IOCU 2026 Conference

The 3rd International Online Conference on Universe

4–6 March 2026 | Online

MDPI

Scalar Field Cosmology with Logarithmic Deceleration Parameter

Değer Sofuoğlu, Bhupendra Kumar Shukla, Aroonkumar Beesham

Department of Physics, Istanbul University, Vezneciler 34134, Fatih, Istanbul, Turkey
Department of Mathematics, Govt. Tilak PG College, Katni Madhya Pradesh 483501India
Department of Mathematical Sciences, University of Zululand, P Bag X1001, Kwa-Dlangezwa 3886, South

INTRODUCTION & AIM

Motivation & Background

Understanding the dynamics of late-time cosmic acceleration remains a primary goal in modern cosmology. While standard models rely on a cosmological constant, adopting a **model-independent reconstruction** allows the cosmic evolution to be determined empirically from observational data.

The Logarithmic Ansatz

In this study, we propose a novel framework using a **logarithmic parametrization of the deceleration parameter** $q(z)$. This specific form facilitates the reconstruction of the expansion history in a closed analytical form, providing crucial theoretical tractability.

Theoretical Framework

The model is constructed within **Scalar Field Cosmology** under General Relativity. The cosmic dynamics are governed by a minimally coupled scalar field (ϕ) with a generalized potential $V(\phi)$, meticulously designed to coherently reproduce the observed late-time acceleration.

Aim of the Study

We aim to constrain the free parameters of this logarithmic model using a robust combination of datasets (**CC, Pantheon+ SNe Ia, BAO, and the R19 prior**) to reconstruct fundamental dynamic quantities and determine the transition redshift (z_{tr}) with high precision.

METHOD

1. Theoretical Setup

We consider a spatially flat universe governed by General Relativity. The cosmic dynamics are driven by a minimally coupled canonical scalar field ϕ acting as dark energy. The fundamental physics of the model is described by the action:

$$S = \int d^4x\sqrt{-g}\left[\frac{R}{2\kappa^2} - \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - V(\phi)\right] + S_m$$

where R is the Ricci scalar, $\kappa^2 = 8\pi G$, $V(\phi)$ is the generalized scalar potential responsible for the late-time acceleration, and S_m represents the action for standard matter fields.

2. Logarithmic Parametrization

To achieve a model-independent reconstruction of the expansion history, we propose a specific **logarithmic parametrization** for the deceleration parameter $q(z)$:

$$q(z) = q_0 + q_1 \ln(1+z)$$

where q_0 is the present-day deceleration value, and q_1 governs its cosmic evolution. This mathematically robust form allows all fundamental dynamic quantities—such as the Hubble parameter $H(z)$ and the scalar potential $V(\phi)$—to be derived in a closed analytical form.

3. Observational Data & Statistical Analysis

To tightly constrain the core free parameters of our model (H_0, q_0, q_1), we performed a robust combined χ^2 minimization using Markov Chain Monte Carlo (MCMC) methods. The analysis incorporates an extensive set of recent observational data:

- **Cosmic Chronometers (CC):** Direct measurements of $H(z)$.
- **Standard Candles (SC):** High-precision Type Ia Supernovae from the latest Pantheon+ sample.
- **Baryon Acoustic Oscillations (BAO):** Data from various large-scale structure surveys.
- **R19 Prior:** The strong local Hubble constant constraint from local observations.

REFERENCES

[1] B. Ratra, P. J. E. Peebles, *Phys. Rev. D* **37**, 3406 (1988).
[2] A. G. Riess et al., *Astrophys. J.* **876**, 85 (2019).
[3] D. Brout et al. (Pantheon+), *Astrophys. J.* **938**, 110 (2022).
[4] S. Alam et al. (eBOSS), *Phys. Rev. D* **103**, 083533 (2021).

RESULTS & DISCUSSION

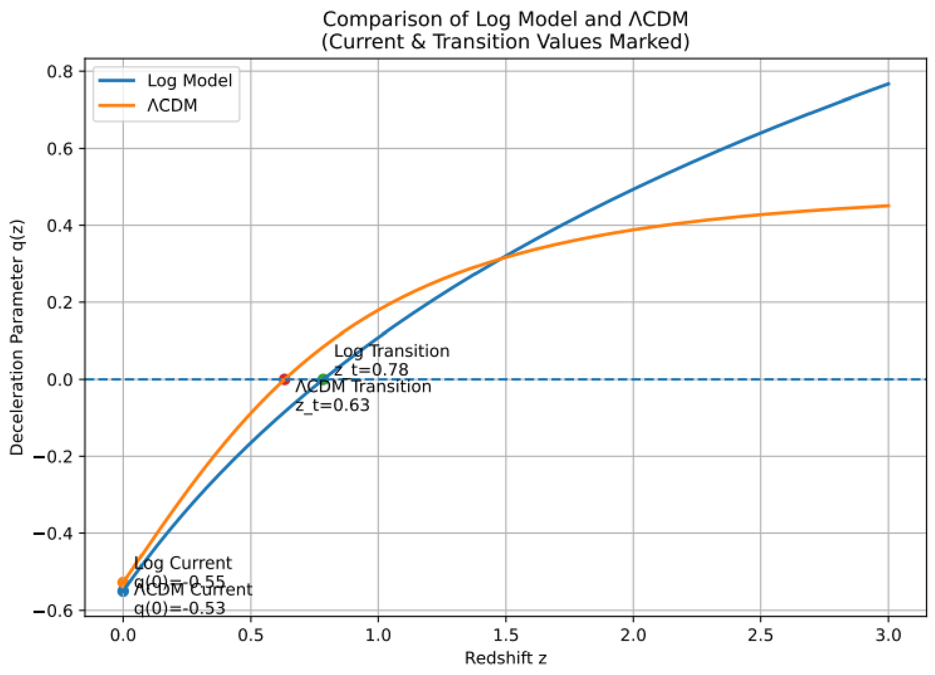


Fig. 1: Evolution of the logarithmic deceleration parameter $q(z)$ versus redshift.

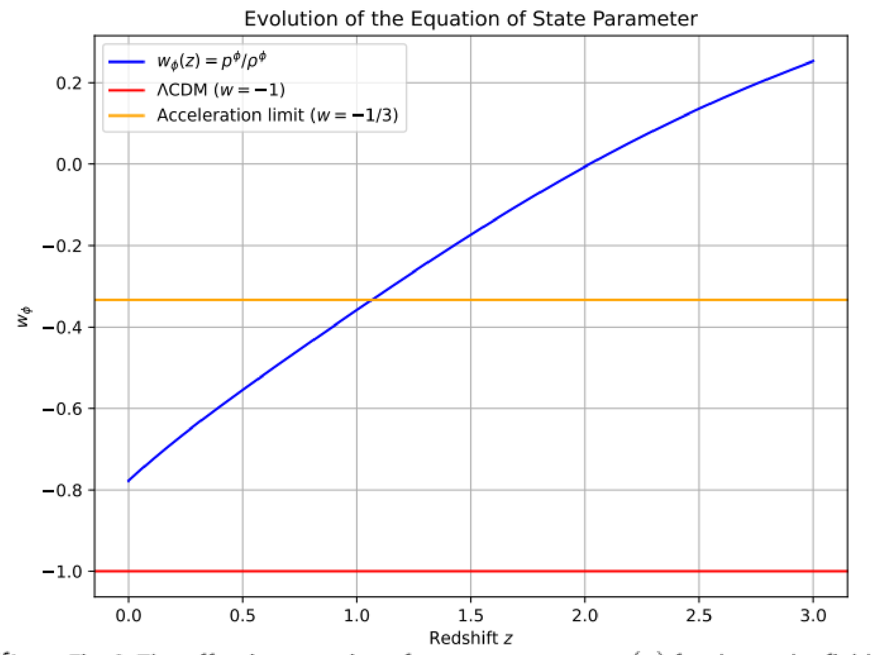


Fig. 2: The effective equation of state parameter $\omega_\phi(z)$ for the scalar field,

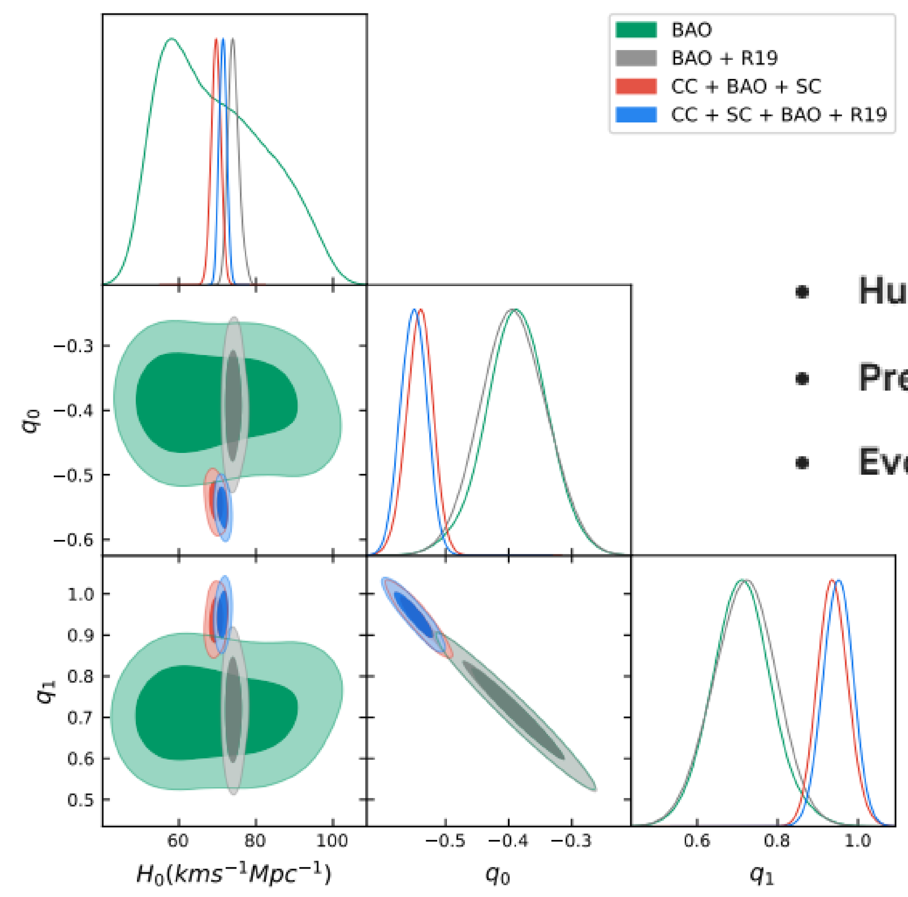
Kinematic Evolution & Transition

Our logarithmic parametrization successfully reconstructs the cosmic expansion history. The deceleration parameter $q(z)$ confirms a clear evolutionary phase transition from a past decelerating, matter-dominated universe to the current accelerating epoch. The transition redshift is precisely determined to be $z_{tr} \approx 0.785$, which is in excellent agreement with modern cosmological findings and standard ΛCDM predictions.

Scalar Field Dynamics

The reconstructed dimensionless energy density (ρ_ϕ) and pressure (p_ϕ) confirm the physical viability of the scalar field, producing the necessary negative pressure to drive late-time acceleration. Furthermore, the equation of state parameter $\omega_\phi(z)$ exhibits dynamic behavior distinct from a static cosmological constant (Λ), characterizing the specific nature of the dark energy component in our model.

Statistical Best-Fits (TotR: CC + SC + BAO + R19)



- **Hubble Constant:** $H_0 = 71.41 \pm 0.98$ km/s/Mpc
- **Present Deceleration:** $q_0 = -0.55 \pm 0.02$
- **Evolution Parameter:** $q_1 = 0.95 \pm 0.04$

Fig. 3: 1D marginalized posterior distributions and 2D confidence contours

CONCLUSION

- **Successful Reconstruction:** The logarithmic parametrization, $q(z) = q_0 + q_1 \ln(1+z)$, successfully reconstructs the late-time cosmic expansion in a model-independent manner.
- **Cosmic Transition:** The model confirms the transition to the accelerating epoch at a precise redshift of $z_{tr} \approx 0.785$, aligning perfectly with standard cosmological expectations.
- **Tight Constraints & Hubble Tension:** Combined MCMC analysis (TotR) yields $H_0 = 71.41 \pm 0.98$ **km/s/Mpc** and $q_0 = -0.55 \pm 0.02$. This intermediate H_0 value offers a viable pathway to alleviate the Hubble tension.
- **Scalar Field Dynamics:** Reconstructed physical quantities confirm that the cosmic acceleration is robustly driven by a dynamic scalar field within General Relativity.
- **Future Studies:** Future work will analyze structure formation via cosmological perturbations and confront the model with upcoming DESI and Euclid data.