論文の内容の要旨

Tests of Alternative Theories of Gravity through Gravitational-Wave Polarizations

(重力波偏極モードによる重力理論検証)

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Einstein's general theory of relativity is a nonlinear and dynamical theory of gravity that describes space-time as a four-dimensional Lorentzian manifold. General relativity is now widely accepted as the basic theory of gravity through the experimental and observational tests in weak gravitational fields. On the other hand, however, many extended theories of gravity have been proposed to explain the accelerated expansion of the universe and to integrate quantum theory and gravity theory. The first observation of gravitational waves by the gravitational wave telescope LIGO in 2015 made it possible to test the gravity theory with gravitational waves. The polarization mode search of gravitational waves from compact binary mergers, such as binary black holes and binary neutron stars, allows us to test the gravity theory in a strong gravity field. Gravitational waves are a phenomenon in which distortions of space-time propagate as waves. As light has polarization degrees of freedom, gravitational waves have the polarization modes, which exerts different effects on the free masses. In addition to the two tensor modes allowed in general relativity, four additional non-tensorial (vector and scalar) modes are allowed in the alternative theories of gravity. Therefore, we can probe into the nature of gravity by separating the polarization modes in the gravitational wave signal from the strong and dynamical system of compact binary coalescences. Furthermore, separation of polarization modes may be able to lead to the verification and elucidation of unknown gravitational nonlinear phenomena and the structure of the universe that can be observed only with the polarization tests.

So far in the observational tests using gravitational waves from compact binary mergers, the tensor, vector, and scalar modes have been explored separately. However, such a purely polarized mode search cannot test the realistic theories of gravity. In this thesis, first we revealed the polarization separability of the mixed polarizations with the current and future ground-based detector networks with the waveforms including the factors independent of the theories of gravity. Second, we searched for non-tensorial polarization modes with real gravitational wave signal such as GW170814 (binary black hole merger) and GW170817 (binary neutron star merger). In the pure polarization tests, we reanalyzed the signal with the waveforms consistent with modified theories gravity and utilized the information about the binary neutron star source from the electromagnetic counterpart. As a result, We obtained Bayes factors supporting general relativity that outperform the LIGO-Virgo Collaboration results by a factor of 5 in the binary black hole and 32 orders of magnitude in the binary neutron star. In the scalar-tensor search, we searched for a mixed scalar-tensor modes with the amplitude and phase corrections from additional scalar radiation. Consequently, we found the first direct constraints on the ratio of the scalar mode amplitude to the tensor mode amplitudes, which support general relativity.