Summary of My Research to Date

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Research Background

I study the theoretical properties of black holes without singularities—so-called *regular black holes*. There are three main reasons to consider regular black holes. First, general relativity is currently the most compelling theory of gravity and successfully explains a wide range of observational results; however, as indicated by the singularity theorems, gravitational collapse inevitably leads to singularity formation, revealing a limitation in the self-consistency of the theory. Regular black holes provide a minimal effective description that can evade the conclusion that "the center after gravitational collapse must necessarily become singular," and they serve as a concrete example of treating the expected singularity resolution due to quantum-gravity effects or high-curvature corrections in the language of geometry. Second, black holes are expected to evaporate via Hawking radiation, but the final stage of evaporation remains unresolved; for standard black holes containing singularities, the information-loss problem arises, in which events in the future become unpredictable from the past, undermining the foundations of physics. Regular black holes intrinsically allow the possibility that no singularity remains at the center even as evaporation proceeds, and they provide a foothold for addressing the information-loss problem from the viewpoint of spacetime structure, i.e., geometry. Third, methods for constructing regular black holes are still under development. Therefore, before delving into the details of specific models, extracting and understanding the geometric properties of regular black holes contributes to establishing a theoretical foundation for deepening our understanding of real black holes and, ultimately, of the universe.

My Research to Date

I have mainly studied the global structure of evaporating regular black holes. This is because many of the concepts that characterize black holes are defined and discussed on the basis of global structure. Starting from the fact that a black hole itself is defined in terms of the global structure of spacetime, the global structure also plays a central role when discussing the information-loss problem and the stability of spacetime. Hence, investigating the global structure of spacetime provides a foundation for black hole research. In particular, I have studied the following two qualitatively different scenarios for the evaporation of regular black holes.

(A) Complete evaporation in finite time (model analysis, [1])

Assuming a situation in which the black-hole mass reaches zero in finite time and the spacetime subsequently transitions to Minkowski spacetime, Wr analyzed a time-dependent model describing this process. We demonstrated that no event horizon forms in this spacetime; namely, from the viewpoint of predictability, it is a spacetime in which the information-loss problem is avoided.

(B) Infinite-time evaporation (asymptoting to an extremal state) (model-independent classification, [2])

In a quasi-static evaporation picture, a regular black hole can asymptote to an extremal state, so that evaporation takes an infinite amount of time. In this study, without relying excessively on a specific metric form, We systematically investigated the possible global structures by using the asymptotic behavior of outgoing radial null geodesics under geometric assumptions such as spherical symmetry, regularity, asymptotic flatness, the existence of inner and outer trapping horizons, and asymptotic approach to an extremal state. In particular, the main results are (i) a complete classification of the possible global structures and (ii) the derivation of sufficient conditions determining which spacetime structure is realized.