Research Results

Yota Endo

It is believed that supermassive (with a mass greater than one million times that of the Sun) objects, whose energy is localized in an extremely small region, exist in the center of galaxies. Here, we call such objects, which localize energy, compact astronomical objects. Recently, the region near these objects can be observed. It is the main topic for astrophysics to understand the formation mechanisms of compact astronomical objects and the phenomena around those objects. Compact astronomical objects have been thought to be possibilities, including the black hole (BH). I have studied the theoretical descriptions and analyses of supermassive compact astronomical objects and the phenomena surrounding them.

Boson stars as candidates for supermassive compact astronomical objects [1]

It is known that stable solutions, whose energy is localized in a spatially bounded region, exist in some kinds of non-linear field theories. As an example of such solutions, solutions, called non-topological soliton (NTS) solutions, exist in the theory of complex scalar fields with U(1) symmetry. The theory I consider, which includes a complex scalar field, a gauge field, a Higgs scalar field (the GH scalar model), and a gravitational field, also admits NTS solutions (boson stars).

I have obtained numerical solutions of the spherical and stationary boson stars, and discussed their properties. These results were published in the physics journal Physical Review D. This study was carried out in collaboration with H. Ishihara and T. Ogawa (affiliated with OCAMI).

Vacuum magnetosphere around Kerr black hole with a thin disk [3]

There is a region around compact astronomical objects where plasma and electromagnetic fields are believed to exist, and this region is called a magnetosphere. This study aims to construct a theoretical model to describe the structure of the magnetosphere. As a first step of this study, we considered the case that compact astronomical objects were regarded as BHs of vacuum magnetospheres around BHs, where plasma was ignored. The advantage for this approximation is to obtain analytical solutions to the Maxwell equations, which determine electromagnetic fields.

We analyzed the stationary, axisymmetric and vacuum magnetosphere with the electric current flowing in the azimuthal direction on the disk at the equatorial plane (toroidal currents) as the source, in the Kerr spacetime as the background spacetime representing the rotating BH. It is known that, by using the Newman-Penros formalism, the Maxwell equations become separable, and are expressed as a set of ordinary differential equations in the electromagnetic field quantities. Boundary conditions at the event horizon and infinity were imposed. The whole solutions were constructed by matching the vacuum solutions, which were regular only in either the upper (northern) region or lower (southern) region with respect to the equatorial plane. The matching was performed using a junction condition given by the current distribution on the equatorial plane. In previous studies, the vacuum magnetospheres with a ring current on the equatorial plane as the source are known. However, to extend this to the case of a disk current, it was necessary to superpose the magnetosphere with ring currents at different radii. In contrast, in this study, the current distribution on the equatorial plane was directly given as the source, and the analytical solutions for the magnetosphere with a disk current were obtained. The novelty of our approach lies in obtaining these analytical solutions.

Next, in order to understand the properties of this magnetosphere, we analyzed the magnetosphere with a given current distribution. It was found that, if the current distribution was fixed regardless of the BH's rotation, the global structure of the magnetic field is independent of the BH's rotation. If the BH has no electric charge, the magnetic field lines are expelled from the event horizon as the BH's rotation approaches its maximum allowed value. It was also found that, when the direction of the toroidal current was reversed at some radius, two regions with distinct magnetic field structures were formed in the magnetosphere. In this model, the main feature is that the electric field is generated by the magnetic field due to the BH's rotation. The existence of the electric field suggests the acceleration of charged particles and charge accretion onto the BH. These results provide a fundamental understanding of the structures of BH magnetospheres and the occurrence of electric fields. This study was carried out in collaboration with H. Ishihara (affiliated with OCAMI) and M. Takahashi (affiliated with Aichi university of education), and was also published in the physics journal Physical Review D.