Summary of research

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Estimation of Dark Matter around Sgr A* from S-star Observations :

At the center of the Milky Way Galaxy, there exists a cluster of stars known as S stars that orbit the supermassive black hole Sgr A*. Observations of their orbital motions provide a powerful tool not only for testing black hole physics in strong gravitational fields, but also for probing the distribution of dark matter in the central region. In recent years, for example, observations of the pericenter passage of the S2 star have confirmed consistency with the first post-Newtonian (1PN) correction terms predicted by the post-Newtonian approximation, yielding significant results as a test of general relativity in the strong-field regime. At the same time, dark matter that may exist around Sgr A*—such as axion fields or Proca fields—is expected to contribute as small deviations from general relativity.

In this study, we have developed analysis methods in preparation for estimating dark matter distribution parameters using forthcoming pericenter passage data of the S24 star to be obtained with the Subaru Telescope. In particular, we organized statistical approaches for estimating various parameters appearing in the equations of motion of S stars described within the post-Newtonian approximation, as well as in the observational model, including orbital parameters such as eccentricity, positions on the sky, and line-of-sight velocities. As a preliminary step prior to the availability of S24 observational data, we investigated the behavior of parameter fitting using the least-squares method and examined its applicability. In addition, we studied the framework of posterior distribution sampling using the Hamiltonian Monte Carlo (HMC) method and explored its potential applicability to S-star orbital analyses.

As a result, we found that for the least-squares method, the parameters to be estimated enter directly into the equations of motion of S stars, which requires solving the corresponding differential equations numerically each time the model predictions are evaluated. Consequently, the standard least-squares fitting routines implemented in *Mathematica*, which assume that the model can be expressed in an analytic functional form, cannot be used directly. This led to the conclusion that a custom fitting code must be constructed in order to apply the least-squares method. On the other hand, for the HMC method, this year ' s work focused primarily on studying its theoretical background and algorithms. In future work, we plan to implement posterior sampling on top of the fitting code developed for the least-squares analysis and to estimate various parameters, including the orbital elements of the S24 star.