Illusion about weakness of gravity hides new way to unify gravity with particle physics

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Abstract. Well known weakness of Gravity in particle physics is an illusion caused by underestimation of the role of spin in gravity. We argue that spin deforms space along with mass, and great spin/mass ratio of elementary particles shifts effective scale of gravitational interaction from Planck to Compton distances. It opens new way to unify gravity and quantum theory, which is achieved by a supersymmetric bag model, creating a flat Compton zone near the core of particle required for consistent work of quantum processes. Super-bag is naturally upgraded to Wess-Zumino supersymmetric QED model, forming a bridge to perturbative formalism of conventional QED.

1. Introduction
One of the requirement for unification of Quantum theory with Gravity is a field description of an extended particle, since the pointlike particles cannot give a stress-energy tensor which is necessary for the right side of the Einstein equations, \( G_{\mu\nu} = 8\pi T_{\mu\nu} \). A perfect theory of unification was given by the old Kaluza-Klein model, where 4d Einstein-Maxwell equations \( 4G_{\mu\nu} = 8\pi T_{\mu\nu} \), were created from 5-dimensional Einstein’s tensor \( 5G_{MN} = 0 \), where the fifth component was generated by vector potential of electromagnetic field \( A^5 \), forming a circle with cylindrical boundary conditions. The experimental invisibility of this extra dimension created idea to shift size of circle to Planck scale, where experiment cannot resolve this structure. The idea of extra dimension was inherited by string theory together with idea of invisibility at the Planck scale, and was generalized to many extra dimensions. It was revolutionary step since the pointlike and structureless quantum objects turned into extended stringlike objects, retaining close relationship with general relativity. Planck scale appeared “... as a rough estimate of the fundamental string length scale as well as the characteristic size of compact extra dimensions.” [1] The additional arguments in favor of fundamentality of the Planck length was inclusion of the constant of gravitational interaction \( G \) with remarkable ‘naturalness’ of the Planck units, \( \hbar = c = G = 1 \), and also the fact, that at the Planck length \( l_P = (\hbar G/c^3)^{1/2} \), impact of gravitational Schwarzschild solution on space becomes commensurate with other interactions. As a result, during last century weakness of gravitational interaction and Planck scale of gravitational interaction were turned into an indisputable truth.

However, similarly to problems in Kaluza-Klein theory, the problems with unification appeared in superstring theory, and “...Since 1974 superstring theory stopped to be considered as particle physics...” and “... a realistic model of elementary particles still appears to be a distant dream ...”, J. Schwarz [2]. However science moves, and about half century ago Kerr
obtained a new gravitational solution for a spinning black hole (BH) [3]. It was obtained, the spinning and charged Kerr-Newman (KN) solution has strong influence on space not on the expected Planck scale, but on the much lower energy scale. In particular, it was obtained in [4, 5, 6] that the KN solution with parameters of an electron deforms space topologically at the Compton distance, which exceeds the Planck length on 22 orders.

The zone of space distortion depends on spin/mass ratio \( \frac{a}{m} = J/m \), showing that spin deforms space along with mass, and it should be taken into account at estimation of the gravitational influence.

Indeed, formation of BH horizons is related with gravitational effect of “frame-dragging” [7], which is a local deformation of the light cone system. In the Schwarzschild solution, BH horizons are formed by a centrally-symmetric frame-dragging, while in the Kerr and KN solutions frame-dragging forms a vortex, which cannot be removed by a global Lorentz transformations, and was called as a Lense-Thirring effect. One can say that spin is gravitating, but its action on the metric is different. Contrary to spherically symmetric Schwarzschild solution with mass \( m \), which distorts space in zone \( r_g \approx 2m \), the Kerr spinning solution with angular momentum \( J \) and mass \( m \) distorts space in zone

\[
r_K \sim \frac{J}{m},
\]

which becomes very essential for particle physics, because the spin/mass ratio of particles is typically about \( \approx 10^{20} - 10^{22} \). \(^1\)

So large extension of the zone of gravitational influence, about 20 orders for typical spinning particles shows that due to energy of spin influence of gravity on space-time is shifted from Planck scale to Compton distances \( r_K \), just to zone of action of quantum theory. Because of the huge spin/mass ratio, gravitational influence cannot be considered as weak.

It’s natural to compare this situation with Cosmology, where nobody says that gravity is weak because of giant masses. In the same way, Gravity is not weak in particle physics, because of the giant energy contribution from spinning particles.

The caused by spin effective deformation of space at Compton scale creates principally new situation, in which gravity and quantum theory become equally strong in vicinity of the Compton region, and should be considered on equal footings. Contrary to the old concept in which gravity is subordinated to quantum theory and must be quantized, rank of gravity is raised to theory of background space which may be theory of the deepest level. This requires a new conceptual approach to the problem of unification of quantum theory and gravity, and we present here a way to resolution of the conflict between these theories without quantization of gravity or modifications of the Einstein-Maxwell equations. We show that this remarkable mechanism is SUPERSYMMETRY which separates inner quantum region from gravity. We use a nonperturbative supersymmetric Higgs field model forming the super-bag, in which the region inside the bag is regularized by supersymmetric vacuum state with broken gauge symmetry. Inside the bag, gravitational and EM field acquire a mass and fall off, while the external space is retained as the exact KN solution.

The based on supersymmetric Higgs (or Landau-Ginzburg) field model nonperturbative solution has remarkable relationships with Wess-Zumino SuperQED model which gives a link to perturbative technics of the conventional QED. Here we discuss some features of this approach. For more details see [8, 9, 10, 11].

\(^1\) We use the ‘natural’ (Planck) units \( \hbar = c = G = 1 \), in which Planck’s mass, length and energy are \( M_P \), \( l_P \) and \( E_P \) are the Planck mass, length and energy. In this system the energy equivalent to spin \( \hbar = 1 \) is \( E_P = 1 \), while the typical masses of particles are about \( 10^{-22} \).
2. Supersymmetric bag model compatible with spinning Kerr-Newman solution

The spinning Kerr-Newman (KN) solution [3, 12] is of particular interest, since, as it was obtained by Carter, it has gyromagnetic ratio $g = 2$, the same as that of the Dirac electron [12, 13].

Metric of KN solution in the Kerr-Schild form is [12]

$$g_{\mu\nu} = \eta_{\mu\nu} + 2Hk_\mu k_\nu,$$

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

$$H_{KN} = \frac{mr - e^2/2}{r^2 + a^2 \cos^2 \theta},$$

is given in oblate spheroidal coordinates $r$ and $\theta$, determined by transformations [12],

$$x + iy = (r + ia)e^{i\phi_K} \sin \theta, \quad z = r \cos \theta, \quad \rho = r - t.$$

The null field $k_\mu(x)$, $(k_\mu k^\mu = 0)$ determines directions of ‘frame-dragging’, which takes vortex form Fig.1., Fig.2. For ultra-high spin of spinning particles, $a = J/m >> m$, ‘frame-dragging’ becomes so strong that black hole horizons disappear and field $k_\mu(x)$ focuses on singular ring $r = 0$, $\cos \theta = 0$. The congruence $k^-_\mu$, which towards the disk $r = 0$ as ‘in-going’, intersects disk and turns into an ‘out-going’ one $k^+_\mu$, 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, $g^{\pm}_{\mu\nu} = \eta_{\mu\nu} + 2Hk_{\mu}^\pm k_{\nu}^\pm$. The Kerr singular ring $r = 0$, $\cos \theta = 0$ of the Compton radius $a = \hbar/2m$ breaks space topologically, playing the role of a branch line of the Kerr space.

Strange twosheetedness of Kerr space and remarkable coincidence with gyromagnetic ratio of the Dirac electron led to study of source of the Kerr 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 [14] 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, 15], where Kerr singular ring was compared with Nielsen-Olesen (NO) vortex string model in superconductor [16]. 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 [17, 18].

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 was not observed experimentally, where electron looks like a point without structure? Answer follows from mechanism of Lorentz contraction [19] (see also metric on relativistically rotating disk in Landau and Lifshitz book The Classical Theory of Fields, Sec.89) – for external observer Kerr’s vortex, as well as the lightlike circular string of Compton radius shrink to point by Lorentz contraction.

The suggested in [8, 9, 10] supersymmetric bag model merges the directions A) and B) on the base of Higgs mechanism and simultaneously solves the problem of unification with gravity.
Quantum theory requires flat space, at least in the Compton zone, but spinning Kerr’s gravity spoils space topologically, and it is unclear, how quantum theory can work on such background. 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.

For the giant values of spin, these demands become so restrictive that structure of bag is determined almost unambiguously.

Surface (R) is defined by the continuous transition of KN solution to Minkowski interior of the bag, (C. López [6]). According (2) and (3), zone (R) corresponds to $H_{KN}(r) = 0$, which gives

$$r = R = e^2/2m,$$

(5)

and (4) shows that boundary of bag must form an ellipsoidal domain wall, 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.
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, [16],

$$\mathcal{L}_{NO} = -\frac{1}{4}F_{\mu \nu}F^{\mu \nu} - \frac{1}{2}(\mathcal{D}_\mu \Phi)(\mathcal{D}^\mu \Phi)^* - V(\Phi),$$  \hspace{2cm} (6)

where $\mathcal{D}_\mu = \nabla_\mu + ieA_\mu$ are $U(1)$ covariant derivatives, $F_{\mu \nu} = A_{\mu \nu} - A_{\nu \mu}$ the corresponding field strength. Usually, potential $V$, has the form $V = \lambda(\Phi^2 - \eta^2)^2$, which is inappropriate, since it breaks gauge symmetry in external zone (E), distorting gravitational field. To satisfy all the conditions (I),(E),(R) one should use the supersymmetric LG model with three Higgs-like fields, [22] $(H, Z, \Sigma) \equiv (\Phi_1, \Phi_2, \Phi_3)$.

Corresponding Lagrangian differs from (6) only by summation over the fields $\Phi_i$, $i = 1, 2, 3$, while the potential $V$ should be formed from a superpotential $W(\Phi_i)$,

$$V(r) = \sum_i F_i F_i^*, \quad F_i = \partial_i W/\partial \Phi_i \equiv \partial_i W,$$  \hspace{2cm} (7)

where

$$W(\Phi_i, \bar{\Phi}_i) = Z(\Sigma \Sigma - \eta^2) + (Z + \mu)H\bar{H}.$$  \hspace{2cm} (8)

The conditions $F_i = \partial_i W = 0$ determine two vacuum states with $V = 0$:

- internal- (I), where $r < R - \delta$, and Higgs field $|H| = \eta$, and
- external- (E), where $r > R + \delta$ and Higgs field $H = 0$, separated by domain wall with $V > 0$, forming ellipsoidal boundary - zone (R), in correspondence with (I),(E),(R).

Note that quartic potential used in known bag models forms a "cavity in superconductor", while the supersymmetric potential (7)-(8) concentrates Higgs field in zone (I), giving supersymmetric and superconducting vacuum state inside bag, where we can use the NO Lagrangian (6) leading to equations

$$\partial_\nu \partial^\nu A_\mu = J_\mu = e|H|^2(\chi_{\mu} + eA_\mu),$$  \hspace{2cm} (9)

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 $r = R = c^2/2m$ where it takes maximal value $A_\mu^* dx^\mu = -Re \frac{2m}{c}(dt - ad\phi)$ 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 $\chi(\phi) = \chi(\phi + 2\pi)$ leads to remarkable consequence - quantization of angular momentum, [8, 9, 10], $J = n/2$, $n = 1, 2, 3, \ldots$.

By nature bag models are assumed to be soft and flexible [25, 23, 24]. Under excitations bags are deformed and take the shape of a stringy flux-tube joining the quark-antiquark pair [20, 23], or toroidal string [21, 24, 25].

The bag adopted to KN gravitational field acquires an ellipsoidal shape, see Fig.4, and circular string is formed on the boundary of the disk, closely to Kerr singular ring. So, the string is really formed by singular ring and regularized by bag boundary. The assumption, that Kerr singular ring is similar to NO model of dual string was done long ago in [5, 15], where it was noted that excitations of the KN solution create traveling waves along the Kerr ring. Later, it was obtained in [17] close connection of the Kerr singular ring with the Sen fundamental string solution to low energy string theory, and other relations of Kerr geometry with string theory.

[20, 21].
String admits traveling waves, which deform position of the bag boundary according \( \mathbf{R} \), creating a circulating lightlike node, where surface of the deformed bag touches the Kerr singular ring, creating a circulating lightlike singular pole, which can be associated with a confined quark, Fig.4B, and super-bag turns into a single “bag-string-quark” system, resembling D2-D1-D0-brane sistem of string-Mtheory.

In turn, capture of quarks, is one more special feature of the bag model, requiring consistent implementation of the Dirac equation \([20, 21, 24, 25]\). In KN geometry, it is defined according to famous Kerr Theorem \([12]\) which defines the shear-free Kerr congruences in twistor terms, and gives two roots \( Y^\pm \) for projective spinor coordinate

\[
Y = \phi_1/\phi_0,
\]

which is equivalent to two-component Weyl spinor \( \phi_\alpha \), and defines the null direction as

\[
k_\mu = \bar{\phi}_\alpha \sigma_\mu^{\alpha \beta} \phi_\beta.
\]

As it was shown in \([26, 8]\), two roots of the Kerr theorem \( Y^\pm \) give us two Weyl spinors, \( \phi_\alpha \) and \( \bar{\chi}_\alpha \), consistent with ingoing and outgoing KN solutions in zone \( \mathbf{E} \). Inside the bag, these solutions unite, forming the Dirac spinor

\[
\Psi = \begin{pmatrix} \phi_\alpha \\ \bar{\chi}_\alpha \end{pmatrix}
\]

which gets mass through Yukawa coupling to condensate of the Higgs field.

Finally, Super-Bag can be naturally upgraded to Wess-Zumino SuperQED model, \([11]\), revealing connections between the non-perturbative solutions of the supersymmetric LG model and the conventional perturbative technics used in QED.

### 3. Conclusion

The giant spin/mass ratio of spinning particles shows that the known earlier concept of weakness of gravitational interaction was incorrect. The shift scale interaction from Planck to Compton distances opens new way to consistent with gravity particle physics based on supersymmetric Higgs model which resolves the conflict between these theories without quantization of gravity or modifications of the Einstein-Maxwell field equations.

Using supersymmetric Higgs (LG) field model we find a nonperturbative supersymmetric bag solution, which separates the external curved space from Compton zone of quantum processes. Bag model naturally merges two old directions of investigation of the problem of source of the KN solution, A) and B).

Applying this model to electron, we should note the fact that for electron \( g_e \approx 2 \) plus the correction \( \alpha/\pi \). The KN model gives only \( g_e = 2 \) as the Dirac model before QED. Of course, the considered KN model is not final, since many effects are not taken into account. In particular, the effect of back reaction of the excitations cannot be considered at present time, since the accelerated KN solutions are not obtained so far because the extraordinary difficulty of the mathematical part of this problem.

Note also, that \( r_K \) is just the Compton zone of the dressed electron which is responsible for the appearance of the Lamb shift which is described perturbatively in QED. The described superBag model is nonperturbative and there appears natural requirement to reproduce all remarkable results obtained by QED. The recent paper \([11]\) is just the work in this direction, since it states a link between perturbative QED and remarkable cancellations between component diagrams obtained for the perturbative version of the supersymmetric Wess-Zumino superQED model.

There are a lot of other open problems in this direction of investigation.
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