Quantum Fluctuations in the Early Universe

1. Introduction

In terms of one of the Friedmann-Lemaître-Robertson-Walker models of cosmology (FLRW models of which there are three) the universe is completely spatially *isotropic and homogeneous.* Basically isotropic means the universe looks the same in all directions and spatially homogeneous means the universe looks the same at each point in space, at any one time. The assumptions of isotropy and homogeneity are so basic that it became known as cosmological principles and are the cornerstones of the widely accepted Standard Model of Cosmology. Observation proved that isotropy cannot be exact since we see individual galaxies, clusters of galaxies and matter not always visible at incredible distances, such as the 'Great Attractor'. The deviations from isotropy became smaller and smaller, the farther away we look. We know from the 2.7 K Cosmic Microwave Background Radiation (CMBR) that there are very slight temperature deviations which support isotropy very well. It is thought that these tiny irregularities in the CMBR became the seeds from which stars and galaxies formed.

2. Fluctuations in the early universe

The extraordinary special state of the early universe described above gave the early universe its very low entropy and enable us to to explain the thermodynamic arrow of time. The universe's spacetime geometry is still remarkably close to the state of homogeneity and isotropy. But what about quantum fluctuations? In terms of Einstein's $E = mc^2$ the quantum fluctuations in energy levels in the early universe is a source of gravity, and gravity is attractive clumping matter together, in contrast to the special state of low entropy of the early universe,

Let's look at what quantum fluctuations are. It is a feature of Heisenberg's uncertainty relations as applied to fields. Any attempt to accurately measure the value of a quantum field in a very small region will lead to a very large uncertainty in other (canonically) related field quantities and to a rapidly changing value of the quantity being measured. The act of accurately measuring the value of a field quantity will result in that quantity fluctuating wildly. The measurement of a component of spacetime metric will result in enormous changes in that metric. It was these considerations that led John Wheeler, in the 1950's, to describe the nature of spacetime at the Planck level of 10^{-33} cm as a wildly fluctuating foam. However, Heisenberg's uncertainty relations do not describe a 'fuzzy' or 'incoherent' behaviour of nature at the Planck level of 10^{-33} cm. It restricts the accuracy whereby two non-commuting measurements can be carried out. We cannot measure the position and velocity of a single particle accurately at the same time. This is a perfectly well defined quantum state. If no measurement is made the state of the particle will evolve according to Schrödinger's equation.

How does this apply to the state of the early universe? In other words, can the deviations from exact symmetry be attributed to quantum fluctuations, assuming that the entire initial state is exactly according to the FLRW cosmological symmetry? Some quantum physicists argue that the FLRW symmetry can indeed be maintained because the entire state is a *superposition* of such irregular geometries, not an individual geometry. The superposition can possess a symmetry not possessed by the individual geometries of which it is composed.

It is interesting to note that the many worlds view of quantum mechanics in terms of which the FLRW symmetric state of the universe would be maintained until the present day representing this state as a grand superposition of many constituent spacetime geometries. It is only when observers try to accurately carry out measurements that the resolution into alternative spacetime geometries are appropriate, there being a superposition of conscious observers, each one perceiving a single world.

3. Conclusions

The reader would have noticed that the use of quantum mechanics in its present form represents considerable difficulties. It is a very successful theory and can be compared to Einstein's general relativity in terms of the radical way in which it changed our view of the universe. Many physicists argue that the quantum measurement paradox does not reveal an aspect of reality, but is nothing more than just a measurement. I do not know if this correct because I don't know what reality is. Some physicists prefer to come to terms with the use of the present formalism of quantum mechanics while not attempting to change it in any significant way. My view is that quantum mechanics is a partial theory that needs to be changed if we wish to find out how gravity and matter behave at the quantum level in extreme conditions such as a singularity.

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Readers who wish to read more will find the following book fascinating:

Penrose, R. (2004). The Road to Reality. A Complete Guide to the Laws of the Universe. Jonathan Cape, London, U.K.