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Scalar Field and Quintessence in Late-Time Cosmic Expansion

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The persistent Hubble tension - marked by a notable disparity between early- and late-universe determinations of the Hubble constant H_0 —poses a serious challenge to the standard cosmological framework. Closely linked to this is the $H_0 - r_d$ tension, which stems from the fact that BAO-based estimates of H_0 are intrinsically dependent on the assumed value of the sound horizon at the drag epoch, r_d. In this study, we construct a scalar field dark energy model within the framework of a spatially flat FLRW model to explore the dynamics of cosmic acceleration. To solve the field equations, we introduce a generalized extension of the standard ΛCDM model that allows for deviations in the expansion history. Employing advanced Markov Chain Monte Carlo techniques, we constrain the model parameters using a comprehensive combination of observational data, including Baryon Acoustic Oscillations, Cosmic Chronometers, and Standard Candle datasets from Pantheon Type Ia Supernovae (SNe Ia), Quasars, and Gamma-Ray Bursts (GRBs). Our analysis reveals a transition redshift from deceleration to acceleration at $z_{\rm tr} = 0.69$, and a present-day deceleration parameter value of $q_0 = -0.64$. The model supports a dynamical scalar field interpretation, with an equation of state parameter satisfying $-1 < \omega_0^\phi < 0$, consistent with quintessence behavior, and signaling a deviation from the cosmological constant. While the model aligns closely with the ΛCDM scenario at lower redshifts (z $lesssim 0.65$), notable departures emerge at higher redshifts (z $gtrsim 0.65$), offering a potential window into modified early-time cosmology. Furthermore, the evolution of key cosmographic quantities such as energy density ρ^ϕ, pressure p^ϕ, and the scalar field equation of state highlights the robustness of scalar field frameworks in describing dark energy phenomenology. Importantly, our results indicate a slightly elevated value of the Hubble constant H_0 for specific data combinations, suggesting that the model may provide a partial resolution of the current H_0 tension.

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