Why No Energy Can Be Extracted From Rotating Kerr Black Holes

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The Blanford-Znajek mechanism is frequently invoked to explain extraction of energy from spinning Kerr Black Holes (BH). In addition, the "Membrane Paradigm" is also invoked to explain the same. However it was shown by Punsly & Coroniti (1989, 19990) that some of the key assumptions behind these two scenarios, like the existence of "force -free" magnetosphere around the BHs, are not realizable. And therefore these two mechanisms fail. Punsly however has considered the possibility of energy extraction from Kerr BHs by relying upon electromagnetic effects in the ergosphere of the same. But, here we point out that, there is a fundamental reason as to why one cannot extract any energy from uncharged BHs by any classical physics: the source of the moment of inertia and the kinetic energy in a Kerr BH is the central ring singularity. No ergosphere/exterior magnetosphere or anything else can have any *electromagnetic coupling* with this ring singularity. Consequently neither can there be any current from the singularity to any exterior magnetosphere or any *load*. Thus there cannot be any energy extraction from the ring singularity. Note, this paper does not deny that, once one would accept the existence of finite mass BHs, there may be a poloidal magnetic field at or even within the Event Horizon. Also, a similar interior boundary/magnetic magnetic field may exist for an insulator immersed in an exterior magnetic field. But this does not mean that either the insulator or the BH can develop *indued electromagnetic* property and get electromagnetically coupled with the exterior magnetosphere. At a more fundamental level, it has been shown that the so-called BH candidates are not BHs at all (Mitra 2004a,b; 2009). On the other hand, there are observational evidences that the so-called BH candidates possess intrinsic magnetic moment, and hence they are expected to be ultramagnetized ultracompact balls of conducting plasma (Schild et al. 2006, 2008; Lovegrove et al. 2011). Following such a realization, one can easily explain energy extraction from spinning BH candidates the same way one can explain release of rotational kinetic energy of pulsars.

Keywords: Blandford - Znajek Process, Membrane Paradigm, Kerr Black Hole, Astrophysical Jet, Magnetospheric Eternally Collapsing Object

I. INTRODUCTION

For the past 34 years, the physics of astrophysical jets has heavily relied upon the "Blandford - Znajek" (BZ) hypothesis (Blandford & Znajek 1977) which envisazes that spinning Kerr BHs can spin down **just like magnetized Neutron Stars**: "It is therefore of interest to ask whether or not a spinning black hole can also liberate its rotational energy as a result of electromagnetic processes like those in a pulsar".

"it is shown that the energy and angular momentum from a rotating hole can indeed be extracted by a mechanism directly analogous to that of Goldreich and Julien (1969)".

Then they **assumed** that there exists an electric field $\mathbf{E}$ which obeys the law *meant of a perfect MHD plasma like the interior of a pulsar*: $\mathbf{E}.\mathbf{B} = 0$, where $\mathbf{B}$ is the exterior magnetic field. Having made this assumption, they derived a Goldreich -Julien (i.e., pulsar interior type) charge density ρ. Though there may be pair creations anywhere including in the vicinity of a black hole or a piece of stone, the fact remains that BZ never derived any charge density either in the exterior or the interior of the BH by means of any *first principle calculation.* Thus effectively, they assumed what they are *believed* to have proved.

In other words, their scenario is based on two crucial assumptions like (i) existence of sufficiently strong Force - Free magnetosphere around Kerr BHs and (ii) its firm electromagnetic coupling with the BH itself. In order to make progress, they were bound to make such assumptions. And they justified all such assumptions by tacitly arguing that they were needed to explain the quasar acrtivities in terms of spinning black holes. However, later, the presence of supermassive BHs in quasars are often explained by citing the Blanford-Znajek mechanism. Thus, in a stict sense, the whole scheme becomes a perfect tautology rather than any *explanation based on any independent reasoning.*

Having started with Kerr BHs, the BZ mechanism tries to involve the accretion disks too:

"The overall efficiency of electromagnetic energy extraction from a disk around a black hole is difficult to calculate with any precision. Neither of the ectromagnetic solutions presented in the last two sections have been matched satisfactorily to solutions in regions where the magnetic field lines are attached to the disk Within the transition region, separating the horizon from the disk, the efficiency of energy extraction depends critically on the dynamical behaviour of the accreting material and this is where the greatest uncertainty in the physics lies."

And eventually, BZ talk of energy extraction by the joint hole-disk system.

"If we assume that the disc is electromagnetic then we can attempt to compare the Poynting fluxes radiated by the hole and the disc beyond the last stable circular orbit. For $a \ll m$, and a paraboloidal field, the power radiated by the hole, L_H, satisfies $L_H \sim 0.3(a/m)^2 L_D$ where L_D is the power radiated by the disk." Here a is the rotation parameter and m is the gravitational mass of the Kerr BH.

It however became apparent to some authors that in the absence of a conducting surface at the event horizon (EH), it would be difficult to sustain this scenario despite the general belief in the "Blandford - Znajek" hypothesis. Thus subsequently, the 'Membrane Paradigm' (McDonald et al. 1986) was introduced. But in the following we first point out that it has already been shown that none of these two processes work (Punsly & Coroniti 1989, 1990; Punsly 1991). Then we discuss why it is fundamentally impossible to extract rotational kinetic energy of Kerr BHs.

II. BASIC REASON

In the BZ scenario, there is no conducting surface associated with the BH with which the exterior magnetosphere can get coupled to. And this must be the basic reason for introducing the Membrane Paradigm. Here one imagines the presence of a "membrane" behaving like a perfect conductor somewhere above the EH, to explain classical electromagnetic phenomenon near the EH. But this is obviously a self-delusion because there is no such conducting physical membrane at or above the event horizon (EH).

In fact, these authors themselves (MacDonald et al. 1986) admit that (p. 46):

" The **mental deceit** of stretching the horizon is made mathematically viable, indeed very attractive, by the elegant set of membrane-like boundary conditions to which it leads at the stretched horizon...."

If BHs were physical objects, there would not have been any need for a *mental deceit*, and they could have been treated exactly without the prop of a "membrane" (Mitra 2005, 2006).

The basis of both Blandford - Znajek hypothesis and Membrane Paradigm has also been partly analyzed by few authors mostly from the view point of whether there can really be a "force -free" magnetosphere around the event horizons (Punsly & Coroniti 1989, 1990; Punsly 1991). And they find that

"It is demonstrated that the event horizon behaves quite generally as an asymptotic vacuum infinity for axisymmetric, charge-neutral, accreting electromagnetic sources. This is in contrast with the general notion that the event horizon can be treated as an imperfect conductive membrane with a surface impedance of $4\pi/c$" (Punsly & Coroniti 1989).

Despite this, Punsly however thinks that a Kerr BH may get coupled to the exterior magnetosphere through its ergosphere, lying outside the EH, and which may contain force -free pair plasma (Punsly 1999). In this case, in view of likely *induced* electromagnetic activity at the ergosphere, a Kerr BH is termed as "Magnetized Black Hole" in direct violation of the Black Hole *No Hair Theorem.* However we discuss why an uncharged BH cannot have any electromagnetic coupling with *exterior* magnetosphere.

III. FUNDAMENTAL REASON

An accretion disk can of course possess an intrinsic magnetic field and even a magnetosphere. But, this can at the most mean that *one might extract the kinetic energy of a differentially rotating accretion disk.* However, this does not at all mean that an object immersed in the magnetosphere **of the disk** becomes not only the owner of that magnetosphere, but also develops a much more intense *intrinsic* magnetosphere. In fact since a chargeless BH is inert, **a piece of vacuum without any net free charge or electrical conductivity, it cannot have any electrodynamical coupling with the magnetized accretion disk**.

To appreciate this, first consider the fact that *the matter in a Kerr BH lies in a ring singularity*; otherwise it is all vacuum everywhere. So the source of moment of inertia and the rotational kinetic energy of the BH is this ring singularity. And in order to tap this kinetic energy, there must be some mechanism which can draw energy out of this ring singularity.

For further appreciation, recall the original experiment by Michael Faraday where a spinning *metal disk* is kept between the poles of an external magnet, and the *center of the disk is connected with the rim of the same to complete a circuit.* Only after such a circuit completion, the *unipolar induction mechanism* works, and a current is recorded in the circuit. The source of energy of this current is the spin kinetic energy of the **metal** disk.

If in this experiment, the *metal* disk would be replaced by a perfect *insulator*, there would still be a magnetic field *at the boundary surface of the disk.* Yet **there will be no current, no extraction of energy**. Further, if the disk would be replaced by an imaginary disk, i.e., a vacuum, there would again be no current anywhere. Now let us assume that there might be a finite magnetic fields at the event horizon (B_{EH}). And one may even work out a "spin down rate" by using this value of B_{EH} by copying the pulsar physics. However, physically, such a compuation will be fictitious, and actually no energy is extracted from the BH. Mere existence of a peripheral magnetic field does not mean that the object is really *threaded by the exterior magnetic field* and there are currents flowing within the object. Otherwise any spinning insulator would radiate electromagnetic waves when placed in an exterior magnetic field.

However, since the Kerr BH contains a central ring singularity where density of matter is infinite and which may be conducting too, one might like to modify the "Farady Disk" in the following manner. Let there be a *conduct-*

ing ring at the center of an otherwise perfectly insulating disk. Let there be also another conducting trapped ellipsoidal plasma touching the insulator disk. Here this trapped plasma ellipsoidal may represent the ergosphere of the Kerr BH. Now as the disk would rotate in the presence of the exterior magnetic field, a current would indeed flow *within the conducting ring.* But this current will be confined within the ring. There may also be a current and an induced electromagnetic activity in the ergosphere in case it would indeed be filled with plasma.

However this exterior spinning plsama must have negligible moment of inrertia and kinetic energy. On the other hand the real contribution of moment of inertia and kinetic energy must be assigned to the central conducting ring. Obviously there will be no current from the ring singularity to the ergosphere or any other exterior region. And since there is no electrical connectivity between the ergosphere plasma and the central ring, *the kinetic energy of the ring cannot be extracted* by either the ergosphere or by any other exterior agent. Thus, it is fundamentally impossible to extract energy from a spinning Kerr BH by any classical physics.

The situation here is something like the following: If one would like to extract the spinning kinetic energy of, say, the moon, it will not be enough to put a sail or a balloon in the atmosphere of the moon. By such attempts, one can at best extract part of the kinetic energy associated with the atmosphere of the moon. On the other hand, in order to really extract the rotational kinetic energy of the moon, some contraption must be rigidly fixed deep within the crust of the moon!

In general, if there would be a spinning object (say a piece of metal) in the field of another magnet, the former does develop magnetic property by "unipolar induction mechanism", and both of them indeed get electromagnetically coupled. However, if the piece of metal would be replaced by an insularor or vacuum which has no source of uninhibited free charges, then the former would not acquire any electrodynamic property; and neither would it get coupled to the genuine magnet. Thus, in reality, the BH paradigm completely fails to explain the launch of relativistic jets and any other high energy astrophysics activity (except those related exclusively to the accretion disks).

IV. DISCUSSIONS

Blanford and Znajek (1977) assumed that (p.444)

"Nevertheless we can demonstrate that **if** (as seems likely) the electrical circuit is complete inside the hole, then precisely the correct amount of energy and angular momentum transfer takes place between the matter and the electromagnetic field **inside the horizon**."

But neither BZ nor anybody else claiming that energy can be extracted from BHs, have ever really shown how there can be flow of *outward* current first from the ring singularity and then from the trapped region surrounding it. Note, *by the very definition of "singularity" and "trapped region"*, **there cannot be any such outward current** which can complete the BH - Exterior load circuit.

In general, no amount of complex mathematics, covert assumptions and discussions based on the pattern of the Pulsar Magnetosphere can render a vaccum into a rigid body of infinite electrical conductivity or *convert a vaccum region into a pulsar*! Further if the vacuum region would contain a gravitational singularity, the possibility of any energy outflow gets ruled out. No one can extract a current from the central singularity by any amount of mathematical physics whose *region of applicability* lies outside the supposed BH. Atleast, not by any classical electrodynamics and physics.

Some authors may argue that the "No Hair Theorem" is meant for isolated BHs and not for BHs immersed in an exterior electromagnetic field. Though we have already addressed to this question by considering the *Farady Disk*, let us emphasize our point again by considering a simpler situation:

Let us put a stainless steel bar into the field of a strong bar magnet. If the stainless bar will be pulled, will the bar magnet move in tow? Obviously NO, because the stainless steel is not a ferro-magnet and cannot get magnetically coupled to the exterior magnetic field. On the other hand, had the bar been made of a ferromagnetic material like soft iron, it would have been able to pull the bar magnet along by virtue of its induced magnetization. Thus the *presence of an exterior electromagnetic field itself does not guarantee electromagnetic coupling.* On the other hand, the *inherent electromagnetic property* of a given body determines whether it can get electromagnetically coupled to an exterior electromagnetic field. Unfortunately, the entire development of BH Electrodynamics has *pretended that the BH intrinsically behaves like a ball of non-singular conducting fluid* a-la a pulsar! Note, Znajek (1976) thought that electromagnetic forces could be so strong that

"It is concluded that accreting plasma may be in quasi-static equilibrium near some black holes and that this is a consequence of the strength of electromagnetic forces in comparison with that of gravity."

If the EH is not a physical surface and further if gravity is so strong there that even light cannot escape, then how can there be "quasi-static" plasma hanging over it? Yet, if one would accept this mental picture, one question would arise: If really so, then electromagnetic processes *can probably arrest the gravitational collapse and inhibit the formation of a true BH.*

A. Magnetized Black Holes

BZ considered Kerr BHs and invoked "No Hair Theorem" to justify some of their assumptions. However, as already mentioned, many authors justify the possibility of BH electrodynamics by claiming that there are exact solutions for Kerr -Newman BHs immersed in exterior magnetic fields (Ernst & Wild 1976, Krori, Chaudhury, and Dowerah 1983). In particular, the famous Ernst and Wild solution may suggest that a Kerr BH having an angular momentum of $J = ma$ acquire a charge of $Q = 2B_0J$ when placed in an uniform exterior magnetic field of strength B_0. However, the fact remains that, all such solutions are **stationary** ones indicating they do not suggest **emission of any electromagnetic or gravitational waves**. Therefore, such mathematical analogies/interpretations of "induced charge" may be misleading as far as physics is concerned. At the best, since the BH has no physical surface, the charge must be deposited in a singularity rendering the Kerr BH into a Kerr -Newman BH. But that does not imply any energy extraction. To appreciate this, consider the fact that, if an inert stone would be placed in an exterior magnetic field, the Ernst & Wild solution (in its Newtonian limit) would ascribe some "charge" and associated electromagnetic properties. But as far as physics is concerned, the spinning inert stone will not acquire any electromagnetic property, will not launch any Poynting flux or jet even though it has a physical surface. On the other hand, a spinning Farady disk **made of conducting metal** would indeed acquire genuine electromagnetic properties by virtue of its **inherent physical properties**. Further, one need not justify such genuine induced electromagnetic properties of the Farady disk by means of any Ernst -Wild solution.

Note, in contrast, a charged and spinning Kerr Newmann BH moving with uniform acceleration in an exterior magnetic field has a much better chance to radiate gravitational and electromagnetic waves (Krori, Chaudhury and Dowerah 1984; Krori and Barua 1984). However, even in such cases, there is really no clear indication whether the solutions could be non-stationary and whether there could be any genuine emission of radiation. Such accelerating BH solutions originated from the vacuum C-metric derived by Levi-Civita and which is interpreted as the motion of a Schwarzschild BH with uniform acceleration. In view of such an "acceleration", one would expect emission of gravitational waves. But this solution is static and there is no emission of any radiation! What could be the explanation?

V. CONCLUSION

So far, we subscribed to the idea that there can be Kerr BHs with finite values of rotation parameter a and gravitational mass m. But it transpires that in oder than timelike geodesics of an infalling particle must remain timelike, there cannot be any (finite mass) Schwarzschild or Kerr BH (Mitra 2002; Kiselev, Logunov, & Mestvirishvili 2010). Further it was independently shown that the integration constants associated with the Kerr BH are zero ($a = m = 0$) (Mitra 2004a,b). Naturally, a Schwarzschild BH too has $m = 0$ (Mitra 2009). The result $m = 0$ for BHs seems to be in perfect agreement with the fundamental fact that *all BH solutions are vacuum solutions.* And this may explain *why the accelerating BH in the Levi-Civita solution* does not emit any radiation. Physically such results imply that, during continued gravitational collapse, the object must radiate out entire angular momentum and mass-energy asymptotically to attain a state of absolute rest with $a = m = 0$, a state which has no *closed time like curves* in its interior unlike the case of a Kerr BH (Mitra 2004a,b).

Thus the observed BH candidates with finite a and m must be non-singular objects.

And it has been found that indeed some of the spinning quasars have *strong intrinsic magnetic fields* which Kerr BHs cannot possess (Schild, Leiter & Robertson 2006, 2008; Lovegrove, Schild, & Leiter 2011). Similarly, the detection of a strong magnetic field $B \sim 10^8$ G near the inner edge of the accretion disk of the compact object in Cygnus X-1 too suggests that the relevant compact object has strong intrinsic magnetic moment (Gnedin, Borisov, Natsvlishvili, Piotrovich, & Silant'ev, 2003). Such evidences support the paradigm that the so-called BH candidates are actually "Magnetospheric Eternally Collapsing Objects" (MECOs): ultracompact quasi-static balls of ultramagnetized plasmas.

By using this paradigm, one can easily understand how the so-called BH candidates radiate their rotational kinetic energy; essentially the spinning MECOs act like extremely general relativistic pulsars (Mitra 2005). By using such a paradigm, most of the observations associated with the BH candidate X-ray binaries have already been explained (Robertson & Leiter 2002, 2003, 2004). The observed features of the supposed supermassive BH Sgr A* at the center of our galaxy too can be understood in the same paradigm (Robertson & Leiter 2010).

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