Wave Function and Probabilities in Quantum Cosmology

The evolution of the field of cosmology (theoretical and experimental) has allowed for the creation of a complete new arena to explore the limits of Physics. In spite of the persisting difficulties of unifying quantum mechanics and general relativity, there are a number of semiclassical approaches that permit physicists to create models and test them with great precision, apparently connecting the quantum origins of the Universe with its classical current state. However, those models deliberately avoid more fundamental questions that are connected to the foundational problems of both General Relativity and Quantum Mechanics.

The Standard Cosmological Model describes a Universe that started from a singularity (where General Relativity breaks down and some quantum gravity physics must be assumed) and evolves with an initial exponentially accelerated expansion driven by a scalar field that allows quantum density fluctuations, evolving on a classical background, to be expanded and ultimately responsible for the formation of large scale structure. In that description alone two major problems appear, namely, the singularity problem and the quantum-to-classical transition of the cosmological perturbations.

In this talk, I will describe how this problems are treated in a particular model of cosmology that avoids the singularity issue and coherently describes the evolution of quantum cosmological perturbations until they reach the classical regime. This model is constructed by applying the de Broglie-Quantum Theory to Cosmology [5]. However, by introducing this quantum theory in the realm of cosmology other fundamental problems are also brought to light. Specifically, by quantizing the whole Universe one is immediately is led to question what is the definition and the role of the wave function in this context.

The problem of the ontology of the wave function is a widely debated subject in the philosophy of physics [7]. In this cosmological context this problem is further stressed. I will address an aspect of this issue that arises in the de Broglie-Bohm quantum theory when considering the relation between the wave function and the distribution of probabilities. The dynamical role of the wave function can be connected to the probabilistic experimental results of quantum mechanics through a process of quantum relaxation quantified by a 'subquantum H-function' [2]. This scenario can be referred to as the "Quantum Equilibrium Hypothesis" (QHE) and it creates the possibility to test the validity of the de Broglie-Bohm quantum theory if one finds signatures of "quantum nonequilibrium". Considering this hypothesis in cosmology, one is again led to the question of what is the definition and the role of the wave function in this context.

There is a debate in the literature around the necessity of the QHE to explain the relation between probabilities and the wave function in the de Broglie-Bohm quantum theory [3, 4]. There is also a debate on how to interpret probabilities and the wave function in the context of quantum gravity and cosmology [6, 8]. In this talk I will present the main arguments on both sides of the debate and present two scenarios that explain the role of the wave function and how to treat probabilities quantizing the whole Universe. Although I will not try to resolve any ontological issues of quantum mechanics, I believe that this discussion might be useful to present to the philosophers of physics some new aspects of the problem that arise in the context of Quantum Cosmology.

Selected Bibliographies

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