Holographic structure of the Kerr-Schild black-holes, Twistor-beam excitations and fluctuating horizon

Alexander Burinskii

NSI, Russian Academy of Sciences, Moscow, Russia

MSU, 22-th August, 2009

based on

A.B. First Award of Gravity Research Foundation 2009, Gen.Rel.Grav.July 2009

A.B., Elizalde E., Hildebrandt S.R., Magli G., *Phys. Rev.* **D 74**(2006) 021502

A.B., Elizalde E., Hildebrandt S.R., Magli G., *Phys. Lett.* **B 671**(2009) 486

A.B., arXiv: 0903.2365 [hep-th]

Recent ideas and methods in the black hole physics are based on complex analyticity and conformal field theory, which unifies the black hole physics with (super)string theory and physics of elementary particles [G.'t Hooft, NPB(1990)]

Kerr-Newman solution: as a Rotating Black-Hole and as a Kerr Spinning Particle: Carter (1968), ($g = 2$ as that of the Dirac electron), Israel (1970), AB (1974-2009), Lopez (1984) ...

About 40 years of the Kerr-Schild Geometry and Twistors.

Based on twistors Kerr Theorem and Kerr-Schild geometry (1969).

Twistor Algebra, R. Penrose, (1967).

- Real and Complex Twistor Structures of the Kerr-Schild Geometry
- Twistor-beams – New results on Black-Holes (AB, First Award of GRF 2009, arXive: 0903.3162).

Kerr-Schild form of the rotating black hole solutions:

$$g_{\mu\nu} = \eta_{\mu\nu} + 2H k_\mu k_\nu, \qquad H = \frac{mr - e^2/2}{r^2 + a^2 \cos^2\theta}. \tag{1}$$

Vector field $k_\mu(x)$ is tangent to Principal Null Congruence (Kerr congruence).

$$k_\mu dx^\mu = P^{-1}(du + \bar{Y} d\zeta + Y d\bar{\zeta} - Y\bar{Y} dv), \tag{2}$$

where $Y(x) = e^{i\phi}\tan\frac{\theta}{2}$, **and** $\zeta = (x+iy)2^{-\frac{1}{2}},\ \bar{\zeta} = (x-iy)2^{-\frac{1}{2}},\ u = (z-t)2^{-\frac{1}{2}},\ v = (z+t)2^{-\frac{1}{2}}$ *are the null Cartesian coordinates.*

The Kerr Theorem: The geodesic and shear-free null congruences (type D metrics) are determined by holomorphic function $Y(x)$ which is analytic solution of the equation $F(T^a) = 0$, where F is an arbitrary analytic function of the *projective twistor coordinates* $T^a = \{Y, \quad \zeta - Yv, \quad u + Y\bar{\zeta}\}$.

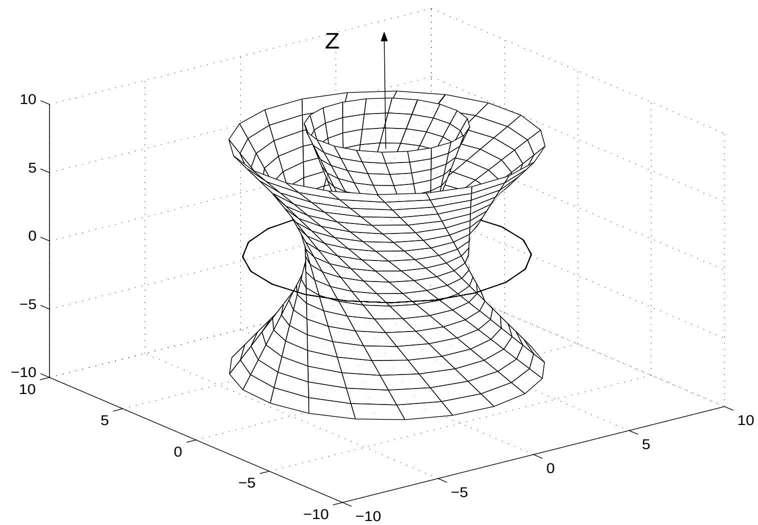

Figure 1: The Kerr singular ring and the Kerr congruence.

The Kerr singular ring $r = \cos\theta = 0$ is a branch line of space on two sheets: "negative (−)" and "positive (+)" where the fields change their directions. Twosheetedness! Mystery of the Kerr source! The Kerr ring as a "mirror gate" to "Alice world".

Stringy source: **E.Newman 1964, A.B. 1974-1999, W.Israel 1975, ...**

Rotating disk. **W.Israel (1969), Hamity (1973), L'opez (1983)9; A.B. (1989)**

Superconducting bag **($U(1) \times U(1)$ model), A.B. (2002-2004).**

New Look: Holographic BH interpretation. A.B.(2009) based on the ideas C.R.Stephens, G. t' Hooft and B.F. Whiting (1994), 't Hooft (2000).

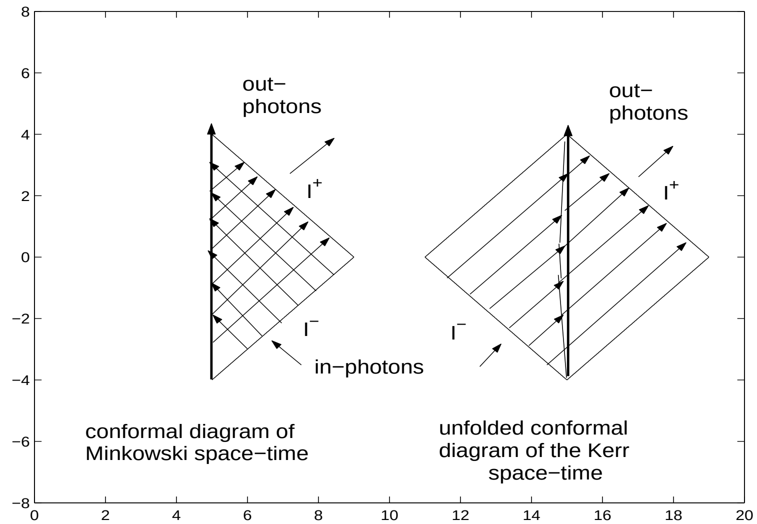

Figure 2: Penrose conformal diagrams.

Unfolded Kerr-Schild spacetime corresponds to holographic BH spacetime. Kerr congruence performs holographic projection of 3+1 dim bulk to 2+1 dim boundary.Desirable structure of a quantum BH spacetime (Stephens, t' Hooft and Whiting (1994)).

Exact solutions demand Alignment of the electromagnetic field to Kerr congruence, $A_\mu k^\mu = 0$!

Twosheetedness $\Rightarrow$ $k^{\mu(+)} \neq k^{\mu(-)}$ $\Rightarrow$ $g^{(+)}_{\mu\nu} \neq g^{(-)}_{\mu\nu}$. **It is ignored in perturbative approach. Exact solutions have twistor-beams!**

Twistor-Beams. The exact time-dependent KS solutions.

Debney, Kerr and Schild (1969). The black-hole at rest: $g_{\mu\nu} = \eta_{\mu\nu}+2Hk_\mu k_\nu$, $P = 2^{-1/2}(1+Y\bar{Y})$.

Tetrad components of electromagnetic field $\mathcal{F}_{ab} = e_a^\mu e_b^\nu \mathcal{F}_{\mu\nu}$,

$$\mathcal{F}_{12} = AZ^2, \quad \mathcal{F}_{31} = \gamma Z - (AZ)_{,1}\,, \tag{3}$$

here $Z = -P/(r + ia\cos\theta)$ **is a complex expansion of the congruence. Stationarity** $\Rightarrow \gamma = 0$.

Kerr-Newman solution is exclusive: $\psi(Y) = const.$

In general case $\psi(Y)$ **is an arbitrary holomorphic function of** $Y(x) = e^{i\phi}\tan\frac{\theta}{2}$, **which is a projective coordinate on celestial sphere** S^2, $A = \psi(Y)/P^2$, **and there is infinite set of the exact solutions, in which** $\psi(Y)$ **is singular at the set of points** $\{Y_i\}$, $\psi(Y) = \sum_i \frac{q_i}{Y(x)-Y_i}$, **corresponding to angular directions** $\phi_i,\ \theta_i$.

Twistor-beams. Poles at Y_i **produce semi-infinite singular** *lightlike beams, supported by twistor rays of the Kerr congruence.* **The twistor-beams have very strong backreaction to KS metric**

$$g^{\mu\nu} = \eta^{\mu\nu} - 2Hk^\mu k^\nu, \qquad H = \frac{mr - |\psi|^2/2}{r^2 + a^2\cos^2\theta}. \tag{4}$$

How act such beams on the BH horizon?

Black holes with holes in the horizon, **A.B., E.Elizalde, S.R.Hildebrandt and G.Magli, Phys. Rev. D74 (2006) 021502(R)**

Singular beams lead to formation of the holes in the black hole horizon, which opens up the interior of the "black hole" to external space.

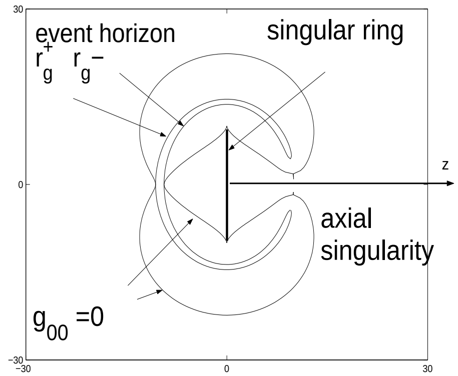

Figure 3: **Near extremal black hole with a hole in the horizon. The event horizon is a closed surface surrounded by surface $g_{00} = 0$.**

Twistor-beams **are exact stationary and time-dependent Kerr-Schild solutions (of type D) which show that 'elementary' electromagnetic excitations have generally** *singular beams supported by twistor null lines.* **Interaction of a black-hole with external,** *even very weak,* **electromagnetic field results in appearance of the beams, which have very strong back reaction to metric and horizon and form a fine-grained structure of the horizon pierced by fluctuating microholes.** [**A.B., E. Elizalde, S.R. Hildebrandt and G. Magli, Phys.Lett. B 671 486 (2009), arXiv:0705.3551[hep-th]; A.B., arXiv:gr-qc/0612186.**]

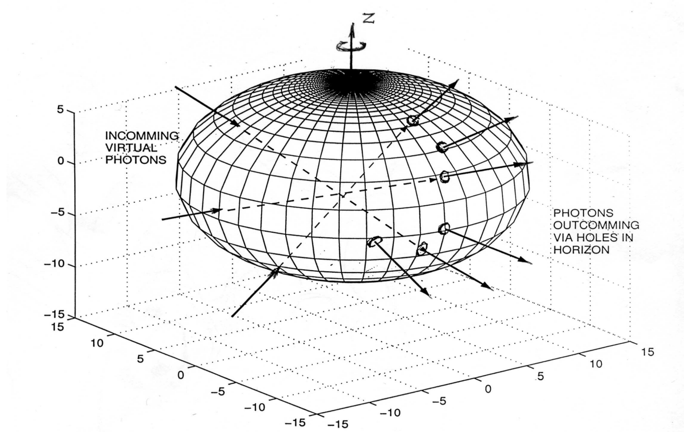

Figure 4: Horizon covered by fluctuating micro-holes.

Time-dependent solutions of DKS equations for electromagnetic excitations, $\gamma \neq 0$, A.B. (2004-2008)

a) Exact solutions for electromagnetic field on the Kerr-Schild background, (2004),

b) Asymptotically exact wave solutions, consistent with Kerr-Schild gravity in the low frequency limit, (2006-2008)

c) Self-regularized solutions, consistent with gravity for averaged stress-energy tensor, (A.B. 2009)

Electromagnetic field **is determined by functions** A **and** γ,

$$A,_2 - 2Z^{-1}\bar{Z}Y,_3 A = 0, \quad A,_4 = 0, \tag{5}$$

$$\mathcal{D}A + \bar{Z}^{-1}\gamma,_2 - Z^{-1}Y,_3 \gamma = 0, \tag{6}$$

and

Gravitational sector: **has two equations for function** M, **which take into account the action of electromagnetic field**

$$M,_2 - 3Z^{-1}\bar{Z}Y,_3 M = A\bar{\gamma}\bar{Z}, \tag{7}$$

$$\mathcal{D}M = \frac{1}{2}\gamma\bar{\gamma}. \tag{8}$$

where $cD = \partial_3 - Z^{-1}Y,_3 \partial_1 - \bar{Z}^{-1}\bar{Y},_3 \partial_2$.

Similar to the exact stationary solutions, typical time-dependent (type D) solutions contain outgoing singular beam pulses which have very strong back reaction to metric and perforate horizon.

Eqs. of the electromagnetic sector were solved (2004).

GSF condition $Y,_2 = Y,_4 = 0, \Rightarrow k^\mu \partial_\mu Y = 0.$

Stationary Kerr-Schild solutions

$A = \psi/P^2$, **where** $\psi,_2 = \psi,_4 = 0 \Rightarrow \psi(Y) \Rightarrow$ **alignment condition** $k^\mu \partial_\mu \psi = 0.$

Time-dependent solutions need a *complex retarded time parameter* τ, **obeying** $\tau,_2 = \tau,_4 = 0$, **and** $\psi = \psi(Y, \tau)$.

There appears a dependence between $\dot{A}$ **and** γ

$(\partial_3 - Z^{-1} Y,_3 \partial_1 - \bar{Z}^{-1} \bar{Y},_3 \partial_2) A + \bar{Z}^{-1} \gamma,_2 - Z^{-1} Y,_3 \gamma = 0.$

Integration yields

$$\gamma = \frac{2^{1/2} \dot{\psi}}{P^2 Y} + \phi_0(Y, \tau)/P, \qquad (9)$$

which shows that nonstationarity, $\dot{\psi} = \sum_i \dot{c}_i(\tau)/(Y - Y_i) \neq 0$, **creates generally the poles in** $\gamma \sim \sum_i q_i/(Y - Y_i)$, **leading to twistor-beams in directions** $Y_i = e^{i\phi} \tan \frac{\theta}{2}$.

Self-regularization.

Structure of KS solutions inspire the regularization which acts immediately on the function γ. Free function $\phi_0(Y,\tau)$ of the homogenous solution may be tuned, to cancel the poles of function $\dot\psi = \sum_i \dot c_i(\tau)/(Y-Y_i)$.

i-th term

$$\gamma_{i(reg)} = \frac{2^{1/2}\dot c_i(\tau)}{Y(Y-Y_i)P^2} + \phi_i^{(tun)}(Y,\tau)/P. \tag{10}$$

Condition to compensate i-th pole is

$$\gamma_{i(reg)}(Y,\tau)|_{\bar Y=\bar Y_i} = 0. \tag{11}$$

We obtain

$$\phi_i^{(tun)}(Y,\tau) = -\frac{2^{1/2}\dot c_i(\tau)}{Y(Y-Y_i)P_i}, \tag{12}$$

where

$$P_i = P(Y,\bar Y_i) = 2^{-1/2}(1+Y\bar Y_i) \tag{13}$$

is analytic in Y, which provides analyticity of $\phi_i^{tun}(Y,\tau)$.

As a result we obtain

$$\gamma_{i(reg)} = \frac{\dot{c}_i(\tau)(\bar{Y}_i - \bar{Y})}{P^2 P_i(Y - Y_i)}. \tag{14}$$

First gravitational DKS equation gives

$$m = m_0(Y) + \sum_{i,k} \frac{c_i \dot{\bar{c}}_k (Y_k - Y)}{(Y - Y_i)} \int_{\bar{Y}_k} \frac{d\bar{Y}}{P\bar{P}_k(\bar{Y} - \bar{Y}_k)}. \tag{15}$$

Using the Cauchy integral formula, we obtain

$$m = m_0(Y) + 2\pi i \sum_i \frac{(Y_k - Y)}{(Y - Y_i)} \sum_k \frac{c_i \dot{\bar{c}}_k}{|P_k|^2}. \tag{16}$$

Functions c_i **and** $\bar{c}_k$ **for different beams are not correlated,** $< c_i \dot{\bar{c}}_k >= 0$. **Time averaging retains only the terms with** $i = k$,

$$< m >_t = m_0 - 2\pi i \sum_k \frac{c_k \dot{\bar{c}}_k}{|P_k|^2}. \tag{17}$$

Representing $c_i(\tau) = q_i(\tau)e^{-i\omega_i\tau}$ via amplitudes $q_i(\tau)$ and carrier frequencies ω_i of the beams. The mass term retains the low-frequency fluctuations and angular non-homogeneity caused by amplitudes and casual angular distribution of the beams,

$$< m >_t = m_0 + 2\pi \sum_k \omega_k \sum_k < \frac{q_k \bar{q}_k}{|P_{kk}|^2} > . \tag{18}$$

Second gravitational DKS equations is definition of the loss of mass in radiation,

$$\dot{m} = -\frac{1}{2}P^2 \sum_{i,k} \gamma_{i(reg)}\bar{\gamma}_{k(reg)} = -\frac{1}{2}\sum_{i,k} \frac{\dot{c}_i \dot{\bar{c}}_k}{P^2 P_i \bar{P}_k} \tag{19}$$

Time averaging removes the terms with $i \neq k$ and yields

$$< \dot{m} >_t = -\frac{1}{2}\sum_k \frac{\dot{c}_k \dot{\bar{c}}_k}{P^2 |P_k|^2}. \tag{20}$$

In terms of the amplitudes of beams we obtain

$$< \dot{m} >_t = -\frac{1}{2}\sum_k \omega_k^2 < \frac{\dot{q}_k \bar{q}_k}{|P_{kk}|^4} >, \tag{21}$$

which shows contribution of a single beam pulse to the total loss of mass.

The obtained solutions are consistent with the Einstein-Maxwell system of equations for the time-averaged stress-energy tensor.

Obtained results.

- Exact time-dependent solutions for Maxwell eqs. on the Kerr-Schild background $\Rightarrow$ singular twistor-beam pulses.

- Exact back reaction of the beams to metric and horizon $\Rightarrow$ fluctuating metric and horizon perforated by twistor-beam pulses.

- Exact time-dependent solutions for Maxwell eqs. on the Kerr-Schild background leading to *regular*, but fluctuating radiation $\Rightarrow$ *regular* $< T^{\mu\nu} >$, but metric and horizon are covered by fluctuating twistor-beams!

- Consistency with averaged Einstein equations

$$R^{\mu\nu} - \frac{1}{2} R g^{\mu\nu} = < T^{\mu\nu} > . \tag{22}$$

We arrive at a semiclassical geometry of fluctuating twistor-beams which takes an intermediate position between the Classical and Quantum gravity.

THE END. THANK YOU FOR YOUR ATTENTION!