THESIS ABSTRACT (English)

Einstein's theory of General Relativity forms the basis of modern cosmology. According to this framework, approximately 96% of our Universe is made of Dark Matter and Dark Energy. The important role of these dominant components in influencing the dynamics of our Universe is well-understood. Dark Matter explains the stability of large-scale structures, whereas Dark Energy accounts for the accelerated expansion of the Universe. Hence, one of the most important goals of modern cosmology is to understand the nature of these two cosmic entities.

According to the standard ΛCDM (Λ-Cold Dark Matter) cosmological model, Λ (or the cosmological constant) is the leading Dark Energy candidate, and explains the cosmic speed-up. However, Λ faces notable theoretical and observational challenges. As a result, there are a wide variety of beyond- ΛCDM theories that seek to explain the apparent accelerated expansion by assuming modifications to the standard gravity theory on cosmological scales. In this thesis, we work with two such modified gravity (MG) models: namely f(R) and nDGP gravity. These MG theories offer a very good test-bed to explore the freedom of modifying Einstein's gravity theory, in order to produce a physical mechanism which effectively mimics the action of the cosmological constant, resulting in the cosmic acceleration. The effect of these MG models is incorporated in the gravitational dynamics of large-scale structures, and can potentially impact the formation and evolution of Dark Matter halos. Thus, the statistical properties of halos, that form the building blocks of cosmological observables associated with large-scale structures in the Universe, offer opportunities for testing modifications to the gravitational forces. Studying the cosmological implications of these MG theories, and constraining them using observations is an active research topic in cosmology.

Owing to the non-linear character of these beyond-ΛCDM theories, numerical simulations are the most reliable tools to study these MG models, which are, however, computationally expensive. The greater computational cost of MG simulations makes it difficult to achieve the resolution and volume which we have attained for the state-of-the-art ΛCDM simulations. This further limits the scope of accurately testing gravity on cosmological scales using precise observational data. Therefore, in order to make the best use of the wealth of data for MG tests from our current and future surveys, it is important to prepare accurate theoretical predictions. These theoretical templates can be safely combined with observations to make precise and unbiased constraints on cosmological observables. The first part of this thesis addresses this need for reliable analytical modelling of the cosmological properties in MG.

In the second part of the thesis, we quantify the impact of additional attributes on the large-scale statistics, and how these properties further influence the impact of MG. Particularly, we study additional dependencies induced by the internal halo properties, and the cosmic environments. These factors introduce additional systematics in the study of large-scale clustering and should be properly accounted for to obtain unbiased and accurate constraints in cosmological parameter analysis. Achieving the percent-level accuracy we aim for in our present and future cosmological surveys demands this attention.