

Abstract:

This thesis presents a comprehensive exploration in the realms of cosmology and gravitational wave physics, investigating various aspects and challenges within the standard Λ CDM model while also scrutinizing motivated alternative theories. Our purpose is to shed light on unresolved dilemmas within the Λ CDM framework (such as the singularity problem, the origin of cosmological perturbations, the Cosmic Microwave Background (CMB) anomalies on large scales, the dark energy and the dark matter problems) and on possibly new phenomena in the realm of gravitational wave resonance (such as the conversion of gravitational waves to photons and the gravitational wave resonance in Ultralight Dark Matter (ULDM) halos). By scrutinizing a plethora of scenarios, we aim to elucidate fundamental aspects of cosmological physics, offering new perspectives to longstanding puzzles in the field.

The first chapter presents a novel nonsingular cosmological model exhibiting a rich evolution, which encompasses a contracting phase, a bounce, a quasi-de Sitter inflationary epoch, and a subsequent radiation-dominated expansion. The bounce and the quasi-de Sitter phases appear due to quantum effects originating from the Wheeler-DeWitt equation. The model is compatible with the observed almost scale invariant scalar power spectrum, while further developments are needed to address the magnitude of the tensor-to-scalar ratio.

Chapter two investigates non-Gaussianities in bouncing models aimed at mitigating large-scale anomalies in the CMB data. While these models exhibit interesting features, they are excluded with high significances when comparing the CMB reduced bispectrum with the Planck data. Although the bispectrum decays exponentially, the signal surpasses the noise for very large scales, leading to a large cumulative signal-to-noise ratio. This result highlights the sensitivity of the Planck data to scales beyond the pivot scale.

The third chapter investigates the implications of holographic dark energy (HDE) on single-field slow-roll inflation, demonstrating compatibility with observational constraints on both scalar and tensor power spectra.

Gravitational wave physics takes center stage in the fourth chapter, where we explore the possibility of damping gravitational waves via parametric resonance with an electromagnetic field. We elucidate the conditions under which such damping occurs and discuss potential astrophysical implications.

Lastly, the fifth chapter investigates the amplification of gravitational waves due to parametric resonance with the gravitational potentials of Ultralight Dark Matter (ULDM) halos. We explore various masses of Ultralight Axions (ULA) and halo densities, considering their implications for current gravitational wave amplification.

Throughout these chapters, we probe diverse aspects of the early Universe

and gravitational wave physics, shedding light on fundamental questions and paving the way for further exploration and refinement of theoretical and phenomenological frameworks.