論文の内容の要旨

Higgs Dynamics in the Early Universe

(初期宇宙におけるヒッグス場のダイナミクス)

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After the Higgs mass measurement by the large hadron collider, all the parameters in the standard model are now fixed. One of the most important consequences is probably the so-called electroweak vacuum metastability. Assuming that the standard model is valid up to high energy scale, we can compute the high energy behavior of the Higgs quartic self coupling by using the renormalization group equation. With the current center values of the Higgs and top quark masses, it actually turns to negative at around the renormalization scale of 10^{10} GeV, which we call an instability scale, indicating that the standard model Higgs potential develops a true minimum deeper than the electroweak vacuum at a large field value region. It does not necessarily contradict with the present universe since the lifetime of the electroweak vacuum is longer than the age of the universe. This situation is called the electroweak vacuum metastability.

If the electroweak vacuum is indeed metastable, we should carefully follow the dynamics of the Higgs field during the whole cosmological history. The universe, especially in its early state, is controlled by high energy phenomena, and hence it is possible that the Higgs field rolls down to the true minimum at some cosmological epoch. Once it happens, it is expected to be difficult to realize the present universe where the Higgs lies in the electroweak vacuum. Thermal effects are not likely to cure this situation since particles that couple to the Higgs must be quite heavy due to the large Higgs field value once the Higgs rolls down to the true minimum. Thus the electroweak vacuum metastability has non-trivial implications on the cosmology, especially the early universe, and this is the main topic of this thesis.

In this thesis, we study implications of the electroweak vacuum metastability in the context of the inflationary cosmology. In particular we pay attention to the Higgs-inflaton dynamics after inflation. An inflaton typically oscillates at around its potential minimum after inflation, and it causes resonant Higgs particle production if there are sizable couplings between the inflaton/gravity sector and the Higgs sector. Provided that the inflaton mass scale is higher than the instability scale, the produced Higgs particles induce a tachyonic mass to the Higgs itself due to finite density effect, and push the Higgs to roll down to the true minimum. Thus we can obtain bounds on the strength of the interaction between the inflaton/gravity sector and the Higgs sector by requiring that the electroweak vacuum survives such a "preheating" epoch. More specifically, we assume that there exists the following interaction between the inflaton/gravity sector and the Higgs sector:

$$\mathcal{L}_{\rm int} = -\lambda_{h\phi}\phi^2 \left|H\right|^2 - \sigma_{h\phi}\phi \left|H\right|^2 - \xi_h R \left|H\right|^2 ,$$

where H is the standard model Higgs doublet, ϕ is the inflaton, R is the Ricci scalar, and $\lambda_{h\phi}$, ξ_h and $\sigma_{h\phi}$ are coupling constants. These couplings are expected to be present in general, and are also useful to stabilize the Higgs during inflation for high-scale inflation models. In this thesis, we have specified the parameter region of $\lambda_{h\phi}$, ξ_h and $\sigma_{h\phi}$ where the electroweak vacuum is destabilized during the preheating epoch. We have estimated such a parameter region analytically first, and then verified it by using a numerical method called the classical lattice simulation.