A non-geometrical approach to quantum gravity

Michael A. Ivanov
Physics Dept.,
Belarus State University of Informatics and Radioelectronics,
6 P. Brovka Street, BY 220027, Minsk, Republic of Belarus.
E-mail: michai@mail.by.

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Abstract

Some results of author's work in a non-geometrical approach to quantum gravity are reviewed here, among them: a quantum mechanism of classical gravity giving a possibility to compute the Newton constant; asymptotic freedom at short distances; interaction of photons with the graviton background leading to the important cosmological consequences; the time delay of photons due to interactions with gravitons; deceleration of massive bodies in the graviton background which may be connected with the Pioneer anomaly and with the problem of dark matter.

1 Introduction

Attempts to construct a quantum model of gravity starting from the geometrical description of classical case in general relativity may be characterized as very poor in its possible consequences. The classical limit has not any clear physical mechanism of formation of the metric, and it is similar to the Newtonian version where the law of gravity is postulated. There are a few facts which may be considered as contradicting to the mainstream in this field of physics: the Pioneer anomaly [1, 2], the discovery of quantum states of ultra-cold neutrons in the Earth's gravitational field with very low energies of levels [3]; perhaps, we should include in the list the problem of dark matter in galaxies. Many people are searching for dark energy, an existence of which has been claimed on a basis of the standard cosmological model; but the initial cause for this conclusion may be put in our list, too.

I would like to review here some results of my work in a non-geometrical approach to quantum gravity, which is based on the assumptions that: 1) gravitons are super-strong interacting particles and 2) the low-temperature graviton background exists. This model of low-energy quantum gravity has many interesting consequences, and the one may pave the alternative way to the future theory. To be shorter, I use here notations of my cited works.

2 A quantum mechanism of classical gravity

It was shown by the author [4, 5] that screening the background of super-strong interacting gravitons creates for any pair of bodies both attractive and repulsive forces due to pressure of gravitons. For single gravitons, these forces are approximately equal. If single gravitons are pairing, an attractive force due to pressure of such graviton pairs is twice exceeding a corresponding repulsive force if graviton pairs are destructed by collisions with a body. In such the model, the Newton constant may be computed. The attractive force F_1 due to pressure of single gravitons in this model is equal to: $F_1 \equiv G_1 \cdot m_1 m_2/r^2$, where the constant G_1 is: $G_1 \equiv 1/3 \cdot D^2 c(kT)^6/\pi^3\hbar^3 \cdot I_1$, with $I_1 = 5.636 \cdot 10^{-3}$. By $T = 2.7\ K : G_1 = 1215.4 \cdot G$, that is of three order greater than the Newton constant, G. If single gravitons are elastically scattered, they create a repulsive force $F_1^{'}$ which is equal to F_1. But for black holes which absorb any particles and do not re-emit them, we will have $F_1^{'} = 0$. It means that such the objects would attract other bodies with a force which is proportional to G_1 but not to G, i.e. Einstein's equivalence principle would be violated for them.

In a case of graviton pairing, a force of attraction of two bodies F_2 due to pressure of graviton pairs will be equal to: $F_2 = 8/3 \cdot D^2 c(kT)^6 m_1 m_2/\pi^3\hbar^3 r^2 \cdot I_2$, where $I_2 = 2.3184 \cdot 10^{-6}$. The difference F between attractive and repulsive forces is twice smaller: $F \equiv F_2 - F_2^{'} = 1/2 F_2 \equiv G_2 m_1 m_2/r^2$, where the constant G_2 is: $G_2 \equiv 4/3 \cdot D^2 c(kT)^6/\pi^3\hbar^3 \cdot I_2$. If one assumes that $G_2 = G$, then it gives for the new constant D: $D = 0.795 \cdot 10^{-27} m^2/eV^2$.

The inverse square law takes place in the model if the condition of big distances is fulfilled: $\sigma(E, <\epsilon>) \ll 4\pi r^2$ [4, 5]. It leads to the necessity of some "atomic structure" of matter for working the described quantum mechanism; it is a unique demand for known models of gravity.

3 Asymptotic freedom at short distances

Recently, it was shown in [6] that asymptotic freedom appears at very short distances in this model. In this range, the screened portion of gravitons tends to the fixed value of 1/2, that leads to the very small limit acceleration of the order of $10^{-13}\ m/s^2$ of any screened micro-particle. The ratio $\sigma(E_2, <\epsilon_2>)/4\pi r^2$ describes the screened portion of gravitons for a big distance r.

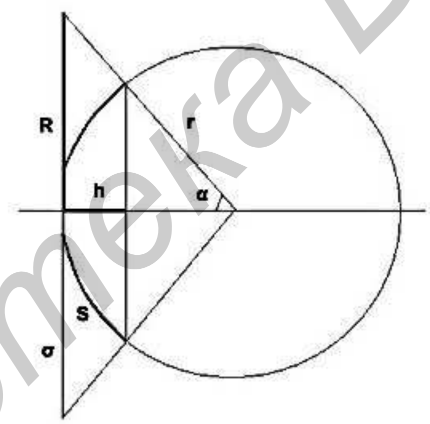

Figure 1: To the computation of the screened portion of gravitons at small distances: σ is the cross-section, S is a square of the spherical segment of a hight h.

For small r, let us consider Fig. 1, where $R = (\sigma(E_2, <\epsilon_2>)/\pi)^{1/2}$, S is the screening area. It is necessary to replace the ratio $\sigma(E_2, <\epsilon_2>)/4\pi r^2$ by the following one: $\rho(y) \equiv S/4\pi r^2$.

To find the net force of gravitation F at a small distance r, we should replace the factor $\sigma(E_2, <\epsilon_2>)/4\pi r^2$ in Eq. (31) of [5] with the more exact factor $S/4\pi r^2$. Then we get:

$$F(r) = \frac{4}{3} \cdot \frac{D(kT)^5 E_1}{\pi^2 \hbar^3 c^3} \cdot g(r), \qquad (1)$$

where E_1 is an energy of particle 1, and $g(r)$ is the function of r:

$$g(r) \equiv \int_0^\infty \frac{x^4(1-\exp(-(\exp(2x)-1)^{-1}))(\exp(2x)-1)^{-3}}{\exp((\exp(2x)-1)^{-1})\exp((\exp(x)-1)^{-1})} \cdot \rho(y)dx, \quad (2)$$

where $y = y(r,x) = r/R(x)$. By $r \to 0$, this function's limit for any E_2 is: $g(r) \to I_5 = 4.24656 \cdot 10^{-4}$. For comparison, graphs of the function $g(r)$ are shown in Fig. 2 for the following different energies: $E_2 = m_p c^2$ and

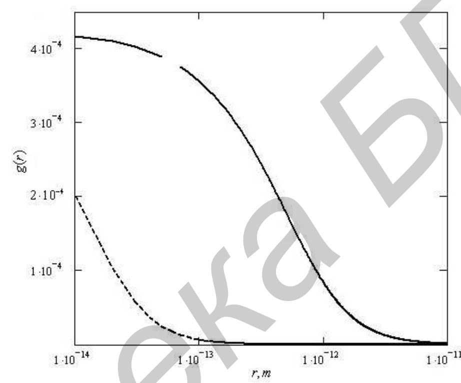

Figure 2: Different transition to the limit value of the function $g(r)$ by $E_2 = m_p c^2$ (solid) and by $E_2 = m_e c^2$ (dot).

$E_2 = m_e c^2$. The functions have the same limit by $r \to 0$, but the most interesting thing is their different transition to this limit when r decreases. The range of transition for a proton is between $10^{-11} - 10^{-13}$ meter, while for an electron it is between $10^{-13} - 10^{-15}$ meter.

The property of asymptotic freedom leads to the important consequence: a black hole mass threshold should exist [7, 8].

4 Interaction of photons with the graviton background

Due to forehead collisions with gravitons, an energy of any photon should decrease when it passes through the sea of gravitons. From another side, none-forehead collisions of photons with gravitons of the background will lead to an additional relaxation of a photon flux, caused by transmission of a momentum transversal component to some photons. It will lead to an additional dimming of any remote objects, and may be connected with supernova dimming. Average energy losses of a photon with an energy E on a way dr will be equal to: $dE = -aEdr$, where $a = H/c$. In this model, $H = 1/2\pi \cdot D \cdot \bar{\epsilon} \cdot (\sigma T^4)$, where $\bar{\epsilon}$ is an average graviton energy. As a result, we have: $E(r) = E_0 \exp(-ar)$, where E_0 is an initial value of energy. Both redshifts and the additional relaxation of any photonic flux due to non-forehead collisions of gravitons with photons lead in the model to the following luminosity distance D_L : $D_L = a^{-1} \ln(1+z) \cdot (1+z)^{(1+b)/2} \equiv a^{-1} f_1(z)$, where $f_1(z) \equiv \ln(1+z) \cdot (1+z)^{(1+b)/2}$, with the factor $b \simeq 2.137$ for soft radiation. It is easy to find a value of the factor b in another marginal case - for a very hard radiation. Due to very small ratios of graviton to photon momenta, photon deflection angles will be small, but collisions will be frequent because the cross-section of interaction is a bilinear function of graviton and photon energies in this model. It means that in this limit case $b \to 0$. For an arbitrary source spectrum, a value of the factor b should be still computed. It is clear that $0 \leq b \leq 2.137$, and in a general case it should depend on a rest-frame spectrum and on a redshift. It is important that the Hubble diagram in the model is a multivalued function of a redshift: for a given z, b may have different values [9].

Using only the luminosity distance and a geometrical one as functions of a redshift in this model, theoretical predictions for galaxy/quasar number counts may be found [10]. For example, galaxy number counts as a function of a redshift z may be characterized with the function $f_2(z)$ for which we have in this model: $f_2(z) = ln^2(1+z)/z^2(1+z)$. A graph of this function is shown in Fig. 3; the typical error bar and data point are added here from paper [11] by Loh and Spillar. There is not a visible contradiction with observations. *There is not any free parameter in the model to fit this curve;* it is a very rigid case.

5 Time delay of photons due to interactions with gravitons

To compute the average time delay of photons, it is necessary to find a number of collisions on a small way dr and to evaluate a delay due to one act of interaction. Let us consider at first the background of single gravitons. Given the expression for H in the model, we can write for the number of

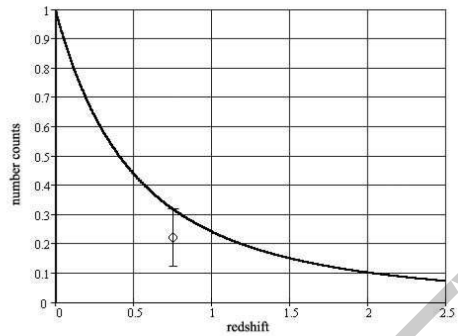

Figure 3: Number counts f_2 as a function of the redshift in this model. The typical error bar and data point are taken from paper [11] by Loh and Spillar.

collisions with gravitons having an energy $\epsilon = \hbar\omega$:

$$dN(\epsilon) = \frac{|dE(\epsilon)|}{\epsilon} = E(r) \cdot \frac{dr}{c} \frac{1}{2\pi} D f(\omega, T) d\omega, \tag{3}$$

where $f(\omega, T)$ is described by the Plank formula. In the forehead collision, a photon loses the momentum ϵ/c and obtains the energy ϵ; it means that for a virtual photon we will have:

$$\frac{v}{c} = \frac{E - \epsilon}{E + \epsilon}; \; 1 - \frac{v}{c} = \frac{2\epsilon}{E + \epsilon}; \quad 1 - \frac{v^2}{c^2} = \frac{4\epsilon E}{(E + \epsilon)^2}. \tag{4}$$

The uncertainty of energy for a virtual photon $\Delta E = 2\epsilon$. If we evaluate the lifetime of a virtual photon on a basis of the uncertainties relation: $\Delta E \cdot \Delta\tau \geq \hbar/2$, we get $\Delta\tau \geq \hbar/4\epsilon$. In the time $\Delta\tau$, the time delay Δt will be equal to:

$$\Delta t(\epsilon) = \Delta\tau(1 - \frac{v}{c}) \geq \hbar/2 \cdot \frac{1}{E + \epsilon}. \tag{5}$$

The full time delay due to gravitons with an energy ϵ is: $dt(\epsilon) = \Delta t(\epsilon) dN(\epsilon)$. Taking into account all frequencies, we find the full time delay on the way dr:

$$dt \geq \int_0^\infty \frac{\hbar}{2} \frac{E}{E + \epsilon} \cdot \frac{dr}{c} \frac{1}{2\pi} D f(\omega, T) d\omega. \tag{6}$$

The full time delay on the way dr will be maximal for $E \to \infty$, and it is easy to evaluate the one:

$$dt_\infty \geq \frac{\hbar}{4\pi} \frac{dr}{c} \cdot D\sigma T^4. \tag{7}$$

On the way r the time delay is:

$$t_\infty(r) \geq \frac{\hbar}{4\pi} \frac{r}{c} \cdot D\sigma T^4. \tag{8}$$

In this model: $r(z) = c/H \cdot \ln(1+z)$; let us introduce a constant: $\rho \equiv \hbar/4\pi \cdot D\sigma T^4/H = 37.2 \cdot 10^{-12} s$, then

$$t_\infty(z) \geq \rho \ln(1+z). \tag{9}$$

We see that for $z \simeq 2$ the maximal time delay is equal to $\sim 40\ ps$, i.e. the one is negligible. If we take into account graviton pairing, the estimate of delay becomes smaller.

If we consider another possibility of lifetime estimation, for example, $\Delta\tau_0 = const$, where $\Delta\tau_0$ is the proper lifetime of a virtual photon (it should be considered as a new parameter of the model), taking into account that now:

$$\Delta\tau = \Delta\tau_0/(1 - \frac{v^2}{c^2})^{1/2}, \tag{10}$$

we shall get in the same manner (my paper about the time delay is now in progress):

$$t(z) = \Delta\tau_0 \sqrt{E_0/\epsilon_0} \cdot \frac{\sqrt{1+z} - 1}{\sqrt{1+z}}, \tag{11}$$

where E_0 is an initial photon energy, ϵ_0 is a new constant: $\epsilon_0 = 2.391 \cdot 10^{-4}\ eV$.

In this case, the time delay of photons with different initial energies E_{01} and E_{02} will be proportional to the difference $\sqrt{E_{01}} - \sqrt{E_{02}}$, and more energetic photons should arrive later, also as in the first case. It is still necessary to calculate the dispersion of the delay. To find $\Delta\tau_0$, we must compare the computed value of time delay with future observations. Recently, an analysis of time-resolved emissions from the gamma-ray burst GRB 081126 [12] showed that the optical peak occurred (8.4 ± 3.9) s *later* than the second gamma peak; perhaps, it means that this delay is connected with the mechanism of burst.

6 Deceleration of massive bodies in the graviton background

The observed Pioneer anomaly [1, 2] has the following main features: 1) in the range 5 - 15 AU from the Sun it is observed an anomalous sunward acceleration with the rising modulus which gets its maximum value; 2) for greater distances, this maximum sunward acceleration remains almost constant for both Pioneers; 3) it is observed an unmodeled annual periodic term in residuals for Pioneer 10 [13] which is obviously connected with the motion of the Earth. In a frame of this model, a universal character of gravitational interaction should lead to energy losses of any massive body due to forehead collisions with gravitons, so the body acceleration $w \equiv dv/dt$ by a non-zero velocity v is equal to: $w = -ac^2(1 - v^2/c^2)$. For small velocities: $w \simeq -Hc$. If the Hubble constant H is equal to its theoretical estimate in this approach $2.14 \cdot 10^{-18} s^{-1}$, a modulus of the acceleration will be equal to $|w| \simeq Hc = 6.419 \cdot 10^{-10}\ m/s^2$, that is of the same order of magnitude as a value of the observed additional acceleration $(8.74 \pm 1.33) \cdot 10^{-10} m/s^2$ for NASA probes. The acceleration w is directed against a body velocity in the frame of reference in which the graviton background is isotropic. This acceleration will have different directions by motion of a body on a closed orbit. The observed value of anomalous acceleration of Pioneer 10 should represent the vector difference of the two accelerations [4]: an acceleration of Pioneer 10 relative to the graviton background, and an acceleration of the Earth relative to the background. Perhaps, namely the last one is displayed as an annual periodic term in the residuals of Pioneer 10 [13]. An observed value of the projection of the probe's acceleration on the sunward direction w_s should depend on accelerations of the probe, the Earth and the Sun relative to the graviton background. If the Sun moves relative to the background slowly enough, then anomalous accelerations of the Earth and the probe would be directed almost against their velocities in the heliocentric frame, and in this case: $w_s = -w \cdot cos\alpha$, where α is an angle between a radius-vector of the probe and its velocity in the frame. By the very elongate orbits of the both Pioneers, it would explain the second (and main) peculiarity. For example, for Pioneer 10 at the distance 67 AU from the Sun one has $\sin\alpha \approx 0.11$, i.e. $cos\alpha \approx 0.994$. If for big distances from the Sun we use the conservation laws of energy and angular momentum in the field *of the Sun only*, then in the range 6.7 - 67 AU a value of $cos\alpha$ changes from 0.942 to 0.994, i.e. approximately on 5 per cent only. Due to this fact, a projection of the probe's acceleration on the sunward direction would be almost constant [14].

As Toth and Turyshev report [15], they intend to carry out an analysis of newly recovered data received from Pioneers, with these data are now available for Pioneer 11 for distances 1.01 - 41.7 AU. If the serious problem of taking into account the solar radiation pressure at small distances is precisely solved (modeled) [16], then this range will be very lucky to confront the expression $w_s = -w \cdot cos\alpha$ of the considered model with observations for small distances when Pioneer 11 executed its planetary encounters with Jupiter and Saturn. In this period, a value of $cos\alpha$ was changed in the non-trivial manner. For example, when the spacecraft went to Saturn, $cos\alpha$ was *negative* during some time. If this model is true, the anomaly in this small period should have *the opposite sign*. It would be the best of all to compare the two functions of the probe's proper time: the projection of anomalous acceleration of Pioneer 11 and $cos\alpha$ for it. These functions should be very similar to each other if my conjecture is true. At present, a new mission to test the anomaly is planned [17]. It is seen from this consideration that it would be desirable to have a closed orbit for this future probe, or the one with two elongate branches where the probe moves off the Sun and towards it.

This deceleration of massive bodies by the graviton background may lead to an additional *relative* acceleration of bodies in a closed system. For example, when a galaxy moves through the background, a deceleration of its center will be constant, but for orbiting it stars the same deceleration will change its sign. The kinetic energy of stars should increase with time in the rest frame of the center. Perhaps, namely the fact obeys successes of MOND by M. Milgrom in explanation of flat rotation curves of galaxies [18] (and its failure for clusters of galaxies). In MOND, when a body acceleration gets the threshold value of $\sim Hc$, one introduces by hand the growth of interaction; but namely this value characterizes the Pioneer anomaly in this model.

7 Conclusion

I hope that this model may help us to see and to realize some fresh ideas in the very old area. The coincidence of the magnitude of the anomalous deceleration of Pioneer 10/11 with the product value of Hc, and an appearance of the same quantity in the MOND cannot be due to a chance. Many consequences of the model have an impact on our understanding of cosmological problems, and these very close ties between micro and macro cosmoses are very exiting.

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