論文内容の要旨

# Non-thermal leptogenesis under gravitino problem

## 非熱的起源によるレプトン数生成とグラビティーノ問題

氏名：　　高山　務

Non-thermal leptogenesis scenarios are considered as a solution that reconciles leptogenesis with gravitino problem.

Leptogenesis itself is a very attractive explanation of the origin of the baryon asymmetry, whose abundance is determined by observation of cosmic microwave background (CMB) and the theory of big-bang nucleosynthesis (BBN) combined with observed abundances of light elements. In this scenario, lepton and $B - L$ asymmetry is produced in the early evolution of the universe, and lepton asymmetry is converted into baryon asymmetry via sphaleron processes. Since non-vanishing $B - L$ asymmetry is produced in this scenario, washout of baryon asymmetry via sphaleron processes can be avoided. Lepton asymmetry can be produced by $CP$ and $L$ violating decay of heavy Majorana right-handed neutrino, which is introduced in seesaw models to explain light neutrino masses confirmed by neutrino oscillations.

In thermal leptogenesis, the simplest version, right-handed neutrino is produced via thermal processes at an early epoch of the universe. Lepton asymmetry can be produced by out-of-equilibrium decay of thermally produced right-handed neutrino. Thus, this scenario does not require additional assumptions other than the existence of right-handed neutrino, provided with sufficiently high reheating temperature of the universe. The condition for successful thermal leptogenesis is thoroughly investigated in literatures. Results of detailed numerical calculation of the Boltzmann equations, the condition for thermal leptogenesis is shown to be $T_R \gtrsim M_N \gtrsim 10^9$GeV, where $T_R$ and $M_N$ is the reheating temperature of the universe, which is defined as the temperature of the universe at the beginning of radiation-dominant epoch, and mass of lightest heavy right-handed neutrino, respectively.

However, in supersymmetric theories, thermal leptogenesis conflicts with the thermal gravitino problem.

The abundance of the gravitino is constrained by BBN (if it is unstable and have sufficiently log lifetime) and/or the abundance of dark matter. Thus, $T_R$ is bounded for evading the overproduction of gravitino by thermal scattering. Both the abundance of gravitino produced by thermal scattering and the effect of gravitino on the evolution of the universe depend on the gravitino mass, $m_{3/2}$. Therefore, the bound from gravitino overproduction depends on $m_{3/2}$. For a range $10^2\text{GeV} < m_{3/2} < 10^4\text{GeV}$, which is predicted in the gravity-mediated SUSY breaking, the constraint is $T_{\rm reh} \lesssim 10^{6-9}\text{GeV}$. In this case, thermal leptogenesis is severely constrained. In chapter 2, we review thermal leptogenesis and see how it conflicts with gravitino problem.

Supersymmetry (SUSY) itself is a very attractive for new physics beyond the SM for several theoretical reasons. Thus, it is interesting problem to find a solution that reconcile leptogenesis scenario with gravitino problem. We consider non-thermal leptogenesis as possible solutions. The basic concept of these scenarios is very simple: high reheating temperature $T_R \gtrsim M_N$ is not required if sufficient initial abundance of right-handed neutrino is generated without thermal scattering.

In chapter 3, we consider two kinds of non-thermal leptogenesis. The first is leptogenesis from non-thermally produced right-handed neutrino. Among many scenarios proposed by literatures, we focus on leptogenesis from inflaton decay and leptogenesis from sneutrino condensate. Particularly, for leptogenesis from inflaton decay, besides the well-investigated case that the neutrino decays instantaneously after produced by inflaton decay, leptogenesis is possible if neutrino decays after it dominates the universe. In this case, gravitino problem can be avoided, since the universe is reheated only after the decay of neutrino. We survey broad parameter region including the latter case, and show the condition for this scenario and dependence on parameters, the inflaton decay rate (the reheating temperature), the right-handed neutrino mass, the lightest neutrino mass, and the constraint from the gravitino problem. As a comparison, we also consider another important scenario, leptogenesis from sneutrino condensate, and show the condition for this scenario in the same format as above result.

We also consider leptogenesis via Affleck-Dine (AD) mechanism in chapter 4. In AD mechanism, charge asymmetry is produced by dynamics of a flat direction. Generation of lepton asymmetry by the dynamics of $LH_u$ flat direction via AD mechanism is one of attractive scenario, and studied in many literatures. We consider another possibility: generation of large asymmetry in the number density of right-handed sneutrino, $n_{\Delta\tilde{N}} \equiv n_{\tilde{N}} - n_{\tilde{N}^*}$. This scenario is once considered by Allahverdi & Drees, assuming that the $LH_u$ direction is not participate in the dynamics. Large asymmetry $\Delta n_{\Delta\tilde{N}}$ can be converted into lepton asymmetry at the decay of sneutrino condensate, through the SUSY breaking effect at finite temperature. However, in general, the $LH_u$ direction takes part in the dynamics. because of interaction with right-handed sneutrino. We consider multidimensional evolution of scalar fields, and show that the asymmetry is produced first in the dynamics of right-handed sneutrino, and then it is nonperturbatively transfered to the lepton asymmetry in $LH_u$ direction condensate via the interaction between these scalar fields.