Abstract

This thesis investigates gravitational theory and cosmological observables across theoretical, phenomenological, and empirical regimes.

The first part develops the Hamiltonian formulation of a class of gravitational theories that may be interpreted as spontaneously broken gauge theories of the complexified Lorentz group. In this framework, the gravitational field is described by a gauge field in the Lie algebra of $SO(1,3)_{\mathbb{C}}$ and by a Higgs-like field in its fundamental representation. The analysis shows that the number of propagating degrees of freedom depends crucially on the parameter controlling the relative weighting of the self-dual and anti-self-dual sectors. For nonzero values of this parameter, the theory propagates three complex degrees of freedom on general backgrounds, while the purely imaginary values $\pm i$ recover an extension of General Relativity in a symmetry-broken regime. By contrast, the null value yields no local degrees of freedom. Thus, in this class of models, the existence of local gravitational degrees of freedom is tied to chiral asymmetry in the gravitational sector.

An inflationary model motivated by left-right symmetric extensions of the matter sector and by the first-order formulation of gravity is then considered. The enlarged Higgs sector permits non-minimal couplings to gravity, giving rise to effective inflationary dynamics after reduction to a homogeneous and isotropic cosmological background. The background dynamics are implemented numerically, allowing the viable parameter space to be explored and the associated inflationary observables to be analyzed. Particular attention is given to the role of the Barbero–Immirzi parameter, which may take either real or imaginary values in this framework. The exploration of the model indicates that, within the viable region, variations of the effective Barbero–Immirzi parameter have no statistically significant direct impact on the scalar observables.

The empirical chapters first study weak gravitational lensing by photometric density ridges. The analysis reports a high-significance detection of this effect in Dark Energy Survey Year 3 data, although not independently of galaxy–galaxy lensing. It further develops improvements to the subspace-constrained mean-shift (SCMS) algorithm used to locate ridges efficiently at survey scale and investigates the dependence of the lensing signal on cosmological and algorithmic parameters in simulations. The signal is found to depend primarily on $S_8 = \sigma_8(\Omega_m/0.3)^{1/2}$, while further methodological improvements are required before precision parameter estimation can be performed.

Finally, an examination of tomographic constraints on the astrophysical stochastic gravitational-wave background through cross-correlations between gravitational-wave intensity maps and galaxy surveys is performed. Using large-scale SGWB maps constructed from the first three LIGO–Virgo observing runs and several tomographic galaxy samples, the analysis searches for correlations tracing the astrophysical production of unresolved gravitational waves across cosmic time. No statistically significant galaxy–SGWB cross-correlation is detected with current data. Nevertheless, the tomographic structure of the analysis allows upper bounds to be placed on the bias-weighted production rate density of gravitational waves by astrophysical sources, commonly parametrized by $\langle b\dot{\Omega}_{\rm GW}\rangle$.