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Gauss-Bonnet Gravity with Curvature and Torsion: Addressing Late Time Cosmic Phenomena of the Universe

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Abstract. To address the late time cosmic acceleration issue of the universe, we have attempted to study the Gauss-Bonnet gravity with curvature and torsion as an alternative approach. The modified gravity theories are examined with the cosmological datasets to constrain the free parameters to find the appropriate theoretical models that supports the observational results. Also the profiles of cosmographic parameters using the model parameter values from the standard range to verify the intermediate epochs. Our analysis shows that the highly promising cosmological models are feasible candidate for explaining the current epochs. We presented a dynamical system analysis framework to examine the stability of the model. Our study identified critical points depicting various phases of the Universe and explained the evolutionary epochs.

Introduction. The quest to understand the gravitational force led to the development of general relativity (GR) by Einstein. This theory revolutionized our understanding of gravity by describing it as the curvature of space-time caused by the presence of mass and energy. Although GR has successfully passed numerous experimental tests and remains the cornerstone of modern gravitational physics, it struggles to fully explain phenomena such as the accelerated expansion of the Universe. In response to these challenges, several modified theories of gravity have been proposed.

The interest in Gauss-Bonnet gravity lies in its potential to explain the observed late-time cosmic acceleration in the Universe. This acceleration could be caused by a gravity modification rather than an unusual source of matter with negative pressure. In recent years, significant research has been conducted into modified gravity to understand the nature of dark energy. Modified gravity models are particularly attractive because they align more closely with cosmological observations and local gravity experiments than models that rely on exotic matter sources. It is suggested that this theory can pass Solar system tests and may describe the most exciting features of late-time cosmology, such as the transition from deceleration to acceleration and the current acceleration of the Universe.

Methods and materials; results. We have intended to frame cosmological models of the universe in $f(R,G)$, $f(T,TG)$ and $f(G)$ gravity models to address the late time cosmic phenomena. At the first stage we have derived the field equations of the gravitational theories and solved in numerically using the cosmological da-

tasets such as H(Z), Pantheon+ and BAO. We use the MCMC method to establish correlation between the gravity model and observational data to determine the best-fits for the model parameters. Additionally, we present plots of various cosmological parameters such as deceleration parameter, effective equation of state, Om diagnostic and state finder diagnostic.

Subsequently, we construct a dynamical system framework to analyze the critical points of the gravity model. This analysis is crucial for assessing the stability and viability of the model and its alignment with current cosmological observations. The critical points and existing conditions for the model are obtained and the present value for the deceleration, EoS, and density parameters. Among five critical points two are showing stable behavior whereas three are showing unstable behavior. During the de-Sitter phase of the Universe, stable critical points appeared, whereas unstable behavior was observed during the radiation-dominated phase. A signature of eigenvalues and a phase-space portrait support the behavior of critical points. The trajectory behavior indicates that the unstable critical points act as release points while the stable ones act as attractor points. The accelerating behavior of the model has been confirmed from the value of EoS ($\Omega = -1$) and deceleration parameter ($q = -1$). The density parameters are obtained to be $\Omega_m \approx 0.28$, $\Omega_{DE} \approx 0.679$, and $\Omega_r \approx 0.047$. The evolutionary history shows the radiation dominance, followed by matter dominance, and finally, de-Sitter dominance.

Conclusion. In this study, we explored the cosmological properties of a specific modified Gauss-Bonnet gravity models. Initially, we discussed the main features of a gravitational action, which includes a general combination of the Ricci scalar and the Gauss-Bonnet invariant. Then, assuming a flat FLRW cosmological background, we derived the point-like Lagrangian of the theory and the corresponding equations of motion. However, our study does not explicitly converge to the cosmological constant case, making it particularly interesting as a potential alternative to the standard Λ CDM model. This model shows the ability to replicate dark energy behaviour while avoiding the conceptual issues associated with Λ . Importantly, we showed that the right-hand sides of the modified Friedmann equations can be understood as effective energy density and pressure resulting from curvature.

By numerically solving the first Friedmann equation, we determined the redshift behaviour of the Hubble parameter. We used the Λ CDM model to establish appropriate initial conditions for $H(z)$ and its derivatives. Subsequently, we utilized the most recent low-redshift observations to compare our theory directly with the model-independent predictions of the cosmic expansion. Specifically, we used a Bayesian analysis with the MCMC method, analysing using the Pantheon+ and CC data sets separately. By assuming uniform prior distributions, we obtained constraints on the free parameters of the model at the 1σ and 2σ confidence levels. This enabled us to reconstruct the cosmological evolution of the Hubble expansion rate and the total effective EoS parameter. Our analysis identifies a notable discrepancy between the H_0 values obtained from the CC sample and the Pantheon data sets highlighting the ongoing H_0 tension in cosmology. This result emphasizes

the necessity for further research into possible systematic errors or new physics to resolve this issue. Addressing these discrepancies is essential for enhancing our understanding of the expansion rate of the Universe.

In the second phase of our study, we conducted a dynamical system analysis, which has enabled us to assess the global behaviour and stability of the cosmological model. It provided insights into the critical points associated with the model and their characteristics, which could be relevant to observable cosmology and the evolution of the Universe. Our findings revealed stable critical points describing the late-time cosmic accelerated phase. This indicates non-standard matter and radiation-dominated eras of the Universe. Interestingly, our results align with the standard quintessence model on $z > 0$. We made notable preliminary discoveries regarding the finite phase space of a power-law class of the Gauss — Bonnet gravity model. Finally, the proficiency of the model in depicting the evolution of dark matter, radiation, and dark energy densities, effectively capturing the transitions through various cosmic epochs and reinforcing the model's robustness in explaining late-time cosmic phenomena.

References

- [1] Lohakare S.V, Rathore Krishna, Mishra B. Observational Constrained $F(R,G)$ gravity cosmological model and the dynamical system analysis. *Classical and Quantum Gravity*, 2023, vol. 40, art. no. 215009.
- [2] Lohakare S.V., Mishra B., Maurya S.K, Singh Ksh Newton. Analyzing the geometrical and dynamical parameters of modified Teleparallel-Gauss-Bonnet model. *Physics of the Dark Universe*, 2023, vol. 39, art. no. 101164.
- [3] Lohakare S.V, Mishra B. Cosmology in Modified $f(G)$ Gravity: A Late Time Cosmic Phenomena. *Monthly Notices of Royal Astronomical Society*, 2024, vol. 535, art. no. 1136.