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Growth and merging phenomena of black holes: observational, computational and theoretical efforts

G.Ter-Kazarian*

Byurakan Astrophysical Observatory, 378433, Aragatsotn District, Armenia

Abstract

We briefly review the observable signature and computational efforts of growth and merging phenomena of astrophysical black holes. We examine the meaning, and assess the validity of such properties within theoretical framework of the long-standing phenomenological model of black holes (PMBHs), being a peculiar repercussion of general relativity. We provide a discussion of some key objectives with the analysis aimed at clarifying the current situation of the subject. It is argued that such exotic hypothetical behaviors seem nowhere near true if one applies the PMBH. Refining our conviction that a complete, *self-consistent* gravitation theory will smear out singularities at huge energies, and give the solution known deep within the BH, we employ the *microscopic theory of black hole* (MTBH), which has explored the most important novel aspects expected from considerable change of properties of space-time continuum at spontaneous breaking of gravitation gauge symmetry far above nuclear density. It may shed further light upon the growth and merging phenomena of astrophysical BHs.

Keywords: *galaxies: nuclei—black hole physics—accretion*

1. Introduction

One of the achievements of contemporary observational astrophysics is the development of a quite detailed study of the physical properties of growth and merging phenomena of astrophysical black holes, even at its earliest stages. But even thanks to the fruitful interplay between the astronomical observations, the theoretical and computational analysis, the scientific situation is, in fact, more inconsistent to day. Wheeler in 1967 coined a spacetime region, where the gravitational field is so strong that no information carrying objects and signals can escape it, by the term 'a black hole' (BH), although the possibility of the existence of such objects was discussed a long time before this. At the end of the eighteenth century Michell and Laplace independently came to the conclusion that if the mass of a star were large enough its gravity would not allow light to escape. Though this conclusion was based on the Newtonian theory the obtained result for the size of such 'dark stars' (the gravitational radius) coincides with the later prediction of Einstein's theory of gravity (see e.g. Barrow & Barrow, 1983, Israel, 1987). A principle feature that makes general relativity (GR) distinctively different from other field theories is the occurrence of curvature singularities in spacetime. The singularities lead to regions of the universe that cannot be observed. This causes an observer's inability to access the degrees of freedom that are hidden beyond the horizon which, in turn, leads to thermodynamical behavior of BHs. Notwithstanding, much remarkably efforts have been made in understanding of BH physics, many important issues still remain unresolved and, thus, a situation is unclear, than described so far. The astrophysical significance of the issue, and the importance of considering the gravitational collapse of a matter cloud within the framework of the GR theory, with reasonable physical properties for the matter included, stems from the fact that GR predicts that a star more massive than about five to eight times the mass of the Sun, cannot stabilize to a neutron star final state at the end of its life cycle. It must collapse continually under the force of its own gravity on exhausting its

*gago_50@yahoo.com

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internal nuclear fuel, and there are no known forces of nature that would halt such a collapse. General relativity predicts that such a star must then terminate into a spacetime singularity where densities and spacetime curvatures blow up and the physical conditions are extreme. The estimates on the mass limit for a star in order to collapse, of course, are indefinitely vary depending on different models for the star's interior and equation of state for matter at very high densities. One of the most important open issues in the theory and astrophysical applications of modern day BH and gravitation physics is that of the Roger Penrose's Cosmic Censorship Conjecture (CCC) (Penrose, 1969). The CCC assumption that any physically realistic gravitational processes must not lead to the formation of a singularity which is not covered by an horizon, thus hiding it from external observers in the universe. This of course includes the complete gravitational collapse of a massive star which, if the CCC is true, must terminate generically into a BH final state only. Such a singularity is then crucial and is at the basis of much of the modern theory and astrophysical applications of BHs today. Despite the past four decades of serious efforts, we do not have as yet available any proof or even any mathematically precise formulation of the cosmic censorship hypothesis. The consideration of dynamical evolution of collapse is a crucial element of the CCC. Many solutions of Einstein field equations are known which present naked singularities (such as, for example, the super-spinning Kerr solutions), nevertheless almost none of these solutions can be obtained as the dynamically evolved final state of some initially regular matter configuration. For this reason, over the last decades a great deal of work has been done to test the CCC in the few dynamically evolving spacetimes we know. These are typically the scenarios that describe gravitational collapse in spherical symmetry, and some non-spherical collapse models have also been considered, for examples of critical collapse with angular momentum. In recent years, a wide variety of gravitational collapse models have been discovered where exact analytical calculations (e.g Giambo, 2004, Goswami & Joshi, 2002, Joshi & Malafarina, 2011, 2013, Villas da Rocha & Wang, 2000, and ref. therein) have meanwhile shown that mass concentrations collapsing under their own weight will no longer form BHs as collapse endstate, rather naked singularities, except for configurations of highest symmetry which are, however, of measure zero among all initial data. By this, even the theoretical existence of BHs is no longer justified. The first examples were restricted to some classes of inhomogeneous dust collapse, and they were extended to the case of collapse in the presence of only tangential pressures, and perfect fluids. The existence of classes of pressure perturbations is shown explicitly, which has the property such that an injection of a small positive (or negative) pressure in the Oppenheimer, Snyder and Datt (OSD) model (Datt, 1938, Oppenheimer & Snyder, 1939), or in a Tolman-Bondi-Lemaitre (TBL) (Bondi, 1947, Lemaìtre, 1933, Tolman, 1934) inhomogeneous dust collapse to a BH (simplest generalization of the OS model), leads the collapse to form a naked singularity, rather than a BH (Joshi & Malafarina, 2013). The classic OSD scenario is the basic paradigm for BH physics today, and the TBL models describe the most general family of dust, i.e. pressureless, collapse solutions. This result is therefore intriguing, because it shows that arbitrarily close to the dust BH model, we have collapse evolution with non-zero pressures that go to a naked singularity final state, thus proving a certain "instability" of the OSD BH formation picture against the introduction of small pressure perturbations. In such a case, the super-ultra-dense regions, or the spacetime singularity, that forms at the end of collapse would be visible to faraway observers in the universe, rather than being hidden in a BH. Thus, rigorous calculations have shown that the expectations of the 1970s have been hasty, that CCC assumption has been premature, because while the CCC states that the OSD collapse final fate is necessarily replicated for any realistic stellar collapse in nature, the result here shows that an arbitrarily small pressure perturbation of the OSD model can change the final outcome of collapse to a naked singularity and therefore the OSD BH may be considered 'unstable' in this sense.

In this respect, the first goal of this communication is to review briefly the necessary ideas behind the various specific constructions and suggestions on the conceptual problems of GR, the singularities and the thermodynamics of BHs in semiclassical and quantum physics. The second goal is to concentrate on the critical discussion of the past and present states, evaluating those strategies, approaches etc., that are explicitly and unambiguously given and applicable in any generic spacetime. This short review encompasses the many discoveries which unlocked the mysteries or exposed some of the illusions of the considered field. Without it we cannot show how the matters stand, we almost bound of

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necessity to enter upon it, if we would write of them at all.

To innovate the solution to aforementioned problems, the third goal is to advocate with alternative proposal by utilizing the MTBH, which has explored a novel aspects expected from considerable change of properties of space-time continuum at spontaneous breaking of gravitation gauge symmetry far above nuclear density. It may shed further light upon the growth and merging phenomena of astrophysical BHs.

Although some key theoretical ideas were introduced with a satisfactory substantiation, we have also attempted to maintain a balance between being overly detailed and overly schematic. With this perspective in sight, we will proceed according to the following structure. To start with, in Section 2, we provide a brief discussion of the observable signature and computational efforts on understanding of growth and merging properties of BHs. Section 3 deals with the analysis aimed at clarifying the current situation of such properties within theoretical framework of PMBH. To fill the void which the standard PMBH presents and to innovate the solution to alluded problems, in Section 4 we recount some of the highlights behind of the MTBH, whereas the infra-structures will inevitably be accommodated inside the EH. The concluding remarks are given in Section 5.

2. The observable signature and computational efforts on understanding of growth and merging properties of BHs

With typical bolometric luminosity $\sim 10^{45-48}\mathrm{erg\,s^{-1}}$, the active galactic nuclei (AGNs) are amongst the most luminous emitters in the universe, particularly at high energies (gamma-rays) and radio wavelengths. From its historical development, up to current interests, the efforts in the AGN physics have evoked the study of a major unsolved problem of how efficiently such huge energies observed can be generated. This energy scale severely challenges conventional source models. The fact that accretion processes really take place in AGNs is already established and proven by many observations. The huge energy release from compact regions of AGN requires extremely high efficiency (typically ≥ 10 percent) of conversion of rest mass to other forms of energy. This serves for the majority of theoreticians as the main argument, without any physical justification, in favour of supermassive BHs (SMBHs), in the centers of, almost all, galaxies as central engines of massive AGNs. Within this scenario, a BH has been formed as an almost inevitable endpoint of the gravitational collapse of a large fraction of total mass of supermassive configuration occurring after entire burning of the whole amount of spared intrinsic energy. The BHs are fueled steadily from the thick accretion disks. Such evolutionary processes of accretion onto massive BHs as the prime energy sources have immense emissive power. The astrophysical BHs come in a wide range of masses, from $\geq 3\,M_\odot$ for stellar mass BHs (Orosz, 2003) to $\sim 10^{10}\,M_\odot$ for SMBHs (Lauer, 2007, Lynden-Bell, 2013). Demography of local galaxies suggests that most galaxies harbour quiescent SMBHs in their nuclei at the present time and that the mass of the hosted BH is correlated with properties of the host bulge. The visible universe should therefore be contained at least 100 billion supermassive BHs. A complex study of evolution of AGNs requires an answer to the key questions how the first black holes formed, how did massive BHs get to the galaxy centers, and how did they grow in accreting mass, namely an understanding of the important phenomenon of mass assembly history of accreting seeds of SMBHs. Given the current masses, most BH growth happens in the AGN phase. A significant fraction of the total BH growth, 60% (Treister, 2010), happens in the most luminous AGN, quasars. In an AGN phase, which lasts $\sim 10^8$ years, the central SMBH can gain up to $\sim 10^{7-8}M_\odot$, so even the most massive galaxies will have only a few of these events over their lifetime. The observations support the idea that BHs grow in tandem with their hosts throughout cosmic history, starting from the earliest times. These ideas gather support especially from a breakthrough made in recent observational, theoretical, and computational efforts on understanding of coevolution of BHs and their host galaxies, particularly through self-regulated growth and feedback from accretion-powered outflows (see e.g. Kelly (2010), Natarajan (2011), Shankar et al. (2009), Treister & Urry (2012), Volonteri & Natarajan (2009), Volonteri et al. (2010)). Whereas the multiwavelength methods are used to trace the growth of seed BHs, and the prospects for future observations are reviewed. The observations provide strong support for the existence of a correlation between SMBHs and their hosts out to the highest redshifts. Particularly, the observations of the

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quasar luminosity function show that the most supermassive BHs get most of their mass at high redshift, while at low redshift only low mass BHs are still growing (Barger, 2005). This is observed both in optical (Croom, 2009) and hard X-ray luminosity functions (Barger, 2005), which indicates that this result is independent of obscuration. Natarajan (2011) has reported that the initial BH seeds form at extremely high redshifts from the direct collapse of pre-galactic gas discs. Populating dark matter halos with seeds formed in this fashion and using a Monte-Carlo merger tree approach, he has predicted the BH mass function at high redshifts and at the present time. The most aspects of the models that describe the growth and accretion history of supermassive BHs, and evolution of this scenario have been presented in detail by Volonteri & Natarajan (2009), Volonteri et al. (2010). In these models, at early times the properties of the assembling BH seeds are more tightly coupled to properties of the dark matter halo as their growth is driven by the merger history of halos. While a clear picture of the history of BH growth is emerging, significant uncertainties still remain (Treister & Urry, 2012), and in spite of recent advances (Natarajan, 2011, Treister, 2010), the origin of the seed BHs remains an unsolved problem at present.

While the exact mechanism for the formation of the first BHs is not currently known, there are several prevailing theories (Volonteri, 2010). A large number of representative models towards this are available in literature, (see e.g. Bromm & Loeb, 2003, Devecchi & Volonteri, 2009, Kelly, 2010, Natarajan, 2011, Natarajan & Treister, 2009, Shankar et al., 2009, Vestergaard, 2004, Volonteri, 2010, Volonteri & Natarajan, 2009, Volonteri et al., 2010, Willott, 2010), but all they are subject to many uncertainties. Each proposal towards formation and growth of initial seed BHs has its own advantage and limitations in proving the whole view of the issue. For example, most aspects of the models that describe the growth and accretion history of SMBHs, the evolution and assembly history of this scenario have been explored in detail in (Volonteri & Natarajan, 2009, Volonteri et al., 2010). In these models, at early times the properties of the assembling SMBH seeds are more tightly coupled to properties of the dark matter halo as their growth is driven by the merger history of halos. Specifically, the Hubble Space Telescope measurements of stellar kinematics highlight an evidence for the ubiquity of SMBHs.

However, the most important characteristics of the AGN powerhouse, the central masses and structures, and the BH formation and growth processes are not understood well. This issue is many-sided and fundamental, and can be settled fairly only by more investigations to be done for its better understanding. The scientific situation is, in fact, more inconsistent than described so far. Within respect to standard models, a hard look at the BH physics reveals following severe problems.

The observed time-scales for flux variations of some objects are inconsistent with contemporary BH accretion models. That is, on the basis of the diagram of the minimum variability time-scale versus the bolometric luminosity for 60 sources it has been shown that, in spite of auxiliary assumption of asymmetric emission geometry, a few BL Lac objects - B2 1308 + 72, 3C 66A, OJ 287, AO 0235 + 16 and Quasars - 3C 345, 3C 446, 3C 454.3, LB 9743 remained in forbidden zone (particularly the three of them) (Bassani et al., 2010), namely their observed sizes appeared to be less than the sizes of corresponding spheres of the event horizon.

The growth behavior of BHs widely based on the premises of runaway core collapse scenario. The latter has always been a matter of uncertainties because we do not have a thorough understanding of details of accretion physics, say, of the physical properties of invoked relativistic plasma flows outside a horizon, with compact coruscating bright spots due to beaming, or magnetohydrodynamic shocks and reconnection in the inner jet. Distinguishing these possibilities requires spatially resolved images much finer than the horizon size, which could be feasible in the near future. Then it is interesting to compare the accretion method with other methods such as radio timing or even the current research of BH imaging using Event Horizon Telescope. Although a thorough comparison is beyond the scope of the present communication, it will be an interesting topic for discussion elsewhere. Timing observations provide a useful means to study the properties of space–time around extreme gravity systems, such as BHs. That is, if external tracers lead to an estimated horizon radius, R_g, under a very generic assumption that the object is a BH, then it is possible that finer observations will reveal internal substructures smaller than R_g or flaring events quicker than the time-scale R_g/c. Pulsar timing, therefore, has been identified as a space–time probe because of the high precision achievable in the

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timing measurements. It is also because of the unique nature of pulsars – highly compact and thus uneasily disrupted, narrow mass range, and for millisecond pulsars, high stability in the rotation rate (a stable, reliable clock). Saxton (2016) proposed that pulsar timing observations will be able to distinguish between systems with a centrally dense dark matter sphere and conventional galactic nuclei that harbour a SMBH. The lack of a perfect horizon means that the effective strong-lensing silhouette of the central structure may differ significantly from SMBH predictions. Besides, there are some theoretical expectations for swarming of pulsars (and other compact stars) to concentrate in galaxy nuclei (Freitag et al., 2006, Miralda-Escudé & Gould, 2000, Pfahl & Loeb, 2005). So far, one magnetar is known near Sgr A*, and there is debate about how many pulsars might also be discoverable (e.g. Macquart & Kanekar (2015)). In particular, our Galactic Center (Sgr A*) deviates from containing a SMBH for at least 15 reasons (Kundt, 2012), the 15th being the happy survival, so far, of cloudlet G2 during its ongoing approach of Sgr A*.

What kind of observational signature the BHs bear, if any, and whether such phenomena can possibly be observed? Wouldn't they hide forever, on grounds of their expected dimness, their not being able to radiate? Such questions were first asked seriously between theorists and observers, with a distinct emphasis on candidates of stellar mass. A first, promising suggestion was the X-ray emitting stellar binary system Cyg X-1, the brightest stellar X-ray source in the Cygnus region, whose optically invisible component had to be more massive than a neutron star. And how to blow the jets seen to spring forth from the dark component of the Cyg X-1-system? Binary neutron stars are observed to blow jets, whereas BHs cannot do that because they lack an inclined, co-rotating magnetosphere, for generating the jets' pair plasma (Kundt, 2011). In Fischer and Kundt could not find a single BH in the whole class of (stellar-mass) BH-candidates (Kundt & Fischer, 1989).

Most impressive evidence against a BH at our Galactic center presented by Su et al. (2010, 2011). The FERMI Bubbles (or plumes), at photon energies $\lesssim 10^2$GeV, probably emitted by buoyantly rising relativistic pair plasma from the near vicinity of Sgr A*, throughout the Milky-Way halo, to heights well above 20 kpc. These same halo structures had already been detected and mapped decades earlier by Sofue (2000), from radio and X-ray data.

Galactic centers are often observed to be quite luminous, stormy, jet-blowing, and pluming (at $\lesssim 10^2$ GeV), from their center all the way out into their halo. How is this central activity powered? Kundt (1996) assumed that it caused by nuclear burning of the central disk, combined with magnetic reconnections in its (very) fast and deferentially rotating corona. A burning disk avails of abundant rotational, infall, and nuclear energy, for both non-thermal and thermal ejections: of radiation, jets, winds, and plumes. A SMBH would suppress all this.

3. Assessment of Growth and Merging Properties of Black Holes With in Phenomenological Models

With aforementioned observational advances, a tacit assumption of theoretical interpretation of astrophysical scenarios is a general belief reinforced by statements in textbooks, that the PBHM is capable to describe the growth and merging behavior of accreting BHs. Altogether, the question then arises: What procedure is in fact employed by the astronomers in the course of reaching the conclusion while estimating a growth of energy-mass of astrophysical BH? The following stepwise properties are commonly attributed to above procedure:

- From observations of surroundings of the BH, at first, the astronomers by simulation estimated a total amount of the outside mass that potentially can be swallowed driven by an accretion onto BH.
- Secondly, this quantity of mass, without any substantiation, is simply accepted as a real *physical* measure of growth of energy-mass of the astrophysical BH.

Although arguably all these reasoning seemed appealing and attractive, nevertheless there is no convincing reason to rely on a validity of such procedure and, therefore, we do not share this view. It is rather surprising that the PBHM is routinely used to explore the growth and merging phenomena of

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astrophysical BHs. Such beliefs are suspect and should be critically re-examined. In the framework of PMBHs there is no provision for growth and merging behavior of BHs because of the nasty inherent appearance of BH *singularities*, and that if the *infinite collapse to the singularity* inside the BH is accepted as a legitimate feature of Nature. Certainly, during a super-increasing of total mass of configuration one undoubtedly will arrive (irrelevant to gravitational theory in use) to a critical turning point of relativistic collapse, beyond which the gravitational forces of compression prevail over all the other forces. Than it is enough to add from the outside a small amount of energy near-by the critical point in order to begin a process of irresistible infinite catastrophic compression of configuration under the pressure of grand forces. The improbability of such an inference has been greatly enhanced by the breaking down of the theory inside the event horizon which is causally disconnected from the exterior world. Either the Kruskal continuation of the Schwarzschild metric, or the Kerr metric, shows that the static observers fail to exist inside the horizon. The PMBH then presents a major challenge that renders time reversibility impossible. Objects thrown into the BH can never be retrieved, because it will get into infinite collapse to the central singularity inside the BH. Any timelike worldline must strike the central singularity which wholly absorbs the infalling matter. Therefore, the ultimate fate of collapsing matter once it has crossed the BH surface is unknown. This certainly inhibits one to answer quantitatively such purely academic question, say, what is a further evolution of the decrease of the energy and entropy carried by the accreting mass that was swallowed by the BH; or what is further evolution of the coalescence and merger of binary BHs at grazing collision of members, when triggered by the emission of gravitational waves their orbits will tighten by spiraling inwards. At this, immediately the question arises whether or not yet observable four laws of the mechanics for a stationary, asymptotically flat, black BH in four will be valid as well for not stationary processes of BH formation and growth.

3.1. Some Conceptual Problems Plagued GR

A general relativity has stood the test of time and can claim remarkable success, although there are serious problems of the energy-momentum conservation laws of gravitational interacting fields, the localization of energy of gravitation waves, the role of singularities of BHs, and also severe problems involved in quantum gravity. This state of affairs has not much changed up to present and proposed abundant models are not conductive to provide non-artificial and unique recipe for resolving these controversial problems. Eventually, experimental gravitation is a major component of the field, characterized by continuing efforts to test the GR's predictions. GR certainly can claim remarkable success at the post-Newtonian level where the experiments have reached high precision, including the light deflection, the Shapiro time delay, the perihelion advance of Mercury, the Nordtvedt effect in lunar motion, and frame-dragging (Will, 2014). Thereby gravitational wave damping has been detected in an amount that agrees with general relativity to better than half a percent using the Hulse-Taylor binary pulsar system (Hulse & Taylor, 1975), also see subsequent observations of its energy loss (Taylor & Weisberg, 1982). A growing family of binary pulsar systems is currently yielding new tests focusing on strong gravity and gravitational waves. These experiments will search for new physics beyond GR at many different scales: the large distance scales of the astrophysical, galactic, and cosmological realms; scales of very short distances or high energy; and scales related to strong or dynamical gravity.

The geometrical interpretation of gravitation, having arisen from the dual character of the metrical tensor in its metrical and gravitational aspects, is a noteworthy result of GR. Although this has the advantage in solving the problems of cosmology, nevertheless such a distinction of the gravitational field among the fields yields the difficulties in the unified theories of all interactions of elementary particles, and in quantization of gravitation. Moreover, there are problems of energy-momentum conservation laws of gravitational interacting fields, the localization of energy of gravitation waves, the singularities or BHs, and also severe problems involved in quantum gravity. The well defined local energy-momentum density for the gravitational field may set the conceptual basis for the understanding of energy loss by gravitational radiation.

The difficulty for this is rooted in the weak principle of equivalence (WPE), i.e. the *universality of free fall*. The gravitational action only depends on the gravitational field, since any further background structure would be precluded by diffeomorphism invariance. Since the WPE can be used to get rid

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of the gravitational field on a given point of spacetime, a crucial conceptual and practical caveats are involved in the association of energy and angular momentum with the gravitational field. That is, Riemannian geometry in general does not admit a group of isometries, therefore, it is impossible to define energy-momentum as Noether local currents related to exact symmetries. This has challenged validity of the concepts of energy and angular momentum, when one attempts to perform their straightforward extension to the gravitational field.

Such an approach rapidly meets important conceptual difficulties. Namely, the formulation of meaningful global or quasi-local mass and angular momentum notions in GR and in the particular context of BH spacetimes always needs the introduction of some additional structure in the form of quasi-local quantities and quasi-symmetries that restricts the study to an appropriate subset of the solution space of GR. Although a remarkable surge of activity of investigations in this field has arisen recently, but the theory of quasi-local observables in general relativity is far from being complete. It is surprising that one has not only no ultimate, generally accepted expression for the energy-momentum and especially for the angular momentum, but there is no consensus in the relativity community even on general questions, for example, *what should one mean by energy-momentum?*

In the literature there are various, more or less *ad hoc*, lists of criteria of reasonableness of the quasi-local quantities (e.g. Christodoulou & Yau (Christodoulou & Yau)). However, finding an appropriate quasi-local notion of energy-momentum has proven to be surprisingly difficult (for the comprehensive review see Szabados (2004)). The situation is much less clear in the case of extended but finite spacetime domains, otherwise there are still controversies and open issues. For example, the Bartnik mass (Bartnik, Bartnik, 1989), which is a natural quasi-localization of the ADM mass, overestimates the physical quasi-local mass; or, the Hawking energy (Hawking, 1968) and its slightly modified version, the Geroch energy (Geroch, 1973), which are a well defined 2-surface observable, have not been linked to any systematic (Lagrangian or Hamiltonian) scenario. Similar situation holds for, e.g., the Penrose mass (Penrose, 1982, Penrose & Rindler, 1986), Dougan-Mason energy-momenta (Dougan & Mason, 1991), Brown-York-type expressions (Brown & York, 1993), etc, (for details see (Szabados, 2005)).

The emphasis in modern gravitational research is on the fundamental questions at the intersection between particle physics and cosmology, including quantum gravity and the very early universe. The GR as a geometrized theory of gravitation clashes from the very outset with basic principles of field theory. In accord to above said, this rather stems from the fact that Poincaré transformations no longer act as isometries, which posed severe problems in a Riemannian space interacting quantum field theory. The major unsolved problem is the non-uniqueness of the physical vacuum and the associated Fock space. A peculiar shortcoming is in the following two key questions to be addressed yet: (i) the absence of the definitive concept of space-like separated points, particularly, in the canonical approach, and the *light-cone* structure at each spacetime point; (ii) the separation of positive- and negative-frequencies for completeness of the Hilbert-space description. Due to it, a definition of positive frequency modes cannot, in general, be unambiguously fixed in the past and future, which leads to $|in>\neq|out>$, because the state $|in>$ is unstable against decay into many particle $|out>$ states due to interaction processes allowed by lack of Poincaré invariance. A non-trivial Bogolubov transformation between past and future positive frequency modes implies that particles are created from the vacuum and this is one of the reasons for $|in>\neq|out>$. This state of affairs has not much changed up to present and proposed abundant models are not conductive to provide non-artificial and unique recipe for resolving such controversies.

3.2. Curvature Singularities

In the framework of GR, the PBHM implies the most general Kerr-Newman BH model, with the only independent observable integral parameters of total mass (M), angular momentum (J) and charge (Q). Note that, even in the vacuum, asymptotically flat, four dimensional case relatively little is known about stability of the solutions to Einstein's equations beyond the linear level. In particular, the Kerr solution has not been proved to be stable, although both linearized analytic calculations and numerical calculations indicate that it is (e.g. Krivan et al. (1997)). Even though being among the most significant advances in astrophysics, it is rather surprising that PBHM is routinely used to explore the BH growth and merging phenomena as though it cannot be accepted as convincing model

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for addressing this problem. Certainly, in this framework the very source of gravitational field of the BH is a kind of meaningless curvature singularity at the central point of the stationary nonrotating ($J = 0$, $Q = 0$) Schwarzschild BH, or a ring singularity at the center of the rotating axisymmetric Kerr BH, which are hidden behind the event horizon. The theory breaks down inside the event horizon which is causally disconnected from the exterior world. The Kruskal manifold is the maximal analytic extension of the Schwarzschild and Kerr solutions inside event horizon, so no more regions can be found by analytic continuation. But, the Kruskal continuation shows that the static observers fail to exist inside the horizon. This interior solution is not physically meaningful and essentially irrelevant.

Black holes then present a major challenge that they render time reversibility impossible. Objects thrown into a BH can never be retrieved, because any timelike worldline must strike the central singularity which wholly absorbs the infalling matter. Any object that collapses to form a BH will go on to infinite collapse to a singularity inside the BH. This feature is interpreted either as BHs connect our world to other universe via wormholes (Coleman, 1988, Hawking, 1988), or as an information thrown into a BH can not be retrieved anymore. There is also an opposite view point that any object thrown into a BH actually does leave some signals behind in own world (Dray & 't Hooft, 1985a,b). Whatever it will be, in both cases the PBHM ultimately precludes any accumulation of matter inside event horizon and, thus, neither the growth of BHs nor the increase of their mass-energy density could occur at accretion of outside matter, or by means of merger processes.

Admitting an *infinite collapse to the singularity* inside the BH as a physical law of Nature, it is impossible to answer, for example, what is further evolution of the coalescence and merger of binary BHs at grazing collision of members when, triggered by the emission of gravitational waves, their orbits will tighten by spiraling inwards? The nasty inherent appearance of BH singularities, in fact, inhibit one to answer such purely academic questions. It is why an excising the BH interior, for example, is currently considered as an approximate solution to avoid singularities in dynamical simulations (e.g. Baumgarte & Shapiro (2003)).

3.3. Black Hole Thermodynamics in Semiclassical Physics

A current theoretical understanding of growth and merging behavior of BHs is based on the Hawking's theorem of surface area of a BH (Carter, 1979, Hawking, 1968). Namely, in any interaction between matter or radiation with the BH, the time dependent horizon area is never allowed to decrease with time. This is the meaning of the irreducible mass of the horizon, i.e. in a possible collision of several BHs, the surface area of the resulting merged black hole always exceeds the sum of the separate progenitor BHs. Say, if a BH was being off the ordinary mass shell and carried no entropy, it would be possible to violate the law of energy conservation and 2^{nd} law of thermodynamics, because the energy and entropy in the exterior spacetime could be decreased by throwing matter into a BH. In the framework of incomplete theory, therefore, the only way to maintain these laws there is nothing left but to admit stepwise, without any substantiation, that (i) the BH resides on the *ordinary mass shell* ($E_{BH} = M_{BH}\, c^2$) and (ii) it has entropy (S_{BH}). Then the increase of these quantities may compensate the decrease of the energy and entropy carried by the mass that was swallowed. This is the meaning of the first and 2^{nd} laws of BH dynamics (Bardeen et al., 1973). The law of increase of area looks like the 2^{nd} law of thermodynamics for the increase of entropy, if one assigns an entropy to BH that is proportional to its surface, and that the surface gravity stands for a temperature (Bekenstein, 1973). At first sight, this choice seems quite natural, but at closer inspection one finds that these intriguing ideas have encountered to severe objection: *the entropy of a thermodynamic system is a measure of the large number of the real physical microstates* that an observer would not be aware of when measuring macroscopic parameters, and so-called *no hair* theorems allow BH, in best case, to have only a single microstate.

Classically, BHs are perfect absorbers but do not emit anything; their physical temperature is absolute zero. However, the spacetime associated to gravitational collapse to a BH cannot be everywhere stationary. Therefore, in semiclassical geometric optics approximation, a particle creation determined by details of the collapse is allowed in non-stationary curved spacetime. This is a transient phenomenon because exterior spacetime is stationary at late times of existence of horizon independent of the details of the collapse. The infinite time dilation at the horizon of Schwarzschild BH suggests

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a possible flux of such particles, which is the meaning of the Hawking radiation - the radiation seen by an observer in the space-time background of a Schwarzschild BH when gravity will pull one of the members of pair into the BH permanently, while the other assumed to be escaped from the BH. Due to this radiation, a BH that forms from gravitational collapse will eventually evaporate, after which the spacetime has no event horizon. The equation for Hawking's black body radiation temperature, $T_H = c^3\hbar(8k_B G_N M)^{-1}$, clearly shows that the more mass is radiated away from the BH, the hotter this becomes. What then is the endpoint of BH evaporation? Moreover, the thermal properties of thermodynamic systems reflect the statistical mechanics of underlying microstates. Entropy is normally a measure of the degeneracy of microstates, Σ, in some underlying microscopic description of a physical system, determined by Boltzmann's formula $S = k_B log\Sigma$. Since the Bekenstein-Hawking entropy of generalized second law (GSL) of BH thermodynamics, $S_H k_B^{-1} = 4G_N M^2(c\hbar)^{-1} = A_H(2l_{Pl})^{-2}$ of a BH, where A_H is the area of the horizon and l_{Pl} is the Planck length $l_{Pl} = \sqrt{G_N\hbar/c^3} \approx 10^{33}$ cm, is naturally a huge number, how can one exhibit such a wealth of microstates? Within string theory, there is a class of BHs where these problems can be conveniently addressed, the so-called extremal BHs, for which the mass is tuned, so that the tendency to gravitational collapse is precisely balanced by the electrostatic repulsion. Consequently, the temperature vanishes and the BH behaves somehow in this limiting case as if it were an elementary particle. These results, however, rely heavily on supersymmetry and serious difficulties are met in attempts to extend them to non-supersymmetric BHs (see below).

Continuation of the Schwarzschild metric to the *Euclidean Schwarzschild metric* implies that the non-singularity of the Euclidean metric is required for equilibrium. The quantum field theory (QFT) can be in equilibrium with a BH only at the Hawking temperature, which is inversely proportional to the mass of BH. Thereby the thermal equilibrium of a BH with an infinite reservoir of radiation at Hawking temperature is unstable since if the BH absorbs radiation its mass increases and its temperature decreases.

Similarly, the two features violet Hawking's area theorem: (i) in pair creation effectively a spacelike energy flux is involved - in contrast to the one of the essential postulates of the area theorem which requires that the energy-momentum tensor $T_{\mu\nu}$ should satisfy the dominant energy condition. This held if for all future-directed timelike vector fields v, the vector field $j(v) \equiv -v^\mu T_\mu{}^\nu \partial_\nu$ is future-directed non-spacelike, or zero, i.e. no spacelike energy fluxes are allowed; (ii) the mass of BH decreases during evaporation by energy conservation, as well as inevitably do the surface area and entropy.

Hawking radiation allows an interpretation of the laws of BH mechanics as physically corresponding to the ordinary laws of thermodynamics. Having associated the entropy $S_{BH} := [kc^3/(4G\hbar)] \times Area(S)$ to the (spacelike cross Section 5 of the) event horizon, the area theorem was replaced by a generalized 2^{nd} law (GSL) of thermodynamics, which includes the sum of the entropies of all BHs plus the entropy of matter in exterior spacetime (Bekenstein, 1974). The GSL provides means for the quantity S_{BH} to be the physical entropy of a BH. Notwithstanding it is possible to construct thought experiments (e.g. the so-called Geroch process) in which the GSL is violated, unless a universal upper bound $S_m/E \leq (2\pi k/\hbar c)R$ for the entropy-to-energy ratio for bounded systems exists, where E and S_m are, respectively, the total energy and entropy of the system, and R is the radius of the sphere that encloses the system (Bekenstein, 1981, 1982).

A semi-classical method of modeling Hawking radiation as a tunneling of particles through a gravitational barrier has been developed in the framework of QFT on a curved gravitational background (e.g. Birrell & Davies (1982), Kerner & Mann (2008) and references therein). Certain gravitational backgrounds gave rise to thermal radiation from the vacuum. This provides an alternate conceptual means for understanding the physics of cosmological pair production at a wide variety of cosmological event horizons in exotic spacetimes. However, all these processes for certain do not give physical insight regarding the nature of the *microstates of a BH* and nor does it offer a substantiated reason for the *BH entropy* S_{BH}. Moreover, in semi-classical analysis of the Hawking evaporation process, if the correlations between the inside and outside of the BH are not restored during the evaporation process, then by the time that the BH has evaporated completely, an initial pure state will have evolved to a mixed state, i.e., *information* will have been lost in the process of BH formation and evaporation - the *black hole information paradox* (e.g. Will (2014)). If information is lost into the BH, which is

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ascribable to the propagation of the quantum correlations into the singularity within the BH, this put QFT in curved spacetime in conflict with a basic principle of quantum mechanics (Townsend, 1997), because of incompatibility with the unitary time evolution of a state vector in a Hilbert space. This violates the causality and energy-momentum conservation laws.

Some authors claim that the resolution requires an understanding of the Planck scale physics. Putting together the basic laws of physics, i.e. Heisenberg's uncertainty principle $\triangle p \triangle x \sim \hbar$, the existence of gravitating mass $E = mc^2$ and Schwarzschild radius $R_g = 2Gm/c^2$ in Einstein's theory of gravity, these unambiguously assert the Planck's length $L_P := \sqrt{\hbar G/c^3} = 1.6 \cdot 10^{-33}$ cm to be a lower limit on the possible accuracy of position measurements (e.g. Fredenhagen (1995)). The universe at the Planck scale is strong gravity where the Riemannian curvature of spacetime is comparable to the inverse square of a favorite Planck length scale. Another possible scale for strong gravity is the TeV scale associated with many models for unification of the forces, or models with extra spacetime dimensions.

3.4. Black Hole Thermodynamics in Quantum Physics

Stemming primarily from classical and semiclassical analyses, the discovery of the thermodynamic behavior of BHs has given rise to quantum physics occurring in strong gravitational fields. At the purely classical level, BHs with in GR, of course, has nothing to do with the Planck scale quantum physics, because just outside the event horizon of an astrophysical black hole is weak gravity. Moreover, if pure states evolve to mixed states in a fully quantum treatment of the gravitational field, then at least the aspect of the classical singularity as a place where *information can get lost* must continue to remain present in quantum gravity. Nevertheless, the efforts to understand the mysterious statistical mechanical properties of BHs has led to many speculations about their quantum gravity origin. This in part is also due to the fact that the QFT in curved spacetime predicts an infinitely increase of a local temperature on the horizon of a BH. This should not be believed when kT reaches the Planck energy $(\sim \hbar c/G)^{1/2}c^2$ because quantum gravity effects cannot then be ignored and this temperature is then of the order maximum temperature in string theory. The latter appeals to GR as the low energy effective theory. Certainly, the quantum gravity is not needed to derive the BH entropy, since it can be derived even from the general principles of a conformal field theory (CFT) on the horizon of the BHs Carlip (e.g. 2002), Park (e.g. 2002).

However, BHs are localized objects, thus one must be able to describe their properties and dynamics even at the quasi-local level. The Schwarzschild BH, fixing its temperature at infinity, has negative heat capacity. Similarly, in an asymptotically anti-de-Sitter spacetime fixing the BH temperature via the normalization of the timelike Killing vector at infinity is not justified because there is no such physically distinguished Killing field (Brown et al., 1994). These difficulties lead to the need of a quasi-local formulation of BH thermodynamics. While the laws of BH thermodynamics refer to the event horizon, which is a global concept in the spacetime, the subject of the recent quasi-local formulations is to describe the properties and the evolution of the so-called *trapping horizon*, which is a quasi-locally defined notion (e.g. Hayward (1998)).

The area scaling character of the entropy perhaps implies a *holographic principle* (Susskind, 1995, 't Hooft, 1993), formulated in the (spacelike) holographic entropy bound. This suggests that, at the fundamental (quantum) level, one should be able to characterize the state of any physical system located in a compact spatial domain by degrees of freedom on the surface of the domain too. This relation holds whenever holography dual of the QFT exists. In accord, the number of physical degrees of freedom in the domain is bounded from above by the area of the boundary of the domain instead of its volume, and the number of physical degrees of freedom on the 2D surface is not greater one-fourth of the area of the surface measured in Planck area units L_P^2. If Σ be a compact spacelike hypersurface with boundary S, then the entropy $S(\Sigma)$ of the system in Σ should satisfy $S(\Sigma) \leq kArea(S)/(4L_P^2)$. Formally, this bound can be obtained from the Bekenstein bound with the assumption that $2E \leq Rc^4/G$, i.e. that R is not less than the Schwarzschild radius of E. Also, as with the Bekenstein bounds, this inequality can be violated in specific situations (Bousso, 2002, Wald, 2004). The origin of the holographic principle must lie in the number of fundamental degrees of freedom involved in a unified description of spacetime and matter (Bousso, 1999, 2002). This covariant entropy bound

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is much more quasi-local than the previous formulations, and is based on spacelike 2D surfaces and the null hypersurfaces determined by the 2D surfaces in the spacetime. Its classical version has been proved by Flanagan et al. (2000).

Another quasi-local formulation of the holographic principle is suggested by Szabados (2005). Though not yet fully understood in general, the holographic principle is the key issue to the correspondence of anti-de Sitter spaces/conformal field theories (AdS/CFT) (Aharony, 2000, Maldacena, 1998). The AdS/CFT argues that the quantum gravity on (d + 2)-dimensional anti-de Sitter spacetime (AdS_{d+2}) is equivalent to a certain conformal field theory in d + 1 dimensions (CFT_{d+1}). By appealing to a duality between gravitational systems and conformal field theories, consequently the string theory seems to be able to count the described above microstates explicitly (e.g. Gubser et al. (1996)). In fact, the microstates are those due to entanglement of the vacuum of the BH (Israel, 1976). Indeed, one can always define the entanglement entropy in any quantum mechanical system. This is the entropy for an observer in the d-dimensional space-like submanifold A, in a given (d + 1)-dimensional QFT, who is not accessible to B, which is a complement of A, as the information is lost by the smearing out in region B.

This origin of entropy looks analogous to the BH entropy. That is, the microstates of the BH are due to the entangled nature of the BH vacuum, and are a result of an observer's inability to access the degrees of freedom that are hidden beyond the horizon. The subsystem B is analogous to the inside of a BH horizon for an observer sitting in A, i.e., outside of the horizon. Indeed, this was the historical motivation of considering the entanglement entropy in QFT (Aharony, 2000, 't Hooft, 1985). Brustein et al. (2006) argue that the entanglement mechanism is not specific to BHs but to any spacetime with a bifurcating Killing horizon.

For a comprehensive review of recent progresses on the holographic understandings of the entanglement entropy in the AdS/CFT correspondence, BH entropy and covariant formulation of holography, see (Nishioka et al., 2009). As notably pointed out by these authors, even after quite intense efforts in AdS/CFT for recent years, fundamental mechanism of the AdS/CFT correspondence still remains a mystery. In particular, one cannot answer which region of AdS is responsible to particular information in the dual CFT. There is also an essential discrepancy between the entanglement entropy and the BH entropy, that the entanglement entropy is proportional to the number of matter fields, while the BH entropy is not. The former includes ultraviolet divergences as opposed to the latter. Thus, due to the existing discrepancies and the lack of clear predictions verified by observations, there is no compelling reason to rely on string theory as it stands.

3.5. Where Our Analysis is Leading to

Many important issues still remain unresolved. Primary among these are the *BH information paradox* and issues related to the *degrees of freedom responsible for the BH thermodynamics*.

Yet about 47 years after its conjecturing, solid physical information regarding the physical origin of BH entropy is still lacking, which arises several puzzling questions. For example, since there is no unique rigid notion of *time translations* in a classical GR-dynamics, the BH entropy at least appears to be *incompatible* with any notion of *ergodicity*. Up to date no one was able to make a convincing calculation of BH entropy based on statistical mechanics, which associates entropy with a large number of microstates being compatible with a concept of *ergodicity*. In this regard, proving the GSL is generally valid would require using quantum-statistical mechanics, but this discipline does not exist. This then ruptures the familiar BH entropy illusion which has insufficient dimensions.

Although no results on BH thermodynamics have been subject to any experimental or observational tests, the attempts of theoretical interpretation of the BH thermodynamics provide a basis for further research and speculation on the nature of its quantum gravitational origin. In the entanglement entropy and thermal atmosphere approaches, the relevant degrees of freedom are those associated with the ordinary degrees of freedom of quantum fields outside of the BH.

The string theory implies weak coupling states, so it is not clear what the degrees of freedom of these weak coupling states would correspond to in a low energy limit where these states may admit a BH interpretation. There is no indication in the calculations that these degrees of freedom responsible for BH entropy should be viewed as being localized near the BH horizon. As pointed out by Will

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(2014), it is far from clear as to whether one should think of these degrees of freedom as residing outside of the BH (e.g., in the thermal atmosphere), on the horizon (e.g., in Chern-Simons states), or inside the BH (e.g., in degrees of freedom associated with what classically corresponds to the singularity).

At first sight described above choice for the definition of the laws of gravitation, and thereof for that of thermodynamics and entropy of BHs, seems quite natural, however, we do not share this view. It seems that the holographic principle, even at quantum level, indeed could not ultimately restore the *complete information* on the real physical state, but rather the *elusive* one, of any system located in a compact spatial domain by the degrees of freedom on the surface of the domain. Moreover, since there is no unique rigid notion of *time translations* in a classical general relativistic dynamics, the BH entropy at least appears to be *incompatible* with any notion of *ergodicity*. This then ruptures the BH entropy illusion which has insufficient dimensions. Only the complete *internal solution* was able to give a *reliable information* on the thermodynamic behavior and entropy of black hole, if and only if it is known deep within the BH. Thus, it is premature to draw conclusions and only time will tell whether any of described above intriguing arguments is correct and actually realized in Nature.

Our misgiving about the views above also comes in part from a leading principle, that *an appearance of singularities indicates only to the actual limits of validity of the theory, beyond which the laws of physics are violated*. This we might expect to be reinforced by a robust intuition founded on past experience of simple physics. From this perspective, the aforementioned predictions on the BH physics are then suspected to be only *artifacts of incomplete* theory. Consequently, a new conceptual framework will be required in order to have a proper understanding of the BH physics.

Thus we conclude that PBHM, at least at its current state of development, is quite incapable of making predictions on growth and merging properties of the astrophysical BHs. One should therefore deliberately forebear from presumption of such behaviors, which seem nowhere near true if one applies the phenomenological model. That in this framework there is no provision for growth behavior of BHs, is because one assigns only an insufficient attributes to this. The PBHM is a rather restricted model.

Yet, it is still thought provoking how one can be sure that some hitherto unknown source of internal pressure does not become important above such extreme densities and halt the collapse? The failure of the PMBH does not necessarily imply a failure of the BH concept in general. In spite of a thorough search no reason could be found to introduce the required huge energy scale in BH physics but considerable change of properties of space-time continuum in density range far above nuclear density. We believe that a complete, *self-consistent* gravitation theory will smear out singularities at huge energies, and give the solution known deep within the BH. Only such a true solution was able to give a reliable information on the thermodynamic behavior and entropy of BH. This may shed further light upon the growth and merging phenomena of astrophysical BHs.

4. The MTBH

To fill the void which the standard PBHM presents, one plausible idea to innovate the solution to mentioned above key problems would appear to be MTBH (Ter-Kazarian, 2010, 2014, 2015, 2016a,b, Ter-Kazarian & Shidani, 2017, 2019) and references therein. Being suitable for applications in ultra-high energy astrophysics, the MTBH is a bold assumption in its own right. Needless to say that we will refrain here from providing lengthy details of MTBH. Wherever new results follow from earlier work, we restricted ourself only by a simple reference to earlier papers.

The MTBH is an extension of PBHM and rather completes it by exploring the most important processes of spontaneous breaking of gravitation gauge symmetry at huge energies, and thereof for that of rearrangement of vacuum state. Whereas a significant change of properties of space-time continuum, so-called inner distortion (ID), arises simultaneously with the strong gravity. This manifests its virtues below the ID-threshold length (0.4fm), yielding the transformations of Poincaré generators of translations, see e.g. (Ter-Kazarian & Shidani, 2019). Accordingly, a matter found in ID-region of spacetime continuum is undergone phase transition of II-type, i.e., each particle goes off from the mass shell. Hence, a shift of mass and energy-momentum spectra occurs upwards along the energy scale. The thermodynamics of a resulting matter, so-called *proto-matter*, is drastically differed from the

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thermodynamics of strongly compressed ordinary matter. The energy density and internal pressure have sharply increased in the central region of configuration, proportional to gravitational forces of compression up to $\sim 10^{25}$ order of magnitudes with respect to corresponding central values of neutron star. In the resulting so-called proto-matter, the pressure becomes dominant over gravitational force at very short distances when matter falls into central singularity as the collapse proceeds and, thus, it halts the infinite collapse. This supplies a powerful pathway to form a the equilibrium superdense *proto-matter* core (SPC), subject to certain rules. The stable equilibrium holds for outward layers too. This counteracts the collapse and equilibrium condition remains valid even for the masses up to $\sim\ 10^{10}M_\odot$. As a corollary, this theory has smeared out the central singularities of BH at very strong gravitational fields. One of the most remarkable drawback of MTBH is the fact that instead of *infinite collapse* and *central singularity*, an inevitable end product of the evolution of massive object is the stable SPC, where static observers exist. It will ultimately circumvent a principle problem of an observer's inability to access the degrees of freedom that are hidden beyond the horizon, and a necessity to assign the *elusive entropy to BH.* This in somehow or other implies that a physical entropy is assigned to SPC as a measure of the large number of thermodynamical real microstates of proto-matter, which is compatible with a concept of *ergodicity.* This may shed further light upon the growth and merging phenomena of astrophysical BHs, that are in evidence throughout the universe.

The ID mechanism accommodates the highest energy scale in central SPC. Encapsulated in an entire set of equations of equilibrium configuration, the SPC is a robust structure that has stood the tests of the most rigorous theoretical scrutinies of a stability (Ter-Kazarian et al., 2007). It also helps to reassure us that the stable equilibrium holds in outward layers too. In this way, an accumulation of matter is allowed about SPC. Moreover, above nuclear density, the SPC always resides inside the event horizon, therefore it could be observed only in presence of accreting matter. The external physics of accretion onto the SPC in first half of its lifetime is identical to the processes in phenomenological BH models. In other words, there is no observable difference between the gravitational field of SPC and Schwarzschild BH, so that the observable signature of BHs available in literature is of direct relevance for the SPC-configurations too. But MTBH manifests its virtue when one looks for the internal physics, accounting for growth and merging behavior of BHs.

To clarify the distinction between the PBHM and the MTBH, it should help a few noteworthy points of Figure 1 which schematically plotted non-rotating BH in phenomenological and microscopic frameworks.

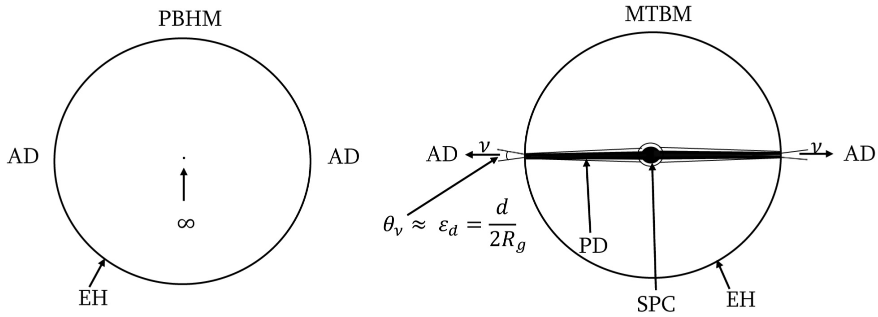

Figure 1. *Left panel*: Phenomenological model of non-spinning BH. The meaningless singularity occurs at the center inside the BH. *Right panel*: Microscopic model of non-spinning BH, with the central stable SPC. An infalling matter with the time forms PD around the SPC. In final stage of growth, a PD has reached out the edge of the event horizon. Whereas a metric singularity inevitably disappears and UHE neutrinos may escape from event horizon to outside world through vista - a thin belt area $S = 2\pi R_g d$ - with opening angle θ_ν. *Accepted notations:* EH=Event Horizon, AD=Accretion Disk, SPC=Superdense Proto-matter Core, PD=Proto-matter Disk.

A crucial point of the MTBH is that a central singularity cannot occur, which is now replaced by SPC, where the static observers are existed. The seed BH might grow up driven by the accretion of outside matter when it was getting most of its mass.

Some evidence for a rotating BH in phenomenological and microscopic frameworks is highlighted

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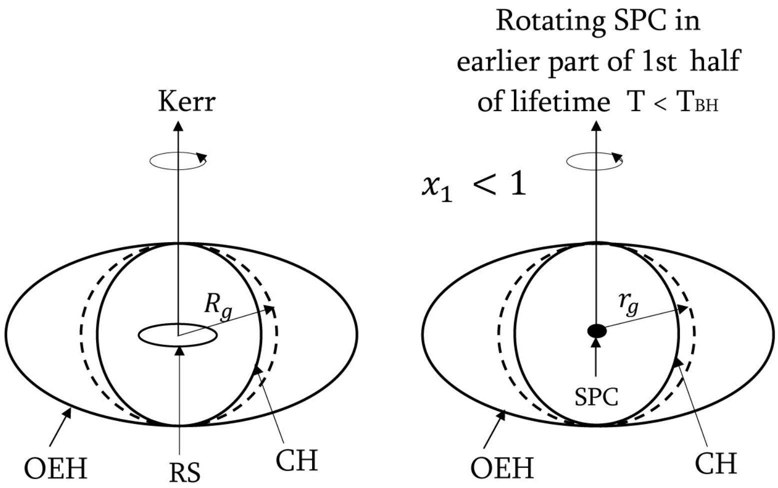

Figure 2. *Left panel*: Kerr model of spinning BH. The meaningless ring singularity occurs at the center inside the BH. *Right panel*: Microscopic model of rotating SPC in earlier part of first half of its lifetime $T < T_{BH}$. The picture is not to scale. *Abbreviated notations*: OEH :=Oblate Event Horizon, SPC :=Superdense Proto-matter Core, RS :=Ring Singularity, PCH := Prolate Cauchy Horizon.

in Figure 2. In the first half of its lifetime, the external physics outside of outer oblate event horizon of accretion onto the rotating SPC is very closely analogous to the processes in Kerr's model. But a difference between Kerr and microscopic models is the interior solutions. The interior solution of MTBH is physically meaningful, because it has smeared out a central ring singularity of the Kerr BH replacing it by the equilibrium SPC inside event horizon. The Figure 3 emphasizes an apparent distinction between Kerr model and rotating SPC in second half of its lifetime. That is, a thin co-spinning proto-matter disk with time has reached out the edge of the outer oblate event horizon, where a metric singularity inevitably disappears. Then, similar to previous non-rotating case, the ZeV-neutrinos produced in deep layers of SPC and proto-matter disk may escape from event horizon to outside world. These neutrinos are collimated in very small opening angle.

Without loss of generality, the typical features of SPC-configurations are summarised in the Figure 4 and Figure 5, to guide the eye. The radial profiles of the pressure, the density, the dimensionless gravitational (x_0)- and ID (x)- potentials are plotted in Figure 2, for example, for the given SPC of the mass $\sim 6.31 \times 10^3 M_\odot$ (that of the Sun, $M_\odot$), and the state equation is presented in Figure 3. The special units in use denote $P_{OV} = 6.469 \times 10^{36}\,\mathrm{erg\,cm^{-3}}$, $\rho_{OV} = 7.195 \times 10^{15}\,\mathrm{g\,cm^{-3}}$ and $r_{OV} = 13.68\,\mathrm{km}$.

The available solar system observational verifications, at weak gravitational fields, offer many opportunities to improve tests of relativistic gravity. As it is seen from Figure 2 and Figure 3, the agreement is satisfactory between the proposed theory of gravity, underlying MTBH, and mentioned observational verifications. Thereby the free adjustable parameter ε in metric component, in case of static spherically symmetrical system, $g_{00} \simeq 1 - \frac{R_g}{\tilde{r}} + \varepsilon \frac{R_g^2}{\tilde{r}^2}$, can be written in terms of Eddington-Robertson expansion parameters β and γ, as $\varepsilon = 2(\beta - \gamma)$. The best fit for satisfactory agreement between the proposed theory of gravity and observation is reached at $\varepsilon = (2.95 \pm 3.24) \times 10^{-5}$. Moreover, it is consistent with GR up to the limit of neutron stars. However, this theory manifests its virtues applied to the physics at huge energies.

For preceding developments of MTBH, and its implications for ultra-high energy (UHE) astrophysics, the interested reader is invited to consult the original papers.

We have undertaken a large series of numerical simulations with the goal to trace an evolution of the mass assembly history of plausible accreting supermassive BH seeds in 377 AGNs to the present time, and examine the observable signatures today (Ter-Kazarian, 2014, 2015). The MTBH explains the origin of ZeV-neutrinos, which are of vital interest for the source of UHE-particles. We compute the ZeV-neutrino fluxes from plausible accreting supermassive BHs, closely linked with the 377 AGNs.

We reconcile the observed unusual high luminosity of NuSTAR X-ray pulsations from M82X-2 with

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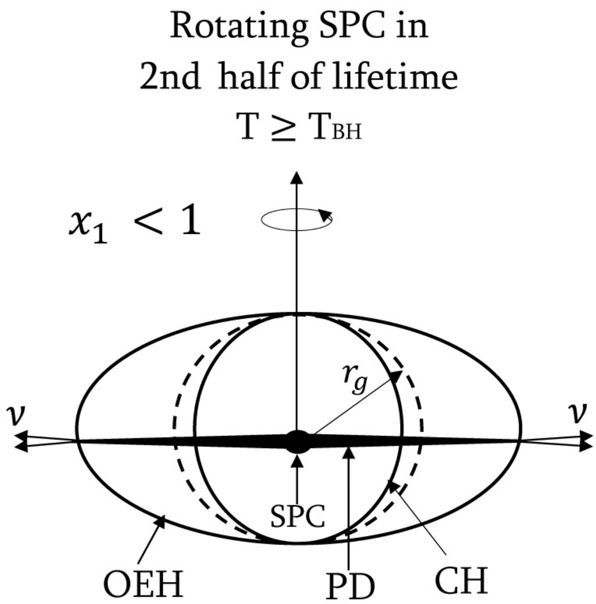

Figure 3. Microscopic model of rotating SPC in second half of its lifetime. An infalling matter already formed a thin co-spinning proto-matter disk which has reached out the edge of the outer oblate event horizon. A singularity inevitably disappears and the neutrinos escape to outside world through the vista. *Abbreviated notations*: OEH :=Oblate Event Horizon, SPC :=Superdense Proto-matter Core, PCH := Prolate Cauchy Horizon, PD :=Proto-matter Disk.

the most extreme violation of the Eddington limit (Ter-Kazarian, 2016a,b, Ter-Kazarian & Shidani, 2017).

We construct microscopic models of accreting intermediate mass BHs (IMBHs). The mass estimates collected from the literature of all the observational evidence for 137 IMBH-candidates, allow us to calculate all their essential physical characteristics (Ter-Kazarian & Shidani, 2019).

5. Concluding Remarks

Below we briefly reflect upon a few relevant points. There are deep conceptual and technical problems involved, and these provide scope for the arguments discussed. Despite the past four decades of serious efforts, we do not have as yet available any proof or even any mathematically precise formulation of the cosmic censorship hypothesis. We present examples of rigorous calculations, which have shown that the expectations of the 1970s have been hasty, that CCC assumption has been premature. We review briefly the observable signature and computational efforts of growth and merging phenomena of astrophysical BHs We collect and briefly discuss the necessary ideas behind the various specific constructions and suggestions on the conceptual problems of GR, the singularities and the thermodynamics of BHs in semiclassical and quantum physics. We concentrate on the critical discussion of the past and present states, evaluating those strategies, approaches etc., that are explicitly and unambiguously given and applicable in any generic spacetime. It was far from being complete, and our claim here is not to discuss the problems considered in detail, but rather to give a collection of problems that are effectively or potentially related to interpretation of the growth and merging properties of BHs with in the phenomenological model.

We argue that PBHM, at least at its current state of development, is quite incapable of making predictions on growth and merging properties of the astrophysical BHs. To innovate the solution to aforementioned problems, we outline the key points of MTBH, which has explored a novel aspects expected from considerable change of properties of space-time continuum at spontaneous breaking of gravitation gauge symmetry far above nuclear density. It may shed further light upon the growth and merging phenomena of astrophysical BHs. Of course, much remains to be done before one can

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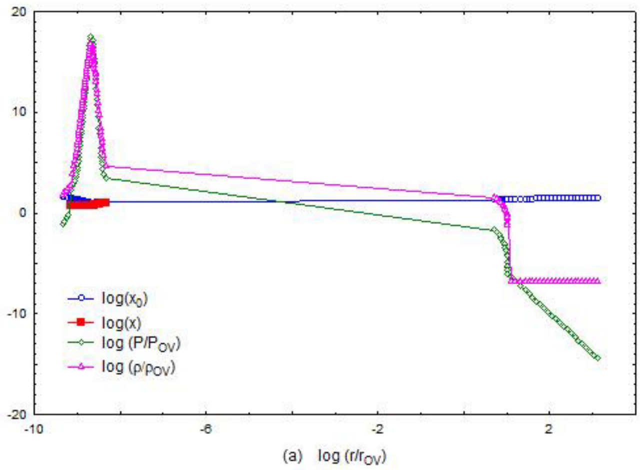

Figure 4. The radial profiles of the pressure, the density, the dimensionless gravitational (x_0)- and ID (x)- potentials of the SPC of mass $\sim 6.31 \times 10^3\, M_\odot$.

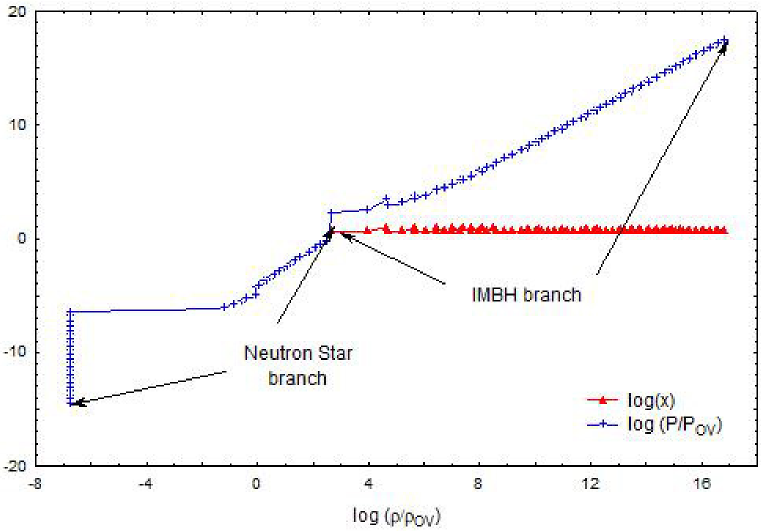

Figure 5. The state equation of the SPC of mass $\sim 6.31 \times 10^3\, M_\odot$.

determine whether this approach can ever contribute to the larger goal of gaining new insight into the growth and merging phenomena of astrophysical BHs.

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