

Summary of my past research

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I have been studying physical phenomena in strong gravitational environment, in particular, black holes. While my research is based on the theory of general relativity, my main purpose is to clarify the method for finding evidences of new physics that have not been established so far. Technically, I am very good at performing heavy numerical simulations. At the same time, I also study properties of black holes with purely mathematical approaches. I list up my research topics one by one.

Higher-dimensional black holes (Before 2011)

In this period, I studied gravitational phenomena in higher-dimensional spacetimes. The motivation is that many theories, e.g., string theories, suggest that our spacetime has invisible extra dimensions. In particular, the “braneworld model” suppose that gauge particles and interactions are confined on a three-dimensional brane, and only gravity propagates the extra dimensions. The extra dimensions can be as large as 1mm, and the Planck energy, at which all four interactions are supposed to be unified, becomes as low as $O(\text{TeV})$. Then, mini black holes could be produced by particle accelerators. My papers with particular importance are:

- [I-29]: Calculation of black hole production cross section in high-energy particle collisions;
- [I-14]: Formulation and code development of higher-dimensional numerical relativity.

Using the method developed in [I-14], I and a collaborator have shown that rapidly rotating higher-dimensional black holes are unstable against non-axisymmetric perturbation [I-8].

Phenomena caused by axion fields around a black hole (2011–present)

From 2011, I have been studying the behavior of massive scalar fields in four-dimensional black hole spacetimes. This study is related to the trial to detect low energy phenomena caused by string theories. There are various modes of changing shape of extra dimensions, and they behave as fields in the four-dimensional spacetime. Some of them are scalar fields with tiny mass (axion-like fields). Such axion-like fields may cause observable phenomena in the context of cosmology and astrophysics. My important results obtained so far are

- [I-4, I-9]: Simulations of axion-like field around a rotating black hole.

Around a rotating black hole, the field grows by extracting the rotation energy of the black hole (i.e. superradiant instability) to form an axion cloud. I have shown that when the field amplitude grows to a certain point, nonlinear self-interaction causes violent phenomena. Also, I have been developing codes to calculate gravitational waves emitted by the axion cloud. I have completed the code for the case that the black hole is nonrotating, and reported it in the paper [I-4]. The results indicate that burst gravitational waves are emitted when the scalar field behaves violently.

Behavior of light around black holes (Recent research)

Recently I am interested in the behavior of photons around black holes [I-1, I-2, I-3]. The motivation is that it would become possible to observe neighborhood of black holes with electromagnetic waves in near future, with which we can access validity of general relativity. So, it is important to study propagation of light around a black hole in advance. I studied the property of the “photon surface” on which propagating photons stay eternally. I clarified the fact that the photon surface exists only in a very special situation (i.e., the Schwarzschild black hole) [I-3], and proved that its area is bounded from above as $A \lesssim 4\pi(3M)^2$ [I-1].