Research Achievements

Recently, the idea of brane world has proposed a possibility that the spacetime has the spatial extra dimensions with the sub-millimeter scale. If our universe is such a brane world, the scale of the gravity is unified with those of other gauge interactions in the TeV scale and hence it is expected that the higher-dimensional mini-black holes are produced in accelerators. I considered the five-dimensional black holes for clarifying the physical properties of higher dimensional spacetime as the first step. In the five-dimensional spacetime, even if we impose the asymptotic flatness to the four-dimensional part of the spacetime, there are various possibilities of the structures of total spacetime with the extra dimension.

Squashed Kaluza-Klein Black Holes

I constructed charged static Kaluza-Klein black holes with squashed S^3 horizons in the five-dimensional Einstein-Maxwell theory [12]. We can regard the three dimensional sphere, S^3, as the Hopf bundle, i.e., a twisted S^1 bundle over an S^2 base space. In the squashed Kaluza-Klein black holes, the shape of the outer horizon is oblate, the radius of S^2 is larger than that of S^1, while the inner horizon is prolate, the radius of S^2 is smaller than that of S^1. These black holes are fully five-dimensional in the vicinity of the black hole while effectively four-dimensional with a compact extra dimension at the infinity. In the degenerate horizon limit, we obtain a BPS black hole solution, the extremal charged Kaluza-Klein black hole on the Taub-NUT space. I extended this BPS solution to multi-black holes on the multi-centered Gibbons-Hawking space [11]. The spatial cross section of each black hole horizon is admitted to have the topology of a different lens space $L(\mathrm{n};1) = S^3/Z_n$ (n:natural numbers) in addition to S^3. I also obtained multi-black holes with a positive cosmological constant [9].

I extended these static squashed Kaluza-Klein black holes to have angular momenta in the five-dimensional Einstein-Maxwell system with a Chern-Simons term [3, 5]. These solutions describe non-BPS charged black holes rotating in the direction of the extra dimension. These solutions can have two parameters which describe a “Kerr rotation” and a “Gödel rotation”. The black hole solution in [5] has a “Kerr rotation” parameter associated with the rotation of the black hole, while the squashed Kerr-Gödel black hole solution in [3] has two independent rotation parameters associated with the “Kerr rotation” and the “Gödel rotation”. The squashed Kerr-Gödel black holes admit two disconnected ergoregions, an inner ergoregion attached to the black hole horizon and an outer ergoregion with a shape of shell disjointed from the inner one. These two ergoregions can rotate in the opposite direction as well as in the same direction.

I also obtained slowly rotating charged Kaluza-Klein black hole solutions of the five-dimensional Einstein-Maxwell-dilaton theory with arbitrary dilaton coupling constant α [1]. The dilaton field and the non-trivial asymptotic structure of the solutions modify the gyromagnetic ratio of the black holes. I found that the gyromagnetic ratio crucially depended on the dilaton coupling constant and decreased with increasing α for any size of the compact extra dimension.

Coalescence of Rotating Black Holes

There exist five-dimensional black hole solutions with the different horizon topologies, i.e., the S^3 horizons and the lens space $L(\mathrm{n};1) = S^3/Z_n$ horizons. The variety of the horizon topologies are related to the asymptotic structures of the spacetime. To discuss these properties, I constructed new charged rotating multi-black hole solutions on the Eguchi-Hanson space in the five-dimensional Einstein-Maxwell system with a Chern-Simons term and a positive cosmological constant [7]. In the two-black holes case, these solutions describe the coalescence of two rotating black holes with the horizon topologies of S^3 into a single rotating black hole with the horizon topology of the lens space S^3/Z_2 in the space with the non-trivial asymptotic structure. On the other hand, the two-centered Klemm-Sabra solutions describe the coalescence of two rotating black holes with the horizon topologies of S^3 into a single rotating black hole with the horizon topology of S^3 in the space with the trivial asymptotic structure. Thus I compared my solutions with the two-centered Klemm-Sabra solutions. As a result, I saw that the horizon areas of the final black hole after the coalescence depended on the angular momenta. It was clarified that the difference of the dependence between two cases was related to the asymptotic structures of the higher dimensional spacetime.

I also extended the squashed Kerr-Gödel black hole to rotating multi-black holes with the Gödel parameter [4]. Each black hole can have an inner and an outer ergoregions. I explicitly presented the various shapes of these ergoregions in the case of two black holes with the phenomena of merging ergoregions.