**Report on PhD Thesis: Primordial Quantum Cosmology and Effective Spacetimes, by Andrea Dapor**

The study of the problem of quantum gravity has two main aspects, the structural foundations on the one hand, and phenomenological applications on the other. Ideally one needs the former before addressing the latter, as is the historical sequence for example in classical general relativity. However it is not always so. For example the phenomenological theory of mesons was formulated before the completion of QCD as a theory.

The latter is the case with quantum gravity, where a final theory is still debated and incomplete: In canonical quantum gravity in its latest incarnation in the Loop Quantum Gravity program, there is so far no solution to the full problem of dynamics with matter, although matter reference frames provide one perspective; in string theory there is no final formulation of string field theory.

The present thesis is an exploration of phenomenological consequences that might follow from a completion of the LQG program. It is a study in the context of symmetry reduced cosmological models known as Loop Quantum Cosmology (LQC), which has been widely studied in the last decade. LQC gives a symmetry reduced quantum spacetime. The topic of the thesis is an exploration of the quantum matter on the quantum spacetime derived from LQC.

Two specific questions are addressed. One is the question of violation of Lorentz invariance at the fundamental level, and its potential consequences in modified dispersion relations. The second is an extension of earlier work to include a mass term for quantum matter on a quantized cosmological background. I comment on both in detail below.

The thesis is organized into three chapters. This is followed by a list of about 50 references, the bulk of which are from the LQG/LQC research area. The main results of the thesis appear in 5 papers published in quality journals; these are the references [15] and [17-19], [29]. This is significant and clearly constitutes work of sufficient originality for the award of a PhD.

The first chapter provides a clear and highly readable summary of the standard model of cosmology. However, the theory of linear perturbations in its covariant form is not included in this review, but left to the beginning of chapter 3. There may have a been a slight advantage in initially reviewing all known work for a cumulative historical development, but this is not a major criticism.

The second chapter is a review of the Hamiltonian formulation of general relativity in the ADM variables, with an application to cosmology and including cosmological perturbations. This compensates for the missing covariant treatment in the first chapter. The chapter also discusses deparametrization and physical time, which is an important topic in the current literature. The author could have discussed this in a bit more detail, to compare and contrast "strong time gauge fixing" with the relational formalism, where the gauge fixing is implicit. To my knowledge this is not done anywhere in the literature, and would have provided a useful continuation of the author's discussion.

The third chapter contains the main original work of the author (except for the review of covariant cosmological perturbation theory in 3.1). The original work here begins in Sec. 3.2 on QFT on quantum spacetime. While the content of this section is new and clearly of interest, in my view its main limitation is where the author states: "Let us now consider the test field approximation" where "the back-reaction of the perturbations on the homogeneous degrees of freedom can be disregarded." But this is also a limitation in every other approach I am aware of, and it requires a fully non-perturbative treatment at the outset.

One main result here is the derivation of an effective metric from quantum cosmology eqn. (3.47), which is arrived at by assuming the universe is in a quantum state $\Psi_0(a)$, and the effective scale factor and lapse are computed.

A related result here is a derivation of "rainbow" metrics from more elementary principles. The issue of whether the mass term in the Hamiltonian is shifted or not is discussed in some detail, which is important. The central assumption in the analysis is that the Universe is in a product state (eqn. (3.36)), rather than an entangled one. A second assumption is what I would call the"comparison method" where the Hamiltonian of quantum field on a quantum background is compared with one on a fixed classical background with arbitrary lapse. This leads to formulae for the classical metric components which are wave vector dependent.

One would have intuitively expected that rainbow metrics should necessarily involve back reaction because disturbing a metric with a matter mode k, would in turn excite the metric at the same frequency, which would then affect the matter mode. In particular, self-interaction terms through a potential would involve mode mixing, thereby preventing a single mode rainbow metric. These are possible topics for further investigation involving back reaction, and could have a significant impact on these results in this thesis.

Lastly the reference list is on the shorter side with a count of 51. A majority of these are works in LQG/LQC, which reflects the content of the thesis. The focus of the concluding section is also concerned mainly with LQC and cosmology. This is fine given that there are practically no other approaches that have much to say about quantum fields on effective quantum backgrounds. This would have been worth commenting on in this section, as it provides additional strength to the thesis.

In summary, I consider the thesis to be scientifically sound, original, and well-written. It is worthy of a PhD.

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