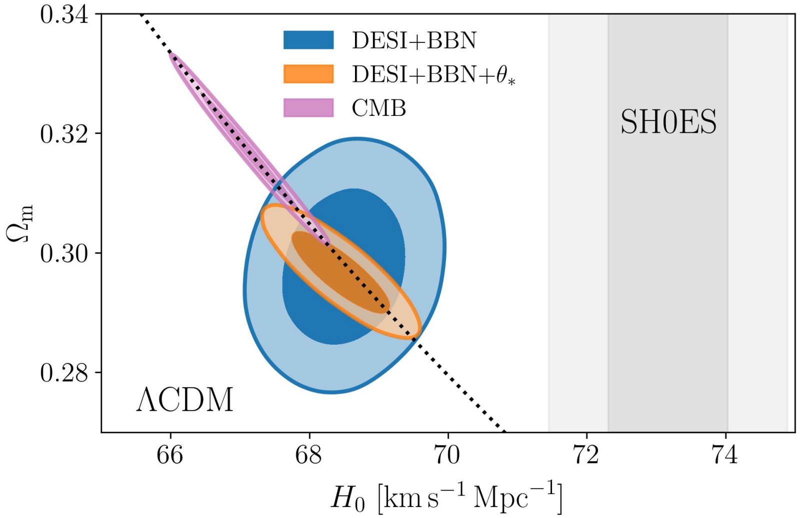
BAO: From DR1 to DR2



Calibrating BAO distances through external data



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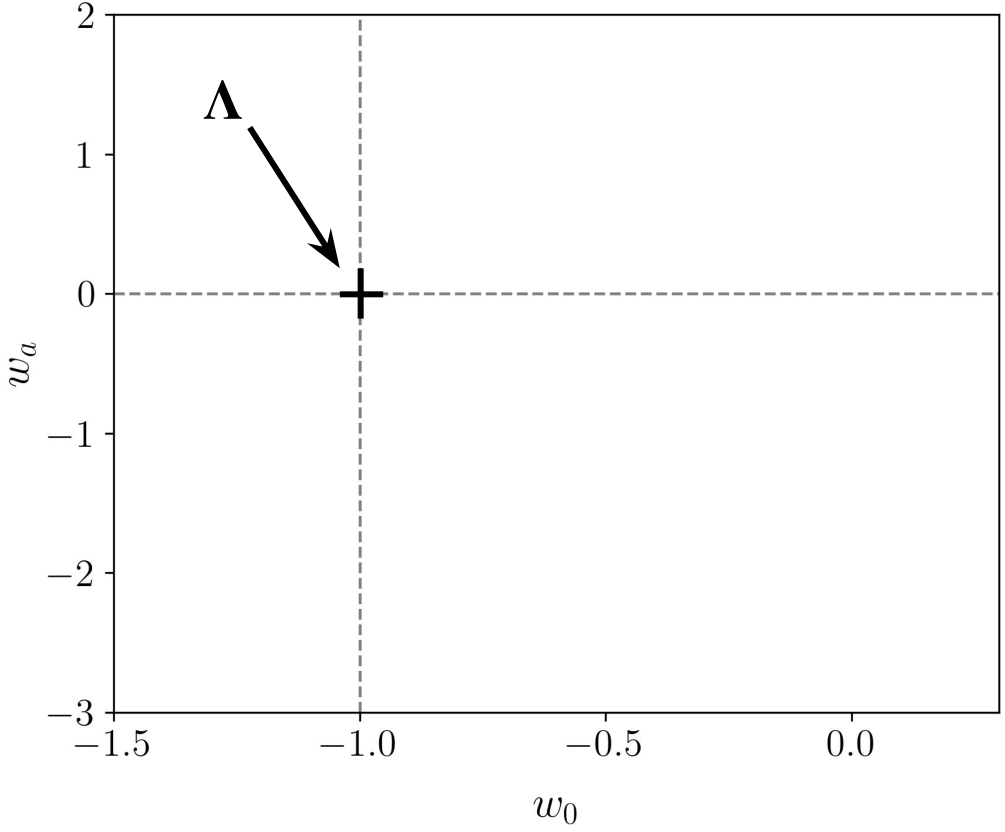
DR1 → DR2: 40% improvement in precision on Ω_m and hr_d

BBN prior on ω_b : $H_0 = (68.51 \pm 0.58)$ km/s/Mpc

Adding prior on *angular acoustic scale* θ_* : $H_0 = (68.45 \pm 0.47)$ km/s/Mpc

On the consistency between CMB (including the new ACT results) and DESI, see [arXiv:2504.18464](https://arxiv.org/abs/2504.18464)

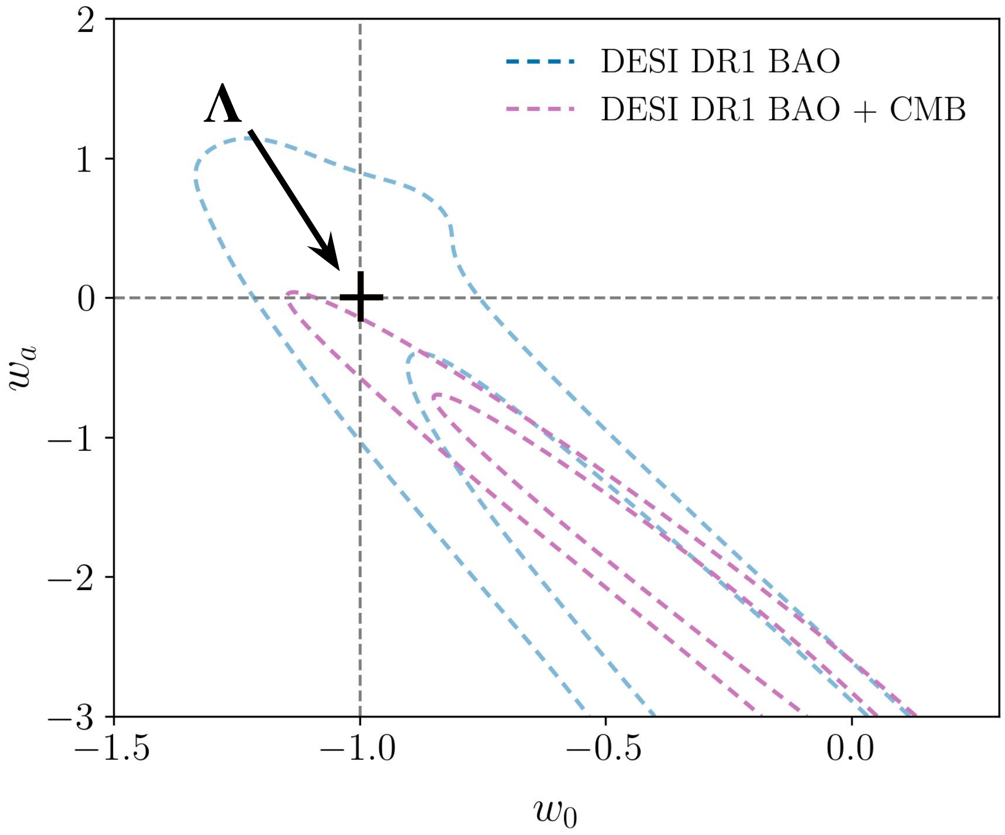
Dark Energy Equation of State



We model a varying Dark Energy equation of state through:

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

Dark Energy Equation of State



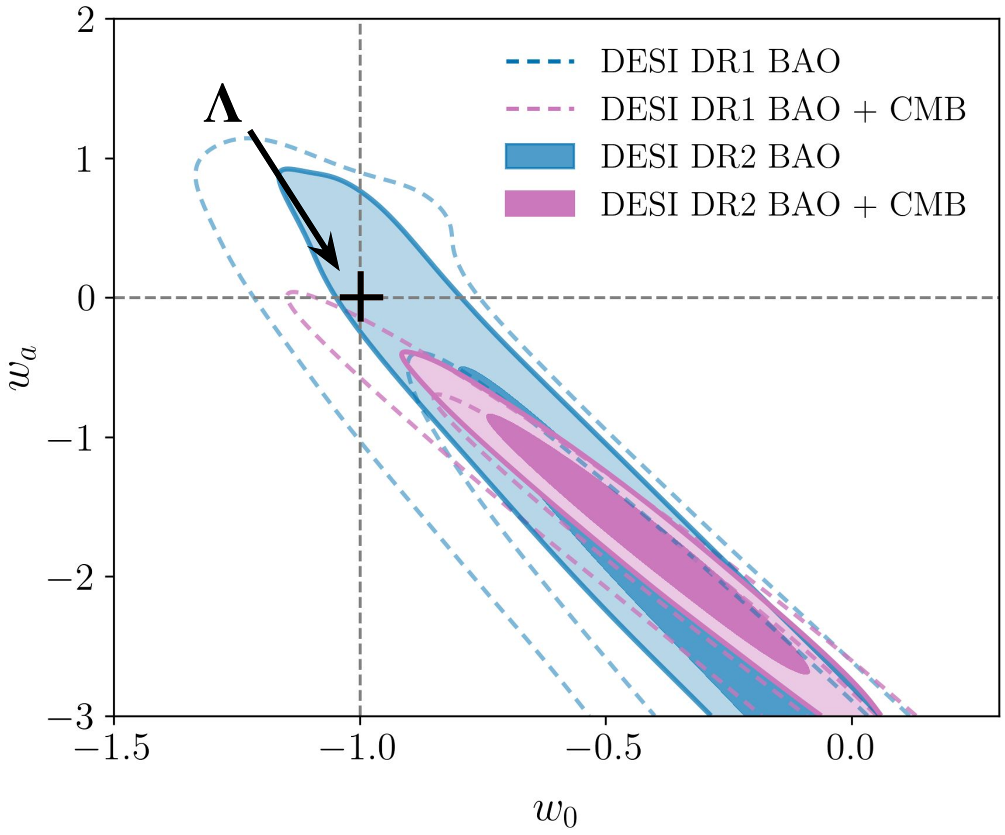
We model a varying Dark Energy equation of state through:

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

$$\underbrace{w_0 = -0.45^{+0.34}_{-0.21} \quad w_a = -1.79^{+0.48}_{-1.00}}_{}$$

DR1: DESI + CMB ⇒ 2.6σ

Dark Energy Equation of State



We model a varying Dark Energy equation of state through:

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$$\underbrace{w_0 = -0.45^{+0.34}_{-0.21} \quad w_a = -1.79^{+0.48}_{-1.00}}$$

DR1: DESI + CMB ⇒ 2.6σ

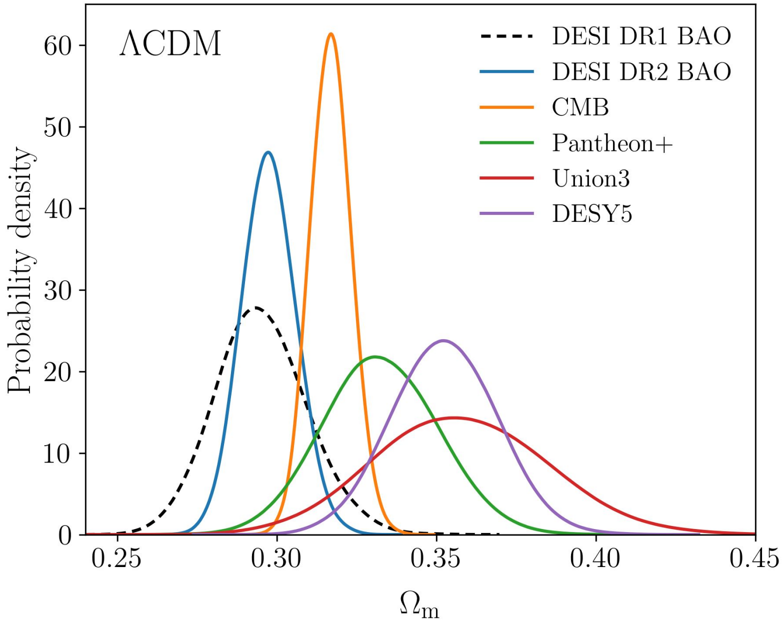
$$\underbrace{w_0 = -0.42 \pm 0.21 \quad w_a = -1.75 \pm 0.58}$$

DR2: DESI + CMB ⇒ 3.1σ

Dark Energy Equation of State

In **ΛCDM**:

→ DESI BAO predicts slightly lower values of $\mathbf{\Omega_m}$ than Planck
→ SN data sets predict higher values of $\mathbf{\Omega_m}$ than Planck



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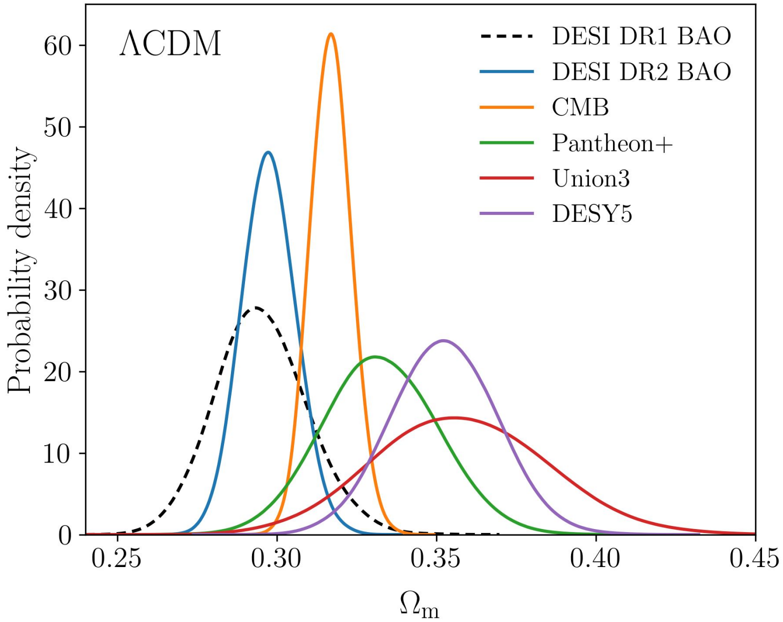
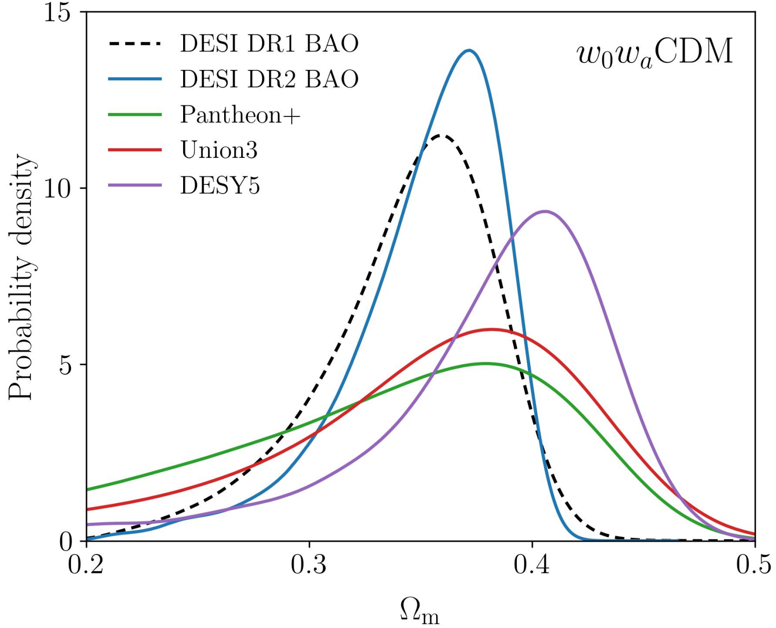


In **w0waCDM**:

→ Prediction of $\mathbf{\Omega_m}$ from DESI BAO consistent with SNe Ia data sets



Dark Energy Equation of State

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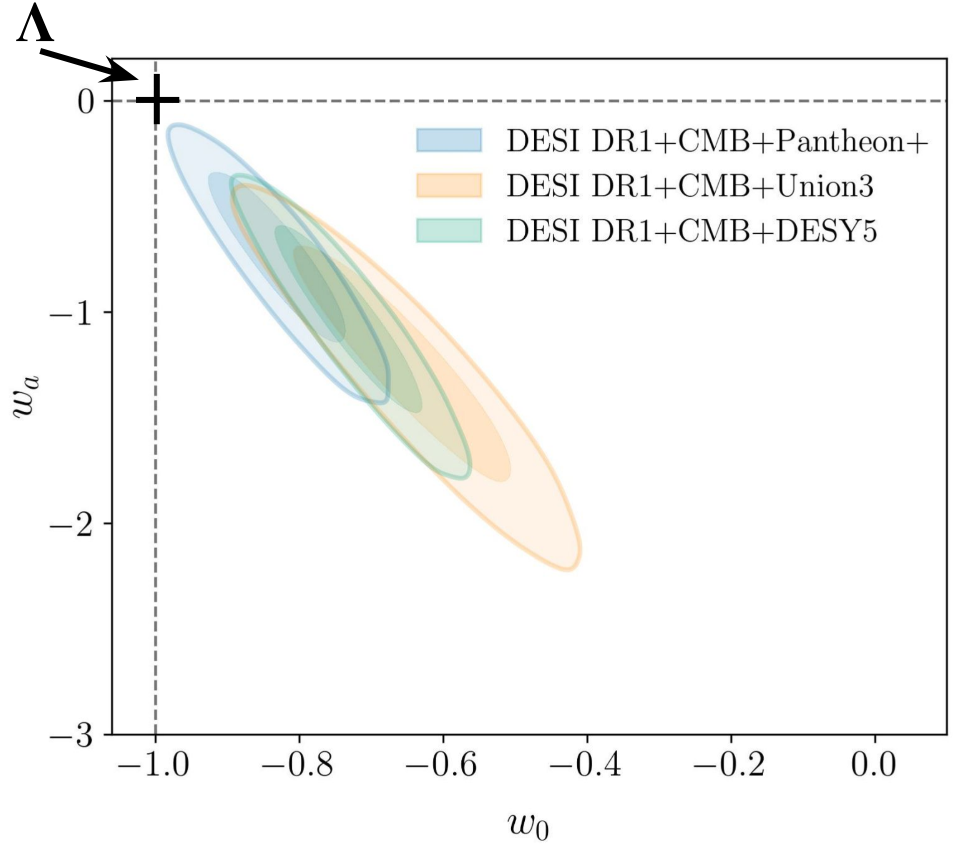


Combining DESI + CMB + SN:

$$\underbrace{w_0 = -0.827 \pm 0.063 \quad w_a = -0.75^{+0.29}_{-0.25}}$$

DR1: DESI + CMB + Pantheon+ ⇒ 2.5σ

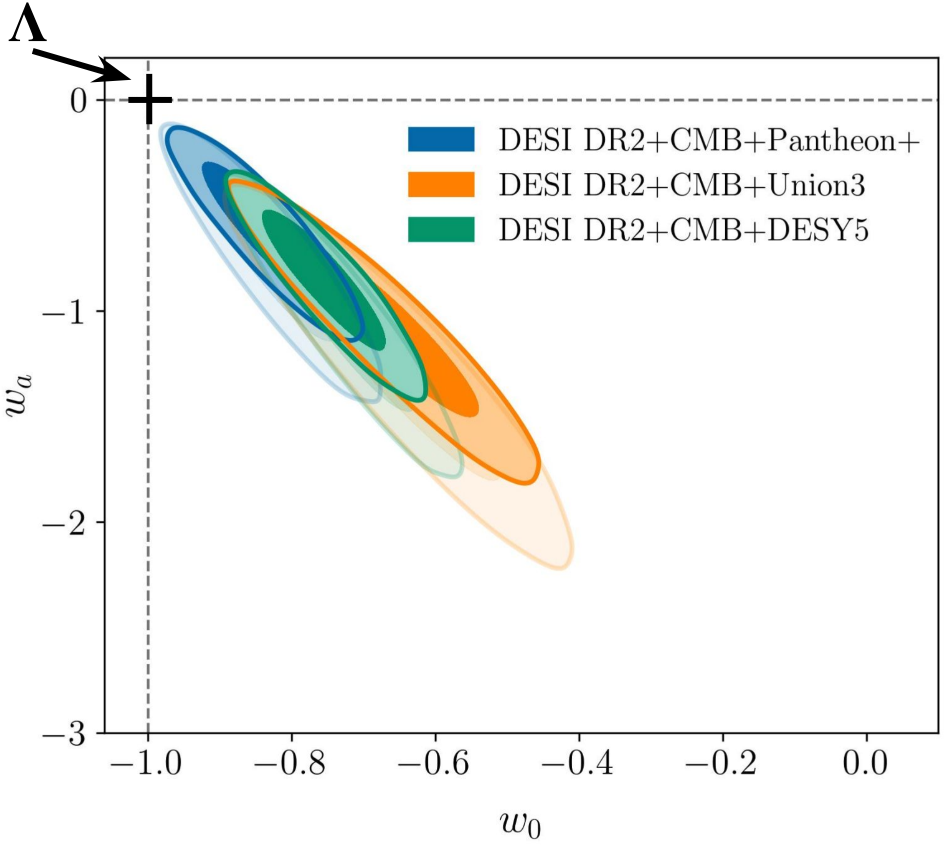
$$\underbrace{w_0 = -0.64 \pm 0.11 \quad w_a = -1.27^{+0.40}_{-0.34}}$$

DR1: DESI + CMB + Union3 ⇒ 3.5σ

$$\underbrace{w_0 = -0.727 \pm 0.067 \quad w_a = -1.05^{+0.31}_{-0.27}}$$

DR1: DESI + CMB + DESY5 ⇒ 3.9σ

Dark Energy Equation of State



Combining DESI + CMB + SN:

$$\underbrace{w_0 = -0.838 \pm 0.055, \quad w_a = -0.62^{+0.22}_{-0.19}}_{\text{DR2: DESI + CMB + Pantheon+} \ \Rightarrow \ 2.8\sigma}$$

$$\underbrace{w_0 = -0.667 \pm 0.088, \quad w_a = -1.09^{+0.31}_{-0.27}}_{\text{DR1: DESI + CMB + Union3} \ \Rightarrow \ 3.8\sigma}$$

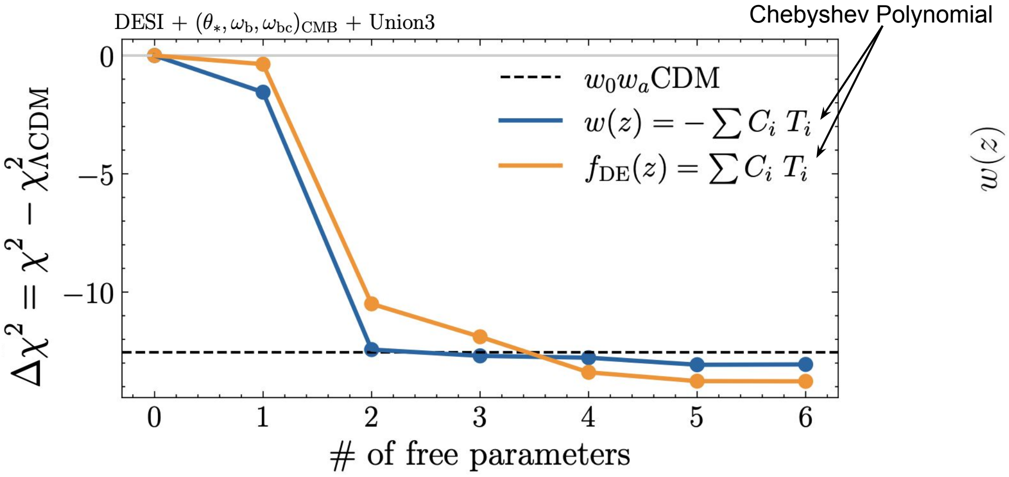
$$\underbrace{w_0 = -0.752 \pm 0.057, \quad w_a = -0.86^{+0.23}_{-0.20}}_{\text{DR1: DESI + CMB + DESY5} \ \Rightarrow \ 4.2\sigma}$$

Extended DE study

For more details, see arXiv:2503.14743

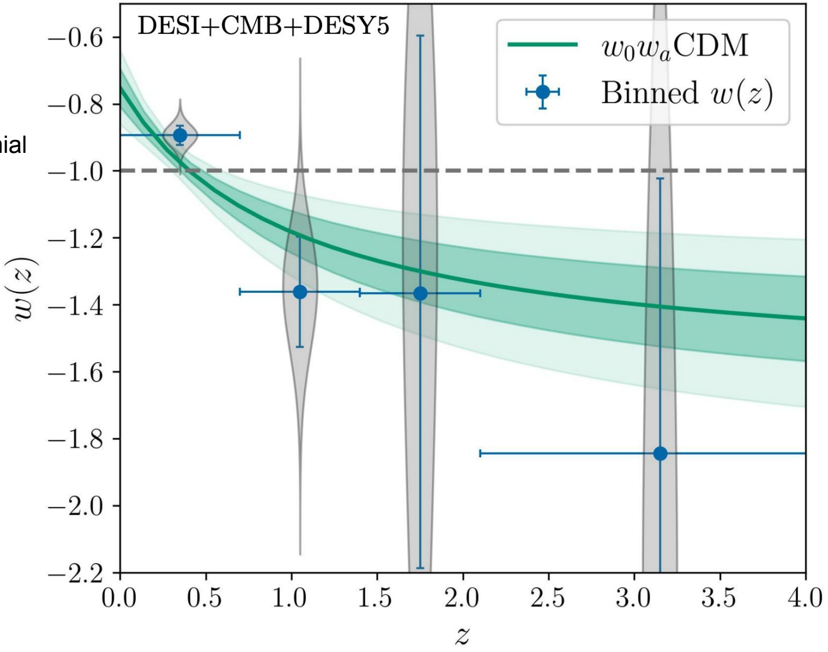
Testing **different parameterisation** of either w(z) or $\rho_{DE}(z)$:

→ alternative 2 parameter models with different functional forms
→ introduction of additional degree of freedom



Non-parametric way of determining w(z) through **binning**:

→ comparison of different redshift intervals without the assumption of a specific functional form



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Conclusion:

- Full-shape MG constraints compatible with GR
- DR2 is fully consistent with DR1 with error bar smaller by almost ~2x
- DESI + CMB prefer dynamical DE at 3.1σ
- Including SN data strengthens this to 2.8σ - 4.2σ

Thanks to our sponsors and 72 Participating Institutions!

APPENDIX

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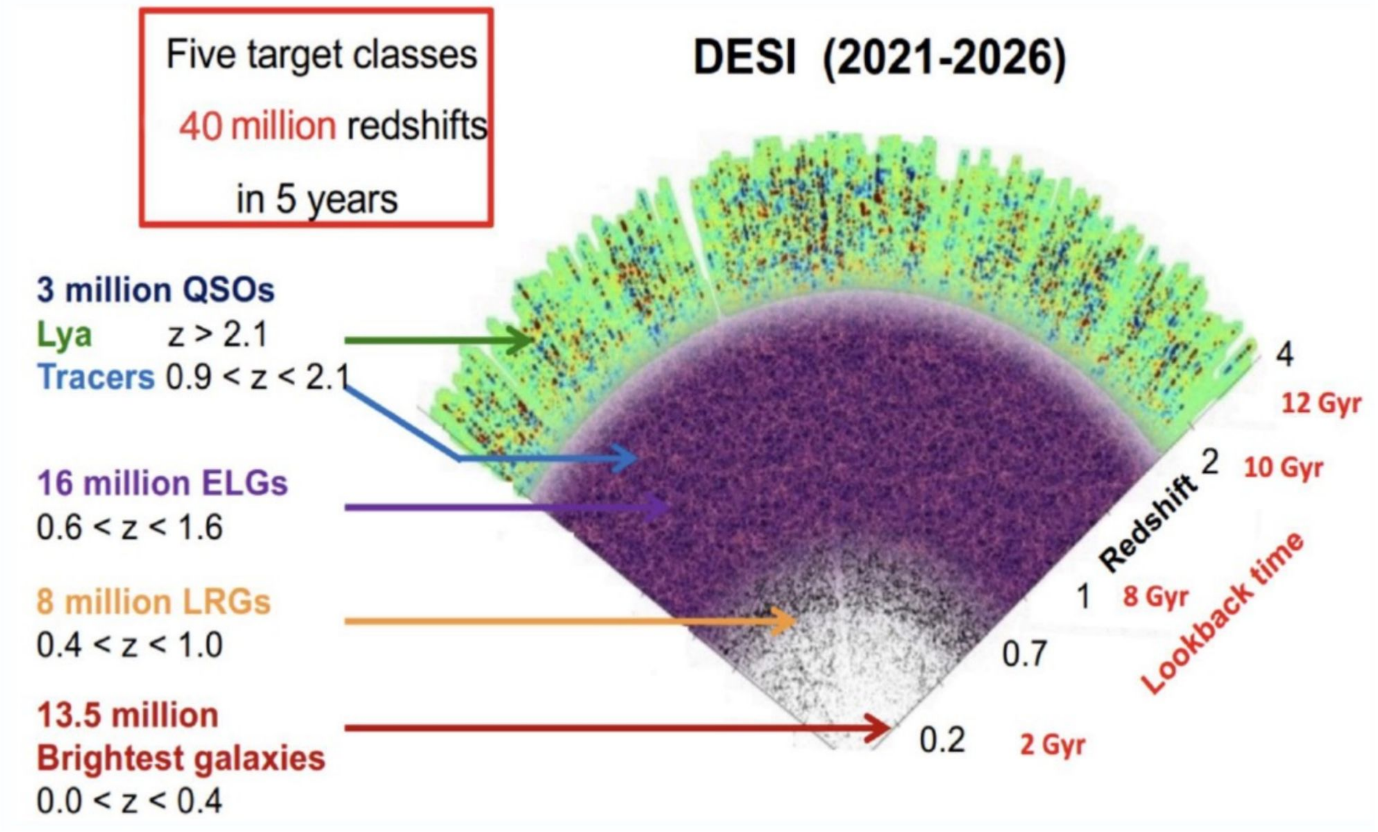
Redshifts for the BAO analysis

Tracer	DR1	**DR2**
BGS	300,043	**1,188,526**
LRG	2,138,627	**4,468,483**
ELG	2,432,072	**6,534,844**
QSO	1,223,391	**2,062,839**
Total	6,094,133	**14,254,692**



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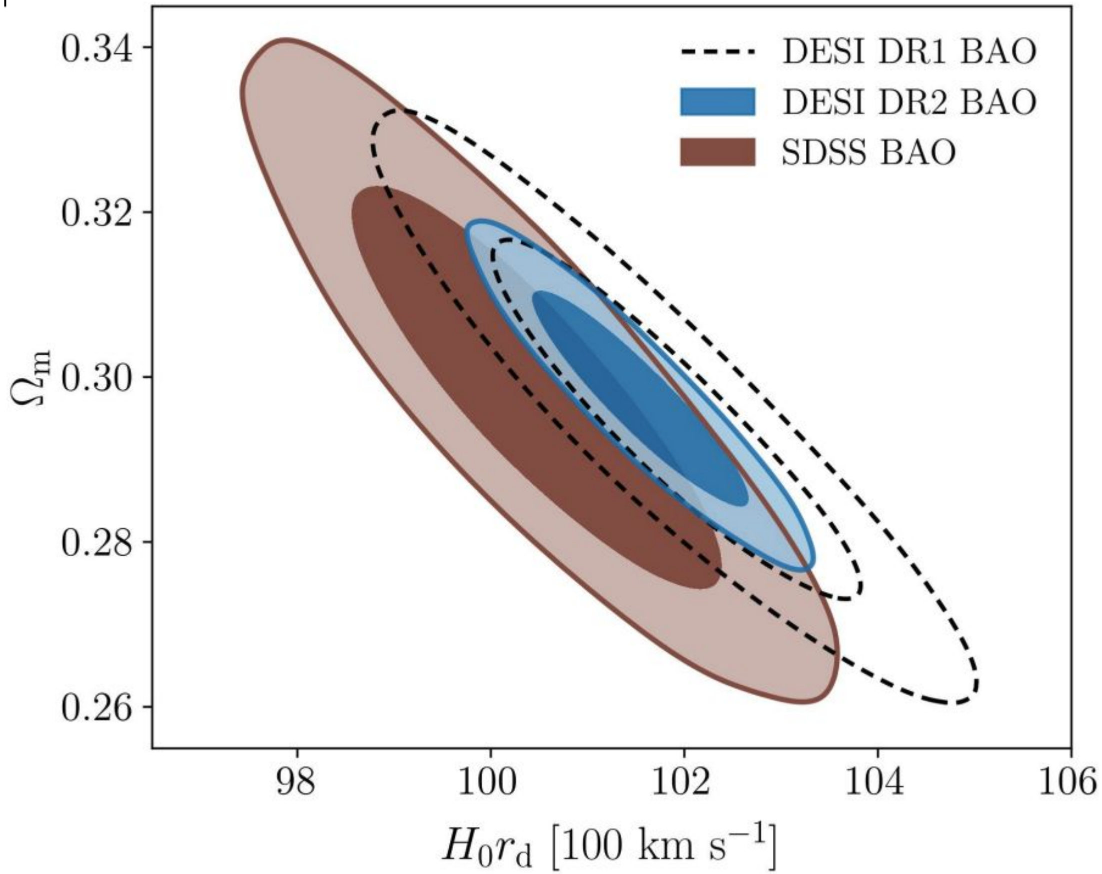
Consistency with SDSS



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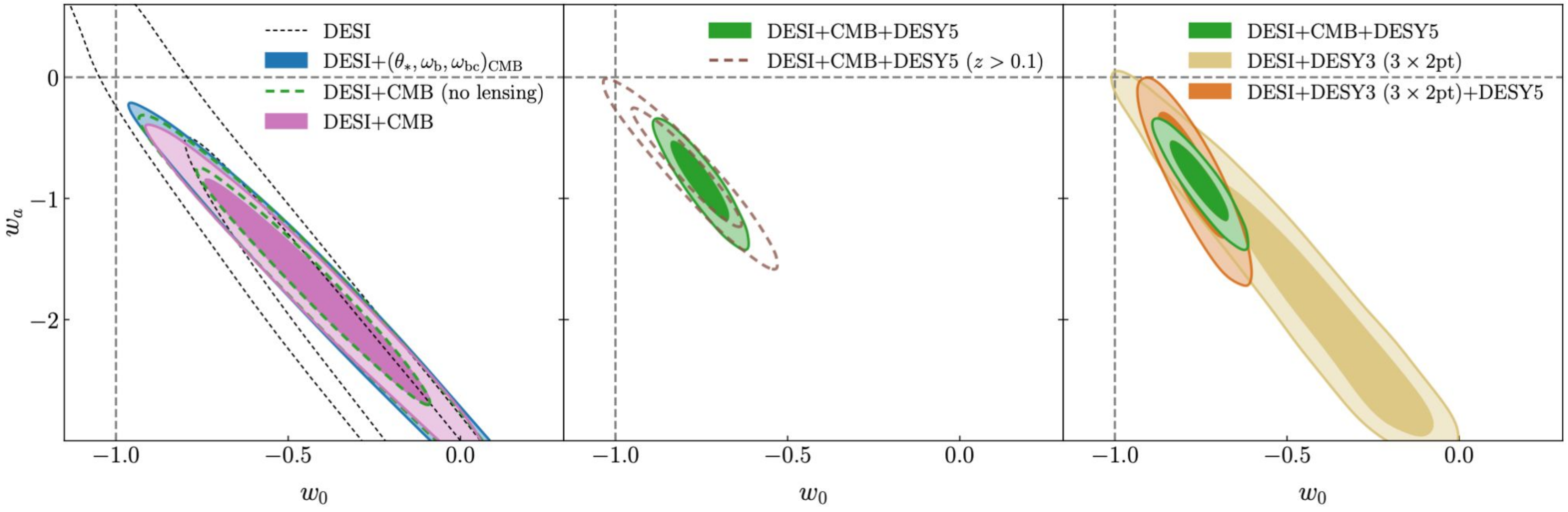
DR2: Level of Significance for the different data sets

Datasets	$\Delta\chi^2_{\mathrm{MAP}}$	Significance	Δ(DIC)
DESI	-4.7	1.7σ	-0.8
DESI+$(\theta_*, \omega_{\mathrm{b}}, \omega_{\mathrm{bc}})_{\mathrm{CMB}}$	-8.0	2.4σ	-4.4
DESI+CMB (no lensing)	-9.7	2.7σ	-5.9
DESI+CMB	-12.5	3.1σ	-8.7
DESI+Pantheon+	-4.9	1.7σ	-0.7
DESI+Union3	-10.1	2.7σ	-6.0
DESI+DESY5	-13.6	3.3σ	-9.3
DESI+DESY3 (3×2pt)	-7.3	2.2σ	-2.8
DESI+DESY3 (3×2pt)+DESY5	-13.8	3.3σ	-9.1
DESI+CMB+Pantheon+	-10.7	2.8σ	-6.8
DESI+CMB+Union3	-17.4	3.8σ	-13.5
DESI+CMB+DESY5	-21.0	4.2σ	-17.2

TABLE VI. Summary of the difference in the effective χ^2_{MAP} value (defined as twice the negative log posterior at the maximum posterior point) for the best-fit w_0w_aCDM model relative to the best ΛCDM model with $w_0 = -1$, $w_a = 0$, for fits to different combinations of datasets as indicated. The third column lists the corresponding (frequentist) significance levels given 2 extra free parameters, and the final column shows the results for $\Delta(\mathrm{DIC}) = \mathrm{DIC}_{w_0w_a\mathrm{CDM}} - \mathrm{DIC}_{\Lambda\mathrm{CDM}}$.

Robustness of the Dark Energy results



Different level of CMB information:
→ **CMB-derived priors** (late-time dark energy independent)
→ full **CMB information** (with or without lensing)
→ tighten constraints on w0wa through fixing $\mathbf{\Omega}_m$

DESY5 calibration:
→ remove **samples for z > 0.1**
→ best fit still lies in the lower quadrant

Replacing the CMB with DESY3:
→ constraints on w0wa **purely depending on low-z probes**

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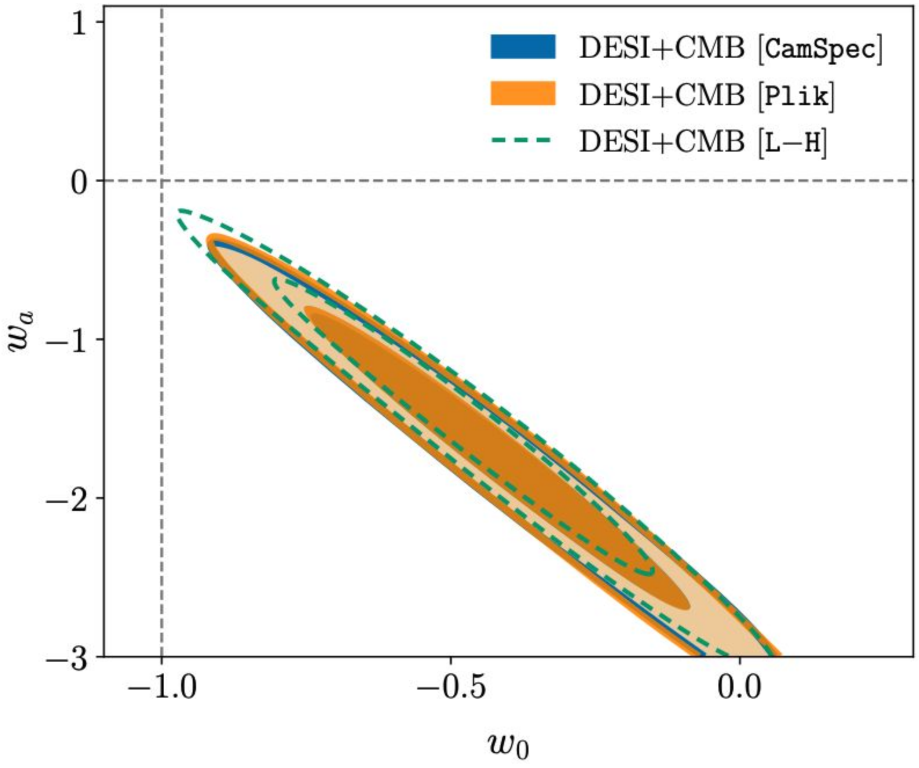
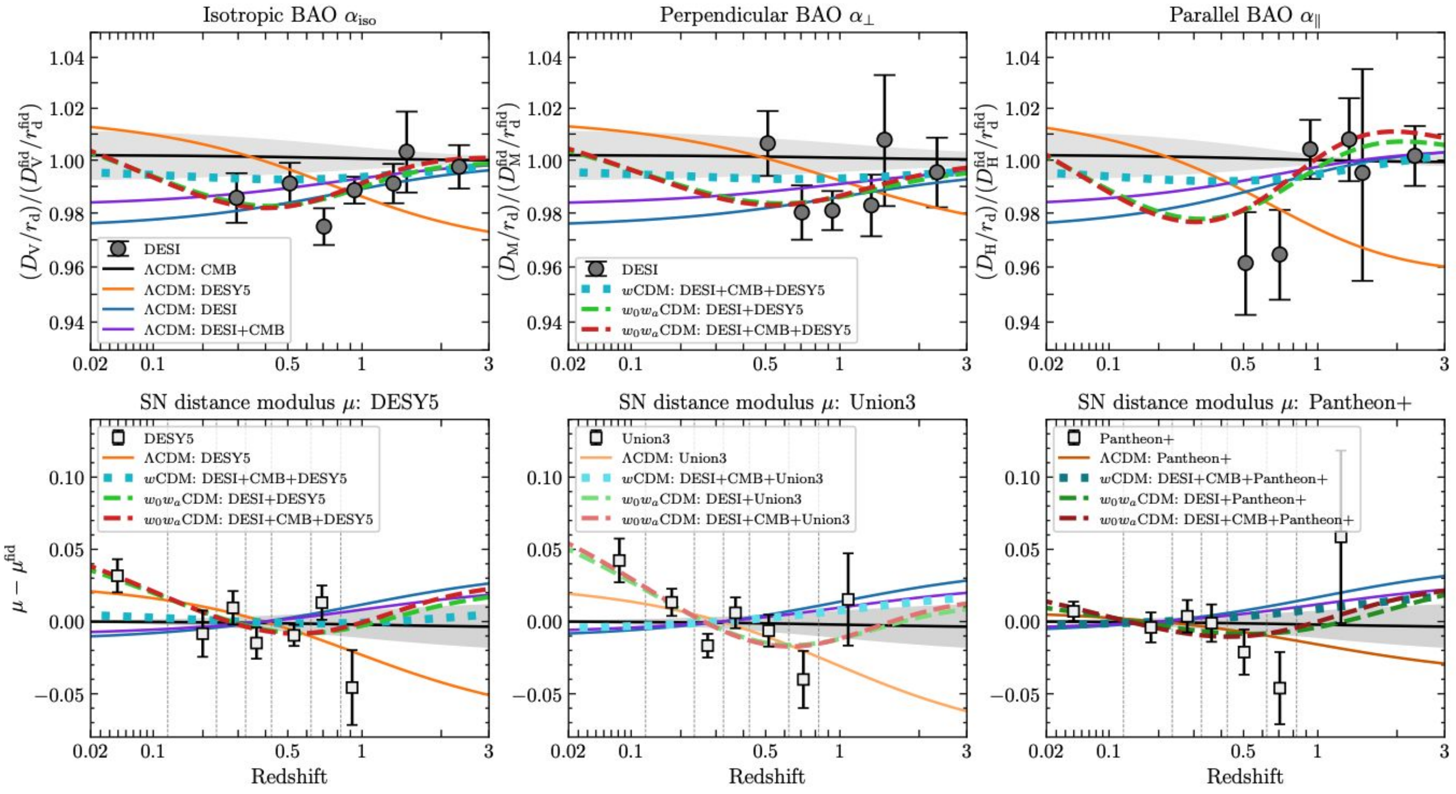
Robustness of the Dark Energy results



Results are robust to different CMB likelihoods

Robustness of the Dark Energy results

For supernovae at z > 0.1, which partially overlap the redshift range of DESI, the ΛCDM model that best fits the DESI data is also a good fit to the SNe data (blue line)



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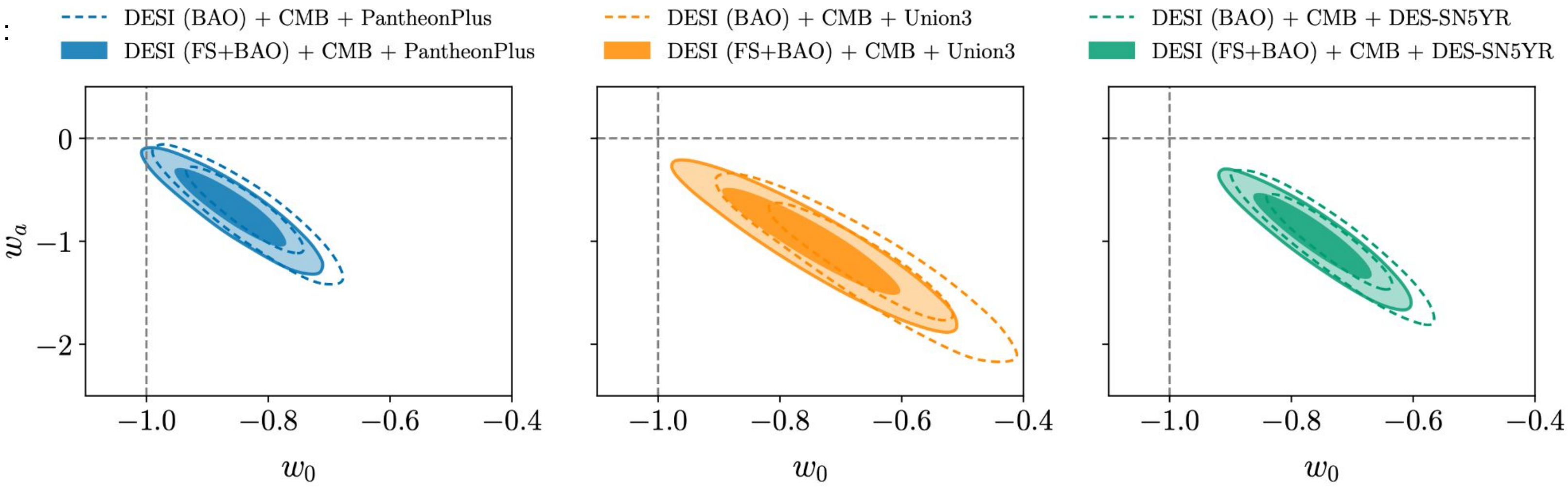
Evolving DE: Adding Full-shape to the mix

For DR1:



2.5σ ⇒ 2.5σ

3.5σ ⇒ 3.4σ

3.9σ ⇒ 3.8σ

Full-shape DR1: Modified Gravity

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Combination of clustering and lensing:

$$\mu_0 = 0.21 \pm 0.24$$
$$\Sigma_0 = 0.166 \pm 0.074$$

DESI +CMB

$$\mu_0 = 0.04 \pm 0.22$$
$$\Sigma_0 = 0.044 \pm 0.047$$

DESI +CMB-nl+ DESY3