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Investigating late-time cosmic acceleration in the extended symmetric teleparallel equivalent of general relativity

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Abstract. The accelerated expansion of the Universe remains a fundamental challenge in modern cosmology, often attributed to dark energy within the Λ CDM framework. However, issues such as fine-tuning and the cosmic coincidence problem motivate the exploration of alternative theories. This study investigates late-time cosmic acceleration within the framework of $f(Q, T)$ gravity, a modified gravity theory where gravity is governed by nonmetricity Q instead of curvature or torsion. We formulate the field equations for $f(Q, T)$ gravity and derive a specific model parameterized by α and β . The model is constrained using observational data from Cosmic Chronometers (CC), and the Pantheon+ Supernova dataset. We employ Bayesian inference with a Markov Chain Monte Carlo (MCMC) approach to estimate key cosmological parameters, including the Hubble constant H_0 , and the model-specific parameters α and β . The results are compared against Λ CDM using statistical criteria such as Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). Our findings suggest that $f(Q, T)$ gravity can provide a viable explanation for cosmic acceleration while offering insights into the nature of dark energy.

Keywords: $f(Q, T)$ gravity, symmetric teleparallel gravity, observational dataset, analysis of dynamic systems

Introduction. The observation of the Universe's late-time acceleration has significantly reshaped modern cosmological theories. Although the standard Λ CDM model attributes this phenomenon to the presence of dark energy, persistent theoretical challenges such as the fine-tuning problem and the cosmic coincidence issue have sparked interest in alternative explanations. One such approach is $f(Q, T)$ gravity, a modified gravity theory that replaces the role of curvature and torsion with the nonmetricity scalar Q , and introduces an explicit dependence on the trace of the energy-momentum tensor T in the gravitational action [1]. This added coupling enriches the interaction between matter and geometry, providing a broader framework for cosmological modeling. Both $f(Q)$ and $f(Q, T)$ models hold promise for addressing foundational cosmological problems, including the cosmological constant dilemma and the elusive nature of dark energy [2–4]. These modified gravity theories offer novel perspectives on gravitational dynamics and their influence on the Universe's evolution.

Methods and materials; results. I. Observational analysis in the $f(Q, T)$ gravity framework. We consider the $f(Q, T)$ gravity model as proposed in [1], where the action is given by

$$S = \int \left[\frac{1}{16\pi} f(Q, T) \sqrt{-g} d^4x + L_m \sqrt{-g} d^4x \right],$$

with L_m as the matter Lagrangian and g the determinant of the metric $g_{\mu\nu}$. Varying the action yields the field equations:

$$\begin{aligned} -\frac{2}{\sqrt{-g}} \nabla_k \left(F \sqrt{-g} g_{\mu\nu}^{pk} \right) - F \left(P_{\mu kl} Q_{\nu}{}^{kl} - 2Q^{kl}{}_{\mu} P_{kl\mu} \right) - \frac{1}{2} f g_{\mu\nu} = \\ = 8\pi T_{\mu\nu} (1 - \tilde{G}) - 8\pi \tilde{G} \Theta_{\mu\nu}, \end{aligned} \quad (2)$$

with $F = \partial f / \partial Q$ and $\tilde{G} = 1/8\pi \partial f / \partial T$.

Using the FLRW metric

$$ds^2 = -N^2(t) dt^2 + a^2(t) (dx^2 + dy^2 + dz^2),$$

the modified Friedmann equations become

$$8\pi\rho = \frac{f}{2} - 6FH^2 - \frac{2\tilde{G}}{1+\tilde{G}} (\dot{F}H + F\dot{H}), \quad (3)$$

$$8\pi\rho = -\frac{f}{2} + 6FH^2 + 2(\dot{F}H + F\dot{H}), \quad (4)$$

Assuming a dust-dominated Universe, we adopt the exponential form $f(Q, T) = -Qe^{\alpha \frac{Q_0}{Q}} + \beta T$ [5]. This form leads to a first-order differential equation for the Hubble parameter and matter density parameter, converted to redshift using $d/dt = -(1+z)H d/dz$.

We numerically solve these eqns using the “Odeint” method. To constrain the model parameters (α, β, H_0) and initial conditions, we perform a Markov Chain Monte Carlo (MCMC) analysis. This approach samples the posterior distribution, providing best-fit values and uncertainty estimates. The model is tested against cosmological data to ensure observational consistency.

Table. Constrained parameter values, deceleration parameter and χ^2 for CC and pantheon+ data sets and its difference with Λ CDM

Data sets	H_0	α	β	q_0	$\chi^2_{\min}$	AIC	BIC	$\Delta\chi^2_{\min}$	Δ AIC	Δ BIC
CC + Pantheon ⁺	72.76 ± 0.23	$-2.43^{+0.19}_{-0.085}$	$2.24^{+2.27}_{-0.68}$	-0.445	849.72	861.72	882.34	3.09	7.09	13.97
Priors	(60, 80)	(-10, 10)	(-10, 10)	—	—	—	—	—	—	—

Conclusion. The $f(Q)$ gravity model, examined here through both observational and dynamical lenses, demonstrates its potential to explain cosmic acceleration without invoking dark energy explicitly. The consistency of the model with

recent observational datasets and its theoretical viability via stability analysis reinforce its credibility as an alternative to the Λ CDM paradigm.

References

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