Monodromic Dark Energy and DESI

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MPA

with
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arXiv:2507.16970

arXiv:1709.01544

Cambridge-LMU workshop Sep 16, 2025

Protagonists

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Dark Energy *can* cross phantom divide

- If observations are consistent with w=-1, have we proven that DE=Λ?

$$S = \int d^4x\sqrt{-g}\left[\frac{1}{2}M_{\rm Pl}^2 R + p(\phi, X) + \mathcal{L}_m\right]$$

$$X \equiv -\frac{1}{2}(\partial_\mu\phi)^2$$

  - Canonical scalar field: yes

$$p(\phi) = X + V(\phi) \quad \Rightarrow \quad w = \frac{\dot\phi^2/2 - V(\phi)}{\dot\phi/2 + V(\phi)}$$

- Not true in general: could have equation of state that *varies around* w=-1

- *Monodromic k-essence:*

$$p(\phi, X) = \tilde V(\phi)\left[-X/M^4 + (X/M^4)^2\right]$$

$$\tilde V(\phi) = C\left(\frac{\phi}{\phi_0}\right)^{-\alpha}\left[1 - A\sin(\nu H_0\phi + \delta)\right].$$

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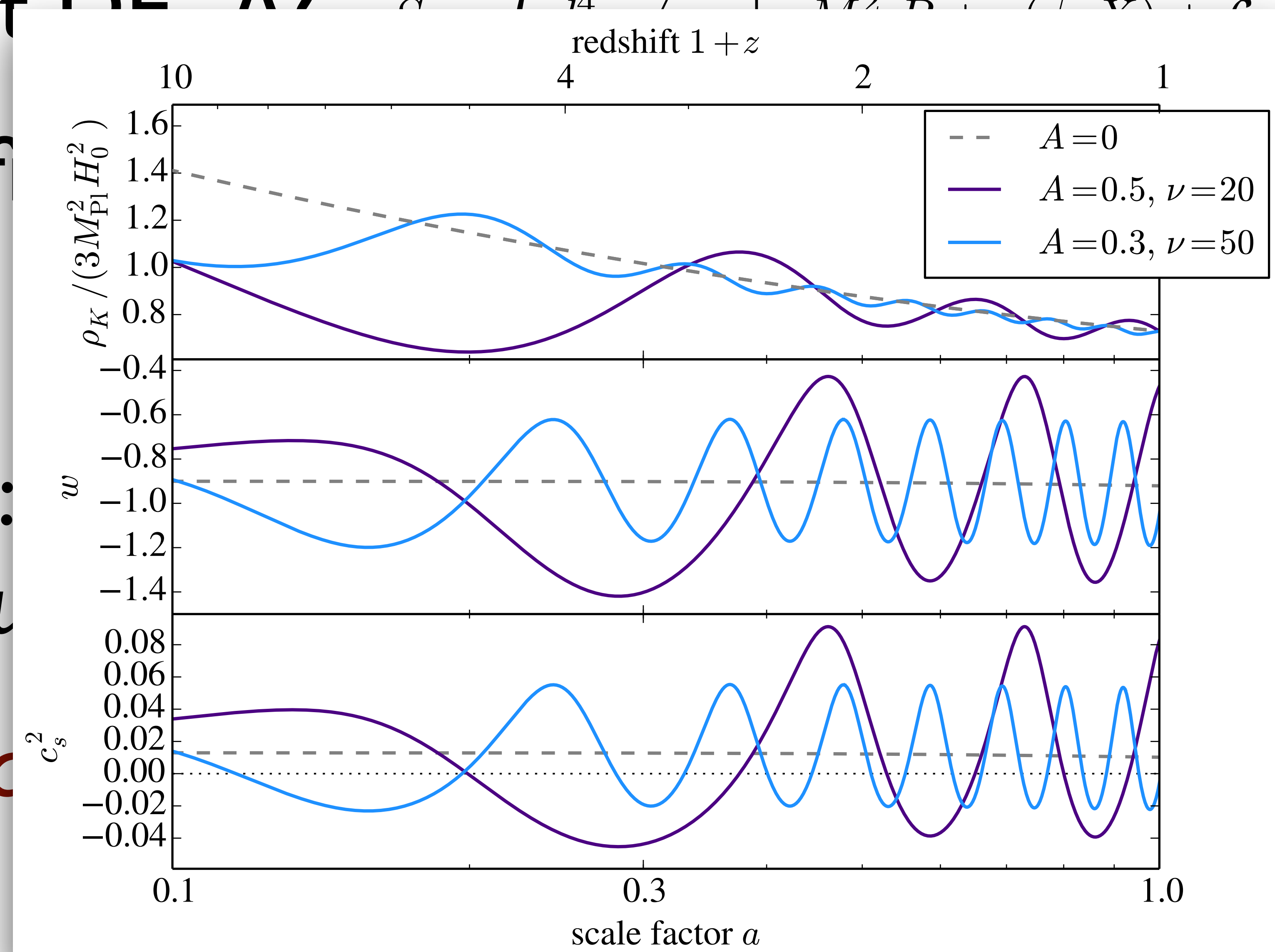


On tachyonic instabilities

- Fine at the background level, but DE perturbations suffer tachyonic instabilities if $c_s^2 < 0$
- k-essence case naturally has $c_s^2 \ll 1$; in fact, $c_s^2 \sim (1+w)$ in $1+w \to 0$ limit, leading to tachyonic instabilities as $1+w < 0$
- These can be dealt with consistently if
  - Higher-derivative contributions are present:

$$\ddot{\delta\phi} \sim -c_s^2 k^2 \delta\phi + \frac{k^4}{\bar{M}^2}\delta\phi + \ldots$$

e.g., from

$$\Delta\mathcal{L}_{\mathrm{DE,h.deriv.}} = -\frac{\bar{M}^2}{2}\left[\Box\phi + 3H(\phi)\right]^2$$

  - c_s^2 stays infinitesimally below 0
- Lowers cutoff of the theory, but not ruled out.

Creminelli, D'Amico, Noreña, Vernizzi (2009)

Dark Energy *can* cross phantom divide

- An example viable model (due to Marco Celoria):

$$p(\phi, X) = \frac{\bar{M}^4}{2}(2X-1)^2 - F(\phi) + G(\phi)(2X+1)$$

$$F(\phi) = V_0\left[1 - \tilde{A}\sin(\tilde{\nu}H_0\phi)\right]$$

$$G(\phi) = V_0\tilde{A}\tilde{\nu}H_0\cos(\tilde{\nu}H_0\phi).$$

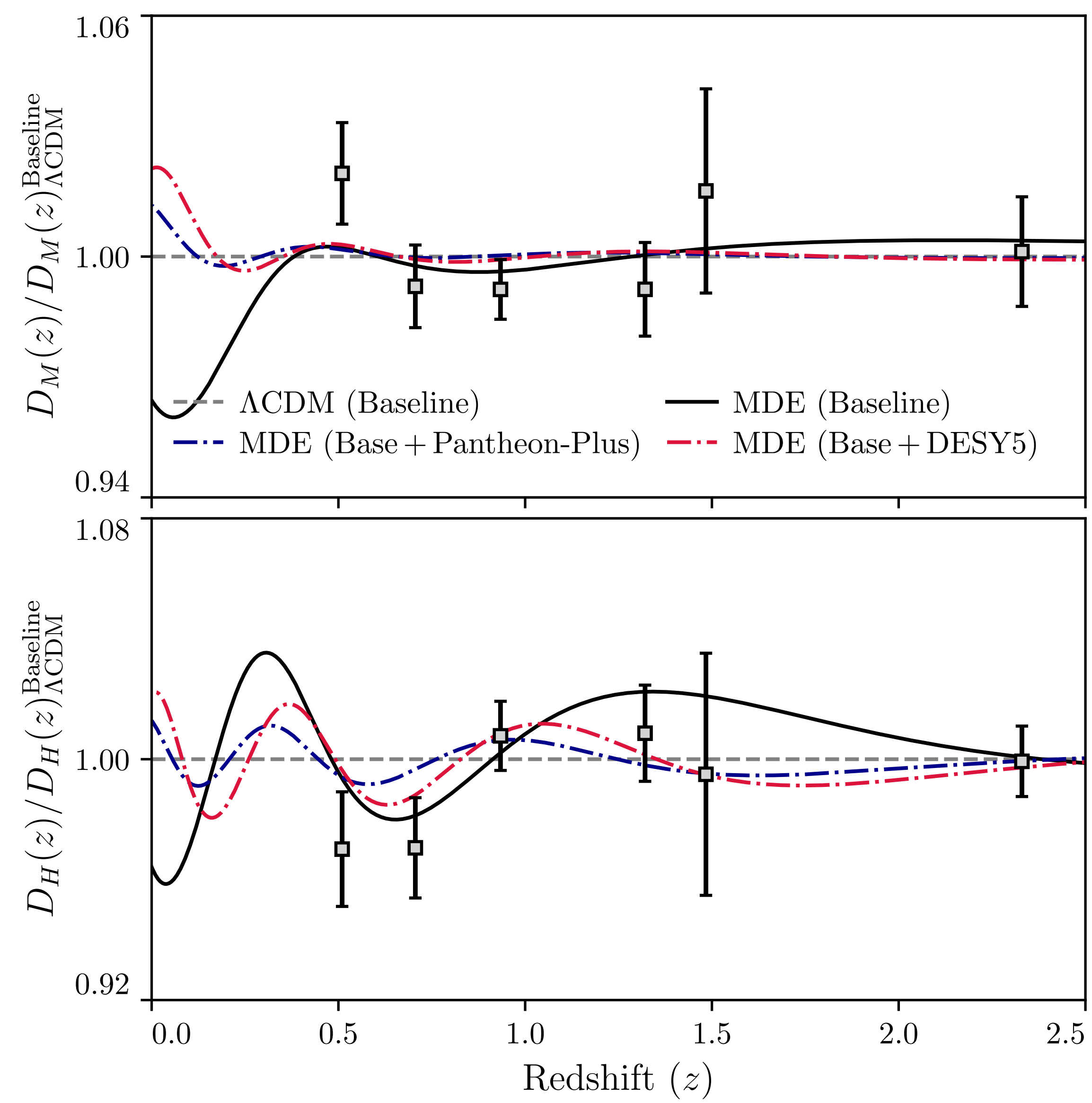
- Oscillations with amplitude Δw~0.1 around w=-1 easily possible while satisfying constraints on instabilities and having cutoff > eV scale.

Goldstein, Celoria, FS (2025)
See also Rebouças et al (2024

arXiv:2408.14628

Monodromic k-essence and DESI

- 3 free parameters (FS 2017 model) in addition to Ω_{de}, potential tilt α <=> mean w:
  - amplitude, frequency, phase of oscillations
- Exclude all observables sensitive to perturbations here



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Monodromic k-essence and DESI

- 3 free parameters (FS 2017 model) in addition to Ω_{de}, potential tilt α <=> mean w:
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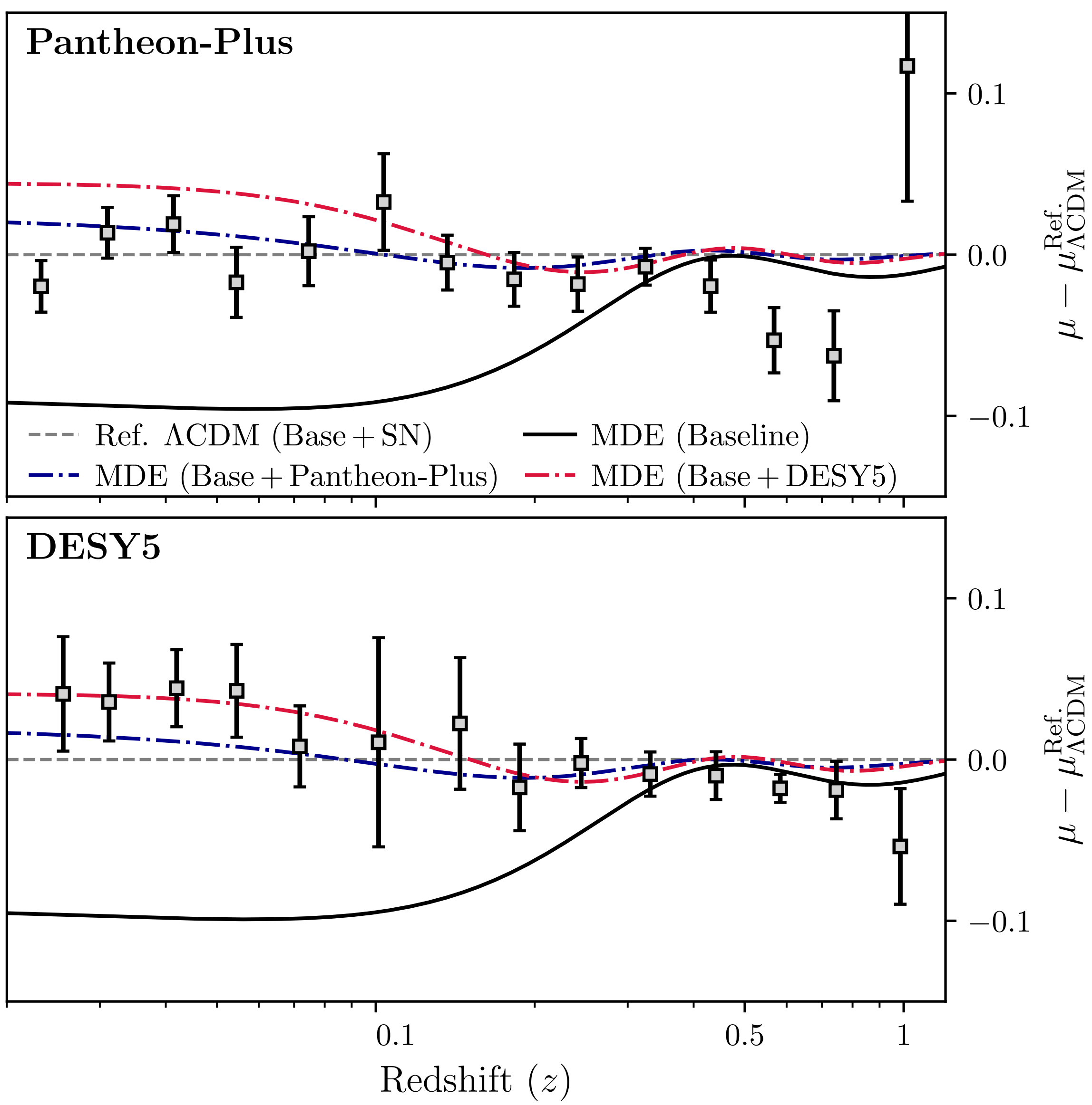
- Exclude all observables sensitive to perturbations here
- Similar fit quality to DESI BAO + SN as w_0, w_a
- Mean w consistent with -1 (motivated by theory as well); then, only 1 more free parameter than w_0, w_a !



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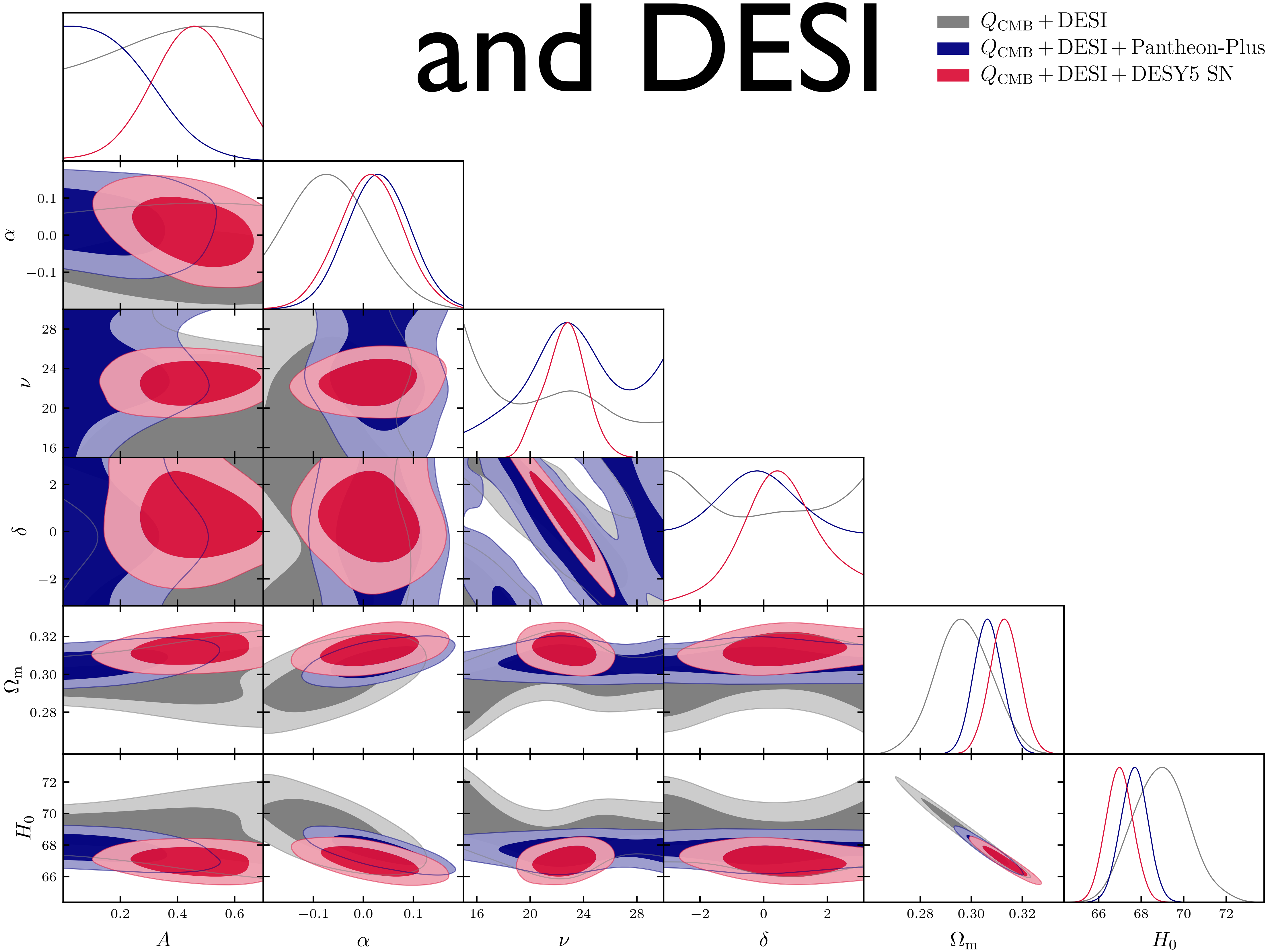

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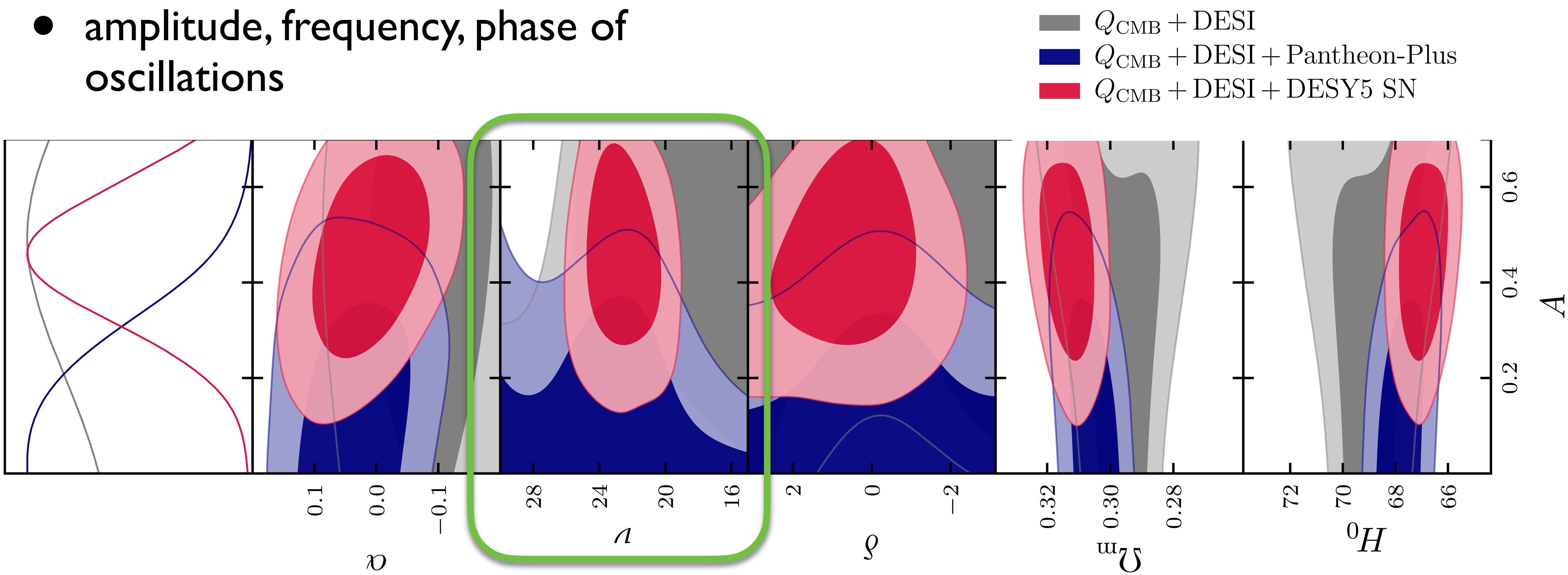


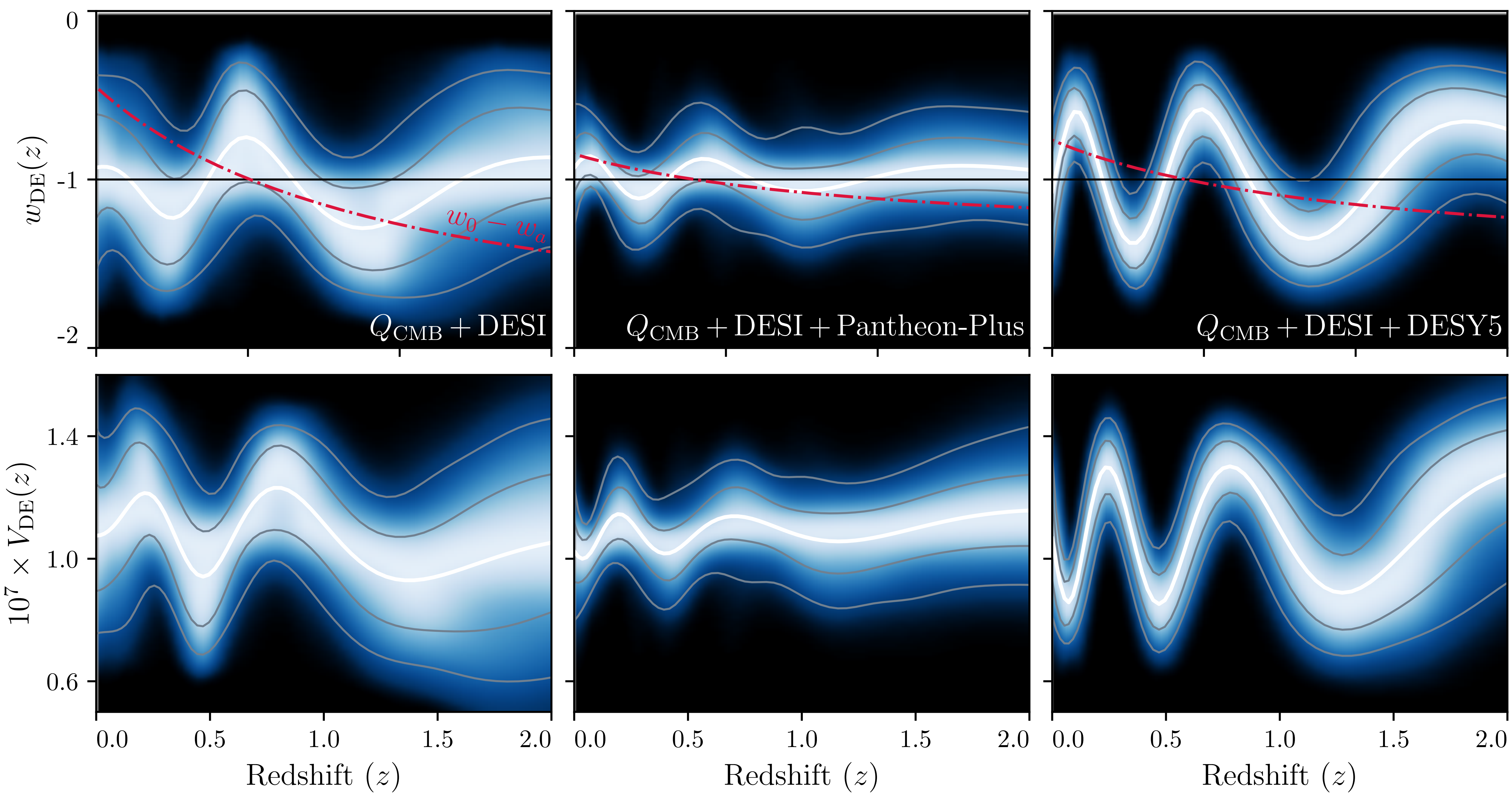
Monodromic k-essence and DESI

	A	α	ν	δ	Ω_m	H_0 [km/s/Mpc]	$\Delta\chi^2$
Base: $Q_{\rm CMB}$+DESI	— (0.58)	$-0.06^{+0.06}_{-0.09}$ (-0.08)	— (15.2)	— (-2.2)	0.297 ± 0.011 (0.281)	68.9 ± 1.3 (71.0)	-7
Base+Pantheon-Plus	< 0.44 (0.25)	0.03 ± 0.06 (0.01)	— (22.1)	— (0.2)	0.307 ± 0.006 (0.308)	67.7 ± 0.6 (67.5)	-5
Base+DESY5 SN	$0.44^{+0.15}_{-0.12}$ (0.47)	0.01 ± 0.06 (0.00)	$22.6^{+1.6}_{-1.5}$ (22.8)	0.5 ± 1.2 (0.5)	0.313 ± 0.006 (0.314)	67.0 ± 0.6 (66.9)	-16

TABLE I. Marginalized constraints on monodromic dark energy and other cosmological parameters for the datasets considered in this work. For each dataset, we report the posterior mean and 68% two-tailed C.L. for all parameters that are detected at $> 2\sigma$, otherwise we report the one-tailed 95% C.L.; "—" denotes parameters that are entirely constrained by the prior at 2σ. Maximum *a posteriori* values are shown in parentheses. The final column reports the $\Delta\chi^2$ values computed with respect to a ΛCDM cosmology.

Monodromic k-essence and DESI

- Reconstruction of w(z) and k-essence "potential"



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Outlook

- Monodromic k-essence: physically viable model that crosses phantom divide and provides reasonable improvement over ΛCDM to DESI+SN
  - Would be interesting to combine with more high-z/low-z data
- Key next step: calculate evolution of perturbations
  - Expect interesting constraints from growth rate
  - Especially if extending to higher frequencies
- c_s=0: Dark energy clusters, and perturbations become nonlinear on small scales
  - Need N-body simulations that jointly solve for DE (ongoing work with Linda Blot)