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Geometry of Space or Quantum Field in Space

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Abstract. Thirring-Feynman's tensor field approach to gravitation opens new understanding on the physics of gravitational interaction and stimulates novel experiments on the nature of gravity. According to Field Gravity, the universal gravity force is caused by exchange of gravitons - the quanta of gravity field. Energy of this field is well-defined and excludes the singularity. All classical relativistic effects are the same as in General Relativity. The intrinsic scalar (spin 0) part of gravity field corresponds to "antigravity" and only together with the pure tensor (spin 2) part gives the usual Newtonian force. Laboratory and astrophysical experiments which may test the predictions of FG, will be performed in near future. In particular, observations at gravity observatories with bar and interferometric detectors, like Explorer, Nautilus, LIGO and VIRGO, will check the predicted scalar gravitational waves from supernova explosions. New types of cosmological models in Minkowski space are possible too.

1. WHAT IS GRAVITY?

Physical understanding of fundamental interactions - strong, weak, and electro-magnetic, are based on the quantum fields. Then why is the most evident interaction in the world - gravity - not in the above list? In fact, this question concerns the nature of gravitational interaction. Is gravity a manifestation of material field, whose exitations - gravitons, are responsible for the fall of Newton's apple? Or, is it a reflection of the geometry of space, whose curvature gives the apple the natural state of free fall? In other words: is gravity a kind of matter in space, or is it the curved space itself?

The generally accepted answer is that the gravity well presented by the geometric theory – General Relativity (GR), which has a successful history of experiments, but only in weak gravity conditions. Also, GR is not a quantum theory.

In this report I discuss another possible answer that gravity may be described as a material relativistic field in Minkowski space, which is called Field Gravity (FG) theory. I shall argue that field understanding of gravity opens new possibilities for experimental testing of the nature of gravity. Also new types of cosmological models in Minkowski space are possible.

2. THIRRING-FEYNMAN FIELD APPROACH TO GRAVITATION

In 1960's Thirring (1961) [13] and Feynman (1971, 1995) [6, 7] made an attempt to describe gravity as a relativistic tensor field in Minkowski space. In his *Lectures on Gravitation* Richard Feynman discussed a standard quantum field description of gravity "just as the next physical interaction". He emphasized that "the geometrical interpretation is not really necessary or essential to physics" ([6], p.110, Lecture 8). Hence Feynman's Field Gravity is a natural starting point for understanding the physics of gravity phenomena similarly as other fundamental forces.

According to Feynman, the gravity force between the proverbial Newtonian apple and the Earth is caused by the exchange of gravitons. Gravitons (real and virtual) are mediators of the gravitational interaction and actually represent the quanta of the relativistic tensor field ψ^{ik} in Minkowski space η^{ik}.

The Field Gravity naturally brings about the solution of the long standing energy problem of General Relativity. It is well known (see e.g. Landau & Lifshitz: *The classical theory of fields*, 1971 [8], p.304) that in GR there is no satisfactory concept of energy-momentum tensor (EMT) of gravity (pseudotensor is not a tensor). However in the FG

the Minkowski space implies the invariance under the Poincaré group transformation and hence the usual definition of the gravity field EMT, which follows from Noether's theorem. This well-defined EMT allows one consistently to consider energy quanta of gravity field, which transmit the gravity force.

The first step in the construction of the Field Gravity is to choose the Lagrangians for the free field and for the interaction in the low energy regime. And the result is relativistic tensor field gravity theory in Minkowski space. Discussion of main equations and predictions of the Field Gravity theory are presented in [2]. Here I highlight the most interesting points which this Feynman's approach uncovers for the physics of gravity.

3. SURPRISES OF THE LOW ENERGY REGIME

It should be noted that in the literature one may often find incorrect claims about the field approach to gravity, such that it is impossible to construct a consistent field gravity theory or that FG and GR are completely equivalent (see e.g. Misner, Thorn & Wheeler 1973 [9] sections 7 and 17). However the principal difference between GR and FG was demonstrated by Baryshev (1996) [2] and Straumann (2000) [12] – the main point is that in curved geometry there is no conserved energy-momentum tensor of gravity field.

Another widespread mistake is the statement that the symmetric tensor field only corresponds to particles with spin 2. Indeed, the multicomponent structure of the tensor potential is one of the most important things for quantum field theory. In the case of the symmetric second rank tensor field ψ^{ik} there are 10 independent components which represent particles with spins two, one, and zero (two particles with spin 0), participating in virtual quantum processes:

$$\{\psi^{ik}\} = \{2\} \oplus \{1\} \oplus \{0\} \oplus \{0\} \ .$$

Because the field equations are gauge invariant under the transformation $\psi^{ik} \longrightarrow \psi^{ik} + \lambda^{i,k} + \lambda^{k,i}$ one may use 4 additional functions λ^i to delete 4 components corresponding to spin 1 and the first spin 0, so leaving only the spin 2 and the second spin 0 parts of the tensor potential:

$$\{\psi^{ik}\} = \{2\} \oplus \{0\} \ .$$

This means that tensor FG theory is actually a scalar-tensor theory, where the scalar part of the field is simply the trace $\psi = \eta_{ik}\psi^{ik}$ and it corresponds to the scalar part of the source $T = \eta_{ik}T^{ik}$. Hence in the case of free field the potential is the sum of two independent parts: a pure tensor wave with spin 2 and a scalar wave with spin 0.

The scalar ψ is an intrinsic part of the gravitational tensor potential ψ^{ik} and does not relate to extra scalar fields usually introduced in the Jordan-Fierz-Brans-Dicke theories. So all constraints on the extra scalar field φ, do not restrict the scalar part ψ of the tensor field ψ^{ik}.

The most intriguing consequence of the Field Gravity is that the scalar part (spin 0) corresponds to a repulsive force, while the pure tensor part (spin 2) corresponds to attraction. Hence the usual Newtonian force is actually the sum of two parts where the attractive force is three times the repulsive force [2, 3]:

$$\vec{F}_N = (\vec{F}_{(2)} + \vec{F}_{(0)}) = -\frac{3}{2}m\vec{\nabla}\varphi_N + \frac{1}{2}m\vec{\nabla}\varphi_N = -m\vec{\nabla}\varphi_N \ ,$$

which directly follows from the equation of motion for test particles. This understanding of the Newtonian potential opens new ways for experimental studies of the scalar "antigravity" even in the weak field laboratory conditions.

The field equation for the scalar part ψ is the usual wave equation:

$$(\triangle - \frac{1}{c^2}\frac{\partial^2}{\partial t^2})\psi(\vec{r},t) = -\frac{8\pi G}{c^2}T(\vec{r},t) \ .$$

which describes the generation of scalar gravitational waves by the trace of the EMT of the source. Scalar gravitational waves are longitudinal and are generated by spherical pulsations of the source [1]. This essentially influences the supernova explosion phenomenon and the predictions for expected signals in gravitational wave antennas [4, 10, 11].

4. UNIVERSALITY OF GRAVITY FORCE

The basic principles of the Field Gravity are the same as for other relativistic quantum fields. These include the Minkowski space, the quantum uncertainty principle and the many-path approach.

The equivalence principle of GR cannot be a basis of the Field Gravity, because it eliminates gravity force and accepts the equivalence between inertial motion and accelerated motion under gravity. E.g. the equivalence principle creates such a puzzle as the radiating electric charge resting in the Earth's gravity field on a laboratory table, just due to the equivalence of this frame to a constant acceleration of the table.

The concept of inertial frame is preserved in Field Gravity and there is no equivalence between inertial and accelerated motions. Instead of the principle of equivalence, FG is based on the principle of universality of gravitational interaction, first formulated by Marcos Moshinsky in 1950 as the universal form of the interaction Lagrangian:

$$\Lambda_{int} = -\frac{1}{c^2}\psi_{ik}T^{ik} \ .$$

As a consequence of this principle, inertial and gravitational masses of a usual test body are simply equal to its rest mass. The charge on the table does not radiate, and all classical relativistic gravity effects have the same values in FG and GR.

The equation of motion of a test particle in a static weak field in Post-Newtonian approximation is

$$\frac{d\vec{v}}{dt} = -(1+\frac{v^2}{c^2}+4\frac{\varphi_N}{c^2})\vec{\nabla}\varphi_N + 4\frac{\vec{v}}{c}(\frac{\vec{v}}{c}\vec{\nabla}\varphi_N) \ .$$

From this equation immediately follows a possible generalization of the old Galileo-Stevinus experiment. Such a "Galileo-2000 experiment" would test the fact that the gravitational force acting on a test particle depends on the value and direction of its velocity. Hence rotating bodies with differently oriented angular momenta will fall with different accelerations. Another version of this experiment is weighing rotating bodies with a balance scale, where one can measure directly the difference in gravity forces. For astronomical binary systems this effect will appear as a periodical modulation of the orbit of a rapidly rotating body (Baryshev 2002 [3]).

5. THE ABSENCE OF SINGULARITIES IN FIELD GRAVITY

The energy density of the gravitational field in FG theory for the case of a static weak field is

$$\varepsilon_g = T_g^{00} = \frac{1}{8\pi G}(\vec{\nabla}\varphi_N)^2 \ .$$

It is positive, localizable, and does not depend on a choice of the coordinate system.

A very general energy argument leads in FG to exclusion of singularities. Indeed, the total energy of the gravity field existing around a body, should be less than the rest mass energy of the body:

$$E_g < Mc^2 \Rightarrow R_o > GM/2c^2 \ .$$

Thus black holes and singularities are excluded by the energy of gravity field. This argument is a precise analogue to that of the classical radius of electron $R_e > e^2/m_ec^2$, following from the requirement that the field energy E_e should be less than the electron's rest-mass energy.

Instead of black holes in Field Gravity there are compact relativistic objects having radiuses close to gravitational radius $R_m = Gm/c^2$.

6. ASTROPHYSICAL TESTS OF FIELD GRAVITY

All classical relativistic gravity effects in the Solar System and binary pulsars up to now do not probe the genuine difference between FG and GR. Though, also some differing effects exist even in the weak gravity field, such as the periodical modulation of the orbit of a rapidly rotating body (Baryshev 2002 [3]).

In the case of strong gravity the predictions of FG and GR diverge dramatically. In FG there is no black holes and singularities, and no such limit as the Oppenheimer-Volkoff mass. This means that compact massive objects in binary star systems and active galactic nuclei are good tests for the FG theory (Baryshev 1996 [4]).

Scalar gravitational radiation is predicted by the FG for the spherical pulsations of exploding cores of massive supernovae. This prediction will be tested in a few years by the new-generation gravitational antennas (Baryshev 1995 [1]; Baryshev & Paturel 2001 [4]; Paturel & Baryshev 2003a,b [10, 11]) .

In cosmology FG provides the possibility to study infinite matter distributions in Minkowski space, without the gravity paradox, and naturally gives the zero curvature models. The EMT of the interaction plays the role of an effective cosmological Λ-term (see Baryshev et al. 1994 [5]). The possibility of a non-zero rest mass of the graviton may lead to new cosmological solutions.

7. CONCLUSIONS

Feynman's field approach to gravity clearly deserves more attention. It opens new understanding on the physics of gravitational interaction and gives new ideas for the development of gravity experiments in the laboratory and the cosmos.

It seems that general relativity will be included partly in the frame of the quantum field theory as a classical limit, similarly as geometrical optics is a limiting case of quantum electrodynamics. Further experiments will show which principle is more fundamental: the uncertainty principle of quantum physics or the principle of equivalence of general relativity.

In his third letter to Bentley, Newton wrote: "Gravity must be caused by an Agent acting constantly according to certain Laws; but whether this Agent be material or immaterial, I have left to the Consideration of my Readers."[14] Because of the testable predictions of general relativity and field gravity, one may hope that the forthcoming astrophysical observations will be able to answer Newton's question - What is the nature of gravity?

ACKNOWLEDGMENTS

REFERENCES

1. Baryshev Yu., On a possibility of scalar gravitational wave detection from the binary pulsar PSR 1913+16, Proceedings of the First Edoardo Amaldi Conference on *Gravitational wave experiments*, eds. E.Coccia, G.Pizzella, F.Ronga, World Scientific Publ.Co., 1995, p.251 (gr-qc/9911081).

2. Baryshev Yu., Field Theory of Gravitation: Desire and Reality, Gravitation,v.2,p.5, 1996 (gr-qc/9912003).

3. Baryshev Yu., Translational motion of rotating bodies and tests of the equivalence principle. Gravitation & Cosmology, vol.8, 232, 2002 (gr-qc/0010056).

4. Baryshev Yu., Paturel G. Statistics of the detection rates for tensor and scalar gravitational waves from the local galaxy universe. Astron. Astrophys., vol.371, 378-392, 2001.

5. Baryshev, Yu., Sylos Labini F., Montuori, M., Pietronero, L., Facts and ideas in modern cosmology, Vistas in Astronomy 38, 419, 1994.

6. Feynman R., *Lectures on Gravitation* ,1962-63, California Institute of Technology, 1971.

7. Feynman R., Morinigo F., Wagner W., *Feynman Lectures on Gravitation*, Addison-Wesley Publ. Comp., 1995.

8. Landau, L.D., Lifshitz, E.M., *The Classical Theory of Fields*, (Pergamon Press), 1971.

9. Misner C., Thorn K., Wheeler J., *Gravitation*, (W.H. Freeman and Company), 1973.

10. Paturel G., Baryshev Yu., Sidereal time analysis as a tool for the space distribution of sources of gravitational waves, Astron. Astrophys., vol.398, 377, 2003.

11. Paturel G., Baryshev Yu., Prediction of the sidereal time distribution of gravitational wave events for different detectors Astrophys. J. Lett., vol.592, L99, 2003.

12. Straumann N., Reflections on gravity 2000 (astro-ph/0006423).

13. Thirring W. E., An alternative approach to the theory of gravitation, Ann. of Phys., v. 16, 96, 1961.

14. Newton Isaac, From *Four Letters from Sir Isaac Newton to Doctor Bentley*, London: Printed for R. and J. Dodsley, Pall-Mall, M DCC LVI (p.26)