Thermal field theory in curved spacetime

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In the early stages of evolution following the Big Bang, the universe appears to be filled with different components of matter-energy in interaction with each other. Generally these interactions make it extremely difficult to study the dynamic evolution of these components and the only information we can have on the system is that it is in a local thermodynamic equilibrium configuration. In the early universe the temperature of the cosmological plasma is extremely high (several orders of magnitude higher than the mass of the fundamental particles) and therefore thermal effects dominate the dynamic of the system.

The fundamental theory in the description of the cosmological universe is general relativity. Einstein's field equations determine the coupling between the curvature of spacetime and a generic distribution of matter described in terms of an energy-momentum tensor. From the fundamental point of view matter is quantum and therefore more correctly described in terms of a quantum field theory. Assuming that we can ignore the quantum effects of gravity, it is possible to describe the evolution of a quantum distribution of matter by replacing the classical energy-momentum tensor with the expectation value of a suitable quantum operator constructed in terms of the fundamental fields. The goal of my research is to study the evolution in cosmological space-time of a distribution of quantum matter at local thermodynamic equilibrium with the cosmological plasma. In this situation the expectation value of the energy-momentum tensor is calculated on a quantum state of local thermodynamic equilibrium.

The fundamental object is therefore the quantum operator associated with the more generic configuration of local thermodynamic equilibrium in curved space-time. This operator was first introduced in the context of non-equilibrium statistical mechanics [1] and subsequently generalized in a fully covariant context [2]. Having defined this operator, it is possible to study the evolution of various mass-energy components in the cosmological universe in a theory that takes into account both thermal and quantum effects that we expect to be equally important in the early stages of the universe's evolution. Usually this analysis was performed using the relativistic Boltzmann equation [3] assuming a quantum probability distribution as initial condition for matter. The fundamental novelty of my work involves the use of relativistic quantum statistical mechanics in the calculation of the expectation value for the energy-momentum tensor components using quantum field theory in the description of the distribution of matter.

The first step was to study the equation of state for a scalar field after its decoupling, ie the last instant in which it was in interaction and therefore in local thermodynamic equilibrium with the cosmological plasma [4]. As a first result we have obtained that the equation of state presents significant differences with what would be obtained using the Boltzmann equation. The expressions for energy density and pressure of the field have correction terms that are present only using a quantum field theory in the description of the distribution of matter. The presence of such corrections can substantially modify the dynamics of the field, resulting in extremely interesting

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applications to modern cosmological theories such as inflation or the production of dark matter.

My research project first of all foresees studying in greater detail the self-consistent solutions of the model, ie integrating the Einstein field equations and the Klein-Gordon equations with the initial condition of thermodynamic equilibrium at the moment of decoupling. Subsequently, the following points are highlighted for future study:

- Study the evolution in the same configuration for fermionic and gague fields;
- Determine the effect of quantum field corrections on inflationary dynamics and dark matter production processes;
- Generalize the formalism to the case of other curved metrics of physical interest such as the Schwarzschild metric.

References

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