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COMPARATIVE COSMOLOGICAL CONSTRAINTS ON HU–SAWICKI F(R), TELEPARALLEL F(T), AND HORNDESKI GRAVITY MODELS IN THE DESI ERA

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ABSTRACT

The accelerated expansion of the Universe motivates tests of gravitational theories beyond General Relativity and the standard flat ΛCDM model. The Dark Energy Spectroscopic Instrument (DESI) has improved baryon acoustic oscillation (BAO) measurements, creating new opportunities to constrain the background expansion and, when combined with growth-sensitive observations, the gravitational sector. This article develops a comparative framework for three representative modified-gravity classes: Hu–Sawicki f(R) gravity, teleparallel f(T) gravity, and Horndeski scalar–tensor gravity. Their theoretical foundations, potential observational signatures, stability requirements and data needs are compared with emphasis on DESI BAO, Planck cosmic microwave background (CMB) information, Type Ia supernovae, cosmic chronometers, full-shape clustering, lensing and late-time potential evolution. Published studies show that BAO and CMB information provide complementary constraints, while DESI-era analyses of modified gravity generally find allowed deviations consistent with the General Relativity limit for the tested parameterizations. Recent f(T) work also illustrates that late-time-only inferences can shift toward the standard limit when early-Universe CMB information is added. This manuscript is a literature-grounded comparative synthesis and reproducible analysis framework; it does not claim new joint MCMC constraints or original posterior regions. Quantitative values from prior studies are identified as published benchmarks. The framework specifies how a future unified likelihood analysis could test whether the three gravity classes are distinguishable with current and forthcoming cosmological observations.

KEYWORDS: Modified Gravity, Hu–Sawicki f(R), Teleparallel f(T), Horndeski Gravity, DESI, Baryon Acoustic Oscillations, Planck CMB, Cosmic Acceleration, Structure Growth, Bayesian Inference

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INTRODUCTION AND BACKGROUND OF THE STUDY

The accelerated expansion of the Universe is commonly described by the flat ΛCDM model, in which a cosmological constant contributes to the late-time energy budget. The model successfully accounts for a broad range of observations, but the physical nature of the cosmological constant and the origin of cosmic acceleration remain open questions. Modified gravity addresses this problem by changing the gravitational dynamics rather than attributing acceleration solely to an additional dark-energy component.

A central challenge is that different theories can generate similar expansion histories while predicting different evolution for matter perturbations and gravitational potentials. Consequently, constraints based only on distance measurements do not fully determine the behaviour of gravity. BAO observations provide geometric information across redshift, whereas CMB anisotropies, lensing, galaxy clustering and integrated Sachs–Wolfe (ISW) observables probe

Research Paper

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complementary aspects of the cosmological model.

DESI BAO measurements have strengthened the late-time geometric basis for cosmological tests. The first-year DESI analysis reported BAO measurements across seven redshift bins and demonstrated the precision of the resulting distance constraints [1]. Subsequent DR2 analyses expanded the spectroscopic sample and provided updated BAO measurements and cosmological constraints [2]. Planck PR4 analyses provide a complementary early-Universe anchor through temperature and polarization information [3]. These datasets must be combined using consistent likelihoods and covariances, rather than by transferring baseline ΛCDM parameter constraints directly to an extended gravity model.

The present article compares three distinct theoretical constructions. Hu–Sawicki f(R) gravity modifies the curvature sector and introduces an additional scalar degree of freedom [4]. Teleparallel f(T) gravity modifies the torsional description of gravity, with predictions dependent on the chosen function of the torsion scalar [5]. Horndeski gravity provides a broad scalar–tensor framework whose linear perturbations can be described using effective functions such as those controlling kinetic interactions, braiding and effective Planck-mass evolution [6]. The models are not interchangeable, and their parameters cannot be compared as if they represented the same physical quantity.

Aims and Objectives

- To compare the theoretical foundations and characteristic cosmological signatures of Hu–Sawicki f(R), teleparallel f(T) and Horndeski gravity.
- To describe the complementary roles of DESI BAO and CMB observations in constraining the expansion history and gravitational perturbations.
- To identify the additional data needed to distinguish background expansion effects from changes in structure growth and gravitational potentials.
- To summarize theoretical viability requirements, including stability, screening and recovery of the General Relativity limit.
- To outline a reproducible Bayesian workflow for future model-by-model parameter estimation and statistical comparison.

METHODOLOGY

Observational inputs and scope

The baseline observational framework comprises DESI BAO measurements and Planck CMB information. BAO likelihoods constrain combinations of transverse distance and expansion rate relative to the sound horizon. CMB temperature and polarization constrain the acoustic scale, physical densities and primordial perturbations, while CMB lensing probes the integrated matter distribution and gravitational potentials. Type Ia supernovae and cosmic chronometers can add late-time expansion information. Full-shape galaxy clustering, redshift-space distortions and weak-lensing observations are especially valuable for testing perturbation growth, but should be included only when the relevant likelihoods, covariance matrices and systematic models are consistently implemented.

Model hierarchy

The common reference is spatially flat ΛCDM. Hu–Sawicki f(R) gravity is treated as a curvature-based model in which a nonlinear function of the Ricci scalar modifies the field equations. The scalar degree of freedom can produce scale-dependent growth and modified metric potentials, while screening can suppress departures from General Relativity in high-density environments [4].

Teleparallel f(T) gravity is based on torsion rather than curvature as the central geometrical quantity. The teleparallel equivalent of General Relativity reproduces standard gravitational dynamics, whereas a nonlinear f(T) function can change the background evolution and perturbation equations. Different power-law, Linder and exponential parameterizations have different parameter meanings and must be tested individually. A recent DESI DR2 study of representative f(T) models combined BAO with cosmic chronometers, DES-Y5 supernovae and early-Universe CMB distance priors; it found that the combined information pulled model parameters closer to the ΛCDM limit than late-time data alone [7].

Horndeski gravity describes a broad class of scalar–

tensor theories with second-order field equations under the standard formulation. At the level of linear cosmological perturbations, the effective α-functions provide a useful organization of kinetic energy, kinetic braiding, effective Planck-mass running and tensor-speed effects [6]. A viable implementation must state the specific subclass and parameterization, since the general framework is broader than any single numerical model.

Inference and comparison protocol

A quantitative comparison should use a suitable Boltzmann solver for each model and a common parameter-estimation interface. Standard cosmological parameters and model-specific parameters should be sampled jointly, with priors, nuisance parameters and theoretical cuts documented. The same observational data selection and consistent sound-horizon assumptions should be used across the baseline and extended models wherever applicable. Multiple chains, convergence diagnostics, posterior predictive checks and sensitivity tests should be reported. Bayesian evidence or information criteria may be used only after the likelihood and prior choices have been specified.

For reproducibility, the final numerical analysis should archive the exact DESI likelihood release, Planck likelihood configuration, covariance matrices, software versions, parameter priors, stability conditions and chain files. Posterior constraints and correlations should be reported rather than relying solely on best-fit values. This manuscript does not claim that a new common MCMC analysis has been executed; therefore, the numerical discussion below is restricted to published findings and qualitative theoretical comparisons.

RESULTS AND DISCUSSION

Complementarity of geometric and growth-sensitive probes

The main result of this comparative synthesis is that BAO and CMB measurements constrain overlapping but distinct combinations of cosmological quantities. BAO provides late-time geometric information, while the CMB anchors the early-Universe acoustic scale and physical densities. Their combination can reduce degeneracies in the background parameters, but does not by itself guarantee a strong direct constraint on every modified-gravity parameter. Growth-sensitive observables are needed to test the evolution of matter perturbations and gravitational potentials.

Published DESI full-shape analyses have tested phenomenological modifications to the effective gravitational response and Horndeski-like descriptions. The reported constraints for the examined parameterizations are broadly consistent with the General Relativity limit when multiple datasets are combined, although particular parameter combinations and model assumptions affect the posterior widths [8]. These published constraints are useful context, but they are not direct constraints on every Hu–Sawicki or f(T) realization.

Table 1 summarizes the roles and limitations of the principal observational probes.

Table 1: Observational probes and their principal roles in modified-gravity tests.

Probe	Primary information	Relevance to modified gravity	Main caution
DESI BAO	Distance–redshift relation and distances relative to the sound horizon	Restricts background expansion and its redshift dependence	BAO alone does not uniquely determine perturbation growth
Planck temperature and polarization	Acoustic scale, physical densities and recombination-era physics	Anchors early-time parameters and tests consistency of model evolution	Late-time gravity is often constrained indirectly
CMB lensing	Integrated matter distribution and gravitational potentials	Adds sensitivity to growth and potential evolution	Sensitive to reconstruction, foregrounds and model assumptions
Full-shape clustering / RSD	Scale- and redshift-dependent clustering and growth rate	Tests scale-dependent effective gravitational response	Requires bias, nonlinear and survey-systematic modelling
ISW / ISW–lensing	Late-time evolution of large-scale gravitational potentials	Potentially sensitive to evolving gravity	Large-scale signal is statistically limited

Type Ia supernovae	Relative luminosity-distance relation	Complements BAO in the late-time expansion sector	Calibration and sample systematics must be modelled
Cosmic chronometers	Expansion rate as a function of redshift	Adds direct H(z)-related information	Depends on stellar-population modelling

Comparative signatures of the three gravity frameworks

The three frameworks differ in their fundamental construction and in the mechanisms through which they modify cosmological observables. Hu–Sawicki f(R) gravity can produce a characteristic scale dependence associated with the additional scalar degree of freedom. Teleparallel f(T) models modify the torsional gravitational sector, and their predictions depend on the selected function and perturbation prescription. Horndeski gravity can alter the effective gravitational coupling, scalar–metric interactions and evolution of the metric potentials. These distinctions mean that matching the background expansion alone is insufficient for a meaningful model comparison.

Table 2: Comparative characteristics and viability requirements.

Model class	Modified sector	Potential observational signatures	Essential viability checks
Flat ΛCDM reference	Einstein gravity with a cosmological constant	Reference expansion and growth history	Consistency of parameter inference and standard perturbation treatment
Hu–Sawicki f(R)	Nonlinear function of Ricci scalar R	Scale-dependent growth; modified potentials; possible ISW and lensing changes	Scalar stability, high-curvature GR limit and screening
Teleparallel f(T)	Nonlinear function of torsion scalar T	Model-dependent expansion and perturbation response	Consistency of teleparallel formulation, perturbation sector and GR limit
Horndeski scalar–tensor	Scalar–metric interactions and effective gravitational functions	Changes in effective Planck mass, braiding, growth and lensing	No-ghost and gradient stability; tensor-speed constraints and validity of the selected subclass

Published DESI-era findings and interpretation

Recent analyses demonstrate why the dataset combination must be stated precisely. A published DR2 study of power-law, Linder and exponential f(T) models combined DESI BAO, cosmic chronometers, DES-Y5 supernovae and CMB distance priors. The study reported that late-time observations alone allowed indications of non-zero deviations at approximately the 1–2σ level, while adding early-Universe information shifted the models closer to the ΛCDM limit. The authors also reported that model-selection conclusions depended on the statistic used and on the included dataset combination [7]. These are findings from that published analysis and should not be interpreted as new estimates from the present manuscript.

DESI full-shape work has also examined phenomenological modified-gravity parameterizations and Horndeski effective functions. For the parameterizations considered, joint clustering, CMB and supernova information produced constraints broadly consistent with General Relativity [8]. This does not establish that every modified-gravity theory is excluded; it shows that departures are restricted within the tested parameterizations, priors and datasets.

For Hu–Sawicki f(R), the key issue is the combined treatment of background distances, scale-dependent growth and screening. BAO and supernova distances constrain the background, whereas full-shape clustering, lensing and CMB potential-sensitive observables are needed to exploit the distinctive perturbation signatures. A fair comparison with f(T) and Horndeski models would require each theory to be implemented in a compatible inference pipeline and tested against the same data selection.

Table 3: Published findings relevant to a DESI-era comparison.

Framework / study	Dataset scope	Published conclusion	Interpretive limitation
DESI BAO baseline [1,2]	DESI BAO, with specified combinations of CMB information in published analyses	Provides precise geometric constraints and useful reference cosmological parameters	Baseline ΛCDM constraints are not modified-gravity posteriors
Teleparallel f(T) models [7]	DESI DR2 BAO + cosmic chronometers + DES-Y5 SNe, with early-Universe CMB distance priors	CMB information pulls representative model parameters closer to ΛCDM than late-time data alone	Applies to the specific parameterizations and likelihood setup tested
Phenomenological MG / Horndeski [8]	DESI DR1 full-shape and BAO with CMB and complementary late-time datasets	Tested modified-gravity parameters are broadly consistent with the GR limit	Does not directly constrain every f(R) or f(T) construction
Hu–Sawicki f(R) [4]	Model-specific analysis required for each dataset combination	Characteristic scalar-mediated scale dependence motivates growth-sensitive tests	No new joint f(R) posterior is calculated in this manuscript

Implications for model selection

A model should not be considered preferred solely because it achieves a lower best-fit likelihood than ΛCDM. Additional parameters can improve the maximum likelihood even when the extension is not statistically warranted. Model comparison therefore requires clearly defined priors and a stated statistic, such as Bayesian evidence or an information criterion. The prior volume, stability cuts, treatment of nuisance parameters and covariance assumptions can all affect the outcome.

The comparison should also avoid treating parameters with different physical meanings as equivalent. The scalaron parameter in f(R), the distortion parameters in f(T), and the effective functions in Horndeski gravity describe different mechanisms. A common analysis can compare their predictions and statistical performance, but it cannot identify a one-to-one correspondence between their parameter values without additional theoretical assumptions.

The most informative future test will combine geometric and dynamical observables. BAO and supernovae constrain the background expansion; full-shape clustering, redshift-space distortions and lensing constrain growth and gravitational potentials; and CMB temperature, polarization and lensing link these measurements to early-Universe physics. Cross-correlations such as ISW–lensing can add complementary information, although their large-scale statistical limitations must be recognized.

LIMITATIONS OF THE PRESENT STUDY

This manuscript is a literature-grounded comparative framework and does not present newly sampled posterior chains, a newly evaluated common likelihood, or original numerical confidence regions for the three gravity classes. Published values are described as benchmarks only. A submission claiming new cosmological constraints would require execution and validation of the inference pipeline, including likelihood and covariance verification, model-specific Boltzmann calculations, documented priors, convergence tests, posterior tables and figures generated from the resulting chains.

The comparison is also limited by the different levels of maturity and implementation available for the three theories. A consistent comparison requires an explicit choice of f(R) and f(T) parameterizations and a clearly defined Horndeski subclass. Nonlinear clustering, baryonic feedback, galaxy bias, screening and local-gravity constraints may alter the conclusions and require dedicated treatment.

CONCLUSION

DESI BAO and CMB observations provide a powerful complementary basis for testing modified gravity because they connect late-time geometry with early-Universe physics. Hu–Sawicki f(R), teleparallel f(T) and Horndeski gravity represent distinct ways of modifying the gravitational sector, and their predictions can differ even when their background expansion histories are similar. A robust comparison must therefore consider structure growth, gravitational potentials, lensing and theoretical

stability alongside distance measurements. Published DESI-era results show that combined datasets can significantly restrict modified-gravity parameter space and that the inferred deviations depend on the model and data combination. These findings do not establish a universal preference for one of the three frameworks. Instead, they motivate a unified, reproducible parameter-estimation analysis using consistent likelihoods, priors and model-comparison criteria. The framework presented here provides a structured basis for such a study while avoiding unsupported claims of original numerical constraints.

Data Availability and Reproducibility Statement

This manuscript synthesizes published findings and proposes a comparative analysis protocol. No new observational data products, MCMC chains or posterior samples were generated for this draft. A future quantitative version should identify the exact public DESI BAO likelihood release, Planck likelihood configuration, software versions, parameter priors, covariance files, stability conditions and chain diagnostics.

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