Unification of Gravitation with the Particle Physics: Lessons from the Kerr-Newman Spinning Particle.

A. Burinskii, NSI Russsian Academy of Sciences

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Based on: *A.B., Illusion of the Weakness of Gravity...* arXiv:1701.01025,
A.B., *Gravitating Lepton Bag Model* , JETP, v.148 (8), 228 (2015),
A.B., *Stability of the Lepton Bag Model ...*, JETP, v.148(11), 937 (2015), arXiv:1706.02979,
***A.B., Source of the Kerr-Newman solution ...* Phys.Lett. B754, 99 (2016), arXiv:1602.04215.**

Unification of Gravity and Particle physics is main modern problem.

Superstring theory and Loop Quantum gravity are based on Planck scale 10^{-33}cm which first originated as "invisible" fundamental length in Kaluza-Klein theory.

Gravity is negligible and estimated by Schwarzschild "gravitational radius"

$$\mathbf{R_g = 2Gm}.$$

1963 – Spinning Gravity – Kerr solution.

B. Carter (1968) – Kerr-Newman solution has gyromagnetic ratio $g = 2$, of the Dirac electron.

The Kerr-Newman spinning particle is by nature consistent with gravity. To study and get lessons!

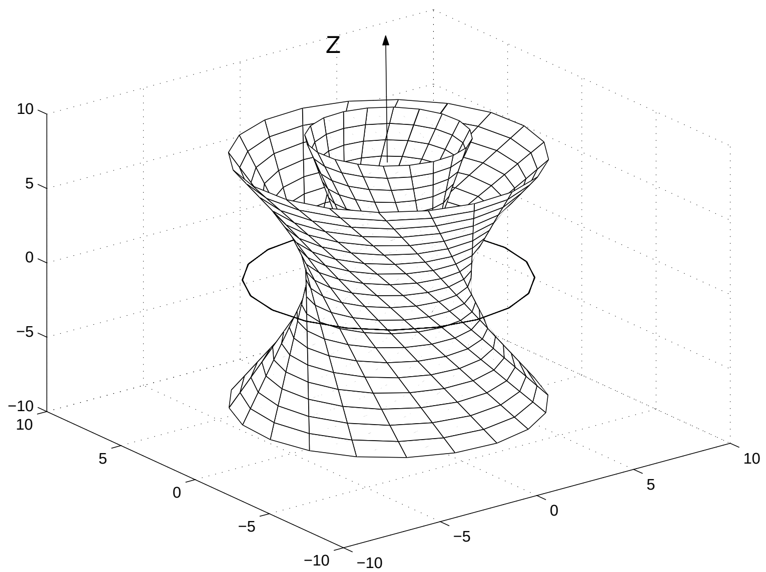
Structure of the spinning Kerr gravity differs radically from the Schwarzschild solution. Black hole horizons disappear – naked Kerr singular ring of the Compton radius

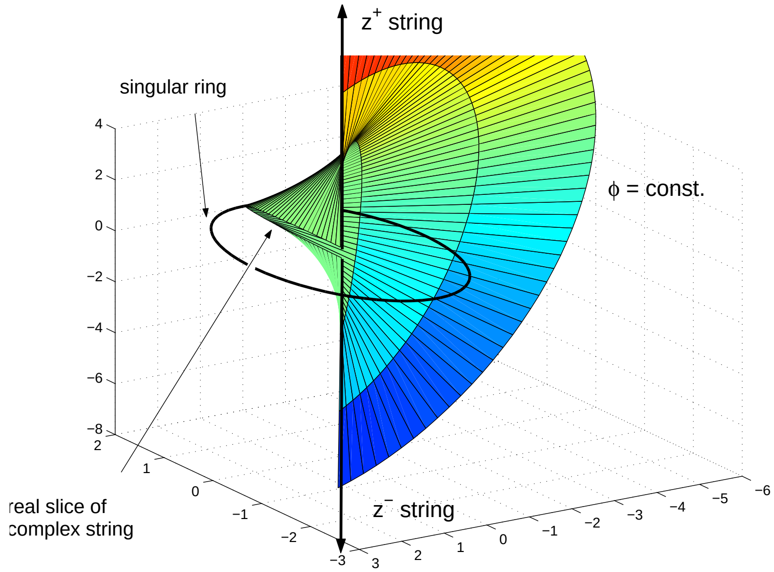
$$\mathbf{a = J/m \sim \hbar/mc}$$

Huge SPIN/MASS ratio of spinning particles distorts space topologically.

Kerr singular ring is branch line creating two-sheeted space.
Structure of the Kerr solution is defined by field of the Principal Null Congruence $\mathbf{k}^\mu(\mathbf{x})$ – direction of frame-dragging.

$$\mathbf{g}^{\mu\nu} = \eta^{\mu\nu} + \mathbf{2H}(\mathbf{r},\theta)\mathbf{k}^\mu\mathbf{k}^\nu, \quad \mathbf{A}^\mu = \frac{-\mathbf{er}}{\mathbf{r^2} + \mathbf{a^2}\cos^2\theta}\mathbf{k}^\mu, \quad \mathbf{H} = \frac{\mathbf{mr} - \mathbf{e^2}/2}{\mathbf{r^2} + \mathbf{a^2}\cos^2\theta}$$





Two sheets. HOLE of the Compton radius $\mathbf{a} = \hbar/\mathbf{mc} \sim \mathbf{10^{-11}cm}$.

QUANTUM THEORY CANNOT WORK IN SUCH SPACE.

Conflict between Gravity and Quantum Theory increases.

Kerr-Newman model of electron – series of the works: (B.Carter 1968, W.Israel 1970, A.B. 1974, C.López 1984).

Kerr-Newman Spinning Particle shows that instead of confrontation, gravity collaborates with quantum theory, creating series of quantum parameters of electron:

- **gyromagnetic ratio** $g = 2$,
- **Compton wavelength** $r_c = \hbar/2mc$**,**
- **classical radius of electron** $r_e = e^2/2m$,
- **fine structure constant** α,
- **stringy structure.**

Works: (B.Carter 1968, W.Israel 1970, J.Tiomno 1973, A.B. 1974, V.Hamity 1976, C.López 1984).

Development:*"50 Years to the problem of source of KN solution:"* AB, *Phys. Lett. B 754 (2016) 99.*

CONCEPTUAL CHANGES:

- Gravitational interaction is shifted from Plank to Compton scale – zone of coverage of Quantum theory
- Gravity is no more the weakest interaction and appears on an equal footing with Quantum theory.
- Sharp conflict is replaced by cooperation!

No need to quantize or modify gravity – HOLE IN SPACE IS CURED BY SUPERSYMMETRY.

SUPERSYMMETRIC BAG model – the flat vacuum state is formed inside the Bag!

WHY BAG?

- **Bags are soliton solutions based on the Higgs mechanism.**
- **Bags are soft and flexible, and deformed bags create strings.**
- **Landau-Ginzburg models of superconductivity, and deep relations with conformal and integrable systems.**

WHY SUPERSYMMETRY?

John Ellis, Where is Particle Physics Going? hep-th:1704.02821, ***bad news is that the LHC experiments have found not even a hint of supersymmetry …***

Nonperturbative field model of bag is formed by the N=1 supersymmetric Landau-Ginzburg (LG) field model in the form of *domain wall* solution.
BASIC IDEA: Domain Wall separates the zones of coverage: Gravity acts OUTSIDE the bag, leaving INSIDE flat area for quantum vacuum!

Importance of the LG models.

N=0: Nielsen-Olesen model of the vortex line, bag models,
N=1: domain walls in strongly coupled theories (G.Dvali and M.Schifman 1996),
N=2: Landau-Ginzburg models related with superstring theory, constructions of σ models, heterotic strings and classification of the conformal theories and string vacua (C.Vaffa 1989, E. Witten hep-th/0504078), integrable soliton and domain wall structures (P.Fendley at al.1990).

50 years to problem of source of the Kerr-Newman solution.

- **Bubble or solitonic source:**

  H.Keres, *Soviet Phys. JETP* 25, 504, (1967),

  B.Carter, *Phys. Rev.* 174, 1559 (1968),

  W.Israel, *Phys. Rev.* D 2, 641, (1970),

  M.Gürses & F.Gürsay, *J.Math. Phys.* 16, 2385, (1975),

  A.Krasinski, 1978,

  C.López *Phys. Rev.* D 30, 313, (1984), A.B. 2000-2010 etc.

- **String-like source,** inspired by process of annihilations of the electron-positron pair and by Wheeler's model of a "mass without mass": A.B. *Soviet Phys. JETP* 39, 193, (1974),

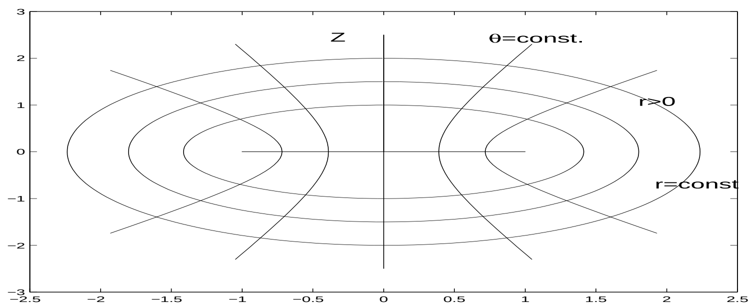
  Ivanenko and A.B. *Izv. Vuz. Fiz.*, 5, 135 (1975).

- **Bag models are soft, deformable and sensitive to external conditions. Also, it is related with string models –** unite the solitonic and string models. A.B. *JETP,* v.148 (8), 228 (2015) and *JETP*, v.148(11), 937 (2015), arXiv:1706.02979.

Shape and size of the Kerr-Newman bag is *fixed by gravity.* External Kerr-Newman solution is matched with FLAT CORE (López 1985).

$$\mathbf{g}^{(\mathbf{KN})}_{\mu\nu} = \eta_{\mu\nu} + \mathbf{2H}_{(\mathbf{KN})}\mathbf{k}_\mu\mathbf{k}_\nu, \quad \textbf{where} \quad \mathbf{H}_{(\mathbf{KN})} = \frac{\mathbf{mr} - \mathbf{e}^2/\mathbf{2}}{\mathbf{r}^2 + \mathbf{a}^2\cos^2\theta},$$

where r is oblate spheroidal coordinate



Gravity controls:

- **The reduced Compton wavelength** $a = J/m = \hbar/2mc$
- **the Compton and classical radius of the electron,**
- **the fine structure constant,**
- **quantum angular momentum:**

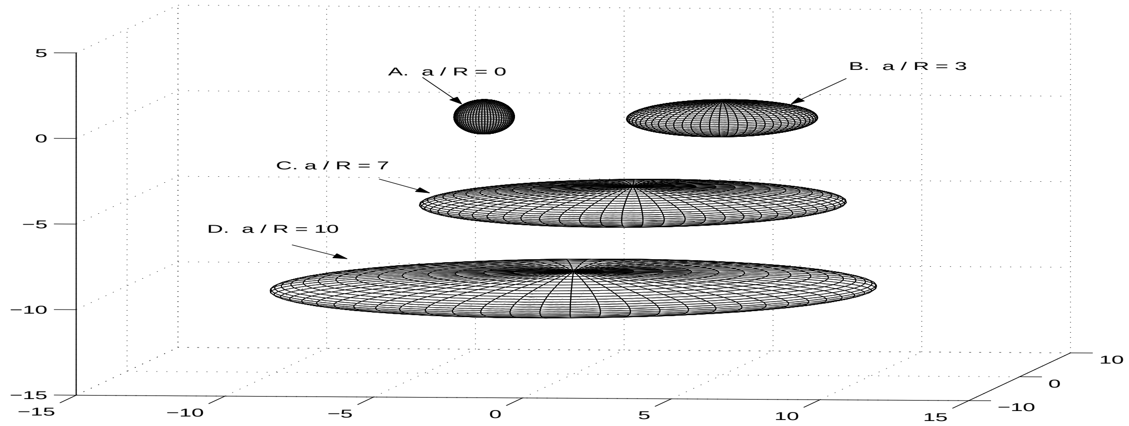


Figure 1: **Shape of the bag is fixed by angular momentum.**

– **Classical radius and shape of the bag: setting $H_{(KN)} = 0$ we obtain boundary of bag at $r = R_e = e^2/2m$, and flat interior at $g_{\mu\nu}^{(KN)} = \eta_{\mu\nu}$.**

– **The fine structure constant α: Since $a = J/m = \hbar/2m$, and** $R_e = e^2/2m, \Rightarrow R_e/a = e^2/\hbar = \alpha$.

– **Wilson loop along border determines quantization of the angular momentum.**

– **Bag takes ellipsoidal form. Circular string is formed on the sharp border of the Bag.**

Quantization of the angular momentum

Near the border, at Kerr's radial distance $r = r_e = e^2/2m, \ \cos\theta = 0,$ vector-potential takes maximal value

$$A_\mu^{max} dx^\mu = -\frac{2m}{e}(dr - dt - a d\phi). \qquad (1)$$

At the border of bag, the dragged by Kerr congruence angular component

$$A_\phi^{max} d\phi = \frac{2m}{e} a d\phi \qquad (2)$$

forms closed loop. Integral for period $\phi \in [0, 2\pi]$, is

$$e \oint A_\phi^{max} d\phi = 4\pi m a. \qquad (3)$$

Using the basic relation $J = ma$ we obtain

$$e \oint A_\phi^{max} d\phi = 4\pi J, \qquad (4)$$

which for integer or half-integer spin, $J = \frac{1}{2}, 1, \frac{3}{2}...,$ gives the closed Wilson loops along border of the bag.

Vacuum state inside the bag is separated from external gravitational field by the supersymmetric Domain Wall boundary.
SUPERCONDUCTIVITY: Supersymmetric BAG is formed by Domain Wall solution of the N=1 Landau-Ginzburg (LG) field model.

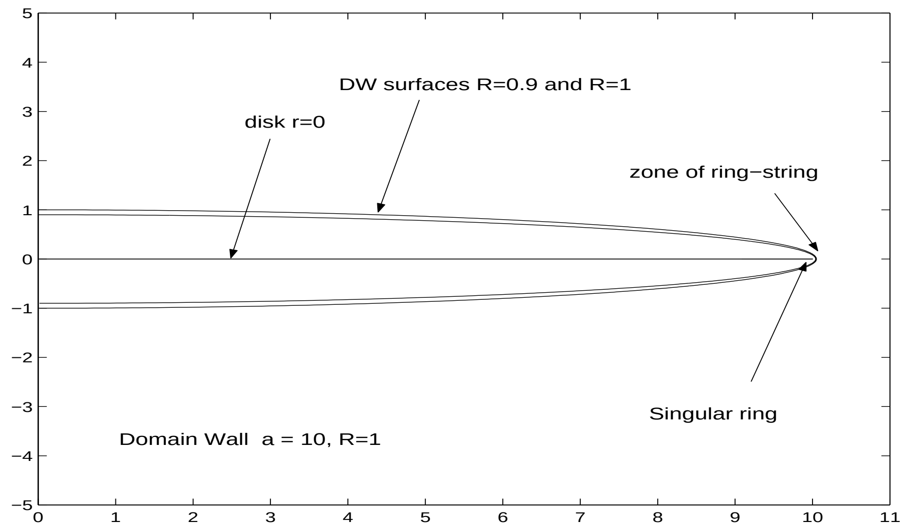


Figure 2: **Profile of the bag boundary.**

The LG model was used by Nielsen-Olesen (NO) as a dual string model, also in soliton models and in the MIT and SLAC bag models.

$$\mathcal{L}_{NO} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{2}(\mathcal{D}_\mu H)(\mathcal{D}^\mu H)^* - V(|H|).$$

The superficial current in superconductor $\Box A_\mu = J_\mu = e|H|^2(\chi,_\mu + eA_\mu)$.

Important peculiarities!

The usual potential $V = g(H\bar{H} - \sigma^2)^2$ gives incorrect model, in which bag is formed as a cavity in superconductor.

To form superconducting bag, it is necessary several Higgs-like fields (Witten, 1985) $\Phi^i, i = 1...5$, and the corresponding pseudo-supersymmetric model (J. Morris, 1996) requires potential

$$V(r) = \sum_i |\partial_i W|^2 \tag{5}$$

to be formed from superpotential

$$W(\Phi^i) = \Phi^{(2)}(\Phi^{(3)}\tilde{\Phi}^{(3)} - \eta^2) + (\Phi^{(2)} + \mu)\Phi^{(1)}\tilde{\Phi}^{(1)}. \tag{6}$$

Supersymmetry provides concentration of the Higgs field INSIDE the bag.
(A.B. *JETP* 2015, *Phys.Lett.B* 2016).

Phases of two oscillating Higgs fields $H^+(x) = |H^+|e^{i\chi^+(x)}$, $H^-(x) = |H^-|e^{i\chi^-(x)}$ interact with vector potential A^μ:

$$\Box A_\mu = J^-_\mu + J^+_\mu = e[|H^+|^2(\chi^+,_\mu + eA^+_\mu) + |H^-|^2(\chi^-,_\mu - eA^-_\mu)].$$

Superficial currents vanish inside the superconducting bag $J^+_\mu + J^-_\mu = 0$.

SUPERSYMMETRIC scheme of phase transition is built of the N=1 LG Lagrangian

$$\mathcal{L} = -\frac{1}{4}\sum_{i=1}^{3} F^{(i)}_{\mu\nu}F^{(i)\mu\nu} - \frac{1}{2}\sum_{i=1}^{3}(\mathcal{D}^{(i)}_{\mu}\Phi^{(i)})(\mathcal{D}^{(i)\mu}\Phi^{(i)})^{*} - V,$$

where covariant derivatives $\mathcal{D}^{(i)}_{\mu} = \nabla_{\mu} + ieA^{(i)}_{\mu}$ and we use the five chiral fields $\Phi^{(i)} = \{H^{+}, H^{-}, Z, \Sigma^{+}, \Sigma^{-}\}$, where H^{+}, H^{-} are selected as two Higgs fields.
Holomorphic superpotential (suggested by J. Morris, 1996)

$$W = Z(\Sigma^{+}\Sigma^{-} - \eta^{2}) + (Z + \mu)H^{+}H^{-}, \tag{7}$$

determines the potential

$$V(r) = \sum_{i} |\partial_{i}W|^{2}. \tag{8}$$

Vacuum states $V_{(vac)} = 0$, are determined by the conditions $\bar{F}_{i} = \partial_{i}W = 0$.
SUPERSYMMETRIC Domain Wall generates two supersymmetric vacuum states:

(I) supersymmetric vacuum inside the bag:

$$H^{-}H^{+} = \eta^{2},\ \ Z = -\mu,\ \ \Sigma^{+} = \Sigma^{-} = 0,$$

(II) external supersymmetric vacuum state: $H^{-}H^{+} = 0;\ Z = 0;\ \Sigma^{+}\Sigma^{-} = \eta^{2}$.
Phases of the Higgs fields H^{+} and H^{-} inside the bag become correlating .

Two Higgs superfields

$$\mathbf{\Phi_1 = \Phi_+(y) = H_+(y^\mu) + \sqrt{2}\theta\psi_+(y^\mu) + \theta\theta F_+(y^\mu).}$$

$$\mathbf{\Phi_2 = \Phi_-(y) = H_-(y^\mu) + \sqrt{2}\theta\psi_-(y^\mu) + \theta\theta F_-(y^\mu).}$$

completed by two Weyl spinors $\psi_+(\mathbf{y}^\mu)$, $\psi_-(\mathbf{y}^\mu)$ of the Dirac equation. Other chiral fields $\Phi_i, i = 3, 4, 5$ we leave undetermined

$$\mathbf{\Phi_i(y) = A_i(y^\mu) + \sqrt{2}\theta\psi_i(y^\mu) + \theta\theta F_i(y^\mu).}$$

Kinetic term super-QED has two chiral fields Φ_+ and Φ_-,

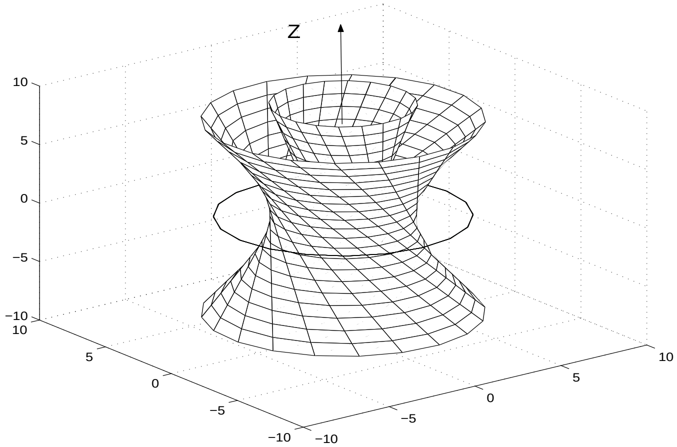
$$\mathcal{L}_{kinQED} = \frac{1}{4}Re \int d^4x\, d^2\theta\, W^a W_a + \int d^4x\, d^4\theta\, (\Phi_+^+ e^{eV}\Phi_+ + \Phi_-^+ e^{-eV}\Phi_-), \qquad (9)$$

and potential term is the sum of chiral and anti-chiral parts $W + W^+$. The Feynman rules are stated in terms of superfield vertices and propagators with miraculous cancellations between component diagrams. (Wess and Bagger "Supersymmetry and Supergravity".)

Supersymmetric Bag model acquires spinor structure. SuperQED forms a bridge to perturbative Quantum theory and shows that Compton zone of the dressed electron can be formed from a supersymmetric vacuum state of the Higgs field.

Structure of the Kerr solution is defined by field of the Principal Null Congruence $\mathbf{k}^\mu(\mathbf{x})$ – direction of frame-dragging.

$$\mathbf{g}^{\mu\nu} = \eta^{\mu\nu} + \mathbf{2H}(\mathbf{r},\theta)\mathbf{k}^\mu\mathbf{k}^\nu, \quad \mathbf{A}^\mu = \frac{-\mathbf{er}}{\mathbf{r}^2 + \mathbf{a}^2\cos^2\theta}\mathbf{k}^\mu, \quad \mathbf{H} = \frac{\mathbf{mr} - \mathbf{e}^2/2}{\mathbf{r}^2 + \mathbf{a}^2\cos^2\theta}$$



KERR THEOREM: Geodesic and Shear-free congruences $\mathbf{k}^\pm(\mathbf{x})$ ***are obtained as analytic solutions of the equation*** $\mathbf{F}(\mathbf{T}^\mathbf{a}) = \mathbf{0}$ ***, where*** F ***is a holomorphic function of the projective twistor coordinates***

$\mathbf{T}^\mathbf{a} = \{\mathbf{Y}, \quad \zeta - \mathbf{Y}\mathbf{v}, \quad \mathbf{u} + \mathbf{Y}\bar{\zeta}\}.$

$\mathbf{Y}^+ = \phi_1/\phi_0$, **is equivalent to Weyl spinor** ϕ_α **and** $\mathbf{Y}^-$, **to** $\bar{\chi}^{\dot{\alpha}}$.

TWISTOR ⇔ SPINOR relation is origin of the consistent Dirac field.

DIRAC EQUATION splits in the Weyl representation into two equations

$$\sigma^{\mu}_{\alpha\dot{\alpha}}\mathbf{i}\partial_\mu \bar{\chi}^{\dot{\alpha}} = \mathbf{m}\phi_\alpha, \quad \bar{\sigma}^{\mu\dot{\alpha}\alpha}\mathbf{i}\partial_\mu\phi_\alpha = \mathbf{m}\bar{\chi}^{\dot{\alpha}}, \tag{10}$$

the "left-handed" and "right-handed" electron fields, Weyl spinors.

Two antipodally conjugate solutions of the Kerr theorem $Y^+ = -1/\bar{Y}^-$ determine two Weyl spinor fields ϕ^α and $\bar{\chi}_{\dot{\alpha}}$, corresponding to antipodal congruences $\mathbf{Y}^+ = \phi_\mathbf{1}/\phi_\mathbf{0} \quad , \quad \mathbf{Y}^- = \bar{\chi}^{\dot{\mathbf{1}}}/\bar{\chi}^{\dot{\mathbf{0}}}$.

Weyl spinors of the WZ model (Dirac spinors) are aligned to two Kerr's principal null congruences.

For Y^+ we have

$$\phi_\alpha = \begin{pmatrix} e^{-i\phi/2}\cos\frac{\theta}{2} \\ e^{i\phi/2}\sin\frac{\theta}{2} \end{pmatrix}, \tag{11}$$

and for $\mathbf{Y}^- = -\mathbf{1}/\bar{\mathbf{Y}}^+$,

$$\bar{\chi}^{\dot{\alpha}} = \begin{pmatrix} -e^{-i\phi/2}\sin\frac{\theta}{2} \\ e^{i\phi/2}\cos\frac{\theta}{2} \end{pmatrix}. \tag{12}$$

STRINGY STRUCTURES IN THE BAG MODELS:

Bags are soft and elastic. Rotating bags are deformed and turn into string-like flux-tubes. (K. Johnson and C. B. Thorn, PRD 13, 1934 (1976); Chodos et al. PRD 9, 3471 (1974).)

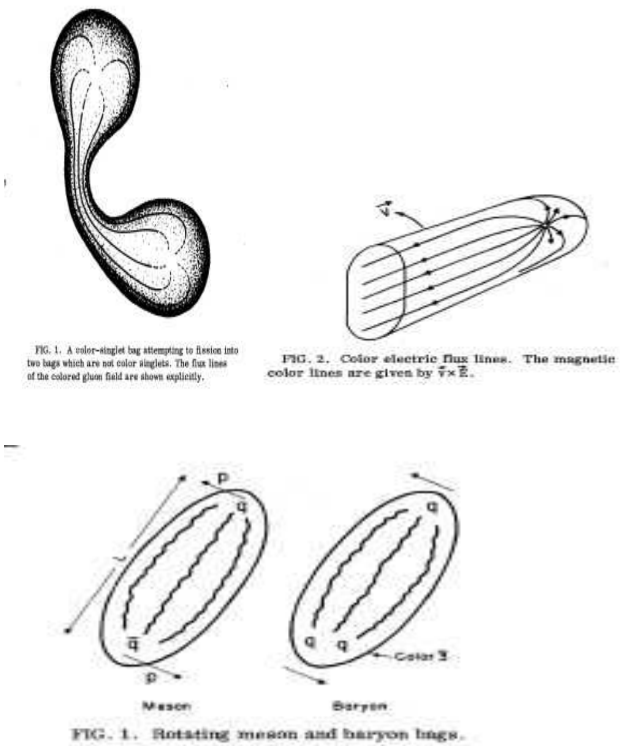


Figure 3: **Rotating bags are deformed and generate flux-tube strings.**

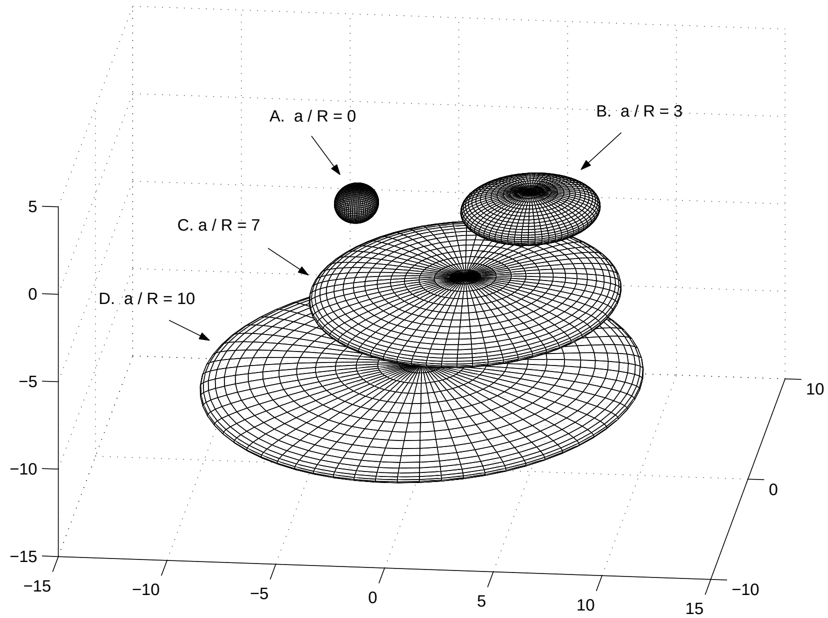


Figure 4: **Deformation of the KN Bag under rotation. Circular string is formed at the sharp border of the bag.**

Emergence of the Kerr stringy structure.

The Kerr singular ring as a circular string – "gravitational waveguide" for traveling EM waves (pp-waves), (A.B. 1974. A.B.& Ivanenko 1975.)

Kerr singular ring is lightlike, and coordinate system is dragged by ring.

String is formed by sharp border of the bag, and it can be identified with the Kerr singular ring up to the cut-off parameter $\delta \sim \alpha^2$

The Kerr string is light-like and can be considered as tangential to the Kerr singular ring

$$\mathbf{k}^+_\mu \mathbf{dx}^\mu = (\mathbf{dt} - \mathbf{a}\mathbf{d}\phi) \tag{13}$$

Really, the string direction $d\phi$ deviates slightly from the lightlike direction of the Kerr congruence k^+_μ, and the real velocity of the bag border becomes smaller than the speed of the light.

This effect can be described as a small component A^-_μ in direction

$$\mathbf{k}^-_\mu \mathbf{dx}^\mu = (\mathbf{dt} + \mathbf{a}\mathbf{d}\phi), \tag{14}$$

which is opposite (antipodal) to k^+_μ.

The real potential forming the closed string at the bag border takes the form

$$\mathbf{A}^{\mathbf{max}}_\mu \mathbf{dx}^\mu = \mathbf{A}^+_\mu \mathbf{dx}^\mu + \mathbf{A}^-_\mu \mathbf{dx}^\mu \approx -\frac{\mathbf{2m}}{\mathbf{e}}(\mathbf{dt} - \mathbf{a}\mathbf{d}\phi) + \mathbf{A}^-_\mu(\mathbf{dt} + \mathbf{a}\mathbf{d}\phi). \tag{15}$$

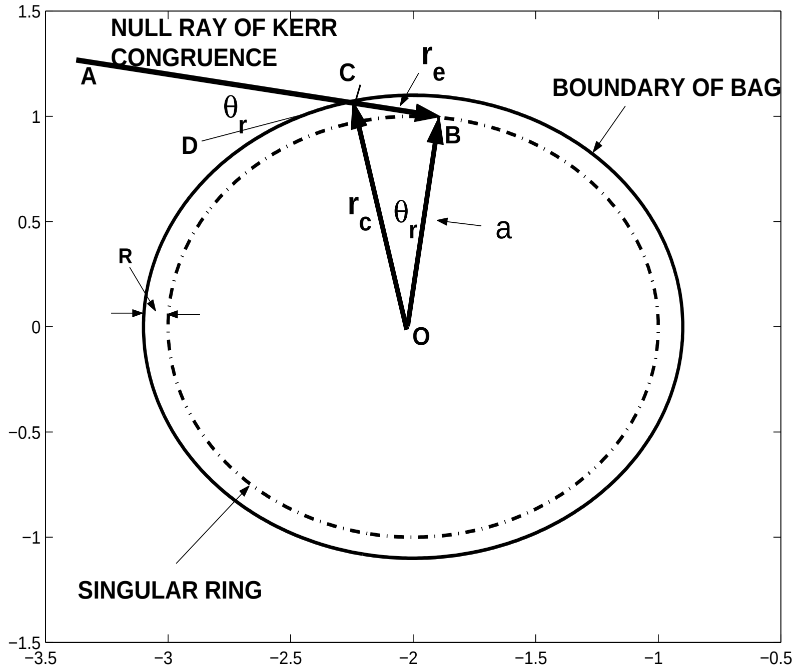


Figure 5: **Kinematic relation in the equatorial plane** $\cos\theta = 0$. **A light-like beam of the Kerr congruence crosses edge of the bag at angle** $\theta_{\mathbf{c}} = \arctan \mathbf{r_e}/\mathbf{a} \sim \alpha$ **.**

Kinematic relations show that the related lengthening of the string, caused by contribution A^-_μ, is proportional to

$$\tan\theta_r = r_e/a = \alpha. \tag{16}$$

Why electron looks like a point?

External observer perceives lightlike string as a point (Punsly 1985 , Arcos & Pereira, 2006, A.B. 2009.) **Lightlike string forms worldline – not worldsheet. Kinematic analysis of the Kerr-Newman string shows that there is a lapse** $\tan\theta_c = R_e/a = \alpha$, **and therefore, the (closed) string length** $l = 2\pi a$ **should be extended to** $\tilde{l} = 2\pi a + \alpha$.

As a result, the magnetic momentum of the Dirac electron $\mu_B = \hbar e a$ **increases to** $\mu_e = \frac{\hbar e}{2\pi}(2\pi a + \alpha) = m_B(1 + \alpha/2\pi)$ **.**

The lightlike "left" mode is indeed completed by a weak "right" mode. The surface current splits into the "left" and "right" components

$$\Box \mathbf{A}_\mu = \mathbf{J}^-_\mu + \mathbf{J}^+_\mu = \mathbf{e}[|\mathbf{H}^+|^2(\chi^+,_\mu + \mathbf{e}\mathbf{A}^+_\mu) + |\mathbf{H}^-|^2(\chi^-,_\mu - \mathbf{e}\mathbf{A}^-_\mu)].$$

The "left" and "right" null coordinates $\chi^- = t - \sigma$ **and** $\chi^+ = t + \sigma$, **are phases of the oscillating Higgs fields** H^+ **and** H^- **(**$\sigma = a\phi \in [0, 2\pi]$**).)**

CONCLUSION:

- **Spinning Kerr's gravity shifts effective scale of gravitational interaction from Plank to Compton distances.**
- **Analysis of the role of Kerr-Newman solution shows that instead of confrontation with quantum theory, spinning gravity start collaborate on Compton scale, fixing basic parameters of the particle models and their shape. In particular, it fixes:**
  - **gyromagnetic ratio $g = 2$ of the Dirac electron,**
  - **phase transition at the Compton wavelength,**
  - **Classical electron radius,**
  - **Fine structure constant,**
  - **Wilson loop defining spin quantization,**
  - **string structure**
- **The nonperturbative bag model based on the supersymmetric N=1 Landau-Ginzburg field model becomes equivalent to Wess-Zumino model of the supersymmetric QED.**

THANK YOU VERY MUCH FOR YOUR ATTENTION!