論文の内容の要旨

論文題目：Primordial blackhole formation and gravitational wave production in a curvaton model

（カーバトン模型における原始ブラックホール形成及び重力波生成）

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Recent cosmological observations such as Planck or Wilkinson Microwave Anisotropy probe (WMAP) strongly supports the existence of an accelerated expansion era called inflation in the very early stage of the universe. In addition to solving some difficulties in the standard Big Bang cosmology such as the horizon problem, inflation can naturally generate the primordial seeds of density perturbations on superhorizon scale by expanding the quantum fluctuations of some scalar field on very small scales. This mechanism for generating the density perturbations generally predicts the almost scale-invariant spectrum of curvature perturbations obeying the Gaussian statistics, which is consistent with the observed temperature anisotropies of the cosmic microwave background (CMB).

In addition, the CMB observations have also revealed that our present universe is filled with the unknown matter called dark matter, which cannot be explained within the framework of the well-established standard model of particle physics. The observed density parameter for the cold dark matter (CDM) is found by the Planck to be

$$\Omega_{\rm CDM}h^2 = 0.1196 \pm 0.0031, \tag{1}$$

where h is the dimensionless Hubble parameter defined via the present Hubble parameter: $H_0 = 100h$ km sec^{-1} Mpc^{-1}. In order to detect the dark matter, many experiments have been performed by now, but we have not found any meaningful signature yet. Therefore it is one of the most important problems of modern cosmology and particle physics to answer what the dark matter is.

Primordial blackhole formation in a curvaton model

It is often said that the dark matter is the weakly-interacting massive particles (WIMPs). The supersymmetric (SUSY) model, which is one of the most promising model beyond the standard model, naturally provides such WIMPs as the lightest supersymmetric particle (LSP). Another promising candidate of dark matter is the axion, which is originally introduced to solve the strong CP problem in the standard model. In addition, it is known that the primordial black holes (PBHs), the black holes formed in the early universe, can behave like CDM.

In this thesis, we argue the scenario in which the currently observed abundance of CDM is partially explained by PBHs. PBHs are expected to be formed through the collapses of the high density regions caused by the large primordial density perturbations. In order for PBHs to form through the primordial density perturbations, we need the strongly blue-tilted power spectrum of the curvature perturbations, which gives the large density perturbations at small scales while the large scale density perturbations are consistent with the CMB observation. However, the observation indicates that the scale dependence of the power spectrum is slightly red-tilted at large scales. This inconsistency is solved by employing a curvaton. In the curvaton model, a scalar field (called curvaton) acquires fluctuations during inflation and after inflation it decays into the standard model particles producing the adiabatic perturbation in the radiation dominated universe.

In this thesis, we consider that the curvaton is responsible for generating only the small-scale curvature perturbations while the large-scale perturbations are generated by an inflaton. After the decay of the curvaton, a significant number of PBHs can be formed through large density perturbations due to the curvaton. We show that a significant number of primordial blackholes can be formed in an axion-like curvaton model, in which the highly blue-tilted power spectrum of primordial curvature perturbations is achieved. It is found that the produced blackholes with masses $\sim 10^{25} - 10^{26}$ g account for the present cold dark matter. We also argue the possibility of forming the primordial blackholes with mass $\sim 10^5 M_\odot$ as seeds of the supermassive blackholes.

Gravitational wave production in a curvaton model

The inflation is driven by some scalar field called inflaton whose potential is nearly flat. Although various inflation models have been proposed so far, unfortunately, there is no promising candidate for an inflaton. Moreover, the density perturbation may be produced by another scalar field like the curvaton model. One of the difficulty to identify the model is due to lack of clues from the observations on small scales. While the CMB observation is a powerful tool for constraining the spectrum of the curvature perturbations on large scales, we know little about the one on small scales, so we have only a little information to constrain the inflation model. On the other hand, future and current detectors of gravitational waves have a high sensitivity at higher frequency modes corresponding to the smaller scale fluctuations than that observed by CMB anisotropies. Thus, it is interesting to investigate the signal of the primordial gravitational waves on small scales, which would be a powerful tool to reveal the inflationary dynamics over a long period in combination with the CMB observations.

In this thesis, we also investigate the gravitational wave background induced by the first order scalar perturbations in the curvaton models. We consider the quadratic and axion-like curvaton potential which can generate the blue-tilted power spectrum of curvature perturbations on small scales and derive the maximal amount of gravitational wave background today. We find the power spectrum of the induced gravitational wave background has a characteristic peak at the frequency corresponding to the scale reentering the horizon at the curvaton decay, in the case where the curvaton does not dominate the energy density of the Universe. We also find the enhancement of the amount of the gravitational waves in the case where the curvaton dominates the energy density of the Universe. Such induced gravitational waves would be detectable by the future space-based gravitational wave detectors or pulsar timing observations.