CPL dark energy as quintessence

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CPL dark energy as quintessence within GR

The universe is filled with fluids with known density parameters Ω_i^0 and equation of state parameters ω_i.

We want to find a scenario in which a homogeneous quintessence $\phi(t)$ plays the role of the CPL ($\omega_0\omega_a$) dark energy. Thus, we need to find its scalar potential $V_s(\phi)$.

Reverse-engineering the potential

To find $V_s(\phi)$ such that the quintessence possesses some equation of state $\omega_\phi = p_\phi/\rho_\phi$, we follow the following steps:

1. Introduce dimensionless quantities: $\tau = t/t_0$, $\varphi = \phi/m$, $\epsilon = mt_0$. $V(\varphi) = V_s(m\varphi)/m^4$, $\mathcal{H} = \frac{da}{d\tau}/a$.

2. Invert the equation for ω_ϕ: $V(\varphi(\tau)) = \frac{1}{2\epsilon^2}\frac{1-\omega_\phi}{1+\omega_\phi}\varphi'^2(\tau)$.

3. Plug V into the Klein-Gordon: $\varphi'' + \frac{1+\omega_\phi}{2}(3\mathcal{H} - \frac{\omega'_\phi}{(1+\omega_\phi)^2})\varphi' = 0$.

4. Solve for $\varphi(t)$ and write it as $\varphi = F(\tau)$, so that $\tau = F^{-1}(\varphi)$.

5. Compute $V(\varphi) = \frac{1}{2\epsilon^2}\frac{1-\omega_\phi(F^{-1}(\varphi))}{1+\omega_\phi(F^{-1}(\varphi))}\left(F'(F^{-1}(\varphi))\right)^2$.

Results

For example, assume constant Hubble parameter H and constant ω_ϕ:

$$V_s(\phi) = \frac{9H^2}{8}\left(1-\omega_\phi^2\right)(\phi-\phi_0)^2.$$

To compute V for the actual universe. characterised by data given in [1], we needed numerical estimations. The best fit occurred to be of the form:

$$V(\varphi) = \frac{A}{(\varphi-\varphi_0)^p} + B\varphi + C.$$

[1] Chul Chung et al. "Strong Progenitor Age Bias in Supernova Cosmology and Alignment with DESI BAO". In: *Mon. Not. Roy. Astron. Soc.* 544.1 (2025), pp. 975–987. DOI: 10.3390/universe12010022. arXiv: 2510.13121 [astro-ph.CO].

Results of the fit

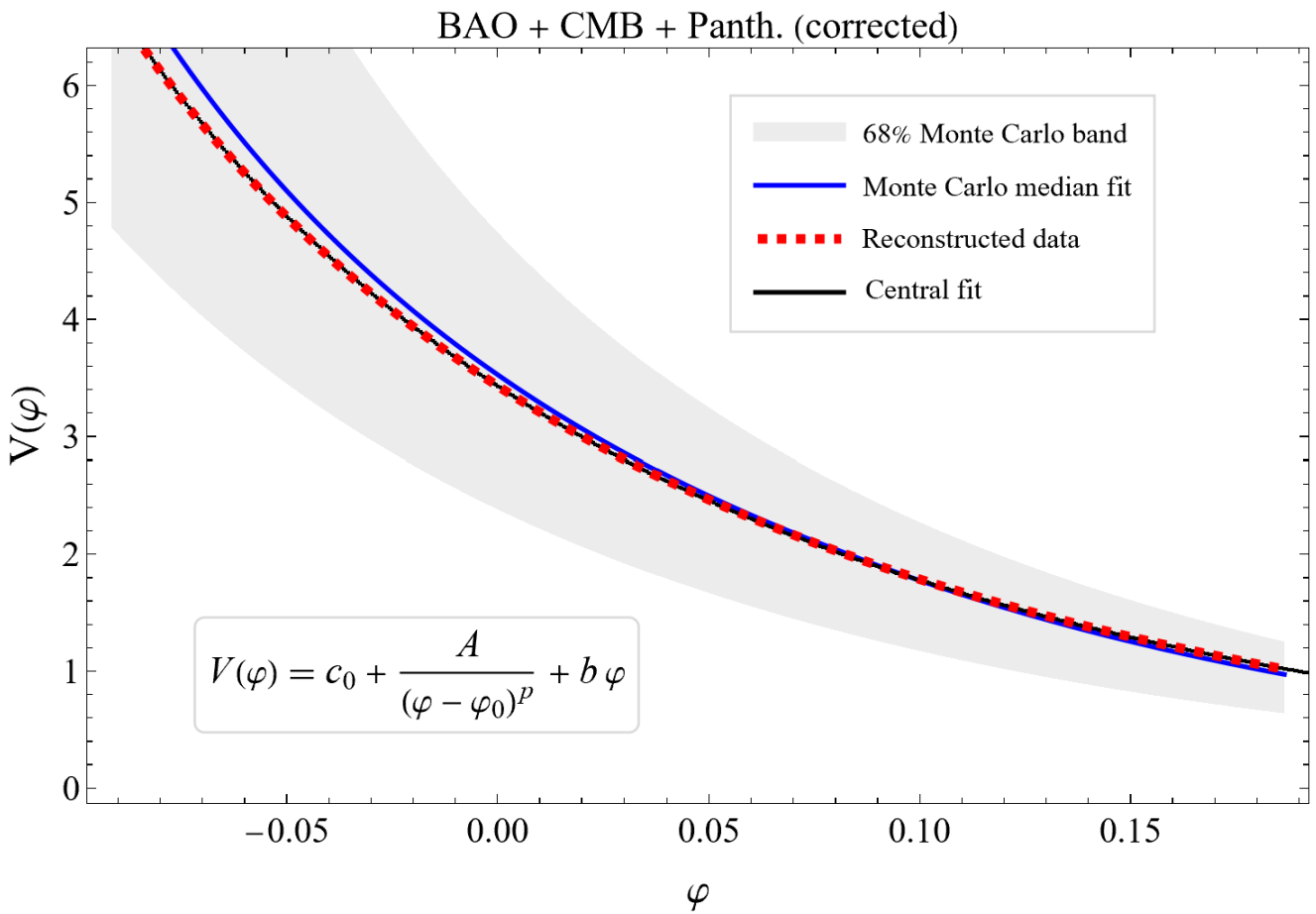


Figure: Pole-like fits to the reconstructed scalar-field potential $V(\varphi)$. The shaded region denotes the 68% MC uncertainty band, the blue curve - the MC median fit, the black curve - the fit evaluated at the central cosmological parameters, and the red points show the reconstructed numerical data.

Einstein-Cartan theory

In EC we decompose the full non-symmetric connection in Levi-Civita and contorsion:

$$\Gamma^{\alpha}_{\mu\nu} \equiv \mathring{\Gamma}^{\alpha}_{\mu\nu} - K_{\mu\nu}{}^{\alpha}$$

We define the curvature tensors with respect to such connection. Then, we can consider theory of gravity based on the action:

$$\mathcal{S} = \frac{1}{2\kappa} \int d^4x \sqrt{-g} R + S_m,$$

Equations of motion are given by $\frac{\delta S}{\delta g^{\mu\nu}} = 0$ and $\frac{\delta S}{\delta K_{\mu\nu}{}^{\alpha}} = 0$. Because of the second one, pure dust and quintessence are insufficient for the torsion to occur, so something more is needed.

Thank you for attention

Results of the fit for the quintessence dark energy

Par.	BAO, CMB, Panth. (corr)	BAO, CMB, DES5Y (corr)
Ω_{matter}	0.35 ± 0.01	0.36 ± 0.01
ω_0	-0.45 ± 0.06	-0.34 ± 0.06
ω_a	-1.59 ± 0.23	-1.90 ± 0.25
C	-6.67	-3.72
A	3.77	1.73
B	4.55	3.48
p	0.70	0.87
φ_0	-0.24	-0.27