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Report on the doctoral thesis by Jaime de Cabo Martin "Modelling the primordial universe with quantum spacetimes".

The doctoral dissertation under the title "Modelling the primordial universe with quantum spacetimes", delivered by Jaime de Cabo Martin, consists of 107 pages and constitutes six chapters plus 'Conclusions for the future researches' and bibliography. The thesis was written under the supervision of Prof. Przemysław Małkiewicz and Prof. Patric Peters.

It has been written as self-contained work based on the results achieved by the Author with the coworkers. The Autor investigates cosmological model of Friedmann- Lemaitre-Robertson-Walker (FLRW) Universe, filled with a perfect fluid, containing primordial scalar perturbations. The covariant quantization method was proposed as a tool for studying the Early Universe physics.

Chapter 1 of the dissertation contains primary remarks and motivations for the conducted studies. In **chapter 2** the main theoretical concepts needed fot the further investigations were introduced. The Author presented the basic ideas concerning the Hamiltonian formalism in gravity, described the relativistic perfect fluid and homogeneous isotropic FLRW model with the choice of internal clock. Then the perturbative expansion in scalar modes was discussed. The Bianchi IX cosmological model was also paid attention to.
In the next stage of the chapter the coherent state method in application for phase space covariant quantization was discussed.

In **chapter 3** the semi-quantum bouncing model for equivalent cosmological models, possessing scalar perturbations was proposed. The fundamental ambiguity in definitions of quantum bouncing model with scalar perturbations (perturbed FLRW universe filled with a perfect fluid) was analyzed.

Instead of using Wheeler-de Witt equations the Author propose to take into account semi-quantum approximation. It all leads to the regular bouncing effect. It turns out that one has the ambiguity in the choice of the basic perturbation variables in quantum background, which may be the cause of the potential incompatibility of observational physical predictions.

The main ideas of this chapter were published in Phys.Rev.D105, 023522 (2022) and presented by the Author during talks given on various conferences (56th Recountres de Moriond (20220, Conference on Gravitation and Cosmology-Lahore Pakistan, PhD Seminar NCNR, Poland).

Chapter 4 constitutes the further developments of the investigated previously conducted. Namely, it tackles the problems of dynamical ambiguity arising in models of the primordial Universe. The power spectrum of scalar perturbations for the semi-quantum models was calculated and the relevant quantum parameters producing different predictions in the model in question was found. It turns out that there are only two possible predictions for spectral index, one for the conformal parametrisation (when the amplitude depends on on the parameters of the trajectories) and the other having its roots in fluid parametrisation. The final conclusion is that the fluid case is peculiar while the conformal one seems to be generic.

In **chapter 5** the studies of the final quantum state of the perturbations or the two non-equivalent semi-quantum theories elaborated in the previous chapters and physical predictions of the models are given. It was revealed that the primordial amplitude have to be expressed in terms of physical parameters, in order to constraint obtained results with observations. Among all it was found that in order to meet the agreement with the current observations, the quantum bounce have to posses an anomalously large strength.

Moreover, it happens that studied bouncing model explains the constancy of the primordial amplitude of the comoving curvature perturbations. This fact is important from the point of view of CMB observations.

These results were presented by the Author on "Szczecin Cosmology Group - Informal cosmology, particles and nuclear physics seminar" (Institute of Physics, University of Szczecin).

In **chapter 6** the problem of whether a quantum anisotropic primordial universe is able

to spontaneously induce a phase of inflationary dynamics was elaborated. The coherent states method was applied to find quantum model of mixmaster universe via integral covariant quantization. It was revealed that neither classical nor quantum, was unable to induce a sustained inflationary phase.

The presented results partly constitute the scope of the article in Acta Physica Polonica B Proceedings Supplement 16, 6-A20 [arXiv:2302.01111] and have been presented during talks given in: "The 8th Conference of The Polish Society on Relativity", "Cosmology on Safari" (Hluhluwe, South Africa) and "NCBJ PhD Seminar 2023".

Chapter 7 is devoted to the summary of the achieved results and pointed future researches in the field under consideration.

The Jaime de Cabo Martin PhD dissertation is well organized and written. The figures are legible and carefully performed. My opinion about the dissertation originality and quality is very positive.

Summing it all up, I have to admit that the Author demonstrated a good command of relativistic cosmology, mathematical aspects of general relativity, especially connected with the modifications of the ADM formalism. The results obtained by Jaime de Cabo Martin are valuable and interesting, mainly in the context of the new data and facts revealing by the Webb telescope observations of the Early Universe.

The achievements presented in the thesis were partially devoted to the investigations and results accomplished with the PhD supervisors and published in prestigious journal like Phys. Rev. D. Some of them are available in preprints waiting for publications. Having all these in mind my positive evaluation of the doctoral thesis has its confirmation in reviewers' opinions before acceptance of the works for publishing.

My final conclusion is of course positive. In my opinion the results of investigations presented by Jaime de Cabo Martin in PhD dissertation are the valuable contributions and they meet the criteria prescribed by the law for doctoral dissertations. I recommend Jaime de Cabo Martin to the subsequent stages of the PhD procedure, including the public defence.