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Dissertation abstract
"Higher Order Statistics of the Large Scale Structure"

On the surface, our current understanding of the Universe appears to be accurate. General Relativity (GR) appropriately describes gravity, and the standard ΛCDM model provides reasonable explanations for most cosmological observations. However, the assumptions underlying ΛCDM reveal its two greatest mysteries: Λ (the cosmological constant) is a dark energy candidate to reproduce the observed accelerated expansion of the Universe, while CDM (cold dark matter) interacts only via gravity. Although adding these components yields agreement with data, their physical origin remains unknown.
In this context, testing gravity at cosmological scales is highly motivated - especially since gravitational interactions have not been robustly tested at scales larger than the Solar System.
A variety of extended gravity theories can drive cosmic acceleration without Λ. By comparing simulations in standard GR to those in extended models, we can begin to constrain the gravity. In this thesis, we consider two popular scenarios generalizing Einstein-Hilber action: the Hu–Sawicki f(R) model and the normal branch of the Dvali–Gabadadze–Porrati (nDGP) model. Although nDGP alone does not self-accelerate, studying both families provides complementary tests of two distinct extended gravity models.
Because gravity is nonlinear, it imprints non-Gaussian features into an evolving density field. Under the assumption of an initially Gaussian field, deviations from Gaussianity observed later can be interpreted as gravity signatures. These can be quantified via the central moments of number density counts. Since different gravity models leave distinct imprints, higher-order statistics, specifically, averaged correlation functions and cumulants based on central moments offer powerful discrimination. Working in a controlled suite of cosmological simulations, we establish a testbed for future observations and identify the regimes where the gravity scenarios can be distinguished (extended gravity signals, or EG signals). First, in a light-cone geometry that mimics real surveys, we measure angular statistics. We identify the optimal redshift range for detecting EG signals as $0.15 < z < 0.3$. We find that extended-gravity deviations from GR reach up to 20%. Analyzing dark-matter and mock galaxy catalogs separately, we detect these signals at $2-4\sigma$ significance, reaching even ~$3\sigma$ for sparse galaxy samples (15 $\text{deg}^{-2}$), demonstrating the feasibility of observational tests with robust catalogs.
Encouraged by these results, we then study fully three-dimensional clustering in both real and redshift space. Focusing on skewness, we show that the Fingers-of-God (FoG) effect suppresses small-scale skewness in redshift space and EG signals become reduced compared to real-space measures. The z-space signal still reaches ~ 4% for galaxies. Notably, galaxy catalogs exhibit stronger deviations than halo catalogs, underscoring the potential of skewness as an observational probe.
Next, motivated by the richness of information contained in redshift space, we introduce

ellipsoidal averaged correlation functions: an analogue of the anisotropic two-point function built from central moments. Employing dedicated simulations we find that developed ellipsoidal functions reveal features inaccessible to spherical counts: the optimal shape of ellipsoid at given volume corresponds with strength of FoG and Kaiser effects. We further show that, for skewness, redshift-space measurements outperform real-space ones in distinguishing models with different structure-growth histories.
Finally, we place our findings in the context of current and upcoming cosmological data, and discuss prospects for employing higher-order study in new observations.

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