DOCTORAL DEFENSE

Anti-Newtonian Expansions, Hadamard States, and the Spatial Functional Renormalization Group

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Abstract: The validity of general relativity almost up to the Big Bang entails that the Einstein equations themselves can be used to study the detailed structure of spacetime in the vicinity of the (spacelike) singularity. Within the cosmological paradigm of a Friedmann-Lemaitre spacetime, where a description of physics in terms of quantum field theories on such a curved background is deemed to be valid, this mandates the existence of a pre-inflationary epoch following the Big Bang. Accepting this physically well-motivated scenario of the existence of a pre-inflationary phase as valid, the aim of this thesis has been to develop a customized theoretical framework for interacting scalar quantum field theories (QFTs) on generic Friedmann-Lemaitre backgrounds. Importantly, such a framework cannot be in Euclidean signature as the expanding spacetime generically prohibits a Wick rotation, nor should it be tailored towards de Sitter spacetime. Motivated by the subdominance of spatial gradients in the approach to the singularity, the major themes of this thesis are variants of spatial averaging and spatial gradient expansions.

In the first part of this thesis we present the Anti-Newtonian expansion in a spatially discretized setting, where the flat spatial sections of the Friedmann-Lemaitre background are replaced with a hypercubical lattice. In this framework, the solution of the QFT decouples into two sub-problems: (1) The solution of the cosmological quantum mechanics, conceptually associated with the decoupled wordlines in the Anti-Newtonian limit; and (2) The solution of the combinatorial problem that allows one to analytically control the terms of the linked cluster expansion, which is conceptually associated with restoring the spatial interaction between the neighboring world lines. With the goal of making contact to the Functional Renormalization Group, we focus on developing a linked cluster expansion for the Legendre effective action. We show that this expansion may be efficiently recast in terms of graph theoretic methods, with the resulting graph rules largely model independent. Next, we present a ``proof-of-principle'' study showing that the Functional Renormalization Group can be applied to efficiently calculate the critical parameters of the hopping expansion of Euclidean lattice quartic scalar theory.

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