Exponential $f(Q)$ Gravity in Symmetric Teleparallel Geometry: Cosmological Dynamics and Observational Viability

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We investigate a modified geometric gravity theory within the framework of symmetric teleparallelism, wherein gravitation is governed by the non-metricity scalar Q. In this context, we propose and analyze an exponential model given by $f(Q) = Q + \eta_1 Q_0 \left(1 - e^{-\eta_2 \sqrt{Q/Q_0}}\right)$, which enables a smooth and theoretically consistent deviation from General Relativity. This functional form is constructed to accommodate both the early inflationary epoch and the present phase of accelerated cosmic expansion. To constrain the model parameters η_1, η_2, H_0, and Ω_{m_0}, we perform a Bayesian statistical analysis employing Markov Chain Monte Carlo (MCMC) methods, using the latest observational data from Cosmic Chronometers (CC), Pantheon, and Pantheon$^+$ Supernova compilations. The resulting fits indicate excellent concordance with observational data and support a viable late-time acceleration scenario. We perform a detailed dynamical analysis using geometric and kinematic diagnostics, including the deceleration parameter, the equation of state, the Statefinder hierarchy, and the $Om(z)$ diagnostic. The reconstructed Hubble parameter $H(z)$ and distance modulus $\mu(z)$ show strong consistency with the predictions of the standard ΛCDM model, while exhibiting meaningful deviations at higher redshifts. Furthermore, energy condition analyses confirm the satisfaction of the Null and Dominant Energy Conditions (NEC, DEC), with a late-time violation of the Strong Energy Condition (SEC), consistent with cosmic acceleration. The model's cosmic age predictions also align with Planck 2018 constraints. These results demonstrate that exponential $f(Q)$ gravity provides a mathematically robust and observationally viable alternative to ΛCDM, offering new insights into non-Riemannian geometric formulations of gravitational theory.