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July 13, 2023

Review of the PhD Thesis presented by Danilo ARTIGAS

Danilo Artigas presents a thesis "Searching for quantum features in cosmology: stochastic inflation and non-linear field spaces" prepared at the Université de Paris-Saclay (France) and the Jagiellonian University (Poland). This thesis explores various aspects of quantum cosmology and quantum fields on curved space-times. Its centerpiece is the in-depth exploration of the dynamics of cosmological inhomogeneities in the separate universe formalism in cosmology, with the thorough and detailed analysis of gauge fixing choices and related issues. The other results on a new non-linearly deformed cosmological mini-superspace model with no singularity, on the propagation of matter with generalized quantum uncertainty and of a spin field on curved space-times in general relativity, show the broadness of Danilo's research work as a PhD student, and illustrate his comprehensive knowledge and understanding of quantum cosmology and quantum gravity.
These original resultants have led to 5 high-quality papers, all included in the thesis. Among them, three have already published in excellent peer-reviewed international scientific journals (JCAP, CQG, PRD), which underlines the relevance of Danilo's results and their recognition by the scientific community. These three publications are also available on the open access archive arxiv.org.

The context of Danilo's research work is quantum effects in general relativity and cosmology. This is a booming field of research, with tremendous progress in cosmological and astrophysical measurements and the rising development of experiments at the interface of quantum theory and gravitational physics. It is thus of increasing interest to have general, rigorous and efficient schemes to predict the effects of the classical perturbations and quantum fluctuations of the space-time geometry in cosmology.
The introduction and first part of the thesis shortly explains this context and presents the tools and methods in broad terms. Parts II and III are the body of the thesis and are dedicated to the technical presentation of the results and their scope. The original results are actually presented as articles, written by Danilo and collaborators, included as a whole in the manuscript. They are introduced by large review sections, written in a clear and pedagogical style, on the topics at hand, which explains the key notions, questions and challenges, motivating Danilo's original research.
In part II, chapter 5 introduces the fundamentals of cosmological background and inflation. Chapter 6 then discusses the theory of cosmological perturbations and inhomogeneities, their origin as quantum fluctuations and their evolution in a Hamiltonian formalism. Chapter 7 tackles the more sophisticated question of the back-reaction of the perturbations on the cosmological evolution. It introduces the Stochastic-δN formalism, leading up to Danilo's two articles on the dynamics of cosmological perturbations. These are self-contained, thorough, well-written and mathematically rigorous publications on the Hamiltonian formulation of the separate universe approach and its equivalence with the standard cosmological perturbation theory (CPT) for well-defined gauge choices. Written with one of Danilo's PhD supervisor, Julien Grain, and another collaborator, Vincent Venin, these are meant to become benchmark papers for the field.

In part III, chapter 8 reviews the quantization of classical systems whose phase space carries a Kahler geometry. Chapter 9 presents the applications of those methods to three physically-relevant examples. Danilo first presents a publication, written in collaboration with one of his PhD supervisor, Jakub Mielczarek, on a new mini-superspace model for the dynamics of an isotropic and homogeneous cosmological background. Inspired from loop quantum cosmology, he introduces a completely new model, based on a compactified phase space, which is naturally cyclic and singularity-free. The model is quantized and the fate of quantum fluctuations is carefully studied. Although this is meant as a toy-model for quantum cosmology, it is a plausible cosmological scenario and illustrates how far one can go in the study of the quantumness of the cosmological background.
The second result presents the corrections to a photon propagation, whose dynamics follows a generalized uncertainty principle and modified dispersion relation, and computes the evolution of the squeezing of wave-packets over large cosmological distances. This could lead to testable predictions.
The third result discusses the definition and propagation of a spin field (i.e. a normalized vector field, not to be confused with a spinning particle) in general relativity. It makes a beautiful natural connection with Born-Infeld models, and opens a path towards the study of condensed-matter systems coupled to gravity.
All the results are mathematically rigorous. Their physical relevance is honestly discussed. They set solid foundations for future investigations in quantum cosmology.

To conclude, I consider this manuscript of very high scientific level and I believe it fully meets the requirements for the obtention of a PhD degree. Therefore, I recommend that this thesis should be admitted for public defense.

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