論文の内容の要旨

Origin of Big Bang in Mixed Higgs-R^2 Inflation Model

(ヒッグス-R^2 混合インフレーションモデルにおけるビッグバンの起源)

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This thesis is devoted to investigating the origin of the Big Bang in an observationally favored two-field inflationary model, namely the mixed Higgs-R^2 inflation model.

Inflation, a period of accelerated expansion before the Hot Big Bang, can elegantly solve the unexplained problems in the conventional cosmology scenario, namely the homogeneity, isotropy, and flatness of the observable Universe. After a graceful exit from the inflationary phase, the Universe is cold and empty, so creating a large number of relativistic particles is necessary to realize a hot and dense initial state for the subsequent Hot Big Bang. In the inflationary cosmology, reheating plays such an essential role in connecting inflation and the radiation-dominated epoch, serving as the origin of the Big Bang by particle production and thermalization. Moreover, the temperature and duration of reheating can have significant impacts on various observables and phenomena that can probe physics in the very early Universe.

The reheating process is highly model-dependent, during which the energy that drives inflation is transferred to other matter fields through many different mechanisms according to the concrete models. Generally speaking, reheating is characterized by two sequential stages for models where inflation is followed by coherent inflaton oscillation. The first is preheating, dominated by non-perturbative particle production, leading to a rapid energy transfer from the inflaton to relativistic particles. Typical examples for the preheating mechanism are parametric resonance and tachyonic instability, resulting in an exponential growth of the number density of produced particles. The second is perturbative reheating, during which inflaton experiences perturbative decay to deplete all its energy, ultimately determining the reheating temperature. The decay rate is mostly controlled by the coupling strength between inflaton and other matter fields, so is the reheating temperature.

The mixed Higgs-R^2 inflation model is a theoretically well-motivated and observationally favored inflationary model, possessing rich and interesting phenomena at different stages of reheating. This model consists of two scalar degrees of freedom besides the two tensor modes in general relativity, the

scalaron from the R^2 term and the Standard Model (SM) Higgs field, with three model parameters, scalaron mass M, Higgs non-minimal coupling ξ and self-coupling λ. It can be shown that this model can serve as a UV extension of the Higgs inflation with the cutoff scale lifted to the Planck scale due to the presence of scalaron. Moreover, as analyzed in the thesis, the UV issue in preheating in the Higgs inflation is resolved by the R^2 term. During inflation, the system behaves as an effective Starobinsky model or effective Higgs inflation, so the inflation predictions are identical to the two single-field limits and are observationally favored. On the other hand, the multi-field nature plays an essential role in the particle production mechanism throughout the whole reheating process where the effective single-field description breaks down, which provides possibilities of new observables and a way to distinguish the two-field models from the well-known single-field limits.

Following the brief review of the mixed Higgs-R^2 inflation, different stages of the reheating process in this model are discussed in the thesis, including the first stage of preheating, the occurrence of tachyonic preheating, and the perturbative reheating. The first stage of preheating is involved in the unitarity issue discussion due to the large spikes induced in the effective mass of the longitudinal modes of gauge bosons, which, however, is proved to be too weak to reheat the Universe. It is shown analytically and numerically that the high and sharp spikes are significantly weakened by the scalaron, which ensures the absence of the strong coupling issue but diminishes the particle production efficiency. Other reheating mechanisms are necessary to reheat the Universe in subsequent evolution, for example, tachyonic preheating. The occurrence of tachyonic instability in the Higgs field and the longitudinal modes of gauge bosons is possible for specific parameter choices, called critical parameters, that are found analytically and numerically. Almost all the critical parameters can realize an efficient tachyonic effect that completes preheating within one scalaron oscillation, except for those close to the R^2-limit, which is estimated analytically. However, a small deviation from critical parameters leads to a significant reduction of the tachyonic effect, implying the necessity of fine-tuning. The numerical investigation of the necessary degree of fine-tuning is shown, finding that at least $\Delta M/M \sim \mathcal{O}(0.1)$ is needed while much severer is required for parameters closer to the R^2-limit. If the tachyonic instability is not efficient enough to complete preheating, perturbative decays of the scalaron field and Higgs field at the late time dominate the reheating process, finally determining the reheating temperature and duration. The dominant decay channel for scalaron is decaying into two Higgs particles, which becomes efficient only when the effective mass of Higgs gets small as the oscillation amplitude of scalaron decreases. On the contrary, the Higgs field directly couples with all the SM particles, which induces many efficient decay channels. The decay of produced Higgs particles can reduce the efficiency of rescattering between homogeneous background and decay products, while the decay of the homogeneous Higgs accelerates the perturbative reheating process. Therefore, the resulting reheating temperature for the most part of parameter space is much higher than the R^2-limit.