Summary of research achievements

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My doctoral thesis focused on constructing phenomenological models of elementary particles based on exceptional Lie groups. In particular, I demonstrated that quark and lepton spectra consistent with observations can be derived from supersymmetric nonlinear sigma models of type E_ℓ (ℓ=6,7,8). Furthermore, by applying the index theorem, I classified the homogeneous spaces of exceptional groups that are free from quantum anomalies [2]-[6].

Following this work, I studied perturbative superstring theory and soliton (BPS) solutions in supergravity theory. To formulate superstring perturbation theory in a manifestly supersymmetric manner, I attempted to extend the standard theory of Riemann surfaces to that of super Riemann surfaces [10]-[15]. Around 2000, my research gradually shifted toward Einstein's theory of gravity, particularly toward Ricci-flat Einstein metrics with special holonomy. These metrics play an essential role in describing soliton solutions in supergravity and string theory. A notable achievement from this period is my joint work with Hiroaki Kanno at Nagoya University [31][32], in which we discovered new Ricci-flat metrics with Spin(7) exceptional holonomy.

After Maldacena's proposal of the AdS/CFT correspondence, solutions of the Einstein equation with a cosmological constant, $Ric(g) = \Lambda\ g$, also became relevant as gravitational solitons. In collaboration with Yoshitake Hashimoto (Osaka City University) and Makoto Sakaguchi (COE Researcher, Osaka City University), we constructed new compact Einstein manifolds using black-hole geometries [35]. This work generalized Page's famous 4-dimensional Einstein metric (1979) to the 5-dimensional setting and revealed that infinitely many Einstein metrics can be induced from AdS black hole metrics. In intensive lecture series at University of Shizuoka and Nara Women's University in 2006, I also surveyed my work on the geometry of Kerr black holes and Sasaki-Einstein metrics [36]-[44].

Through these developments, understanding black hole geometry became a major motivation for constructing explicit Einstein manifolds. Page's metric is well known in differential geometry as the first example of inhomogeneous Einstein metrics, but originally it arose in an attempt to model Hawking's idea that the universe may nucleate from "nothing" via quantum tunneling, using a black hole metric. This historical background led me to approach black hole geometry from a perspective different from that of specialists in gravitational physics.

In [51][52], we classified higher-dimensional black hole spacetimes possessing conformal Killing-Yano tensor symmetries. This work was selected as one of the Highlights of 2008/2009 by Classical and Quantum Gravity. We were also invited to contribute to the special issue on higher-dimensional black holes edited by Maeda, Shibata, and Tanaka, where we reviewed our series of results on black-hole geometry [45]-[60] in [59].

In the JSPS Grant-in-Aid for Scientific Research (A) project "AdS Correspondence and GIT Stability" (PI: Akito Futaki), our aim was to provide a mathematical framework for the AdS/CFT correspondence from the viewpoint of Sasaki manifolds, and I contributed to this effort through my work on Einstein metrics and geometric structures related to black hole spacetimes.