ФИЗИКА ЭЛЕМЕНТАРНЫХ ЧАСТИЦ И АТОМНОГО ЯДРА
2012. Т. 43. ВЫП. 5

GRAVITY BEYOND QUANTUM THEORY: ELECTRON AS A CLOSED HETEROTIC STRING

A. Burinskii

Theoretical Physics Laboratory,

Nuclear Safety Institute, Russian Academy of Sciences, Moscow

The observable gravitational and electromagnetic parameters of an electron determine that its background should be the Kerr–Newman (KN) solution of the rotating black hole without horizons. This metric has a topological defect — the Kerr singular ring which, as we show, is a closed heterotic string of the Compton radius $a = \hbar/(2m)$. We show that the Dirac equation emerges as a consequence of the underlying KN gravity and string theory. Regularization of the KN solution leads to a model of gravitating soliton of the oscillon type, in which the closed heterotic string is positioned on the edge rim of a disklike vacuum bubble. It is suggested that the string-like core of the electron should be experimentally observable by the novel methods of the «deeply virtual (nonforward) Compton scattering».

PACS: 11.15.-q; 11.10.-z; 14.60.Cd

One of the principal contradictions between quantum theory and gravity is the question on the shape and size of the electron. Quantum theory states that electron is pointlike and structureless, while gravity indicates that the core of electron should form a closed string of the Compton size. In 1968 Carter obtained that the Kerr–Newman (KN) solution for the charged and rotating black holes has $g = 2$ as that of the Dirac electron, which led to a consistent with gravity classical model of the electron. The observable gravitational and electromagnetic parameters of an electron determine unambiguously that its background should be the KN solution of the rotating black hole. Mass of the electron in the units $G = \hbar = c = 1$ is $m \approx 10^{-22}$, while $a = J/m \approx 10^{22}$. Due to the great spin of the electron $a \gg m$, and the black hole horizons disappear, opening a nontrivial topological defect and twosheeted spacetime generated by the naked Kerr singular ring of the Compton radius. Gravitational field of the KN solution, concentrating near the Kerr ring, forming a closed gravitational waveguide — an analog of the closed gravitational strings [1].

The Kerr ring takes the Compton radius, corresponding to the size of a «dressed» electron in QED and to the limit of localization of the electron in the Dirac theory. There appear two questions: 1) How does the KN gravity know about one of the principal parameters of quantum theory? and 2) Why does quantum theory works successfully on the flat spacetime, ignoring the stringlike peculiarity of the background gravitational field? The stringlike KN singularity forms a branch line of the spacetime and creates a twosheeted topology, ignorance of which cannot be justified. A simple answer to these questions is to assume that there is a general underlying theory providing the consistency of quantum theory and gravity. This puzzle can be resolved by a rather unexpected suggestion, that the underlying theory is the Einstein–Maxwell gravity as a fundamental part of the theory of superstrings [2].

The Kerr–Newman solution in the Kerr–Schild form has the metric

$$g_{\mu\nu} = \eta_{\mu\nu} + 2H k_\mu k_\nu, \tag{1}$$

where

$$H = \frac{mr - \mathrm{e}^2/2}{r^2 + a^2 \cos^2\theta}, \tag{2}$$

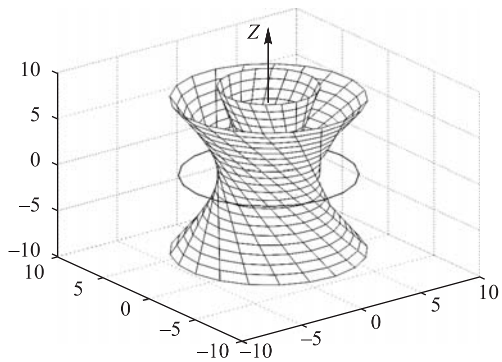
and $\eta_{\mu\nu}$ is the metric of auxiliary Minkowski space in the Cartesian coordinates (t, x, y, z), and the electromagnetic (EM) vector potential of the KN solution is

$$\alpha^\mu_{\mathrm{KN}} = \mathrm{Re}\,\frac{\mathrm{e}}{r + ia\cos\theta}\,k^\mu, \tag{3}$$

where r, θ, and ϕ are the Kerr oblate spheroidal coordinates, which are related to the Cartesian coordinates as follows $x + iy = (r + ia)\,\mathrm{e}^{i\phi}\sin\theta$ and $z = r\cos\theta$. The function H is singular at $r = 0$, $\cos\theta = 0$, corresponding to the Kerr singular ring. The function H is singular at $r = 0$, $\cos\theta = 0$, corresponding to the Kerr singular ring. The KN potential as well as the KN metric are aligned with the null direction k^μ, which forms the Kerr principal null congruence (PNC) determined by the differential form

$$k_\mu\,dx^\mu = dt + \frac{z}{r}\,dz + \frac{r\,(x\,dx + y\,dy)}{r^2 + a^2} - \frac{a\,(x\,dy - y\,dx)}{r^2 + a^2}. \tag{4}$$

The potential and metric are singular at the Kerr ring, which forms a branch line of the Kerr spacetime in two sheets, corresponding to $r > 0$ and $r < 0$ in the Kerr oblate coordinate system. Vector field k^μ forms Principal Null Congruence (PNC) of KN space, which is determined by the Kerr theorem in twistor terms. The Kerr PNC is smoothly propagated via the Kerr disk $r = 0$ from the «negative» sheet ($r < 0$) of spacetime to the «positive» one ($r > 0$) (see the Figure), and therefore, it covers the KN space twice: $k^{\mu(+)}$ for $r > 0$ and $k^{\mu(-)}$ for $r < 0$, leading to different metrics and different electromagnetic field on the «positive» and «negative» sheets [3]. Therefore, the Kerr ring creates a twosheeted background topology. This twosheetedness forms a principal puzzle



Vortex of the Kerr congruence. Twistor null lines are focused on the Kerr singular ring, forming a circular gravitational waveguide, or string with lightlike excitations

of the Kerr geometry over a period of four decades. There appeared two lines of investigations:

A) The regular bubble model, in which the negative KN sheet, $r < 0$, is truncated and replaced by the *rotating disklike source* spanned by the Kerr singular ring (Keres, Israel, Hamity); in further development (López) the Kerr ring is regularized, being covered by a disklike ellipsoidal surface, and turned into a rotating and charged oblate bubble with a flat interior. Finally, the bubble source is realized as a regular soliton-like model formed by a domain wall interpolating between the external KN solution and a flat pseudovacuum state inside the bubble (see refs. in [4]).

B) Stringlike model, in which twosheeted topology is retained, forming a closed «Alice» string [2].

Structure of the KN string is very close to that of the fundamental heterotic string, fundamental solution to the low-energy string theory. The heterotic strings carry the lightlike circular current and the lightlike traveling waves, which is similar to the lightlike structure of the Kerr singular ring. In [2] we showed relationship of the KN string model to the Dirac equation. Starting from the massless traveling waves (zitterbewegung) we obtain the massive Dirac theory, in which mass is generated by the Kaluza–Klein mechanism from the dynamics of traveling waves. However, contrary to the superstring constructions, we deal with 4D space-time, in which the role of a compact manifold is played by the Kerr ring. Exact solutions for electromagnetic excitations on the Kerr–Schild background, [3], showed that there are no smooth harmonic solutions on the KN background. Excitations of the KN background have a «paired» character: the lightlike «circular» traveling waves appear coupled with the propagating outward «axial» traveling waves (see Fig. 2.1 [3]). Axial waves are singular and tend asymptotically to the well known pp-wave (plane fronted) solutions, for which k_μ is asymptotically a covariantly constant Killing direction. The pp-waves form singular classical solutions to a low-energy string theory, forming the massless field around the lightlike fundamental strings. They may carry traveling electromagnetic and gravitational waves which represents propagating modes of the fundamental strings. In the nonperturbative approach based on analogues between the strings and solitons, the pp-wave solutions are considered as fundamental strings forming fundamental classical solutions to the low-energy string theory. The «solution-generating transforms» allowed Sen to get corresponding charged string with the lightlike moving current and oscillations, which was interpreted as a charged (and superconducting) heterotic string. There appeared also an extra axion field and the resulting dilaton field turns out to be singular at the string core. It has been noticed that the field structure of the Kerr singular ring is lightlike, similarly to the closed pp-wave or heterotic string. The twisted Kerr congruence (see the Figure) represents a «hedgehog» defocused by the rotation. The null lines of the Kerr congruence are focused only in equatorial plane ($z = \cos\theta = 0$). The Eq. (4) shows that PNC takes near the ring the form

$$\tilde{k} = k\big|_{r=\cos\theta=0} = dt - (x\,dy - y\,dx)/a = dt - a\,d\phi, \tag{5}$$

and therefore, the lightlike vector field k_μ near the ring is tangent to the Kerr string world sheet, and the Kerr ring is sliding along itself with the speed of the light. As a consequence, the vector potential (3) and the metric (1) near the Kerr ring are lightlike and aligned with the local direction of the Kerr string reproducing the structure of the closed heterotic-string. This similarity of the KN ring with the closed string is not incidental, since many solutions to the Einstein–Maxwell theory turn out to be particular solutions to the low energy string theory with a zero (or constant) axion and dilaton fields. The stringy analog to the Kerr–Newman solution with nontrivial axion and dilaton fields was also obtained by Sen, and it was shown in [5], that the field around the singular string in the «axidilatonic» Kerr–Sen solution is similar to the field around the heterotic string. The usual KN metric written in the Kerr–Schild tetrad form is $ds^2_E = 2e^3e^4 + 2e^1e^2$, where e^3 and e^4 are real, and e^3 is directed along the Kerr congruence, $e^{3\mu} \sim k^\mu$, while e^1 and e^2 are the two complex conjugate null vectors orthogonal to k^μ. The metric of the axidilatonic Kerr–Sen solution has the form (we use here the Einstein metric)

$$ds^2_E = 2e^3\,\tilde{e}^4 + 2e^1\,e^2\,\mathrm{e}^{-2(\Phi-\Phi_0)}, \tag{6}$$

which shows that the KN metric is deformed by the dilaton field, $\mathrm{e}^{-2(\Phi-\Phi_0)}$ is the orthogonal to the Kerr congruence directions. Traveling waves of the heterotic string may be generated by dual rotations of the vector field (which corresponds to generalization of the low energy string theory to the F-theory), which is controlled by a complex axion-dilaton field.

In the regularized KN bubble model (A), the regular stationary KN electromagnetic field forms a closed heterotic string positioned on the disklike boundary of the vacuum bubble near the Kerr ring. The twisted KN vector-potential (3) forms a nontrivial closed Wilson line which interacts with the Higgs field, resulting in the quantization of the soliton spin $\hbar/2$, [4].

For the stringy model (B), traveling waves along the KN string form a circulating string-antistring pair which may be considered as a lightlike zitterbewegung generating mass of the Dirac equation [2], and it was conjectured that the KN gravity and the heterotic string theory may lie beyond the Dirac equation.

The predicted by KN gravity closed Kerr string of the Compton size on the boundary of the electron core should be experimentally observable. There appears the question while it has not been obtained so far by the high-energy scattering. Explanation of this fact may be related with the lightlike character of the closed heterotic strings, for which the Lorentz effect should shrink their observable length. Meanwhile, observation of the relativistic objects is a very nontrivial process depending on the method of observation. For example, as it was shown by Penrose, the momentary photo-image of a relativistic sphere shouldn't be underwent the Lorentz contraction. We argue in [2] that the KN closed relativistic string, being probed by a real photon of high energy, shall display a pointlike structure. However, the situation may be different by a deeply virtual scattering with a low energy momentum transfer. Specifically, to visualize the KN relativistic string of the Compton size, there are necessary two special conditions: a) the scattering should be *deeply virtual*, which means very large $Q^2 = q_{12}^2$, and $p \cdot q_{12}$; and b) the momentum transfer should be *relatively low* to provide a coherent diffractive scattering with the wavelengths comparable with the Compton extension of the string. Both these conditions are satisfied in the novel approach, the Deeply Virtual Compton Scattering (DVCS), or a «nonforward Compton scattering», [6] which represents a new regime for probing the transverse shape and tomography of the particles [7].

REFERENCES

1. *Burinskii A. Ya.* // Sov. Phys. JETP. 1974. V. 39. P. 193;
   Ivanenko D. D., Burinskii A. Ya. // Izv. Vuz. Fiz. 1975. No. 5. P. 135.
2. *Burinskii A.* // Proc. of the QTS7 Conference, Prague, Aug. 2011; arXiv:1112.0225, see also arXiv:1104.0573, arXiv:1109.3872.
3. *Burinskii A.* // Gen. Rel. Grav. 2009. V. 41. P. 2281; arXiv:0903.3162 [gr-qc].
4. *Burinskii A.* // J. Phys. A: Math. Theor. 2010. V. 43. P. 392001; arXiv: 1003.2928.
5. *Burinskii A.* // Phys. Rev. D. 1995. V. 52. P. 5826; arXiv:hep-th/9504139.
6. *Radyushkin A. V.* // Phys. Rev. D. 1997. V. 56. P. 5524;
   Ji X. // Ibid. V. 55. P. 7114.
7. *Hoyer P., Samu Kurki* // Phys. Rev. D. 2010. V. 81. P. 013002; arXiv:0911.3011.