別紙４

報告番号	※　　　　　第　　　　　号

主　論　文　の　要　旨

論文題目　Quantum and semiclassical features of the de Sitter universe: time evolution and relativistic quantum information
ド・ジッター宇宙の量子的及び半古典的特徴：時間発展と相対論的量子情報

氏　　名　ROTONDO Marcello

論 文 内 容 の 要 旨

Quantum cosmology is the attempt to extend the quantum theory to the universe as a whole. Such attempt is motivated both from a theoretical point of view by the desire to make the established quantum theory more comprehensive as well as from a more practical point of view concerning the understanding of the initial conditions of the universe. Furthermore, the universe is by definition a true closed system and as a consequence there is no external environment justifying a transition to a classical regime. Therefore, if the principles of quantum physics are truly fundamental in Nature, a quantum description of the universe is necessary. Since gravity is dominant at large physical scales, the problems and difficulties that the path to a theory of quantum cosmology is riddled with are in large part common to those of a complete quantum theory of the former, both in its own regard and in its unification with the already established description provided by quantum physics.

One of the earliest and most conservative approaches to the quantization of gravity is the canonical one, where the traditional methods of Hamiltonian analysis are applied. Already since the time of its adoption, this approach has presented various technical obstacles concerning the quantization of the classical first-class constraints, the proper definition of a Hilbert space for the theory, the regularization of its diverging operators, and so on. Some of these issues have been addressed and solved both within and without the canonical approach. On the other hand, the treatment of toy models or minisuperspace models where, by making use of special symmetries, appropriate boundary conditions and approximations, only few of the degrees of freedom of the full superspace of the theory are taken into account, has allowed to avoid some of the technical issues of the quantization providing some insights on the possible phenomenology of a quantum universe. Some other issues are instead of conceptual rather than technical nature and attributable to the difficulty to extend familiar concepts and tools such as those of time evolution, of external observer and of quantum amplitudes of probability to the case where the universe in its wholeness is taken into account and fundamental classical categories lose their validity.

In the present work, we will address some of these latter aspects of the approach in its geometrodynamical representation, both in the quantum and semiclassical gravity regime. For its conjugation of technical simplicity with practical interest, we will put special emphasis on the de Sitter universe, which provides a valuable model to describe the early inflationary phase of the universe and a late-time dark-energy-dominated evolution.

After a introduction of the reader to the basics of the canonical approach to the quantization of gravity, the elements of quantum cosmology in the geometrodynamical representation and the derivation of the semiclassical theory where quantum fields are defined on a purely classical gravitational background, we will first address the so-called problem of time, in other words the apparent lack of a explicit time variable for the quantum evolution of the spatial geometry and the difficulties encountered when trying to introduce one such variable. After reviewing some relevant results of previous research, we will show one possible simple way to retrieve a unambiguous notion of time and non-trivial time evolution for a cosmological quantum state in association with a dynamical clock. The obtained notion of time remains valid even in the regime where the coupling between geometry and the clock is strong. Next we will consider the superposition and interference of arrows of time in the WKB limit of gravity and discuss the role of the quantum decoherence induced by quantum matter fields in leading to the emergence of classical time taking into account the second quantization effect of particle creation. Within a short decoherence time, interference of opposite arrows of time may lend itself to observation.

Finally, in the semiclassical limit of pure classical gravity with quantum perturbations, we will show an application of relativistic quantum information theory, and especially estimation theory, to probe the characteristic parameters of the classical cosmological background by making use of the quantum properties of matter fields. We evaluate the Fisher information for two specific choices of measurements as well as its maximization over all possible quantum measurements, thus providing a lower bound on the variance of cosmological estimators. We compare the results for a pure de Sitter phase and a de Sitter phase followed by a radiation-dominated phase, which allows to discuss the character of accessible and inaccessible information.