Electromagnetic Beams Overpass the Black Hole Horizon

A Burinskii
Gravity Research Group NSI Russian Academy of Sciences. B. Tulskaia 52, Moscow 115191, Russia

We show that the electromagnetic excitations of the Kerr black hole have very strong back reaction on metric. In particular, the electromagnetic excitations aligned with the Kerr congruence form the light-like beams which overcome horizon, forming the holes in it, which allows matter to escape interior. So, there is no information lost inside the black hole. This effect is based exclusively on the analyticity of the algebraically special solutions.

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1. Introduction. The problem of the origin of Hawking radiation [1] is not fully understood yet, and many new suggestions and proposals appears up to now. New arguments on the role of quantum anomalies in evaporation [2], and new derivations of spectrum [3, 4, 5, 6, 7] differ very much from the original Hawking idea and display the relationships of the black hole physics with the particle physics and (super)string theory, core of which is based on complex analyticity of two dimensional conformal field theories with spherical or 1 + 1 topologies, and on the important role of diffeomorphism group related with metric deformation.

In particular, in the recent paper by Asthekar, Taveras and Varadarajan [8] the issue of information loss in two-dimensional space-time is analyzed using the model of dilatonic gravity model [9], having the lagrangian of low energy string theory. Using a very complicate (but approximate) analysis authors argue that information is not lost in this model, due to essential peculiarities of null infinity in the quantum space-time with respect to the classical one.

In this short note we would like to show that the problem of information lost is to be resolved already on the classical level of the Einstein-Maxwell field theory based on the analytical properties of the algebraically special solutions, in particular, the Kerr space-time [17].

Main arguments are very simple and based on the fact that the black hole horizon, even in the classical Einstein-Maxwell field theory, is very elastic and compliant with respect to electromagnetic field. For example, the position of the external horizon of the Reisner-Nordström black hole, \( r_+ = m + \sqrt{m^2 - e^2} \), is very sensitive to the value of charge \( e \), and for \( e^2 > m^2 \) horizon disappear at all. Indeed the position of event horizon is determined by the local values of electromagnetic field. Horizon is a null surface \( S = \text{const.} \) determined by metric \( g_{\mu\nu} \) in accord with the equation

\[
 g^{\mu\nu} \nabla_\mu \nabla_\nu S = 0, \quad (1)
\]

and the aforementioned dependence of the horizon for Reisner-Nordström black hole from charge really is its dependence from the ratio of the electromagnetic and gravitational fields in its neighborhood. For more complicate cases, it is convenient to consider black hole metric in the Kerr-Schild form

\[
 g_{\mu\nu} = \eta_{\mu\nu} - 2H k_\mu k_\nu, \quad (2)
\]

which is based on the metric of auxiliary Minkowski space-time \( \eta_{\mu\nu} \). Here \( k^\mu(x), x \in M^4 \) is the null vector field which determines symmetry of space, its polarization, and in particular, direction of gravitational ‘dragging’. This vector field is tangent to the Kerr congruence of the geodesic lines for some especial family of photons. The structure of Kerr congruence is shown in Fig.1.

This congruence is twisting, which determines the complicate form of the Kerr solution, in spite of the extremely simple form of the metric (2). Horizon is determined by function \( H \), and elasticity of horizon follows from the form of function \( H \) which in accord with the general Kerr-Schild solutions [14] is

\[
 H = \frac{mr - |\psi|^2/2}{r^2 + a^2 \cos^2 \theta}, \quad (3)
\]

where the function \( \psi \equiv \psi(Y) \) determines electromagnetic field, and it may be any analytic function of the complex angular coordinate

\[
 Y = e^{i\phi} \tan \frac{\theta}{2}, \quad (4)
\]
which represents a stereographic projection of celestial sphere on the complex plane.

The Kerr-Newman solution is the simplest solution of the Kerr-Schild class having \( \psi = q = \text{const.} \), where \( q \) is the value of charge. However, any holomorphic function \( \psi(Y) \) yields also an exact solution of this class \([14]\). The form of horizon for the nontrivial functions \( \psi(Y) \) was analyzed in \([15]\), and a convincing proof of the elasticity of horizons with respect to electromagnetic field was obtained. In particular, it was shown that electromagnetic field corresponding to the simplest non-trivial functions \( \psi(Y) = qY^{\pm 1} \) has a beam-like form, which pierce the horizons, forming a hole allowing matter to escape interior of black hole. The surfaces of the event horizons are null ones and obey the differential equation \( \partial_i S^2 + a^2 + (g/ \tan \theta)^2 - 2Mr - (\partial_i S)^2 = 0 \). The initially separated \( \pm \) solutions for the internal and external horizons of the usual black hole turn out to be joined by a tube, conforming a simply connected surface. Similarly, two boundaries of the ergosphere, \( r_{+} \) and \( r_{-} \), determined by the equation \( g_{00} = 0 \) form a new united surface, being joined by tube which represents a wormhole to escape interior. The resulting structure of horizons is illustrated on the Fig. 1 (taken from \([15]\)).

![Fig. 1: The simplest function \( \psi = qY \) leads to electromagnetic beam along z-axis and causes the appearance of hole in the horizon of rotating black hole.](image)

**FIG. 1:** The simplest function \( \psi = qY \) leads to electromagnetic beam along z-axis and causes the appearance of hole in the horizon of rotating black hole.

2. **Aligned electromagnetic solutions.** The discussed above consequence of the simplest beam-like solution may be extended to the case of arbitrary numbers of beams propagating in different angular directions \( Y_i = e^{i\alpha_i} \tan \frac{\theta_i}{2} \):

\[
\psi(Y) = \sum_i \frac{q_i}{Y - Y_i},
\]

In accord with \([14]\), such a function \( \psi \) determines electromagnetic field which describes the corresponding set of light-like beams along the null rays of the Kerr congruence (see details in \([15]\)) which have strong back reaction on the metric, via the function \( \psi(Y) \) in \([3]\). And again, for the constant values \( q_i \) we will have the exact and self-consistent solutions of the full system of Kerr-Schild equations, which describe the set of light-like beams destroying horizon.

In the recent paper \([14]\) we showed that this picture is retained also for the wave light-like solutions in the low-frequency limit.

The main property of the considered beam-like Kerr-Schild solutions is their analyticity. They are special ones, satisfying the condition

\[
k^\mu F_{\mu\nu} = 0,
\]

which means that they are aligned with the Kerr congruence \( k^\mu(x) \) depicted on Fig.1. The appearance of the light-like beam is related with the complex analyticity of the Kerr-Schild solutions.

Note, that even the very weak aligned excitations destroy horizon, changing its topology. In particular, considering quantum evaporation, one has to take into account that the black hole horizon is very sensitive to vacuum fluctuations, and the related aligned electromagnetic modes of excitations lead to topological fluctuations of horizon. It means, that the real horizon subjected by vacuum fluctuations has to be pierced by a multitude of migrating holes braking the usual classical image of black hole, as it is illustrated in Fig. 2.

![Fig. 2: The simplest function \( \psi = qY \) leads to electromagnetic beam along z-axis and causes the appearance of hole in the horizon of rotating black hole.](image)

**FIG. 2:** The simplest function \( \psi = qY \) leads to electromagnetic beam along z-axis and causes the appearance of hole in the horizon of rotating black hole.

![Fig. 3: Excitation of a black hole by the zero-point field of virtual photons forming a set of micro-holes at its horizon.](image)

**FIG. 3:** Excitation of a black hole by the zero-point field of virtual photons forming a set of micro-holes at its horizon.

We are arriving at the conclusion that horizon is not irresistible obstacle with respect to the beam-like excitations, and information will not be lost inside black hole. Note, that this effect is based exclusively on the analyticity of the Kerr-Schild geometry, caused by algebraically special solutions of the Einstein-Maxwell theory.

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[17] The analytic structure of the Kerr geometry is four-dimensional and based on a twistor analyticity claimed by the Kerr theorem [10, 11], which is close to the Nair [12] and Witten [13] concept on the role of twistor space analyticity in quantum theory.