論文の内容の要旨

Cosmological consequences of quantum processes in strong gravity

(強重力場における量子的過程の宇宙論的帰結)

大下 翔誉

In the modern cosmology, there are several problems and interesting predictions involving strong gravity such as the initial cosmological singularity problem, problem of initial conditions for cosmic inflation, consistency of the generalized second law of thermodynamics, black hole information loss paradox, and metastability of the Higgs vacuum. It is one of the priorities of modern cosmology to provide plausible cosmological scenarios which can be resolutions to these problems or are consistent with some theoretical or experimental predictions. In this dissertation, we approach these problems and provide some plausible scenarios regarding the beginning and fate of the Universe by taking into account quantum effects in strong gravity.

Cosmic inflation is a standard scenario describing the early universe, which solves several fine-tuning problems, and is consistent with the observational data of Cosmic Microwave Background radiation. However, it has been expected that in order for inflation to start, homogeneity of the Universe is necessary to some extent. The problem of initial conditions for inflation is to assert how inflation began at the early stage of the Universe without assuming homogeneity of space from the outset. Our scenario implies that the quantum tunneling effect of the initial inhomogeneous space could lead to the birth of baby universes that accommodate inflating domains. This can be one of the possible scenarios to solve the problem of initial conditions for inflation. We also investigate the thermodynamical aspect of inflation, especially, the consistency of the generalized second law of thermodynamics during inflation.

After the end of inflation, the Universe is thermalized since the energy of inflation is converted to thermal radiation and the large scale structure eventually forms. In the present Universe, black holes, originating from gravitational collapses of matter, are ubiquitous. The evaporation process of black holes is still controversial due to the black hole information loss paradox. In particular, the firewall argument in the paradox perhaps requires a drastic modification of the picture of the multiverse and eternal inflation. We then provide a reasonable reason for rejecting the firewall argument by focusing on the gravitational decoherence inside a black hole.

Regarding the future of the Universe, a number of interesting scenarios have been proposed so far. For example, the metastability of the Higgs vacuum may lead to a catastrophic scenario of the Universe. This is because the metastability implies that the Higgs vacuum we live in until now might be metastable and the Universe could be filled by vacuum bubbles including large and negative vacuum energy because of the first order phase transition of the Higgs vacuum. Furthermore, it has been proposed that "impurities" in the Universe such as black holes would be catalysts for the vacuum decays of the Higgs field. We then investigate horizonless compact objects as the catalysts for the vacuum decays.

We also discuss another interesting scenario regarding the fate of the Universe, and this may give us a deeper insight into the beginning of the Universe as well. The original initial singularity problem is an implication from the general relativity, which states that as long as a plausible energy condition (strong energy condition) is satisfied, the initial singularity is unavoidable at the finite past of the Universe. However, our scenario tells us that the initial singularity or the real beginning of the Universe are no longer necessary and the Universe can be eternal to past. Evaporating black holes in the far future of the Universe emit high-temperature Hawking radiation. In our scenario, the energy of Hawking radiation around the mini black hole is converted to vacuum energy due to the symmetry restoration of a related quantum field, and then the symmetry restored region eventually start to inflate after the quantum tunneling process. This implies that our Universe may have been created from a black hole in the previous generation of the Universe, and in this sense, the Universe can be eternal to past.