Abstract

The early history of our observable universe and its development are based on two major poles: cosmic inflation and big-bang nucleosynthesis (BBN). The inflation successfully creates the homogeneous, isotropic, and spatially flat universe, and BBN successfully produces all the light elements with correct abundance values. These two phenomena happen at two widely separated energy scales with inflation at around 10^{16} GeV and BBN at around 10 MeV. However, except in some phenomenological studies, not much physics is understood of the stage which occurs between the two, mainly because of the lack of observations. Inflation creates exponentially large empty space contained with only homogeneous inflaton fields. Hence, the natural physical process that could occur is the transfer of inflaton energy into the standard model fields, which can subsequently set the initial condition for BBN. The phase where this energy transfer from inflaton to radiation happens is called reheating. Based on our current theoretical understanding, this phase consists of many non-trivial physical phenomena such as perturbative, non-perturbative quantum particle production, thermalization, etc. In all these physical phenomena during reheating, what assumes that the central stage is the homogeneous oscillating inflaton. How the radiation fields are coupled with the inflaton, how the produced radiation is thermalized, and how long the decay processes last are some of the central questions that are still the active areas of research in reheating. The lack of experimental observations makes this phase essentially unconstrained. However, there are many attempts to constrain the reheating phase through some indirect cosmological observables such as primordial gravitational wave, primordial magnetic field, dark matter abundance, and cosmic microwave background (CMB) anisotropy, and these are the main topics of discussion in our present thesis work. We have two main themes of the present thesis, which are as follows:

Modeling the dynamics of reheating: Suppose the inflaton coupling with the radiation field is sufficiently high. In that case, the initial stage of the reheating phase may become non-perturbative, and the resonant non-thermal growth of particle number dominates the process as compared to the perturbative one due to coherent inflaton oscillations. Motivated by this, in the second chapter, we propose a Two-phase reheating scenario where the dynamics describe the aforementioned initial non-perturbative stage with an effective equation of state followed by the standard perturbative reheating. Some model-independent lattice simulation results are incorporated as the boundary conditions while solving the dynamical equations of the proposed scenario. Due to the initial non-thermal phase, it predicts maximum reheating temperature (T_{re}^{max}), which turned out to be lower than that of the standard perturbative single-phase prediction. However, the initial seed value of the effective equation of state significantly affects the value of that maximum reheating temperature. We further generalize the scenario by including dark matter (DM), which is assumed to be produced from the radiation bath. We studied possible constraints on different inflaton coupling and DM production cross-sections considering CMB anisotropy and DM abundance.

Reheating phase is observationally not very well understood, and hence phenomenological construction of such phase is challenging. In the conventional approach, we introduce arbitrary coupling among the inflaton and daughter fields which could only be constrained through indirect observations. Therefore, any cosmological predictions of such approaches depend on the unknowns and hence are not robust, which could be observationally verified. To obtain universal predictions and gain an insight into the reheating process itself, in the second part of chapter five, we took a model-independent approach by switching off all unknown couplings between the inflaton and daughter sector. Surprisingly, we discovered that universal gravitational interaction is enough to reheat our universe with some definite predictions. We named such a scenario Gravitational reheating (GRe). Our analysis revealed that gravitational reheating is consistent with a very restricted class of inflation

models and narrow reheating temperature and DM mass ranges.
Signatures of reheating on cosmological observable: To decode the signatures of reheating, we have studied the evolution of various fundamental fields while passing through the reheating phases, which are as follows:

- **Through primordial magnetic field:** In the third chapter, we have shown that the reheating phase can play a crucial role in alleviating strong coupling and back-reaction problems in the inflationary magnetogenesis model along with the CMB. Faradays, electromagnetic induction changes the magnetic field dynamics drastically during the reheating phase, and this phenomenon not only converts a large class of magnetogenesis models observationally viable without any theoretical problem but also can uniquely fix the average inflaton equation of state.
- **Through primordial gravitational waves (GWs):** In chapter four, we closely examine the effects of the reheating phase on the spectrum of primordial GWs observed today. We show that the perturbative decay of the inflaton leads to oscillations in the GWs spectrum, which can possibly help us interpret finer aspects of the reheating mechanism if observed. We also examine the effects of a secondary phase of reheating driven possibly by an exotic, non-canonical, scalar field, and interestingly for a suitable value of the Equation of state parameter, the GWs can be of the strength, as suggested by the recent NANOGrav observations.
- **Through Gravitational dark matter:** In the first part of chapter five, we have analyzed a minimal production mechanism of dark matter, where dark matter is assumed to be produced from inflaton and radiation bath through only the gravitational interaction during reheating. Ignoring any other internal parameters except the dark matter mass and spin, a particular inflation model such as α-attractor, with a specific scalar spectral index (n_s), has been shown to uniquely fix the dark matter mass.