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Abstract

Modelling the primordial universe with quantum spacetimes

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The understanding of the origins and evolution of the Universe is the fundamental goal of cosmology. The available mathematical description breaks down at the very beginning of the evolution - the big-bang singularity, which is a long-standing issue of the classical cosmology, hindering the comprehension of the nature of the Universe at its earliest stage.

This doctoral thesis investigates a simple cosmological model of Friedmann-Lemaitre-Robertson-Walker universe, filled with a perfect fluid, and furnished with primordial inhomogeneous scalar perturbations. The quantization of the background spacetime by means of covariant quantization methods is our proposal for a novel approach to studying the early universe. Our research shows that this model resolves the initial singularity by replacing it by the so-called big-bounce, a propitious alternative to the current paradigm based on inflation.

The quantum effects in the dynamics of the perturbations can lead to nonequivalent evolutions. We observe that an ambiguity arises due to the quantization of the background space-time, leading to physically inequivalent evolutions at the quantum level despite being equivalent classically. This results in ambiguous predictions for the amplitude power spectrum of primordial perturbations. This result of our research raises new questions and challenges for the development of quantum cosmology. In addition, we study the physical predictions that follow from the final quantum state of perturbations amplified by the big bounce and constrain our model with observational results. Our research shows that the final quantum state of perturbations contains a lot of information about the early universe, which can be used to further refine the model and to make more detailed predictions.

Finally, we investigate the homogeneous but anisotropic quantum mixmaster universe. First, we quantize the model and apply to it a semi-quantum approximation. Then we examine the possibility for the existence of a sufficient amount of inflationary dynamics in the semi-quantum model. We show that this model can undergo only limited amount of inflation and thus does not include a robust inflationary mechanism for generating the primordial structure. Our findings provide new insights into the behaviour of anisotropic cosmologies in the quantum regime.

Overall, this doctoral thesis describes a comprehensive investigation into the quantum dynamics of the early universe and its evolution, expanding our viewpoint on the fundamental nature of the Universe.