Inflation in Bimetric Gravity

Yuki Sakakihara

So far general relativity has passed almost all tests to explain various observations and experiments. Not only general relativity precisely predicts the solar system experiments, but also the standard cosmology based on general relativity agrees well with the cosmological observations. However, there are several questions unanswered by general relativity, such as the origin of dark matter and dark energy. Dark matter and dark energy are necessary for the standard cosmology. As one of the possible ways to explain such dark components, modified gravity in the infra-red region has been discussed.

Though general relativity foresees massless gravitons, no one has experimentally proven that they are really massless. If gravitons have their mass, the mass works as an infra-red modification of gravity. Recently, a consistent theory including massive gravitons was proposed as a new candidate for the gravity theory describing the universe. Such a theory inevitably includes another spin-2 field in addition to the physical metric, so, it is called bimetric gravity theory. To examine whether bimetric theory is in harmony with the current understanding of cosmology, we investigate the inflation scenario in bimetric theory. The inflation scenario has succeeded in explaining cosmological observations, such as the fluctuations of the cosmic microwave background and the large-scale structures of the universe, as well as the cosmological problems unsolved in the context of the Big Bang scenario, such as the horizon problem and the flatness problem. Therefore, it is important to discuss whether bimetric theory has inflationary spacetime as a solution. It is also meaningful to predict the observable quantities originating from inflation in bimetric theory and to compare the results with observations. (Chapter 1.)

We construct de Sitter solutions as approximate solutions of homogeneous isotropic inflationary spacetime in the minimal bimetric theory which has flat spacetime as a vacuum solution. As a result, we obtain two branches of de Sitter solutions, where the physical metric is proportional to another spin-2 field, i.e. the other metric. We examine whether an anisotropy decays or not during inflation for each branch since the growth of an anisotropy during inflation means the breakdown of the assumption of isotropic background spacetime. We consider Bianch type I anisotropic perturbations imposed on de Sitter spacetime in the minimal bimetric theory and find that the effective mass of massive gravitons governs the growth of the perturbations. Evaluating the effective mass for each branch, we find that the anisotropy never grows for one branch, while it can grow for the other. (Chapter 2.)

What concerns us next is vacuum stability of de Sitter solutions in bimetric theory. It is well-known that a ghost instability, called the Higuchi ghost, can appear in the theories with massive gravitons. The scalar (helicity-0) mode of massive gravitons can have negative sign in its kinetic term, and such a ghost instability is avoided if and only if a certain condition on the mass relative to the Hubble expansion rate, which is called Higuchi bound, is satisfied. We derive the bimetric version of the Higuchi bound, roughly speaking, which requires the effective mass of massive gravitons to be larger than the Hubble expansion rate during inflation. We confirm that the Higuchi bound is satisfied for the branch in which an anisotropy decays while it is not for the other branch. Consequently, we find the unique stable branch of de Sitter solutions in the minimal bimetric theory. (Chapter 3.)

We construct inflationary solutions in the minimal bimetric theory with a scalar field coupled to the physical metric. We find the solution which reduces to the stable branch of de Sitter solutions, though the proportionality of the metrics breaks down under the assumption that the scalar field slowly rolls down the potential and the universe is well-approximated by de Sitter spacetime. We further investigate the inflation scenario in bimetric theory focusing on cosmological perturbations. We calculate the tensor perturbations generated by quantum fluctuation during inflation, i.e. primordial gravitational waves, to the first order in slow roll. The physical modes are expressed as a superposition of massive modes and massless modes owing to the interaction between the physical metric and the other metric. Hence, the rapid decay of the self-correlation of massive modes and the cross-correlation of massive modes and massless modes results in the suppression of the physical tensor power-spectrum compared with the general relativity case. We also observe the red-tilt of the spectral index of the tensor spectrum. Except for such differences, the basic features of the tensor spectrum such as the flat spectrum originating in massless modes and the slight tilt are kept in bimetric theory and there is no significant change in the predictions of the inflation scenario. (Chapter 4.)

We extend the previous analysis to the cases of general bimetric theory, removing the restriction on the bimetric parameters other than the assumption that flat spacetime is realized in the low-energy regime, which became possible by making use of the decay of massive gravitons. The analysis is valid in the leading order in slow roll. For comparison with current observational constraints, we calculate the scalar modes, i.e. so-called curvature perturbations, generated during inflation as well as gravitational waves. Both the spectra are suppressed owing to the bimetric interaction, but the suppression factors are slightly different from each other, resulting in the amplification of the tensor to scalar ratio compared to the general relativity counterpart. As a concrete example, we discuss power-law scalar potential cases. The amplification can be universal for any scalar potentials since the origin is the difference between the effective gravitational constants felt by different helicity modes in bimetric theory, in contrast that the gravitational constant is unique in general relativity. Bimetric effects make the constraint on the potential of the scalar field tighter since the tensor to scalar ratio is already constrained from above by the cosmic microwave background observations. The fact does not immediately exclude bimetric theory while the bimetric parameters can be constrained when a scalar potential is chosen. (Chapter 5.) Our study presented in this thesis supports the statement that bimetric theory can realize the standard picture of inflation and is worth being tested by observations.