DESI Priors & PhantomX Coincidence

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DESI claims that data prefers evolving dark energy over ΛCDM

What is DESI?

Dark **E**nergy **S**pectroscopic **S**urvey (**DESI**) provides state-of-the-art redshift measurements using its '5000 robotic eyes'. In their 2024 paper[1], DESI used five types of tracers to measure Baryon Acoustic Oscillations and constraint cosmological parameters.

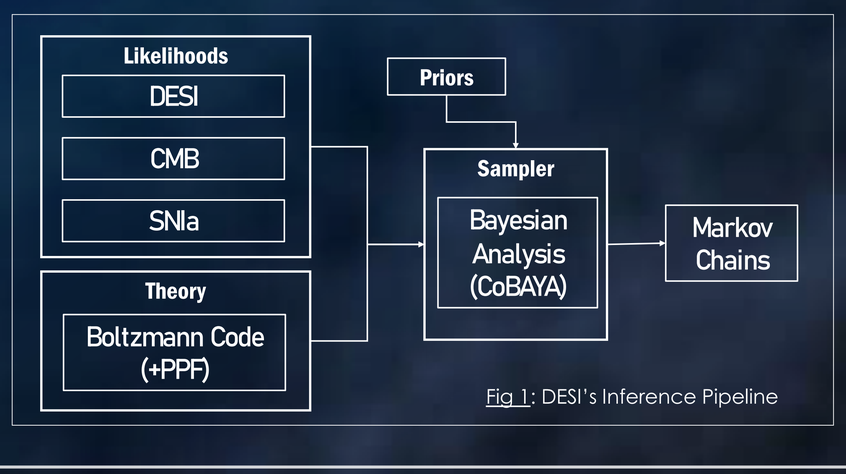

Fig 1: DESI's Inference Pipeline

What was DESI's Claim?

DESI's data suggests that on testing a dynamic dark energy model (eq. 1), the maximum likelihood parameters stand in significant tension with the standard model of cosmology.

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

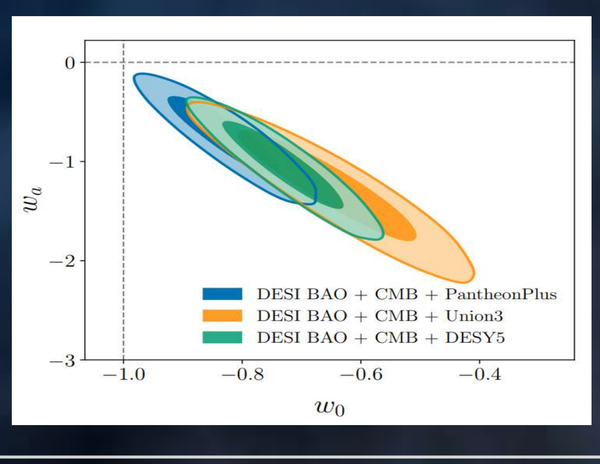

Fig 2: Maximum likelihood contours[1] (for different supernova datasets) on w_0w_a-plane. The intersection of dotted lines (w_0 = -1 and w_a = 0) represents ΛCDM. All contours are offset from SMoC.

DESI's BAO analysis found a 2.5σ–3.9σ pull away from ΛCDM, in favor of w0wa-CDM cosmology

The analysis implies a new cosmic coincidence

Phantom Dark Energy

Dark energy models with an equation-of-state parameter w less than -1 present theoretical challenges (such as negative kinetic energies). The space of parameters leading to such models is called the '**Phantom Regime**'.

A '**Phantom Crossing**' occurs if dark energy evolves from having w < -1 to having w > -1. These phantom crossings lack a theoretical motivation and can only be modelled via interpolation, commonly with **Parameterized Post-Friedman** (PPF).

Phantom Crossing at Pivot Scale

A **Pivot Scale** is the redshift at which the data's constraining power is the highest. DESI's analysis suggests for our universe, the **Phantom Crossing occurs within 1% of the pivot scale**.

This new cosmic coincidence is called the **PhantomX Coincidence**[2].

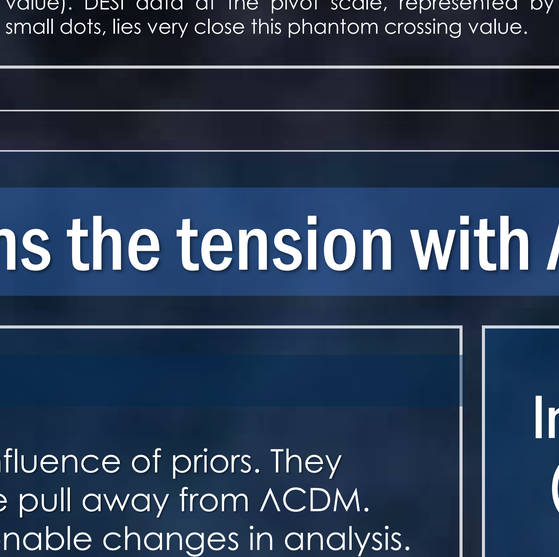

Fig 3: Dark-energy equation-of-state parameter plotted against scale factor. Blue dotted line demarcates phantom and non-phantom regimes (and the ΛCDM value). DESI data at the pivot scale, represented by small dots, lies very close this phantom crossing value.

Is Dark Energy density the highest where we observe it? Or, are there uncontrolled systematics in the analysis?

Removing unphysical priors lessens the tension with ΛCDM

Testing the Influence of Bayesian Priors

Cortes and Liddle[2] remarked that PhantomX coincidence could arise from the influence of priors. They conjectured that tapering priors may lessen this coincidence but also reduce the pull away from ΛCDM. Though there are no 'right' priors, scientific claims should be robust against reasonable changes in analysis.

On replicating DESI's inference pipeline, we discovered that even drastic changes in priors yield an insignificant influence on the sampler's preference for PPF models and that the aforementioned PhantomX coincidence persists robustly.

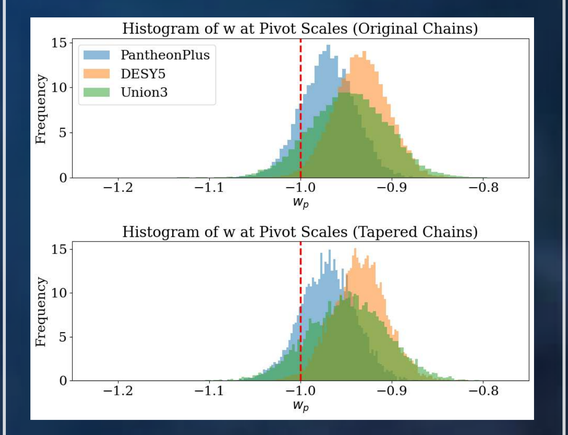

Fig 4: Comparing w-parameter at the pivot scale for chains with DESI's original and our 70% reduced priors. We find no meaningful difference in the posterior of the two Markov chains.

If we mask interpolated solutions and only search for evolving dark energy in non-phantom regime (i.e. Quintessence-Compatible models), the posterior shifts radically.

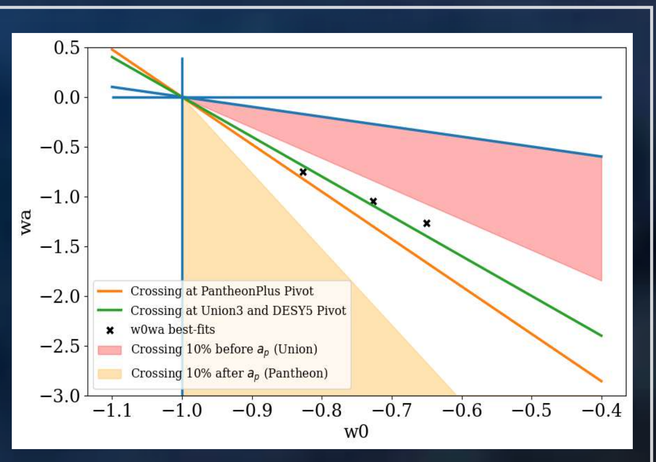

Fig 5: Parameter pairs lying above the red region represent quintessence compatible models. Black-crosses are DESI's results. ΛCDM solutions lies at the intersection of the blue lines.

Even amongst linearly evolving dark-energy models, imposing quintessence compatibility can leads the sampler back to ΛCDM solution.

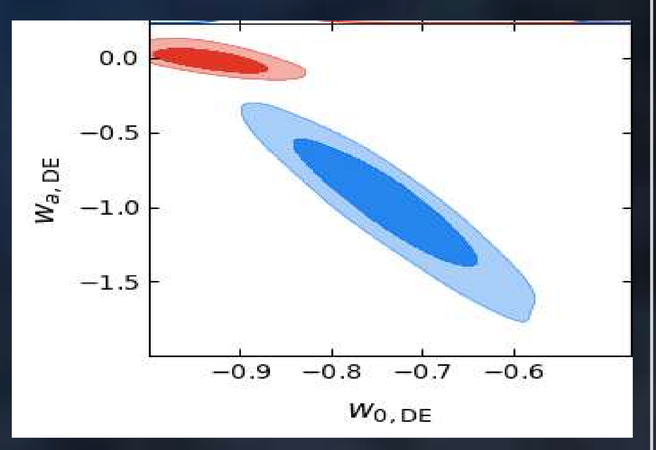

Fig 6: Same set-up as Fig. 2 except DESI's original result for PantheonPlus dataset is plotted in blue and the posterior after imposing Quintessence compatibility is displayed in red.

Interpolated Models (*a la* PPF) strongly preferred over physical models, even against drastic changes in priors.

Ensuring quintessence compatibility can, however, restore posterior closer to ΛCDM

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[1] A. G. Adame et al., "DESI 2024 VI: cosmological constraints from the measurements of baryon acoustic oscillations," Journal of Cosmology and Astroparticle Physics, vol. 2025, no. 02. IOP Publishing, p. 021, Feb. 01, 2025. doi: 10.1088/1475-7516/2025/02/021.
[2] M. Cortês and A. R. Liddle, "Interpreting DESI's evidence for evolving dark energy," Journal of Cosmology and Astroparticle Physics, vol. 2024, no. 12. IOP Publishing, p. 007, Dec. 01, 2024. doi: 10.1088/1475-7516/2024/12/007.
[3] Background Image Credits to V.Springel, Max-Planck Institut für Astrophysik, Garching bei München