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Editorial

Black Holes: Insights and Enigmas

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The study of black holes has been a central feature of general relativity since its birth in 1915. Shortly after Einstein wrote down the field equations of general relativity, Karl Schwarzschild discovered the first and simplest solutions which represented the gravitational field of a massive body with spherical symmetry, but without any other features like angular momentum or charge. It was noticed that this Schwarzschild solution had a place where the metric apparently became singular, the Schwarzschild radius, which for a spherical body of mass M occurred at the distance $2\,\mathrm{Gm/c^2}$. It was initially hoped that "realistic" objects could never be compressed to the extent that the material of the body would be less than this Schwarzschild radius. In the late 1930s starting with the work of Oppenheimer and Snyder, it became clear that it was possible for a material object to be compressed past its Schwarzschild radius and become a black hole. But what of the apparent singularity at the Schwarzschild radius? In the early 1960s, Kruskal and Szekeres were able to find a coordinate system which showed that the Schwarzschild singularity at $r = 2\,\mathrm{Gm/c^2}$ was an artifact of the coordinates that had been used by Schwarzschild and others. The only real singularity in the Schwarzschild solution was the one at the origin, namely, $r = 0$. Thus the study of black holes has been a prompt for pushing forward the understanding of the physical meaning of general relativity as well as better understanding what the complex math was saying physically.

In the mid-1970s, research led by Bekenstein, Hawking, and others showed that there was a deep connection between black hole physics and quantum mechanics and thermodynamics. Bekenstein was the first to argue that a black hole should have an entropy associated with it and that this entropy should be proportional to the surface area of the event horizon as defined by the Schwarzschild radius. Following on this work, Hawking showed, by applying quantum field theory in the background of a black hole, that black holes emitted thermal radiation and had a temperature now known as the Hawking temperature. These seminal works have led to researchers viewing black holes as a theoretical laboratory to giving hints as to the proper path toward a formulation of the as yet undiscovered theory of quantum gravity. This has led to the concepts like black hole information paradox, the holographic principle and the firewall puzzle, and a host of other interesting conjectures and puzzles.

Finally, with the advent of more powerful telescopes and observing equipment, both on the ground and in space, researchers have begun to gather observational evidence for the existence of black holes, including finding that in the heart of most galaxies there are enormous black holes of million plus solar masses. In our galaxy this "center of the galaxy" black hole is called Sagittarius A^*. More recently, with the detection of gravitational waves by the LIGO scientific collaboration, we have very strong evidence of binary black hole coalescence, which resulted in the awarding of the 2017 Physics Nobel Prize.

This special issue is devoted to works which carry on the tradition of studying various aspects of black holes to

understand the workings of gravity as well as other branches of physics.

In the paper by D.-Q. Sun et al. entitled "Hawking Radiation-Quasinormal Modes Correspondence for Large AdS Black Holes" the authors investigate the not exactly thermal nature of the Hawking radiation emitted by a black hole. They find a connection between Hawking radiation and the quasi-normal modes of black holes. They apply their analysis to Schwarzschild, Kerr, and nonextremal Reissner-Nordstrom black holes. They pay particular attention to these black holes in anti-de Sitter spacetime.

In the paper "P-V Criticality of a Specific Black Hole in $f(R)$ Gravity Coupled with Yang-Mills Field" by A. Övgün, a study is made of specific charge anti-de Sitter black holes in $f(R)$ gravity with a Yang-Mills field. Using thermodynamics analogies, it is found that this complex gravitational system behaves like the thermodynamic system of a van der Waals gas at critical points of the system. It is also found that the phase transition between small and large specific charge AdS black holes is a first-order phase transition.

In the paper by S. Chakraborty, entitled "Field Equations for Lovelock Gravity: An Alternative Route," the author studies an alternative derivation of the gravitational field equations for Lovelock gravity starting from Newton's law, which is closer in spirit to the thermodynamic description of gravity. Projecting the Riemann curvature tensor appropriately and taking a cue from Poisson's equation, the generalized Einstein's equations in the Lanczos-Lovelock theories of gravity are derived.

In the paper by W. Zhang and X.-M. Kuang, entitled "The Quantum Effect on Friedmann Equation in FRW Universe," the quantum mechanically modified Friedmann equation for the Friedmann-Robertson-Walker universe is derived. The authors also analyze the modified Friedmann equations using the conjecture by Padmanabhan of a modified entropy-area relation.

In the paper by M. He et al., entitled "Discussion of a Possible Corrected Black Hole Entropy" by using T. Padmanabhan's local formalism, which avoids addressing the asymptotically flat structure of spacetimes, the authors derive the analogue of the first law of thermodynamics for the AdS black holes in Eddington-inspired Born-Infeld (EiBI) gravity with and without matter fields. The same formalism has also been used to express Einstein's field equations in the form of the first law of thermodynamics, for a static spherically symmetric spacetime near any horizon of a definite radius. In accordance with their results, the authors conclude that since Einstein gravity and EiBI gravity give the same results, from thermodynamics' point of view, both of these theories of gravity could be equivalent on the event horizon.

The present volume collects together works which use black holes as a theoretical laboratory for understanding how gravity works and how gravity might fit in with the other theories of modern physics and in particular quantum mechanics.

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