Spin shifts scale of gravitational interaction, opening new path to particle physics

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Abstract. We argue that spin deforms space along with mass, and the great spin/mass ratio of the elementary particles shifts gravitational interaction from Planck to Compton scale, opening new way to unification of gravity with quantum theory, based on the supersymmetric bag model.

1. Introduction
During last century the weakness of gravitational interaction based on the Planck scale of gravitational interaction was considered as indisputable truth. It was also supported by Schwarzschild solution, which distorts space in zone \( r_g \sim 2m \), commensurable with other interactions only at Planck scale. As is well known, until all of the projects were based on this concept and failed, and “... a realistic model of elementary particles still appears to be a distant dream ... ”, J. Schwarz [arXiv:1201.0981]. About half century ago, Kerr obtained a new solution for a spinning black hole (BH) [1], and Carter noticed [2], that the Kerr-Newman (KN) solution (charged version of the Kerr solution) has gyromagnetic ratio \( g = 2 \), i.e. the same as Dirac electron [2, 3]. In addition, it was noticed in [4, 5, 6], that the KN solution with parameters of an electron had influence on space not on the expected Planck scale, but changed really topology of space on the Compton distances, which are on 22 orders higher than Planck scale. In particular, the horizons disappeared and there appeared a naked singular ring deforming space topologically. The zone of space distortion becomes depending on spin/mass ratio \( a = J/m \), showing that spin deforms space along with mass, which should be taken into account by estimations of gravitational influence.

The action of spin on space is connected with gravitational effect of “frame-dragging” [7], which is a local deformation of the light cone system. Contrary to centrally symmetric “frame-dragging” in spherical black hole solutions, in the Kerr and KN solutions frame-dragging forms a vortex, which was called as Lense-Thirring effect. One can say that spin is gravitating, but its action on the metric is different. Contrary to Schwarzschild solution, which distorts space in zone \( r_g \sim 2m \), the Kerr solution with angular momentum \( J \) and mass \( m \) distorts space in zone \( r_K \sim J/m \). This becomes especially essential for particle physics, because \( J/m \) ratio of particles is giant, about \( \approx 10^{20} - 10^{22} \), and just underestimations of the role of spin led to failure of superstring project and others modern theoretical constructions.

1 We use the ‘natural’ (Planck) units \( \hbar = c = G = 1 \), in which Planck’s mass, length and energy are \( M_P = l_P = E_P = 1 \). In this system the energy equivalent to quantum spin \( \hbar = 1 \) is \( E_P = 1 \), while the typical masses of particles are about \( \approx 10^{-20} \).
Account of spin shifts scale of gravitational interaction from Planck to Compton scale, just to zone of action of quantum theory, leading to new concept: gravity and quantum theory become equally strong and should be considered on equal footings. Rank of gravity is raised to theory which lies in the heart of particle physics along with quantum theory.

We present here a model which is based on this new concept. This is a nonperturbative bag-like solution base on supersymmetric Higgs (or Landau-Ginzburg) field model, [8, 9, 10].

2. Supersymmetric bag model compatible with spinning Kerr-Newman solution

Metric of the KN solution in the Kerr-Schild form is [3]

\[ g_{\mu\nu} = \eta_{\mu\nu} + 2H k_{\mu} k_{\nu}, \]  

where \( \eta_{\mu\nu} \) is metric of auxiliary Minkowski space \( M^4 \), (signature \((-+++)\)), where scalar function

\[ H = \frac{mr - c^2/2}{r^2 + a^2 \cos^2 \theta}, \]

is given in oblate spheroidal coordinates \( r, \theta \), determined by transformations [3],

\[ x + iy = (r + ia) \exp\{i\phi_K\} \sin \theta, \quad z = r \cos \theta, \quad \rho = r - t. \]

The null field \( k_\mu(x), (k_\mu k^\mu = 0) \) determines the lightlike directions of ‘frame-dragging’, which takes vortex form Fig.1., Fig.2. For ultra-high spin of spinning particles, \( a = J/m \gg m \), ‘frame-dragging’ becomes so strong that black hole horizons disappear, opening a naked singular ring at \( r = 0, \cos \theta = 0 \). The congruence \( k^- \), which goes to disk \( r = 0 \) as ‘in-going’, intersects disk and turns into ‘out-going’ \( k^- \), which is extended analytically on the same background, forming a second sheet of the metric. The space becomes two-sheeted, with two different metrics on the same background, \( g_{\mu\nu} = \eta_{\mu\nu} + 2H k^\pm k_\pm \). The Kerr singular ring \( r = 0, \cos \theta = 0 \) of the Compton radius \( a = h/2m \) breaks space topologically, playing the role of a branch line.

Remarkable features of Kerr space led to study of KN solution as a classical model of electron, mainly in two directions:

A) W. Israel [4] first suggested to truncate negative sheet of Kerr space along disk \( r = 0 \) and put at the disk a distribution of matter in accord with right hand side of the Einstein equations. He got a very strange matter distribution without a clear physical interpretation, however, he found an analogue with a quantum process of mass renormalization and first declared that this disk-like source of Compton radius can be considered as a classical model of electron. Very important consequent calculation by Hamity [11] showed that the matter distribution of the source took diagonal form in the corotating coordinate system, and thus, the source of Kerr solution turned into a relativistically rotating disk, boundary of which is moving with speed of light. Later on López generalized this model to model of a rotating bubble [6].

B) Another stringy version of the Kerr source was developed in our works with Prof. D. Ivanenko [5, 12], where Kerr singular ring was compared with Nielsen-Olesen (NO) vortex string model in superconductor [13]. It was shown that Kerr’s singular ring can be considered as a lightlike string which can bear the electromagnetic and spinor traveling waves. Much later, such pp-wave strings were considered as solitonic string solutions to low energy string theory [14, 15].

Bag model merges directions A) and B). In the both these directions of investigation source of the Kerr geometry created a gravitational vortex of the Compton size, and there appeared the question: Why this vortex and singular ring were not observed experimentally, and electron looks like a point? Answer follows from mechanism of Lorentz contraction [16]. For external observer Kerr’s vortex shrinks to point by Lorentz contraction.

The suggested in [8, 9, 10] supersymmetric bag model solves problem of unification with gravity by separation of their zones of influence. Quantum theory requires flat space, at least in
the Compton zone, while spinning Kerr’s gravity spoils space topologically. Supersymmetry expels gravitational field from Compton zone of spinning particle, similar to expulsion of electromagnetic field from superconductor. Supersymmetric bag model realizes such expulsion of gravity and electromagnetic field, forming tree zones: flat quantum interior (I), external zone with exact KN solution (E), and a thin zone of transition (R), see Fig.3.

Surface (R) is defined by the continuous transition of KN solution to Minkowski interior of the bag, (C. López [6]). According (1) and (2), zone (R) corresponds to \( H_{KN}(r) = 0 \), which gives \( r = R = c^2/2m \), and (3) shows that domain wall boundary has an ellipsoidal form, the disk with radius \( r_c = \sqrt{R^2 + a^2} \) and thickness \( R \), see Fig.4.

To satisfy (I),(E),(R), it is natural to use Higgs mechanism of symmetry breaking which is used in many nonperturbative electroweak models and in the MIT and SLAC bag models [17, 18]. The corresponding Lagrangian is also known as Landau-Ginzburg (LG) field model for superconducting phase transitions and used in famous Nielsen-Olesen (NO) model of vortex string in superconductor, [13], \( \mathcal{L}_{NO} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{2}(D_\mu \Phi)(D^\mu \Phi)^* - V(|\Phi|) \), where \( D_\mu = \nabla_\mu + ieA_\mu \) are \( U(1) \) covariant derivatives, \( F_{\mu\nu} = A_{\mu\nu} - A_{\nu\mu} \) the corresponding field strength. Usual potential \( V = \lambda(\Phi^4 - \eta^2)^2 \), is inappropriate, since it breaks gauge symmetry in external zone (E). To satisfy conditions (I),(E),(R) one should use supersymmetric LG
model with three Higgs-like fields, [19] \((H, Z, \Sigma) \equiv (\Phi_1, \Phi_2, \Phi_3)\). Corresponding Lagrangian differs from \(L_{NO}\) only by summation over fields \(\Phi_i, i = 1, 2, 3\), while the potential \(V\) is to be formed from a superpotential \(W(\Phi_i)\), as \(V(r) = \sum_i F_iF_i^*\), \(F_i = \partial W/\partial \Phi_i \equiv \partial_i W\), where \(W(\Phi_1, \Phi_2) = Z(\Sigma - \eta^2) + (Z + \mu)H\bar{H}\). The conditions \(F_i = \partial_i W = 0\) determine two vacuum states with \(V = 0\): internal-(I), \(r < R - \delta\), condensation of Higgs field, \(|H| = \eta\), and external-(E), where \(r > R + \delta\) and \(H = 0\), separated by domain wall with \(V > 0\), – zone (R), in correspondence with (I),(E),(R).

Supersymmetric potential concentrates Higgs field in zone (I), creating superconducting vacuum state inside bag, where we can use the Lagrangian \(L_{NO}\) leading to equations

\[
\partial_\nu \partial^\nu A_\mu = J_\mu = e \phi \frac{e}{|H|^2} (\chi_\mu + eA_\mu),
\]

where \(\chi\) is oscillating phase of Higgs field \(H = |H|e^{i\chi(t, \phi)}\). Vector potential of the KN solution concentrates in equatorial plane near the Kerr singular ring and forms a circular string which is similar to Nielsen-Olesen vortex string in superconductor, but placed on the boundary of superconducting disk at \(r = R = e^2/2m\) where it takes maximal value \(A_\nu^* \partial_{\nu}^\mu = -Re \frac{e}{2m} (dt - a d\phi)\) and forms a longitudinal lightlike field dragged in \(t, \phi\) direction by the Kerr congruence near the ring, see Fig. 4. It forms a stringy Wilson loop which is compensated by phase of Higgs field, \(\chi_\mu + eA_\mu = 0 \Rightarrow J_\mu = 0\) inside the disk, leading to \(\chi = 2m(t + a\phi)\). Thus, current \(J_\mu\) is expelled to surface layer of the superconducting disk. Periodicity of the phase \(\chi(\phi)\) leads quantization of angular momentum, \([8, 9, 10]\), \(J = n/2\), \(n = 1, 2, 3, ...\).

By nature bag models are assumed to be soft and flexible \([22, 20, 21]\). Under excitations bags are deformed and take the shape of a stringy flux-tube joining the quark-antiquark pair \([17, 20]\), or toroidal string \([18, 21, 22]\). In the KN gravitational field, bag takes ellipsoidal shape, see Fig. 4, and acquires circular string at the sharp boundary, closely to Kerr singular ring \([9]\). This string bears lightlike traveling wave and creates circulating singular pole, reproducing zitterbewegung of a naked electron. On the other hand, this singular pole can be treated as a quark-antiquark pair, playing the role of end-points of the closed circular string, by analogy with the string models and with hadron bag models \([9, 23]\).

3. References

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