Hindawi
Advances in High Energy Physics
Volume 2019, Article ID 5726836, 4 pages
https://doi.org/10.1155/2019/5726836

Editorial

Classical and Quantum Approaches to Black Holes

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Received 6 March 2019; Accepted 6 March 2019; Published 1 April 2019

This special issue aims to investigate both classical and quantum approaches to black holes. The result is a collection of eighteen original research articles submitted by authors representing fifteen countries across Asia, Europe, North America, and South America.

In their article "An Alternative Approach to the Static Spherically Symmetric, Vacuum Global Solution to the Einstein Equations", L. Herrera and L. Witten propose an alternative description of the Schwarzschild black hole solution by extending the solution outside the horizon to its interior. Indeed, based on the requirement that the solution is static not only outside but also inside the horizon, the authors consider the entire space-time resulting from the union of two static 4-manifolds, one for $0 < R < 2m$ with signature (+ - - -) and one for $2m < R < \infty$ with signature (- + + +) with the horizon as a common boundary. In this way, the entire space-time is described by a complete 4-manifold for the interior and a complete 4-manifold for the exterior, and a global static solution is obtained representing a "phase transition" on the horizon with a different symmetry on both sides of the latter. The horizon surface $R = 2m$ is excluded from both manifolds which meet there only for $\theta = 0$. As a result, within the horizon the time independence is kept but the spatial symmetry is changed. Then, by examining test particles, it is concluded that the complete picture of their motion near the horizon cannot be fully understood by use of Einstein's field equations alone and the need of a quantum theory approach is stressed.

When sound perturbations are trapped in a supersonic fluid flow system, they behave similarly to trapped photons in black holes and the system considered is a black hole analogue called acoustic (or sonic) black hole or simply *dumb hole*. The border at which the fluid speed changes from greater to lesser than the local speed of sound is the event horizon of the acoustic black hole. The article "Interactions in an Acoustic World: Dumb Hole", by I. Simaciu et al., is a follow-up to earlier published work on the so-called "acoustic world", the latter being defined as the finite volume of a fluid or of a solid containing the fluid, together with the processes occurring within this volume. By assuming that the acoustic processes are similar to the processes occurring in vacuum, the authors examine interactions between inhomogeneities of an acoustic medium that are produced by acoustic perturbations travelling in this medium. In this context, the inhomogeneities induced by a wave or a wave packet are studied and the dumb hole corresponding to the acoustic wave packet is examined.

The *polymer quantization* procedure was developed in background independent approaches to quantum field theory and its name relied on the fact that the basic quantum excitations of gravity and gauge field theories are one-dimensional, polymer-like excitations. In loop quantum gravity space-time exhibits a granular structure, thus supporting the existence of a fundamental length in the theory. Polymer quantization comes forward as an *effective theory* that uses a minimal length scale and, in fact, one is led to polymer quantization

in mini-superspace models of quantum cosmology. Now, the polymeric length (that shows the scale of the segments of granular space-time) plays the role of the minimal length of the theory and labels the granular properties of space entering, as an additional quantum parameter, the Hamiltonian of the system deforming it into the *polymeric Hamiltonian*. In the article "Classical Polymerization of the Schwarzschild Metric", B. Vakili studies how the Schwarzschild black hole metric is modified by applying the classical polymerization procedure. The energy-momentum tensor of the matter field corresponding to the new polymerized metric and some of its thermodynamic properties are examined, while radial null as well as time-like geodesics are also examined and some interesting conclusions are drawn showing that the polymerized metric still describes a black hole space-time.

In their paper "Localization of Energy-Momentum for a Black Hole Spacetime Geometry with Constant Topological Euler Density", I. Radinschi et al. address the topic of energy-momentum localization in General Relativity by using various energy-momentum complexes. They calculate the energy and momentum of a four-dimensional black hole space-time geometry with constant topological Euler density with the aid of the Einstein and Møller prescriptions. The energy obtained depends on the mass M and the charge q of the black hole, the cosmological constant λ, and the radial coordinate r, while in both prescriptions all the momenta vanish. Some limiting and particular cases are analyzed and discussed, illustrating the rather extraordinary character of the space-time geometry studied. The conclusion is that the Einstein and Møller prescriptions may provide an instructive tool for the energy-momentum localization.

In recent years, two issues of great interest that are extensively studied are the black hole information paradox and the black hole entropy. In his article "Revisiting the Black Hole Entropy and the Information Paradox", O. C. Stoica revisited some paradoxes and also the black hole complementarity and the rewall proposals, with an emphasis on the less obvious assumptions. In order to carry out this study, arguments used in the literature are reviewed, and also some new counterarguments are presented. Furthermore, some less considered less radical possibilities are examined, and the subject of an interesting discussion is a conservative solution, which is more consistent with the principle of equivalence from General Relativity and also with the unitarity from quantum theory.

In their article "Nonlocal Black Hole Evaporation and Quantum Metric Fluctuations via Inhomogeneous Vacuum Density", A. Y. Yosifov and L. G. Filipov examine the back-reaction of a Schwarzschild black hole to the highly inhomogeneous vacuum density. Also, the authors argue that the fluctuations lead to deviations from General Relativity in the near-horizon region. It has been found that vacuum fluctuations onto the horizon trigger an adiabatic release of quantum information. In the vicinity of the horizon vacuum fluctuations produce potentially observable metric fluctuations of the order of the Schwarzschild radius. The authors propose a form of strong nonviolent nonlocality in which it is possible to obtain simultaneously a nonlocal release of quantum information and observable metric fluctuations.

In the paper "Tunneling Glashow-Weinberg-Salam Model Particles from Black Hole Solutions in Rastall Theory", A. Övgün et al. solve an equation of motion for the Glashow-Weinberg-Salam model with the aid of the semiclassical WKB approximation and the Hamilton-Jacobi method. This is especially useful for understanding the unified gauge-theory of weak and electromagnetic interactions. In this light, the tunneling rate of the massive charged W-bosons in the background of an electromagnetic field has been calculated, in order to study the Hawking temperature in the case of black holes surrounded by a perfect fluid in Rastall theory. Further, the quantum gravity effects on the generalized Proca equation with generalized uncertainty principle (GUP) on this background have been examined. It is demonstrated that quantum gravity effects leave their remnants on the Hawking temperature. Also, it is proved that the Hawking radiation becomes nonthermal.

In the letter "Thermodynamic Volume Product in Spherically Symmetric and Axisymmetric Spacetime", P. Pradhan investigates the thermodynamic volume products for spherically symmetric and axisymmetric space-time in the framework of extended phase space. These volume products are expressed in terms of the outer and inner horizons of black holes and, together with other thermodynamic expressions like volume sum, volume minus, and volume division, are useful in the case of different spherically symmetric space-times and axisymmetric space-times. The thermodynamic volume products for the outer horizon and for the inner horizon of several classes of spherically symmetric and axisymmetric black holes including the AdS black hole metric are calculated. In these cases, it is found that the simple volume product of $H^{\pm}$ is not mass independent, but more complicated volume functional relations are mass independent.

Due to its multifunctional properties the entropic force attracts a lot of interest. In their paper "Rainbow Gravity Corrections to the Entropic Force", Z.-W. Feng and S.-Z. Yang, employing the new kind of rainbow gravity model of Magueijo and Smolin, investigate the quantum gravity corrections to the entropic force. In order to make this study, they derive the modified thermodynamics of a rainbow black hole via its surface gravity, and after this the quantum corrections to the entropic force are obtained according to Verlinde's theory. The conclusion is that the modified entropic force is related to both the properties of the black hole and the Planck length l_{p} and the rainbow parameter γ. Also, modified Einstein's field equations and the modified Friedmann equation are obtained based on the rainbow gravity corrected entropic force.

In their paper "Perfect Fluid Dark Matter Influence on Thermodynamics and Phase Transition for a Reissner-Nordstrom-Anti-de Sitter Black Hole", Z. Xu et al. have studied the thermodynamics and phase transition by extending the phase space defined by the charge square and the conjugate quantity, with the latter being a function of the horizon radius. They found that the thermodynamics

systems are similar to van der Waals systems and can be explained by mean field theory. The Ruppeiner thermodynamic geometry feature and the connection with microscopic structure have also been studied. The authors found that in extended phase space there are singularity points of Ruppeiner curvature and these points could be explained as phase transitions.

In their paper "New Phase Transition Related to the Black Hole's Topological Charge", the authors S.-Q. Lan et al. performed a study about a new phase transition related to the topological charge in Einstein-Maxwell theory. They derived the explicit solutions corresponding to the divergence of specific heat in order to determine the phase transition critical point. Furthermore, the curves T-r and T-S are investigated and found to exhibit an interesting van der Waals system's behavior. Also, a van der Waals system's swallow tail behavior is observed when the topological charge is greater than the corresponding value in the critical point in the F-T graph. The analytic phase transition coexistence lines have been obtained by using the Maxwell equal area law and free energy analysis, the results of which are consistent with each other.

In his paper "A Covariant Canonical Quantization of General Relativity" S. Marongwe presents a Hamiltonian formulation of General Relativity within the context of the Nexus Paradigm of quantum gravity. He demonstrates that the Ricci flow in a compact matter free manifold serves as the Hamiltonian density of the vacuum as well as a time evolution operator for the vacuum energy density. An interpretation of General Relativity in terms of the fundamental concepts of quantum mechanics has been possible in the condition of the metric tensor of General Relativity expressed in terms of the Bloch energy eigenstate functions of the quantum vacuum.

In the work "λ Phase Transition in Horava Gravity" the author W. Xu has presented a superfluid black hole containing a λ phase transition in the context of Horava gravity. After studying the extended thermodynamics of general dimensional Horava-Lifshitz AdS black holes, it is found that only the one with a spherical horizon in four and five dimensions has a λ phase transition, which is a line of (continuous) second-order phase transitions and was famous in the discussion of the superfluidity of liquid ^{4}He. The "superfluid" black hole phase and the "normal" black hole phase are also distinguished. Particularly, six-dimensional Horava-Lifshitz AdS black holes exhibit infinitely many critical points in $P - \nu$ plane and the divergent points for specific heat, for which they only contain the "normal" black hole phase while the "superfluid" black hole phase disappears due to the physical temperature constraint and therefore there is no similar phase transition. In this context, the author has shown that, in more than six dimensions, there is no $P - \nu$ critical behavior. After choosing the appropriate ordering field, the author studied the critical phenomena in different planes of thermodynamical phase space along with a calculation of the critical exponents, which are the same as for the van der Waals fluid.

In the investigation "Anti-de-Sitter-Maxwell-Yang-Mills Black Holes Thermodynamics from Nonlocal Observables Point of View", H. El Moumni analyzes the thermodynamic properties of the Anti-de-Sitter black hole in the Einstein-Maxwell-Yang-Mills- (EMYM-) AdS gravity via many approaches and for different thermodynamical ensembles (canonical/grand canonical). First, the author gives a concise overview of this phase structure in the entropy-thermal diagram for fixed charges and then he investigates this thermodynamical structure for the fixed potentials ensemble. The next relevant step is recalling the nonlocal observables such as holographic entanglement entropy and two-point correlation function to show that both observables exhibit a van der Waals-like behavior in numerical accuracy and just near the critical line as the case of the thermal entropy for fixed charges by checking Maxwell's equal area law and the critical exponent. In the light of the grand canonical ensemble, the author also finds a new phase structure for such a black hole where the critical behavior disappears in the thermal picture as well as in the holographic one.

The thermodynamic property of a charged AdS black hole is studied in rainbow gravity. In their article entitled "Thermodynamics of Charged AdS Black Holes in Rainbow Gravity", P. Li et al. got a deformed temperature in a charged AdS black hole using no-zero mass of a test particle. Their result shows that the phase structure has a relationship to an AdS radius l. In particular, an analogy between the charged AdS black hole in the rainbow gravity and the liquid-gas system is discussed. Finally, the Gibbs free energy has been examined and a characteristic "swallow tail" has been obtained that can be the explanation of a first-order phase transition.

In the work "Particle Motion around Charged Black Holes in Generalized Dilaton-Axion Gravity", the authors S. Sarkar et al. have studied the behavior of massive and massless test particles around asymptotically and spherically symmetric, charged black holes in the context of generalized dilaton-axion gravity in four dimensions. The motion of a massive and charged test particle in the gravitational field of a charged black hole in generalized dilaton-axion gravity has been examined by exploiting the Hamilton-Jacobi equation.

In mid 2010's, full discreteness of the Hawking radiation spectrum and the Maxwell-Boltzmann nature of the Hawking radiation spectrum were found. So, a new area spectrum is presented. In his paper entitled "Hawking Radiation of a Single-Partition Black Hole", Y. Yoon showed what the thermodynamics of a single-partition black hole implies about the degeneracy of the area spectrum. As a consequence, the decay time of a single-partition black hole is roughly constant.

In the article "Spectroscopy of $z = 0$ Lifshitz Black Hole" G. Tokgoz and I. Sakalli have studied the thermodynamics and spectroscopy of a 4-dimensional, z = 0 Lifshitz black hole. The entropy/area spectra of the z = 0 Lifshitz black hole are computed. The quantum spectra of the z = 0 Lifshitz black hole were studied using the Maggiore method, which is based on the adiabatic invariant quantity. Their finding is in agreement with Bekenstein's conjecture, and the equispacing of the entropy/area spectra of the z = 0 Lifshitz black hole supports Kothawala et al.'s hypothesis.

Conflicts of Interest

The editors declare that they have no conflicts of interest regarding the publication of this special issue.

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