# Study Results

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**Cosmic strings produced in the early universe**

It has been verified by some observations that the early universe was very hot and high-density state, and the present universe is realized as a result of expansion of the universe and decrease of temperature. Along the expansion process, it is theoretically expected that the phase transition, due to the spontaneous symmetry breakdown, took place necessarily. Because of the occurrence of that phenomena in the early universe, it is expected that the four fundamental interactions, that are electromagnetic, weak, strong and gravitational interactions, were realized due to the branching off of original one. Productions of topological defects are very interesting phenomena by means of the phase transion. What types of the topological defects were produced depends on how the symmetry were broken. For example, monopoles, which are zero-dimensional point objects, cosmic strings, which are one-dimensionally extended objects, domain walls, which are two-dimensionally extended objects, and so on. At the present these topological defects, for example cosmic strings, have high energy line densities, i.e., tensions, because these were produced in the hotter early universe in comparison with the present universe. These survive now because of topological stabilities of that.

**Gravitational waves**

The general relativity which is proposed by A. Einstein is one of the most successful work. This theory predicts the existence of gravitational waves, which are fluctuations of spacetime. It is expected that gravitational waves are directly detected by interferometers which run all around the world in future. One of the most important role of theoretical physicists is to prepare the "template" of gravitational waves which are radiated from some kind of gravitational wave sources. The source objects, the physical law of which obey the general relativity, i.e., which are high energy densities and travel near the velocity of light, are considered, for example, process of coalescence of binary stars, moving cosmic strings and so on. The motions of cosmic strings are described by the Nambu-Goto action.

## Gravitational wave radiation from stationary rotating cosmic strings

It is desirable that the existances of cosmic strings and gravitational waves are realized. My study, which is stated as follows, must be one of the most important in order for the object to realize by observations.

I have studied the gravitational wave radiation from cosmic strings which has been derived analytically. Generally, the equations of motion of cosmic strings can not be solved analytically, because of the extensities of that.

I have noticed that the equation of motion of "a cosmic string with a symmetry" is able to be reduced to an ordinary differential equation. Solving an equation of motion of a cosmic string correspond to determination of the world sheet of the cosmic string. At the same time, consider the background spacetime with some symmetries, there are some Killing vector fields, the number of which is equal to that of symmetries. I have considered the case that the world sheet of a cosmic string is tangent to a certain Killing vector field. Then, it has been found that the equation of motion of the cosmic string can be reduced to an ordinary differential equation by means of appropriate choice of coordinate system.

As the case that the ordinary differential equations can be solved analytically, I have especially considered the solutions of stationary rotating cosmic strings in Minkowski spacetime. By solving the equations of motion, it has been found that the motions and shapes of cosmic strings are determined by only two parameters.

Because stationary rotating states are stable end states of almost all objects in the universe, stationary rotating cosmic strings have been considered. For example, it has been verified that even if motions of black holes are very complicated when these are created, the motions become to be stationary rotating states (Kerr black holes) eventually.

By using the analytical solutions of the cosmic strings, I have estimated the waveforms of gravitational waves from this type of cosmic strings, by solving the linearised Einstein equations numerically. It has been also found that the waveform of gravitational waves are characterised by means of the two parameters which are included in the solutions of the cosmic strings.